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Triassic Sequence Stratigraphy in the Dolomites (Italy)

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ABSTRACT - A major handicap to correlations within the Triassic in the Dolomites has always been the difficulty of comparison between carbonate platform deposits, often "undifferentiated", and the corresponding basinal successions. By means of an integrated approach of lithostratigraphic, biochronostratigraphic and sequence stratigraphic methodologies a number of 3rd order depositional sequences have been recognized, far more numerous than in the cycle chart in Haq *et al.* (1987): six in the Scythian, four in the Anisian, three in the Ladinian, four in the Carnian, at least two in the Norian. Data from Norian and Rhaetian are very uncertain. From the biochronological point of view a new ammonite standard zonation has been used (Mietto and Manfrin, in progress), ranging from Early Anisian to Early Carnian, integrated for the Carnian by the ammonite scale in Krystyn (1978). Therefore depositional sequences in this interval are well dated. Volcanism is an independent variable in the depositional sequences. As a consequence, it causes greater difficulty in recognizing the eustatic signal. However the latter can be identified in those areas where volcanism is either lacking or moderate. In spite of syndepositional extensional tectonics, which influences the accomodation space, it seems to be demonstrated that, when a good biochronostratigraphic setting is available, the eustatic signal is always recognizable. It is worth underlining that in this work our only goal is the proposal of a general frame for the Triassic sequence stratigraphy in the Dolomites. Detailed contributions on particular arguments or stratigraphic intervals will be given in the future.

RIASSUNTO - Viene proposta una sintesi del Triassico delle Dolomiti in termini di stratigrafia sequenziale. In passato una delle maggiori difficoltà di comprensione della stratigrafia triassica nella Regione Dolomitica è stata l'incertezza nel correlare le piattaforme carbonatiche, spesso "indifferenziate", con i corrispondenti depositi bacinali. Il risultato è stato raggiunto grazie ad un approccio integrato tra litostratigrafia, biostratigrafia e metodi della stratigrafia sequenziale, tenendo ovviamente conto anche della cospicua bibliografia esistente. Le sequenze deposizionali di 3° ordine sono state riconosciute in numero maggiore di quelle indicate nella scala di Haq *et al.* (1987): 6 nello Scitico, 4 nell'Anisico, 3 nel Ladinico, 4 nel Carnico e almeno 2 nel Norico. Per quanto riguarda l'intervallo Norico-Retico le notizie sono scarse e incerte soprattutto a causa della difficoltà di reperire dati biostratigrafici. La nuova scala standard ad ammoniti (Anisico inferiore - Carnico inferiore) di Mietto e Manfrin (in preparazione), integrata da quella di Krystyn (1978) per il Carnico e valida almeno per il dominio della Tetide, ha costituito un preciso e insostituibile strumento di lavoro che ha permesso di tracciare superfici isocrone affidabili attraverso il complesso intreccio stratigrafico e paleogeografico del Triassico delle Dolomiti. L'analisi in parallelo delle successioni bacinali e di mare basso, delle loro geometrie, dei loro rapporti e delle loro età ha consentito di ottenere i risultati che vengono qui presentati. Il vulcanismo costituisce una variabile indipendente nelle sequenze deposizionali. Di conseguenza esso può rendere difficile il riconoscimento del segnale eustatico che, comunque, può essere individuato in aree poco o punto interessate da eventi vulcanici. Dal quadro sequenziale risulta che il segnale eustatico, in un regime tettonico di tipo estensionale come quello triassico delle Dolomiti e quando siano disponibili superfici isocrone sicure, è sempre riconoscibile.

Key words: *Sequence Stratigraphy, Lithostratigraphy, Ammonites, Triassic, Dolomites, Southern Alps, Italy.*

INTRODUCTION

In order to propose a complete sequence stratigraphic scheme of the Triassic in the Dolomites, two ideal stratigraphic columns have been built and correlated (Plate 1), one consisting of paleoshelf units (including continental, lagoonal, shallow marine and carbonate platform units), the other formed by basinal units. However the two columns do not represent "real" successions, because in reality transitions from one evolutive trend to the other are often recognizable, in connection with the complex paleogeographic and paleotectonic setting in this area during Triassic. Correlations have been made possible by an integrated approach between lithostratigraphy, biostratigraphy and sequence stratigraphy.

Plate 2 includes a number of chronostratigraphic columns from selected areas throughout the Dolomites. Due to the lack of good radiometric ages, we used the subzones of a new ammonite standard scale (Mietto and Manfrin, in progress; cfr. De Zanche *et al.*, 1992c) as units of measure. Therefore our "time scale" is arbitrary because up to now no sure relation between subzones and time is available. Lithostratigraphy has been developing over the last twenty years thanks to the research of many groups on the Triassic in the Dolomites (Universities of Bologna, Ferrara, Innsbruck, Milano, Padova, etc.). Without any doubt this stratigraphic setting is the basis of our work, even if necessary revision has led us to add, change, enlarge or restrict some stratigraphic names. On the other hand the results of the application of the sequence stratigraphy have permitted us of better understanding the meaning of the lithostratigraphic setting.

A major handicap to correlations within the Triassic in the Dolomites has always been the difficult comparison between shelf deposits and the corresponding basinal successions. A detailed investigation of the latter and the collection of a great number of ammonites, both in carbonate platform and in basin, has made it possible to draw reliable time lines throughout the Triassic in the Dolomites.

Furthermore in this work we have referred to the new ammonite standard scale proposed for the Bithynian-Early Carnian interval by Mietto and Manfrin, integrated for the Carnian by the scale in Krystyn (1978). When ammonites were absent, conodonts and tetrapod footprints supplied biochronological data.

The application of the sequence stratigraphic methodology (Van Wagoner *et al.,* 1988; Vail *et al.,* 1991) to the Triassic in the Dolomites is mostly the result of original research on the part of the writers; only the Lower Triassic depositional sequences have been defined mainly by a re-interpretation of the most recent articles (Broglio Loriga *et al.,* 1983, 1990; Neri, 1991).

GEOLOGICAL SETTING

The Dolomites are located in the eastern Southern Alps; they are bounded by the Neogene Insubric Lineament to the North and by the Valsugana - Pieve di Cadore Thrust to the South (Fig. 1).

Some tectonic phases can be recognized in the Dolomites from Permo-Triassic rifting to Neogene compression (*cfr.* Winterer and Bosellini, 1981; Doglioni, 1987).

Even if two compressional tectonic events, the W to WSW vergent "Dinaric" phase (pre Upper Oligocene) and the Neogene S to ESE vergent "Valsugana" phase, deformed the Dolomites during the Tertiary, these two Alpine deformations were not intense enough to totally obliterate the pre-existing stratigraphic patterns and tectonic features (Doglioni and Castellarin, 1986; Doglioni and Bosellini, 1987).

During Triassic time, the Dolomites underwent extensional conditions referable to strike-slip tectonics which is even responsible for local compressional features (Doglioni, 1984, 1987). Therefore the Dolomites represent a "chess-board", set up by blocks with different subsidence, controlled by roughly E-W and N-S structural trends. The subsidence history is documented by different thicknesses of the same lithostratigraphic unit within the Triassic sedimentary cover.

The main source area of siliciclastics was to the South, as demonstrated by the supply of metamorphic clasts from the basement (*cfr.* Assereto *et al.,* 1977; Viel, 1979;

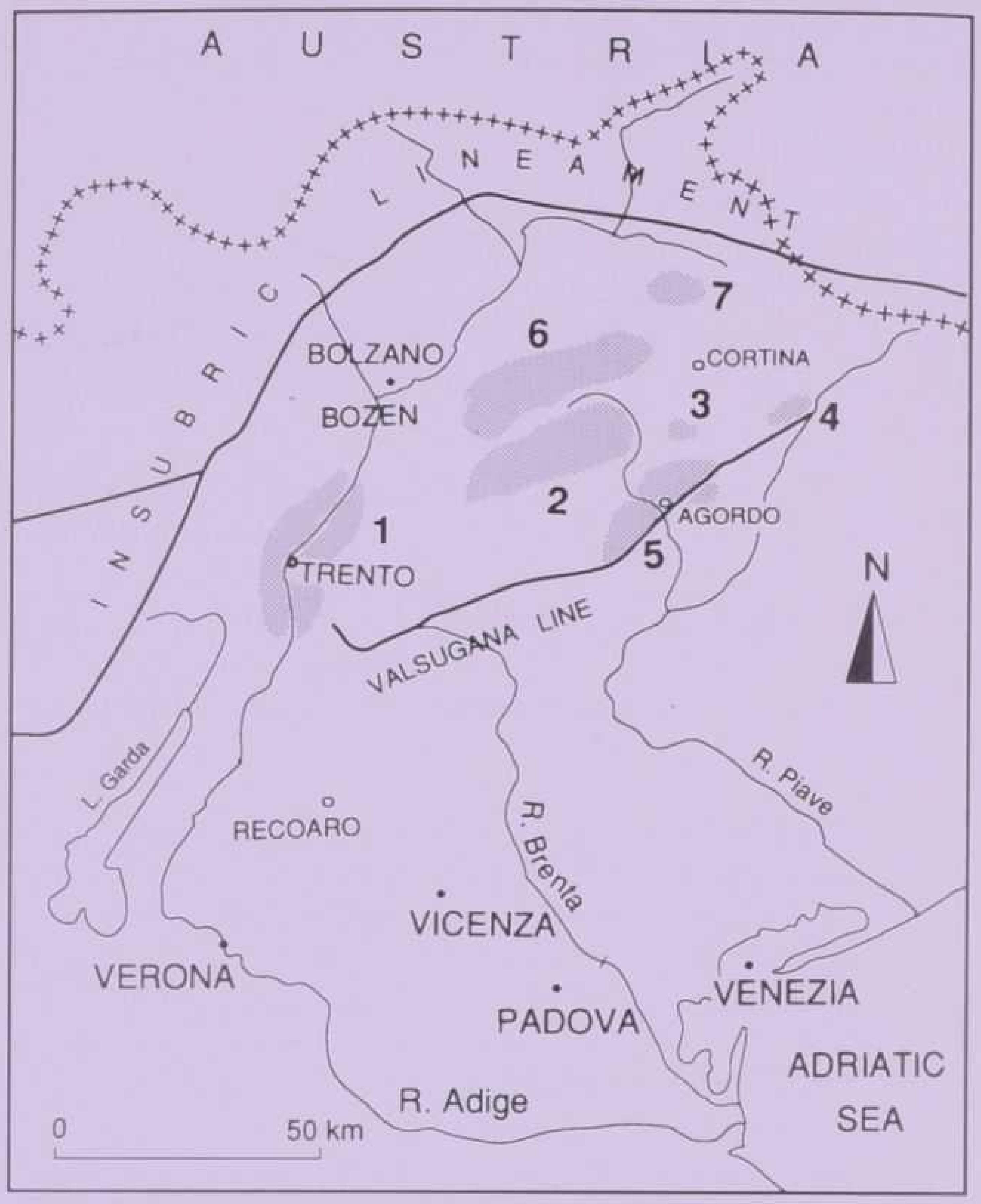


Fig. 1 - Selected areas in the Dolomites corresponding to the columns in plate 2. Legend: 1, Adige Valley; 2, SW Dolomites; 3, W Cadore; 4, eastern-central Cadore; 5, Agordo and Zoldo area; 6, NW Dolomites; 7, Braies area.

Brusca *et al.,* 1982; De Zanche and Mietto, 1984).

Volcano-tectonic compressional structures have been recognized around the Predazzo-Monzoni volcanic complex.

LITHOSTRATIGRAPHY

In the Dolomites many Triassic rock unit names are in use, due to 200 years of research carried out by numerous authors from Europe and North America. Of course the bibliography is immense.

As one can easily see in plate 2, in different parts of the Dolomites the same unit often has a different name. In our schemes we have tried to maintain the original names for each area, except for those cases in which it could create confusion. The appendix consists of a bibliographic guide which is useful in order to go back to the original definition, to eventual revisions and to the main characteristics of each unit.

However the Triassic succession in the Dolomites can be schematized as follows.

1. On the whole the Early Triassic is occupied by the Werfen Fm., a terrigenous and terrigenous-carbonate unit essentially deposited in a shallow marine to tidal flat environment. The Werfen Fm. overlies the Bellerophon Fm. which is Late Permian in age. For problems on the Permian-Triassic boundary see articles in the Field Guide-book of the Conference on Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys (S.G.I., 1986) and Posenato (1991).

The Werfen Fm. is subdivided into nine members. As some of them have been redefined over the past few years, in this work we follow the most recent version in Broglio Loriga *et al.* (1990).

2. The Scythian-Anisian boundary seems to be placed within the Lower Serla Dolomite (Broglio Loriga *et al.,* 1990), a peritidal carbonate platform extended throughout the Southern Alps, which in the easternmost Dolomites and in Carnia is known as Lusnizza Formation.

3. Several terrigenous and terrigenous-carbonate units follow, essentially Anisian in age, named the Braies Group (Pisa *et al.,* 1979; De Zanche and Farabegoli, 1982) including a number of rock units deposited in basinal, lagoonal, peritidal and continental environments. Three conglomerates (Piz da Peres Cgm., Voltago Cgm. and Richthofen Cgm.) have been found within the Braies Group in the Anisian Piz da Peres section (Fig. 2) located in Pusteria Valley-Pustertal, Northern Dolomites (De Zanche *et al.,* 1992a). Their correlation has been extended throughout the Dolomites and the Recoaro area.

In our opinion confusion exists on the definition of the Lower Serla Dm. and of the Lusnizza Formation. The latter corresponds to the Lower Serla Dm., as pointed out by De Zanche and Farabegoli (1982), as it is overlain by siliciclastics to be correlated with the Piz da Peres Conglomerate. In this sense the "Lower Serla Dm." overlying the Lusnizza Fm. in the easternmost Dolomites (*cfr.* Casati *et al.,* 1982) and in Carnia is incorrectly defined and, on the contrary, corresponds to more recent units (*e.g. Gracilis* Fm.).

4. So far in the Dolomites two Anisian carbonate platforms (Upper Serla Fm. and Contrin Fm.) are generally recognized. However in the Dolomites we have recognized and dated, but not yet formally defined, two other Anisian carbonate platforms, one Late Bithynian and the other Bithynian-Pelsonian in age (De Zanche *et al.,* 1992b). In the past both of them have been confused with the Upper Serla Formation.

5. In 1979 Viel revised the basinal Ladinian interval in the Dolomites. He distinguished a Buchenstein Group and a Wengen Group. The former includes the Livinallongo Fm., the Zoppè Sandstones and the Acquatona Fm.; the latter is divided into Fernazza Fm. and La Valle Formation. Previously the names Buchenstein and Wengen have often been used as synonymous respectively of Livinallongo and La Valle.

6. Within the Latest Anisian-Early Ladinian carbonate platforms in the Latemar region first Gaetani *et al.* (1981) distinguished a "lower edifice" to be separated from the Contrin Fm. below and the Sciliar Dm. above. Then the contributions of Goldhammer *et al.* (1987, 1990), Goldhammer and Harris (1989), Hardie *et al.* (1991) demonstrated that a high frequency cyclicity is pervasive. We think that the "Lower Edifice" is widely recognizable in the Dolomites and is to be considered a backstepping (give-up and/or catch-up) carbonate platform of Latest Anisian - Early Ladinian age (De Zanche *et al.,* 1992b).

7. The sequence stratigraphic approach allowed us to divide the Ladinian carbonate platform into three parts (see Sciliar Dolomite 1, 2 and 3 in plates 1 and 2). This result was inferred by an integrated work both on carbonate platforms and basins (Buchenstein and Wengen Groups). As a matter of fact in the basinal proximal successions the history of the platform areas is recognizable (*cfr.* Fois, 1982). However erosional and karst surfaces on the top of the buildups have been recognized. In many

Fig. 2 - Piz da Peres section from Pass Furcia (Braies/Prags area). V = Voltago Cgm.; Re = Recoaro Lm.; US = Upper Serla Fm.; R = Richthofen Cgm.; C = Contrin Fm.; S = Sciliar Dolomite.

