Depositional environment and age of some key Late Pliocene to Early Quaternary deposits on the underfilled Cedrino paleovalley (Orosei): Insight into the Neogene geodynamic evolution of Sardinia

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In order to better constrain the relationship between tectonics and sedimentation of the Eastern Sardinian Margin, from the Messinian to the present day (METYSS project), a lithostratigraphic study was carried out on the Late Neogene deposits along the Cedrino Valley (eastern Sardinia). The late Neogene evolution is documented from sedimentological and tectonic analysis, biostratigraphic dating, and by mapping and logging stratigraphic sections. Previous authors have differentiated an early Pliocene marine formation from an older continental formation, possibly Miocene, the entire system being covered by late Pliocene to Quaternary lava flows. Preliminary biostratigraphic data suggest the absence of the lowermost Pliocene, based on the absence of *Globorotalia margaritae* and the presence of *Glo-borotalia puncticulata*, implying a sediment age between 3.81 and 2.41 Ma. At the foot of the Fiuli cliff, some mud clasts include a coccolith microflora, Tortonian in age, suggesting reworking. The Pliocene marine deposits consist of a single filling sequence instead of a succession of superimposed sequences as we would expect during this period of time; the occurrences of terms rarely respect the usual transgressive-regressive succession. Contrasting bathymetric environments (fore-shore, pro-delta, shelf or upper slope) can be abruptly superimposed on top of the other, along few meter thick intervals. A rapidly flooded term is observed in several sites and indicates a spatial variability over only a few kilometers distance. Some deep water deposits are in the middle of the infilling Pliocene sequence, whereas shallower water deposits can be repeated along a vertical section, or even interrupted by emersion. These marked differences can express syn-, or possibly post-sedimentation tectonic uplifts. The 10–25° bed dips originated through local tectonic uplift. At Fiuli, the geometry of the bedding planes is indicative of tilting toward the west, in a direction opposite to the one observed at Onifai. These Pliocene series form a wide syncline with an approximately NNE–SSW axis. This morpho-structural behavior appears to be largely atypical of this East-Sardinian coastal area.

1. Introduction

The Tyrrhenian Sea is usually considered to be a Neogene back-arc basin. It opened by continental rifting and oceanic spreading induced by the eastward migration of the Apennine subduction system from Tortonian to Pliocene times (Moussat et al., 1986; Faccenna et al., 2002; Rosenbaum and Lister, 2004). This study takes place within the framework of the development of the METYSS (Messinian Event in the Tyrrhenian from Seismic Study) project. This project aims to better constrain the relationship between crustal tectonics, salt tectonics and sedimentation from

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Messinian times to the present day on the Eastern Sardinian Margin, Western Tyrrhenian, from Messinian times to the present day (Gaullier et al., 2014). The northwestern domain of the Tyrrhenian Basin provides a key area, including, in particular, a narrow and partially carbonated East-Sardinian margin.

The Orosei-Gonone canyon system constitutes a remarkable morphological feature across this margin. It faces the mouth of the Cedrino River valley where the only known marine Neogene deposits (*sensu lato*) known on the continent in the region are exposed onshore, according to the geological maps of Calvino et al. (1972) and Beccaluva and Macciotta (1983). In this study, we examined these Neogene deposits, exposed on the valley flank from the Cedrino river mouth to 15 km upstream. These sediments precede and are contemporary to the effusion of basaltic lava that have given K—Ar ages of 3.56 ± 0.23 to 1.99 ± 0.06 million years (Savelli and Pasini, 1973) according to successive Late Pliocene to Early Quaternary effusions in this region. Near Orosei, Beccaluva et al. (1983) indicated 2.75 ± 0.11 Ma and 2.67 ± 0.16 Ma; K/Ar ages. We examined these deposits on the valley flank from the Cedrino river mouth to 15 km upstream.

In order to better constrain the Messinian to present-day evolution of the margin, in a region poorly studied in this respect, we present the results of our sedimentological analysis of continental and marine facies associations and biostratigraphic investigations together with detailed mapping. The Pliocene marine deposits overlie a major erosional surface, possibly Miocene. If lower Pliocene Gilbert-type deltas filling the palaeovalley of the Cedrino River exist, they are expected to be located more downstream, in the main offshore canyon of the eastern Sardinian Margin.

2. Geological setting

Sardinia has a complex structural history spanning from the Hercynian orogeny during late Paleozoic, to recent times. During the Cenozoic, the major tectonic deformation within the Corsica—Sardinia continental block was related to the Pyrenean-Alpine orogeny with a climax occurring during the Late Eocene (Durand-Delga, 1986; Egal, 1992; Marroni and Pandolfi, 2003; Lacombe and Jollivet, 2005). Oligocene to recent deformation in the western Mediterranean domain is then dominated by rifting and extension (Cherchi and Montadert, 1982, 1984; Sowerbutts and Underhill, 1998; Casula et al., 2001; Faccenna et al., 2002; Cherchi et al., 2008; Oggiano et al., 2009).

The extension of the South Tyrrhenian Basin started on its western side (Eastern Sardinian Margin) during the Middle to Late Miocene (Mascle and Réhault, 1990; Sartori et al., 2001; Doglioni et al., 2004; Rosenbaum and Lister, 2004; Carminati et al., 2012). The rifting area successively gradually migrated eastward, toward the Apennine belt. As a consequence of this rifting history, the offshore Eastern Sardinian Margin was already a deep basin during Messinian times. Various seismic studies have recognized the offshore presence of thick Messinian evaporitic series in this part of the Tyrrhenian domain (Curzi et al., 1980; Moussat et al., 1986; Gaullier et al., 2009, 2014). Onshore, on the Eastern Sardinian Margin, some tectonic activity along pre-existing faults is assigned to the Middle to Late Miocene period, and is considered as the reactivation of former Hercynian to Eocene structures (Helbing et al., 2006; Dieni et al., 2008).

The pre-Neogene basement is mainly composed of highly deformed and metamorphosed Paleozoic series that are intruded by generally calc-alkaline granitoids widely exposed in Eastern Sardinia. These formations, attributed to the Hercynian orogeny, are unconformably overlain by Middle to Late Jurassic limestones (Costamagna et al., 2007).

In the Orosei area, the Paleozoic basement is locally overlain by Eocene deposits, composed of nummulitic limestones and conglomerates (Dieni et al., 2008). Along the Cedrino valley (Fig. 1), some recent Neogene deposits have been identified and reported on geological maps (Calvino et al., 1972). These Neogene deposits have been previously described as marine sands and alluvial sands and gravels (Calvino et al., 1972; Massari and Dieni, 1973; Dieni et al., 2008). Calvino et al. (1972) distinguished an Early Pliocene marine formation upstream from an older, possibly Miocene, continental formation downstream.

Over a distance of 40 km, the Gulf of Orosei coast displays some tidal notches within Mesozoic limestones. These notches are assigned to the Tyrrhenian MIS 5e high stand (Coltorti et al., 2010). Their elevation ranges from 7.6 m asl (above sea-level) in the south to 11.5 m asl in the north of the Gulf, and is indicative of a significant uplift in the Orosei area. This local uplifted area has been attributed to the upwelling resulting from the emplacement of recent volcanic bodies within this area (Mariani et al., 2009).

3. Materials and methods

The studied sites will be presented according to their location along the Cedrino Valley. The upper slope of the continental deposit will be described first, followed by the accumulations of the alluvial plain close to the present Mediterranean shoreline, and finally by the littoral and deep-sea marine deposits (Fig. 2). We document the Late Neogene evolution of the Orosei area from sedimentological analysis, including facies analysis and paleoenvironmental interpretations from both outcrop data and samples analysis (R.X diffractometry, calcimetry, grain-size distribution, thin-section studies).

Biostratigraphic data and paleoecological interpretations were based on foraminiferal assemblages observed in 20 samples. Among them, the occurrence of certain planktonic foraminifers allowed to assign an age to the deposits emplaced in a deep-water marine setting. Residues for micropaleontological analyses were wet-sieved in the laboratory and the fraction over 63 μm extracted. The residues were then dried and dry-sieved again using a 150 μm sieve. Semi-quantitative counts were carried out from the >150 μm fraction.

The samples with a significant proportion of fine-grained sediments were processed to search for Coccolithophoridae nannoflora. The preparation followed standard techniques. A smear slide was mounted with Norland Optical Adhesive. No centrifugation was applied to concentrate the biogenic fraction in order to retain the original composition of the nannofossil assemblage. Semi-quantitative analyses were performed with a light microscope at 1250× magnification. The biostratigraphic zonation of Cita (1975), revised by Sprovieri (1992), was used for the foraminifera; the zonation scheme of Martini (1971) and Rio et al. (1990) revised by Raffi et al. (2006) was used for the calcareous nannoplankton. Other biostratigraphical definitions lean mainly on the works of Colalongo and Sartori (1979), AGIP (1982), Iaccarino (1985), Van Morkhoven et al. (1986), Colalongo et al. (1990). The terms "Quaternary" and "Pliocene" and relative stages used in this work allude to the geological time scale definition, with reference to the accepted stratigraphic boundary approved in 2008 by the International Commission on Stratigraphy at the bottom of the Gelasian stage dated 2.58 Ma (Ogg and Pillans, 2008; Head et al., 2008; Gibbard et al., 2010).

