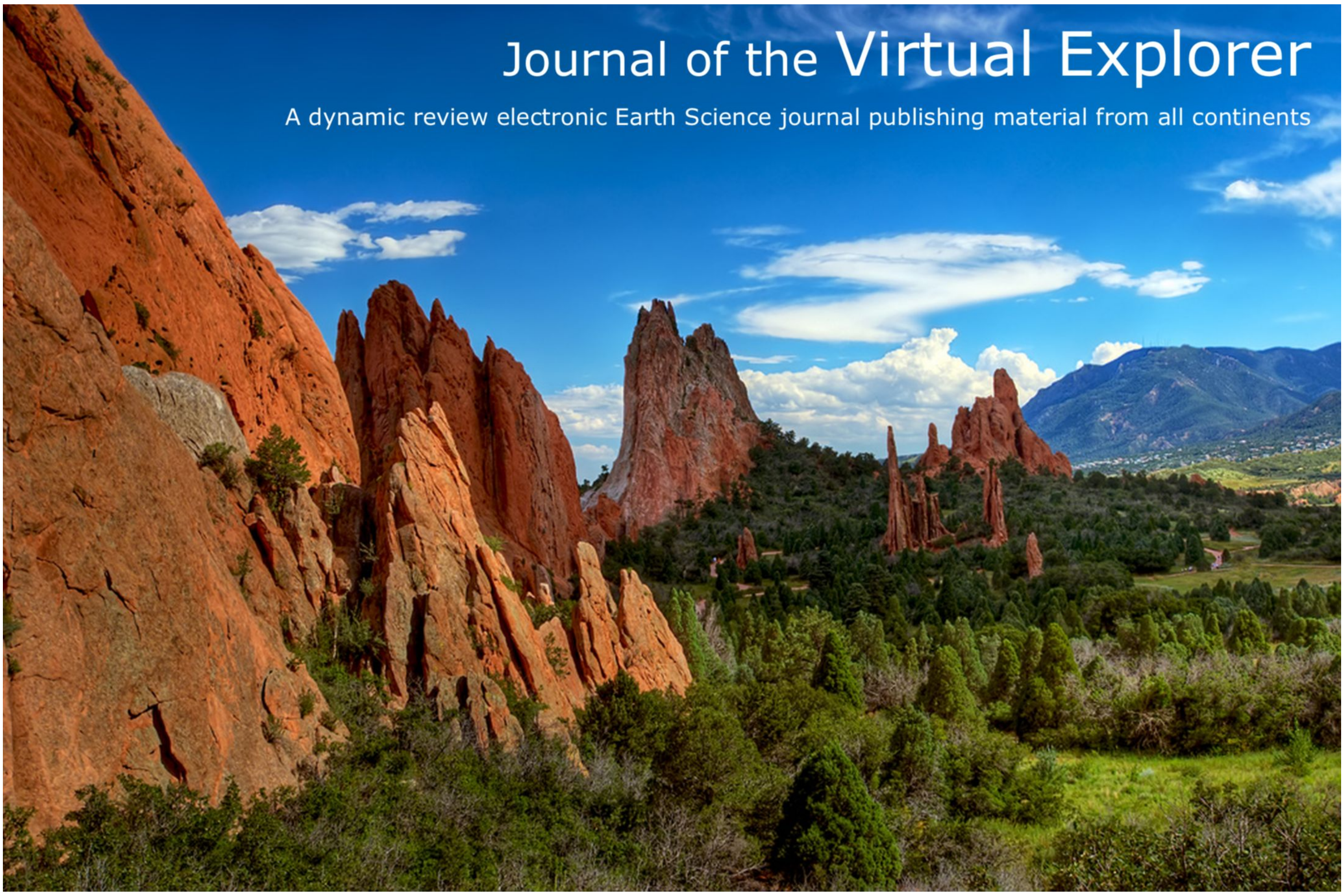

From Permian to Cretaceous: Adria as pivotal between extensions and rotations of Tethys and Atlantic Oceans

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From Permian to Cretaceous: Adria as pivotal between extensions and rotations of Tethys and Atlantic Oceans