Fig. 3 - Mt. Gusela del Nuvolau in the neighbourhood of Pass Giau (western Cadore), SW of Cortina d'Ampezzo, seen from Forcella Giau. Two Carnian carbonate platforms prograde on marls and marly limestones of the S. Cassiano Formation. In the background the Carnian - Norian succession in the Lagazuoi area. SC = S. Cassiano Fm.; CD1 = Cassian Dm. 1; CD 2 = Cassian Dm. 2; Dü = Dürrenstein Fm.; f = fault.

cases drowning facies, overlying these unconformities, have been dated by ammonites and conodonts.

The partition of the Sciliar Dm. into three bodies creates some problems in nomenclature. According to a general opinion, in the Dolomites the name "Sciliar" refers to the pre-volcanic carbonate platform, while the post-volcanic platforms are named "Cassian" (*cfr.* Bosellini, 1984, Brandner, 1991; Yose, 1991). In this sense our Sciliar Dm. 3 is post-volcanic, therefore it should be named Cassian Dolomite. As the distinction between Cassian Dm. 1 and 2 (or lower and upper) is in general use and as the original definition of Sciliar Dm. at the Sciliar area (*Schlern Dolomit* in Richthofen, 1860) includes our Sciliar Dm. 3, we prefer to maintain this name and to introduce variations only where the possibility of confusion is minimum. Otherwise the option, strictly following the rules of stratigraphic nomenclature, is to create a new name for each division of the Sciliar Dolomite.

8 - Names such as Latemar Lm., Marmolada Lm. and Rosetta Dm. need more profound investigation as in literature they refer to facies or parts of not well defined Anisian, Ladinian and Carnian carbonate platforms.

9 - In the Wengen Group some submarine debris flows are known. They are mainly included in the Fernazza Fm. and are to be referred to megaslumps related to tectonic events concomitant to Upper Ladinian volcanism. In literature they have been named "*agglomerati*" and "*caotico eterogeneo*". For a more accurated analysis see Viel (1979).

10 - It is generally accepted (Assereto *et al.,* 1977; Fois and Gaetani, 1981; Bosellini, 1984) that two Carnian carbonate platforms exist, Cassian Dm. 1 and 2, prograding and interfingering with the basinal S. Cassiano Fm. (Fig. 3).

11 - A major problem with Triassic nomenclature in the Dolomites is the definition of the S. Cassiano Formation.

As a consequence of the existence of two prograding Cassian platforms, two intervals consisting of dominant oolite packstones-grainstones are recognizable in the basins. Therefore in our opinion the S. Cassiano Fm. includes the two oolitic intervals and the interval beetwen them (skeletal grainstones, marls, shales and volcanic siltstones and sandstones) independently from the volcaniclastic supply which depends on the paleogeography. In this sense our definition is quite different from the one in Ogilvie (1893) and in Urlichs (1974) where the distinction between a Lower and an Upper S. Cassiano Fm. is based on the presence of volcaniclastics.

12 - In our scheme, lithostratigraphic units such as Dürrenstein Dolomite (Pia, 1937), Dürrenstein Fm. *p.p.* (Pisa *et al.,* 1980b), *Areniti del Dibona* and "*equivalente carbonatico delle Arenarie del Falzarego*" (Bosellini *et al.,* 1982b) belong to the Dürrenstein Formation.

13 - The vari-coloured terrigeous-carbonate interval underlying the Dolomia Principale, known as the Raibl Group or Raibl Fm., has never been clearly defined. In this paper by Raibl Fm. we mean a succession of mainly continental and paralic terrigenous-carbonate sediments which lies between the Dürrenstein Fm., or more ancient units, and the Dolomia Principale.

VOLCANISM

An understanding of the different depositional patterns within volcanic sediments is very important in the definition of depositional sequences in areas strongly affected by volcanism. In the Triassic of the Dolomites a great quantity of volcanic material is present. It is the product of a complex volcanic activity which evolved from Late Anisian to Early Carnian (Pisa *et al.,* 1980a; Bosellini *et al.*, 1982a).

In the Illyrian a moderate amount of acid to intermediate volcaniclastics (distal fallout deposits or distal turbidites rich in volcanic debris) is interbedded in terrigenous and terrigenous-carbonate basinal deposits. The depositional patterns seem to indicate hydroclastic eruptions which occurred relatively far away from a depositional site. Therefore the sediment supply from volcanism has only minor influence on the sedimentation rate. Examples are submarine fallout ash layers and/or crystal tuffs in the Bivera Fm. and submarine distal pyroclastic flows in the Ambata Formation.

During the Ladinian the depositional patterns related to volcanism are much more complicated. Early Ladinian volcaniclastics are more abundant and consist mainly of acid fallout layers and submarine pyroclastic flows interbedded with pelagic limestones (*e.g.* "pietra verde" within the Livinallongo Fm.). Even if the location of the majority of the source vents is unknown, their products seem to have originated mainly from relatively proximal hydroclastic eruptions. As an example, a pure pyroclastic layer, bearing accretionary lapilli, has been found covering more than 600 km^2 within the Recubariensis Subzone (Uppermost Fassanian). It consists of an easily recognizable key-bed and testifies to a Late Fassanian phreatoplinian event (Gianolla, 1991).

In addition to this pyroclastic layer, abundant reworked volcaniclastics (turbiditic sandstones and conglomerates including acid to intermediate lithoclasts) are recognizable. The distinction between stratigraphic intervals characterized by prevalent paleo- or neovolcanic clasts, tentatively discriminated on the basis of the methodology suggested by Zuffa (1987), can be used to define sequence boundaries and systems tracts quite conclusively.

In the Late Ladinian of the Dolomites the volcanic material was basic and was fed from fissural vents and central edifices. The extrusive rocks mainly consisted of pillow lavas, pillow breccias and hyaloclastics. Volcanic and volcaniclastic products were widespread and thick, strongly modifying the sedimentary evolution of the area. Because of the strong volcanic and volcaniclastic supply, stratal patterns of the depositional sequences may be masked and sometimes carbonate and terrigenous-carbonate deposition can be inhibited so that the sedimentary evolution inside a depositional sequence may no longer be easily recognizable. This is the reason why, during the La 3 highstand time, the prograding carbonate platform Sciliar Dm. 3 developed only in few sites.

The western Dolomites were also affected by local intrusions which are related to subaerial volcanoes (*e.g.* Predazzo-Monzoni and Cima di Pape areas). Due to emplacement of these intrusive bodies or to a caldera formation, local volcano-tectonical-related exposure surfaces or angular unconformities can be formed. These stratal discontinuities are not necessarily sequence boundaries.

Volcano-tectonic events together with strike-slip tectonics caused fault scarps which generated a lot of chaotic material, which was deposited as megabreccia sheets on the basin floor. Examples are the numerous chaotic bodies included in the Fernazza Fm. (Viel, 1979). In the literature these bodies are also known as "*agglomerati*" or "*caotico eterogeneo*". The local submarine erosional surfaces caused by the deposition of these chaotic bodies are not in general sequence boundaries. However the erosional surface, which separates the interbedded volcanics and volcaniclastics of the Fernazza Fm. from the overlying volcaniclastic wedge of the La Valle Fm., is a true sequence boundary. This interpretation is based on the fact that the overlying succession has the features of a complete depositional sequence.

During the Latest Ladinian-Carnian, volcanism was not as widespread and consists of local effusions at the top of the Marmolada Cgm. in the Padon area (Rossi *et al.*, 1974) and of fallout layers interbedded in the La Valle Fm. in the Zoldo area. However, adjacent basinal areas received a great amount of volcaniclastic debris from the erosion of previous volcanics.

The volcanic material was mainly derived from the West. During the same time interval paleovolcanic lithoclasts, together with metamorphic and extrabasinal carbonate and terrigenous clasts, came from the South. These sediments represent a normal siliciclastic supply. Biochronostratigraphy correlates the sequence stratigraphic interval of the southern source with the volcanics of the western source. Therefore it is possible to understand how the sequences were modified by the volcanism.

BIOCHRONOSTRATIGRAPHY

The revision of the Triassic stratigraphy in the Dolomites and the interpretation in terms of sequence stratigraphy have been made possible by a new, highly resolved ammonite standard scale, which exploits the finding of a great number of ammonites.

This new standard scale by Mietto and Manfrin (in progress, *cfr.* De Zanche *et al.*, 1992c) extends the philosophic approach for the Carnian biostratigraphy in Krystyn (1978) to Middle Triassic. It is based on the definition of a zone succession characterized by genera; in turn each zone is subdivided into a number of subzones defined by species (Fig. 4). Within Middle Triassic these subzones allow a biochronostratigraphic resolution which was previously unthinkable and are extendible throughout the Tethys; moreover they have been compared with all the available data in the provinces outside of the Tethys.

The sections in the Southern Alps, which have furnished the biostratigraphic data for the development of the new Middle Triassic ammonite standard scale, are shown in figure 5 (from Mietto and Manfrin, in progress). The scheme points out the succession of the subzonal markers or of other faunas outside the Southern Alps, but inside the Mediterranean domain, inferred from literature.

This biochronostratigraphic frame has made it possible to date the 3rd order Latest Bithynian to Early Carnian depositional sequences quite accurately. Dating of the other Triassic depositional sequences is much more inaccurate as biostratigraphic data are occasional and/or scanty.

The application of this scale to the successions in the Dolomites has been markedly advantageous as many of the type sections are placed within the Dolomites and as the number of new ammonites, collected bed to bed in the

STAGES & SUBSTAGES		ZONAL SCHEME from MIETTO & MANFRIN (Julian p.p. / Tuvalian from KRYSTYN in ZAPFE, 1983) ZONES	SUBZONES	ZONAL SCHEME from TOZER in HAQ et al. (1987)
CARNIAN	TUVALIAN	ANATROPITES	Italicus	ANATROPITES
			Plinii	
		SUB-BULLATUS	Subbullatus	TROPITES
			Crasseplicatus	
		DILLERI	no subdivision yet	SUBBULLATUS
	JULIAN	AUSTRIACUM	"Sirenites"	AUSTRO-TRACHYCERAS AUSTRIACUM
			Austriacum	
		TRACHY-CERAS	Aonoides	TRACHYCERAS AONOIDES
			Aon	
			Daxatina sp.	
LADINIAN	LONGOBARDIAN	PROTRA-CHYCERAS	Regoledanus	PROTRACHYCERAS ARCHELAUS
			Neumayri	
			Longobardicum	
			Gredleri	
			Margaritosum	EOPROTRACHYCERAS CURIONII
	FASSANIAN	EOPROTRA-CHYCERAS	Recubariensis	
			Curionii	
		NEVADITES	Chiesense	TICINITES POLYMORPHUS
			Serpianensis	
			Crassus	
ANISIAN	ILLYRIAN	HUNGARITES	Avisianum	
			Friccense	PARACERATITES TRINODOSUS
		PARACERA-TITES	Trinodosus	
			Abichi	
	PELSO-NIAN	BALATONITES	Binodosus	PARACERATITES BINODOSUS
			Balatonicus	
			Cuccense	
	BITHYNIAN	KOCAELIA	not yet defined	ANAGYMNOTOCERAS ISMIDICUM
			Ismidicus	
			not yet defined	
			Osmani	NICOMEDITES OSMANI
	AEGEAN	PARACRO-CHORDI-CERAS	no subdivision yet	?

Fig. 4 - A comparison between the new ammonite standard scale by Mietto and Manfrin and the one by Tozer in Haq *et al.* (1987).

Dolomites, and the amount of examined materials in the historical collections is enormous.

Rich ammonites faunas, found both in basinal deposits and in terrigenous and carbonate shelf successions, made it possible for the first time to draw time lines not only in the Dolomites but throughout the Southern Alps.

In default of ammonites, conodonts have been used. However it is worth underlining that, in comparison with the new ammonite scale, conodont resolution is far lower.

Rich associations of tetrapod footprints, either in continental or sometimes in tidal flat facies, suggest the possibility in the future of useful ichnofossil biochronostratigraphy.

DEPOSITIONAL SEQUENCES

Six 3rd order depositional sequences have been recognized within the Scythian succession, four in the Anisian, three in the Ladinian, four in the Carnian, while those in the Norian-Rhaetian are not well defined (Fig. 6, Pls. 1 and 2). They are far more numerous than those in literature (Brandner, 1984; Haq *et al.,* 1987; Doglioni *et al.,* 1990; Bosellini, 1991), but well comparable with the Triassic 3rd order sequences in the Barents Sea (Skjold *et al.,* 1992).

Biochronological control is not uniform. The depositional sequences from An 2 to Car 2 are well calibrated by means of ammonites or conodonts; the remaining ones are dated only by isolated biostratigraphic data from field or from literature.

The Sc 1 - Sc 6 depositional sequences (Fig. 7) have mainly been proposed on the basis of a re-interpretation of data from literature (Farabegoli and Viel, 1982; Broglio Loriga *et al.* 1983, 1990; Ghetti and Neri, 1983; Neri, 1991).

Every depositional sequence will be briefly described.

The following abbreviations are used in the text, in the plates and figures:

DS = depositional sequence, SB = sequence boundary, LST= lowstand systems tract, SMW= shelf margin wedge, TST= transgressive systems tract, HST= highstand systems tract, lpc= lowstand prograding complex, tlpc = top lowstand prograding complex, ts = transgressive surface, mfs = maximum flooding surface.

Sequence Sc 1

It consists of the uppermost Bellerophon Fm., the Tesero Horizon and of the Mazzin Member of the Werfen Formation.

The lower SB is to be placed at the sharp contact within the uppermost part of Bellerophon Fm. where an increase in skeletal grains and siliciclastics (*cfr.* Bosellini, 1964) and where a sea-level drop (*cfr.* Farabegoli *et al.,* 1986) are shown. In the western Southern Alps (Assereto *et al.,* 1973) the Tesero Hor. unconformably overlies a Permian continental substratum (Verrucano Lombardo).

The upper SB is to be placed at the base of the Andraz Hor., in correspondence to an abrupt boundary between open shelf sediments and supratidal deposits.

The unit A_0 in Broglio Loriga *et al.* (1990, fig. 4), consisting of bioclastic packstones and wackestones and terrigenous-carbonate grainstones (corresponding to the top of the Bellerophon Fm.), could be related to a clastic wedge referred to not yet clearly defined LST or SMW deposits.

The Tesero Hor., a widespread oolitic event throughout the northern margin of the Tethys (oolite grainstones and intraclastic intercalations), and the lower part of the Mazzin Mb. (grey marly-silty mudstones) form the TST. The mfs is to be placed way down half the Mazzin Mb. where maximum depth and bioturbation are reached.

The HST includes the upper part of the Mazzin Mb. (characterized by an increase in storm layers) which shows a shallowing upward trend (Broglio Loriga *et al.,* 1990).

