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STRATIGRAPHY OF RHAETIAN TO LOWER SINEMURIAN CARBONATE PLATFORMS IN WESTERN LOMBARDY (SOUTHERN ALPS, ITALY): PALEOGEOGRAPHIC IMPLICATIONS

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Abstract. A stratigraphical revision of the Upper Triassic-Lower Jurassic succession of the western Southern Alps (Varese area) leads to the introduction of one new lithostratigraphical unit: the ?upper Hettangian-lower Sinemurian Alpe Perino Limestone and the recognition, also in the western Lombardy, of the Rhaetian Zu Limestone, consisting of subtidal cycles, with inner platform facies at the base (Campo dei Fiori Dolomite). These formations represent lagoonal-peritidal to subtidal carbonate depositional systems. A locally angular unconformity between the Rhaetian (or the lower Hettangian) and the upper Hettangian-Sinemurian formations, characterised by 'terra rossa' paleosols and pedogenetic carbonate breccias, can be correlated through all of the investigated profiles.

The Lower Jurassic paleogeography of the western Lombardy Basin was characterised by an emerged area from Hettangian until earliest Sinemurian times in a warm humid paleoclimate. The Alpe Perino Limestone represents a small peritidal to subtidal carbonate platform developed only in a shallow-water gulf of the M. Nudo area. The platform was surrounded by a wide emerged area (island or peninsula?), in the west to southeast, and by open subtidal and basinal environments, in the east to northeast (M. Generoso basin).

Riassunto. La revisione stratigrafica della successione retico-sinemuriana inferiore delle Alpi Meridionali occidentali ha portato alla caratterizzazione di due nuove unità di piattaforma carbonatica, che si sono sviluppate sull'articolato alto strutturale del Varesotto. (1) Il Calcare di Zu presenta, alla base, facies di piattaforma interna e oolitico bioclastiche, sovente dolomitizzate (Dolomia del Campo dei Fiori, nel presente lavoro considerata una associazione di litofacies del Calcare di Zu), e superiormente cicli prevalentemente calcarei e subtidali di rampa medio prossimale; (2) il Calcare d'Alpe Perino (?Hettangiano superiore-Sinemuriano basale) documenta, a livello locale, l'ultimo sistema di piattaforma carbonatica, che precede l'annegamento regionale in connessione al rifting liassico. La parte superiore di tale unità è probabilmente eteropica con le calcareniti di Saltrio, affioranti dal M. Campo dei Fiori verso oriente. Il Calcare d'Alpe Perino rappresenta, inoltre, l'equivalente della piattaforma della Corna sviluppatasi sul margine orientale del Bacino Lombardo.

La discordanza stratigrafica (localmente angolare) tra la successione retica o hettangiana inferiore e la successione sinemuriana è caratterizzata da paleosuoli a terra rossa, associati a brecce carbonatiche pedogenetiche. Essa è stata identificata e correlata regionalmente.

La ricostruzione paleogeografica dell'area investigata suggerisce l'esistenza di una vasta area emersa presente dall'Hettangiano al Sinemuriano basale, in condizioni paleoclimatiche caldo-umide. In particolare, il Calcare d'Alpe Perino documenta ambienti peritidali e lagunari verosimilmente sviluppatisi in un golfo, in corrispondenza del futuro bacino liassico del M. Nudo, circondato da un'estesa area emersa (isola o penisola estesa da ovest a sud-est) e ambienti subtidali e bacinali (verso est e nord-est: Bacino del M. Generoso).

Introduction

In the western Southern Alps (Varese area, Italy) the reduced Upper Triassic-Lower Jurassic succession is mainly represented by carbonate platform to ramp depositional systems. During this time the western Lombardy Basin was characterised by shallow-water depositional environments and extensional tectonics which finally led to platform drowning during the Sinemurian (Liassic rifting). The investigated carbonate succession,

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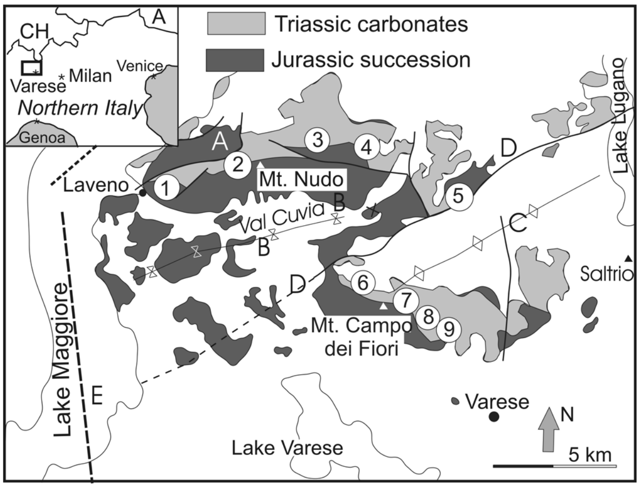

Fig. 1 - Geographical and geological sketch-map of the Varese area with the investigated sections: (1) M. Sasso del Ferro; (2) M. Nudo; (3) Alpe Perino; (4) S. Giuseppe; (5) M. Scerrè; (6) Castello Cabiaglio-Orino; M. Campo dei Fiori sections: (7) Giardino Botanico; (8) M. Tre Croci; (9) Villa Edera. A: Pizzoni di Laveno thrust; B: Valcuvia syncline; C: Brinzio-Maroggia anticline; D: Marzio line; E: Lake Maggiore Fault.

due to depositional gap and/or low sedimentation rate, includes the Campo dei Fiori Dolomite, the Conchodon Dolomite (Gnaccolini 1964) and part of the 'Saltrio Beds' of previous authors (Saltrio Schichten: Wiedenmayer 1963; Kälin & Trümpy 1977; Formazione di Saltrio: Gnaccolini 1964; Saltrio Calcarenites: Gaetani 1975). Although a wealth of stratigraphical, sedimentological and paleontological data was collected since the beginning of the 19th century (Leuzinger 1926; van Houten 1929; Wiedenmayer 1963; Gnaccolini 1964; Kälin & Trümpy 1977), several litho-chronostratigraphical issues remained controversial.

The focus of this work is a stratigraphical revision and a more detailed paleogeographic reconstruction of the Rhaetian-Lower Jurassic succession of the M. Nudo and the M. Campo dei Fiori areas. Our investigation follows on from the work of Kälin & Trümpy (1977), who studied in detail the upper Sinemurian and younger time successions. Nine stratigraphic sections were investigated and correlated using lithofacies and microfacies analysis. The local stratigraphy is compared with other coeval Lombardian areas in order to reconstruct the regional paleoenvironmental evolution across the latest Triassic-Early Jurassic time interval in the western Southern Alps.

Geological setting

The studied area is located in western Lombardy, between Lake Maggiore and Lake Lugano (Fig. 1). The main regional structural elements (the Pizzoni di Laveno thrust, the Valcuvia syncline, the Brinzio-Maroggia anticline and the Marzio line) are east-west oriented (De Sitter 1939). Thrusts and folds formed during the Alpine orogeny (cf. Schumacher 1979), whereas the Marzio Line, associated with post-Variscan extensional tectonics (Casati 1978), was active during the late Paleozoic and was reactivated during the Alpine orogeny. The Mesozoic succession is involved in large wavelength folds displaced by folds of minor throw. Because in the north-western sector thrusts represent mainly a N-S crust shortening, the original W-E trend of the depositional areas is largely preserved.

The Upper Triassic-Lower Jurassic lithostratigraphy of western Lombardy is compared with previous studies (Fig. 2). The Norian Dolomia Principale, very reduced in thickness in the investigated area (M. Campo dei Fiori), documents the restoration of a peritidal carbonate-platform very rich in planar stromatolitic laminations, local tepee and loferitic breccia horizons. The overlying Rhaetian-Lower Jurassic shallow-water succession is reduced in thickness (about 150 m) in comparison with the central and eastern Lombardy and includes unconformities with paleosols (Leuzinger 1926; van Houten 1929; Wiedenmayer 1963; Gnaccolini 1964; Kälin & Trümpy 1977).

The sedimentary record of the Lombardy Southern Alps reflects the Upper Triassic-Lower Jurassic rifting stage, with the lowest subsidence rates documented on the structural high of the Varesotto (Assereto & Casati 1965; Bertotti et al. 1993; Gaetani et al. 1998). The Upper Triassic tectonic activity, led to a horst and graben pattern (Jadoul et al. 1992; Bertotti et al. 1993; Picotti et al. 1997 and references therein) and to sharp lateral thickness variations of the Dolomia Principale and its lateral equivalents. The Upper Trias-

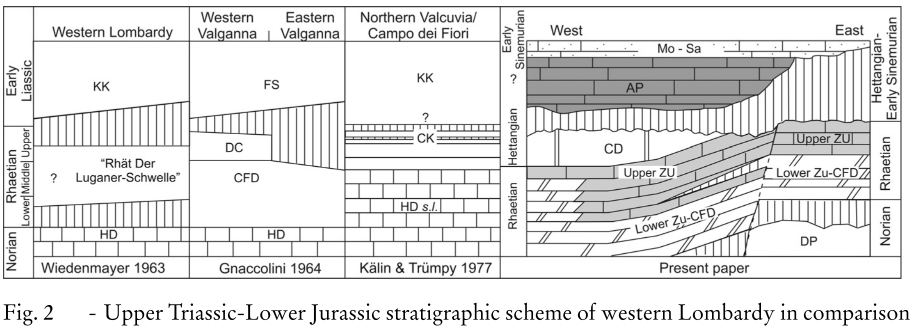

Fig. 2 - Upper Triassic-Lower Jurassic stratigraphic scheme of western Lombardy in comparison with previous studies. HD: Hauptdolomit; CFD: Campo dei Fiori Dolomite; DC: Dolomia a Conchodon; CK: Conchodon-Kalk; KK: Lombardischer Kiesenkalk; FS: Formazione di Saltrio; DP: Dolomia Principale; CD: Conchodon Dolomite; Zu: Zu Lmst.; AP: Alpe Perino Lmst.; Mo-Sa: Moltrasio Lmst. with Saltrio calcarenite intercalations.