4. Continental deposits, sedimentology and facies association

4.1. *Fabric characteristic of subaerial slope deposits*

The uneven slopes of the granitic reliefs above the valley of Cedrino are covered from upstream to downstream by chaotic

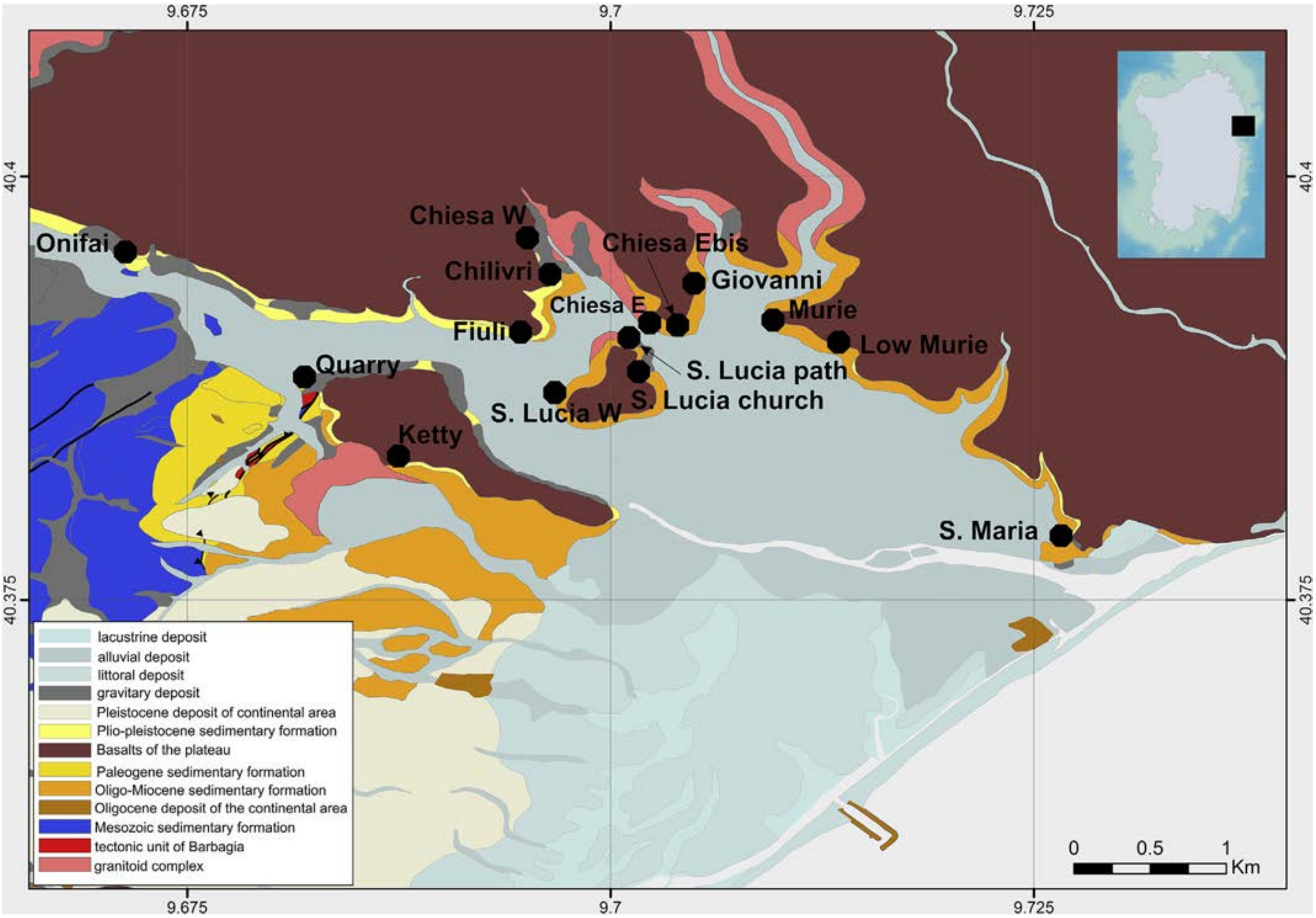

Fig. 1. Location of studied sites on the digitalized Geological map of Sardinia (2008) after Calvino et al. (1972).

blocks, followed by accumulations of conglomerate and polygenic or monogenic breccias reaching globally 40 m in thickness. These more or less cemented deposits are mapped as Miocene on the existing geological maps (Calvino et al., 1972) (Figs. 1 and 2).

4.1.1. Murie road

Along the Murie Road, at 14 m asl, the granitic basement shows large fault planes directed N100°E to N120°E and dipping 65–75° northward (Fig. 3). Striations on fault planes are dip-slip and therefore indicate only vertical movements with no strike-slip component. The markers on striated fault planes are not sufficiently preserved to assign a normal or reverse displacement on these faults.

Above the basement, chaotic accumulations of polygenic blocks (granite, Jurassic limestone, Paleozoic schist) occur on gentle (5° or less) to some steeper slopes (30–40°). These blocks are irregularly angular and packed in very poorly-sorted granitic sand. Downslope, stratification patterns are observed from predominantly coarse gravel units in NW–SE axial position to mainly fine matrix-rich elements at the distal side of the deposit. Decimeter-thick fining-upward sequences form the talus zone, where ridges made of heterogeneous sediment (levees) are found on both sides of the depocenter. More locally, sandy and gravelly graded bedded sequences show small U-shaped structures.

Downstream deposit sequences with a lower unit showing very angular blocks (Fig. 4a and b), are covered by late Pliocene or early Pleistocene lava flows. Most of the depositional sequences consist of a coarse lower term with irregularly-angular gravel passing upward to an upper term, sandy or sometimes silty term (Fig. 5a and b). Some lower terms can reach 1 m in thickness, while the upper terms of the sequence are only 10–30 cm thick because they have been more or less flattened during the deposition of the successive sequence. Under microscopic observation, subangular and mat quartz grains are associated with feldspars, mainly of the plagioclase group, and with micas attached to quartz grains. Similar very coarse sequences are also observed further west between 10 and 25 m asl in the lower part of the cliff, near Giovanni.

4.1.2. Chiesa-East

The quarries of Chiesa-East (Figs. 1 and 2), on the hillside opposite to that of Giovanni, show a 40 m-thick succession starting with a granitic base, chaotic and granitic sand, gently dipping stratified slope deposits and ending with marine deposits. The chaotic deposits include angular pebbles (most frequently). The clasts are essentially of granitic nature, but some small elements are of schistose lithology, thus indicating a mixed allochthonous origin. The fossilization of chaotic deposits was enhanced by calcite cementation (Fig. 6a). As at Murie road, in the stratified deposits, polymineral grains, large sub-angular quartz grains, and biotite stacks are common, and the clay fraction is almost non-existent. These stratified deposits are poorly sorted, azoic, and totally lack glauconite grains. They form 30–60 cm-thick roughly graded sequences. The lower terms are gravelly and sandy. The upper and

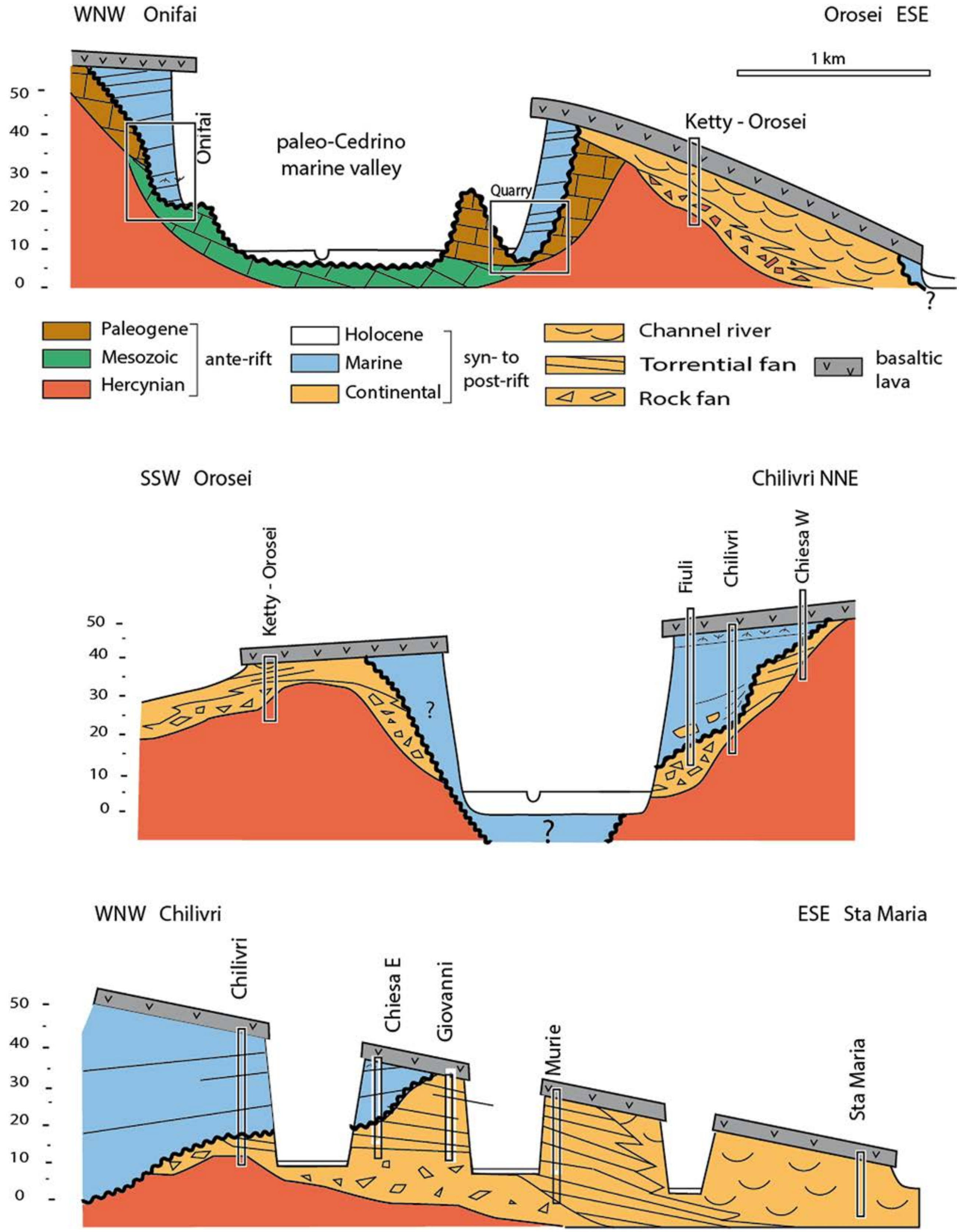

Fig. 2. Three simplified sections showing the geomorphological and stratigraphic framework of the Cedrino Valley and the transition of the piedmont deposits (Murie Road) towards the main alluvial plain (Santa-Maria). Locations of outcrops in Fig. 1.

