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STRATIGRAPHY OF THE CARNIAN – NORIAN CALCARI CON SELCE FORMATION IN THE LAGONEGRO BASIN, SOUTHERN APENNINES

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Abstract. The Upper Triassic Calcari con Selce Formation, cropping out in the Southern Apennines (S Italy), consists of 400 m of micritic limestones, often nodular, with chert beds and nodules, organized in dm to m beds intercalated with mm (rarely centimetric) marly horizons. Three intervals characterized by higher siliciclastic content have been recognized within this formation, and stratigraphically ordered after an accurate conodont biostratigraphical investigation: 1) the green clay-radiolaritic horizon, previously named in literature with the informal expression of "livello argilloso ad *Halobia superba*", Tuvalian (upper Carnian); 2) an interval of some tens of meters of limestones and brown shales with abundant chert beds, here informally termed the "brown member", Tuvalian/Lacian (upper Carnian/ lower Norian; 3) the ca. 3 m thick red shale horizon, Sevatian (upper Norian) in age. All these intervals are characterized by micritic limestones or marly limestones with bivalves, radiolarians and conodonts alternating with shales (green, brown or red) having thicknesses of 50 cm or more. These intervals are also associated to an increase of calciturbidites, consisting of echinoderm fragments, isolated thin-shelled bivalves and reworked, partially lithified intraclasts of the Calcari con Selce Fm.

The Carnian green clay-radiolaritic horizon and the Sevatian red siliciclastic interval are useful lithostratigraphic markers recognizable throughout the Lagonegro Basin and have been used as guide horizons to evaluate the lateral continuity of contiguous limestone beds. The green clay-radiolaritic horizon has been logged in 4 sections (Pignola 2, Mt. Armizzone, Pezza la Quagliara, San Michele). The sections are presently at approximately 50 km distance - but Tertiary thrusts occur between the sections, suggesting a larger separation at the time of the deposition of the Formation. Above the green clay-radiolaritic horizon, single carbonate beds or banks with the same stratigraphic position and common characteristics are recognizable in all sections. The thickness of these limestone beds may vary, but the shale interlayers and cherty beds are identical, thus, the carbonate beds have been correlated. The stratigraphic interval comprising the Sevatian red shale horizon has been acquired in two sections separated by 7 km, Monte Buccaglione (i.e lower portion of the Sasso di Castalda section) and Monte Cugnone, with a Terrestrial Laser Scanner (TLS). TLSs produce high resolution and high accuracy 3D representations of outcrops, stored as point-clouds. A regular sequence of limestone beds and shale interlayers, distinguished because of their different reflectance, has been recorded below the red shale horizon, and the thickness of single carbonate banks resulted identical within the instrumental resolution. Calcareous beds or banks thus can be correlated at the basinal scale. This implies that the Lagonegro Basin is characterized by laterally continuous carbonate sedimentation, most probably controlled by allocyclic factors, providing potential for cyclostratigraphic investigations.

Riassunto. La Formazione dei Calcari con Selce, datata Triassico Superiore e attualmente affiorante nell' Appennino Meridionale (Potenza, Basilicata), consiste in circa 400 m di calcari micritici, spesso nodulari, con noduli e liste di selce, organizzata in strati da dm a m con intercalaziondi livelli millimetrici (a volte centimetrici) di argille o marne. In questa formazione sono stati riconosciuti 3 intervalli caratterizzati da un elevato contenuto terrigeno, oggetto di un accurato studio biostratigrafico basato sui conodonti e illustrati in ordine stratigrafico in questo lavoro: 1) il livello argillitico/radiolaritico verde, conosciuto come "livello argilloso ad *Halobia superba*", di età Julico/ Tuvalico (Carnico inf/sup); 2) un intervallo, spesso alcune decine di metri di calcari e argille marroni, con abbondanti letti di selce, età Carnico/Norico; 3) il livello rosso, spesso 3 metri, datato Sevatico 1 (Norico superiore). Tutti questi intervalli sono caratterizzati da calcari micritici o calcari marnosi con bivalvi, radiolari e conodonti, alternati strati argillosi (verdi, marroni e rossi) di spessore superiore a 50 cm. Questi intervalli sono associati ad un aumento di calciturbiditi, costituite da frammenti di echinodermi, bivalvi a guscio sottile isolati e intraclasti rimaneggiati di Calcari con Selce, parzialmente litificati.

Il livello argillitico/radiolaritico verde (1) e il livello rosso (3) sono utili marker litostratigrafici, riconoscibili in tutto il Bacino di Lagonegro e sono stati usati come orizzonti guida per valutare la continuità di letti carbonatici contigui. Il livello argillitico/radiolaritico verde è stato studiato in 4 sezioni (Pignola 2, M. Armizzone, Pezza la Quagliara, San Michele), attualmente distanti tra loro fino a 50 km,

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anche se sovrascorrimenti Terziari, documentati tra questi affioramenti, suggeriscono una distanza maggiore al tempo della deposizione. Uno studio preliminare di continuità laterale degli strati, con misurazione manuale, ha evidenziato come gli strati calcarei e i letti di selce delle 4 sezioni studiate soprastanti all'intervallo argillitico/radiolaritico verde presentano posizioni stratigrafiche e caratteristiche comuni. Il livello rosso sevatico è stato invece ripreso tramite Terrestial Laser Scanner (TLS), in 2 successioni stratigrafiche distanti 7 km affioranti sul Monte Buccaglione (che corrisponde alla porzione inferiore della sezione di Sasso di Castalda) e sul Monte Cugnone. Una acquisizione TLS produce una rappresentazione tridimensionale ad alta risoluzione e accuratezza della superficie di un bersaglio, nel caso in esame un affioramento, sotto forma di una nuvola di punti. Sotto il livello rosso, è stata quindi registrata una successione regionale di strati calcarei e interstrati argillitici, distinguibili per la loro riflettanza. In questo modo è stato dimostrato che lo spessore dei singoli banconi carbonatici risulta identico tra le due sezioni, permettendo quindi di correlarli almeno a scala bacinale. Grazie allo studio in dettaglio di questi due livelli argillitici, con tecniche di misurazione differenti, è possibile affermare che il Bacino di Lagonegro è caratterizzato da una sedimentazione carbonatica lateralmente continua, probabilmente controllata da fattori allociclici che potrebbero essere investigati tramite studi ciclostratigrafici.