Sequence Sc 2

On the whole the Andraz Horizon, the Siusi Mb., together with the lowermost part of the Gastropod Oolite

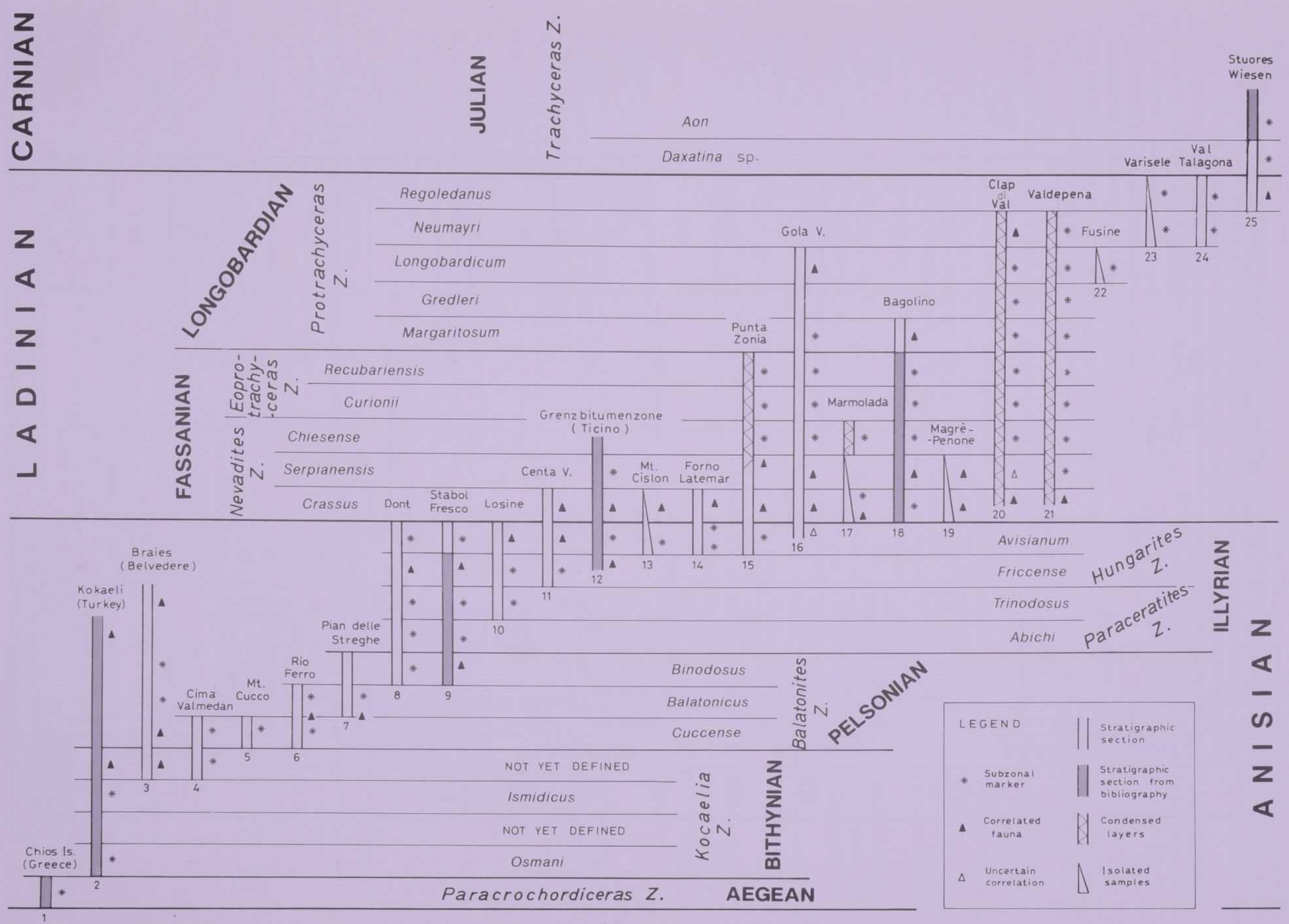


Fig. 5 - Ammonite zonal markers in the Triassic sections in the Mediterranean area (from Mietto and Manfrin).

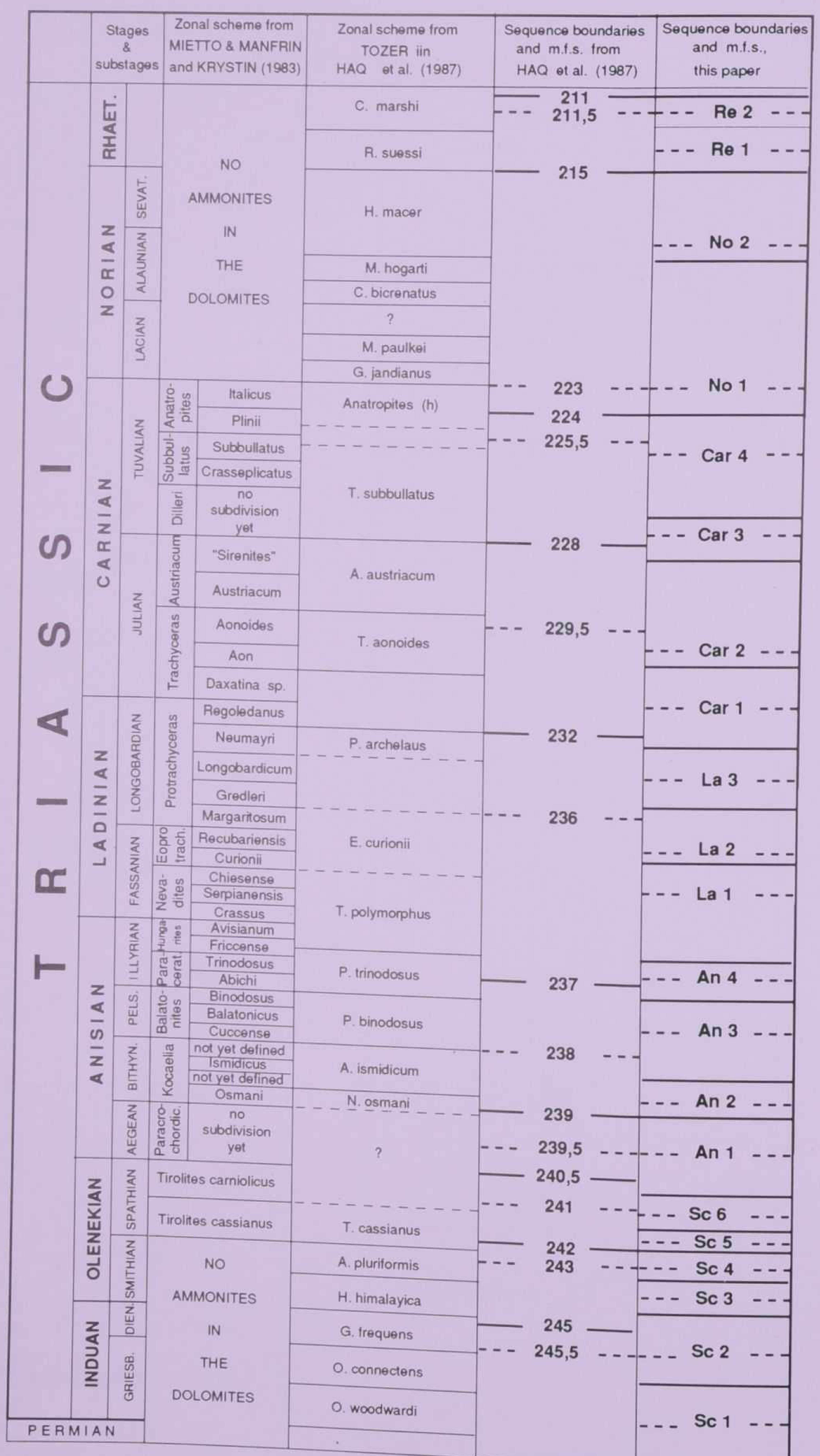


Fig. 6 - A comparison between the 3rd order sequence scale in this paper and the one by Haq *et al.* (1987).

Mb., could well correspond to a type-2 depositional sequence.

Due to a downward shift of coastal onlap, the lower SB is to be placed at the abrupt superimposition of yellowish marly-silty dolomites (Andraz Hor.) above marls and marly mudstones (Mazzin Mb.).

The upper SB corresponds to the top of the supratidal carbonate-terrigenous interval of the lowermost Gastropod Oolite Member.

The SMW deposits consist of stacking shallowing upward cycles made up of yellowish silty dolomites and multicoloured laminated marls and siltstones.

The ts is to be placed at the boundary between the supratidal facies of the Andraz Hor. and the subtidal deposits of the Siusi Member.

The TST includes a few metres of oolite-intraclastic-bioclastic packstones and grainstones overlain by alternating marly mudstones and bioclastic packstones. Ravinement surfaces and conglomerate layers (Koken Cgm. *Auct. p.p.*) are common and suggest a backstepping pattern.

Mfs can be placed at the middle of the member, where offshore facies prevail and bioturbation is stronger.

The upper part of the Siusi Mb., including sandstones and hummocky laminated calcarenites, and the inter-supratidal marls and siltstones of the basal part of the Gastropod Oolite Mb., corresponds to the HST and is to be related to the basinward migration of facies. The Siusi Mb./Gastropod Oolite Mb. boundary is transitional.

Sequence Sc 3

It includes the majority of the Gastropod Oolite Mb. and the Campil Member.

The lower SB lies within the Gastropod Oolite Mb. at the sharp transition from supratidal and subtidal deposits.

The upper SB corresponds to the abrupt superimposition of the supratidal lowermost Val Badia Mb. on the open shelf deposits of the uppermost Campil Member.

The TST includes the upper part of the Gastropod Oolite Mb. (alternating sandstones, arenaceous limestones, oolite-bioclastic-intraclastic grainstones and packstones). Ravinement surfaces are common at the base of intraformational breccias (= Koken Cgm. *Auct. p.p.*).

The mfs could be placed at the top of the Gastropod Oolite Member.

The Campil Mb., consisting of red laminated siltstones and sandstones with an upwards increasing sand content and wave influence, forms the HST.

Sequence Sc 4

The lower part of the Val Badia Mb. constitutes a type-2 depositional sequence.

The lower SB is placed at the sharp contact between the sandstones and siltstones of the Campil Member and the supratidal marly dolomites of the basal Val Badia Member.

The upper SB corresponds to the surface separating the supratidal lithozone lying within the Val Badia Mb. (unit C in Broglio Loriga *et al.,* 1990, fig. 8) from the upper part of the same member.

The SMW consists of peritidal yellowish-grey marly dolomites and reddish siltstones (unit A in Broglio Loriga *et al.,* 1990, fig.8).

The TST begins with a well marked ts and includes alternating biocalcarenites and marly mudstones (unit B in Broglio Loriga *et al.,* 1990). This interval includes a lot of ammonites (*Tirolites* beds *Auct.*).

The mfs could be placed within the ammonite beds.

The HST corresponds to the peritidal terrigenous-carbonate interval (lower unit C in Broglio Loriga *et al.,* 1990).

Sequence Sc 5

The upper part of the Val Badia Mb. corresponds to a new depositional sequence.

The lower SB is to be placed inside the peritidal interval in unit C (Broglio Loriga *et al.,* 1990, fig. 8). Unfortunately the generalized poor outcrop conditions do not permit exact placing of this surface.

The upper SB corresponds to the surface separating the sandstones of the Val Badia Mb. from the calcarenites of the Cencenighe Member.

The TST includes alternating mainly grey bioturbated mudstones, silty/sandy bioclastic packstones and grainstones. Wave influence and strong reduction of sand/pelite ratio decrease upwards.

The mfs is to be placed in correspondence with ammonite rich beds about half way down unit D in Broglio Loriga *et al.* (1990).

The uppermost part of the Val Badia Mb. shows a new progradational feature and testifies to a shallowing upward trend and an upward increase in hummocky and cross bedded sandstones (HST).

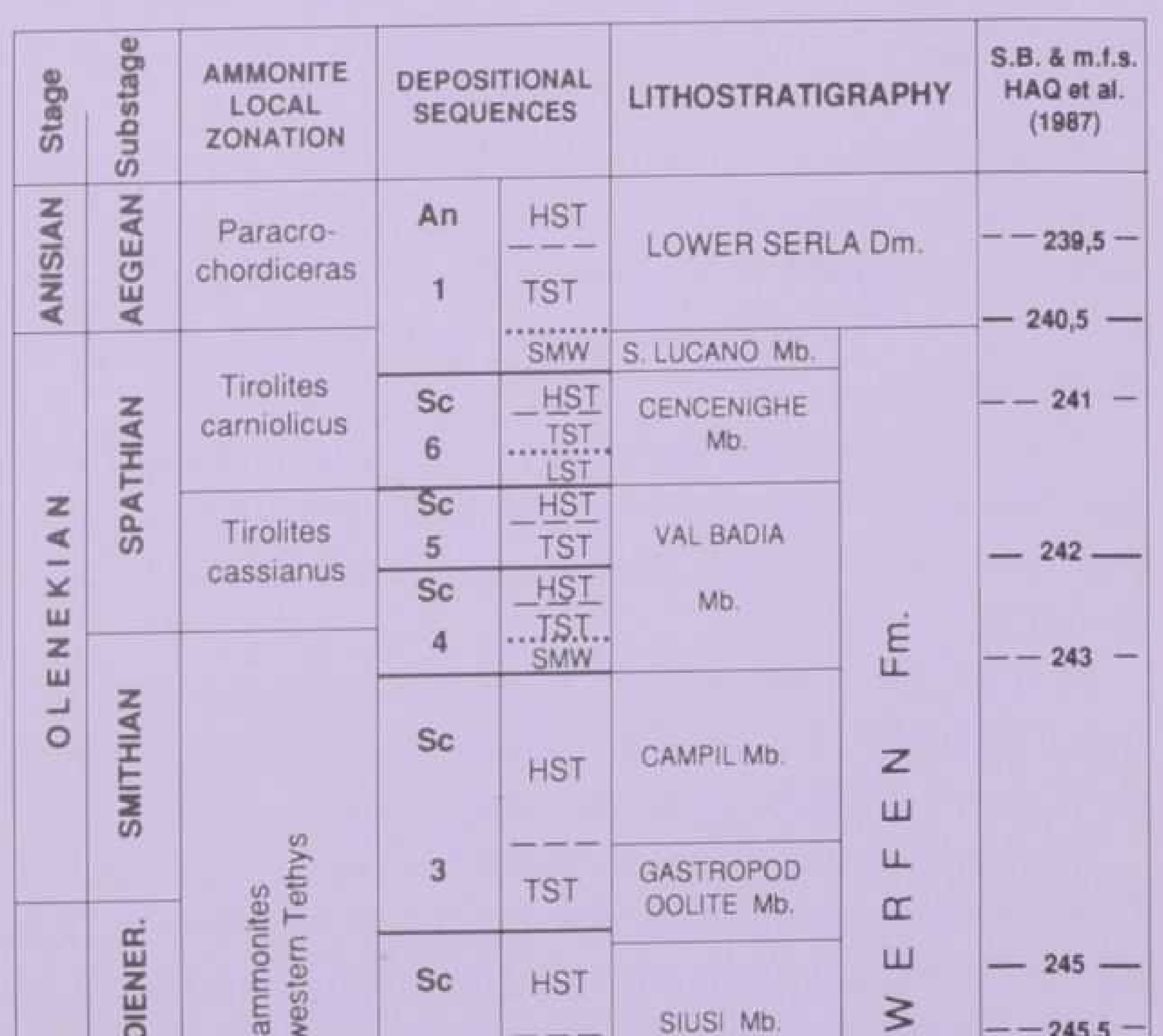


Fig. 7 - A scheme of the Scythian depositional sequences in the Dolomites. This proposal is a re-interpretation of data from literature, mostly Broglio Loriga *et. al.* (1983, 1990) and Neri (1991).

Sequence Sc 6

The Cencenighe Mb. forms a third order depositional sequence.

The lower SB corresponds to the surface separating the sandstones of the Val Badia Mb. from the oolite-bioclastic calcarenites of the basal Cencenighe Member. Locally this boundary corresponds to a subaerial exposure surface (Broglio Loriga *et al.,* 1990).

In the Recoaro area (southernmost Southern Alps) this surface corresponds to the erosional base of the Mt. Naro Breccia, a fluvial deposit mostly consisting of crystalline metamorphic clasts, which grades upwards to the Cencenighe Mb. (De Zanche and Farabegoli, 1981). Due to its stratigraphic position the Mt. Naro Breccia could correspond to the Terra Rossa Siltones mb. (Ghetti and Neri, 1983), defined in the neighbourhood of Trento and comprised between the Campil Mb. and the Cencenighe Member.

