Displaced/re-worked rhodolith deposits infilling parts of a complex Miocene multistorey submarine channel: a case history from the Sassari area (Sardinia, Italy)

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Abstract

In the Sassari area (north-western Sardinia, Italy), the Miocene Porto Torres sub-basin sequences represent the complex multistorey mixed carbonate–siliciclastic submarine feature called the Sassari Channel. During the late Burdigalian–early Serravallian, repeated terrigenous supplies from uplifted Paleozoic crystalline substrata fed the Sassari Channel system by means of turbidity and locally hyper-concentrated turbidity flows. Shelfal areas were the source of terrigenous clasts, but open shelf rhodalgal/foramol carbonate areas were very productive and largely also contributed to the channel infilling. Re-worked sands and skeletal debris were discontinuously re-sedimented offshore as pure terrigenous, mixed and/or carbonate deposits. Major sediment supply was introduced between the latest Burdigalian and the start of the middle Langhian, during which a large amount of carbonate, mixed and siliciclastic sediments reached the Porto Torres Basin (Sassari Channel I). Contributions from shallow proximal source areas typify the lower intervals (Unit A) in marginal sectors of the channel. Upward, these evolve into autochthonous rhodolith deposits, winnowed by strong currents in relatively shallow well lit settings within a complex network of narrow tidally-controlled channels (Unit D) locally bearing coral assemblages. Conversely, re-sedimented rhodoliths from the Units B and C accumulated under conditions of higher turbidity. In deeper parts of the channel taxonomically diversified rhodoliths point to the mixing of re-deposited skeletal components from different relatively deep bathymetric settings. In the latest early Langhian major re-sedimentation episodes, resulting in large prograding bodies (Unit D), triggered by repeated regression pulses in a frame of persistent still stand. During these episodes photophile assemblages dwelled in the elevated margin sectors of the channel. A significant latest early Langhian drop in relative sea-level resulted in impressive mass flows involving early cemented channel-margin and levee blocks and culminated in the formation of major erosional surface. Such events seemingly correlate with the long-term global cooling trend of the mid-Miocene climatic transition. Episods of middle Langhian re-sedimentation concluded with the channel abandon phase after which new erosive episodes followed. Overall, this led to a shift in the Sassari Channel II, with phases presumably started during the earlymost Serravallian, subsequent to the major sea-level drop at the Langhian–Serravallian boundary.

Keywords:
submarine channels,mixed carbonate-siliciclastic sediments, rhodolith deposits, Miocene
Sardinia
Italy

1. Introduction

Intensive Oligocene–Miocene tectonism affected the Cenozoic Mediterranean region and led to the formation of extensional basins such as the Sardinia Graben in its western ragion (“Fossa sarda” *Auctorum*, Vardabasso, 1963), central Mediterranean Sea (Italy). The tectonic structure related to the Sardinia Graben runs S-N from Cagliari to Sassari (Fig. 1), extending northward into the Asinara Gulf and offshore toward western Corsica (Rossi et al., 1998; Ferrandini et al., 2003). Oligocene–Miocene mainly siliciclastic and subordinately carbonate deposits fill the tectonic-driven basin. Significant volcanic contributions are linked to a coeval calc-alkaline cycle (Lecca et al., 1997; Funedda et al., 2000).

The Sardinia Graben comprises several minor sub-basins which formed on smaller grabens and half-grabens with opposing polarity (Cherchi and Montadert, 1982, 1984; Casula et al., 2001; Cherchi et al., 2008) influenced by the initial tectonic fragmentation of the pre-Oligocene basement made up of metamorphic and magmatic rocks of Ercinian origin (Sowerbutts and Underhill, 1998; Sowerbutts, 2000; Casula et al., 2001; Oggiano et al., 2009). Mesozoic marine limestone and intensely fractured and weathered Middle Eocene continental material locally underwent Oligocene–Miocene deformation (Barca and Costamagna, 2010). Oligocene continental deposits (i.e., the Ussana Formation**;** Cherchi and Montandert, 1984**;** Cherchi et al., 2008) accumulated during the first stages of the basement dissection (syn-rift stage according to Casula et al., 2001) mainly in the southern parts of the Sardinia Graben where they pass, through a disconformity surface, to Miocene marine and terrigenous sediments. In the central-northern sectors, only very thin and discontinuous Lower Miocene continental deposits reached the deformed basement, but were rapidly enriched by open-marine biotic components (Cherchi et al., 2000; Funedda et al., 2000, 2003; Vigorito et al., 2005, 2006).

Active tectonics, relative sea-level oscillations and localized ecological factors combined to control the rate and type of sediment input to the minor sub-basins as well as the location, development and demise of patchy localized carbonate factories (Cherchi et al., 2000; Vigorito et al., 2005, 2006; Bassi et al., 2006). Carbonate factories developed locally at the top of fault-blocks along the submerged margins of the sub-basins where the environmental and topographic settings were suited to different biotic benthic components (Cherchi et al., 2000). Tectonics largely controlled the physiography of the sub-basins and in turn the location and trend of sediment pathways which locally included large submarine channel-systems (Murru et al., 2001; Vigorito et al., 2005, 2006).

Several different sub-basins have been described from the northern sector of the Sardinia Graben (Thomas and Gennesseaux, 1986; Pecorini et al., 1988; Funedda et al., 2000; Oudet et al., 2010). Among them the largest are: Castelsardo (CB), Logudoro (LB) and Porto Torres (PTB; Fig. 1). In the Sassari area, Vigorito et al. (2006) investigated complex successions pertaining to the PTB, located at the top of a 16 km-wide East-dipping half-graben and extending both onshore and off-shore, in the northern sector of the Sardinia Graben. The analysis of extensive exposures of the Porto Torres sub-basin fill sequences allowed the reconstruction of discrete phases of active channel filling. Individual channel units are are partly nested and vertically stacked resulting as a whole in the multistorey aggradational architecture of a submarine channel, called the Sassari Channel (Fig. 2; Vigorito et al., 2006). In the present paper**,** the detailed description of the carbonate to mixed siliciclastic–carbonate sediments of this channel and the more detailed biostratigraphic assessment of the sedimentary succession are discussed in the context of previous stratigraphic studies.

The aims of this paper are (1) to characterize the rhodolith lithofacies which represent the bulk of the carbonate infilling sequences in PTB, and (2) to analyze the hemipelagic planktonic foraminiferal silty marls in which the re-sedimented coarser carbonate and siliciclastic deposits intercalate in order to increase the stratigraphic time-span resolution of the sedimentary succession. A more detailed stratigraphic setting of the channel system's sedimentary bodies is necessary to understand the complex stratigraphical architecture made up of re-worked sediments and infilling sequences and to frame the major re-sedimentation phases in the complex Miocene palaeoclimatic context.