Introduction

The Upper Triassic in the Lagonegro Basin is represented by two formations: the Calcari con Selce (i.e. Cherty Limestone) and the Scisti Silicei (Siliceous Shales). The typical microfacies of the Calcari con Selce Fm. are wackestones and mudstones with thin-shelled bivalves and calcified radiolarians. This formation is also characterized by an alternation of calcilutites and centimeter-thick marly or clayey interlayers, organized in sedimentary cycles, with abundant nodules and beds of chert. The sedimentary cyclicity of the Calcari con Selce Formation could have allocyclic origin (at Milankovitch frequencies), which if demonstrated could be used as chronologic and paleoclimatic archives (e.g. Einsele 1982, 1991; Westphal et al. 2010). The maximum estimated thickness of the unit is 500 m (Scandone 1967). However, a complete section representing all the Calcari con Selce Formation is missing, and in the past studies most of the attention was focused on the terminal portion, at the transition with the overlying Scisti Silicei Formation (e.g. Amodeo 1999; Rigo et al. 2005; Bertinelli et al. 2005; Reggiani et al. 2005; Bazzucchi et al. 2005; Giordano et al. 2010, 2011). Here we present a digest of the stratigraphy of the Calcari con Selce, calling attention to three stratigraphic intervals characterized by higher siliciclastic component, well calibrated with a detailed conodont biostratigraphy. Furthermore, we make use of two of these three stratigraphic intervals, the green argillitic/radiolaritic horizon close to the base and the red horizons at the top of the Calcari con Selce Fm. as reference levels, to prove the lateral continuity of contiguous limestone beds within the Lagonegro Basin.

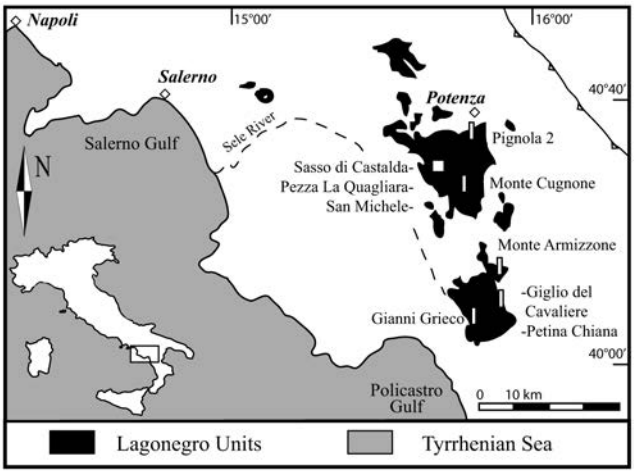


Fig. 1 - Outcrops of the Lagonegro units (in black) in the Southern Apennines (Southern Italy), and location of the cited sections.

Geological setting

The Southern Apennines represent a mountain chain of stacked NE- verging tectonic units of sedimentary cover with basinal affinity, named Lagonegro Units, always detached from their basement (Fig. 1). The Lagonegro Units are in fact piled up between the Apenninic and Apulian carbonate platforms, which lay respectively at the bottom and at the top, and they testify for a basinal domain that existed between the Middle Triassic and Miocene (e.g., Scandone 1967; Ciarapica & Passeri 2002). The lower portion of the succession, known as "Lagonegro lower sequence" (Mostardini & Merlini 1986; Ciarapica & Passeri 2005) consists of four formations that are in stratigraphic order the Monte Facito Fm. (? Permian-Middle Triassic), Calcari con Selce Fm. (Upper Triassic), Scisti Silicei Fm. (Upper Triassic-Upper Jurassic) and Flysch Galestrino Fm. (Upper Jurassic-Lower Cretaceous). The upper portion of Lagonegro sequence is instead represented by the Flysch Rosso Fm. (Lower Cretaceous-Lower Miocene), Flysch Numidico Fm. (Lower-Middle Miocene), and Flysch Irpino Fm. (Middle-Upper Miocene), always detached from the lower one. Scandone (1967, 1972, 1975) recognized two main structural levels: Lagonegro Unit I, representing distal successions and positioned below the Lagonegro Unit II characterized instead by proximal facies, basing on the amount of resedimented material derived from adjacent carbonate platforms as calcarenites and calcirudites. Afterwards, further studies demonstrated that there is no connection between the two structural levels with respect to facies distributions (Miconnet 1983; Carbone et al. 1998; Torrente 1988, 1990; Mazzoli 1992).

Paleogeography of the Lagonegro Basin

The origin of the Lagonegro Basin is still under debate. For over 30 years, many authors considered the Mesozoic Lagonegro Basin or a part of the Ionian Tethys or belonging to the Ionian Ocean (e.g. Finetti 1982, 2005; Ciarapica & Passeri 2002, 2005; Catalano et al. 2001; Argnani 2005). Finetti (1982) suggested for the first time the ocean affinity of Ionian Tethys, based mainly on geophysical data. Later, Stampfli et al. (1991) recognized a phase of rifting at northern edge of Gondwana, identifying the East-Mediterranean Basin as a part of the Neo-Tethys starting from the Late Paleozoic and considered the Ionian Ocean as a western extension of the East-Mediterranean Ocean. Catalano et al. (2001) suggested that this continental rifting started during the Late Permian/Early Triassic, subsequently evolving into an open ocean. Ciarapica & Passeri (2002), instead, dated the rifting event to the late Middle Triassic basing on stratigraphical and paleontological data. In particular, they related the opening of the East-Mediterranean Basin to the deposition of the radiolarites and megabreccias of the Monte Facito Formation, Ladinian in age (Ciarapica & Passeri 2002; Passeri & Ciarapica 2010), suggesting a direct connection of the Lagonegro Basin (and other basins) to the western branch of the Ionian Ocean. Unfortunately there are no evidences of oceanic crust in the Southern Apennines where the Lagonegro Units crop out, but the sedimentary evolution of the Lagonegro sequences in very similar to those of Cyprus and the Tauridis (Robertson et al. 1996; Tekin 1999, 2002).

