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Stratigraphy, Facies and Synsedimentary Tectonics in the Jurassic Rosso Ammonitico Veronese (Altopiano di Asiago, NE Italy)

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KEYWORDS: PELAGIC FACIES – BIOSTRATIGRAPHY – NEPTUNIAN DYKES – SLIDES – SOUTHERN ALPS – JURASSIC

CONTENTS

SUMMARY

The red, pelagic limestones of the Rosso Ammonitico Veronese (Upper Bajocian-Tithonian) of the Altopiano di Asiago area can be subdivided into eight facies. They differ from each other in structure (bedding style, presence and type of nodularity) and texture (nature of components, grain- vs mud-support, compactional features). Several discontinuities could be recognized, based on sedimentological or biostratigraphic evidence. In the context of a drowned platform, where sediments essentially consist of skeletal remains of both planktonic and benthic organism, the different facies are interpreted as reflecting a varying influence of currents on the winnowing of micrite and on triggering early cementation. Early cementation in turn, controlled the patterns of bioturbation and the response of sediments to later compaction and pressure-dissolution. At times, microbial mats, of unidentified nature, were important in trapping and binding sediment, giving rise to early lithified nodules and layers of stromatolitic aspect.

The Rosso Ammonitico Veronese can be subdivided into three units: lower Rosso Ammonitico (RAI: Upper Bajocian-Lower Callovian), middle Rosso Ammonitico (RAM: Upper Callovian-Middle Oxfordian), and upper Rosso Ammonitico (RAS: Lower Kimmeridgian-Tithonian). Frequent ammonite moulds allow the precise dating of the base and top of each unit, and the documentation of facies heteropies and hiatusses in the more fossiliferous RAS. The lower unit (RAI) is massive and essentially nodular; the middle unit (RAM) is well bedded, non-nodular, and cherty; the upper unit (RAS) is richer in clay and typically nodular.The RAI and the RAS are present everywhere, though significant facies and thickness changes affect particularly the RAS; the RAM is much more variable, ranging from 0 to 10 metres. These variations, that may be gradual or abrupt, are interpreted as the result of Middle-Late Callovian block-faulting which generated an irregular sea floor topography where the swells were more exposed to currents that continuously removed sediments, inducing long-lasting periods of non-deposition. Sediments preferentially accumulated in the adjacent lows. A confirmation of this hypothesis is provided by evidence of synsedimentary tectonics, described for the first time in the Rosso Ammonitico Veronese. Neptunian dykes, both vertical and horizontal, are developed at the top of the RAI and are filled with laminated sediments or collapse breccias. Glides of metre-size blocks and slumps are present at the top of the RAI and at the base of the RAM, respectively. Cm-thick layers of mud supported breccias are intercalated in the upper part of the RAI and within the RAM: they are interpreted as seismites. All these features document a tensional regime that generated fractures in more or less lithified sediments and failure along steep fault scarps or gently dipping slopes of tilted fault blocks. Recognition of this Callovian-Oxfordian tectonic activity shows that, after the Bajocian drowning, the Trento Plateau did not

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simply experience a uniform and general foundering: a small-scale block-faulting was still active and affected the pattern of facies distribution.

1 INTRODUCTION

The Rosso Ammonitico Veronese (RAV) is a thin (about 30m), still unformalized, lithostratigraphic unit consisting of Middle to Upper Jurassic red pelagic limestones, commonly nodular and rich in ammonites. It is developed on the Trento Plateau, a paleogeographic unit that came into existence, on the Mesozoic passive margin now exposed in the Southern Alps, during late Triassic extension, which finally led to the opening of an arm of the Tethys ocean during the Middle Jurassic (Gaetani, 1975; Winterer & Bosellini, 1981). Listric normal faults separated the Trento Plateau from two adjacent basins, the Lombardy Basin to the West and the Belluno Trough to the East (Fig.1; Castellarin, 1972; Sarti et al., 1992; Bertotti et al., 1993). The Trento Plateau is characterized by a several hundred meter-thick succession of Hettangian to Aalenian platform carbonates, deposited first in restricted environments (Calcari Grigi di Noriglio: Bosellini & Broglio Loriga, 1971; Clari, 1975), and then in open marine conditions (S.Vigilio Group: Clari & Marelli, 1983; Barbujani et al., 1986). In the Altopiano di Asiago, the S.Vigilio Group is absent and the RAV directly overlies the Domerian Calcari Grigi (Sturani, 1971). Bivalve- and ammonite-bearing coquinas are locally present at the top of the Calcari Grigi, mainly as fillings of cavities (Sturani, 1971; Winterer et al., 1991). These sediments, known as Lumachella a *Posidonia alpina* were studied in detail by Sturani (1971) who showed their Early to Late Bajocian age. A regional unconformity, commonly encrusted by Fe-Mn-oxides, separates the shallow water facies from the overlying pelagic limestones of the RAV and marks the drowning of the platform below the photic zone. This drowning has been classically viewed as the result of the onset of thermal subsidence of most of the South-Alpine basin, which caused the sinking of the sea floor to a depth of several hundred meters where RAV deposition took over (Winterer & Bosellini, 1981). An alternative interpretation has been recently proposed (Zempolich, 1993) which suggests drowning to shallower depths, within the reach of strong storms. This was caused by a concomitant sea level rise and eutrofication which in turn "killed" the platform sediment factory and dramatically reduced the sediment supply (cf. Bice & Stewart, 1990; Schlager, 1993).

The Mesozoic succession ends with two other calcareous, pelagic formations: the thin-bedded, white, micritic limestones of the Biancone (Maiolica Veneta, Lower Cretaceous), and the pink-red, more or less nodular, marly limestones of the Scaglia Rossa (Upper Cretaceous. Fig.1).

The RAV has been the subject of paleontological studies since the last century because of the richness of some layers in ammonite moulds (e.g. Catullo, 1850; Benecke, 1865; Parona, 1880, 1931; Nicolis & Parona, 1885; Del Campana, 1905; Dal Piaz, 1907). From 1960 onwards, the renewed interest in carbonate sediments and rocks resulted in the flourishing of studies on both the stratigraphy of the RAV and, more in general, on the sedimentology and diagenesis of the Ammonitico Rosso facies. Sturani's work (1964a, b) was essential to establish a modern biostratigraphic framework in the RAV, and led to the distinction of two members separated by an important hiatus: a lower one (Rosso Ammonitico Inferiore, RAI: Upper Bajocian - Lower Callovian) and an upper one (Rosso Ammonitico Superiore, RAS: Upper Oxfordian - Tithonian). More recent papers have improved the biostratigraphic knowledge, and evidenced the frequency of discontinuities and their temporal and spatial variability within the formation (Clari et al., 1984; Sarti, 1985, 1986a, b, 1993; Pavia et al., 1987).

On the sedimentological/diagenetic side, several authors have attempted to give an explanation for the peculiar nodular structure of the Ammonitico Rosso facies. Only the most specific works will be cited here. Hollmann (1962, 1964) attributed the origin of nodules to dissolution on the sea floor by undersaturated waters ("subsolution"), and contemporaneous cementation of the underlying sediments. Shallow burial dissolution of the most delicate fraction of sediment (aragonite and micrite) was proposed by Jenkyns (1974) as a source for localized cementation and formation of nodules. Ogg (1981), instead, suggested that pressure dissolution during deep burial supplied the carbonate for lithification of nodules. A totally different hypothesis proposed by 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). Clari et al. (1984) recognized the presence of different kinds of nodules with different origins: predepositional nodules, already lithified at the time of deposition (e.g. intraclasts, ammonite moulds, oncoids), and postdepositional nodules, cementated during early or late diagenesis. The interplay of early and late diagenesis has been recently highlighted by Clari & Martire (1996). The great contrast in texture, composition, and fabrics between calcareous nodules and marly matrix is explained as the result of selective early cementation of nodules, which prevented them from the following compaction; the uncemented matrix, instead, was deeply transformed by mechanical and subsequent chemical compaction.

Some aspects of RAV stratigraphy and deposition are however still unclear. In particular, a cherty unit, locally present between the lower and the upper members, has never received due interest. This happened probably because of the absence of biostratigraphically significant fossils, in spite of the problems raised by its patchy distribution and of the presence of several bentonite layers (Bernoulli & Peters, 1970, 1974) suitable for radiometric dating. A first attempt of dating this unit was made by Sturani (1964a) who, on the basis of a wrong correlation with a marly bed in the RAS (Martire et al., 1991), suggested a late Kimmeridgian age for it. A much older age was proved by the finding of Middle Oxfordian ammonites in a bed overlying the cherty unit (Clari et al.,1984).

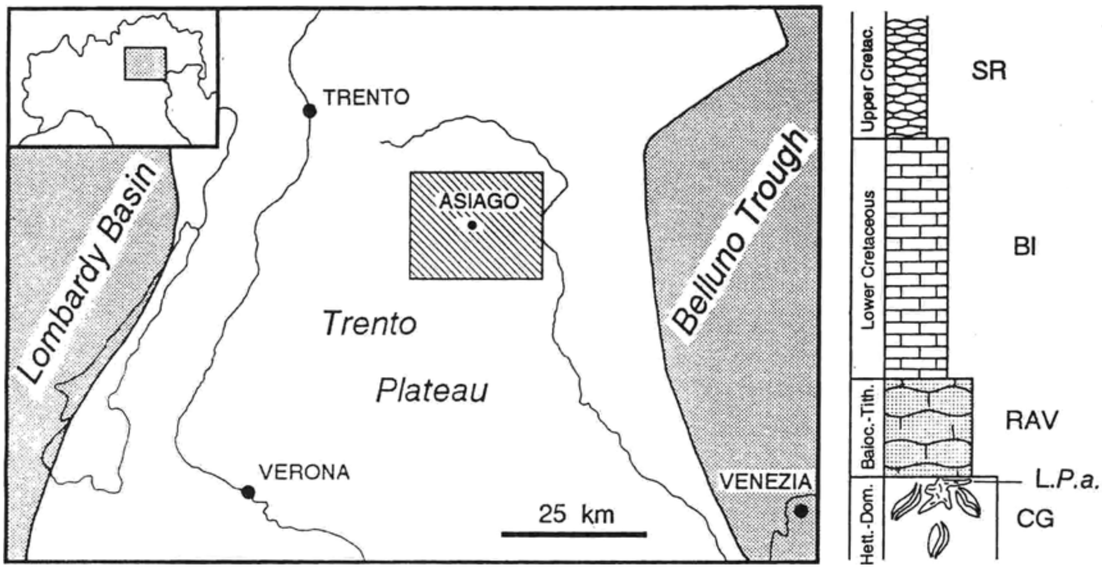


Fig. 1. Geographic and paleogeographic framework of the studied area (oblique ruling) and the typical Jurassic-Cretaceous stratigraphic succession (CG: Calcari Grigi; *L.P.a.*: Lumachella a *Posidonia alpina*; RAV: Rosso Ammonitico Veronese; BI: Biancone; SR: Scaglia Rossa). Paleogeographic units after WINTERER & BOSELLINI (1981).

As ammonites are generally absent within this unit, other fossil groups have been studied (rhyncolites, belemnites, crinoids: DE VECCHI & DIENI, 1974; LAUB, 1994; radiolarians: BAUMGARTNER, 1987) which have provided a general attribution to the Oxfordian-Lower Kimmerdigian.

A recent study of the RAV in the Altopiano di Asiago, corresponding to the central part of the Jurassic Trento Plateau, showed that facies are more varied, and discontinuities more frequent, than previously described; explained the lateral and vertical relationships among facies; and documented the fact that synsedimentary, extensional, tectonics exerted a major control on facies and their distribution within the pelagic succession (MARTIRE, 1989).

The purpose of this work is essentially twofold. Of regional interest are the refinement of the bio-chronostratigraphy and the description of the facies recognized within the RAV of the Altopiano di Asiago. Of more general concern is the recontruction of the history of a pelagic plateau sited on a passive continental margin, and of the factors controlling deposition and early diagenesis of condensed, pelagic sediments. The geometrical relationships among unconformity-bounded units eventually allow insights into the Middle-Upper Jurassic tectonic evolution of the Trento Plateau.

The study has been carried out in the Altopiano di Asiago (province of Vicenza, northeastern Italy), over an area of about 300 km², geographically limited to the north and to the east by the Sugana Valley, to the west by the Astico Valley and to the south by the Venetian plain. In this region the RAV is actively quarried and a lot of fresh quarry fronts allow observation of the formation from base to top with continuity. Most of the natural outcrops and quarry fronts were measured and sampled, and gradual or abrupt variations in thickness and facies of lithosomes could be documented in detail. More than 400 peels and 200 thin-sections have been analyzed, and 263 ammonites collected and determined from several sections. Cathodoluminescence (CL) petrography and SEM observations helped to unravel the diagenetic history.

2 FACIES ANALYSIS

2.1 Introduction

The RAV can be roughly subdivided into three units on the basis of macroscopic features (Fig.2; Pl. 55/1). The lowest one (Rosso Ammonitico Inferiore: RAI) has a massive appearance and only on weathered surfaces partitions can be seen; this is due to stylolitic pseudobedding surfaces rather than to true bedding planes. The middle unit (Rosso Ammonitico Medio: RAM) is easily distinguished because of its thin, mostly plane-parallel bedding, the overall absence of nodules, and the abundance of chert layers. The upper unit (Rosso Ammonitico Superiore: RAS) is often characterized by a marked nodularity with a great contrast in clay content between nodules and matrix, which results in the typical knobby aspect of outcropping surfaces (Pl. 56/2). The RAI and the RAS are nearly always present whereas the RAM displays significant thickness variations, from 0 to about 10 metres.

Eight facies (pseudonodular, mineralized, bioclastic, nodular, thin-bedded limestone, thin-bedded cherty limestone, subnodular, stromatolitic) have been distinguished according to structural (bedding style, presence and kind of nodules) and textural features (nature, abundance, and organization of components). Some of the facies occur only in a certain stratigraphic unit, but other do not. Although the late diagenetic imprint, mainly due to compaction and pressure dissolution, is often important, the different rock types defined by relatively homogeneous petrographic characteristics have been named "facies". The behaviour of sediments during burial depends much on their early diagenetic history that in turn is controlled by the conditions present on the sea floor during and/or just after deposition (BATHURST, 1987; CLARI & MARTIRE, 1996). Textures and structures cannot be always directly interpreted in terms of depositional processes (for example, grain-supported rocks may result from uncemented, and hence strongly compacted, mud-supported sediments; cf. WRIGHT, 1992); yet, layers with conspicuous petrographic differences can be considered as separate facies because they derive from peculiar combinations of interconnected environmental parameters like hydrodynamic energy and bioturbation.

A macro- and microscopic description is given for each facies, and for discontinuity surfaces that frequently bound packages of strata. In a concluding section, depositional, early, and late diagenetic processes are discussed briefly.

