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NUCLEATION PROCESSES IN HIGH-RELIEF CARBONATE PLATFORMS: SEDIMENTOLOGIC CHARACTERIZATION, FACIES COMPOSITION AND DEPOSITIONAL EVOLUTION OF THE ESINO LIMESTONE (LADINIAN-LOWER CARNIAN) IN LOMBARDY

Ph.D. Thesis

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"Sampling error, identification error, as well as the natural perversity of geological data, all contribute to disorder."

Imbrie and Purdy (1962)

SUMMARY

ABSTRACT

High-relief carbonate platforms evolve from a poorly known nucleation stage that has different environmental conditions and depositional processes with respect to the mature stage of the platform. To understand the processes that lead to the development of a high-relief carbonate platform, it is crucial to analyze facies type and distribution during the early phase of their development.

The Esino Limestone (up to 800m thick, with a final platform-to-basin relief of 550 m) preserves exposed the inception stage deposits. In its mature configuration the carbonate system was characterized by a wide inner platform (bedded peritidal limestones with stromatolites, oncoids, fenestrae and dasycladaceans), bordered by a narrow reef (*Tubiphytes* and microbial mounds associated with coral framestones with calcisponges and intrabioclastic packstone) that sourced the breccias of the steep slopes.

20 stratigraphic sections have been measured and about 600 samples for microfacies analysis have been collected in the 30-130 meters-thick succession of the nucleation stage. Facies type and distribution led to the stratigraphic reconstruction and to the identification of major phases in the early platform evolution, which are linked with relative sea-level changes. A first transgression, following the drowning of the antecedent peritidal platform (Camorelli Limestone), is characterized by the deposition of dark bioturbated bio-intraclastic packstone and wackestone passing to bedded black marly limestones and marls (Prezzo Limestone). A general regressive trend is characterized by intraclastic packstones and decreased terrigenous input. Sparse reefal bafflestones (porifera, algae, corals, *Tubiphytes*) and peritidal facies (stromatolitic bindstone with fenestrae, early marine cements, intrabioclastic packstone) record the final onset of the core of the future high relief carbonate platform. The end of the inception stage is thus controlled by the progradation of sparse patch reefs that fill up the depositional space, leading to the coalescence of isolated small nuclei of carbonate production.

This study documented the key role played by antecedent topography and sea-level changes in the localization and growth of the first platform nuclei. Furthermore, environmental conditions (e.g. terrigenous input, water circulation) possibly exerted a control on the organisms' associations that characterized the first stages of platform evolution.

1 - AIM OF THE STUDY

High relief carbonate platforms are extensively studied, both from living and fossil examples, in their mature stage whereas very little information are available on their early phase of development, that is the “inception stage”. This early stage, the moment at which the first platform nuclei set down and start their growth, was proved to have a key role on the successive evolution of the carbonate system.

In this project we studied the inception stage of a middle Triassic high relief carbonate platform: in particular, we investigated which conditions triggered the birth and the development of this carbonate platform and the factors that could be important on the early evolution, influencing sediment types, their distribution and the final platform architecture.

2 - INTRODUCTION

2.1 - High-relief carbonate platforms: overview and premises

High-relief carbonate platforms are carbonate systems that were developed throughout the Phanerozoic up to the present days and were responsible for the accumulation of thick and extensive carbonate successions, capable of being important hydrocarbon plays (READ, 1985). These platforms (fig.1) are characterized by a generally shallow and nearly flat platform-top that is connected to the underlying deep (hundreds of meter) basin by means of steep slopes (often more than 30 degrees). This morphology is the result of a high in-situ carbonate production and accumulation on the platform, with lower export to the basin (WILLIAMS ET AL. 2011), that progressively rises the platform-basin relief and steepens the slopes (READ, 1985). This commonly drives gravitative instability in the platform margins, making the slope deposits peculiar (platform-derived grainy sediments with rock falls, slides, slumps, debris flows, turbidity currents, bypass surfaces) (KENTER, 1990; PLAYTON ET AL. 2010; WILLIAMS ET AL. 2011).

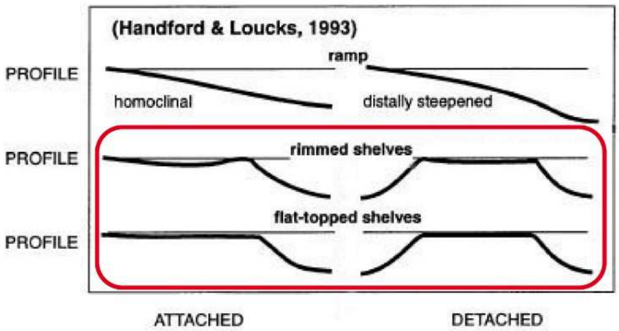


Fig. 1 – Carbonate platform profiles (Modified after POMAR, 2001; original image from HANDFORD AND LOUCKS, 1993). High relief platform profiles within the red box.

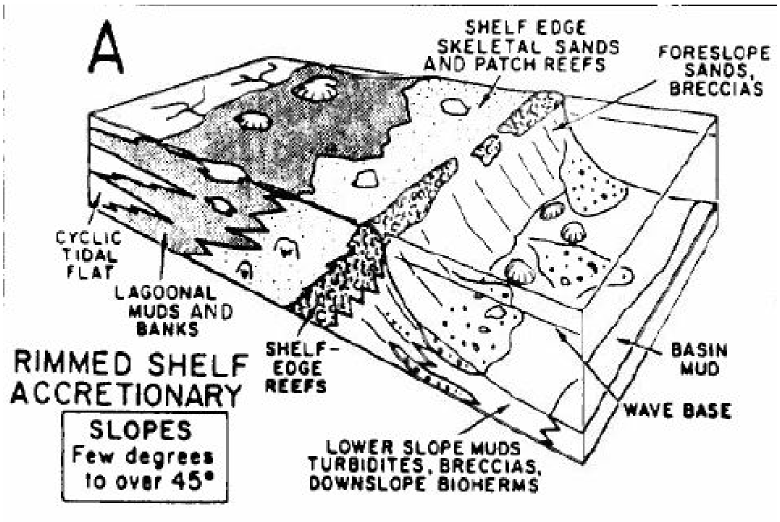


Fig. 2 – Carbonate platform sub-environments and deposits (rimmed shelf) (from READ, 1985)

Modern high-relief carbonate platforms are tropical rimmed shelves (fig.2), characterized by a semi-continuous or continuous rim at the shelf margin that restricts circulation and wave action to form a low-energy lagoon in a landward position (GINSBURG AND JAMES, 1974). Rims, that may consist of barrier reefs, skeletal and ooid sands, but also islands from an earlier depositional phase (READ 1985), represent the loci of maximum carbonate production. Here photo-autotrophic organisms (T-Factory of SCHLAGER, 2003) dominate, having their maximum growth rate in the uppermost 10 m of the water column where sunlight penetration is highest (LONGMAN, 1981; BOSSCHER & SCHLAGER, 1992). Living examples of this carbonate platform type are the Great Barrier Reef, the Belize Shelf, the South Florida Shelf, the Great Bahama Bank. These platforms have been widely studied for what regards the present carbonate system (in particular the reef environment and its biota) but their early development stage is less known due to the fact that the growth of the platform progressively leads to the mantling of older sediments, that thus result stored and hidden in the core zone of the platform, a position that makes more difficult their study. Nonetheless a few studies based on cores and seismic have revealed the importance that the inception stage has on the later evolution. MAZZULLO (2006) for example studied the Belize Shelf and showed that the early development, during the Pleistocene, of the flat-topped reef-rimmed platform occurred on the unconform top of a shallowing upward ramp (fig.3) and was induced by differential subsidence related to the activity of a fault system that still delineates the present-day platform margin (barrier reef). The rimmed platform morphology was then maintained and accentuated during the Holocene by barrier reef growth, lowstand karstification, differential platform-to-basin subsidence, and low magnitude of eustatic accommodation-space increase during highstands (MAZZULLO, 2006). The elevation of the topography with respect to sea-level, tectonically controlled, was a primary control in the localization of the reef during the inception stage but also during the successive transgressive phases that followed platform exposures and karstification (GISCHLER AND HUDSON, 1998; 2004). Also BOSENCE (2005) states the general importance of the tectonic setting in such cases where a rimmed platform develops over a ramp. Exposure to waves and currents was also considered an important but subordinated factor.

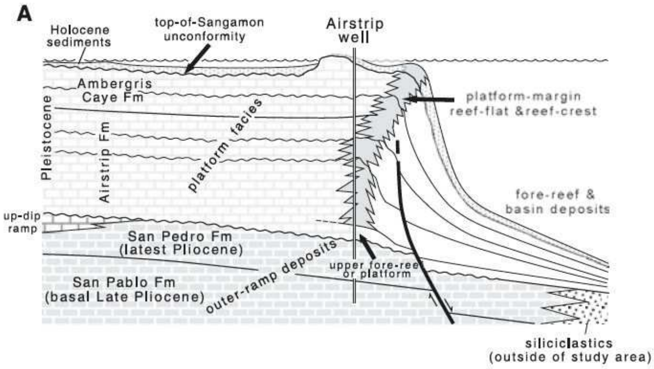


Fig. 3 – Cross section of the Belize shelf. Faulting of the Pliocene ramp deposits created a structurally defined platform margin along which Pleistocene barrier-reef growth was focused. (from MAZZULLO, 2006).

The factors that control the inception of a carbonate platform have been discussed by POMAR (2001) and are among those that also at present control the evolution of the mature platform and that are complexly interrelated: environmental energy (surficial and internal waves, currents, upwelling) and water characteristics (salinity, turbidity, oxygen, nutrients, temperature) are critical in the life of carbonate factory and determines the association of life forms and the carbonate production rate. The generated sediments and bioconstructions in turn shape the depositional surface, together with tectonics and sea-level change, and are potentially capable of modifying the water circulation and thus also the local environmental conditions. Furthermore, an important link between physiography, sea-level and carbonate production exists in present-day carbonate systems due to the fact that the T-Factory is dominated by autotrophic organisms, in particular by scleractinian (hermatypic) corals, which significantly contribute to the building of the modern platforms with fast-growing rigid organic frameworks and also with a lot of skeletal debris (LONGMAN, 1981). POMAR (2001) highlights the primary role exerted by the biological association on the depositional profiles and facies distribution of carbonate platforms and warns that the modern reefs are not a good analogue for platforms older than the Neogene because of the different biotic communities.

In the middle Triassic in fact the composition of the carbonate factory was considerably different from the modern one. The metazoan reef community was recovering from the End-Permian mass extinction, scleractinian corals were still minor contributors to the carbonate production and no other organisms had a comparable frame-building ability. Brachiopods, mollusks, foraminifers and echinoderms were common while calcareous and siliceous sponges, calcareous green and red algae and bryozoans acted as binders, bafflers and sediment-stabilizers (LONGMAN, 1981; STANLEY, 1988; PRUSS AND BOTTJER, 2005). These organisms however were not dominant in the platform margin environment, which was mainly constituted by microbial communities and Problematica (*Tubiphytes* was the main form), micrite (probably of microbial origin; SCHLAGER, 2003; PAYNE ET AL. 2006) and early marine cements (RUSSO ET AL. 1997, 2000; KEIM AND SCHLAGER, 2001). The middle Triassic biotic community thus commonly fits the M-Factory of SCHLAGER (2003) and, being dominated by oligophotic forms, its growth ability was probably not limited to the photic zone but extended far deeper. As a result, a different response of carbonate production to sea-level variations, with respect to the present-day T-Factory, may be expected, influencing the architectural construction of the platform as proposed by KENTER ET AL. (2005) (Slope shedding model; Fig.4).

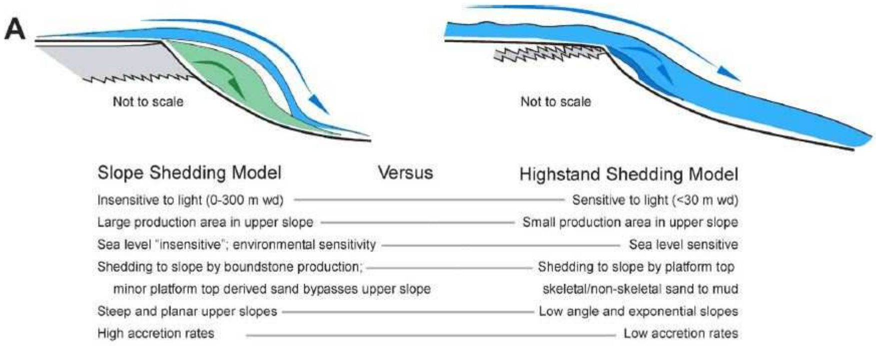


Fig.4 – Schematic diagrams illustrating the main differences between the Sope shedding and Highstand shedding depositional models. (from KENTER ET AL. 2005).

A few studies on the inception stage of high relief carbonate platforms are available from middle Triassic examples, in favorable cases where deep erosion exposed their nuclei to outcrop-based research. This is the case of the Great Bank of Guizhou (Nanpanjiang Basin, China), a high relief Triassic isolated platform whose cross section is exposed by a faulted syncline (LEHRMAN ET AL. 1998). The platform results to develop on the top of the antecedent drowned Permian Yangtze Platform. The initial accumulation of the Great Bank of Guizhou occurred near the margin of the previous platform (fig.5) and is represented by a central open-marine shallow-subtidal environment occasionally winnowed by wave action (skeletal grainstone-packstone), margined by deeper subtidal patch reefs of sponge boundstone and bafflestone. No structural control drove here the platform initiation but a link between topography, sea level and water circulation can be deduced from the position near to the margin plus the fact that surrounding areas experienced a deeper water sedimentation. This nucleus then firstly evolved to a low-relief bank with differentiated environments (shallow subtidal-peritidal interior and oolite margins) and later progressively increased its relief developing wide *Tubiphytes* reef margins and steep slopes (LEHRMAN ET AL. 1998).

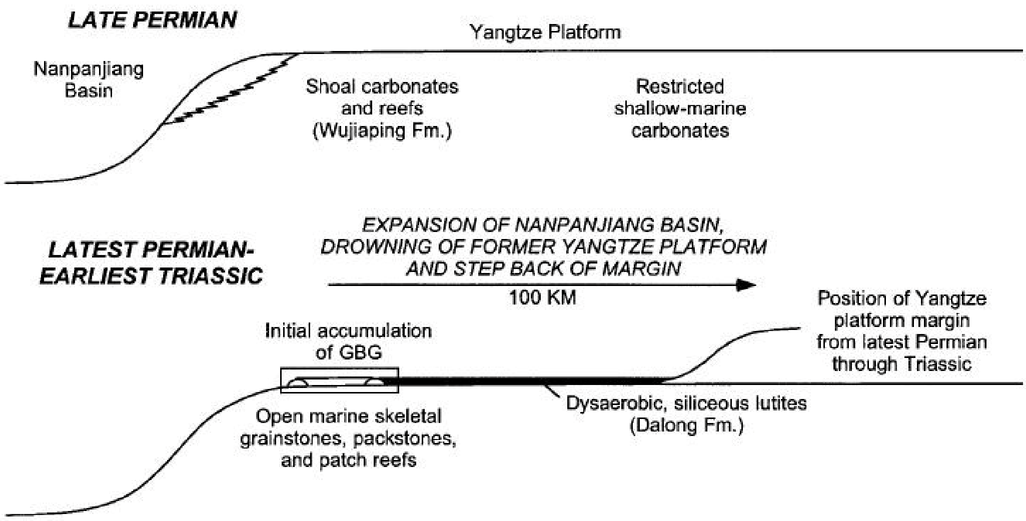


Fig. 5 - Schematic cross sections illustrating latest Permian drowning of the Yangtze platform and initial accumulation of the Great Bank of Guizhou (GBG) (from LEHRMANN ET AL.1998).

Another example is the Latemar platform (Italy): this is a middle Triassic flat-topped platform with steep slopes (up to 35°) and high relief. MARANGON ET AL. (2011) described its structure as being composed by a most elevated interior area with cyclical peritidal deposits that passes, deepening, to a margin dominated by boundstones with calcisponges, microbialites, *Tubiphytes* and cements. Cement and Tubiphytes boundstones also characterize the upper slope while the lower slope is composed by skeletal packstone to wackestone and margin/upper-slope-derived breccias. In this case synsedimentary tectonics primarily influenced the initial and successive development of the platform: the first nuclei in fact, in the late Anisian, grew on the top of a fault-bounded horst carved onto an older carbonate bank (fig.6) and was characterized by microbial boundstones making lateral transition to slope grainstones and rudstones. Faults continued to control the position of the margins and thus the shape and facies arrangement of the carbonate platform also in the successive growth phases of the platform (PRETO ET AL. 2011).

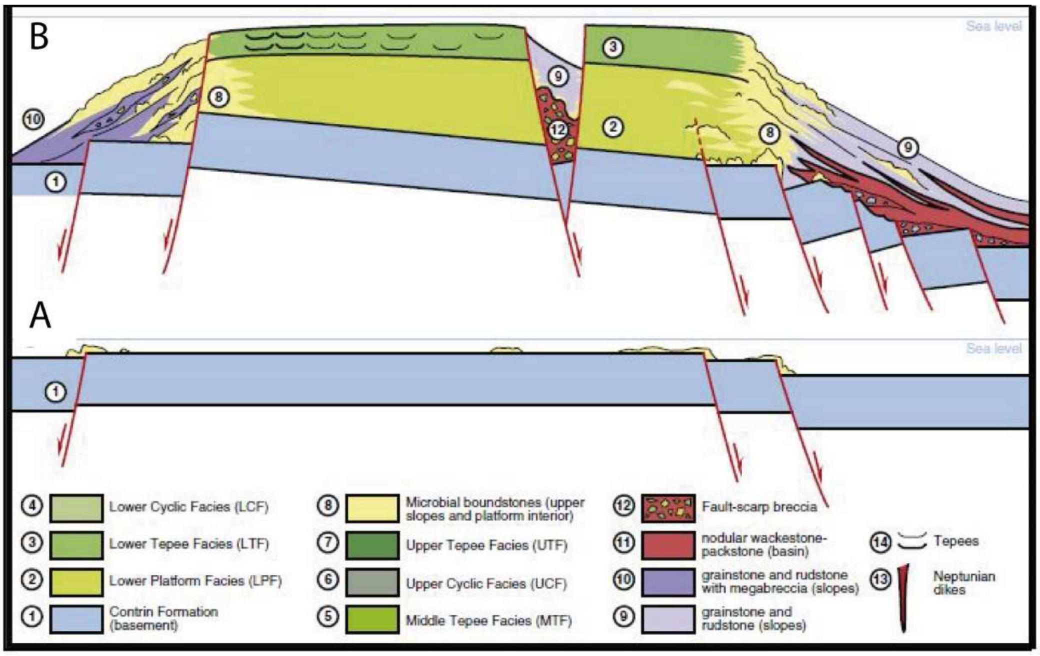


Fig.6 – Latemar platform cross section. Is showed the inception of the platform, which starts on the top of fault-bounded horst (A). Fault activity continues to control the position of the platform margin and the type of slope deposits during the later evolution (B). (from PRETO ET AL *2011)*

Also in these Triassic examples the elevation of antecedent physiography was important in the localization of the platform inception but this linkage is not explained in terms of dependency from light, environmental energy or other factors.

In this research we present the results from the study of the inception stage from another Triassic carbonate platform, whose deposits crop out in Italy. The target area was identified by BERRA ET AL. (2011) as the core zone of the Esino Limestone carbonate platform. Here Quaternary deep fluvial erosion has dissected the platform bank down to the underlying formations and thus represents a further favorable case for the study of the inception stage of high relief carbonate platforms. The results of the study are discussed and confronted with these and others selected case studies in order to better comprehend the main controls on platform initiation.

3 - GEOLOGICAL SETTING

3.1 - Geographic position and tectonic setting

The target succession crops out in the Western Southern Alps of Italy, in the Bergamo Province, along an L-shaped belt that extends from Piazzatorre town in the North, down along the Brembana Valley to Lenna town and then Eastwards on the left side of the Valsecca di Roncobello up to the watershed mountains with the Seriana Valley (fig.7). The area structurally belongs to the Southern Alps, the sector of the Alps which is comprised between the Insubric line at North and the Po plain at South and which is referred to the African promontory. The Southern Alps structural unit is composed of a Variscan basement unconformably overlaid by a thick stratigraphic record that starts with Permo-Carboniferous continental deposits () and are followed by Triassic marine carbonate deposits first (in this period many shallow water carbonate platforms develop), then by Jurassic to upper Cretaceous mostly pelagic sediments (related to the opening of the Ligure-Piemontese Ocean) and lastly by flyschoid deposits related to the Alpine orogenesys. The Alpine orogenesis produced within this unit South-verging folds and thrusts, that has fragmented the original stratigraphic asset.

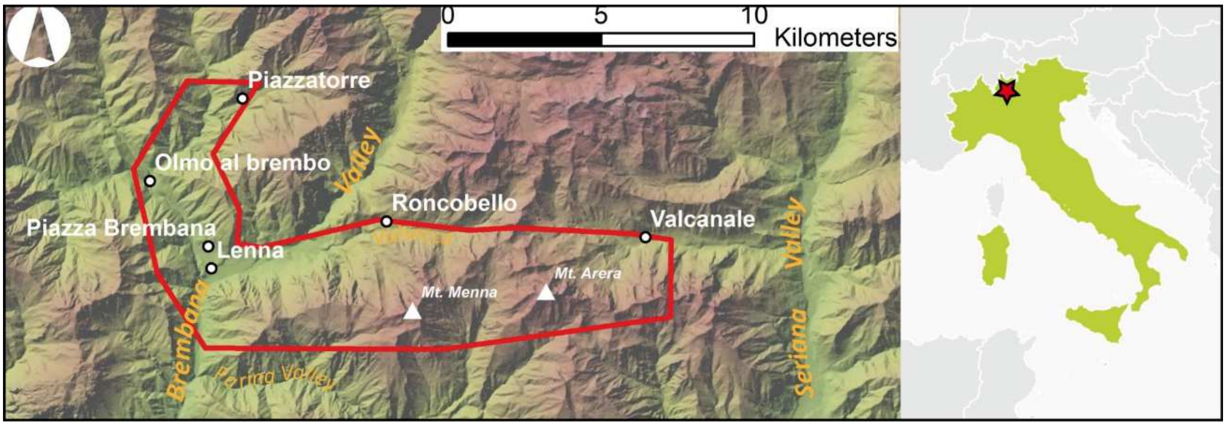


Fig.7 - Geographic position (red star in the Italy map) and shape (red polygon in the left map) of the study area.

The study area in fact is placed at the South and West side of an anticline, the Trabuchello-Cabianca anticline, which exposes at its nucleus the Variscan metamorphic basement and its mostly continental sedimentary Permian and lower Triassic succession. At its Southern margin an important fault system, the Valtorta-Valcanale Fault, separates the Paleozoic-lower Triassic succession from the detached middle Triassic succession, mostly represented by marine carbonates (Fig.8 and fig.9). The target deposits of this study belong to this domain, which is affected by several thrusts and faults that shortened the original paleogeography and locally lead to the repetition of the succession (e.g. Mt. Arera) (JADOUL ET AL. 2012, ZANCHI ET AL. 2012).

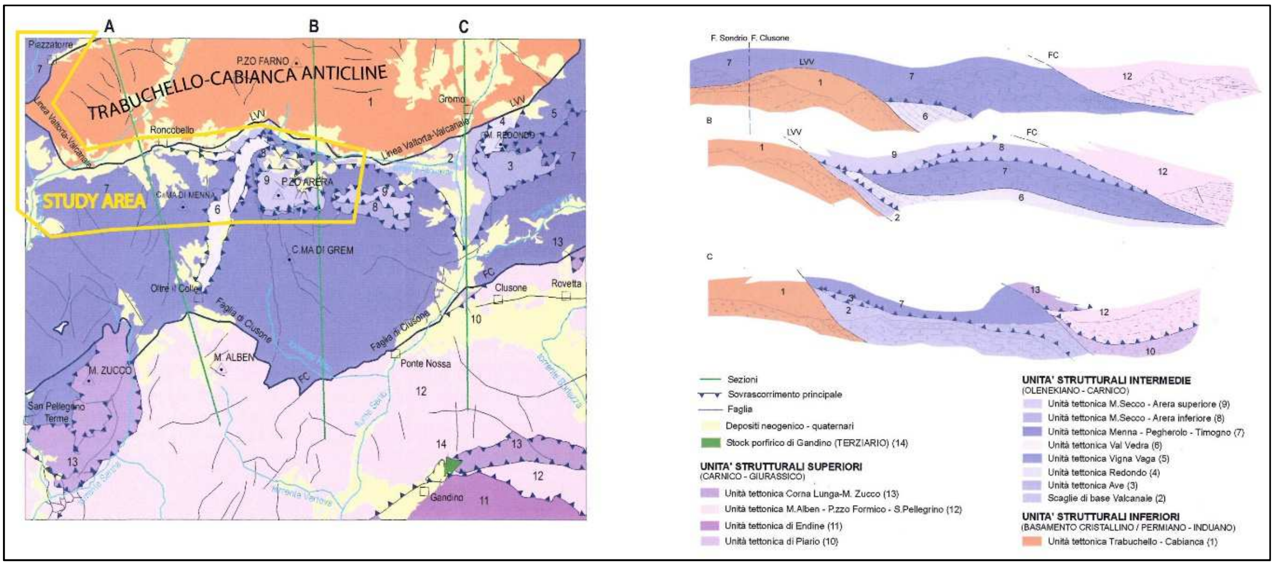


Fig.8 – Structural map and cross sections. Note the Valtorta-Valcanale fault separating the northern mostly Paleozoic units (red in the map) from the southern middle Triassic units (blue in the map). In the cross sections thrusts within the Triassic deposits are visible. The study area is highlighted by the yellow polygon. (from JADOUL ET AL. 2012).

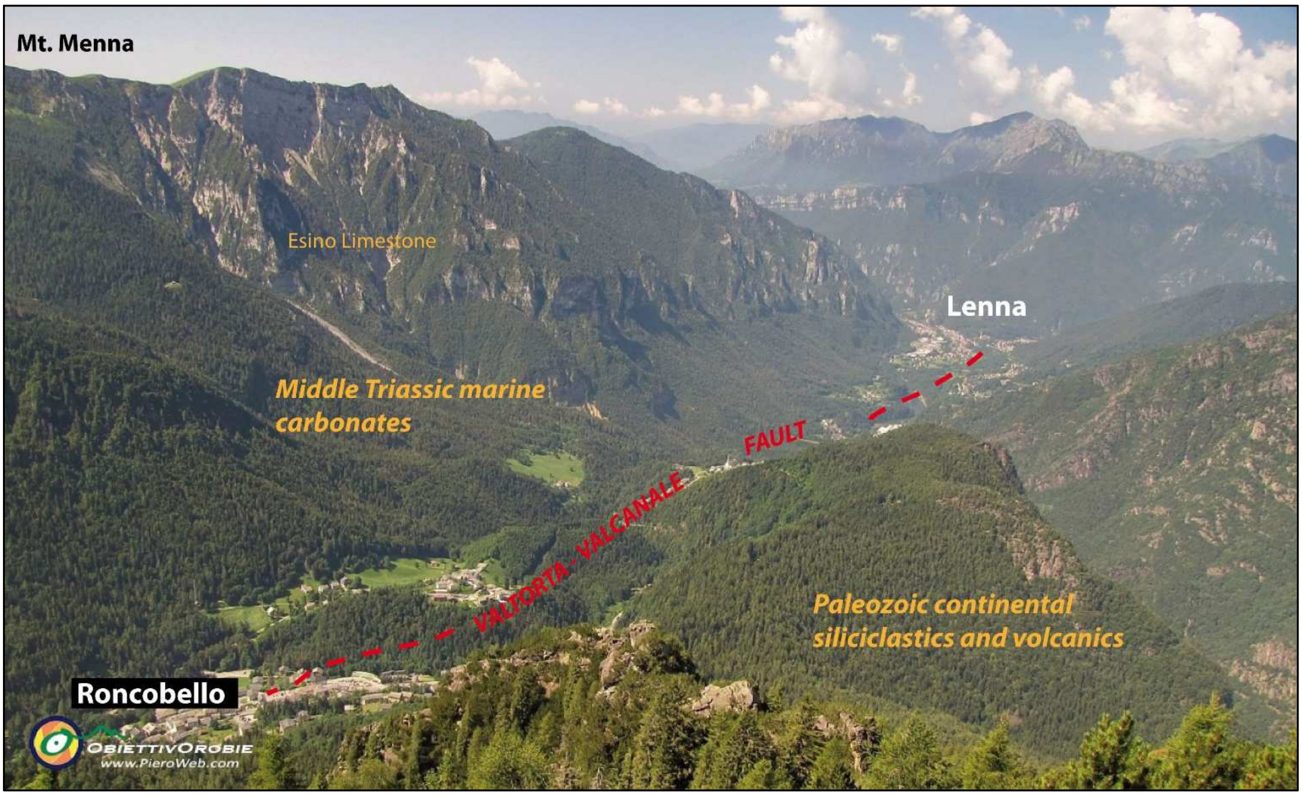


Fig.9 – Panoramic view of the Valsecca di Roncobello from NE to SW (photo from www.pieroweb.com). Note the valley separating rounded morphologies at North, in the Paleozoic domain, and steep calcareous mountains (Esino Limestone) at South, in the middle Triassic domain.

3.2 - The pre-Esino Limestone succession

The analysis of the succession predating the inception stage of the Esino Limestone is critical to define its possible role in the setting of the nuclei of the Esino Limestone platform, as well as the bathymetric conditions that existed when the nucleation took place.

The middle Triassic deposits that crop out in the study area include different formations and testify a story of changing sea level and depositional environments: starting from the peritidal deposits of an Anisian carbonate platform (Camorelli Limestone) the area firstly experiences a drowning, that leads to pelagic deposition (Prezzo Limestone), and then a shallowing trend, related with the growth of the Ladinian carbonate platform (Esino Limestone), that eventually restores peritidal conditions. This transgressive-regressive succession, corresponding to the A2L1 sequence of GAETANI ET AL. (1998), includes the inception stage of the Esino Limestone platform and therefore was the object of the present study.

3.2.1 - The Anisian platform

The development of the Esino Limestone platform was preceded, during the Anisian, by the deposition of carbonate platform facies referred to as Camorelli Limestone (ASSERETO ET AL. 1965; DELFRATI ET AL. 2000). According to BERRA ET AL. (2005) this carbonate platform identifies a slow subsiding sector, extending from Val Seriana westwards till the fan-delta siliciclastic deposits of the Bellano Formation near the Como Lake (fig.10). Here prevailing grey to yellowish bedded dolostone with microbialites and fenestral fabric (Camorelli Limestone, corresponding to the "Membro delle dolomie peritidali" of JADOUL AND ROSSI 1982) indicates a peritidal environment. The study area places within this slow subsiding sector. A faster subsiding sector was present instead East of this platform, from Val Seriana to East Val Camonica. Here planar-bedded dark grey limestones, sometimes weakly nodular and with thin marl intercalations, belong to the coeval Angolo Limestone (ASSERETO AND CASATI, 1968) and represent a subtidal bay environment, below fair-weather wave base (BERRA ET AL. 2005). Nonetheless also in this sector km-sized shallow-water carbonate banks of Camorelli Limestone are present (GAETANI AND GORZA, 1989; FALLETTI AND IVANOVA, 2003). The facies are intrabioclastic packstones with peloids, *Tubiphytes* and forams, algal and *Tubiphytes* boundstones, bioclastic packstones with abundant forams indicating shallow water carbonate banks with poorly differentiated environments (GAETANI AND GORZA, 1989). Between the slow-subsiding western sector and the fast-subsiding eastern sector a narrow platform margin is recognized by BERRA ET AL. 2005 in the presence of small coral framestones. The absence of breccia aprons indicates anyway a low relief of the platform on the underlying basin.

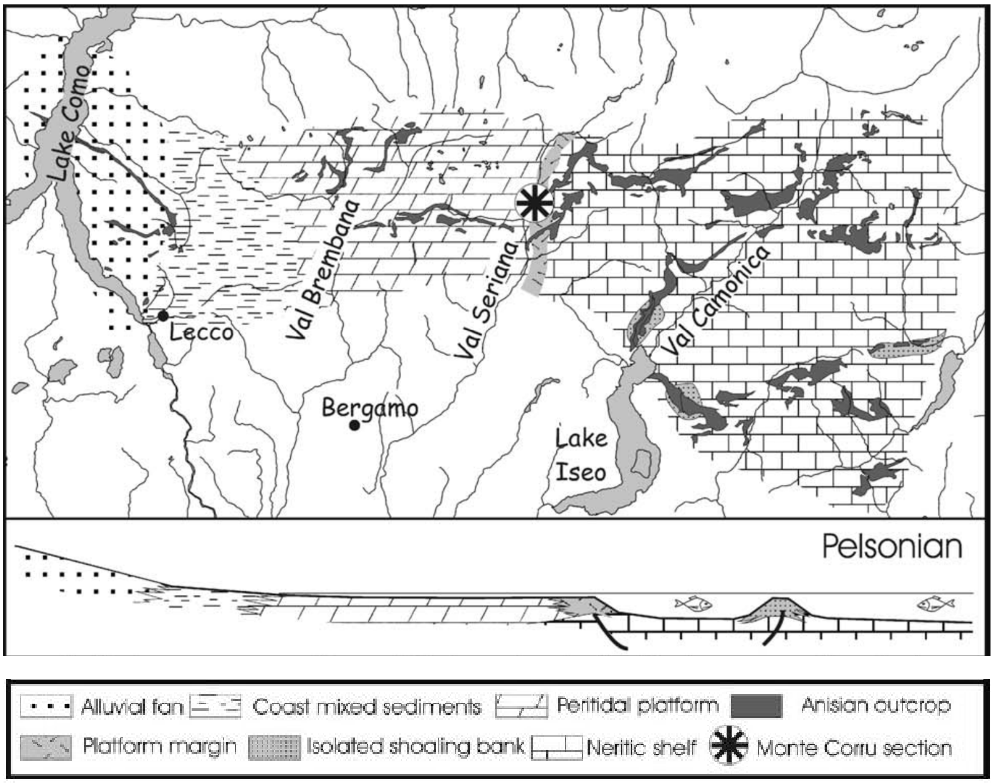


Fig. 10 – The Anisian paleogeography (Lombardy). (from BERRA ET AL. 2005)

3.2.2 - The drowning of the Anisian platform

An important transgression, documented in the whole Tethian area (GAETANI ET AL. 1986) drove deeper sedimentation during the uppermost Anisian on both platform (that drowned) and basin. These sediments are ascribed to the Prezzo Limestone. The basal transgressive sediments that directly cover both the Camorelli Limestone peritidal facies and the basinal Angolo Limestone are a very distinctive facies association known as "Banco a Brachiopodi" (or "Cimego Limestone"; ASSERETO ET AL. 1977), consisting of planar-bedded or nodular bioclastic calcarenites rich in crinoids and locally also in brachiopods (*Tetractinella trigonella*) (JADOUL ET AL. 2012). Grains and bioclasts coated with blue-green algae and abundant forams (*Pilammina densa* and *Palaeomiliolina judicariensis*) are also common features (GAETANI ET AL. 1986). This unit paraconformably covers the Camorelli Limestone and conformably overlies the Angolo Limestone in the basin, where it has been dated with ammonoids (*Rieppelites cimeganus* Zone, uppermost Pelsonian; MONNET, 2008).

The overlying typical Prezzo Limestone, defined by ASSERETO AND CASATI (1965) in Valli Giudicarie, consists of a well-bedded succession of grey-blackish planar limestone beds and clay-marly joints (BALINI, 1992). The thickness of the formation reaches more than 100 m East of the Seriana Valley (Val di Scalve). In the area west of Seriana valley the formation is thinner (26 meters or less) or absent. The different thickness could result from condensed deposition on the platform top or from lateral transition between the uppermost Angolo-Camorelli limestone and the Prezzo Limestone, but the question is not resolved (BALINI, 1992). The Prezzo Limestone is famous for the rich ammonoid fauna that allowed precise dating (Illyrian; BALINI, 1992), but also contains brachiopods, bivalves (Daonella) and gastropods (ASSERETO AND CASATI 1965, CASATI AND GNACCOLINI 1967, ASSERETO 1969, GAETANI ET AL 1987, JADOUL ET AL 1992). JADOUL

ET AL. (2012) suggest for the slow subsiding sector an open marine environment, not very deep, with restricted circulation at the bottom. This area was probably adjacent to the first carbonate nuclei of the Esino Limestone platform: debris flows with platform-derived material are in fact reported in the lower part of the Prezzo Limestone in the Grigne Massif area from GAETANI ET AL. (1986) documenting the early development of the first Esino Limestone nuclei and the lateral transition between the two formations. The Prezzo Limestone is conformably covered in the western sector by the prograding Esino Limestone while in the east by a succession of basinal formations (i.e. Buchenstein Formation, Wengen Formation, Perledo-Varenna Limestone).

3.3 - The Esino Limestone

The Esino Limestone is a Late Anisian? to Early Carnian carbonate formation of the Southern Alps that crops out in a 100km wide and 20 km high belt between the Como Lake, at West, and the Garda Lake, at East (fig.11). The formation reaches a maximum thickness of more than 800 meters (Val Camonica and Pegherolo Massif) and records the life cycle, from inception to demise, of a high relief carbonate platform in response to sea level changes (BERRA ET AL. 2011).

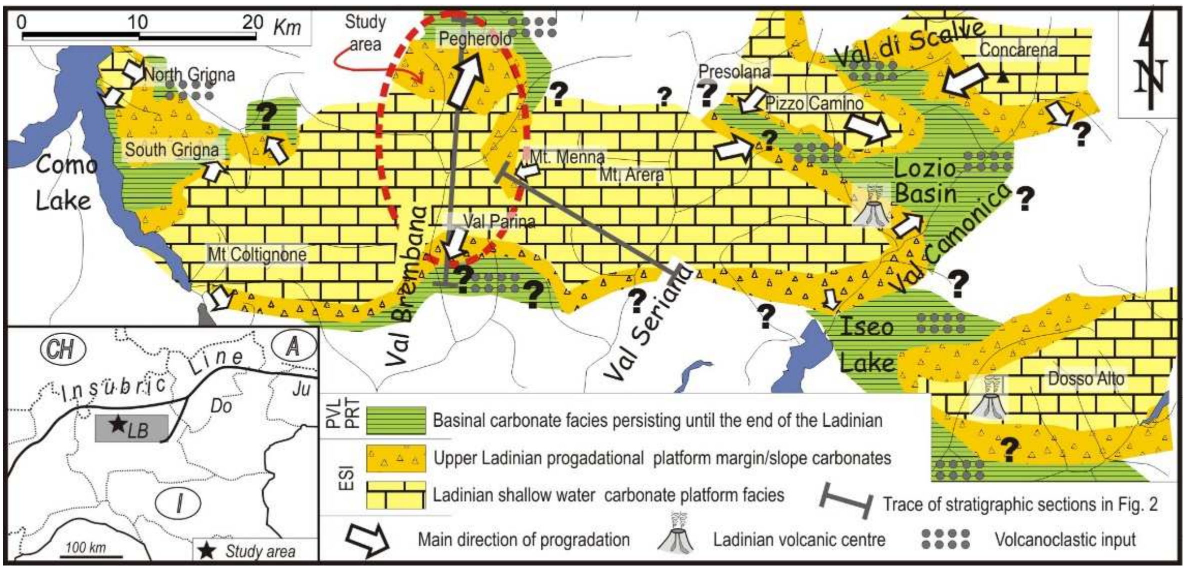


Fig.11 - Paleogeographic distribution of carbonate highs and intraplatform basins in the Lombardy Basin at the end of the deposition of the Esino Limestone. In the inset: LB: Lombardy Basin; Do: Dolomites; Ju: Julian Alps. From BERRA ET AL 2011

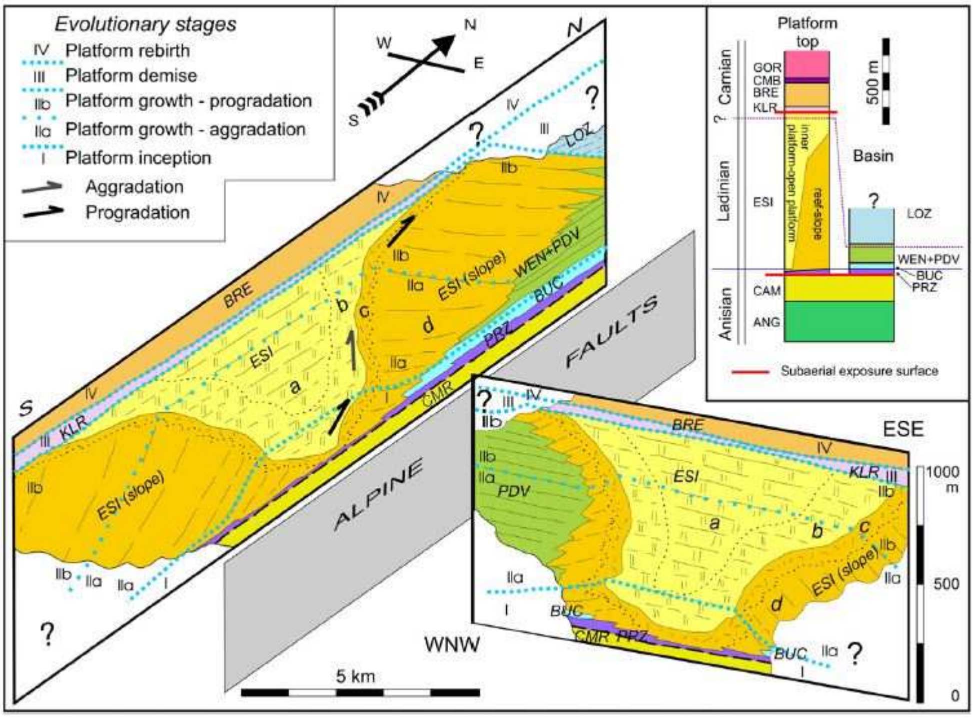


Fig.12 – Schematic facies distribution along two stratigraphic sections across the study area (Pegherolo Massif–Middle Val Brembana). The trace of the stratigraphic sections is indicated in Fig. 11. On the top right, a simplified stratigraphic diagram summarizes the stratigraphy in basinal (right) and platform top (left) settings. ANG: Angolo Limestone; CAM: Camorelli Limestone; PRZ: Prezzo Limestone; BUC: Buchenstein Fm.; PDV: Perledo-Varenna Limestone; WEN: Wengen Formation; ESI: Esino Limestone, consisting of: a) bedded inner platform facies; b) massive bioclastic facies (open platform); c) reef belt; d) slope breccias; KLR: Calcare Rosso; LOZ: Lozio Shale; BRE: Breno Formation; CMB: Calcare Metallifero Bergamasco; GOR: Gorno Formation. From BERRA ET AL *2011*

The huge sediments of the formation have been described and subdivided first by JADOUL ET AL. (1992) and later by BERRA ET AL. 2011 into different parts, that are related with the evolutionary phases of the carbonate platform. The main part of the Esino Limestone is composed by the "growth phase" of the carbonate platform (fig.12, IIa and IIb), which initially displays a prevailing aggrading trend, during fast transgression, and then a prevailing prograding trend, during regression. In this major phase the platform reaches its highest plaform-to-basin relief (up to 550 m) on the surrounding basins and acquires its characteristic high relief rimmed architecture, crossed by intraplatform basins and seaways and facing a deep ocean. Three main facies belts can be recognized in this carbonate system (BERRA ET AL. 2011) during its aggradation to progradation stage:

A) the *inner platform facies* firstly developed above the nucleation areas and then enlarged toward the basinal areas as a consequence of platform progradation (fig.12). They are composed of thick bedded subtidal limestones (intra-bioclastic packstone) with dasycladaceans, crinoids and mollusks, oncolitic rudstone and stromatolitic bindstone. These facies become massive and coarser near the reef belt, where energy was higher and skeletal components more abundant, also accumulated from the open sea.

B) The *reef facies* is preserved in a narrow belt (fig.12) and is composed by massive limestone and patch reefs with meter-size coral framestone associated with calcisponges and intrabioclastic packstone, together with *Tubiphytes* and microbial mounds.

C) The reef facies is bordered basinward by the *slope facies* (fig.12), represented by a monotonous succession of massive to crudely bedded, clinostratified, clast-supported intraformational breccia deposits. The sediments originated by fall of unstable portions of the upper slope and reef belt. The slope was 25° to 35° steep. Both the reefal facies and the slope facies are characterized by a pervasive network of cavities partially or totally filled with marine cements (Frisia-Bruni et al. 1989; precedently described as "grossoolith" by German, 1971 or "evinosponge" by Stoppani, 1858).

Coeval with the Esino Limestone are different basinal formations (fig.12). The prograding slope facies of the Esino Limestone cover and interfinger with the Prezzo Limestone, the Buchenstein Formation (cherty limestones with thin tuffitic layers), the Perledo-Varenna Limestone (dark bedded intraclastic packstones) and the Wengen Formation (volcanoclastic deposits and resedimented limestones).

Close to the Ladinian-Carnian boundary the Esino Carbonate platform came to a sudden end due to a marine regression that subaerially exposed the top of the platform to weathering. The platform was overlaid by reddish carbonate deposits (Calcare Rosso) characterized by karst structures, paleosols, collapse and sedimentary breccias, vadose cements and sedimentary dikes up to 10 m deep and filled with marly limestones. In the basin the demise of the platform is marked by the deposition of shales and siltstones (Lozio Shale), which also cover the slope breccias (Berra et al. 2011).

3.4 - The Inception stage of the Esino Limestone – previous studies

The inception stage of the Esino Limestone is identified by Jadoul et al. 1992 in a thin layer (50-60 meters thick) at the base of the formation. This layer, described by Jadoul et al. 1992 (fig.13), consists of light to dark grey massive, bioclastic and intraclastic calcarenites (their "lithofacies association 1a") and bioclastic, fossil-rich limestones with brachiopods, gastropods, pelecypods, ammonoids and crinoids ("lithofacies association 1b", corresponding to the "Lumachella di Ghegna" of Tommasi 1911, 1913). These deposits represent the first evidence of platform production after the drowning documented by the Prezzo Limestone and were assigned to a transitional environment between the platform and the basin. At the same time or immediately after is the development of the first reefs, built by organisms like *Tubiphytes*, and the development of an inner platform area, characterized by well-bedded limestones and dolomitic limestones organized in peritidal cycles ("lithofacies association 2" of Jadoul et al. 1992) with stromatolites, fenestral cavities, tepees and radial fibrous cements ("raggioni" of Assereto & Folk, 1980). According to the authors the inner platform "lithofacies association 2" probably interfingers with the margin "lithofacies association 1b", some tens of meters above the basal part of the formation.

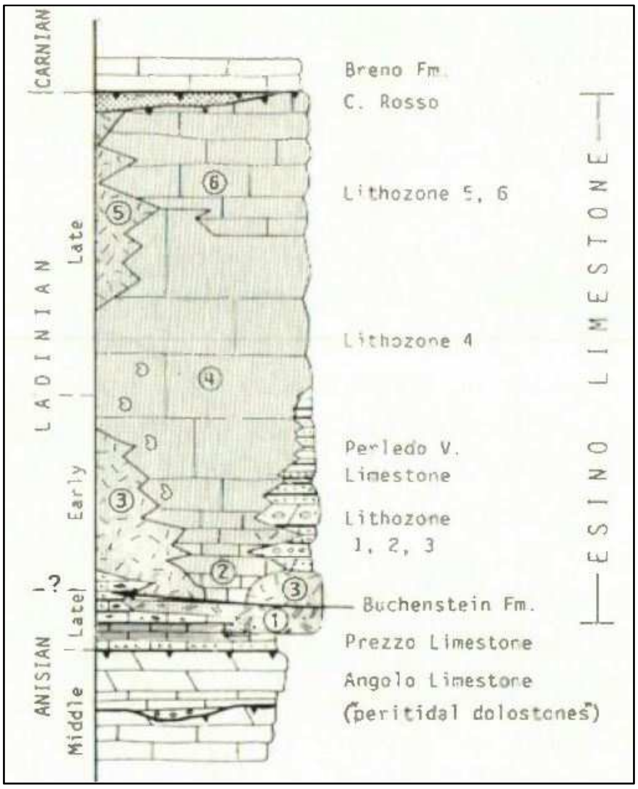


Fig. 13 - Lithostratigraphy of the Middle Triassic succession of the Val Brembana. Lithozone 1, 2 and 3 form the inception stage of the Esino Limestone. Lithozone 1 are light to dark grey massive, bioclastic and intraclastic calcarenites and/or bioclastic, fossil-rich limestone with brachiopods, gastropods, pelecypods, ammonoids and crinoids (Lumachella di Ghegna); Lithozone 2 are well bedded limestone and dolomitic limestone organized in peritidal cycles with stromatolites and fenestral cavities; Lithozone 3 are massive bioclastic limestone and patch reefs with Tubiphytes and Porostromata. (from JADOUL ET AL. 1992).

The inception of the Esino Limestone platform was controlled, according to JADOUL AND ROSSI (1982), by the existence of paleohighs and less subsident areas. This interepretation was lately accepted by JADOUL ET AL. 1992, who highlighted that nucleation sites were already characterized in the Anisian by peritidal deposition (Camorelli Limestone).

Also GAETANI ET AL. 1986 in an easternmost area (Grigne), report the presence of the Esino Limestone directly overlying Anisian peritidal deposits (Dolomia dell'Albiga). Here the base of the Esino Limestone is composed by prevailing massive micrite-rich bioclastic packstones that are partially stabilized by Tubiphytes and blue-green algae, with porifers and corals being minor contributors. According to these observations the authors suggest that the platform initiated as a subtidal sandy carbonate bank with limited relief on the surrounding areas. Above these basal deposits the platform continued its growth developing the high relief morphology, characterized by diversified subenvironments and lithofacies (PAGNI FRETTE, 1993).

4 - METHODS

The study of the inception stage of the Esino Limestone platform required a fieldwork campaign, in order to describe in detail, across the study area, the stratigraphic interval at the base of the platform.

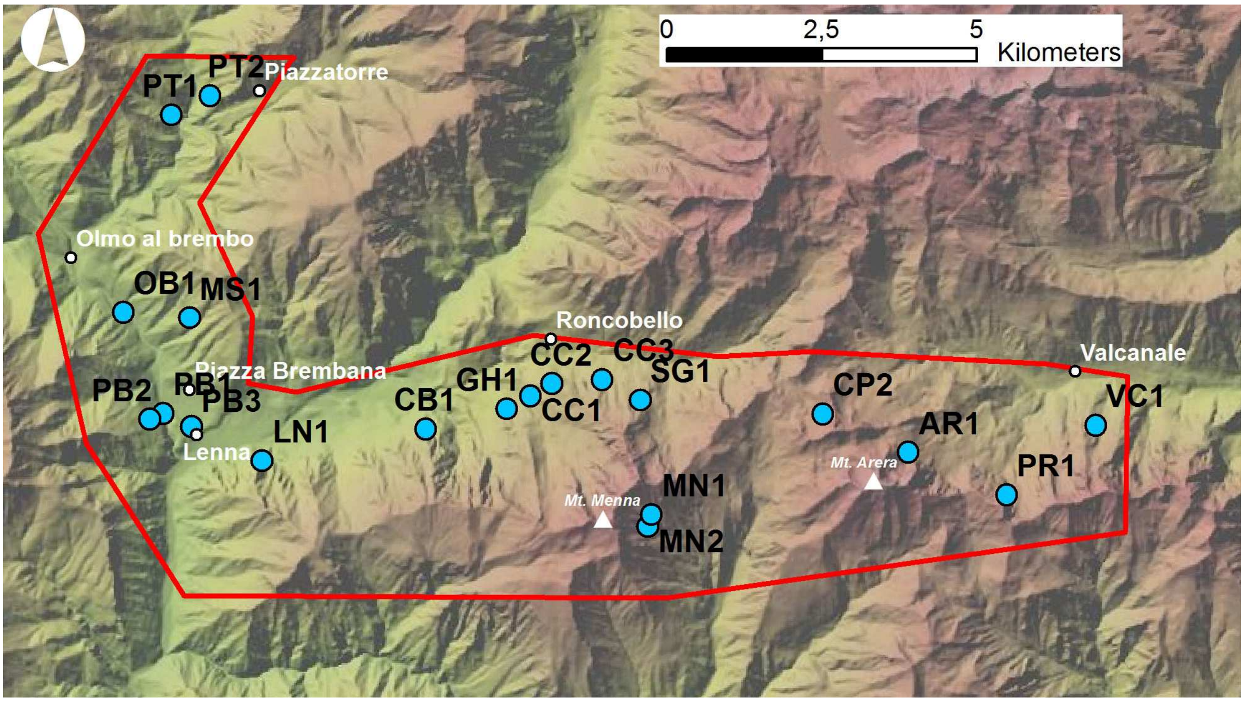


Fig.14 – The position of stratigraphic sections (blue dots) within the study area (red polygon). Each stratigraphic section is labelled with a code, which is used in the text.

Detailed geological maps at 1:50'000 and 1:10'000 scale (BINI ET AL. 2012; JADOUL ET AL. 2012), showing the surface distribution of the target formations, were used to identify where the base of the Esino Limestone is exposed.

Twenty outcrops were selected at the transition from the Camorelli Limestone to the Esino Limestone (fig.14). Outcrop quality is very heterogeneous, being generally poor at low altitudes due to debris and forest cover (exposures are commonly confined to water cuts); at higher altitudes instead formations are well exposed and often also panoramic views on the succession are possible. In these cases, the contrasting rock quality of the formations is best evident: Camorelli Limestone and Esino Limestone, very solid, tend to form steep inaccessible cliffs, while Prezzo Limestone in between, softer (marly limestones and marls), is often gently inclined and partially covered by soil or debris (fig.15).