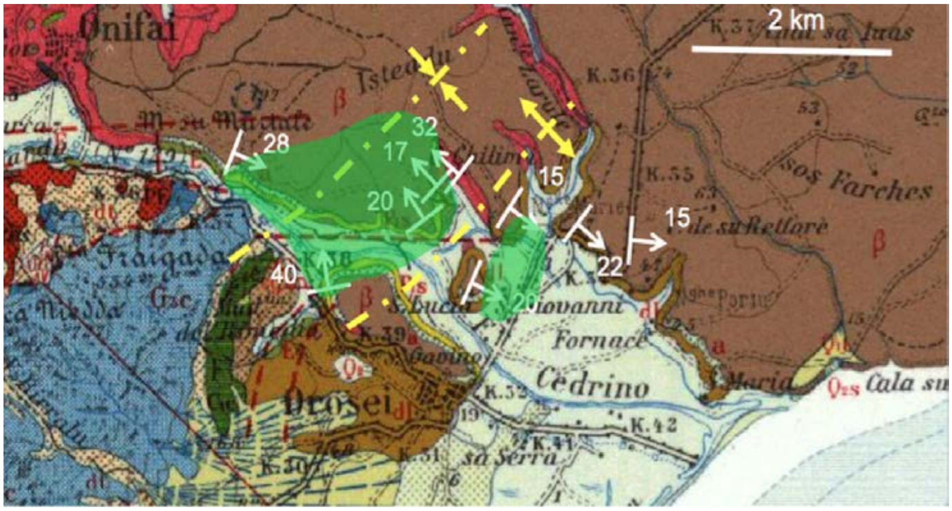

Fig. 3. Measured dips in the Neogene infra-lava series of the Orosei region and indicated on the 1/100,000 geologic map (Calvino et al., 1972). The overload of green colour added to this map corresponds to the zones of outcrops of the marine silty-sandy series attributed to the upper Pliocene. Dips (in white) are organized according to folds of NE–SW axis, which are indicated in yellow on the map. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

thinner terms are sandy and silty-sandy, sometimes truncated by the lower term of the overlying sequence. Various grains are covered by iron and manganese oxide coatings. Upward, the beds are interrupted by an erosional surface (Fig. 6b), which coincides with the beginning of littoral marine sedimentation with dark grains of glauconite and dispersed broken shells of marine macrofauna (pecten, oysters).

4.1.3. *Chiesa-West, Fiuli and Orosei-Ketty*

The hillside of Chiesa-West (Figs. 1 and 2) was not incised deeply enough to reach the granitic basement. At Santa Lucia locality (Fig. 1), at ~15 m asl, some 10 m of sandy bedded deposits show numerous granitic clasts concentrated in the lower term of the sequences. Poorly sorted sediments are of granitic origin and contain some highly abraded or even rounded gravels of quartz, indicating the contribution of a more distant or older source. As well as in Chiesa-East, iron and manganese oxide coatings, and goethite cutans were observed around grains. Dessication cracks characterize some upper terms of the sequence, covered by a lava flow.

At Fiuli quarry (Figs. 1 and 2), from about 10 m asl, the continental deposits overlying the granitic basement are much thinner, being restricted to a few-meter thick chaotic and conglomeratic accumulations. The site of Orosei-Ketty is the westernmost site of the study area, and includes coarse-grained sequences exclusively composed of reworked granitic materials. Here, the thickness is significant, and its coarse lower terms can be up to 1 m-thick.

Graded bedded sand and gravel sequences seem related to torrential floods. Considering the low elevation of the area, the observed stratified slope deposits cannot be considered typical of periglacial conditions, with solifluction lobes originated from frost-related conditions and occurring in environments characterized by numerous annual freeze and thaw cycles (Combourieu-Nebout, 1993). Such rapid mass movement of poorly sorted granular solids, water and air form channelized debris-flows characterized by several hundred meters long flow-tracks.

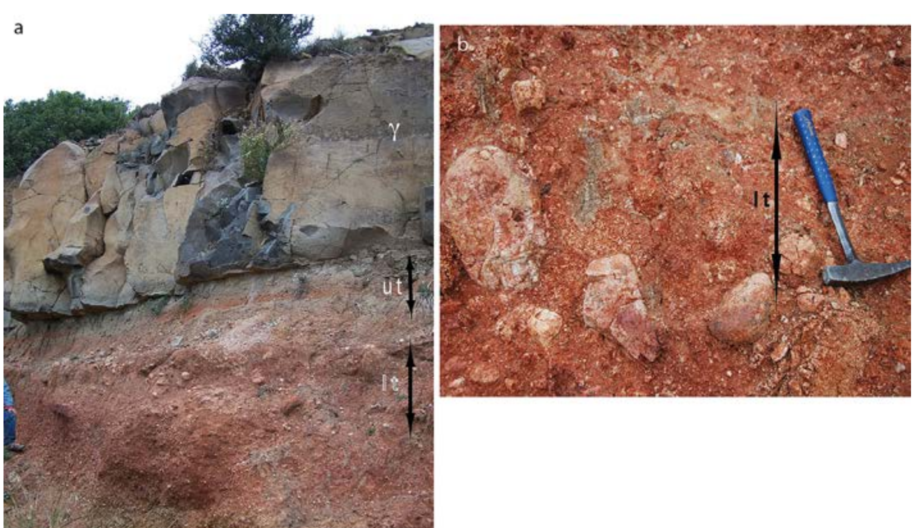

Fig. 4. Murie downslope section (location Fig. 1; geological log Fig. 2). (a) Downstream accumulation of slope, top of the sequences of torrential deposit sequence covered by post-Pliocene basalt lava (γ, pigmentation by the ferric iron arises from this basalt, lt: lower term, ut: upper term; (b) zoom section of the lower term (lt) showing the very angular blocks (wind abrasion) of the torrential sequence.

Fig. 5. Murie section (location Fig. 1; geological log Fig. 2) showing the graded bedded sequences of torrential floods, (a) coarse lower term (lt) and fine upper term (ut) of equal thickness, (b) Succession of torrential sequences: the lower pebbly term (lt) grades to a sandy-gravelly upper term (ut) some 20 cm thick, likely levelled during the accumulation of the coarse term of the following sequence.

These clast-supported deposits with very limited fine-matrix are comparable with the Holocene torrential deposits that are observed in short torrent gullies on the hillsides of the Moroccan South Atlas or the Mauritanian Adrar (Giresse et al., 2012). On the basis of the Mauritanian model, such mass transport usually occurs as a reaction to high-density rainstorms that play a dominant role in triggering debris-flows (Caine, 1980; Nemec and Steel, 1984); a general lack of vegetation also promoted debris-flow activity. Repeated episodes of exposure are indicated by oxide coatings and cutans and by dessication cracks.

4.2. Facies association of alluvial deposition

The site of Santa Maria (Figs. 1 and 2), located downstream is the only one to show, below the lava cover, large exposures of alluvial plains deposits. On the left bank of the Cedrino valley, fans of braided channels are associated with well-developed levees joining to form terminal lobes 2–6 m thick (Fig. 7). The fans present accumulations of coarse sand and gravel with oblique stratification with a dominant tilt toward the southeast. Rough stratification allows the observation of faint graded bedded successions, but locally very coarse ungraded accumulations stem directly from the closest slopes. Between the reliefs of these coarse accumulations, lenses of silt lenses settled in the topographic lows of the alluvial plain at the end of flood events.

The deposits of Santa Maria display some E–W trending faults (N090°E to N110°E) dipping 60–70° northward (Fig. 3). Their offsets clearly show normal displacements with pure dip-slip striations. Occasional nearly horizontal striations demonstrate a certain amount of strike-slip movement along some of these faults. From the sparse outcrops, these faults show minimum normal offsets ranging from 1 to 3 m.

The Santa Maria fluviatile deposits were fed by the numerous ephemeral stream flows, related to the torrential deposits appearing upslope at varied elevations. A hot but dry climate could explain such flooding processes. The upward transition of trough cross-stratification into planar stratification, with a fining and thinning upward trend, suggests a braided river subject to a progressive lowering of stream gradient.

The position of these deposits below the lava flow indicates an Upper Pliocene or very Early Pleistocene age. Marine deposits could be locally preserved under the fluviatile accumulation. However, this suspected geometry could not be observed from outcrop within the specific area.

