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'Isolated base-of-slope aprons': An oxymoron for shallow-marine fan-shaped, temperate-water, carbonate bodies along the south-east Salento escarpment (Pleistocene, Apulia, southern Italy)

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ABSTRACT

This paper regards the lower Pleistocene temperate-water carbonate deposits disconformably overlying an escarpment made up of faulted Cretaceous to Miocene limestones of the Apulia Foreland (southern Italy). Study deposits discontinuously crop out along the present-day eastern Salento sea cliff, and form isolated fan-shaped bodies, up to 1 km wide and up to 40 to 50 m thick, each of them covering an area of a few square kilometres. The internal arrangement of beds is represented by up to 25° to 30° lobate, seaward dipping clinobeds thinning and onlapping onto a rocky foreslope in the proximal sector and passing to gently inclined to sub-horizontal strata in the distal sector. Seven facies were distinguished, mainly composed of coarse-grained skeletal carbonates made up of a heterozoan association including coralline algae, large and small benthic foraminifera, echinoids, molluscs, bryozoans and serpulids. Since clinobeds were formed thanks to hyperconcentrated density flows (grain flows) bypassing the upper part of the inherited escarpment, these skeletal grains represent *ex situ* deposits whose shallow-marine factory was located upward (landward) with respect to the bypassed zone, likely in the almost flat area on top of the Salento Peninsula. Clinobeds are often affected by tens of metres wide and long channel-like structures interpreted as landslide scars. Inside these gullies, contorted beds (slumps) or matrix-supported intra-bioclastic floatstone/rudstone (massive deposits) are present. The occurrence of supercritical-flow structures (for example, backset-bedded beds) indicates the development of hydraulic jumps along the steep slope of gullies. Since these clinostratified, fan-shaped carbonate bodies represent carbonate slopes, and that the latter are known as aprons, normally related to linear sourced sediments, an acceptable oxymoron for studied fan-shaped carbonate bodies is suggested: 'isolated base-of-slope aprons'.

Keywords Apulia Foreland, carbonate slope, cool-water factory, foreslope lobes, heterozoan association, Salento.

INTRODUCTION

During the late Pliocene and early Pleistocene, coarse-grained, bioclastic and locally bio-lithoclastic cool-water carbonate systems developed on faulted Cretaceous to Miocene rocks of the Apulia Foreland (southern Italy; Iannone & Pieri, 1979, 1982). This carbonate bedrock, representing the exposed outer foreland basin of the Apennines Chain, became a wide slow-drowning archipelago during late Pliocene and early Pleistocene foreland subsidence (Tropeano *et al.*, 2002a,b). The inherited faulted bedrock exerted the main control on the development of depositional systems, which were variable both along strike and over time according to the wide spectrum of physiographic conditions met by the carbonate factories during the long-term subsidence-induced transgression (Tropeano & Sabato, 2000).

In such a context, carbonate sedimentation developed in several bedrock-constrained settings: (i) in shallow-sea basins (grabens) separated by exposed morpho-structural highs (horsts; Iannone & Pieri, 1979); (ii) on drowned morpho-structural highs (horsts), i.e. when flat top of submerged islands became sea-banks (Tropeano & Sabato, 2000); (iii) on variably inclined sloping sides of islands (Tropeano & Sabato, 2000; Pomar & Tropeano, 2001; Meloni *et al.*, 2013); (iv) on steep slopes flanking flat shallow-marine areas (Tropeano *et al.*, 2004; Mateu-Vicens *et al.*, 2008; Meloni, 2016). All of these features were controlled by the vertical fault displacement (from a few metres up to about 100 m) and by the horizontal spacing of block-bounding faults affecting the bedrock. Highly-spaced faults with a relatively small displacement led to the development of homoclinal ramps, with bioclastic sedimentation (Tropeano & Sabato, 2000). Closely-spaced faults led to the development of relatively steeper ramps, where along-dip sigmoidal bodies composed of either bioclastic or mixed bio-lithoclastic carbonate sediments were laid down. They were interpreted by Pomar & Tropeano (2001) as 'transition-slope' (i.e.: 'Infralittoral Prograding Wedge' *sensu* Hernández-Molina *et al.*, 2000; or 'subaqueous deltas' *sensu* Cattaneo *et al.*, 2003). Highly-spaced faults with few tens of metres displacements formed a step-like morphology associated with either bypassed cliffs, or coarse-grained deltas made up of carbonate extraclasts (Sabato, 1996; Tropeano & Sabato, 2000), or either bioclastic base-of-slope aprons or fan-shaped bodies if fed by a shallower carbonate factory (Tropeano *et al.*, 2004; Mateu-Vicens *et al.*, 2008).

This paper deals with the description of the internal architecture of some of these carbonates of the Apulia Foreland exposed along the Otranto Channel cliffed coast (south-east Salento, between the towns of Otranto and Santa Maria di Leuca; Fig. 1). Here, lower Pleistocene fan-shaped carbonate deposits, accumulated in a middle–lower foreslope setting, show decametric-scale downlapping clinobeds with an overall along strike lobate geometry (Tropeano *et al.*, 2004). Excellent outcrops led to the study of the two-dimensional and three-dimensional anatomy of the undeformed carbonate lithosomes, their internal architecture, and sediment composition (including palaeoecological requirements of carbonate-producing biotas). This paper aims to: (i) describe the carbonate facies and their distribution along the slope focusing on the composition of either *ex situ* or *in situ* bioclastic association; (ii) propose a comprehensive depositional model for base-of-slope sedimentation consistent with the palaeogeography of this sector of the Apulia Foreland during early Pleistocene; and (iii) contribute to the understanding of carbonate slopes fed by temperate-water coarse-grained bioclastic sediments.

GEOLOGICAL SETTING

The Salento Peninsula represents the southern part of the Apulia Foreland, which is the exposed (uplifted) foreland area for the Apennines and Dinaric thrust belts (Ricchetti *et al.*, 1988; Doglioni *et al.*, 1994; Bernoulli, 2001; Cicala *et al.*, 2021; Fig. 1). The Apulia Foreland is a relic of the Adria Plate, which is considered either a Mesozoic African lithospheric promontory (Channel *et al.*, 1979) or an independent plate ('Greater Adria' *sensu* Gaina *et al.*, 2013; see data in van Hinsbergen *et al.*, 2014, 2020).

The backbone of the Apulia Foreland is a 6 km thick succession of shallow-water Mesozoic carbonate rocks (Ricchetti *et al.*, 1988) belonging to the peri-Adriatic Apulia Carbonate Platform (D'Argenio, 1974), a Bahamian-type carbonate platform developed at the southern passive margin of Adria in the Tethys Ocean (Eberli *et al.*, 1993). This thick carbonate succession is discontinuously covered by more recent units showing a dominant carbonate composition (Ricchetti, *et al.*, 1988). The most recent of these units developed during the Late Pliocene and, mainly, the Early Pleistocene, when a subsidence-induced transgression, due to the eastward migration of the Apennines orogenic system, led to the progressive submersion of the Apulia Foreland, favouring cool-water bioclastic carbonate sedimentation (Fig. 2). These carbonate particles mainly comprise benthic foraminifera and skeletal fragments of bivalves, echinoids, bryozoans, brachiopods, serpulids and coralline algae (Pieri, 1975; Mateu-Vicens *et al.*, 2008). These organisms live in the present-day Mediterranean Sea on bottoms

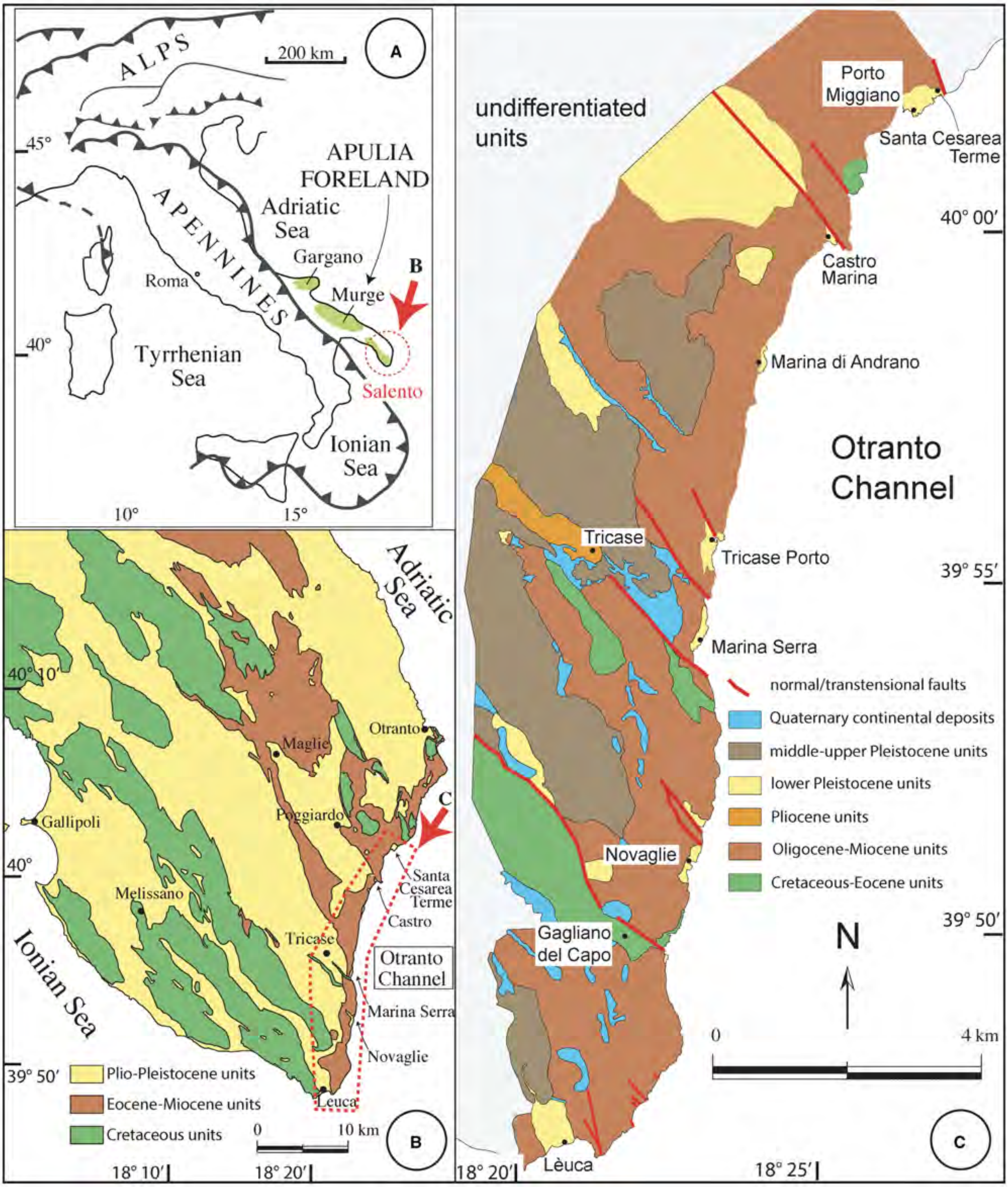


Fig. 1. Location of the study area in south-eastern Italy: (A) schematic structural map of Italy; (B) simplified geological map of the Salento Peninsula (modified from Bossio *et al.*, 1997); and (C) geological map of the eastern Salento (modified from Meloni, 2016).

whose depth ranges from a few metres to a few hundreds of metres for the light-independent ones (Betzer *et al.*, 1997; Fornós & Ahr, 2006; Tropeano & Spalluto, 2006; Laugié *et al.*, 2019). They represent a heterozoan association (*sensu* James, 1997) that basically characterizes Plio-Pleistocene shallow-marine carbonate successions in the Mediterranean region (Pedley *et al.*, 2001; Pedley & Grasso, 2002, Pedley & Grasso, 2006; Martín *et al.*, 2004; Titschack *et al.*, 2005, 2008, 2013; Nielsen *et al.*, 2006; Steinthorsdottir *et al.*, 2006; Checconi *et al.*, 2007; Nalin & Massari, 2009; Massari & D'Alessandro, 2010; Betzler *et al.*, 2011; Massari & D'Alessandro, 2012; Aguirre *et al.*, 2012; among others). Starting at least from the beginning of the Middle Pleistocene, the Apulia Foreland underwent uplift (Doglioni *et al.*, 1996; Spalluto *et al.*, 2010), and the skin of the previous marine stratigraphic 'history' of the area, represented by shallow-marine carbonates developed during the phase of subsidence on the foreland margins, are today exposed. Thanks to the negligible deformation suffered by these sediments, depositional systems preserve their original shape, and facies can be observed along dip and strike with their original relationships.