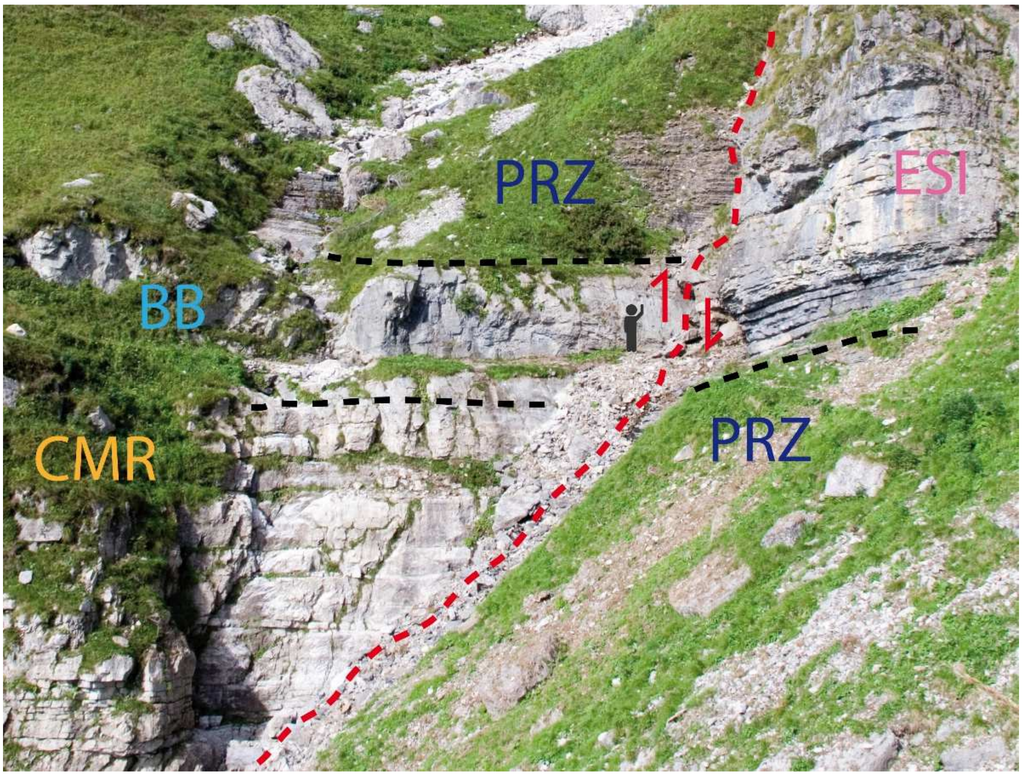


Fig.15 – The studied interval at Mt. Menna stratigraphic section (MN1). CMR: Camorelli Limestone; BB: Banco a Brachiopodi; PRZ: Prezzo Limestone; ESI: Esino Limestone. A high angle fault (red dotted line) dislocates the succession (arrows indicate relative movements of the blocks). Human figure for scale.

More than 600 rock samples were collected from the stratigraphic sections and observation points. The samples were cut and described at the macroscopic scale with a lens. A selection of these samples were destined to peel and thin section preparation. 179 Peels and 191 thin sections were eventually realized and then described at the petrographic microscope.

Microfacies were described following the guidelines and the modified Dunham classification scheme from LOKIER AND JUNAIBI (2016). Percent estimation of different grains abundance was made by means of visual comparators. Bioclasts and fossils were identified in thin sections. With regards to these last grains in this work we use "fossil" to indicate the entire skeletal remain of a living being (e.g. foraminifer shells, bivalve and brachiopod articulated shells) while we use "bioclast" or "skeletal grain" to indicate a broken or disarticulated skeletal part of a living being (e.g. a single valve or a fragment of a bivalve shell, a spine of an echinoid)

The wet cut surface of rock samples was digitally acquired with a table scanner or with a camera, prior to the preparation of the thin sections. From these images the average RGB value of the carbonate matrix was measured with a graphic software package (Adobe Photoshop CS2) in order to objectively compare color trends along the different stratigraphic sections and to keep a record of the original sample.

The data collected from macroscopic and microscopic observations filled a database (based on MS Access), that was used for rapidly recognize the distribution of grains and characteristics as well as for grouping and characterizing the lithofacies.

5 - RESULTS

The stratigraphic sections recorded during the fieldwork in the selected outcrops are illustrated with detail in Appendix 1. The facies analysis allowed the distinction of 5 lithological units:

1) Camorelli Limestone
2) Banco a Brachiopodi
3) Prezzo Limestone
4) Basal Esino Limestone
5) Peritidal Esino Limestone

whose main characteristics are resumed in fig.16.

Stratigraphic unit	Code		Thickness	Lithology	Key features
PERITIDAL ESINO LIMESTONE	ESIP		hundreds of meters	Limestone	Bedded (horizontal) Light grey color Stromatolites, fenestrae, oncoids Scarce fossils Marine cements
BASAL ESINO LIMESTONE	ESIB3		up to 50 meters	Limestone	Poorly bedded (horizontal) Light grey color Scarce fossils Oncoids and Dasicladaceans
	ESIB2		up to 50 meters	Limestone	Poorly bedded (inclined about 20°) Grey to brownish color Scarce fossils Margin-builder Little cemented cavities
	ESIB1		up to 35 meters	Marly limestone	Poorly bedded (horizontal) Dark grey to grey color Abundant skeletal grains (echinoderms in particular) Oncoids and coated bioclasts
	ESIB0		up to a few meters	Marly limestone	Bedded (horizontal) Black or dark grey color Local bioclastic lags (broken shells and gastropods)
PREZZO LIMESTONE	PRZ		up to 18 meters	Marly limestone and marl	Bedded (horizontal) Black or dark grey color Scarce fossils (mainly Ammonoids and brachiopods) Local bioclastic lags (broken shells and gastropods)
BANCO A BRACHIOPODI	BB2		up to 11 meters	Marly limestone	Poorly bedded (horizontal) Sediments bioturbation and brecciation Black or dark grey color Abundant skeletal grains
	BB1		up to 9 meters	Marly limestone	Poorly bedded (horizontal) Sediments bioturbation and brecciation Black or dark grey color Scarce fossils (mainly ostracods and forams)
CAMORELLI LIMESTONE	CMR		tens of meters	Dolostone	Bedded (horizontal) Light grey color Stromatolites, fenestrae Scarce fossils (mainly ostracods and forams)

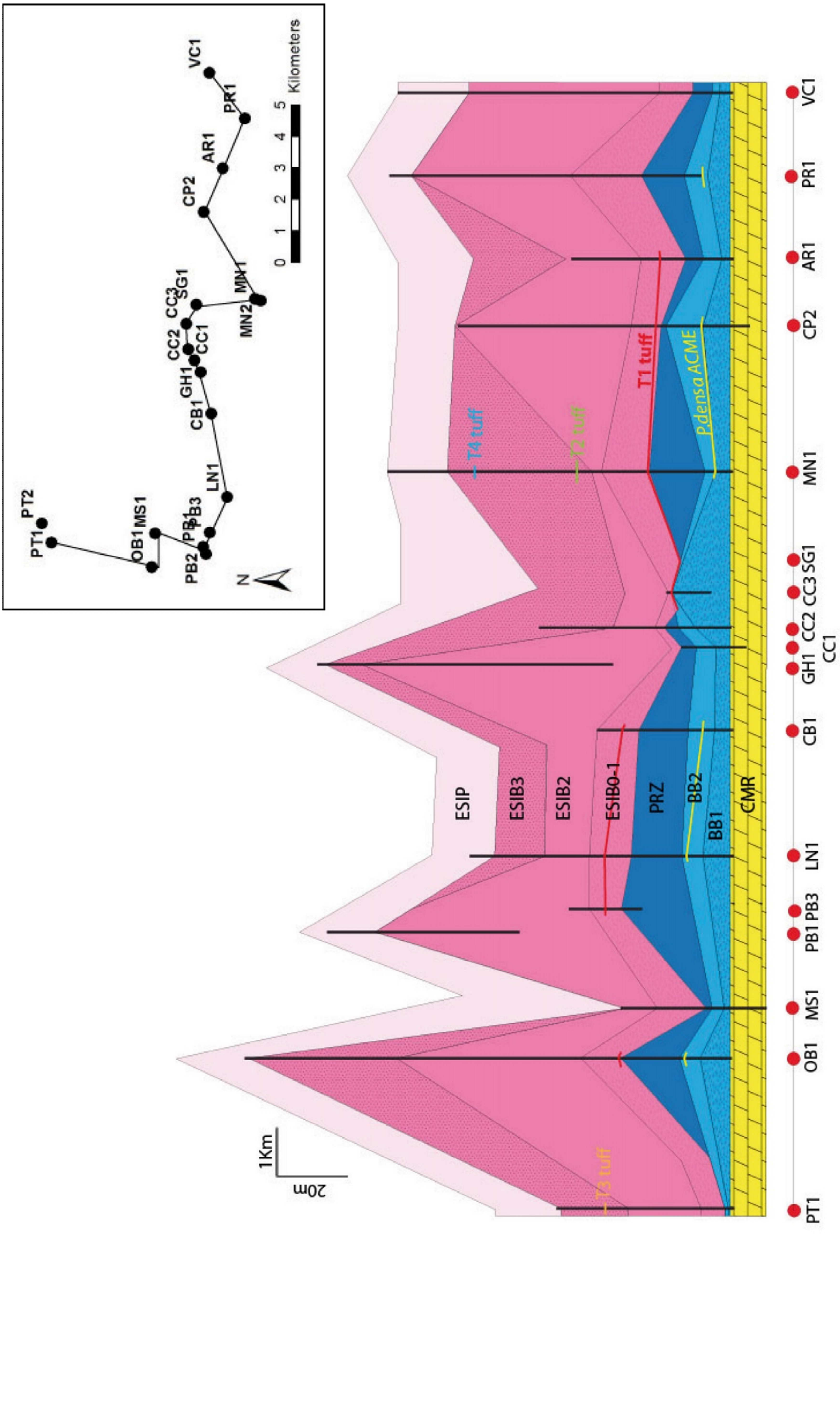
Fig.16 – The table presents the unit and subunit subdivision of the studied interval and their key features.

The stratigraphic sections, despite are distributed in an area that is intensely interested by alpine tectonics, mostly belong to the same thrust sheet (Menna-Nossana tectonic unit of ZANCHI ET AL. 2012). This implies that the stratigraphic sections can be correlated and the present-day distances among them can be grossly considered as original distances. The Arera Massif stratigraphic section (AR1 in fig. 14) instead belongs to an overlying tectonic unit, thus in our reconstruction an original northernmost position has to be considered.

The correlation of the stratigraphic sections was performed using the units and sub-units subdivision described in fig. 16 and later in this chapter, which reflect homogeneous subenvironments/environmental conditions. The result is a cross section (Correlation scheme 1) of the area showing the distribution in space and time of the deposits of the different subenvironments. The reconstruction of the evolution of the area, after the Anisian platform drowning, is constrained by a few time lines, consisting of volcanic events and biostratigraphic events, which are later discussed in the text (chapter 5.3).

Correlation Scheme 1 – Raw Data

Correlation Scheme 1 (in the next page): The figure shows the raw correlation of the stratigraphic sections (labels on the bottom; detailed stratigraphic sections are illustrated in the Appendix) according to the formations/units subdivision presented in chapter 5.1; See fig.16 for quick reference of the formations/units. CMR: Camorelli Limestone; BB1: Banco a Brachiopodi – Lithofacies 1; BB2: Banco a Brachiopodi – Lithofacies 2; PRZ: Prezzo Limestone; ESIB0-1 to ESIB3: subunits of the Basal Esino Limestone (the subunits ESIB0 and ESIB1 are represented together cause of the thinness of the ESIB0); ESIP: Peritidal Esino Limestone. Time lines are represented by 1) the top of the Camorelli Limestone, 2) the Pilammina densa Acme interval (yellow line), 3) the T1 tuff layer (red line). The vertical black lines represent the extension of the stratigraphic sections. Note that, despite the stratigraphic sections share a similar vertical evolution through the different formations/units, considerable thickness differences exist across the study area.



PT1
PT2
MS1
OB1
PB1
PB3
PB2
LN1
CB1
GH1
CC1
CC2
CC3
SG1
MN1
MN2
CP2
AR1
PR1
VC1
N
0 1 2 3 4 5
Kilometers
ESIP
ESIB3
ESIB2
ESIB0-1
PRZ
BB2
BB1
CMR
T1 tuff
T2 tuff
T3 tuff
T4 tuff
P.densa ACME
1Km
20m

5.1 - The Succession

This chapter describes the units and subunits that compose the stratigraphic succession.

5.1.1 - Camorelli Limestone (Anisian Carbonate platform)

In this study only the topmost part of the formation was described.

Previous studies

In the area JADOUL ET AL. (2012) describe the upper part of the formation ("Dolomie Peritidali" of JADOUL AND ROSSI, 1982 and JADOUL ET AL. 1992) as a planar-bedded (beds are pluricentimeter to meter-thick) succession of cyclic subtidal-peritidal limestone and dolostone characterized by dasycladaceans, stromatolitic laminae and loferitic breccias. Early dolomitization occurs in the inter-supratidal intervals and is pervasive close to the top of the formation.

The fossil content, according to JADOUL ET AL. (2012), includes dasycladaceans and benthic foraminifers (*Meandrospira dinarica*, *Trochammina almtalensis*, *Nodosaria sp.*, *Endotriadella sp.*, *Diplotremina astrofimbriata*, *Duostomina sp.*). The Camorelli Limestone in the study area is middle-upper Anisian (Bithynian-Pelsonian; BERRA ET AL. 2005).

Characteristics

In the study area the uppermost Camorelli Limestone is a succession of amalgamated or poorly bedded (10 cm to 1.5 meters thick) light grey or grey dolostone, white-yellowish on weathered surface (fig.15). Horizontal planar bedding is highlighted by stromatolitic laminations (fig.17, B; fig.18, A and B) or by distinct calcarenite or doloarenite layers (fig.17, A).

Calcarenite and doloarenite are fine to coarse grained and at the microscope the microfacies encompass:

- Ooid Packstone and Grainstone (fig.19, C). Skeletal grains and fossils are almost absent. Normal and inverse grading are common, visible at the macroscopic as well as at the microscopic scale. Oncoids are rare. Fenestral fabric is common.
- Peloid Packstone and Wackestone (fig.19, D). Skeletal grains are rare and include crinoid ossicles, bivalves and dasycladaceans. Fossils are rare as well and include ostracods, benthic foraminifers and gastropods. Fenestral fabric is common (fig.18, D).

Stromatolitic dolostone are:

- Laminated Microbial Boundstone. Thin irregular laminations and, sometimes, laminoid fenestral fabric are visible at the macro scale (fig.18, B). Microbial filaments are locally recognized at the microscope. Pervasive dolomitization is common.

Loferitic breccias (fig.18, A) typically characterize both microbial and granular deposits of this upper part of formation. In the Valcanale stratigraphic section (VC1) a thin body (about 2 meters thick) of brecciated peritidal limestones in a dark dolomitized muddy matrix (fig.17, C; fig.18, C) characterizes the boundary with the overlying Banco a Brachiopodi, that is here and everywhere marked by the sudden and paraconformable deposition of dark sediments.

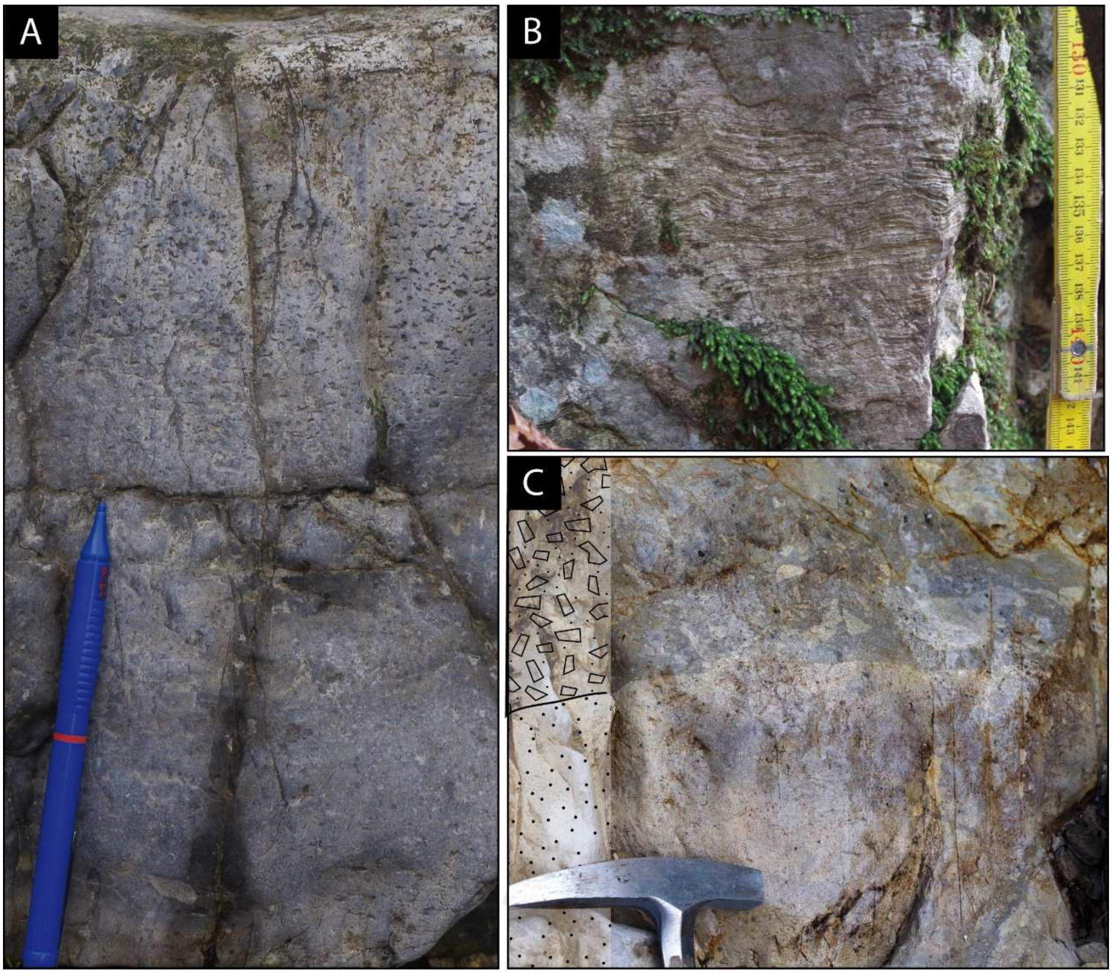


Fig.17 – Camorelli Limestone in the outcrop. A) Fine-grained doloarenite beds. The lower bed shows faint horizontal current lamination. The upper bed is punctuated by fenestral cavities that increase in density upwards. Olmo al Brembo stratigraphic section (OB1). B) Stromatolitic dolostone at Corna delle Coste stratigraphic section (CC1). Microbial laminae, highlighted by the alteration of the surface, are flat or wavy. C) A breccia deposit overlying, with slight erosional boundary, mid-grained doloarenite with fenestrae. Breccia clasts (peritidal doloarenite) float into a dark fine-grained dolostone matrix. Valcanale stratigraphic section (VC1). This is interpreted as a storm deposit (see also Fig.18-C).

Fig.18 –Cut samples from the Camorelli Limestone. A) Laminated microbial boundstone. Microbial laminae are thin and planar. In the upper part the boundstone is broken in a loferitic breccia. Sample TX111f. Lenna stratigraphic section (LN1). B) Laminated microbial boundstone with laminoid fenestral fabric. Crinkled microbial laminae. Sample TX445. Monte del Sole stratigraphic section (MS1) (See microfacies in Fig.19, A and B). C) Dolostone breccia. Breccia clasts (ooilitic doloarenite [ooid packstone]) are floating in a dark fine-grained dolostone matrix with crinoid ossicles (dark small grains). Sample TX105. Val Canale stratigraphic section (VC1). D) Two fine-grained calcarenite layers (peloid packstone) with fenestral fabric. The light grey horizontal boundary in the middle of the sample is a subaerial exposure surface. The lower layer has dense and large fenestrae. This layer is covered, with unconform boundary, by a layer with small fenestrae and faint laminations. (see microfacies in Fig.19, D). Sample TX400b. Canale delle Betulle stratigraphic section (CB1). The pink rectangle is 29 x 48 mm.

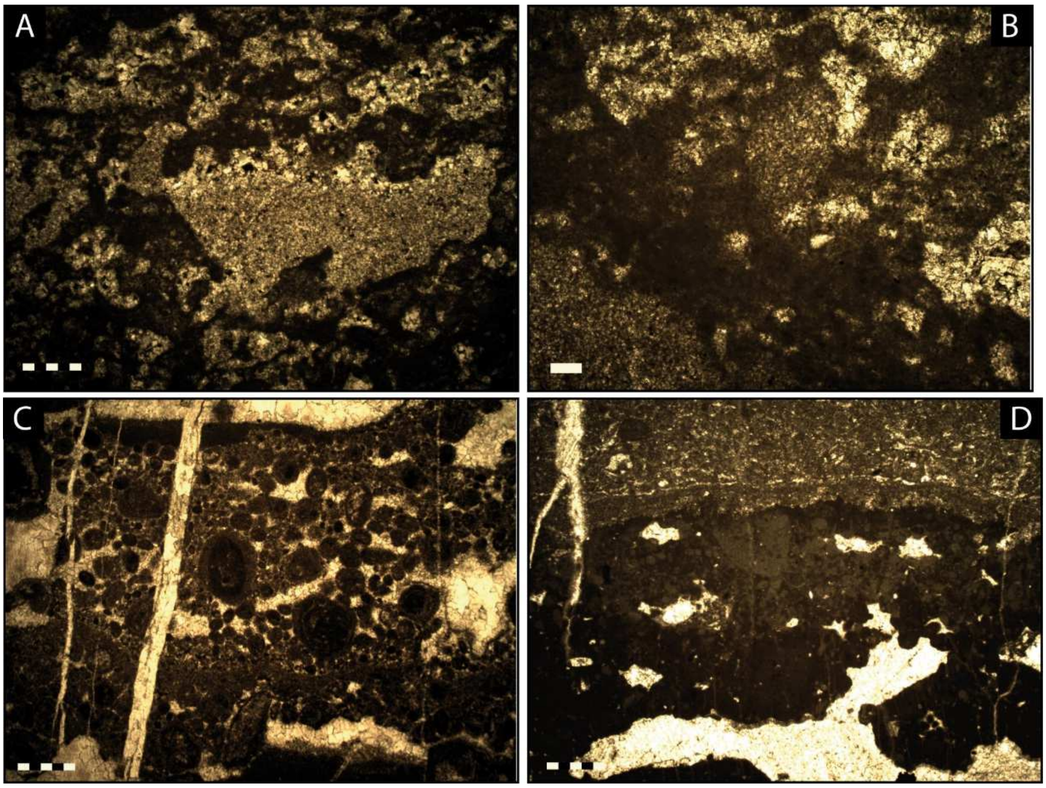


Fig.19 – Microfacies of the uppermost Camorelli Limestone. A) Microbial boundstone. The structure is built by dark irregular to globular micritic masses. In the middle of the photo is present a big fenestral cavity with recrystallized geopetal infilling. Cross polarized light. Sample TX445 (Fig.18, B). Monte del Sole stratigraphic section (MS1). Scale bar is 500 µm. B) Close up of the microbial boundstone reveals clots and dark little peloids with indistinct margin (clotted peloidal micrite). Sample TX445 (Fig.18, B). Monte del Sole stratigraphic section (MS1). Scale bar is 100 µm. C) In the lowermost part is ooid packstone. In the central part is ooid grainstone. Ooids are dark (micritized) and variable in size but have a general good selection. Bigger ooids have thin cortexes (surficial ooids). A big fenestral cavity with geopetal infilling is visible in the lower part. Vertical calcite-cemented fractures are late diagenetic. Sample TX510. Olmo al Brembo stratigraphic section (OB1). Scale bar is 500 µm. D) Detail of the exposure surface showed in fig.18, D. The underlying peloid packstone with fenestral fabric is overlaid by a finer-grained peloid packstone. The boundary between the two packstone layers is characterized by a thin alteration band in the topmost part of the lower layer, that highlight the grainy texture. Sample TX400b. Canale delle Betulle stratigraphic section (CB1). Scale bar is 500 µm.

Environmental interpretation

The sediments refer to peritidal environment, with subtidal to supratidal deposition. The recurrent fenestral fabric and loferitic breccias indicate frequent subaerial exposures (GERDES AND KRUMBEIN, 1994), that are also probably responsible for the reported very scarce fauna.

The macroscopic and microscopic features indicate both low and high energy conditions:

- Laminated microbial boundstone and peloid wackestone and packstone can be ascribed to a quiet algal flat, distant from the platform margin (breakers zone). The water was very shallow, environmental energy was low (closed-texture sediments) and subaerial exposure was common.
- Ooid packstone and grainstone could be referred instead to wide tidal channels entering the platform or more likely, as cross cutting relations are never observed in the outcrop, to storm events transferring sediments from the marginal zone of the platform to the interiors.

- One (or more than one) higher energy storm event is probably responsible for the accumulation of the peritidal-dolostone breccia in the Valcanale stratigraphic section (VC1), reflecting a major exposure of this eastern sector to open-sea influence.

We thus consider, in substantial agreement with the previous authors, the topmost Camorelli Limestone deposits as being associated with a very shallow and quiet platform top, dominated by algae and peloids, subject to recurrent subaerial exposure and to high energy deposition for marine incursions from the open sea during storm events.

5.1.2 - Banco a Brachiopodi

The Banco a Brachiopodi is formally included within the Prezzo Limestone formation (JADOUL ET AL. 2012), nonetheless in this work we separately describe it for the different facies and microfacies assemblage as well as different paleoenvironmental interpretation.

Previous studies

The Banco a Brachiopodi (or "Cimego Limestone"; ASSERETO ET AL. 1977), is a thin (up to 15 meters thick) unit that is extensively recognized in Lombardy above the Camorelli Limestone or the Angolo Limestone and is characterized by bedded or nodular calcarenite rich in crinoids, brachiopods (*Tetractinella trigonella*) and foraminifers (*Pilammina densa* and *Paulbronnimannia judicariensis*) (GAETANI ET AL. 1986).

In the study area the unit is described by JADOUL ET AL. (2012) as a 0,5 to 4 meters thick body of dark grey limestone, bioturbated at the base, and bioclastic calcarenite rich in crinoids and locally in brachiopods (*Tetractinella trigonella* SCHLOTHEIM, 1820). The reported microfacies are bioclastic packstone and rudstone with prevailing crinoids, bivalves and brachiopods, peloids, benthic forams (*Pilammina* sp.) and rare dasycladaceans. This body paraconformably lies on the peritidal deposits of the Camorelli Limestone, the surface being locally erosional with thin breccia layers or red clay drapes.

Characteristics

In this work we include in the "Banco a Brachiopodi" term all the deposits that lay between the top of the Camorelli Limestone and the base of the typical Prezzo Limestone (fig.15). This unit is easily distinguished in the field from the underlying and overlying formations for its typical aspect: the lower boundary with the Camorelli Limestone is a sharp paraconformity that separates the dark grey-blackish deposits of the unit from the underlying light-colored limestone. The upper boundary with the Prezzo Limestone, also a paraconformity, separates the non-bedded deposits of the unit from the overlying well bedded limestones. The Banco a Brachiopodi in fact commonly lack distinct bedding and have a bioturbated or brecciated sediment texture (the sediment is broken in pieces that at places show a plastic or fragile behavior), which is also highlighted by light grey or ochre colored patches (fig.19). The thickness of the unit in the study area ranges from 1.8 meters (Piazzatorre stratigraphic section - PT1) to 19.3 meters (Corna Piana stratigraphic section – CP2).

Within the Banco a Brachiopodi two main lithofacies can be distinguished, reflecting different microfacies and also different stratigraphic positions: Lithofacies 1 tipically constitutes the lower part of the unit, while Lithofacies 2 constitute the upper part.

- Lithofacies 1 (fig.19, A and B; fig.20, A; fig.21, A to D): Amalgamated or poorly bedded (centimeters to tens of cm) grey to blackish marly limestone. These are carbonate mudstone or very fine to fine-grained calcarenites. Macrofossils are scarce (rare gastropods and brachiopods). The sediments are commonly bioturbated and/or fragmented into a breccia-like deposit (the matrix is generally dolomitized and clasts subrounded). The microfacies (14 thin sections) include:
    - Carbonate mudstone
    - Peloid packstone with ostracods and foraminifers
    - Packstone with extraclasts (mainly quartz and muscovite grains)
    - Bioturbated peloid packstone and wackestone with ostracods, foraminifers and fenestrae
    - Pseudobreccia-rudstone of peloid packstone and wackestone with ostracods and foraminifers. The matrix is peloid packstone, carbonate mudstone or crystalline dolostone.

  Skeletal grains (ostracods, bivalves, crinoids, gastropods, brachiopods) are rare while fossils (less than 5%) are mainly ostracods and benthic foraminifers (typical are *Endotriadella wirzi* KOEHN-ZANINETTI, 1968 and *Meandrospira dinarica* KOCHANSKI-DEVIDÈ & PANTIC, 1965). Small vegetal fragments are common. Fenestral cavities, evaporite pseudomorphs and possible rizoliths are sometimes present. Detrital quartz and mica grains (silt or very-fine sand size) are commonly present but do not exceed 5%.

  These sediments commonly directly cover the Camorelli Limestone top. Transported cm-size fragments of coral colonies are found only at the Mt. Menna section (MN1) within a brecciated interval (fig.19, B).
- Lithofacies 2 (fig.19, A and C; fig.20, B; fig.21, E to F): Highly bioturbated dark grey marly limestone, massive mottled or with ondulated-nodular bedding (centimeters to tens of cm). These are very fine to mid-grained calcarenite. Burrow tunnels, commonly dolomitized, are highlighted on the rock surface by a typical ochre alteration color. Sometimes brittle deformation of the sediment is visible. Macrofossils include gastropods and brachiopods *(Tetractinella trigonella)*. Vertebrate bones and fish teeth are also locally found. Echinoderm fragments (in particular crinoid ossicles) are locally abundant. Sparse oncoids and coated bioclasts are locally present (Corna Piana stratigraphic section – CP2). Microfacies (14 thin sections) are:
    - Micritized Intraclast Packstone and Grainstone with scarce crinoid ossicles and fragmented shells
    - *Pilammina densa* Packstone with crinoid ossicles and fragmented shells
    - Peloid Packstone with abundant bioclasts.

  Grain sorting can be good and bioclasts and intraclasts commonly show evidence of reworking (micritized and rounded borders, borings). Skeletal grains include crinoid ossicles (generally prevailing, up to 30%), gastropods, sponge spicules, echinid radioles, thin and thick shelled bivalves, brachiopods, vertebrate bones, fish teeth. Small vegetal fragments are common. The benthic foraminifer *Pilammina densa* is generally present and locally can be the main constituent of the sediment (fig. 20). Detrital quartz and mica grains (silt or very-fine sand size) are commonly present but do not exceed 5%. The sediments of this lithofacies fit the typical Banco a Brachiopodi description from the precedent authors (GAETANI ET AL. 1986; JADOUL ET AL. 2012).

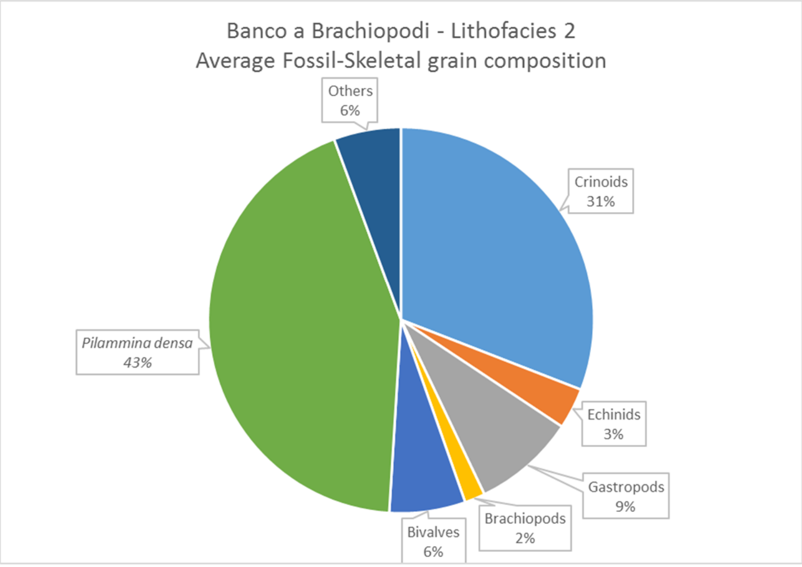


Fig.20 – The pie chart shows the average fossil plus skeletal grain composition of the Banco a Brachiopodi – Lithofacies 2. For this estimation only the observed thin sections were considered. Note that the benthic foraminifer Pilammina densa is generally abundant, followed by crinoid ossicles and gastropods.

Marl, calcareous siltstone or sandstone beds (fig.21, D) are sometimes found isolated, intercalated within this unit (e.g. Olmo al Brembo and Mt. Menna stratigraphic sections). Their thickness does not exceed 35 cm. The color is grey with a brownish alteration color. These sediments are commonly rich in quartz and muscovite and devoid of macrofossils. Current planar laminations are sometimes visible.

One thin section (Sample TX512, Olmo al Brembo stratigraphic section – OB1) from one of these beds (marl) confirms the presence of quartz and mica grains, estimated in 30% of the total volume. Other minerals are not found. Skeletal grains are scarce and mainly include shell fragments. Ostracods and foraminifers are scarce as well.

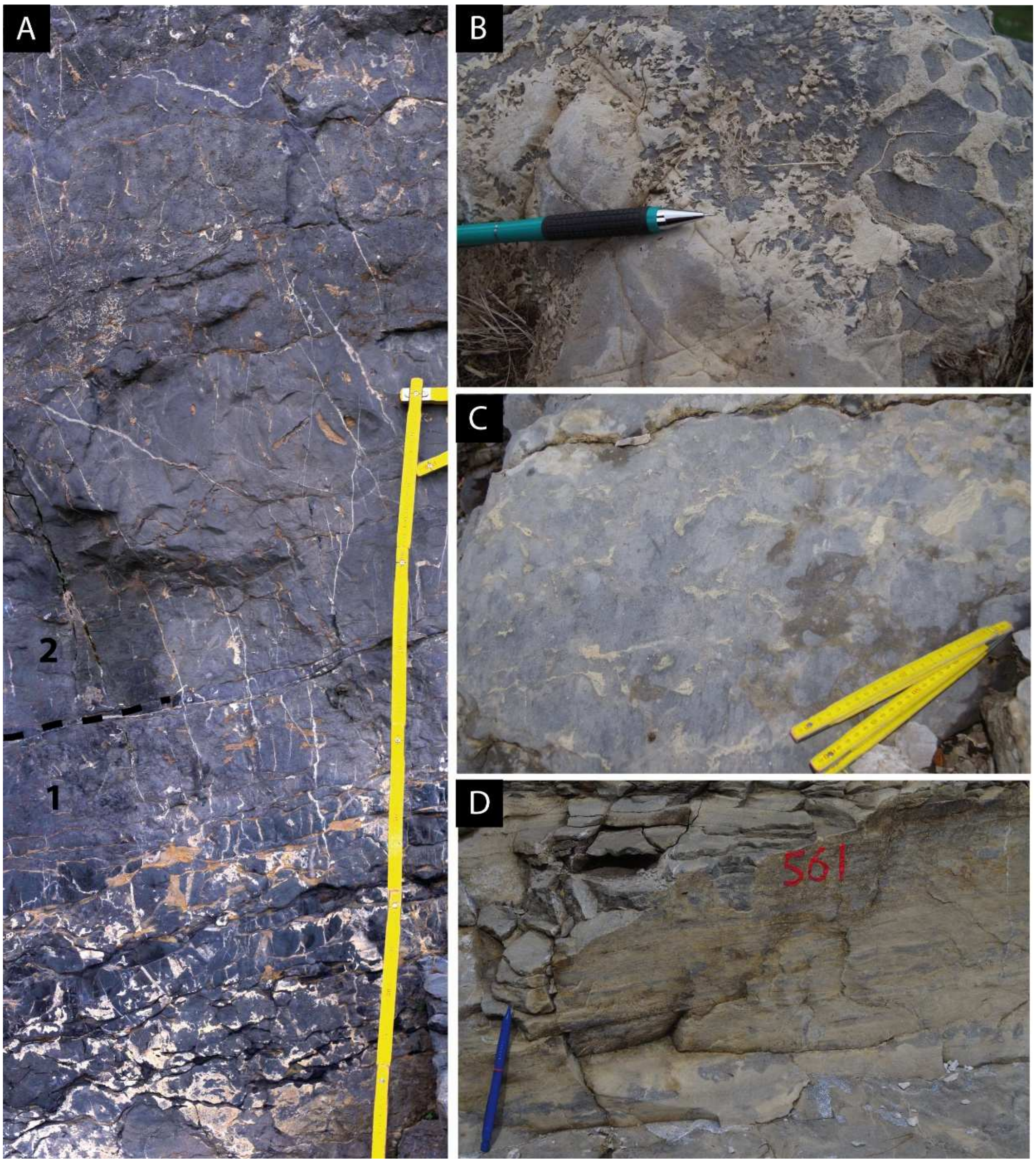


Fig.21 – Banco a Brachiopodi in the outcrop. A) The photo shows a detail of the succession in fig.15 (MN1). In the lower part the brecciated grey limestone (very fine-grained calcarenites) of the lithofacies 1. The structure is highlighted by ochre alteration color of the dolomitized matrix of the breccia. Above this is the massive amalgamated and bioturbated limestone (fine to mid-grained calcarenites rich in crinoid ossicles) of lithofacies 2. Dolomitized burrows are evident for their ochre alteration color. Mt. Menna stratigraphic section (MN1). The yellow stick is 90 cm tall. B) Brecciated limestone (lithofacies 1) at Mt. Menna stratigraphic section (MN1) showing allochthonous coral colonies. C) Highly bioturbated limestone (lithofacies 2). Darker little grains are crinoid ossicles. Partial dolomitization is highlighted by the typical ochre alteration color. Mount Arera stratigraphic section (AR1). D) A fine-grained sandstone bed intercalated within the Banco a Brachiopodi. Horizontal laminations are visible. Mt. Menna stratigraphic section (MN1).

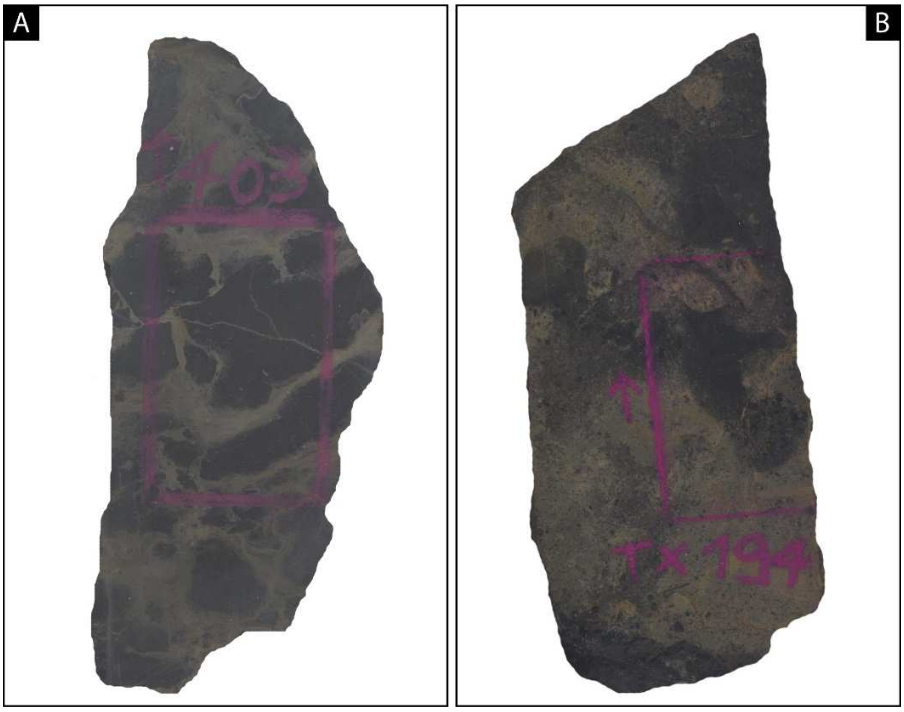


Fig.22 - Cut samples from the Banco a Brachiopodi A) Lithofacies 1: sample TX403. The clasts of the dark grey brecciated limestone (fine-grained calcarenite) are within a grey dolostone matrix. Canale delle Betulle stratigraphic section (CB1). Microfacies detail in fig.23, C. B) Lithofacies 2: Sample TX194. Highly bioturbated fine-grained calcarenite with crinoid ossicles. Partial dolomitization (altered in light brown color) highlights bioturbation. Mt. Menna stratigraphic section (MN1). Pink rectangle is 29 x 48 mm.

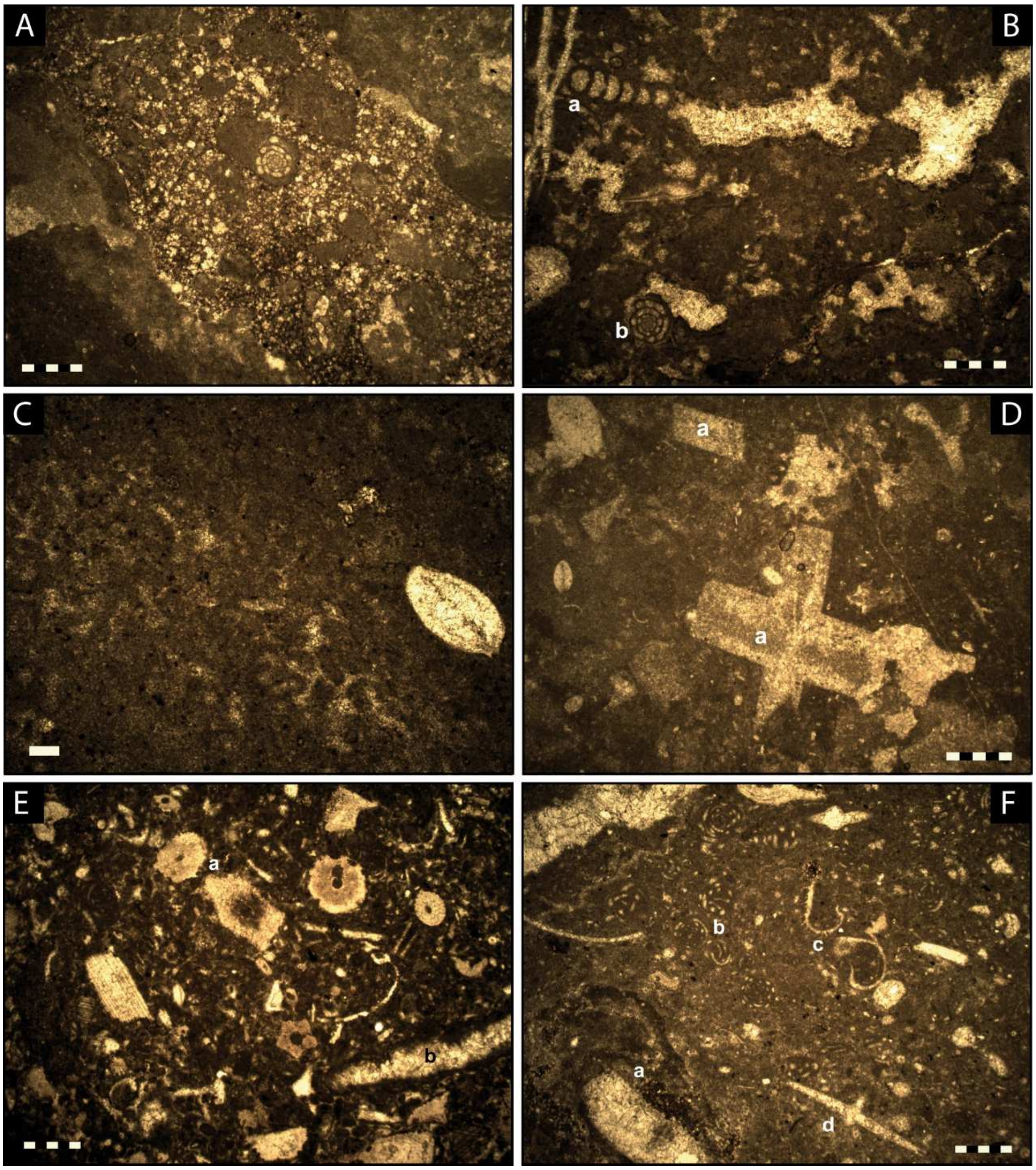


Fig.23 – Microfacies of the Banco a Brachiopodi – A-D: Lithofacies 1; E-F: Lithofacies 2. A) Pseudobreccia of peloid packstone in crystalline dolostone matrix. At the center of the photo is visible the benthic foraminifer Meandrospira dinarica. Sample TX506. Corna delle Coste stratigraphic section (CC2). Scale bar is 500 µm. B) Peloid packstone with calcite-cemented fenestral cavities and benthic foraminifers (a: Endotriadella wirzi; b: Meandrospira dinarica). Sample TX402. Canale delle Betulle stratigraphic section (CB1). Scale bar is 500 µm. C) Close up of peloid packstone of fig.22, A. Oval peloids are visible in the zones where calcite cement fills the intergranular porosity. An ostracod with calcite-cemented internal cavity is present on the right. Sample TX403. Canale delle Betulle stratigraphic section (CB1). Scale bar is 100 µm. D) Peloid packstone with ostracods and evaporite pseudomorphs (a: possible dolomite crystals). Sample TX506. Corna delle Coste stratigraphic section (CC2). Scale bar is 500 µm. E) Peloid packstone with abundant echinoderm fragments (a; mostly rounded and star-shaped crinoid ossicles), often showing abrasion traces. Also thin shell fragments are present. A thick mollusk shell fragment (b) is interested by micritization at the border. Peloids are visible and constitute the main part of the sediment. Sample TX310. Corna delle Coste stratigraphic section (CC1). Scale bar is 500 µm. F) Peloid packstone with abundant foraminifers and sparse bioclasts. One oncoid (a) is present, with a bioclast as nucleus and a dark micritic and asymmetric coating. The benthic foraminifer Pilammina densa (b) is

abundant. Two gastropods are recognizable and display a darker sediment filling the internal cavity, probably evidence of redeposition. Sponge spicules are also present (d). Sample TX111b. Lenna stratigraphic section (LN1). Scale bar is 500 µm.

Environmental interpretation

Lithofacies 1: The dark color and the fine-grained texture of the deposits indicate low energy and scarce oxygenation, that is also reflected by the scarce fossil content. The local presence of fenestrae, possible rizoliths and evaporite pseudomorphs indicate occasional subaerial exposure and sometimes restricted highly saline conditions. This evidence constrains the deposition of this lithofacies to a very shallow environment: being the first deposits above the Camorelli Limestone, we argue that early marine transgression turned the platform top into a very shallow and quiet lagoonal area. Restricted conditions were probably induced locally by weakly irregular bottom morphology coupled with eustatic variations. Sediment brecciation instead is a probable consequence of storm waves entering the lagoonal area and disturbing the partially consolidated bottom sediments. The finding of transported corals within a brecciated interval in the Mt. Menna stratigraphic section (MN1) supports this interpretation.

Lithofacies 2: The high bioturbation and the abundant skeletal content, often showing evidence of reworking (mechanical abrasion, micritization, borings), point to a deeper and agitated environment. Nonetheless the sediment is dark and rich in mud. Sparse almost undeformed vertebrate bones recovered from this lithology as well as the occasional brecciation indicate early cementation. Comparable sediments are the middle Triassic "vermicular limestones" of the Tatra Mountains (Poland) of JAGLARZ AND UCHMAN (2010), who interpreted them as deposited below fair-weather wave-base in hypersaline waters on the restricted part of a carbonate ramp. Also PEREZ-LOPEZ AND PEREZ-VALERA (2012) faced with similar amalgamated and bioturbated Triassic sediments in the Betic Cordillera (Spain) and interpreted them as storm-winnowed deposits below fair-weather wave-base in a low energy lagoon or restricted sea. In a similar way we interpret these sediments as subtidal (between fair-weather and storm wave-base) sand shoal deposits accumulated by storm events in an open low energy lagoonal area with highly saline water.

5.1.3 - Prezzo Limestone

Previous studies

In the study area JADOUL ET AL. (2012) reported the discontinue presence of the formation, with a maximum thickness of 26 m. The formation is a rhythmical succession of black marly micritic limestone beds (thickness is in the order of decimeters) with subordinated micaceous marl interbeds. The formation gradually but rapidly passes upwards to the Esino Limestone or to a facies that is transitional between the Esino Limestone and the basinal Buchenstein Formation. Near the transition to the Esino Limestone intra-bioclastic packstone with rare dasycladaceans and reworked ooids are described. In the upper part of the formation also bio-intraclastic packstones and tuff intercalations are reported (JADOUL ET AL. 2012). Within the study area BALINI (1992) studied the ammonoid fauna along one stratigraphic section at Mt. Menna, reporting a 24 meter thick succession of alternated grey-blackish limestone (7-18 cm thick beds) and grey marl or black shales (20-30 cm thick beds) often with wavy bedding surfaces. BALINI AND RENESTO (2012) then, dealing with the dating of some vertebrate remains, described another stratigraphic section northwest of Piazza Brembana town, reporting a 17 meters succession of alternated limestone and marl/shale beds with a bed thickness of 10-15 cm.

Characteristics

In the study area the formation is a succession of dark grey-blackish limestone or marly limestone beds (commonly between 5 and 20 cm thick, sometimes consisting of aligned nodules) with black marl interbeds (commonly about 10 cm thick) (fig.24, A). Bedding surfaces are commonly wavy-nodular (fig.24, B). The limestone has mud to very fine sand grain-size, with sparse macrofossils including cephalopods (mostly ammonoids [fig.24, C]; orthocones are rare) and brachiopods and sometimes with small mud clasts. 15 thin sections from the limestone beds of the Prezzo Limestone have been described and the microfacies (fig.25, A) are dominated by:

- Peloid Carbonate Mudstone or Peloid Packstone with scarce pelagic fauna
- Bioclast Wackestone with pelagic fauna.

At the microscope small benthic foraminifers (*Ophthalmidium* is typical) and ostracods are also observed. Skeletal grains are sparse, generally less than 10% and include brachiopods, thin-shelled bivalves, ammonoids, ostracods, crinoids, bones, vegetal frustules. Tiny quartz and mica grains are also commonly present but together they don't exceed 3% (estimated).

Locally the unit has local concentrations of brachiopods and more frequently it has cm-scale layers that are enriched in gastropods and thin-shell fragments (pelagic bivalves). At the microscope (fig.25, B) the microfacies are:

- Bioclast Packstone and Wackestone with abundant thin-shelled bivalve and gastropod fragments.

Skeletal grains can be very abundant within this microfacies and locally reach 50% of the volume, with thin-shelled bivalves and gastropods being strikingly dominant. Within these layers gastropod shells are locally filled with a darker mudstone than the surrounding matrix. Rarer skeletal grains (less than 5%) include crinoid ossicles, brachiopods, echinids, thick-shelled bivalves, ammonoids, vegetal frustules, vertebrate bones and fish teeth.

Grading and laminations are rarely visible in the Prezzo Limestone deposits while bioturbation traces (curved cylindrical tunnels) are more commonly observed. The formation in the studied sections reaches the maximum thickness of 18 meters in the Olmo al Brembo stratigraphic section (OB1) while the minimum thickness occurs in the Corna Piana stratigraphic section (CP2) where it is about 2 meters. In the Piazzatorre stratigraphic section (PT1) the typical Prezzo Limestone is lacking and only an about 2 meters thick succession of bedded limestone is present. The well-bedded Prezzo Limestone conformably rests on the bioturbated-amalgamated deposits of the Banco a Brachiopodi and is overlaid by the massive-amalgamated deposits of the Esino Limestone. The transition to the Esino Limestone is rapid and is marked by the passage to bedded dark grey or blackish marly limestone with reduced (less than 1 cm) or absent marl interbeds (fig.24, A). These limestones in a few meters rapidly loose bedding upwards.

Fig.24 – The Prezzo Limestone in the outcrop. A) The typical Prezzo Limestone (PRZ) is a succession of dark grey limestone beds with blackish marl intercalations. The formation is overlaid by horizontally bedded dark limestone without significant marl intercalations (ESI). The yellow stick is 1 meter tall. Arera Mount stratigraphic section (AR1). B) Limestone beds (layers with light grey alteration color) and marl interbeds (the dark layers). The lower and thick limestone bed show bioturbation traces. Note the bedding planes are nodular. Olmo al Brembo stratigraphic section (OB1). C) A sectioned ammonoid of the surface of a limestone bed in the Brembo riverbed (Olmo al Brembo stratigraphic section - OB1).