4.3. Facies association of aeolian deposition

Unlike the previously described continental accumulations, directly overlying the granitic basement, the aeolian sands are observed at many localities (Onifai, Fiuli, Chiesa) at the top of the

Fig. 6. Chiesa-Est site (location Fig. 1; geological log Fig. 2), (a) Masses of fallen rocks of slope rest on the granitic base, overlain by about ten roughly graded bedded sedimentary sequences, the yellow broken line indicates the transition; (b) The rhythmic character tends to disappear upward, where the sand becomes finer and more micaceous. The transition between both types of sedimentation is expressed by a clear stratigraphical hiatus (yellow line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

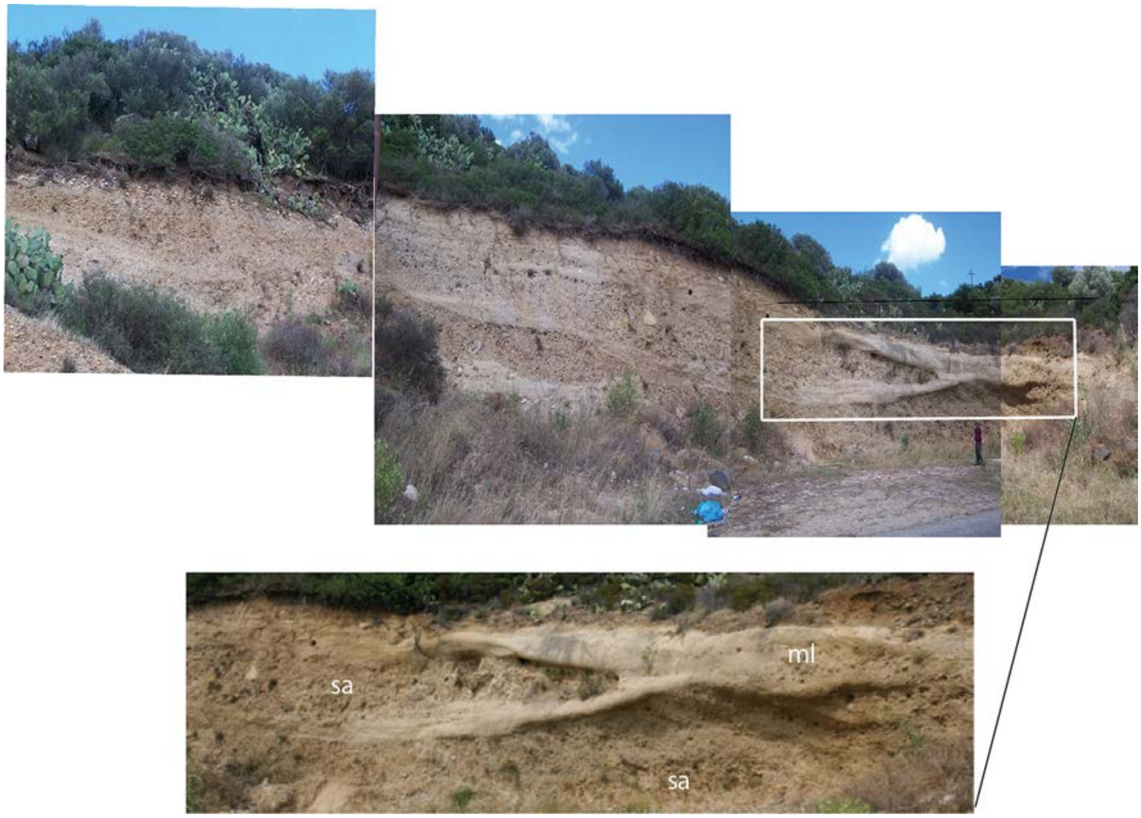

Fig. 7. Santa Maria section (location Fig. 1; geological log Fig. 2) showing the deposits of alluvial plain of Cedrino; anastomosed channels associated with bars of side accretion (sa) and muddy lenses (ml) of settling of floods.

Neogene sequence and under the lava cover. At the locality of Onifai (Figs. 1 and 2), the accumulation of fine and azoic sands and micaceous silts reaches about 10 m thick. These aeolian deposits are composed of well-sorted medium to fine-grained loose sands and are slightly cemented by calcite, but local processes of leaching *per descenso* induced a decalcification ending in pedogenetic formation consisting of small globular calcareous concretions and small veins of calcium carbonate; also, 1–2 cm thick and 10–30 cm long vertical concretions are observed along fossil root-tracks. The only fossils are continental gastropods, such as *Cyclostoma* and *Helix*. These deposits have some sub-horizontal laminated layers (1–4 mm thick; Fig. 8a). The planar structures are locally underlined by poorly developed light yellow to yellowish brown accumulation horizon (Bh), usually characteristic of podzolic processes (Fig. 8b). Moreover, at some distance, occasional intercalations of high-angle (35–40°) aeolian deposits were also observed.

Low-angle aeolian deposits of the sand sheets are known to originate mainly by gentle deceleration of wind in the lee of small topographic features. Low to moderate wind velocities generally remove fine sand from exposed areas (probably coastal dunes). Subsequently, the sand is deposited in nearby topographical lows or sheltered places (Fryberger et al., 1979). The recognition on the field of low-angle aeolian deposits may assist in identification of the limits of ancient dune fields. Such low-angle or horizontal beddings are commonly observed on deflation surfaces and at the

Fig. 8. Onifai section, showing (a) sub-horizontal planar stratifications of well-sorted aeolian sand; (b) poorly developed Bk or A1K iron accumulations, light yellow to yellowish brown, usually characteristic of podzolic processes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 9. Onifai section, above the surface of erosion (black line) which makes an incision here in the basement schists (Paleozoic ?), fan-shaped silty-sandy benches with westward dips which are more than 25° in the lower part and lower than 10° at the summit.

transition with the interdune areas in the Pleistocene of the Orosei region (Coltorti et al., 2010). Similar podzolic paleosols have been described in the Pleistocene aeolianites of Elba Island (Cremaschi and Trombino, 1998) and the Viticcio Gulf (D'Orefice et al., 2007). Widespread coastal dune systems also developed during the Pleistocene on the northwest coast of Sardinia under cold and relatively dry conditions. They are interlayered by colluvial and paleosols, the oldest wind dominated system being dated from MIS 8 (Andreucci et al., 2010, 2013; Pascucci et al., 2014). It is suggested that this uppermost Orosei succession of aeolian origin was emplaced under the first cooling conditions of the Late Pliocene or the Early Pleistocene around 2.6 Ma (Ruddiman et al., 1989).

5. Marine facies associations and depositional sequences

The Neogene marine deposits preserved along the Cedrino River show contrasting bathymetric environments (fore-shore, pro-delta, shelf or top of slope) that can be abruptly superimposed on top of the other along few meter thick intervals. Several marine deposits contain a macrofauna of coastal mollusks such as pecten, oysters, turritella, brachiopods, madrepores, rock-dwelling sea urchins, and a diversified microfauna consisting of foraminifers and ostracods. This allowed a rough estimation of the paleo-bathymetry. The following list of foraminifera is not exhaustive but indicates the most abundant species or genera that have been mainly used to define the paleoenvironments.

Among the benthic foraminifera, the most important are *Bulimina elegans, Melonis barleanuum, Elphidium sp, Cibicides sp., Bolivina spathulata, Cibicidoides pachyderma*. Two species in particular, *Siphonina reticulata* and *M. barleanuum,* indicate water depths greater than 100 m and full marine conditions. Among the planktonic foraminifera, *Turborotalia quinqueloba*, *Orbulina universa, Globigerinoides bulloideus, Sphaerodinellopsis sp.* are abundant. Among the ostracods, *Aurila sp., Loxoconcha sp., Callistocythere sp.,* and *Eucythere sp*. are the most commonly found.

Only the deep-sea water deposits, which are also the muddiest, contain benthic foraminifers such as *Bulimina marginata, Valvulinera bradyania, B. elegans, Sphaerodinella sp.* or ostracods such as *Cytherella robusta* and *Henryhowella* sp. Only a few sites display a sufficiently continuous succession of the transgressive sequences over a total thickness of 20–30 m: Onifai, Chilivri, Fiuli, and Chiesa East.

5.1. *Onifai section*

The section, sealed at the top by the lava flows, corresponds to a 30 m thick accumulation starting at 8 m asl over the highly deformed schist basement (Figs. 9 and 10). Beds dip toward SE, with an upward decrease in the dip of strata indicating some fanning toward the SE, i.e. toward the depocenter of a small and confined Pliocene basin (Figs. 3 and 9) (Fig. 11).