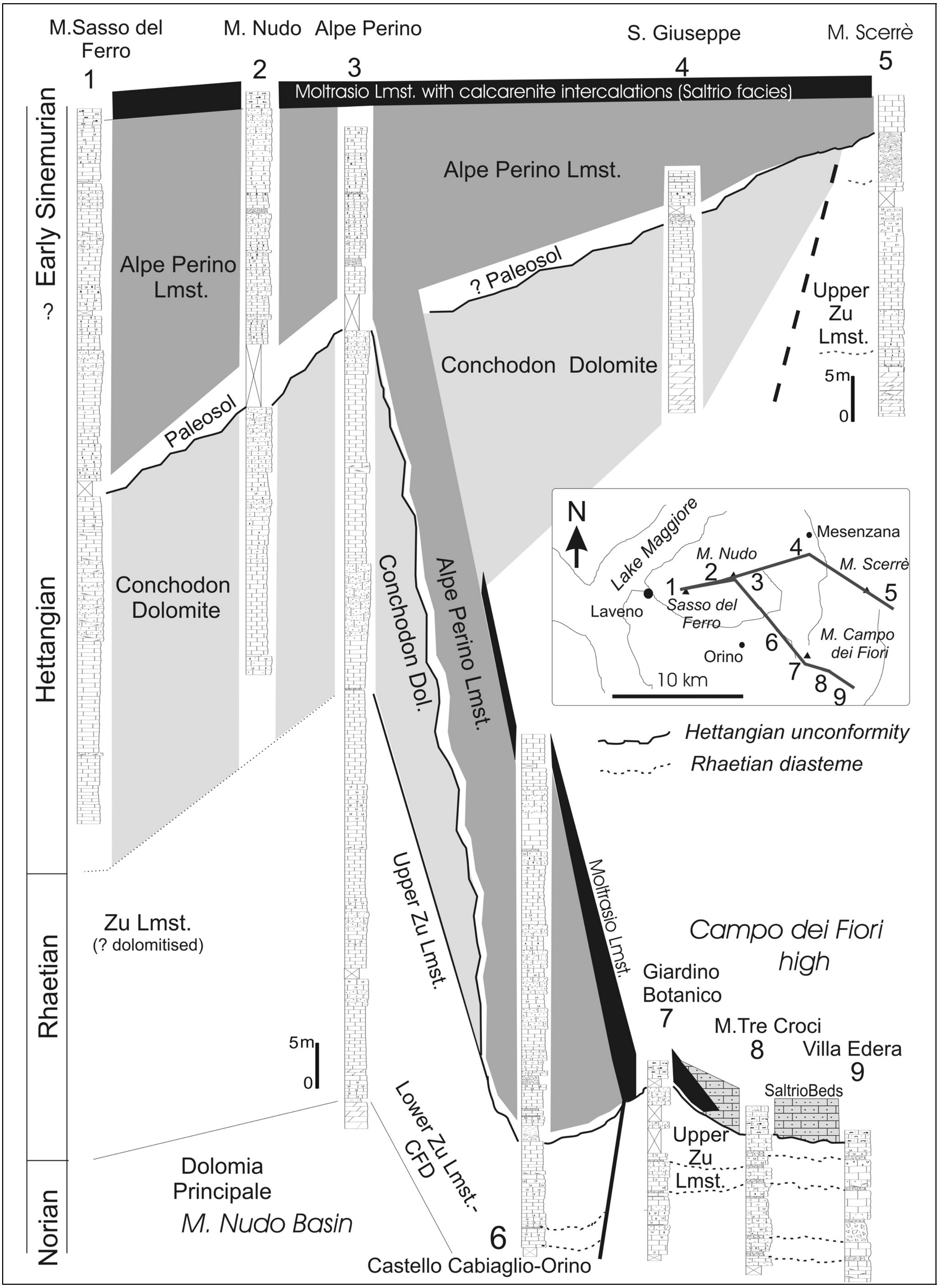

Fig. 3 - Stratigraphic correlations of the Upper Triassic-Lower Jurassic successions across the M. Nudo-Campo dei Fiori areas. For legend see Fig. 6.

sic-Lower Jurassic stratigraphy reveals the presence of structural highs separating the subsiding basins (M. Nudo and M. Generoso: Wiedenmayer 1963; Bernoulli 1964; Kälin & Trümpy 1977; Bernoulli et al. 1979). Faults were active close to Lake Maggiore and Lake Lugano, and persisted until the middle Pliensbachian time (Bernoulli 1964). The Lake Maggiore fault (Bernoulli 1964; Bertotti 1991) separated the Invorio-Gozzano swell (west of Lake Maggiore) from the M. Nudo basin (to the east), whereas the Lugano fault separated the Arbostora (Lugano) high from the M. Generoso basin. Several emersion events are recorded by the carbonate platforms deposited on the structural highs. In the Invorio-Gozzano swell, in the west, intervals of non-deposition and erosion events are documented between the Late Triassic and the Early Jurassic (Rasetti 1897). The Arbostora swell, in the east, is characterised by reduced Rhaetian (0-100 m thick)-Sinemurian (up to a few hundreds metres thick) sequences (Frauenfelder 1916; Senn 1924; Wiedenmayer 1963; Kälin & Trümpy 1977).

The Upper Triassic-Lower Jurassic M. Nudo basin succession developed between the two major structural highs (Invorio-Gozzano swell and Arbostora swell), including the M. Campo dei Fiori local structural high (Leuzinger 1926; Gnaccolini 1964; Kälin & Trümpy 1977). This succession is composed of Rhaetian shallow-water limestones and dolostones, which may have persisted locally until the earliest Sinemurian (Kälin & Trümpy 1977). A regional emersion is locally documented beneath the Sinemurian drowning unconformity. Gnaccolini (1964) underlines the presence of an angular unconformity in the area between Valganna and M. Saltrio, where the major stratigraphic gap has been found (Wiedenmayer 1963; 'Saltrio Beds' directly above the Dolomia Principale). The local tilting of the Triassic succession is related to the lower 'Liassic' tectonics on the western shoulders of the Arbostora swell (Wiedenmayer 1963; Bernoulli 1964; Bertotti 1991; Bertotti et al. 1993). The age of the transgression in the Arbostora swell has been referred to the early Sinemurian and locally to the late Sinemurian (Wiedenmayer 1963; Sacchi Vialli 1964; Lualdi 1999). In the M. Nudo succession the drowning can be ascribed as the early Sinemurian (Kälin & Trümpy 1977; Lualdi 1999).

The lower part of the Liassic basinal limestones (Moltrasio Limestone: Stoppani 1857 or Lombardischer Kieselkalk: Bernoulli 1964) shows an eastward transition to the 'Saltrio Beds' (M. Campo dei Fiori).

Lithostratigraphy and facies analysis

Using facies analysis, regional unconformities (exposure surfaces, paleosols) and lateral facies evolution we propose two different carbonate units (the Zu Limestone and the Alpe Perino Limestone) which are separated by the Conchodon Dolomite. Our stratigraphical subdivision corresponds only in part to the previous one (Campo dei Fiori Dolomite, Conchodon Dolomite and 'Saltrio Beds') described in the literature (e.g. Wiedenmayer 1963; Gnaccolini 1964; Kälin & Trümpy 1977; Fig. 2). In this paper, we suggest to extend the name 'Zu Limestone' in western Lombardy, as the lithofacies organization of the Campo dei Fiori Dolomite, the basal Conchodon Dolomite and the 'Tremona series' Auct. is very similar to the Zu succession of central Lombardy (Gnaccolini 1965; Lakew 1990; Jadoul et al. 1994). For the upper unit of shallow-water carbonates we propose the name 'Alpe Perino Limestone' (Appendix 1).

Nine stratigraphic sections were investigated and correlated over an E-W distance of 15 km and a N-S distance of 10 km (Fig. 3).

The Zu Limestone (Rhaetian)

1) The lower Zu Lmst. (Campo dei Fiori Dolomite Auct.), whose local stratigraphical and paleontological aspects were formally treated in detail by Gnaccolini (1964), is characterised by prevalent peritidal fenestral limestones, with local emersion horizons and oolitic-bioclastic calcarenite intercalations (Gnaccolini 1964). In the more complete sections (M. Campo dei Fiori area), the transition with the Dolomia Principale is marked by a basal green marly horizon (0.5-2m thick), followed by well-bedded carbonates, with intercalated marls and marly limestones. Diagenetic dolomitization processes are dominant at the base and gradually decrease upward. The facies association is commonly organised in shallowing-upward cycles (up to 4-5 m thick). In the M. Campo dei Fiori, a few intraformational loferitic breccias are intercalated. In the north-eastern sector (e.g. M. Scerrè section; Fig. 3), thin beds (10-15 cm) of fine to medium grained carbonate litharenites with quartz grains are intercalated with the limestones. The fauna is dominated by *Triasina hankteni* Majzon, in association with *Auloconus permodiscoides* (Oberhauser) and *Glomospirella pokornyi* (Salaj) (Fig. 4). It is comparable to that described from the upper Zu Lmst. in central-eastern Lombardy (Lakew 1990; Jadoul et al. 1994; 2004) and indicates a Rhaetian age.

2) The upper Zu Lmst. is marked by a basal transition from light-grey to light nut-brown micritic to bioclastic or oolitic calcarenites, with rare thin marly interbeds. Brecciated pedogenetic carbonates, thin discontinuous horizons of 'terra rossa', and shales are present at the top of the succession from M. Sasso del Ferro to M. Campo dei Fiori (Castello Cabiaglio-Orino sec-

