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THE ROSSO AMMONITICO VERONESE (MIDDLE-UPPER JURASSIC OF THE TRENTO PLATEAU): A PROPOSAL OF LITHOSTRATIGRAPHIC ORDERING AND FORMALIZATION

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Abstract. We here propose a revision of the stratigraphic interval comprised between the top of platform carbonates, mainly of Early Jurassic age, and the base of the Maiolica, in the Trento Plateau. Most of this interval (upper Bajocian – upper Tithonian) is represented by ammonite-bearing, red nodular limestones known with the historical name of Rosso Ammonitico Veronese (RAV). It has been subdivided in three units: a lower unit, calcareous and massively bedded; a middle unit, thinly bedded and cherty; and an upper unit, calcareous and nodular. In addition to these units, other sedimentary bodies are known below the base of the RAV. These are thin and discontinuous, such as the Lumachella a *Posidonia alpina* (LPa) and the Calcari a *Skirroceras* (CSk), both spanning the upper Aalenian – upper Bajocian. A lithostratigraphic redefinition of the RAV is proposed by addition of two members (LPa e CSk) to the three classical members. The new members are easily distinguished by their lithofacies and are always separated from the lower unit by discontinuities. Two sections located on the Altopiano di Asiago are described: Kaberlaba shows all the three members (lower, middle and upper) and is proposed as the reference section for a formalization of the RAV; Rabeschini is characterized by the absence of the middle member and may be held as a complementary section. The RAV lower boundary is everywhere very sharp and marked by a facies contrast; the upper boundary, instead, is transitional and is defined by a progressive change from red, nodular, *Saccocoma* packstones to white, non-nodular calpionellid wackestones. Calpionellid associations indicate that the upper boundary falls within the upper Tithonian.

Riassunto. In questo lavoro viene proposta una revisione dell'intervallo di successione stratigrafica del Plateau di Trento compreso tra il tetto delle formazioni di piattaforma, per lo più di età giurassica inferiore, e la base della Maiolica. La maggior parte di tale intervallo (Baiociano sup. – Titoniano sup.) è rappresentato da calcari rossi nodulari ad ammoniti noti con il nome storico di Rosso Ammonitico Veronese (RAV). Esso è stato suddiviso in tre unità: inferiore, calcareo a stratificazione massiccia; intermedio, a stratificazione sottile e con liste e noduli di selce; superiore, calcareo nodulare. Oltre a questi, però, sono noti altri corpi sedimentari, sottili e discontinui, quali la Lumachella a *Posidonia alpina* (LPa) e i Calcari a *Skirroceras* (CSk) posti sotto la base del RAV e compresi tra l'Aaleniano superiore e il Baiociano superiore. Viene proposta una ridefinizione litostratigrafica del RAV, che prevede oltre ai tre membri classici, altri due membri (LPa e CSk) che se ne distinguono facilmente per la facies e che sono sempre separati dal membro inferiore del RAV da discontinuità. Due sezioni ubicate sull'Altopiano di Asiago vengono descritte: Kaberlaba, con i tre membri inferiori, medio o superiore è proposta come sezione di riferimento per una formalizzazione del RAV; Rabeschini, dove manca il membro intermedio, può essere considerata come sezione complementare. Il limite inferiore del RAV è sempre molto netto e segnato da un brusco salto di facies; il limite superiore, più transizionale, corrisponde ad una perdita di nodularità e di colore rosso e, più precisamente, è segnato dal passaggio da packstone a *Saccocoma* a wackestone a calpionellidi. Le associazioni a calpionellidi indicano che il limite superiore del RAV cade nel Titoniano superiore.

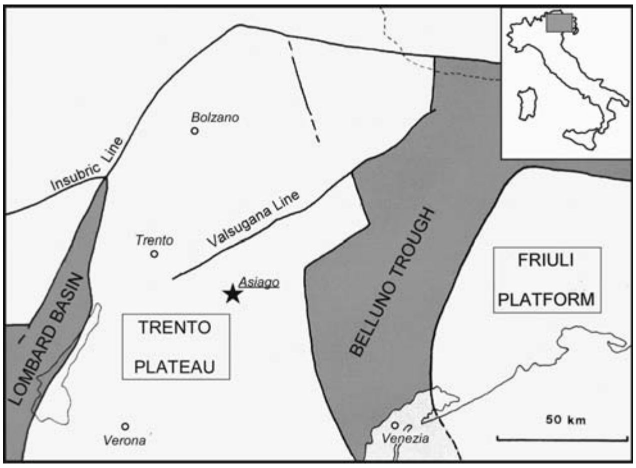

Fig. 1 - Geographic and palaeogeographic framework of the Trento Plateau. Modified after Bosellini et al. (1981).

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Introduction

The Rosso Ammonitico Veronese (Middle-Upper Jurassic) is a very distinctive lithostratigraphic unit in the Mesozoic succession of the Trento Plateau (Venetian part of the Southern Alps, Fig. 1). It consists of red, ammonite-bearing, nodular limestones that are easily distinguished from the underlying, mainly grey, shallow platform limestones (Lower Jurassic) and from the overlying white micritic pelagic limestones of the Maiolica (Biancone of older authors) (uppermost Jurassic-Lower Cretaceous).

Rosso Ammonitico as a term first appeared in the geological literature in the 19th century ("calcarie rosse ammonitiche": Catullo 1827). This term was loosely used in descriptions of the local stratigraphy for more than a century before being officially introduced in the stratigraphic lexicon by Dal Piaz (1956) as Rosso Ammonitico Veronese. Furthermore, the term Rosso Ammonitico has been generally used with a twofold meaning: lithostratigraphic unit and lithofacies.

Many sedimentary bodies, mainly Jurassic in age, in Southern Alps, Central Apennines, Sicily have been referred to informal lithostratigraphic units named "Rosso Ammonitico". In some places, a geographical denomination has been added in order to distinguish one from the others (e.g. Rosso Ammonitico Lombardo: Bernoulli 1964; Gaetani 1975; Rosso Ammonitico Umbro: Centamore et al. 1969). Red, nodular, pelagic limestones commonly, but not necessarily, containing ammonite moulds have been described as the Rosso Ammonitico facies (or Ammonitico Rosso according to the Anglo-Saxon usage), irrespective of age. This dual use generated some confusion: in fact, in some places, grey-green, non nodular and even ammonite-free sediments are included in a lithostratigraphic unit informally named Rosso Ammonitico (e.g. thinly and evenly bedded cherty limestones of the middle part of the Rosso Ammonitico Veronese or Middle Jurassic massive dark grey limestones at Rocca chi Parra, Western Sicily); on the contrary, pelagic red limestones with ammonite moulds have been given a lithostratigraphic name that does not make any reference to Rosso Ammonitico (e.g. Calcare di Campotorondo, Belluno area: Casati & Tomai 1969).

After many years of researches and at the end of a Symposium completely devoted to this facies (Farinacci & Elmi 1981), it was clear that there is not a single "Rosso Ammonitico" facies. In fact, this name was given to many different lithotypes widespread in the Mediterranean area, sharing, of course, some common features but being different in significant aspects.

Rosso Ammonitico should basically be characterized by red colour, presence of ammonite moulds, and nodular structure, although grey or green colours also occur and ammonites may be lacking. The nodular structure derives from the juxtaposition of cm-sized, rounded portions of lighter coloured, nearly pure limestones (i.e. the nodules), and of the so-called matrix consisting of dark red marls or marly limestones. The lack of carbonate grains typical of shallow platform and the scarcity of terrigenous sediments are common features of the pelagic Rosso Ammonitico limestones; most of the sediment is biogenic, being represented by the skeletal remains of both planktonic and benthic organisms (e.g. calcareous nannofossils, calcispheres, foraminifers, radiolarians, thin shelled bivalves, gastropods, echinoderms). Average sedimentation rates are consequently very low, of the order of mm/ky, and stratigraphic discontinuities frequent. Many hypotheses have been formulated on the origin of the nodular structure. To cite only the main papers: Jenkyns (1974) proposed that nodules are generated by precipitation of cement supplied in a very shallow burial phase by dissolution of the less stable carbonate grains; Ogg (1981) suggested that later diagenetic processes (pressure dissolution) sourced the carbonate for nodule lithification; Massari (1979, 1981) stressed the importance of biomats in binding and cementing sediments and giving rise to spheroidal nodules (oncoids) or to dome-shaped structures (stromatolites); a polygenetic origin of nodules was recognized by Clari et al. (1984) who, similarly to what Kennedy & Garrison (1975) concluded about the Chalk, distinguished pre-depositional nodules, represented by portions of reworked sediment with a rocky coherence at the moment of deposition (e.g. intraclasts, oncoids, reworked ammonite moulds), from diagenetic nodules generated by selective early cementation. Compaction and pressure-dissolution, then, enhance the textural contrast between early lithified nodules and the unlithified matrix (Clari & Martire 1996). Finally, gravity mass movements may affect precursor, not completely lithified Rosso Ammonitico sediments with important modifications in the original lithosome geometry and in nodule-matrix relationships (e.g. Elmi 1981).

Because no present-day analogue exists for Rosso Ammonitico facies (Cecca et al. 1992), the paleoenvironmental and paleobathymetric interpretation of this peculiar facies is still uncertain. In spite of this, on the basis of a univocal geological evidence, all authors agree on many points such as: 1) Rosso Ammonitico is the typical product of condensed sedimentation on top of blocks resulting from the rifting and drowning of carbonate platforms below the photic zone; 2) being detached from the continent and surrounded by deeper basins, the only source of sediments is the slow pelagic rain, plus a benthic component; 3) currents were intermittently active, as documented by intraclasts, taphonomically reworked ammonites also of considerable size, frequent erosional discontinuity surfaces, and traction laminae mainly preserved within neptunian dykes; 4) bottom conditions were oxygenated, as the red colour of the rock indicates.

Much debated, on the contrary, is the depth at which Rosso Ammonitico sediments were deposited. In a classical paper on the tectono-sedimentary evolution of Southern Alps, Winterer & Bosellini (1981) estimated a depth of about 1000 m for the Rosso Ammonitico Veronese. This figure has been recently revised on the basis of new data coming from ocean drilling, and shallower depths of a few hundreds metres hypothesized (Winterer 1998). In the last decade, moreover, some studies in Central Apennines and Southern Alps have reported paleontological and sedimentological evidence pointing to even shallower depths: Monaco (1992), Santantonio (1993) and Zempolich (1993) described hummocky cross stratified beds, interlayered with Rosso Ammonitico facies, which they related to deposition above storm base level; hermatypic, zooxanthellate corals, for which lower photic zone habitats may be inferred, were found in place within Rosso Ammonitico beds and point to comparable depths (Pallini & Schiavinotto 1981; Gill et al. 2004) (however see Winterer 1998 for critical views).

Regardless of interpretations, the Rosso Ammonitico facies is particularly important in the geological history of an area because it marks the demise of the carbonate platform on top of which it rests, and the renewal of sedimentation in pelagic, albeit condensed, environments.

Rosso Ammonitico deposits are widely represented in Italian Jurassic successions. Among these, the Rosso Ammonitico Veronese is one of the most renowned and studied, and is extensively exposed also thanks to a plurisecular quarrying activity. "Outcrops" of Rosso Ammonitico Veronese may in fact be observed in many historical buildings in northern Italy as well as facings and floorings of modern buildings all over the world.

The purposes of this paper are: 1) to summarize the state of the art of lithostratigraphy in the Middle-Upper Jurassic of the Trento Plateau; 2) to propose an ordering of the lithostratigraphy and to define type sections of the Rosso Ammonitico Veronese which records a large (over 20 m.y.) and relevant interval in the history of the Trento Plateau and in general of Southern Alps. This seems particularly useful in the frame of the ongoing new mapping project of Italy (CARG).

The Rosso Ammonitico Veronese: previous studies

The Rosso Ammonitico Veronese has been the object of several studies since the 19th century. At the beginning the focus was on the rich paleontological assemblages mainly represented by ammonites (Catullo 1827, 1853; De Zigno 1852; Benecke 1865; Neumayr 1873; Bittner 1878; Parona 1880a, 1880b, 1896, 1931; Nicolis & Parona 1885; Del Campana 1903, 1904, 1905; Dal Piaz 1907; Trener 1910, 1913, 1957; Pia 1920). Of fundamental importance for a modern biostratigraphy of the Rosso Ammonitico Veronese are the studies by Sturani (1964a, b, 1967, 1968, 1971). He distinguished two members, the lower one of late Bajocian-Callovian age and the upper one Oxfordian-Tithonian, and showed the occurrence of some gaps. These two members are separated by a hard ground or locally (e.g. the Altopiano of Asiago) by cherty limestones that in the upper part contain some red clay beds interpreted as bentonites (Bernoulli & Peters 1970; 1974). The cherty limestones were described by other authors and variously named: Radiolariti (Cita et al. 1959); Calcare selcifero di S. Martino (Castellarin 1972); Scisti ad Aptici (Fögelgesang 1975; Benigni et al. 1982); Livelli selciferi di S. Giorgio (Clari et al. 1984); Radiolarit-Rhyncholithen-Kalken (Laub 1994). They were considered late Oxfordian-Kimmeridgian in age on the basis of a correlation made by Sturani (1964a) and therefore time equivalent of part of the upper member. This conclusion has been shown to be incorrect on the basis of later ammonite findings in the Monti Lessini and the Altopiano di Asiago (Clari et al. 1984, 1990; Martire 1989, 1996; Martire et al. 1991), and confirmed also by the study of radiolarian associations (Baumgartner et al. 1995), showing that the siliceous beds are bracketed between early Callovian and middle Oxfordian. The cherty unit therefore partially fills the gap between Sturani's lower and upper units of the Rosso Ammonitico Veronese and a possible heteropy with coeval dm-thick stromatolitic layers of the middle Oxfordian can be inferred for the topmost beds of the cherty unit. Detailed biostratigraphic studies of the rich ammonite associations contained in the upper unit have highlighted the occurrence of gaps of variable duration and of different degrees of condensation in the middle Oxfordian-Tithonian interval (Sarti 1985, 1986a, 1986b, 1988a, 1988b, 1990a, 1990b, 1993, 2003; Pavia et al. 1987).