The first marine deposit is very rich in schistose fragments and blocks of Eocene nummulitic limestones, indicating reworking of the underlying basement. Abundant macrofauna remains (oysters and sea urchin spines) indicate the nearby existence of a rocky basement. Such shell-bearing coarse deposits (coquina), about 40 cm thick, suggest a high-energy depositional environment in the littoral zone. Directly above, dark-brown clayey-silty layers up to 10 cm thick contain foraminifera. In particular, the presence of numerous planktonic species suggests deposition extending from the outer shelf to the upper slope. The relative deep-water environment is also attested by the presence of glauconite grains. Directly above, a well-sorted micaceous fine sand contains a rather abundant macrofauna (mainly bivalves and mud-dwelling sea-

Fig. 10. Onifai section. (a) photo of the bottom part of the Onifai outcrop site showing the Pliocene marine sequential deposits resting on the schistose basement. A small accumulation above the erosion surface is protected in the interface basement-Pliocene deposits (white broken line) and contains pebbles of Eocene nummulitic limestones (yellow arrow). About 1 m above, various deformed brown silty lenses or clay pockets (cp), indicate deep sea water deposition. (b) photo of the upper part of the Onifai section showing the sandy series of the Upper Pliocene with alignment of calcareous nodules representing early diagenesis. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

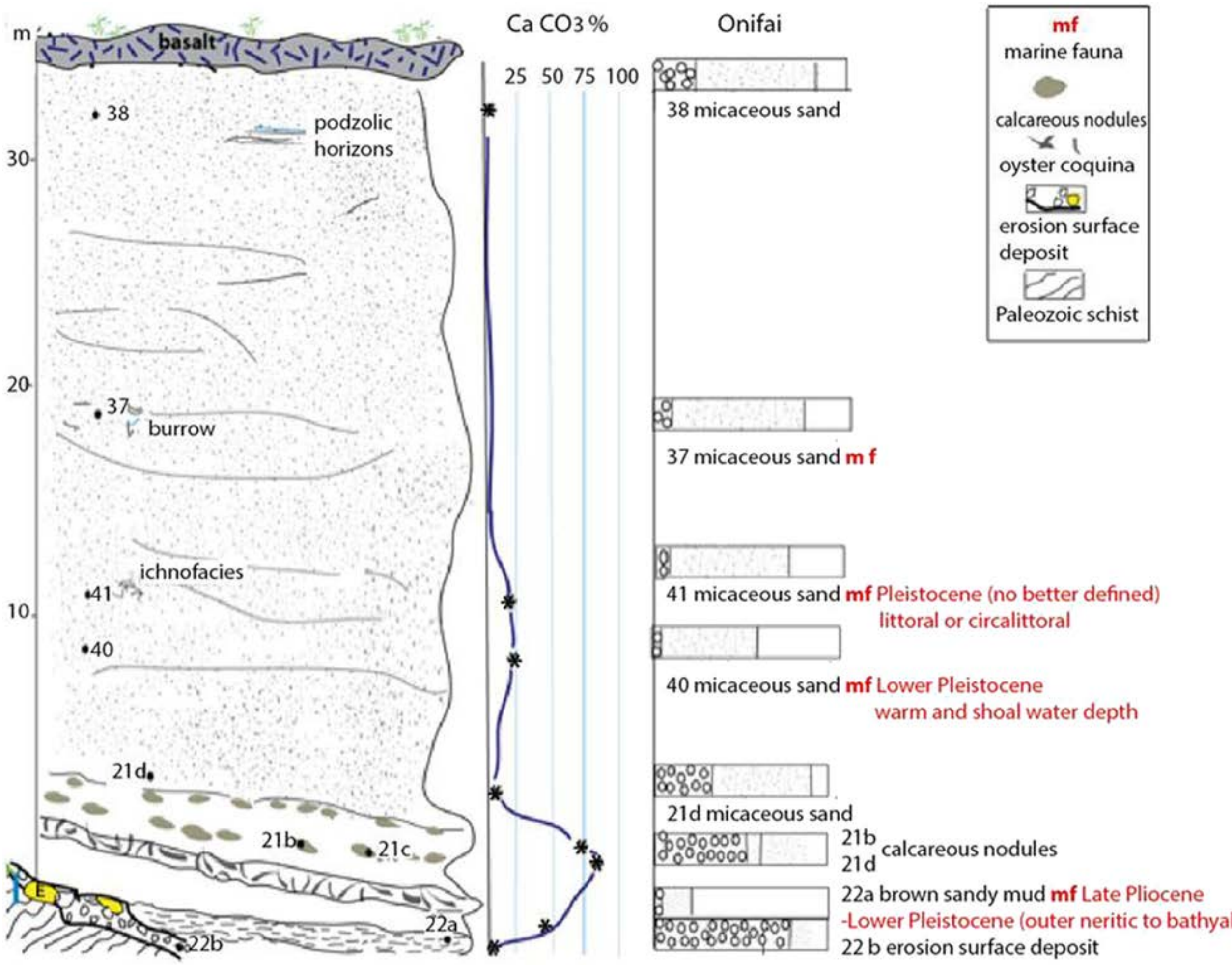

Fig. 11. Geological log of the Onifai section showing the lithology and sequence of the Upper Pliocene marine transgression.

urchins spines) and a foraminifer microfauna suggests a mixed slope environment with both deep-water and nearshore influences.

Moving upward, examination of the macrofauna shows the succession of a lower neritic-upper bathyal fine-grained accumulation, followed by littoral accumulation (oysters and rocky-substratum fauna). The benthic microfauna (*B. elegans, M. barleanuum, Elphidium sp, Cibicides sp*) indicates a littoral environment, possibly shore-reef and some ichnofacies (*Palaeophicus*, *Ophiomorpha*) reflect a lower shoreface environment. Then, a brief emersion is indicated by rubefaction and the disappearance of bioclasts. Above, a mixed deposit with both deep-water and nearshore influences stops approximately 10 m below the basalt. The final regression step is represented by the aeolian interdune accumulations.

5.2. Chilivri section

The marine sediments below the lava are observed over a distance of 100 m along the left bank of a small tributary of the Cedrino River. It corresponds to a 25–30 m thick continuous vertical section observed through stream erosion. This section is described from bottom to top (Fig. 12).

At 21 m asl, the section begins with an autochthonous granitic sand containing numerous granitic pebbles and packages of sediment, sometimes slightly cemented by carbonate. The first allochthonous deposition is represented by azoic layered deposits consisting of several mm-to-cm-thick graded bedded micro-sequences, in which oxidized sandy microbeds alternate with greenish or red silty micro-beds. Sandy microbeds are quartzo-feldspathic and contain coarse well-rounded quartz grains and angular fine grains. Silty microbeds consist essentially of very small grains of plagioclase feldspars (anorthite, albite). Above, a slight increase in carbonate content (reaching 7%) coincides with the presence of benthic foraminifera. Bioclasts become are varied and abundant: large benthic foraminifers (*Elphidium*), mollusks, radioles, and some barnacle fragments, reflect the vicinity of the shoreline. Above, similar micro-sequences contain a more diversified microfauna where the relatively deep-water benthic foraminifera (*Uvigerina* and *Bolivina*) coexist with rare littoral benthic species (*Elphidium* mainly) and indicate a deeper marine depositional environment.

Slightly above, a light beige shelly sand is composed of numerous and diversified bioclasts: large benthic foraminifers (*Elphidium*), mollusks, radioles, and barnacle fragments. These indicate the closeness of the shoreline. However, various planktonic foraminifera are associated with benthic ones. Above, some slightly tilted 10 cm-thick layers are prominent in the outcrop. These layers consist of a shelly accumulation forming a weakly cemented coquina limestone bed, rich in debris of nearshore fauna. The poor sorting, the scarcity of micas, and the concentration of the sea-urchin radioles suggest a rocky, high-energy, coastal

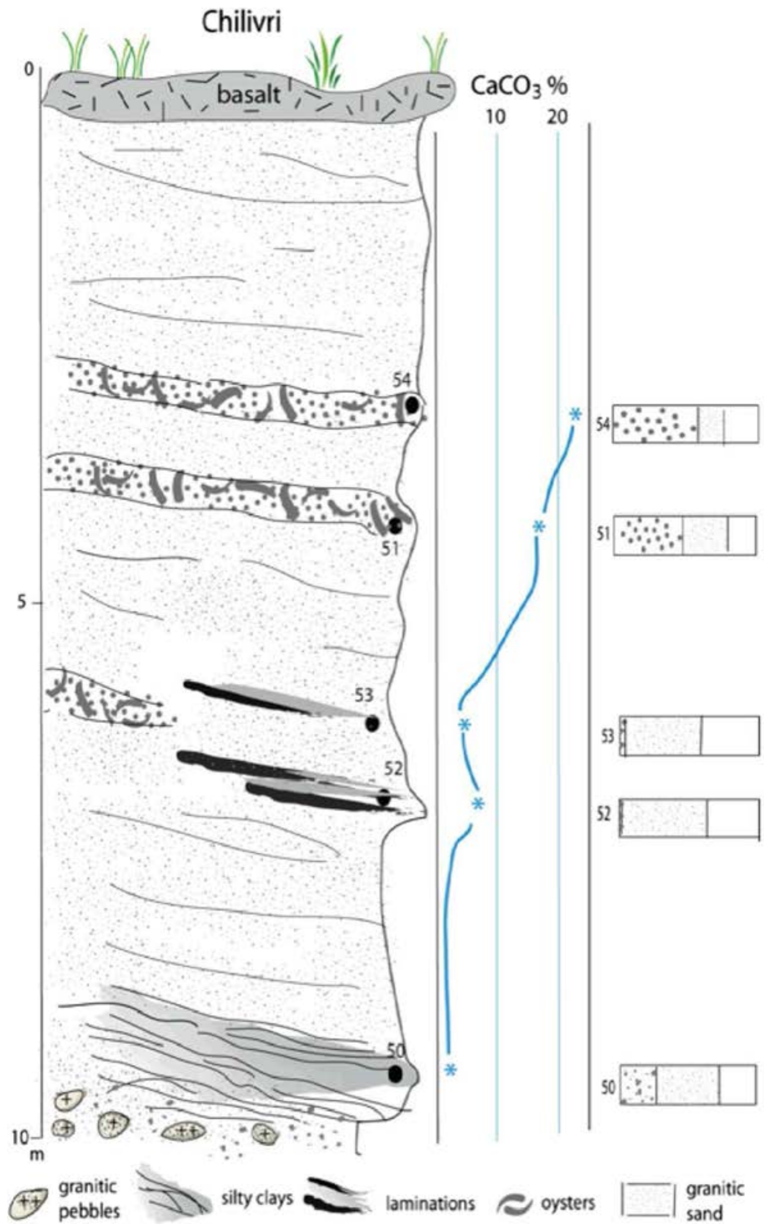

Fig. 12. Geological log of the Chilivri section showing the lithology of the Upper Pliocene marine transgression sequence.

environment. Further above and up to the base of the lava layer, the deposits, fed by granitic alteration, are largely bioturbated (*Ophiomorpha* and various burrows) but are completely azoic.