The upper SB is to be placed at the boundary between the Cencenighe Mb. and the S. Lucano Member.

The TST consists of oolite grainstones, marls and siltstones from the lower part of the member. The mfs is to be placed in the rich ammonites beds (*Dinarites dalmatinus* Hauer).

The HST is made up of crinoid and oolite grainstones and packstones, siltstones and sandstones.

Sequence An 1

Sequence An 1 includes the S. Lucano Mb. of the Werfen Fm. and the Lower Serla Dolomite. The latter is considered in the sense of De Zanche *et al.* (1992a). Due to Anisian erosion this sequence is normally lacking in the Dolomites. It is however recognizable in peripheral or external areas of the Badioto-Gardenese High.

Bad and scanty exposure does not permit a good definition of the lower part of this sequence. The lower SB seems to be placed at the base of the S. Lucano Mb. as its lower part shows prevalent supratidal features (Farabegoli *et al.,* 1977).

The upper SB corresponds to a subaerial erosional surface (northern Dolomites) or to a paraconformity (central-eastern Cadore) at the top of the Lower Serla Dolomite.

In the Dolomites the TST seems to correspond to the upper part of S. Lucano Mb. and to the lower portion of the Lower Serla Dm., which are subtidal.

The mfs could be placed within the Lower Serla Dolomite between its subtidal and supratidal parts. This unit is a peritidal carbonate platform extended throughout the Southern Alps and consisting of white or pale grey dolomitic mudstones and wackestones. In its upper part an increase in supratidal events (mud cracks, tepees, caliches, red surfaces) is related to a decrease in accomodation space. Therefore this interval corresponds to the HST.

Sequence An 2

It includes the Piz da Peres Cgm. (Braies area) or its lateral corresponding siliciclastics, the *Gracilis* Fm. and a not yet formally defined carbonate platform.

The lower SB is placed in correspondence to a subaerial erosional surface at the top of the Lower Serla Dm. (Fig. 8) underlying the Piz da Peres Cgm. (*e.g.* Braies area, northern Dolomites, in De Zanche *et al.,* 1992a). In central-eastern Cadore it corresponds to a paraconformity between the Lower Serla Dm. and fine-grained siliciclastics at the base of the *Gracilis* Formation.

Outside the Dolomites (*e.g.* Recoaro area, Valsugana and neighbourhood of Trento) this unconformity is emphasized by the superimposition of the Val Leogra Breccia on the Lower Serla Dolomite (De Zanche *et al.,* 1981; Cucato *et al.,* 1988; De Zanche and Mietto, 1989).

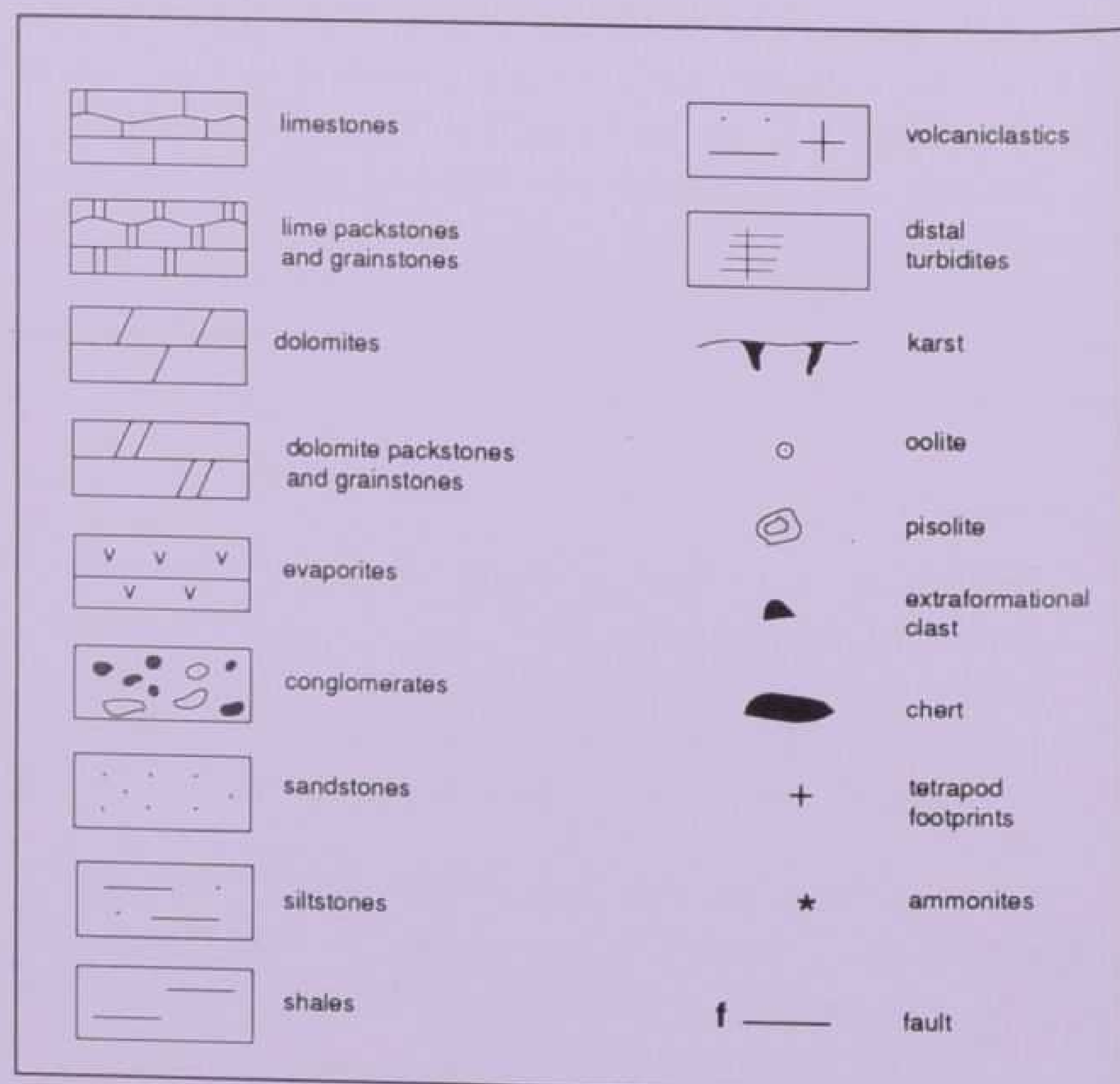
The upper SB is to be placed at a subaerial erosional surface between the *Gracilis* Fm. and the Voltago Conglomerate.

As this sequence is deposited in a ramp setting, the LST only consists of infilling of weakly incised valleys (*e.g.* Piz da Peres in De Zanche *et al.,* 1992a).

The TST corresponds to terrigenous-carbonate sediments in the upper part of the Piz da Peres Cgm. where an upward decrease in siliciclastics is shown. The mfs is to be placed at the base of the *Gracilis* Fm., consisting of wackestones and dasycladacean packstones-grainstones interlayered by calcsiltites and siltstones (HST).

Locally in the Braies area, in the Zoldo area and in Carnia the *Gracilis* Fm. is heteropically overlain by a carbonate platform (not yet formally defined and containing dasycladaceans, foraminifers and *Tubiphytes*) which corresponds to the late HST in those areas.

Only indirect biochronostratigraphic data permit us to determine the age of this sequence. However ammonite data from the Aegean domain (Chios and Kokaeli, Bender, 1967; Assereto, 1974; Assereto *et al.,* 1980; Fantini Sestini, 1981, 1988) allows us to place the SBs at the base of An 2 and An 3 (Fig. 4, Pl. 2). It is possible to correlate the conglomerates in Chios and Kokaeli respectively with the Piz da Peres Cgm. and Voltago Cgm. in the Dolomites where Latest Bithynian ammonites have been



Legend to figure 8.

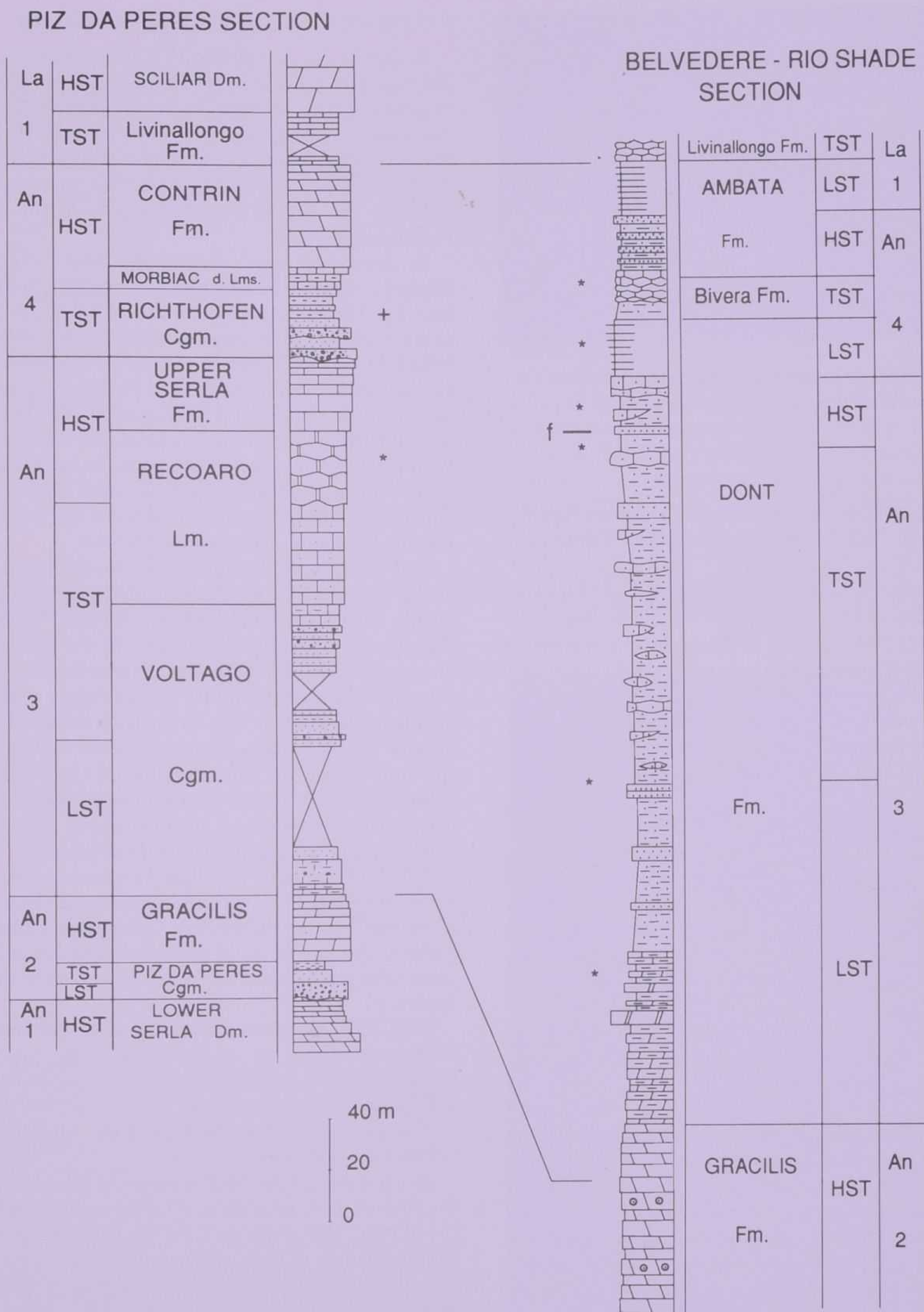


Fig. 8 - Schematic relationships of the Anisian units in the Braies/Prags area (northern Dolomites).

found in sections at the base of the An 3 depositional sequence.

Sequence An 3

In the Dolomites this sequence includes the Voltago Cgm., the Agordo Fm., the Recoaro Lm., the Dont Fm. *p.p.* and the Upper Serla Formation *s.s.* and a not yet formally defined backstepping carbonate platform.

The lower SB is marked by an erosional surface which in shelf areas deeply cuts the *Gracilis* Fm. (Braies area *p.p.*, Adige Valley, westernmost Valsugana) or older units (Agordo and Zoldo area, Mt. Cernera). In the Recoaro

Fig. 9 - Rio Shade (Braies/Prags area). Lowermost Dont Fm., LST of the An 3 DS.

area it is a surface of abrupt facies change between the *Gracilis* Fm. and the overlying continental Voltzia beds (De Zanche and Mietto, 1981).

The upper SB is placed at the erosional and karst surface at the top of the Upper Serla Fm.; in the basins the correlative conformity lies at the beginning of a strong increase in siliciclastics which characterizes the upper part of the Dont Formation.

The Voltago Cgm. is made up of conglomerates, sandstones, siltstones and claystones mostly red in colour. In the emerged areas the late LST consists of the infilling of incised valleys (*e.g.* NW slope of the Piz da Peres, Bechstädt and Brandner, 1970; Spitz Agnellessa, Farabegoli *et al.,* 1977; Mt. Pore, Blendinger, 1983).

In the areas characterized by a ramp setting (*e.g.* Piz da Peres area) the LST consists of a wedge of siliciclastics and biocalcarenites while in the basinal areas it is composed of sandstones, siltstones and biocalcarenites containing scanty Latest Bithynian-Early Pelsonian ammonites (Fig. 9).

The TST includes sandstones, siltstones and limestones in the upper part of the Voltago Cgm., the lower part of the Recoaro Lm. and of the Agordo Fm. as they show a fining and deepening upward trend. Locally a not yet formally defined backstepping carbonate platform (Fig. 10) grew above previous Bithynian prograding carbonate platforms (De Zanche *et al.,* 1992b). The mfs is to be placed in an ammonite-rich bed (Balatonicus Subzone) inside the Dont Fm.; in the Recoaro Lm. and in the Agordo Fm. it corresponds to the appearance of nodular, bioturbated, fossil-rich wackestones-packstones.

The HST corresponds to the upper part of the Recoaro Lm.-Agordo Fm. (aggradational part of HST), generally rich in biocalcarenites, due to the growth and prograding of the Upper Serla carbonate platform (progradational part of HST). In the basinal succession the deposits relating to HST time are characterized by a new increase in siliciclastics and biocalcarenites (*e.g.* Dont Fm. in the Zoldo area). The age of HST is well defined as Balatonicus Subzone *p.p.* to lowermost part of Abichi Subzone.

Sequence An 4

Sequence An 4 includes the Richthofen Cgm., the Morbiac dark Lms. and the Contrin Fm. in the shelf areas (Badioto-Gardenese High, on the whole corresponding to the western Dolomites), whereas it includes the Moena Fm. *p.p.* in the marginal and tectonically active areas. In the basins sequence An 4 includes the uppermost Dont Fm., the Mt. Bivera Fm. and a part of the Ambata Formation (Fig. 10).

In continental areas, such as the Badioto-Gardenese High, the lower SB corresponds to a strong erosional surface (Fig. 11) which deeply cuts the underlying units as far as the Scythian and Permian ones (Bosellini, 1968). In the Villaverla 1 A.G.I.P. well the lower SB coincides with an angular unconformity on the pre-Permian metamorphic basement (De Zanche and Farabegoli, 1981). In the shelf areas it corresponds to the erosional and karst surface at the top of the Upper Serla Formation. In basinal areas the lower SB is represented by a conformity lying inside the upper part of Dont Fm. and is placed at the beginning of a strong increase in siliciclastic turbidites.

In the shelf areas the upper SB corresponds to the top of the Contrin Fm. which is eroded and/or karstified locally in the Dolomites (Cime d'Auta, Costabella, Viezzena), but also in Carnia and in the Recoaro area (lower part of the Mt. Spitz Lm., unpublished data). The correlative basinal conformity can be drawn at about the middle of the Ambata Fm. in correspondence to a new increase in siliciclastics. However in the Dolomites it is common to find the superposition of the *Plattenkalke* (Livinallongo Fm.) on the Contrin Formation. This boundary seems to correspond to a drowning unconformity emphasized by a marked increase in subsidence .