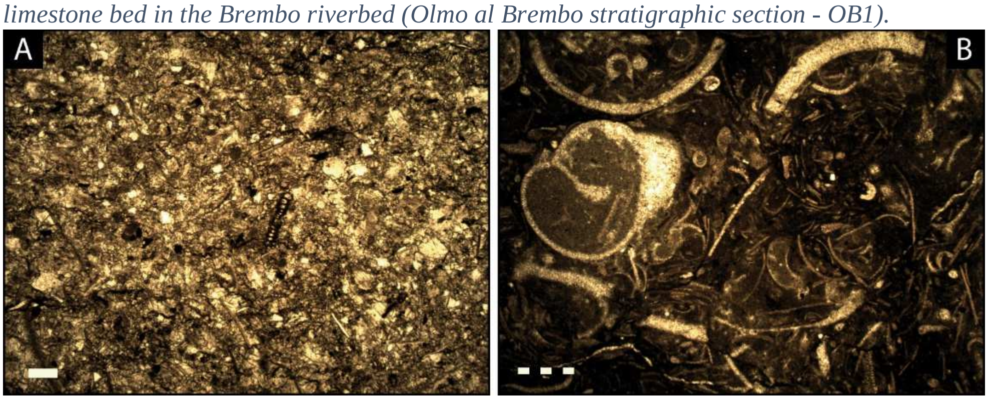


Fig.25 – Microfacies of the Prezzo Limestone. A) Carbonate mudstone. The sediment is interested by recrystallization (microsparite) and in origin was probably composed of small peloids. At the center of the photo is one benthic foraminifer (Ophthalmidium ubeyliense) Sample TX104. Valcanale stratigraphic section (VC1). Scale bar is 100 µm. B) Bioclast packstone. Skeletal grains are mainly mollusk broken shells (bivalves, gastropods). Entire gastropod shells are probably also present. The matrix is micrite. Sample TX115. Lenna stratigraphic section (LN1). Scale bar is 500 µm.

Environmental interpretation

The general fine-grained texture and the dark color point to a low energy, poorly oxygenated environment. Casati and Gnaccolini (1967) noted contrasting evidence: the high organic matter content would indicate rapid burial of sediments deposited in restricted environment, nonetheless the abundance of ammonoids and benthic fauna are indicative of open marine (pelagic) conditions. The benthic foraminifer *Ophthalmidium* instead, frequently found within this formation, has been linked by Maurer and Rettori (2002) to shallow water environments (backreef or lagoon). Considering the extensive bioturbation, we agree with Balini (1992) that the environment could not be anaerobic but it was at least dysaerobic at the sediment-water interface. At last, the observed bioclast accumulations match with the tempestite description of Perez-Lopez and Perez-Valera (2012), placing the environment in the depth range of storm waves. On the base of these considerations we propose for the formation a subtidal open shelf environment, below fair-weather wave-base and subject to storm deposition.

Esino Limestone

In the study area the Esino Limestone extensively crops out with thickness of a few hundreds of meters. The “inception stage” (basal part) of this formation, target of the study, can be easily distinguished in the field from the overlying mature platform deposits on the base of bedding characteristics (fig.26): this basal part, corresponding to the “lithozone 1” of Jadoul et al. 1992, is mostly poorly bedded (“Basal Esino Limestone”). The overlying deposits (“Peritidal Esino Limestone”) are instead horizontally bedded limestone, corresponding to “lithozone 2” of Jadoul et al. 1992.

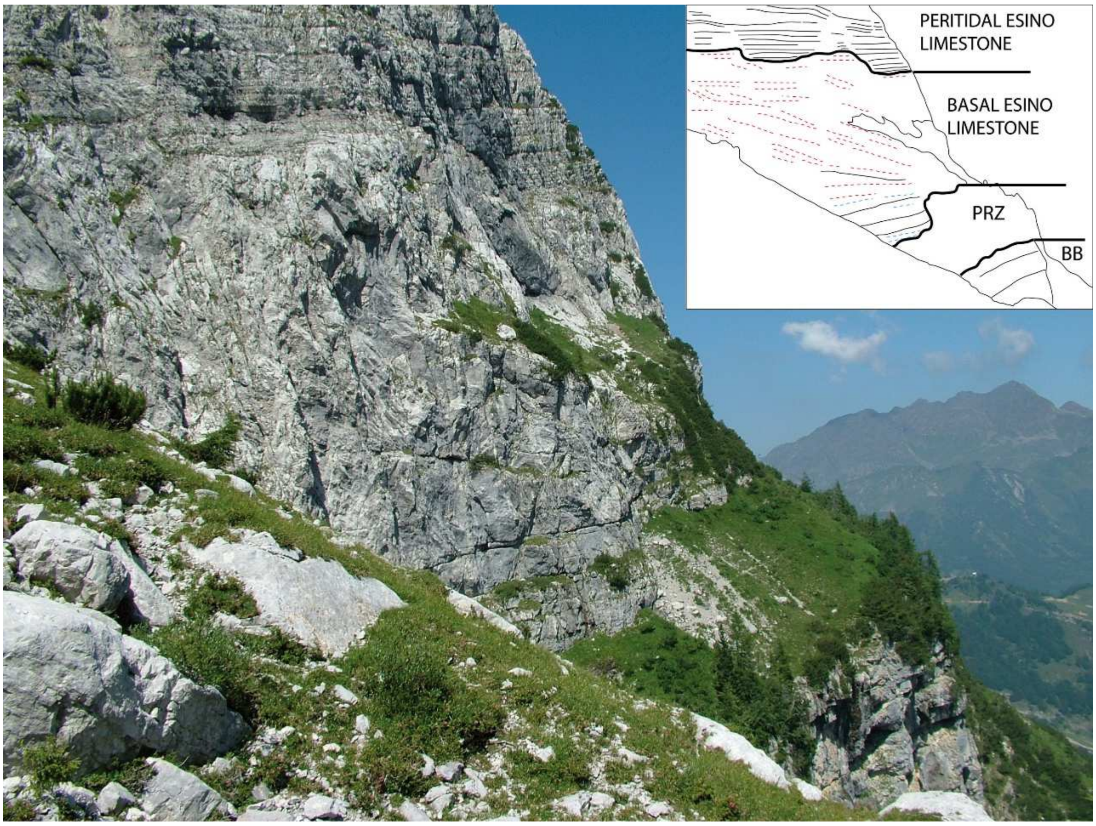


Fig.26 - Panoramic view of the Esino Limestone at Passo del Re stratigraphic section (PR1). The sketch in the upper right angle highlights the different formations and the interpreted depositional surfaces (dotted lines). From the base is visible

the Banco a Brachiopodi (BB), the poorly outcropping Prezzo Limestone (PRZ) and the Esino Limestone, that is subdivided in a lower massive-amalgamated part (Basal Esino Limestone) and an upper horizontally bedded part (Peritidal Esino Limestone). Within the Basal Esino Limestone faint depositional surfaces are visible, being horizontal in the lower part (blue dotted lines in the sketch) and prevailing inclined (20-30°) in the middle-upper part (red dotted lines in the sketch). The presence of horizontal depositional surfaces in the upper part would indicate more phases of platform progradation in response to relative sea-level variations.

5.1.4 - Basal Esino Limestone

Previous studies

JADOUL ET AL. (1992) recognized in the basal 10 to 85 meters of the Esino Limestone the moment of carbonate platform nucleation. Within this part the authors identified two different lithofacies, one characterized by light to dark grey massive, bioclastic and intraclastic calcarenite (lithofacies association 1a), the other characterized by bioclastic, fossil-rich limestone with brachiopods, gastropods, pelecypods, ammonoids and crinoids (lithofacies association 1b). This last lithofacies, more than 10 m thick, corresponds to the "Lumachella di Ghegna" of TOMMASI (1911, 1913) and is stratigraphically placed at least 60 meters above the boundary with the Prezzo Limestone. The "Lumachella di Ghegna" according to BERRA ET AL. (2011) would document the first reef association of the Esino Limestone. BRACK & RIEBER (1986) reported the presence in the Ghegna fauna of the ammonoid *Chieseiceras chiesense*, a marker for the "Chiesense horizon" which is located between the Nevadites and Curionii Zones, thus referring these sediments to the Anisian-Ladinian boundary. The base of the Esino Limestone would thus fall, according to Triassic time scale of BRACK ET AL. 2005, into the late Anisian.

Characteristics

In the study area we found the Basal Esino Limestone ranging from a minimum thickness of 23 meters in the Monte del Sole section (MS1) to a maximum of 105 meters in the Olmo al Brembo section (OB1). This unit conformably rests on the Prezzo Limestone by means of an about 2 meters thick interval of horizontally bedded dark grey-black limestone with very thin marl intercalations (ESIB0; fig.32, A). This thin transitional unit has microfacies (10 thin sections) that are equivalent to the bioclast-rich microfacies of the Prezzo Limestone and are mostly composed by:

- Bioclast packstone and wackestone with abundant thin-shelled bivalve and gastropod fragments

Skeletal grains are abundant and locally reach 50% of the volume, with thin-shelled bivalves and gastropods being strikingly dominant. Gastropod shells are locally filled with a darker mudstone than the surrounding matrix. Rarer skeletal grains (less than 5%) include crinoid ossicles, brachiopods, echinids, thick-shelled bivalves, sponge spicules, calcispheres, ammonoids, vegetal frustules, vertebrate bones. Thick-shelled bivalves, gastropods and brachiopods can have borings or micritized borders. With respect to the Prezzo Limestone these sediments have more intense bioturbation. Peloids are common. Silicization occurs locally in patches or substituting the carbonate shell of some bioclasts (usually brachiopods, gastropods).

Above these thin basal and transitional deposits the formation rapidly evolves to a massive-amalgamated limestone unit whose depositional surfaces are only weakly recognized in panoramic view, being horizontal in the lowermost part (10-30 m), mostly inclined (about 20°-30°) in the overlying mid-upper part (fig.26, 31 and fig.32, B) and again horizontal in the uppermost part. Despite precise boundaries are not easily traceable we propose the distinction within the Basal Esino Limestone of 3 parts, that are also characterized by different microfacies:

- ESIB1 [fig.32, C and fig.33, A]: The lower part, horizontally bedded or amalgamated with faint horizontal bedding, is commonly dark grey in color. It consists of very fine to mid-grained intra-bioclastic calcarenites, generally rich in echinoderm fragments (crinoids are dominant; fig. 27 and 28) and containing sparse little oncoids (fig. 29). In some intervals (e.g Corna Piana stratigraphic section – CP1) the sediment resembles lithofacies 2 of the Banco a Brachiopodi unit, with dolomitized burrow traces. The different stratigraphic position (above the Prezzo Limestone) or the microfacies characteristics (*P.densa* is absent) allow the distinction of the two units. The microfacies from the ESIB1 (fig.34, A-D) in fact include:
    - Peloid Packstone with bioclasts and coated grains (microfacies group 1)
    - Oncoidal Floatstone and Peloid Packstone with coated grains and detrital problematica (microfacies group 2).

  The microfacies are always characterized by the presence of coated grains: oncoids and/or cortoids. Oncoids are typically dark with irregular coatings, that can be dense micritic or porous peloidal. They are up to a few centimeters in diameter (but generally less than 1 cm) and are commonly floating within finer-grained sediment. Cortoids have single dark micritic constructive coatings. Coated grains commonly have crinoid ossicles, echinoid spines, mollusk or brachiopod fragments at their nuclei. Skeletal grains are commonly micritized at the border when they are not coated. Skeletal grains can be abundant and are generally dominated by crinoid ossicles, echinoid spines, bivalves, gastropods. Minor findings include ostracods, ammonoids, brachiopods and sponge spicules. Partial dolomitization commonly occurs. Silicization occurs locally in patches or substituting the carbonate shell of some bioclasts (usually brachiopods, gastropods). Ornamentation (spikes) commonly occur on the shells of some brachiopods, gastropods, bivalves and echinoids. Calcispheres commonly occur and were probably radiolarians in origin.

  The presence of sparse reworked *Baccanella floriformis* PANTIC and/or rare fragments of calcareous sponges (*Olangocoelia otti* BECHSTÄDT AND BRANDNER, *Plexoramea cerebriformis* MELLO, 1977), corals and *Tubiphytes* characterizes the microfacies group 2.

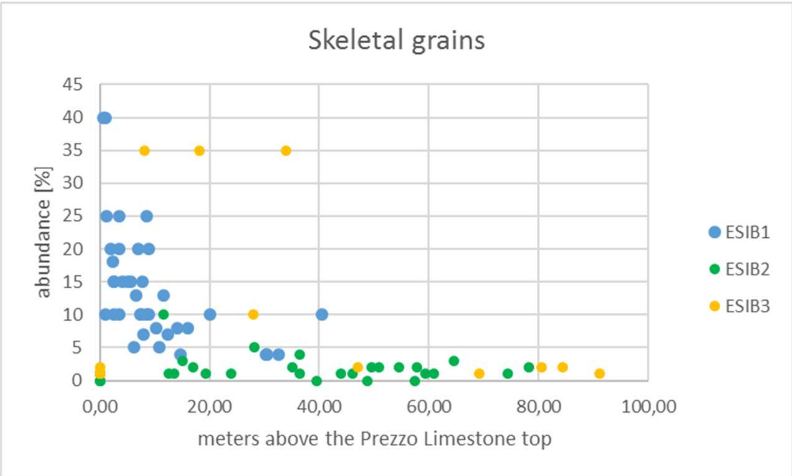


Fig.27 – Skeletal grain abundance in the Basal Esino Limestone. The information from all the observed thin sections is plotted on the graph. Note the highest abundance in the unit ESIB1 and the scarce abundance in the other units.

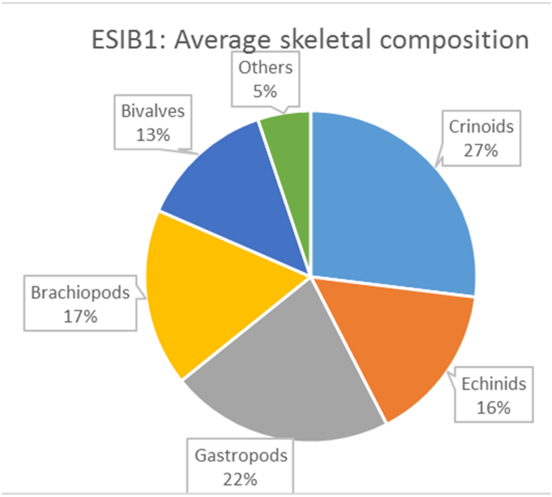


Fig.28 – Average skeletal grain composition of the ESIB1 sediments. For this estimation only the observed thin sections were considered. Note that echinoderms are dominating, followed by gastropods, brachiopods and bivalves.

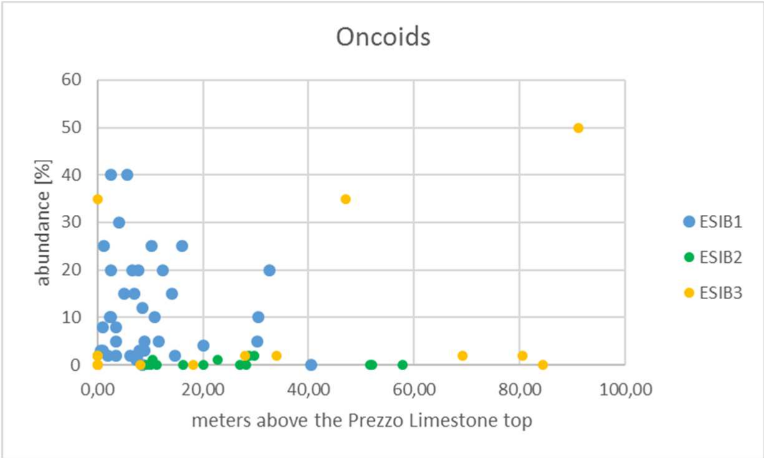


Fig.29 – Oncoid abundance in the Basal Esino Limestone. The information from all the observed thin sections is plotted on the graph. Highest abundance is in the ESIB1 unit. In the other two units oncoids are rare.

- ESIB2 [fig.32, D-E and fig.33, B-E; fig.35, A-D]: The mid-upper part, massive amalgamated with faint inclined depositional surfaces (fig.30), is the largest part of the unit and is mainly composed of monotonous intraclastic calcarenite (fig.32, D; fig.33, B), generally coarser (up to coarse-grained sandstone), lighter in color (mid grey, nut grey, light grey) and with a scarce macrofossil content (sparse gastropods and bivalves).

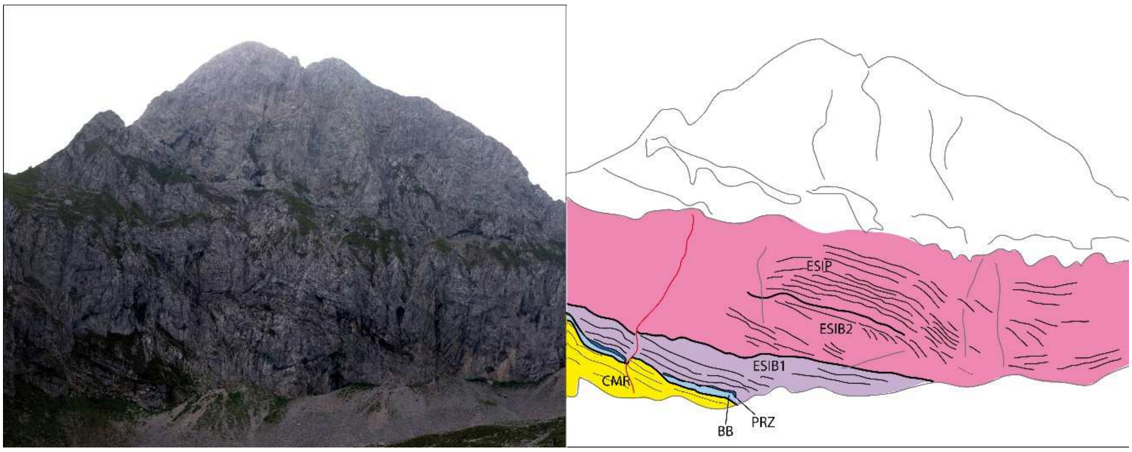


Fig.30 – Panoramic view on the Carna Piana (CP2) outcrop and interpretation. In the scheme are highlighted the depositional surfaces, that are horizontal in the Camorelli Limestone (CMR), Banco a Brachiopodi (BB), Prezzo Limestone (PRZ) and lower Basal Esino Limestone (ESIB1). Above, in the ESIB2, deposiotional surfaces are visible inclined towards right and gradually pass upwards to the horizontal bedding of the Peritidal Esino Limestone (ESIP), delineating a carbonate bank that prograde on the surrounding area.

At the microscope (10 thin sections) these mostly are:

- Intraclast and peloid packstone or grainstone with scarce skeletal grains

Skeletal grains include gastropods, dasycladaceans, thick-shelled bivalves, crinoid ossicles, echinid radioles, brachiopods. Fossils mainly include benthic foraminifers, ostracods, gastropods and calcispheres. These sediments also contain scarce (up to 5%) reworked *Baccanella floriformis* and/or fragments of calcareous sponges (*Olangocoelia otti*, *Plexoramea cerebriformis*), corals and *Tubiphytes.*

Locally the sediments of the ESIB2 have patches of different colors, often brownish (fig.33, D-E), and sometimes also small (cm-size) and irregular dark grey cement-filled cavities (calcite). These characteristics at the macro scale identify the zones where in-place margin building biota are present: at the microscope in fact (32 thin sections) these rocks often show delicate branching structures of *Tubiphytes*, clotted peloidal micrite or other sessile organisms (*Olangocoelia otti*, *Baccanella floriformis* and microproblematica). These rocks at the microscope can be classified as:

- Microbial boundstone (clotted peloidal micrite)
- Tubiphytes boundstone
- Porifer boundstone

These different microfacies can be associated in the same rock. The space between the bioconstructed part of the rock is usually filled with fine grained granular sediments (intraclast and peloid packstone with scarce skeletal grains), sometimes with calcite marine cements.

Rarely small phaceloid colonies of corals (fig.32, D) and algae (fig.33, C) are observed in the outcrop (Ghegna stratigraphic section – GH1). Oncoids in ESIB2 are absent or rare.

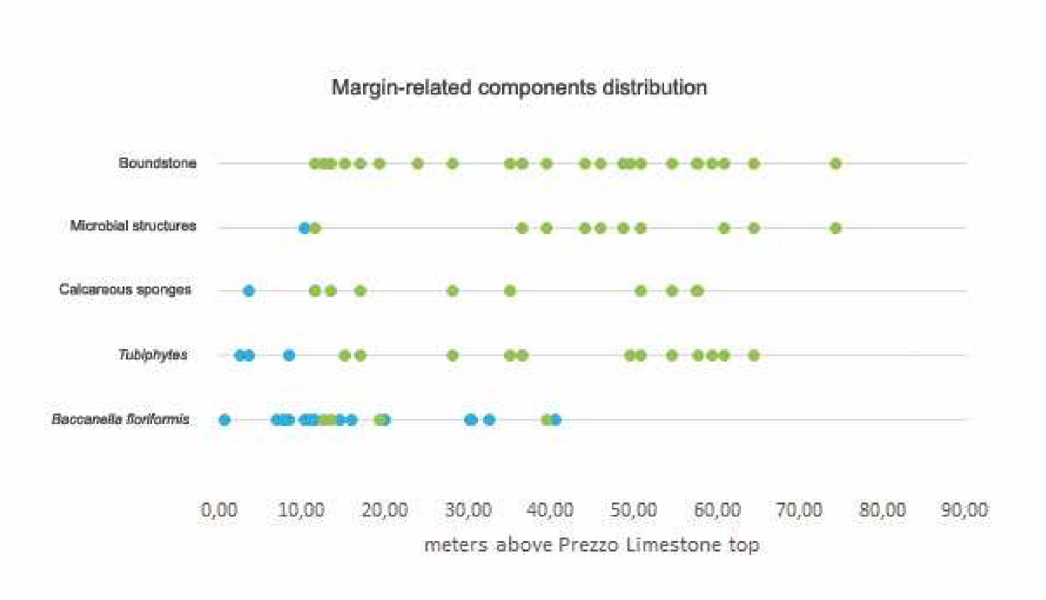


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Fig.31 – Distribution of margin-builder biota in the Basal Esino Limestone. Only data from described thin sections have been considered. Blue dots = ESIB1; Green dots = ESIB2. Note that Baccanella floriformis is more frequently found in the ESIB1, while the other forms are more typical of the ESIB2. Microbial structures, mainly composed by clotted peloidal micrite, are typical of the highest part of the succession.

- ESIB3 [fig.32, F and fig.33, F; fig.36, A-B]: The uppermost part, massive amalgamated with faint horizontal depositional surfaces, is generally less than 40 meters thick and is characterized by coarser sediments than ESIB2, rich in oncoids (up to a few cm) and/or dasycladaceans. The color is mid to light grey and the rock displays zones where the porosity is filled by dark grey calcite cement. The microfacies (15 thin sections) mainly are:
    - Peloid packstone and grainstone with oncoids and Dasycladaceans.

    The oncoids have a rough grossly oval shape, have a clotted peloidal fabric with few or no visible laminations but sometimes Cayeouxia-like filaments are observed. Dasycladaceans can be abundant (Dasycladacean rudstone). Cavities filled with different generations of cement can occur. Skeletal grains, apart from Dasycladaceans, are generally absent. Fossils include scarce benthic foraminifers, rare gastropods and ostracods.

This part conformably passes upwards to the well-bedded Peritidal Esino Limestone ().

Tuffs [fig.37]: Tuff layers are reported by JADOUL AND ROSSI (1982) in the Buchenstein formation, the basinal equivalent of the Esino Limestone, while in the study area JADOUL ET AL. (1992) indicate the presence of few tuffaceous layers at the top of the Prezzo Limestone and also within the Esino Limestone ("Lithozone 2"). In this work we found tuff layers at different stratigraphic levels within the Esino Limestone but more commonly they are found in the lower part of the unit, near the passage to the Prezzo Limestone. These tuff layers are thin, 1 to 10 cm thick, light grey or ochre in color, altered and soft. They are present as single stand-alone levels or as a group of 2-3 spaced levels. Two thin sections have been prepared from tuff samples and the observation at the microscope reveals that they are constituted by a fine grained altered matrix (clay minerals now) with sparse preserved quartz and zircon crystals. In a few cases the contact with the underlying sediments is weakly erosional (fig.37, B) and dark mud floating clasts are visible at the base of the deposit.

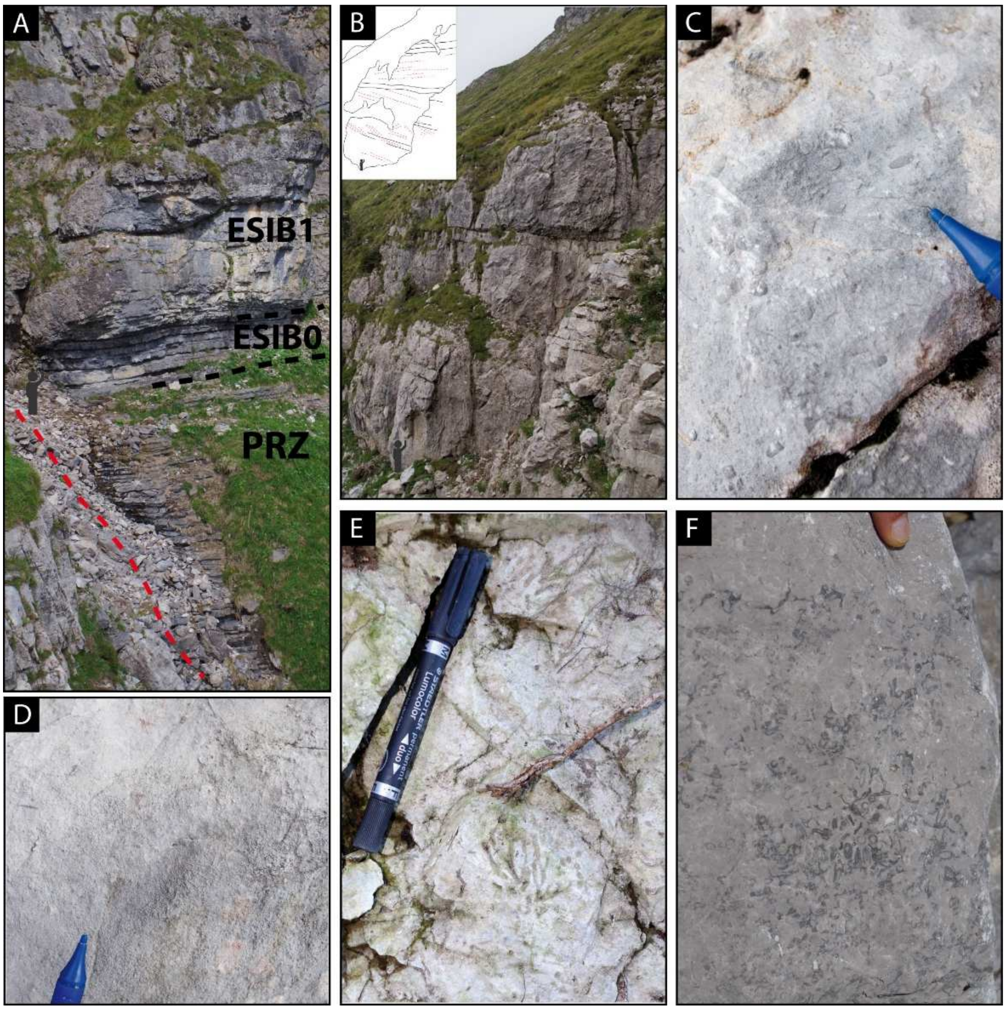


Fig.32 – Basal Esino Limestone in the outcrop. A) The photo shows the transition between the Prezzo Limestone (PRZ) and the Esino Limestone (ESI) at Mt. Menna stratigraphic section (MN1). The transition is sharp and characterized by the thinning of marl intercalations and an increase in bed thickness. The first meters of Esino Limestone are in fact bedded then the bedding planes tend to disappear and the limestone becomes massif with gross pluri-metric bedding (ESIB1). Man figure for scale. B) Outcrop of the mid-upper part of the Basal Esino Limestone (ESIB2) at Mt. Menna (MN1 stratigraphic section). Within the horizontal pluri-metric bedding are evident some inclined depositional surfaces, that are drawn (dotted red lines) in the small sketch in the upper-left angle. Man figure for scale. C) Bioclastic calcarenite with abundant crinoid ossicles. This limestone is typical of the lowermost part (ESIB1) of the Esino Limestone. Passo del Re stratigraphic section (PR1). D) Grainy limestone from the mid-upper part (ESIB2) of the Esino Limestone. No recognizable structures or grains are visible. Passo del Re stratigraphic section (PR1). E) Limestone (calcarenite) with branching coral colonies. The structures are visible due to differential weathering on the surface. This facies is from the mid-upper part (ESIB2) of the Basal Esino Limestone. Ghegna stratigraphic section (GH1). F) Dasiclad rudstone. Calcite-cemented porosity (dark-colored parts) highlights the texture of the rock and the nature of the grains. This facies is found in the topmost part (ESIB3) of the Basal Esino Limestone. Mt. Menna stratigraphic section (MN1).

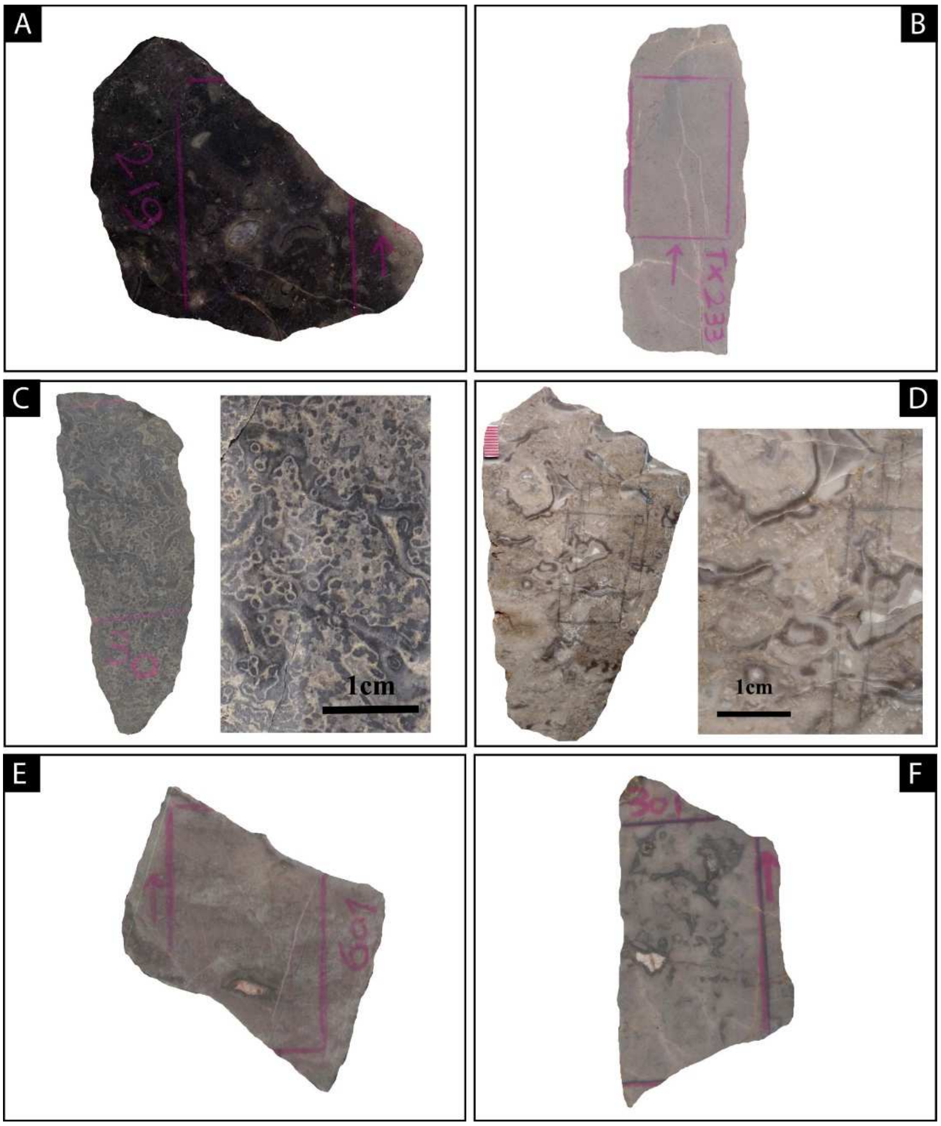


Fig.33 - Samples from the Basal Esino Limestone. A) Sample TX219. Very fine-grained oncoidal calcarenite (Oncoid floatstone). The patchy color is due to bioturbation. ESIB1. Passo del Re stratigraphic section (PR1). B) Sample TX233. Fine grained calcarenite (Intraclast packstone). ESIB2. Arera Mount stratigraphic section (AR1). C) Sample TX30. Algal(?) boundstone. The framework is built by tubular structures (see close-up on the right). The sediment experienced strong recrystallization. ESIB2. Piazza Brembana stratigraphic section (PB1). D) Sample TX21. Mottled-globular limestone (Tubiphytes boundstone). Diffuse margin-building biota is visible (thin light-colored tubules in the close-up). Irregular cavities are filled with several generations of cement (calcite is darker at the border of the cavity and gets lighter towards the center). ESIB2. Piazza Brembana stratigraphic section (PB1). E) Sample TX601. Mottled limestone (Tubiphytes boundstone). Faint horizontal layering is visible. ESIB2. Corna Piana stratigraphic section (CP1). (microfacies in fig.35, C). F) Sample TX301. Dasiclad rudstone. The dark calcite cement highlights the texture of the rock and the nature of the grains. ESIB3. Corna delle Coste stratigraphic section (CC2). (Microfacies in fig.36, A). The pink rectangle is 48 mm x 29 mm.

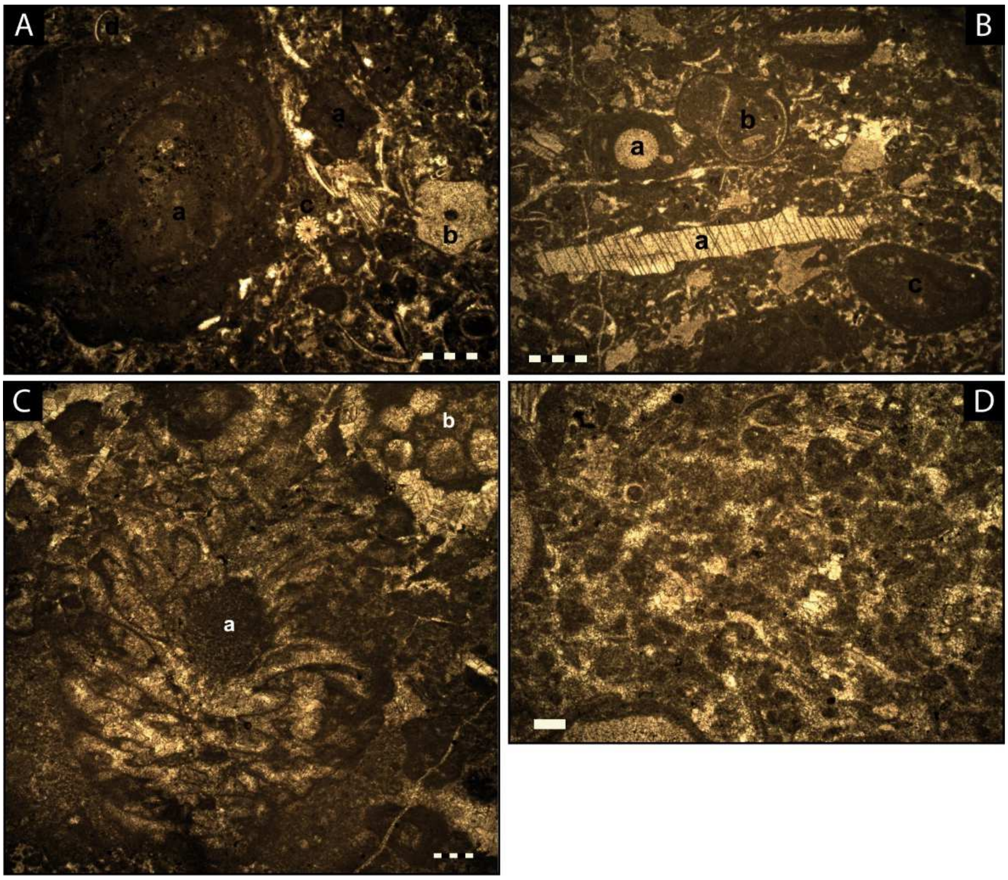


Fig.34 – Microfacies of the Basal Esino Limestone - Lower part (ESIB1): A) Oncoid floatstone and peloid packstone matrix. Oncoids (a) have dark micritic irregular coatings. Crinoid ossicles (b) and echinid radioles (c) are common skeletal grains. An ostracod valve (d) is also present. Sample TX417a. Canale delle Betulle stratigraphic section (CB1). Scale bar is 500 µm. B) Peloid packstone with oncoids and cortoids. The coated bioclasts include ornamented echinid radioles (a), gastropods (b) and possible echinid plates. Non-coated bioclasts include ostracod valves, echinoderm and gastropod fragments, foraminifers. Dark micritic rounded oncoids (c) are present. Sample TX98. Valcanale stratigraphic section (VC1) Scale bar is 500 µm. C) Peloid packstone with platform-derived biota. A dasycladaceans (a) is at the center of the image while in the upper right corner is a fragment of the porifer Olangocoelia otti (b). Sample TX163. Corna Piana stratigraphic section (CP2). Scale bar is 500 µm. D) Detail of the peloid packstone: dark rounded or oval peloids are visible. Sample TX473. Monte del Sole stratigraphic section (MS1). Scale bar is 100 µm.

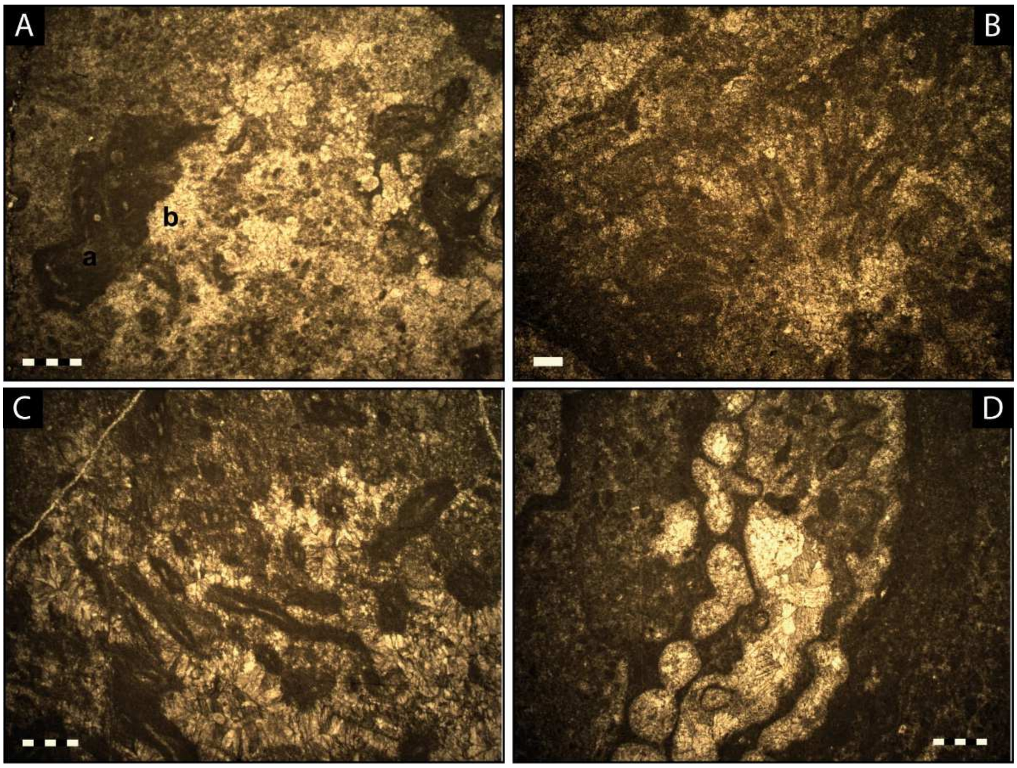


Fig.35 – Microfacies of the Basal Esino Limestone – mid-upper part (ESIB2): A) Microfacies of the sample TX95. Tubiphytes (a) encrusts masses of Baccanella floriformis (b). Tubiphytes builds dark areas characterized by black micritic tubular structures with a cemented central cavity. Baccanella floriformis builds sparitic flower-like structures that are organized in clots. The matrix is clotted peloidal micrite. Valcanale stratigraphic section (VC1). Scale bar is 500 µm. B) Detail of clotted peloidal micrite of sample TX95. A granular peloidal texture is perceived but no grains have definite borders. Faint tubular structures are visible at the center of the photo (Ortonella?). Valcanale stratigraphic section (VC1). Scale bar is 100 µm. C) Tubiphytes boundstone. The tubular structures with central cavity are evident and grow within a clotted peloidal matrix. Calcite cementation occur between Tubiphytes tubules. Sample TX601. Corna Piana stratigraphic section (CP1). Scale bar is 100 µm. D) The porifer Olangocoelia within a peloid packstone matrix. The porifer has a cilindrical shape with a central cavity and thick walls characterized by rounded cemented cavities. Sample TX212. Passo del Re stratigraphic section (PR1). Scale bar is 500 µm.

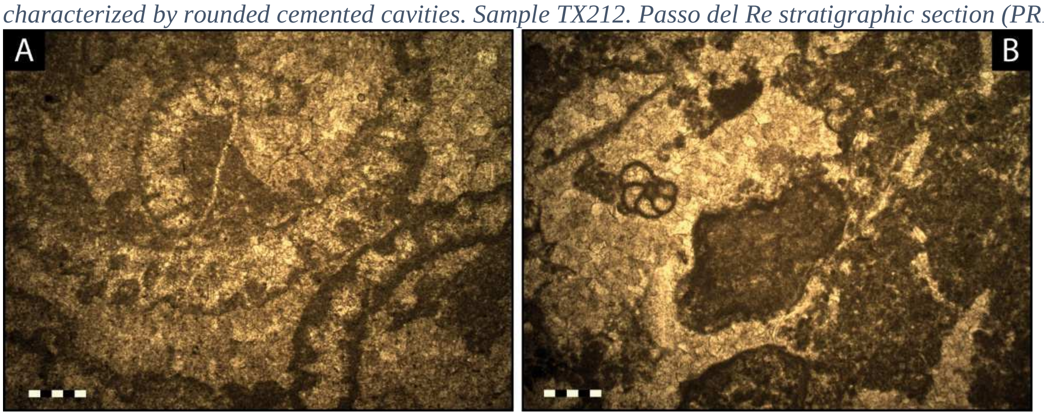


Fig.36 – Microfacies of the Basal Esino Limestone - uppermost part (ESIB3). A) Dasiclad rudstone and peloid packstone matrix. A calcite mosaic replaces large parts of the peloidal matrix, deleting the original texture. Sample TX301. Corna delle Coste stratigraphic section (CC2). Scale bar is 500 µm. B) Peloid packstone with oncoids. An oncoids, with clotted peloidal texture and lacking laminations, is visible in the center of the picture. A benthic foraminifer (Endoteba) is visible on the left. The peloidal matrix is extensively replaced by a mosaic of calcite. Sample TX502. Corna delle Coste stratigraphic section (CC2). Scale bar is 500 µm.

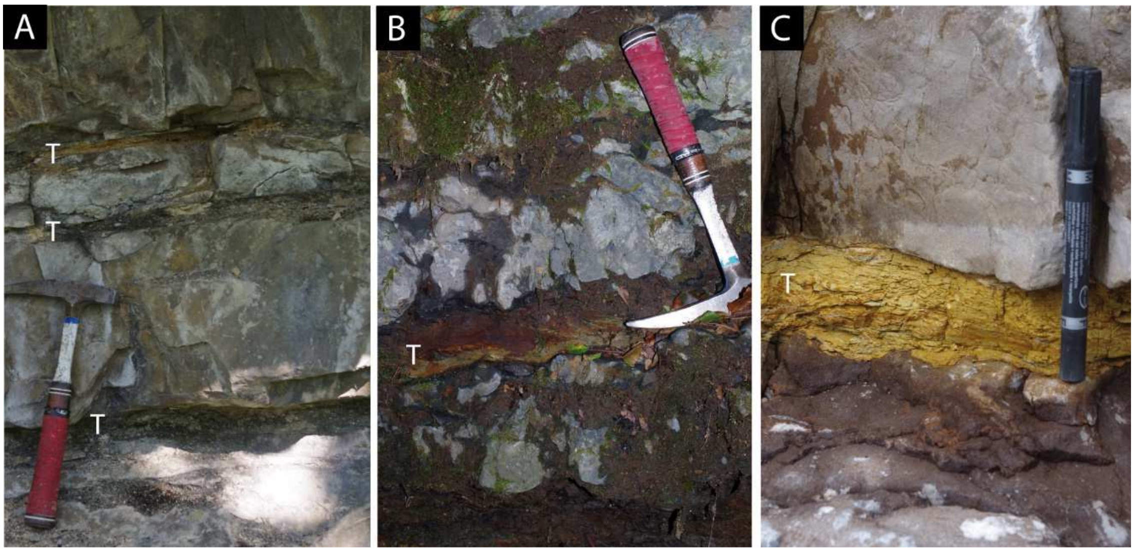


Fig.37 – Tuff layers in the outcrop. A) 3 tuff layers (T) intercalated within the ESIB3 limestone at Piazzatorre (PT1) stratigraphic section. B) Yellow tuff layer (T) within ESIB0 limestone at Olmo al Brembo stratigraphic section (OB1). Ripped black mud chips are visible within the tuff. C) Yellow tuff layer (T) within ESIB1 limestone at Mount Menna stratigraphic section (MN1).

Environmental interpretation

ESIB0: the 2 meters thick basalmost part of the Esino Limestone has microfacies similar to that of the bioclast-rich deposits of the Prezzo Limestone. For this similarity we analogously attribute these sediments to storm accumulations that fit the tempestite description of Perez-Lopez and Perez-Valera (2012). Also for these deposits thus we propose a subtidal open shelf environment, below fair-weather wave-base, subject to storm deposition.

ESIB1: The rich variety of skeletal grains that is found within these sediments refers to different environments: thin-shelled bivalves and ammonoids are common in deep pelagic environment; *Baccanella floriformis*, *Tubiphytes*, Calcareous sponges and corals are referred to shallow water ramp, margin or reef environment (Ruffer and Zamparelli, 1997; Harris, 1993); Dasycladaceans are from shallow-water open lagoon or back-reef environment (Flugel, 2010). Associated constructive cortoids and micritized grains are generally produced in shallow water tropical environments (Flugel, 2010). Irregular oncoids, according to Badenas and Aurell (2010), form under calm conditions favoring coating and micritization of skeletal grains. These sediment characteristics are told to be indicative of low-energy conditions in protected but open lagoonal areas (Badenas and Aurell, 2010). Faint horizontal depositional surfaces within this part are coherent with this interpretation. The poor sorting, with oncoids floating in a finer matrix, and mixed texture is probably produced by bioturbation (tunnel traces are sometimes visible) as well as by storm reworking (the sediment sometimes is locally very similar to the lithofacies 2 of the Banco a Brachiopodi unit). The presence of shallow-water biota skeletal grains evidences, during this phase, the existence of carbonate platform nuclei nearby and possibly identifies the toe-of-the-slope zone. These sediments are thus interpreted as the deposits of an open lagoonal area with depth in the reach of storm waves and sourced also by sediments coming from neighboring carbonate platforms. The higher abundance of crinoids in this part probably indicates that their living position was proximate (Meyer and Meyer, 1986).

ESIB2: Inclined depositional surfaces indicate that these deposits belong to a slope environment. The grainy peloidal sediments and the boundstone facies (*Thubiphytes* is prevailing) match with the margin-slope deposits described in the Latemar carbonate platform (EMMERICH ET AL. 2005, MARANGON ET AL 2011). The upward decrease in crinoid ossicles, oncoids and cortoids abundance supports the hypothesis they are genetically linked with the deeper ESIB1 environment. Cements are limited and the abundance of carbonate mud point to a low-energy environmental setting. The growth forms of the margin-biota are dominated by tubular structures and fit the "filled frame reef" definition of RIDING (2002) who relates it with high sedimentation rate and low energy conditions. The grainy sediment probably moved downslope by avalanching and was then amalgamated by bioturbation. Articulated crinoid ossicles found at the passage between ESIB1 and ESIB2 indicate this part (toe of the slope) as the place where burial was more rapid and thus preservation potential was higher.

ESIB3: The presence of dasycladaceans, often abundant, are typical of open-marine lagoon environment (FLUGEL, 2010). Also oncoids and peloidal deposits are common in these settings. The lack of margin building biota and deep water fauna also supports the fact that these sediments deposited in a shallower position with respect to the slope/margin. These sediments are in fact analogue to the lagoon deposits of the Latemar carbonate platform (EMMERICH ET AL. 2005, MARANGON ET AL. 2011). The return to faint horizontal bedding, sometimes observed, supports this interpretation.

Tuffs: the pyroclastic origin points to an accumulation by vertical fall with draping of the depositional surface and possible later reworking by waves, currents and bioturbation. In a few cases where dark mud chips are observed in the lower part of the tuff layer we can guess an underwater flow of pyroclastic material probably occurred. The mantling process of the depositional surface makes these levels, where they are preserved, of extreme importance for time-correlations. This important feature is discussed later in the text (chapter 5.3.3)

5.1.5 - Peritidal Esino Limestone

The onset of this unit defines the top of the study interval. We thus described only the lowermost deposits of this unit.

Previous studies

This part of Esino Limestone is described by JADOUL ET AL. (1992) as a 50-60 meters thick succession of well bedded limestones and dolomitic limestones organized in peritidal cycles with stromatolites and fenestral fabric. Dolomitized inter-supratidal horizons, tepees and radial fibrous cements ("raggioni" of ASSERETO & FOLK, 1980) are observed. Few discontinuous layers of micaceous shales intercalations are reported at the base and top of the succession. This association of structures are related by the authors to local stratigraphic unconformities due to periodic subaerial exposures of the platform.
This unit is considered interfingering in its lower part with the "Lumachella di Ghegna" margin facies and being coeval with younger deposits in its upper part (JADOUL ET AL. 1992).

Characteristics

The Peritidal Esino Limestone is easily recognized from the underlying deposits for its distinct horizontal bedding (beds are a few dm thick) as well as for its lithology. The unit is mainly composed of light grey limestone or dolostone displaying planar stromatolitic laminations and fine to very coarse grained calcarenites. Oolitic and oncolitic deposits are also present but generally subordinate (at Piazza Brembana instead these grains are abundant). Normal and inverse gradings are commonly observed within these granular sediments. Fenestral cavities are common. Tepee and loferitic breccias locally occur (e.g. Piazza Brembana section – PB2; Lenna section – LN1). The analyzed microfacies (19 thin sections) are:

- Laminated or poorly laminated Microbial Boundstone with fenestral cavities (fig.40, C)
- Peloid Packstone (fig.40, B)
- Ooid-oncoid Packstone and Grainstone (fig. 40, A, E and F)

Microbial tubules (Cayeouxia-like) are sometimes visible within the microbial boundstone (fig.40, C), that is commonly characterized by clotted peloidal fabric. Inverse (fig.40, A) and normal gradings are common in well-sorted ooid-oncoid packstone and grainstone. Ooids have generally thin coating (surficial ooids) and oncoids are generally ovoid, with alternating dark micritic and porous peloidal coatings.

In this unit dark cm-scale marine cement layers, characterized by botryoidal fibrous calcite ("raggioni" of ASSERETO & FOLK, 1980), are intercalated within the succession. At the microscope these are made up of fibrous-radial calcite fans (probably pseudomorphs on botryoidal aragonite) and often have thin dark leiolitic microbial laminae intercalated (fig.40, D). Fossils are rare within this unit and include ostracods (also disarticulated), benthic foraminifers and micritized gastropods.