2. Geological setting

The NNW-SSE oriented Porto Torres Basin (PTB; Fig. 1) is located on the hanging wall of the Osilo fault (Fig. 2). The related footwall fault block, made up of Aquitanian calc-alkaline volcanics (Osilo palaeohigh, 22.3 ± 1.1 Ma; Lecca et al., 1997), and an E-W oriented transtensive fault (Ittiri fault) bound respectively to the East and to the South the PTB (Funedda et al., 2000). The Ittiri fault (IF in Fig. 1) separates the east-dipping half-graben of PTB from an adjacent west-dipping half-graben, the Logudoro Basin (LB in Fig. 1). The PTB and the LB shared a common tectonic-sedimentary evolution. An on-going debate concerns the tectonic style of the region during the Oligocene–Miocene. Rift-related extensional *versus* transtensive/transpressive events were discussed for the genesis of the Sardinian Oligocene–Miocene basins (Funedda et al., 2000; Carmignani et al., 2001; Casula et al., 2001; Faccenna et al., 2002; Oggiano and Funedda, 2007; Dieni et al., 2008; Cherchi et al., 2008; Dieni and Massari, 2011; Oggiano et al., 2009, 2011).

According to Pecorini et al. (1988), in the PTB the Mesozoic carbonate substrate subsided up to 2.000 m below ground surface and volcanic deposits mainly filled the related depression. Active PTB extensional phases were associated with deposition of calc-alkaline volcanics with ages spanning between 22 Ma and 18 Ma (Lecca et al., 1997). The volcanic deposits are overlain by lower Burdigalian lacustrine and fluviatile-lacustrine epiclastic deposits ("Lacustre" *Auctorum*; Pomesano Cherchi, 1971; Cherchi, 1985; Tilocca, 2003). The late extensional phases led to a down-faulting of previous sequences and created new accumulation space.

In the Porto Torres Basin and Logudoro Basin, Mazzei and Oggiano (1990) subdivided the deposits in 5 main lithostratigraphic units. Later, Funedda et al. (2000, 2003) defined the related geological formations (Fig. 3). Based on preliminary data, Vigorito et al. (2006) suggested a late Burdigalian–earliest Serravallian age for the Sassari sequences (Fig. 3), partially confirming the previous dating by Cherchi (1985) and Arnaud et al. (1992).

3. Material and methods

Ten stratigraphic sections representing different areas of the reconstructed Sassari Channel system (see Vigorito et al., 2006) have been sampled (Fig. 4): eight sections represent the left side of the reconstructed channel (Santa Maria Section SM, Ittiri new road Section IXS, Costa Mascari Section CM, Ippodromo Section IP, Setti Funtani Section 7F, Monte Sant'Antioco Section MSA, Monte Istoccu Section MI, Costa Chighizzu Section CH) and two sections represent the right margin of the channel (Scala di Giocca Section SG, Calancui CL; Figs. 2–5).

Facies analysis of the studied material was based on field observations and on microfacies analysis on thin sections. A semi-quantitative analysis of the dominant biotic components (paying particular attention to the coralline red algae) was carried out at the outcrop scale. The datation of the succession, which crops out with impressive exposures along the road connecting the S.S.131 to the Sassari town (Scala di Giocca Section, SG samples), did not provide valuable results due the little biostratigraphic significance of the benthic biotic component and the rare and badly preserved planktonic foraminiferal specimens. In order to find out better preserved planktonic foraminiferal faunas, many different outcrops have been selected in which planktonic foraminiferal silty-marly deposits intercalate or laterally pass into the rhodolith deposits.

Rhodolith were described in terms of sphericity, size, nature of the nuclei, inner arrangement, outer growth forms and coralline taxonomic assemblages. The sphericity of the rhodoliths was calculated by measuring the three main diameters (longest L, intermediate I, shortest s; see Sneed and Folk, 1958 and Bassi et al., 2015). These data were plotted in triangular diagrams by using the TRI-PLOT software (Graham and Midgley, 2000). Coralline family and subfamily ascription follows Woelkerling (1988), Verheij (1993), Braga et al. (1993), Harvey et al. (2005) and Iryu et al. (2012). Taxonomic uncertainties concerning fossil coralline taxonomy as discussed by Braga and Aguirre (1995), Rasser and Piller (1999), and Iryu et al. (2009, 2012) were avoided by using generic names only. The identification at genus level was based on the circumscriptions proposed by Woelkerling (1988), Braga et al. (1993), Braga (2003) and Iryu et al. (2009, 2012). Coralline algal growth-form terminology follows Woelkerling et al. (1993).

4. The Sassari Channel

The studied different stratigraphic sections constituting the Sassari Channel represent the high architectural complexity of the sedimentary bodies. The exposed sequences comprise two superimposed channel complexes (Sassari Channel I and Sassari Channel II in Fig. 2), a few kilometres wide and 250–300 m full-thick fringed to the west by marly sheet deposits (Vigorito et al., 2006). Erosional or mixed erosional–depositional structures show multiple, stacked, partly nested channel-fill sequences which relate to different filling phases (Fig. 5). Sand- to cobble-sized deposits fill individual channels and are locally capped by thin-bedded, intensely bioturbated, hemipelagic marls. Quartz-rich mixed carbonate–siliciclastic deposits alternate with quartz–feldspathic sandstones and carbonate skeletal rudstone/floatstone in the coarse fillings of the channels. Rhodoliths represent the main component of the carbonate fraction. Megabreccias, which include up to a few tens of metres high and hundreds of metres wide displaced and\or tilted blocks (black triangle in Fig. 5), locally occur. Vigorito et al. (2006) distinguished mid-channel, margin-levee and overbank complexes as well as sheets and drapes of marly basinal deposits. Very complex depositional architectures characterize the channel margins and include up to 15–20 m high lateral bars. Mid-channel complexes are commonly parallel to concave up stratified and locally exhibit minor order nested channel bodies. These complexes erode, overlap or lie alongside each other and suggest repeated channel thalweg digressions and avulsions (Vigorito, 2005; Vigorito et al., 2006).

4.1. Sassari Channel fill Units

In the multi-storey, mixed erosive-depositional Sassari channel, six complexly arranged channel fill units (Units A–F in Fig. 5) were identified by Vigorito et al. (2006), corresponding to discrete phases of active channel filling. The present study included a lower hemipelagic interval, which underlies the Unit A, namely the interval Pre-Unit A.