The LST includes infilling of incised valleys (*cfr.* Farabegoli *et al.,* 1977) and a progradational clastic wedge in the shelf areas (Richthofen Cgm. *p.p.*), while in the basins it consists of distal turbidites and lenses of conglomerates and sandstones (uppermost part of the Dont Fm.).

The TST comprises the remaining part of the Richthofen Cgm. or, in the basins, the Mt. Bivera Formation which is made up of red and grey pelagic nodular limestones and siltstones.

The mfs is placed at the top of the Mt. Bivera Fm. (Trinodosus Subzone).

In basinal areas the HST consists of the lower part of the Ambata Fm., whereas in shelf areas it is made up of the Morbiac dark Lms. and the Contrin Formation. Due to progradation of the carbonate platform (Contrin Fm.) and to basinward migration of the source of terrigenous supply, the lower part of the Ambata Fm. consists of fine silty and sandy calcarenites interbedded with marls, siltstones and sandstones.

On the whole the age of HST deposits belonging to the An 4 depositional sequence is to be referred to Trinodosus *p.p.* and Friccense Subzones.

Sequence La 1

In the basins, sequence La 1 includes the upper part of the Ambata Fm., the *Plattenkalke* and a part of the

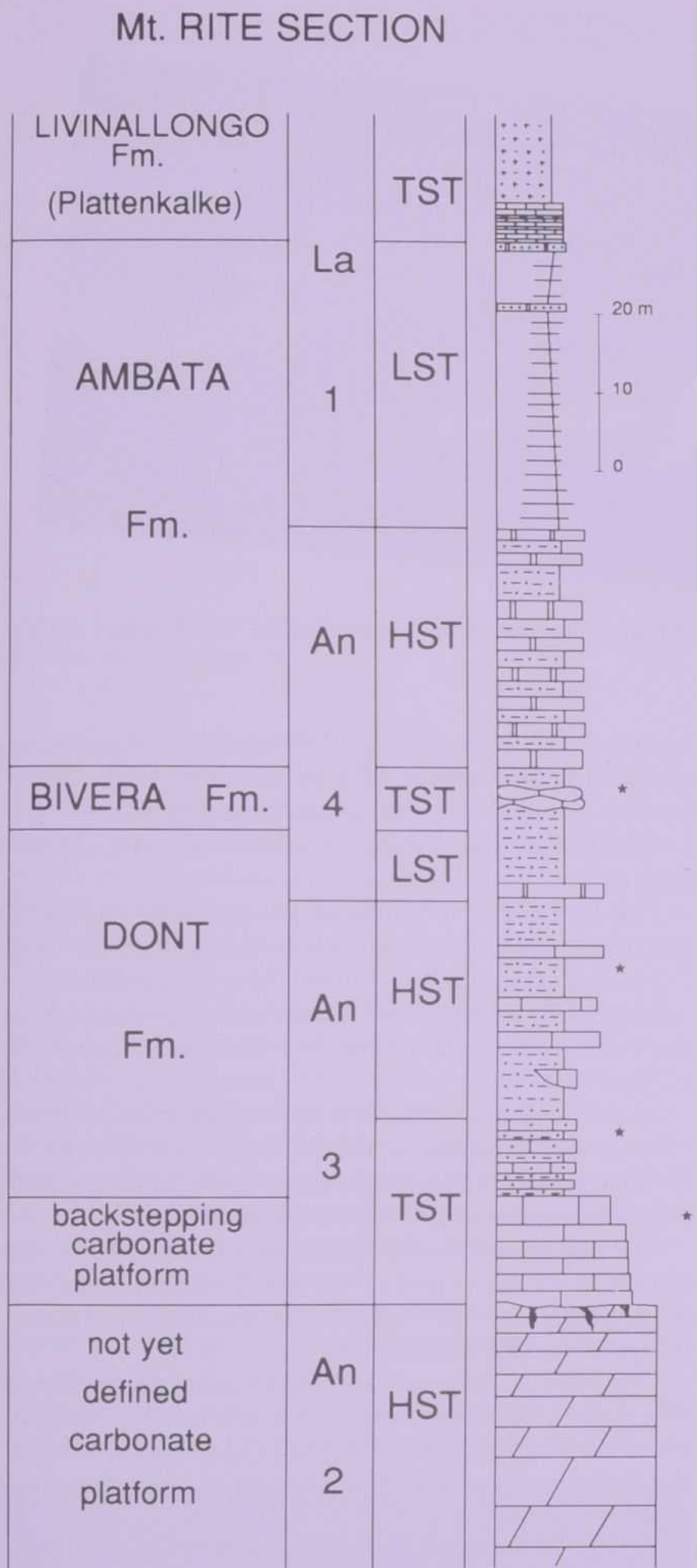


Fig. 10 - Mt. Rite section (central-eastern Cadore). Early Bithynian-Early Ladinian stacking depositional sequences. So far the two lower carbonate platforms correspond to the "Upper Serla Dolomite" in Farabegoli and Guasti (1980). Legend as in figure 8.

Knollenkalke of the Livinallongo Fm., while in the shelf areas it comprises the "Lower Edifice" and the Sciliar Dm. 1.

The lower SB mainly corresponds to the non depositional unconformity, or the locally erosional surface, on top of the Contrin Fm. and, in the basins, to the sharp conformable boundary between calcarenites and marls (lower Ambata Fm., previous HST) and the hemipelagites and fine turbidites (LST) which characterize the upper part of the Ambata Fm. (= "*Marne a Daonella*" of the Authors). Locally the lpc includes conglomerates and sandstones (*cfr.* Casati *et al.*, 1982, eastern Cadore).

In the western Dolomites the Contrin Fm. was affected by synsedimentary extensional tectonics which generated the basins where the Moena Fm. was deposited. So far within the Moena Fm. it has not always been easy to distinguish the sediments deposited during the La 1 LST time from those corresponding to the An 4 HST.

The lower SB is to be placed in the Friccense Subzone and the tlpc within the Avisianum Subzone.

The upper SB corresponds to the top of the Sciliar Dm. 1. In the Latemar massif it corresponds to the boundary between the upper tepee facies, which exhibits a decrease in accomodation space (HST La 1), and the overlying subtidal facies (transgressive part of the Sciliar Dm. 2). In the basins it lies within the *Knollenkalke* of the Livinallongo Fm. in correspondence to a strong increase in siliciclastics (mainly reworked volcaniclastics).

The TST of this sequence is complex as it develops with different characteristics in the various situations. In

Fig. 11 - Rio Ruaz section (neighbourhood of Livinallongo, NW Dolomites). Angular unconformity between the Werfen Fm. and the Richthofen Cgm., lower SB of the An 4 DS. W = Werfen Fm.; R = Richthofen Conglomerate.

Fig. 12 - Mt. Cavignon (Latemar area, SW Dolomites). Backstepping carbonate platform of the "Lower Edifice". TST of the La 1 DS. (Photo by G. Roghi)

the basins it includes the *Plattenkalke* and/or a part of the *Knollenkalke* of the Livinallongo Fm., whereas in the strongly subsiding shelf areas it consists either of the *Plattenkalke* or of a catch-up (locally give-up) carbonate platform ("Lower Edifice"). Both the *Plattenkalke* and the "Lower Edifice" started in the Avisianum Subzone.

The *Plattenkalke* consist of pelagic bituminous dark laminated limestones, calcsiltites and shales to be related to an anoxic environment; the part of the *Knollenkalke* which is included in the TST is made up of pelagic nodular cherty limestones with tuff and tuffite intercalations ("pietra verde"). The "Lower Edifice" (Fig. 12) grew only above previous Contrin platforms and consists of a set of backstepping shallowing-upward carbonate parasequences frequently bearing ammonites (De Zanche *et al.*, 1992b).

On the basis of the lithostratigraphic and biostratigraphic setting throughout the Southern Alps, the mfs is to be placed within the Chiesense Subzone. As a matter of fact during this period the transgressive platform was definitely drowned, whereas in the basins an ammonite-rich interval ("*Chiesense* groove" in Brack and Rieber, 1986), or a condensed layer, was formed (Fig. 13).

During HST time a carbonate platform (Sciliar Dm. 1) aggraded and moderately prograded basinward; therefore the proximal basinal sediments (*Knollenkalke*) are characterized by upwardly increasing calcarenites.

The age of the HST ranges between the Chiesense and lowermost Recubariensis Subzones.

Sequence La 2

Sequence La 2 includes the Sciliar Dm. 2 and the upper part of the Livinallongo Formation.

The lower SB corresponds to the top of the Sciliar Dm. 1; the correlative conformity in the basinal succession corresponds to the strong increase in siliciclastics which divides the *Knollenkalke* of the Livinallongo Fm. into two parts.

The upper SB is placed at the top of the eroded and karstified Sciliar Dm. 2 (*e.g.* Col Piombin, in Assereto *et al.*, 1977; Schlern region, Sd I in Brandner, 1991). In the basin it corresponds to the sharp boundary between the Livinallongo Fm. (*Bänderkalke*) and the Zoppè Sandstones.

The LST mainly consists of volcaniclastic turbidites deriving from erosion of volcanic belts (*e.g.* Ru Torto near Zoppè di Cadore, Colle S. Lucia). Near the platform margins the LST deposits may be formed by carbonate arenites, rudites and megabreccias (*e.g.* Sass da Putia in Fois, 1982).

In the shelf areas the TST consists of subtidal dolomites probably located at the base of Sciliar Dm. 2 (*cfr.* Goldhammer, 1991); in the basins it corresponds to a portion of the upper part of the *Knollenkalke*.

The mfs lies within the Recubariensis Subzone, recognizable in the upper part of the *Knollenkalke*; on the top of the Sciliar Dm. 1 it is locally documented by red pelagic limestones (*e.g.* Mt. Cernera).

The HST is characterized by a strong progradation (Fig. 14) of the Sciliar Dm. 2 (*e.g.* Catinaccio, Schlern), often masking the Sciliar Dm. 1 which, on the contrary, in the Dolomites seems to be much more aggrading than prograding.

In the basins the platform progradation is testified to by an upward increase in biocalcarenites within the upper part of the Livinallongo Formation.

The HST is to be referred to the Recubariensis-Gredleri *p.p.* Subzones.

Sequence La 3

In the Dolomites this sequence includes the Sciliar Dm. 3 in shelf areas, whereas basinal successions are composed by the Zoppè Ss., Acquatona Fm. and the Fernazza Formation (Fig. 15). Basic volcanics are widespread.

The lower SB is to be placed on the top of the eroded and karstified Sciliar Dm. 2, while in the basins it corresponds to the boundary between the Livinallongo Fm. and the Zoppè Sandstones (*e.g.* Rio Sacuz in the Cernera

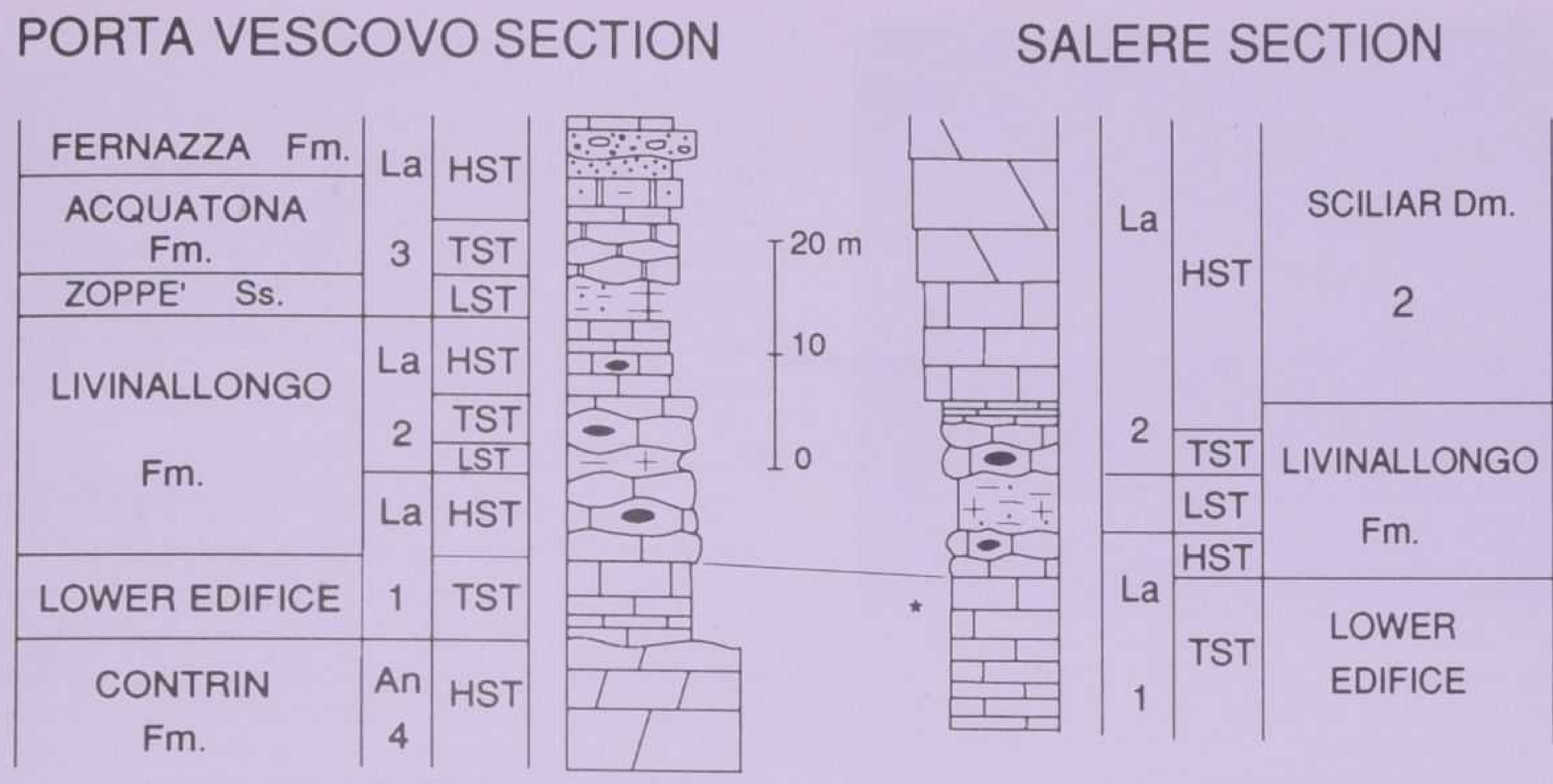


Fig. 13 - Porta Vescovo - Salere sections (Marmolada area, SW Dolomites). Relationships between a basinal and a proximal succession. Legend as in figure 8.

massif; Zoppè di Cadore).

The upper SB coincides with the top of Sciliar Dm. 3, strongly eroded and karstified (*e.g.* Schlern region, "Rosetta Dm." in Brandner, 1991); in the basins it corresponds to the boundary between the Fernazza Fm. and the La Valle Fm. (*e.g.* Piz Zorlet in Viel, 1979; Pass Duran in Siorpaes and Gianolla, 1991; Padon; Punta Grohmann).

The LST is represented by the Zoppè Ss. which consist of arkosic turbiditic sandstones. The lower part of the Zoppè Ss. is composed of massive or amalgamated turbidites (basin floor fan). A lithozone, consisting of thin-bedded turbidites, the highest of which are channelized, overlies the massive sandstones and is interpreted as a slope fan. The upper part of the unit is characterized by a thickening and coarsening upward turbiditic succession, considered to be a lpc (Fig. 16).

The ts is marked by the sudden transition between the sandstones and the dark calcilutites of the Acquatona Formation.