Methods

Several stratigraphic sections were logged and sampled throughout the Lagonegro Basin. Recognition of lithologies and sedimentological observations in the field were integrated with petrographical observations on > 50 thin sections, mostly from calciturbidite facies.

Biostratigraphy was based on conodonts. More then 130 conodont samples (Petina Chiana - 48, Pignola 2 - 42, Giglio del Cavaliere - 3, Gianni Grieco - 7, Sasso di Castalda - 36) of limestones with an average weight of 8-10 kg have been collected from the studied sections. All the samples were washed and then dissolved with 7% of acetic/formic acid. Conodonts were handpicked from the insoluble residues under binocular microscope.

Data on the continuity of beds was approached differently for the two intervals that we considered. Field logging with a wood meter was the method of choice for the green clay-radiolaritic horizon, because the measured successions are short and accumulation of a significant measurement error was unlikely. Furthermore, outcrop conditions were ideal for manual field logging (e.g., exposures along road cuts or on accessible quarry fronts).

Limestone banks adjacent to the red shale horizon at Monte Cugnone are hardly accessible because of the steepness of the quarry front, and have been thus studied mostly in-remote, with a Optech ILRIS 3D TLS (OPTECH, 2011); see Franceschi et al. (2009) for more technical details on this instrument. TLS are instruments capable of producing a detailed 3D model of the surface of an object in the form of a point-cloud, in which each point is characterized by spatial coordinates and intensity value. TLS is routinely used to obtain three dimensional representations of outcrops (Bellian et al. 2005) because of its rapidity in acquiring high resolution spatial information. Furthermore, it has been demonstrated that intensity values can be used to distinguish different lithologies (Franceschi et al. 2009), and this property can be successfully applied to detailed stratigraphic analyses (Franceschi et al. 2011). In this study, beds have been recognized on the base of both reflectance (pure limestones are brighter, while marly and clayey layers are darker) and morphology (marly limestones and marlstones are recessive). The Monte Cugnone section has been acquired with a point to point spacing of 0.06 m, from a distance of approximately 170 m, while Monte Buccaglione section has been acquired with 0.08 m resolution at a distance of 400 m.

The Calcari con Selce Formation

At the end of 1800s, De Lorenzo (1892a, b) first described the "calcari con liste e noduli di selce" (i.e. limestones with beds and nodules of chert), later called Monte Sirino formation by Selli (1962), and finally formalized as Calcari con Selce Formation (Petti 2006) after Scandone (1967).

The Calcari con Selce Formation is characterized by carbonate layers with cherty beds and nodules, with an average thickness of 20-30 cm, alternating with thin clayey horizons (Fig. 2). Most of the carbonate strata are lime mudstones or wackestones with radiolarians, bivalves (genus *Halobia*) and rare ammonoids. Packstones or grainstones are subordinately present. Graded grainstone-rudstone and calcareous breccias (calciturbidites) are also documented within the Calcari con Selce Fm., at different stratigraphic positions and with different thicknesses (from some centimeters to some meters). Most of these resedimented layers contain material from the surrounding carbonate platforms, such as benthic foraminifers, echinoderm fragments and other bioclasts, and they are often silicified, in particular in the upper portion of the formation (e.g. Amodeo 1999; Bertinelli et al. 2005; Bazzucchi et al. 2005; Rigo et al. 2007; Giordano et al. 2011). Most of the carbonate layers consist of micrite which origin is difficult to determine: carbonate mud derives from adjacent carbonate platforms, carried by nepheloid suspension, but a strictly pelagic origin should not be excluded. Recently, a strong planktonic component has been documented both from the Lagonegro Basin and coeval cherty limestone (Scillato Fm.) cropping out in the Sicani Mountains (Sicanian Basin – Sicily) that can reach more than 50% of the whole rock (Di Nocera & Scandone 1977; Bellanca et al. 1995; Guaiumi et al. 2007).

Scandone (1967) recognized 4 different and interfingering lithofacies both for the Calcari con Selce and for the overlying Scisti Silicei fms, basing on the amount of resedimented materials and the thickness of the stra-