5.3. Chiesa East section

The basement consists of granite overlaid by granitic sand with some apparently *in situ* large angular blocks. It is covered by decimeter-thick beds of coarse sands dipping at 20° toward the NW. The rhythmic aspect of this deposition is underlined by the beginning of cementation and an increase in carbonate content up to 20%.

The first observed marine deposit is rather rich in radioles of rock-dwelling sea urchins and pecten shells, some of the shells undergoing dissolution at the present time. It also contains angular quartz grains associated with feldspar and some glauconite grains. Several tens of centimeters above, micaceous fine sand with very scarce shell debris but abundant light green glauconite suggests a sheltered nearshore environment. Upward, the microfauna extracted from silty layers (especially two species: *S. reticulata* and *M. barleanuum*) indicates a trend towards a deep-water environment. This weakly rhythmic accumulation continues over a 10–15 m thick interval. The carbonate content remains close to 20%, in spite of the absence of cementation. The deposit is rich in glauconite grains in various stages of mineralogical evolution.

The rhythmic character tends to disappear upward whereas the sand becomes finer and more micaceous. The transition between both types of sedimentation is expressed by a clear stratigraphic hiatus (Fig. 6b). Then, a decrease in water depth of the depositional environment is attested by the diminution of previously cited markers, *S. reticulata* and *M. barleanuum*, and by the reappearance of the benthic macrofauna characteristic of rocky shorelines.

The uppermost 6 m are siliceous and nearly azoic, with the exception of some rare fragments of indefinite mollusks. Microscopic observation reveals the presence of coatings of both iron and of manganese oxides around the quartz grains. These deposits show faint beddings underlined by the impregnation of ferrous or ferric iron, which has infiltrated from the overlying basaltic lava.

5.4. Fiuli Quarry

An about 30 m thick sedimentary accumulation starts at 10 m asl over the granitic basement which top correspond to a highly irregular erosional surface (Fig. 13). The beds are tilted toward the northwest. Moreover, they show a clear fan-shaped geometry with bedding dipping from ~25°NW at the base, close to the basal unconformity on granite, to a few degrees (4°–7° NW) at the top of the series, directly below the lavas.

Above one to two meter-thick nearshore deposits, a sandy and organic matter-rich grey mud contains about 30% carbonate. Its abundant planktonic microfauna reflects both the outer edge and to the top of the slope. It is the deepest marine deposit observed in this study of this Cedrino valley.

At about 18 m asl, and overlying a granitic relief, is a succession of fine carbonated and glauconitic muds (20–40% of $CaCO_3$), rich in planktonic foraminifera. Concentrations of discontinuously cemented, coarse shell debris are commonly observed. Towards 22 m asl, the decrease in carbonate content, the disappearance of glauconite and some indications of rubefaction reflect a general trend to emergence. The uppermost evidence for clear open marine sedimentation appears at about 24 m asl, with the presence of planktonic microfauna. These deposits grade upward to littoral sands including some iron-coated pecten shells. Lastly, overlying this marine section, and below the basaltic lava, the youngest sedimentary facies corresponds to well-sorted azoic sands, most probably of aeolian origin.

The earlier coastal deposits vary from a thin layer of pebbles to some few meter-thick deposits. Nearshore deposits appear rather widely, either towards the base of the outcrop, or at intermediate heights. Beach-rock exposures are commonly observed throughout the section. They provided a hard substrate for oysters and sea-urchins. Generally, coarse bioclasts and quartz gravels indicate a high-energy beach. Magnesian calcite cements of beach-rocks are characteristic of supersaturation with $CaCO_3$ through direct evaporation of seawater, as commonly observed in the Mediterranean phreatic zone (Milliman, 1974).

In several successions, such as those of Onifai and Fiuli, deep-sea deposits abruptly occur without any transition with the nearshore deposits previously emplaced. The appearance of the deepest-water sedimentation, namely the outer edge of the shelf or upper slope, implies a relative rise in sea level of at least 100 m. This sea-level rise occurred shortly after the beginning of the transgression on sites dispersed over 15–20 km and requires a significant collapse of a local part of the Sardinian margin. On the other hand, the Chilivri sequence records relatively coastal environments, the greatest water depth being observed towards the top of the sequence. This indicates very local, but perceptible, differences of the trend of the transgression, because Chilivri and Fiuli are separated by only 4 km.

According to the observed indications, a sketch of the succession of the sea level changes going from the coastline down the outer shelf edge (from 1 to 4) is proposed (Fig. 14). The most complete records (Fiuli, Onifai and Chilivri) are indicative of a general transgression–regression cycle but with several positive or negative oscillations of the sea level. At Onifai, with two of these negative oscillations, this results in fleeting trends towards emergence. Several times, the maximal water depth was reached abruptly in the lower part of the sequence, before the intervention of recurrent and small sea level oscillations. At Fiuli, the final emergence occurred after a last short marine episode. Accordingly, the succession of the terms of a sequence is not that of a usual marine transgression–regression cycle. These oscillations of the sea level can be understood through the intervention of significant tectonic processes, contemporary to the deposition.

The observed fine-grained lagoonal deposits dipping at high angle (up to 20–25°) were controlled by post-depositional tectonic activity. The upward decrease in the dip angle (from 20–25° to 4–7°) reveals a fan-shape geometry, due to the progressive deformation of the whole sequence during the Pliocene.

6. Biostratigraphy and inferred origin of pre-Messinian erosion surfaces

6.1. Biostratigraphic analysis considerations of Pliocene deposits at Fiuli quarry

A muddy and organic greyish level (SAR-16) contains an association of foraminifera rather rich in planktonic species. No evidence of the lowermost Pliocene was observed in this sample. In samples SAR-15 and SAR-16 (Fig. 13), *Globorotalia puncticulata* is

Fig. 13. View of the cliff of Fiuli site (Fig. 1 for location) showing the progressive dip variation (black lines) that indicates the geometry of the fan-shaped deposits towards the northwest. Location of analysed samples is shown.

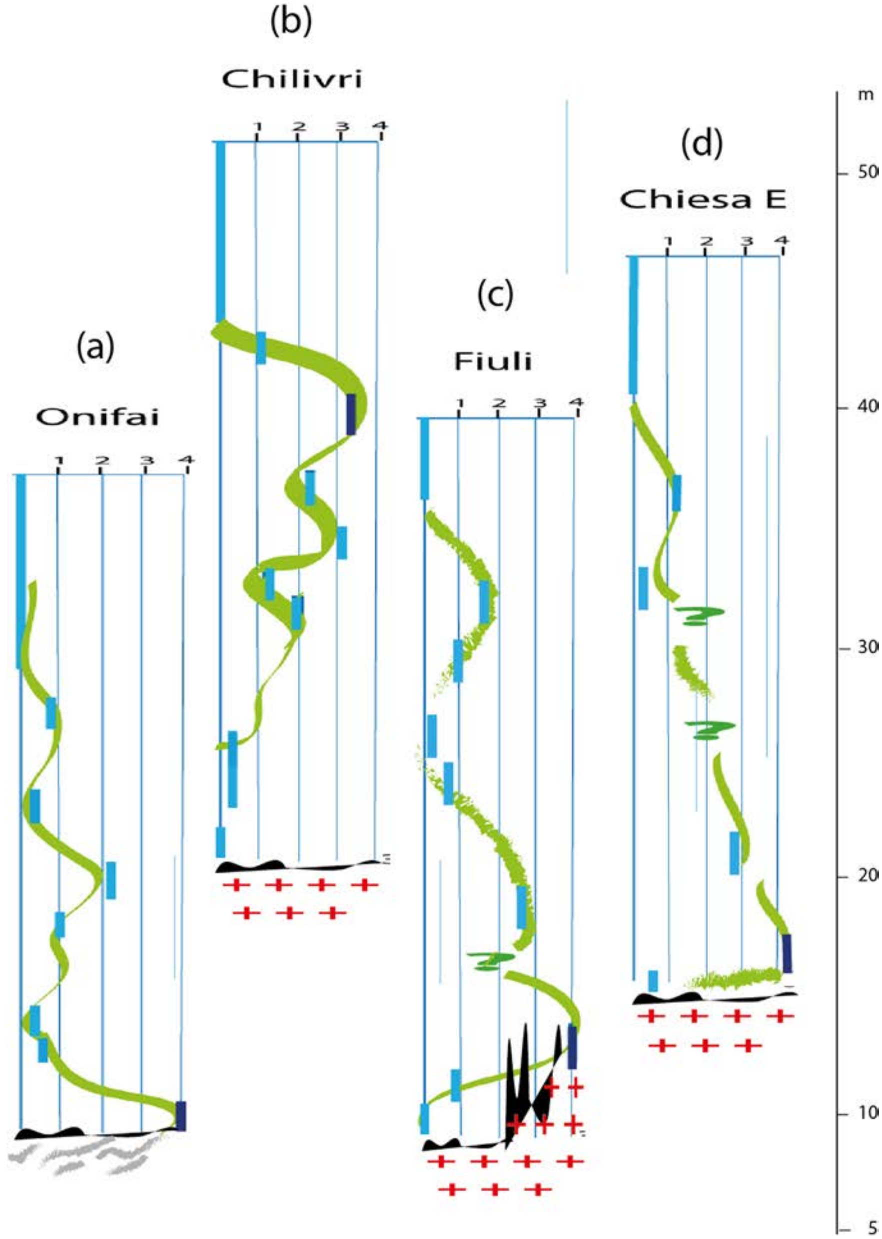

Fig. 14. Terms (in blue) of the transgressive sequence (in green) of the sites of Onifai (grey schist basement), Chilivri, Fiuli and Chiesa East (granitic basement). 1. Coastal or lagoonal; 2. Inner shelf; 3. Outer shelf; 4. Outer shelf and upper slope. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

commonly found, even if it was difficult to determine, as the morphotype is slightly different from the holotype described for the deep sea. *Sphaerodinellopsis dehiscens, Globigerinoides obliquus* and *Globigerinoides obliquus extremus* are concomitant and show good preservation (we thus assumed that they have not been reworked). According to the established planktonic foraminifera stratigraphy in the Mediterranean (Langereis and Hilgen, 1991), the absence of *Globorotalia margaritae* and the presence of *G. puncticulata* suggest that the sediment is younger than 3.81 Ma. Considering that *G. obliquus and G. obliquus extremus* became rare after the disappearance of *G. puncticulata* (2.41 Ma, Serrano et al, 1999) and they are abundant in the studied samples, we believe that the biostratigraphic age is between 3.81 and 2.41 Ma.