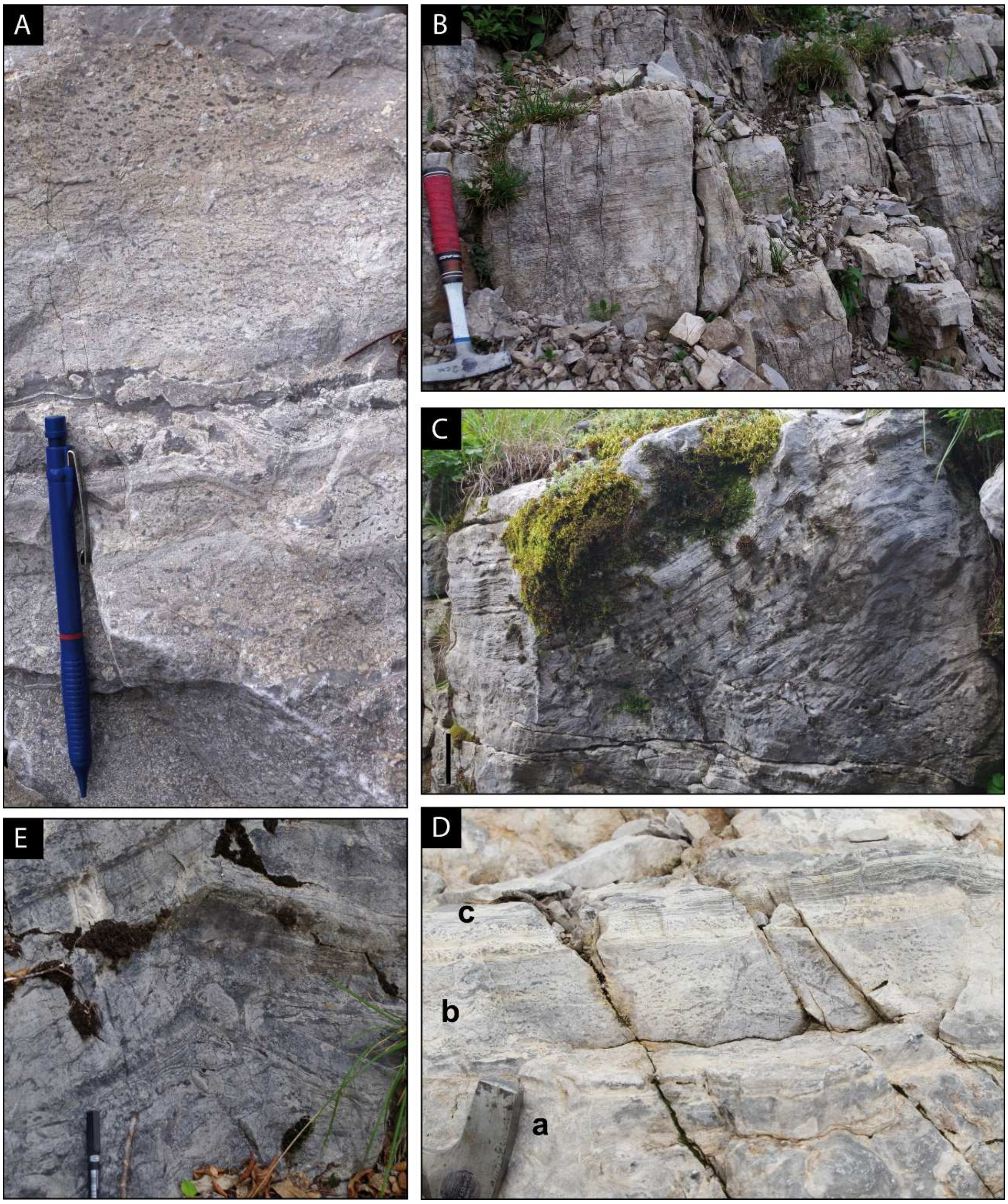


Fig.38 – Peritidal Esino Limestone in the outcrop. A) Oolitic-oncolitic coarse-grained calcarenites with abundant fenestrae. In the middle is evident a calcite-cemented loferitic breccia of microbial limestone. Valcanale stratigraphic section (VC1). B) Stromatolic limestone with thin planar laminations. Mt. Menna stratigraphic section (MN1). C) The margin of a little stromatolitic mound displaying lateral progradation. Piazza Brembana stratigraphic section (PB1). Black scale bar is 10cm tall. D) Peritidal limestone. Subtidal grey fine-grained bioturbated limestone at the base (a), overlaid by inter-supratidal grey fine-grained limestone with fenestral fabric (b). the topmost part is probably altered by subaerial exposure (yellowish part). Above (c) is a dark marine cement layer (fibrous-radial calcite, "raggioni" of ASSERETO & FOLK, 1980). Passo del Re stratigraphic section (PR1). E) Tepee structure in peritidal limestone. Piazza Brembana stratigraphic section (PB2).

Fig.39 – Cut sample surfaces from Peritidal Esino Limestone. A) Sample TX55. Very coarse grained calcarenite (ooid-oncoid grainstone). Coarsening upward pockets are visible. Piazza Brembana stratigraphic section (PB1). B) Sample TX569. Mid-grained calcarenite (peloid packstone and intraclast packstone) and microbial boundstone with fenestral cavities. Mt. Menna stratigraphic section (MN1). Microfacies in fig.40, B. C) Sample TX60. Black cement layer made of radial fibrous calcite. Piazza Brembana stratigraphic section (PB1). D) Sample TX206. Peritidal limestone breccia. Pink-reddish clasts are weathered limestone (intraclast packstone). Dark layers are microbial-cement coatings. The light grey part is a fine grained limestone (peloid packstone and clotted peloidal micrite) with fenestrae. Passo del Re stratigraphic section (PR1). The pink rectangle is 48 mm x 29 mm.

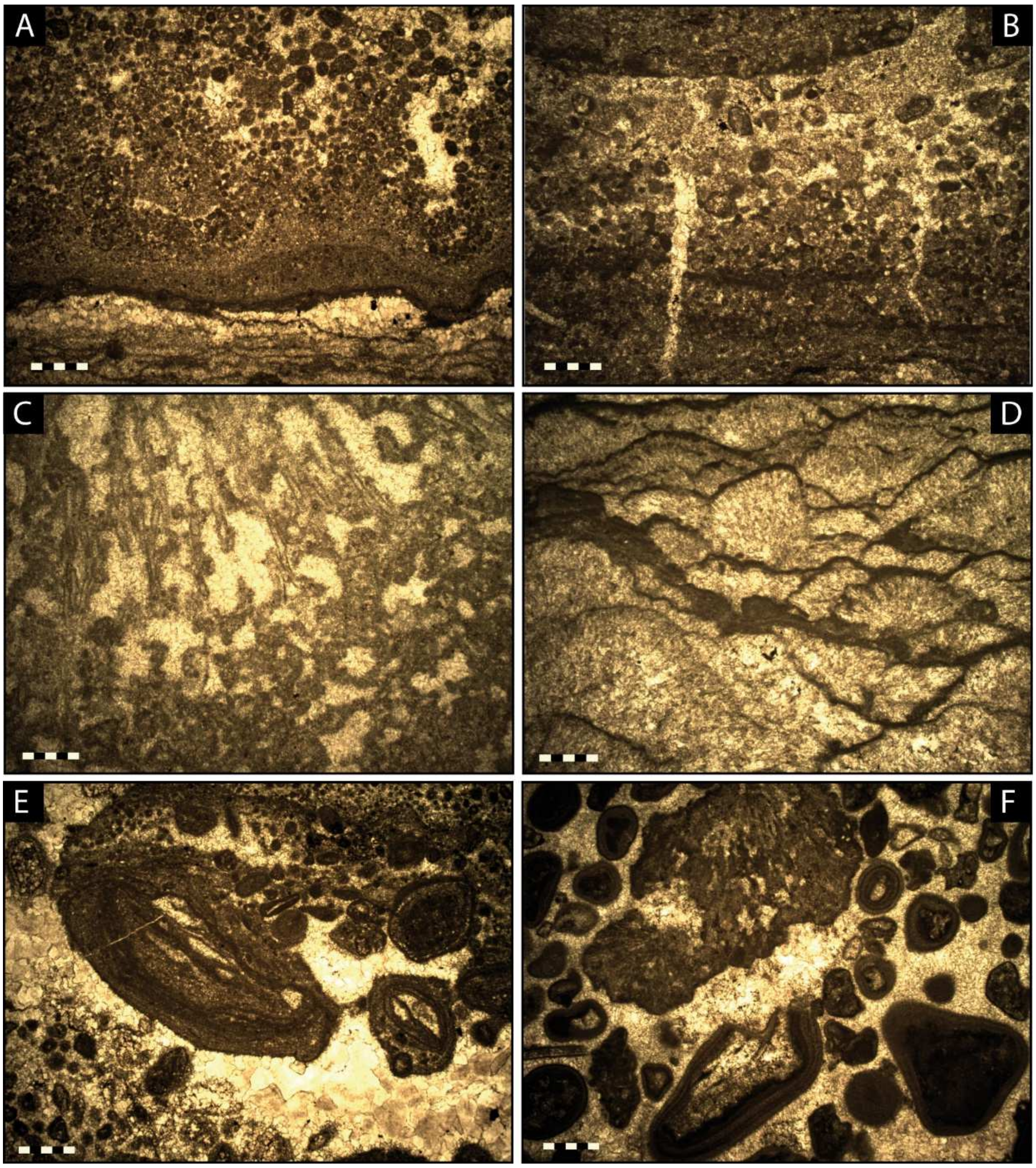


Fig.40 – Microfacies of the Peritidal Esino Limestone. A) Coarsening upward ooid packstone-grainstone overlying a cement-microbial (leiolithic) boundstone. Sample TX477. Monte del Sole stratigraphic section (MS1). Scale bar is 500 µm. B) Peloid packstone. In the middle a coarsening upward pocket is visible. Vertical calcite-cemented cracks. Sample TX569. Mt. Menna stratigraphic section (MN2). Scale bar is 500 µm. C) Microbial boundstone. The structure is highly porous, with dense, cement-filled, fenestral fabric. Cayeouxia-like algal filaments are visible. Sample TX549b. Olmo al Brembo stratigraphic section (OB1). Scale bar is 500 µm. D) Cementstone (fibrous-radial calcite cement layer). Botryoidal aragonite and microbial (leiolithic) laminae. Sample TX204. Passo del Re stratigraphic section (PR1). Scale bar is 500 µm. E) Ooid packstone with oncoids. Recrystallization of micrite in sparite is deduced by floating oncoids. Sample TX477. Monte del Sole stratigraphic section (MS1). Scale bar is 500 µm. F) Ooid (surficial) grainstone. A detrital boundstone clast is present. Sample TX53. Piazza Brembana stratigraphic section (PB1). Scale bar is 500 µm.

Environmental interpretation

The facies association reflects typical peritidal depositional setting, as already highlighted by previous authors (JADOUL ET AL. 1992). Microbial boundstone and peloid packstone are indicative of a low energy tidal flat. Episodic subaerial exposure is evidenced by common fenestral fabric and local loferitic breccias and tepees. The very scarce fauna is compatible with the inter-supratidal stressing environment. The well-sorted ooid-oncoid packstone and grainstone instead indicate more agitated and subtidal conditions that could be referred to wide tidal channels entering the inner platform area.

5.2 - Vertical evolution

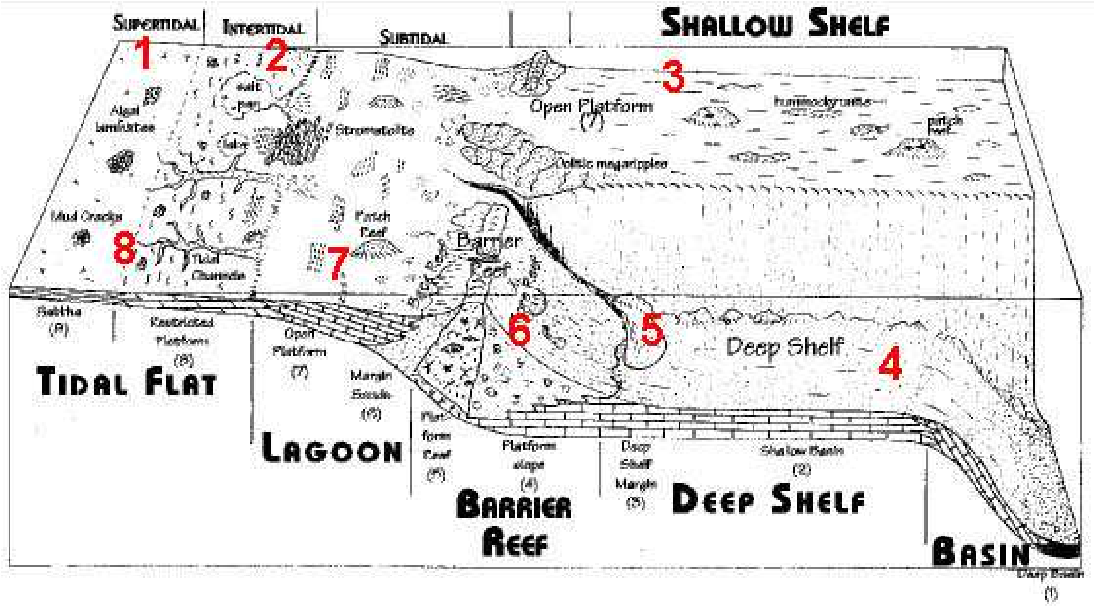


Fig.41 – The environmental path (red numbers) recognized within the studied succession: From the initial peritidal platform conditions (1), the succession shows a deepening trend that brings the depositional surface first to very shallow lagoon conditions (2), then to shallow shelf or deeper lagoon conditions (3) and finally to deep shelf conditions (4). The successive shallowing trend encompasses platform related environments: first the return to shallow shelf or lagoon conditions with local detrital contribute from platform margin (5) is recognized. Then the advance over the area of platform slope and margin facies is generally documented (6). Shallow lagoon conditions (7) are commonly encountered before peritidal platform conditions are restored (8).

(image from http://www.seddepseq.co.uk/DEPOSITIONAL_ENV/DEP_ENV_TEXT/carbdepoenvir.htm)

As can be seen in the correlation scheme (Attached 1), most of the stratigraphic sections display a similar vertical transgressive-regressive evolution which encompasses, with different thickness, the formations/units and the facies assemblages described in chapter 5. The passage from one formation/unit or facies association to another occurs without evidence of significant unconformities, thus indicating that the recording of the succession is continuous and the passage from one facies association to another, according to Walther's law, reflects the passage between adjoining environments. The general paleoenvironmental evolution observed in the stratigraphic sections, from the base to the top, can be summarized as follows (red numbers in fig. 41):

1. Peritidal platform - The succession starts with the shallow water peritidal carbonates of the Anisian carbonate platform (Camorelli Limestone). The environment, within an inner platform and protected low-energy setting, is characterized by a wide algal flat subject to short-time subaerial exposures and to storm incursion.
2. Very shallow lagoon - The early transgressive trend develops, on the top of the terminated peritidal platform, a very shallow lagoon, characterized by dark fine-grained deposits contaminated with siliciclastics (Banco a Brachiopodi – lithofacies 1). Due to eustatic variations the deposits are still subject to local subaerial exposures (fenestral cavities) and also to evaporite growth due to saline restricted conditions. In this very shallow and quiet environment the poor water circulation is probably responsible for the scarce fauna (ostracods and benthic forams).

3. Shallow lagoon/shelf - The continued transgression deepens the depositional surface and the deposits turn to fully subtidal (Banco a Brachiopodi – lithofacies 2). The area is a shallow open lagoon or a shelf. Better water circulation is evidenced by the accumulation of abundant and varied skeletal material, as well as by intense burrowing and storm reworking of the sediments.
4. Deep shelf - The transgression culminates in the deposition of black pelagic deposits (Prezzo Limestone), representing the deepening of the depositional surface to a relatively deep subtidal shelf environment, characterized by mixed carbonate-siliciclastic input and dysoxic conditions. The depositional surface is below fair-weather wave base but in the reach of dilute storm events, that accumulate thin bioclastic lags.
5. Shallow lagoon or shelf - The start of the regressive trend brings back the depositional surface to shallower more oxygenated conditions and the deposits are again lighter in color and rich in skeletal components (ESIB1). The environment is a lagoon or a shallow shelf. Algal-microbial community flourishes and produce dark irregular oncoids and cortoids. The existence during this phase of carbonate nuclei nearby is evidenced by the presence of little material (allochtonous *Tubyphytes*, carbonate sponges and *Baccanella*) coming from platform margin environment.
6. Platform slope and margin - The horizontal layering is covered by the advance of slope-margin faintly clinostratified deposits of carbonate banks (ESIB2). Sparse patches of delicate boundstone built by *Tubiphytes*, sponges or problematica are immersed in prevailing grainy, mud-rich sediments indicating low energy conditions.
7. Inner platform shallow lagoon - The regressive trend continues and the horizontal bedding is restored above the slope-margin deposits. The environment is a shallow lagoon, characterized by oncoid and dasycladacean growth (ESIB3).
8. Peritidal platform - The regressive trend finally restores inner platform peritidal conditions, where a complex of stromatolitic buildups subject to subaerial exposure and oolitic-oncolitic channels is developed (ESIP).

In a few cases this vertical evolution is not observed:

- In the Piazzatorre (PT1) stratigraphic section the typical Prezzo Limestone is not recognized. Here the deepening trend culminates in a few meters of dark bedded limestone which are best ascribed to the ESIB0. We suggest that this difference is due to the fact that the required depth condition for the Prezzo Limestone deposition were not reached.
- In the Corna delle Coste (CC3) stratigraphic section both the Banco a Brachiopodi – lithozone 2 and the Prezzo Limestone are not recognized. Here a particular situation is observed: above the Camorelli Limestone, bioturbated limestone are present, overlaid by limestone showing in-place fragmentation, intrasediment evaporite crystal growth and possibly also pedogenesis. These regressive trend, which is just below a tuff level, is not reported in the other stratigraphic sections. These sediments are tentatively attributed to the Banco a Brachiopodi unit (lithofacies 1). Above these, transgressive sediments are present, represented by thin oolitic deposits and then, above the tuff level, by calcarenite deposits that we ascribe to the ESIB1 unit.

  The regressive and transgressive trends observed here are not coherent with the other stratigraphic sections and the attribution of this outcrop to the stratigraphic interval that is object of the thesis is in doubt. Nonetheless, supported by the presence of the tuff layer, we considered also this stratigraphic section in the correlation.

5.3 - Time correlation of the stratigraphic sections

The correlation scheme (attached 1) shows the space distribution of formations, units and sub-units reflecting homogeneous subenvironments/environmental conditions. The difference in thickness that exists between the described stratigraphic sections opens the possibility of different interpretations in the evolution of the area. A few time lines were drawn and helped clarifying the existing rapport between the different environments and units.

First of all, in the correlation scheme we set the top of the Camorelli Limestone as a reference (flat) surface: the top of the Camorelli Limestone, in fact, is constrained at nearly zero meters' depth (fenestrae and loferitic breccias are common at its top) and the limit with the overlying Banco a Brachiopodi unit always appears as a flat boundary, with no evidence of existing reliefs or active tectonics. This means that drowning of the Anisian platform grossly occurred at the same moment within this area, thus we can consider Camorelli top a grossly isochronous surface.

Other two times lines were traced using biostratigraphy and volcanics.

5.3.1 - Biostratigraphy

(This chapter and the related biostratigraphic work was realized in collaboration with Roberto Rettori from the University of Perugia)

A great variety of fossils are found within these sediments but only a few groups are useful as biostratigraphic tools in the studied time interval: among these benthic foraminifers were abundant in the lower part of the studied succession and were studied in thin section. Conodonts at last were not found in the few samples that were analyzed from the Banco a Brachiopodi unit.

Benthic Foraminifers

The benthic foraminiferal assemblages that are observed across the studied stratigraphic sections include taxa with high biostratigraphic significance, as well as cosmopolitan taxa with long stratigraphic range. The key species observed (fig.42) are:

Meandrospira dinarica Kochansky-Devidè & Pantic, 1965

Endotriadella wirzi Koehn-Zaninetti, 1968

Pilammina densa Pantic, 1965

Paulbronnimannia judicariensis Premoli Silva, 1971

Ophthalmidium abriolense Luperto, 1965

Ophthalmidium ubeyliense Dager, 1968

Turriglomina mesotriasica Koehn-Zaninetti, 1968

Paleolituonella meridionalis Luperto, 1965

The biostratigraphic analysis herein highlights a succession of events that allows for a tentative correlation of the stratigraphic sections. In particular, from the bottom to the top, we firstly observe the appearance of the *Meandrospira dinarica-Endotriadella wirzi* association. *M. dinarica* is a species that is well known in the Tethyan domain, with a range that correlates to an interval from the early Anisian (Aegean-Bithynian) to the late Anisian (Pelsonian), while *E. wirzi* is known from the middle Triassic (Anisian-Ladinian) of Tethys. This association is typical within peloid packstones and wackestones, along with fenestrae and ostracods (Lithofacies 1 of Banco a Brachiopodi), that have been related to a very shallow and low energy lagoonal environment. Within the Mt. Menna stratigraphic succession (MN1), the association occurs until the point at which, in sample TX194 at the base of the lithozone 2 of Banco a Brachiopodi, the lowest occurrence of *Pilammina densa* is reported. This species, whose paleogeographic distribution covers the whole Tethys, is widespread in the Anisian stage starting from the early Pelsonian onwards, but without reaching the uppermost Illyrian (*P. densa* Range-Zone of SALAJ ET AL. 1988 and TRIFONOVA 1992). Also, in the other stratigraphic sections, *P. densa* appears within the lithozone 2 of Banco a Brachiopodi (peloid packstone with abundant crinoid ossicles, interpreted as subtidal shelf deposits), sometimes associated with *M. dinarica* (Mt. Arera stratigraphic section - AR1) but never associated with *E. wirzi*. *P. densa* also displays an ACME interval (the foraminifera can constitute more than 30% in volume of the peloid packstone) occurring within the *Paulbronnimannia judicariensis* distribution interval in the lithozone 2 of Banco a Brachiopodi. In the uppermost part of the *P. judicariensis* distribution interval, in correspondence with the deepening of the depositional environment (Banco a Brachiopodi transitional deposits to the Prezzo Limestone), *P. densa* disappears and is substituted by the genus *Ophthalmidium (O. abriolense* and *O. ubeyliense*). *P. judicariense* is a species that was erected by Premoli Silva (1971, as *Agathammina judicariensis*) in the Anisian of the Giudicarie area (*Binodosus* horizon), and which was then recognized also in other Tethyan areas (RETTORI-ZANINETTI 1993; RETTORI 1995). This species is limited to the uppermost Pelsonian and is often associated with *P. densa*, but not with *M. dinarica*, probably due to environmental incompatibility. With the onset of the Illyrian Prezzo Limestone deposition (carbonate mudstone and peloid packstone, with ammonoids and shell concentrations, that are referred to a relatively deep shelf) the genus *Ophthalmidium* spreads (*O. abriolense* being more abundant) while the Pelsonian foraminifera disappear. The genus is still present in the lowermost and deeper deposits of the Esino Limestone, and then disappears also. Only well above this stratigraphic position, in the slope-margin deposits of the Basal Esino Limestone, the lowest occurrences of *Turriglomina mesotriasica* and *Paleolituonella meridionalis* are recorded - two species that are well known from the upper Anisian.

On the basis of these taxa and their distribution, we can therefore make a preliminary conclusion that the data collected from the analyzed stratigraphic successions are potentially useful for a future detailed zonation of the Pelsonian-Illyrian stages (fig.43).

In addition, despite the occurrence of these genera within well-defined microfacies indicates that their distribution in the succession is strongly controlled by the existence of favorable environmental condition to their life, as already suggested by FARABEGOLI ET AL. (1976), we can state that the Acme interval of *P. densa*, which is always a single and thin interval running through the Banco a Brachiopodi unit, can be considered a time line.

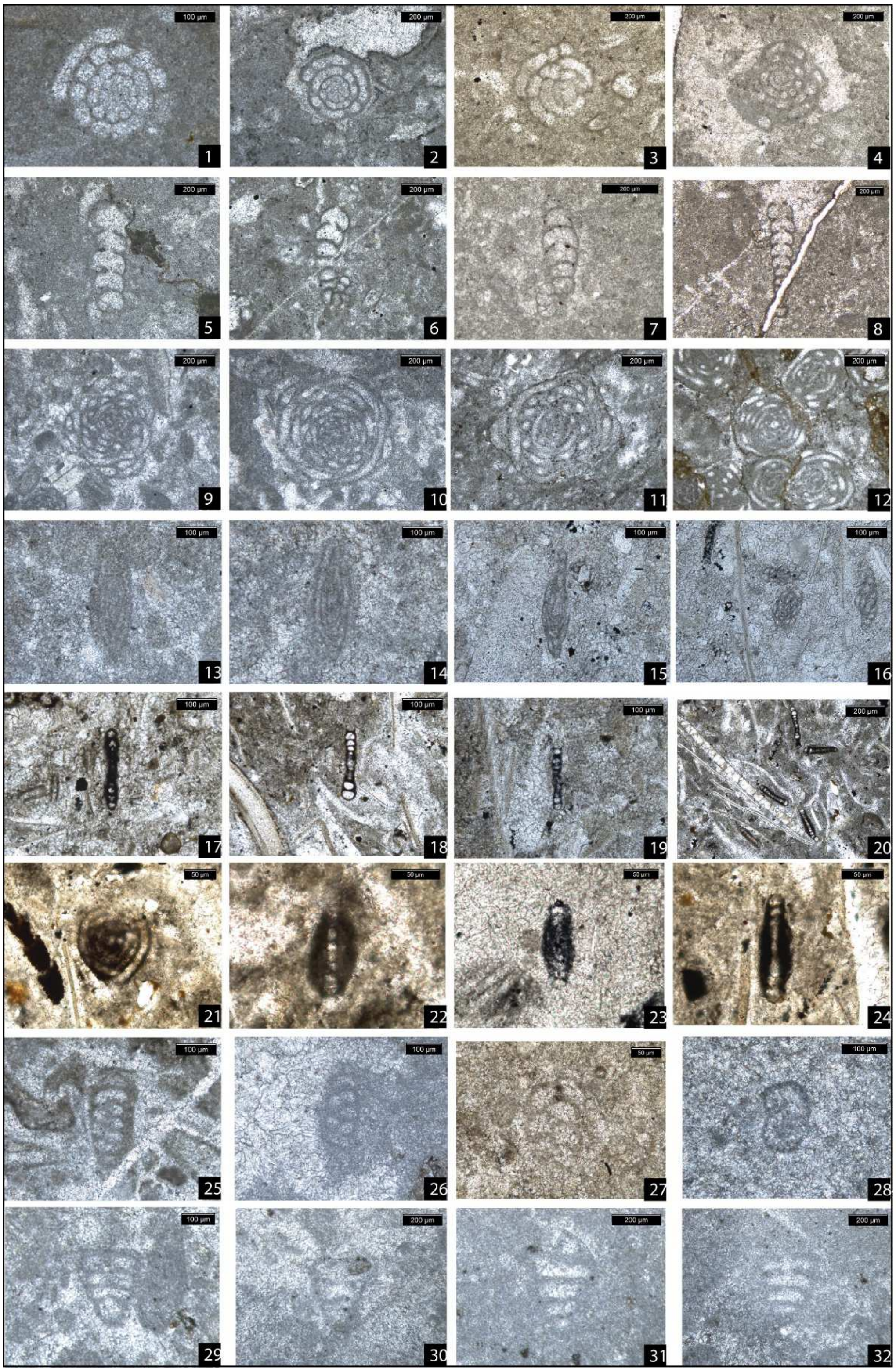


Fig.42 – Benthic foraminifers from the studied succession: main forms.1-4 Meandrospira dinarica; 5-8 Endotriadella wirzi; 9-12 Pilammina densa; 13-16 Paulbronnimannia judicariensis; 17-20 Ophthalmidium ubeyliense; 21-24 Ophthalmidium abriolense; 25-28 Turriglomina mesotriasica; 29-32 Paleolituonella meridionalis.

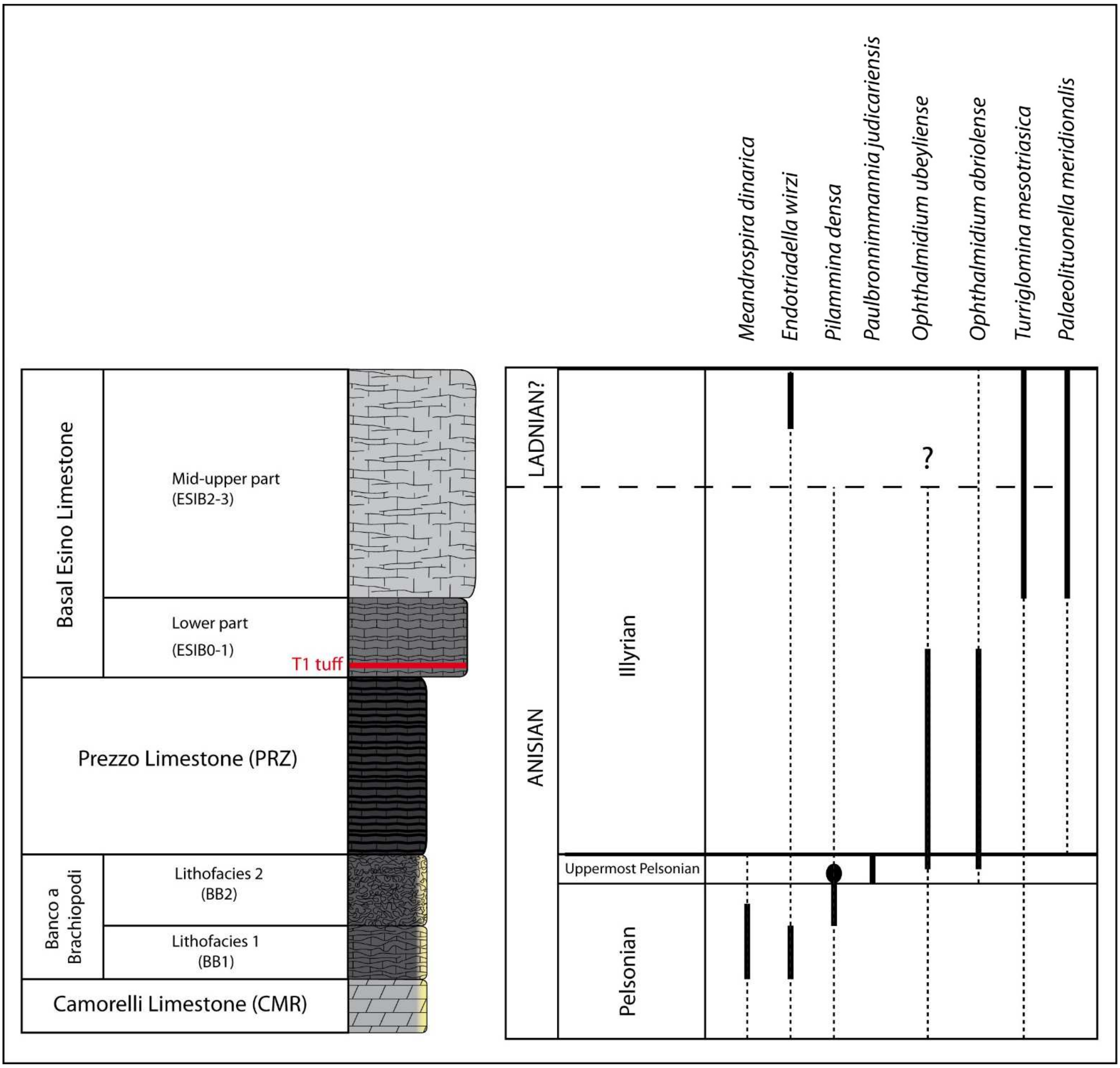


Fig.43 – Distribution chart of the main benthic foraminifers across the studied succession. The black lines indicate the observed presence in the formations/units. The dotted lines indicate the form distribution as result from bibliography. The thickened tract of the Pilammina densa distribution line indicate the Acme interval.

5.3.2 - Volcanics

In the Orobic Alps sinsedimentary tectonics is reported during the upper scythian-lower anisian time but without significant volcanics (JADOUL AND ROSSI, 1982). An important volcanic event is instead recognized near the Anisian-Ladinian boundary and has been related to the rising of northern (Dorsale Badiota-Gardense, Catena Paleocarnica) and southern ("fascia mobile" of BRUSCA ET AL. 1981) ridges. JADOUL AND ROSSI (1982) recognize two main horizons within this volcanic event, characterized by pyroclastic layers (tuffs) in the basinal successions: the lower one is placed at the boundary between Prezzo Limestone and Buchenstein formation; the upper one is instead within the Buchenstein Limestone and may be associated with volcanic sandstones. A more detailed distinction of tuff levels in these basinal successions is provided by the study on the GSSP for the base of the Ladinian stage (BRACK ET AL. 2005). In our study we found few and thin pyroclastic layers intercalated within the Basal Esino Limestone succession, which is at least in part coeval with the Buchenstein formation. In particular, we recognized:

T1) one or two volcaniclastic layers just above the boundary between with the Prezzo Limestone and the Esino Limestone (ESIB0) in the Olmo al Brembo (OB1), Canale delle Betulle (CB1), Mt. Menna (MN1) and Corna Piana (CP2) stratigraphic sections. The volcanic layers are thin (cm-thick), soft and yellowish tuff or fine to mid-grained grey volcanic sandstone (locally with floating blackish mud chips) that are intercalated within dark limestone. The two tuff levels observed at the Olmo al Brembo stratigraphic section (OB1) perfectly correspond with the two levels reported by Balini and Renesto (2012) in the same area and match, according to the authors, the Contrada Gobba tuffs (CGt) of BRACK ET AL. (2005). These last are recognized in the Stabol Fresco section, where they bracket a level with a rich ammonoid fauna dominated by *Asseretoceras camunum* (level SF105A) making possible a solid and valuable link with the ammonoid biostratigraphic scale (*Paraceratites trinodosus* zone, Illyrian; fig.44).

At Corna delle Coste (CC3) stratigraphic section a 5cm yellowish tuffitic (very fine-grained sandstone) layer is reported at the base of a succession that lacks the Prezzo Limestone. The tuff has little black mud chips at the base. Because of its position with respect to the facies below and above, we tentatively attribute also this tuff layer to the Contrada Gobba tuffs.

One or two volcaniclastic layers occur slightly higher, within the ESIB1, in the Piazza Brembana (PB3), Lenna (LN1) and Mt. Arera (AR1) stratigraphic sections. On the base of other correlation evidences (e.g. Ar1 vs CP2 sections; fig.45) we consider also these tuffs equivalent to the Contrada Gobba tuffs.

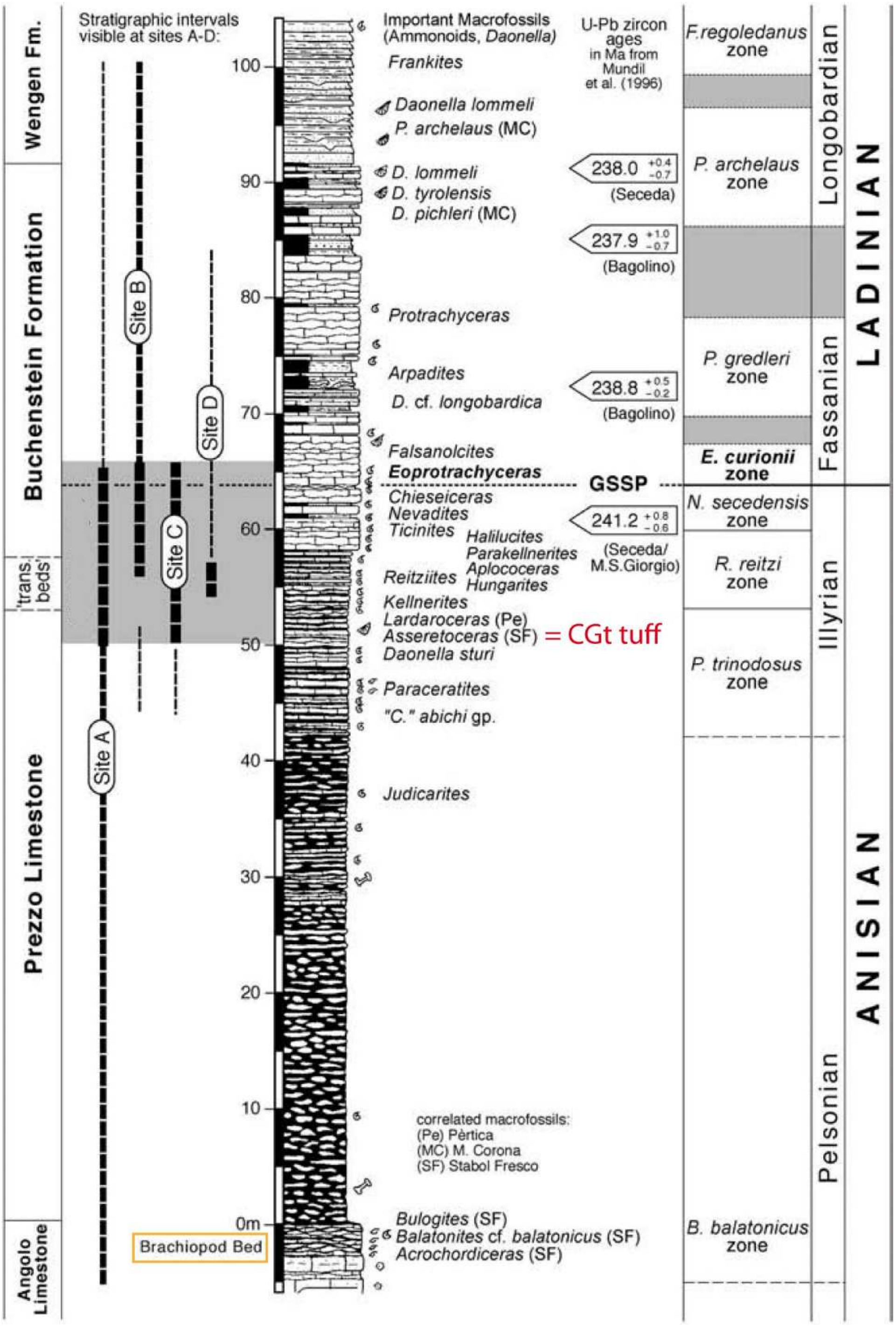


Fig.44 – Summary log of the middle Triassic pelagic succession at Bagolino. Ammonoid zones are indicated on the right. Note the Banco a Brachiopodi (orange rectangle) in the lower part of the succession. The position of the CGt tuffs, corresponding to the T1 tuffs of this study, is indicated (red label) next to the level characterized by the ammonoid Asseretoceras camunum.The tuffs result to be in the Paraceratites trinodosus zone (Illyrian). (from BRACK ET AL. *2005)*

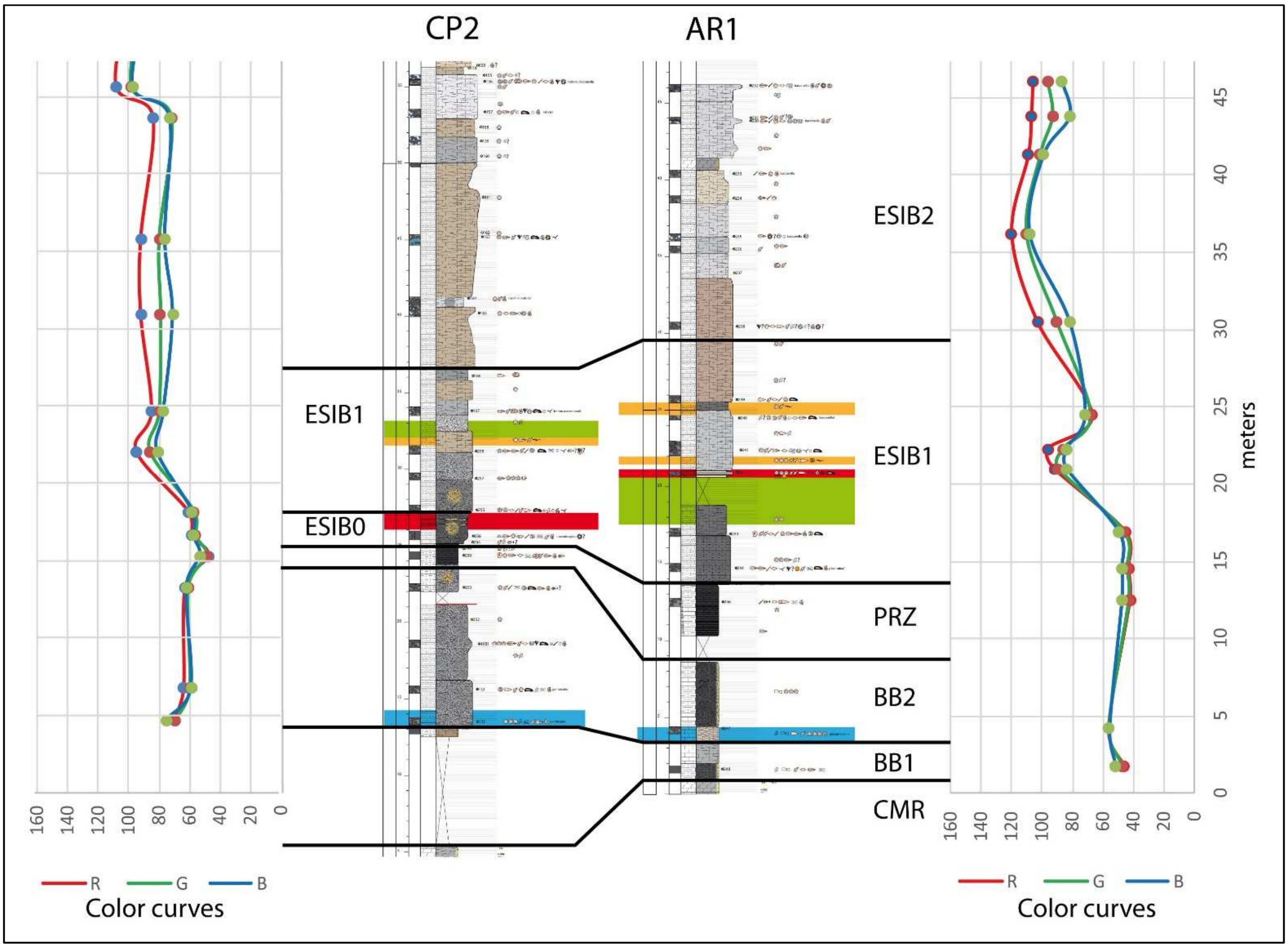


Fig.45 – Correlation of the CP2 and AR1 stratigraphic sections. Stratigraphic units are drawn and labeled in black. In order to support the correlation some layers are highlighted: Blue layer= P.densa Acme; Red layer= T1 tuffs; Green layer= last occurrence of siliciclastic grains in thin section (see chapter 5.3.3); Orange layer= red clay seams. Note the similar trend of the RGB color curves (RGB values were determined in the matrix of collected samples) in the two stratigraphic sections: low values for the both R, G and B in the Banco a Brachiopodi, Prezzo Limestone, Basal Esino Limestone 0 (ESIB0) and lowermost Basal Esino Limestone 1 (ESIB1). Higher values of the three curves, with the R component being slightly higher, is observed in the nearby of clay seams. The RGB values rise (in particular the R component is higher than the other two) passing from the ESIB1 to the ESIB2 unit. The detailed stratigraphic sections are found in the Appendix.

T2) one soft and yellow tuff layer about 20 meters above the Prezzo Limestone top, in the Mt. Menna (MN2) stratigraphic section. The layer is 3 cm thick, intercalated within bioturbated grey limestone. The attribution of this layer to a specific level is not possible for the lack of certain reference points.

T3) three thin (up to 2 cm) yellowish tuff layers in the upper part (ESIB3) of the Basal Esino Limestone at Piazzatorre (PT1) stratigraphic section. These layers are intercalated within doloarenite beds. The attribution of this layers to a specific level is not possible for the lack of certain reference points.

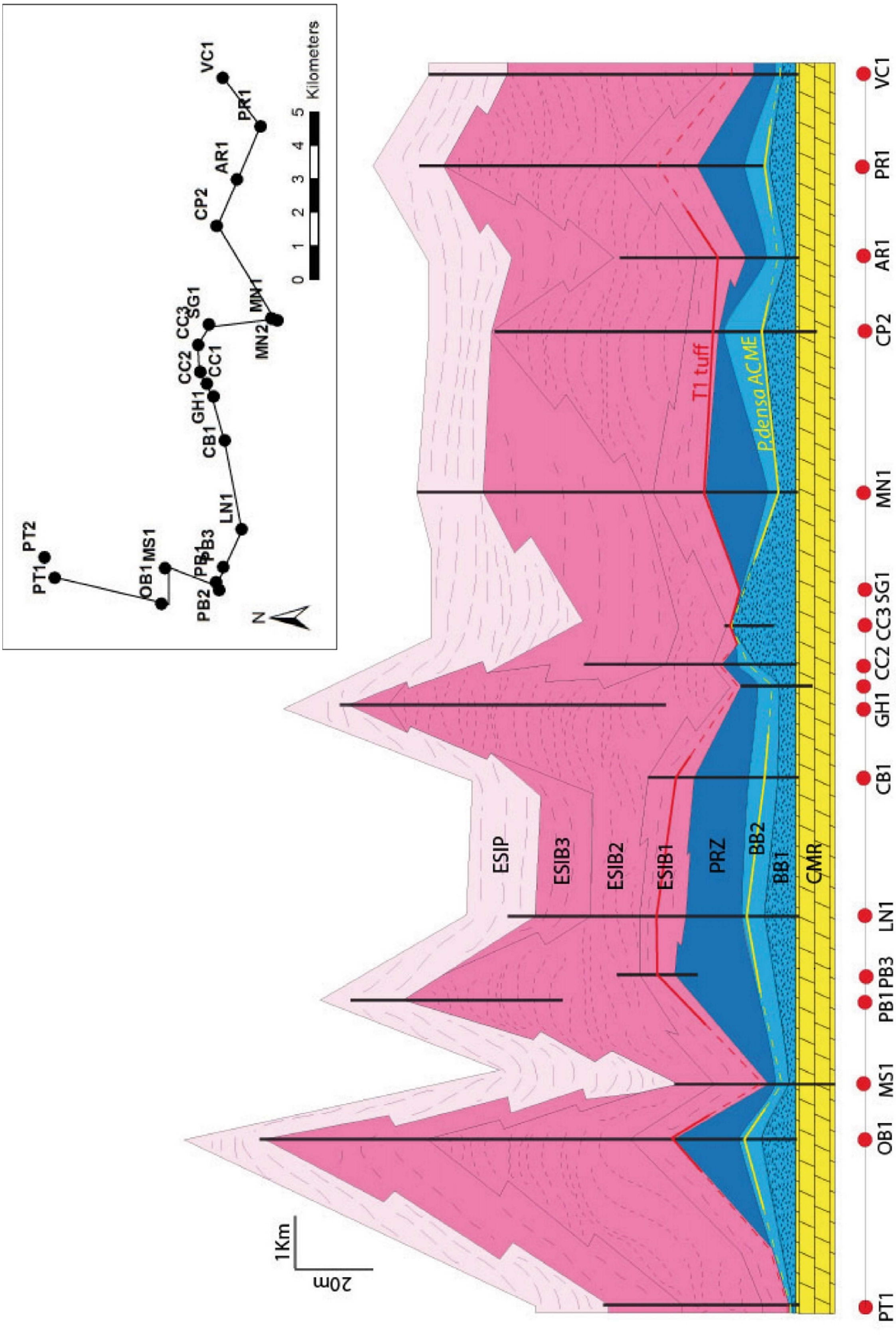
T4) one yellowish tuff layer in the upper part (ESIB3) of the Basal Esino Limestone at Mt. Menna (MN2) stratigraphic sections. The layer is intercalated within doloarenite beds. The attribution of this layer to a specific level is not possible for the lack of certain reference points.

5.3.3 - Siliciclastics

An upward reduction of the terrigenous content was reported by BALINI (1992) within the Prezzo Limestone. In our sections we recognize that siliciclastic influx is present from the drowning of the Anisian Platform till the ESIB1. These siliciclastics, spanning from clay to fine-grained sand, are present as contaminant of limestone and marl (e.g. Prezzo Limestone), as isolated thin beds (e.g. Banco a Brachiopodi) or also as sparse quartz and mica grains that are observed at the microscope (within the limestone microfacies these grains are generally estimated in up to 3% of the total volume). The dimension of these last grains is often less than 100 µm. For such small grains we can consider a very high dispersion potential, both from fluvial plumes as well as from wind. We noticed in fact that in close-range correlations the upward reduction of the siliciclastics (in particular the last occurrence of quartz and mica grains in the thin sections) occur grossly at the same stratigraphic level (fig.45), probably representing a regional signal. Moreover, we recognize that the last occurrence of siliciclastic grains is generally higher moving from East to West, probably reflecting the proximity to the siliciclastic input.

Correlation Scheme 2 - Interpreted

Correlation Scheme 2 (in the next page): The figure shows the interpreted correlation of the stratigraphic sections (labels on the bottom;) according to the formations/units subdivision presented in chapter 5.1 and to the time lines; See fig.16 for quick reference of the formations/units. Time lines are represented by 1) the top of the Camorelli Limestone, 2) the Pilammina densa Acme interval (yellow line), 3) the T1 tuff layer (red line). The scheme shows a lower succession, below the Prezzo Limestone, characterized by weak lateral facies variation: the time lines approximate the unit boundaries, indicating that the evolution of the area was characterized by the vertical succession of extensive environments. The difference in thickness are mainly attributed to differences in subsidence. The higher occurrence of the P.densa Acme interval in the sector west of the CC3 section, indicates slightly different timing in the environmental evolution (later) with respect to the Eastern sector. The succession above the Prezzo Limestone instead show high lateral facies variations: in this part the high unit thickness differences are attributed to the growth of carbonate banks, whose peritidal facies (ESIP) pass downward to lagoon (ESIB3) or slope/margin (ESIB2) facies and ultimately to the shallow shelf (ESIB1) and deep shelf (ESIB0 and uppermost PRZ). Differences in subsidence ratio emphasize the thickness differences between the stratigraphic units. The vertical black lines represent the extension of the stratigraphic sections. Detailed stratigraphic sections are illustrated in the Appendix. CMR: Camorelli Limestone; BB1: Banco a Brachiopodi – Lithofacies 1; BB2: Banco a Brachiopodi – Lithofacies 2; PRZ: Prezzo Limestone; ESIB0-1 to ESIB3: subunits of the Basal Esino Limestone (the subunits ESIB0 and ESIB1 are represented together cause of the thinness of the ESIB0); ESIP: Peritidal Esino Limestone.



PT1
PT2
MS1
OB1
PB1
PB2
PB3
LN1
CB1
GH1
CC1
CC2
CC3
SG1
MN1
MN2
CP2
AR1
PR1
VC1
N
0 1 2 3 4 5
Kilometers
1Km
20m
ESIP
ESIB3
ESIB2
ESIB1
PRZ
BB2
BB1
CMR
T1 tuff
P.densa ACME

6 – DISCUSSION

The inception stage of carbonate platforms is an important but still poorly studied argument: this first phase in the development of a carbonate system is crucial in locating the position of the platform and influences its successive evolution. Unfortunately, related sediments, being in the core part of the carbonate system, are often difficult to be investigated. For this reason and since the study deals with past conditions, the factors that triggered the birth and drove the early growth of a platform are rarely evident. On the contrary most of times their comprehension is puzzling.

Our study investigated an area of about 20 x 5 km in the Southern Alps, a small window in the core zone of the Esino Limestone carbonate platform (middle Triassic). Since the succession has been faulted and shortened by alpine compression in N-S direction, the distance between different stratigraphic sections in this direction could be considerably less than the original one. By contrast the actual E-W distance between the described outcrops probably approximates the original one. The correlation scheme however gives a good qualitative portrait of the vertical evolution of the area as well as the general architecture of the carbonate system and the relationships between different environments.

6.1 – Facies distribution and their control

As can be observed in the correlation scheme most of the stratigraphic sections share a similar vertical evolution. Nonetheless, the thickness of the succession, from the top of the Anisian platform (CMR top) to the base of the Peritidal Esino Limestone (ESIP), is at places very different. For example, if we consider the Monte del Sole (MS1) and Olmo al Brembo (OB1) stratigraphic sections, that are presently distant only about one km, the thickness of the succession is only 30 meters in the first one while it's 136 meters in the second. Despite the two stratigraphic sections are probably closer than originally, this considerable difference must be explained as a result of differential subsidence or lateral facies transition.

Above the Camorelli Limestone top the Banco a Brachiopodi - Lithofacies 2 already shows thickness variations, but this can be due to the related depositional process: storms possibly moved the sediments, accumulating them into a wavy drape on the bottom that resulted in different thickness across the area.

A major thickness variation is observed in the Prezzo Limestone formation, which spans from zero to 18 meters. In particular, considering the Prezzo Limestone thickness we can make a two-group distinction among the stratigraphic sections:

A. stratigraphic sections where the Prezzo Limestone is thicker (more than 10 meters). These are OB1, PB3, LN1, CB1, MN1, PR1.
B. Stratigraphic sections where the Prezzo Limestone is thinner or possibly absent. These are PT1, MS1, CC2, CC3, CP2, AR1, VC1.

Being a basinal formation, The Prezzo Limestone would identify the more subsiding sectors of the area. The possibility that its thickness differences were due to lateral facies variation is unlikely since interfingering with other formations is never observed and the passage from the Prezzo Limestone to the underlying and overlying formations is always rapid and single. Furthermore, looking at the correlation scheme, the time lines below and above the formation (*P. densa* Acme and T1 tuff respectively), when present, run within the same stratigraphic units, proving that the enclosed interval is coeval throughout the study area despite its thickness variations. This suggests that the main factor responsible for the different thickness of the Prezzo Limestone shall be the subsidence ratio. By looking at the distribution of the Prezzo Limestone thickness we can also recognize that a gross tendency in thickness increase exists moving from North to South, where in fact the transition to the basin is realized in the Parina Valley (fig.7; here, above the Prezzo Limestone, instead of the Esino Limestone is the basinal Buchenstein Formation). Not surprisingly, the group A stratigraphic sections more completely record the stratigraphic events: in these sections in fact both the *Pilammina densa* Acme zone and the tuff layers are more frequently observed.

The fact that the two time lines run in specific units/environments about horizontally, without crossing their boundaries, also indicates that in the interval from the top of the Camorelli limestone to the base of the ESIB1, the environments extended uniformly across the study area, which was characterized by quite homogeneous conditions and a nearly flat horizontal depositional surface (coherently bedding surfaces are horizontal). Actually a slight difference in the position of the *P. densa* ACME zone and T1 tuff across the study area exists: west of the Corna delle Coste area the time lines are slightly higher with respect to the East. This suggests that slight differences in subsidence existed between the west and the east basinal sectors, with the west being earlier subsident. Weak lateral facies variations are consequently deduced.

The group B sections by contrast show shorter successions, often lacking any time line useful for correlation with the other ones. These areas were probably characterized by minor subsidence and possibly could have been closer to the first inception nuclei of the Esino platform.