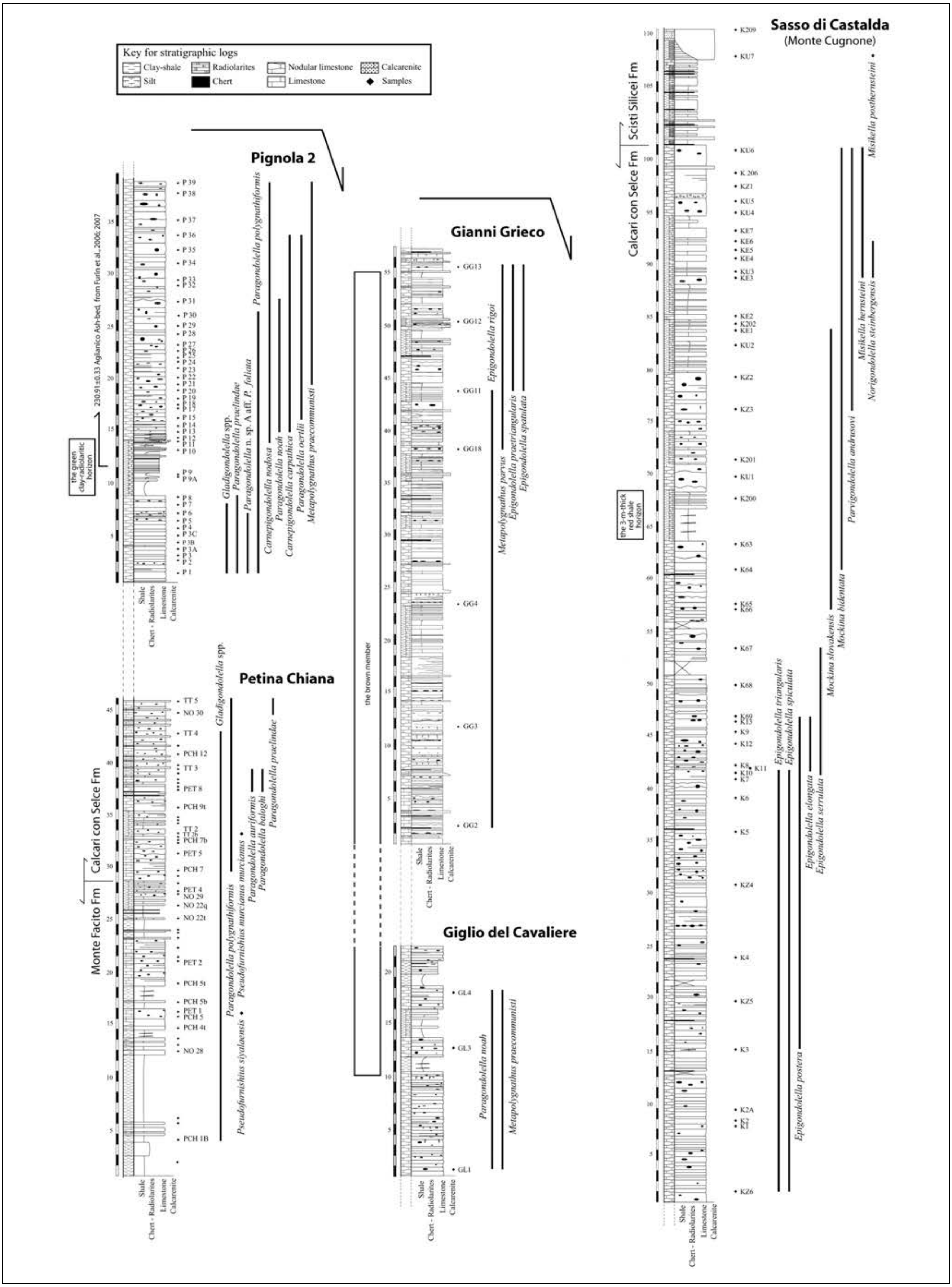


Fig. 2 - Hypothetical reconstruction of a complete section representing the Calcari con Selce Formation. Stratigraphic logs of the studied sections with indication of the 3 siliciclastic levels and distribution of the most biostratigraphically valuable conodonts. Geochronologic age of 230.91 +/- 0.33 Ma from Furin et al. (2006, 2007).

tigraphic successions. These lithofacies have been named by the outcropping areas and are ordered from the more distal to the more proximal as Lagonegro-Sasso di Castalda facies (mapped as SLC_a), Armizzone facies (SLC_b), Pignola-Abriola facies (SLC_c), and S. Fele facies (SLC_d) (Petti 2006).

The Calcari con Selce Fm. follows with transitional contact on the Monte Facito Formation. In the transitional interval between the two formations the clayey-radiolaritic horizons characteristic of Monte Facito Fm. are replaced by the clayey-micritic limestones of the Calcari con Selce Fm. A clear contact between these two formations is observable at Petina Chiana section, on the SW mountainside of Murge del Principe, close to Tempa di Rocca Rossa (Petti et al. 2006; Rigo et al. 2007) (Figs 1, 2). The upper boundary with the overlying Scisti Silicei Fm. is well-documented in different sections throughout the Lagonegro Basin, such as Sasso di Castalda, Pignola-Abriola, Lagonegro, Monte Volturino, Monte Sant'Enoc (e.g., Rigo et al. 2005; Bertinelli et al. 2005; Reggiani et al. 2005; Bazzucchi et al. 2005; Passeri et al. 2005; Giordano et al. 2010, 2011), and similar to the lower boundary with the Monte Facito Fm., it is characterized by a transitional interval, separated as a distinct upper member of the Calcari con Selce Fm. by Amodeo (1999). The base of this transitional interval is marked by the deposition of a 3 meter-thick (2-4 m) horizon of red shales occurring within the conodont *Mockina bidentata* biozone, and thus Sevatian 1 in age, which is a useful lithological marker throughout the Lagonegro Basin (Rigo et al. 2005) (Fig. 2).

The green clay-radiolaritic horizon

The green clay-radiolaritic horizon is a 3-6-m thick interval of prevailing shales and radiolarites that lie with sharp contact on nodular cherty limestones of the Calcari con Selce Fm. (Fig. 2). The horizon starts with 30-200 cm of laminated shales alternating with clay-rich radiolarite beds, mostly greenish in color. The succession continues with green and white radiolarites alternating with thin shale interlayers. The white radiolarites are bioturbated, while green radiolarites are laminated and more erodible. At least three thin (3-5 cm) crystal tuffs are present, the coarser of which was termed "Aglianico ash-bed", and dated to 230.91 +/- 0.33 Ma by Furin et al. (2006, 2007) (Fig. 2). The last meters of the green clay-radiolaritic horizon are composed of thin, polychromous radiolarites and shales, siliceous bivalve coquinas, and capped by a 16-49 cm-thick calciturbidite. This calciturbidite exhibits uniform characteristics throughout the Lagonegro Basin. It has strongly erosive base and, thus, widely varying thickness both within and between sections. The basal part (horizon A of Bouma) is normally graded, and composed mostly of cm-size intraclasts of semi-lithified Calcari con Selce (i.e., wackestone-packstone with thin-shelled bivalves and calcified radiolarians), and includes abundant echinoderm fragments in the finer part. The upper horizons may show planar or cross-bedded laminations, most common components are fragmented thin-shelled bivalves, calcified radiolarians and small lithoclasts, but shallow-water bioclasts as mollusk fragments and foraminifers are also present.
Above the calciturbidite, hemipelagic – pelagic carbonate sedimentation starts off again with the typical facies of the Calcari con Selce Formation, but the limestone beds are more nodular and thicker (40 cm-thick), rich in cherty nodules and beds compared to the interval below the green clay-radiolaritic horizon. Shale interlayers are initially abundant and thick but decrease rapidly upward (Fig. 2). The green clay-radiolaritic horizon represents the Carnian Pluvial Event (Simms & Ruffell 1989; Rigo et al. 2007; Rigo & Joachimski 2010; Preto et al. 2010) in the deep-water setting of the Lagonegro Basin.