4.1.1. Interval Pre-Unit A

This interval is well exposed in the Riu Mascari area (Costa Mascari section, CM; Figs. 2–4) with planktonic foraminiferal sandy silt deposits, grey-greenish in colour and up to 30 m in thickness. In that area, the interpreted left margin (Fig. 2) of the Sassari Channel crops out (Vigorito et al., 2006). This unit crops out also in the Santa Maria stratigraphic section (SM, Fig. 4) and at the very base of the Setti Funtani section (7F, Fig. 4). In these localities, echinoid and small mollusc fragments, fish teeth, rare bryozoan colonies, sponge spicula and rare radiolarians also occur.

4.1.2. Unit A

This unit, largely cropping out in the analysed sections (Fig. 4), is about 50 m thick near the Osilo palaeohigh (Calancui outcrop; Figs. 2, 4, 6A–B). A maximum thickness, up to 70 m, can be estimated from the deeper left side of the Sassari Channel (7F, MSA, MI sections; Figs. 2, 4).

Strata are arranged in asymmetric planar–convex bodies with steeper inner (in respect to the channel axis) sides and gentler outer sides which pinch out rapidly westward, fringing into silty/fine sandy mixed deposits. The Unit A is represented by rhodolith rudstones and subordinately floatstones usually moderately to well sorted (Fig. 6A). Subordinated bivalve, bryozoan and echinoid (such as *Amphiope hollandei*, *Clypeaster intermedius*, *Echinolampas* sp.) debris, as locally dense accumulations, are also present. Thin-shelled bivalve remains as well as large moulds of gastropods (*Conus*, *Strombus*) are locally frequent. In the Calancui outcrop rhodoliths and pectinid valves along with rare coral fragments characterize massive beds directly overlying the Osilo palaeohigh volcanic bedrock. Skeletal grains appear densely packed with not preferred orientation. In contrast, in the 7F, MSA, MI sections, strata from 0.05 to 0.5 m in thickness, show sharp basal and upper contacts, locally ending with silty marls rich in planktonic foraminiferal tests and siliceous sponge spicules. The fine silty intercalations, which drape the rhodolith carbonate bodies, have been sampled and analysed for biostratigraphic purposes.

4.1.3. Unit B

In the eastern side of the Sassari Channel (SG section), mixed carbonate–siliciclastic sands and silty sands of Unit B crop out (Fig. 6C–D). These sands thin upwards and disappear in the channel axis passing to silty-marls. Normal gradation, significant biorturbation and dewatering structures are present in the sandy sediments of the Unit B that is barren in planktonic foraminifera and contains rare rhodoliths. This unit is truncated at the top by a sharp erosive surface (ER-C; Fig. 5), which is in turn onlapped by quartz-rich mixed carbonate-siliciclastic poorly cemented sands of the Unit C.

4.1.4. Unit C

This unit is mainly made up of coarse carbonate-siliciclastic sandstones. Locally, biogenic sandy floatstone shows normal graded, parallel laminated and lenticular strata; the floatstone includes small fragments of the Paleozoic substrate. Complex internal truncation surfaces in the clinostratified lateral bar deposits result in lateral channel terraces (Fig. 6E). Rhodoliths and bivalve, echinoid and bryozoan fragments are locally present in heavily bioturbated (mainly horizontal burrows) beds mainly at the base of the interval (Fig. 6F). The Unit C reaches 50 m in thickness in the SG section, where a clear erosive surface (ER-D; Fig. 5) marks the passage to the overlying Unit D (Fig. 6G). Unit C deposits tend to thin towards the left side of the channel (7F and MI sections; Figs. 2, 4) up to disappear laterally passing to sikty deposits.

4.1.5. Unit D

This unit is made up of coarse pebble- to cobble-sized rhodolith rudstone (Figs. 6H, 7A). No planktonic foraminifera have been recognized. The thickness of Unit D tends to thin towards the left side of the channel (7F and MI sections) and in its western margin (MSA section; Figs. 4–5). Coralline red algae are the main components with rare, although locally significant, occurrence of bivalves (ostreids, pectinids), bryozoans and echinoids. Noteworthy, hermatypic coral assemblages characterize the clinostratified right lateral bar (SG section; Figs. 5–8) and the elevated left levee (MSA section) respectively. Displaced coral colonies and fragments can be common and locally coral colonies occur in life position). In the right side of the channel axis impressive megabreccia beds characterize the Unit D where large to very large blocks of early cemented channel-margin and levee complexes lie (Fig. 5), chaotically arranged, on a deep erosional surface (Fig. 9). The SG section offers a superb exposure of the Unit D along the narrow hairpin bends extended from the S.S. 131 to the Sassari town (Fig. 6H). In the upper interval, multiple minor order shallow-water channels are filled mainly and even exclusively of well-sorted rhodoliths (Fig. 7C). The top of Unit D is crossed by multiple erosive surfaces which suggest repeated sea level oscillations in a general regressive trend which culminated in the formation of a major erosion surface (ER-E, Figs. 3–5). The ER-E surface may be correlated across most of the Sassari Channel and passes into non-depositional surfaces in the adjacent overbank areas. The Unit D passes upward, through the ER-E, into silty marls of the Unit E.

4.1.6. Unit E

This unit consists of siliciclastic, mixed carbonate-siliciclastic and silty deposits with planktonic foraminifera and subordinate pteropods. Normal gradation, dewatering structures and rare parallel lamination are the most prominent sedimentary features. The grains, as in the similar mixed deposits of Units B and C, regularly show a homogeneous grain size sorting. Skeletal fragments (bivalves, gastropods, echinoids, crabs, balanids; Fig. 7D) are dispersed in the silty-sandy sediment in which rare, displaced thin coral branches also locally occur. Locally, mollusc fragments, bryozoan nodules and sponges are present in subordinated rhodolith rudstones/floatstones whose coarse bioclastic matrix contains *Amphistegina,* echinoid spines and coralline fragments. A similar bioclastic grainstone forms discrete intercalated beds that locally show burrows up to 2 cm in diameter. Locally abundant crab remains occur testifying the significant bioturbation that characterize this unit. Heavily bioturbated mixed sandy/silty limestone with discontinuous reddish crusts, commonly tops the hemipelagic marly Unit E (Fig. 7E). A new major erosion surface (ER-F, Figs. 3–5) cuts into the Unit E and is in turn overlain by the coarse-grained rhodalgal limestones belonging to Unit F.