The mfs coincides with a fossil-rich layer lying in the upper part of the Acquatona Formation. In the Latemar Massif ammonite bearing neptunyan dikes have been found (Gaetani *et al.,* 1981). This mfs is well documented throughout the Southern Alps, in shelves as well as in the basins (Longobardicum Subzone).

In the Dolomites the La 3 HST is generally influenced by a strong volcanism which produced a great quantity of lavas and volcaniclastics. Volcanic activity seems to be strictly connected with a strike-slip tectonics which is responsible for local uplifts, compressional structures, normal faults and chaotic deposits (*cfr.* Rossi *et al.,* 1977; Viel, 1979).

In the areas not or less affected by volcanism the La 3 HST is made up of marls and sandstones (*e.g.* Pass Duran in Siorpaes and Gianolla, 1991), to be related to the progradation of the southern shoreline. In shelf areas carbonate platforms are also present (Sciliar Dm. 3) prograding on volcaniclastics of the Fernazza Fm. (*e.g.* Schlern region, Sd II, tongue 1, in Brandner, 1991 and FS-1 in Yose, 1991; Sass da Putia in Fois, 1982; S. Lucano area, in Gianolla, 1988). The age of the HST is well documented as the interval Longobardicum - Neumayri Subzones.

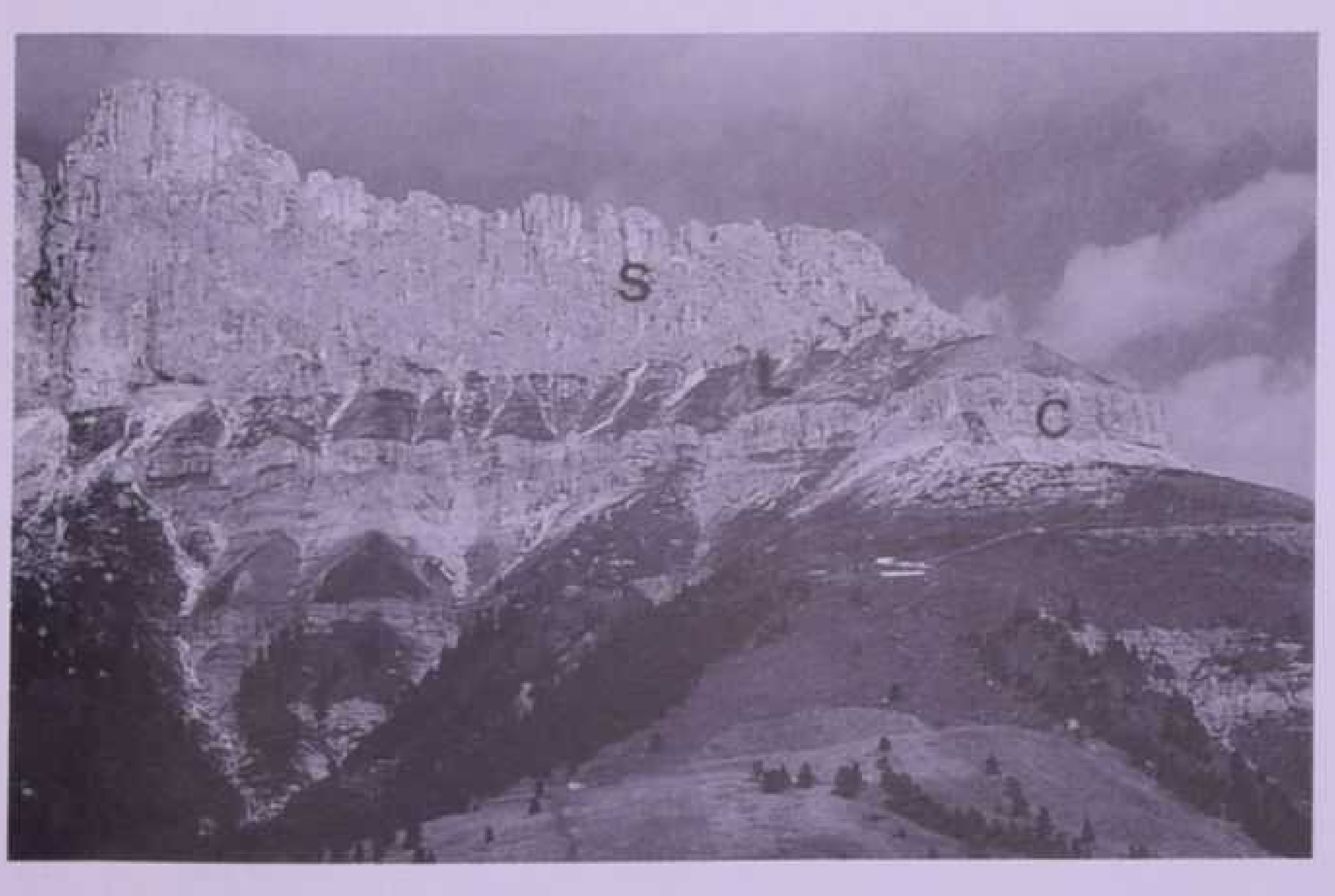


Fig. 14 - Catinaccio/Rosengarten (NW Dolomites). Basinward strong progradation of the Sciliar Dm. 2 on the Livinallongo Formation. C = Contrin Fm.; L = Livinallongo Fm.; S = Sciliar Dm. 2. (Photo by L. Iovane).

Sequence Car 1

This sequence includes Cassian Dm. 1 in the shelf areas while in the basinal areas it comprises the La Valle Fm. (including its Civetta Cgm. and Marmolada Cgm. members) and the lower part of the S. Cassiano Formation.

The lower SB corresponds to a strong karst surface on top of the Sciliar Dm. 3 or older carbonate platforms (*e.g.* Pale di San Martino in Zampieri, 1987). In the basins the SB is marked by the transition from the volcaniclastics of the Fernazza Fm. to a few metres of distal turbidites (overlain by paraconglomerates). In the western Dolomites the lower SB is a major submarine erosional surface between the Fernazza Fm. or volcanics and the Marmolada Conglomerates. Locally the erosion cuts deeply into the underlying units (Castellarin *et al.,* 1977; Bosellini *et al.,* 1977; Doglioni, 1984).

The upper SB is placed at the top of Cassian Dm. 1, eroded and karstified; in the basins it corresponds to a

Fig. 15 - Mt. Cernera (western Cadore). Late Ladinian volcaniclastics onlap the Sciliar Dm. slope (La 2 - La 3 SB).

submarine erosional surface or to a correlative conformity inside the S. Cassiano Fm. above which a strong increase in siliciclastics has been recognized (Fig. 18).

In the basins the early LST (Neumayri Subzone) corresponds to distal turbidites and hemipelagites of the La Valle Formation. In the western Dolomites the early LST is characterized by coarse strongly erosional volcaniclastic conglomerates (Marmolada Cgm. *p.p.*) deriving from erosion in nearby subaerial volcanic areas. The late LST (Regoledanus Subzone) consists of a turbiditic complex made up of conglomerates (Civetta Cgm., Marmolada Cgm. *p.p.*), sandstones and shales (Fig. 17). Skeletal grain supported calcarenites and hybrid sandstones often bearing karstified carbonate blocks are widespread.

Marls, marly limestones and calcilutites, belonging to the Regoledanus Subzone, define the TST.

During HST time the Cassian Dm. 1 prograded on the lower part of the S. Cassiano Fm. (*e.g.* Richthofen Riff, Sasso Bianco, Mt. Coldai and Dürrenstein), consisting of alternating marls, marly limestones, oolite packstones-grainstones, biocalcarenites and sandstones (Fig. 19). In the southern areas, where there are no carbonate platforms, the HST is made up of prodelta to submarine delta deposits (*e.g.* Pass Duran in Siorpaes and Gianolla, 1991).

SEQUENCE CAR 2

The depositional sequence Car 2 includes the upper part of the S. Cassiano Fm. and Cassian Dm. 2.

The lower SB is a karst surface located on top of the Cassian Dm. 1. In the S. Cassiano basinal facies this surface corresponds to the beginning of a strong increase in

Fig. 17 - Pecol (Zoldo area). Coarsening and thickening upward sandstones of the La Valle Fm. (lpc of Car 1 DS).

Fig. 16 - Piz del Corvo (Mt. Cernera area, western Cadore). View of the La 3 DS. Z = Zoppè Ss.; A = Acquatona Fm.; F = Fernazza Fm.; c = chaotic debris flow within the Fernazza Formation.

siliciclastics and skeletal grain calcarenites.

The upper SB is placed at the top of Cassian Dm. 2 which is an erosional and karst surface (*e.g.* Mt. Coldai in Fois and Gaetani, 1981). In basinal areas it is placed in correspondence to the sharp boundary between alternating sandstones and oolitic calcarenites of the uppermost S. Cassiano Fm. and the dolomites of the Dürrenstein Formation.

The lpc consists of prevailing siliciclastics of the S. Cassiano Fm. (Aon-Aonoides Sbzs.) onlapping on the slope of Cassian Dm. 1 (Fig. 20).

The TST consists of ammonite-rich marls and marly limestones and the mfs is referred to the Aonoides Subzone (*fide* Urlichs, 1974).

The HST is represented by Cassian Dm. 2 strongly prograding onto the basinal sediments (oolite grainstones-packstones, biocalcarenites and marls) of the upper S. Cassiano Fm. (Aonoides Subzone - Austriacum Zone).

At the end of this sequence the Triassic basins in the Dolomites are almost completely infilled.

Sequence Car 3

The Car 3 depositional sequence consists of sediments of carbonate-terrigenous shallow water facies

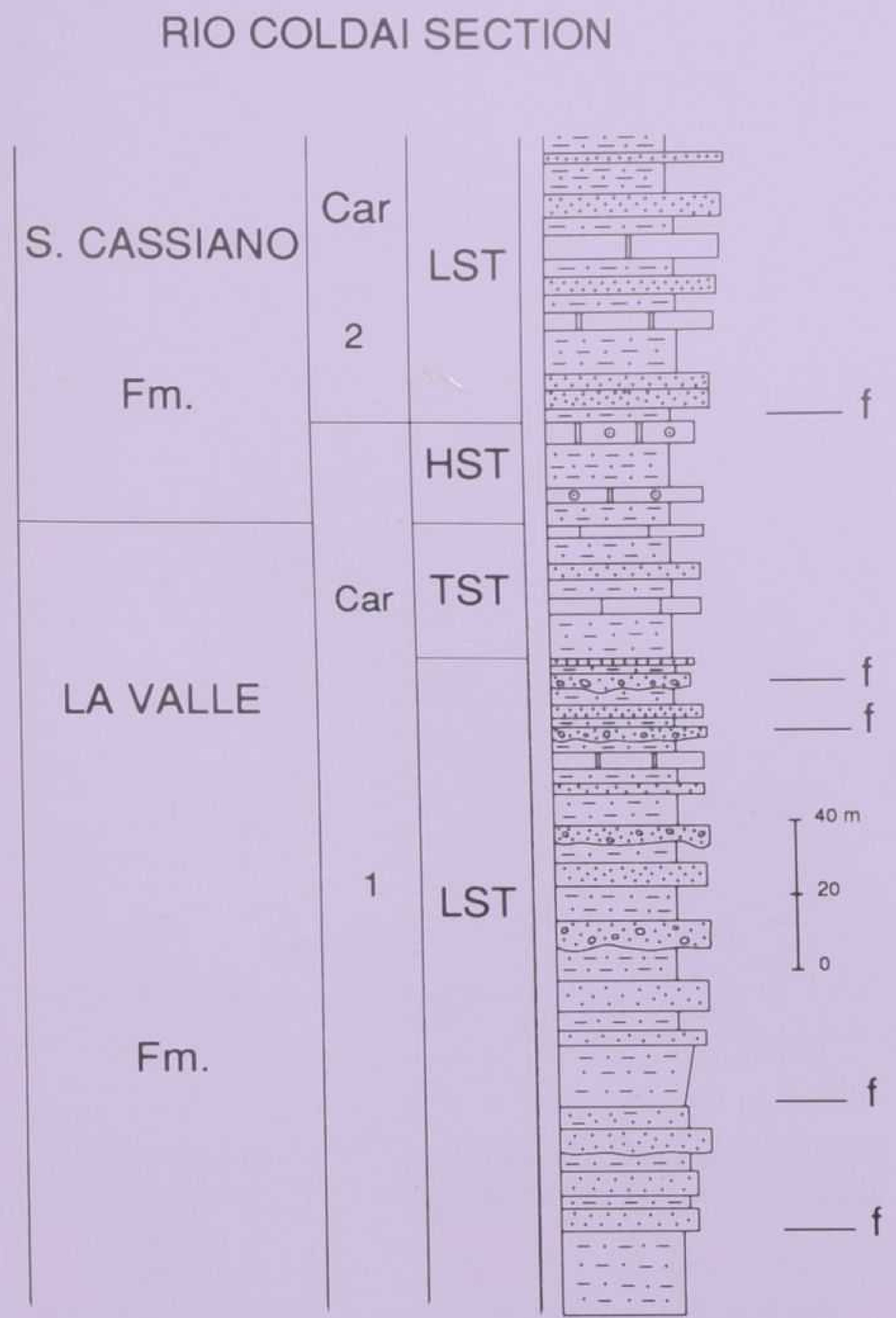


Fig. 18 - Schematic column of the Rio Coldai section (Zoldo area). Legend as in figure 8.

Fig. 19 - Pralongià (Stuores Wiesen, Arabba area, NW Dolomites). Alternating sandstones, shaly siltstones and oolite packstones/grainstones of the S. Cassiano Fm. (Car 1 DS). In the background the Settsass and Richthofen Riff Carnian carbonate platforms.

(Dürrenstein Fm.).

The lower SB is placed at the top of the eroded and karstified Cassian Dm. 2. In the previous basinal areas, occupied by prograding deltas of the Car 2 HST (*e.g.* Marmarole area), it corresponds to the pedogenetic horizon developed on coastal deposits.

The upper SB consists of a well developed erosional surface on the peritidal dolomites of the upper part of the Dürrenstein Formation.

This sequence starts with a carbonate SMW (Fig. 21) onlapping on the Cassian Dm. 2 slope; the arenaceous dolomites, deposits related to this systems tract, pinch out landward of the offlap break of the previous HST (*e.g.* Pass Falzarego area). In the southern and eastern areas a siliciclastic input is also present.

Calcarenites, sandstones and shales, overlying the shelf margin sediments, form the TST (Fig. 22). On top of this package, fossil-rich marls define the mfs; ammonites are also present but they are not classifiable. Where the Dürrenstein Fm. is mainly carbonate the TST is made up of thickening upward peritidal dolomites whose subtidal intervals are prevalent.

The HST is shown by prograding inner carbonate plat-

Fig. 20 - Richthofen Riff. Onlap of S. Cassiano Fm. on the slope of the Cassian Dm. 1 (Car 1 - Car 2 SB). CD 1 = Cassian Dm. 1; SC = S. Cassiano Fm.; CD 2 = Cassian Dm. 2.