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Abstract: During the latest Palaeozoic and Mesozoic, most of Italy was connected to the Gondwana assemblage of plates, representing the Adria Spur of Africa. After the Variscan collision and orogeny in the Carboniferous, Adria was situated in a peculiar position for several geodynamic major events. During the Permian, it was situated in the belt affected by the shear movements that led Pangea to its eventual Pangea A configuration. Studies of the volcanics of the Southern Alps give significant support to the palaeomagnetic evidence for these events. From the Late Permian to the Triassic, Adria mostly acted as a passive margin facing east towards the Palaeo-Tethys, even though regional rotations complicated this evolution, because Adria was in the pivotal position for the rotational movements that closed the Palaeo-Tethys and opened the Neo-Tethys. From the Late Triassic to the Jurassic, Adria started to be involved in the propagation of the ongoing rifting of the Central Atlantic Ocean, which eventually opened as a true ocean during Middle-Jurassic, forming the Ligurian-Piedmont Ocean or Alpine Tethys. In the Southern Alps and Apennines, large sections of the passive margin facing this new opening ocean are preserved, as well fragments of the oceanic crust and its sedimentary cover. The rifting and opening of the Southern Atlantic Ocean caused the anticlockwise rotation of Africa, with consequent convergence between Adria and Europe. This rotation led to the progressive closure of the Ligurian-Piedmont Ocean and formed the earliest reliefs of the future Alps.

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Introduction

The aim of this paper is to briefly review the most important events that affected Adria from the Permian - when the movements of the Variscan Orogeny were definitively over - to the onset of the first deformations in the Cretaceous, linked to the convergence that eventually led to the Alpine collision in the Cenozoic. A long list of references will enable interested readers to go more deeply into the subject.

Alpine deformations severely affected most of the margins of Adria. However, in the Southern Alps one segment is better preserved not far from the actual margins of Adria. The original relationships, especially in W-E alignment, allow stratigraphic, facies and paleogeographic reconstructions along a transect more than 300 km long. Therefore, emphasis will be put on the Southern Alps. The sedimentary cover on which the Permian-to-Mesozoic evolution is recorded is usually at least 3–4 km thick, with areas such as in eastern Lombardy where sediment accumulation from the Permian to the mid-Cretaceous may reach 10 km in thickness.

Geological research in the Southern Alps over the past 150 years, given the complexity of the sedimentary covers, has resulted in a large volume of literature, mostly in Italian and German. Only in the last few decades has the use of English spread. I will not enter into the details, but most of them will be described through drawings and pictures.

Southern Italy, from Basilicata to Sicily, preserves patchy fragments of sediments deposited on a seaway that evolved differently during the Permian and the Triassic. Attention will be paid also to this area. The remaining parts of the Apennines will not be considered here.

The concept of Adria is not unanimously agreed, even in the name. "Apulia" or "African Promontory" are often considered as synonyms. The main discussion is whether Adria was really a spur of the African Plate (Barrier and Vrielynck, 2008) or an independent microplate (Stampfli, 2005; Finetti, 2005). I assume in this paper that Adria was driven in its main movements by the movements of Africa because, even if Adria during part of the Mesozoic was a microplate independent from Africa, its behaviour would have been like the present Arabian Plate. There are no doubts that the Red Sea separated Arabia from Africa, but the general motions of Arabia are still the same as those of Africa, driven by the opening of the Atlantic Ocean, due to the small width of the Red Sea and hence the reduced rotation of Arabia.