4.1.7. Unit F

This unit, up to 30 m in thickness, is made up of rhodolith rudstone intercalated with thick bioclastic grainstone/floatstone banks barren in biostratigraphic markers. The carbonate deposits show large- to medium-scale cross-stratification, derived from avulsion, digression and aggradation of minor order channel-bodies, and multiple megabreccia beds. These beds include boulders and blocks that are derived from the disruption of Unit D deposits, suggesting pervasive early cementation processes. Rhodolith rudstone/floatstone deposits with pectinid and ostreid shells, intensely bored by clyonids, and bryozoan nodules characterize the Unit F (Fig. 7F). These rhodolith rudstone/floatstone deposits fill a new channel conduit (Sassari Channel II; Fig. 2) with a high width/height ratio and a complex fill–architecture, characterised by the presence of multiple minor-order channel-bodies and large lateral bars.

4.2. Assessment of the biostratigraphic setting

The analysed planktonic foraminiferal silty-marly samples span all along the entire PTB succession, they pertain both to hemipelagic intervals (i.e., Unit E) draping mixed/carbonate wedges made up of re-sedimented grains and to silty marly packages to which the mixed/carbonate bodies laterally pass.

The most interesting samples with biostratigraphic meaning were collected in the western side of the interpreted channel in hemipelagic silty marl sediments of the Interval Pre-Unit A, in the hemipelagic deposits lateral passing to the re-sedimented deposits of the Units A to D, and from the hemipelagic beds (Unit E) that seal the re-worked coarse deposits of the Unit D. From the latest Burdigalian to the latest Langhian, no significant discontinuities have been found in the stratigraphic succession. Table 1 shows the distribution chart of planktonic foraminifera in the Sassari Channel stratigraphic sections. The biostratigraphic data are summarized in Table 1**.** Three main biostratigraphic intervals (based on the foraminiferal zonation of Mancin et al., 2003) were distinguished:

1) Late Burdigalian: in the the CM Section, the silty Interval Pre-Unit A yelds the marker *Globigerinoides bisphaericus*; no species of the evolutionary trend pertaining to the genera *Praeorbulina* and *Orbulina* have been recognized. A late Burdigalian age subsequent to the F.O. of *Globigerinoides bisphaericus* and preceeding the F.O. of *Praeorbulina* is suggested.

2) Langhian: no stratigraphic gaps have been recognized in the marly deposits from the Pre-Unit A, cropping out in the SM and 7F sections, up to the Unit E. All the typical Langhian markers, such as *Praeorbulina glomerosa glomerosa, Praeorbulina glomerosa circularis, Globigerinoides bisphaericus* and *Orbulina suturalis*, are present in the studied samples. In particular, in 7F (samples 1/2/3/4), MSA (samples 1/2/3/4/6/7/8/10), MI (samples A/B) e di SM (samples A/B) sections, the markers *Praeorbulina glomerosa glomerosa* and *Globigerinoides bisphaericus,* in association with species of the early evolutionary trend of *Praeorbulina* (*P. sicana*, *P. glomerosa curva*), point to a lower Langhian interval.

Samples from the middle-high intervals in the sections 7F (samples 5/6) and MSA (samples 11/12) still contain *Praeorbulina glomerosa glomerosa* with no later taxa (e.g., *Praeorbulina glomerosa circularis*). This suggests a middle Langhian age. In the SXI section the marker *Globigerinoides bisphaericus* is associated with species pertainig to the evolutionary trend of *Praeorbulina* (*P. transitoria*, *P. glomerosa curva*, *P. glomerosa glomerosa*). Conversely, *Praeorbulina glomerosa circularis* is missing. This suggests a presumably middle–late Langhian age. Middle-upper Langhian intervals also occur in the upper part of the MI section (samples C/D/E/F). These intervals are marked by the occurrence of *Praeorbulina glomerosa glomerosa* and *Praeorbulina glomerosa circularis*, while *Orbulina* is missing.

In the 7F (samples 7/8/9) and in the IP (samples1/2) sections, the markers *Globigerinoides bisphaericus* and *Praeorbulina glomerosa circularis*, along with the absence of *Orbulina*, point to a late Langhian age. Finally, in CH section (samples A/B) on the base of the occurrence of *Orbulina suturalis* together with *Praeorbulina glomerosa circularis* a latest Langhian is assessed.

3) Early Serravallian: in the CH section, at the top of Unit E (sample CH-C), *Orbulina universa*, whose F.O. marks the Langhian–Serravallian boundary, occurs; no specimen belonging to the *Praeorbulina* evolutionary trend was recognised. As a consequence an early Serravallian age can be assumed.

Based on the distribution of planktonic foraminifera in the investigated sections, the time span of the different Units is assessed as (Figs. 3–4):

- Interval Pre-Unit A: late Burdigalian–earliest Langhian;
- Units A, B, C and D: early Langhian;
- Unit E: from middle Langhian to the Langhian–Serravallian boundary and early Serravallian *pro parte*.

The top of the outcropping succession (Unit F), being barren in significant fossil markers, might be referred to the early Serravallian.

4.3. Rhodolith deposits

Coralline red algae are from dominant to subordinate components in the studied lithostratigraphic units. In the Sassari Channel filling Units A, D and F, corallines are represented by rhodoliths in rudstones/floatstones and by coralline algal debris in skeletal silty packstone of the matrix. Rhodoliths only sporadically occur in the siliciclastic to mixed carbonate–siliciclastic Units B, C and E (Table 2).

In the CL section Unit A (Fig. 2), rhodoliths are spheroidal and sub-spheroidal in shape with the maximum diameter ranging from 4 to 11 cm (Fig. 6B). Their dominant outer growth forms are encrusting and warty; lumpy growth forms are also present. The massive inner arrangement (low percentage of constructional voids) shows encrusting and lumpy morphologies with subordinate warty growth-forms. Dominating mastophoroids (*Spongites*) are associated with subordinate melobesioids (*Lithothamnion*) and rare sporolithaceans (*Sporolithon*). Locally coralline algal debris deposits are present. Abundant encrusting acervulinids contribute to the rhodolith growth.

In the Setti Funtani/Costa Chighizzu area, the coarse rhodolith rudstone with coralline algal debris packstone matrix of the Unit A overlies, through an erosive surface, and passes westward to planktonic foraminiferal marly siltstone with siliceous sponge spicules. In this area, spheroidal and sub-spheroidal rhodoliths, with maximum diameter ranging from 2 to 6 cm, usually occur at the base of the beds. Rhodoliths show encrusting outer growth-forms with dense inner arrangement made up of melobesioids (?*Lithothamnion*). Fruticose coralline fragments were recognised in the sediment matrix.

The rare rhodoliths of the Unit B are scattered in discrete deeply bioturbated beds (Fig. 6D). They are sub-spheroidal and sub-ellipsoidal in shape, with maximum diameter ranging from 2.6 to 6.8 cm, and show warty/lumpy outer growth-forms and dense inner arrangement.