2.2 Pseudonodular facies

This facies is organized in meter-thick beds and owes its name to the fact that nodules are not apparent in outcrop (Pl. 55/1). This is due to a very similar degree of coherence of nodules and matrix which do not weather differentially. Because of this, the pseudonodular facies, typical of most of the RAI but present also in the RAS, is still actively quarried; meter-sized blocks are cut and polished, and used as stone facings. On these surfaces, the heterogeneity of the rock appears clearly because of the great colour contrast between pink nodules and the brick red matrix. The term "nodules" includes all those parts of the rock of variable shape (from ellipsoidal to very irregular but normally rounded) and size (from a few mm to several cm), limited by transitional or sharp boundaries with the surrounding matrix from which they are distinguished by a marked contrast in texture, colour, and compactional fabrics. The largest variety of nodules is present in the pseudonodular facies. In accord with CLARI et al. (1984), the following types of nodules have been identified: a) intraclasts, b) oncoids, c) stromatolite domes, d) ammonite moulds, and e) early diagenetic nodules.

a) Intraclasts are recognized with certainty when they are bored and coated by Fe-Mn oxide crusts up to 1 mm thick (Pl. 55/2-3). Two kinds of borings occur: very small, straight or branching microborings, less than 10 mm in diameter and a few hundred mm in length, usually attributed to cyanobacteria or fungi (BROMLEY, 1970; GOLUBIC et al., 1975, 1984); larger and irregular borings (a hundred mm in diameter and a few mm in length) referable to *Meandropolydora* and ascribed to worms (BROMLEY & D'ALESSANDRO, 1983). Other intraclasts show a larger size (up to some centimeters) and neither borings nor mineralization. Their nature is inferred from their sharp boundaries, limited size, slight differences in texture and CL colour with respect to other adjacent nodules. Intraclasts mostly consist of wackestones with disarticulated valves of thin-shelled bivalves (*Bositra*), echinoderm fragments, calcite-filled radiolarian moulds, gastropod protoconchs, planktic foraminifers (*Protoglobigerina*), benthic foraminifers (*Frondicularia, Lenticulina, Spirillina, Valvulina*), *Globochaete*, ostracods, peloids, and rare calcitized sponge spicules. *Saccocoma* usually replaces bivalves in the RAS. Grain-supported textures, dominated by bivalves and echinoderms, are found only occasionally.

b) Oncoids. Nodules of several cm in diameter often show subspherical shapes and complex internal structures due to the presence of fine laminae enveloping a homogeneous nucleus (Pl. 55/2). These nodules were described in detail by MASSARI (1979, 1981) who related the laminae to some kind of microbial mat, and named them oncolites for their morphological similarity with spherical stromatolitic structures (LOGAN et al., 1964). In the RAV of the Altopiano di Asiago oncoids are poorly developed, i.e. the nuclei (mainly intraclasts) make up a large part of the oncoid and the laminated envelope is rarely developed on all sides and hardly arranged in a concentrical way. Texturally, the laminated part consists of fine-grained packstone, or even grainstone, very rich in peloids and bivalve debris, irregularly alternating with subordinated thinner laminae of wackestone (Pl. 55/4).

c) Isolated stromatolitic domes are developed over oncoids, intraclasts or ammonite moulds and give rise to dm-sized columnar structures (Pl. 55/5). They are characterized by the same finely laminated, internal fabric seen in the oncoids (Pl. 55/4). Often, stromatolitic domes growing over neighbouring nuclei come in contact and merge into one larger dome. The spaces between the columns usually correspond to burrows with geopetal fillings. Continuous layers of LLH stromatolites (LOGAN et al., 1964) are commonly interlayered with the pseudonodular facies.

d) Ammonite moulds are not frequent in the pseudonodular facies. They may be intact or more commonly abraded or in fragments, demonstrating their reworked (or reelaborated: FERNANDEZ LOPEZ, 1984; GOMEZ & FERNANDEZ LOPEZ, 1994) nature due to exhumation after a first phase of burial and early lithification.

e) Early diagenetic nodules are the hardest to be defined because in this category fall all those portions of sediment which bear no sign of compaction, are texturally identical to intraclasts, lack any internal stromatolitic biolamination, and cannot be mistaken for intraclasts since boring and staining are missing, and the shape is the most irregular (Pl. 55/6). A variety of traces demonstrates activity of a rich community of bottom dwellers, both in soft- (*Chondrites*) and firm grounds (spar-filled or geopetally filled tubular cavities. BROMLEY, 1975). In some instances, layers are massive and nearly matrix-free, and the early diagenetic nodules actually make up the frame of the rock, enclosing oncoids, intraclasts etc.

All the described nodules are separated by a darker and more clay-rich matrix that usually consists of packstone with bivalves, echinoderms, peloids, benthic foraminifers and *Globochaete* (Pl. 55/6). The more delicate grains (planktic foraminifers, radiolarians, gastropods, sponge spicules), which are common in nodules, are never present in the matrix. Bivalve shells are often flattened, aligned parallel to the edge of nodules, and very closely packed, though true fitted fabrics, i.e. sutured contacts between grains (Buxton & Sibley, 1981; Bathurst, 1987), are found only occasionally.

Stylolites are widespread in the rock and sometimes hamper direct observation of the original spatial relationships between nodules and matrix. Nevertheless, the matrix often appears to fill firm-ground burrows of about 1 cm in diameter, attributable to *Thalassinoides*, which typically deviate when they meet oncoids or stromatolitic domes: this shows that the sea bottom consisted of hard objects surrounded by a firm matrix. More regular shapes are seen in layers mainly consisting of early diagenetic nodules, whose geometry appears to be determined, in negative, by the multi-phase bioturbation (Pl. 55/7).

The pseudonodular facies can be compared to the oncolitic-stromatolitic facies of Massari (1979, 1981). Sometimes, a certain organization is detectable in the vertical succession of stromatolitic structures within a given layer. Oncoids are sparse at the base, then stromatolitic domes are increasingly developed, and eventually, at the top of the bed, they merge and give rise to a continuous biolaminated horizon. This cyclicity, however, in the Altopiano di Asiago is less frequent and less developed than in other localities of the Venetian Prealps. Because of the variety in nature, abundance, and arrangement of nodules, the pseudonodular facies in fact varies widely in aspect from one layer, or one section, to the other. The two extremes are at one hand massive, nearly matrix-free, layers composed of early diagenetic nodules, intraclasts and/or oncoids, and at the other layers where nodules are scattered within the matrix giving rise to intraformational paraconglomerates (cf. Kennedy & Garrison, 1975. Pl. 55/2). In the latter repeated phases of bioturbation are documented by heterogeneous colours and textures of the matrix.

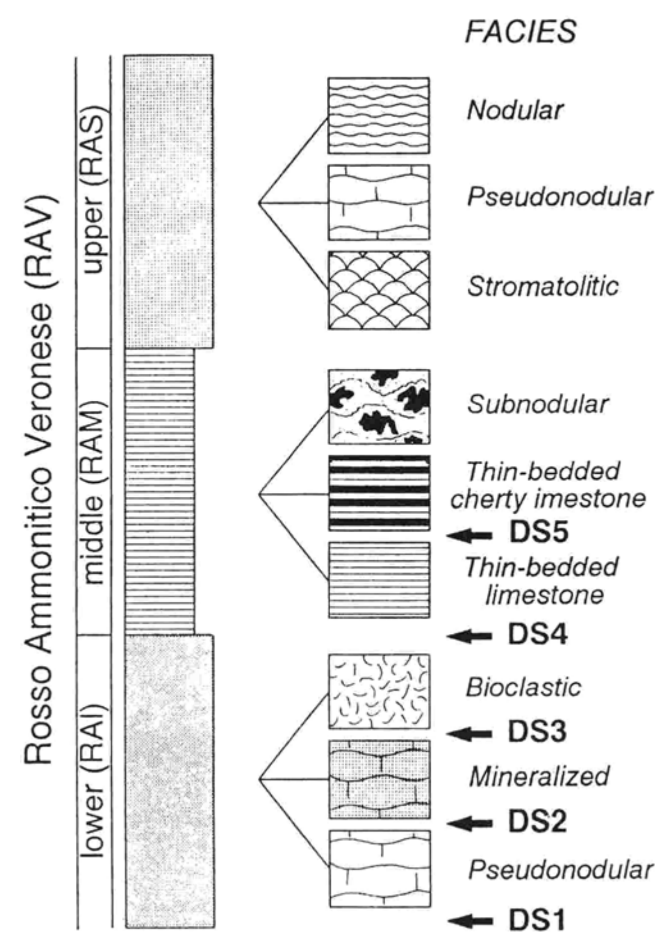


Fig. 2. Subdivision of the RAV in three units: lower (RAI), middle (RAM), and upper (RAS) units. The most frequent and typical facies are reported for each unit, and the position of the sedimentary discontinuities easily recognizable in outcrop is indicated (DS1-DS5). The thicknesses of the units are not to scale.

2.3 Mineralized facies

This facies is architecturally very similar to the pseudonodular facies. The main differences are the abundance of mineralized intraclasts and bioclasts, and the darker, brown colour due to a great amount of small, mineralized grains (Pl. 55/8). Stromatolitic structures, however, are uncommon and limited to sparse oncolitic coatings on intraclasts. Nodules hence are represented almost totally by intraclasts and early diagenetic nodules. Both of them consist of wackestone or packstone with the grains already described for the pseudonodular facies. The matrix too is less abundant, and consists of packstone filling *Thalassinoides* burrows. The intraclasts, up to 2 cm across, are always bored and coated by black crusts up to 1 mm thick. Under the microscope, these crusts show alternating Fe-Mn oxides and calcite laminae of stromatolitic aspect, referable to *Frutexites* (Szulczewski, 1968; Böhm & Brachert, 1993). Sometimes larger mineralized intraclasts are made up of small mineralized intraclast-bearing wackestones (polyphase intraclasts. Pl. 55/8). The mineralized facies is only found in the RAI, where it overlies the pseudonodular facies, and is clearly recognizable only in some sections; in all the measured sections, however, a marked increase in mineralized intraclasts is recognizable in the uppermost part of the pseudonodular facies.

2.4 Bioclastic facies

The distinctive features of this facies are the grain-supported texture (packstones to grainstones) and the dominance of bioclasts (bivalves, both thin-shelled and larger ones like e.g. *Inoceramus*, echinoderms, benthic and planktic foraminifers), other grains being essentially peloids. Two subfacies may be distinguished: a massive, and a bioturbated subfacies. The massive subfacies shows a speckled red and white colour, and an internal ill-defined lamination of stromatolitic aspect. The bioturbated subfacies is characterized by a dark red to brown colour given by a significant amount of mineralized grains, and by a dense network of perfectly recognizable Y- or T-shaped *Thalassinoides* burrows (Pl. 55/9), filled with mainly echinoderm-bearing, brown, packstones displaying fitted-fabrics. Often, the vertical shafts of such burrows, up to 2 centimetres in diameter, are incompletely filled with sediment and a clear, blocky calcite cement occludes the former cavity (Pl. 56/1). Actually, minor textural and colour differences are present, showing that previous burrow systems have been crosscut by the last generation of burrows. Burrow fills are the only parts of the rock showing compactional fabrics; the rest of the bioclastic facies is rather rich in cement, mainly syntaxial overgrowth on echinoderms and bivalve shells. Ammonite moulds are quite frequent in the bioclastic facies. They are always incompletely filled with sediment, but, in spite of this, no flattening has taken place, and the former void is occluded by a coarse blocky spar.

The bioclastic facies is typical of the upper part of the RAI. One section (Casa Silvagno) is exceptional as it includes, in the middle part of the RAS, a 2 m interval with the same features described for the bioturbated subfacies. In this case, however, the skeletal grains are almost totally represented by sand-sized fragments of *Saccocoma*.

In spite of the lithological similarity, the coquinoid sparry limestones of the Lumachella a *Posidonia alpina* are not included in the RAV and hence in this facies. They pertain, in fact, to a previous and different depositional phase whose interpretation is still debated (Sturani, 1971; Winterer & Bosellini, 1981; Winterer et al., 1991; Martire, 1992 a; Zempolich, 1993).

2.5 Nodular facies

This facies is characterized by a marked nodular aspect in outcrop due to the differential weathering of the pink calcareous nodules and of the brick-red, clay-rich matrix (Pl. 56/2). Intraclasts, oncoids and stromatolitic domes are almost absent, and nodules are represented exclusively by early diagenetic nodules, which show ellipsoidal shapes and transitional boundaries with the matrix (Pl. 56/3). The nodular facies is typical of the RAS, but, in some sections, it occurs also in the uppermost part of the RAI. In both the units, nodules consist of uncompacted, grainstones and packstones. Thin-shelled bivalves, dominating in the RAI, are replaced by *Saccocoma* in the RAS. Both skeletal grains show syntaxial overgrowths of calcite cement. Benthic and rare planktic foraminifers, peloids, and micritic moulds of radiolarians are also present in the nodules. The matrix is made up of clay-rich, densely packed packstones crossed by undulose dissolution seams. Grains are flattened, welded along sutured contacts giving rise to a fitted fabric (Pl. 56/4. Clari & Martire, 1996), and arranged parallel to the nodule surface. Ammonite moulds are present, or even abundant in some layers, but they are never fragmented, abraded or iron-coated as in the

Plate 55 — Middle-Upper Jurassic Rosso Ammonitico Veronese: facies and microfacies (Altopiano di Asiago, NE Italy)

Fig. 1. Active quarry front where most of the RAV is exposed. Note the massive aspect of the RAI, and the well bedded, mainly cherty, limestones of the RAM. Arrows mark the boundaries between the RAI, RAM, and RAS. Quarry front is approximately 17 m high. Voltascura section.

Fig. 2. Pseudonodular facies. Sharp contrast in nature and organization of nodules between two beds. The upper part of the sample mainly consists of early diagenetic nodules and mineralized intraclasts, whereas in the lower part the matrix is abundant and oncolites are present (arrow). RAI, Castelletto section. Polished slab, scale bar = 2 cm.

Fig. 3. Pseudonodular facies. Intraclast with a heavily bored and mineralized periphery. The encrustation shows alternating calcite and Fe-Mn oxide laminae strongly resembling *Frutexites* stromatolites. RAI, Kaberlaba section. Thin section, scale bar = 1 mm.

Fig. 4. Pseudonodular facies. Oncoidal laminae overgrowing a not mineralized intraclast. Laminae are convex, ill defined, and evidenced by textural variations. RAI, Rabeschini section. Thin section, scale bar = 1 mm.

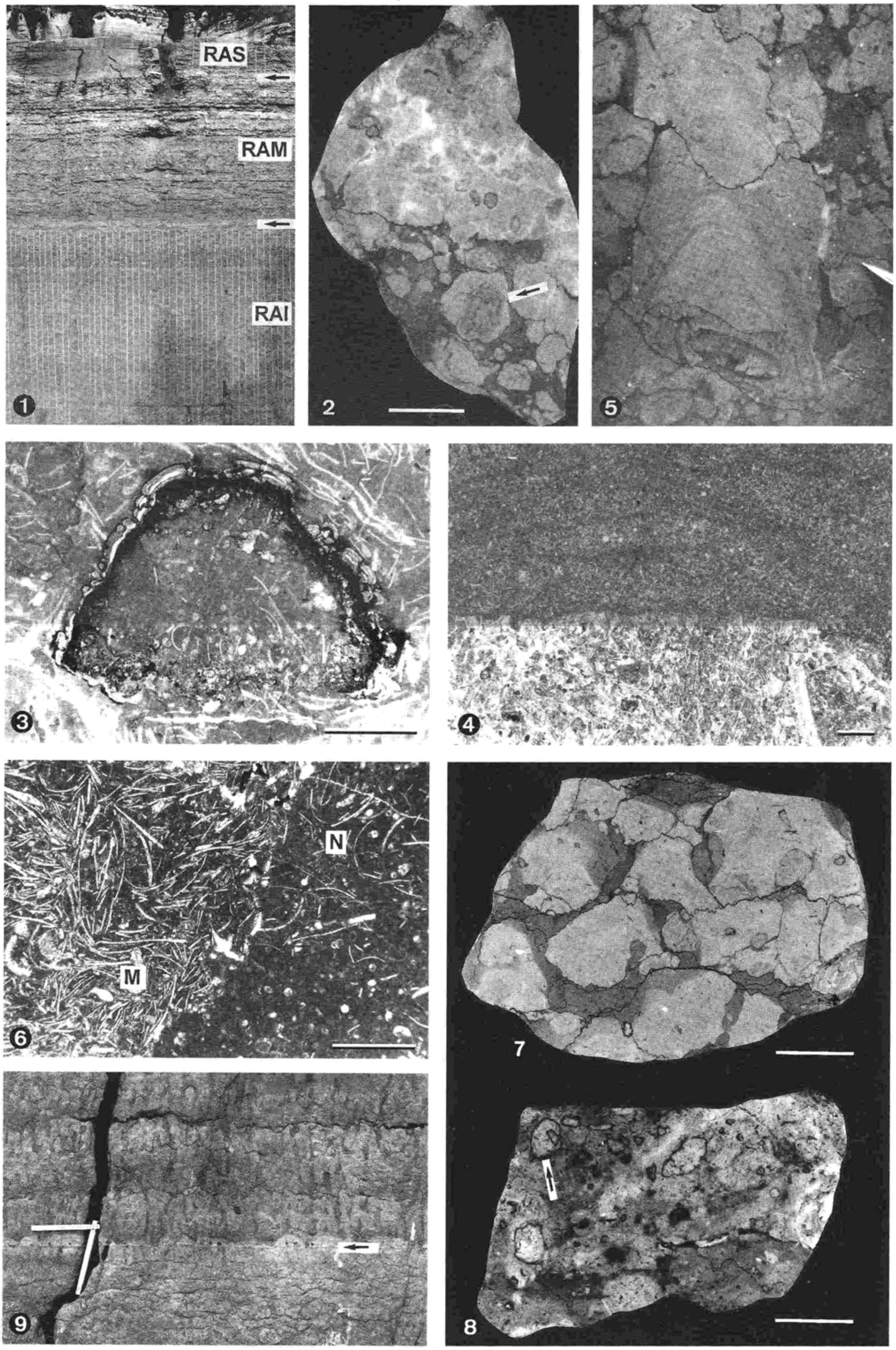
Fig. 5. Pseudonodular facies. Stromatolitic domes overlie an ammonite mould and a oncolite. Note the deep stylolitic indentation between the two complex nodules. RAI, Rabeschini section. Tip of pencil as a scale.