The Brown member

A second interval with a prominent terrigenous content crops out in several localities in the area of Monte Sirino - Tempa di Rocca Rossa – Lagonegro. It is a ca. 60 m thick interval including abundant brown shales. At the base, shales account for ca. 50% of the sediment (Giglio del Cavaliere section), but become less abundant upward (Gianni Grieco section) (Fig. 2). Limestones contain less chert than in the regular facies of the Calcari con Selce Fm., and calciturbidite beds are much more common. The latter are graded beds up to 60 cm thick with erosive base and often a median interval with crossed lamination. Main components are fragments of thin-shelled bivalves and radiolarians, but platform derived intraclasts and bioclasts (as foraminifers, mollusk and echinoderm fragments) are always present in the coarser, basal portion of the beds. Bioturbation might be preserved, especially at the base of calcareous beds, which include *Planolites* and *Chondrites*. This interval, informally identified here as the "brown member", was included by Scandone (1967) in the "livello argilloso ad *Halobia superba*", but it is in fact distinct and younger. The brown member fades upwards into the typical nodular cherty limestones of the Calcari con Selce Fm.

The 3-m-thick red shale horizon

The transition between the Calcari con Selce and Scisti Silicei fms is conventionally marked by the deposition of a red shale horizon, with a thickness of 2 to 4 meters, representing a useful lithological marker easily recognizable throughout the Lagonegro Basin (Rigo et al. 2005; Bertinelli et al. 2005; Passeri et al.

2005; Reggiani et al. 2005) (Fig. 2). This red shale level represents the beginning of the Transitional Interval (Amodeo 1999). This transition consists of cherty limestones, red shales and cherts, sometimes also black shales (e.g. Pignola-Abriola section) and it documents the progressive replacement of carbonate by shales, radiolarites and cherts. This change in sedimentation may be referred to different causes, such as decrease of carbonate input (Amodeo 1999), deepening of sedimentary environment below the Calcite Compensation Depth (CCD) or shallowing of the CCD (Scandone 1967), or upwelling currents promoting siliceous, as opposed to carbonate, sedimentation (Passeri et al. 2005; Giordano et al. 2011).

Biostratigraphy

All the studied sections were sampled in detail for conodont investigation, since conodonts are the best biostratigraphic tool for Upper Triassic (e.g. Rigo et al. 2007; Giordano et al. 2010; Mazza et al. 2011). The revised distribution of the most important taxa are reported in Fig. 2. For more details and conodont plates refer to previous articles (Amodeo 1999; Bazzucchi et al. 2005; Bertinelli et al. 2005; Reggiani et al. 2005; Rigo et al. 2005, 2007; Giordano et al. 2010, 2011). Hereinafter, we report the description of the conodonts collected around the 3 siliciclastic intervals, characterizing the Calcari con Selce Fm.

The green clay-radiolaritic horizon

Conodonts were extracted from the green clay-radiolaritic horizon at Pezza la Quagliara (latitude 40°30'17. 60"N, longitude 15°42'36.48"E), San Michele (latitude 40°29'58.82"N, longitude 15°42'56.92"E) and Monte Armizzone (latitude 40° 8'51.24"N longitude 15°58'41.80"E) sections for biostratigraphic investigations. Conodont biostratigraphy of Pignola 2 section (latitude 40°32'53.59"N, longitude 15°47'12.02"E) was already illustrated and described in Rigo et al. (2007) and is here compared to those of the other three sections in order to better constrain the age of the horizon. Each sample had an average weigth of 5 kg (of limestones), with content in conodont of ca. 100 specimens (both ramiform and pectiniform conodonts) per kg for Pignola 2 and San Michele and ca. 30 specimens per kg for Pezza la Quagliara and M. Armizzone. The CAI (Conodont Alteration Index, Epstein et al. 1977) of conodonts is 1.5 for Pignola 2 and San Michele; 2 for Pezza la Quagliara and 4 for M. Armizzone. A typical Julian conodont fauna occurs in the lower part of the section, just below the horizon. It consists of *Paragondolella polygnathiformis*, *P. praelindae*, *P. inclinata*, *P. tadpole*, *Paragondolella* n. sp. A aff. *P. foliata, Nicoraella postkockeli* and *Gladigondolella* ssp. A Tuvalian conodont assemblage has been recorded from the calcareous layers above the greenish shale horizon in San Michele, M. Armizzone and Pignola 2 section. At Pezza la Quagliara, the Tuvalian portion of the succession is missing. This fauna includes *P. polygnathiformis*, *Metapolygnathus carpathicus*, *Carnepigondolella zoae* (=*Metapolygnathus nodosus*) and *M. praecommunisti* (Mazza et al. 2010, 2011a, b) (Fig. 2).

The Brown member

Conodont investigation allows to refer the Giglio del Cavaliere facies to Tuvalian for the presence of *Metapolygnathus praecommunisti* and *Paragondolella polygnathiformis*, and the Gianni Grieco facies to Lacian because of the joint occurrences of *Epigondolella rigoi* and *Metapolygnathus parvus*, together with conodonts *Epigondolella praetriangularis* and *Epigondolella spatulata* (Fig 2). For ages see Mazza et al. 2010, 2011a. The CAI of conodonts is 2.5-3.5 (Epstein et al. 1977).

The 3-m-thick red shale horizon

This horizon has been well calibrated with conodont biostratigraphy to the Sevatian 1 (upper Norian) (Rigo et al. 2005; Bertinelli et al. 2005; Reggiani et al. 2005; Giordano et al. 2010), within the *Mockina bidentata* Zone, sensu Kozur & Mock (1991) (Fig. 2).