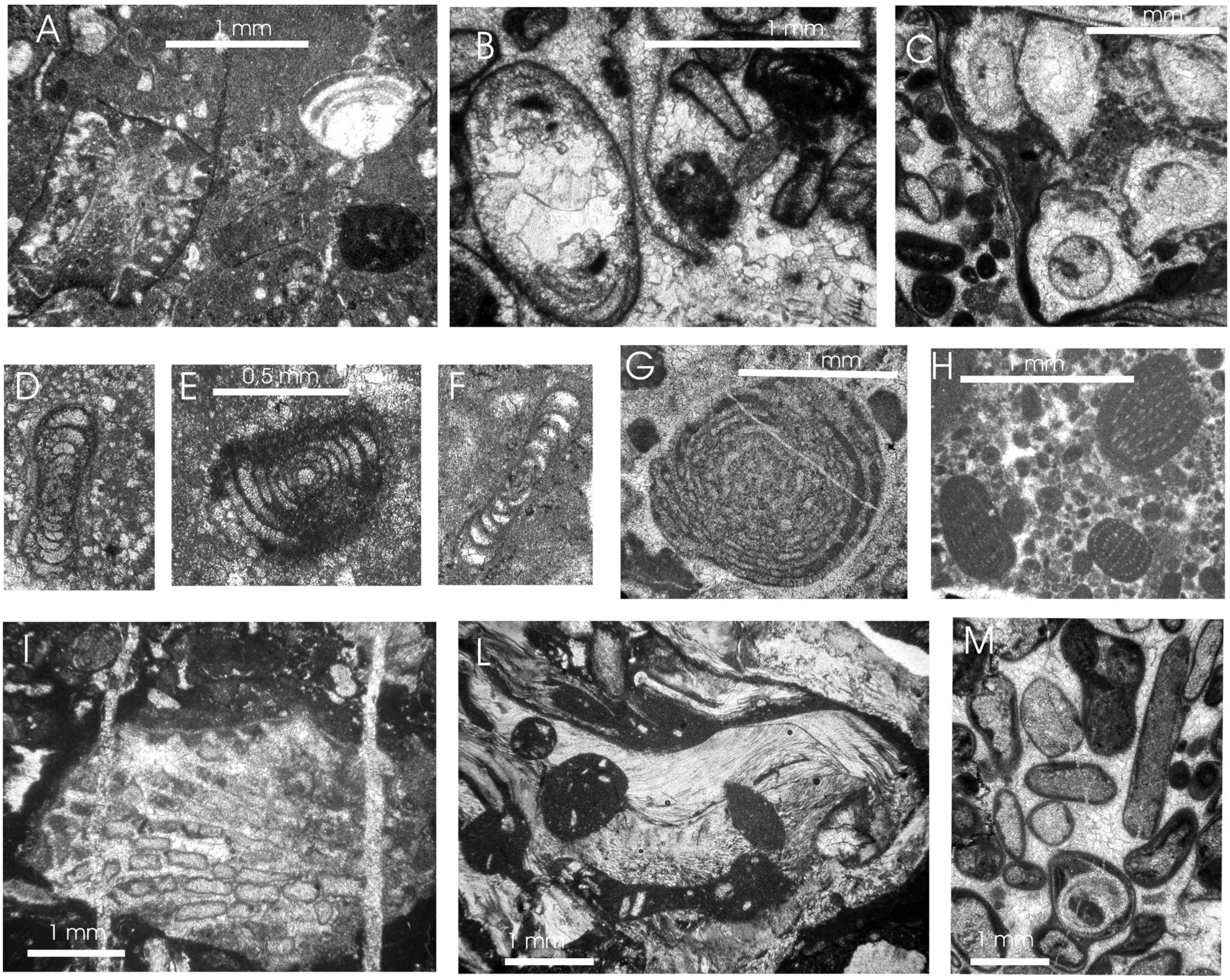

Fig. 4 - Rhaetian microfacies of the upper Zu Limestone. A) Bioclastic wackestone with dasyclad algae and *Auloconus permodiscoides* (Oberhauser) (sample 5, Campo dei Fiori-Giardino Botanico); B) bioclastic grainstone with *Aulotortus* sp., *Glomospirella* sp. (sample V28, Alpe Perino); C) serpulids with small micritised ooids and peloids (sample J240, M. Sasso del Ferro); D, E, F) *Glomospirella pokornyi* (Salaj) (sample V26, Alpe Perino); G) *Triasina hantkeni* Majzon (sample V6, Alpe Perino); H) peloidal packstone with fecal pellets (*Parafavreina* sp.) (sample V95, M. Scerrè); I) bioclastic packstone with coral, *Aulotortus* sp. (sample V94, M. Scerrè); L) bioclastic packstone with a brachiopod bored shells (V98, M. Scerrè); M) grainstone with superficial ooids, lumps and micritised bioclasts (J240, M. Sasso del Ferro).

tion; Fig. 3, 5). The succession, 40-50 m thick in the central and western sector of the studied area, shows a strong reduction in thickness eastwards next to M. Campo dei Fiori and M. Scerrè (Fig. 3).

Three different facies associations have been recognised in the upper Zu Lmst.:

a) fossiliferous (corals, sponges, megalodontids) packstones to wackestones in decimetre amalgamated strata. This facies is most common and includes bioturbation, frequent peloids, pellets, lumps, gastropods, dasyclad algae, foraminifera (*Triasina hantkeni*, *Glomospirella* sp., aulotortids, lagenids) and bivalves (Fig. 4). These carbonates were deposited in lagoonal and inner-platform environments;

b) bioclastic and oolitic packstones to grainstones, with coated grains, lumps and skeletal grains (bivalves, algae, gastropods, echinoids and foraminifera). These beds were deposited on high-energy shoals;

c) fenestral packstones and wackestones, composed mostly of peloids and foraminifera (valvulinids, textularids, nodosarids), indicating very shallow subtidal to intertidal environments.

The three facies associations show a meter scale cyclic pattern, with local shallowing and shoaling-upward trends (Fig. 5, 6). In the Alpe Perino section (Fig. 6), up to 15 m-thick cycles consist of fossiliferous wackestones at the base, overlain by bioclastic and oolitic grainstones and packstones. These cycles document an alternation of low-energy inner-platform (tidal flat, lagoon) and high-energy bank-margin environments (cf. Enos 1983). Eastwards (Castello Cabiaglio-Orino section; Fig. 5), the facies associations testify to more open

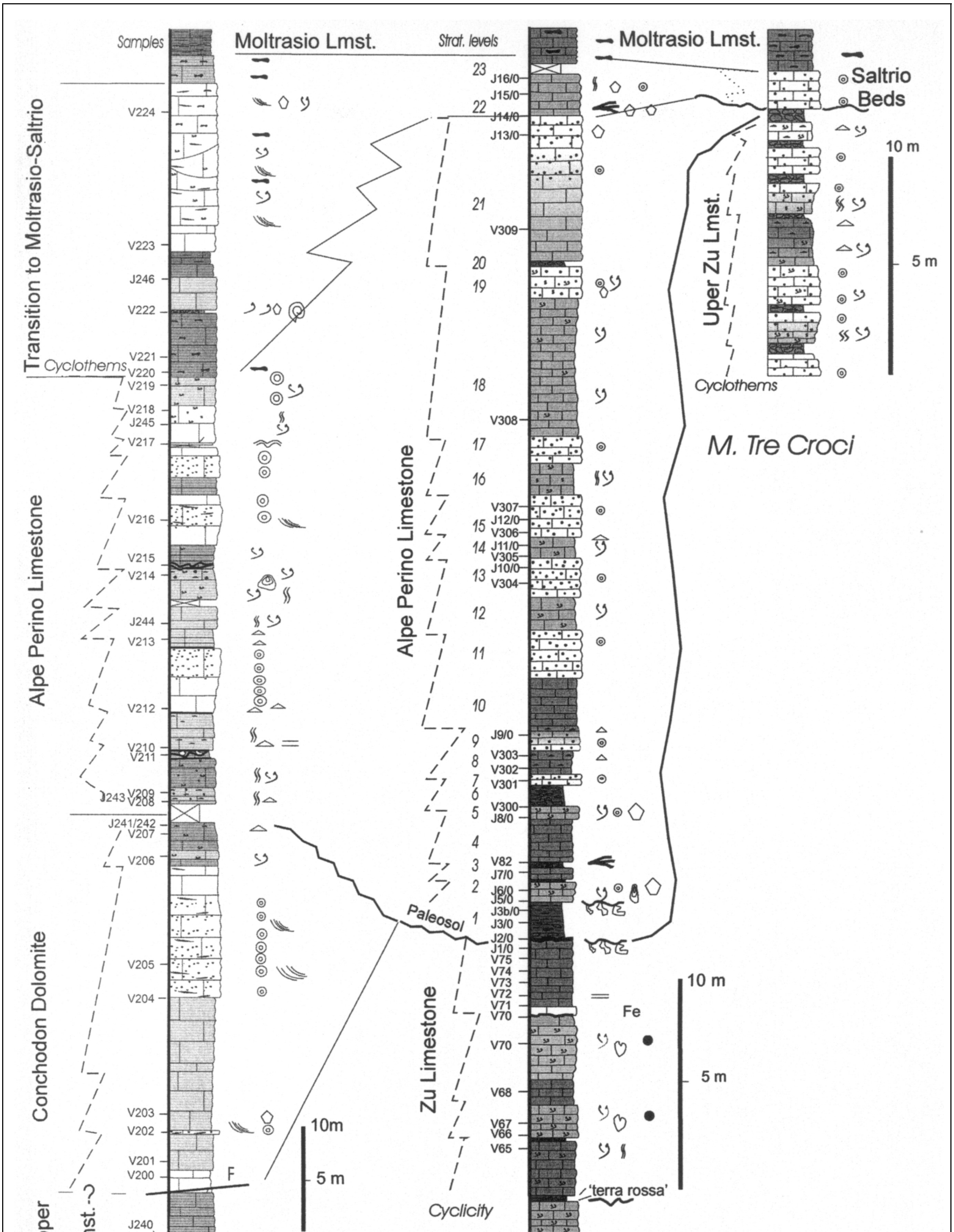

Fig. 5 - Stratigraphic sections of M. Sasso del Ferro, Castello Cabiaglio-Orino and M. Tre Croci. Castello Cabiaglio-Orino represents the type section of the Alpe Perino Limestone (see Appendix 1). Legend in Fig. 6.

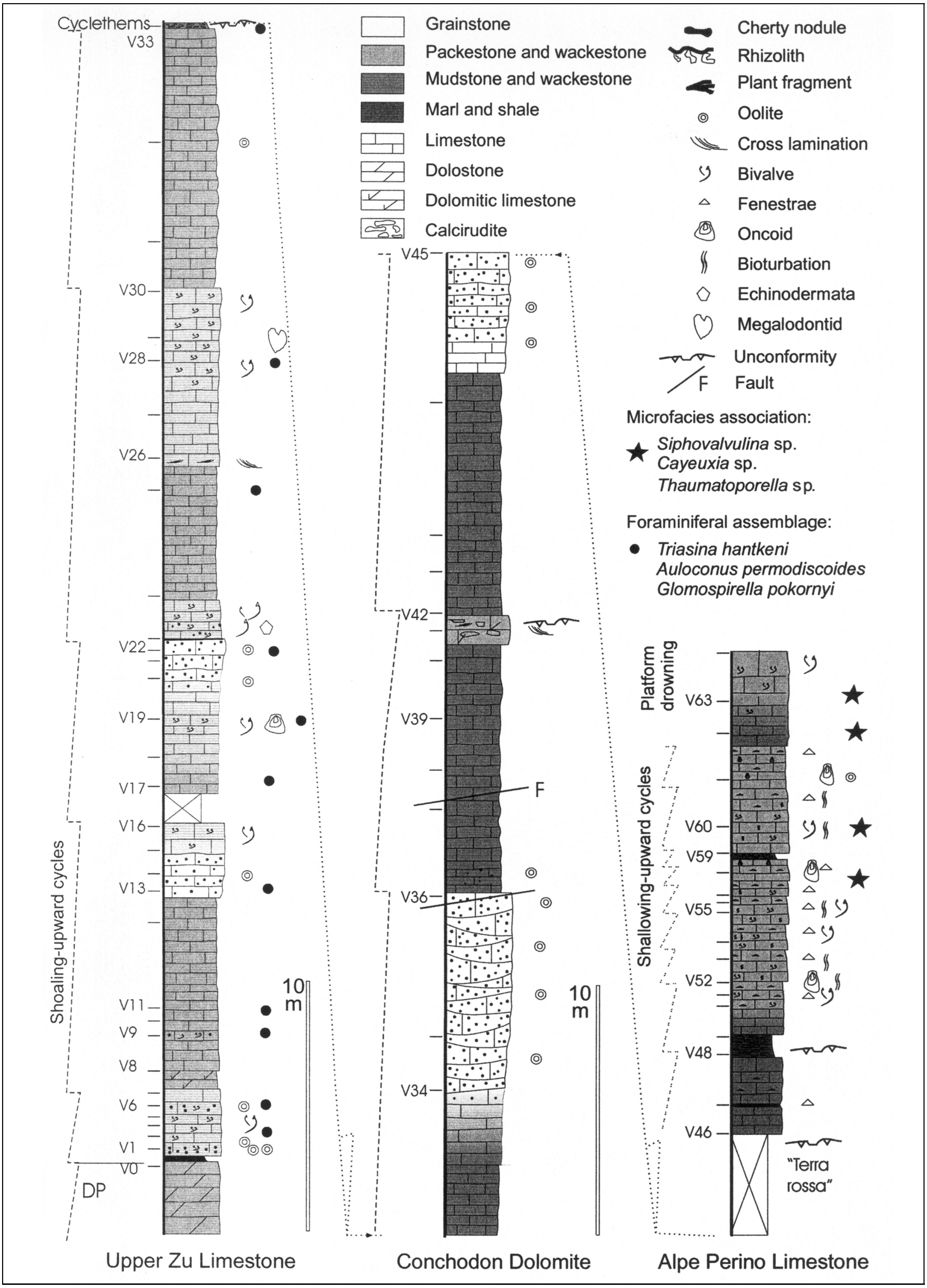

Fig. 6 - Rhaetian-lower Sinemurian stratigraphic section of Alpe Perino.

subtidal environments with patch reefs (corals, megalodontids and calcisponges). In the south-eastern sector (M. Campo dei Fiori), the cycles are thinner and locally characterised by oolitic and skeletal grainstones, overlain by fenestral wackestones. The cycles are capped by red to white brecciated carbonates with calcite cements (equant sparite), locally associated with red-green marls and shales (M. Campo dei Fiori sections; Fig. 3). This facies sequence documents the evolution from beach to tidal and finally subaerial environments.