In such scenery, the Salento Peninsula is a block of the Apulia Foreland forming a poorly elevated relief made up of Cretaceous–Eocene limestones and characterized by an NNW–SSE oriented system of horsts ('Serre salentine') and grabens (Martinis, 1962; Tozzi, 1993; Festa *et al.*, 2014). This system influenced the sedimentation of the Neogene units, which were deposited in the structural depressions (Ciaranfi *et al.*, 1988). The south-eastern coastal sector of the Salento Peninsula facing the Otranto Channel (between the towns of Otranto and Santa Maria di Leuca) shows a different evolution. This area is nearly perpendicularly oriented to the horst and graben system, and it is connected to the sea through an articulated and steep rocky slope roughly corresponding to the local Mesozoic structural margin of the Apulia Platform (Del Ben *et al.*, 2015). Post-Cretaceous carbonate rocks cropping out along this inherited margin show well-preserved tens of metres thick and up to 25°/30° of primary non-tectonic dip clinoforms corresponding to Priabonian to Messinian carbonate units (Bosellini & Parente, 1994; Bosellini *et al.*, 1999; Bosellini, 2006; Pomar *et al.*, 2014).

Along and at the toe of the same cliff, discontinuous outcrops of Lower Pleistocene carbonates were described as coastal deposits whose

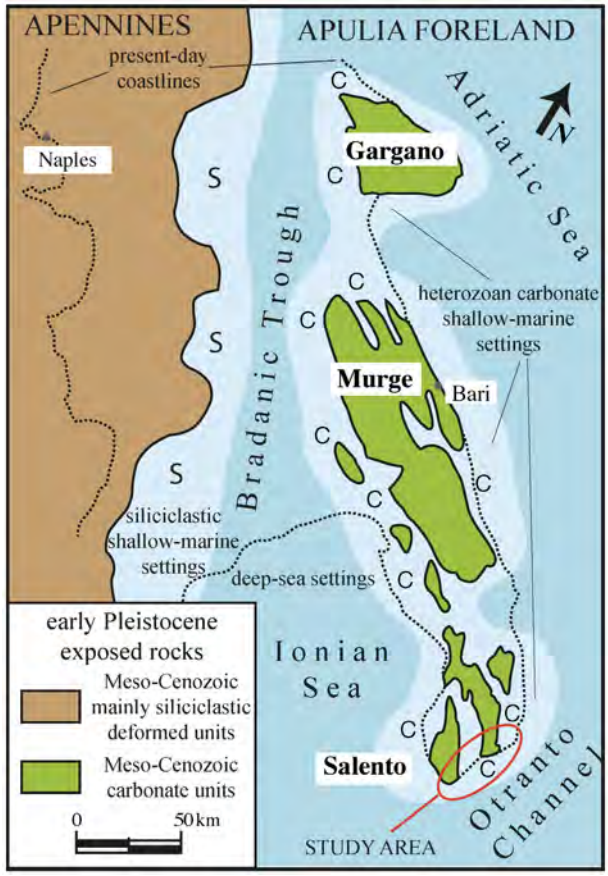


Fig. 2. Palaeogeographic reconstruction of the Apulia Foreland during the early Pleistocene: S: siliciclastic sedimentation; C: carbonate sedimentation.

position at the base of the sea cliff (Fig. 1B) was interpreted as the result of a sea-level still-stand that occurred after an Early Pleistocene regional phase of uplift (Bossio *et al.*, 1987a,b). These interpretations contrast with palaeoecological studies performed on *in situ* brachiopod associations found in the same successions and indicating a depth of about 100 to 150 m, spanning a time between the Emilian and Sicilian (Taddei Ruggiero, 1983, 1993, 1994). Following these data, subsequent stratigraphic and sedimentological studies suggested that these carbonates developed along and at the base of the cliff when it was a submerged escarpment (Tropeano *et al.*, 2004; Meloni, 2016).

The present-day cliff forms an about 120 m high scarp that connects the top of the Salento Peninsula to the present-day continental shelf. All of the stratigraphic units cropping out along the exposed cliff are cut by the most recent tectonic structures, showing displacements ranging from a few metres to more than 200 m (Martinis, 1962, 1967). Main structures are subvertical NNW–SSE, north-west/south-east and subordinately north–south striking faults (Martinis, 1962). Studied deposits mainly lie adjacent to some of these faults, and crop out in morphostructural indentations of the cliffed coast; slumps and other soft-sediment deformation structures affecting these deposits most likely testify syndepositional tectonics (Moretti, 1997; Tropeano *et al.*, 2004).

MATERIAL AND METHODS

The eastern Salento rocky coast offers an excellent opportunity to analyze facies, 3D anatomy and internal architecture of the Pleistocene fan-shaped carbonate bodies cropping out along the sea cliff for the following reasons: (i) no significant deformation has affected these rocks, which preserve their primary inclined bedding architecture; (ii) the middle–late Pleistocene uplift allows the complete observation of the anatomy and spatial relationships between the sedimentary bodies; (iii) the sea cliff outcrops provide high-quality stratigraphic sections oriented along both strike and dip with respect to the original strata attitude. Among the isolated bodies cropping out along the cliff, the one at Porto Miggiano (Fig. 1) was selected to undertake a detailed sedimentological and stratigraphic study. The other ones were studied to compare data and to improve the proposed depositional system model.

Mapped lithosomes on orthophotographs document the spatial position and relationships between the sedimentary bodies. Facies and bounding surfaces were mapped by line drawings onto photomosaics of the sea cliff, providing detailed information of the 3D anatomy and internal architecture of the sedimentary bodies. The compositional and textural analysis is based on 75 thin sections; textural nomenclature is used according to Dunham (1962) and Embry & Klovan (1971) classifications and sediment grain size is based on the Udden-Wentworth scale (Wentworth, 1922). Taphonomic description of benthic foraminifera is based on the Beavington-Penney Taphonomic Scale (BPTS; Beavington-Penney, 2004).

RESULTS

Lower Pleistocene fan-shaped carbonate bodies, showing the same composition, geometry and internal architecture, crop out in six localities of the eastern Salento rocky sea cliff (Fig. 1C). Facies are mostly composed of coarse-grained skeletal carbonates exclusively made up of heterozoan organisms. Fan-shaped carbonate bodies form small-sized, strike-discontinuous outcrops and occupy some indentations in the cliff (Tropeano *et al.*, 2004). Each outcrop covers an area of a few km^2 and the thickness of the successions is up to 40 to 50 m. The lower boundary of these carbonates is a regional-scale unconformity corresponding to a very irregular sloping erosive surface on the Meso-Cenozoic units. Crudely stratified bioclastic units pinch out against the cliff (a 'slope onlap' *sensu* Nemec, 1990; a 'foreslope onlap' *sensu* Playton *et al.*, 2010) and form laterally confined slope deposits showing a decametric-scale cross-stratification in depositional-dip direction (Fig. 3). The proximal sector comprises well-developed sets of up to 25° to 30° seaward dipping clinoforms; in the distal sector, clinoforms asymptotically grade downdip to gently inclined – up to sub-horizontal – strata (bottomset beds; Fig. 4).

Along strike, clinobeds show low angle cross-lamination to parallel lamination and form several tens of metres wide convex-up lobes (Fig. 3A). The axis-to-flank bed thickness shows a gradual decrease, from beds 2 to 3 m thick in the axial part to 20 to 30 cm in the flanks.

In the depositional-dip direction, up to 20 m long clinobeds are represented by few decimetres-thick to few metres-thick strata with an erosive base and with a sheet-stacked architecture (Fig. 3B). Backsets beds have also been observed within clinobeds (Figs 4 and 5). Foresets are cut in different directions by sharp, channel-like erosive surfaces (Fig. 6), tens of metres wide, and with very steep walls.

Facies analysis

A detailed facies analysis was performed on the basis of composition, texture, geometries and sedimentary structures. Seven facies, from A to G, have been distinguished.

Facies A – Densely-laminated bioclastic grainstone

Bright white to yellowish, planar to cross-laminated, coarse-grained bioclastic grainstone constitute the most recurrent facies since it forms the bulk of clinobeds (Figs 7 and 8). This facies consistently alternates with facies B and occurs in the axial part of convex-up beds

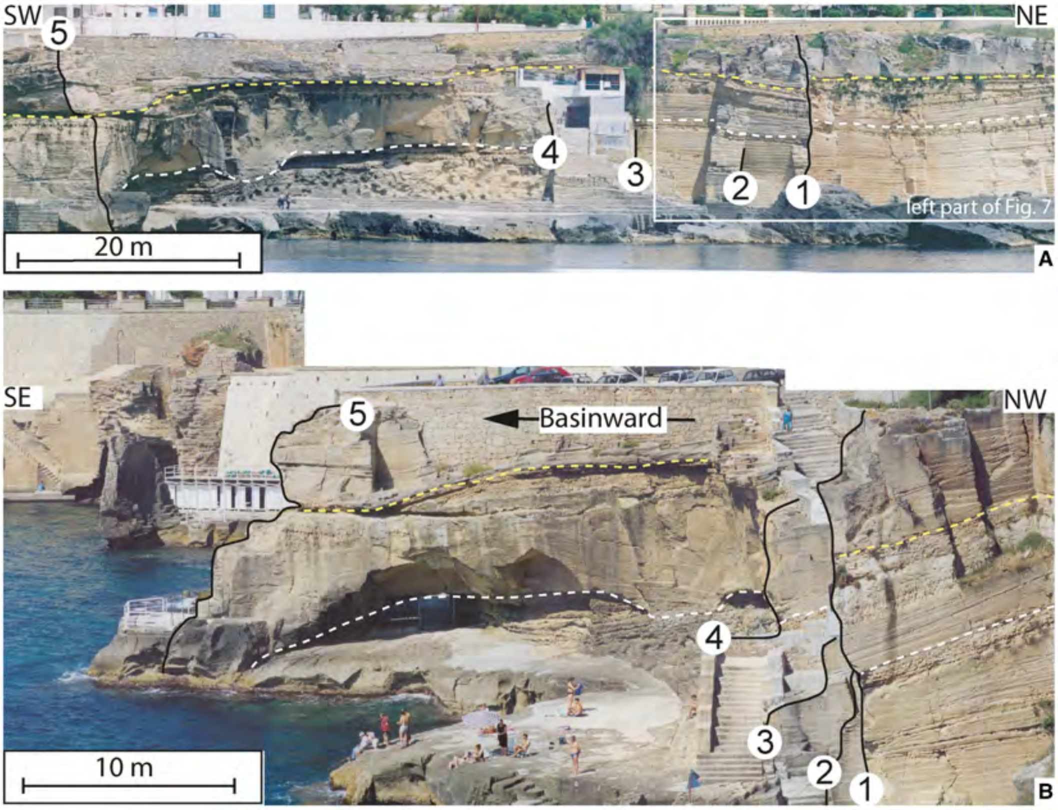


Fig. 3. Panoramic view at Santa Cesarea Terme locality (for location see Fig. 1). (A) Along-strike section showing undulating stratal geometries. (B) Along-dip section showing 25° to 30° seaward dipping clinoforms forming a large-scale cross-stratification. Note some large erosional features on the left. Black lines (1 to 5) indicate main corners on the cliff to help readers view the stratigraphy. White and yellow dashed lines in both images mark the two main erosive surfaces.