Estimating the continuity of beds in Upper Triassic carbonate hemipelagites (Lagonegro Basin)

The occurrence of marker beds intercalated within the limestone-marl alternations of the Calcari con Selce gives the opportunity of testing the continuity of sedimentary cycles (limestone-marl alternations) at the basinal scale. If this sedimentary cyclicity is driven by external (allocyclic) factors, and in particular by oscillations of Earth's orbital parameters at Milankovitch frequencies, limestone-marl alternations can be used as powerful paleoclimatic and chronologic archives (Westphal et al. 2010). However, their allocyclic nature needs to be demonstrated first, e.g., by evaluating the continuity of cycles at the basinal scale. Limestone-marl alternations indeed can be generated, in principle, by a variety of causes, including allocyclic, autocyclic or diagenetic processes (revised in Westphal 2006; Westphal et al. 2010). Stratigraphic sections have thus been logged, including the green clay-radiolaritic horizon and some of the limestone-marl alternations immediately above. Since these occur near a synchronous marker bed recognized throughout the basin, these limestone-marl alternations can be correlated.

The green clay-radiolaritic horizon has been studied in four stratigraphic sections: San Michele, Pezza la

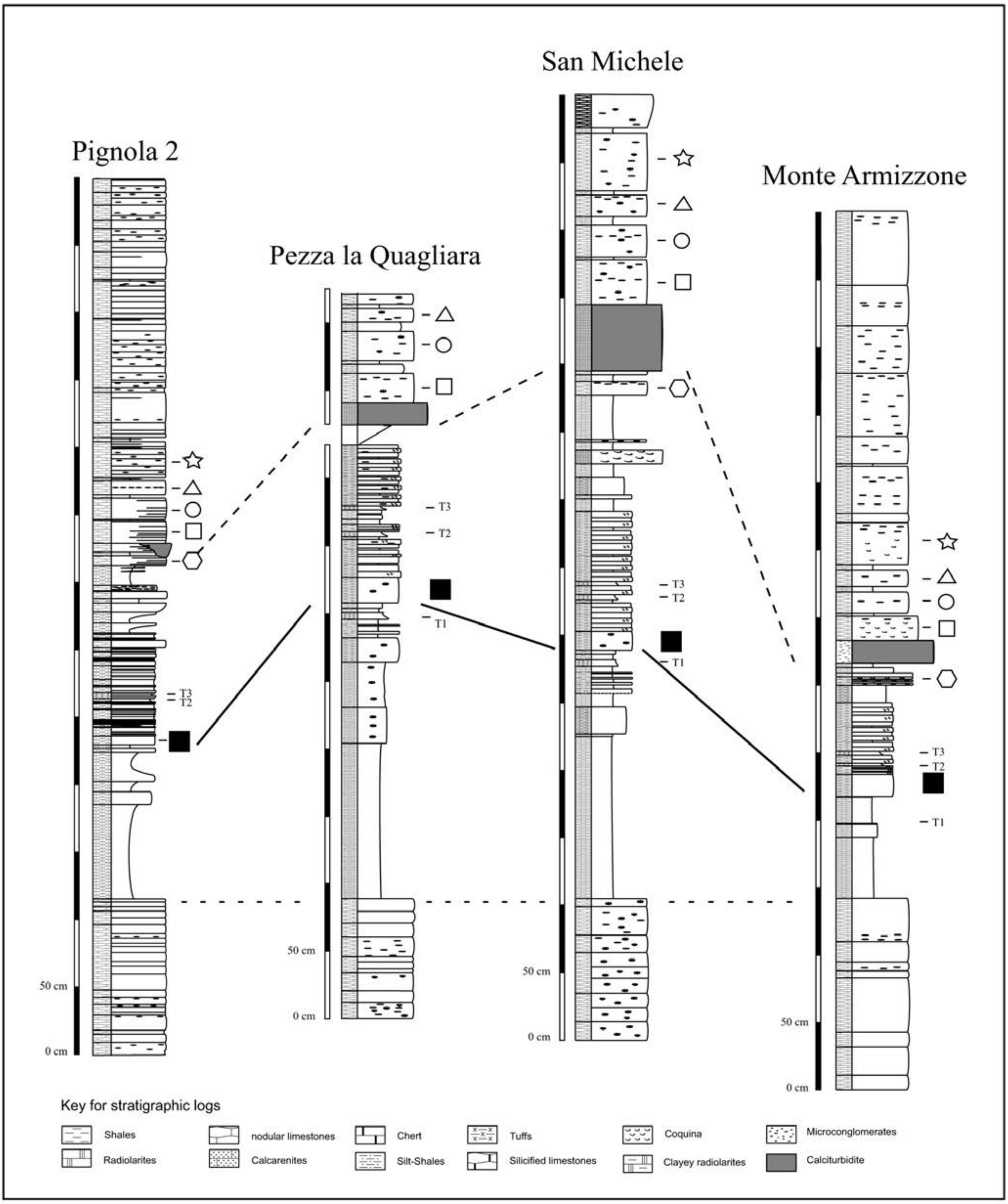


Fig. 3 - Carbonate beds and banks overlying the Green clay-radiolaritic horizon from the four studied sections. The same symbols indicate correlated limestone beds or banks with similar sedimentological characteristics. T1, T2, T3 represent different tuff layers, used for lithostratigraphical correlations.

Quagliara, Pignola 2 and Monte Armizzone (Fig. 1). These four sections are presently up to 50 km apart. Their original distance, however, might reveal substantially greater if tectonic restoration could be performed. As already shown, the green clay-radiolaritic horizon is considered a marker within the Lagonegro Basin, because it includes correlatable ash-beds, and because of conodont biostratigraphy (Fig 2). Above the horizon, single carbonate beds or banks with the same stratigraphic position and common characteristics are present and recognizable in all sections (Fig. 3). The thickness of these limestone beds is different, but the shale interlayers and cherty beds occur in an identical sequence, and thus this set of limestone beds could be correlated (Fig. 3).