No other significant biostratigraphic marker was found either in samples SAR-15 and SAR-16, or in the upper part of the studied section. Based on the results, we cannot define the deposit age more precisely. A more accurate biostratigraphic study would be necessary to determine without ambiguity the precise age of the deposits. This task might be difficult, as the greatest part of the sediment is coarse grained, and reworking processes have affected the preservation of microfossils.

The coccolith assemblages could help to refine the age proposed above. However, a rich and well-preserved coccolith assemblage found in carbonate mud clasts indicates a Tortonian age for this material, that is necessarily reworked. In detail, samples SAR-11 and SAR-16 contain diversified nannoflora, with abundant *Reticulofenestra pseudoumbilicus,* medium-sized *Reticulofenestra spp*., and *Coccolithus pelagicus*. Subordinates are *Calcidiscus leptoporus*, *Calcidiscus macintyrei*, *Sphenolithus abies*, Helicosphaera carteri, *Rhabdosphaera spp*., *Syracosphaera pulchra*, *Syracosphaera* spp. *Scyphosphaera* spp., *Pontosphaera* spp., and *Braarudosphaera* spp.

Among *Discoaster*, no five-ray specimens have been detected: in sample SAR 11 *Discoaster brouweri* occurs abundantly and *Discoaster neohamatus* is common. No horseshoe shaped (*Amaurolithus* or *Ceratolithus*) occur in this sample. Sample SAR-16 shows rare *Discoaster pentaradiatus*, *Discoaster surculus* and abundant *D. brouweri*. In addition, rare specimens of *Amaurolithus primus* and *Amaurolithus delicatus* occur.

SAR 11 appears to be much older than SAR 16, and the calcareous nannofossil assemblage suggests Zone MNN 9 of Fornaciari et al. (1996), and in particular, the interval noted by Raffi et al. (2006) bracketed between the *Discoaster hamatus-D. neohamatus* cross-over and the LO of *D. pentaradiatus*, (9.2–9.8 Ma). Calcareous nannofossils in Sample SAR 16 suggest the NN 11b zone of Martini (1971) and can be more precisely dated between 7.2 and 7.3 Ma because of the concomitant occurrence of *Amaurolithus spp*. and *R. pseudoumbilicus*. No evidence of definitive Pliocene species occurs in both samples.

Based on the above data, we hypothesize that erosional processes and transport occurred along the relatively steep slopes of the Pliocene ria, forming debris-flows and relatively coarse-grained deposits. Pliocene planktonic foraminifera are incorporated in the silt-sand fraction, but contemporaneous Pliocene coccoliths are absent, probably due to the coarse grain size that prevents their preservation. The reworked nannoflora is derived from erosion and transportation of older sediments.

6.2. Pre- Messinian surfaces and Messinian erosion surface

Residual accumulations are observed in several places at the top of the basement and indicate the presence of a surface of subaerial origin below the continental deposits. As these continental deposits are not dated, the age of this surface cannot be determined. They are Miocene according to the geological maps in this area. These sediments are either directly overlying the top of the Eocene (Quarry site) or observed near the outcrops (Chiesa E, Santa Lucia, Onifai) (Table 1). These are patches of restricted spatial extent, overlying both the Paleozoic (or Mesozoic) schistose basement at Onifai or the granite at Fiuli, Chiesa E, and Santa Lucia. Reworked material associated with the erosion surface is found below the Pliocene sequence, as observed at Chiesa (East and West), Fiuli, Santa Lucia, and Onifai. Based on the age model previously proposed for the deep-water Pliocene records, this erosion surface is older than 3.81 Ma. We have no evidence for marine Lowest Pliocene material associated with the reworked material on this coastal sector of Orosei, but we suggest that this erosion may be Messinian, as is often the case at the base of the Pliocene sequence in the Mediterranean basin.

Table 1
Messinian or post-Messinian erosion surface. Evidences of various reworkings on various basements (granite, conglomeratic granite, schists or Eocene limestones).

Site	Deposits	Basement	Altitude
Chiesa West SAR06	Oxidised infillings of large benthic foraminifers	Granitic conglomerate	18 m
Chiesa West SAR08	Oxidised foraminifers. Oligocene and Lower Miocene reworked fauna	Granitic conglomerate	18 m
Chiesa West SAR09	Reworked and oxidised nummulites, oxidised grains (cuttings)	Granitic conglomerate	18 m
Chiesa East SAR36	Reworked Lower Miocene to Oligocene fauna	Granite et granitic conglomerate	16 m
Chiesa East SAR47	Broken and oxidised nummulites	Granitic conglomerate	11 m
Fiuli SAR15	Broken infillings of gastropods and oxidised nummulites	granite	10 m
Fiuli SAR16	Gastropod infillings, oxidized foraminifers, Tortonian microflora (coccoliths)	granite	10 m
Onifai SAR19	Decalcified bioclasts	Palaeozoic schists	15 m
Onifai SAR22	Decalcified bioclasts, nummulites	Palaeozoic schists	15 m
Onifai (SAR22b)	Block of Eocene breccia, pebbles of limestones with nummulites, oxidised bioclasts	Palaeozoic schists	15 m
Santa Lucia Road SAR35	Oxidised and broken nummulites	Granitic conglomerate	29 m
Quarry SAR03	Nummulites	Eocene limestone	5 m

The sediment observed at the base of the Onifai sequence is the only one to contain various clasts supplied directly from the Eocene. Over the basement, there is a discontinuous very coarse layer containing limestone up to 20–30 cm dimension. Within this coarse layer, gravels are mainly schistose in nature, but some calcareous and granitic pebbles are also present (Figs. 9 and 10). Limestone blocks or pebbles correspond to reworked Eocene strata and especially of two facies (sedimentary breccia and nummulitic limestones), that are exposed nearby, on the right bank of the Cedrino River. An interpretation of this coarse accumulation lens would suggest association with a Messinian erosion surface buried under the marine deposits of the Late Pliocene.

Another erosion surface incises the continental deposits and is overlain by the marine Pliocene deposits. Based on the age model previously proposed for the deep water Pliocene records, this erosion surface is older than 3.81 Ma. We have no evidence for marine Lowest Pliocene material infilling this incision on this coastal sector of Orosei, but we suggest that this erosion may be Messinian, as it is often the case at the base of the Pliocene sequence in the Mediterranean basin.

The evidence of erosion under the Pliocene infill in the other sections is outlined by broken and oxidized nummulite tests associated with angular and red quartz grains and with various undetermined mollusk infillings. The base of Chiesa East, and to a lesser degree that of Chiesa West, also contain several markers such as oxidized marine fauna of the Oligocene and the lower to mid Miocene.

7. Discussion

7.1. Structural comments

Sardinia Island is considered as tectonically stable, at least since the Late Quaternary. It is regarded as an eustatic sea-level reference for the entire Mediterranean Basin since the Last Interglacial (Ferranti et al., 2006). No significant tectonic movements are reported during Quaternary times and the latest important tectonic events occurred in the Middle to Late Pliocene in the Campidano rift in southern Sardinia (Casula et al., 2001). Apart from this southern domain, the whole eastern Sardinia Coast is considered as being relatively tectonically stable since the Serravallian-Tortonian and the opening of the Tyrrhenian Basin. However, the Orosei Gulf shoreline presents evidence for moderate uplift during the Quaternary, which is attributed to local volcanic activity (Ferranti et al., 2006; Mariani et al., 2009).

The Early Zanclean deposits are absent from the Orosei area, and the Messinian incisions were directly filled by late Zanclean to late Pliocene marine deposits. This is unusual in respect to the classic early Zanclean filling of Messinian incisions throughout the Mediterranean passive margins (Clauzon, 1982, 1995; Rio et al., 1990). The absence of the earliest Pliocene marine deposits suggests a relatively high elevation of the Paleo-Cedrino area during early Pliocene times, not allowing the deposition of marine sediments. If early Pliocene marine deposits filled the Messinian incision, as is observed in the other incisions around the Mediterranean Sea, they are now either trapped downstream in the Cedrino Valley incision, or were deposited farther upstream and subsequently eroded. The suspected presence of these Zanclean deposits below the present sea level or at higher elevations implies significant vertical movements after the Early Pliocene.

7.2. Overview of the sedimentary records

Within the framework of this study of the Upper Pliocene of the Cedrino valley, an attempt of paleoenvironmental comparison or a synthesis of sections cannot be built solely on the base of the macroscopic observations in the field. Consequently, eight sites were selected according to the continuity of the microscopic observations of lithologic and faunistic characteristics in order to define the vertical and lateral successions of the sedimentary environments (Fig. 15).