In the north-eastern sector (S. Giuseppe and M. Scerrè sections; Fig. 3), micritic limestones are more common, and tidal-flat facies associations have been recognised. In the lower part of the M. Scerrè section, channel deposits overlie an erosional surface, with dolomitic breccias at the base, overlain by cross-laminated grainstones. These deposits are associated with intertidal laminated and poorly fossiliferous (mainly ostracods and foraminifera), partially dolomitized, mudstones to wackestones. Facies sequences show a shallowing-upward trend from subtidal to intertidal-supratidal facies capped by brecciated and recrystallised, probably, pedogenized horizons.

The Conchodon Dolomite (?early Hettangian)

The Conchodon Dolomite (about 40 m thick) occurs only in the north-western sector of the studied area (Fig. 3). The lower boundary in the Alpe Perino section corresponds to a thin level of brecciated carbonates, with a green marly matrix (Fig. 6). The upper boundary, where exposed, is characterised by a 50-60 cm thick 'terra rossa' horizon (M. Sasso del Ferro section; Fig. 5). The unit mostly consists of recrystallised amalgamated mudstones and peloidal wackestones-packstones, with scattered bivalves, ostracods, gastropods and dasyclad algae; oolitic grainstone beds displaying lenticular bedding and with common erosional base are intercalated. Peritidal structures, fenestrae, prism cracks are also present. These carbonates testify to tidal-flat, restricted lagoon and subtidal channel depositional environment. Cross-laminated grainstones (2-10 m thick) are mainly represented by micritised ooids, aggregated grains (lumps), coated grains, peloids and bioclasts (Fig. 7). Skeletal grains includes bivalves, ostracods, echinoids and algae, whereas benthic foraminifera are drastically reduced with respect to the underlying Zu Lmst. communities. These high-energy deposits represent bank margins, subtidal shoals and flood-tidal channels.

The most common facies sequence is represented by shoaling upward cyclothems (up to 15 m thick) with at the base lagoonal and intertidal mudstones to wackestones, followed by cross-bedded oolitic packstones/grainstones (e.g. Alpe Perino section; Fig. 6).

These facies associations are similar to the Conchodon Dolomite of the Bergamasc Alps ascribed to the early Hettangian (Cirilli et al. 2000).

The unconformity of the western Lombardy

The regional unconformity between Rhaetian-Hettangian and lower Sinemurian strata was described by several authors (Leuzinger 1926; van Houten 1929; Gnaccolini 1964; Kälin & Trümpy 1977 and references therein). This boundary occurs between the Zu Lmst. (or the Conchodon Dolomite in the western Varese area) and the overlying Alpe Perino Lmst. (Fig. 8), and it is locally characterised by angular (10-15°) unconformity (e.g. Castello Cabiaglio-Orino; Gnaccolini 1964). A more evident angular unconformity is documented in the central (Alpe Perino, Cittiglio) and in the

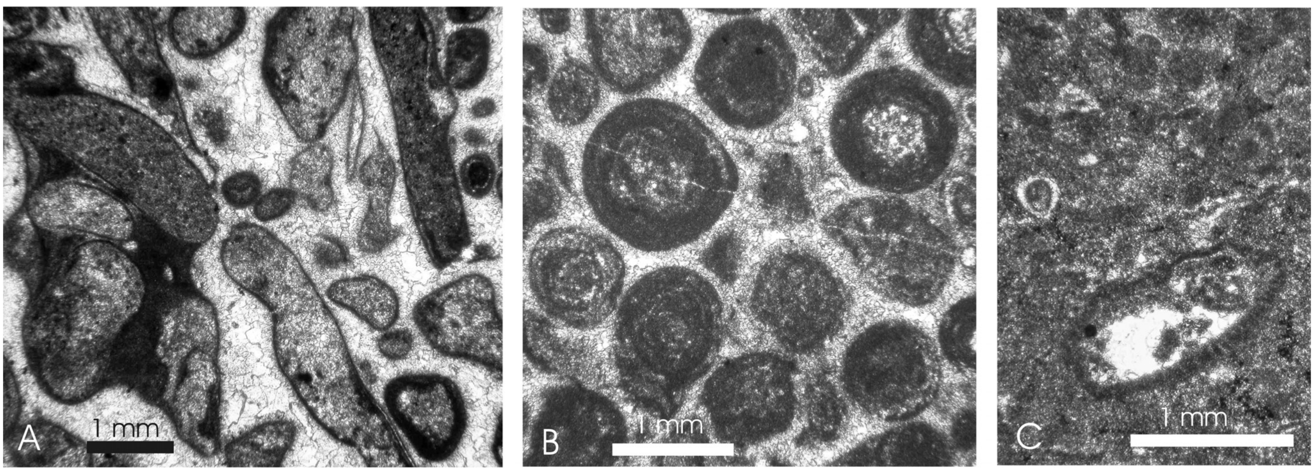

Fig. 7 - Microfacies of the Conchodon Dolomite (Alpe Perino section). A) Grainstone with aggregate grains, micritised bio-intraclasts and small ooids (sample V35); B) grainstone with micritised and recrystallised ooids (sample V45); C) wackestone with peloids, *Thaumatoporella* sp. and ostracods (sample V41).

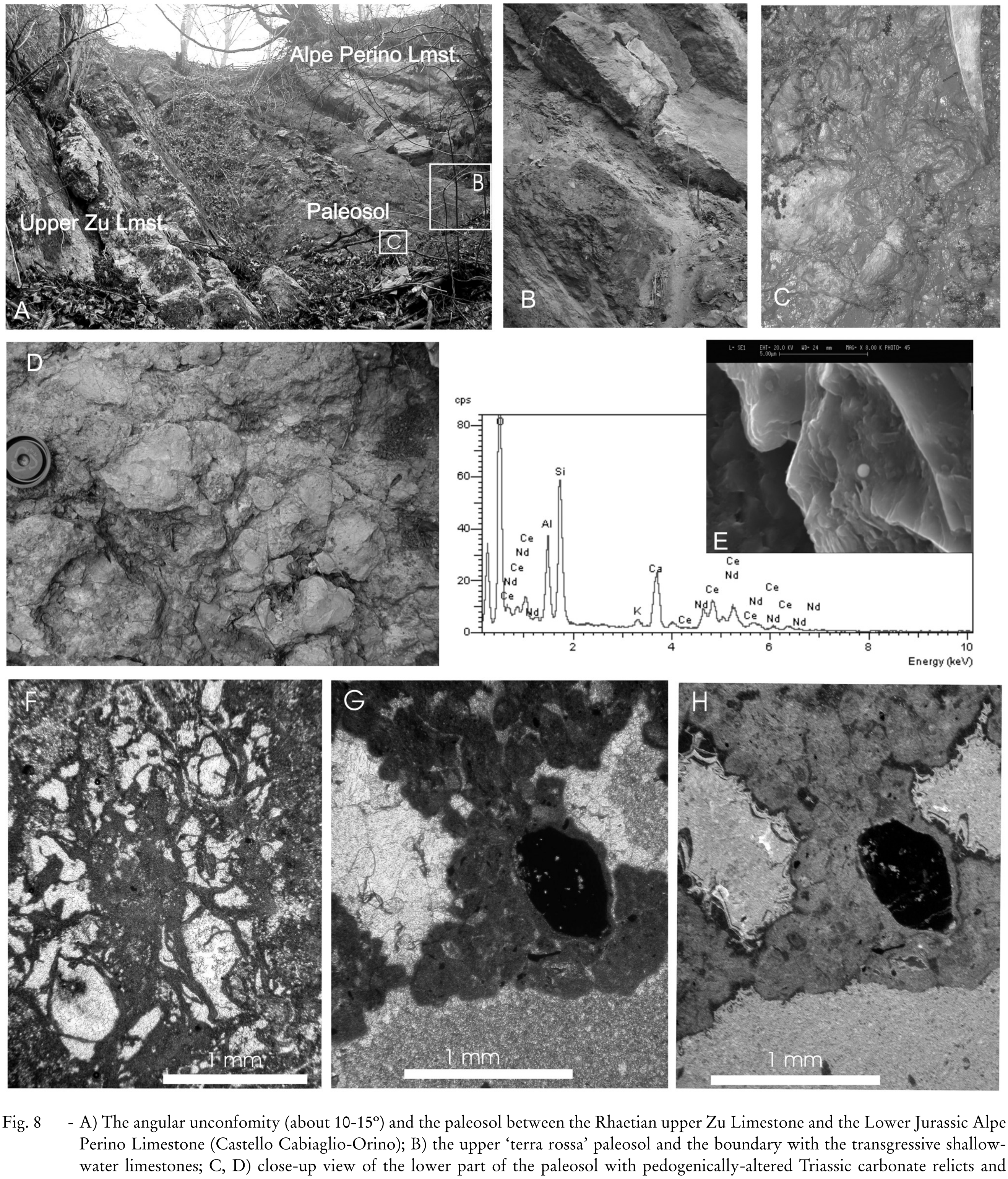

Fig. 8 - A) The angular unconfomity (about 10-15°) and the paleosol between the Rhaetian upper Zu Limestone and the Lower Jurassic Alpe Perino Limestone (Castello Cabiaglio-Orino); B) the upper 'terra rossa' paleosol and the boundary with the transgressive shallow-water limestones; C, D) close-up view of the lower part of the paleosol with pedogenically-altered Triassic carbonate relicts and breccias; E) SEM view of paleosol with a small nodule and related EDX composition; F) rhizolith and alveolar structures in a pedogenically-altered Rhaetian limestones (M. Campo dei Fiori-Giardino Botanico); G) detail of pedogenically-altered peritidal fenestral carbonate with intraclasts and black clast derived from the underlying paleosol (base of Alpe Perino Lmst., M. Sasso del Ferro, sampleV208); H) cathodoluminescence of G). The first generation of equant calcite cement within fenestrae is zoned; the later diagenetic microsparite, could be related to meteoric diagenesis in different pH conditions.

eastern (Viggiù) sectors (Lualdi 1999). Eastward, in the Saltrio area, the unconformity is between the Dolomia Principale and the 'Saltrio Beds' (Fig. 9) (Wiedenmayer 1963).