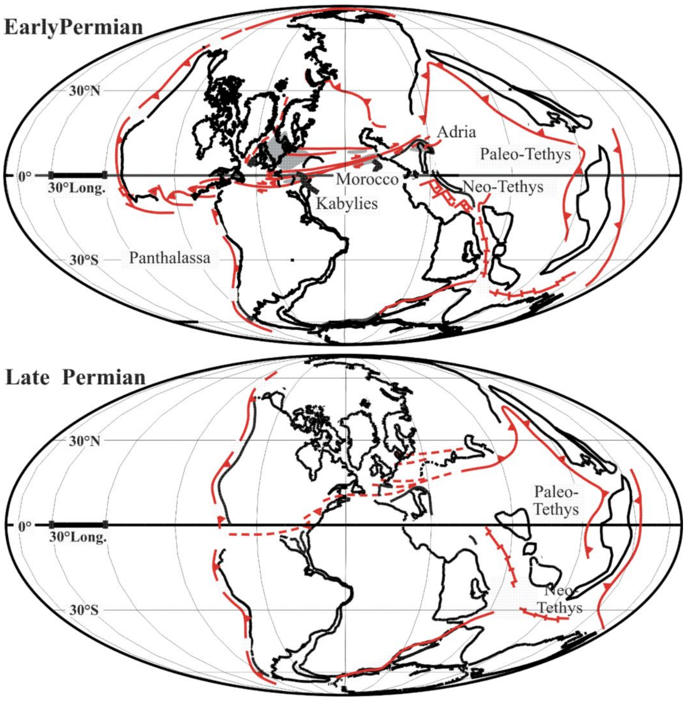
I do not follow the model of Finetti (2005a) or the oft-repeated model of Stampfli (2005, and ref. therein) for at least two reasons. The anti-clockwise rotation of 40° before Anisian assumed by Finetti (2005) is not confirmed by the Lower Permian palaeomagnetic comparative data from the broadly coeval volcanic rocks from Morocco (Muttoni et al., 2003). Significant rotations also do not occurred after the Carnian, as indicated by data on Lybia and the Southern Alps (Muttoni *et al.*, 2001). Palaeomagnetic data do not resolve minor rotations and therefore it is assumed that the width of the hypothetical oceanic seaway interposed between Adria and Africa was smaller than the resolution possible with that method (i.e., about 5° of rotation), while 40° of rotation should be clearly registered. The postulated final width of the Ionian of about 330 km (Catalano *et al.*, 2001) is also less than the paleolatitude discriminant potential of the palaeomagnetic method. Secondly, the earlier rotation should have produced substantial deformations on the margin of Adria and/or of Europe during the Middle Triassic, which are presently unknown. As a matter of fact, Catalano *et al.* (2001) hypothesized an opening of the Ionian later, during the Mesozoic. Detailed discussion on his topic is beyond the scope of this paper.

Aftermath of the Variscan Orogeny

Toward the end of the Pennsylvanian (Late Carboniferous), the Variscan Orogeny was over. Traditionally, tectonic movements driving the earliest sedimentation on the deformed and increasingly metamorphosed westwards orogen were related to the relaxation of the orogen itself (Henk *et al.*, 1997). Recognition of elongated, narrow and highly subsiding basins in the latest Carboniferous (Carnic Alps and Karawanken) and in the Early Permian, introduced the idea of the existence of transtentional movements (Vai, 1994; Cassinis and Perotti, 2007; among others). However, growing evidence from palaeomagnetic studies, developing the initial ideas of Irving (1977) and tectonic models (Arthaud and Matte, 1977; Matte, 1986), suggested the importance of large-scale tangential movements at the boundary between Laurussia and Gondwana. As far as the Southern Alps are concerned, where there are the best-preserved exposures for these phenomena, convincing evidence for palaeomagnetics were given by Muttoni *et al.* (2003, and ref.

therein). The overall geodynamic interpretation with radiometric ages was offered by Schaltegger and Brack (2007). The general engine of this scenario, which should be linked in the transformation from the Pangea B in the Pangea A configurations, occurred up to the middle of the Permian (Fig. 1). Deep-seated phenomena are discussed in Sinigoi *et al.* (this volume).