In order to integrate biostratigraphic analyses, magnetostratigraphic studies were also carried out on the Callovian-Tithonian tracts of Rosso Ammonitico Veronese succession (Channel & Grandesso 1987; Channel et al. 1990; Ogg et al. 1984). The discontinuous and condensed nature, however, inhibited good correlation both among sections and with the oceanic record.

In addition to the contributions on sedimentology and diagenesis, partly cited above (Massari 1979, 1981; Ogg 1981; Clari et al. 1984; Martire 1988, 1989, 1996; Martire & Clari 1994; Clari & Martire 1996), other authors focussed their attention on particular aspects such as: application of sequence stratigraphic concepts

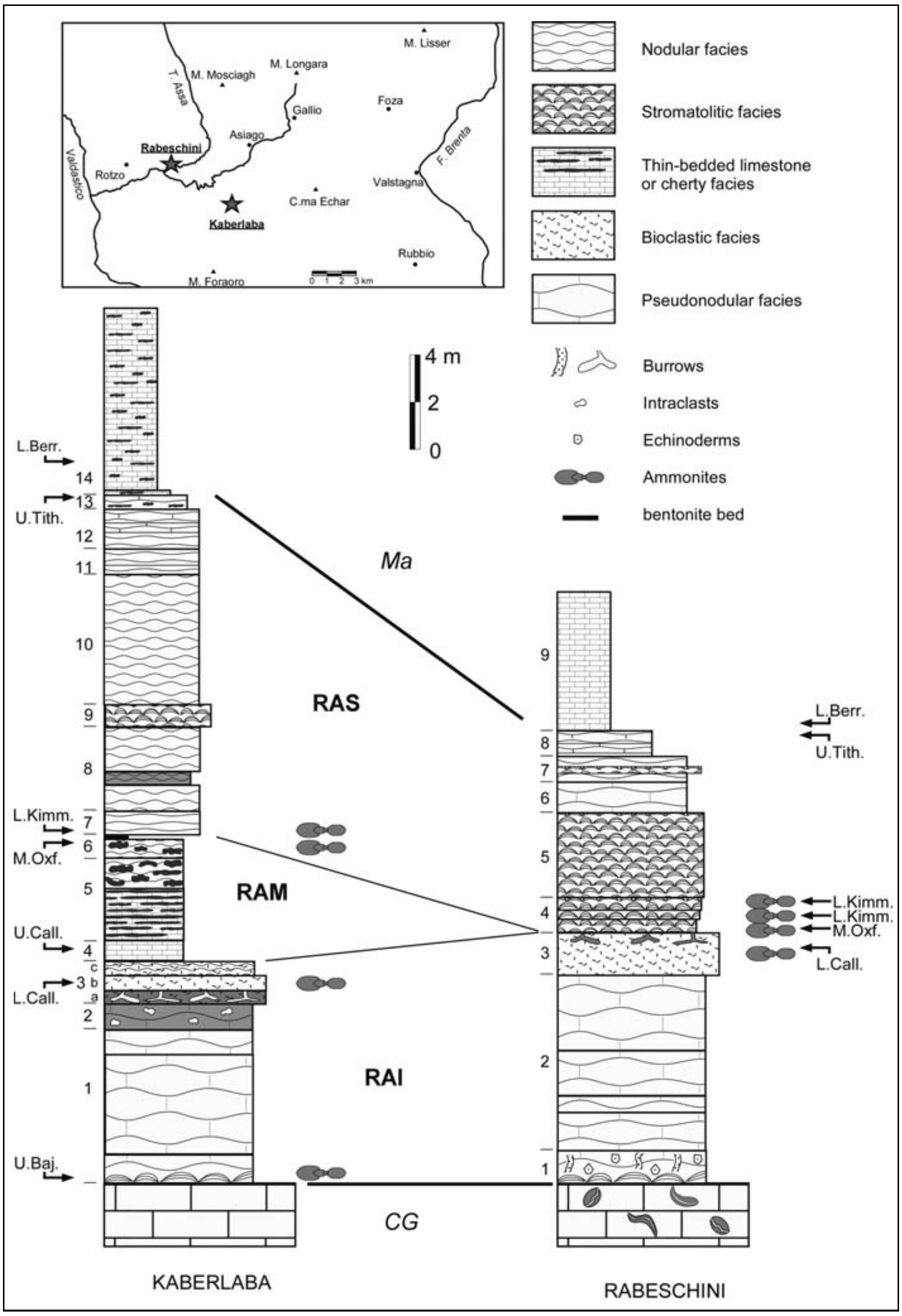

Fig. 2 - Reference stratigraphic sections located in the Altopiano di Asiago. Numbers on the left of the logs refer to the level described in the text. Different degrees of flattening of the undulose lines in the nodular facies symbol indicate variably developed nodular structures. CG: Calcari Grigi; RAI, RAM, RAS: lower, middle and upper members of the Rosso Ammonitico Veronese; Ma: Maiolica.

to Rosso Ammonitico Veronese and the relating of facies to sea level changes (Martire 1992a; Caracuel et al. 1997); interpretation of Rosso Ammonitico Veronese as relatively shallow-water sediments deposited on top of a platform drowned because of a combination of eustatic rise and environmental change (Zempolich 1993); organic geochemistry analyses documenting the role of organic matter in the formation of biosedimentary structures and early diagenesis (Massari et al. 1989; Scudeler Baccelle & Nardi 1991; Scudeler Baccelle et al. 1997).

Rosso Ammonitico Veronese type-sections

Over the whole Trento Plateau there are tens of good sections of Rosso Ammonitico Veronese, many of which have been described by the authors cited above. In order to define a type succession of this lithostratigraphic unit, two sections (Kaberlaba and Rabeschini) have been chosen on the Altopiano di Asiago (Vicenza province: Figs. 1, 2). They represent two end members as one section exposes clearly the middle cherty unit, some metres thick, whereas in the other the upper unit directly overlies the lower one. The same pattern with comparable thicknesses may be found everywhere on the Trento Plateau: Monte Baldo (Sturani 1964a; Papa 1994; Baumgartner et al. 1995); Monte Peller (Castellarin 1972; Lehner 1992); Monti Lessini (Clari et al. 1984; Massari et al. 1988); Monte Pasubio (Sarti 1986b; Giannetti 1989); Monte Grappa (Zempolich 1993). The Altopiano di Asiago sections, however, have been recently

Fig. 3 - Kaberlaba quarry. Temporarily abandoned front where the lower and middle units of the Rosso Ammonitico Veronese are clearly distinguishable. The quarry floor corresponds to the top of the Calcari Grigi. The arrow points to the boundary between the mineralized and the bioclastic facies.

studied in detail from the sedimentologic-diagenetic point of view (Martire 1989, 1996; Clari & Martire 1996) and have provided quite rich ammonite associations that enable good chronostratigraphic constraints over the age of each unit (Clari et al. 1990; Martire et al. 1991).

Kaberlaba section (Fig. 2)

This section is located in an active quarry on the north-west slope of Monte Kaberlaba, a few tens of metres to the south-west of the Hotel Bellevue and was the object of some papers dealing with facies and diagenesis (Martire 1989, 1996; Clari & Martire 1996). Many facies expose different tracts of the whole Rosso Ammonitico Veronese succession. The pavement of the quarry follows the topmost surface of the Early Jurassic (Pliensbachian) Calcari Grigi. They consist of yellow micritic to micropeloidal limestones. Some blocks overturned on the quarry floor show a framework of generally small neptunian dykes filled with red micrites or with the typical white-pink coquinoid deposits of the Lumachella a *Posidonia alpina,* consisting of grainstones with *Bositra* and small ammonite shells. Although Sturani (1971) did not study these deposits as the quarry was not in activity at that time, an early late Bajocian age may be inferred by comparison with analogous deposits in nearby localities of the Altopiano di Asiago. In other places, the top of the Calcari Grigi is paved by a dm-thick lag of cm-sized lithoclasts coated by thick stromatiform laminated Fe-Mn oxides.

Above, the three units forming the Rosso Ammonitico Veronese are clearly recognizable: the lower unit essentially massive; the middle unit well bedded, non-nodular and cherty (Fig. 3); the upper unit thickly

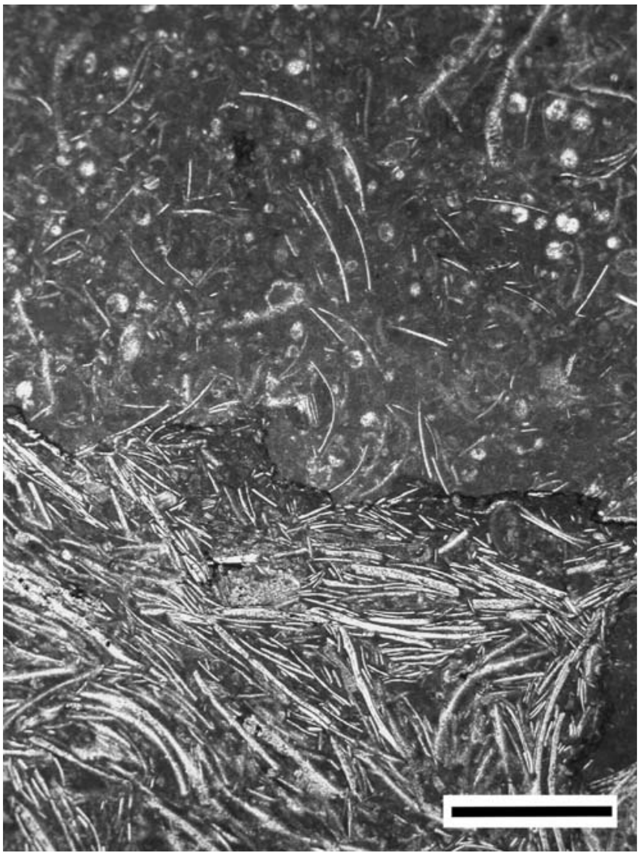

Fig. 4 - Kaberlaba quarry. Photomicrograph of the pseudonodular facies. The textural and compositional contrast between a nodule (top) consisting of a wackestone with protoglobigerinids, radiolarians, thin-shelled bivalves, and the matrix (bottom) made up of a compacted packstone with thin-shelled bivalves is clearly recognizable. Scale bar = 1mm.

bedded and typically nodular. More in detail, the following lithozones may be distinguished:

Lithozone 1 - (650 cm). It starts with a quite continuous 10-20 cm thick bed showing an internal fine lamination and typical stromatolitic LLH morphologies (Laterally Linked Hemispheroids of Logan et al. 1964). It is overlain by red, massive-looking limestones that show no clear stratification, except for a bedding plane at 120 cm possibly corresponding to a minor hiatus. These limestones show a pseudonodular facies that is massive because nodules and matrix do not weather differentially. For this reason this facies is still actively quarried and, after cutting and polishing, is used for stone facings. On polished surfaces the heterogeneity of the rock appears quite clearly because of the strong colour contrast between pink nodules and the brick-red matrix. The nodules are represented by intraclasts, oncoids, ammonite moulds and early diagenetic nodules; all of them on average are made up of wackestones with protoglobigerinids, calcitized radiolarians, thin-shelled bivalves, and *Globochaete*. The dark matrix is made up of a packstone with thin-shelled bivalves, echinoderms, peloids, benthic foraminifers and *Globochaete*

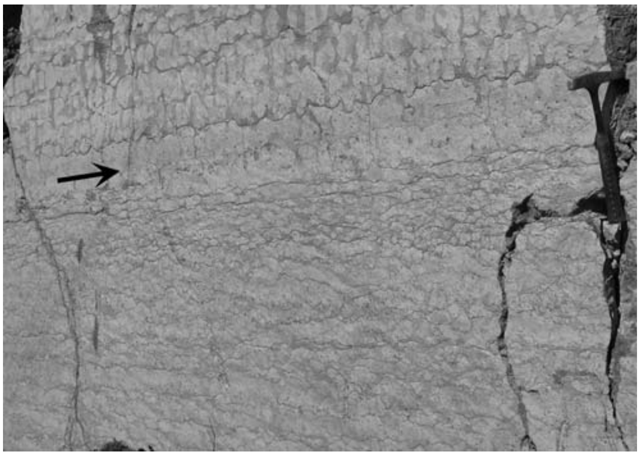

Fig. 5 - Kaberlaba quarry. The discontinuity surface (arrow) at the boundary between the mineralized and the bioclastic facies. (Hammer for scale).