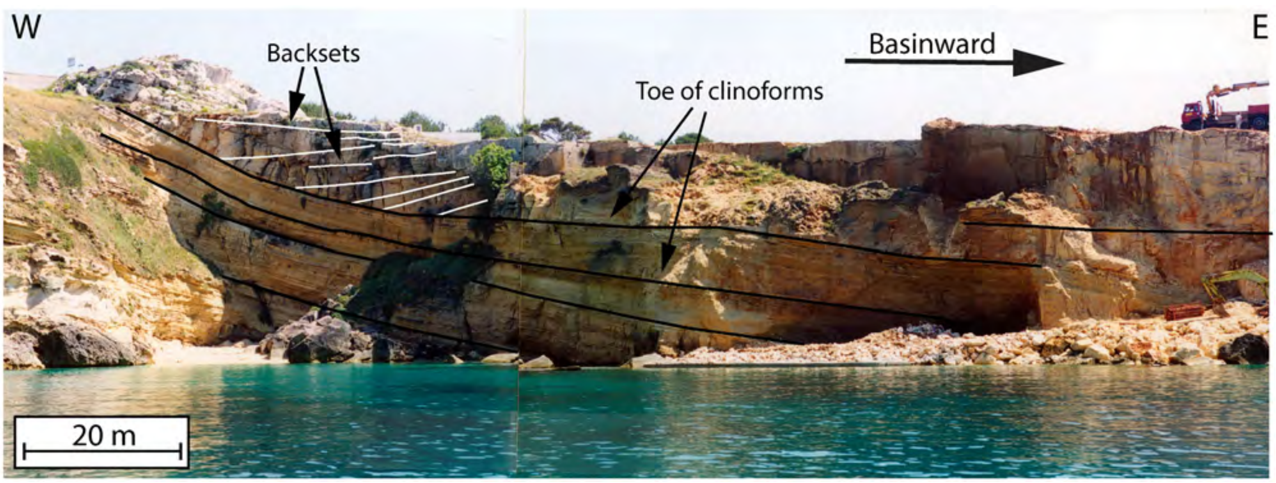


Fig. 4. Panoramic view at Porto Miggiano locality (for location see Fig. 1). Note that clinoforms are gradually less steep and asymptotically grade downdip to sub-horizontal strata (bottomset beds).

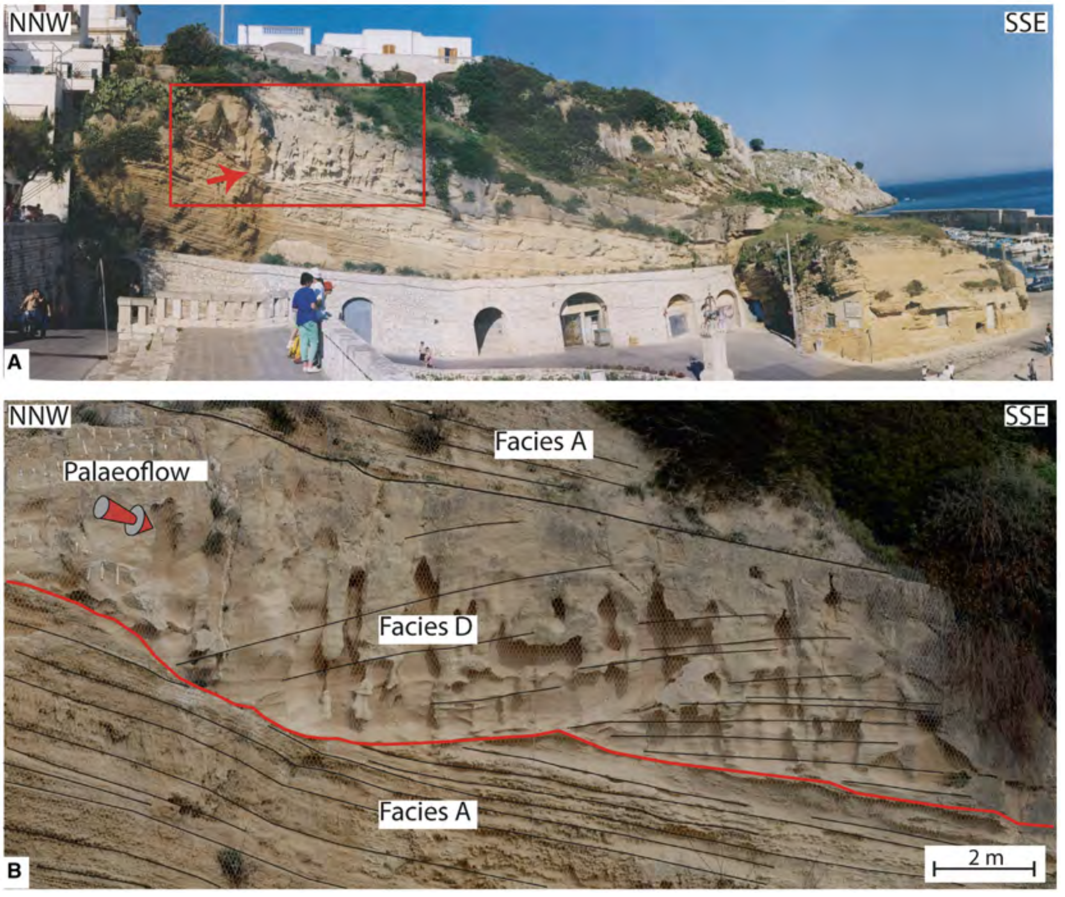


Fig. 5. Panoramic view at Castro Marina locality (for location see Fig. 1). This section is obliquely oriented with respect to the dip of the large clinobeds. (A) The arrow indicates a major scour at the base of backset-bedded deposits. The red box delimits the area shown in (B), the red arrow indicates the landslide-scar surface marked in (B). (B) Close-up view of backset-bedded deposits. The red line marks the landslide-scar surface at the base of backsets.

(Fig. 7). Facies A is densely laminated, showing both planar lamination, which is parallel to the 25° to 30° dipping clinoforms, and large-scale cross-lamination (Figs 3B and 9A). Thin section analysis revealed that lithophylloid-dominated coralline algae are the main microfacies constituents, ranging from 55 to 80% of the total ones (Fig. 10A). Coralline algae morphotypes belong to: (i) articulated and branched forms; (ii) low-density branched forms (II and III ramification groups *sensu* Bosence, 1983); and (iii) laminar forms in nodules. Some coralline algae show peculiar hooked forms (Fig. 10B). Other common components include skeletal fragments of echinoids (both plates and spines), bryozoans (mostly encrusting celleporiforms and erect flexible cellariiforms), serpulids, bivalves, gastropods, large benthic foraminifera (*Amphistegina* sp., *Elphidium* sp.), small benthic foraminifera (*Discorbis* sp., *Ammonia* sp., *Cibicides* sp., *Buliminacea* sp., *Lobatula* sp., *Planorbulina* sp., *Planorbulinella* sp., *Miniacina* sp., Spirillina sp., Triloculina sp., miliolids and textularids), subordinate planktonic foraminifera (*Globigerina* sp., *Globorotalia* sp.) and rare intraclasts. The tests of large benthic foraminifera are abraded. Typically, outer walls of *Amphistegina* sp. are damaged or missing and in some cases their tests exhibit fracturing through the entire thickness and disintegration into fine sand fragments ('BPTS 2 and BPTS 3' *sensu* Beavington-Penney, 2004). Intraclasts are made up of either facies A or facies B sand-sized to granule-sized fragments.

Interpretation

This facies is the most recurrent one in clinobeds and mostly consists of a mixture of bioclasts produced in a shallow-water carbonate

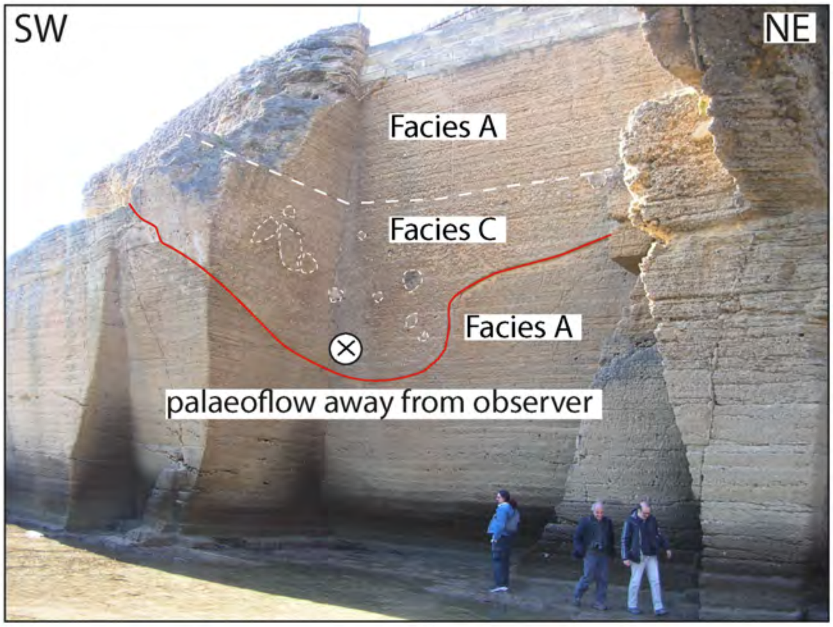


Fig. 6. Porto Miggiano locality (for location see Fig. 1). A channel-like sharp erosive surface cuts foreset beds. The filling deposit is made up of a chaotically-arranged facies (facies C). Some of the largest floating intraclasts are outlined by a white dashed line. People for scale are *ca* 1.8 m tall.

factory. The occurrence of seagrass related epiphytic benthic foraminifera (*Discorbids* sp., *Lobatula* sp. and *Planorbulina* sp.), articulated coralline algae showing a hooked structure, and encrusting bryozoans supports this interpretation since they were produced in seagrass facies belts of the photic zone (Larkum *et al.*, 2006; Moissette, 2013; Sola *et al.*, 2013). Moreover, the occurrence of non-articulated coralline algae, large benthic foraminifera, echinoids and other sciaphile organisms suggests that carbonate components were also produced in relatively deeper mesophotic environments, seaward of seagrass meadows. The occurrence of clinoforms along high-angle sloping surfaces suggests the action of hyperconcentrated density flows (*sensu* Mulder & Alexander, 2001), in particular a grain flow gravity-driven in origin, that achieved high velocities running out on the steep slope (i.e. the inherited escarpment). This kind of flow falls into granular avalanches (*sensu* Talling *et al.*, 2012) occurring on very steep slopes. This physical sedimentary feature together with the extensive reworking of large benthic foraminifera tests indicate re-sedimentation and shedding from a carbonate factory located in shallower water, most likely on top of the Salento plateau along submerged grabens. Therefore, these deposits comprise *ex situ* allochemics on the slope. Facies A occupies the axial part of aggrading and prograding lobes where the good preservation of lamination indicates relatively high rates of sediment supply due to repeated and continuous gravity events that justify the thin lamination and prevent the sediment reworking by biotic activity (see Facies B).