Above the Prezzo Limestone and in particular above the ESIB1 subunit the passage from horizontal bedding to inclined slope-margin bedding surfaces indicates that time lines are no more horizontal. Unfortunately, no useful time lines are available within this part. The clinostratification results into lateral facies transition between the units of the Basal Esino Limestone and the Peritidal Esino Limestone. These units/subunits as well show thickness variations. In order to understand the reason for this, due to the absence of tuffs and biostratigraphic markers, we considered other possible correlation markers. In the comparison between the differently thick OB1 and MS1 stratigraphic sections we considered for the correlation the local last occurrence of siliciclastic grains in thin sections (see chapter 5.3.3) and the presence of silicified shells and authigenic quartz (blue layers in fig.46; the silicification possibly corresponds with the transition Prezzo Limestone – Buchenstein Formation in the basin). The position of these markers at nearly the same position above the Prezzo Limestone top could indicate that different subsidence was no more acting during the deposition of ESIB1 and that the observed thickness variation observed in the succession above the Prezzo could mainly result from lateral facies variation reflecting the existence of articulated topography.

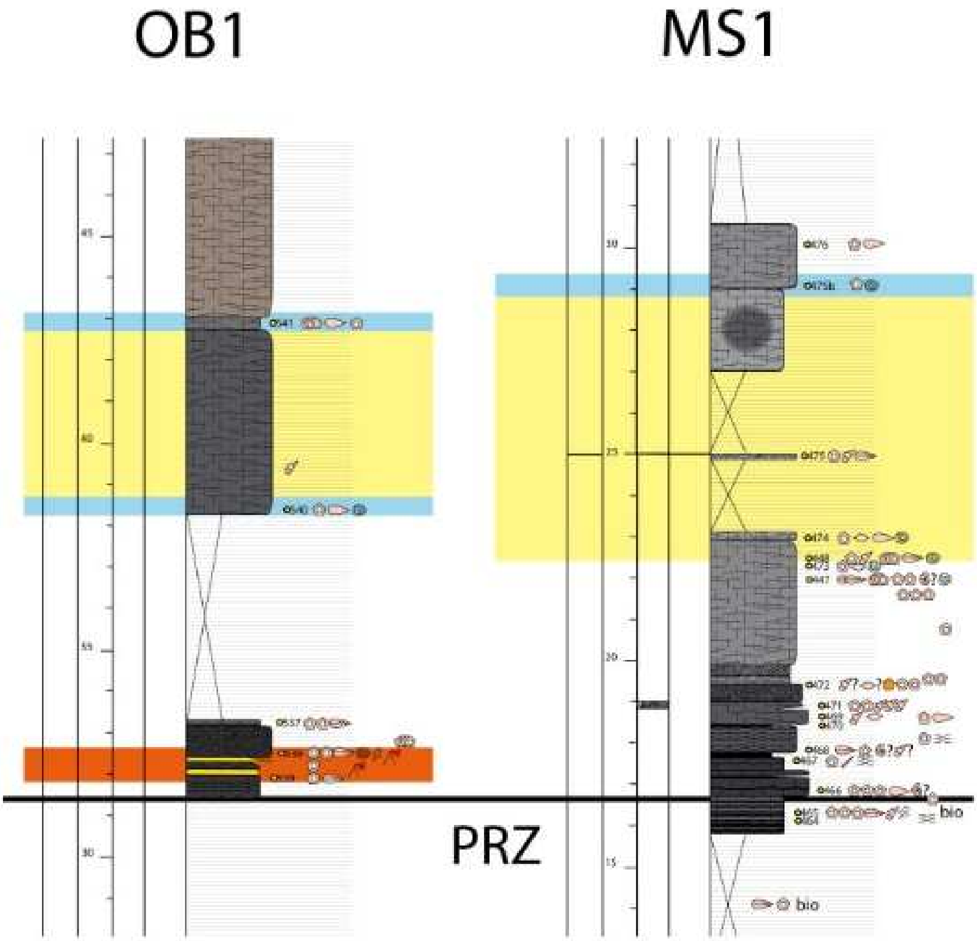


Fig.46 – Proposed correlation of the OB1 and MS1 stratigraphic sections. In order to support the correlation some layers are highlighted: Black horizontal line is the top of the Prezzo Limestone; Red layer is the T1 tuffs in OB1; Yellow layer is the last occurrence of siliciclastic grains in thin section (see chapter 5.3.3); Blue layers indicate the presence of silicification, possibly corresponding, in the basin, to the transition to the Buchenstein Formation. The detailed stratigraphic sections are found in the Appendix.

On the base of these considerations we can say that the observed differences in thickness of the succession in the lower part of the succession, below the tuff T1 level are mostly linked with differences in the subsidence rate. Above the Prezzo Limestone evidence suggest that lateral facies variations were probably a major cause for unit/subunits thickness variations.

6.2 - The drowning of the Anisian Platform

The inception stage of the Esino Limestone platform places on the top of the Camorelli Limestone formation, that is referred to a precedent (Anisian) carbonate platform. This last was a quiet peritidal platform, rich in carbonate mud, subject to intraclast deposition (grains are ooids, oncoids, peloids, carbonate grains) and to stromatolite growth. Fenestral fabric is common and associated with the topmost part of peritidal cycles (short-term subaerial exposure). This area was probably quite far from the high energy platform margin, more to the East (BERRA ET AL. 2011).

Above the light-colored Camorelli Limestone top, which is interested by loferitic breccias deposition, the transgressive dark sediments of the Banco a Brachiopodi (Lithofacies 1, up to 9 m thick) sharply and paraconformably set down, marking the drowning of the peritidal platform. These deposits, which are dominated by marly peloid packstone and wackestone with ostracods and foraminifers, document the onset of different environmental conditions: the change to dark color and mud-richer sediments indicates a decrease in oxygenation level and environmental energy, probably due to reduced water circulation (this is supported by minor evaporite pseudomorphs that are locally observed in thin section). The water depth was still shallow since fenestral fabric is still present. An increase in siliciclastic input is also evidenced by sparse intercalated marl or sandy thin beds as well as by quartz and mica grains within the thin sections. The evidence suggest that the peritidal platform was rapidly turned into a very shallow low-energy lagoon, probably partly restricted by the still surviving platform margin in the East.

The overlying deposits, also belonging to the Banco a Brachiopodi (lithofacies 2, up to 11 m thick), continue the transgressive trend. These are mainly represented by dark bioturbated packstone, rich in skeletal grains (crinoid ossicles the most abundant) and foraminifers (*Pilammina densa*). The observations on the outcrop and the collected material point to interpret the environment as a shallow shelf or lagoon. The rich fossil and bioclast assemblage, together with intense bioturbation indicate a more oxygenated and energetic environment, fully subtidal. On the base of similarities with other fossil deposits we interpreted these sediments as storm-reworked lagoonal deposits. In this phase evidence that the Anisian platform is still somewhere surviving are not found but cannot be excluded.

The transgression finally culminates in the deposition of the Prezzo Limestone (from zero to 18 m thick). The formation consists of a rhythmical alternation of ammonoid-rich black marly limestone beds and marl interbeds. The formation (dominated by carbonate mudstone) is attributed a relatively deep shelf environment, with dysoxic conditions at the bottom, sometimes subject to storm deposition (shell-rich levels). At this time no evidence of still existing platform is found since no platform-derived grains are found within the formation: the Anisian platform could be considered drowned within the study area.

6.2.1 - Mechanisms for Anisian platform drowning

From the analysis of the collected data and the correlation scheme, it results that the drowning of the Anisian platform in the studied area occurred rapidly, successive to short-term subaerial exposure (loferitic breccias). We suggest that the Anisian platform drowned in response to the combined effect of a fast relative sea level rise after platform exposure, coupled with an increase in terrigenous input. This results from the following considerations:

Despite carbonate platform can generally keep the pace even with a fast transgression when they are in healthy conditions (Kendall and Schlager, 1981), relative sea-level variations have been recognized as a major cause of platform demise and drowning. Subaerial exposure in fact can deteriorate the carbonate factory when the process is intense and long-lasted, thus resulting to be a major cause of platform demise and drowning. Szulczewski et al. (1999) for example describe the drowning succession of a Devonian carbonate platform subject to tectonic fragmentation and subsidence, which shares a similar facies evolution with that observed in our succession. The cyclical peritidal facies described by the authors firstly are observed to aggrade in response to fast subsidence, keeping up. The platform is then uplifted and subaerially exposed, resulting in an angular unconformity and paleokarst features. The successive transgression, that was considered less rapid than that experienced during the precedent aggrading phase, led to the drowning of the platform, that was followed first by the deposition of storm-related condensed limestone (packstone and wackestone) with crinoids and cephalopods, and then by deeper-water intercalated clay and limestone (marly wackestone and mudstone) with crinoid ossicles, trilobites, reworked corals and rare brachiopods. A deep and long-lasted subaerial exposure is also responsible for the demise of the Esino Platform at the Ladinian-Carnian boundary. Here the platform was overlaid by reddish carbonate deposits (Calcare Rosso) characterized by karst structures, paleosols, collapse and sedimentary breccias, vadose cements and sedimentary dikes up to 10 m deep and filled with marly limestones. In cases where instead the subaerial exposure is short-time, the platform can recover: this is the case for example of the Belize Shelf during the Holocene (MAZZULLO, 2006), which experienced short-term sea-level variations and karst processes but always recovered after subaerial exposure.

In our case subaerial exposure of the platform is recognized almost everywhere in the study area before of the transgression, but it appears to have been relatively short-term. No karst features are in fact recognized nor soil is developed on its top. Only loferitic breccias, together with fenestral fabric, observed in every outcrop, document the subaerial exposure. Therefore, another cause for the observed rapid drowning would be needed. We suggest that an important factor could have been the increase in terrigenous input. This is considered to be an important factor for present-day tropical carbonate factories (BUDDEMEIER AND HOPLEY, 1988). An increased terrigenous input in fact increases water turbidity on the platform, decreasing light penetration and diminishing the efficiency of the light-dependent biota. KLEYPAS (1996) furthermore stresses the importance of mud settling as a major reef-killing mechanism: this process is more and more effective in the platform interior, where water energy is low and fines settle, while is supposed to be negligible in the platform margin, where water energy prevents fines deposition. We think that this kind of process could be a major responsible for the Anisian peritidal platform demise and drowning after subaerial exposure. The carbonate production on peritidal inner platform, after being weakened by subaerial exposure, was probably halted by terrigenous mud deposition (the encrusting stromatolite morphology are not adapt to face high sedimentation). The platform margin instead could have survived in the first transgressive phase thanks to the higher environmental energy in the form of a discontinuous rim in the East, reducing circulation in the platform interior (Banco a Brachiopodi, Lithofacies 1). The drowning also of the platform margin probably followed during the Banco a Brachiopodi lithofacies 2 phase, incapable of keeping the pace with relative sea-level rise.

The differential subsidence that is recognized in the studied area could be due to a tilting of the Peritidal platform or also to block faulting. The limited thickness differences that are observed in the stratigraphic sections are compatible with both the interpretations. Nonetheless the different evolution that appear to heterogeneously characterize the area better agrees with the faulting of the area in differently subsiding blocks.

6.3 - The Inception of the Esino Limestone platform

After the deposition of the Prezzo Limestone the regressive trend starts and progressively brings back peritidal platform conditions in the area. The first sediments to settle above the Prezzo limestone are bedded dark-blackish limestone belonging to the basalmost Esino limestone (ESIB0). These strata, piling up only about 2 meters, are rich in shells and have microfacies (bioclast packstone and wackestone) comparable to those reported in the storm-related facies of the Prezzo Limestone. Nonetheless these deposits are distinguished from the Prezzo Limestone for not having thick marl intercalations. This basalmost part of the

Esino Limestone represents a transitional facies between the Prezzo Limestone and the Esino Limestone and, analogously to the Prezzo Limestone, is referred to a shelf environment subject to storm deposition.

Above, the stratigraphic interval from the subunit ESIB1 of basal Esino Limestone to the Peritidal Esino Limestone describes the regressive trend where the inception and diffusion of the new carbonate platform is observed. Its thickness ranges from 23 m (MS1 stratigraphic section) to 105 m (OB1 stratigraphic section) but it's generally about 65 meters. The first evidence of the shallowing of the area is recognized in the ESIB1 subunit (up to about 20 m thick): here the facies, mostly peloid packstone with bioclasts and coated grains, are similar to the Banco a Brachiopodi Lithofacies 2, such that at the CP2 stratigraphic section two samples from the two units are hardly distinguishable. Crinoid ossicles return to be frequent. Abundant coated grains are found and are a major characteristic of this unit: the microfacies analysis has revealed that they comprise oncoids and cortoids. These grains were probably typical of this environment and not transported to it. They are in fact abundant only within this part of the succession and progressively reduce upwards and disappear. The faint horizontal bedding of the ESIB1 subunit suggests that these deposits were lying on the flat bottom of the shelf. These kind of sediments have been associated to shallow shelf-lagoon environments. The coated grains were probably formed in consequence of the return to shallower conditions on the shelf bottom, due to the combined effect of algal-microbial growth plus transport by water currents. These deposits sometimes also contain fragments of platform building organisms. Among these *Baccanella* is here the most abundant, but also *Tubiphytes* and calcareous sponges are present. This fact indicates that platform inception was taking place nearby in this phase and that platform material was exported in the surroundings. Unfortunately, in the studied outcrop none of the very early nuclei of the Esino Limestone platform, source of these particles, are observed.

The overlying ESIB2 subunit (up to about 70 m thick) is mainly constituted by intraclast packstone often with platform-derived skeletal grains (less than 5%) and commonly shows faint inclined stratification (about 20°-30°). Most of the platform building biota is found as detrital grains within the sandy sediment. Among these *Tubiphytes* is the most common, followed by calcareous sponges. In-place branching structures (boundstone), produced by *Tubiphytes*, calcareous sponges, corals or problematica, are rare and small. This part identifies the sandy slope and margin of patch reefs/carbonate banks growing on the surrounding shelf. It must be noted that where outcrop conditions allow panoramic view on a large transect of the succession (e.g. CP2, PR1 stratigraphic sections), this part is recognized to be composed by successive phases (see fig. 26 and fig. 30) of bank aggradation-progradation (40-20 m thick each), probably in response to higher frequency sea-level variations.

These deposits pass upwards to the ESIB3 subunit or directly to the Peritidal Esino Limestone. The ESIB3 (from zero to about 50 m thick) includes peloid packstone or grainstone with shallow water oncoids and/or dasycladaceans, which are typical of shallow water lagoons (FLUGEL, 2010). This subunit has faint horizontal bedding. We suggest that these deposits are the filling of shallow lagoonal areas that were realized in between the growing carbonate banks. Its high position in the stratigraphy probably indicates that the required shallow water conditions were achieved only late after the birth of first platform nuclei, when water depth was lower.

The ESIB3, or sometimes even directly the ESIB2, ultimately passes upwards to the Peritidal Esino Limestone, that results quite similar to the Camorelli Limestone. The Peritidal Esino Limestone is composed by light-colored bedded limestone comprising stromatolites and ooidal-oncoidal calcarenites (packstone and grainstone). Fenestral cavities and loferitic breccias are newly present. Tepees and marine cements are also present. This unit makes up a gross part of the successive mature Esino Limestone platform. The sedimentary environment is an inner platform area, with quiet algal flats and tidal channels.

The accomplishing of peritidal conditions occur quite high in the succession, at least 25-30 meters above the Prezzo Limestone top (MS1 stratigraphic section) and commonly more than 40 meters (60 m at CP2 section). This fact indicates that the first inception nuclei were probably fully subtidal patch reefs. Only later, the growing carbonate banks were able, by filling the depositional space, to reach the dimensions and elevation necessary to develop peritidal facies on top. By looking at the outcrop of CP2 section we can hypothesize that the height of the first patch reef above the basin for having peritidal facies on top could be about 30-40 meters. This would be also the approximate water depth. Carbonate banks like this one should have been at least several tens of meter wide.

6.3.1 - Mechanisms for Esino platform inception

None of the studied outcrops intersects one of the very early nuclei, nonetheless information can be indirectly gained by the collected data. The nucleation of the carbonate platform necessarily occurred during the ESIB0 or ESIB1 deposition, that is after the deposition of the Prezzo Limestone (max transgression) and prior to the deposition of ESIB2 (representing the aggradation-progradation of the margin-slope facies of carbonate banks).

The ESIB0 is the first regressive subunit. Despite the strong similarity with the Prezzo Limestone in the microfacies and the environmental interpretation (deep shelf), the lack of significant marl intercalations indicates a sensible increase in the carbonate-vs-siliciclastic ratio with respect to the previous formation. This difference could be explained with:

- a decreased terrigenous input due to an environmental factor
- an increased carbonate production due to the birth of the new platform nuclei

Among the two possibilities, we think the most likely is the decrease in terrigenous input, which also could have favored, due to the reduction of the water turbidity, the subtidal nucleation of the carbonate platform. An increased carbonate production is unlikely because of the lack of platform-sourced material within the ESIB0 microfacies.

The shallow shelf or lagoon deposits of the ESIB1subunit also store skeletal grains from margin-builder biota thus indicating that during its deposition the inception of the Esino Limestone platform had occurred. These skeletal grains, that are found mixed with other skeletal debris from benthic biota and with coated grains, were probably transported from storms. The composition of detrital margin-related biota indicates that *Baccanella floriformis* and to a less extent *Tubiphytes* were pioneers in platform inception. *Baccanella floriformis* probably lived in a deeper environment than *Tubiphytes*, as can be deduced by its higher abundance in the lower part of the Basal Esino Limestone (fig.31).

The inception of the platform shall have required some little areas of stable substrate on which the first nuclei could start to grow. Three different origin for these areas have been considered:

1. Structural highs

2. Sedimentary highs (new or relict)
3. Undrowned Anisian platform banks

1- Despite tectonics appear to have been a leading factor in driving thickness differences during the deposition of the drowning succession, the realization of tectonics highs cut into the precedent substrate where first margin biota could initiate the platform growth, as for the Latemar platform (MARANGON ET AL. 2011), seems here unlikely. Since the Prezzo Limestone deposits were not consolidated a considerable tectonic displacement between blocks would be required in order to expose better consolidated rocks (the first competent substrate could have been the Banco a Brachiopodi – lithofacies 2, which shows early cementation). Nonetheless no Triassic faults are observed in the outcrop nor fault-scarp breccias are recognized and can support this scenery.
2- Another possibility is that the first nuclei emplaced over cemented reliefs from the ESIB1 or Banco a Brachiopodi – Liethofacies 2 phases. The storm reworking process in fact, characteristic of these units, is capable of moving the sediments creating a wavy bottom with small reliefs on which the first reef could have develop. Moreover the deposits from these units are rich in skeletal material and are observed to have been prone to early cementation, thus they could effectively built a solid base for carbonate platform inception. BERRA ET AL (2011) suggest a similar mechanism but place the inception on the cement-rich and fossil-rich deposits that are famous as "Lumachella di Ghegna" (TOMMASI, 1911, 1913), belonging to the Esino Limestone in the Roncobello area. Nonetheless JADOUL ET AL (1992) report this rocks well above (80-100 m) the top of the Prezzo Limestone, thus this rock body could not be identified as the substrate for platform inception. In our fieldwork this rock was not found in place then its exact stratigraphic position cannot be reported from us.
3- The possibility that the Anisian platform did not drowned completely and passed upwards into the Esino Limestone is another possible solution. This could explain the source of the carbonate mud during the Prezzo Limestone deposition. Nonetheless we can say that no detrital grains from the platform are observed during the Prezzo deposition. The passage form one platform to another is observed in thw western sector. The Prezzo Limestone is comparable with the gulf of the Belize shelf.

We suggest that the inception of the carbonate platform more likely occurred on cemented skeletal accumulations that were built during the deposition of the ESIB1 subunit or during the deposition of the Banco a Brachiopodi – lithofacies 2 but were not completely submerged by the Prezzo Limestone deposition (this could have occurred in the less subsiding areas).

The inception of the carbonate platform, provided the favorable stable substrate, was probably favored by the relative sea-level fall and from the observed upward decreasing siliciclastic input from the top of the Prezzo Limestone to the Peritidal Esino Limestone. The inception of the platform cannot be related with a change in the biotic community since the carbonate factory is not different from that described in the older Camorelli Limestone (GAETANI, 1989).

6.3.2 - From inception to coalescence

The fact that the very first inception nuclei of the platform are never observed in our outcrops probably indicates that they were few and small with respect to the shelf area. These nuclei are thought to be initiated as fully subtidal patch reefs and could have been only tens of meters wide. A present-day analogue to this situation could be the Great Barrier Reef, where a number of subtidal patch reefs punctuates the backreef area (fig. 47). From this situation the observed evolution evidences the growth of carbonate banks on the surrounding shelf area, increasing in width and height, finally developing peritidal facies on top.

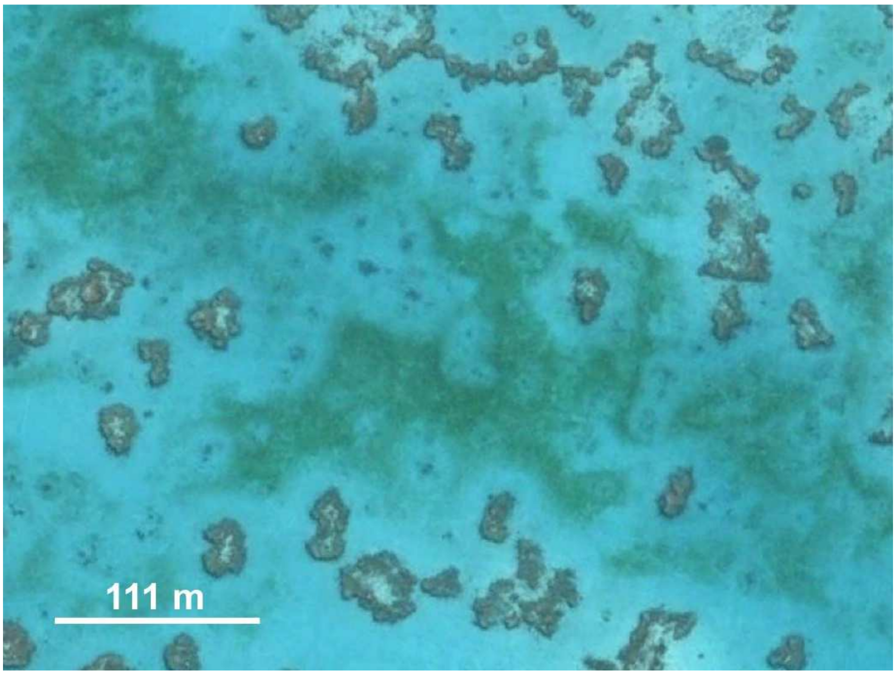


Fig.47: Patch reefs in the backreef area of the Great Barrie Reef (Australia). (From https://biology4me.files.wordpress.com)

Where favorable exposure allows the observation of depositional geometries these carbonate bodies are observed to grow in successive phases, in response to lower-order sea-level fluctuations, with upward-reducing thickness. These carbonate banks thus result to be up to 40 meters high and hundreds of meter wide. The continued carbonate bank growth finally led to the filling of the depositional space and peritidal conditions spread all over the area.

A similar coalescing trend is reported by BACHTEL ET AL. (2011): the authors studied the early evolution of a Miocene carbonate platform in the Browse Basin (Australia) by means of 3D seismic imagery (fig.48). This method allowed the reconstruction, through horizontal cross sections of the areal evolution of the platform. This is observed to be initiated as sparse circular or elliptical (current-dominated environment) buildups 1 km in diameter and 100 meters high. The emplacing of the buildups was not coeval and was focused on structural highs induced by faulting and differential subsidence of the underlying succession. The progradation of the buildups margins resulted in successive phases of buildups coalescence, enhanced also by the growth of new buildups in the seaways between the larger platforms that resulted in the reduction of current flow and the sedimentation and filling of the seaways with sediments.

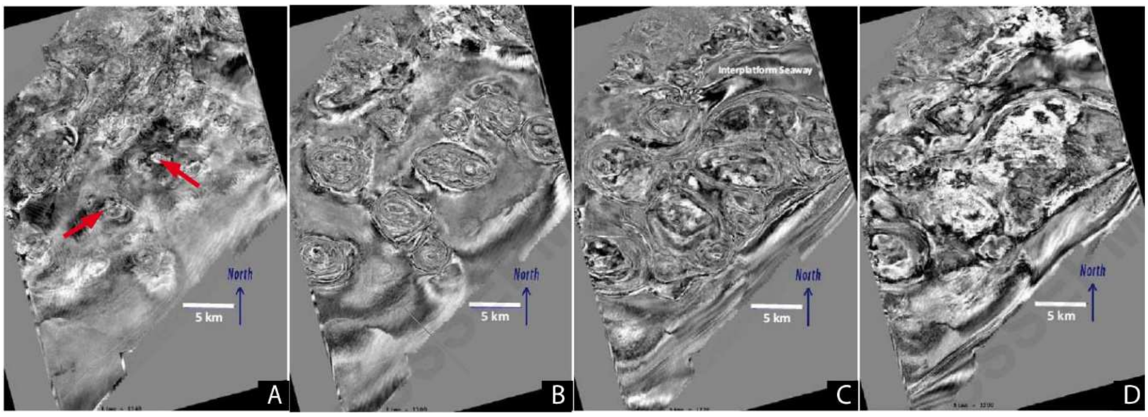


Fig.48: Horizontal slices of the 3D seismic model of a Miocene carbonate platform from the Browse Basin (Australia). The frames from A to D show the growth of the carbonate platform from the inception of sparse nuclei (A, red arrows) to the coalescence of carbonate banks into a single platform (D). (from BACHTEL ET AL. 2011)

6.3.3 – Comparison with the Latemar Platform

The observation of the inception stage of the Esino Limestone platform allowed us to describe the architecture of the carbonate system from the deeper shelf facies up to the peritidal facies. For a comparison we can look at the coeval Latemar platform as was described by MARANGON ET AL. (2011). The fig.48 below summarizes the equivalent deposits and their differences. See also fig.49 for the cross section of the Latemar Platform.

Environment	**Early Esino Platform** (*this study*)	**Early Latemar Platform** (MARANGON ET AL. 2011)	**Comparison**
Shelf / Toe of the slope	ESIB1: Peloid Packstone with skeletal grains (crinoid ossicles, echinoid spines, bivalves, gastropods, radiolarians?) and coated grains. Detrital problematica are locally found.	S3-4: Wackestone to packstone-grainstone rich in skeletal grains (bivalves, radiolarians, echinoderms, gastropods, lumps and fragments of microbial boundstone). Local geopetal structures.	The facies are similar. Breccias are lacking in our deposits and also in the Latemar during the early phase (except the fault-scarp breccias) as a consequence of the low relief.
Slope / Margin	ESIB2: Packstone to grainstone with scarce skeletal grains (also calcisponges, *Tubiphytes*, *Baccanella*, Corals). Various types of boundstone including Tubiphytes calcisponges and clotted peloidal micrite are limited. Cemented cavities (fibrous radial calcite) are found within the boundstone.	M1-5: Various types of boundstone generally dominated by microbial carbonate or clotted peloidal micrite. Calcisponges and *Tubiphytes* are frequent. Botryoidal cement can be present in cavities. Grainstone can be present as well, containing detrital also detrital calcisponges, *Tubiphytes* and calcimicrobes. S1-2: Boundstone with Tubiphytes, calcimicrobes and diffuse radiaxial fibrous cement in locally extensive cavities.	In our deposits boundstone are far less common with respect to the Latemar. Cements as well are less common. Nonetheless the same biota is recognized to most of the boundstone types.
Shallow Lagoon	ESIB3: Packstone and grainstone with oncoids and dasycladaceans. Cemented cavities (fibrous radial calcite) locally occur.	P3-7: Wackestone, packstone and grainstone with oncoids and dasycladaceans; boundstone with clotted peloidal micrite and radiaxial fibrous cements.	The facies are similar. The Latemar facies are attributed to Outermost Platform.
Inner Platform	ESIP: Packstone and grainstone with ooids and oncoids; stromatolitic boundstone. Fenestral cavities, tepees. Botryoidal fibrous calcite.	P1-2: Dolostone and wackestone with stromatolites. The facies exhibit traces of vadose diagenesis. Tepees.	Our facies seems to be more high-energy.

Fig.49: The table summarizes the facies characteristics from the different environment in the early Esino Limestone carbonate platform and in the coeval Latemar platform.

The Latemar platform developed under different conditions with respect to the Esino Limestone: it is in fact an isolated platform that grew on a tectonic high cut into precedent carbonate formation (Contrin Formation). The early Latemar was larger, hundreds of meter width and a few hundred meters high. Nonetheless most of their facies are similar: the shelf/toe of the slope facies are comparable. The margin and slope facies share the same main biota but the Latemar has more boundstone and cements. The early Esino Limestone slope and margin facies are in fact dominated by grainy detrital sediments. Lagoonal facies that were realized between carbonate bank in the inception stage of the Esino Limestone are quite comparable with the outer platform facies of Marangon et al. (2011), referred to the "outermost platform". The Esino peritidal facies area more high energy, probably due to the presence of more channels running through the inner platform area.

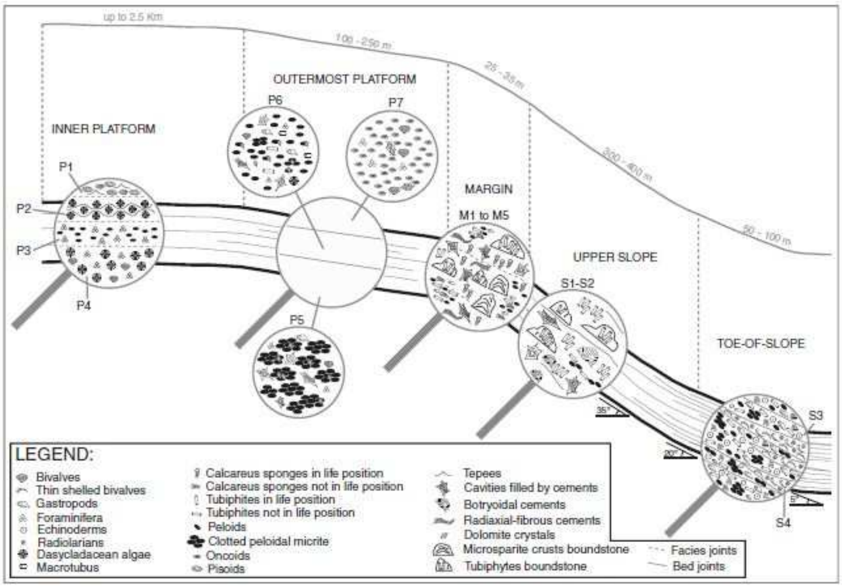


Fig.49: Composite schematic cross section of the Latemar platform with facies distribution. Figure not to scale. From MARANGON ET AL. 2011.

6.4 - The Inception Stage of the Esino Platform: a multistep model

The evolution of the area illustrated in the Correlation Scheme 2, recording the inception stage of the Esino Limestone carbonate platform after the demise of the Anisian platform, can be better represented in a 4 step story:

1- Drowning of the Anisian peritidal platform (fig.50-A and B)
   The top of the peritidal platform (Camorelli Limestone) is briefly exposed. Successive transgression rapidly leads to the drowning of this platform sector for the detrimental effect of subaerial exposure and for the negative effect of terrigenous mud influx in this area. The platform margin, more in the East probably survived longer, in the form of a discontinuous rim that drove low-energy condition and restricted circulation on the platform top (Banco a Brachiopodi, Lithofacies 1; fig.50-A) which

experienced very shallow water lagoonal deposition. The continued transgression probably led to the drowning of the platform margin too. On the platform top the transgression increased water depth while the drowning of the marginal rim allowed more open, high-energy and oxygenated conditions. The sediments, reworked by storms, bioturbated and rich in skeletal grains (mostly crinoids and forams) are associate with a shallow lagoon (Banco a Brachiopodi, lithofacies 2; fig.50-B). The transgression culminated with the deposition of the Prezzo Limestone, indicating relatively deep dysoxic shelf conditions, with occasional storm deposition (carbonate mud with intercalated shell lags). In this phase no traces of nearby carbonate platform are found.

2- Nucleation (fig.50-C)
The regressive trend terminates the Prezzo Limestone deposition and restores shallower conditions: the area is newly in the reach of storm reworking and the deposits again bioturbated and rich of skeletal grains (mostly crinoids). Shallow shelf –lagoonal conditions are restored again (ESIB1). Coated grains are abundant and produced here by the combined algal-microbial activity and current-wave reworking. During this phase, above stable skeletal debris reliefs (formed by storms or relict from a precedent phase) the first platform nuclei set down, dominated by the forms *Baccanella* and *Tubiphytes*. These first nuclei punctuated the surface of the shelf and were fully subtidal.

3- Growth of the nuclei (fig.50-D)
After the inception of the platform nuclei, the carbonate banks (ESIB2) expand over the surrounding areas growing in width and height till developing peritidal conditions on their top (ESIP). This carbonate banks have an estimated height above the shelf of 40-20 m and slopes about 20-30° and grow in more phases in response to sea-level variations. The shallow-water protected areas that are realized in between the carbonate banks are turned to shallow lagoons, where oncoids and dasycladaceans develop (ESIB3). The water depth in this phase, coincident with the height of the carbonate banks, is estimated less than 40 meters, progressively reducing upwards in the succession.

4- Coalescence (fig.50-E)
The growth of the carbonate banks outpaces the generation of depositional space and ultimately fill it up, leading to coalescence of the carbonate banks in a single wide carbonate platform. The peritidal conditions that are typical of the topmost part of the banks (ESIP) spread all over the area.

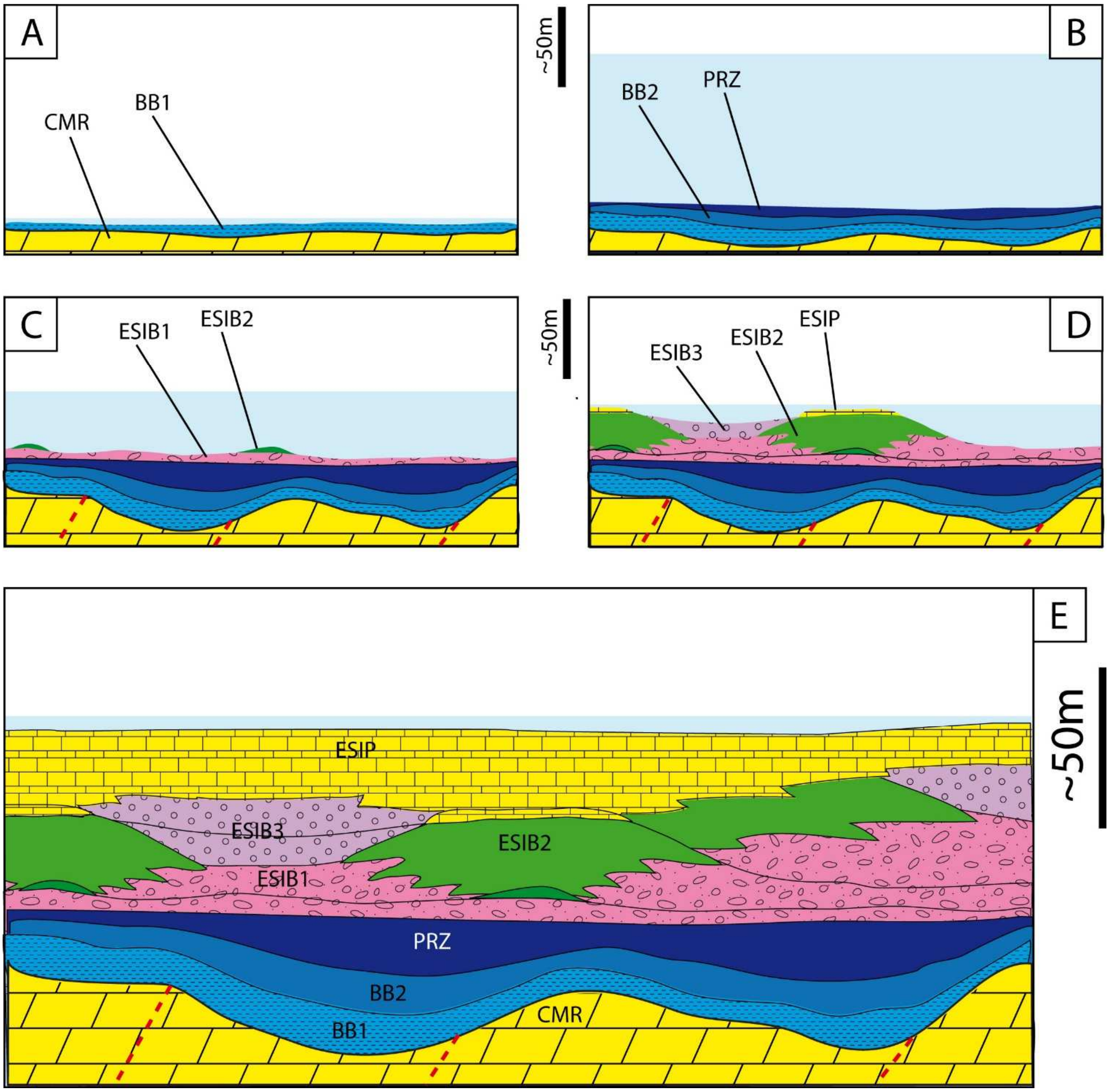


Fig.50: Step-model evolution of studied succession. A) The initial drowning of the Anisian platform: the inner platform (CMR -Camorelli Limestone) is substituted by a very shallow lagoon (BB1 - Banco a Brachiopodi – Lithofacies 1); B) The drowning of the platform is completed and the depositional surface is brought deeper: first fully subtidal lagoon or shallow shelf conditions (BB2 - Banco a Brachiopodi – Lithofacies 2) are developed. Then deeper shelf conditions are reached (PRZ - Prezzo Limestone). C) The inception of the Esino Limestone platform is realized on skeletal debris reliefs. The platform nuclei progressively expand: the margin-slope facies (ESIB2) advance toward the basin, while platform material spreads on the surrounding shallow shelf areas (ESIB1). D) The platform nuclei expand over the basinal areas and reach the water level forming inner platform areas (ESIP). Between the carbonate banks, in the protected shallow areas, lagoons are developed (ESIB3). E) The carbonate bank fills up the depositional space with their deposits and rapidly expand and merge in a single wide inner platform area

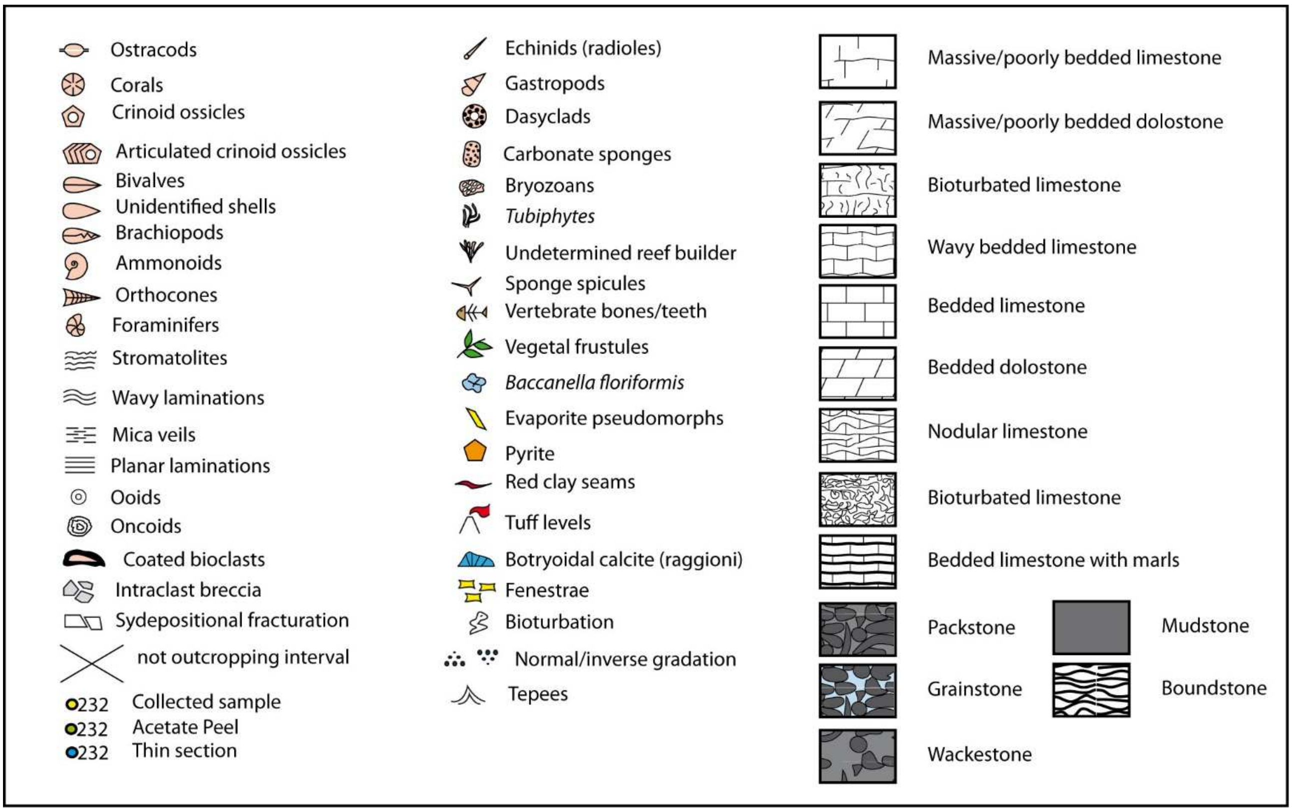
7 – CONCLUSIONS

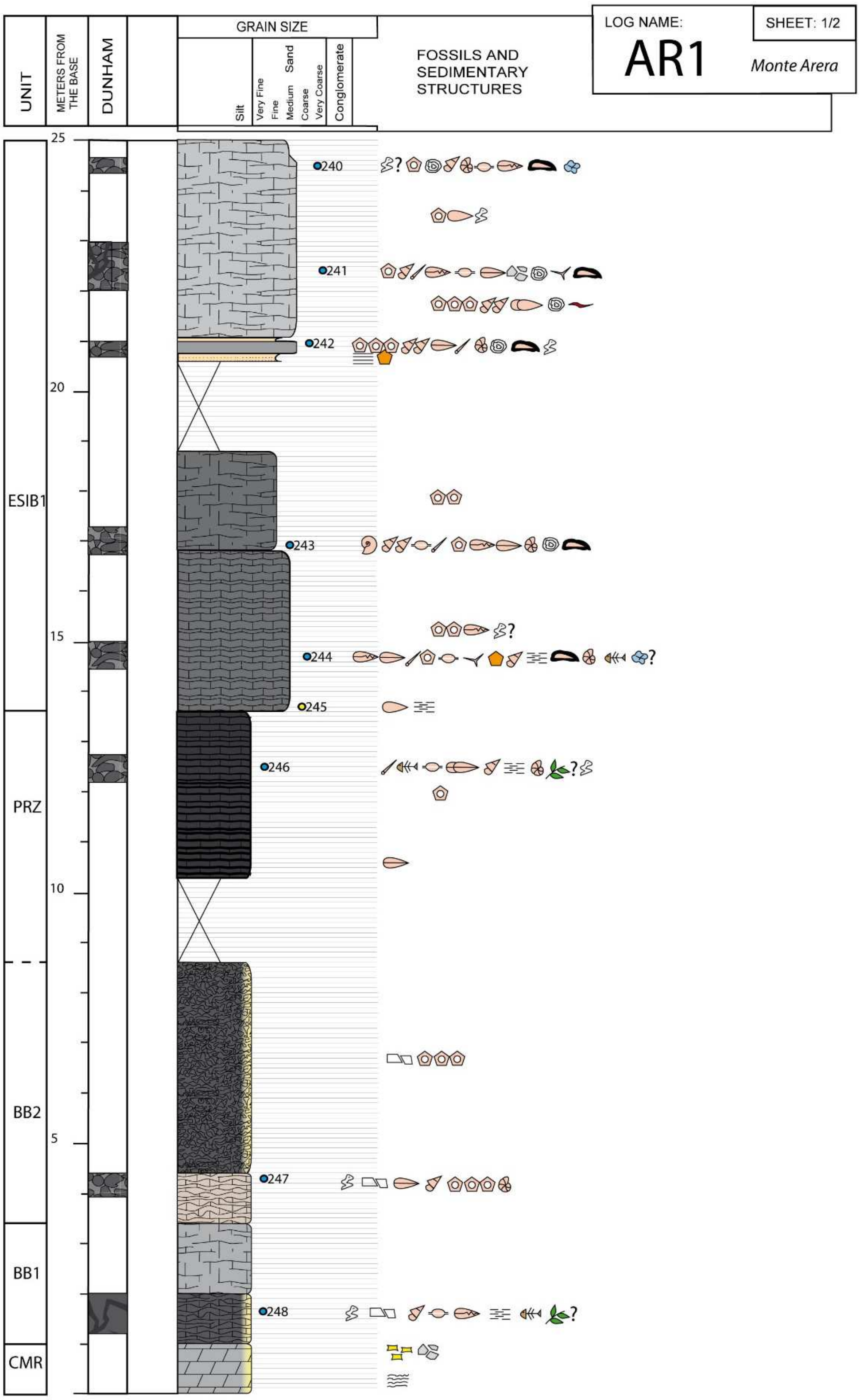
- The Anisian peritidal platform (Camorelli Limestone) was drowned after a subaerial exposure and the successive transgression. We suggest that the demise of the platform was caused by combined factors: the carbonate factory was only weakened by subaerial exposure, that was short-term (no soils or karst features are developed on its top); a major factor for the platform drowning is thought to have been the increased siliciclastic input, that increased turbidity and, above all, led to terrigenous mud settling in the low-energy inner platform area, suppressing stromatolite growth. In the platform margin, the carbonate factory was probably able to keep up thanks to the higher environmental energy (preventing fines deposition) and to biotic forms more adapted to sustain high sedimentation rates (erected forms). The realization of a discontinuous rim was probably responsible for the observed sudden transition from peritidal conditions to dark and low energy (locally restricted) very shallow lagoonal conditions (Banco a Brachiopodi, Lithofacies 1). The continued transgression then progressively rose water depth, moving the depositional surface first to higher energy storm-reworked lagoonal condition (Banco a Brachiopodi, Lithofacies 2) and ultimately to relatively deep shelf conditions (Prezzo Limestone). The complete drowning of the Anisian platform is probably realized during the deposition of the Lithofacies 2 of the Banco a Brachiopodi.
- The Inception of the Esino Limestone is successive to the Prezzo Limestone deposition. The very first platform nuclei are not observed in the studied outcrops, nonetheless we suggest they started on stable skeletal debris reliefs formed by storm reworking during the deposition of the ESIB1 subunit (basal Esino Limestone). These first nuclei were probably few and scattered above the shelf surface and were fully subtidal. The pioneer forms that started these carbonate nuclei were probably the microproblematica *Baccanella* and *Tubiphytes*, which are the first and most common platform-building organisms to be found in this moment. The favorable conditions that triggered their growth would be, other than relative sea-level fall, the reduction of siliciclastic input, which is observed to decrease upwards in the succession. Later, as a result of carbonate bank growth (ESIB2) and relative sea level fall, peritidal facies formed on their top (ESIP). We suggest that these larger carbonate banks were 30-40 meters high above the shelf and hundreds of meters wide. Lagoonal conditions were realized in between the carbonate banks where water depth was shallow (ESIB3). The growth of these carbonate banks in the area outpaced the rate of generation of depositional space leading to coalescence and the emplacing of peritidal conditions all over the area. A single widespread peritidal platform was then newly realized.
- Two important correlation lines, one being the Acme interval of the benthic foraminifer *Pilammina densa* and the other being a tuff layer (T1 tuff, corresponding to the CGt Tuff), are recognized in the area and were found in many of the stratigraphic sections. CGt Tuff is reported also in coeval basinal successions and will allow the calibration of the studied succession with the Ammonoid biostratigraphic scale.
- Thickness differences in the order of several meters characterize the formations of the studied interval. These differences can be explained by differential subsidence or by lateral facies variations. We could recognize that in the stratigraphic interval that goes from the top of the Camorelli Limestone to the lowermost part of the Basal Esino Limestone (basal ESIB1), due to the fact that time lines run through the area always in about the same stratigraphic level and in the same

environment, that the observed differences in thickness are mainly due to diverse subsidence rates. Furthermore, it results that the same environmental conditions were present all across the area, indicating that, as supported also by common horizontal bedding, a flat-lying topography characterized the area and environmental changes coevally interested all the area. The stratigraphic interval which goes from the ESIB1 to the Peritidal Esino Limestone lacks instead strong time lines. Anyway some hypothetical time lines observed in the ESIB1 suggest that in this interval lateral facies variation would be instead a major cause for the observed thickness variations.