In the eastern area, the Conchodon Dolomite has either been eroded or was not deposited. In the Castello Cabiaglio-Orino section (Fig. 8), a paleosol (up to 2 m thick) (Gnaccolini 1964; Jadoul et al. 2000) is characterised by recrystallised and fractured white to pink limestones at the base, passing to red pedogenically-altered nodular limestones with a green and red marly matrix. The upper part of the paleosol consists of rusty red marly shales, with rare recrystallised calcareous nodules. Opaque aggregates, alveolar textures, acicular fibres and rhizoliths (James 1972; Klappa 1980) were also recognised. SEM-EDAX analysis shows the composition of the opaque aggregates to include rare earth elements (Ce, Nd; Fig. 8), relatively abundant also in recent soils and used as element tracers to evaluate soil erosion (Liu et al. 2004).

In the north-eastern sector (M. Scerrè section; Fig. 3), 8-9 m below the top of the Zu Lmst. and the base of the Alpe Perino Lmst., sedimentary dikes and pockets filled by carbonate breccia include dm-scale micritic and fossiliferous lithoclasts with a bioclastic arenite matrix.

Westwards (e.g. M. Sasso del Ferro section), the shallow-water carbonate succession underlying the transgressive 'Saltrio Beds' is less differentiated. The unconformity is at the base of the pedogenetically-altered reddish fenestral limestone (Fig. 5, 8G, H). In this area m-thick 'terra rossa' lenses are present in the same stratigraphical position between the Conchodon Dolomite and the Alpe Perino Limestone. In the M. Campo dei Fiori area (Giardino Botanico), the unconformity separates pedogenetically-altered pink recrystallised limestones at the top of the Zu Lmst. from dark-grey cherty limestones of the Moltrasio Limestone.

In our revision the unconformity has been placed into the Hettangian on account of its stratigraphical position (see discussion).

The Alpe Perino Limestone (?late Hettangian-early Sinemurian)

The Alpe Perino Lmst. (about 35 m thick) is a new stratigraphical unit proposed in this study, cropping out in the western (M. Sasso del Ferro section; Fig. 5) and central sectors of the investigated area. The proposed type section is Castello Cabiaglio-Orino (Fig. 5; Appendix 1).

The lower boundary is represented by the unconformity described above. At the base, pedogenic structures (peds) and intraformational solution breccias are also present. The upper boundary is transitional with the dark-grey bedded basinal cherty limestones of the Moltrasio Lmst., which locally contain grey to dark-grey calcarenite intercalations with reworked shallow-water bioclasts, lithoclasts and small ooids (Moltrasio-Saltrio transition; Fig. 5, 11; Appendix 1).

The Alpe Perino Lmst. rapidly thins out in the eastern part of the study area (e.g. M. Scerrè; Fig. 3) where it overlies the Conchodon Dolomite or, directly, the Zu Lmst. The unit is not present at M. Campo dei Fiori. In the east (e.g. M. Orsa, Saltrio quarry), the grey calcarenites of the 'Saltrio Beds' (about 20 m thick) unconformably (Wiedenmayer 1963) overly Rhaetian or Norian units.

The lower Alpe Perino Lmst. is characterised by shallow-water microsparitic mudstones-wackestones, with abundant ostracods and rare lagenids and valvulinids, dark-grey marly intercalations with plant remains at the base (Castello Cabiaglio-Orino section; Fig. 5). This testifies to an inner platform, with mixed marine-transitional environments at the base (marsh? ponds).

In the middle-upper part, bioturbated fenestral wackestones to packstones with small oncoids are commonly associated with bioclastic (gastropods, bivalves, echinoids, ostracods, dasyclad algae) and oolitic packstones-grainstones with peloids, oncoids, intraclasts and scattered bioclasts (Fig. 10). Dissolution cavities (fenestrae *s.l.*), commonly filled by geopetal crystal silt (Fig. 10M), are associated with stromatolitic bindstones (M. Sasso del Ferro).

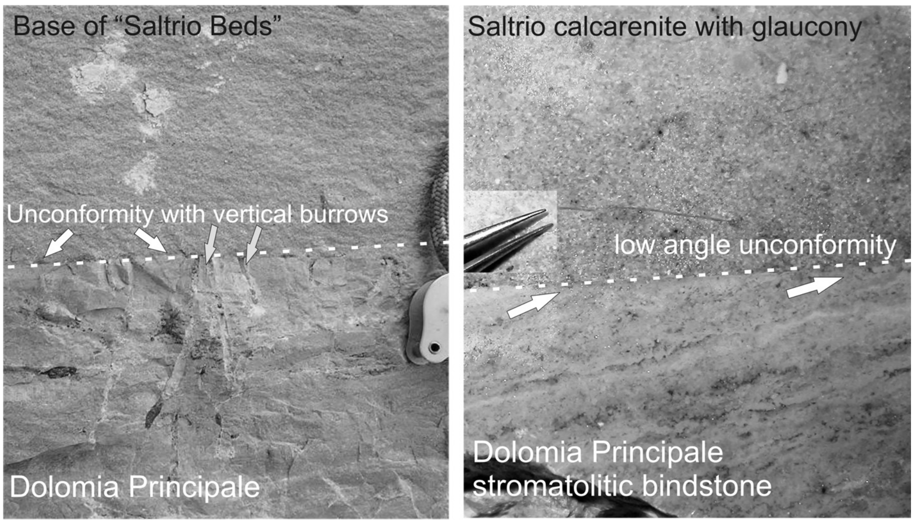

Fig. 9 - The Hettangian unconformity separating the Norian Dolomia Principale and the lower Sinemurian 'Saltrio Beds' in the Saltrio quarry.

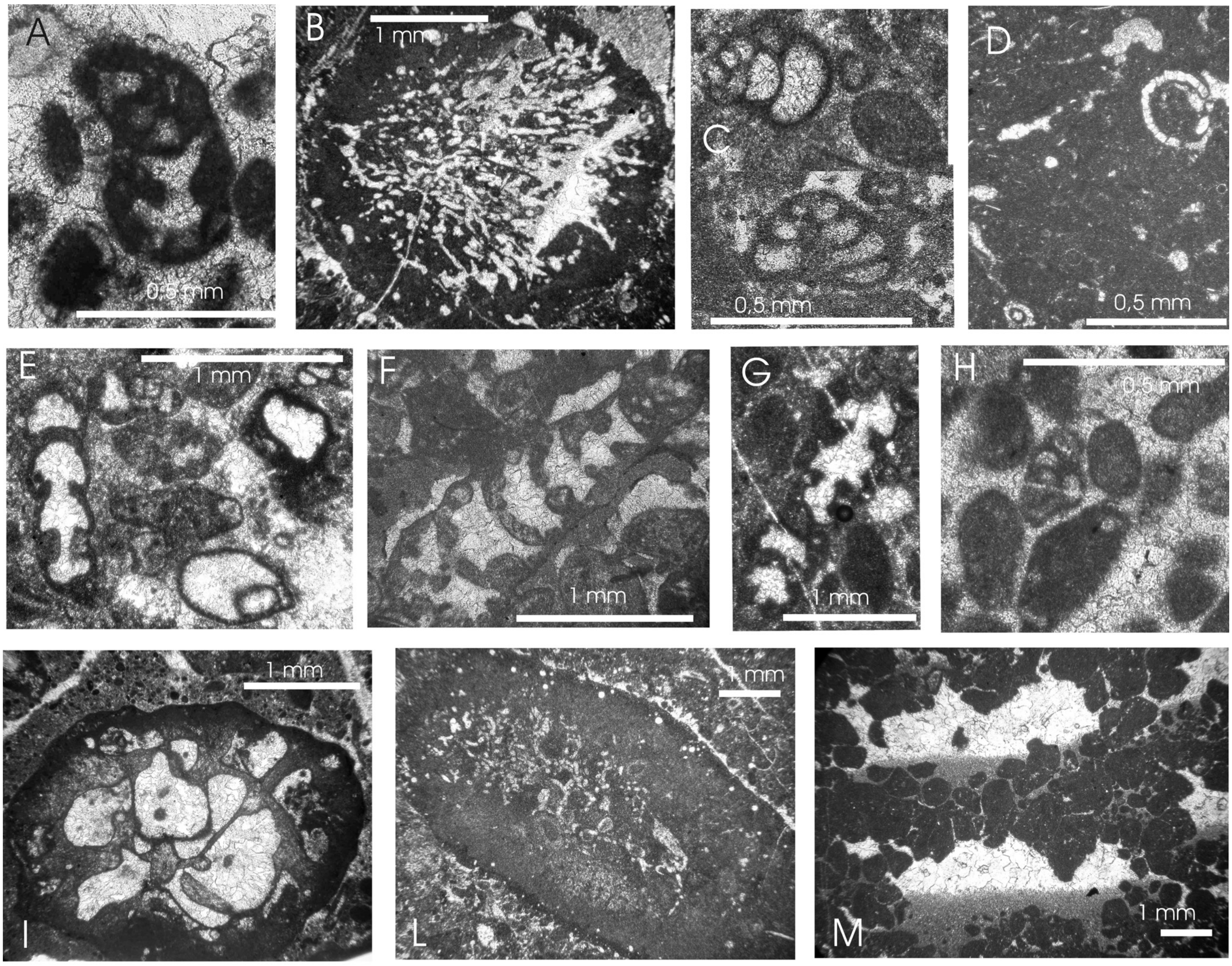

Fig. 10 - Shallow-water microfacies of the Alpe Perino Lmst. from the M. Sasso del Ferro (A, D), Alpe Perino (B, C, E, F, G, H, L, M) and Castello Cabiaglio-Orino (I) sections. Typical associations of benthic foraminifera include: Lituolidae (A, F), *Ammobaculites* sp., *Reofax* sp. (E, G), *Siphovalvulina* sp. (C, H) and ?*Vidalina martana* Farinacci (H) associated with *Thaumatoporella* sp. (E) and *Cayeuxia* sp. (B); D) wackestone with ostracods and small algae (? Characeae) at the base of M. Sasso del Ferro section (sample V207); I) micritised bioclast of problematic organism (sample J4, Castello Cabiaglio-Orino); L) oncoidal intraclastic-peloidal packstone (sample V52); M) intraclastic fenestral packstone with geopetal infilling (sample V51).

These facies associations testify to a shallow subtidal to intertidal depositional setting. Metric shallowing-upward peritidal cyclothems are observed (Fig. 5, 6). They start with subtidal bioclastic wackestones-packstones, followed by inter-supratidal fenestral packstones to bindstones or grainstones with small micritised ooids (Castello Cabiaglio-Orino section; Fig. 5). Open subtidal platform environments are documented in the topmost interval by the abundance of crinoids and lagenids.

The foraminiferal assemblage (Fig. 10) (*Vidalina martana* Farinacci, *Siphovalvulina* sp., *Lenticulina* sp., lituolids), associated with *Cayeuxia* sp. and *Thaumatoporella* sp., is the typical association of the Lower Jurassic platforms of the Southern Alps and the Apennines (e.g. Chiocchini et al. 1994; Schirolli 1997).