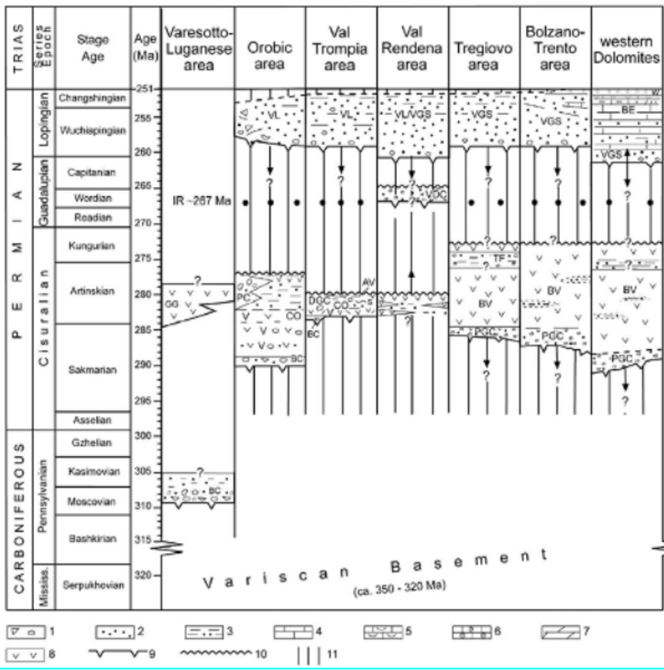
Figure 1. From Pangea B to Pangea A configuration.



The Pangea B configuration changed to the Pangea A configuration during the Permian, along a megashear zone situated between Laurussia and Gondwana (From Muttoni *et al.*, 2003, modified).

The peak period for the transtentional or occasional transpressive basins was in the second half of the Early Permian (Fig. 2) (Schaltegger and Brack, 2007; Cassinis *et al.*, 2009). The basins are characterized by fault-driven shoulders, allowing sediment and volcanic accumulation up to 2–3 km. As they are now preserved, the basins are a few tens of km wide and perhaps less than 100 km in length, but alpine tectonic cuts make these figures tentative. To the west, in Lombardy, the basin infill is a mixing of volcanics and braider river/delta fan/lacustrine complex (Figs. 3, 4) (Cassinis *et al.*, 2007, 2009; Sciunnach *et al.*, 2003). Very rarely, marine ingressions are recorded (Sciunnach, 2001a). The volcanites of the Collio Basin show a subalkaline, calc-alkaline affinity, with scarse intermediate volcanics. The REE patterns are relatively homogeneous with significant fractionation of LREE and an almost flat HREE profile (Cassinis *et al.*, 2008).

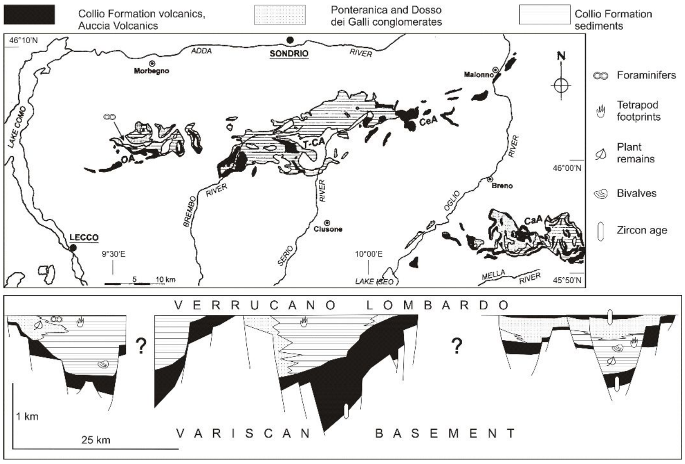
Figure 2. Stratigraphic setting of Late Carboniferous to earliest Triassic.



Chronostratigraphic setting from Late Carboniferous to earliest Triassic in Southern Alps. (From Cassinis *et al.*, 2009, modified) Lithology – (1) conglomerate and breccia; (2) sandstone and siltstone; (3) pelite, siltstone and marlstone; (4) limestone; (5) fossiliferous limestone; (6) oolitic limestone;(7) dolostone; (8) volcanic rocks. Other symbols – (9) unconformity; (10) erosional surface; (11) stratigraphic gap.