Rhodoliths are rare in the Unit C but locally, along with large fragments of bivalves, echinoids and bryozoans can be abundant and occur as small accumulations, arranged parallel to the bedding (from Costa Chighizzu cliff to Scala di Giocca area; Fig. 6G). Rhodoliths are spheroidal in shape (maximum diameter ranges from 3.8 to 6.2 cm) with warty outer growth- forms made up of dominant mastophoroids and subordinate melobesioids. Coralline algal debris deposits are locally present.

Rhodoliths are dominant components of the Unit D superbly exposed in the SG section (Figs. 2, 6H). Sub-spheroidal rhodoliths (up to 6 cm in maximum diameter) with encrusting and lumpy outer growth forms occur in a coarse floatstone organized in concave cross-laminated beds, at the base of the Unit (first metres above the Unit C–Unit D contact). The rhodolith inner arrangement shows high percentage of constructional voids, filled with sediment matrix. Encrusting and lumpy growth forms were recognised. Coralline taxonomic assemblage is represented by melobesioid (*Lithothamnion*) and mastophoroid (*Neogoniolithon*/*Spongites*) taxa. Upward in the SG section, rhodolith rudstone with no matrix are arranged in clinostratified beds representing channel lateral bars. Sub-spheroidal rhodoliths up to 8 cm in diameter (maximum) show encrusting and warty outer growth-forms and a dense arrangement with dominating encrusting growth-forms. Lumpy morphology can locally occur. The coralline taxonomic assemblage is represented only by a melobesioid taxon (*Lithothamnion*). Serpulid-worm tubes are frequent within the rhodoliths. At the top of the studied section densely packed and well-sorted rhodoliths, sub-spheroidal in shape with encrusting and warty outer growth-forms and dense inner arrangement, constitute the filling of multiple minor order channels. The maximum rhodolith diameter ranges from 3 to 8.6 cm. Rhodoliths are composed of mastophoroids (*Spongites*, *Neogoniolithon*, *Lithoporella*) with subordinate lithophylloids (*Lithophyllum*), melobesioids (*Mesophyllum*) and sporolithaceans (*Sporolithon*). Accessory components are bryozoans, serpulids and encrusting foraminifera (*Acervulina*). Benthic foraminifera, such as *Amphistegina*, rotaliids and textulariids occur within the rhodoliths. Rhodoliths show bioerosion including *Gastrochaenolites* and *Entobia*, microborings are also present. Finally, rhodolith floatstone with coarse skeletal grainstone matrix and fine rudstone with abundant echinoid spines and plates occur at the top of the analysed stratigraphic section. The spheroidal rhodolith show inner stucture which consists of laminar concetric thalli which enveloped several serpulid worm-tubes. In the 7F section, the Unit D rhodoliths are sub-spheroidal rhodoliths up to 7 cm in diameter (maximum) with encrusting outer growth-forms. Warty growth-form can also occur. The inner arrangement shows dominating lumpy growth forms and locally superimposed encrusting thalli. Coralline taxonomic assemblage is represented by mastophoroid (*Spongites*) and melobesioid (*Lithothamnion*). Sporolithacean (*Sporolithon*) locally occurs.

Very rare rhodoliths, spheroidal in shape with the maximum diameter ranging in size from 1.9 to 4.6 cm, occur in silty sandstone of the Unit E. These rhodoliths are constituted by mastophoroids as encrusting outer growth-forms. The dense inner arrangement is made up of encrusting thalli.

Large rhodoliths (maximum diameter ranges from 1.8 to 3.7 cm; Fig. 7F) become dominant in the upper intervals of the studied Sassari successions (Unit F). Rhodoliths are mainly spheroidal in shape and show encrusting and rarely warty outer growth forms with a dense inner arrangement made up of encrusting thalli. No information about the coralline taxonomic assemblage was obtained due to the weak fossil preservation of the coralline thalli highly micritized and re-cristallized.

5. Stratigraphic architecture and palaeoenvironmental dynamics of the Sassari Channel filling sequences

Quartz-feldspar sandstones and siltstones, largely present in the Miocene Sassari Channel mixed carbonate-siliciclastic lithostratigraphic units, document a repeated terrigenous supply from uplifted Paleozoic crystalline substrata into the Sassari Channel system in which hemipelagic planktonic foraminiferal silty marls deposited. Sedimentary features suggest deposition from turbidity and locally from hyper-concentrated turbidity flows (Vigorito et al., 2006). The narrow grain size distribution that characterises these deposits is thought to correspond to extensive reworking and sorting in the shelf source areas (staging areas) rather than to long distance transportation. Shelfal areas, source of terrigenous clasts, were also sites of carbonate factories. As a consequence, re-worked sands and skeletal debris were discontinuously re-sedimented offshore as pure terrigenous, mixed and/or carbonate deposits. Underfeeding episodes had to result in drapes of fines (e.g., Unit E) covering mixed/carbonate wedges, laid down during major episodes of sediment supply from neighbouring shelf areas. The carbonate fraction definitely derived from open shelf rhodalgal/foramol productive areas. However, no outcropping records of *in situ* preserved carbonate factory deposits have been found in the Sassari area.
Rhodalgal/foramol carbonate factories are typical of unprotected temperate-type shelves (Carannante et al., 1988) dwelled by sciaphilous (low lit-adapted) biotic assemblages (i.e., oligophotic *sensu* Pomar, 2001a, b) and produce loose, diagenetically stable bioclastic debris which is normally not involved in significant *in situ* cementation processes. On the shelves, both storm- and wind-induced currents and waves exert a strong driving control on the sedimentary arrangement of the shifting biogenic sediments. High-energy episodes lead to repeat and more or less to totally remobilize the sedimentary sheet. Sediments are easily transported across the shelf toward the re-depositional sites. The early and almost continuous sweeping of the finer fraction (bioeroded-derived silt) results in an effective pre-sorting of the skeletal debris. *In situ* preservation possibility of the produced skeletal material (autochthonous/parautochthonous sediments) is low. During stillstands of sea-level, basin-ward transport of sediment largely occur. During falls in sea-level, slope progradation increases as result of basin-ward sweeping of sediments remobilized by lowering of base level, and additionally by a basin-ward shift of the carbonate-production areas (Carannante et al., 1996, 1999; Betzler et al., 1997; James, 1997; James and Clarke, 1997, Pomar, 2001a, b among others). The sediment is generally re-sedimented by means of massive gravity flows through complex channel networks.
As documented from rhodalgal/foramol carbonate open shelves (Carannante et al., 1996, 1999), loose biogenic sediments only partly remained in the area of production (autochthonous/parautochthonous sediments), becoming the site of successive colonizations. The sediment was generally removed from the related open-shelf system, then re-sedimented by means of massive gravity flows through a complex channel network.
A sharp asymmetry characterizes the transversal section of the channel. On the eastern Sassari channel-margin (right margin), individual units drape and/or onlap the basal boundary surfaces and locally pass toward the channel axis into clinostratified units. Well developed lateral bars characterize the right-hand side of the individual channel units, where the contribution from shelfal areas was impressive. These latter pass in turn to slope deposits consisting of alternation of spill-over sediments and hemipelagic sediments which represent the background sedimentation in the basin. In contrast, individual channel units exhibit a more complex and varied internal geometry and reciprocal arrangement on the western Sassari channel-side (left margin). Unit A exhibits an up to 50 m-high levee which confined the successive channel fill sequences (Units B and C, Fig. 5), thus resulting in a nested channel fill architecture which is typical of erosive-type channels (Normak, 1970; Mutti and Normak, 1987).