A second test on the continuity of bedding, and on the persistence of bed thicknesses, took advantage of the Sevatian red shale horizon marking the base of the Transitional interval between Calcari con Selce and Scisti Silicei formations. The Red shale horizon has been studied, measured and correlated in Monte Buccaglione and Monte Cugnone sections, which are separated by 7 km (Fig. 1). The Monte Buccaglione section (representing the lower portion of the composite Sasso di Castalda section of Bertinelli et al. 2005) outcrops near the village of Sasso di Castalda (Potenza Province) (latitude 40°29'29.47"N, longitude 15°40'33.78"E). The Monte Cugnone section is within an abandoned quarry near Marsico Nuovo Village (latitude 40°26'10.74"N, longitude 15°43'34.01"E). A terrestrial laser scanner (TLS) was employed to measure the thickness of limestone beds in the Monte Cugnone and Monte Buccaglione sections (Fig. 4), mostly because the outcrop at Monte Cugnone is hardly reachable and could not be logged traditionally. Furthermore, the use of TLS allows to evaluate the precision and accuracy of measured thickness. Thicknesses of marker beds have been obtained directly from the point clouds on the base of outcrop morphology and contrasts in intensity, and are comparable between the two sections (Fig. 4), within the limits of instrumental resolution as shown in Tab. 1.

	Monte Buccaglione section	Monte Cugnone section
Red Shale	5.47 m	4.28 m
Bed 1	4.46 m	4.34 m
Bed 2	4.44 m	4.44 m

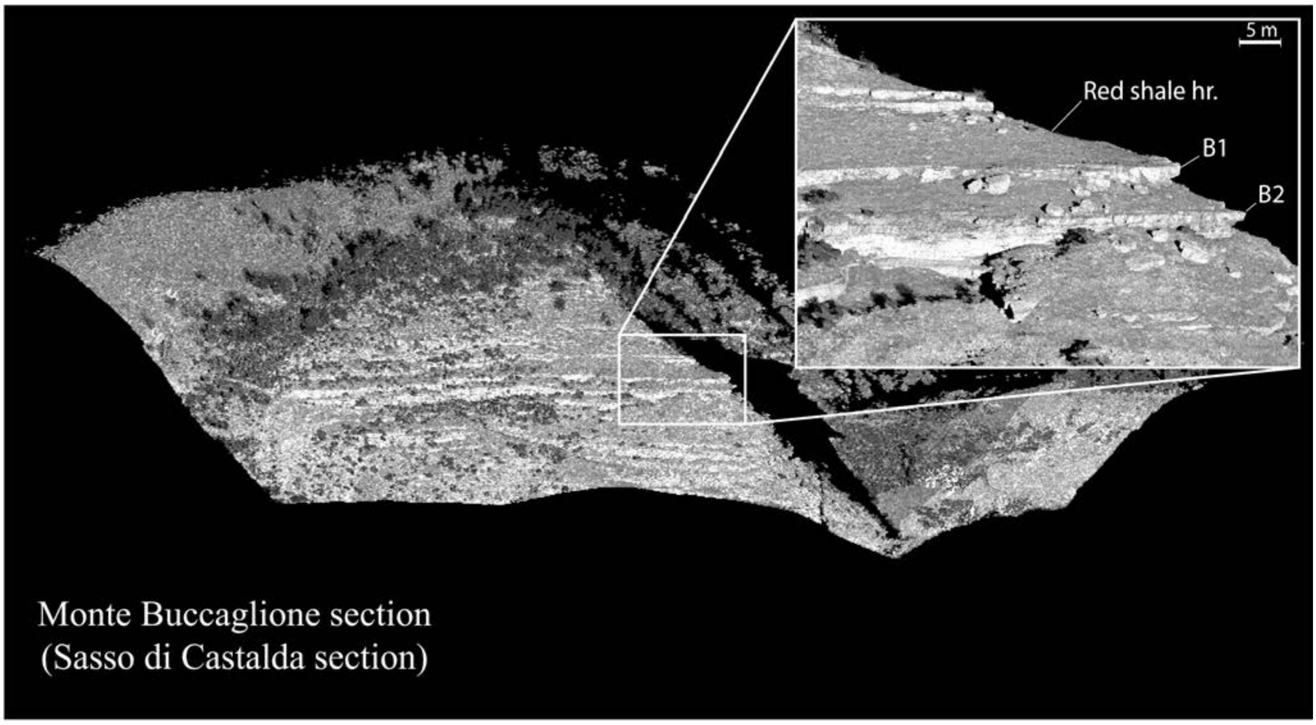
Tab. 1 - Thicknesses and positions of the Red Shale level and the 2 carbonate banks (Bed 1 and 2) measured with laser scanner technique to prove the continuity of carbonate beds belonging to the Calcari con Selce Fm., using the Red Shale level as a lithomarker.

Discussion

Continuity of beds in the Lagonegro Basin and the potential for cyclostratigraphy

The continuity of limestone beds or banks adjacent to well recognizable marker beds has been verified, following the approach of, e.g., Brack & Muttoni (2000). In particular, decimetric to metric scale limestone-marl alternations immediately above the green clay-radiolaritic horizon are persistent on a basinal scale, though their thickness may vary substantially (Fig. 3). Thickness variations can be understood if we suppose that al least part of the carbonate derives from adjacent carbonate platforms (Apenninic and/or Apulian), that is, if we consider the Lagonegro Basin a periplatform setting. In recent examples of this sedimentary environment, carbonate derives partly from adjacent platforms and partly from pelagic rain of calcareous nannoplankton and foraminiferal tests, the platform-derived component diminishing with the distance from the platform. Platform carbonates are transported into the basin by turbidite fluxes and by density cascading (e.g., Droxler & Schlager 1985; Reijmer et al. 1988; Schlager et al. 1994; Wilson & Roberts 1995). These processes are able to transport carbonate to considerable distances: for example, Andresen et al. (2003) showed that platform-derived aragonite is still a major constituent of sediment more than 40 km off Pedro Bank in the Caribbeans. Diminishing contribution of platform carbonates with distance from the platform was also recognized in fossil examples, e.g., in the Middle Triassic of the Dolomites (Maurer & Schlager 2003). Thickness variations exclude a diagenetic origin of the alternations according to the model of Westphal et al. (2000) and Westphal (2006). In this model, in fact, the diagenetic process generating the alternation dictates the thickness of beds, thus, a same process should result in beds of uniform thickness throughout the basin. On the scale of few km, the thickness of meter scale carbonate banks do not change significantly, as verified with the comparison of the upper Norian of Monte Buccaglione and Monte Cugnone sections. This is not, however, in contrast with the idea that part of the carbonate is platform-derived: differences in bed thickness can be negligible on the short distance of few km, and the two localities may have been not perfectly along dip with respect to the carbonate platform slopes.