Facies B – Burrowed bioclastic packstone

Bright white to yellowish fine to medium-sized burrowed packstone represent the lateral and vertical evolution of the facies A in the clinobeds (Fig. 9B). In depositional strike sections, it forms both the top and the flanks of convex-up lenticular beds (Figs 7 and 8). The transition between the two facies is mostly gradual and it is marked by the increase of bioturbation. Because of pervasive burrowing, sedimentary structures are almost completely obliterated within strata and, in places, between strata. Fragments of lithophylloid coralline algae are the main lithofacies constituents (ranging from 30 to 40% of the total ones), although less abundant than in facies A (Fig. 10C). Other facies constituents are skeletal fragments of echinoids (both plates and spines), bryozoans, serpulids, bivalves, gastropods, benthic foraminifera (*Elphidium* sp., *Amphistegina* sp., *Lobatula* sp., *Planorbulina* sp., buliminaceans, textularids and rotaliids) and planktonic foraminifera (*Orbulina* sp., *Globigerina* sp. and *Globorotalia* sp.). Biogenic structures correspond to *Thalassinoides* and *Ophiomorpha* traces. Similar to facies A, also in this facies taphonomic preservation of benthic foraminifera tests indicate deep

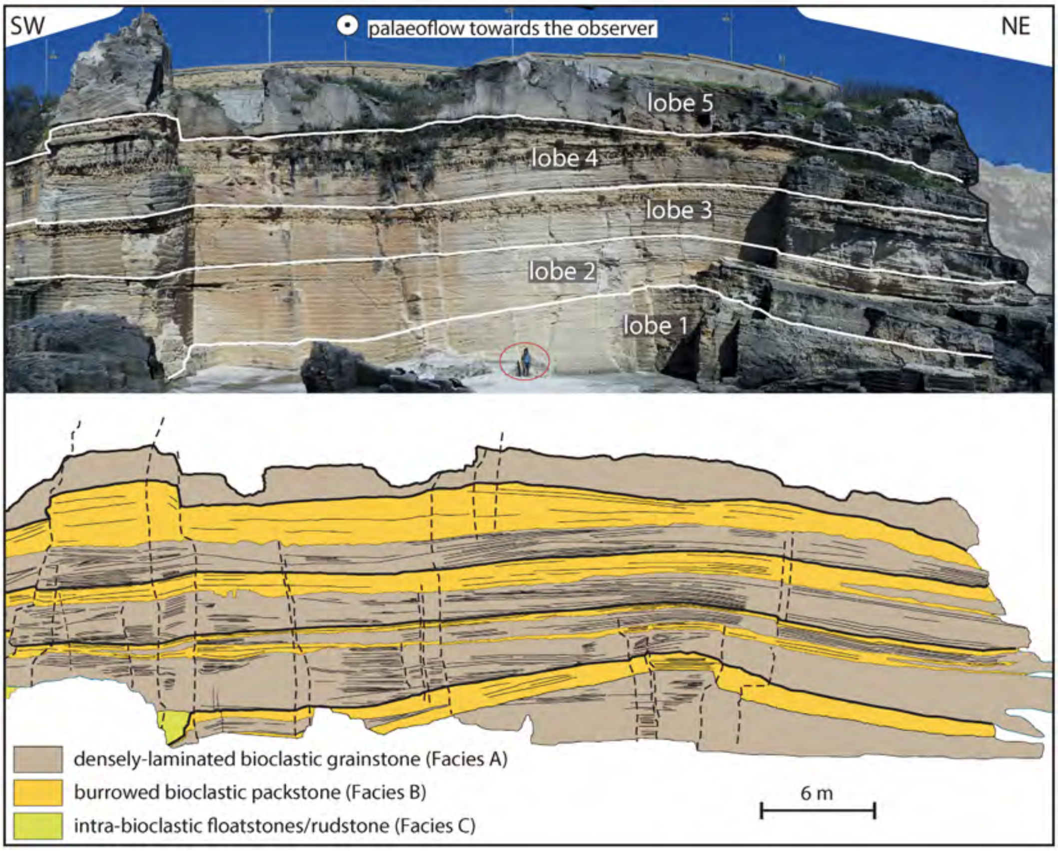


Fig. 7. Photograph and line drawing of the Santa Cesarea Terme (for location see Fig. 1) section along the depositional strike profile. Note that clinobeds show low angle cross-lamination to planar-lamination and form convex-up lobes. The white lines mark the clinoforms.

reworking ('BPTS 2 and BPTS 3' *sensu* Beavington-Penney, 2004).

Interpretation

Pervasively burrowed facies B is strictly related to facies A since it represents its lateral and vertical variation within individual beds. These facies are thus genetically related. The occurrence of *Thalassinoides* and *Ophiomorpha* traces can be indicative of lower rates of sediment supply (mostly *ex situ* transported material) in later stages of sediment deposition (abandoned lobes) or in underfed lateral position of the prograding lobe elements (i.e. the flanks of convex-up lenticular beds). The pervasive burrowing obliterated physical sedimentary structures.

Facies C – Intra-bioclastic floatstone/rudstone

The matrix-supported to clast-supported intra-bioclastic floatstone/rudstone are the coarsest sediments of the studied lower Pleistocene carbonate bodies. This facies lies within channel-like structures (Figs 6, 8 and 9C). These scoured surfaces are tens of metres elongated down the slope, basinward inclined, and can be vertically stacked and/or laterally juxtaposed. The thickness of channel-like fill deposits is largely variable from few decimetres up to several metres in the axis. The channel-like fill deposits are encased within either facies A or B (Fig. 8). Facies C is mostly made up of chaotically-arranged intraclasts (diameter from a few centimetres to about 1 m) and rhodoliths (diameter from 2 to 10 cm; Fig. 9C). Rhodoliths are formed by melobesioid-dominated coralline algae (*Mesophyllum* and *Lithotamnion*). Intraclasts consist of either facies A or facies B pebble-sized to boulder-sized debrites. Matrix is a packstone/grainstone (Fig. 10D), with common well-sorted and well-rounded skeletal fragments of coralline algae (articulated, branched, nodules), echinoids, bivalves, gastropods, large and small benthic foraminifera (*Elphidium* sp., *Lobatula*

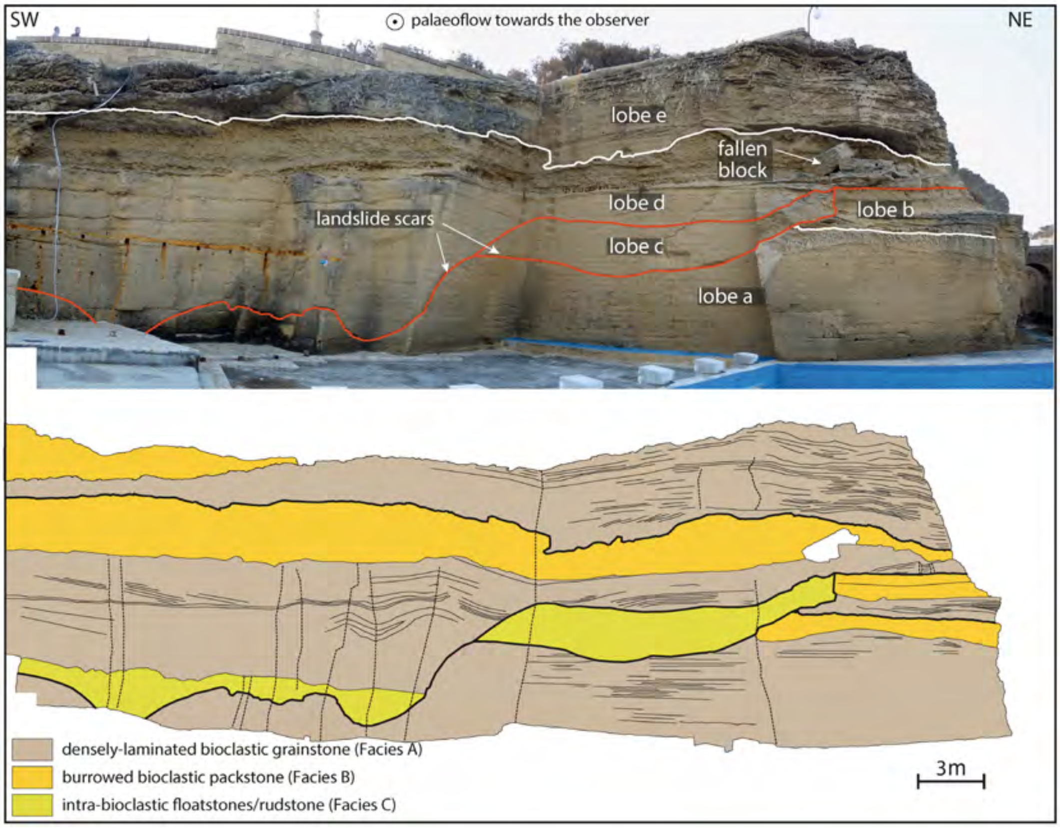


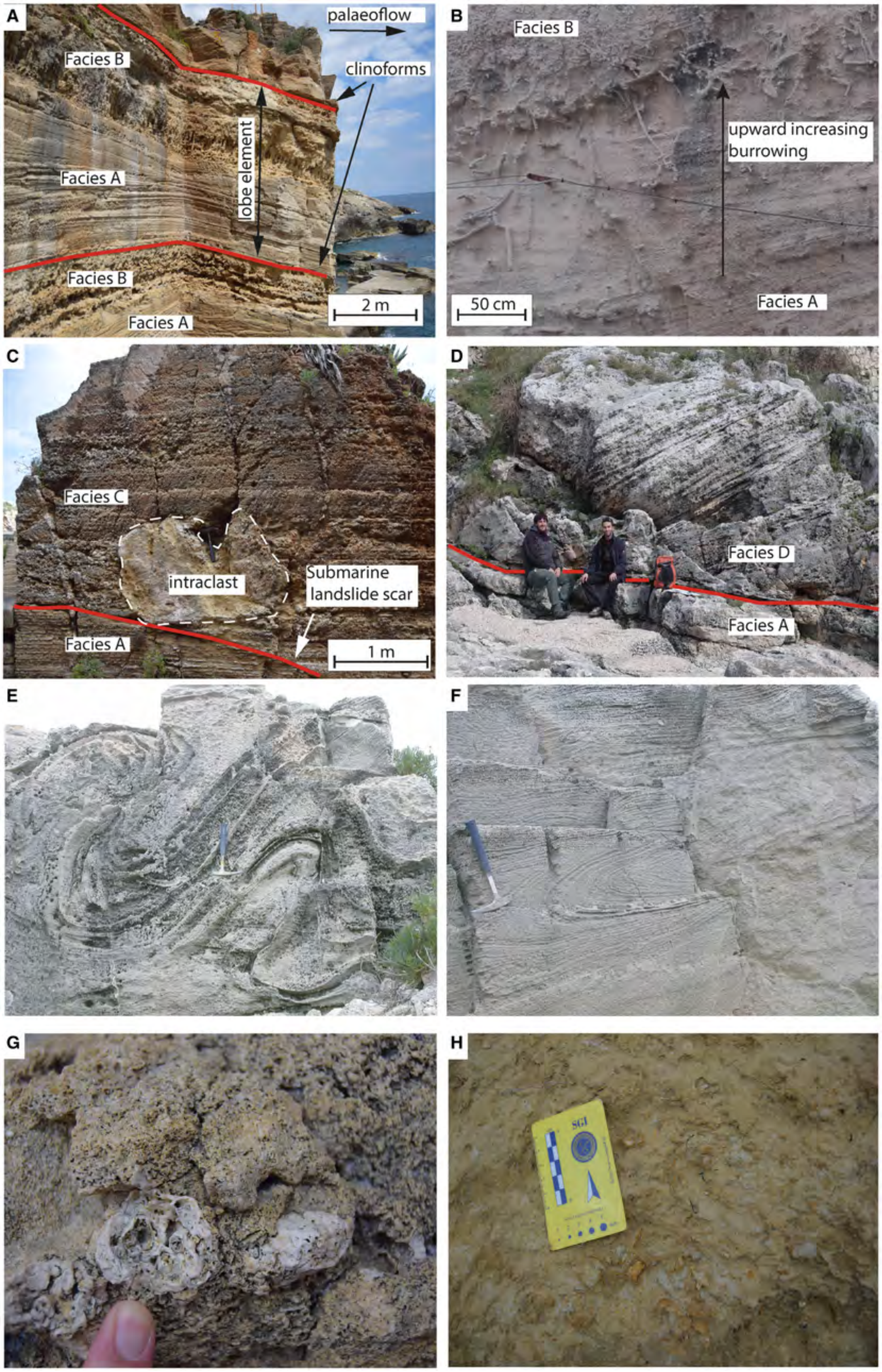
Fig. 8. Photograph and line drawing of the Porto Miggiano (for location see Fig. 1) section along the depositional strike profile. A complex channelized sharp erosive surface cuts foreset beds (red lines). Coarse-grained, chaotically-arranged, intra-bioclastic floatstone/rudstone (facies C) partly fill the scoured surface and pass upwards into facies A and B. The white line in the photograph marks the clinoform capping lobe d.

sp., *Planorbulina* sp., rotaliids and textularids) and subordinate planktonic foraminifera (*Globigerina* sp. and *Globorotalia* sp.). This facies does not record sedimentary structures, except for the progressive coarsening-upward of rhodolith size.