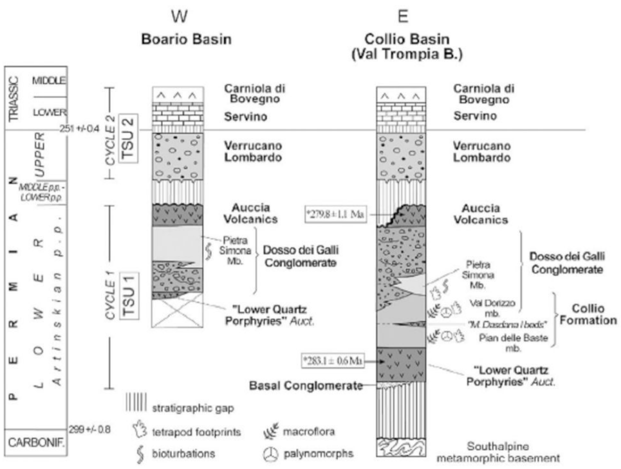
Lithostratigraphic units from west to East. BC, basal conglomerate; V, undifferentiated volcanics; GG, Val Ganna granite; CO, Collio Formation; PC, Ponteranica Conglomerate; DGC, Dosso dei Galli Conglomerate (S, Pietra Simona Member); AV, Auccia Volcanics;VL, Verrucano Lombardo. PGC, Ponte Gardena Conglomerate; BV, undifferentiated Bolzano volcanics; TF, Tregiovo Formation; VDC, Val Daone conglomerate;VL, Verrucano Lombardo; VGS, Val Gardena Sandstone; BE, Bellerophon Formation; W, Werfen Formation.

Figure 3. Lower Permian basins in Lombardy.



The Lower Permian basins in Lombardy (from Sciunnach *et al.*, 2001 modified) Note the narrow and elongated basins, filled with volcanics and siliciclatics. OA – Orobic Anticline; T-CA – Trabuchello-Cabianca Anticline; CE – Cedegolo Anticline; CA – Camuna Anticline.

Figure 4. Volcanic bodies in the Collio Basin.



Details of the Collio basins in eastern Lombardy with positions of the volcanic bodies (from Cassinis *et al.*, 2009 modified).

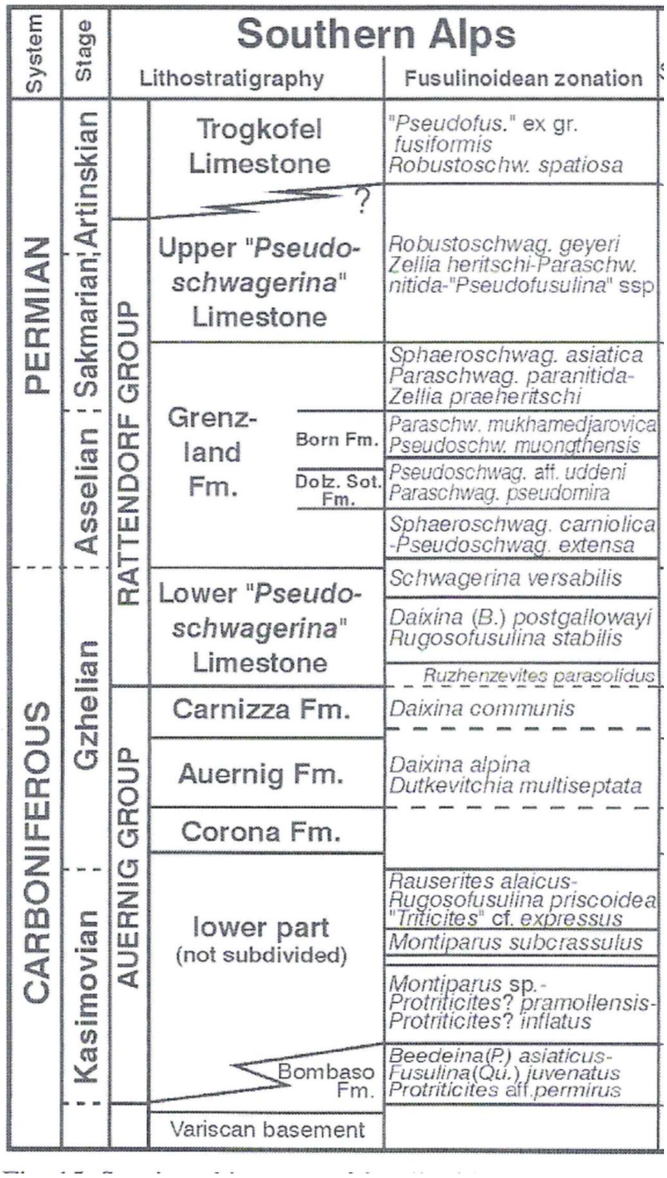
Moving eastwards, the amount of volcanics increases significantly to reach the maximum in the Adige basin where spectacular huge pyroclastic flows form the present shoulders of the Adige valley (Fig. 5). They are presently about 2,000 km^2 in area and consist of calc-alkaline volcanic rocks up to >2 km thick. They include basaltic andesites, andesites, dacites, rhyodacites and rhyolites (Bargossi *et al.*, 1998, and ref. therein). The magmatic rocks comprise domes and lava flows, pyroclastic and surge deposits and ignimbrites (Schaltegger and Brack, 2007).