The origin of limestone-marl alternations in the Calcari con Selce of the Lagonegro Basin should be related to the sediment production of adjacent carbonate platforms. In the modern periplatform settings of the Bahamas, abundant of platform-derived carbonate supply is related to sea level highstands of interglacial cycles (e.g., Kendall & Schlager 1981; Droxler & Schlager 1985; Reijmer et al. 1988). Such mechanism is, however, improbable for the ice-free Triassic world. More



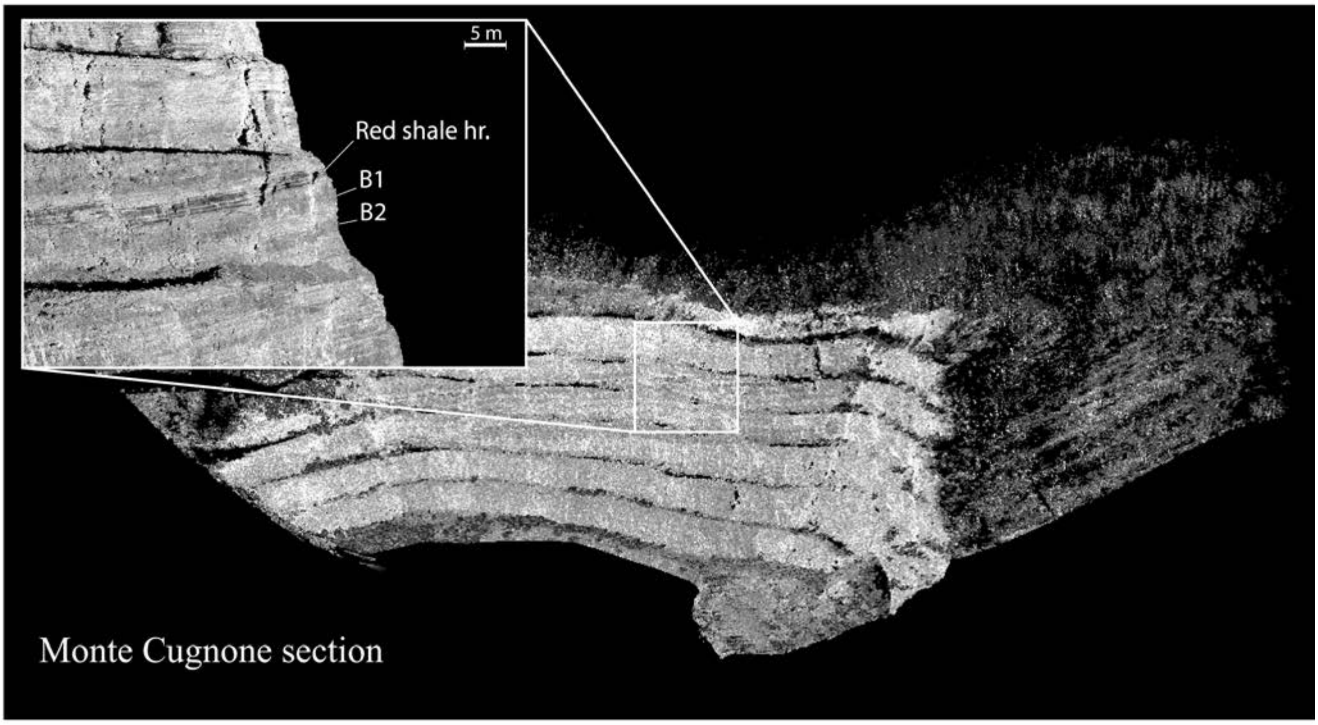


Fig. 4 - Point clouds derived from the TLS acquisitions of the Monte Cugnone (top) and Monte Buccaglione – Sasso di Castalda (bottom) sections. Scans were realized with an Optech^{TM} Ilris 3D TLS at 0.06 m and 0.08 m resolution respectively. Close-ups highlight the position of the red shale horizon and the other carbonate beds (Bed 1 and 2) whose thickness has been measured to verify their continuity at the basinal scale.

likely, cyclical changes of platform-derived carbonate supply reflect ecological changes on the platform that influences their productivity, as discussed, e.g., by Pittet et al. (2000). Summarizing, the limestone-marl alternations of the Calcari con Selce in the Lagonegro Basin deposited in a periplatform setting, and part of the carbonate was supplied from the adjacent Apenninic and Apulian platforms. Regular oscillations of carbonate supply most probably record an external environmental forcing that influenced the platform carbonate productivity, and a cyclostratigraphic study of the Calcari con Selce is thus potentially meaningful.

Conclusions

1. Three intervals characterized by higher siliciclastic content have been recognized within the Calcari con Selce Formation and dated with conodont biostratigraphy: i) the green argillitic/radiolaritic horizon, Tuvalian; ii) the brown member, Carnian/Norian in age; iii) the red shale horizon dated Sevatian 1 (upper Norian). These horizons can be used as lithological markers throughout the Lagonegro Basin;

2. Limestone beds or banks of the Calcari con Selce Formation of different age, above and below of the green argillitic/radiolaritic horizon and the 3-m-thick red shale horizon respectively, have been correlated at the basinal scale. This implies that the Lagonegro Basin is characterized by laterally continuous sedimentation of limestone-marl alternations most probably controlled by allocyclic factors, and opens to future cyclostratigraphic studies.

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