Fig. 6. Pseudonodular facies. Sharp textural and compositional contrast between an early diagenetic nodule (N), consisting of wackestone with thin shelled bivalves, radiolarians, and *Protoglobigerina*, embedded in a matrix (M) of packstone with bivalves and echinoderms. In the central part of the matrix, a burrow disrupts the orientation of shells, normally parallel to bedding. RAI, Bertiaga section. Thin section, scale bar = 1 mm.

Fig. 7. Pseudonodular facies. Most of the nodules are early diagenetic nodules (light coloured parts) containing scattered intraclasts. The shape of the nodules is due to "negative sculpturing" of an originally homogeneous layer by burrowers. The different colour of the burrow-filling matrix denotes subsequent phases of bioturbation. RAI, Montagnola section. Polished slab, scale bar = 2 cm.

Fig. 8. Mineralized facies. The abundance of mineralized intraclasts and bioclasts gives a dark colour to the rock. Note the presence of polyphase intraclasts (arrow). RAI, Giacominarloch section. Polished slab, scale bar = 2 cm.

Fig. 9. Bioclastic facies. The dense network of large *Thalassinoides* burrows is clearly evident on weathered surfaces. Not the sharp, flat, basal boundary of the bioclastic facies (arrow. cf. Pl.57/5). RAI, Voltascura section.


RAS
RAM
RAI
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pseudonodular facies, which means that they are not reelaborated (FERNANDEZ LOPEZ, 1984; GOMEZ & FERNANDEZ LOPEZ, 1994). Bed thickness is of the order of some decimetres; the layers are distinct from each other by their nodule/matrix ratio. A flaser-nodular subfacies is distinguished when nodules "float" in an abundant matrix (GARRISON & KENNEDY, 1977. Pl. 56/5).

2.6 Thin-bedded limestone facies

This facies, exclusively found in the RAM, is clearly identified by the absence of any nodular structure and for the regular, thin bedding (Pl. 56/6). Layers, between 3 and 20 centimetres thick, may consist of one of three different lithologies: a) The most abundant beds are pink to red wackestones with thin-shelled bivalves, echinoderms, calcite-filled radiolarians, benthic foraminifers (*Lenticulina*, *Spirillina*), *Globochaete* and peloids. Bivalves are flattened, and, together with echinoderm plates, oriented parallel to bedding. Locally, grain-poor and grain-rich mm-sized laminae occur, which are occasionally disrupted by small sediment-feeder burrows (*Chondrites*); b) Dark red to brownish packstones to grainstones consist almost exclusively of thin-shelled bivalves. These skeletal grains are very closely packed in a fitted fabric; undulose, clay-rich, dissolution seams are also present; c) White to pink mudstones show sparse calcite-filled radiolarian moulds. Centimetre-sized laminae, characterized by slight textural variations, are often obliterated by the activity of sediment-feeders documented by small dark burrows referable to *Chondrites*. Larger burrows, sometimes with geopetal fillings, are occasionally observed and document firmground conditions. Compactional fabrics (deformation of radiolarians, dissolution seams) are absent. This lithology makes up a single, but very distinctive, layer in the RAM (Pl. 56/6). On the weathered bedding planes of the thin-bedded limestone facies aptychi, rhyncolites, belemnites, single corals, crinoid stalks, and flattened, whole or fragmented, *Inoceramus* valves are commonly found.

2.7 Thin-bedded cherty limestone facies

This typical facies of the RAM is characterized by dark red chert layers and nodules (Pl. 56/7). Bedding style and abundance of cherts vary vertically. In the lower part, chert prevails over limestone; the lenses may be quite extensive (several decimetres wide, and up to 20 cm thick), and give rise to pinch-and-swell structures. Higher up in the succession, chert layers are thinner, bedding planes are plane parallel, and limestone and chert layers are more or less equally abundant (Pl. 56/7). Limestones are wackestones to packstones with radiolarians and sponge spicules, peloids, echinoderms, and benthic foraminifers; thin-shelled bivalves are subordinate. Clay-rich dissolution seams are very closely spaced in the limestones (Pl. 56/8). Cherts are composed of microquartz, however radiolarians and spicule ghosts are still recognizable. They are preserved as calcite-filled moulds in the limestones, and as calcedony- or microquartz-filled moulds in the cherts and in the partly silicified limestone rimming chert nodules. As in the thin-bedded limestone facies, *Chondrites* burrows are ubiquitous and lamination is only occasionally recognizable.

Plate 56 — Middle-Upper Jurassic Rosso Ammonitico Veronese: facies and microfacies (Altopiano di Asiago, NE Italy)

Fig. 1. Bioclastic facies. Geopetal filling of a large vertical *Thalassinoides* burrow, with clear sparry calcite at the top (arrow). RAI, Voltascura section. Polished slab, scale bar = 2 cm.

Fig. 2. Nodular facies. This typical outcrop aspect of the nodular facies is due to the differential weathering of calcareous nodules and marly matrix. RAS, Malga Slapeur section.

Fig. 3. Nodular facies. Subspherical nodules laterally grade into the darker matrix; vertical boundaries instead are sharper and tipically stylolites, at nodule-nodule contacts, or bundles of dissolution seams, along nodule-matrix contacts. RAI, Bertiaga section. Polished slab, scale bar = 2 cm.

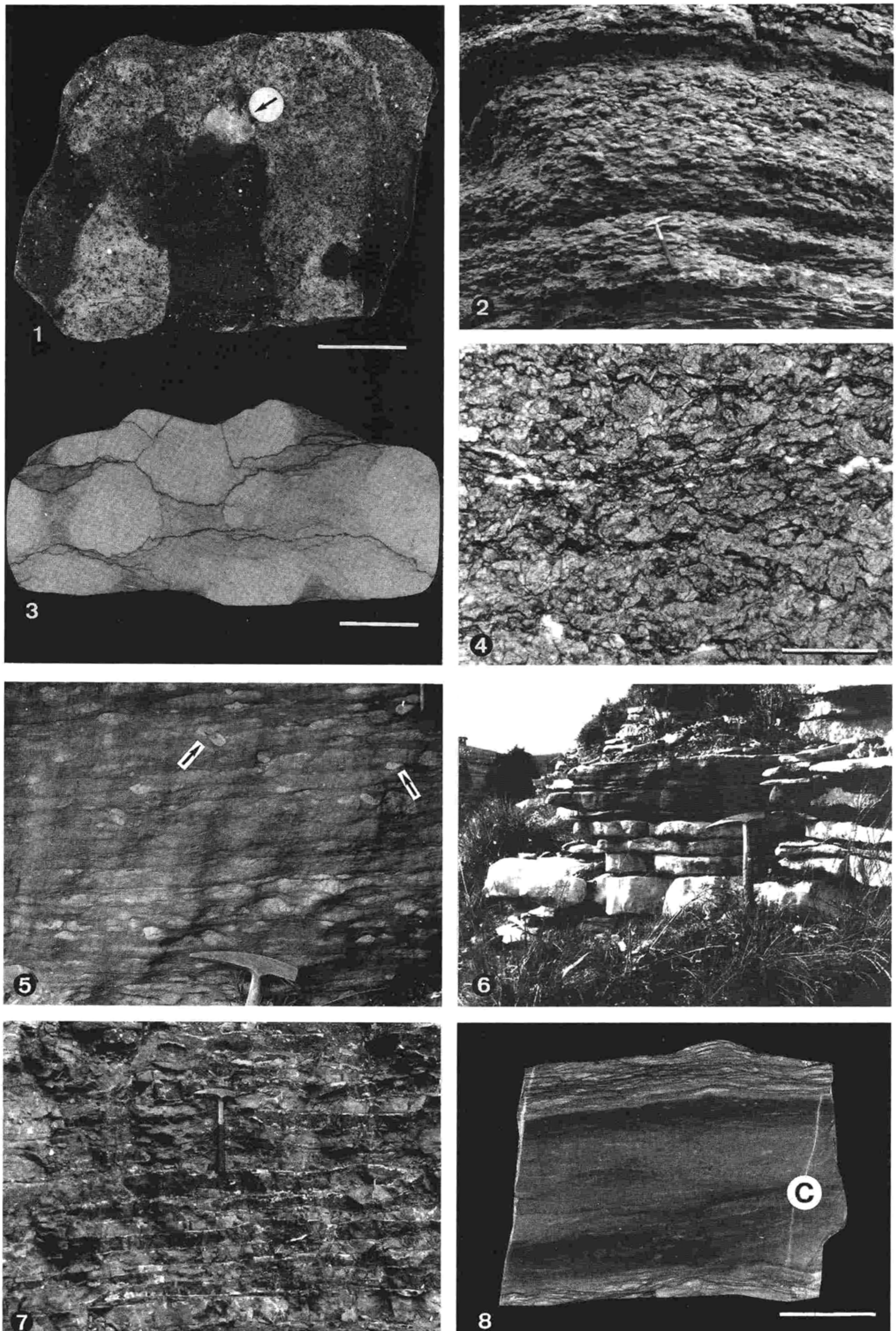
Fig. 4. Nodular facies. Fitted fabric in a *Saccocoma* packstone making up the inter-nodule matrix. RAS, Mazze section. Thin section, scale bar = 0.5 mm.

Fig. 5. Nodular facies. In this flaser nodular subfacies, nodules float in a matrix that is strongly affected by intergranular pressure-dissolution. Note that some nodules are ammonite moulds (arrows). RAS, Mazze section.

Fig. 6. Thin-bedded limestone facies. Bedding is thin and regular, and nodules are absent. The hammer handle leans against a white mudstone bed; the overlying beds consist of bivalve wackestones and packstones. RAM, Mazze section.

Fig. 7. Thin-bedded cherty limestone facies. Chert layers (darker coloured) are evenly bedded and regularly alternated with limestone layers. RAM, Voltascura section.

Fig. 8. Thin-bedded cherty limestone facies. Closely spaced, clay-rich dissolution seams are present in the calcareous parts of a bed of cherty limestone; the central, silicified, lens (C) does not show any compactional fabric, and small lighter coloured burrows (*Chondrites*) are recognizable. RAM, Mazze section. Polished slab, scale bar = 2 cm.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Larger burrows (more than 1 cm in diameter) are referable to *Planolites*. They are strongly flattened in the limestones but retain the original cylindrical shape in the silicified sediment. Ellipsoidal oblate calcareous concretions (Clari et al., 1991), and some cm-thick red bentonite layers also occur (Bernoulli & Peters, 1970, 1974).

2.8 Subnodular facies

This facies owes its name to the highly undulose dissolution seams which give the rock a vaguely nodular aspect (Pl. 57/1).Other distinctive features are the white to light pink colour, a grain-supported texture, the presence of highly irregular red chert nodules, and the peculiar nature of grains, mainly represented by micritic radiolarian internal moulds (Pl. 57/2). They are distinguished from peloids by their perfectly spherical shape, and the common geopetal fillings. Echinoderm fragments, benthic foraminifers and rare planktic foraminifers are also present. The dominant texture is a rather loosely packed grainstone, with limpid, sparry calcite filling the pores. In the parts of rock crossed by the dissolution seams, echinoderm packstones are present. In the grainstone portions, textural inhomogeneities and large cement patches document intense bioturbation, but no distinct burrow has been identified. The subnodular facies is typical of the upper part of the RAM. In contrast to the other two facies occurring in the RAM, thin-bedded limestone and the thin-bedded cherty limestone facies, rare and poorly preserved ammonite moulds are present in some sections. Some red bentonite layers are present and may reach 20 cm in thickness.

2.9 Stromatolitic facies

Rocks have been attributed to this facies when massive layers show the subtle biolaminations already described for the oncoids and stromatolitic domes of the pseudonodular facies. Thin layers, around 10 cm thick, showing distinct undulated tops and laminae, and forming laterally linked domes (Logan et al., 1964), are frequent in the RAI alternating with pseudonodular facies. Thicker beds (up to 50 cm) characterize the lower part of the RAS in some sections (Pl. 57/3). They consist of wackestones to packstones with abundant *Protoglobigerina*, frequently recognizable

Plate 57 Middle-Upper Jurassic Rosso Ammonitico Veronese: facies, microfacies and discontinuities (Altopiano di Asiago, NE Italy)

Fig. 1. Subnodular facies. Undulose dissolution seams, irregular chert nodules, and white colour of the limestone are typical features of this facies in outcrop. RAM, Kaberlaba section.

Fig. 2. Subnodular facies. Micritic radiolarian moulds are the most abundant grains in these grainstones. Note the loose packing, and the clear, sparry calcite cement filling the intergranular voids and some radiolarian moulds. RAM, Kaberlaba section. Thin section, scale bar = 1 mm.

Fig. 3. Stromatolitic facies. Fe oxides highlight the uncommonly well developed stromatolite domes. Note the concentration of iron-coated reworked ammonite moulds (arrow) and large polymetallic nodules between the domes. RAS, Castelletto section. Polished slab, scale bar = 2 cm.

Fig. 4. Stromatolitic facies. Gastropods and *Protoglobigerina* are by far the most abundant skeletal grains in the wackestones of the stromatolitic facies. The dark colour of the chamber fillings is a proof of the reworked nature of some fossils. RAS, Castelletto section. Thin section, scale bar = 1 mm.

Fig. 5. Discontinuity surface (DS3, arrow) between the mineralized (M) and the bioclastic (B) facies. The surface is flat and overlain by a continuous horizon of LLH stromatolite domes. RAI, Voltascura section. Pencil as a scale.