(Fig. 4). A certain degree of mechanical compaction of the matrix may be locally recognized.

Lithozone 2 - (110 cm). A sharp bedding surface bounds this lithozone from the underlying one. In other localities of the Altopiano di Asiago it clearly shows evidence of a discontinuity such as coating by black Fe-Mn oxides or a thin LLH stromatolitic bed. This lithozone is recognizable also in the distance because of its brown colour. It consists of the mineralized facies which differs from the pseudonodular one in the abundance of mineralized bioclasts and intraclasts, and in general for the darker colour of the micritic matrix. The intraclasts, up to 2 cm across and commonly polyphasic, are bored and coated by a black Fe-Mn oxide crust up to 1 mm thick.

Lithozone 3 - (180 cm). Another sharp discontinuity surface bounds this lithozone at the base (Figs. 3, 5). It is characterized by a flat or irregular morphology, the latter being due to scouring, as proved by the occurrence of lithoclasts of lithozone 2 at the base of lithozone 3. Lithozone 3 is in general composed of the bioclastic facies whose distinctive features are the coarse grain size, the grain-supported texture (packstones to grainstones) and the dominance of skeletal remains (bivalves, echinoderms, benthic and planktic foraminifers) over other grains that are essentially represented by peloids. Three sublithozones may be distinguished. From bottom to top, the first (3a) is characterized by a brown colour, owing to a high proportion of Fe-Mn-stained grains, and by a regular network of mainly subvertical *Thalassinoides* burrows with geopetal fillings (Fig. 5); the second sublithozone (3b) is massive and pinkish-red because of the much less common mineralized grains; the third (3c) is subdivided by clay-rich dissolution seams in some dm-thick beds that are characterized by an incipient nodularity.

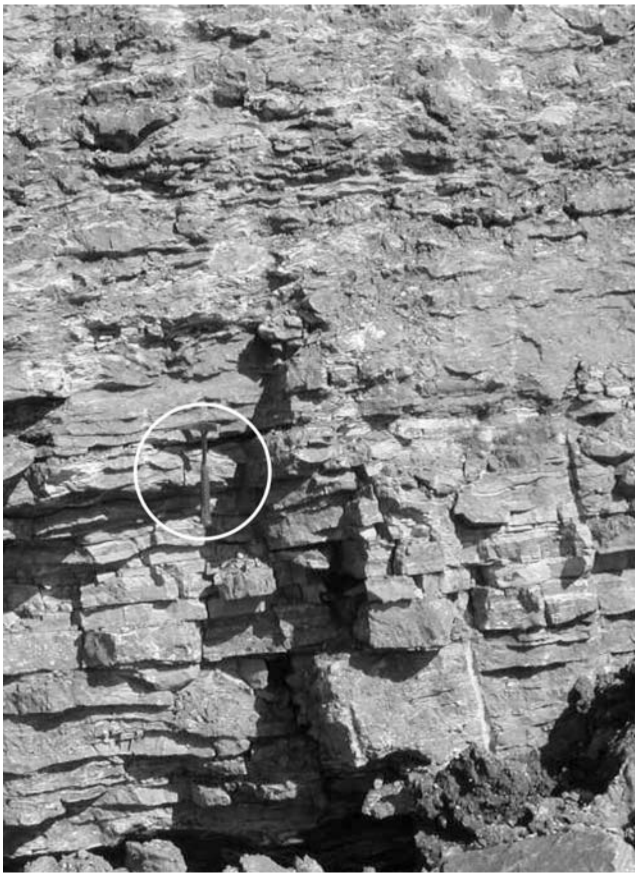

Fig. 6 - Kaberlaba quarry. The thin-bedded cherty limestone facies. A change in the bedding style occurs in the central part of the picture. (Hammer for scale encircled).

Lithozone 4 - (85 cm). Thin bedded, non-nodular layers, 3 to 20 cm thick, consisting of: pink to red wackestones with thin-shelled bivalves, echinoderms, calcite-filled radiolarians, benthic foraminifers; dark red to brownish packstones to grainstones with thin-shelled bivalves closely packed in a fitted fabric; white to pink mudstones with sparse calcite-filled radiolarian moulds. The latter lithology commonly makes up a distinctive, 20 cm thick bed at the base of the lithozone. All these lithologies have been put in the thin-bedded limestone facies by Martire (1996).

Lithozone 5 - (220 cm). This lithozone differs from the underlying one for the presence of red chert nodules and lenses, up to 20 cm thick (Fig. 6), and for the higher abundance of siliceous skeletal grains (radiolarians, sponge spicules and rhaxes). It corresponds to the thin-bedded cherty limestone facies. Bedding planes are plane in the lower part and become irregular and wavy in the upper part. Ellipsoidal oblate calcareous concretions up to 30 cm in diameter occur within these cherty beds (Scudeler Baccelle et al. 1997).

Lithozone 6 - (210 cm). This lithozone is composed of the subnodular facies. It is white to light pink and vaguely nodular owing to the frequency of undulose dissolution seams, and the presence of highly irregular red chert nodules. It consists of grain-supported textures mainly with micritic radiolarian internal moulds that can be distinguished from peloids by their spherical shape and the common geopetal fillings. Echinoderm fragments and benthic foraminifers are also present. "Nodules" are loosely packed grainstones, whereas the "matrix" is an echinoderm packstone with dissolution seams. Ammonite moulds, albeit rare and poorly preserved, occur at the top of the lithozone. Some red bentonite layers, already reported in the past (Bernoulli & Peters 1970, 1974) are present and range in thickness from 1 to 20 cm; the thickest one occurs at the top of the lithozone and is clearly distinctive in outcrop.

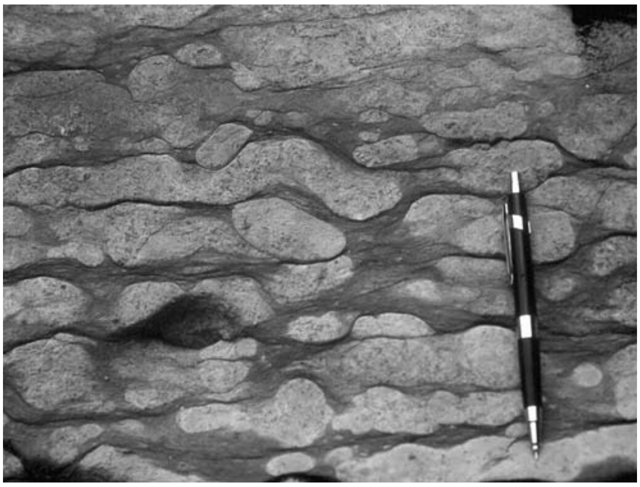

Fig. 7 - Kaberlaba quarry. Detail on the nodular facies.

Lithozone 7 - (100 cm). This lithozone shows features that are transitional between the underlying and the overlying ones. It is still white to pinkish and microscopically similar to the subnodular facies, but it is more massive and free of cherts. A nodular structure is more clearly developed in the middle part of the lithozone. Some ammonite moulds, again poorly preserved, occur at the base of the lithozone.

Lithozone 8 - (350 cm). This lithozone displays the most typical feature of the upper part of the Rosso Ammonitico Veronese, i.e. nodularity, and fits into the nodular facies. It is defined by the juxtaposition of pink calcareous nodules and of the brick-red, clay-rich matrix that are differentially weathered in oucrop (Fig. 7). Intraclasts, oncoids and stromatolitic domes are almost absent and nodules are represented only by early diagenetic nodules and ammonite moulds. Nodules consist of uncompacted *Saccocoma* grainstones and packstones with sparse benthic foraminifers and micritic moulds of radiolarians. The brick-red, clay-rich matrix is represented by *Saccocoma* packstone with fitted-fabric. Shape and size of nodules and the nodule-matrix ratio may change from one bed to another. In particular, a 55 cm-thick bed approximately in the middle part of Lithozone 8, is distinguished because nodules "float" in an abundant dark red clay-rich matrix. According to a terminology by Garrison & Kennedy (1977), Martire (1996) referred this lithology to a flaser-nodular subfacies.

Lithozone 9 - (95 cm). This lithozone consists of very massive limestones that, when cut and polished, reveal dome-shaped, finely laminated structures that may be closely compared to the stromatolitic beds described in the pseudonodular facies in the lower part of the Rosso Ammonitico Veronese. This lithology, referred to as stromatolitic facies, is more common in the Rabeschini section and will be described in more detail below.

Lithozone 10 - (555 cm). It shows basically the same features as the nodular limestones of lithozone 9. Lithozone 10 is bounded at the top by a sharp and laterally continuous bedding surface.

Lithozone 11 - (110 cm). Same features as Lithozone 10 except for a thinner and more regular bedding. Also Lithozone 11 is bounded at the top by a sharp and laterally continuous bedding surface.

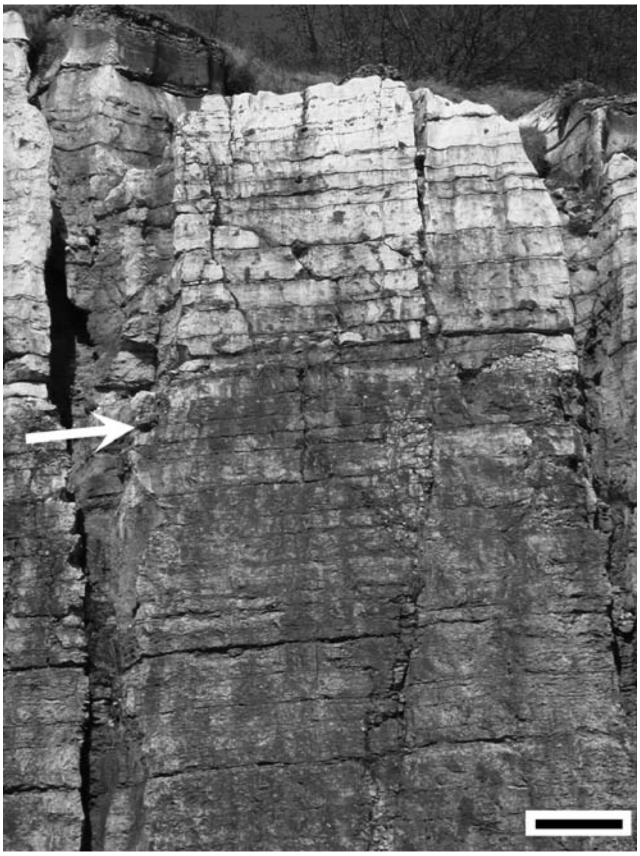

Fig. 8 - Kaberlaba quarry. Abandoned quarry front where the Rosso Ammonitico Veronese-Maiolica boundary (arrowed) is exposed. Scale bar = 1m.

Lithozone 12 - (170 cm). Compared to the underlying lithozone, the colour becomes lighter, pink or even white, bedding is thinner and nodularity less developed (Fig. 8). As a result, beds are more massive. Microscopically, nodules consist of wackestones with calcitized ammonite nuclei and fragments of ammonite shells, brachiopods, apthychi, radiolarians, *Globochaete*, benthic foraminifers or with abundant *Saccocoma* and sparse calpionellids (for a detailed description see below the paragraph Rosso Ammonitico Veronese-Maiolica boundary); the matrix is essentially a reddish *Saccocoma* packstone with dissolution seams.

Lithozone 13 - (61 cm). This lithozone consists of two beds that are characterized by an almost completely white colour and absence of nodularity. Clay-rich red and green dissolution seams however still occur. The lowest bed contains cm-sized chert nodules. Microfacies ranges from wackestones with the same skeletal grains described for Lithozone 12, to packstones or even grainstones with prevailing micrite moulds of radiolarians.

Lithozone 14 - (98 cm). White wackestones, locally packstones, with more common and better preserved calpionellids. The latter are common in the lower part and become dominant in the upper part where, moreover, *Saccocoma* fragments are very scarce. Nodularity and red clay seams are completely lacking. Red chert nodules occur in the lower part. Bedding surfaces are plane and parallel. This lithozone, already referable to the Maiolica Formation (for more details about the boundary see below), ends with a green marly bed 1 cm thick.

Above, calpionellid-bearing white wackestones crop out for some metres. They are characterized by a regular bedding and by the occurrence of chert nodules, up to 20 cm in diameter, concentrated in selected beds.

Fig. 9 - Rabeschini quarry. Abandoned quarry front where most of the Rosso Ammonitico Veronese succession is exposed. The quarry floor corresponds to the top of the Lower Jurassic Calcari Grigi. The arrow points to the boundary between the lower and upper unit, the middle one being absent. G. Pavia (encircled) for scale.