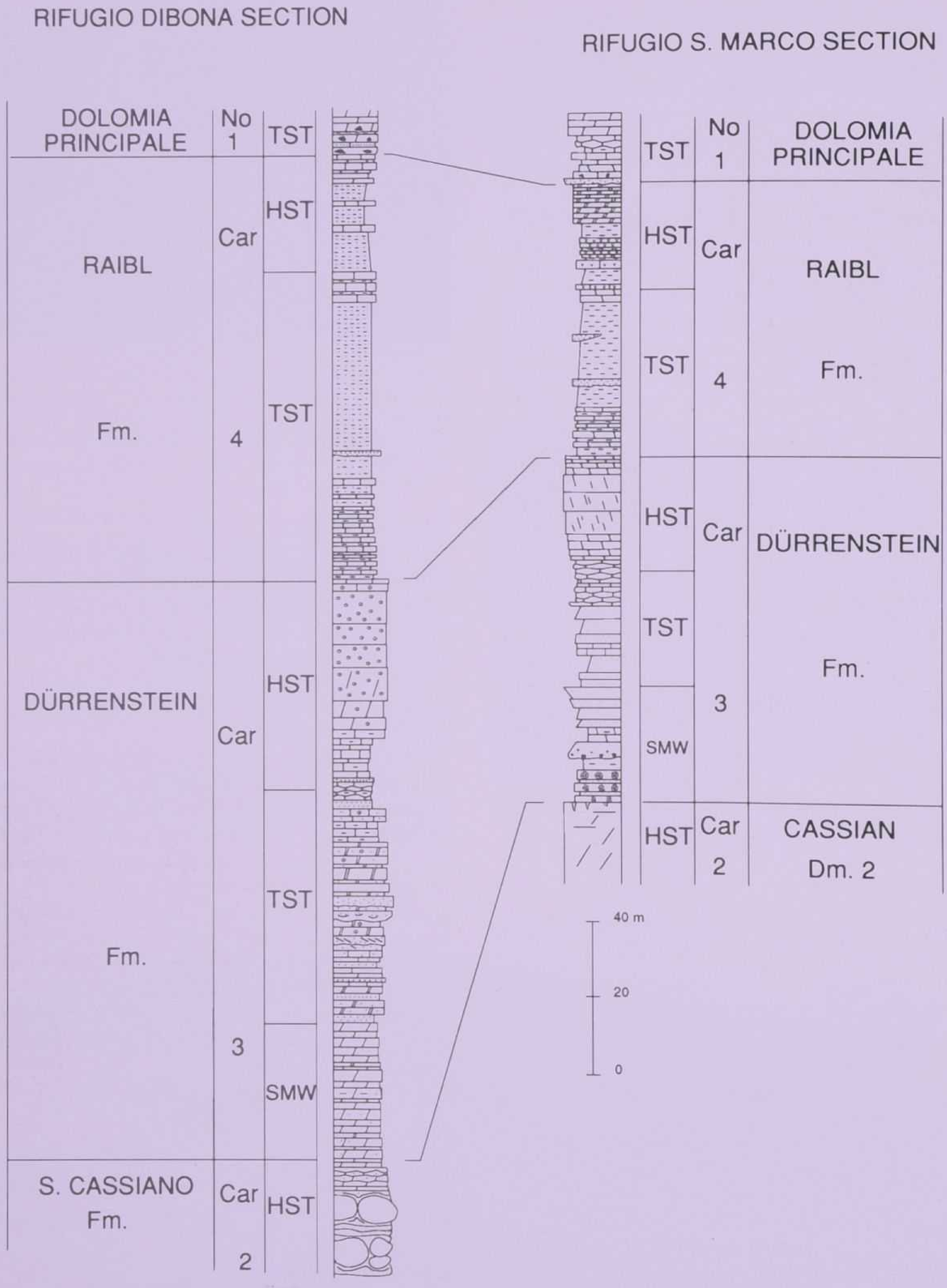


Fig. 21 - Relationships between the Carnian units in the neighbourhood of Cortina d'Ampezzo. Schematic columns of the Rifugio S. Marco section (Mt. Antelao area) and Rifugio Dibona section (Tofane area). Legend as in figure 8.

form facies on outer platform facies (*e.g.* Lastoi di Formin in Bonaga *et al.*, 1989). On the whole the former are characterized by upward thinning, by an upward increase in paleosoils and by widespread supratidal facies. A dolomitized oolitic complex is created in the Tofane-Antelao area.

The age of this sequence has not yet been well defined. Data from outside the Dolomites (Carnia and Tarvisio areas) seem to indicate a Latest Julian - Early Tuvalian age.

SEQUENCE CAR 4

The Car 4 depositional sequence corresponds to the Raibl Formation.

The lower SB is a major regional unconformity. South

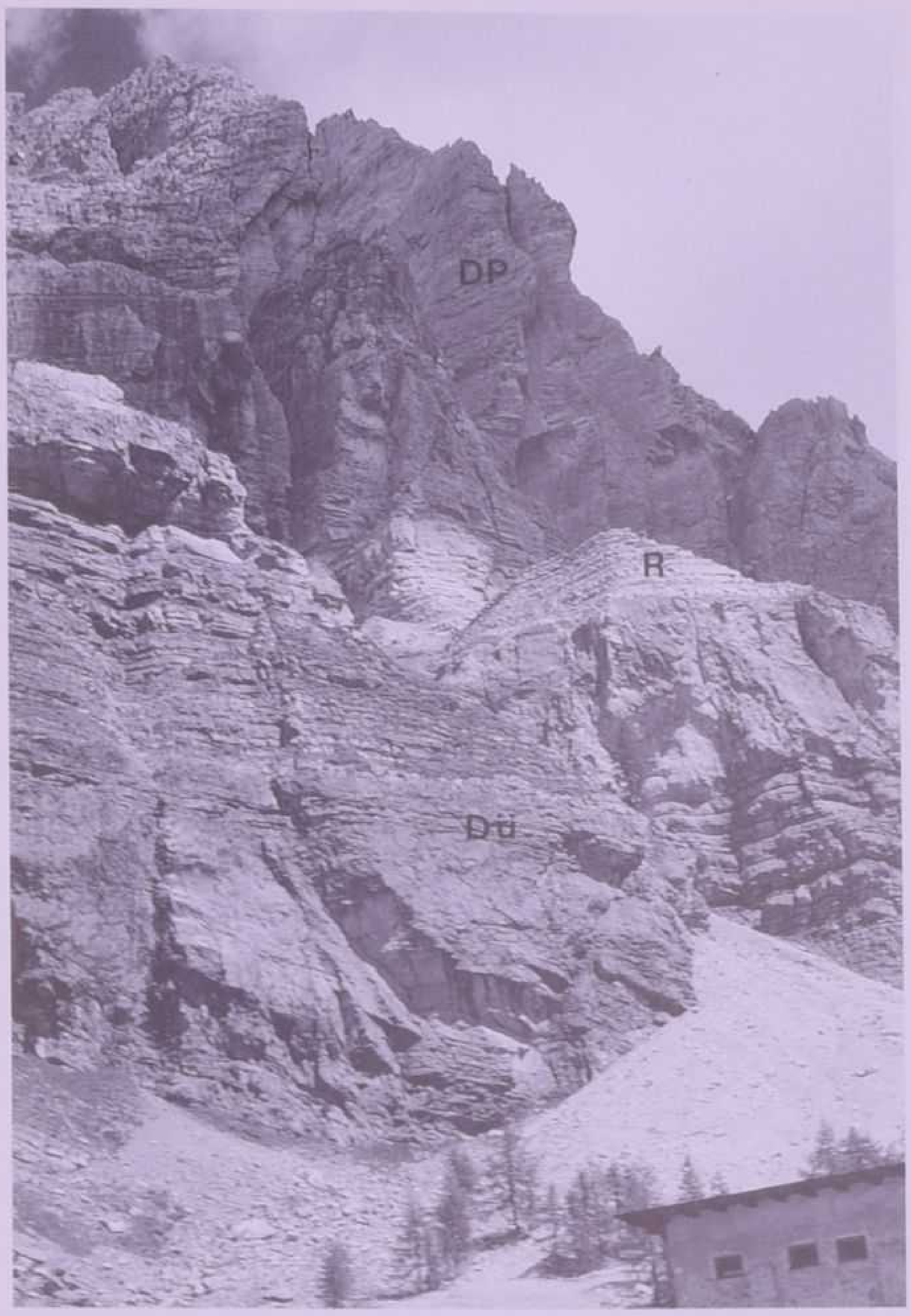


Fig. 22 - Rifugio Dibona section (Tofane area). Dü = Dürrenstein Fm.; R = Raibl Fm.; DP = Dolomia Principale.

of the Dolomites (*e.g.* Recoaro area) it cuts the underlying units deeply.

The upper SB corresponds to an unconformity marking the top of the Raibl Formation (Fig. 21).

The LST is recorded only in the southern Dolomites (Fig. 23) and mainly consists of the infilling of incised valleys (Pass Duran, Siorpaes and Gianolla, 1991). Due to extensional tectonics local basins have been generated and infilled by polygenic conglomerate wedges (*e.g.* Mt. Pelmetto, Mt. Framont).

The well-known sandstones, siltstones, varicoloured shales, aphanitic dolomites and muddy limestones belong to the TST (Fig. 24). The mfs is reached at the base of the overlying paralic and sabkha deposits.

The limestones, calcarenites, shales, vuggy dolomites and gypsum, forming the upper part of the Raibl Fm., can be referred to the HST as they show a thinning upward trend and increasing supratidal features.

The age of this sequence has not yet been defined in the Dolomites as no ammonites or conodonts are known in this area. Scanty data from eastern basins seem to suggest a Tuvalian age for lateral correspondents of the Raibl Formation.

Norian-Rhaetian Sequences

In the Latest Carnian - Rhaetian the Dolomites were occupied by a carbonate tidal flat and lagoon environment (Bosellini, 1973) in which the Dolomia Principale (Fig. 25) and the Dachstein Lm. were respectively deposited.

The definition of third order depositional sequences inside these formations is a real problem throughout as, in an interval of about ten Ma, more than one SB should exist. So far however, with the exception of the No 1 DS, up to date other depositional sequences have not yet been defined. The analysis of the variation in accomodation space inside the units may solve this problem in the future.

Sequence No1

This sequence includes the lower part of the Dolomia Principale.

The lower SB is to be placed at the base of the breccias and the erosional extraformational fine conglomerates which characterize the base of the Dolomia Principale.

The upper SB is uncertain. Hypothetically it could correspond to the base of the shale layer at about a hundred m from the base of the unit (Tofane, Mt. Pelmo, Piz Boè, etc.). These shales form a typical ledge within the lower part of the Dolomia Principale (*cfr.* top of the Membro I of the Dolomia Principale in Bosellini, 1965a). Moreover these shales could be correlated with the Passo Buse Scure Breccia (a channellized fluvial deposit bearing crystalline basement clasts) cropping out in the Recoaro area (De

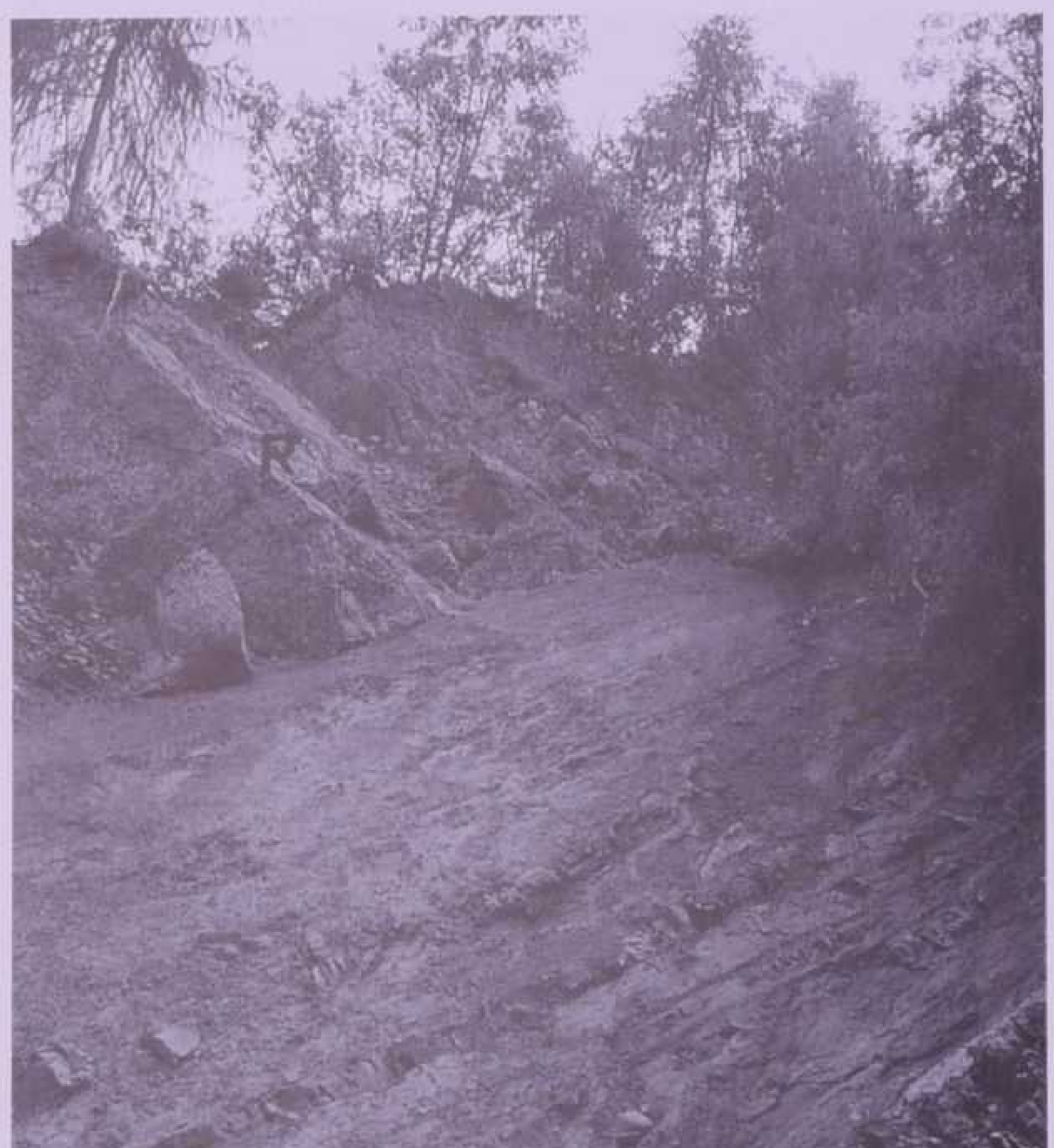


Fig. 23 - Pass Duran (Agordo area). Fluvial conglomerates of the Raibl Fm. infilling a valley incised in marls of the Car 2 DS. R = Raibl Formation.