The gravity flow-related carbonate-dominated sedimentary bodies were locally capped by the settling of fine materials that resulted in intensely bioturbated, hemipelagic thin beds. Presumably these latters deposited during temporary abandon phases of the channel, likely in relation to sea level rise and/or reduced sediment supply. Minor order relative sea level variations triggered the repeated supplies of the coarse skeletal component while, in the late early Langhian, major episodes of sea level drop resulted in the collapse of both the early cemented channel-margin and levee complexes, and in the initiation of impressive debris flows and emplacement of the multiple megabreccia beds (Unit D, Fig. 5) finally resulting in a major erosional surface (ER-E in Figs. 3, 5). Megabreccias (Fig. 9) represent channel margin collapses boosted presumably by pore water overpressures generated in horizons hydrologically confined between early cemented bed packages. In addition, the shallowing trend made the colonization of the mobile substrate possible to hermatypic coral assemblages at the top of the channel margins where lateral bars and elevated levees developed. From the middle Langhian to the latest Langhian–Serravallian boundary, Unit E deposits appear to have progressively buried the post-Unit D channel topography (abandon phase of the Sassari Channel I) and are in turn eroded by the new shifted channel conduit filled by Unit F (Sassari Channel II; Fig. 2).

No significant stratigraphic discontinuities have been found in the analysed sedimentary succession. The inception of the exposed channel started in the early Langhian with first erosion events resulting in a major discontinuity surface (ER-A in Fig. 5) that deeply cuts into the upper Burdigalian–lowermost Langhian hemipelagic substrate (Interval Pre-Unit A), resting at the base of the coarse rhodolith deposits of the Unit A. Lower Langhian planktonic foraminifera characterize the hemipelagic silty marls intercalated with and/or laterally passing into the re-sedimented deposits of the Unit A to Unit D. The hemipelagic beds of Unit E, spanning from the middle Langhian to the Langhian–Serravallian boundary, seal the re-worked coarse deposits of the Unit D. Significantt gravitative episodes of channel filling (Sassari Channel I**)** are thus constrained between the latest Burdigalian and the base of the middle Langhian. The Unit E related abandon stage was dramatically interrupted by new erosion episodes that gave rise to the inception of a new conduit (Sassari Channel II). This latter shifted westward in respect to the previous channel axis and was in turn filled by the rhodolith facies of the lower Serravallian Unit F.

No evident differences among the rhodolith assemblages of the different Units have been recognized (Table 2). Based on shape parameters, growth-form morphologies and inner arrangement, rhodoliths occurring in the Unit A of the right margin of the Sassari Channel I (CL section; Fig. 2) suggest contributions from shallower proximal source areas. Such a shallow water source is confirmed by the coralline algal taxonomic assemblage dominated by mastophoroids with subordinate melobesioids and sporolithaceans (Table 2). The dominance of Mastophoroideae in shallow water settings with an increase in the occurrence of Melobesioideae with depth has been observed in many areas including the Hawaiian Islands (Adey et al., 1982), Ryukyu Islands (Iryu et al., 1995), Papua New Guinea (Webster et al., 2004), Gulf of Mexico (Minnery, 1990; Perrin et al., 1995), Great Barrier Reef (Braga and Aguirre, 2004), and Brazilian Shelf (Tâmega and Figueiredo, 2005). Lumps of bioclastic sediment constitute the nuclei of many rhodoliths. Similar early-hardned lumps occur in the gravitative deposit as expression of concrectionated firm-grounds subject to erosion. In the Calancui Unit A, rhodolith deposits directly lie on the pre-channel eroded volcanic substrate and on its first marine cover made up of echinoid-rich limestone. The presence of rare coral fragments and coralline algal debris testify proximal conditions to shallow-water settings.

Subordinated contributions of skeletal debris supplied episodically the channel during major episodes of siliciclastic input (i.e, mixed siliciclastic/carbonate Units B and C). The rare rhodoliths occurring in the Units B and C share similar taxonomic algal assemblage characters (i.e, dominated by mastophoroids with subordinate melobesioids and sporolithaceans) and constructive features (i.e., warty/lumpy, massive inner arrangement, maximum axis *ca*. 6 cm, spheroidal and sub-spheroidal). Present-day melobesioid/mastophoroid assemblages thrive in mid-latitudes in shallow water warm-temperate settings (e.g., Aguirre et al., 2000). Melobesioids and *Sporolithon* become important components below 10–15 m water depth at One Tree Reef at the southern end of the Great Barrier Reef (Braga and Davies, 1993) and in reefs of the Northern Bay of Safaga in the Red Sea (Rasser and Piller 1997). The lower coralline taxonomic diversity of the assemblages in respect to those identified in the other units suggests that the rhodoliths were formed in a relative higher turbidity and/or in deeper water than the other rhodolith deposits occurring in the Units A, D and F.