Rabeschini section (Fig. 2)

This section is located in an abandoned quarry on the north side of the Val d'Assa, 2 km south-west of Roana village, just in front of Cima Tre Pezzi, a locality described by Sturani for the Lumachella a *Posidonia alpina* (Sturani 1971). After the study of Martire (1989), the main quarry front was filled and revegetated but a good exposure of the whole Rosso Ammonitico may be observed on the two opposite flanks.

The uppermost beds of the Lower Jurassic (Pliensbachian) Calcari Grigi (Fig. 9) mainly consist of light grey micritic to micropeloidal limestones in thick beds characterized by densely packed large bivalves generally known as "*Lithiotis*" (Bosellini & Broglio Loriga 1971; Clari 1975; Masetti et al. 1998). Some of these shells were dissolved and the resulting cavity filled with fibrous cements and pink to red micrite.

Fig. 10 - Rabeschini quarry. Close up on the boundary (arrowed) between the lower and upper unit. G. Pavia (encircled) for scale.

Differently from the previously described Kaberlaba section, the middle cherty unit of the Rosso Ammonitico is not present; consequently, the upper unit directly overlies the lower one (Figs. 9, 10). In more detail the following lithozones may be distinguished:

Lithozone 1 - (140 cm). The first lithozone of Rosso Ammonitico is quite massive in outcrop and starts with a finely laminated, stromatolitic bed. On the whole, it consists of red packstones with thin-shelled bivalves, echinoderms, peloids, protoglobigerinids, and *Globochaete*. Subvertical burrows about 1 cm in diameter filled with grainstones with thin-shelled bivalves, echinoderms, peloids, are recognizable by their light colour.

Lithozone 2 - (740 cm). This lithozone, internally organized in beds 30 to 300 cm thick, is composed of the pseudonodular facies already described in the Kaberlaba section. A cyclic alternation of oncoid-bearing and continuous stromatolitic beds, as described by Massari (1979, 1981), is quite well recognizable. In this section, differently from the Kaberlaba section and many localities on the Altopiano di Asiago, the mineralized facies is not distinguishable. However, an increase in the abundance of mineralized intraclasts occurs in the upper part of the last bed, i.e. in the top 2 metres.

Lithozone 3 - (180 cm). With a sharp boundary, grain-supported textures follow which can be attributed to the bioclastic facies. Differently from the Kaberlaba section, the colour is never brown but ranges from dark red to whitish. Bed thickness varies from 20 to 70 cm. Burrows are common and in some beds so abundant as to give a nodular aspect. At the top of the lithozone a discontintuity surface with dark Fe-Mn oxides occurs. The top 25 cm are characterized by the occurrence of cm-size burrows geopetally filled with laminated wackestones bearing calcitized radiolarians that contrast sharply with the enclosing bivalve-peloidal grainstones.

Lithozone 4 - (140 cm). This lithozone consists of three massive, ammonite-rich beds characterized by a pinkish-red colour with white patches. They are composed of wackestones to packstones with abundant protoglobigerinids, generally recognizable from their Fe-stained micrite fillings, calcite-filled radiolarian moulds, small gastropods, thin-shelled bivalves and fragmentary larger skeletal remains like belemnites, rhyncolites, aptychi, echinoderms, and calcitized ammonite shells. Intraclasts composed of similar wackestones or packstones also occur. Both intraclasts and large bioclasts are commonly bored and coated by brown-red Fe-Mn oxides. Biolamination in these beds is not as well defined as in the stromatolitic beds of the lower unit of the Rosso Ammonitico Veronese; laminae are thicker and plane parallel, and domes are rare. Ammonite moulds, also of large size (up to 30 cm), are frequent and well preserved in these beds, although they are commonly sharply truncated above.

Lithozone 5 - (360 cm). This package of beds shows features very similar to the underlying lithozone. Intraclasts are more abundant and as large as 2 cm. In thin section schizosphaerellids are locally identified. Flat, erosional discontinuity surfaces are also recognizable.

Lithozone 6 - (130 cm). This lithozone is characterized by a darker, pinkish-red colour and by a nodular structure. The difference between nodules and matrix is not as marked as in the nodular facies described in the Kaberlaba section where a differential weathering highlights textural contrasts. These limestones are more massive and can be compared to the pseudonodular facies that is characteristic of the lower unit, although the colour is lighter.

Lithozone 7 - (110 cm). It is composed of alternances of beds showing stromatolitic and pseudonodular facies.

Lithozone 8 - (110 cm). Bedding is more regular and plane-parallel; beds are about 10-20 cm thick. Some bedding planes are very sharp and flat and likely correspond to erosional discontinuities. The colour of these package of beds becomes increasingly lighter upward; nodularity is much less marked and defined by the occurrence of bundles of dissolution seams around pure limestone nodules. In the last 25 cm, clay seams change from pink to green.

Lithozone 9 - The rest of the outcropping succession, about 6 metres thick, is composed of white micritic non-nodular limestones that are distinguished from the underlying ones also because of a more massive bedding style in this lithozone (Fig. 11). More details about the microfacies of Lithozones 8 and 9 are given below. This lithozone is referable to the Maiolica Formation.

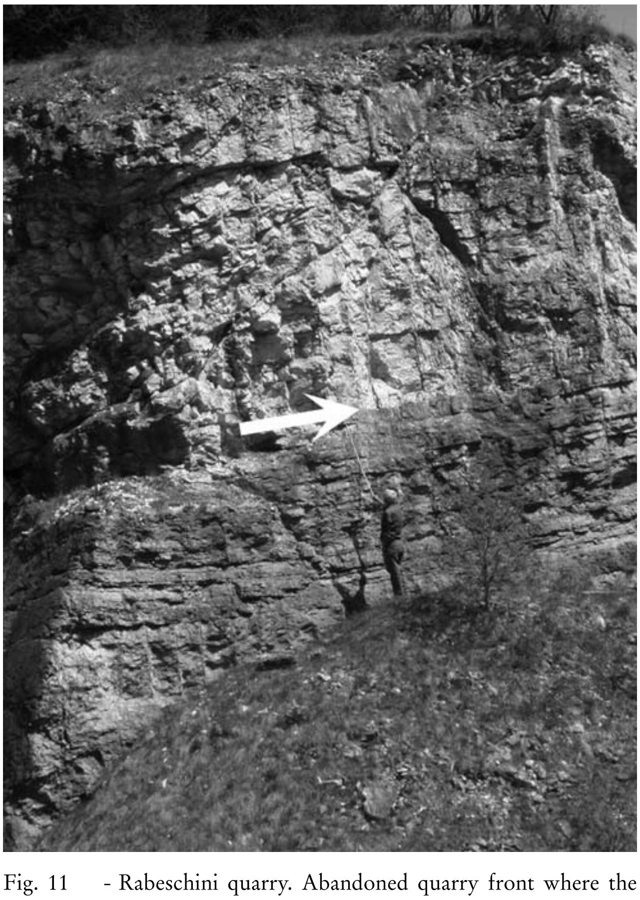

Fig. 11 - Rabeschini quarry. Abandoned quarry front where the Rosso Ammonitico Veronese-Maiolica boundary (arrowed) is exposed. A fault dipping to the left-hand side of the picture is clearly recognizable.

Biostratigraphy of the Rosso Ammonitico Veronese

Ammonites are well known since the first decades of the 19th century with the historical paper of Catullo (1827) who later (1853) subdivided his "Calcarie rosse ammonitiche" in a "calcaria epiolitica inferiore" and a "calcaria epiolitica superiore" on the basis of the paleontological content. Since then many paleontologists described ammonites from the Venetian Jurassic (e.g. Oppel 1863; Benecke 1865; Parona 1880a, 1880b, 1881; Del Campana 1903, 1904, 1905; Trener 1910). Modern monographs, including a biostratigraphic approach too, are from Sturani (1964 a, b), Clari et al. (1984), Sarti (1986b, 1990b, 1993, 2003), Pavia et al. (1987), Martire (1996). The paleobiologic picture deriving from these contributions is sufficiently comprehensive to allow reconstruction of the bio-chronostratigraphic framework of the three units of the Rosso Ammonitico Veronese, at least for their lower and upper boundaries. However, if on one hand signals of taphonomic reworking (reelaboration *sensu* Fernandez Lopez 1984) of ammonite internal moulds are locally clear (Martire et al. 1991), on the other hand no detailed taphonomic analyses of the ammonite assemblages occur in literature. In the studied sections, taphonomic observations on selected assemblages allowed to identify both some surely reelaborated and some surely not reelaborated specimens. Reliable ages of the beds are assigned where non reelaborated ammonites have been found whereas mixed assemblages have been only used to assign the oldest limiting age to the enclosing bed.

The ammonite assemblages recorded in the Rosso Ammonitico Veronese span the late Bajocian – middle Tithonian chronologic interval. In the following remarks we summarize the biostratigraphic data coming from existing literature and personal unpublished data concerning the whole Trento Plateau. As to the biozonation, we refer to the schemes summarized by Cariou & Hantzpergue (1997) with the regional adjustments proposed by Sarti (1993) for the Kimmeridgian.

Lower Unit (Rosso Ammonitico Inferiore: RAI)

Data mainly derive from Monti Lessini Veronesi (Sturani 1964a; Clari et al. 1984) and encompass latest Bajocian to late Callovian. The basal bed of the Rosso Ammonitico Veronese can be dated as latest Bajocian (latest *Parkinsonia parkinsoni* biochron) with ammonite assemblages which are characterized by very frequent *Dimorphinites dimorphus* and other significant ammonites such as *Ptychophylloceras haloricum, Planisphinctes tenuissimus,* and *Procerites costulatosus.* Actually, these fossil assemblages are mixed, i.e. taphonomically condensed; they cover the chronologic interval of the G. *garantiana* biochron (reelaborated specimens of *Vermisphinctes glyphus* and *Garantiana* sp.) and mainly the *P. parkinsoni* biochron from its base (reelaborated specimens of *Parkinsonia rarecostata)* up to the top (non-reelaborated moulds of *D. dimorphus* and others). Most of the lower unit can be referred to the Bathonian, but precise subdivisions are lacking owing to the scanty ammonite record (Clari et al. 1984). The uppermost beds of the lower unit represent the Callovian. The commonest situation is a layer containing ammonites that refer to different biochronologic intervals, with index taxa of both early Callovian (e.g. *Bullatimorphites bullatus, Choffatia recuperoi, Homeoplanulites furculus, Indosphinctes patina)* and middle Callovian (e.g. *Choffatia dumortieri, Erymnoceras coronatum, Hecticoceras turgidum).* In the central Monti Lessini (Clari et al. 1984) the lower part of this layer is possibly referable to the lower Callovian *(Macrocephalites gracilis* biozone), whereas at least the topmost stromatolitic bed is constrained to the uppermost middle Callovian, *Erymnoceras coronatum* biozone. In the Camposilvano section (Clari et al. 1984) a further dm-thick bed delivered scattered ammonites *(Orionoides* cf. *cayeuxi, Peltoceras* sp., *Reineckia hungarica)* that biochronologically represent the earliest late Callovian *(Peltoceras athleta* biochron).

Middle Unit (Rosso Ammonitico Medio: RAM)

It stratigraphically ranges from uppermost Callovian to middle Oxfordian. The base of this cherty unit cannot be directly dated being devoid of any significant fossils. No ammonites were ever found and only locally the analysis of the scarce assemblages of calcareous nannofossils indicated a late Callovian age (Asiago region: Martire 1996). The main body of the middle unit is referable to as lower middle Oxfordian. Precise information comes from the upper part of the cherty succession from Asiago (Martire 1996) where a middle Oxfordian age is testified by non-reelaborated ammonite assemblages: in the Kaberlaba quarry (Asiago) a dm-thick nodular bed, at the top of the middle unit, contains taxa *(Passendorferia birmensdorfensis* and *Perisphinctes elisabethae)* that represent the *Gregoryceras transversarium* biozone.