The basal horizon of the unit, just above the unconformity at Castello Cabiaglio-Orino (sample J7/0, Fig. 5, 12), abundant in amorphous organic matter with particles of inertinite and small-sized vitrinite debris, yielded a rich palynological assemblage including *Cerebropollenites macroverrucosus* (Thiergart) Schulz, *Callialaporites* spp., *Uvaesporites argenteaeformis* (Bolkhovitina) Schulz, *Porcellispora longdonensis* (Clarke) Scheuring, *Classopollis torosus* (Reissinger) Balme and *Gliscopollis meyeriana* (Klaus) Venkatachala. Trilete spores (e.g. *Lycopodiacidites rugulatus* (Couper) Schulz, *Concavisporites crassexinius* Nilsson, *Granulatisporites punctatus* and *Microreticulatisporites fuscus* (Nilsson) Morbey) are present.

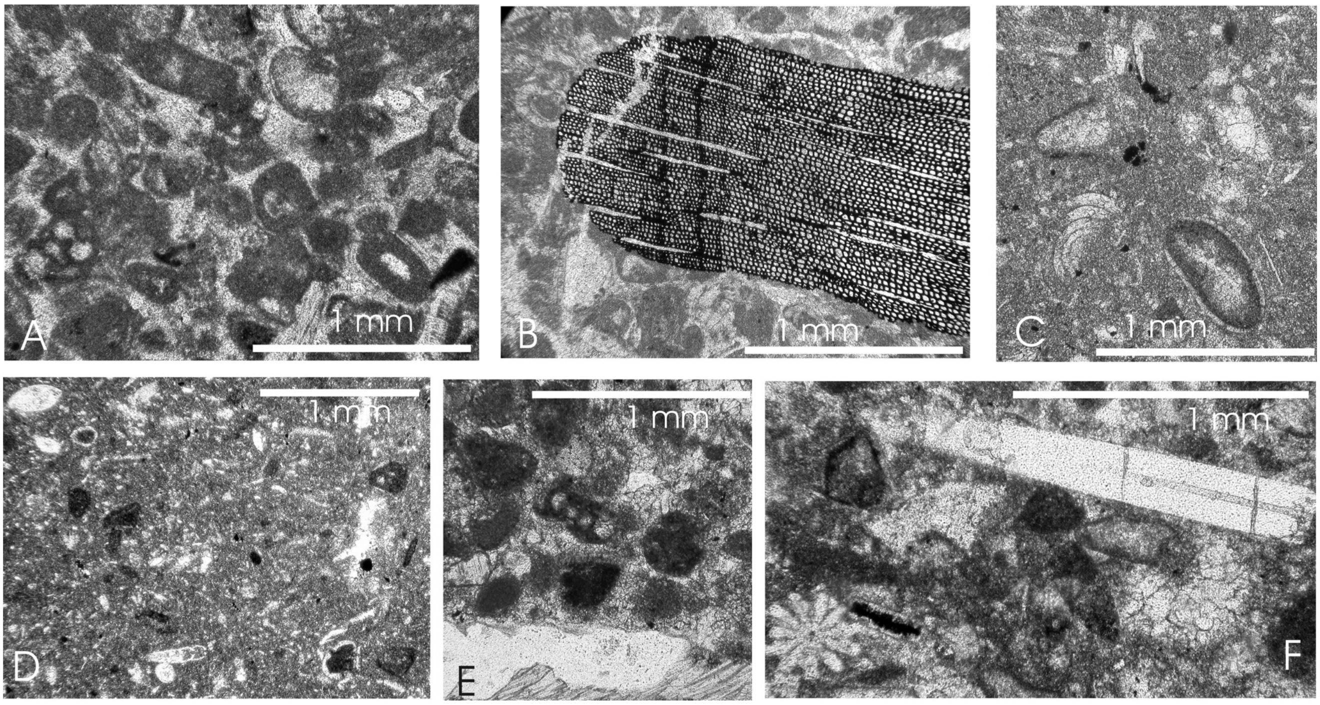

Fig. 11 - Microfacies of the 'Moltrasio-Saltrio' transitional facies in the Castello Cabiaglio-Orino section. A) Fine grainstone with small intraclasts, superficial ooids and foraminifera (sample J14/0); B) plant fragment in fine grained intra-bioclastic grainstones (sample J14); C, D) microsparitic wackestone-packstone with foraminifera (?*Involutina liassica* Jones), ostracods, lagenids, reworked superficial ooids (sample J15/0); E, F) packstone with intraclasts, micritised ooids, forams (?*Vidalina martana* Farinacci) echinoids, brachiopods, sponge spicule (J16).

Discussion

A) The Rhaetian succession

The lithofacies association of the Zu Lmst. (comprising the Campo dei Fiori Dolomite, the basal Conchodon Dolomite and the Arzo 'Tremona serie' Auct.) is characterised by shoaling and shallowing upward marl-carbonate cyclothems. The dolomitic peritidal limestones, more frequent at the base, followed by the oolitic calcarenites, document a transgressive trend from inner platform to high-energy shoals of a carbonate-ramp environment (Burchette & Wright 1992). The inner ramp facies are mainly present at the base of the succession and in the whole Rhaetian of the M. Campo dei Fiori structural high (e. g. M. Tre Croci section). Subordinated terrigenous supply is recorded in the eastern part of the studied area. The minor stratigraphic gaps (diastemes in Castello Cabiaglio-Orino and M. Campo dei Fiori sections), marked by brecciated pedogenetic carbonates or thin 'terra rossa' horizons, document emersion stages (Mylroie & Carew 2003) which may explain the reduced thickness of the Rhaetian succession in eastern Lombardy (Fig. 2). The frequency of stratigraphic gaps suggests that the Varese area was characterised by low subsidence rates since the Late Triassic. The dolomitized ooidal and peritidal carbonates on the base of facies and microfacies analysis is here correlated with the middle Zu Lmst. (Zu2 member of Jadoul et al. 1994), while the overlying mainly subtidal calcareous unit is compared to the upper Zu (Zu3 and Zu4 members of Jadoul et al. 1994).

B) The Hettangian unconformity

The regional unconformity (Kälin & Trümpy 1977 and references therein) directly caps the Rhaetian succession and is overlain by different Lower Jurassic units (Fig. 3).

The Hettangian age is suggested by:

a) the stratigraphical position. In the western area the unconformity is located between the Conchodon Dolomite (here ascribed to the early Hettangian cf. Cirilli et al. 2000) and the Alpe Perino Lmst. In the eastern and central area the stratigraphic gap is bordered by the Rhaetian and the early Sinemurian succession.

b) the Hettangian palynological assemblage (cf. Schuurman 1979), just above the unconformity.

In the M. Nudo basin (Fig. 3), the thicker Lower Jurassic succession, the reduced 'terra rossa' and pedogenetic phenomena testify to a greater subsidence rate and a shorter Hettangian stratigraphic gap between the Conchodon Dolomite and the Alpe Perino formations. The analysis of 'terra rossa' paleosols (at Castello Cabiaglio-Orino), the underlying pedogenetic carbonates (Fig. 8C, D) with rhizoliths, biomicritization processes and alveolar structures (James 1972; Klappa 1980; Retallack 1990; Mylroie & Carew 2003; Fig. 8) and the

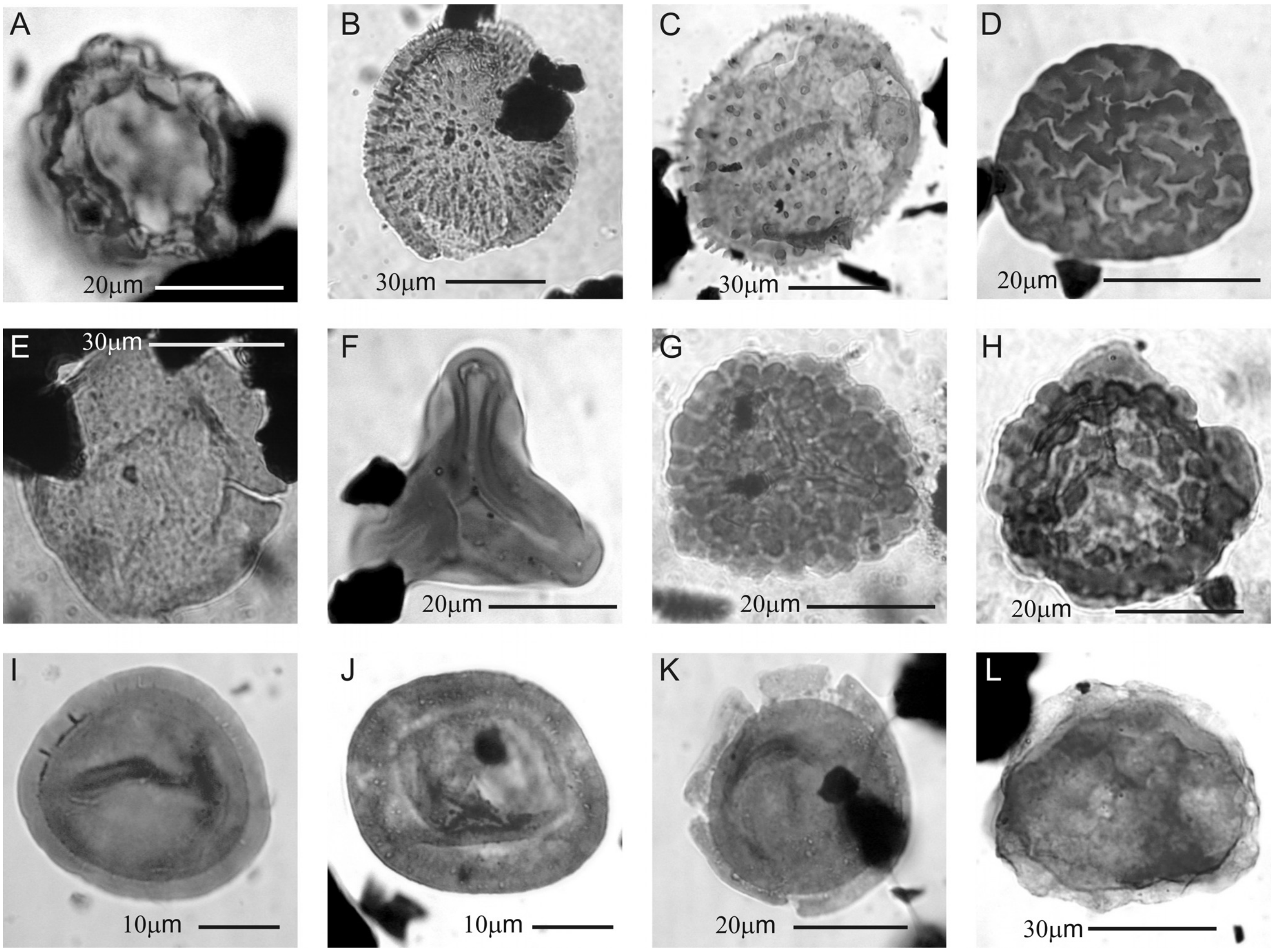

Fig. 12 - Palynological assemblage of the lower Alpe Perino Limestone (Castello Cabiaglio-Orino section: oxidised sample J7/0). A) *Cerebropollenites macroverrucosus* (Thiergart) Schulz; B,C) *Porcellispora longdonensis* (Clarke) Scheuring; D) *Lycopodiacidites rugulatus* (Couper) Schulz; E) *Araucariacites australis* Cookson; F) *Concavisporites crassexinius* Nilsson; G,H) *Uvaesporites argenteaeformis* (Bolkhovitina) Schulz; I) *Classopollis torosus* (Reissinger) Balme; J) *Gliscopollis meyeriana* (Klaus) Venkatachala; K) *Classopollis* sp.; L) *Callialasporites* sp.

hygrophytic palynological assemblages (*sensu* Visscher & Van Der Zwan 1981) (Fig. 12), suggest a tropical subhumid paleoclimatic environment (Bain & Foos 1993). A humid paleoclimate for 'terra rossa' paleosols was also indicated by Gnaccolini (1964). In temperate climatic zones (Mediterranean area) and in tropical-subtropical areas, with consistent rains (at least 1400 mm/year) and distinct dry and wet seasons, recent 'terra rossa' soils develop on a carbonate substratum (cf. Rhure & Olson 1980). Our reconstruction is supported by the presence of large plant fragments, immediately above the discontinuity and in the calcarenites of the basal Moltrasio Lmst. (Fig. 11B). Plant fragments, most of them belonging to the Cheirolepidiaceae (conifers), have been also reported by Lualdi (1999) and are considered indicative of dry-warm conditions, where the areal distribution of the flora was influenced by fresh water, ponds or marshes.