In the clinostratified lateral bar of the Sassari channel, cropping out in the eastern studied area (SG section), rhodoliths become largely dominant and constitute the bulk of the sediment of the Unit D. These rhodoliths record the highest taxonomic diversity even with the occurrence of lithophylloids. Lithophylloids are the most frequent coralline algae in the infralittoral zone assemblages of the Mediterranean (i.e., Cormaci et al., 1985; Braga and Aguirre, 1995; Bressan and Babbini, 2003; Braga et al., 2009). According to their sedimentologic characteristics and the bathymetric distribution of the taxonomic algal assemblage these rudstone deposits were winnowed by significant currents in relatively shallow depositional settings within a complex network of narrow tidally-controlled channels. Rhodoliths built heaps parautochthonous particles, which presumably formed in periferal areas close to the head of tributary channel to the main Sassari channel. The subordinate occurrence up to significant contribution of serpulid-worm tubes in the rhodoliths of the Unit D (SG section) well matches the presence of these opportunistic forms in rhodoliths from different canyon heads both from fossil (Miocene, Sarcidano areas, Sardinia, Bassi et al., 2006; Miocene, Matese Mountains, Central–Southern Apennines, Bassi et al., 2010; Middle Miocene, Vitulano area, Southern Apennines, Checconi et al., 2010) and Recent (Pozzuoli Bay, southern Italy; Toscano et al., 2006) examples. In channel sectors far from the main rhodagal carbonate factory (e.g., 7F section) conditions of very shallow water settings must be excluded on the base of sedimentological evidences (e.g., geometry of the sedimentary bodies, sharp transition to hemipelagic deposits). In those areas, Unit D is thinner and lacks photophyle community components. However, the high rhodolith taxonomic diversity suggests a significant mixing of re-deposited algal nodules from different bathymetric settings. A progressive shallowing of the depositional system locally promoted the development of coral benthic communities that thrived in topographically higher areas located on lateral bars and levees at the margins of the Sassari Channel. Increasing regressive pulses resulted in impressive mass flows of the early cemented channel margins (Unit D megabreccias) and culminated in the latest early Langhian, with the submarine erosive event at the top of the Unit D (ER-E in Fig. 5). Rhodoliths are small in size and very rare in the silt (locally rich in planktonic foraminifera) and carbonate–siliclastic sand of the Unit E (7F section) that drapes the underlying major erosive surface at the top of Unit D (ER-E; Figs. 3, 5). The presence in these units of extensively bioturbated bed packages and of patchy reddish indurated crusts suggests periods of reduced sedimentation rate during a significant abandon phase with deposition of fines. During this phase, on the left side of the channel the levee was initially draped and then progressively smoothed with consequent loss of any residual relief. At the very base of the Serravallian the new erosive event (ER-F) resulted in the westward shift of the new conduit (Sassari Channel II) in which re-sedimented rhodoliths largely contributed again to form the bulk of the infilling sediment.

The overlying cross-stratified carbonate deposits of the Unit F point to avulsion, digression and aggradation episodes in the new shifted erosive channel. Like in the Unit D, the Unit F rhodolith deposits display complex depositional architectures characterised by interfinger and overlap geometries developed at the transition between channel–margin and/or mid-channel deposits and by large to medium-scale cross-stratified complexes built up through intersection, overlap and lateral juxtaposition of multiple minor order channel bodies. Although no coralline taxonomic information regarding these rhodolith assemblages were assessed, rhodolith features are similar to those recognized for the Unit D rhodoliths.

The re-worked sediments cropping out in the south-eastern Corsica Island deposited during similar age time (middle Burdigalian–early Serravallian; Ferrandini et al., 2003; Loÿe-Pilot et al., 2004); these sedimentary successions represent infilling sequences of coheval but different tectonical-driven small basins, out of the "Fossa sarda" *Auctorum* domain (Rossi et al., 1998).

6. Discussion: implications for sequence stratigraphy

The reconstructed scenario of the Sassari Channel allows for a first attempt to interpret this significant re-sedimentation event within the context of the complex Miocene palaeoclimactic background. One of the major changes in the climate system is termed the Miocene climate transition that started from the "mid-Miocene climatic optimum" (MMCO) around 17 to 14.5 Ma (e.g. Goldner et al., 2014). The end of the transition is marked by the major Mi-3b isotope shift reflecting a significant increase in Antarctic ice volume and the final transition into the "Icehouse World" (e.g., Abels et al., 2005; De Leeuw et al., 2012). Estimates for the glacio-eustatic sea-level lowering associated with the Mi-3b isotope event are in the order of *ca*. 60 m (Hilgen et al., 2009). Hilgen et al. (2009) suggest that the associated major glacio-eustatic sea-level drop corresponds with sequence boundary Ser1 of Hardenbol et al. (1998) and supposedly corresponds with the TB2.5 sequence boundary of Haq et al (1987).

Although local tectonic controls cannot be ruled out, at least two major events can be recognized in the Sassari Channel succession (Fig. 3): one is recorded within the succession of the units A–D (culminating in the Unit D), and one at the Unit E/Unit F boundary (erosion surface ER-F). Impressive rhodolith production occurred in the late early Langhian (Unit D) resulting in large prograding bodies presumably triggered by repeated regression pulses in a frame of persistent still stand. The progressive shallowing of the depositional system coupled with suitable climatic conditions promoted the development of scattered hermatypic coral benthic communities that thrived in topographically higher areas. From the still stand to the maximum shallowing, strong erosional events and massive collaps of early cemented deposits occurred. This phase correlates not only with the latter short-term glacial event, but also with the long-term global cooling trend of the mid-Miocene climate transition (Holbourn et al., 2007; Mourik et al., 2011). Following the channel abandon phase spanning from the middle to latest Langhian, new dramatic erosion events acted in the area. At the Langhian–Serravallian boundary, the massive gravitative flows and the erosion surface ER-F suggest a significant drop in the relative sea-level resulting in a forced progradation of the sedimentary bodies. Short-term variations in global climates and cooling steps following the MMCO can be invoked to justify the above development of the channel. In particular, the ER-F related regressive event at the Langhian–Serravallian boundary, corresponds to the 3rd order sequence Ser1 of Hardenbol et al. (1998; see Hilgen et al., 2009; Fig. 3), during which re-sedimented rhodoliths largely contributed again to form the bulk of the Sassari II Channel infilling.

7. Concluding remarks

1. Spanning in age from the late Burdigalian to the early Serravallian the *ca*. 200 m-thick succession cropping out in the Sassari area (northern Sardinia, Italy) corresponds to two main phases of sub-marine channel inception and infilling: the Sassari Channel I and the Sassari Channel II.
2. During the early Langhian, large amount of carbonate, siliciclastic and mixed carbonate-siliciclastic sediments reached the Porto Torres Basin. Such a large mass of displaced/re-worked sediment mainly transported by means of gravitative flows gave rise to the Sassari Channel I.

3. Impressive re-sedimented episodes into the channel ended with a major abandoning phase starting in the middle Langhian to which new erosive episodes followed at the Langhian–Serravallian transition, resulting in the shifted Sassari Channel II.
4. The lower part of the studied succession records evidences of the MMCO, whilst the uppermost deposits record the major drop in the sea-level at the Langhian–Serravallian boundary.
5. The MMCO corresponds to increasing development of rhodalgal carbonate production areas with small and localized coral assemblages (Unit D). Repeated regressive pulses within a persistent still stand resulted in rhodolith-rich prograding bodies. In the latest early Langhian, at the top of the Unit D the submarine erosion event (ER-E) corresponds to a major drop in relative sea-level presumably related with the cooling trend of the mid-Miocene climate transition.
6. At the very base of the Serravallian, the new erosive event (ER-F) resulted in the westward shift of the new conduit (Sassari Channel II) in which re-sedimented rhodoliths largely contributed again to form the bulk of the infilling sediment. This erosive event represents the 3rd order sequence Ser1. This step reflects a major increase in Antarctic ice volume, marking the Earth's transformation into an "Icehouse" climate state.