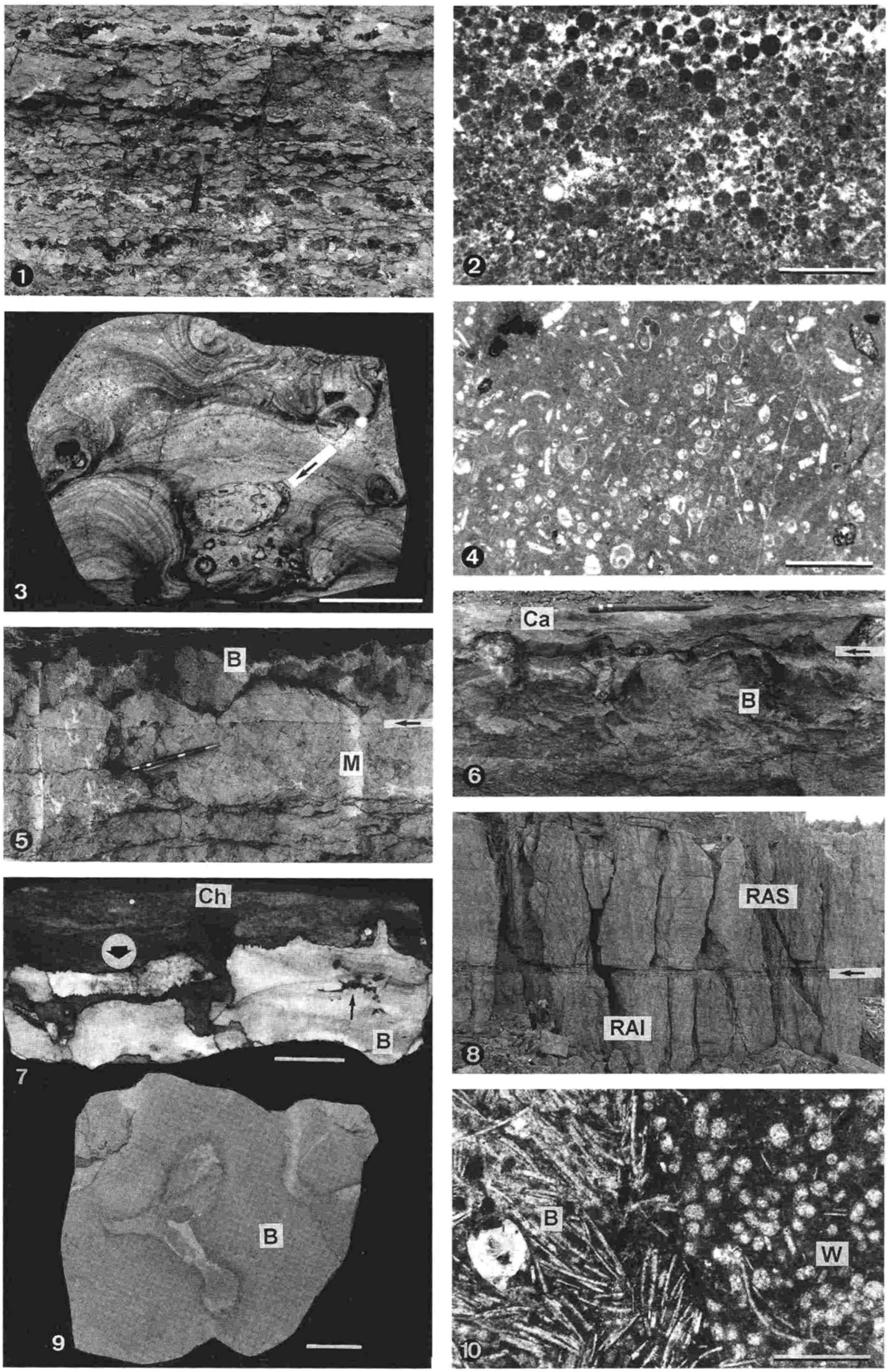
Fig. 6. Discontinuity surface (DS4, arrow) between the bioclastic (B) and the thin-bedded limestone facies (Ca). The surface is knobby and encrusted by black Fe-Mn oxides. RAI/RAM boundary, Monte Baldo section. Pencil as a scale.

Fig. 7. Complex discontinuity surface (DS5) between the bioclastic (B) and the thin-bedded cherty limestone facies (Ch). The surface is very irregular, bored (small arrow), and overlain by bored and mineralized clasts of white mudstone of the thin-bedded limestone facies (large arrow). RAI/RAM boundary, Voltascura section. Polished slab, scale bar = 2 cm.

Fig. 8. Echar section. The RAM (arrow) is very thin and chert-free. The RAS is as massive as the RAI, consisting of pseudonodular and stromatolitic facies. Two persons in the bottom left as a scale.

Fig. 9. Complex discontinuity surface at the RAI/RAM boundary. Firm-ground burrows, excavated in the bioclastic facies (B), have reddened walls and are filled with different generations of internal sediments, separated by reddened surfaces: the burrow system stayed open and mineralized during a long time interval, before being filled.Cima Tre Pezzi section. Polished slab, scale bar = 2 cm.

Fig. 10. Complex discontinuity surface at the RAI/RAM boundary. Close-up of Fig. 9 showing the contact between bivalve packstones of the bioclastic host rock (B) and radiolarian wackestone filling the burrow (W). Cima Tre Pezzi section. Thin section, scale bar = 1 mm.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from their Fe-stained micrite fillings, calcite-filled radiolarian moulds, small gastropods, thin-shelled bivalves and fragmentary larger skeletal grains like rhyncolites, aptychi, echinoderms, and ammonite shells (Pl. 57/4). Locally *Schizosphaerella* is very abundant. Intraclasts may be abundant and as large as 2 cm. Both intraclasts and large bioclasts are often bored and Fe-coated (Pl. 57/3). Biolamination in the RAS is not as well defined as in the RAI; laminae are usually thicker and plane parallel, and domes are only occasionally found. Ammonite moulds, also of large size (up to 30 cm), are frequent and well preserved in the stromatolitic facies, although they are often sharply truncated above.

2.10 Discontinuity surfaces

Several discontinuity surfaces (DS) have been distinguished in the RAV of the Altopiano di Asiago (Fig. 2). The most relevant from a sedimentological point of view are described and discussed below. For terminology and identification criteria the reader is referred to Clari et al. (1995).

DS1 - The most prominent discontinuity is at the base of the RAV, where it directly overlies the yellow, Domerian, lagoonal facies of the Calcari Grigi (Fig. 1). This discontinuity corresponds to a hiatus of 20 m.y. The surface is very sharp, perfectly flat over long distances, and only locally characterized by borings or Fe-Mn oxide crusts. The first layer of the RAV occasionally consists of a sort of conglomerate of heavily mineralized lithoclasts of platform limestones and of *Frutexites*-type stromatolites.

DS2 - Separates the pseudonodular (below) from the mineralized facies (above) in the RAI. It appears as a flat, erosional, surface, and is evidenced by Fe-Mn coatings (Monte Baldo) or by an overlying continuous stromatolite horizon (Zovetto). This DS is not clearly recognizable everywhere.

DS3 - The lower boundary of the bioclastic facies, overlying either the mineralized or directly the pseudonodular facies, is always very sharp. It may be evidenced by black, Fe-Mn-oxide crusts and/or by a continuous stromatolite horizon (Pl. 57/5). The erosional nature of this DS is, in some places, further proved by presence of dm-sized lithoclasts of the underlying rocks at the base of the bioclastic bed.

Plate 58 — Middle-Upper Jurassic Rosso Ammonitico Veronese: neptunian dykes (Altopiano di Asiago, NE Italy)

Figs. 1, 4. Horizontal dykes at the top of the RAI in the Giacominarloch (Fig.1) and Buso (Fig.4) sections. Note the sharp boundaries with the enclosing rocks, and the laminated fills with both plane parallel and oblique laminae.

Fig. 2. Microscopic view of the Giacominarloch dyke fill (Fig.1). Grain-rich and grain-free laminae alternate; they show different thicknesses, and drape a mineralized high in the host rock of the mineralized facies (arrow). Disruption of one lamina in the upper part is probably due to bioturbation. Thin section, scale bar = 4 mm.

Fig. 3. Close up of top left part of Fig.2. Laminae are made up of mudstones or of thin-shelled bivalve wackestones or packstones, supporting the hypothesis of fluctuations in bottom current energy. Thin section, scale bar = 2 mm.

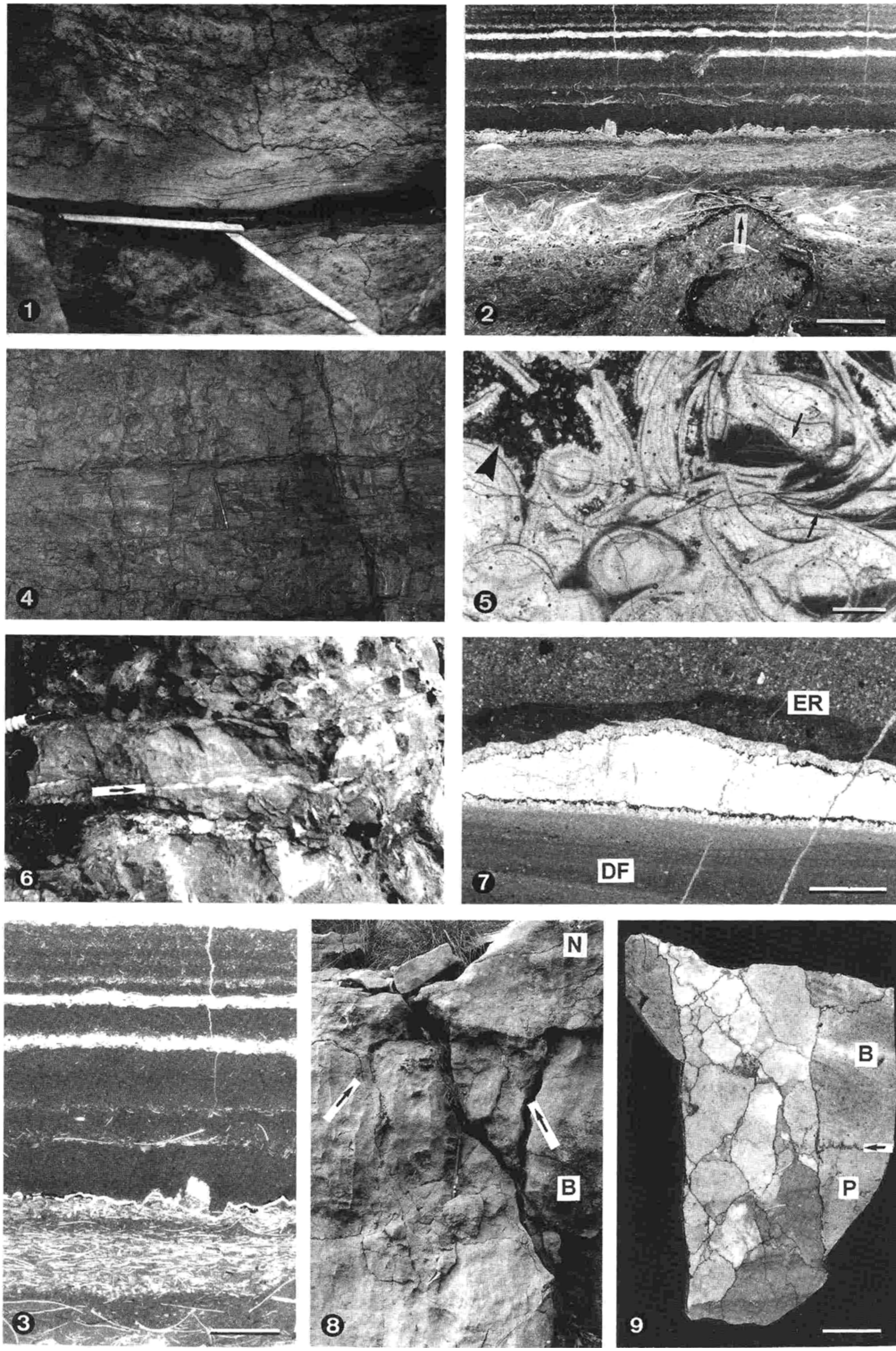
Fig. 5. Microscopic view of the Buso dyke fill (Fig.4). Bivalve shells are chaotically orientated. Two generations of cement are recognizable: isopachous fringes on shells, and a pore-filling blocky spar. Two generations of internal sediments are present as well: the first overlies shells directly (small arrows); the second overlies early cement fringes and is partially dolomitized (large arrow). This polyphase filling of the fissures, by alternating sediment infiltration and cement precipitation, demonstrate good communication with the sea floor, and hydrodynamic fluctuations. Thin section, scale bar = 1 mm.

Fig. 6. Horizontal cavity within the stromatolitic facies at the top of the RAI in the Castelletto section. Stromatactis-like cavities are recognizable by the white colour of the calcite fill (arrow). Note the concentration of black polymetallic nodules at the base of the first stromatolitic layer of the RAS. Tip of pencil as a scale.

Fig. 7. Microscopic view of the small cavity of Fig. 6. The cavity fill consists of laminated micrite sediment (DF), an isopachous cement rimming the walls of the cavity (ER= encasing rock), and a pore-filling blocky spar. The early cement fringe is encrusted by black Fe oxides. Thin section, scale bar = 2 mm.

Fig. 8. Vertical neptunian dykes at Bertiaga. The dykes (arrows) are subvertical in the bioclastic facies (B) and acquire an open funnel shape within the nodular facies (N) that shows a brecciated aspect (cf. Pl. 59/3). Pencil as a scale.

Fig. 9. Vertical neptunian dyke at Bertiaga. The dyke crosses the boundary (arrow) between the bioclastic (B) and the pseudonodular facies (P), and is filled by a clast-supported breccia. Polished slab, scale bar = 2 cm.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DS4 - The upper boundary of the RAI is clearly recognizable because of the great contrast in facies and bedding style with the RAM. In some sections (Voltascura, Monte Baldo), moreover, the top of the bioclastic facies corresponds to a knobby surface encrusted with thick Fe-Mn oxides (Pl. 57/6).

DS5 - The thin-bedded limestone and the thin-bedded cherty limestone facies are separated by a clear-cut, flat surface which usually lacks clear proof of a hiatus. In some places, however, the thin-bedded cherty limestone facies lies directly above the bioclastic facies (Voltascura). In this case the surface is coated with Fe-Mn oxides and floored by bored, iron stained, cm-sized lithoclasts of the white, radiolarian-bearing, mudstones of the thin-bedded limestone facies (Pl. 57/7). In other instances, discontinuities are observable within the thin-bedded limestone facies at the top of the mudstone bed. They may be mineralized hard grounds (Casa Silvagno) or simply omission surfaces documented by geopetally-filled, firm-ground burrows (Kaberlaba).

Other discontinuities are present within the pseudonodular facies of the RAI (flat surfaces with overlying thin, continuous, stromatolite layers), and in the stromatolitic facies in the RAS (flat, bored, and iron stained surfaces). In addition to these discontinuity surfaces with sedimentologic evidence, biostratigraphy highlights other gaps (DS6 and DS7), between the RAM and the RAS, with no apparent lithologic evidence, which will be discussed in a later section.

2.11 Sedimentology and diagenesis of the RAV: discussion

The main factors which appear to have affected deposition and the very early diagenesis (within a few decimetres of burial) of the RAV limestones, are:

a) bottom currents: evidence of current activity during deposition of the whole RAV are: parallel laminae, sometimes preserved in spite of the intense bioturbation; intraclasts and planed off surfaces, which imply erosion of the substrate; Fe-Mn mineralization (Drittenbass, 1979) due to prolonged sediment bypassing; frequency of mud-poor, or even mud-free, winnowed textures.

b) bioturbation: a variety of trace fossils has been recognized. Mottled textures, *Chondrites*, and *Planolites* belong to a first generation of bioturbation, within the soft sediments; larger burrows like *Thalassinoides* record colonization of a firm-ground; finally borings are developed on completely lithified substrates (Bromley, 1975).

c) early cementation: direct evidence of early cement is observable only in grainstones. Indirect evidence, however, is widespread also in mud-supported beds: it results from the presence of bored intraclasts, and from the juxtaposition of compacted and uncompacted, i.e. early cemented, textures.

Variable interplays among these three main factors result in the preservation of lithologically different beds. Two basic points are worth noticing: a) direct precipitation of marine cements requires huge volumes of water to be

Plate 59 Middle-Upper Jurassic Rosso Ammonitico Veronese: neptunian dykes, slides, and seismites (Altopiano di Asiago, NE Italy)

Fig. 1. Thin sill filled of mud-supported breccia within the subnodular facies. Bertiaga section, top of RAM. Pencil as a scale.

Fig. 2. Polished slab of the sill of Fig.1. The clasts consist of the same white radiolarian mould grainstone as the encasing rock; the red matrix is an echinoderm-bearing wackestone crossed by dissolution seams. Polished slab, scale bar = 2 cm.

Fig. 3. Vertical neptunian dyke at Bertiaga. Breccia with stylolite-bound fragments, from the larger dyke in Pl. 58/8, crossing the thin-bedded limestones. Polished slab, scale bar = 2 cm.