8 – Appendix: Stratigraphic sections

Legend

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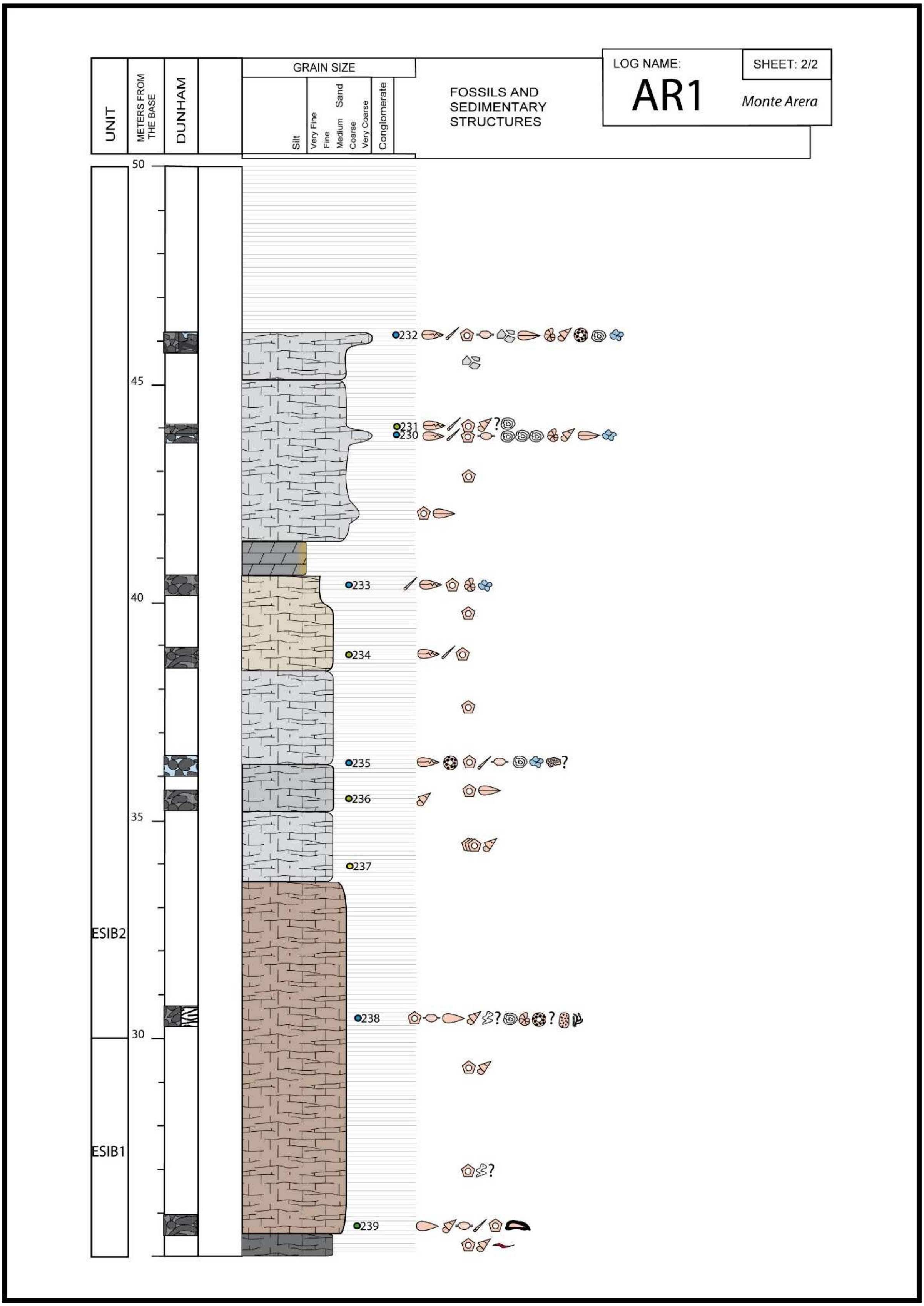
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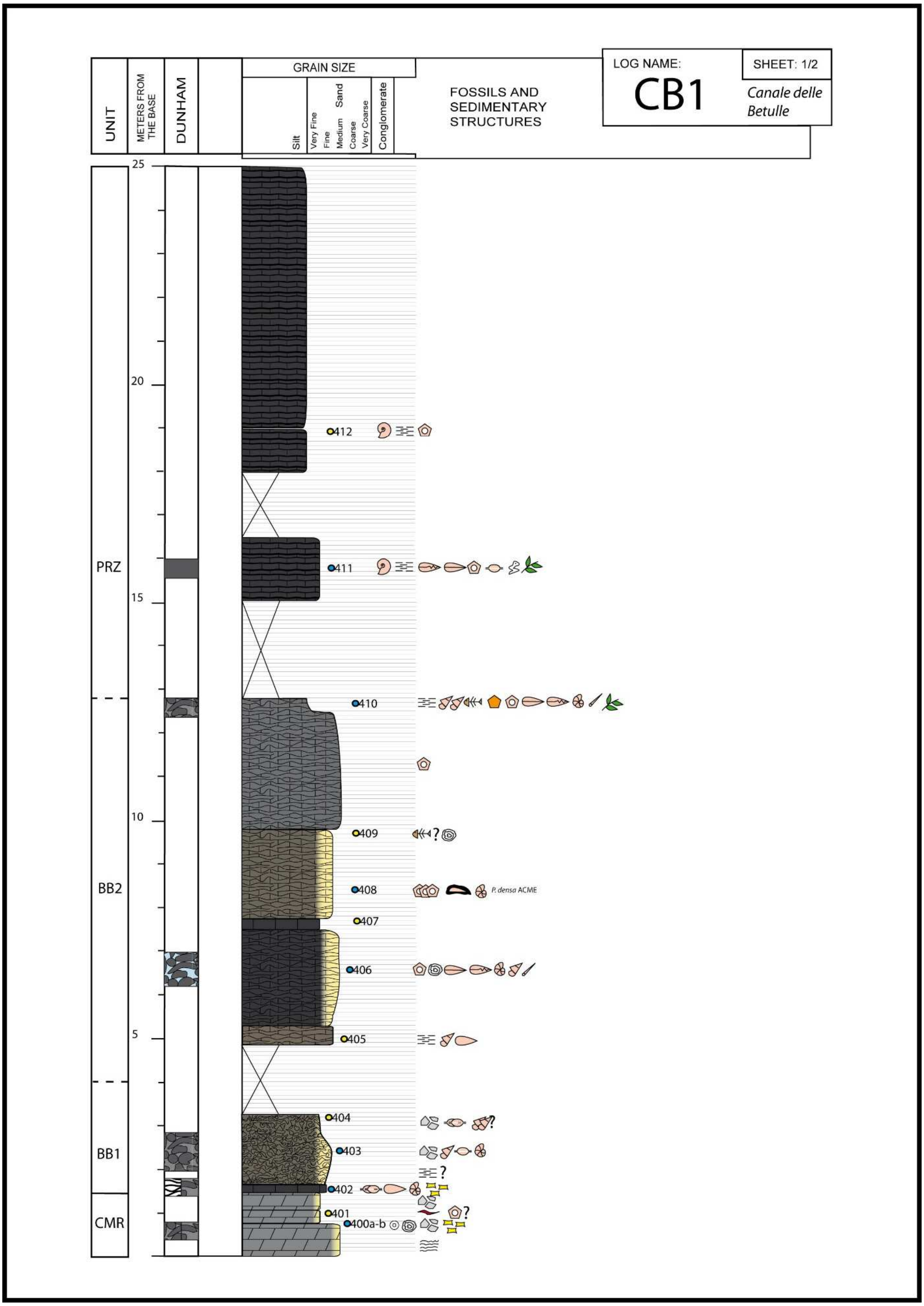

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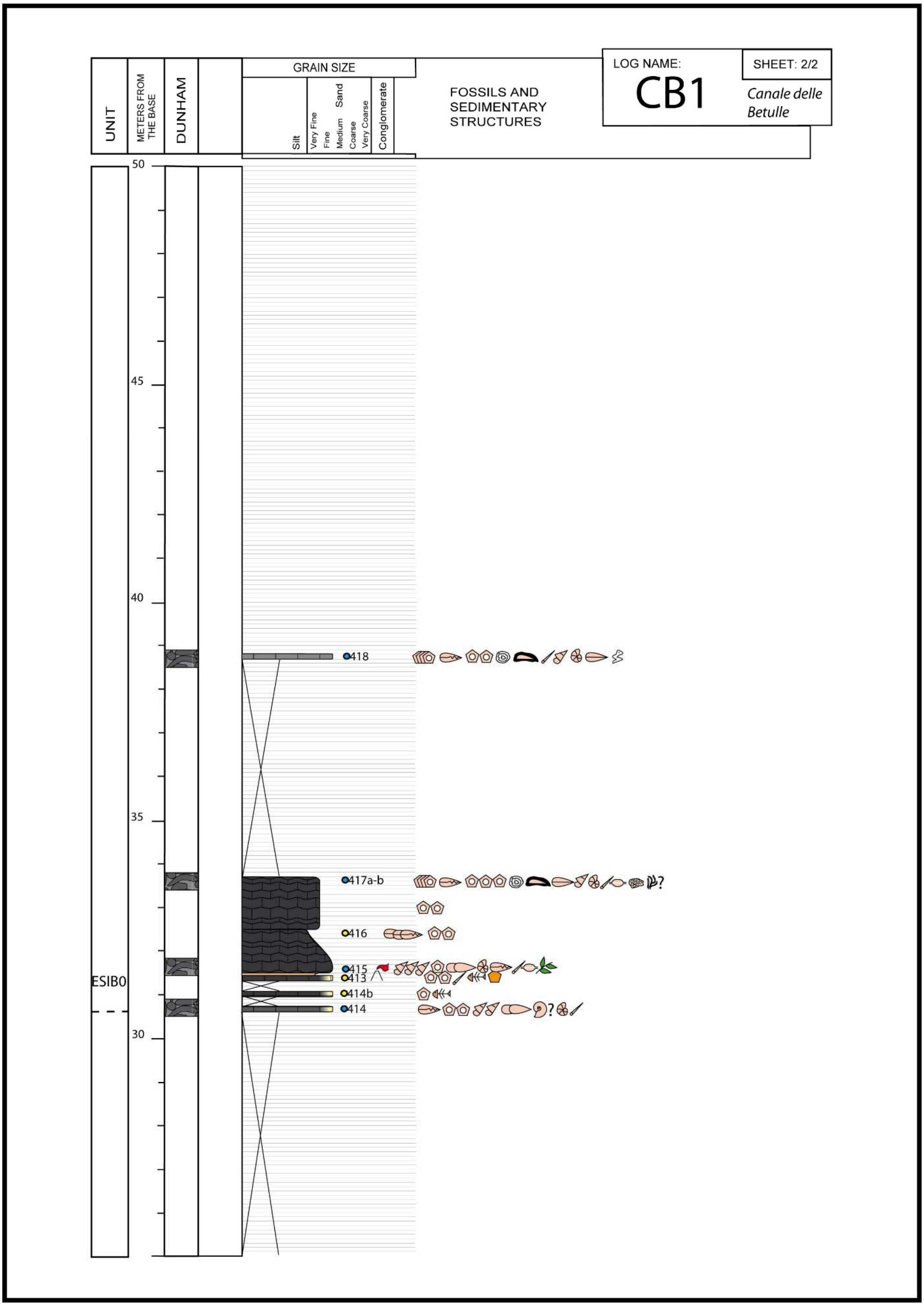
P. densa ACME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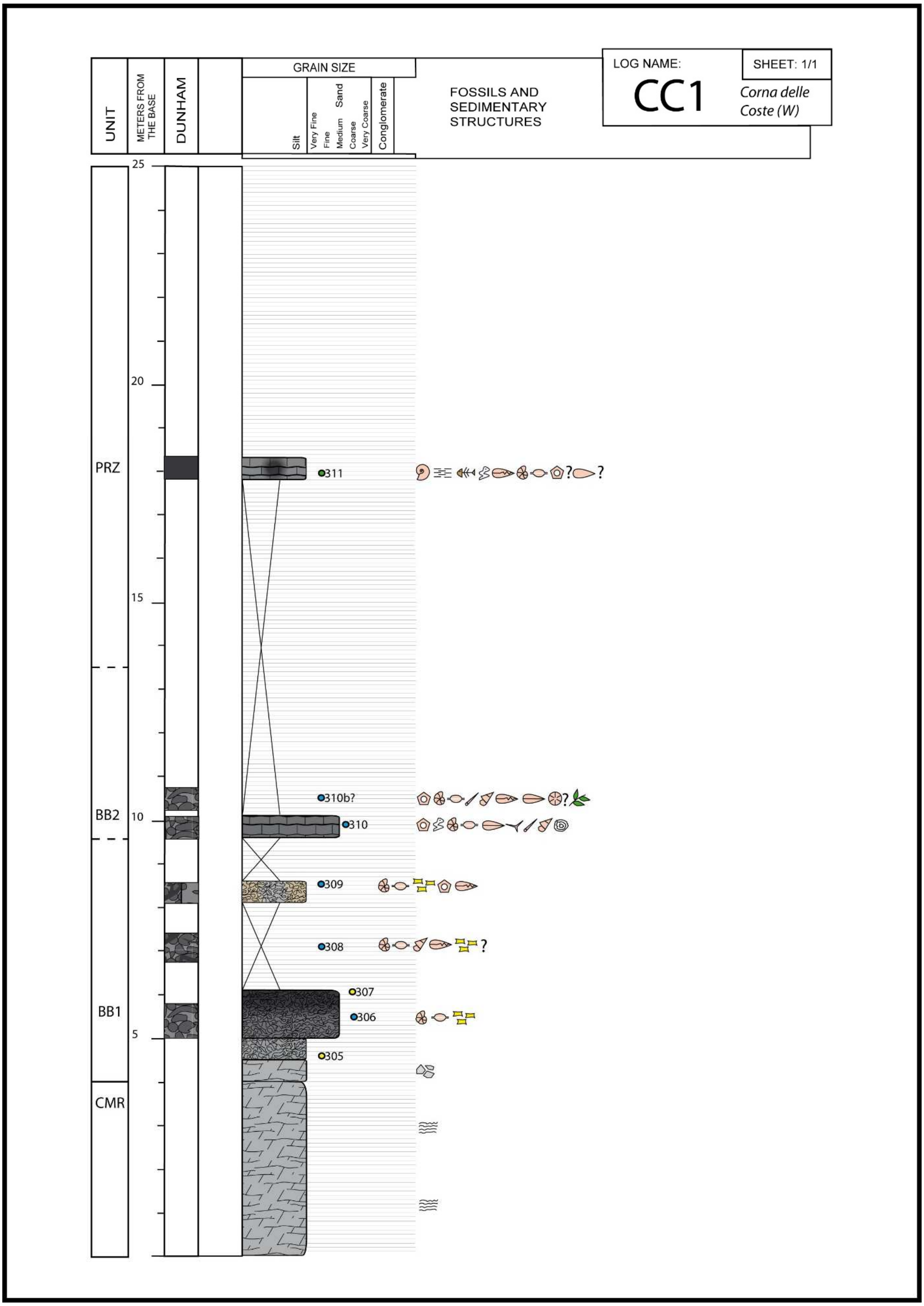
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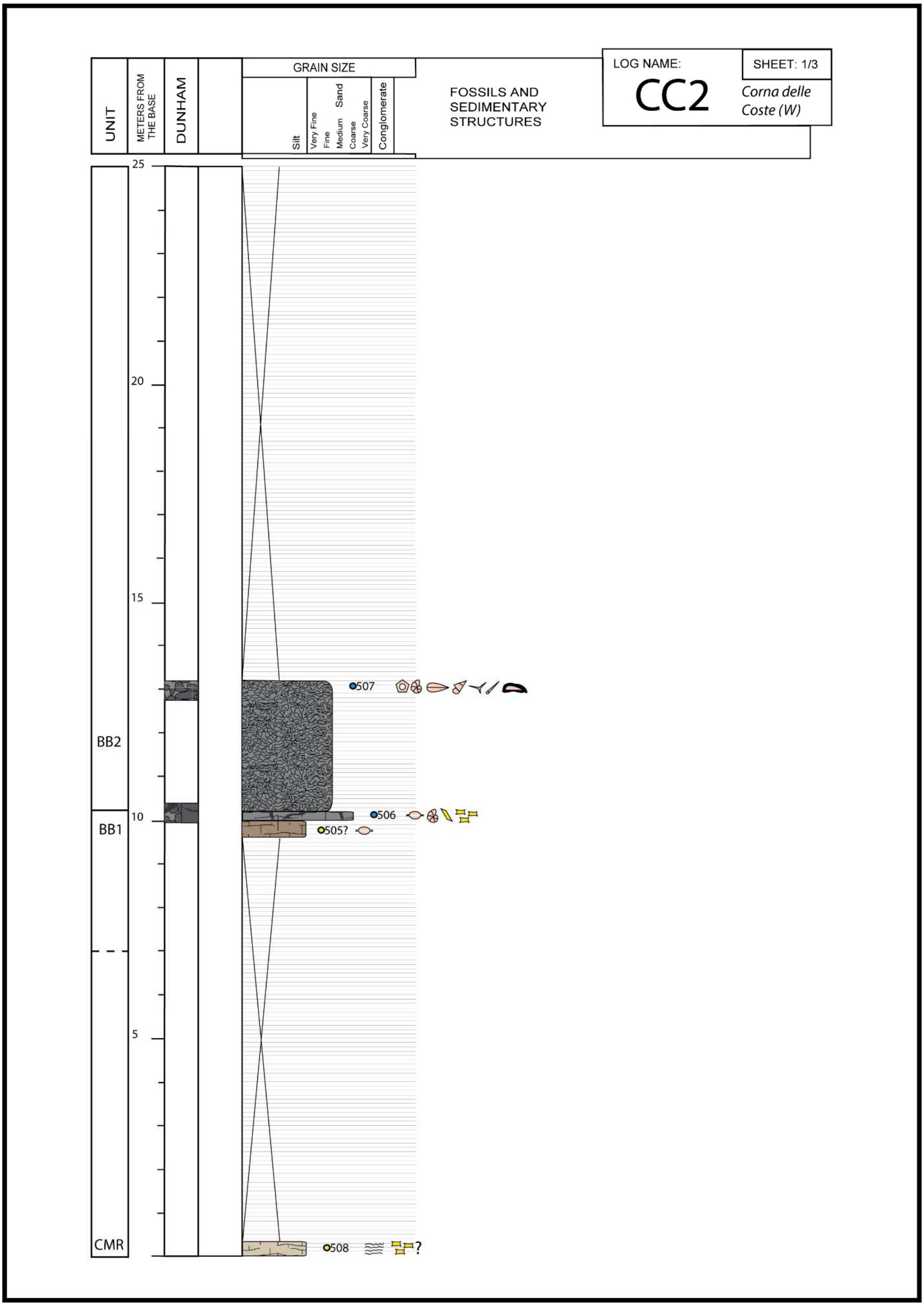

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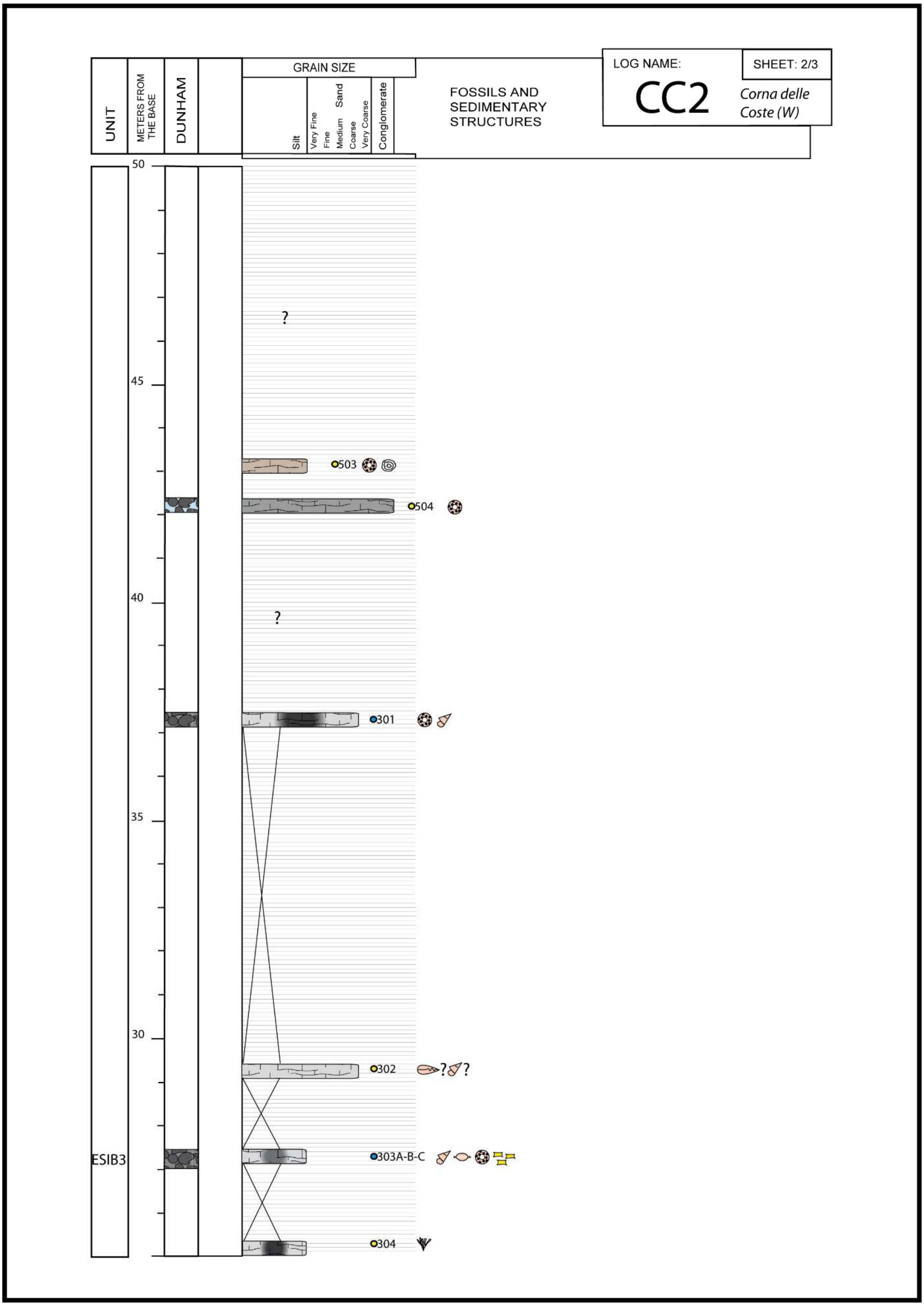

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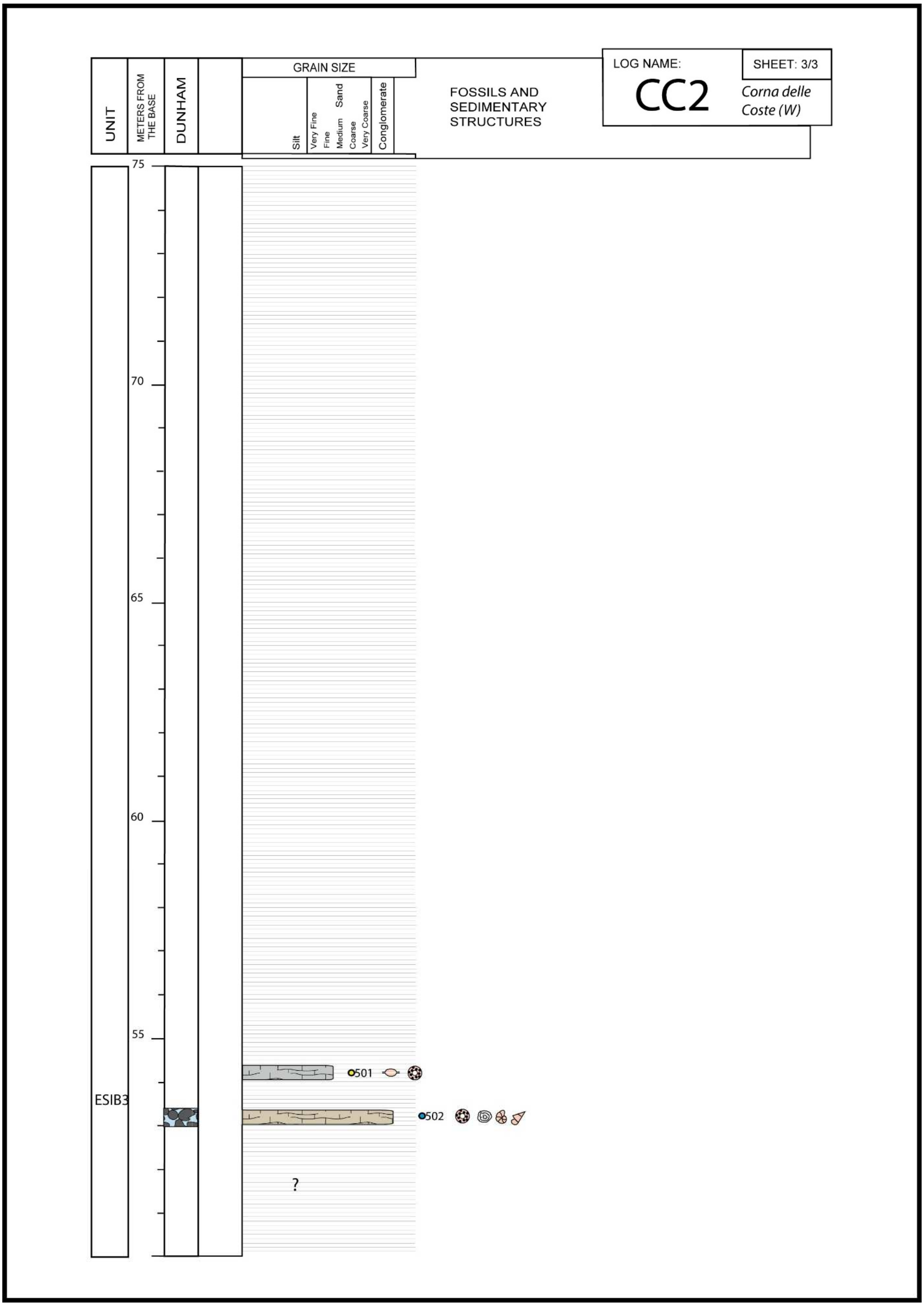
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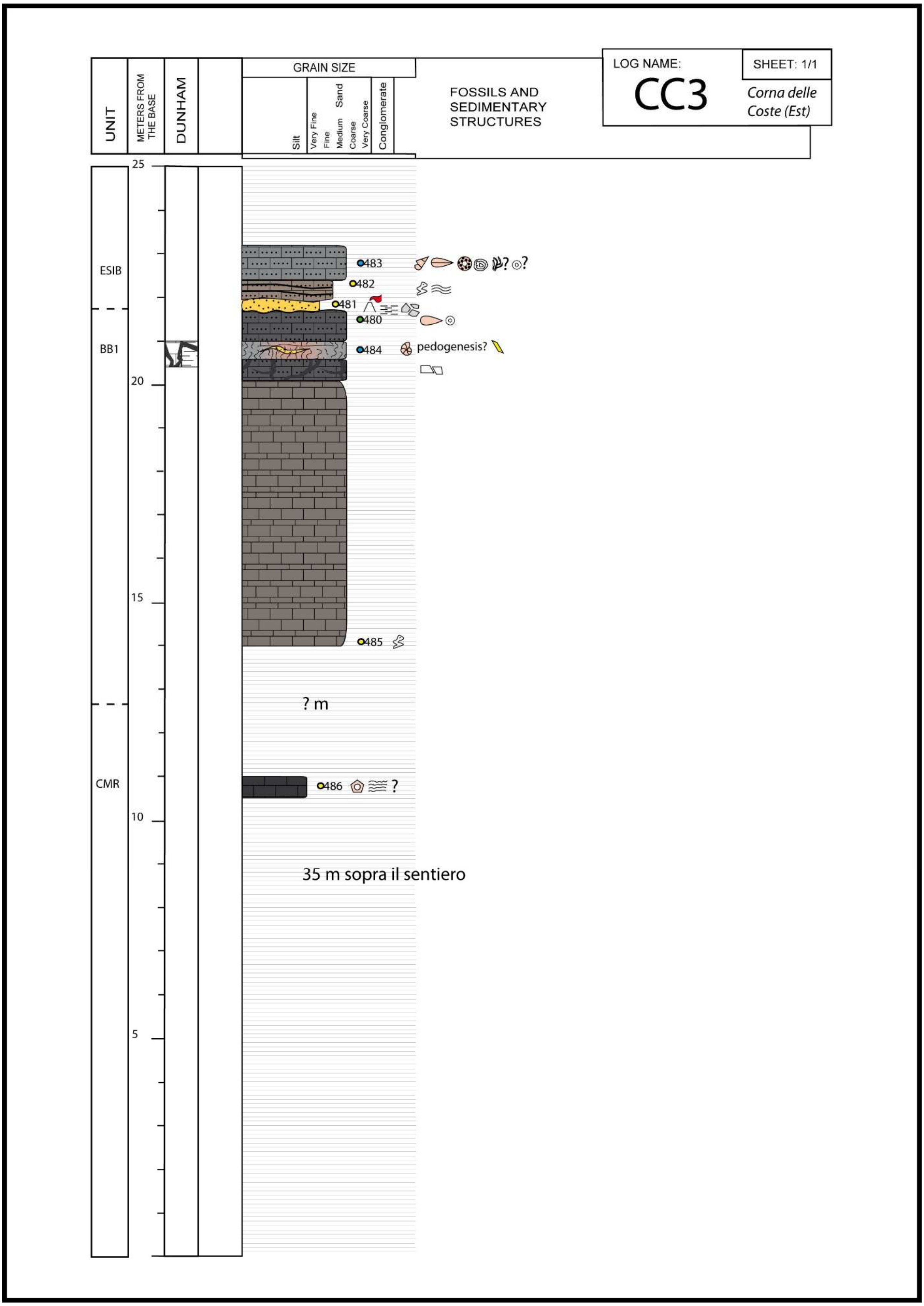
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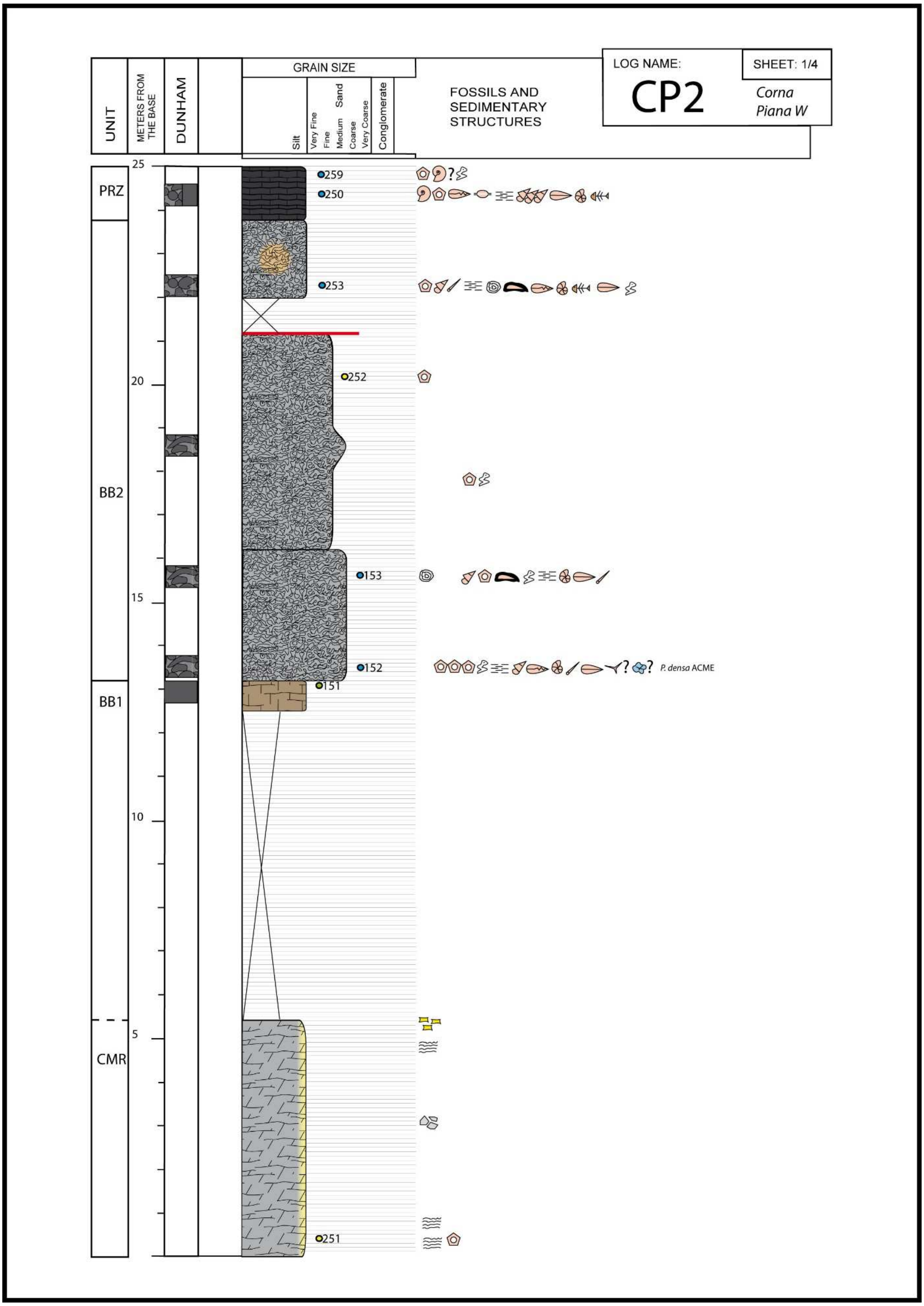

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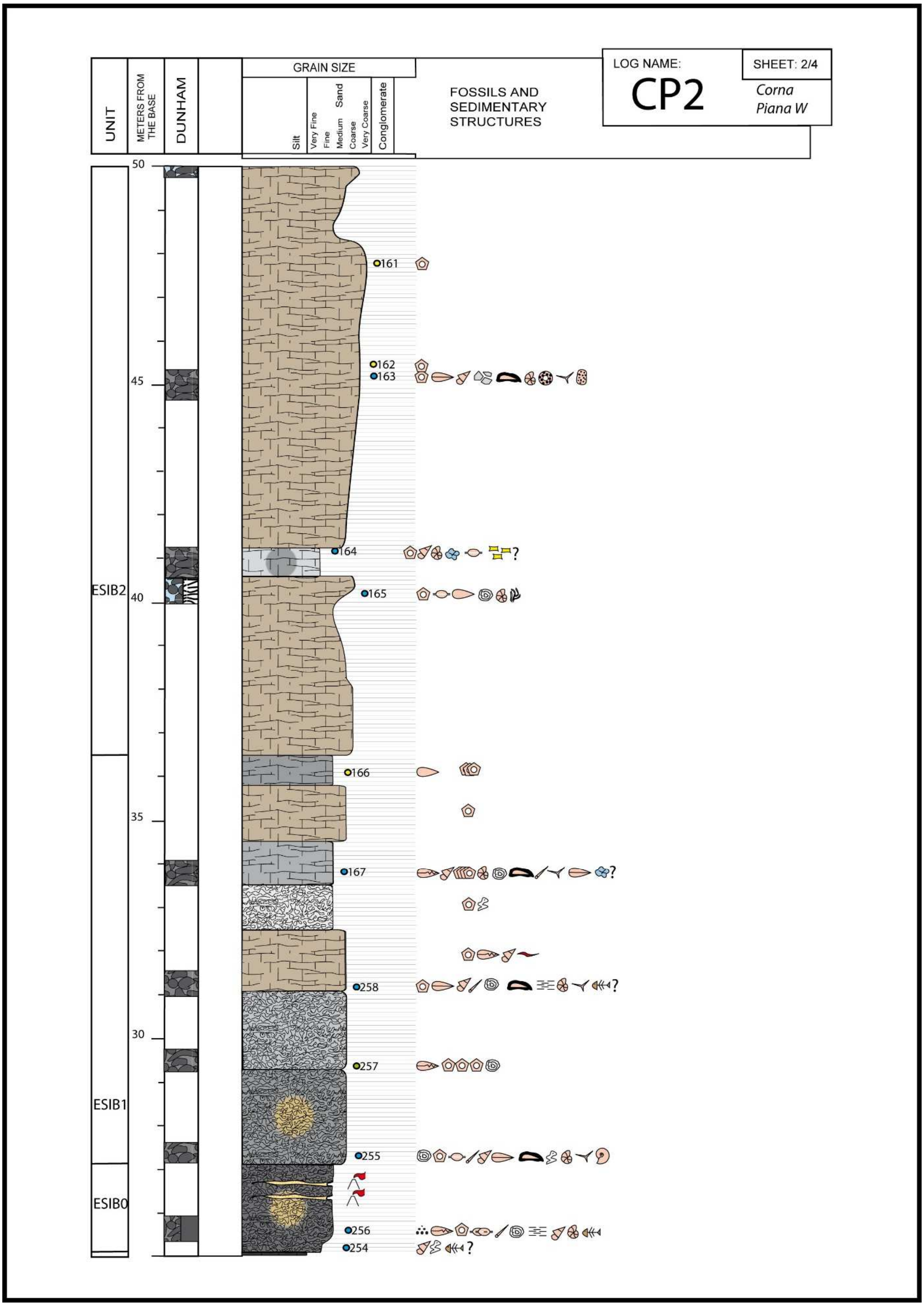
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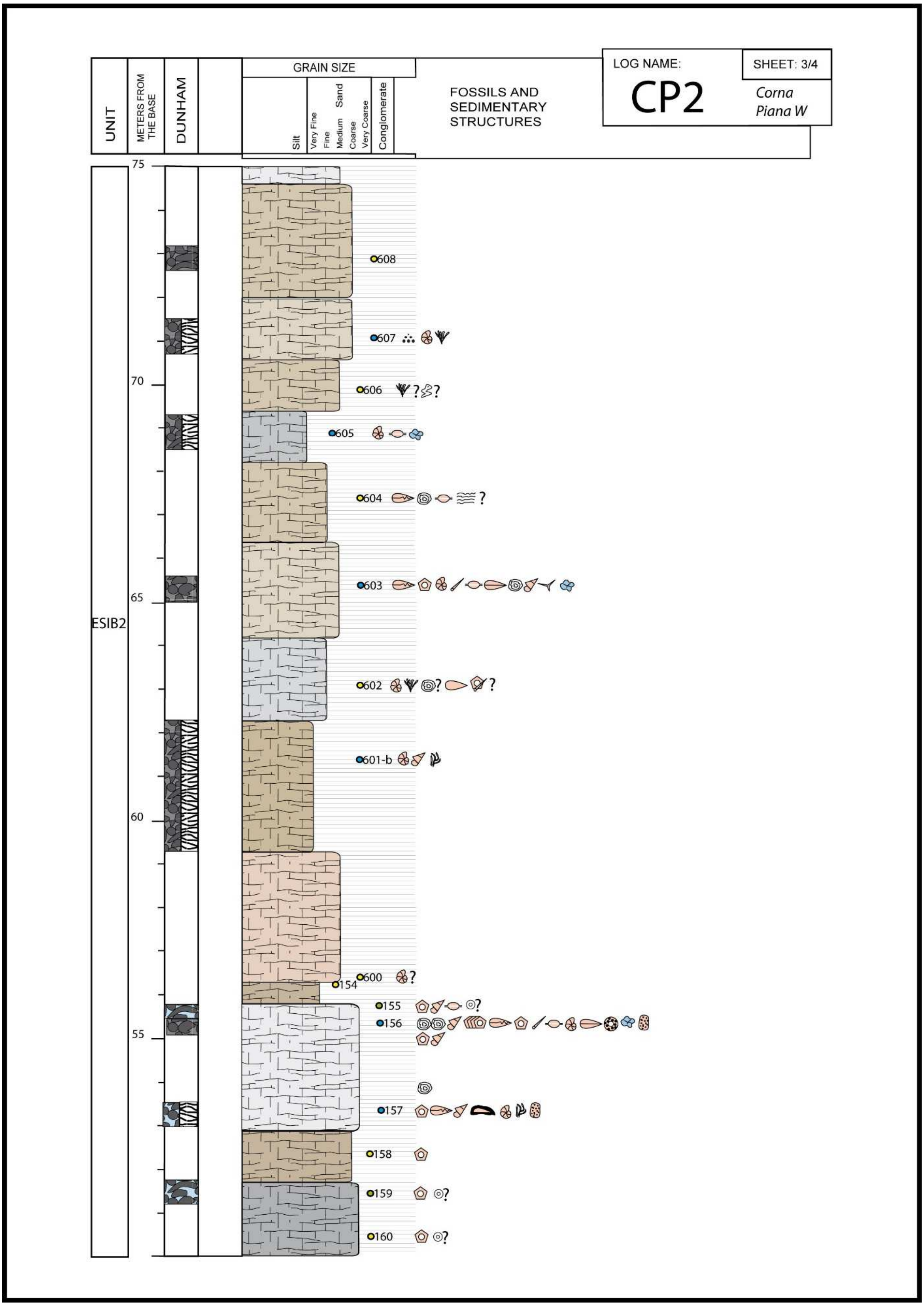

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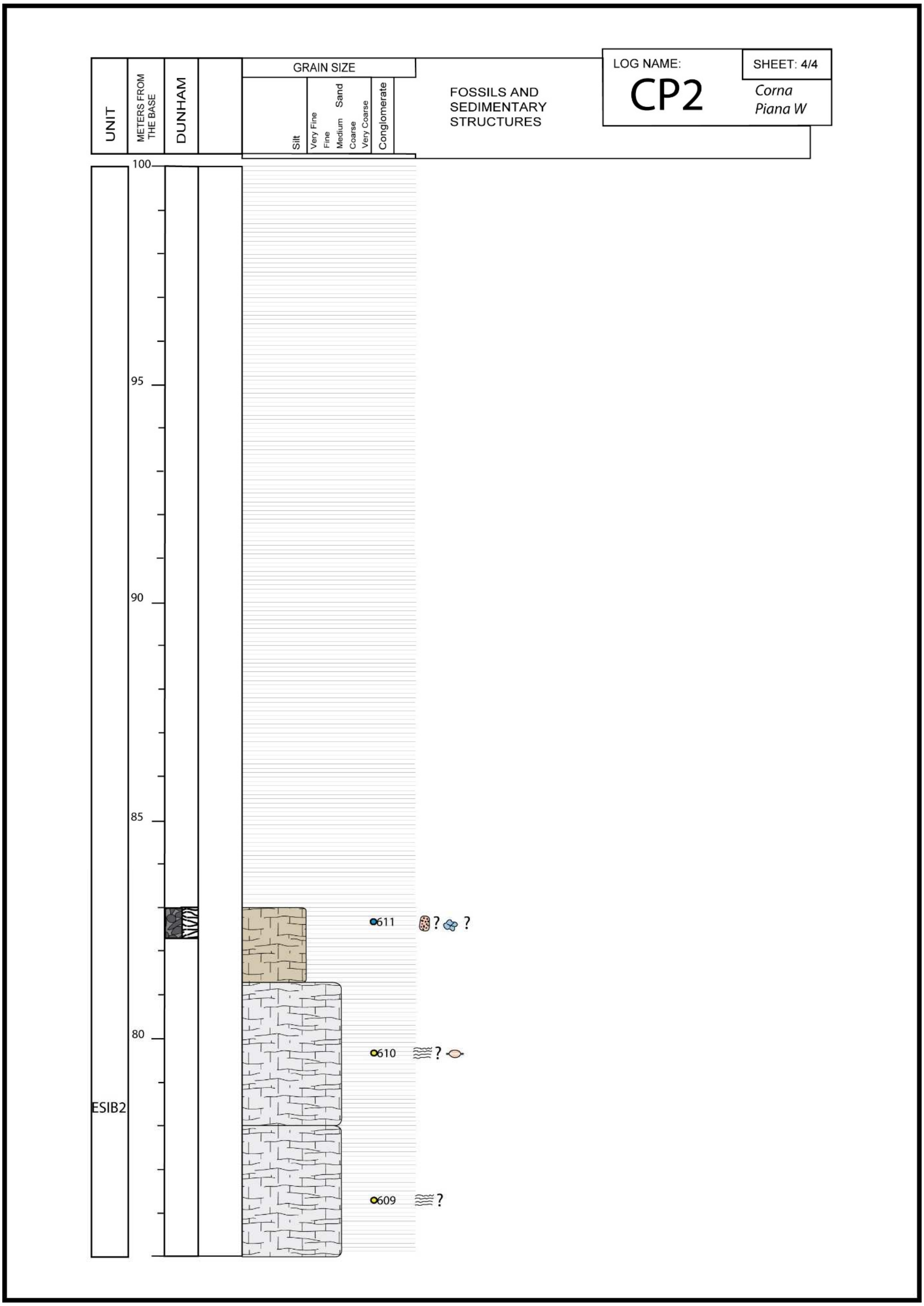

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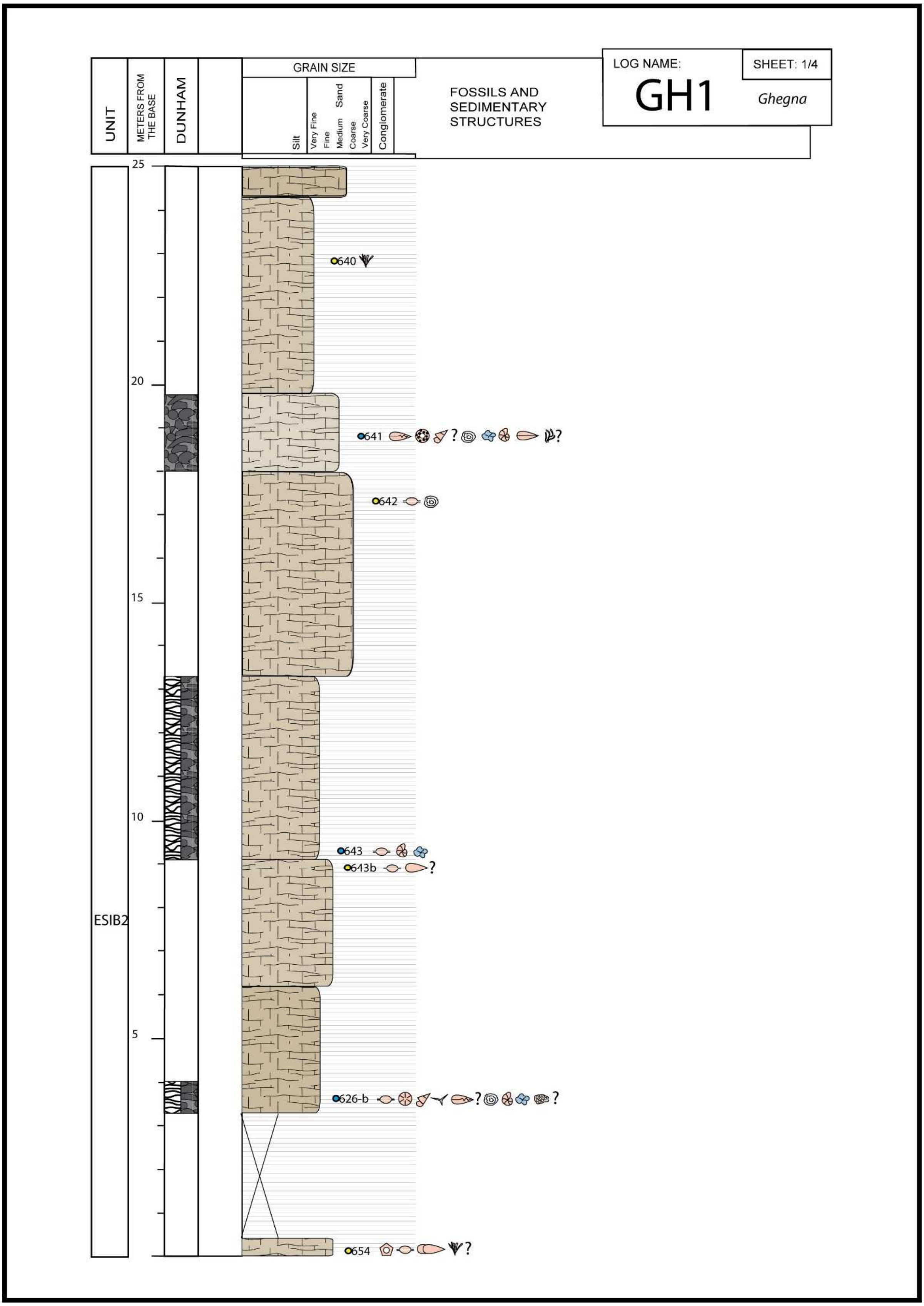

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UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
25
20
15
10
5
ESIB2
640
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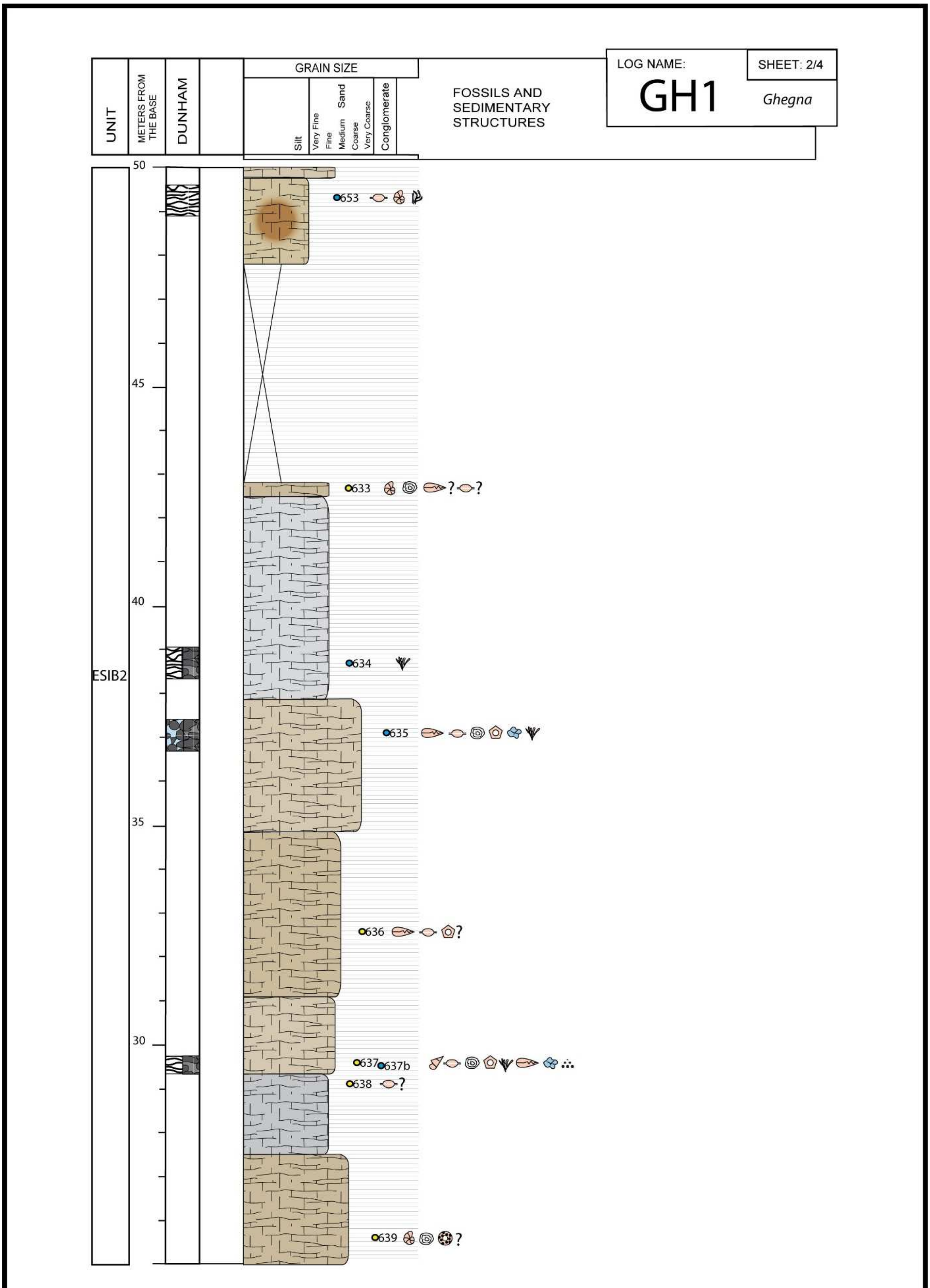
642
643
643b
626-b
654


GRAIN SIZE
UNIT
METERS FROM THE BASE
DUNHAM
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
GH1
SHEET: 2/4
Ghegna
50
45
40
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30
ESIB2
653
633
634
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636
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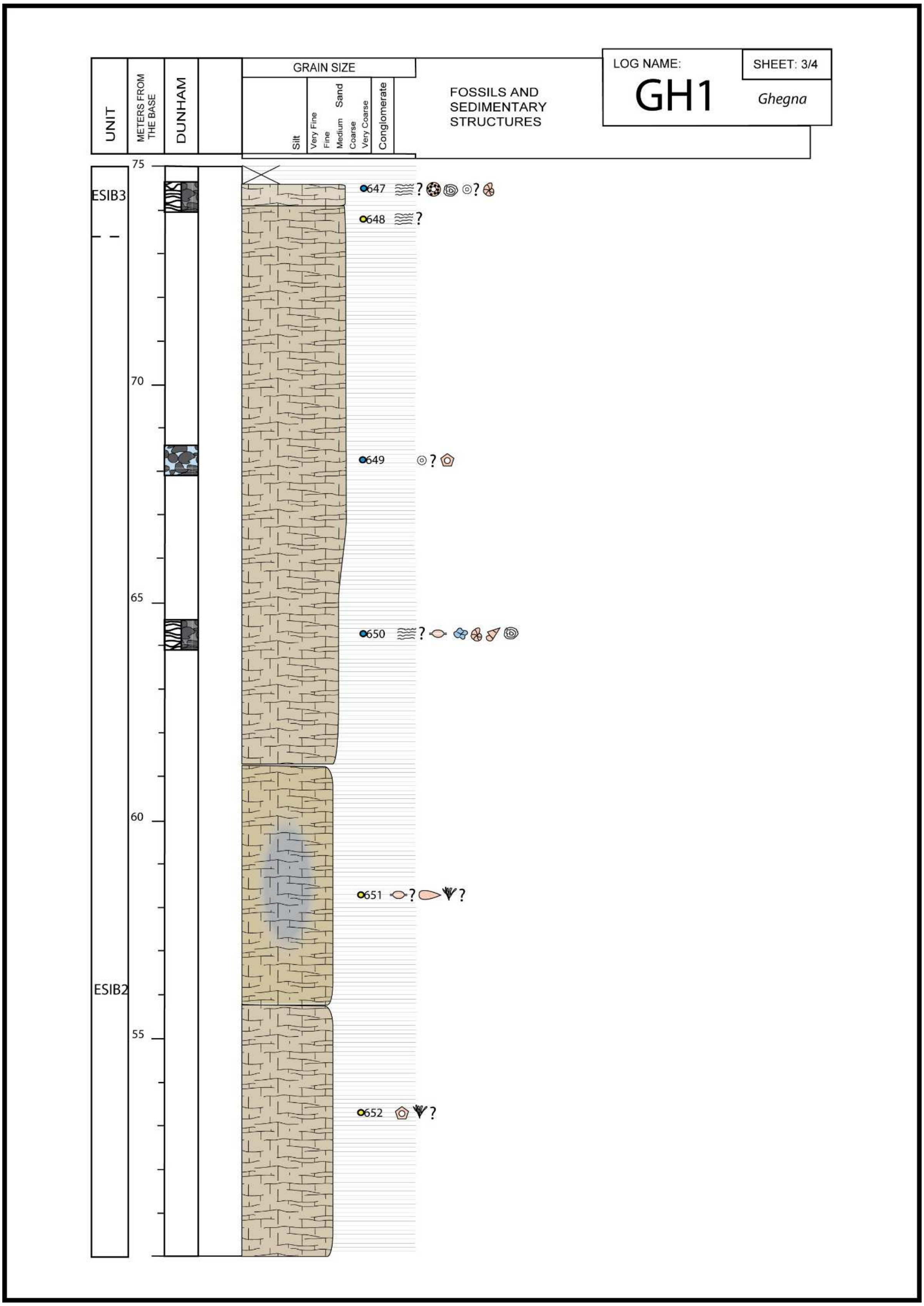
637b
638
639


UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
GH1
SHEET: 3/4
Ghegna
ESIB3
ESIB2
75
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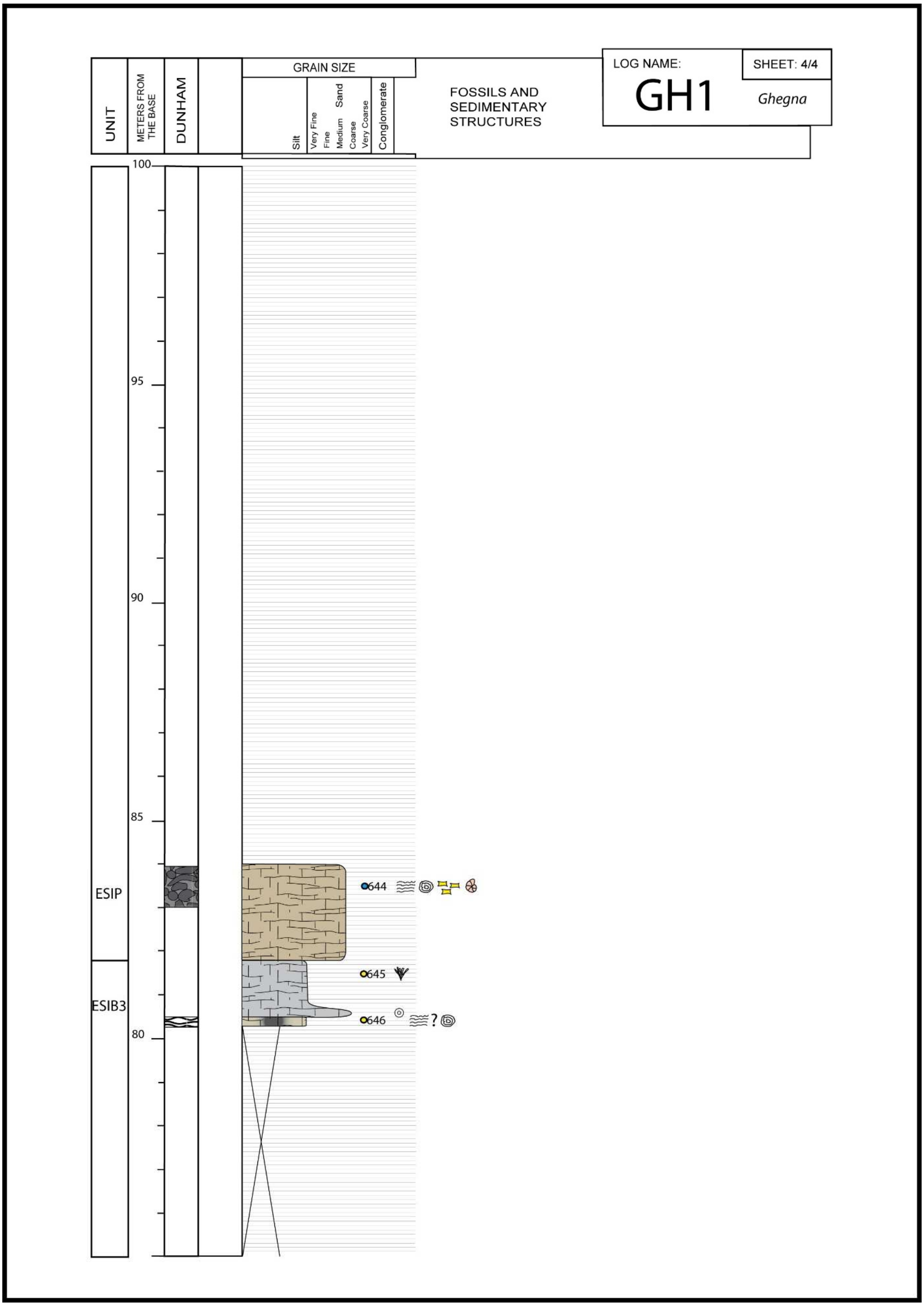
651
652