Upper Unit (Rosso Ammonitico Superiore: RAS)

It starts at different chronostratigraphic levels on the Trento Plateau: in the numerous studied sections the first beds lithologically representing the base of the upper Rosso Ammonitico contain ammonite assemblages ranging in age from middle Oxfordian to early Kimmeridgian, and are ascribed to different biozones depending on the duration of the hiatus associated to the paraconformity that separates the middle and upper units. In general, biostratigraphic information can be summarized as follows. In all the sections of Monti Lessini (e.g. Camposilvano, San Giorgio: Clari et al. 1984; Pavia et al. 1987) a middle Oxfordian, m-thick succession of stromatolitic beds that likely overlie the cherty beds without any stratigraphical gap, delivered species indicative of the *Perisphinctes antecedens* biozone (e.g. *Clambyites tietzei, Paraspidoceras colloti, Pas-*

sendorferia tenuis), the *Gregoryceras transversarium* biozone (e.g. taxa as before plus *Euaspidoceras oegir, Passendorferia ziegleri)* and possibly the *Perisphinctes bifurcatus* biozone (e.g. *Gregoryceras fouquei, Passendorferia uptonioides*). On the contrary, in most of the eastern sections (e.g. Col Santino in Pasubio, Cima Campo in Folgaria, Kaberlaba in Asiago) the basal, discontinuous layers are represented by nodular, rarely stromatolitic facies containing ammonites biochronologically referable to the early Kimmeridgian, i.e. the *Sowerbyceras silenum* biochron (e.g. *Epaspidoceras mamillanum, Lithacosphinctes* gr. *evolutus, Trenerites* pl. spp.) and the *Metahaploceras strombecki* biochron (e.g. *Lessiniceras ptychoides, Metahaploceras* pl. spp., evolute *Orthosphinctes* sp. ind.). In conclusion, the first depositional event of the upper unit is assigned to the middle Oxfordian *P. antecedens* biozone. Above, the stratigraphic record of the late Oxfordian-earliest Kimmeridgian is very discontinuous or even missing (Pavia et al. 1987) and commonly represented by reelaborated ammonites. The clearest, most correlative layer throughout the whole Trento Plateau is referable to the late early Kimmeridgian. In fact most of the ammonite assemblages, so well known from the cited literature, are characteristic of the *Presimoceras herbichi* biozone *(Crussoliceras divisum* Standard Zone); they are dominated by typical taxa belonging to the genera *Taramelliceras, Presimoceras, Nebrodites, Progeronia, Crussoliceras, Pseudowaagenia,* and *Orthaspidoceras* (Pavia et al. 1987; Sarti 1993b; Martire 1996). The overlying *Aspidoceras acanthicum* biozone is also widely represented in nearly all the outcrops of the upper unit of the Rosso Ammonitico Veronese throughout the Trento Plateau; its ammonite assemblages, in addition to the typical Tethyan phylloceratids, are dominated by *Nebrodites* and *Aspidoceras.* On the contrary, the uppermost Kimmeridgian beds *(Mesosimoceras cavouri* and *Hybonoticeras beckeri* biozones) have been studied in only few sections (Sarti 1993). Even scarcer details are available for the Tithonian, although outcrops and ammonites of the uppermost Jurassic are known from literature (e.g. Del Campana 1903), mainly from Monti Lessini. Nevertheless, the biostratigraphic information provided by Sarti (1986a, b) for the sectors of Lavarone and Monte Pasubio allow to document all the biozones of the lower to middle Tithonian. The lowermost biozones (*Hybonoticeras hybonotum, Semiformiceras darwini/Virgatosimoceras albertinum, Semiformiceras semiforme/Haploceras verruciferum* biozones) are documented by rich fossil assemblages, whereas the upper ones (*Semiformiceras fallauxi, "Micracanthoceras" ponti/Burckhardticeras* biozones) are mainly represented by the index species.

In summary, and referring to Asiago outcrops (Martire 1996), which are here assumed as type references, the whole Rosso Ammonitico Veronese succession biostratigraphically ranges from the uppermost Bajocian to the Tithonian. The richest information derives from the Kaberlaba section where scattered ammonites such as *Cadomites rectelobatus* and *Parkinsonia* sp. date the basal layer of the Rosso Ammonitico Veronese to the latest Bajocian (*Parkinsonia parkinsoni* biochron). The upper part of the lower unit is characterized by a mixed assemblage (e.g. *Bullatimorphites bullatus, Homeoplanulites furculus, H. funatus*) whose biostratigraphic meaning points to the lower Callovian; nevertheless it is impossible to state the age of the very top of the unit, which could go up to the middle or even late Callovian as documented in Monti Lessini (Clari et al. 1984). The middle unit ranges possibly from uppermost Callovian to middle Oxfordian, the latter being documented by the not-reelaborated ammonites found at Kaberlaba just below the bentonite bed already reported by Bernoulli & Peters (1970, 1974). As in Monti Lessini, the beginning of the upper unit of Rosso Ammonitico Veronese is different from section to section. At Rabeschini the lower part of this unit is a very discontinuous succession: the basal bed is assigned to the late middle Oxfordian on the basis of typical *Gregoryceras, Passendorferia* and *Perisphinctes*; the overlying bed (40 cm thick) bear abundant ammonite moulds, distributed in two different horizons, which respectively date the *Sowerbyceras silenum* and *Metahaploceras strombecki* biochrons. A third bed delivered ammonites pointing to the uppermost *Presimoceras herbichi* biozone (*Orthaspidoceras uhlandi* subzone). In contrast, in other sections, such as Kaberlaba (Martire 1996), the first bed of the upper unit of Rosso Ammonitico Veronese is dated as latest early Kimmeridgian on the basis of rich ammonite assemblages documenting the *P. herbichi* biochron (*Crussoliceras divisum* Standard Zone).

Unfortunately, the scarcity of ammonites in the uppermost part of the Rosso Ammonitico Veronese in the Asiago outcrops hinders any biostratigraphic assignment of the beds close to the boundary with the overlying Maiolica; for this purpose we turn to microfossil data, as explained in the next section.

Rosso Ammonitico Veronese - Maiolica boundary

Whereas the lower boundary of the Rosso Ammonitico Veronese, in the Kaberlaba and Rabeschini type-sections, is very sharp and easily recognizable because of a very marked facies change from yellow or light grey platform limestones to red nodular limestones, the upper boundary with the Maiolica is transitional. In fact, this transition takes place over a thickness of a few decimetres and, even if for mapping purposes

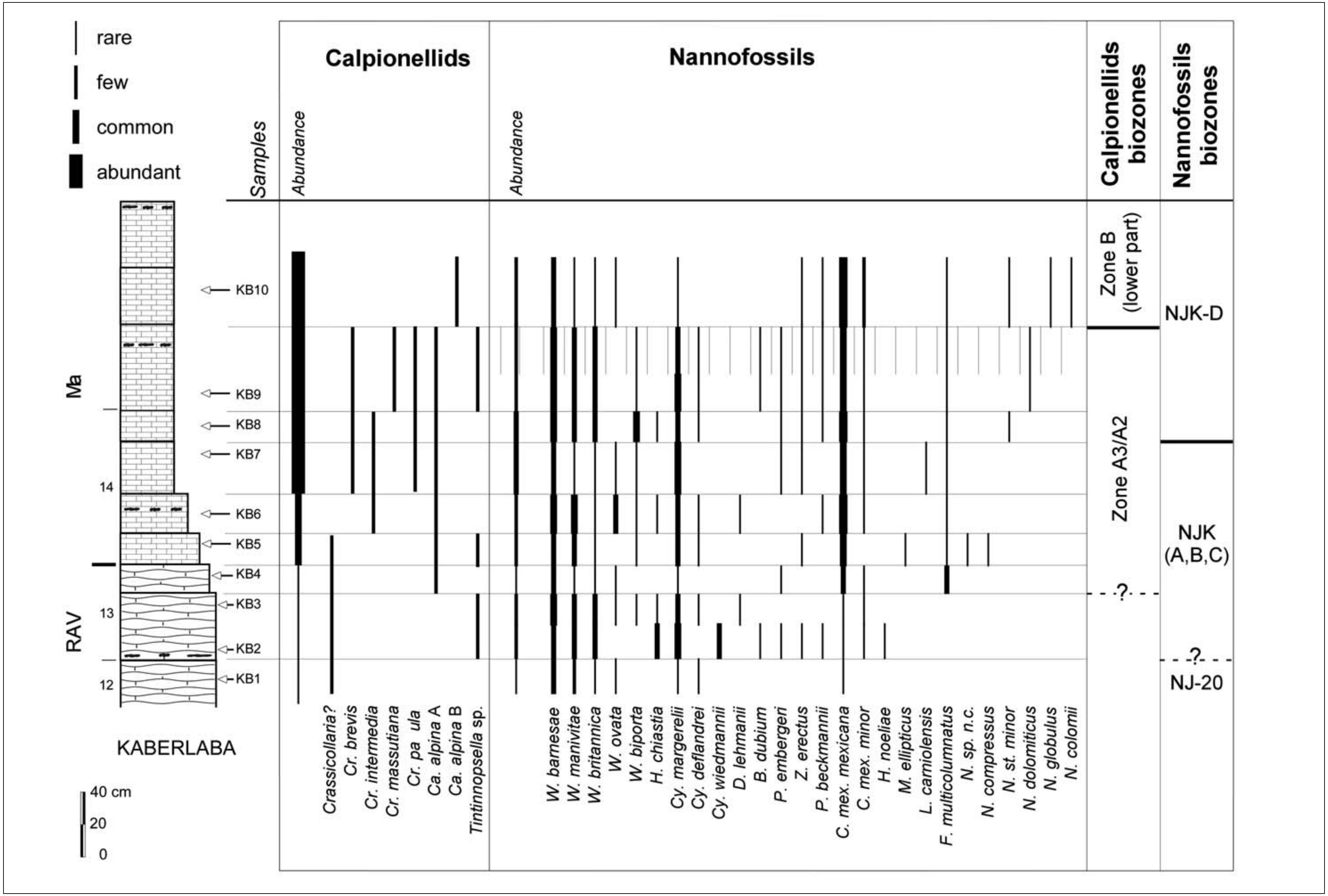

Fig. 12 - Detailed litho- and biostratigraphic log of the Rosso Ammonitico Veronese- Maiolica boundary at Kaberlaba. Arrows point to the exact position of samples.

there is no difficulty in separating the two formations, it is difficult to choose a single bounding surface.

A detailed sampling of the beds occurring across the gradual change from variably nodular and pink Rosso Ammonitico Veronese to white, massive and evenly bedded Maiolica has been carried out in order better to define the boundary both from the lithologic/microfacies and the bio-chronostratigraphic points of view in the Kaberlaba and Rabeschini sections. Because of the extreme scarcity of ammonites, calpionellid and nannofossil associations have been investigated.

Calpionellids

Calpionellids have been studied in thin sections. Biostratigraphy is essentially based on biozonal schemes by Remane (1985, 1998) and Olóriz et al. (1995).

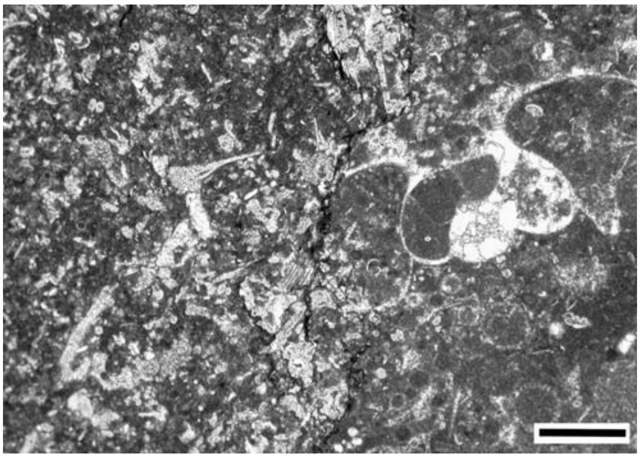

Fig. 13 - Kaberlaba section. Photomicrograph of the nodule-matrix boundary in the nodular facies at the top of the Rosso Ammonitico Veronese (KB1 sample). Note the abundance of *Saccocoma* in the matrix (left). Scale bar = 0.5 mm.

Kaberlaba section (Fig. 12).

The lowermost sample, KB1, still shows a nodular structure with a textural contrast between nodules and matrix. The nodules consist of wackestones with ammonite nuclei, gastropods, brachiopods, aptychi, *Saccocoma*, *Globochaete*, micritic radiolarian moulds, stomiosphaerids, benthic foraminifers (*Spirillina, Lenticulina*) and sparse calpionellids; the matrix is reddish *Saccocoma* packstone with dissolution seams (Fig. 13). Calpionellids are represented by poorly preserved specimens of the genus *Crassicollaria* for which a specific determination is impossible. Samples KB2 and KB3 show a less developed nodularity; the prevailing texture is wackestone with a skeletal content similar to KB1 except for the absence of ammonite and gastropod remains. Calpionellids are scarce; in addition to *Crassicollaria* sp. some specimens of *Tintinnopsella* can be recognized. KB4 shows a better washed texture (packstone to grainstone) with slightly more common calpionellids; together with *Crassicollaria* sp. and *Tintinnopsella* sp., some large ovoidal forms of *Calpionella alpina* occur that have been designated as homeomorphs of *Calpionella elliptica* (Remane 1985; Olóriz et al. 1995). Samples KB5 and KB6 show basically a similar wackestone to packstone texture but a rather sharp microfacies contrast takes place that is mainly due to the abundance increase of calpionellids and to the decrease of *Globochaete* and *Saccocoma*. Calpionellid associations are richer and better preserved and encompass *Crassicollaria intermedia* and large ovoidal forms of *Calpionella alpina*. A sharp increase in calpionellid abundance, paralleled by almost complete disappearance of *Saccocoma*, characterizes samples KB7 to KB9 (Fig. 14). Calpionellid associations are more diversified: in addition to *Crassicollaria intermedia* and large ovoidal forms of *Calpionella alpina*, *Crassicollaria brevis* and *C. massutiana* appear from sample KB7 while *Crassicollaria parvula* occurs in sample KB9. The last collected sample, KB10, is characterized by a looser wackestone texture, the disappearance of all *Crassicollaria* and the explosion of small, sphaerical forms of *Calpionella alpina*. Some calpionellids show a micrite fill darker than the enclosing matrix; cathodoluminescence observations revealed that these specimens result from exhumation and winnowing of previously buried shells (Martire & Clari 1994).