Interpretation

Chaotic and mainly matrix-supported intra-bioclastic floatstone/rudstone represent massive deposits due to gravitational processes that, together with the occurrence of coarser clasts in the upper part of the deposits, suggest the

Fig. 9. (A) Facies A: yellowish, planar-laminated to cross-laminated bioclastic grainstone. This facies shows both planar lamination; that is parallel to boundaries of the clinobeds, and large-scale cross-stratification. Into each lobe element, facies A alternates with burrowed bioclastic packstone (facies B). The red lines indicate the clinoforms delimiting the lobe element. (B) Bioclastic grainstone of facies A gradually passes upward into burrowed bioclastic packstone of facies B. Biogenic structures correspond to *Thalassinoides* and *Ophiomorpha* traces. (C) Facies C: intra-bioclastic floatstone/rudstone made up of chaotically-arranged intraclasts (from few centimetres to about 1 m) in a coarse packstone/grainstone matrix showing abundant rhodoliths. This facies fills a channel-like erosive surface (red line) that deeply cuts the underlying facies A. (D) Facies D: backset-bedded bioclastic grainstone. The red line marks the landslide-scar surface at the base of facies D cutting the underlying bioclastic grainstone of facies A. People for scale are *ca* 1.8 m tall. (E) Facies E: asymmetrical folds in a slumped bedset. Hammer for scale is *ca* 33 cm long. (F) Facies E: recumbent and sheet folds in a slumped bedset. (G) Facies F: crustose coralline algal bindstone made up of coralline thalli of melobesioids and large discoidal rhodoliths. (H) Facies G: burrowed bioclastic wackestone/floatstone. Chalky fine calcarenites showing abundant *in situ* bioclasts of echinoids.



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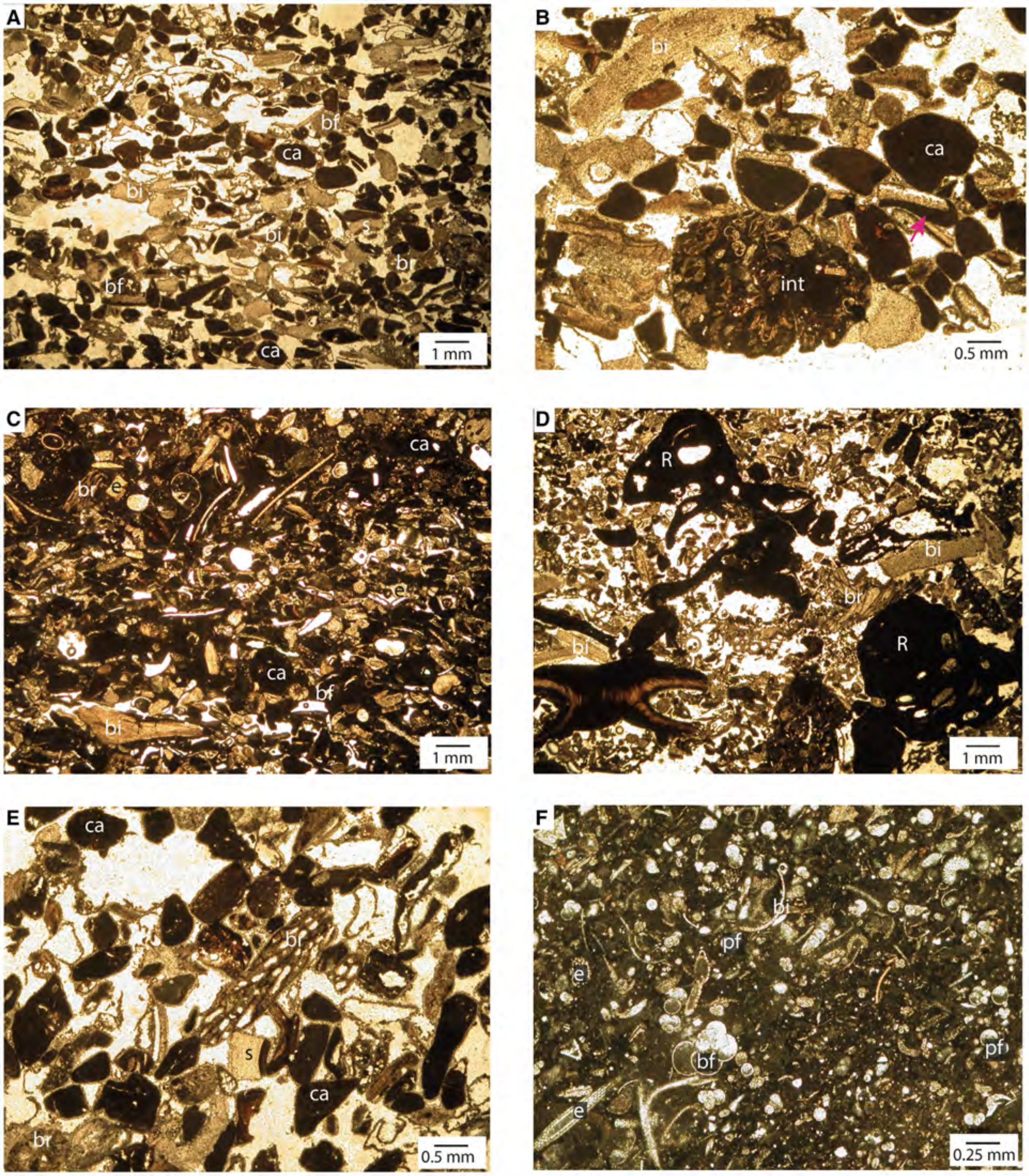

Fig. 10. Thin section microphotographs (plane polarized light). (A) Facies A: bioclastic grainstone consisting predominantly of coralline algal fragments (ca). Serpulids (s), echinoids (e), bivalves (bi) and benthic foraminifera (bf) are also common constituents. (B) Facies A: bioclastic grainstone showing coralline algae (ca), bivalves (bi), echinoids (e) and intraclasts (int). The arrow indicates a coralline algal fragment showing a hooked form. (C) Facies B: burrowed bioclastic packstone showing skeletal fragments of coralline algae (ca), echinoids (e), bryozoans (br), bivalves (bi) and benthic foraminifera (bf). (D) Facies C: intra-bioclastic floatstone/rudstone showing fragments of rhodoliths (R), serpulids (s), bivalves (bi), bryozoans (br) and benthic foraminifera (bf). (E) Facies D: grainstone in the backset-bed showing fragments of coralline algae (ca), bryozoans (br) and serpulids (s). (F) Facies G: burrowed bioclastic wackestone/floatstone showing echinoids (e), thin-shelled bivalves (bi), bryozoans (br), planktonic (pf) and benthic foraminifera (bf).

emplacement by non-cohesive debris flows (*sensu* Talling *et al.*, 2012, and references therein) driven by submarine landslides. The composition of both floating clasts and matrix material is the same as facies A or B, indicating that the landslide involved previously deposited carbonates of the same depositional system. The channel-like erosion surfaces cut into the underlying clinobeds are interpreted as the distal segments of submarine landslide scars promptly occupied by mass deposits (debrite) representing the freezing of downslope flowing material. Vertical and/or lateral stacking of these deposits and the occurrence of crossing multiple channel-like surfaces indicate relatively frequent landsliding events.

Facies D – Backset-bedded bioclastic grainstone

Low-angle to high-angle cross-beds, some decimetres to 1 to 2 m thick, that dip opposite to the master bedding (backsets), often occur within clinobeds. The lower boundary of backsets corresponds to spoon-shaped scours elongated perpendicular to the palaeoslope direction (Fig. 5). Along-dip, the scour inclination may vary from near-vertical to near-horizontal. Facies D sediments show a dense lamination that can be concave-up, planar, slightly convex-up, or in some cases sigmoidal in longitudinal section and concave-up in transverse section (Fig. 9D). The earlier-deposited steeper cross-laminae are generally planar or concave-up, whereas the subsequent, less-inclined laminae tend to broadly convex-up geometry. Successive cross-laminae within individual beds may show an upslope decrease in thickness and dip angle. They grade transitionally upslope into thinner and less inclined laminae, which become nearly conformable to the master stratification of the foresets. Facies D consists of bioclastic grainstone with the same composition and grain size as facies A. The cross-laminae are mostly made up of lithophylloid-dominated coralline algae, bryozoans, benthic foraminifera, echinoids, bivalves, gastropods, serpulids and subordinate planktonic foraminifera (Fig. 10E).

Interpretation

According to Nemec (1990) and Massari (1996, 2017) upstream dipping backset laminae represent scour and fill structures generated by upslope migrating hydraulic jumps; along a steep slope, when a sediment gravity flow becomes supercritical and encounters an obstacle or a surface irregularity, a hydraulic jump may occur. Sediment migrates against the flow direction back to the local break accreting an antidune-like sedimentary structure. In such a context, cyclic steps, consisting of trains of upstream-migrating and upslope-migrating bed undulations, can be produced on an irregular surface. Accordingly, the facies D is interpreted as the result of hydraulic jumps related either to an irregularity along the landslide scar or to its toe. Upward and upslope, laminae of the backsets progressively become laminae of the clinobeds (facies A or B) that seal the scour upward and laterally. It indicates the restoration of downflow ‘normal’ sedimentation in a relatively continuous action of a granular supercritical regime that moves bioclastic particles coming from a shallower marine setting. Although at a different scale and on less steep slopes, a similar evolution of progressive upward migration of backset laminae also grading distally into planar parallel laminae has been recently documented by Di Celma *et al.* (2020).

Facies E – Slump and other soft-sediment deformation structures

At the base and toe of clinoforms, in the axis of large-scale landslide scars, a few metres thick slumped layers occur in a sandwich arrangement with either facies A or G. Slump-related structures are contractional structures and consist of asymmetrical folds, thrusts with decollement surfaces, reverse faults, recumbent and sheet folds and imbricated structures affecting beds (Fig. 9E and F). Where sharp granulometric changes occur between beds additional soft-sediment deformation structures have been observed, such as load-casts and flame structures (Moretti, 1997). Slumps involve sediments belonging to the above-described facies. Other post-depositional structures are represented by extensional structures located at the head of the local landslide-scar surfaces and mainly represented by decimetric normal faults involving limited parts of the clinobeds (for a maximum thickness of 30 cm; Meloni, 2016).

Interpretation

The occurrence of extensional and contractional structures along landslide scars testifies to the slope instability. The possible trigger mechanism for the formation of landslide scars, slump sheets and slide bodies, could be represented by the action of synsedimentary tectonics. Nevertheless, the clinoforms locally show an up to 30° dip attitude representing the original sedimentary slope-inclination and a gravitationally-unstable system. In such a context, slope instability and sediment mass failure could also have been triggered by processes that were able to produce the conditions to overcome the internal friction angle of the involved materials. Extensional structures record stages of incipient landslide scar development. Contractional structures located at the slope toe record the cessation of the downslope slump transport.

Facies F – Crustose coralline algal bindstone

This facies crops out only at the Santa Cesarea locality, where it forms a 35 cm thick deposit lying directly above a channel-like scour. It is mostly made up of crustose coralline thalli of melobesioids (*Lithothamnion* and *Mesophyllum*) with large discoidal rhodoliths (up to 10 to 15 cm in diameter; Fig. 9G). The largest discoidal rhodoliths show an inner arrangement consisting of loosely-packed encrusting to foliose thalli with a high percentage of constructional voids.

Interpretation

This facies is the result of an *in situ* carbonate factory developed along the slope and mostly formed by red algal crusts and large discoidal rhodoliths ('crustal coralline algal bindstone' *sensu* Bassi, 2005). This facies formed under a relatively low hydrodynamic energy and low rates of sedimentation. Rhodoliths of this facies formed in relatively deep environments under oligophotic conditions. Similarities between the crustose coralline algal pavement and the rhodoliths described above for intra-bioclastic floatstones of the facies C suggest that reworked rhodoliths develop from eroded fragments of the crustose pavement.

Facies G – Burrowed bioclastic wackestone/ floatstone

This facies is mostly made up of fine-grained to medium-grained skeletal fragments of *in situ* echinoids, bryozoans, brachiopods, ostracods, sponge spicules, serpulids, bivalves and abundant planktonic foraminifera (*Orbulina* sp., *Globigerina* sp. and *Globorotalia* sp.; Fig. 10F). Biogenic structures include *Thalassinoides* and *Ophiomorpha* traces (Fig. 9F). This facies is organized in 0.5 to 2.0 m thick beds seldom showing 5 to 20 cm thick clay-rich intercalations.