Aknowledgements

The research was in part funded by a local research fund (FAR, D.B.) from the University of Ferrara. N. Mancin (Dipartimento di Scienze della Terra e dell'Ambiente, Università di Pavia, Italy) is thanked for the biostratigraphical analysis. The paper greatly benefited from thoughtful reviews of S. Beavington-Penney and an anonymous reviewer.

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FIGURE and PLATE CAPTIONS

Fig. 1. Sketch of the geological map of Sardinia. In the northern sector of the Sardinia Graben the major sub-basins are Castelsardo (CB), Logudoro (LB) and Porto Torres (PTB). IF, Ittiri Fault.

Fig. 2. Geological sketch-map of the Sassari area with the locations of the studied stratigraphic sections. Trends of the recognized Sassari Channel I (Channel Units A to E) and Sassari Channel II (Channel Unit F) are depicted. SM, Santa Maria; IXS, new road Ittiri; CM, Costa Mascari; MSA, Monte Sant'Antioco; IP, Ippodromo; 7F, Setti Funtani; MI, Monte Istoccu; CH, Costa Chighizzu; SG, Scala di Giocca; CL, Calancui. OF, Osilo fault. A–B, trace of the geological profile illustrated in Fig. 5. For stratigraphic setting see text and Fig. 3.

Fig. 3. Comparison of the various informal lithostratigraphic units and present age setting for the Sassari Channel sedimentary succession. Chronostratigraphy according to Grandstein et al. (2012). The sea-level reconstruction (3rd order sequences) follows Hilgen et al. (2009) except for the Lan1 boundary correlated with the isotope event at the Langhian base (see Iaccarino et al., 2011). In the Sassari Channel succession at the Langhian–Serravallian boundary the global glacio-eustatic sea-level drop (Ser1) is recorded as a new erosive event (as ER-F of Vigorito et al., 2006) resulting in the westward shift of the new conduit (Sassari Channel II). See text for details. MMCO, mid-Miocene climatic optimum (after Goldner et al., 2014).

Fig. 4. Stratigraphic logs representing the Miocene Sassari Channel. 1, sponge spicules; 2, rhodoliths; 3, pteropods; 4, molluscs; 5, bivalves; 6, gastropods; 7, echinoids; 8, crustaceans; 9, corals; 10, serpulids; 11, bryozoans. A–F, Units (further details in the text). See Fig. 2 for the geographic locations of the studied sections.

Fig. 5. Geological profile of the Sassari area (from Setti Funtani–Costa Chighizzu to Scala di Giocca–Calancui studied sections) in which the Miocene Sassari channel fill units are extensively exposed. A–F, Units; ER-A–ER-F, sharp erosional boundary surfaces; further details in the text. Modified from Vigorito et al. (2006). The black triangle shows the location of up to a few tens of metres high and hundreds of metres wide displaced and\or tilted blocks (see also Fig. 9). See Fig. 2 for the geographic location of the sampled logs.

Fig. 6. Miocene Sassari Channel, rhodolith rudstone/floatstone of Units A, B, C, D and F (see Fig. 4 for log details). **A)** Rhodolith rudstone characterized by encrusting and warty rhodoliths and subordinate disarticulated pectinid valves (Calancui, Unit A). **B)** Unit A lumpy rhodoliths with inner dense arrangements (Calancui, Unit A). **C)** Mixed carbonate–siliciclastic sands and silty sands of Unit B in Scala di Giocca section; hardened plagues show dense bioturbation and/or an abundant bioclastic fraction. **D)** Large echinoids (ec) and spheroidal rhodoliths with encrusting (e) outer growth forms occur throughout the unit deposits; Unit B (Scala di Giocca). **E)** Clinostratified coarse to very coarse, quartz-rich carbonate–siliciclastic sands of Unit C (Scala di Giocca); minor order cross-stratification and a sharp erosional surface (channel terrace) characterize this outcrop interpreted as lateral bar deposits. **F)** In Unit C warty rhodoliths (w, arrows) can be locally densely packed (Scala di Giocca). **G)** Erosional contact (arrow) between the Unit C, bearing rare small rhodoliths (r), and the overlying Unit D (outcrop between Scala di Giocca and Costa Chighizzu areas). **H)** Superb exposure of the Unit D along the narrow hairpin bends extended from the S.S. 131 to the Sassari town (Scala di Giocca); coarse pebble- to cobble-sized rhodolith rudstone largely prevail in the thick beds.

Fig. 7. Miocene Sassari Channel, rhodolith rudstone/floatstone of Units D, E and F (see Fig. 4 for log details). **A)** In Unit D rhodoliths show inner dense arrangement with warty (w) and encrusting (e) growth forms (Scala di Giocca). **B, C)** Large rhodoliths floating in a coarse grainstone matrix (Scala di Giocca, upper Unit D). **D)** The heavily bioturbated mixed sandy/silty limestone of Unit E yeld common balanids (b) and inner molds of gastropods (g; top of the Unit E, Costa Chighizzu). **E)** Large rhodoliths (r) become common just above the abrupt passage between Unit E and Unit F (arrow; Monte Istoccu). **F)** rudstone/floatstone made up mainly of large rhodoliths (r) associated with sponges (s) in a coarse bioclastic matrix (Setti Funtani, Unit F).

Fig. 8. Miocene Sassari Channel. Hermatypic corals occurring at the base of the Unit D, in the outcropping margins of the Sassari Channel I. **A)** Monte S. Antioco (elevated left levee). **B)** Scala di Giocca (clinostratified right lateral bar).

Fig. 9. Miocene Sassari Channel. Large overridden and deformed blocks of early cemented channel-margin complex in the thick megabreccia gravitative deposit of the Unit D cropping out in Costa Chighizzu cliff (right side of the channel axis).

Table 1
Distribution chart of planktonic foraminifera in the analysed sections cropping out in the Sassari area. See Fig. 2 for location of the studied samples.

Table 2
Distinctive characteristics of rhodoliths occurring in the different lithostratigraphic units of the Sassari Channel. For the description of the units see text. Max., maximum; undet., undetermined; carb.-sil., carbonate-siliciclastic