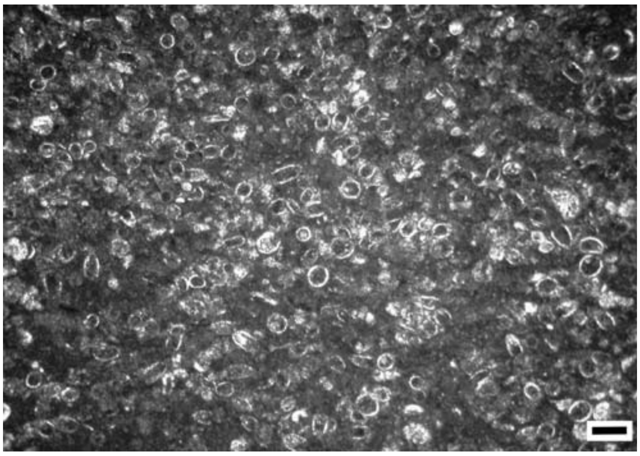

Fig. 14 - Kaberlaba section. Photomicrograph of the typical aspect of the calpionellid-rich, lower part of the Maiolica (KB9 sample). Scale bar = 0.1 mm.

Rabeschini section (Fig. 15)

In this section, a sharper contrast between Rosso Ammonitico and Maiolica exists, both texturally and compositionally, compared to Kaberlaba section. Samples RS1 to RS3 show an ill-defined nodular structure with only a slight textural contrast between nodules and matrix. Both of them consist of wackestone with *Saccocoma*, *Globochaete*, micrite and spar-filled radiolarian moulds, stomiosphaerids, aptychi, and sparse calpionellids. *Saccocoma* are more abundant in the matrix whereas radiolarian and calpionellids prevail in the nodules. Calpionellids are poorly preserved and represented mostly by specimens of the genus *Crassicollaria* (*Cr. brevis, Cr. massutiana, Cr. intermedia*) in addition to *Tintinnopsella* and the same large ovoidal forms of *Calpionella alpina* recognized in the Kaberlaba section. A very sharp increase in calpionellid abundance, paralleled by almost complete disappearance of *Saccocoma*, characterizes samples RS4 to RS6. Texturally these beds consist of looser wackestones containing mainly calpionellids and spar-filled radiolarian moulds. An equally sharp change exists in the calpionellid association: *Crassicollaria* disappears, together with the large ovoidal forms of *Calpionella alpina,* and is replaced by small, sphaerical forms of *Calpionella alpina* and *Remaniella ferasini. Remaniella cadischiana* finally appears with sample RS5. Similarly to the Kaberlaba section, some calpionellids show darker fills due to reworking.

Biostratigraphy - In both sections the topmost bed of the Rosso Ammonitico Veronese is referable to the Calpionellid Zone A3/A2 (Fig. 16). This is in agree-

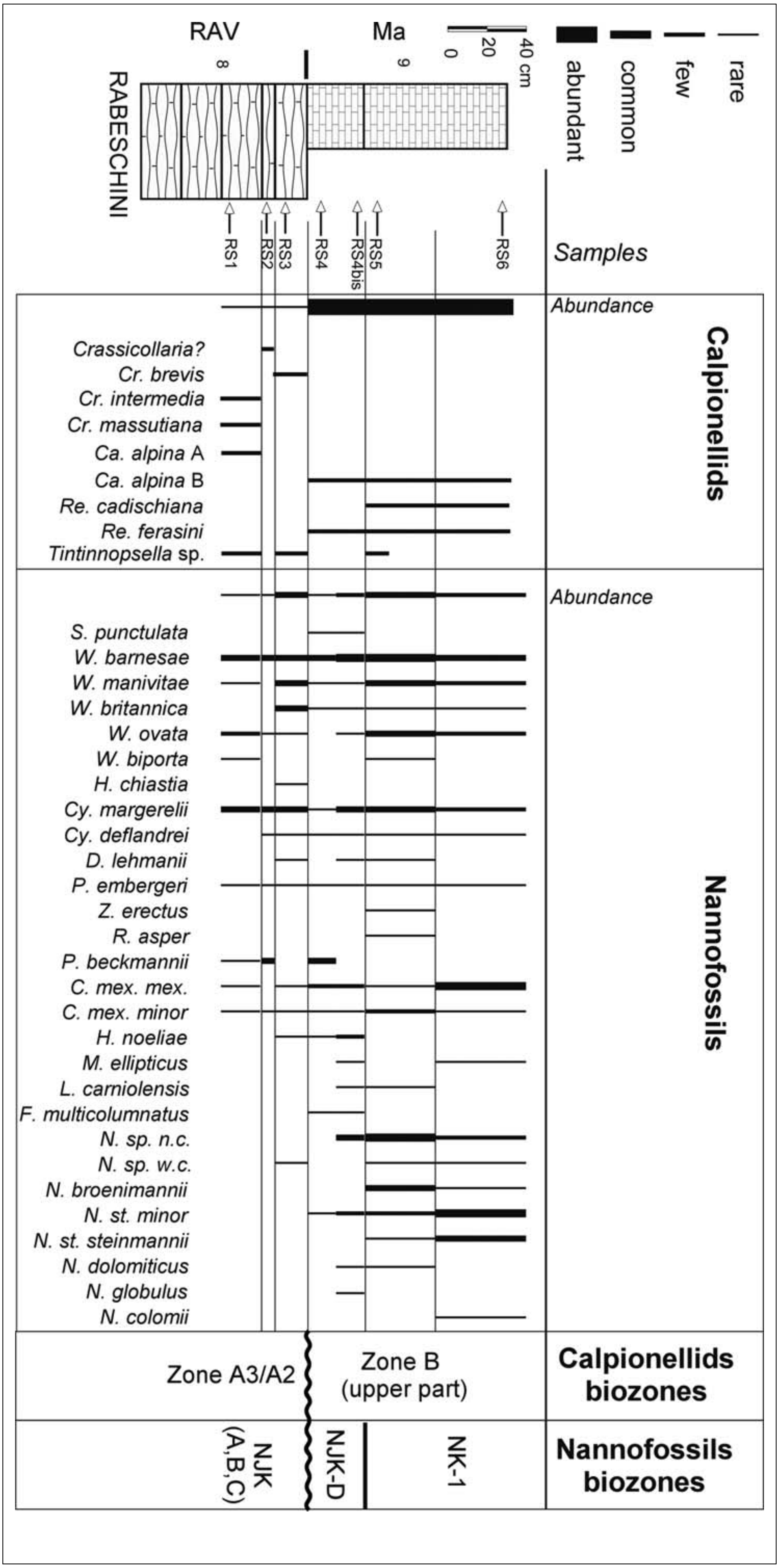

Fig. 15 - Detailed litho- and biostratigraphic log of the Rosso Ammonitico Veronese- Maiolica boundary at Rabeschini. Arrows point to the exact position of samples.

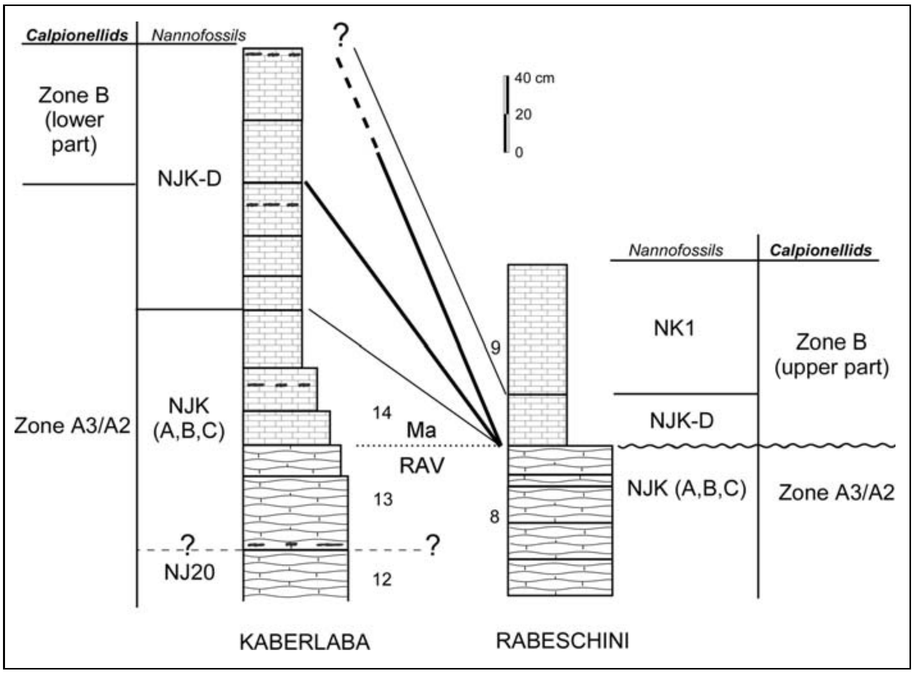

Fig. 16 - Litho- and biostratigraphic correlation scheme between Rabeschini and Kaberlaba sections. Bold lines refer to calpionellid biozone correlation, thin lines refer to nannofossil biozone correlation; dashed lines represent uncertainty; dotted line point to the lithostratigraphic Rosso Ammonitico Veronese- Maiolica boundary.

ment with the conclusion of previous studies carried out in nearby sections (Grandesso 1977; Channel & Grandesso 1987). Because of the presence of *Calpionella alpina*, subzone A1 can be excluded while, given the scarce and poorly preserved *Crassicollaria* specimens, it is impossible to discriminate between subzones A2 and A3. The first sediments of the Maiolica show a different age in the two sections. At Kaberlaba the same calpionellid assemblage (*Crassicollaria* and large forms of *Calpionella alpina*) described in the top Rosso Ammonitico Veronese occurs in the first 120 cm of the Maiolica that are consequently still referable to the A3/A2 subzone; above, the disappearance of *Crassicollaria* and the change of *Calpionella alpina* to sphaerical forms indicate the lower part of Zone B. On the contrary, the lowermost bed of Maiolica at Rabeschini already contains sphaerical forms of *Calpionella alpina* together with common *Remaniella*, which is characteristic of the upper part of Zone B.

Nannofossils

Biostratigraphic and semiquantitative nannofossil analyses were made on a total of 17 samples prepared using standard techniques (Monechi & Thierstein 1985). No ultrasonic cleaning or centrifuge concentration was applied to retain the original biogenic composition of each sample. Smear slides were examined using standard light microscope techniques under crossed polarizers and transmitted light at 1000x magnification. Because of calcite dissolution or over-growth, preservation and abundance of calcareous nannofossil species may vary significantly.

In general, preservation is poor or very poor (most specimens exhibit overgrowth or dissolution), and seldom moderate (specimens exhibit some etching and/or overgrowth). Total calcareous nannofossil abundance, compared to that of other biogenic particles and inorganic components, is low; a marked increase in species diversity may be seen only in the upper part of Rabeschini section (from sample RS4bis). Qualitative estimates of the relative abundance of calcareous nannofossil species in the studied assemblages were also made; the assemblages are dominated by *Watznaueria* species in the Rosso Ammonitico Veronese, and by both *Conusphaera* and *Nannoconus* species in the Maiolica. The nannofossil biozonation here adopted for the Jurassic/Cretaceous boundary interval is after Bralower et al. (1989, 1995).

Kaberlaba section (Fig. 12)

The lower part of the section (samples KB1 to KB4) contain relatively coarse calcareous fragments (10-20 µm) and shows a low abundance of calcareous nannofossils; their assemblages show poor preservation and low diversity (maximum 9 species), partially owing to high dissolution and recrystallization processes. The assemblages are dominated by *Watznaueria* species, a genus very resistant to dissolution and overgrowth, together with *Cyclagelosphaera margerelii* and *C. deflandrei*; less abundant but also present are *Faviconus multicolumnatus*, *Parhabdolithus embergeri*, *Conusphaera mexicana mexicana* and *C. mexicana minor.*

The assemblage in sample KB1 allows the identification of the upper Tithonian *C. mexicana* Zone (NJ20). The first occurrence of *Helenea chiastia* in sample KB2 identifies the base of the *H. chiastia* Zone (NJK) that spans the Jurassic/Cretaceous boundary. Because of the lack of nicely preserved material and the delicate structure of two marker species (*Umbria granulosa* and *Rotelapillus laffittei*), that causes them to be prone to dissolution, Subzones NJK-A, -B, -C could not be distinguished.