Interpretation

This facies alternates with facies E and occurs at the toe of clinobeds where they gradually become subhorizontal forming a bottomset. Facies G mostly consists of an *in situ* deep-water carbonate factory in which light-independent biota, such as echinoids, brachiopods and delicate bryozoans developed. It represents the deepest facies of the studied successions. The presence of thin clay-rich intercalations suggests very low rates of carbonate sedimentation.

Facies distribution

Facies forming the lower Pleistocene fan-shaped deposits are vertically and laterally arranged developing several metres thick clinobeds bounded by complex channelized erosive surfaces. These surfaces are interpreted as the result of large submarine landslides that cut the underlying lobe deposits producing channel-like structures. Depending on the position of the landslide scar on the slope (proximal or distal part) and/or on the rheological behaviour of slide material, these channels were partly filled by debrites of facies C or by slumps of facies E. Backset-bedded deposits are also observed above the erosive surface and formed along the stoss side of hydraulic jumps corresponding to debrites or slump deposits or to the morphological irregularity of the landslide scar. Facies C to E pass upward to prograding bioclastic grainstone of facies A and B that mark the active feeding of the lobe element. Facies A forms the bulk of foreset beds, and laterally and vertically passes to burrowed bioclastic packstone of facies B. Facies B marks the top of the clinobeds. Although most of the carbonate sediment forming clinobeds is fed by an *ex situ* factory, facies F testifies to the occurrence of an *in situ* carbonate factory that developed at the base of the slope, under oligophotic conditions, during periods of low sedimentation rates and low hydrodynamic energy. This facies had a low preservation potential since their constituents are mostly found reworked into intra-bioclastic floatstones of facies C. Facies G developed at the toe of the foreset beds and interfingers with facies A and B. This facies represents the basinward continuation of the clinobeds and testifies to the occurrence of an *in situ* carbonate factory in aphotic conditions.

DISCUSSION

Starting from the attribution of studied carbonate deposits to one or more carbonate factories and determining their original position with respect to both the distribution of sediments in the studied bodies and the present-day physiography of the area, several interesting points emerge constraining collected facies data with regional palaeogeographic features. The complexity of interpretations led to proposing a depositional system for studied carbonates, whose features are difficult to classify using the known models.

Carbonate factories and environmental constraints

Lithophylloid-dominated coralline algae are the major components in the fossil assemblages of the studied deposits; they are well distributed in temperate seas, such as in the present-day Mediterranean Sea (Braga & Aguirre, 2001; Aguirre *et al.*, 2017; and references therein) and are typically produced in a rhodalgal carbonate factory, a kind of factory that develops in shallow-water depositional settings (Carannante *et al.*, 1988). Moreover, the presence of a diverse assemblage of benthic foraminifera seagrass dwellers, including Planorbulina, *Discorbids* sp. and Amphistegina, suggests that at least part of the carbonate sediment was produced in the euphotic zone (*sensu* Pomar, 2001), in a shallow-water depositional environment colonized by seagrass (see Brandano *et al.*, 2010, and Pomar *et al.*, 2012, among many others). This interpretation is also supported by the occurrence of some coralline algae showing a hooked structure and some encrusting bryozoans that lived as epibionts on seagrass leaves or rhizomes in shallow, subtidal seagrass meadows (see Moissette, 2013). The presence of branched and nodular coralline algae fragments, echinoid plates and spines, large and small benthic foraminifera suggests that seagrass meadows interfingered laterally with no vegetated areas, even passing seaward to relative deeper settings within the mesophotic zone. Since carbonate grains of each analyzed facies, except facies F and G, are mostly along-slope resedimented particles, i.e. an *ex situ* skeletal assemblage, the original position of their factories was located upslope with respect to their current position. Upward, in the apex of the fan-shaped bodies, clinobeds abut against a submerged palaeoscarp onlapping with a high angle onto the cliffed bedrock; this suggests that the upper part of the cliff was a bypass zone and that the feeding area of transported carbonate particles was located above it, likely in a flat setting adjacent to the cliff.

Despite the fact that most of the carbonate sediment forming the studied sedimentary system is represented by *ex situ* skeletons, the occurrence of autochthonous accumulations of discoidal rhodoliths in facies F suggests that an *in situ* carbonate factory was active along the slope, also on channel-like surfaces, or at their toe. Rhodoliths are made up of melobesoid-dominated coralline algae that typically, at temperate latitudes, progressively increase their abundance in deeper and deeper water, becoming the dominant group in the oligophotic zone (Aguirre *et al.*, 2017, and references therein). The best conditions for *in situ* rhodolith formation and persistence are good oxygenation, low sedimentation rates and relatively low-moderate water-hydrodynamics (Aguirre *et al.*, 2017). The same rhodoliths of those observed in facies F are present in the chaotic deposits of facies C. In this setting, they represent *ex situ* particles as a result of mass movement processes (see below). Another *in situ* carbonate production led to the formation of lithofacies G; the latter is characterized by echinoids, brachiopods, sponge spicules and bryozoans, which is a light-independent skeletal association indicating its origin in the aphotic zone of the system.

Palaeogeography

In the Mediterranean Sea, there has been, and is, good light penetration in areas around the Salento Peninsula. Additionally, this area has been without terrigenous input during its long geological history, and the boundary between photic and aphotic realms is indistinct, occurring between 80 m and 150 m (Stambler, 2012). Moreover, according to data from coralline algae distribution, it is likely that the boundary between the oligophotic and aphotic carbonate factory lies around 100 to 120 m depth (Canals & Ballesteros, 1997; Basso, 1998). According to Taddei Ruggiero (1983, 1993), palaeoecological data from brachiopods found in the analyzed carbonate bodies, suggests that they lived in environments with depths ranging between 100 m and 150 m. Since the studied brachiopods were found in the middle–lower part of the analyzed carbonate bodies and since the altitude of the upper edge of the present-day escarpment laterally varies between about 80 m and 120 m above sea-level, the present-day steep rocky slope connecting the ‘flat’ top of the

Salento Peninsula to the coastline of the Otranto Channel was a submerged escarpment during early Pleistocene carbonate sedimentation in the area (Tropeano *et al.*, 2004). Actually, the Salento top was not a true flat area, being represented by a wide and mild horsts and grabens system obliquely oriented with respect to the sharp escarpment. This bedrock physiography, basically inherited by the previous stages of the tectono-stratigraphic development of the area, was the main controlling factor in both production and distribution of early Pleistocene carbonate facies. In such a context, shallow-marine carbonate factories were likely hosted in the grabens. Within the exposed Serre, the local name of the structural highs corresponding to the horsts of the system, these shallow-marine settings played the role of embayments or seaways connecting the Ionian Sea to the Otranto Channel (Fig. 2). Towards the Otranto Channel, these shallow-marine areas were likely partly bounded from the basin through a submerged threshold corresponding to the reliefs of the Messinian-reef crests (Fig. 11). The lateral continuity of this morphological threshold was locally interrupted by faults generating crossing points connecting the top of the area to the escarpment (Tropeano *et al.*, 2004). Basically, in correspondence with faults, canyon-like morphostructures were present along the slope, forming lateral indentations along the submerged escarpment (Fig. 11).

The heterozoan skeletal debris produced on the inferred shallow-marine factories was not affected by weak early cementation and the *in situ* carbonate sediment remained unconsolidated on the seafloor, undergoing the same hydrodynamic processes that regulate the redistribution of loose siliciclastic sediments (Burchette & Wright, 1992; Braga *et al.*, 2006; Puga-Bernabéu *et al.*, 2014). Even if both depths of carbonate production and the original size of carbonate particles play an important role in the redistribution of sediments in bioclastic sedimentary systems (Pomar, 2001; Pomar & Kendall, 2008), shallow-marine hydrodynamic processes acting in the factory area could produce traction currents that, encountering the rollover point of the bedrock between the flat area and the cliff, would be transformed in gravity flows along the steep slope. Apart from the occurrence of storm waves, it is important to underline that seaways can induce currents with tide-amplification, and that semi-enclosed gulfs and embayments, due to their reduced depth, could be affected by thermohaline currents moving towards the adjacent basin (Longhitano, 2013; Longhitano & Chiarella, 2020). These flows, shedding coarse-grained carbonates and originating from an isolated carbonate platform, can be achieved by either cascading

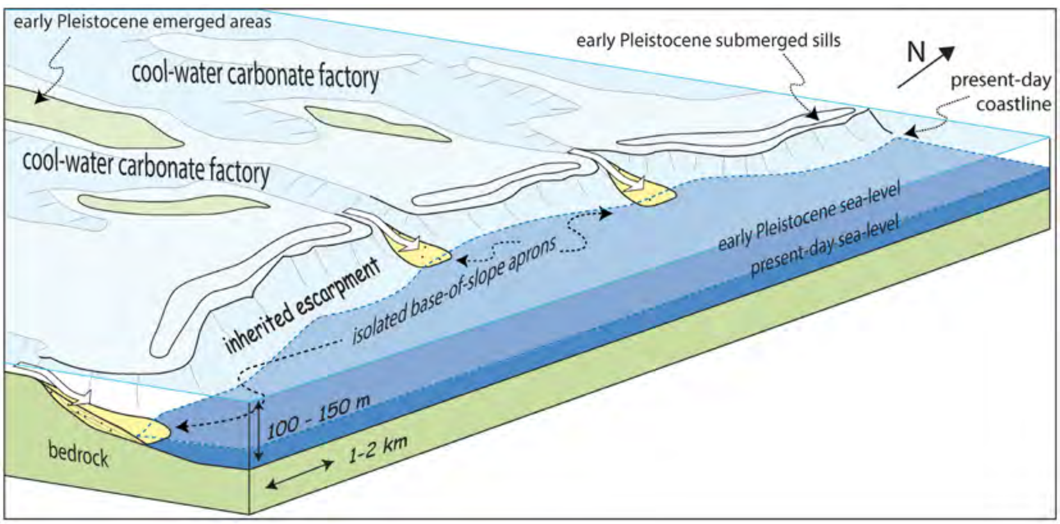

Fig. 11. Palaeogeographic scenario showing slope and base-of-slope sedimentation during the early Pleistocene (after Tropeano *et al.*, 2004). Most of the carbonate sediment was produced upslope by a shallow-water carbonate factory. Loose carbonate sediment was swept off from the loci of production and transported downslope along slope canyons, where it accumulated in base-of-slope fan-shaped carbonate bodies.

density currents or channel-focused shallow currents (Eberli *et al.*, 2019).

Carbonates produced in the early Pleistocene shallow-marine setting of the Salento Peninsula had a low preservation potential since they could be promptly swept off by currents from the shallow area via canyon-like morphostructures (Fig. 11). Moreover, they were prone to being easily eroded and completely dismantled during later regional uplift; indeed, they are recorded within grabens of the top of the Salento Peninsula by thin and discontinuous successions of soft rocks (see discussion in Festa *et al.*, 2018).

Depositional model

The shape and position of studied bodies, their internal architecture, mainly characterized by downlapping up to 25° to 30° originally inclined beds, and the occurrence of either a dense planar lamination parallel to the slope or of interlayered laminae and backset beds suggest that *ex situ* carbonate deposition took place under hyperconcentrated density flows running along the escarpment. This is typical of a high-gradient setting built out of areas influenced by shallow-marine hydrodynamics and fed by coarse grains (Massari, 2017), such as point-sourced Gilbert-type delta-slopes (Nemec, 1990), linear-sourced granule-dominated transition-slopes (Pomar & Tropeano, 2001), slopes of distally steepened ramps fed by a bioclastic factory (Pomar *et al.*, 2002; Massari & Chiocci, 2006; Massari & D'Alessandro, 2012).

According to the 3D architecture of clinobeds detected both along dip and strike sections, fan-shaped carbonate bodies formed as a consequence of lateral accretion of lobes (Fig. 12A). The occurrence of a dense lamination in the axial part of lobes (facies A) suggests that they were continuously fed (relative to the lobe 'life') by bioclastic sediment; conversely, the lobe fringes were underfed as shown by the pervasive burrowing (facies B). When a lobe avulsion occurred, laterally a new lobe was growing, and the top of the abandoned one was affected by pervasive burrowing (facies B). Lobes' growth and their internal sedimentary features suggest that they were relatively continuously supplied by grain flows funnelled along the slope through the pre-existing canyon-like morphostructures. The continuous flux of sediment in a morphostructural confined setting built up a fan-shaped sediment body along the middle–lower escarpment formed by the stacking and lateral accretion of several lobes on steep slopes.