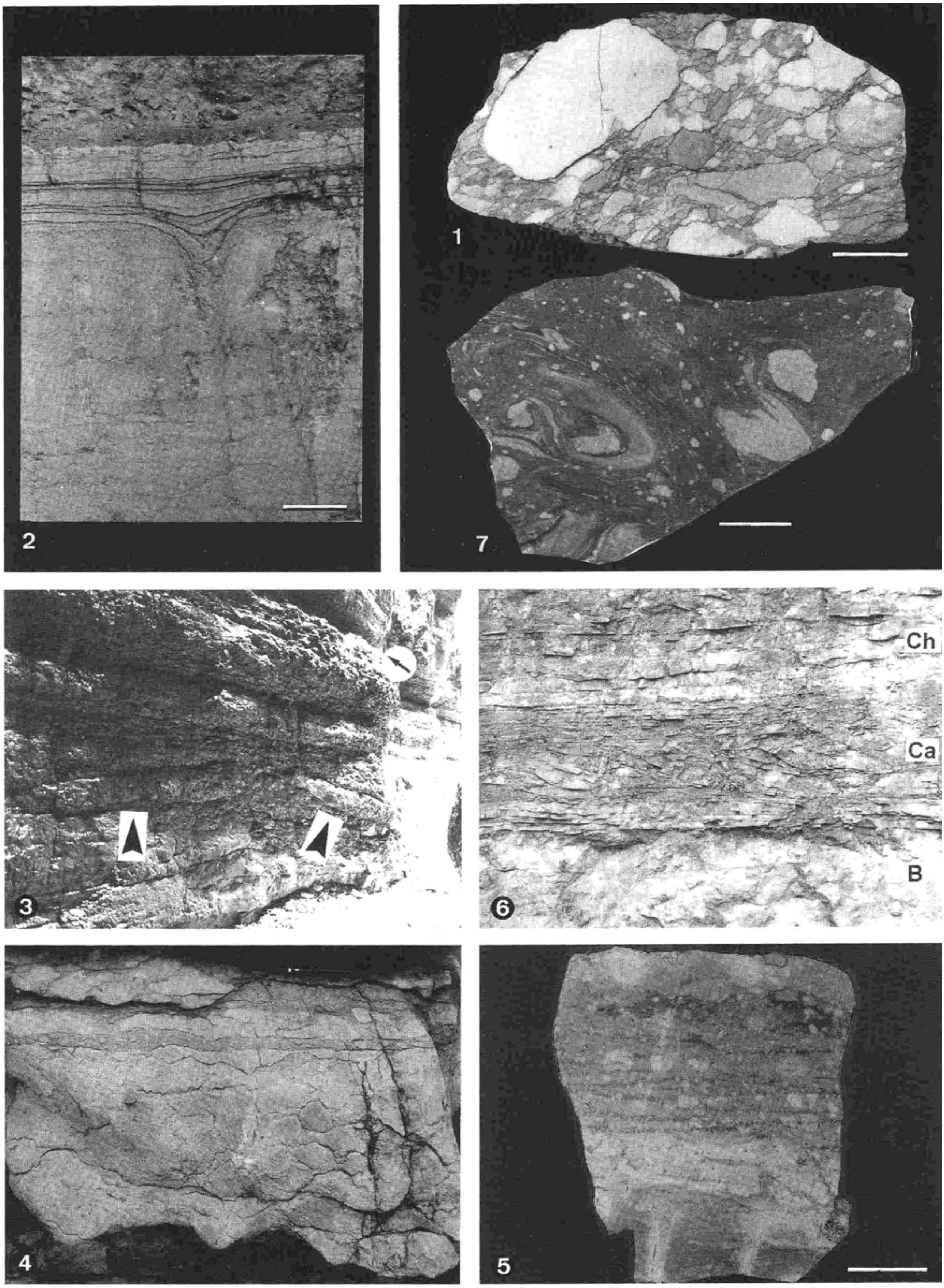
Fig. 4. Vertical neptunian dyke in the Echar section. The beds of the thin-bedded limestone facies were still plastic when the fissure opened, and collapsed within it. Scale bar = 50 cm.

Fig. 5. Seismite in the thin-bedded limestone facies. Progressively higher degree of disruption is recognizable from bottom to top: the base is almost undisturbed, the middle part shows some subvertical cracks, and the upper half consists of a mud-supported breccia. Kaberlaba section. Scale bar = 2 cm.

Fig. 6. Metre-sized glide blocks of pseudonodular facies (large arrows) are chaotically embedded within the RAI. The small arrow indicates the boundary between the RAI and the RAS. Buso section. Hammer on top of the glide as a scale.

Fig. 7. Slump within the thin-bedded limestone facies (Ca) at the base of the RAM in the Zovetto section.(B = bioclastic facies; Ch = thin-bedded cherty limestone facies). The slumped beds are approximately 1 m thick.

Fig. 8. Slump breccia from the thin-bedded limestone facies overlying the horizontal dyke of Pl. 58/1 in the Giacominarloch section. Note the high degree of disruption of former beds into small clasts, the plastic deformation of the larger clasts, and the fluidal aspect of the matrix. Polished slab, scale bar = 2 cm.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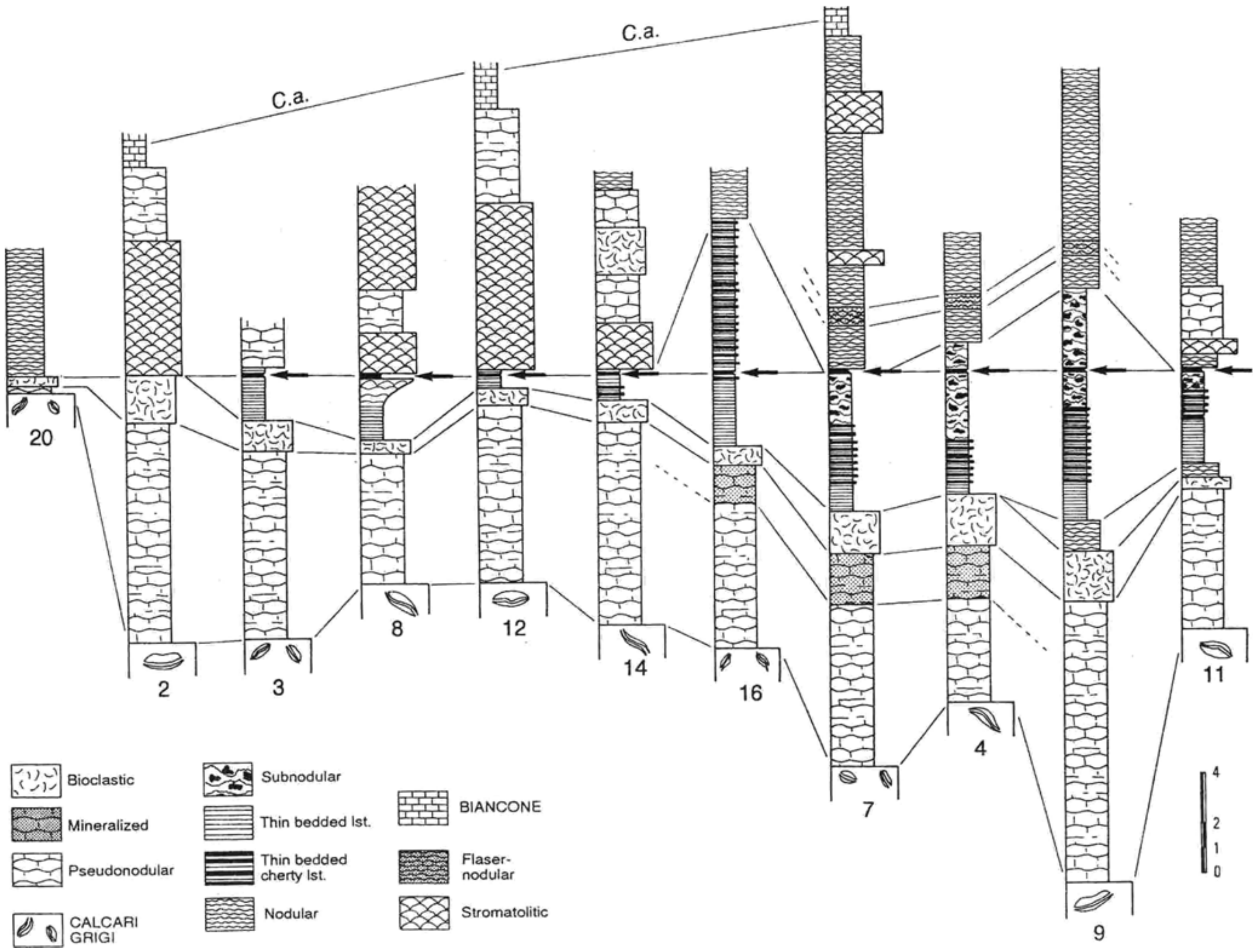

Fig. 3. Detailed stratigraphic columns of some selected sections. Numbers refer to Fig. 4, where the geographic location is shown. The arrows point to the reference bentonite layer. *C.a.* refers to the explosion of *Calpionella alpina.*

pumped through the pores of the sediment (e.g. DUNHAM, 1969); b) the RAV was deposited at very low sedimentation rates (about 3 mm/ka even after decompaction and taking into account hiatusses, MARTIRE & CLARI, 1994), so that sediments remained near the sediment/water interface for long periods of time. On the basis of these premises, the following comparative, and very simplified, interpretation is suggested for the eight facies recognized in the RAV of the Altopiano di Asiago. When the current regime was high, grain-supported sediments were deposited and heavily cemented just after deposition (bioclastic facies). Lower current regimes caused less effective winnowing and a more selective cementation, probably restricted to the more porous burrow fills (nodular facies). Pulsating currents, instead, allowed micrite accumulation followed by long and repeated phases of cementation, bioturbation, and current reworking (pseudonodular facies). Together with inorganic cement precipitation, organic activity could contribute significantly to trap and lithify sediments (oncoids, stromatolitic domes). In some instances, the importance of microbial colonies was absolutely dominant, and massive biolaminated layers resulted (stromatolitic facies): apparently, the presence of a continuous, hard substrate was a prerequisite for their formation. The mineralized facies formed when currents had a strong erosional power affecting semilithified sediments, and accumulation episodes were alternating with long breaks in sedimentation: boring and mineralization was intense, and polyphase intraclasts were generated. Considerably lower hydrodynamic levels permitted deposition of evenly bedded, mud-supported sediments; absence of cementation, and hence of firmground burrowing, hindered formation of any kind of nodular structure. The richness of radiolarians and sponge spicules determined development of cherts (thin-bedded cherty limestone facies); otherwise, the thin-bedded limestone facies resulted from such depositional conditions. Reworking of radiolarian-rich sediments, instead, led to deposition of washed sands with radiolarian micrite moulds, which were early cemented during a prolonged break in sedimentation (subnodular facies). In pelagic sediments like these, discontinuities, of course, reflect the highest hydrodynamic levels, that inhibited sediment accumulation for long periods of time thereby causing cementation of the bottom, Fe-Mn oxides encrustations, and erosion. The final aspect of the rock is related to burial history, and in particular to compactional processes. These processes

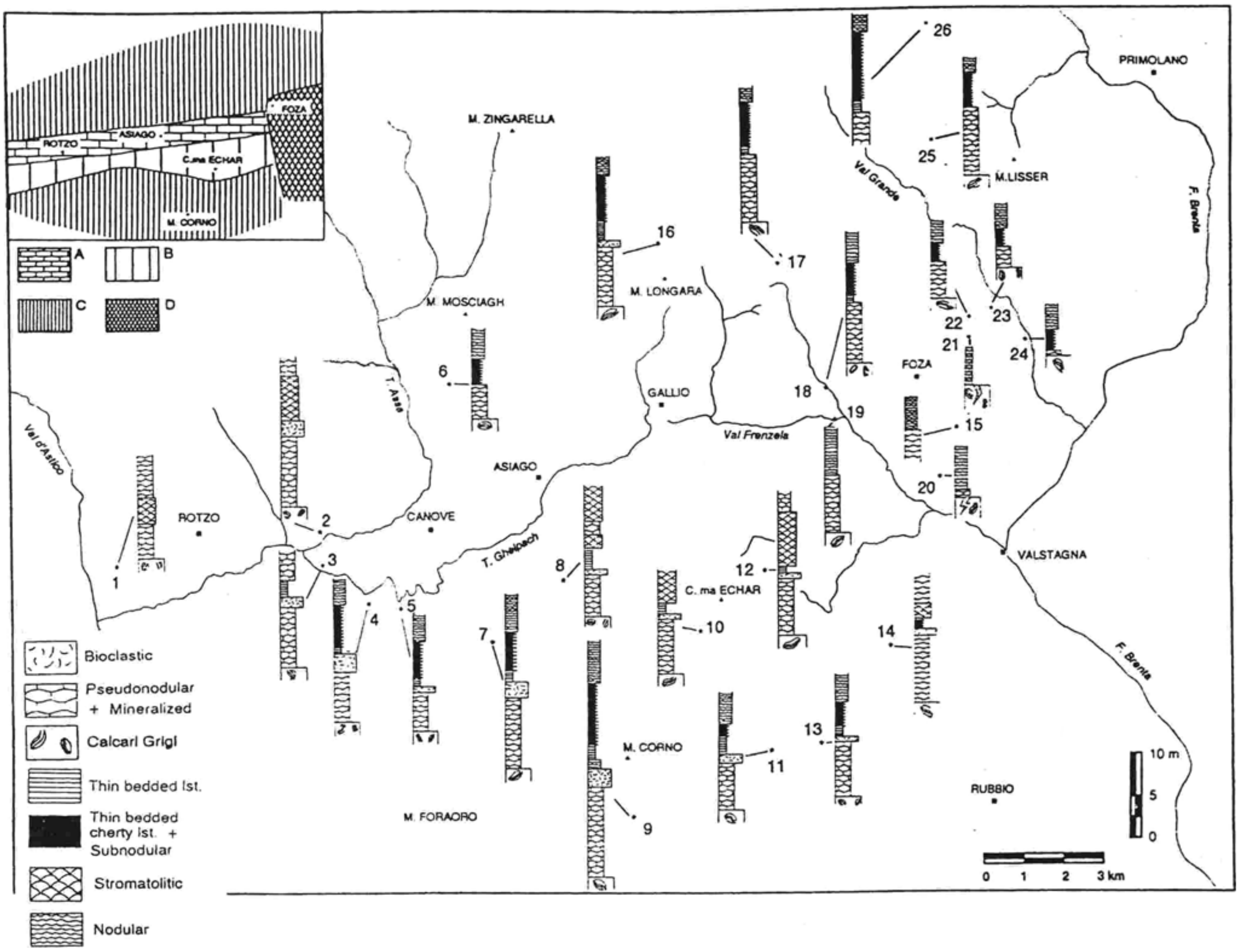

Fig. 4. Geographic locations and simplified stratigraphies of all the 25 measured sections. Mineralized and pseudonodular facies are shown together, as well as the thin-bedded cherty limestone and the subnodular facies. 1: Castelletto; 2: Rabeschini; 3: Cima Tre Pezzi; 4: Voltascura; 5: Giacominarloch; 6: Monte Interrotto; 7: Kaberlaba; 8: S.Sisto; 9: Mazze; 10: Monte Nasa; 11: Bertiaga; 12: Echar; 13: Montagnola; 14: Casa Silvagno; 15: Trolli; 16: Monte Baldo; 17: Malga Slapeur; 18: Val Miela; 19: Buso; 20: S.Francesco; 21: Lazzaretti di Foza; 22: Monte Badenecche; 23: Val Grande; 24: Ori; 25: Monte Brustolac; 26: Malga Val Brutta. Section 21 is after Benigni et al.(1982).
In the upper left, four areas with a different stratigraphic succession are shown: A = virtual absence of the RAM represented only by the thin Middle Oxfordian stromatolitic bed; B = presence of the RAM represented only by the thin-bedded limestone facies; C = presence of all the three facies of the RAM (thin-bedded limestone, thin-bedded cherty limestone and subnodular); D = "anomalous" sections.

greatly enhanced the differences between the sediments with different early diagenetic history: the flattening and breakage of grains, and the formation of fitted fabrics and of dissolution seams took place only in the sediments not affected by early cementation (Clari & Martire, 1996).

3 COMMENTS TO STRATIGRAPHIC SECTIONS

This part is devoted to a comment of the stratigraphic sections measured, both from the lithostratigraphic and the biostratigraphic standpoint.