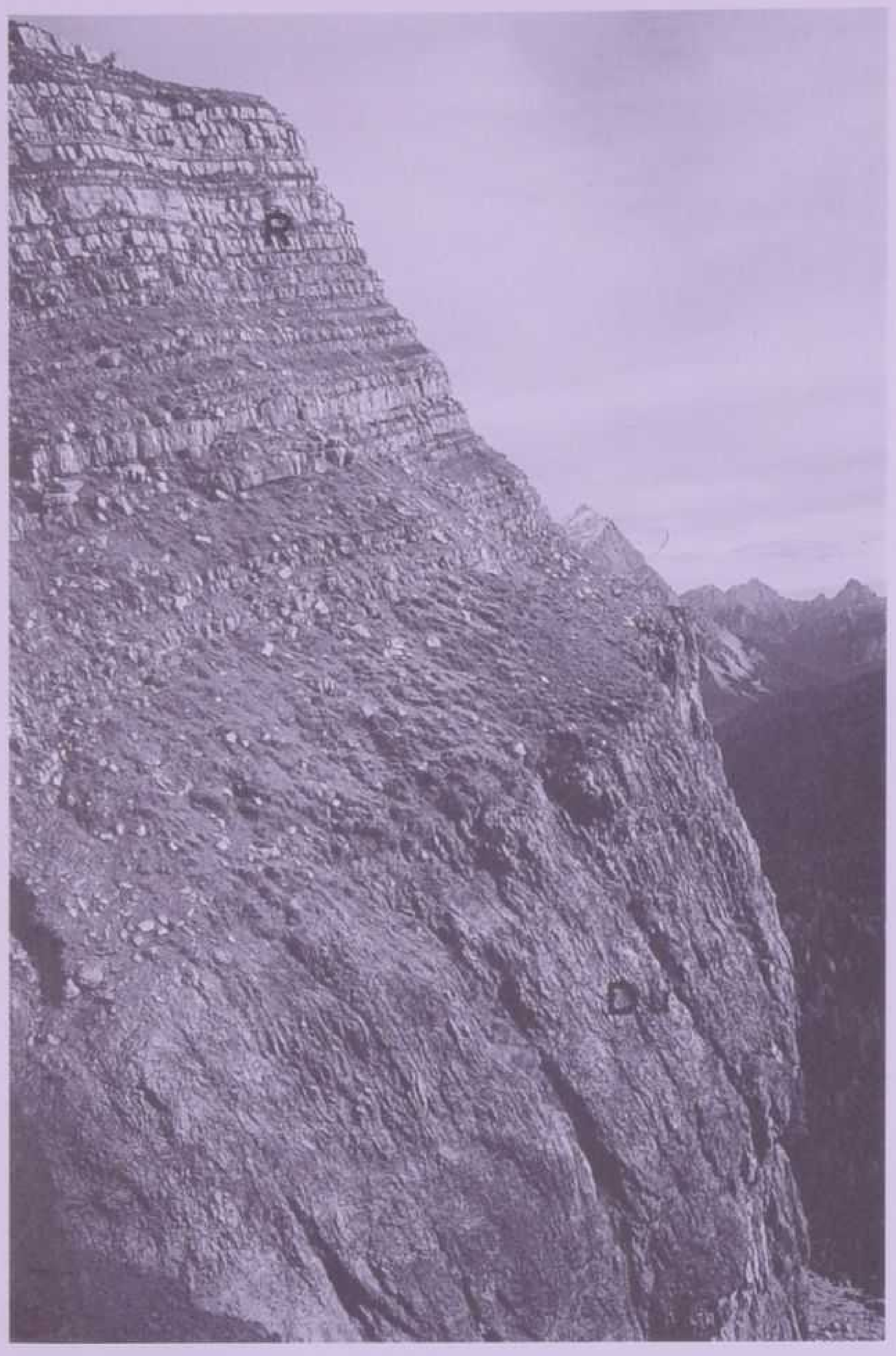


Fig. 24 - Rifugio Dibona section. Unconformity between oolite grainstones of the Dürrenstein Fm. and paralic facies of the Raibl Formation. (Car 3 - Car 4 SB). Dü = Dürrenstein Fm.; R = Raibl Formation.

Zanche and Mietto, 1984). Consequently this suggests the existence of at least a No 2 depositional sequence.

In the Dolomites deposits of LST are not available, because the shoreline break was shifted a long way, probably eastward. Incised valley infillings have not yet been recognized.

Fig. 25 - Tofane group (neighbourhood of Cortina d'Ampezzo). The Dolomia Principale overlies the Raibl Formation.

Fig. 26 - Dinosaurs footprints in the Dolomia Principale of the Mt. Pelmetto (Zoldo area).

The TST deposits are made up of intraformational breccias (*e.g.* Sella Group, Tofane, Pass Duran) interlayered with micritic and pelletiferous dolomites; locally (Mt. Antelao area) dark laminated dolomitic limestones are present. In an inner platform, such as the one where the Dolomia Principale was mainly deposited, the mfs may be placed at the top of the thickest layer, according to the variation in accomodation space.

The HST could correspond to the interval in which dinosaur footprints (Fig. 26) have been discovered (Mt. Pelmetto area, Mietto, 1988), just some metres under the ledge which seems to mark the upper SB of the No 1 depositional sequence.

CONCLUSIONS

In spite of the existence of strong and prolonged extensional synsedimentary tectonics, which influences the accomodation space, it seems to be demonstrated that, with the biochronostratigraphic control available, the signal of Triassic sea level changes in the Dolomites is always recognizable. Compressional structures seem to be only local and to be related to strike-slip tectonics or to volcanotectonics.

Of course the Dolomites comprise too small an area to draw global sequence stratigraphic results. However our data, supported by a highly resolved ammonite scale, have been controlled and are extensible throughout the Southern Alps (De Zanche *et al.,* 1992b; Gianolla *et al.,* 1992).

We think that the proposed sequence stratigraphic frame of the Triassic in the Dolomites has made it possible to understand the known lithostratigraphic setting far better; the course of research will produce new data and therefore an improvement of this scheme.

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APPENDIX

A GUIDE TO TRIASSIC LITHOSTRATIGRAPHIC NOMENCLATURE IN THE DOLOMITES

Lithostratigraphic name (Author)
Age
See also
Remarks

Acquatona Formation (Viel, 1979)
Late Ladinian
Blendinger *et al.* (1984); Casati *et al.* (1982).
A formation of the Buchenstein Group. It corresponds to the "Pseudolivinallongo" in Rossi e Viel (1977).

Agordo Formation (Pisa *et al.,* 1979)
Late Anisian (Pelsonian)
Farabegoli *et al.* (1977); De Zanche *et al.* (1992a).

Andraz Horizon (Bosellini, 1968)
Late Griesbachian
Farabegoli e Viel (1982); Broglio Loriga *et al.* (1983, 1990).
A member of the Werfen Fm.

Ambata Formation (Assereto *et al.,* 1977)
Late Anisian (Illyrian)
Assereto and Pisa (1978); Casati *et al.* (1982).

Bivera Formation (Pisa, 1974)
Late Anisian (Illyrian)
Assereto *et al.* (1977); Pisa *et al.* (1979); Farabegoli e Guasti (1980); Casati *et al.* (1982); Farabegoli *et al.* (1984).

Buchenstein Group (Viel, 1979)
Latest Anisian-Late Ladinian *p.p.*
De Zanche and Farabegoli (1988); De Zanche (1990)

Campil Member (*Campiller Schichten*, von Richthofen, 1860; emend. Bosellini, 1968)
Smithian
Broglio Loriga *et al.* (1983, 1990).

Cassian Dolomite (*Cassianer Dolomit*, Mojsisovics, 1879)
Early Carnian (Julian)
Cros (1974); Van Houten (1930); Pisa *et al.* (1980b); Fois and Gaetani (1981); Gianolla *et al.* (1991); Biddle *et al.* (1992).
The terms Lower and Upper Cassian Dm. were introduced by Assereto *et al.* (1977) and correspond to the Cassian Dm. 1 and 2.

Civetta Member (Viel, 1979)
Latest Ladinian (Late Longobardian)
Siorpaes e Gianolla (1991).
A member of the La Valle Formation. In this work the term Civetta Cgm. is used in the sense of a polygenic conglomerate facies of the Civetta Member.

Contrin Formation (*Contrinkalk*, Ogilvie Gordon und Pia, 1940; emend. Assereto *et al.,* 1977 and Farabegoli *et al.,* 1977)
Illyrian
Pisa *et al.* (1979), Gaetani *et al.* (1981), De Zanche *et al.* (1992a).
This term was introduced in order to define the undolomitized "Oberer Sarldolomit" in the western Dolomites. In this area the "*Oberer Sarldolomit*" coincides with the Contrin Fm., lying above the Richthofen Cgm. and under the *Plattenkalke* of the Livinallongo Fm. or the Sciliar Dolomite. The "*Oberer Sarldolomit*" in Pia (1937)

includes both the Upper Serla Fm. and the Contrin Fm.

Dachstein Limestone (*Dachsteinkalk*, Hauer 1853)
Rhaetian
Casati *et al.* (1982).

Dolomia Principale (*Hauptdolomit*, Gümbel, 1873)
Latest Carnian-Rhaetian
Bosellini (1965a); Bosellini and Hardie (1988)

Dont Formation (*Dontkalk*, Mojsisovics, 1882)
Anisian (Latest Bithynian-Earliest Illyrian)
Assereto (1971); Assereto *et al.* (1977); Farabegoli (1979); Pisa *et al.* (1979).

Dürrenstein Formation (Pia, 1937; emend. Pisa *et al.* 1980b)
Carnian
Bosellini *et al.* (1982b); Casati *et al.* (1982); Gianolla *et al.* (1991); Siorpaes e Gianolla (1991).

Fernazza Formation (*Ialoclastiti del M. Fernazza*, Assereto *et al.*, 1977; emen. Viel, 1979)
Late Ladinian
Rossi *et al.* (1977); Casati *et al.* (1982); Castellarin *et al.* (1982); Doglioni (1982).
A formation of the Wengen Group.

Gastropod Oolite Member (Gastropodenoolith, Lepsius, 1878)
Dienerian - Smithian
Broglio Loriga *et al.* (1983, 1990).
A member of the Werfen Fm.

Gracilis Formation (Schichtenreihen des Dadocrinus Gracilis, Tornquist, 1901)
Bithynian
Barbieri *et al.* (1980); Cucato *et al.* (1987); De Zanche e Mietto (1989); De Zanche *et al.* (1992a).

Koken Conglomerate (Wittemburg, 1908)
Induan
Broglio Loriga *et al.* (1983, 1990).
An intraformational conglomerate facies in the Siusi Mb. and in the Gastropod Oolite Member.

Latemar Limestone (*Kalke des Latemar*, Richthofen, 1860)
Latest Anisian-Early Ladinian
Leonardi(1968); Gaetani *et al.* (1981).
A facies of the Anisian-Ladinian carbonate platforms.

La Valle Formation (*Wengener Schichten*, Wissmann in Wissmann und Münster, 1841; emend. Viel, 1979: *Successione di La Valle*)
Latest Ladinian (Late Longobardian)
Assereto *et al.* (1977); Rossi *et al.* (1977); Siorpaes e Gianolla (1991).
A formation of the Wengen Group.

Livinallongo Formation (*Buchensteiner Schichten*, von Richthofen, 1860; emend. Viel, 1979)
Ladinian
Baccelle e Sacerdoti (1965); Baccelle Scudeler (1972); Bosellini e Ferri (1980); Brack and Rieber (1986); Casati *et al.* (1982); Cros (1974); Fois (1982).
A formation of the Buchenstein Group.

"Lower Edifice" (Latemar Lower Edifice, Gaetani *et al.*, 1981)
Latest Anisian-Early Ladinian
Goldhammer *et al.* (1987, 1990); De Zanche *et al.* (1992a, b)

Lower Serla Dolomite (Pia, 1937, emend. De Zanche *et al.*, 1992a)
Latest Spathian-Aegean
Farabegoli *et al.* (1977); Pisa *et al.* (1979); De Zanche and Farabegoli (1982).

Lusnizza Formation (Assereto *et al.*, 1968)
Latest Spathian-Aegean
Casati *et al.* (1982); De Zanche and Farabegoli (1982).

Marmolada Conglomerate (Leonardi, 1955)
Latest Ladinian
Cornelius und Furlani-Cornelius (1924); Bosellini *et al.* (1977); Castellarin *et al.* (1977); Rossi *et al.* (1977).
A conglomerate facies of the Civetta Mb. (La Valle Fm.) bearing prevalent rounded volcanic pebbles (*cfr.* "*Facies dei paraconglomerati ad elementi vulcanici*" in Viel, 1979).

Marmolada Limestone (Marmolatakalk, Salomon, 1895)
Latest Anisian-Ladinian
Rossi (1962); Leonardi (1968); Gaetani *et al.* (1981); Blendinger (1986).
A facies of the Anisian-Ladinian carbonate platforms.

Mazzin Member (Bosellini, 1968)
Griesbachian
Broglio Loriga *et al.* (1983,1990).
A member of the Werfen Fm.

Moena Formation (Masetti e Neri, 1980)
Late Anisian (Illyrian)
Doglioni (1982).

Morbiac dark Limestones (Pisa *et al.,* 1979)
Late Anisian (Early Illyrian)
Masetti e Neri (1980); De Zanche *et al.* (1992a).

Mt. Naro Breccia (De Zanche and Farabegoli, 1981)
(?) Spathian
Cucato *et al.* (1987); De Zanche e Mietto (1989).

Piz da Peres Conglomerate (De Zanche *et al.,* 1992a)
Bithynian
Pia (1937); Bechstädt und Brandner (1970).

Raibl Formation (*Raibler Schichten,* von Hauer, 1858; emend. Pisa *et al.,* 1980b: Raibl Group)
Late Carnian
Richthofen, 1879; Rossi (1964); Hoffmann (1972); Bosellini *et al.* (1982b); Siorpaes e Gianolla (1991); Gianolla *et al.* (1991).

Recoaro Limestone (Böckh, 1872)
Late Anisian (Pelsonian)
Tornquist (1901); Barbieri *et al.* (1980); De Zanche and Mietto (1981); De Zanche *et al.* (1992a).

Richthofen Conglomerate (von Wittemburg, 1908; emend. Farabegoli *et al.*, 1977)
Late Anisian (Early Illyrian)
Dal Cin (1967); Bosellini (1968); Rossi (1973); Farabegoli *et al.* (1977); Pisa *et al.* (1979); De Zanche *et al.*(1992a).

Rosetta Dolomite (Leonardi, 1961)
Upper Ladinian - Carnian
Rossi (1959); Brandner (1991).
A facies of the Ladinian-Carnian carbonate platforms.

S. Lucano Member (Pisa *et al.*, 1979)
Late Spathian
First defined as a member of the Lower Serla Dm., it is generally considered to be the highest member of the Werfen Fm. (*e.g.* Casati *et al.*, 1982).

S. Cassiano Formation (Münster, 1834)
Early Carnian
Ogilvie (1893); Urlichs (1974, 1977); Fürsich and Wendt (1977); Castellarin e Perri (1982); Bizzarini *et al.* (1986); Masetti *et al.* (1991).

Sciliar Dolomite (*Schlern Dolomit,* von Richthofen, 1860)
Ladinian
Bosellini e Rossi (1974); Cros (1974); Gaetani *et al.* (1981); Brandner (1991); Yose (1991).

Siusi Member (*Seiser Schichten*, Wissmann in Wissmann und Münster, 1841; emend. Bosellini, 1968)
Late Griesbachian-Dienerian
Broglio Loriga *et al.* (1983,1990).
A member of the Werfen Fm.

Tesero Horizon (Bosellini, 1968)
Earliest Griesbachian
Bosellini (1964); Broglio Loriga *et al.* (1983,1990); Farabegoli e Viel (1982).
The basal member of the Werfen Fm.

Upper Serla Formation (*Oberer Sarldolomit*, Pia, 1937; emend. Assereto *et al.*, 1977 and Farabegoli *et al.*, 1977)
Late Anisian (Late Pelsonian)
De Zanche *et al.* (1992a).
The *Oberer Sarldolomit* in Pia (1937) includes both the Upper Serla Fm. and the Contrin Fm.

Val Badia Member (Bosellini, 1968)
Late Smithian
Broglio Loriga *et al.* (1983, 1990).
A member of the Werfen Fm.

Val Leogra Breccia (De Zanche *et al.*, 1981)
Early Bithynian
Cucato *et al.* (1988); De Zanche *et al.* (1992a).

Voltago Conglomerate (Pisa *et al.*, 1979)
Anisian (Latest Bithynian-Early Pelsonian)
Farabegoli *et al.* (1977); Blendinger (1983); De Zanche *et al.* (1992a).

Voltzia Beds (Fabiani, 1920)
Anisian (Latest Bithynian-Early Pelsonian)
Tornquist (1901); De Zanche and Mietto (1981); De Zanche *et al.* (1992a).

Wengen Group (Viel,1979)
Late Ladinian *p.p.*
Casati *et al.* (1982); De Zanche (1990).

Werfen Formation (*Schiefer von Werfen*, L. von Lilienbach, 1830; *fide* Bronn, 1832)
Induan-Olenekian
Bosellini (1968); Farabegoli e Viel (1982); Broglio Loriga *et al.* (1983,1990); Ghetti e Neri (1983).

Zoppè Sandstones (Viel, 1979)
Late Ladinian (Early Longobardian)
Assereto *et al.* (1977); Casati *et al.* (1982).
A formation of the Buchenstein Group.

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