C) The Lower Jurassic carbonate platform

The Lower Jurassic shallow-marine carbonates (Alpe Perino Lmst.) document the development of a small carbonate platform, restricted to the M. Nudo area and close to the M. Campo dei Fiori high. In the south-western sector (M. Sasso del Ferro and Castello Cabiaglio-Orino), a thicker succession suggests faster subsidence (depocentre of the M. Nudo basin first evolutional stage; Fig. 13) and a greater stratigraphical continuity east of the Lake Maggiore paleofault (Bernoulli 1964; Bertotti 1991).

In the condensed M. Campo dei Fiori succession, the lack of the Lower Jurassic shallow-water carbonates may ascribed to emergence during deposition of the Alpe Perino Limestone.

The Alpe Perino lithofacies association documents a transgressive trend with restricted lagoonal and tidal flat sediments at the base, replaced by subti-

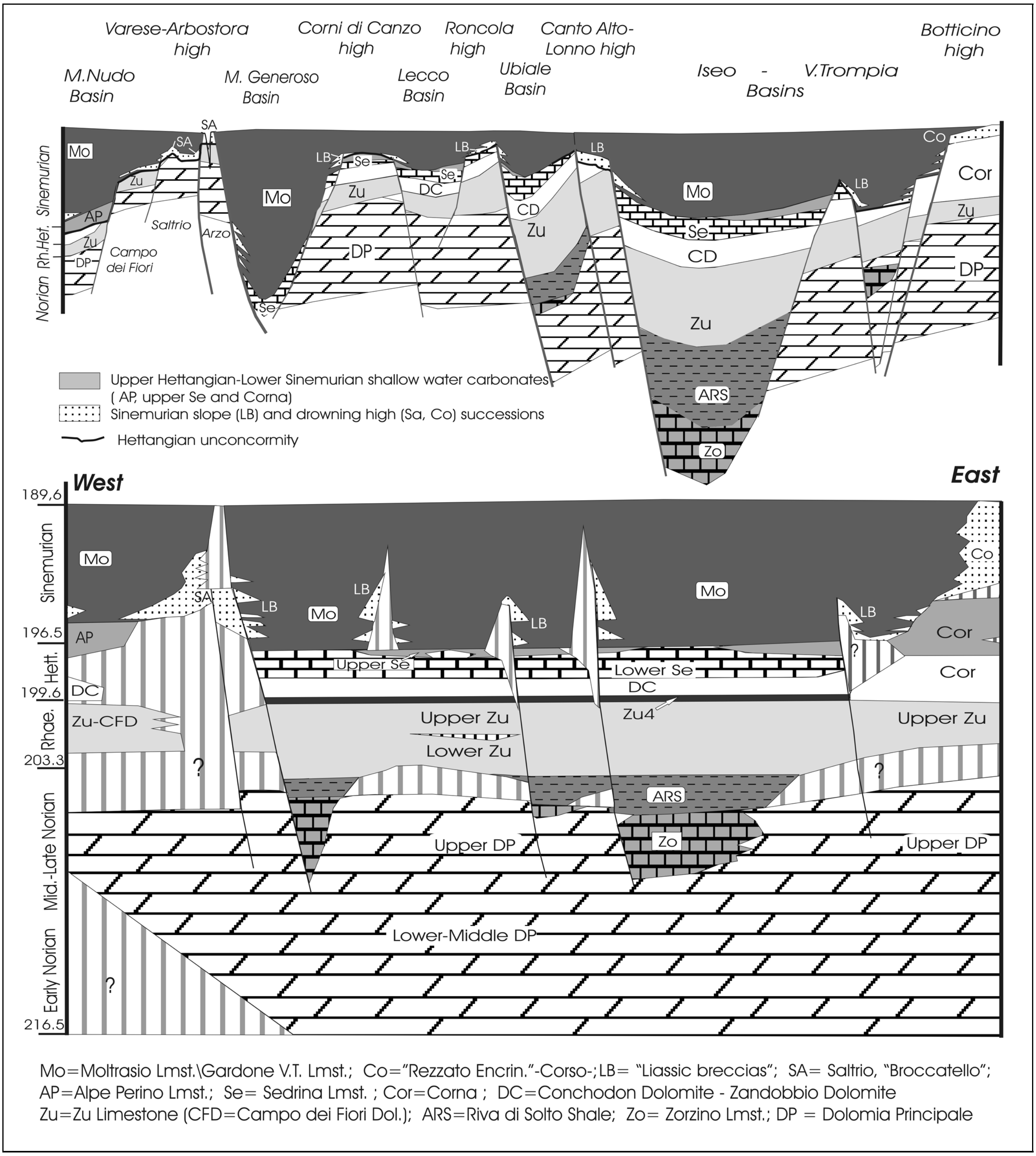

Fig. 13 - Norian-Lower Jurassic litho and chronostratigraphic schemes of the western Southern Alps (Lombardy). Ages from Gradstein et al. (2004).

dal-channel deposits and marginal oolitic bars in the middle part of the unit. The drowning of this Lower Jurassic platform took place gradually as testified to open subtidal wackestones and packstones-grainstones, with reworked shallow-water bioclasts and scattered plant fragments associated with an open-marine fauna (crinoids and lagenids) (Fig. 11). These Moltrasio-Saltrio transitional calcarenites (Fig. 3, 5; 'Saltrio Beds' of the Swiss authors; Saltrio Formation of Gnaccolini 1964), at the base of the Moltrasio Lmst. of the M. Nudo Basin, may be considered the outer shelf-slope or deep steepened ramp facies of the uppermost Alpe Perino depositional system. An alternative interpretation, supported by biostratigraphic data (see D) is to consider the Alpe Perino Lmst. older than the 'Saltrio Beds' of the type area which have been deposited in onlap on a different eastern tectonic block (M. Campo dei Fiori and Saltrio highs).

The stratigraphical relationship, the dating of the first transgressive sediments overlying the Hettangian unconformity (*Semicostatum* Zone; Lualdi 1999) and the palynological assemblage could document a late Hettangian and/or an earliest Sinemurian age for the Alpe Perino Lmst. in the M. Nudo area (Fig. 2, 5).

At the regional scale, the Alpe Perino Lmst. ('early Sinemurian hypothesis') corresponds mainly to the upper Corna, developed eastwards on the Liassic Botticino high (Schirolli 1997 and references therein), and with the very small 'pelagic platforms' developed on the Lower Jurassic highs ('Liassic breccias' of Bersezio et al. 1997) (Fig. 13). Instead, according to the 'late Hettangian hypothesis' the Alpe Perino carbonates may be also correlated with the upper Sedrina shallow-water carbonate of the central Lombardy (Francani 1967; Gaetani 1970; Jadoul & Doniselli 1987).

D) The Sinemurian platform drowning

Eastwards of M. Campo dei Fiori, from the M. Tre Croci section, the transgression is testified to grey, deepening upward subtidal bioclastic (crinoidal) calcarenites (typical of the 'Saltrio Beds') that contain reworked penecontemporaneous shallow-water carbonate grains and lithoclasts eroded from the Triassic substratum. Drowning of the M. Nudo took place earlier, probably in connection with a westward block tilting (Bernoulli 1964) (Fig. 13).

In most sectors of the eastern Varese high (M. Campo dei Fiori-Saltrio-Arzo), the Saltrio-Moltrasio transgressive facies appears to belong to the late early Sinemurian, and locally to the late Sinemurian (Wiedenmayer 1963). The Arbostora and M. Nudo drowning events are differentiated in age (Kälin & Trümpy 1977; Lualdi 1999). In the more condensed succession (Arbostora) the age of the 'Saltrio Beds' and Moltrasio Lmst. is restricted to the *Semicostatum-Obtusum* Zones of the early-late Sinemurian and, locally, to the latest Sinemurian *Raricostatum* Zone. In the M. Nudo area the drowning took place since the earliest Sinemurian (*Bucklandi* or *Semicostatum* Zones; Lualdi 1999).

At regional scale the Saltrio drowning succession is comparable, as thickness, lithofacies association and also chronostratigraphy, with the drowning succession ("Rezzato Encrinite" of Molvina-Botticino) of the Corna platform (Schirolli 1997).