From sample KB5 upwards, the sediment appears finer grained (micarb, Ø 2-10 µm) in smear slide, a feature that usually follows a general increase in nannofossil abundance and/or diversity, but this is not so straightforward in this section as it appears in others (for example: Rabeschini, this work, or Polaveno, in: Erba & Quadrio 1987).

The upper part of the Kaberlaba section (samples KB5 to KB10) shows a relative increase in abundance of calcareous nannofossils; their assemblages show poor preservation and are still dominated by *Watznaueria* species, together with *Cyclagelosphaera margerelii* and *C. deflandrei*; the relative abundance of *Conusphaera mexicana mexicana* increases dramatically, compared to the lower part of the section; less abundant but also present are *Faviconus multicolumnatus*, *Parhabdolithus embergeri*, *Zeugrhabdotus erectus*.

Sample KB5 records the first occurrence of rare *Nannoconus* species (e.g. *N. compressus*), and the relative increase in diversity of the assemblage, despite the fact that calcareous nannofossils are never abundant in this section.

The first occurrence of *Nannoconus steinmannii minor* in sample KB8 identifies the base of Subzone NJK-D, of early Berriasian age. In sample KB10 *N. globulus* and *N. colomii* also occur, but the relative abundance of *Nannoconus* species never overcomes that of *Conusphaera* species in this section.

Rabeschini section (Fig. 15)

The lower part of this section (samples RS1 to RS3) shows a relatively low abundance of calcareous nannofossils; the sediment is composed of calcareous fine grains (micarb, 2-10 µm). Nannofossil assemblages show poor preservation and low diversity, and are dominated by *Watznaueria* species, together with *Cyclagelosphaera margerelii* and *C. deflandrei*; less abundant but also present are *Faviconus multicolumnatus*, *Parhabdolithus embergeri*, *Conusphaera mexicana mexicana* and *C. mexicana minor*. The occurrence of *C. mexicana mexicana, C. mexicana minor* and *Polycostella beckmannii,* and the absence of *Helenea chiastia* could suggest the *P. beckmannii* Subzone, NJ20B. However, the punctual occurrence of *H. chiastia,* found only in sample RS3, points to an important diagenetic control on its distribution, and hinders the correct identification of the base of the NJK Zone.

The upper part of the section (samples RS4-6) is characterized by a sharp increase in both abundance of calcareous nannofossils and species diversity (up to 19 species) from sample RS4bis upward. The first occurrence of *Nannoconus steinmannii minor* in sample RS4 identifies the base of Subzone NJK-D, of early Berriasian age. In sample RS5 *N. steinmannii steinmannii* occurs, thus identifying the base of the *N. st. steinmannii* Zone (NK-1). *N. dolomiticus* and *N. colomii* complete the assemblage. In both samples RS4 and RS4bis the relative abundance of *Conusphaera* species is greater than that of *Nannoconus* species, but from sample RS5 to the top of the studied section the contrary occurs, with *Nannoconus* species being more abundant than *Conusphaera* species.

Discussion

The described microfacies features confirm that the differences between lithozones 13 and 14 of the Kaberlaba section and lithozones 8 and 9 of the Rabeschini section (Figs. 2, 12, 15) observed in outcrop (absence of nodularity and red clay seams, even bedding planes; Figs. 8, 11) correspond to a marked change in biotic composition from *Saccocoma*- and *Globochaete*-dominated wackestone and packstone to calpionellid-rich wackestone (Figs. 13, 14). This is confirmed also by a marked increase in both abundance and species diversity of calcareous nannofossils. This facies and microfacies change can therefore be chosen as the boundary between the Rosso Ammonitico Veronese and Maiolica.

As to bio-chronostratigraphy, the calpionellid and nannofossil assemblages enable to make a good correlation between the two sections and to document some differences in the age of the base of the Maiolica (Fig. 16). The topmost layers of the Rosso Ammonitico Veronese are referred in both sections to calpionellid Zone A2/A3 and to calcareous nannofossils NJK Zone (Bralower et al. 1989). Because of the poor to very poor preservation of the nannofossil assemblages, the separation of the NJK-A, -B, and -C Subzones is impossible. On the contrary, different assemblages in both calpionellids and calcareous nannofossils characterize the basal bed of the Maiolica in the two sections. At Kaberlaba it is still referable to calpionellid zone A3/A2 and to nannofossil zone NJK (A,B,C), whereas at Rabeschini it contains calpionellid assemblages referable to the upper part of zone B and nannofossils typical of Subzone NJK-D. This demonstrates the occurrence of a hiatus at Rabeschini corresponding to part of zone

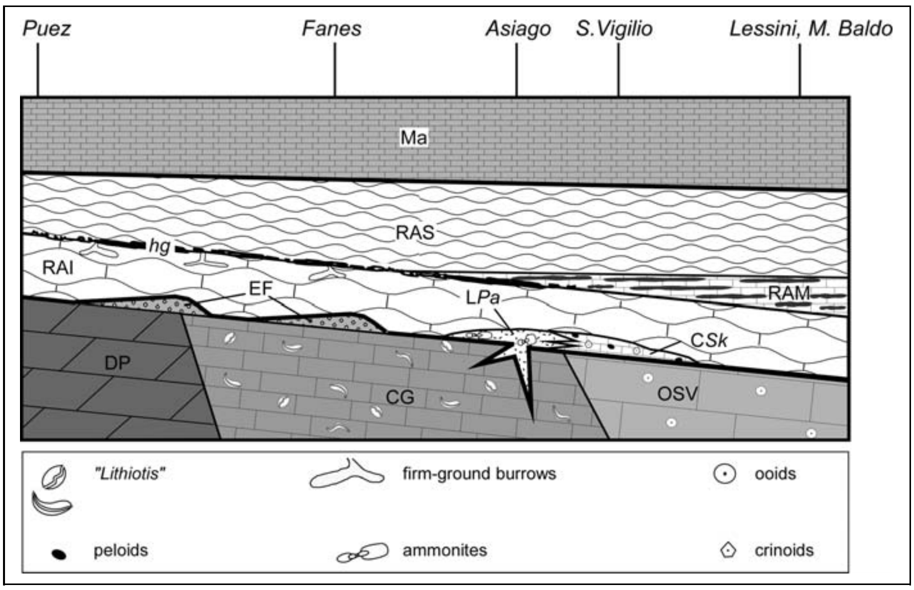

Fig. 17 - Schematic and simplified sketch of the stratigraphic relationships among the different lithostratigraphic units recognized below, within and above the Rosso Ammonitico Veronese. This scheme results from a synthesis of stratigraphies observable in different sectors of the Trento Plateau, some of which are indicated just for reference, but it does not represent a real geological section. DP: Dolomia Principale; CG: Calcari Grigi; OSV: Oolite di S. Vigilio; EF: Encrinite di Fanes Piccola; RAI, RAM, RAS: lower, middle and upper members of the Rosso Ammonitico Veronese; L*Pa*: lumachella a *Posidonia alpina*; C*Sk*: calcari a *Skirroceras*; Ma: Maiolica; hg: hard ground.

A3/A2 and to the whole lower part of zone B. Condensation and stratigraphical gaps in the Maiolica have also been reported, although at a slightly higher stratigraphic level, in literature on other sections in Venetian Alps (Clari & Pavia 1987). In sum, the Rosso Ammonitico Veronese-Maiolica boundary falls within the calpionellid A3/A2 zone and nannofossil NJK(A,B,C), i.e. in the upper Tithonian.

Rosso Ammonitico-related sediments

Rosso Ammonitico Veronese is not the only rock body occurring between the top of shallow platform limestones and the pelagic nannoconid- and calpionellid-bearing white limestones of the Maiolica, as in the two described type-sections on the Altopiano di Asiago. Along both the western and eastern margins of the Trento Plateau, other sedimentary bodies occur below the base of the Rosso Ammonitico (Fig. 17). Because they are thin and discontinuous, and show a rather great variety of both age and facies, they have generated some confusion in stratigraphic nomenclature and erroneous attributions. They consequently require a specific comment.

Calcare di Campotorondo

On the eastern margin, in the Belluno area (Alpi di S. Gregorio) up to 10 m thick massive to slightly nodular, grey to red micritic limestones containing frequent ammonites and belemnites have been named Calcare di Campotorondo by Casati & Tomai (1969) following Dal Piaz (1956). Ammonites refer this formation to the lower Bajocian (Hoernes 1877; Dal Piaz 1902). Similar deposits crop out in the nearby Vette Feltrine where they reach a maximum thickness of about 30 m and range in age from early Aalenian to late Bathonian (Dal Piaz 1907; Clari & Pavia 1980; Della Bruna & Martire 1985).

Calcari a *Skirroceras*

On the opposite, western margin of the Trento Plateau (Garda Lake), other ammonite-bearing, pink to red limestones, of late Aalenian-early Bajocian age and hence approximately coeval to the Calcare di Campotorondo, were recognized by Sturani (1964a) and named Calcari a *Skirroceras* because of the frequence of this genus of ammonites. Thinner bedding and grain-supported textures, commonly represented by grainstone with peloids, thin-shelled bivalves, echinoderm debris and benthic foraminifers, characterize the Calcari a *Skirroceras* (Ambrosi et al. 1991; Callomon et al. 1994) (Fig.18). These lithological features distinguish the Calcari a *Skirroceras* from the immediately overlying Rosso Ammonitico Veronese limestone that in some places contain ammonite moulds referable to the upper Bajocian (Pochettino 1995). The boundary is represented by a clear-cut, erosional discontinuity surface locally coated by thin crusts of Fe-Mn oxides (Fig. 18). Common taphonomic reworking of ammonite moulds and the presence of decimeter-sized Fe-Mn oncoids (snuff boxes of Gatrall et al. 1974) document the intermittent action of bottom currents, and the consequent reworking of sediments and prolonged exposure on the sea floor. The maximum reported thickness is about 6 metres (Callomon et al. 1994; Pochettino 1995).

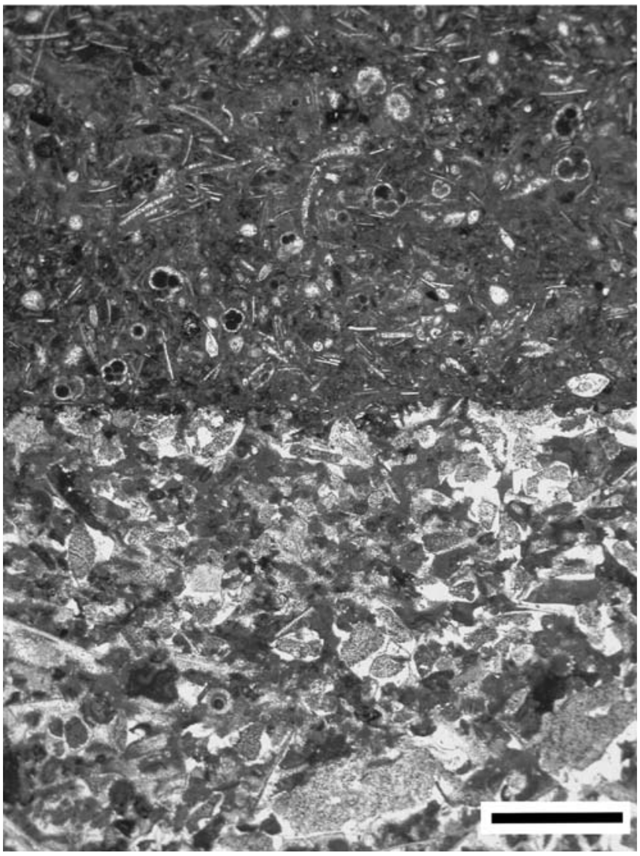

Fig. 18 - Photomicrograph of the Calcari a *Skirroceras*/Rosso Ammonitico Veronese boundary. Note the clear-cut erosional, bioeroded surface and the textural contrast between the peloidal-crinoidal grainstones of the Calcari a *Skirroceras* (bottom) and the wackestone with protoglobigerinids and thin-shelled bivalves of the Rosso Ammonitico Veronese (top). Scale bar = 0.5 mm.