3.1 Lithostratigraphy

Because the facies have already been described, and 25 sections were measured, no detailed description of each section will be given. All of the sections fall, in fact, within one of the following three groups: "complete" sections, where the three units, RAI, RAM, RAS, are present, and show a relatively constant thickness; "incomplete" sections, where the RAM is absent or thin and devoid of cherts; "anomalous" sections, in which the RAI or the RAS are absent or exceptionally thin. Only some general information about the type-succession for each one of the three groups will be given (Figs. 3, 4). Measurement of the stratigraphic sections and detailed facies description were done on active quarry fronts, whereas thicknesses, particularly of RAM , were also determined in natural outcrops, which, however, are often poor and discontinuous.

"Complete" sections - This is the most frequent situation on the Altopiano di Asiago (Pl. 55/1). The RAI ranges in thickness from 5 to 14 metres. The pseudonodular facies is present everywhere (from 3.8 to 11 metres), and constitutes the major part of the RAI; it always occurs in the lower part. The mineralized facies overlies it in some sections only (Monte Baldo, Kaberlaba, Voltascura,

OXFORDIAN Melendez et al., 1984
Subnebrodites planula
Epipeltoceras bimammatum
Perisphinctes bifurcatus
Gregoryceras transversarium
Perisphinctes antecedens
Perisphinctes paturattensis
Prososphinctes claromontanus

KIMMERIDGIAN Sarti, 1993
Hybonoticeras beckeri
Mesosimoceras cavouri
Aspidoceras acanthicum
Presimoceras herbichi
Taramelliceras strombecki
Sowerbyceras silenum

Fig. 5. Biozonal schemes for the Oxfordian and the Kimmeridgian of the Mediterranean province.

Giacominarloch, Zovetto) where it never exceeds a thickness of 190 cm. Apart from Castelletto, where it is replaced by a stromatolitic layer rich in cm-sized nodules of Fe-Mn oxides, the bioclastic facies is present everywhere; it shows however a wider range in thickness (from 35 to 200 cm). In two sections only (Mazze, Bertiaga), the RAI ends with a bivalve-rich, nodular facies (35 - 120 cm). The RAM ranges from 120 to 960 cm. Typically, the succession of facies is, from bottom to top, thin-bedded limestone, thin-bedded cherty limestone, and subnodular. The RAS, in general, shows the greatest variety of facies. The most common is the nodular facies, but pseudonodular and stromatolitic beds are locally intercalated. To the top, the RAV passes transitionally into the overlying Biancone Formation, and it is not possible to define a lithological boundary. In fact, the RAV limestones progressively lose their red colour and nodularity. A conventional boundary has been put where the colour becomes frankly white and the bedding is thin and regular. This corresponds to an abrupt increase in abundance of *Calpionella alpina*. A biostratigraphical study of the upper boundary of the RAV, however, has been made only in few sections. In one of these, belonging to the group of "complete" sections (Kaberlaba), the RAS shows a thickness of 13 metres.

"Incomplete" sections - In this group of sections, the RAM is absent (Castelletto, Rabeschini, Buso, Trolli) or thin and represented by only the thin-bedded limestone facies (Cima Tre Pezzi, Echar, S.Sisto. Figs. 3, 4, Pl. 57/8). At Rabeschini and Cima Tre Pezzi, some cm-large burrows are present in the uppermost decimetres of the bioclastic facies, at the top of the RAI, i.e. below the previously described DS4 (Pl. 57/9). The burrows are filled with wackestones rich in calcite radiolarian moulds (Pl. 57/10). Reddened surfaces within the fillings mark discontinuities in sediment infill into the open system of burrows. Moreover, the thin-bedded limestone facies displays particular features: at Cima Tre Pezzi bedding planes are undulating; at S.Sisto the thin-bedded limestones grade into a massive facies very similar to the stromatolitic one. The RAS, in contrast to the "complete" sections, is represented mainly by the pseudonodular and stromatolitic facies (Pl. 57/8); the nodular facies is present only at Buso and Trolli. At Rabeschini and Echar, where the RAV-Biancone boundary has been studied in detail, the RAS is 8 and 10 metres thick respectively.

"Anomalous" sections - In contrast to all other sections in the Altopiano di Asiago, where the major differences in the distribution of the members of the RAV concern the RAM, some sections show important variations also in the RAI and/or in the RAS (Figs. 3, 4). In the area of Foza, the RAI is very thin (only few decimetres at S.Francesco and Ori), the RAM is absent (S.Francesco) or thin though cherty (Ori). Around Lazzaretti di Foza, the succession is even less complete: the Biancone overlies directly a thin RAI (about 2 m), or appears to rest even on the Calcari Grigi (Benigni et al., 1982).

3.2 Biostratigraphy

The biostratigraphic study, essentially based on ammonites, is aimed at precising the age of the base and top of the three units, and in particular of the RAM which has never been directly dated before. Moreover, the abundance of ammonite moulds in the RAS allowed the better definition of the bio-chronostratigraphy of its lower part. Part of these data have already been presented in a preliminary note (Clari et al., 1990). Zonal schemes are those proposed for the Mediterranean palaeobiogeographic province by Melendez et al. (1985) for the Oxfordian, and by Sarti (1993) for the Kimmeridgian (Fig. 5). Biostratigraphic considerations are mainly based on the following papers: Duong (1974), Sequeiros (1974), Brochwicz-Lewinski (1975), Gygi (1977), Gygi et al. (1979), Enay & Boullier (1981), Melendez (1984) for the Oxfordian, and Schairer (1972), Oloriz (1978), Atrops (1982), Atrops & Melendez (1985), Checa (1985), Pavia et al. (1987) for the Kimmeridgian.

RAI - In the RAI ammonite moulds are quite rare and poorly preserved, with the exception of the base and the top. *Parkinsonia* sp. and *Cadomites rectelobatus*, found at the very base of the RAV in some sections (S.Sisto, Kaberlaba, Voltascura), point to the *P. parkinsoni* Zone (uppermost Bajocian) as already stated by Sturani (1964a). A richer assemblage comes from the bioclastic interval at the top of the RAI at Rabeschini, Bertiaga, Kaberlaba, and S.Sisto. *Bullatimorphites (Kheraiceras)* gr. *bullatus*, *Homeoplanulites (H.) furcula*, *H.(H.)* cf. *balinensis*, *H. (Parachoffatia) funatus*, *Choffatia* sp. are all indicative of the *B. macrocephalus* Zone (lowermost Callovian)(Mangold, 1970; Cariou, 1985).

RAM - The base of the RAM, represented by the thin-bedded limestone facies, is devoid of any significant fossil. Hence the only biostratigraphic data are relative to preliminary analyses of calcareous nannofossils carried out by E.Erba (pers.comm., 1988). The assemblage of *Watznaueria barnesae*, *W. manivitae*, and *Cyclagelosphaera deflandrei*, and the absence of typical Oxfordian taxa,

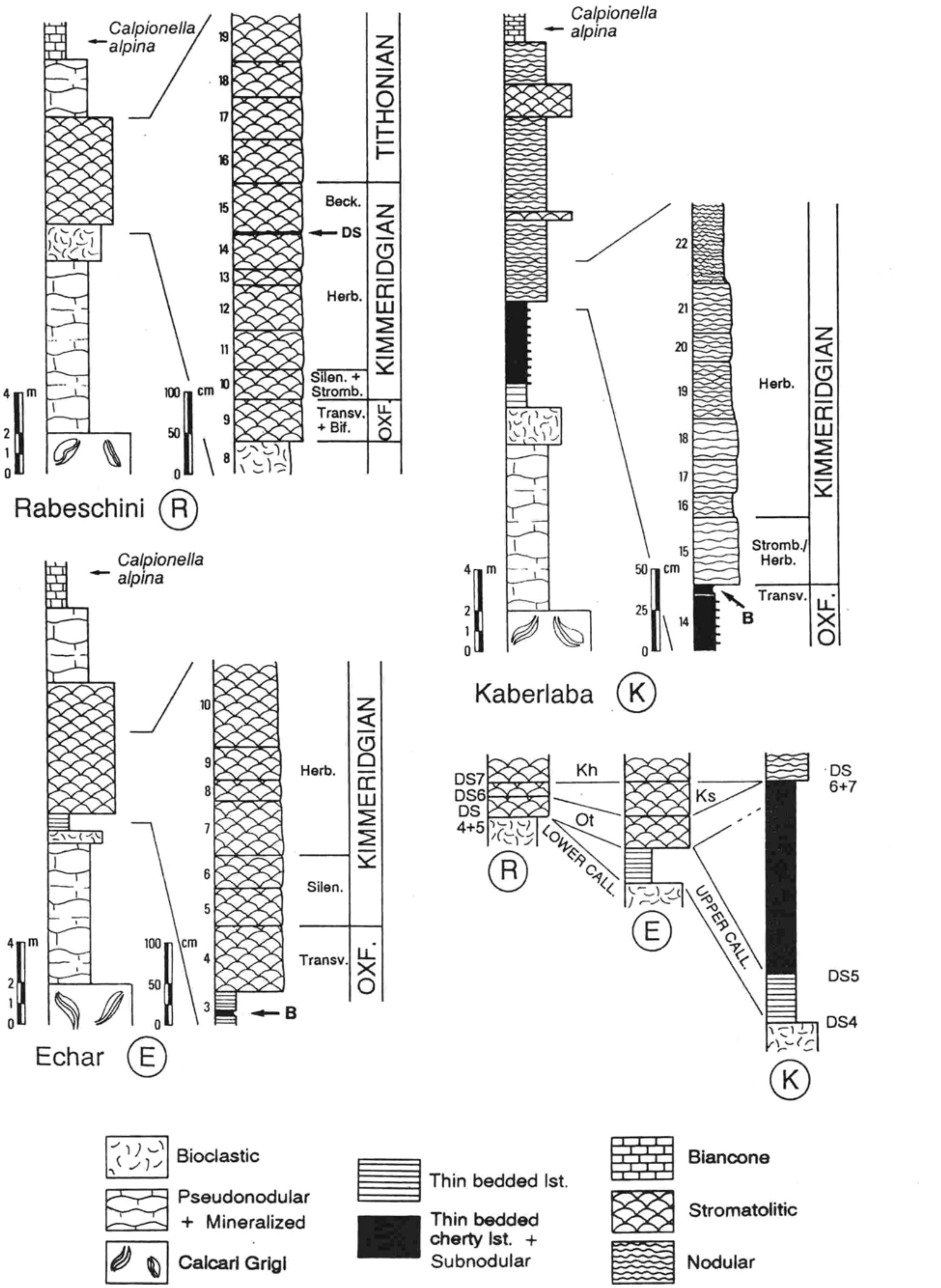

Fig. 6. Detailed litho- and biostratigraphy of the Oxfordian-Kimmeridgian interval in the three sections where paleontological sampling has been carried out. R = Rabeschini; E = Echar; K = Kaberlaba. B = reference bentonite layer. *Calpionella alpina* refers to the great increase in the abundance of this taxon. In the scheme of correlation (bottom right), the following abbreviations are used: Ot = Oxfordian, *G. transversarium* Zone; Ks = Kimmeridgian, *S. silenum* Zone; Kh = Kimmeridgian, *P. herbichi* Zone. DS= discontinuity surfaces.

point to a Late Callovian age for the lowermost part of the RAM. The top of the RAM is instead referable to the Middle Oxfordian (*G. transversarium* Zone) because of the presence of the following, rather poorly preserved ammonite moulds in the Kaberlaba section: *Passendorferia (P.)* cf. *ziegleri, Sequeirosia (Gemmellarites)* aff. *trichoplocus, Perisphinctes (Otosphinctes) nectobrigensis, P. (Dichotomosphinctes)* aff. *elisabethae*. Comparable assemblages have been found in the first stromatolitic layer at Echar (bed 4: *Gregoryceras fouquei, Perisphinctes (Dichotomosphinctes)* cf. *elisabethae*, and *Subdiscosphinctes richei*) and at Rabeschini (bed 9: *Passendorferia (P.) ziegleri, P. (Enayites) birmensdorfensis, Perisphinctes (Otosphinctes) nectobrigensis, P. (Dichotomosphinctes)* cf. *elisabethae, Kranaosphinctes* sp., *Gregoryceras romani, G.* cf. *transversarium, Paraspidoceras helymense*). At Rabeschini other taxa typical of the *P. bifurcatus* Zone (*Passendorferia (P.)* cf. *teresiformis, P. (P.) uptonioides*) occur in the same bed 9. A detailed taphonomic study has not yet been accomplished, but the strictly identical preservation of all the ammonites seems to suggest the absence of reelaboration (FERNANDEZ LOPEZ, 1984; GOMEZ & FERNANDEZ LOPEZ, 1994). The alignment of ammonite moulds truncated in the upper half, moreover, document the existence of a intrastratal discontinuity which justifies the biostratigraphical subdivision of the bed. From a lithostratigraphical point of view, the two stromatolitic beds would be better enclosed in the upper member, but as the focus is on the chronological and geometrical relations of unconformity-bounded sedimentary bodies, they are to be included in the RAM which, on the whole, represents the Late Callovian-Middle Oxfordian interval.

RAS - In order to give a clear picture of the biostratigraphic framework of the RAS, the three sections where a detailed paleontological sampling was made, are discussed separately (Fig. 6).

- Rabeschini. The second stromatolitic layer (bed 10) may be subdivided in two parts. In the lower part, the assemblage is characteristic of the *S. silenum* Zone (lowermost Kimmeridgian): *Taramelliceras (Metahaploceras) rigidum, Idoceras (Lessiniceras)* sp., *Orthosphinctes (Lithacosphinctes) proinconditus* and *O. (L.)* aff. *pseudoachilles, Benetticeras benettii*. In the middle part of the bed, instead, *Mesosimoceras* aff. *teres* is already indicative of the *T. strombecki* Zone. An intrastratal discontinuity with the same features of bed 9 is present. The overlying two beds (beds 11, 12) are characterized by a biostratigraphically homogeneous association referable to the upper part of the *P. herbichi* Zone (*O. uhlandi* Subzone): *Nebrodites peltoideus, Mesosimoceras ludovicii, Orthaspidoceras* gr. *uhlandi, Simaspidoceras irregulare*. After two sterile beds, bed 15 contains a specimen of *Virgalithacoceras* sp. which is characteristic of the *H. beckeri* Zone. A flat and bored discontinuity surface, present at the top of the bed 14, could hence correspond to a significant hiatus since two ammonite biozones (*A. acanthicum* and *M. cavouri* Zones) would otherwise be present in less than 1 m, between the top of bed 12 and the base of bed 15. The presence of *Haploceras (Volanites) verruciferum* and of *Volanoceras vicentinum* in the overlying beds is already evidence of the Tithonian.

- Echar. The stromatolitic beds 5 and 6 contain an association indicative of the *S. silenum* Zone: *Taramelliceras (T.)* cf. *rigidum, Idoceras (Lessiniceras)* cf. *raschii, Mesosimoceras evolutum, Orthosphinctes (Lithacosphinctes)* cf. *stromeri, Euaspidoceras (Epaspidoceras)* sp. The overlying beds 7-9 are referable to the *P. herbichi* Zone on the basis of a rich ammonite association including: *Taramelliceras (T.) trachinotum, Idoceras dedalum, Mesosimoceras herbichi, Simaspidoceras* cf. *bucki, Orthaspidoceras uhlandi*.

- Kaberlaba. The first nodular bed (bed 15) yielded few, poorly preserved, ammonite moulds including *Orthosphinctes (Ardescia)* gr. *inconditus, Crussoliceras aceroides*, and *Idoceras (Lessiniceras)* sp. that indicate the passage between the *T. strombecki* and *P. herbichi* Zones of the Lower Kimmeridgian. The overlying beds (beds 16-22) are all referable with certainty to the *P. herbichi* Zone on the basis of e.g. *Orthaspidoceras uhlandi* and *Taramelliceras (Metahaploceras) nodosiusculum* (CLARI et al., 1990). This section has been recently studied also by SARTI (1993) whose conclusions are in perfect agreement with the data presented here .