As described in previous sections, clinobeds were frequently cut by channel-type scours often covered by massive deposits (facies C) and/or by backset beds (facies D) passing upward to laminated (facies A) and finally to bioturbated (facies B) deposits. Some scour surfaces represent the top of densely bioturbated intervals (facies B) and/or the starting area for rhodolith colonization (facies F). Locally, scour surfaces are overlain by slumps (facies E). Channel-like scours can be explained by the failure of unconsolidated sediments along the slope (Fig. 12B). Both massive deposits of facies C and slumps of facies E represent subaqueous landmass movements that cannot be interpreted as supplied directly from shallow-marine systems on top of the Salento Peninsula since they exclusively involve both redeposited (*ex situ*) and locally produced (*in situ*) along-slope sediments (Fig. 12B, C and D). In order to take into account the presence of these mass-transport deposits, landslide-scar surfaces must have originated on the depositional slope (Fig. 12B and D). Their basinward continuation was represented by the observed channel-like surfaces.

The possible trigger mechanism for the formation of landslide bodies can be attributed to the action of synsedimentary tectonics. Often the studied bodies show a sharp vertical contact with confining fault planes and growth-folds, and locally soft-sediment deformation structures accompany the contact. Along the contact, a damage zone, that indicates a younger activity of confining faults, hides the original vertical contact between carbonate bodies and sectors of the escarpments. Nevertheless, high angle dipping clinobeds represent a gravitationally unstable system, and slope instabilities could have been triggered by several phenomena (for example, oversteepening, earthquakes, etc.) able to produce conditions to overcome the internal friction angle of the involved materials.

When the subaqueous landslide originated in the vicinity of the body apex, the scar acted as a gully funnelling non-cohesive debris flows (Fig. 12B). In this kind of channel, backsets (facies D) developed thanks to channel bed irregularities. Regularly inclined laminae (parallel to the slope – facies A) progressively replaced backward inclined ones (facies C) producing a lobe that laterally lapped onto the flanks of the gully. If not abandoned, the same lobe expanded laterally, overbanking the gully edges. Moving updip

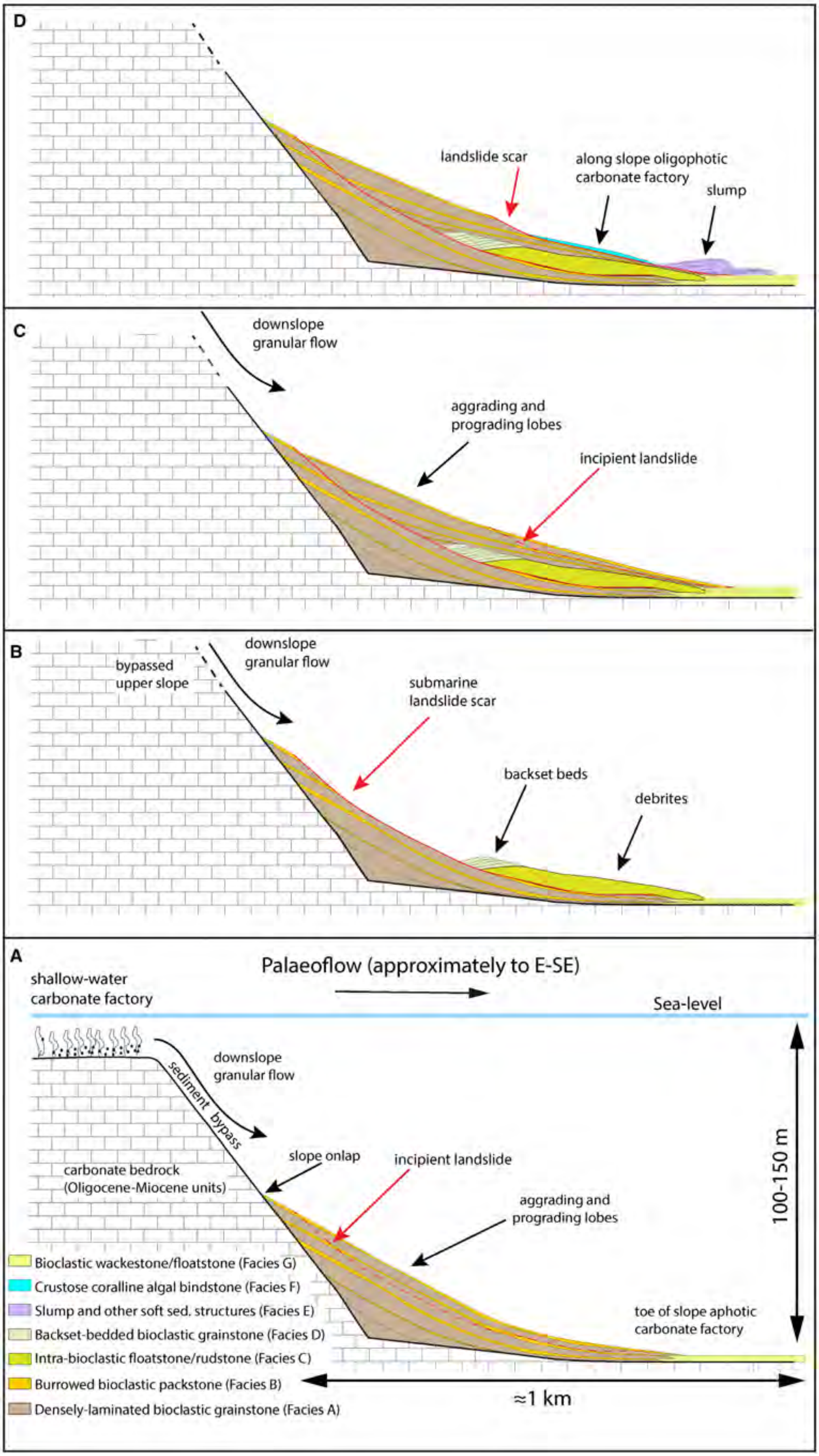
D
landslide scar
along slope oligophotic
carbonate factory
slump
C
downslope
granular flow
aggrading and
prograding lobes
incipient landslide
B
bypassed
upper slope
downslope
granular flow
submarine
landslide scar
backset beds
debrites
A
shallow-water
carbonate factory
Palaeoflow (approximately to E-SE)
Sea-level
downslope
granular flow
sediment bypass
slope onlap
incipient landslide
carbonate bedrock
(Oligocene-Miocene units)
aggrading and
prograding lobes
100-150 m
toe of slope aphotic
carbonate factory
≈1 km
Bioclastic wackestone/floatstone (Facies G)
Crustose coralline algal bindstone (Facies F)
Slump and other soft sed. structures (Facies E)
Backset-bedded bioclastic grainstone (Facies D)
Intra-bioclastic floatstone/rudstone (Facies C)
Burrowed bioclastic packstone (Facies B)
Densely-laminated bioclastic grainstone (Facies A)

Fig. 12. Depositional model proposed for the study area. (A) Lobe elements started to accumulate at the base of the slope (only Facies A and Facies B formed) that interfingered with *in situ* carbonate deposits of Facies G. (B) As a consequence of slope instability, a large slide scar formed on the depositional slope. The downslope continuation of this landslide scar corresponds to a channel-like scour surface filled by debrites (Facies C). Backsets (Facies D) formed back to the debrites. (C) The scar was sutured by the deposition of a new prograding lobe. (D) The formation of a new landslide along the depositional slope led to the deposition of a slump (Facies E). Note that an *in situ* carbonate factory developed on top of the landslide surface (Facies F).

along the slope, laminae of facies A may have filled the scar and, without the presence of bioturbation (facies B), easily they overlaid similar sediments (intraformational unconformities). As a matter of fact, laterally following some gully surfaces they pass to be simple bed boundaries.

When the subaqueous landslide originated in the middle–lower part of the carbonate body in an underfed sector, the scar simply cut previous deposits and became the new colonizing surface with the development of facies F and G until fluxes of debrites affected the area again. The shorter movement of these landslides probably favoured the formation of slumps (facies E) rather than debrites (facies C; Fig. 12D).

Based on the overall described and interpreted features, studied bodies can be partitioned into three depositional zones: proximal, intermediate and distal ones. The proximal zone is marked by the alternation between facies A and B that respectively reflect the aggradation and avulsion of lobes. These facies are arranged in a few metre-thick clinostratified bodies forming clinobeds. The upper part of these beds can be missing because they are eroded by landslide scars.

The intermediate zone shows the same features of the proximal zone but it is marked by a more articulated facies association forming relatively thicker clinobeds (from several metres to a few tens of metres). In the latter case, mass-transported and gravity-driven deposits (facies C and E) lie above gully surfaces. Directly on top of or in the immediate upslope position of the landsliding deposits, i.e. directly onto the erosion surface, backset-bedded deposits (facies D) gradually pass to facies A and then to facies B, indicating that, after the sliding event, normal sedimentation was restored and that the mass-transport features were sealed by the progradation and abandonment of a new lobe on the slope (Fig. 12B and C). Again, the upper part of these clinobeds can be missing because of the occurrence of landslides.

The distal zone is characterized by the toe of the clinobeds grading downdip to gently inclined to sub-horizontal-strata. These are mostly made up of burrowed deposits (facies B and G) interfingering with mass-transport sediments (facies C and E).

Which name for the study system? Not only a semantic challenge

A brief review of the carbonate slope nomenclature

Carbonate depositional slopes at the shelf/platform margin represent an intriguing topic in the study of re-sedimented systems. First of all, in contrast to siliciclastic ones, whose maximum slope gradient reaches 3° to 6°, they can show a slope gradient reaching up to 35° to 40° (Kenter, 1990; Playton *et al.*, 2010; Reijmer *et al.*, 2015). Considering shore to basin depositional equilibrium profiles, slope angle corresponds to the angle of repose of involved particles (Rich, 1951) which means that the steepest carbonate slopes are characterized by very coarse grains (Kenter, 1990; Schlager & Reijmer, 2009). Apart from shore to basin depositional equilibrium profiles, higher gradients of carbonate slopes can be related to the formation of bioconstructed or promptly cemented margins at the platform edge; in these cases, the keep-up capacity of platforms can lead to the build up of subvertical upper foreslopes that become bypass zones for sediments exported from the platform to the lower part of the slope (Enos & Moore, 1983). The bathymetric gap between the platform top and the basin floor progressively increases because of shallow-marine carbonate production. These carbonate systems, even when not rimmed, may aggrade up to sea-level, building a steep margin that could be confused with a fault plane (Kendall & Schlager, 1981; Schlager & Camber, 1986; Antoncecchi *et al.*, 2013). Re-entrants between these bypassed upper foreslopes (steep margins) represent preferential zones for carbonate delivery to the adjacent basin, and coarse-debris talus-cones, detached from the feeding shallow-marine carbonate system, may occupy the base of these steep margins (Enos & Moore, 1983). Moreover, all kinds of margins could be inherited by younger carbonate systems developed in the area, whose sediment distribution can be influenced by the antecedent topography (Eberli *et al.*, 1993; quoted as an example by Playton *et al.*, 2010).

McIlreath & James (1978) called the two kinds of foreslope described above (shore-to-basin continuous profiles versus sub-vertical ones) depositional margins and bypass margins, later defined as accretionary margins and escarpment margins by Playton *et al.* (2010). Foreslope deposits on both kinds of margins were modelled by Cook (1983); that study introduced the terms carbonate slope aprons and carbonate base-of-slope aprons, respectively, for depositional margins and bypass margins. The term 'apron' contrasted with the term 'submarine fan' which at that time was the only term used to described deep-water depositional systems developed at the base of basin margins. Differing from submarine fans, which are point-sourced, carbonate aprons represent line-sourced wedge-shaped bodies parallel to the adjacent shelf/slope break (Mullins & Cook, 1986); moreover, deep-sea-fans mainly develop on the basin floor while aprons are mainly represented by foreslope deposits. Recently, an accretionary and prograding point-sourced (channel-related) carbonate-body was described off the Maldives and defined as a 'carbonate delta drift' (Lüdmann *et al.*, 2018). This term is used to define some point-sourced slope-carbonates (Eberli *et al.*, 2019; Reolid *et al.*, 2019; Slootman *et al.*, 2019).