LOG NAME:
GH1
SHEET: 4/4
Ghegna
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Coarse
Very Coarse
Sand
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
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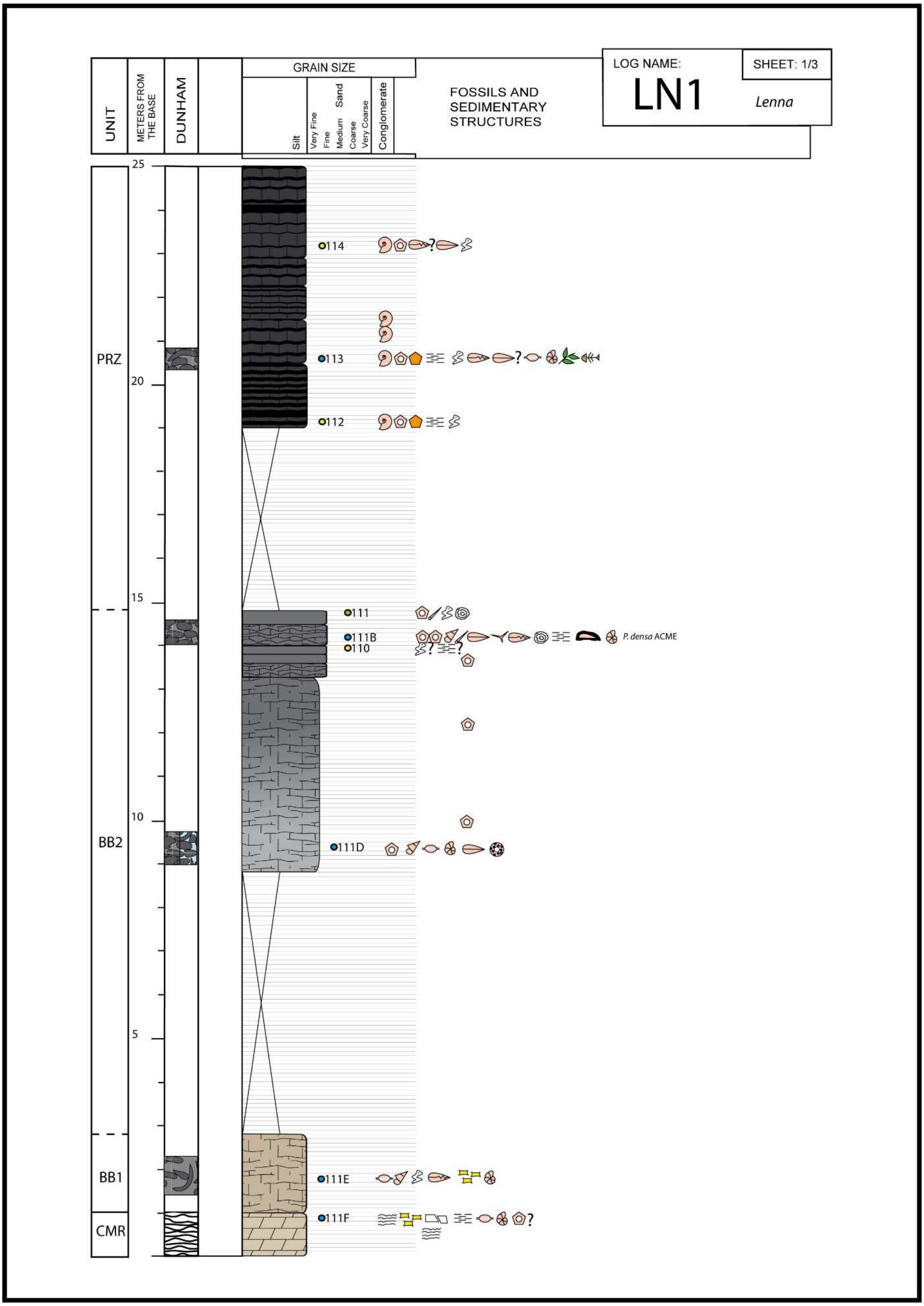
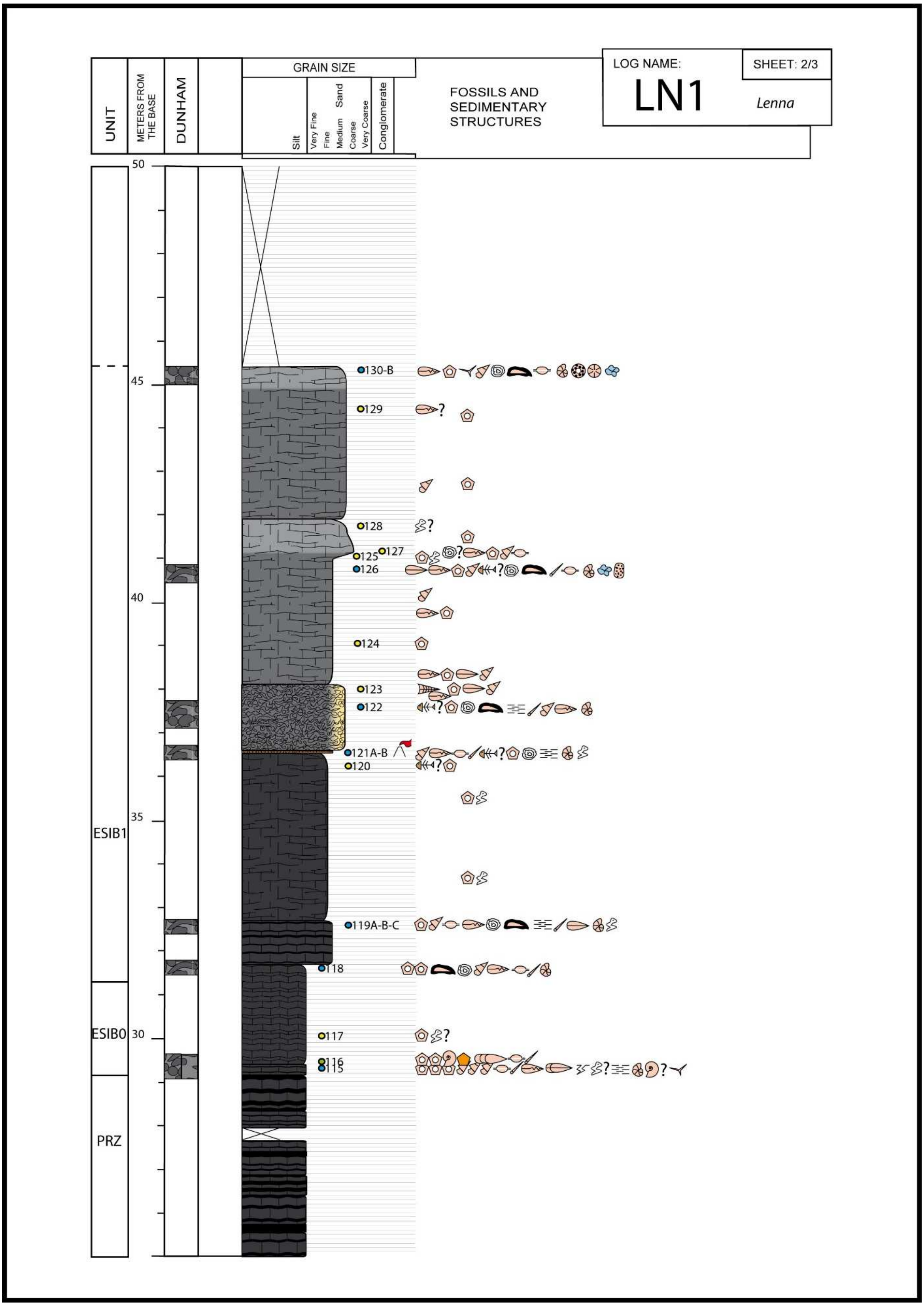
80
ESIP
ESIB3
644
645
646
?



UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
LN1
SHEET: 1/3
Lenna
PRZ
BB2
BB1
CMR
25
20
15
10
5
114
113
112
111
111B
110
111D
111E
111F
P. densa ACME



LOG NAME:
LN1
SHEET: 2/3
Lenna
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
50
45
40
35
30
ESIB1
ESIB0
PRZ
130-B
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127
125
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121A-B
120
119A-B-C
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116
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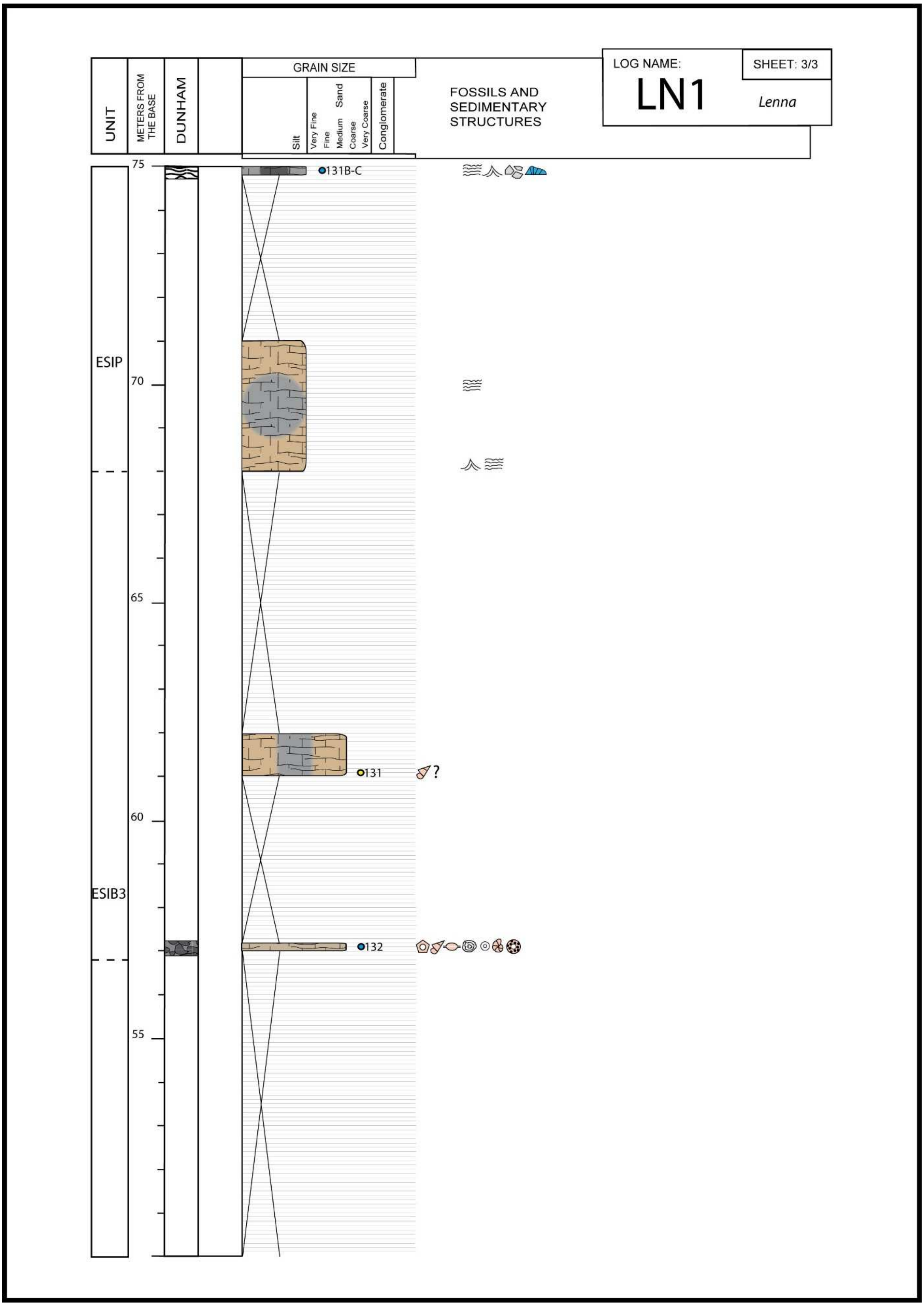
UNIT
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DUNHAM
GRAIN SIZE
Silt
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Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
LN1
SHEET: 3/3
Lenna
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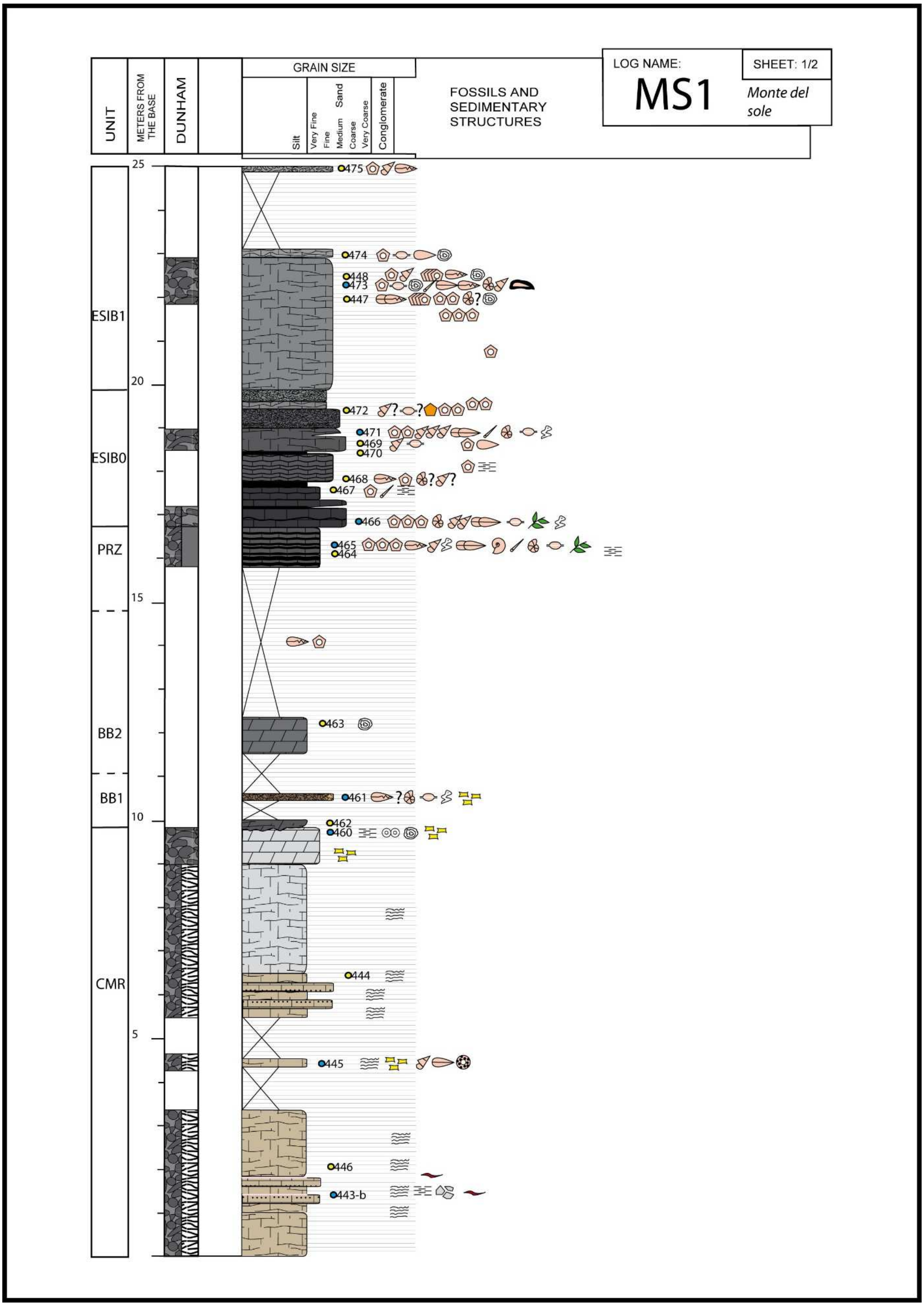
ESIP
ESIB3
131B-C
131
?
132


UNIT
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DUNHAM
GRAIN SIZE
Silt
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Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
MS1
SHEET: 1/2
Monte del sole
ESIB1
ESIB0
PRZ
BB2
BB1
CMR
25
20
15
10
5
475
474
448
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461
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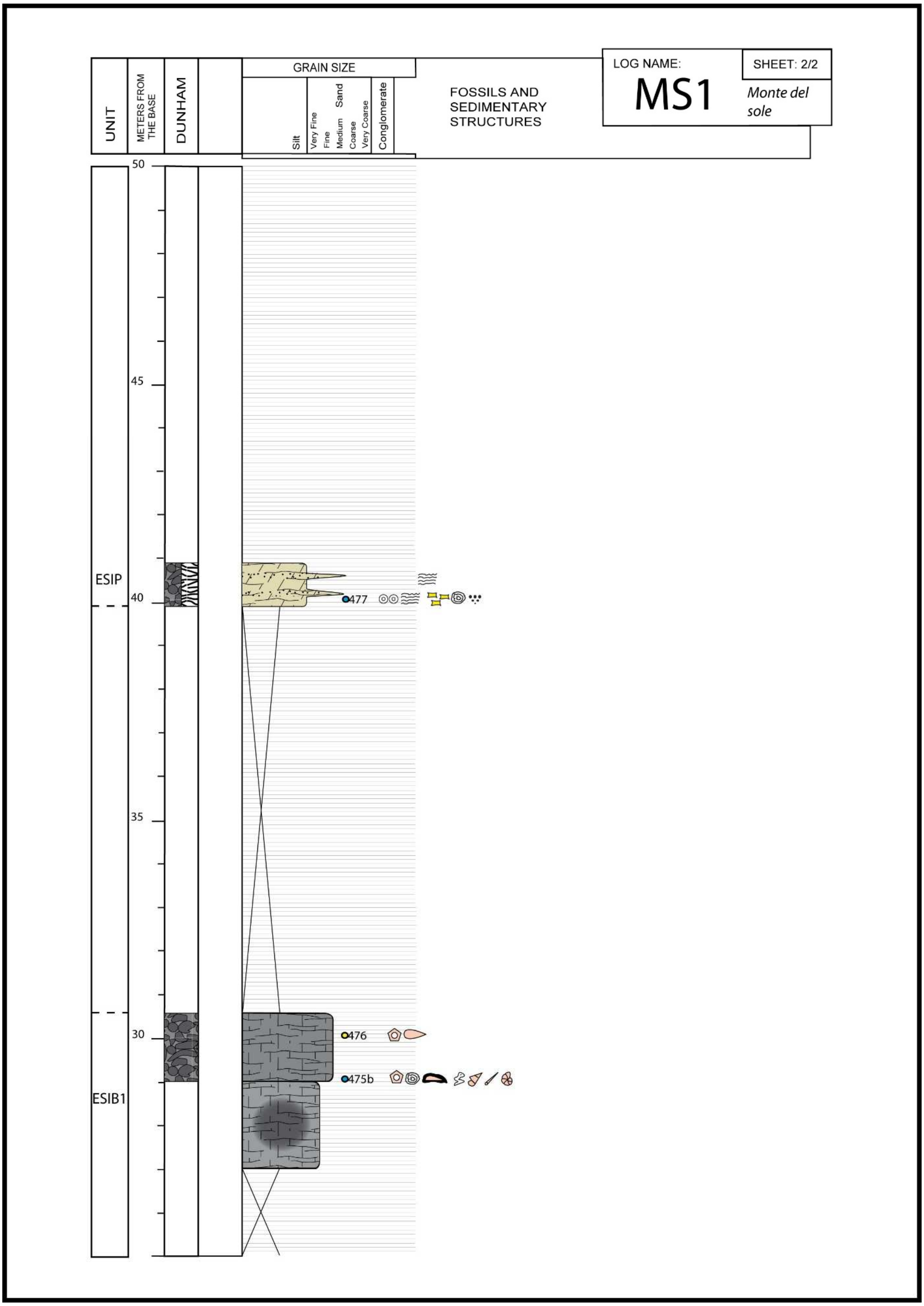
460
444
445
446
443-b


LOG NAME:
MS1
SHEET: 2/2
Monte del sole
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
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45
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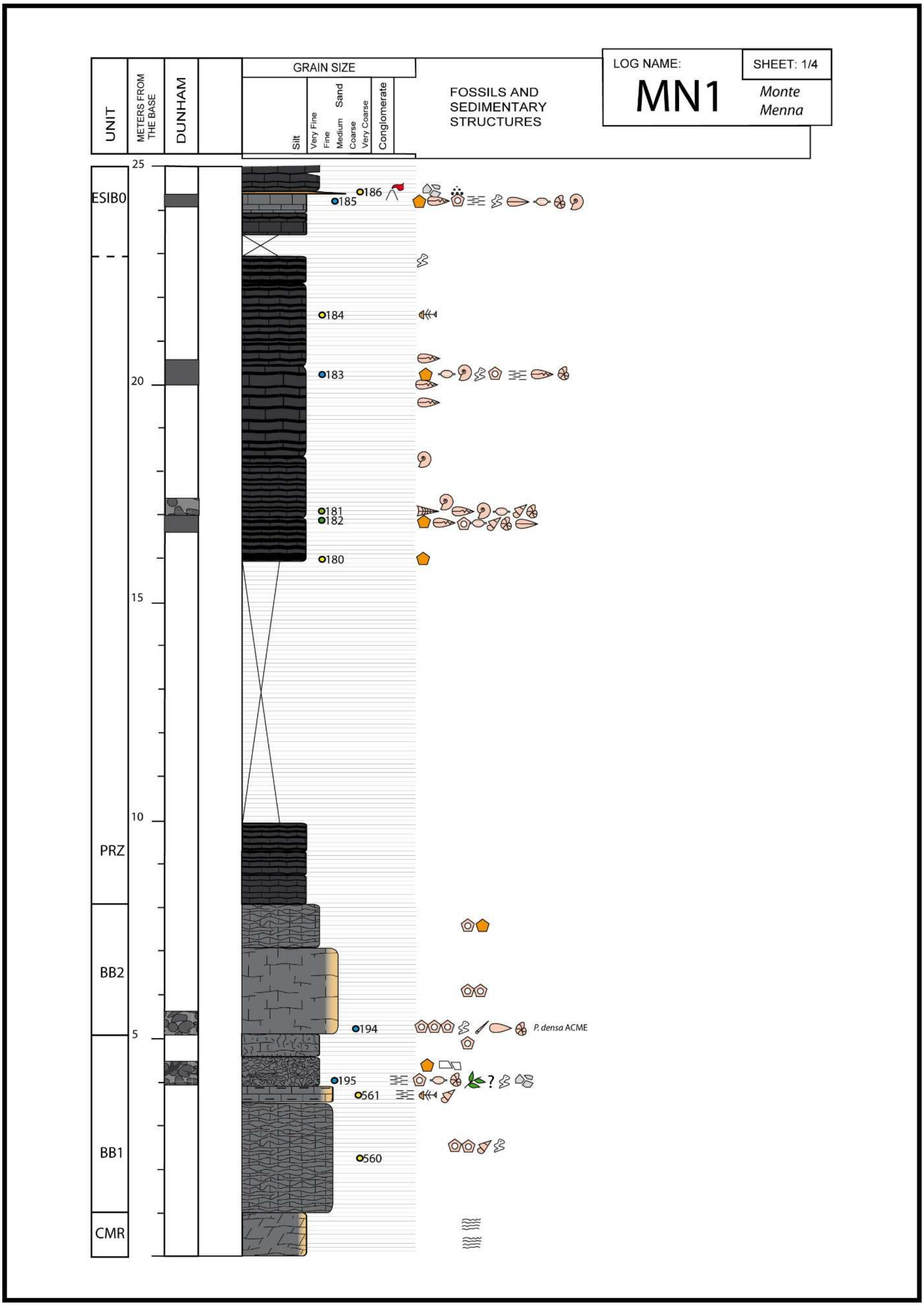
35
30
ESIP
ESIB1
477
476
475b


LOG NAME:
MN1
SHEET: 1/4
Monte Menna
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
ESIB0
PRZ
BB2
BB1
CMR
25
20
15
10
5
186
185
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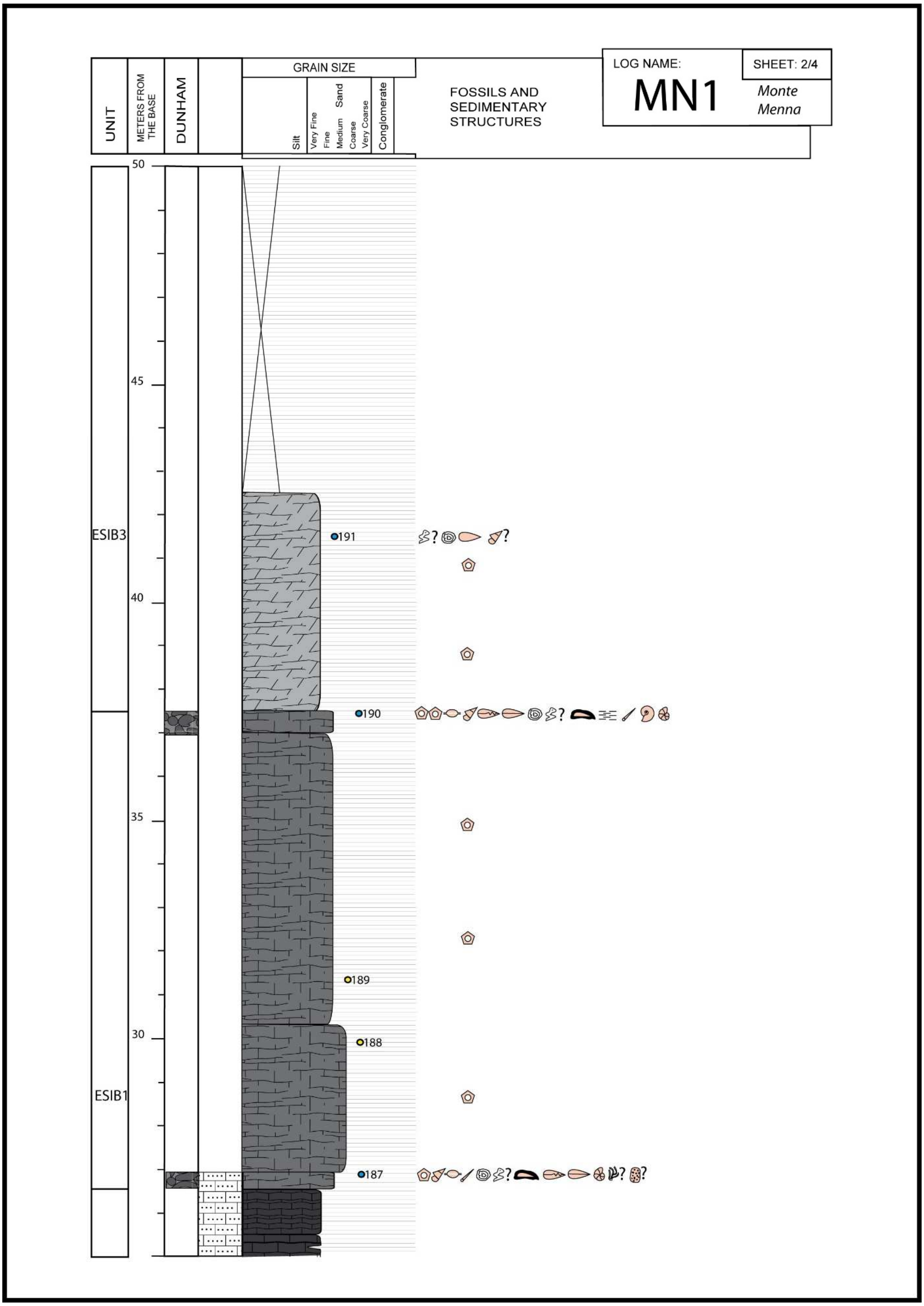
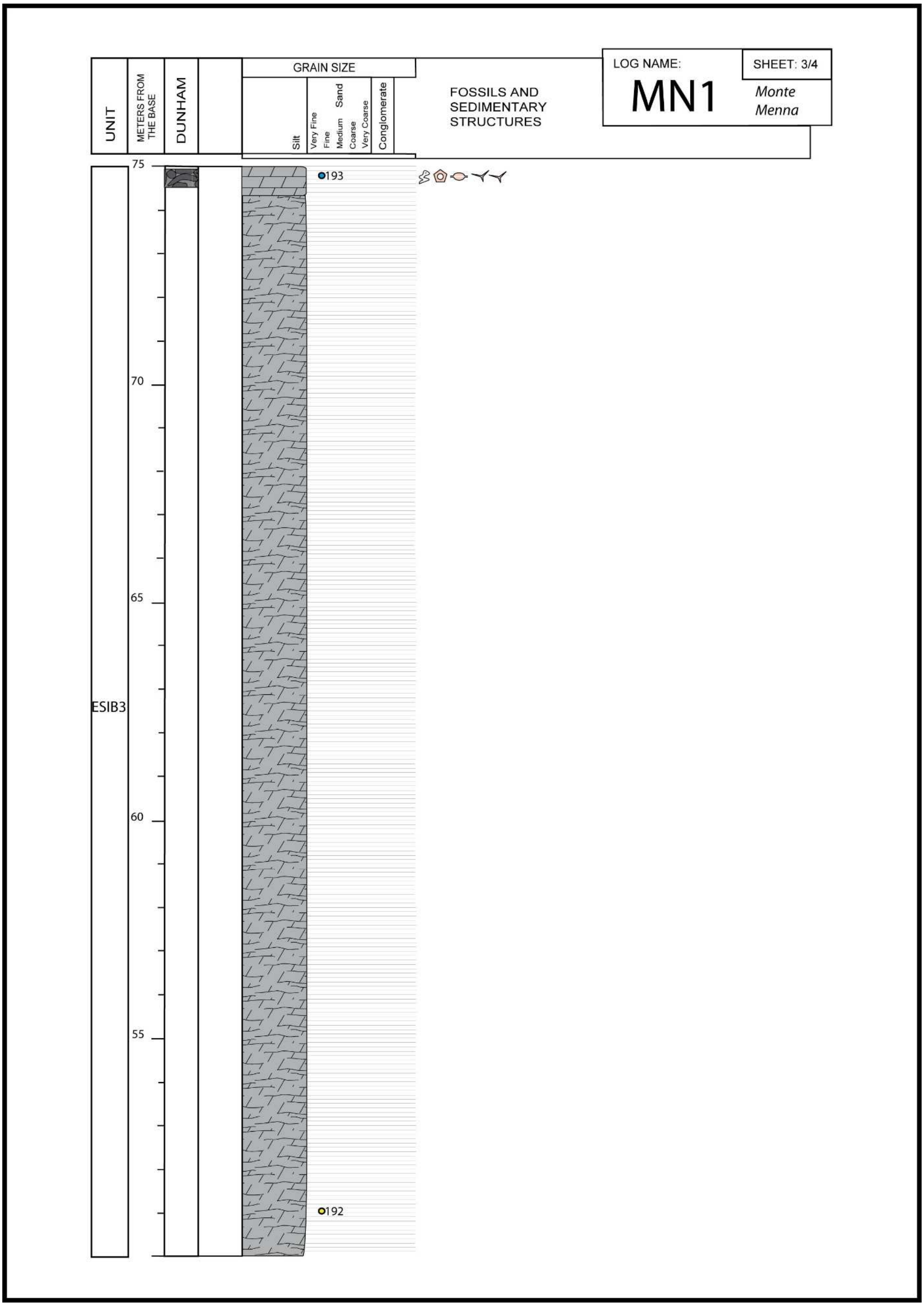
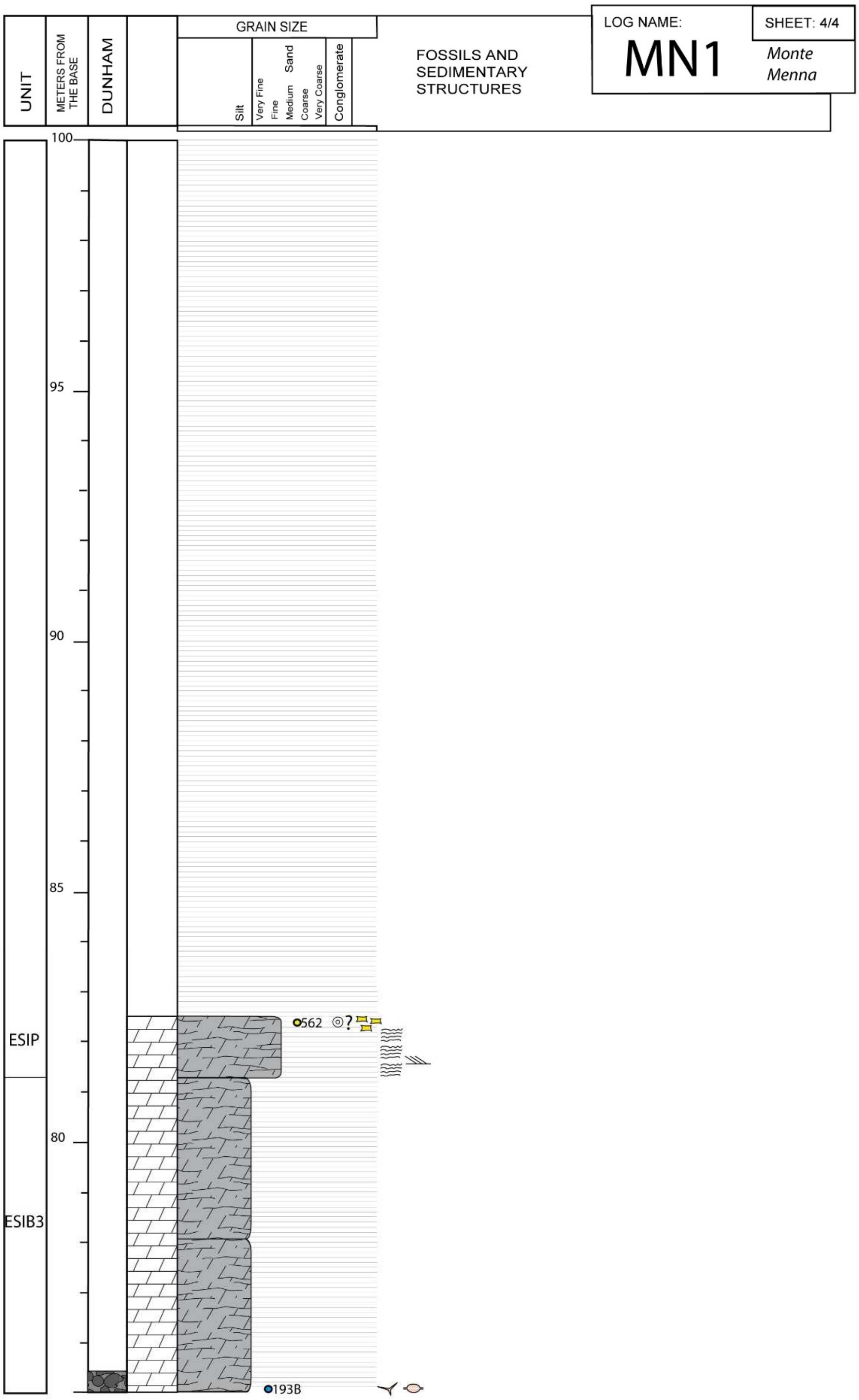
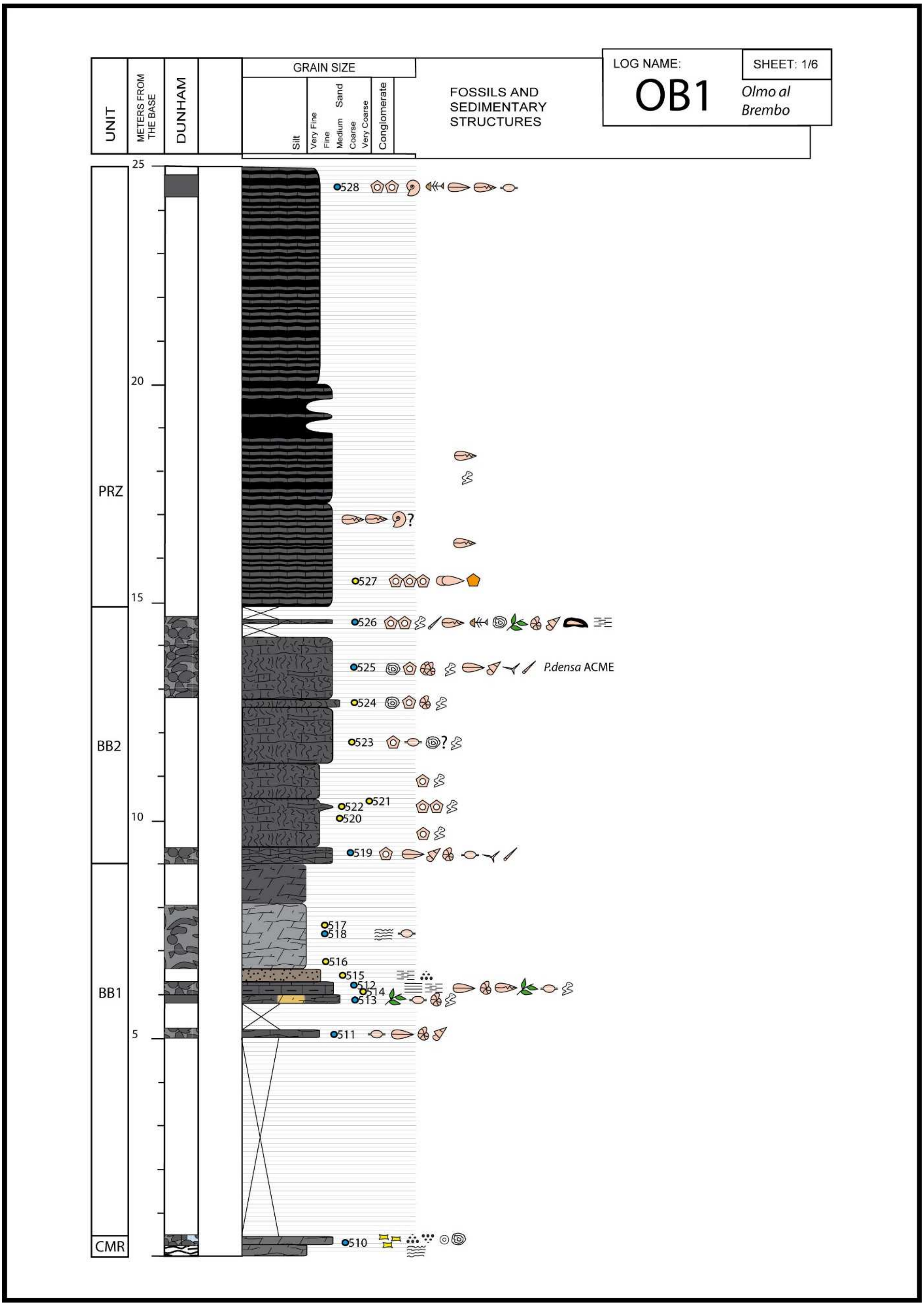
183
181
182
180
194
195
561
560
P. densa ACME

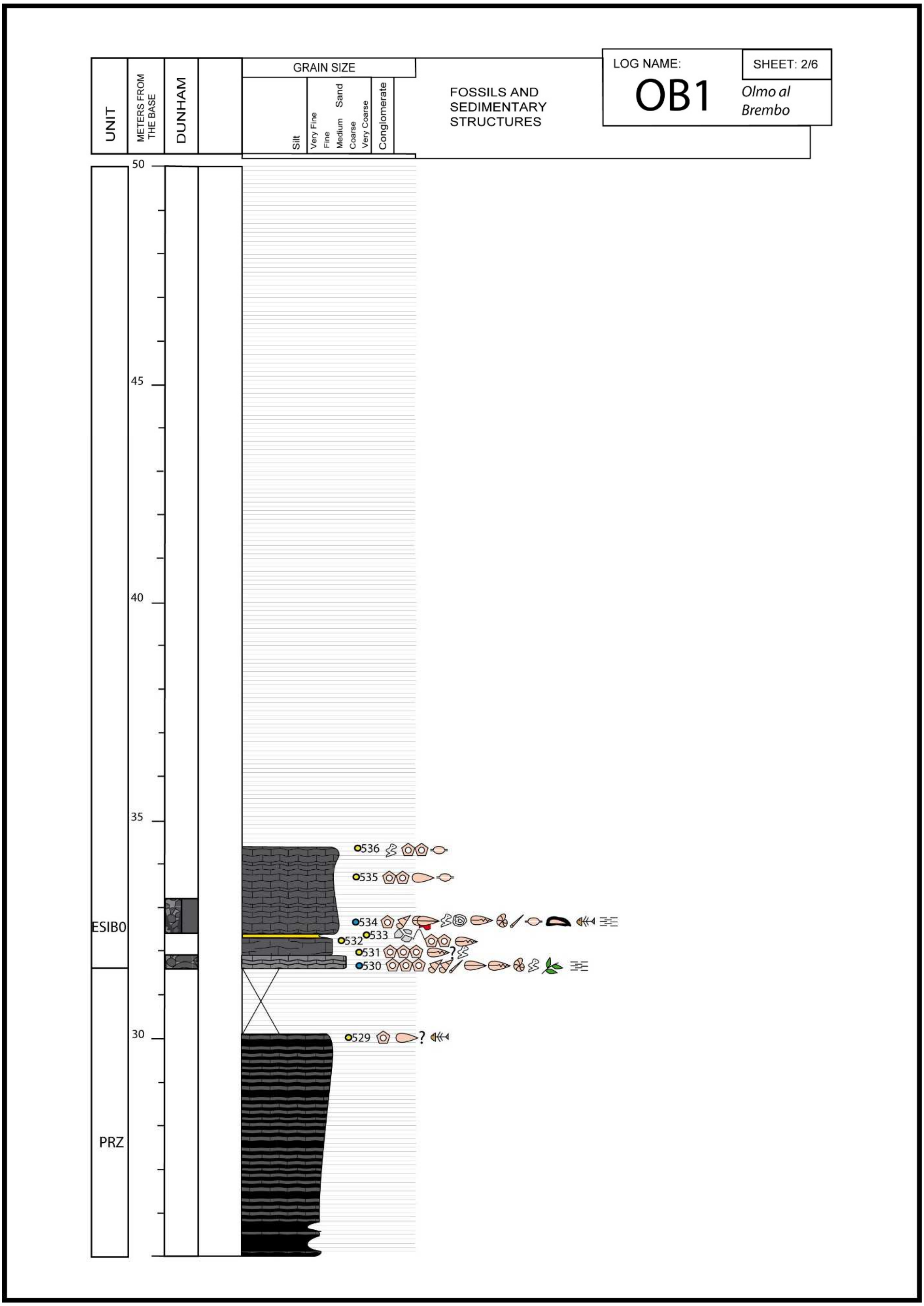

UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
MN1
SHEET: 2/4
Monte Menna
50
45
40
35
30
ESIB3
ESIB1
191
190
189
188
187

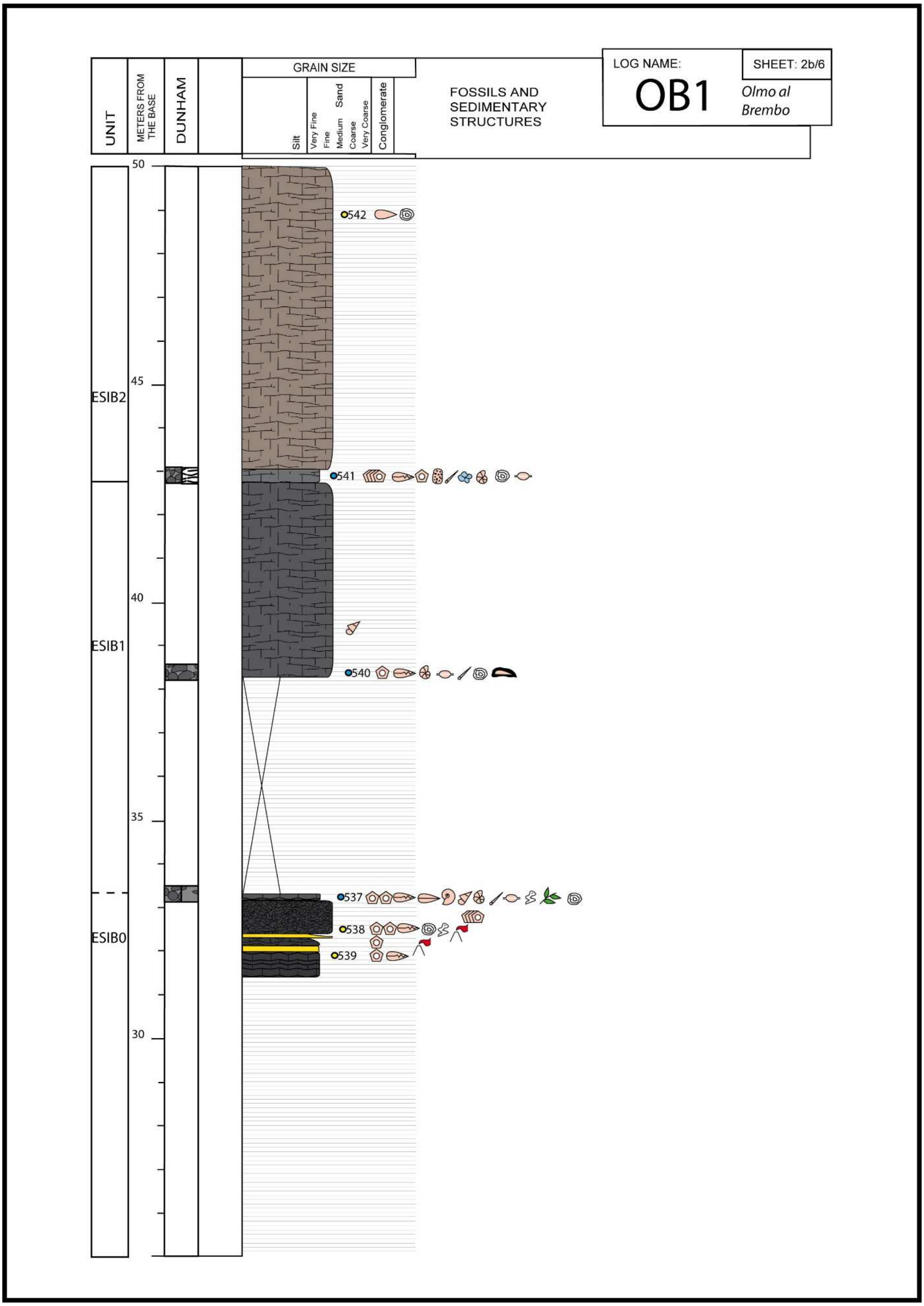

UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
MN1
SHEET: 3/4
Monte Menna
75
70
65
60
55
ESIB3
193
192

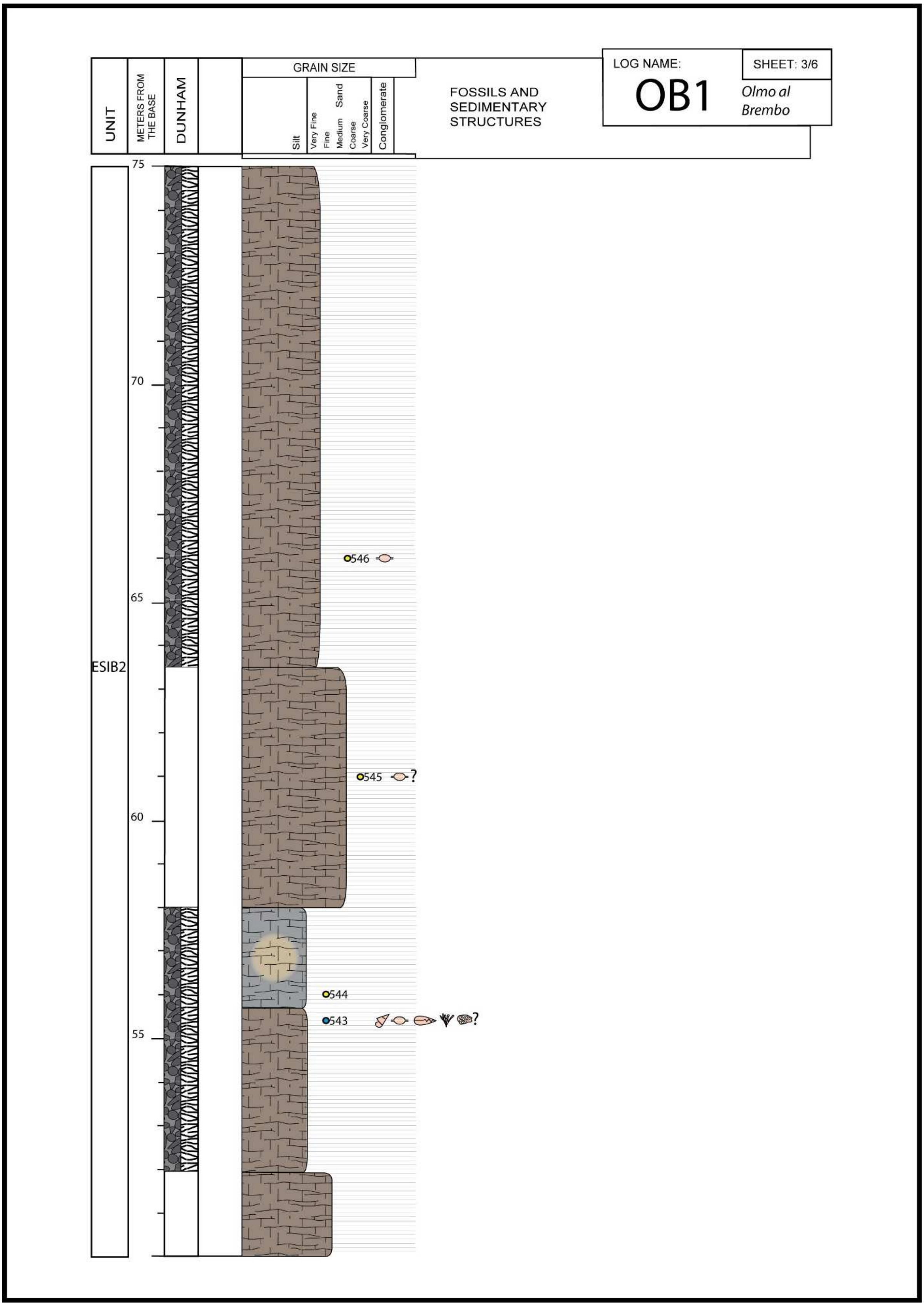

UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
MN1
SHEET: 4/4
Monte Menna
100
95
90
85
80
ESIP
ESIB3
562
?
193B