E) The Early Jurassic paleogeography

The late Hettangian-early Sinemurian paleogeographic setting of the Varese area (Fig. 14) was characterised by a shallow-water gulf (Alpe Perino depositional system) close to emerged areas with forests (as testified by 'terra rossa' paleosols) located in the southern and western sectors of the Lake Maggiore (e.g. M. Fenera; Rasetti 1897). This reconstruction could be supported by the finding, in the basal 'Saltrio Beds', of a large predatory dinosaur bones ('Saltriosaur'; Dal Sasso 2003), needing for its survival of wide emerged area,

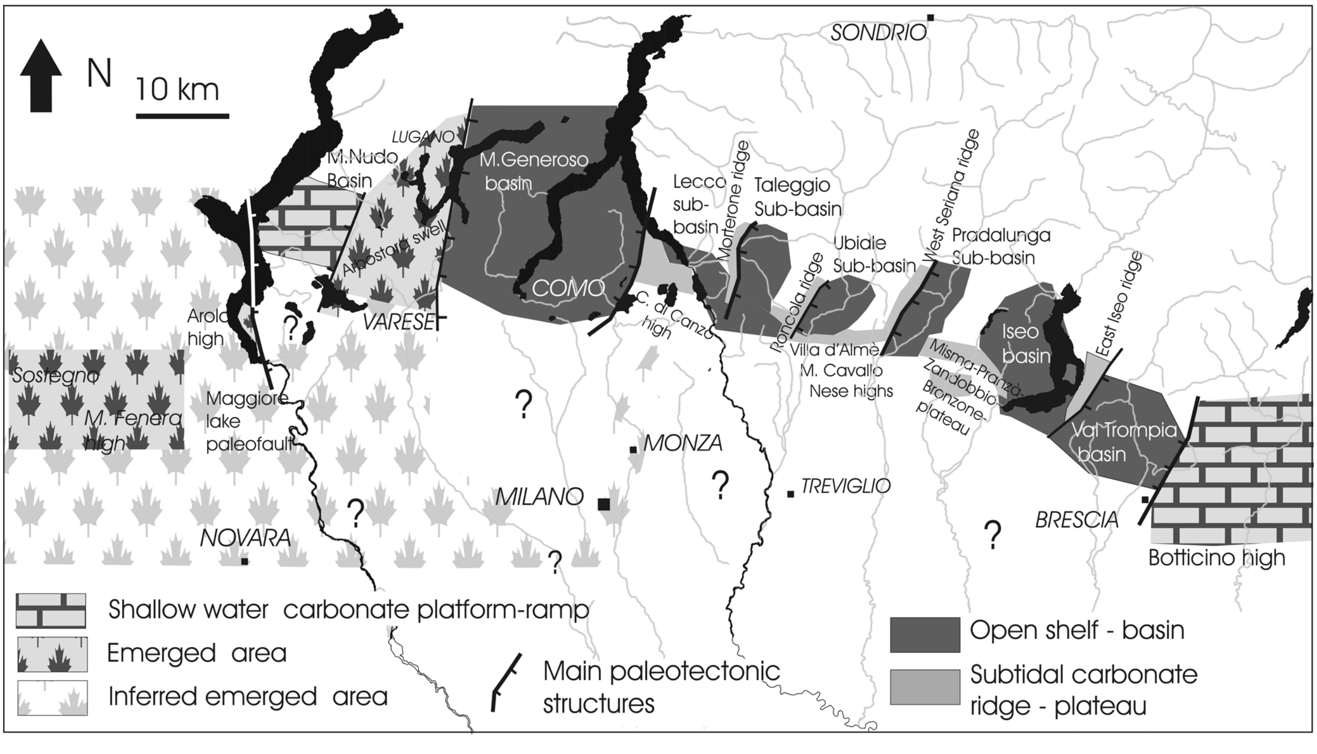

Fig. 14 - Late Hettangian-early Sinemurian paleogeographic map of the western Southern Alps (simplified data from Pieri & Groppi 1981; Bersezio et al. 1997, 2001; Picotti et al. 1997; Jadoul in progress).

populated also by herbivorous (autochthonous hypothesis). However, can not to be excluded that the carcase of the reptile has been carried away by sea currents from a continental area (Gondwanaland or Eurasia?) and beached in the Saltrio area (allochthonous hypothesis).

The age and the duration of the Lower Jurassic emersion cannot be assessed precisely. Emerged areas were present during the late Hettangian-earliest Sinemurian but local emersion stages started, on structural highs, during the late Rhaetian and the early Hettangian (Fig.13)(Bernoulli, 1964), possibly coinciding with the regression events at the top of Zu3 (Jadoul et al. 1994; 2004), the Conchodon Dolomite and Zandobbio Formation (pedogenetic breccias and small tepee; McRoberts 1994; Bersezio & Calcagni 1995). In western Lombardy the two shallowing-upward Hettangian depositional sequences (H1: Zu4 member-Conchodon Dolomite; H2: Sedrina Limestone) described in central Lombardy are not recognised (Jadoul et al. 1994; 2004). In fact, the Varese area was part of a structural high developed since the Norian up to the early Sinemurian p.p. (Fig.13), and became a subsiding basin only in the late early Sinemurian (Kälin & Trümpy 1977).

A Hettangian regressive trend, with large emerged area and karstified surfaces, has been proposed by Pasquini & Vercesi (2002) in some sectors of the 'Triangolo Lariano' (Corni di Canzo-M. Cornizzolo) at the top of the Conchodon Dolomite and during the deposition of the Sedrina Limestone; however, their data are not confirmed by our investigations. A local emersion area was instead located in the eastern Lombardy high (Fig. 13), in fact inter-supratidal horizons with tepee are intercalated in the Corna succession of Nuvolera quarries ("Breccia Aurora" lithofacies). Moreover, the major Lower Jurassic emerged area was located between the Lake Maggiore and the Lombardian plane up to Monza (southwards) (Pieri & Groppi 1975, 1981) (Fig. 14). Westward the continental area extended to Mt. Fenera high and possibly up to the Canavese Zone (Bernoulli et al. 1979).

Conclusion

A stratigraphical revision and facies analysis was carried out on the Rhaetian-lower Sinemurian succession between M. Campo dei Fiori and Lake Maggiore. Two formations are better characterised and one is here introduced. The Zu Lmst. represents the peritidal-subtidal mainly proximal-ramp facies of the Rhaetian succession including the Campo dei Fiori Dolomite (considered herein as lower Zu Lmst.). The Alpe Perino Lmst. represents a small carbonate platform at the base of the M. Nudo Basin succession, developed above the Hettangian unconformity. The upper part of the unit may partially correspond to lower 'Saltrio Beds'. At regional scale the Alpe Perino Lmst. may represent the westward equivalent of the upper Sedrina shallow-water carbonates of central Lombardy and the Corna platform, developed on the eastern part of the Lombardy Basin.

The (locally angular) Hettangian unconformity has been identified in all of the measured successions. This stratigraphical disconformity separating Rhaetian or the lower Hettangian from Sinemurian strata is marked by 'terra rossa' paleosols and pedogenetic carbonate breccias.

The Lower Jurassic paleogeography of Varese area was characterised by a wide continental area from the late Hettangian until the early Sinemurian, and delimited by structural highs bordering a shallow-water gulf deepening northward. The horst and graben tectonic setting controlled the distribution of the Lower Jurassic shallow-water carbonate environments, developed on the western margin of the M. Campo dei Fiori structural high. The Alpe Perino carbonate platform, surrounded from southeast to west by a continental area in a warm humid paleoclimatic environment, provided one possible habitat for large predatory dinosaurs.

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Appendix

The Alpe Perino Limestone

This new formation corresponds to the uppermost Conchodon Dolomite of Gnaccolini (1964; Alpe Perino section, 18 m above the covered interval from level 37 to level 45) and locally with the lower Saltrio Formation of Gnaccolini (1964; Castello Cabiaglio-Orino section, p. 499). The Alpe Perino Limestone is not present in the M. Campo dei Fiori area and on the Arbostora swell succession, where the transgressive coastal to open subtidal grey calcarenites of the Saltrio Beds s.s. are present (Gnaccolini 1964). This unit is equivalent to the informal terms of 'Liassic platform' of Jadoul et al. (2000).

The type section

The section is located in an abandoned quarry (Gauss Boaga coordinates 1479954; 5081480) (Fig.15) along the Castello Cabiaglio-Orino road, about 150 m westward the bridge on the Brovera river and about 20 m above the road.

Description of stratigraphic horizons, from the bottom:

Top of Zu Limestone: Grey recrystallized limestones with amalgamated beds, at the top with reddish pockets, veins (2.6 m).

1. Dark reddish shales (0.6 m) passing upwards to rusty red shale ('terra rossa') with pedogenic light grey carbonate nodules and, at the top (1.15 m), greenish to reddish or grey shales, with pedogenic structures and fragments of plants (paleosol) (1.75 m).

2. Bedded, grey light nut-brown packstones with small oncoids, bioclasts (pelecypods, gastropods, rare corals and crinoids) and lithoclasts, upwards lime mudstones-wackestones with a thin dark grey marly intercalation and local bioturbation (1.4 m).

3. Black shales with pyrite and abundant light carbonate and black shale flat lithoclasts, at the top several plant fragments (0.3-0.4 m).

4. Bedded (30-50 cm) grey nut-brown lime mudstone-wackestones with small pelecypods, gastropods, thin marl intercalations and bioturbation at the base (2 m).

5. Bedded (20-30 cm) grey light nut-brown intraclastic-oolitic grainstones (0.6 m).

6. Carbonate breccias with rounded clasts and greenish marls as matrix (1m).

7. Grey-brown oolitic packstone (0.5 m).

8. Well bedded (5-20 cm) grey light nut-brown wackestone-packstone with planar stromatolites and fenestrae (1.1 m).

9. Fining and thinning upward cycle of packstones and grainstones passing upwards to grey light nut-brown wackestones with small cavities (1.2 m).

10. Well bedded (10-25 cm) light nut-brown wackestones with peloids and irregular bedding surfaces (2.2 m).

11. Thick bedded oolitic grainstones (2.4 m).

12. Well bedded (10-25 cm) wackestones to fine grained packstones with peloids, pelecypods and gastropods (1.5 m).

13. Thinning upward oolitic-bioclastic packstones-grainstones (1.9 m).

14. Light brown wackestones-packstones with local stromatolitic laminations and small fenestrae at the top (1 m).

15. Bedded (20-40 cm) oolitic-bioclastic (pelecypods, gastropods, rare corals) packstones-grainstones (2.5 m).

16. Bioclastic light nut-brown grey wackestones, with upwards grey light brown mudstones (1.5 m).

17 Bank of fine grained ooidal peloidal grainstones-packstones (1.4 m).

18. Light nut-brown grey wackestones and subordinated bioclastic packstones (6.5 m).

19. Bioclastic-oolitic packstones-grainstones with crinoids (1.5 m).

20. Mud-supported conglomerate with carbonate clasts and marly matrix (0.2 m).

21. Bedded (5-30 cm) brown light nut-brown bioclastic packstones with wackestones and grainstones intercalations (7 m).

22. Bedded (10-30 cm) light brown nut-brown packstones-grainstones with local dark grey colour. (transition to Moltrasio-Saltrio) (2 m).

23. Fine grained dark grey bioclastic-intraclastic packstones with parallel laminations and dark cherty nodules (basal Moltrasio Limestones, transitional facies to Saltrio Beds) (5-6 m).

24. Bedded dark grey micritic limestones with cherty nodules (Moltrasio Limestone).

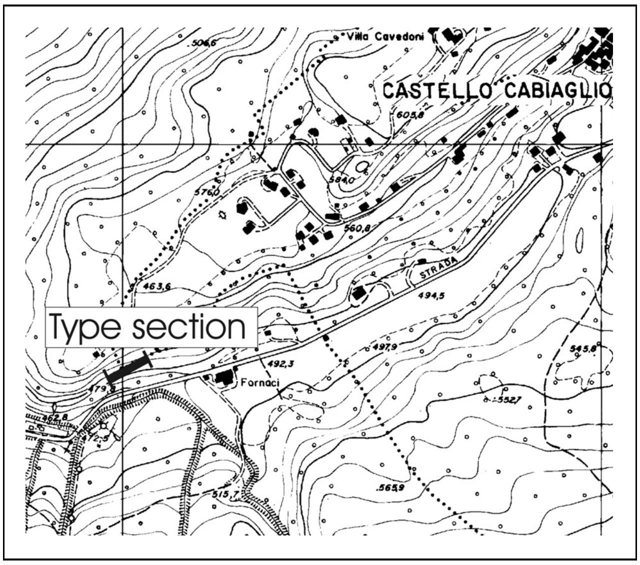

Fig. 15 - Geographical location of the Alpe Perino type section.