The main results of the biostratigraphic studies may be summarized as follows:

a) Contrary to STURANI's opinion (1964a), the RAI (Upper Bajocian - Lower Callovian) on the Altopiano di Asiago consists of several metres of mainly pseudonodular limestones like in most of the other studied localities of the Venetian Prealps (STURANI, 1964a; CLARI et al., 1984);

b) The middle chert-bearing unit (RAM), and consequently also the bentonite layers present in it, are quite well bracketed between the Late Callovian and the Middle Oxfordian (*G. transversarium* Zone) and are therefore older than previously thought (STURANI, 1964a. Fig. 6). In order to correlate the bentonitic beds, that vary in number from 0 to 5, the assumption is made that the most important ash fall events gave rise to the laterally most continuous beds. This means that the thickest bed in each section is regarded as the same bentonitic layer. As this reference bed is overlain at Echar, and underlain at Kaberlaba, by Middle Oxfordian limestones, it can be assigned precisely to the *G. transversarium* Chron.

c) Important gaps are highlighted (Fig. 6): some have already been recognized sedimentologically and the duration can in one case be defined (DS4); others are identified only on a biostratigraphic basis (DS6-7). Summarizing: the Middle Callovian is missing at the RAI-RAM boundary (DS4). Where the chert-bearing unit of the RAM is absent (Rabeschini), a stromatolitic layer of Middle Oxfordian age directly overlies the RAI (DS4+5), and is overlain by a single layer of the lowermost Kimmeridgian (*S. silenum* + part of the *T. strombecki* Zones), the Upper Oxfordian (*E. bimammatum* and *S. planula* Zones) missing (DS6). Another hiatus (DS7), corresponding to the upper part of the *T. strombecki* Zone and the lower half of the *P. herbichi* Zone, separates this layer from the overlying one. Where, instead, the RAM is present, the Late Oxfordian (*E. bimammatum* and *S. planula* Zones) and part of the Early Kimmeridgian (*S. silenum* and part of *T. strombecki* Zones) are not represented along the RAM - RAS boundary (Kaberlaba; DS6+7). Other gaps seem to be present in the Upper Kimmeridgian but as yet there is no definite proofs.

d) The RAM results as a wedge of well stratified, often cherty, limestones, which shows only a very minor heteropy of its top with the Middle Oxfordian stromatolitic bed. On the other hand, a heteropy between stromatolitic/ pseudonodular limestones and nodular facies is found in the RAS.

4 EVIDENCE OF SYNSEDIMENTARY TECTONICS

Neptunian dykes have been reported, since the sixties, in many localities of the Eastern Alps (e.g. WIEDENMAYER, 1963; SCHÖLL & WENDT, 1971; STURANI, 1971; CASTELLARIN, 1972, 1982; WINTERER et al., 1991) as well as from other places from the Italian Jurassic (e.g. WENDT, 1965; JENKYNS, 1971). All these cases refer to fractures opened within mainly liassic platform limestones during rifting phases, and filled with pelagic sediments during, and/or after, the drowning of the platform itself. Several lines of evidence for extensional tectonics are described here for the first time within the pelagic sediments of the RAV of the Altopiano di Asiago. They are present in many sections and at different stratigraphic levels, although most of them are concentrated in proximity of the RAI/RAM boundary (Fig. 7). Direct and indirect evidence may be distinguished.

4.1 Direct evidence

Direct evidence is provided by neptunian dykes and mud-supported breccias intepreted as seismites.

Neptunian dykes are typically developed at the top of the RAI, and may be of two types: subparallel to bedding, and subvertical. The first ones (Buso, Giacominarloch, Zovetto) are a few decimetres thick and a few metres long at most (Pl. 58/1, 4), and show mm- to cm-thick laminae, alternatively grain-rich and grain-poor (Pl. 58/2, 3). Laminae may be bedding-parallel or oblique, giving rise to internal foresets. The fills frequently grade from grainstone/ packstone at the base (Pl. 58/5) to mudstone/wackestone to the top. Thin-shelled bivalves are by far the prevailing grains; lithoclasts of the encasing rock are also present at the base of the dyke fill. Other small horizontal dykes, present at the top of the RAI at Castelletto, differ from the preceeding ones because they are only partially filled with micritic sediment, the remaining cavity being occluded by at least two generations of cement (Pl. 58/6, 7): the first consists of NL, scalenohedral crystals fringing the cavity walls, the second showing a typical blocky morphology with complex CL internal zoning from bright yellow to NL. A different filling mechanism is documented in a horizontal dyke present at the top of the RAM, within the subnodular facies, at Bertiaga. The sill is about 2 cm thick, is laterally continuous over several metres, has sharp boundaries, and is filled with a mud-supported breccia (Pl. 59/1-2): mm-sized, subangular, lithoclasts of white grainstones with radiolarian micrite moulds, identical to those of the subnodular facies, float in a reddish matrix of crinoidal-peloidal packstone with a fitted fabric and dissolution seams. The lack of laminae and the absence of pore-filling cement shows that the cavity was filled by clasts of the encasing rock and by a forcefully injected plastic matrix. Because of the nature of the matrix (crinoid-bearing and *Saccocoma*-free packstone) it is suggested that the injected sediments came from the underlying beds of the thin-bedded cherty limestones, that were not affected by early cementation.

Subvertical dykes are large and well exposed at Bertiaga, where they are however not wider than 10 cm, and extend up to several metres in depth across the thin-bedded limestone facies to the pseudonodular facies, crossing the nodular and bioclastic facies (Pl. 58/8-9). The boundaries are very sharp in the bioclastic facies, whereas in the pseudonodular facies the dyke becomes anastomosed, and the contacts with the internodular matrix is irregular and even transitional. In this part, the dykes are filled by breccias with cm-sized lithoclasts consisting mainly of pink packstones with bivalves and peloids of the nodular facies (Pl. 58/9). A red matrix is present around the clasts, increasing in abundance with depth; it is a packstone with bivalves and peloids. Higher up, where it crosses the nodular and thin-bedded limestone facies, the fissure acquires a funnel-like shape, about 1 m across, with gradual boundaries. The encasing rocks are increasingly disrupted, becoming a breccia with cm to dm-sized clasts of the three lithologies typical of the thin-bedded limestone facies: white radiolarian mudstones, pink bivalve wackestones, and red bivalve packstones (Pl. 59/3). The clasts are compenetrated along stylolites. At Echar, the thin-bedded limestones overlying a dyke are plastically deformed, forming a collapse "syncline" which progressively wanes upwards, the bedding returning horizontal in about 1 metre (Pl. 59/4). Other neptunian dykes are present in the area of Foza. In addition to those already described by BENIGNI et al. (1982), rich in brachiopods and referable to the Aalenian-Bajocian, small dykes were found which contain packstones with abundant and well preserved *Saccocoma*. This proves that in places, the opening of fissures was going on in the Late Jurassic.

Thin layers of mud-supported breccias are present in the RAI, within the bioclastic facies (Giacominarloch), and in the RAM, within the thin-bedded limestone facies. One case will be described in some detail from the Kaberlaba section. The white mudstone layer within the thin-bedded limestone facies transitionally passes from the usual massive aspect to a mud-supported breccia that is rather unconspicuous in outcrop but clearly recognizable on a polished slab (Pl. 59/5). This bed, that is the only one in the thin-bedded limestone facies to bear evidence of early cementation, shows different degrees of internal disruption, from slight breakage and opening of subvertical,

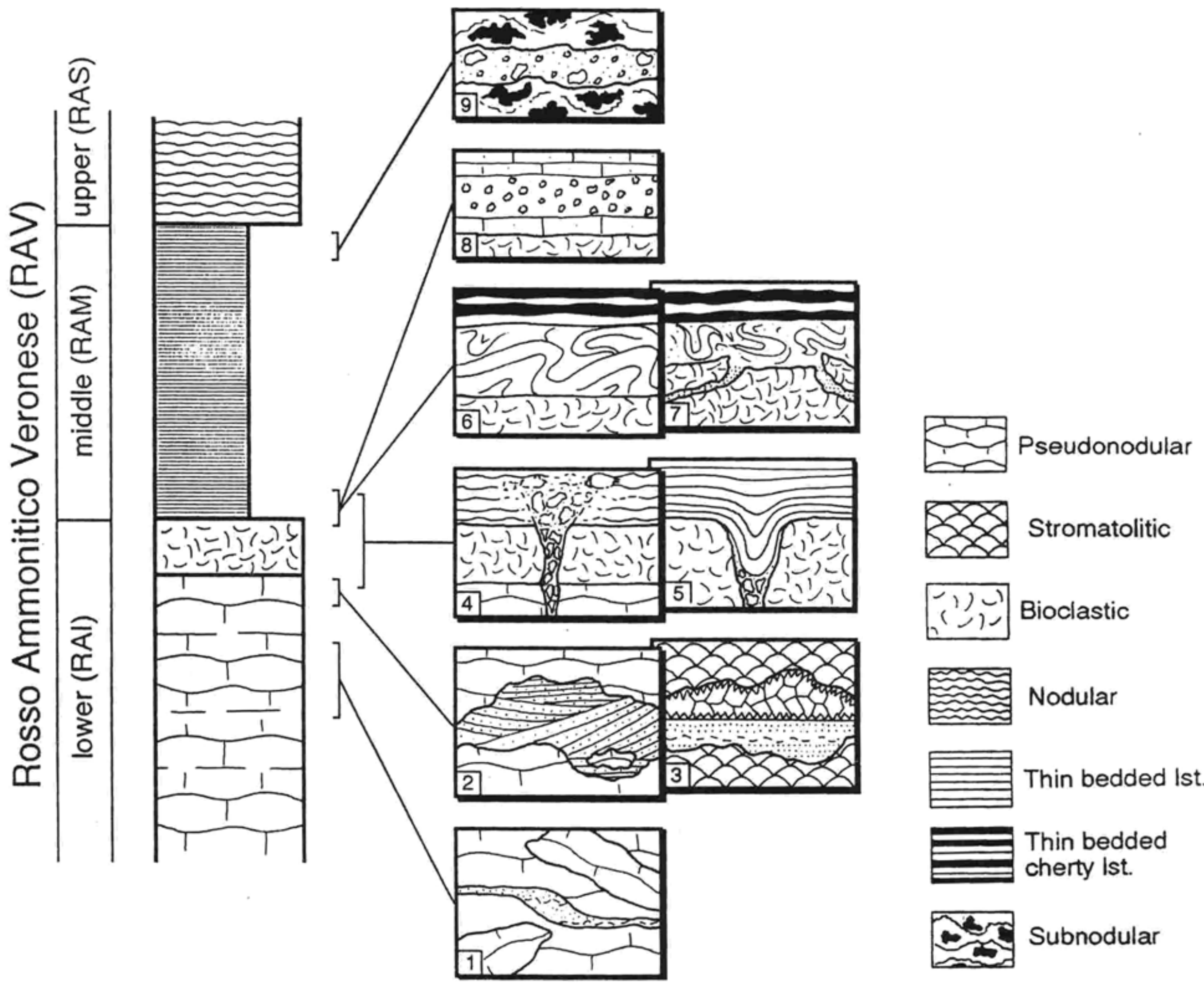

Fig. 7. Synopsis of the evidence of synsedimentary tectonics found in the RAV of the Altopiano di Asiago. Numbers in the bottom left of each "window" indicate location and photographic documentation: 1-Buso, Pl. 58/4,5 and Pl. 59/6; 2-Giacominarloch, Pl.58/ 1-3; 3-Castelletto, Pl. 58/6,7; 4-Bertiaga, Pl. 58/8,9 and Pl. 59/3; 5-Echar, Pl. 59/4; 6-Zovetto, Pl. 59/7; 7- Giacominarloch, Pl. 59/ 8; 8-Kaberlaba, Pl. 59/5; 9-Bertiaga, Pl. 59/1,2.

tensional, cracks, to total chaoticization with consequent production of mm-sized, white micritic clasts floating in a pink micritic matrix. On active quarry fronts, where the layers can be traced laterally for tens of meters, no variations in thickness of this bed, about 25 cm thick, is recognizable. The style of deformation and the regular and limited thickness of the bed would exclude a debris flow origin and strongly suggest in-situ deformation of a semi-lithified bed after a seismic shock (Seilacher, 1984; Plaziat et al., 1990).

4.2 Indirect evidence

Indirect evidence is provided by glides in the RAI, slumps in the RAM, and by the lateral distribution of facies.

At the Buso section, tabular slabs of pseudonodular facies, some dm thick and up to some metres long, are embedded within the pseudonodular facies giving rise to a chaotic bed of variable thickness in the upper part of the RAI, where subhorizontal neptunian dykes are also present (Pl. 59/6). The shape of these rock bodies, and the absence of internal deformation, prove that they are glides (Nardin et al., 1979), i.e. blocks of well lithified sediments fractured and displaced downslope under the effect of gravity.

In one section (Zovetto) the thin-bedded limestone facies is characterized by a flat base and by an ondulated top; internally, beds are rotated, folded, and broken, giving rise to a chaotic, thin, slump horizon (Pl. 59/7). A slump breccia, with a higher degree of bed disruption, is present in the Giacominarloch section, above the neptunian dykes with laminated fills. Clasts, a few mm to some cm across, often show plastic deformation, and float in an abundant chaotic dark red, marly, matrix (Pl. 59/8). Matrix and clasts show the typical textures of the thin-bedded limestone facies.

Facies and thickness variations of sedimentary bodies, then, may be used as a proxy for a pronounced topography of the sea bottom. Significant thickness changes are particularly evident for the RAM, which varies from about 10

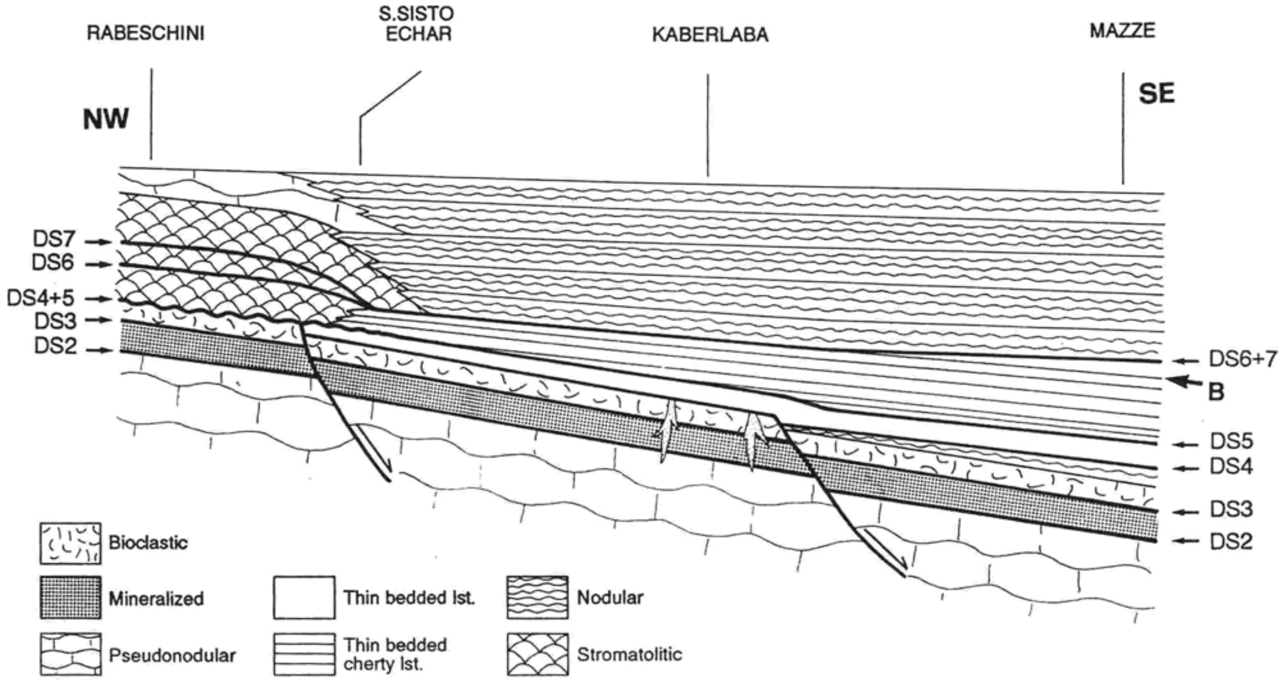

Fig. 8. NW-SE cross-section of the RAV of the central-southern part of the Altopiano di Asiago, along the transect Rabeschini-Kaberlaba-Mazze. The sections of S.Sisto and Echar are projected in order to show where the "incomplete" sections are developed. Thicknesses are not to scale. Bold lines indicate discontinuity surfaces (DS). B = reference bentonite layer. In the thin-bedded cherty limestone (horizontal ruling) the subnodular facies is also included.