This overview indicates the importance of the differences in elevation of the basement top. Thus, it is common to observe gullying or topographic lows, more than 10 m deep and several hundred metres wide, as between Chilivri and Fiuli, the last one acting probably as a channelized seaway. The first indications of sea level

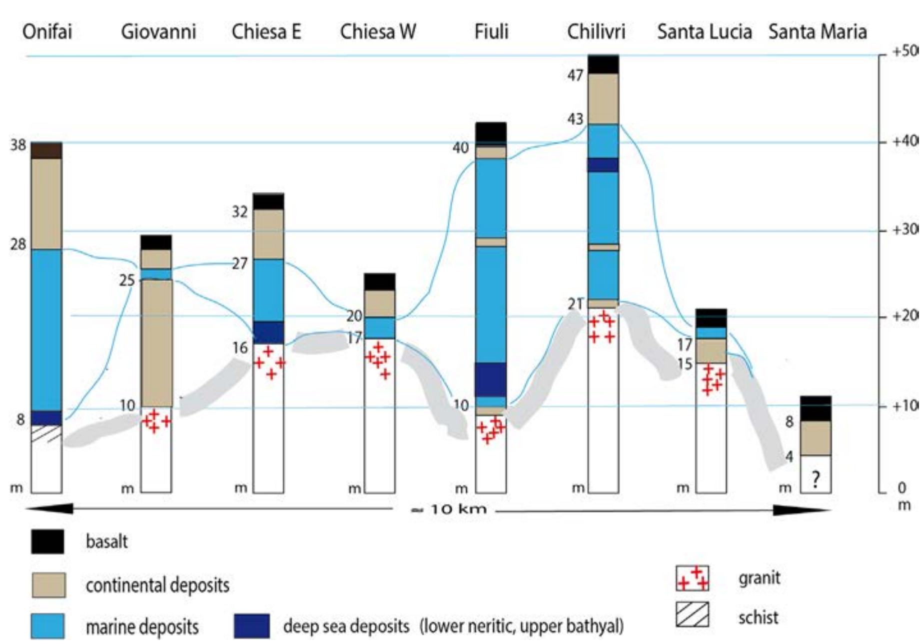

Fig. 15. Simplified geological logs showing the different environmental units recognized in the valley of Cedrino River between Onifai (upstream) and Santa Maria (close to the present-day coastline). Zero above sea level (asl) establishes the arbitrary reference of the altitudes. The light grey thick line indicates the top of the basement. Note the hilly landscape of the top of the granitic basement with marked differences over a short distance. The distance between Onifai and Santa Maria is approximately 10 km, but most of the studied sites lie outside the Onifai-Santa Maria segment (see Fig. 1).

rise are situated at varied altitudes from 8 m asl in Onifai to 22 m asl in Chilivri. These altitudes were dependent on the original paleomorphology of the bay of Cedrino during the Upper Pliocene or on synsedimentary deformation. The evidence is frequent and independent of the nature of the underlying rocks. They are observed both directly above the schistose basement (Onifai) and above the granitic basement (Chiesa East and West, Fiuli and Chilivri) or above the torrential slope deposits covering the basement (Giovanni and Santa Lucia).

Whatever the present topographic context, the deepest marine environments are frequently observed close to the base of the sedimentary column, although some stratified slope deposits have undergone transition in Fiuli, Chilivri, and Santa Lucia. The only noticeable exception concerns the Giovanni site where a very coarse subaerial accumulation reaching about 25 m in thickness suggests a ravine infill that has been spared from erosion. At this locality, marine deposits correspond to only a few metres of beach deposits at an altitude of about 25 m asl, which is rather comparable to that the elevation of the summit of the marine deposits of the nearby sites of Chiesa (West and East) and of the more distant site of Onifai.

The tops of the marine sequences are also located at varied altitudes, ranging from about +20 m asl in Chiesa West and Santa Lucia to +43 m asl in Chilivri. They reflect the marked anisopach character of the Upper Pliocene marine accumulation, which is 2 m thick at Giovanni and about 30 m thick at Fiuli. Subsequently, the relationship between the paleorelief surface of the granitic basement and the top surface of the marine sedimentation tends to disappear, or even to be reversed as at Onifai and Fiuli, where previous high topography points become low topography points. The greatest elevations of this marine sedimentation are in two nearby locations, which correspond respectively to a low at Fiuli and to a high at Chilivri. These marked differences of altitude can express syn- or possibly post-sedimentary tectonic movements.

Another explanation of the differences in elevation can be planation of the roof of the marine sequence as a result of emergence. Such erosion would be associated with the final accumulation of the coarse slope deposits as observed in Chiesa (East and West) and Chilivri. The depositional sequence at the site of Onifai, located upstream, ends with an aeolian accumulation. Santa Lucia and Santa Maria are among those most downstream and lowest altitude sites where no marine sedimentation could be observed. This could imply their erosion before the formation of the basaltic lava. Finally, the basaltic lava flow covered a relative flat paleotopography on top of marine and aeolian deposits.

7.3. Environmental remarks on the upper Pliocene of the East-Sardinian margin

Considering the late Zanclean to Gelasian ages (bracketed between c. 3.81 Ma and c. 2.75 Ma) for the marine deposits of the Cedrino valley, the age of the underlying continental deposits might date to the Lower Pliocene or more likely, as proposed on the geological maps, to the Miocene. The climate was probably hot and dry, comparable to the arid Moroccan South Atlas or Mauritanian Adrar. Under these conditions, the sediment chemical change is relatively weak with a very good preservation of the potassium feldspars and plagioclases. Argillization is limited, and the clay assemblages are totally lacking kaolinite.

On the other hand, physical and mechanical changes and, in particular, thermoclastic processes, resulted in the fragmentation of the granite and in the formation of chaotic deposits at the foot of topographic highs. The blocks and fragments that accumulated in some kinds of granitic breccias are relatively angular when burial is rapid. However, several blocks have subangular outlines, or rounded with the beginning of superficial patina, that indicates a kind of alteration generally attributed to the combination of morning dew and wind abrasion. The water transport is far too brief to produce significant wear.

This climatic context implies rare, irregular, but intense precipitation events feeding flash floods in ravines. The rough flows occur as occasional courses, not exceeding some hundreds of meters. These very turbulent flows are at the origin of faint graded bedded sequences observed on the granitic slopes in the Cedrino Valley. Such flows can remove part of, or all of, the previous deposit. The angle of the slope, and the volume of the chaotic deposit accumulation at the top of the slope, determined the thickness and the grading size of the coarse beds, the first terms that were particularly developed in the sequences over the Murie Road. The uneven and sometimes small thickness of the upper sandy term suggests erosion of the summit, either by the following flow or by active wind deflation between two successive sequences of aquatic deposits.

For comparison, the slopes of the piedmont of the Mauritanian Adrar, more precisely those of Guelb er Richât, present only three graded bedded torrential sequences, each 30–50 cm thick. They were preserved on the scale of a short Holocene interval of 6000 years (Giresse et al., 2012). Downslope, the more or less sorted materials constitute alluvial deltas in the direction of the main alluvial plain. This alluvial plain would thus be represented in the Cedrino Valley only by the Santa Maria deposits.

8. Conclusions

This study considered firstly the upper slope of continental deposit on top of many granitic basements of the Cedrino valley, then the accumulations of the alluvial plain close to the present Mediterranean shoreline, and finally the littoral and deep-sea marine sediments deposited in the incision of the Cedrino valley. Continental slope deposits were formed by channelized debris flows in short erosional ravines. These ephemeral floods piled up weakly graded bedded sand and gravel sequences. Only some remains of these sequences are preserved at various altitudes along slopes.

Fluvial deposits occur only adjacent to the present shoreline (i.e. Santa Maria locality). The fining upward trends and the transition from trough cross-stratification into planar stratification suggest a braided river subject to a progressive lowering of the stream gradient. All these continental deposits are overlain by marine deposits, late Zanclean to Gelasian in age.

Most of the filling sequences end with an aeolian sedimentation that evokes lœss deposits affected by pedogenetic evolution, inferring surface leaching and calcareous precipitations (puppets) toward the base. By this time, the climatic context involves low and irregular precipitation, and long seasonal aeolian transport probably connected to first cooling.

Within the marine sequences, the occurrences of deep-sea deposits are abrupt, occasionally without transition with the nearshore deposits previously accumulated. They indicate a marine flood of at least one hundred meters, requiring collapse of this regional part of the Sardinian margin. The fan-shaped geometry of the Onifai and Fiuli marine series reflects a small amplitude shift of the base level during sedimentation. The sequence of Chilivri records the greatest water depth towards the end of the filling and indicates very local, but perceptible, differences in the trend of the transgression because the sites are separated by some 4 km.

Due to the absence of Lower Pliocene marine deposits, in reference to the chronology proposed for the post-Messinian filling of incised valleys, the Cedrino Valley deposits do not fit the expected sedimentary records. This observation suggests a high elevation of this sector of the margin during or after the middle part of the Pliocene. The presence of an erosion surface under the Pliocene infill is often outlined by patches of coarse residual accumulation, either directly on the top of the Eocene or near the exposed granite area.

The coarse accumulations on the hillsides of the Cedrino valley are characterized by a compound (low-order) lowstand deposition which does not exceed 25 m in thickness and shows only a single conglomeratic basal deposit, interpreted as the remnants of the Messinian erosion. These features are not comparable in both vertical and horizontal scales to the internal characteristics of the Gilbert deltas observed elsewhere in the Mediterranean.

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