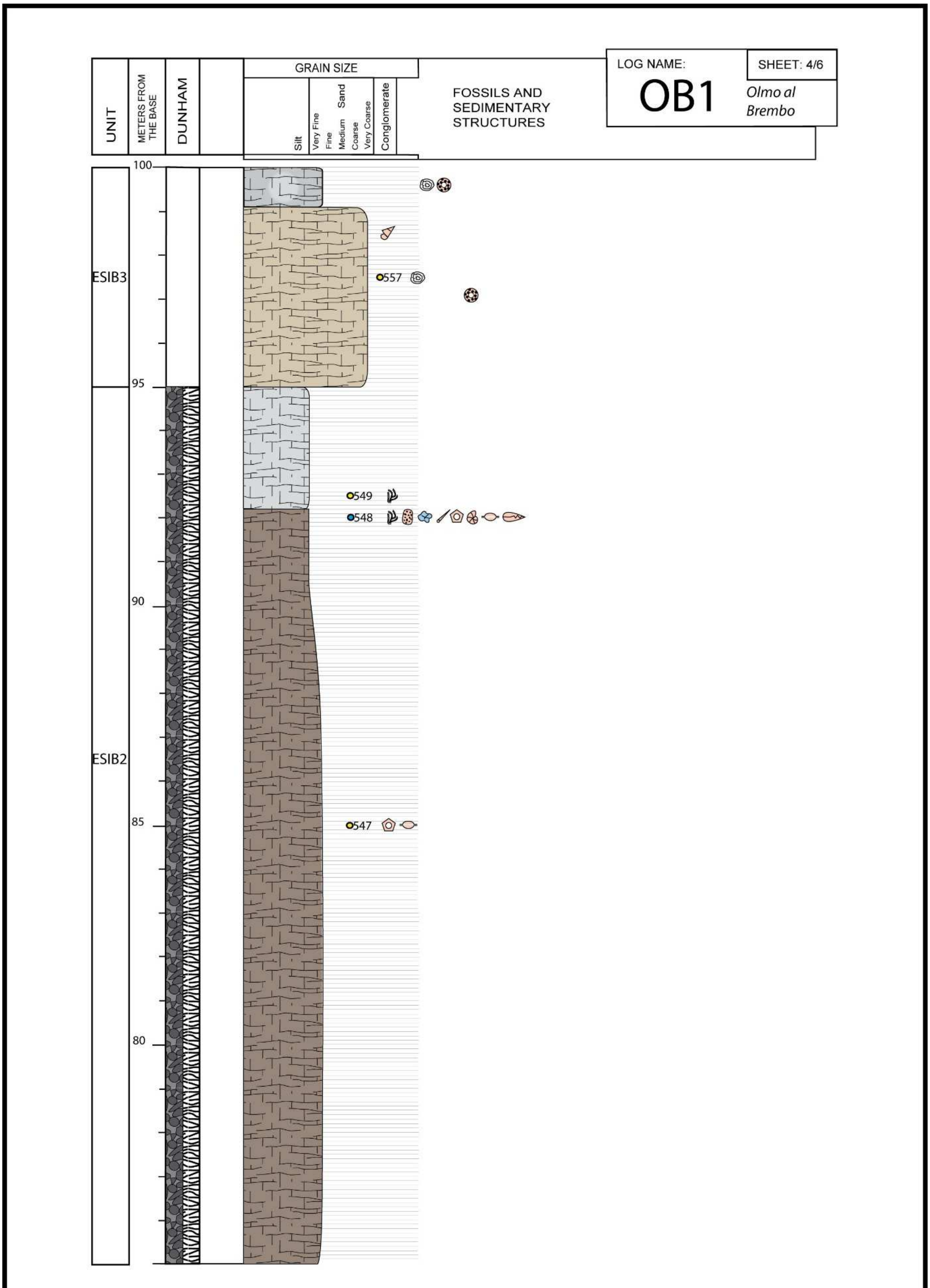


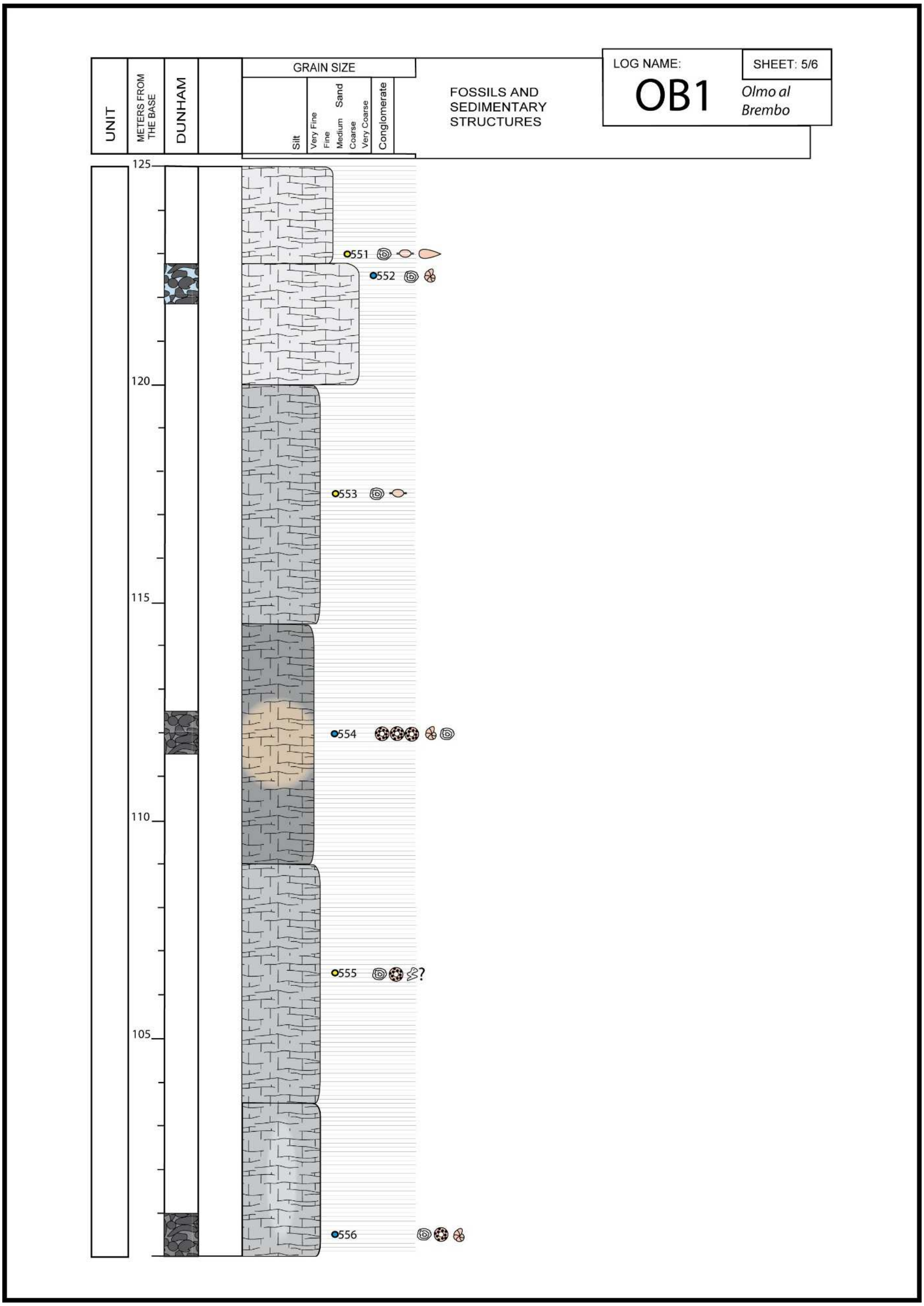
LOG NAME:
OB1
SHEET: 1/6
Olmo al Brembo
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
PRZ
BB2
BB1
CMR
25
20
15
10
5
528
527
526
525
P.densa ACME
524
523
522
521
520
519
517
518
516
515
512
514
513
511
510


UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
OB1
SHEET: 2/6
Olmo al Brembo
50
45
40
35
30
ESIB0
PRZ
536
535
534
533
532
531
530
529

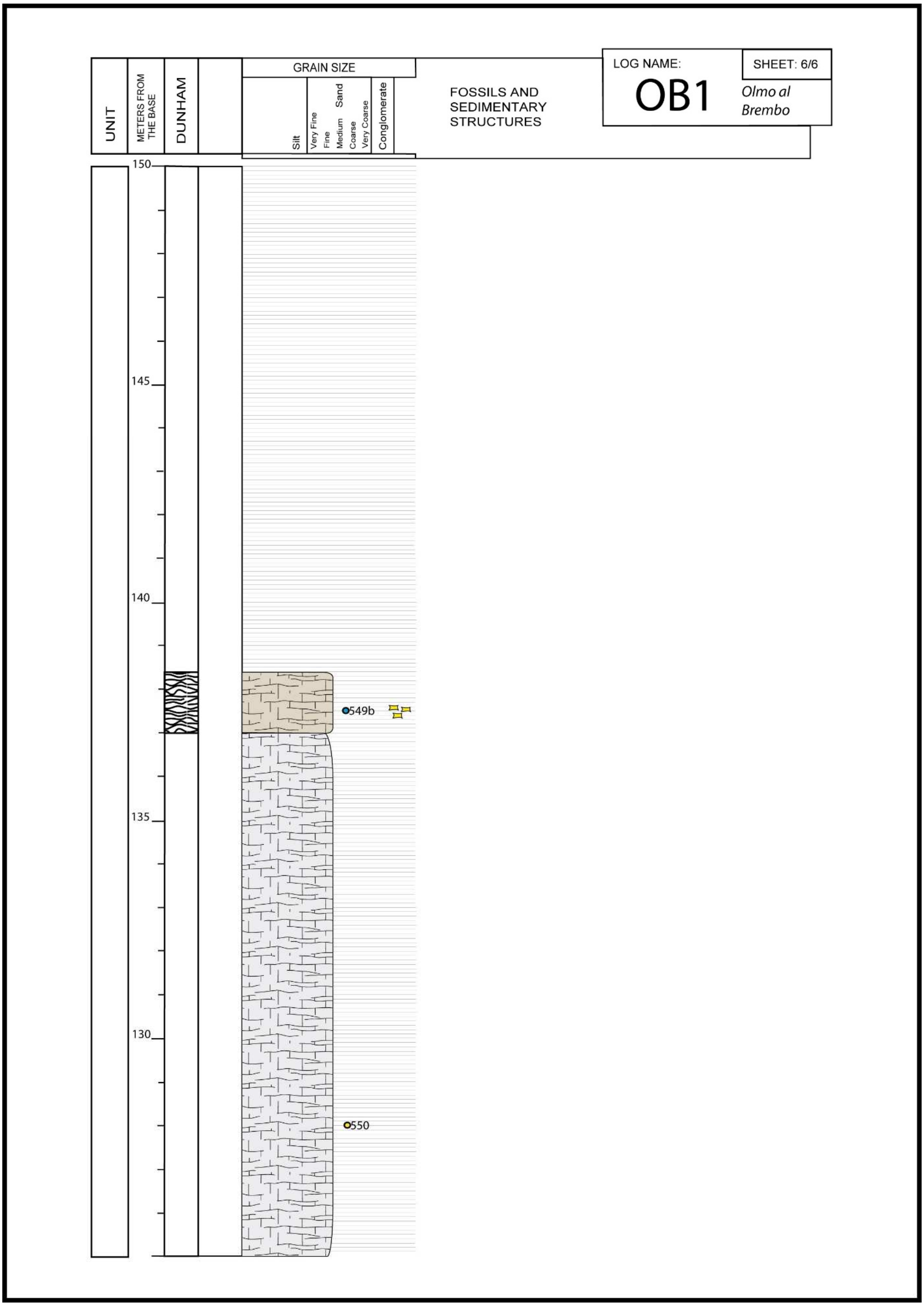

UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
OB1
SHEET: 2b/6
Olmo al Brembo
50
45
40
35
30
ESIB2
ESIB1
ESIB0
542
541
540
537
538
539


UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
OB1
SHEET: 3/6
Olmo al Brembo
75
70
65
60
55
ESIB2
546
545
544
543

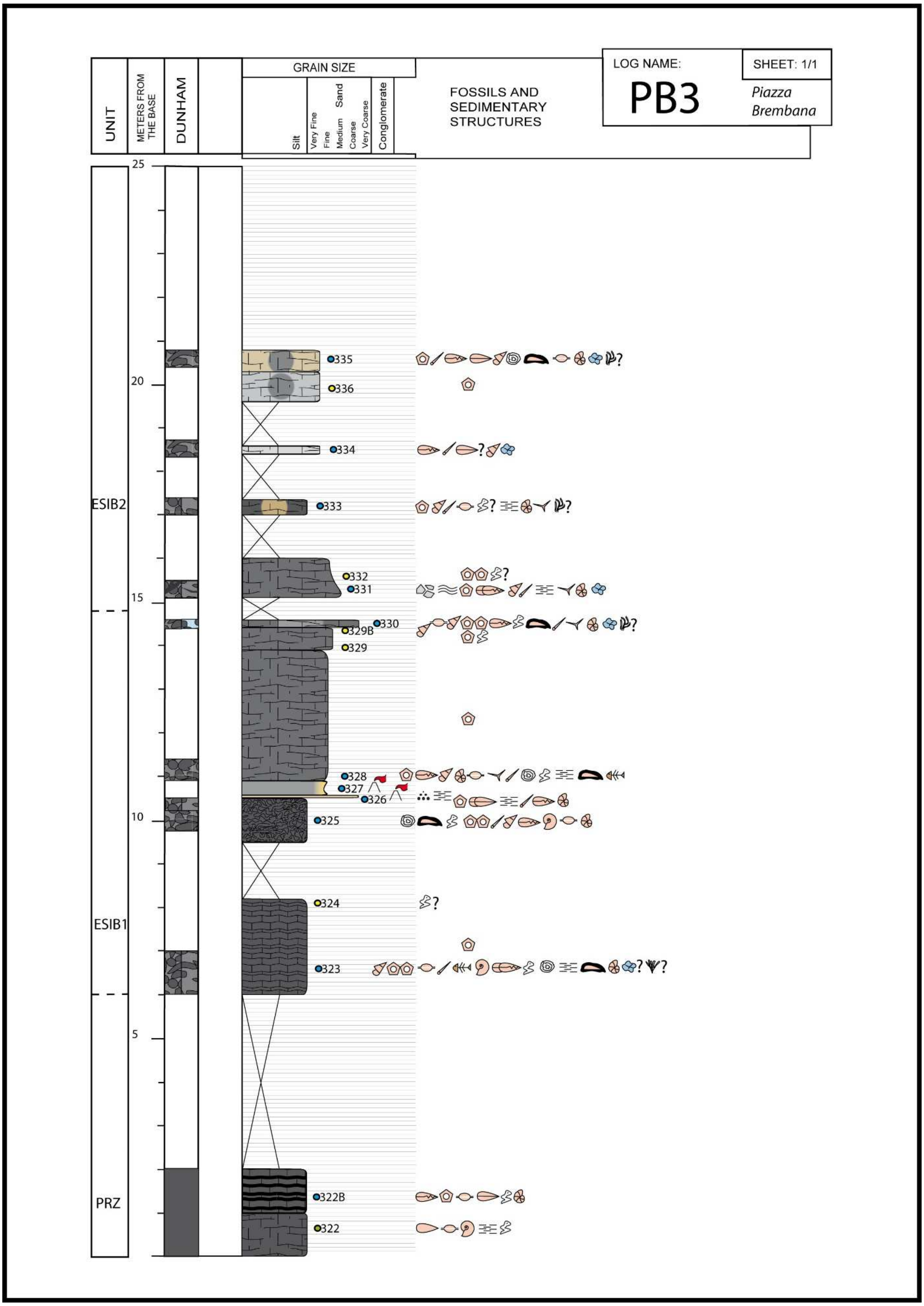

GRAIN SIZE
UNIT
METERS FROM THE BASE
DUNHAM
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
OB1
SHEET: 4/6
Olmo al Brembo
ESIB3
ESIB2
100
95
90
85
80
557
549
548
547

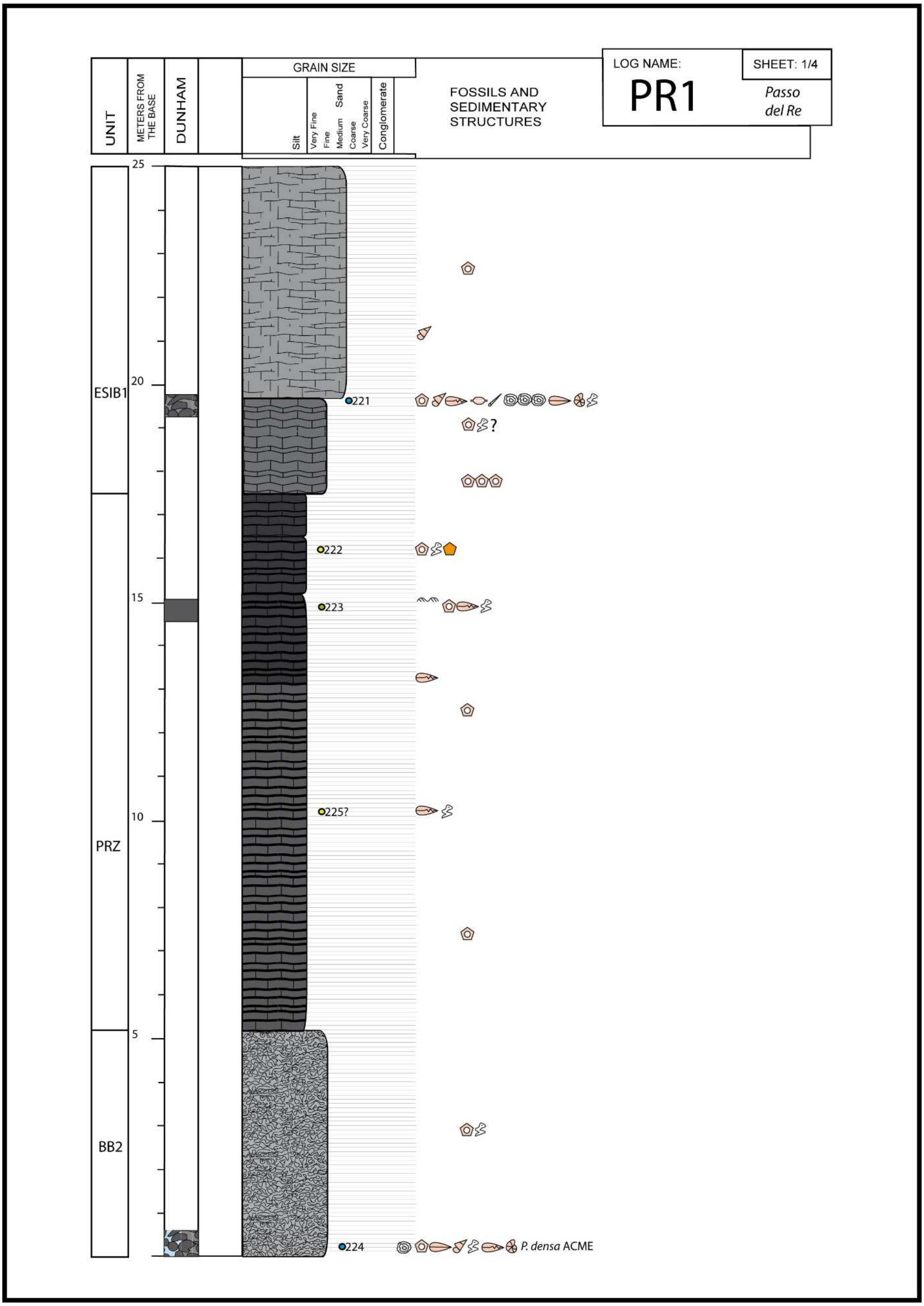


UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
OB1
Olmo al Brembo
SHEET: 5/6
125
120
115
110
105
551
552
553
554
555
556

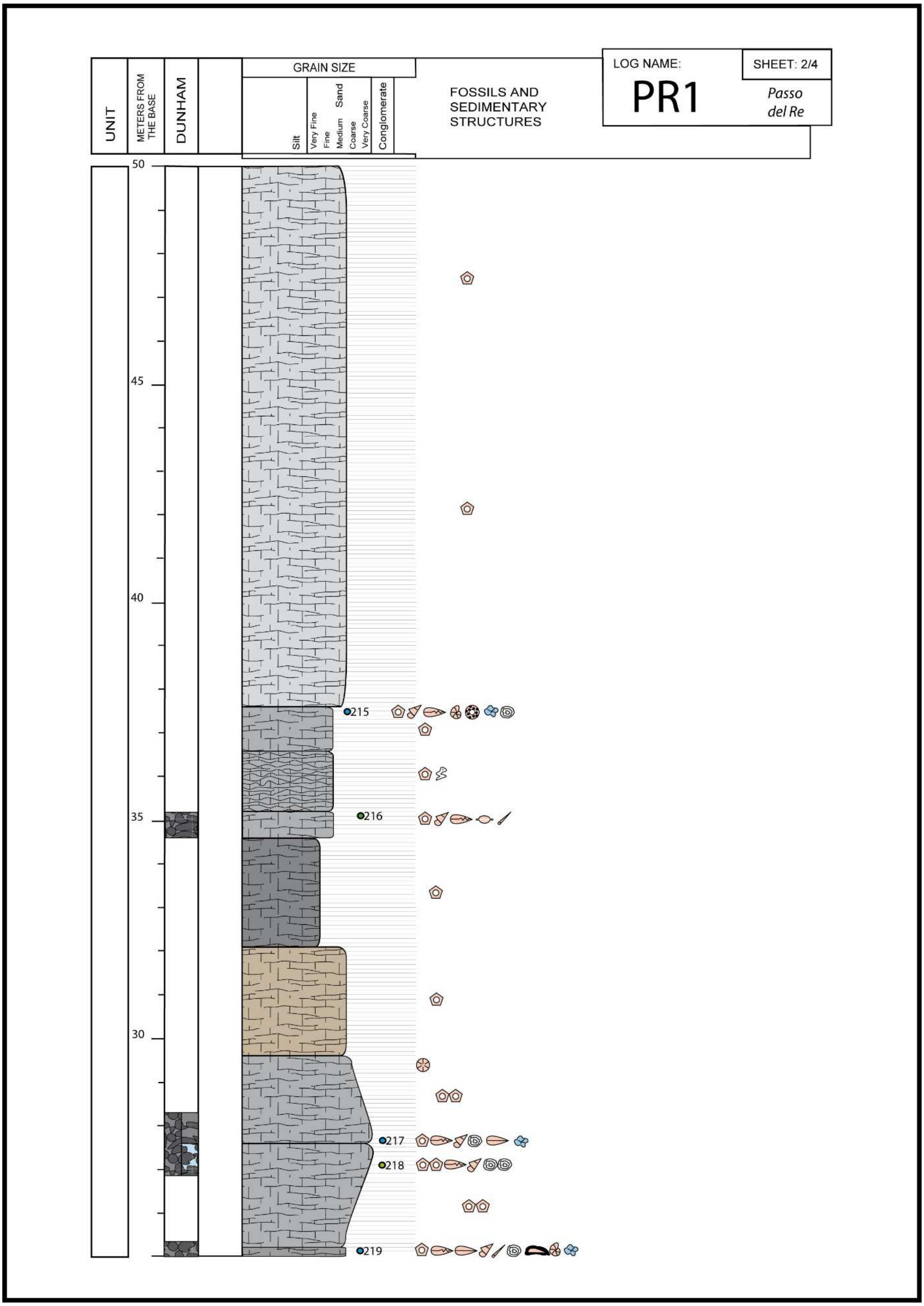


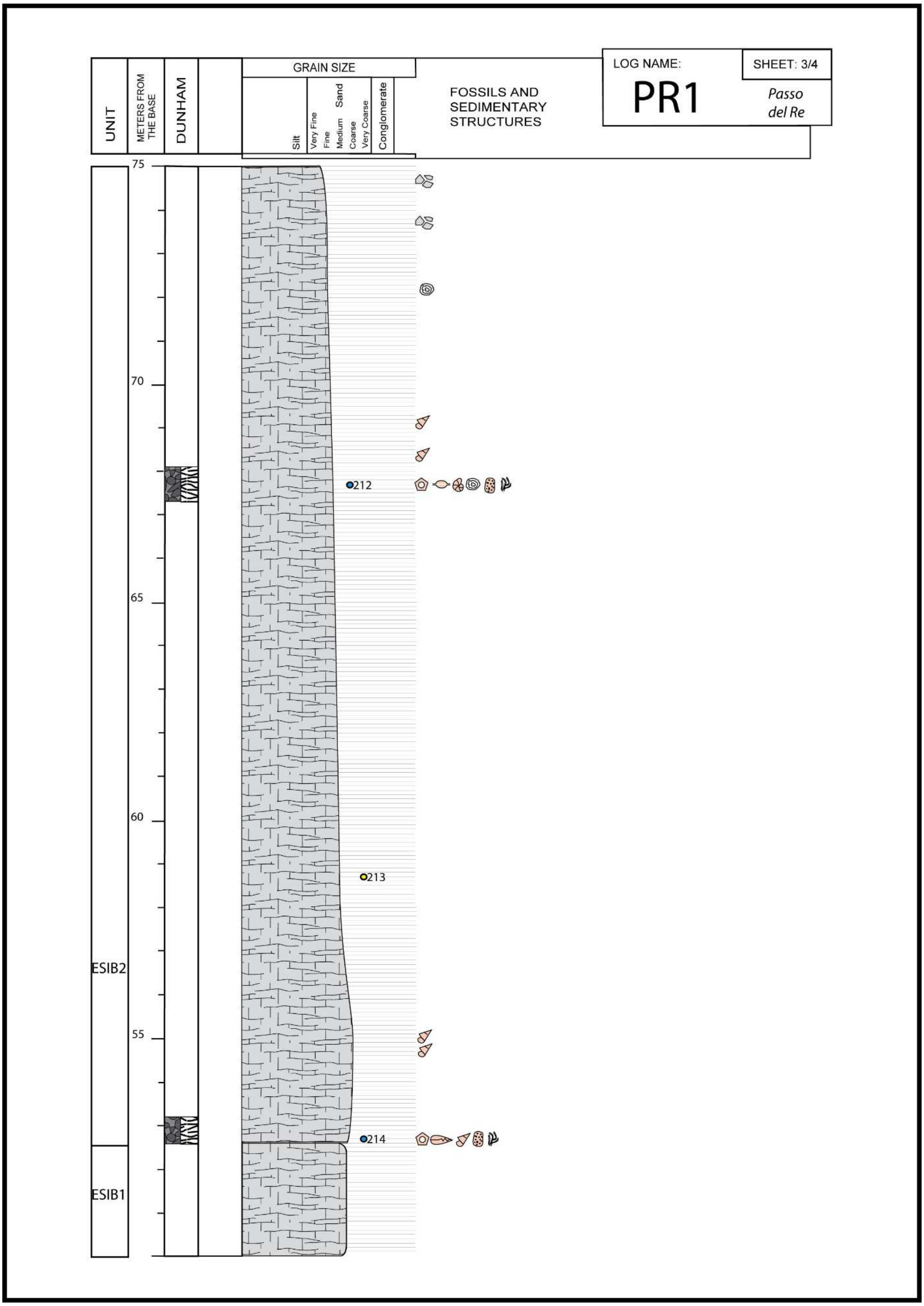
LOG NAME:
OB1
SHEET: 6/6
Olmo al Brembo
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
150
145
140
135
130
549b
550


LOG NAME:
PB3
SHEET: 1/1
Piazza Brembana
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Coarse
Very Coarse
Sand
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
ESIB2
ESIB1
PRZ
25
20
15
10
5
335
336
334
333
332
331
330
329B
329
328
327
326
325
324
323
322B
322

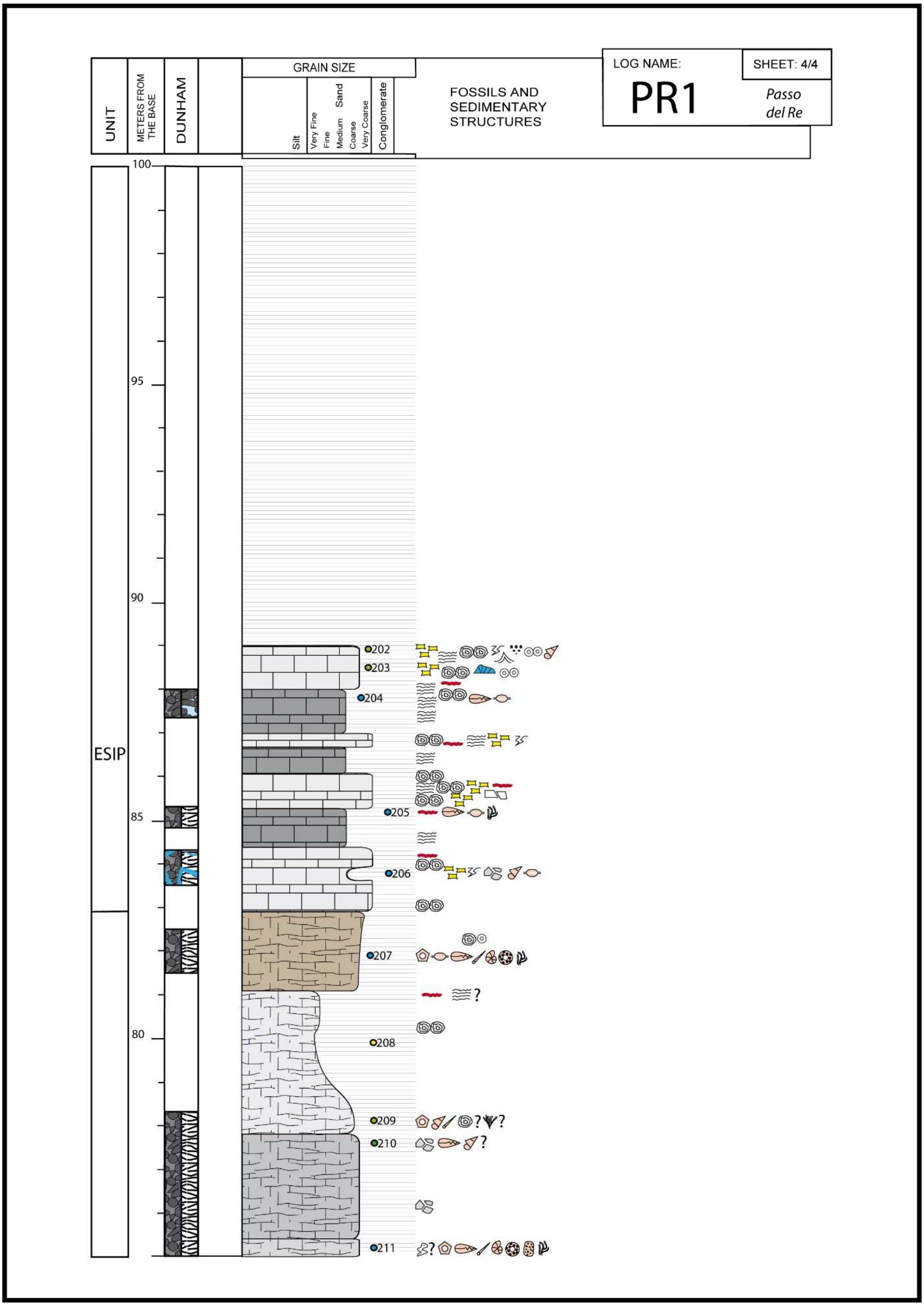


UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
PR1
SHEET: 1/4
Passo del Re
25
20
15
10
5
ESIB1
PRZ
BB2
221
222
223
225?
224
P. densa ACME


UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
PR1
SHEET: 2/4
Passo del Re
50
45
40
35
30
215
216
217
218
219



UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
PR1
SHEET: 3/4
Passo del Re
75
70
65
60
55
212
213
214
ESIB2
ESIB1


LOG NAME:
PR1
SHEET: 4/4
Passo del Re
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
ESIP
100
95
90
85
80
202
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210
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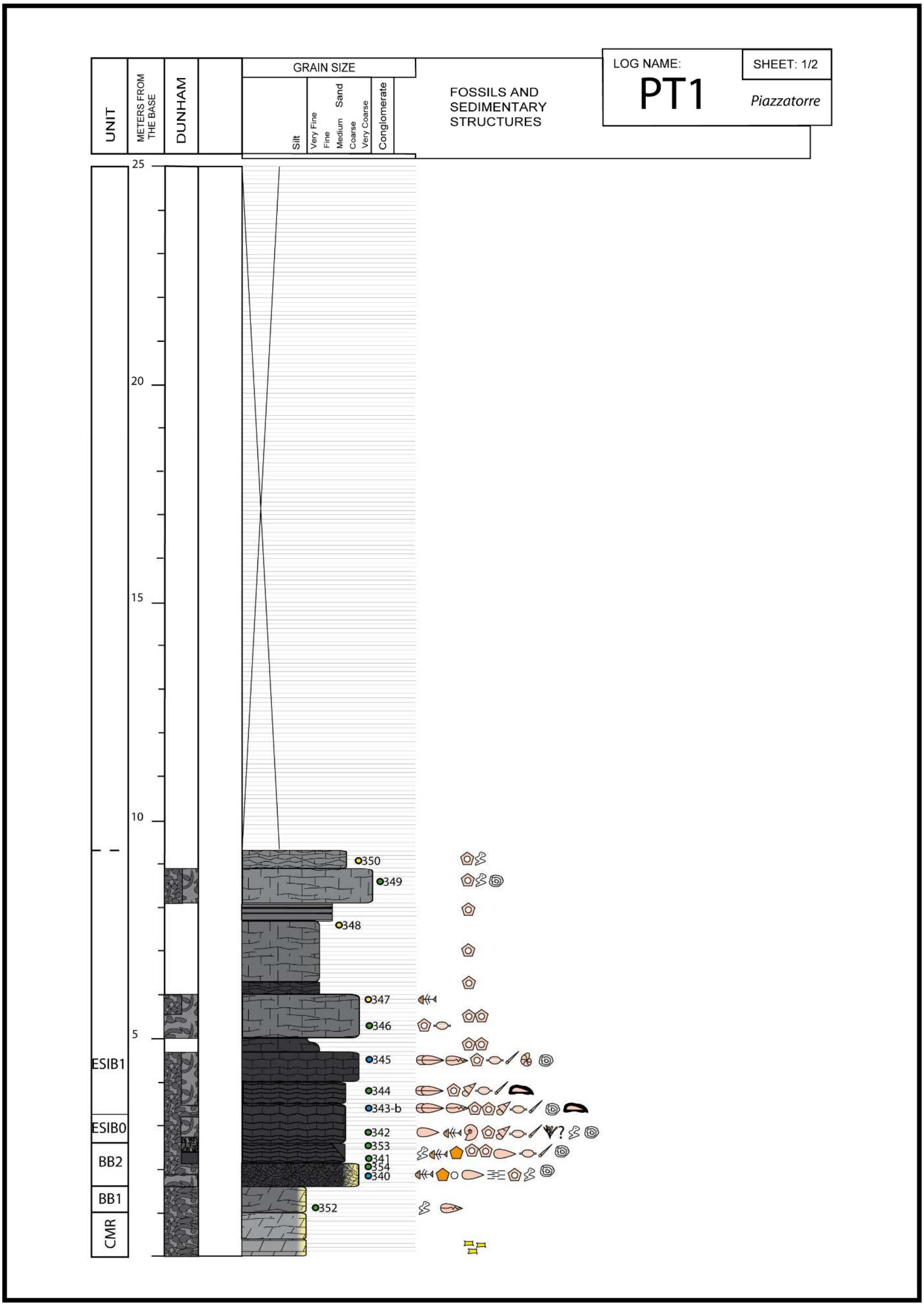
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
PT1
SHEET: 1/2
Piazzatorre
25
20
15
10
5
ESIB1
ESIB0
BB2
BB1
CMR
350
349
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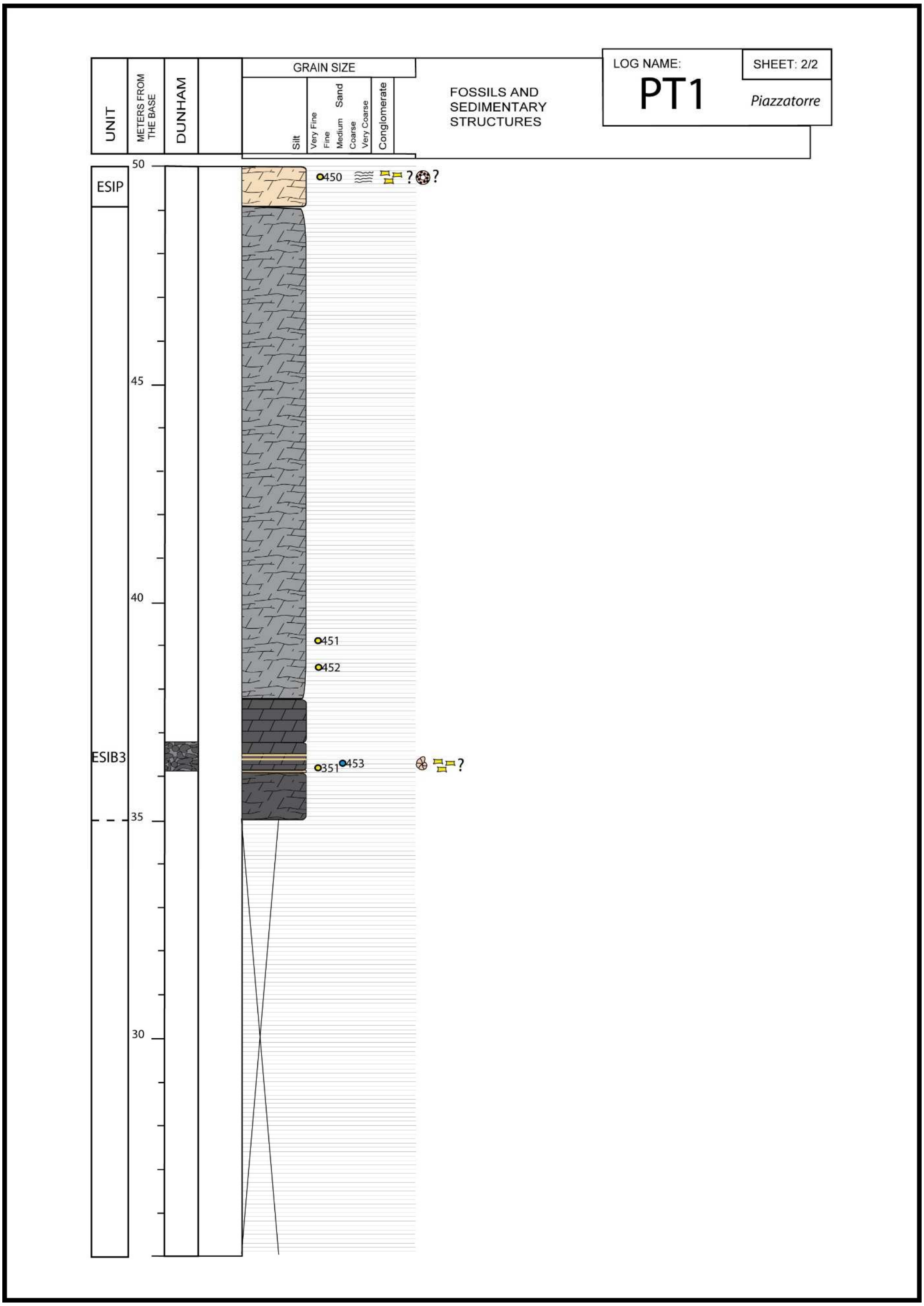
354
340
352
?



LOG NAME:
PT1
SHEET: 2/2
Piazzatorre
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
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45
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35
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ESIP
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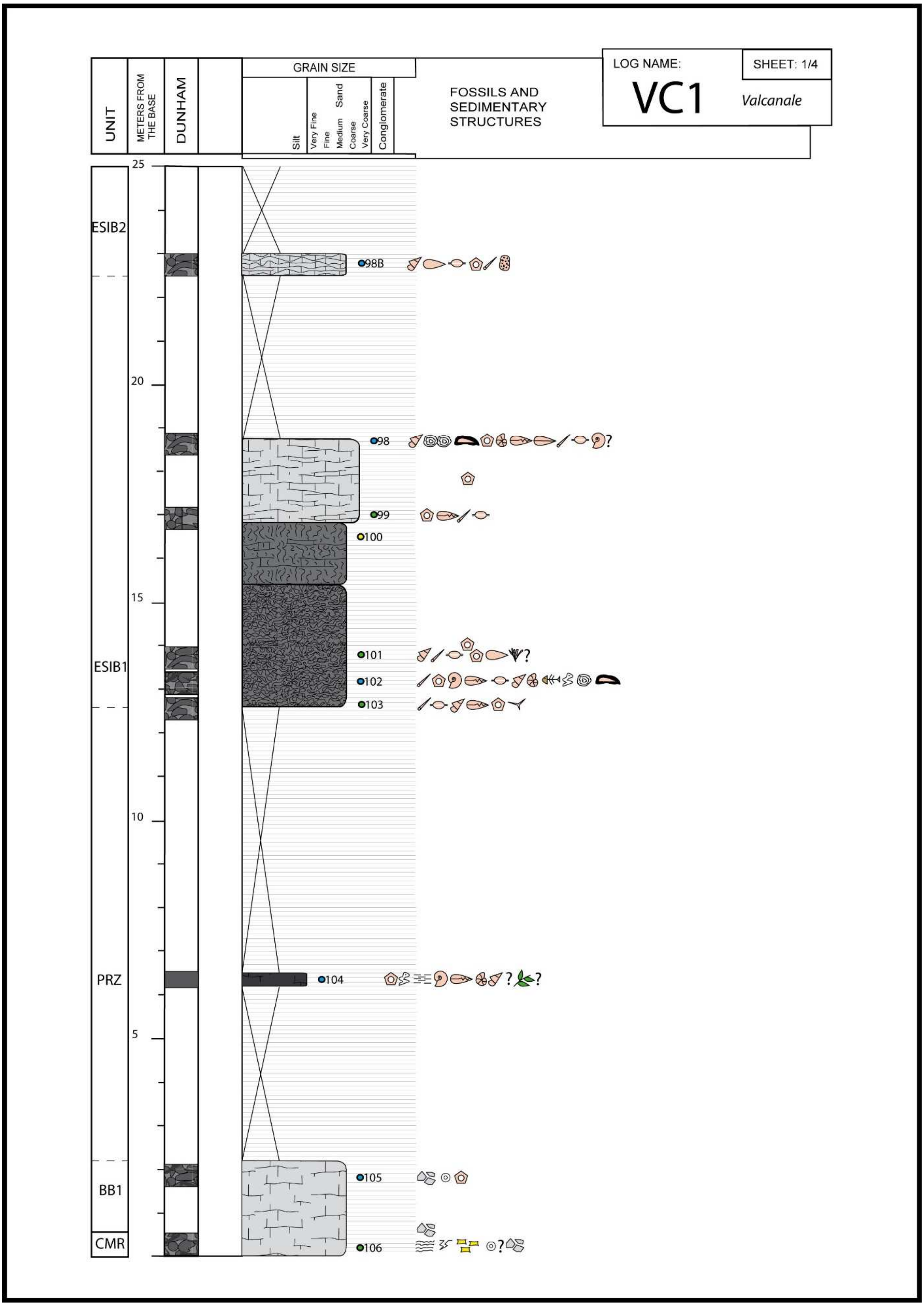
452
351
453


UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Medium
Sand
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
SHEET: 1/4
VC1
Valcanale
25
20
15
10
5
ESIB2
ESIB1
PRZ
BB1
CMR
98B
98
99
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102
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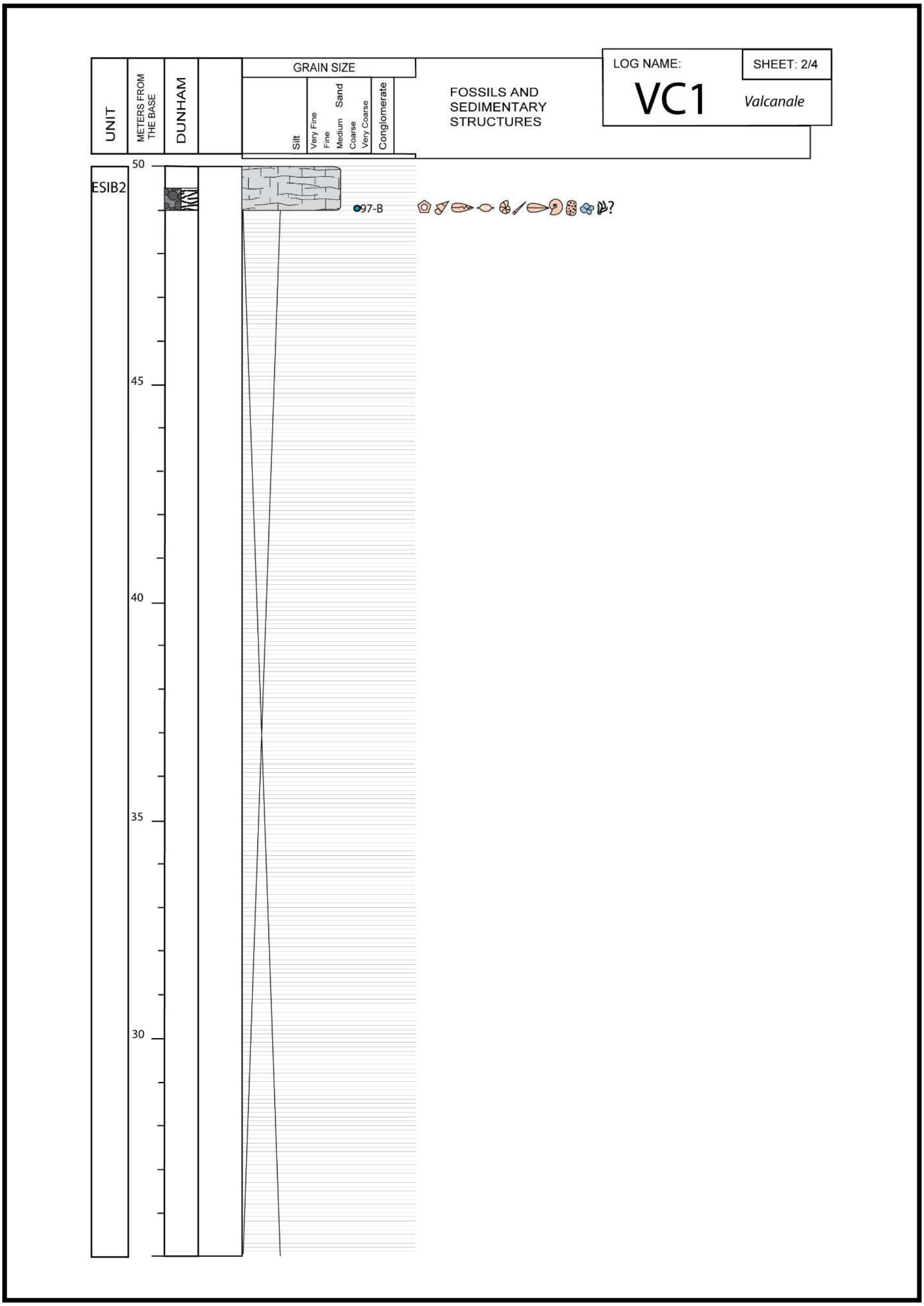
105
106


LOG NAME:
VC1
Valcanale
SHEET: 2/4
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
ESIB2
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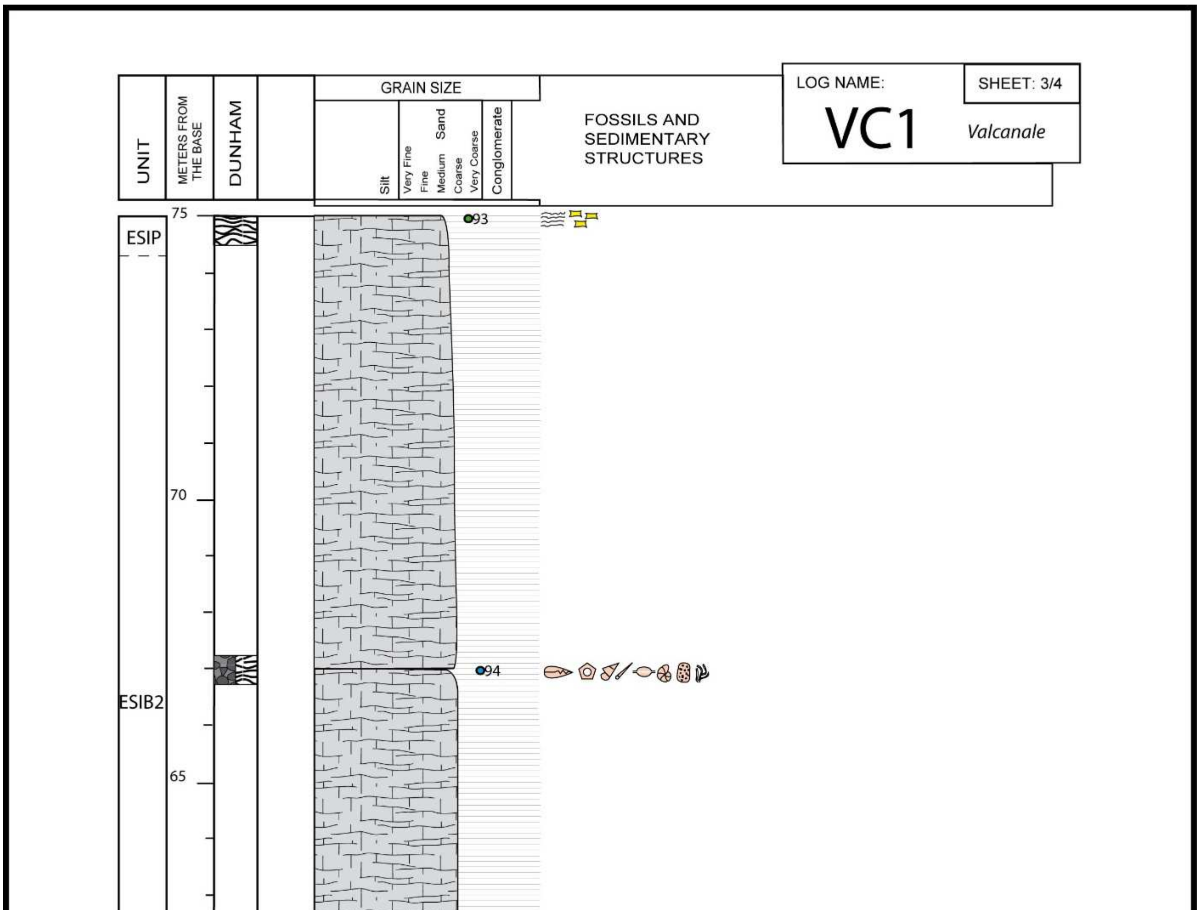
45
40
35
30
97-B
?


LOG NAME:
VC1
SHEET: 3/4
Valcanale
UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
ESIP
ESIB2
75
70
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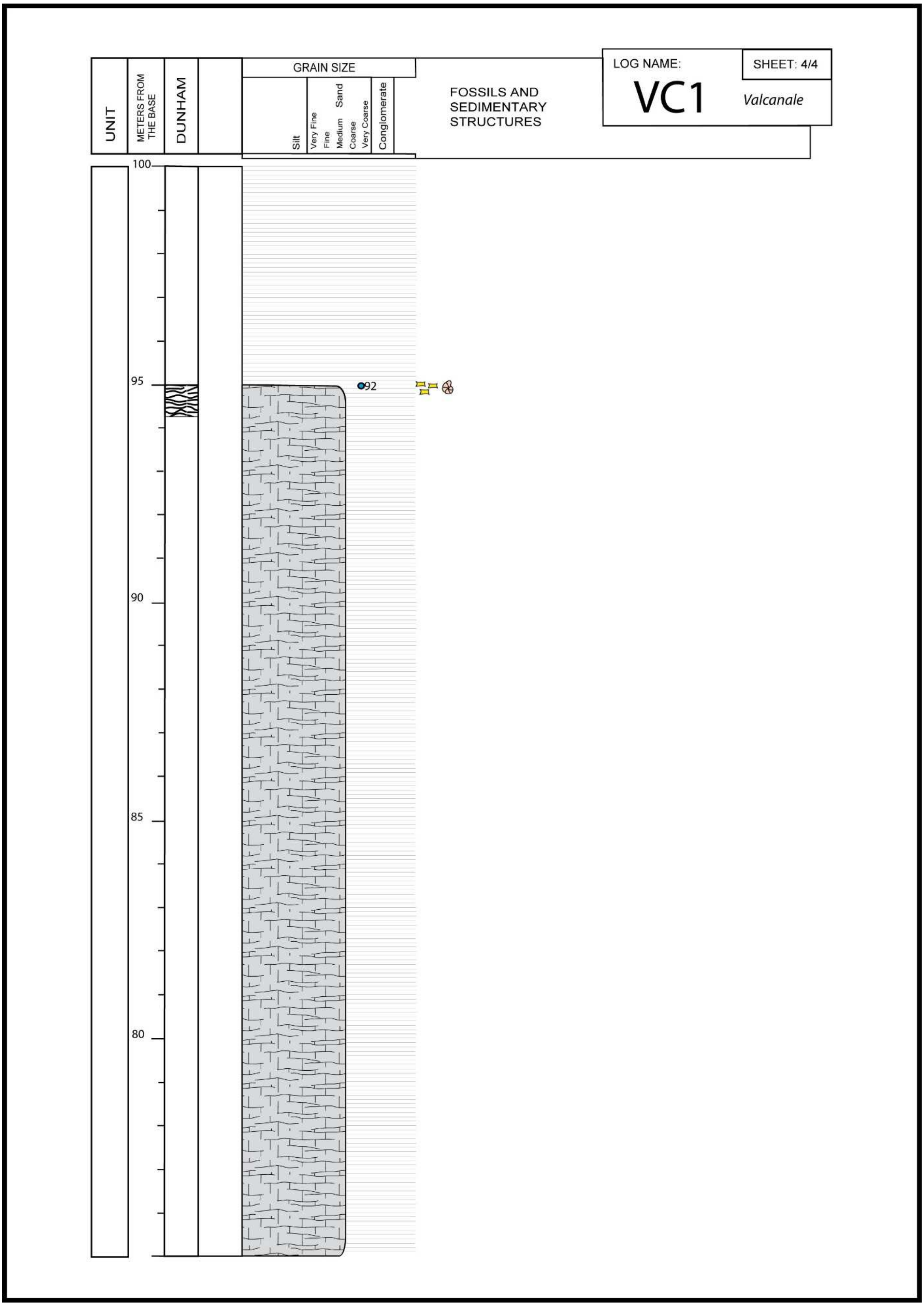
60
55
93
94
95
96


UNIT
METERS FROM THE BASE
DUNHAM
GRAIN SIZE
Silt
Very Fine
Fine
Sand
Medium
Coarse
Very Coarse
Conglomerate
FOSSILS AND SEDIMENTARY STRUCTURES
LOG NAME:
VC1
SHEET: 4/4
Valcanale
100
95
90
85
80
92

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