metres in some places to a few decimetres in others where it is replaced by a thin stromatolitic layer overlying a hard ground corresponding to a very prolonged hiatus. On an isolated submerged plateau, the sediment supply is essentially biogenic and is provided by the slow pelagic rain and by the contribution of the skeletal remains of benthic organisms. Currents winnow sediments away from the more elevated areas and accumulate them in the intervening lows, the deeper the lows the thicker the local succession. This simple model is often applied to pelagic sequences on extensional margins (e.g. BERNOULLI & JENKYNS, 1974; SANTANTONIO, 1993) and is particularly convincing for radiolarian-rich, cherty successions (BAUMGARTNER, 1987, 1990). It finds an analogue in the present-day distribution of facies along the Bahamian slopes (MULLINS et al., 1980): calcareous oozes, accumulating on the deepest parts of the slope, pass upslope into partially and selectively cemented grain-supported sediments, possible precursors to nodular limestones, and at still shallower depths to completely lithified hard-grounds. Four hypotheses theoretically explain the formation of an irregular sea-floor topography. Such topography can be: a) inherited; b) due to differential compaction of the underlying sediments; c) due to irregular pathways of bottom currents; d) generated by synsedimentary tectonics. The first hypothesis is excluded because, if it were inherited, the bottom topography would have controlled, with the same trends, also the previously deposited sediments, i.e. the RAI, which is not the case. Differential compaction is a complex topic and must be discussed at a regional scale. Sediment compaction is controlled basically by lithology and the degree of early cementation (e.g. BATHURST, 1987) which in turn depend on depositional environments and paleogeography. Conspicuous changes in thickness and facies are described in the Calcari Grigi and Oolite di S.Vigilio, which underlie the RAV, in a E-W direction: thicker packages of mainly oolitic limestones, probably early cemented, prevail on the margins of the Trento Plateau, whereas thinner and more marly and micritic limestones are characteristic of the central part (e.g. BARBUJANI et al., 1986; SARTI et al., 1992). Consequently it would be expected that the pattern of geographical distribution of "complete" and "incomplete" RAV successions followed the large-scale, gross internal architecture of the underlying formations, i.e. that the RAV sections on the margin were different from the ones in the central part. Actually the stratigraphy of the RAV changes at a much smaller scale, and chert-free and chert-rich sections are closely juxtaposed all over the Trento Plateau. This shows that the dependence of the RAV stratigraphy on the nature of the underlying sediments is unlikely. Lateral shifts in bottom current axis (Pinet & POPENOE, 1985) cannot explain the synchroneity of major gaps and of the facies change from RAI to RAM over the whole Trento Plateau (e.g. MARTIRE, 1992b; CLARI et al., 1984). Tectonics is therefore favoured as a mechanism causing the formation of an irregular sea-floor topography also because the important facies change from RAI to RAM: a) takes place abruptly after a long period (Late Bajocian-Early Callovian) of relatively uniform sedimentation (RAI); b) is closely associated to neptunian dykes, glides, slumps and seismites (cf. FÜCHTBAUER & RICHTER, 1983; BÖHM et al., 1995).

4.3 Discussion

Cross-cutting relationships between quite well dated rock bodies, neptunian dykes and mass gravity flow deposits allow one to draw some conclusions about the timing of fracture opening and filling, and the events of sliding and to discuss the mechanisms involved. 1) Neptunian dykes, both vertical and horizontal, indicate tensional forces that led to dilation within more or less cemented sediments. The fissures might correspond to small faults and associated fractures, or to cavities due to gravitational movements of indurated rocks along steep slopes (e.g. FÜCHTBAUER & RICHTER, 1983; WINTERER et al., 1991). In both cases, bearing in mind that the RAI is a relatively uniform lithosome lacking any evidence of slope failures, a tectonic origin is involved, either directly causing faults and fractures, or indirectly generating slopes which triggered mass sediment movements. 2) Laminated fills of dykes show that fracturing generated cavities which acted as sediment traps during subsequent phases of no net sediment accumulation on the sea-floor. 3) Complete laminated fillings demonstrate that the cavity system was well connectied to the sea floor, and that water flowed actively within the fissures transporting and depositing sediments (CASTELLARIN, 1982); moreover, the alternating mud- and grain-supported laminae indicate oscillating current regimes. 4) Breccias, on the other hand, filled fractures because of the collapse of overlying and/or adjacent sediments; this obviously happened after the deposition of the Upper Callovian thin-bedded limestone facies. Different degrees of cementation are responsible for the plastic (Echar) or brittle (Bertiaga) response of collapsing sediments. 5) Seismic shocks provoked limited internal fracturing of semi-lithified beds (seismites), and may have triggered mass gravity movements. Metre-sized glide blocks within the RAI proves that rather steep slopes were present at Buso. On the other hand, slumps at the base of the RAM document failures of plastic sediments along gentle slopes. Water escaping from the underlying dyke might be the cause of the high internal, and laterally limited, disruption of the thin-bedded limestones (slump breccia) at Giacominarloch. 7) In conclusion, an Early Callovian, or locally even Bathonian, to Late Callovian episode of extensional tectonic activity is supported by the data. It is responsible for a significant change in RAV basin topography, which controlled the patterns of facies distribution. Sedimentary dykes at the top of the RAM or filled with Saccocoma show that such an activity was still locally present in the Late Jurassic.

5 GENERAL DISCUSSION AND CONCLUSIONS

The presented data, derived from stratigraphy, biostratigraphy, sedimentology and diagenesis analyses, allow the subdivision of the succession of the RAV of the Altopiano di Asiago into a number of rock units defined by major discontinuity surfaces, or by correlative conformities (Fig. 8. For a sequence stratigraphic approach see MARTIRE, 1992 b). Interpreting facies in terms of hydrodynamic levels, we may assume that the thinnest successions with an early cementation were deposited on the submarine highs and the thickest and less cemented in the lows. It is also suggested that distribution of time-equivalent facies documents a synsedimentary tectonic activity controlling the topography of the sea-floor. From this a reconstruction of the paleostructural framework may be attempted. If the stratigraphies of the measured sections are represented on a map, it clearly appears that (Fig. 4): 1) the RAI changes in thickness in an apparently erratic way, which is difficult to intepret. Facies are essentially the same everywhere, apart from the presence of nodular facies at the top of the RAI in the southernmost sections (Mazze, Bertiaga). Moreover, the thinness of the RAI, and its local absence (in the sector of Foza) is worthy of note. 2) Thickness variations in the RAM, on the other hand, display a more systematic trend. The RAM is virtually absent in a E-W oriented central belt (Castelletto-Rabeschini-Buso-Trolli); moving to the south, the RAM reappears, reaching a maximum thickness of about 2 m (Cima Tre Pezzi, S.Sisto, Echar). Here it is represented by the thin-bedded limestone facies; only farther to the south, do the thin-bedded cherty limestone facies appear and the RAM reaches a maximum thickness of about 10 m (Mazze). This passage is very gradual in the southern zone, as can be clearly seen along the Rabeschini-Cima Tre Pezzi-Kaberlaba-Mazze transect (Fig. 8). On the contrary, to the north, there is a "jump" between the so called "incomplete" and the "complete" sections, which is particularly striking between the Buso and Val Miela sections (Fig. 4). Moreover, in the sections where the RAM is well represented and cherty, a conspicuous thickness of chert beds is commonly present above the last reference bentonitic layer, thereby reducing the hiatus between the RAM and the RAS (Fig. 3). 3) The RAS is always present but, consistent with the facies distribution of the RAM, shows stromatolitic and pseudonodular facies in the central belt where the RAM is absent or chert-free, and thicker successions of mainly nodular facies in the adjacent northern and southern sectors. 4) In the zone of Foza, the extreme condensation of the RAV may be due to two concomitant effects: particularly effective exposition to bottom currents, and gravitational slides, actually encountered in the nearby section of Buso (Fig. 7; Pl. 59/6).

As the majority of dykes, slides, and seismites are concentrated along the top of the RAI and at the base of the RAM (Fig. 7), i.e. associated with the most important facies change, the following picture is suggested. After deposition of the relatively uniform package of the RAI limestones on a virtually flat sea floor, the region of the Altopiano di Asiago was affected by an extensional tectonic phase which generated a typical half graben structure, with a central ridge bounded to the north by a steep scarp, and grading into a gentle slope to the south (Fig. 9). During the Early Callovian - Late Oxfordian, this ridge was either completely bypassed (Rabeschini) or recorded a first phase of Late Callovian sedimentation (thin-bedded limestone facies) followed by erosion and bypassing till the Middle Oxfordian when stromatolite facies were pre-

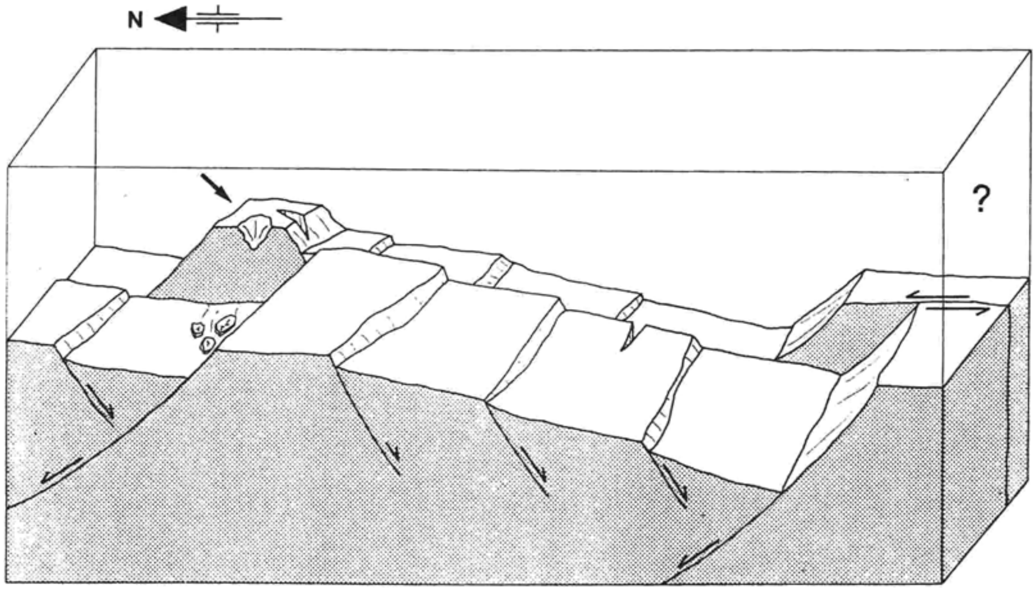

Fig. 9. Hypothetical reconstruction of the structural framework of the Altopiano di Asiago in the Late Callovian. The isolated "pinnacle" in the block displaced to the left (arrow) represents the area of Foza, with slides and neptunian dykes. The question mark on the right is due to fact that no information is available for that sector: the reconstruction is thus highly speculative.

served (Echar). In the deeper parts of the slope, instead, the Upper Callovian - Middle Oxfordian is represented by a thicker and thicker succession of well bedded limestones (thin-bedded limestone, thin-bedded cherty limestone and subnodular facies). Pelagic particles, primarily radiolarians, were transported away from the highs and preferentially deposited on the slopes and lows (BAUMGARTNER, 1987, 1990). The presence of nodular beds at the top of the RAI and of cherty beds above the reference bentonite layer in the RAM documents that in these deeper parts of the basin, less exposed to currents, the succession is more complete, at least since the Early Callovian.

The vertical throw of the normal faults responsible for this topographic articulation was likely of a few tens of metres: differences between highs and lows, suggested by marked facies changes, still existed in the RAS, that is after deposition of all the RAM for which a decompacted maximum thickness of more than 25 m may be inferred (MARTIRE & CLARI, 1994; CLARI & MARTIRE, 1996). The sedimentation rates were so small that irregularities of the sea-floor were not quickly eliminated and hence exerted a basic control on facies. A minor transfer fault, accommodating different extension in adjacent sectors, might be the cause for the generation of an isolated "pinnacle" in the zone of Foza, which was swept by intense currents and prone to slope failures (Fig. 9). Here, the presence of dykes filled with *Saccocoma*-bearing sediments shows that a certain instability persisted till the Kimmeridgian. Unfortunately, the scarcity of outcrop hinders direct observation of the assumed paleostructures.

Two problems arise from this interpretation. One derives from the comparison with the paleogeographic model proposed, at a larger scale, for the entire Trento Plateau by LAUB (1994). Stratigraphic sections are subdivided into two groups depending on the presence of a hard ground or of the "radiolarian-rhyncolith-limestones"(RRL= RAM in the present paper) between the RAI and the RAS. LAUB (1994) suggests that sections of the first type plot geographycally along two discrete NNE-SSW belts which are surrounded by sections of the second type. These NNE-SSW-oriented belts would reflect a submarine relief and, as they are parallel to the Ballino Line, i.e. the boundary between the Lombardy Basin and the Trento Plateau (CASTELLARIN, 1972; CASTELLARIN & PICOTTI, 1990), are considered to be of tectonic origin. This interpretation seems to be an oversimplification of the reality for two reasons: a) The choice of distinguishing sections simply with or without RRL, in a sort of binary way, is too strict and does not allow the separation of sections with 1 m of thin-bedded limestone facies from sections with 10 m of cherty limestones; moreover, gradual vs. abrupt boundaries between the two types of sections are not considered. b) In addition to the situation of the Altipiano di Asiago, personal unpublished observations and other published data in the areas of M. Grappa, M. Peller and M. Pasubio (SARTI, 1986a; LEHNER, 1992; ZEMPOLICH, 1993) show that the pattern of lateral facies variations in the RAV is very complex and cannot be simply depicted as the result of the presence of basins and swells with a NNE-SSW orientation.

The second problem concerns the orientation of the inferred normal faults. The reconstruction of the possible paleotectonic framework of the Altopiano di Asiago at the Callovian-Oxfordian boundary, based on stratigraphic data and sedimentologic interpretation, can hardly be reconciled with the large-scale, basically N-S master normal faults documented as bounding the Trento Plateau from the adjacent basins (GAETANI, 1975; WINTERER & BOSELLINI, 1981; CASTELLARIN & PICOTTI, 1990; SARTI et al., 1992). In the present reconstruction (Fig. 9), in fact, E-W trending normal faults are called upon to explain the gradual versus abrupt transition from "complete" to "incomplete" RAV sections proceeding from south to north. However the two structural schemes, the large, regional, and the small, local scale scheme, do not seem to be incompatible. First because the activity of the N-S master faults is documented mainly for the Late Triassic-Late Liassic (CASTELLARIN & PICOTTI, 1990; BERTOTTI et al., 1993), and scarce information is available about possible changes in the extensional vectors on the South Alpine passive margin during the Middle-Late Jurassic. Second, it is not easy to imagine how the (trans)tensional strain was partitioned between normal and transfer faults within a previously highly dissected, and lithologically non-homogeneous, continental margin. It seems therefore possible to suggest that E-W trending transfer faults, documented in Liassic times in the Riva del Garda zone (CASTELLARIN & PICOTTI, 1990), were reactivated with an extensional component in Middle Jurassic in the Altopiano di Asiago area, farther to the east. These structures could have caused small morphological scarps that were not recorded by the basinal, radiolaritic, succession of the Lombardy Basin, but could have had a remarkable impact on the more sensitive condensed succession accumulating on the current-swept pelagic plateau. Whatever the nature of the inferred faults, the data presented imply a still effective Middle-Upper Jurassic extensional tectonic activity, although obviously on a much smaller scale compared to the Liassic rifting stage. This means that the drowning of the earlier Toarcian-Aalenian platform did not mark the end of the fault-controlled extension, and the Middle-Late Jurassic subsidence history, at least of the Trento Plateau, was not simply due to a generalized, uniform, thermal subsidence.

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