Lumachella a *Posidonia alpina*

On a much wider area, corresponding to the central and western part of the Trento Plateau (e.g. Altopiano di Asiago, Monte Baldo), distinctive white to pink, coquinoid limestones are recognizable at the base of the Rosso Ammonitico. These sediments are known as Lumachella a *Posidonia alpina* and may occur as neptunian dyke fills or as thin lensoidal bodies (maximum reported thickness of about 3 m at Colme di Vignola, Massari 1981). Each lens or dyke fill shows different grain size and composition. On average, thin-shelled bivalves, referred in the past first to *Posidonia alpina*, then *Bositra buchi* and now partly inserted in the new genus *Lentilla* (Conti & Monari 1992), constitute the bulk of the rock. The prevailing lithology is a well washed grainstone or frequently rudstone in which shells may reach 1 centimetre in length, are mainly oriented parallel to bedding, and are surrounded by isopachous rims of inclusion-rich, fibrous cements (Sturani 1971; Martire 1992b) (Fig. 19). Depositional sedimentary structures are generally lacking with some noteworthy exception such as Colme di Vignola (Monte Baldo ridge) where hummocky cross stratification was described and interpreted as storm-dominated and therefore relatively shallow, depositional environments (Massari 1981). However, especially in the dyke fills, finer grained and matrix-supported sediments also occur. Brachiopods and small ammonite shells may also be abundant; ammonite associations allowed precise dating of single dyke fills or lenses which on the whole span the upper Aalenian-upper Bajocian. Actually Sturani (1967, 1971) reported also younger ages, up to early Bathonian, in some localities (e.g. Monte Giovo, Monte Agaro) that, however, cannot be confirmed and may need revision. The term Lumachella a *Posidonia alpina,* in fact, was used by some authors also to indicate sediments that generally contain abundant thin-shelled bivalves (e.g. Castellarin 1972; Masetti & Bottoni 1978; Benigni et al. 1982). As already remarked by Ferrari (1982), this use must be avoided as it generates confusion between different facies, i.e. high energy coquinas vs. mud-supported, pelagic sediments. Moreover, the coquinoid deposits of the Lumachella a *Posidonia alpina* and the red micritic limestones of the lower part of the Rosso Ammonitico Veronese are separated over most of the Trento Plateau by a clear-cut erosional discontinuity surface.

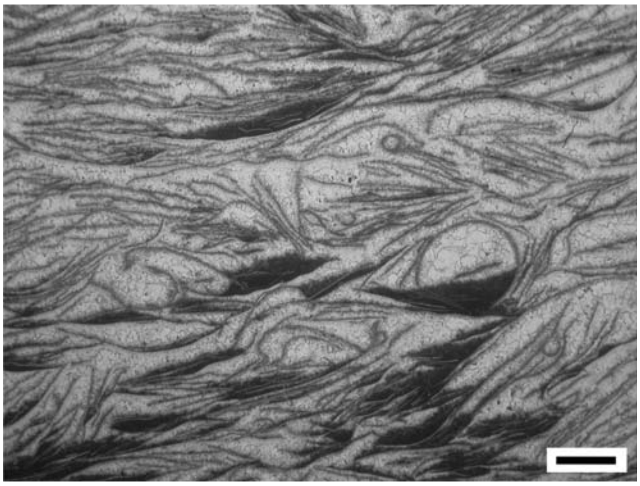

Fig. 19 - Photomicrograph of the lumachella a *Posidonia alpina.* Note the abundance of thin-shelled bivalves, the scarcity of micrite, and the early cement isopachous rims around the shells. Scale bar = 1 mm

Crinoidal limestones

In order to complete the picture of all the sediments that are sandwiched between the top of the shallow platform deposits and the base of the Rosso Ammonitico, some lithosomes of crinoidal limestones must be discussed. They are characterized by greenish grey to dark red colours, thicknesses of up to some tens of meters, large-scale cross bedding, coarse grain size and a diverse age that on the whole is bracketed between the Pliensbachian and the Aalenian. These crinoidal limestones crop out discontinuously in many different places of the Trento Plateau and have been named in different ways depending on the authors: Encrinite di Fanes in the Dolomites (Masetti & Bottoni 1978; Zeiss et al. 1990); Membro Calcarenitico of the Calcari Oolitici (Della Bruna & Martire 1985) or Calcareniti glauconitiche (Masetti & Trevisani 1992; Broglio Loriga et al. 1991) in the Vette Feltrine; Encrinite del Peller in the Peller group (Castellarin 1972; Ferrari & Manara 1972). Similarly to the Lumachella a *Posidonia alpina*, these crinoidal limestones are separated from both the under- and overlying sediments by clear-cut erosional discontinuity surfaces. In spite of the presence of ammonites and of the generally red colour, no confusion with the Rosso Ammonitico is possible because of great textural and compositional differences. The common presence of sedimentary structures pointing to episodic, strong traction currents together with the coarse grain size and the nature of the grains, mostly represented by skeletal remains of benthic organisms, have led since the 70's (Jenkyns 1971) to interpret these crinoidal limestones as the product of sedimentation on top of current-swept fault blocks resulting from dismembering and foundering of extensive carbonate platforms. An alternative hypothesis, calling upon eutrophication as the main cause of the demise of platform sedimentation, has been proposed to explain the genesis of these peculiar deposits (e.g. Zempolich 1993; Cobianchi & Picotti 2001). More recently, paleolatitudinal plate motions have been proposed as facies controlling factors (Muttoni et al. 2005) which could also have affected platform evolution.

Discussion and proposal of formalization

The Rosso Ammonitico Veronese may be subdivided in several members characterized by different lithologies, age and degrees of lateral continuity (Figs. 17, 20). From base to top these are:

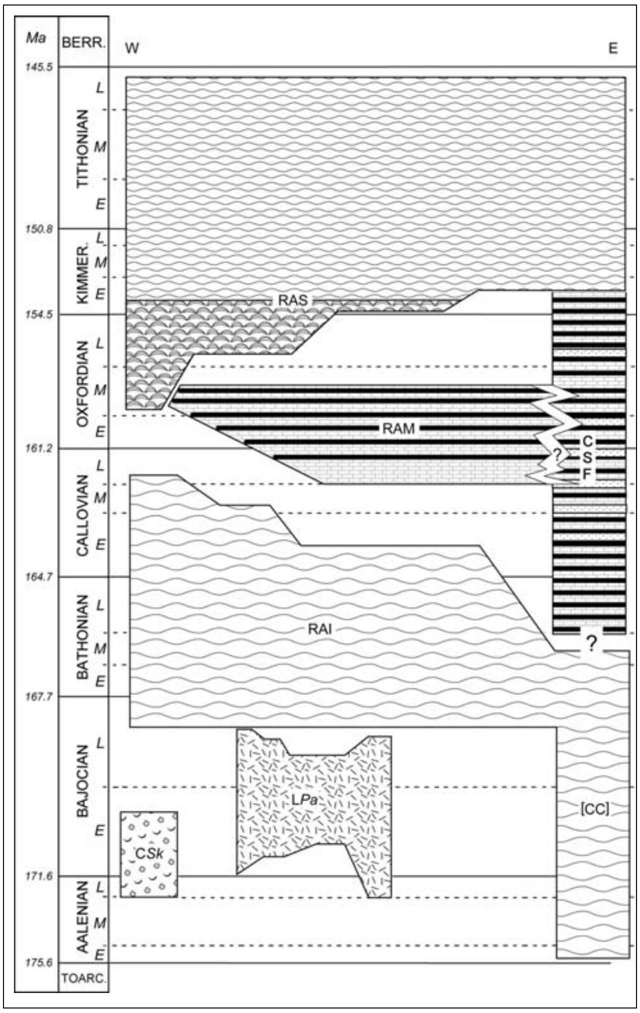

Fig. 20 - Schematic chronostratigraphic chart showing age and interpreted geometry of the different lithostratigraphic units recognized within the Rosso Ammonitico Veronese. This scheme is very simplified and does not represent a real geological section. It may be only considered as a West-East section as far as the stratigraphy of the right-hand side (East) is concerned. Dashed lines refer to substage boundaries. L*Pa*: lumachella a *Posidonia alpina*; C*Sk*: calcari a *Skirroceras*; RAI, RAM, RAS: lower, middle and upper members of the Rosso Ammonitico Veronese; CSF: Calcare Selcifero di Fonzaso; [CC]: Calcare di Campotorondo, now to be included into the RAI. Time scale from Gradstein et al. (2004). Dotted beds within the CSF represent ooidal-peloidal layers interbedded with cherty limestones.

Lumachella a *Posidonia alpina* (upper Aalenian-upper Bajocian) - Even though the sedimentological-palaeoenvironmental interpretation is controversial, coarse grain size, scarcity of micrite, and presence of thick rims of isopachous fibrous cements clearly point to strong-current regimes that contrast with the Rosso Ammonitico Veronese depositional environment. To distinguish these coquinoid deposits from the nodular limestones of the Rosso Ammonitico Veronese, the Lumachella a *Posidonia alpina* is here recognized as a separate member locally occurring at the base of the Rosso Ammonitico Veronese.

Calcari a *Skirroceras* (Aalenian-lower Bajocian) - The lithological similarity at outcrop with the red nodular limestones of the Rosso Ammonitico Veronese would suggest simply to refer these limestones to the Rosso Ammonitico Veronese and to abandon the term Calcari a *Skirroceras*. Nevertheless, the clean-washed grainstone texture with peloids and bioclasts of this unit points to sedimentation in a different environment, i.e. the top of a current-swept drowning carbonate platform before relatively quiet pelagic sedimentation in the submerged plateau phase. In analogy to what said for the Lumachella a *Posidonia alpina*, therefore, the thin and very localized Calcari a *Skirroceras* should also be included in the Rosso Ammonitico Veronese as an independent member at the base of the formation.

Rosso Ammonitico Inferiore (upper Bajocian-lowermost upper Callovian) - It is characterized by a generally massive, apparently not nodular, aspect in outcrop. It shows a good lateral continuity all over the Trento Plateau with a thickness ranging from 6 to 10 metres. Locally, however (e.g. Monte Baldo, Acque Fredde, Foza) much reduced thicknesses have been reported (e.g. Sturani 1964a; Benigni et al. 1982; Martire 1989, 1996). This could be due to anomalous condensation or to submarine slides, even though local alpine tectonic complications cannot be ruled out. The Calcare di Campotorondo shows a substantially identical lithology and hence, albeit the older age, should be simply considered as synonymous with the lower member of the Rosso Ammonitico Veronese and its use discontinued, as already suggested in a review of the traditional Italian lithostratigraphic units.

Rosso Ammonitico Medio (upper Callovian-middle Oxfordian) - This unit, characterized by thin bedding and the presence of red chert nodules and beds, is affected by thickness changes from 0 to about 7 m linked to local irregularities of the sea floor topography. Eastwards, in the Feltre and Belluno areas, above the Calcari di Campotorondo a package of thin-bedded mainly grey cherty limestones follows, which shows a thickness of several tens of meters and includes also resedimented ooidal-peloidal grainstones. They were formalized as Calcare Selcifero di Fonzaso by Bosellini & Dal Cin (1968). Recent studies of radiolarian and nannofossil associations confirmed an age between the middle Bathonian and the early Kimmeridgian (Beccaro et al. 2002; Cobianchi 2002; Cobianchi & Picotti 2002). The Calcare Selcifero di Fonzaso is overlain by the ammonite-bearing, red nodular limestones typical of the upper part of the Rosso Ammonitico Veronese. The Calcare Selcifero di Fonzaso, therefore, correlates to the middle member of the Rosso Ammonitico Veronese, although it is the lateral equivalent also of the uppermost part of the lower member and the lowermost part of the upper member. The transition from the few

Fig. 21 - Panoramic view showing typical weathering of the upper unit of the Rosso Ammonitico Veronese. M. Meletta, Altopiano di Asiago.

metres-thick middle member to the 60-90 m-thick Calcare Selcifero di Fonzaso likely takes place abruptly, through a fault-bounded, early drowned eastern block in a way that, though on a smaller scale, recalls what happens on the western margin where the lateral boundary between the Rosso Ammonitico Veronese and the radiolarites of the Selcifero Lombardo Group corresponds to the Garda Escarpment (Castellarin 1972, 1982; Castellarin & Picotti 1990).

Rosso Ammonitico Superiore (middle Oxfordian-upper Tithonian) - This unit is the most characteristic lithologically, consisting mainly of nodular marly limestones with the typical knobby weathering surfaces (Fig. 21). It is the most continuous geographically as it shows basically the same features all over the Trento Plateau. Commonly the lowermost beds are massive and stromatolitic, especially in the sections where the middle member is lacking.

The boundaries of the Rosso Ammonitico Veronese are easily recognized: the lower one corresponds to the abrupt facies change from shallow platform to pelagic limestones and is everywhere marked by an important stratigraphical gap with clear sedimentological evidence (e.g. erosional surfaces, crusts of Fe-Mn oxides); the upper boundary, on the contrary, corresponds to a gradual transition from red Rosso Ammonitico Veronese limestones to the white Maiolica ones. At a careful analysis, however, at least on the Altopiano di Asiago, the change from the last nodular layer with red clay seams to purely white limestones with even stratification takes place abruptly, across a single bedding plane. This surface corresponds also to a marked change in biotic composition from *Saccocoma*- and *Globochaete*-dominated wackestones and packstones to calpionellid-rich wackestones where calcareous nannofossils show a marked increase in both abundance and species diversity. Locally this boundary is marked by a stratigraphical gap and the lithological change is more distinctive.

The Kaberlaba section in the Altopiano di Asiago is here proposed as the type-section for the Rosso Ammonitico Veronese Formation because it shows a complete gamut of lithofacies and provides the best biochronostratigraphic framework for the different members. The Rabeschini outcrop is considered as a complementary section in order to highlight the variability in facies and stratigraphy that characterizes the Rosso Ammonitico Veronese all over the Trento Plateau.

Acknowledgements. We dedicate this paper to the memory of Carlo Sturani, who died 31 years ago, and who started the study in Torino of the Venetian Jurassic.

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