It must be highlighted that all quoted works deal with tropical/subtropical carbonate systems, both of whose productivity and bioconstructed margins and/or early-cemented margins led to the platform aggradation, with a progressive steepening of the slope up to a vertical bypass zone (Schlager & Ginsburg, 1981). Temperate water carbonate systems, to which the studied example belongs, lack a protecting reef and always show sigmoidal (Gaussian, *sensu* Adams & Schlager, 2000) depositional slope profiles (Adams & Kenter, 2013). These carbonate systems respond to hydrodynamics like siliciclastic shelves (James, 1997; Reijmer *et al.*, 2015) even if feeding loci of siliciclastics are located along the coast while production loci of this kind of carbonate can be located along the whole shallow-marine profile, preferentially in mid-ramp/oligophotic settings (Pedley, 1998; Pomar, 2001). Rather than shelves, these processes led to the development of carbonate ramps, whose depositional profiles often show a distal step (Burchette & Wright, 1992; Pomar, 2020). This step represents a prograding depositional slope which can reach a dip angle of 20° or greater (i.e. Pomar *et al.*, 2002), similar to depositional slopes of Plio-Quaternary cool-water carbonate systems developed in the Mediterranean Sea (Lickorish & Butler, 1996; Martín *et al.*, 2004; Massari & Chiocci, 2006; García-Ramos & Zuschin, 2019). Oversteepening of critical angle along this kind of slope can induce sediment failures, with landslide scars successively filled by along slope deposits, even by backsets, to restore the original steep prograding profile (Pedley *et al.*, 1992; Pedley, 1998; Hansen, 1999; Pomar *et al.*, 2002; Massari & Chiocci, 2006). In contrast, distally steepened carbonate ramps with low-angle slopes favour the development of calciclastic submarine fans rather than a progradation of the slope itself, with a network of bypassed slope gullies feeding a channel-levée system on the adjacent flat sea-floor bottom with lobes and/or extensive sheets at the mouth of the channel (Payros & Pujalte, 2008). The latter, as well as the ramp systems, are not comparable with the here studied carbonates that formed isolated and confined, small-sized, subaqueous bodies in the middle–lower part of foreslope indentations of a pre-existing rocky escarpment. It must be emphasized that Plio-Pleistocene temperate water carbonate deposits in the Mediterranean Sea are often described as influenced by the antecedent morphology. In these cases, unlike tropical/subtropical platform margins, the antecedent morphology was induced by previous tectonics or volcanic highs rather than by previous periods of subvertical growth of the upper foreslope. Therefore, below 'right' relative sea-levels, pre-existent bedrock features, strongly influenced by hydrodynamics, become canyons, foreslopes, ponded basins and terraces bypassed or hosting either factories or resedimented carbonates (Johnson *et al.*, 2005; Titschack *et al.*, 2013). The complexity of Plio-Pleistocene carbonate sedimentary systems in these settings, often characterized by siliciclastic–carbonate mixed deposits, is testified to by the number of works dealing with the morphological control on the distribution of factories/sediments on these highly-structured shallow-marine areas, mainly related to small isolated landmasses (e.g. Hanken *et al.*, 1996; Martín *et al.*, 2004; Titschack *et al.*, 2005; Steinthorsdottir *et al.*, 2006; Mateu-Vicens *et al.*, 2008; among many others).

The isolated base of slope aprons of the Salento case study

As shown, the studied carbonates formed isolated and confined, small-sized, subaqueous bodies in indentations of a pre-existing rocky escarpment. Owing to their features, these bodies located in the middle–lower part of a pre-existing foreslope must be considered as evidence of the original distribution of isolated lower Pleistocene high-angle slope-carbonates (strike-discontinuous fan-shaped bodies) rather than residual limbs of a laterally continuous depositional slope (a wedge later dissected by erosion). The main lithostratigraphic feature is that bodies are characterized by clinobeds, whose size falls in the 'delta-scale clinoforms' of Patruno *et al.* (2015).

Not accounting for biofacies and considering similar examples developed in the Mediterranean realm, the studied carbonate bodies show some analogies with deposits and depositional settings described in the Late Miocene of Almeria, Spain (Sola *et al.*, 2017), in the Plio-Pleistocene of Rhodes, Greece (Titschack *et al.*, 2005; Steinthorsdottir *et al.*, 2006) and in the Pleistocene of Matera, Italy (Mateu-Vicens *et al.*, 2008).

- Late Miocene deposits of Almeria developed at the base of a rocky foreslope expanding in lobate bodies with relative low angles of dip (up to 10° to 12°). Analogies with this example regard the original strike discontinuity of these deposits, the inferred presence of a shallow-marine factory above the foreslope, and the presence along it of bypassed structural depressions acting like canyons through which carbonates were delivered to the basin floor.
- Plio-Pleistocene deposits of Rhodes belong to several different formations, some of which developed on steep slopes as drapes (Kolimbia Limestone) or prograding clinobeds (Cape Arkhangelos Calcarenite). Analogies with the current example regard the high-angle of repose (20° and more) of these carbonates, placing them on the steep pre-existing rocky cliff, and that sedimentary foreslopes, whose toe could reach more than 100 m of depth below sea-level, hosted temperate water factories.
- Pleistocene deposits of Matera, showing a sigmoidal profile, developed on a steep slope induced by the basement structure. Analogies with the current example regard the high-angle of repose and the double supply of skeletal grains: resedimented epiphytic carbonates coming from a flat producing area above the foreslope, and an *in situ* red algae contribution.

In the siliciclastic realm, the Salento case study shows some analogies with underwater conical bodies (*sensu* Nemec, 1990) or base of scarp deposits (*sensu* Chiarella *et al.*, 2021), i.e. coarse-grained deltas lacking subaerial distributary plains, showing high-angle deposits physically disconnected from their feeding area and whose facies record gravity-driven processes. The strike discontinuity of carbonates from this study resembles that of multiple-source gravel-rich siliciclastic ramps (*sensu* Reading & Richards, 1994). In the carbonate realm, the geometry and distribution of these deposits can be compared with those of coarse-debris talus cones produced at the base of forereefs, but the term talus (basically used in subaerial environments) should refer exclusively to rock-fall deposits rather than to gravity flow ones. Therefore, to a first approximation, the Salento carbonate bodies could be considered examples of carbonate deltas, but the term 'carbonate delta' was previously used to indicate alluvial fed shallow-marine bodies comprising exclusively rounded limestone-fragments coming from eroded and exposed carbonate rocks (Babic *et al.*, 1985; Postma *et al.*, 1988; Sabato, 1996; Tropeano & Sabato, 2000). This use is consistent with the meaning of the term delta, that, as described by the United States Geological Survey, is: "the fan-shaped area at the mouth, or lower end, of a river, formed by eroded material that has been carried downstream and dropped in quantities that cannot be carried off by tides or currents". Therefore, the term delta should be applied exclusively to carbonate deposits fed by an alluvial system and avoided for other carbonate deposits. Finally, the term shallow-marine fan or subaqueous fan, even if geometrically correct, must be avoided since it evokes an image and often refers to a deep-sea (turbiditic) fan developed at the toe of a slope and in the adjacent basin-floor rather than, basically, along the same slope. The definition of the studied carbonates was tentatively proposed by Tropeano *et al.* (2000, 2004) describing them as bodies with a fan morphology corresponding to small isolated shallow-marine aprons. Even if not confined, almost similar coeval bodies observed in another setting of the Apulia Foreland were called 'fan-shaped bodies', also referred to here as aprons (Mateu-Vicens *et al.*, 2008). The term apron, even if used also to indicate the along slope deposits of coalescent coarse-grained fan deltas [linear-source gravel-rich slope apron (Reading & Richards, 1994)], is already basically referred to carbonate-slope systems. In fact, the term carbonate apron promptly suggests the presence of a shallow-marine factory feeding the slope that cannot be confused with a terrigenous source. In the study example, the inherited topography led to the development of confined versus conical high-angle depositional carbonate-slopes, respectively constrained or not in rocky re-entrants, fed by a temperate water factory. These deposits resemble the strike discontinuous aprons of Playton *et al.* (2010) but the latter are originated by scallops on a coeval lithified platform margin rather than by pre-existent topographic indentations later used as point sources for skeletal grain delivery. The studied deposits show also an *in situ* production, i.e. the presence of a carbonate factory along the slope. The presence of loose resedimented carbonate particles along the slopes likely acted as positive feedback for the development of an along-slope factory, whose deposits were never found along the adjacent rocky foreslope. Therefore, an acceptable oxymoron for studied carbonate fan-shaped bodies with a double carbonate source is suggested: 'isolated base-of-slope aprons'.

CONCLUSIONS

The major conclusions derived from this study are:

- Lower Pleistocene base-of-slope carbonate deposits form fan-shaped isolated bodies cropping out in some indentations of the cliff. They pinch onto a steep rocky slope that connects the Salento Peninsula to the coastline of the Otranto Channel in the present-day.
- Facies analysis revealed that most of the carbonate grains are made up of *ex situ* bioclasts that were resedimented along-slope. The original position of their factory was located upslope in shallow-water depositional environments colonized by seagrass and dominated by lithophylloid coralline algae. The fossil association was produced in a rhodalgal carbonate factory and proliferated in a temperate sea such as the present-day Mediterranean Sea. Limited autochthonous production of carbonate sediment also occurred along the slope and at its toe where oligophotic (dominated by melobesioid coralline algae) and aphotic *in situ* carbonate factories were active.
- The bedrock physiography, mostly the result of pre-Pleistocene tectonics, was the main controlling factor in both production and distribution of carbonate sediment in the area. In this context, shallow-marine carbonate factories were hosted in embayments or seaways connecting the Ionian Sea to the Otranto Channel (i.e. the grabens formed between the Serre Salentine horst system). Along the Otranto Channel margin, carbonate-producing areas were partly bounded from the basin by a submerged threshold corresponding to the crest of the Messinian reef. The lateral continuity of the threshold was interrupted by canyon-like morphostructures developed in correspondence with north-west/south-east-oriented faults. These canyons crossed the slope and acted as preferential conduits for the downslope transport of bioclastic sediment.
- It is suggested that shallow-marine hydrodynamic processes acting in the factory area promoted the formation of gravity flows funnelled by escarpment indentations.
- According to the internal architecture of clinobeds and to sedimentary structures (dense planar lamination parallel to the slope and backsets) it is here inferred that carbonate re-deposition along the slope took place under relatively continuous grain flows. Synsedimentary tectonics and/or gravity slope instability promoted the formation of subaqueous landslides. As a consequence, landslide scars and related mass-transport deposits originated along the slope interrupting the lateral and vertical continuity of clinobeds.
- Studied carbonate slopes were fed by point-sourced fluxes of sediment coming from a shallow-marine factory. The diffuse use of the term apron for carbonate slopes leads to the introduction of new terminology 'isolated base-of-slope aprons' for the studied bodies, since aprons are related to linear sourced sediments rather than to point sourced ones.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests that might have influenced the work described in this manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author Luigi Spalluto upon reasonable request.

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Supporting Information

Additional information may be found in the online version of this article:

Fig. S1. A young Prof. Luis Pomar when Marcello Tropeano (MT) was a PhD student. The original caption that MT sent him was: "MT with 3 of his students", that the big 3 (Bill Ward, Luis Pomar and Wayne Har) greatly appreciated. The opportunity to meet these carbonate experts was offered by Francesc Calvet, who in July 1993 invited MT to participate in an impressive field trip on the Miocene coral reef of Mallorca (Spain). This excursion was organized and led by Luis and Bill for a research group of the University of Barcelona (Spain). The photo was taken in a laboratory of the UIB (Universitat de les Illes Balears, Spain) after the trip, when Luis and Bill, writing an article later published in Geology in 1994, were taking a little break with Wayne and MT.