Figure 5. Lower Permian volcanics in Adige Valley.

The imposing walls formed by the ignimbrites and other volcanic products line the Adige Valley south of Bolzano. (Photo M. Gaetani).

Moving more toward the east, volcanics are reduced or absent in the Carnic Alps where a mostly marine succession is cropping out. It starts in the late Moscovian-early Kasimovian, unconformably sealing the variscan folded basement, mildly metamorphosed (Krainer, 1992; Vai, 1994; Venturini and Spalletta, 1998; Forke, 2002) (Fig. 6).

Figure 6. Stratigraphy of post-variscan successions in Carnic Alps.



Updated stratigraphic subdivisions and fusulinids zonation in the post-variscan successions of the Carnian Alps (from Korte, 2002, modified).

Meagre remnants of these volcanic/continental deposit settings are also preserved in Tuscany where they are presently mildly metamorphosed (Pandeli *et al.*, 2008; Aldinucci *et al.*, 2008) and in Sardinia (Ronchi *et al.*, 2008; Cassinis *et al.*, 2009).

For a general review of Permian continental deposits in Italy, refer to the special issue of the Geological Society of Italy (Cassinis, 2008).

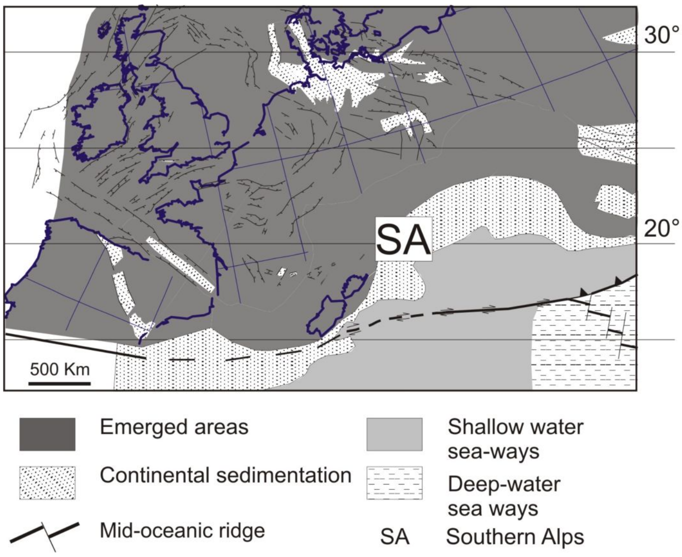
The Permo-Triassic Passive Margin

When, toward the end of the Middle Permian, megashear movements vanished, most of the present Italian territory was in a rather simple paleogeographic setting. The emergent remnants of the Variscan Orogen were lying roughly to the north and west, while a wide, passive margin was opening toward the SE facing a Tethyan seaway. To name this seaway is a matter of discussion, but I think the best choice is to call it Palaeo-Tethys. At the foot of mountains and hills, still under erosion, the landscape setting was with low gradients. There was a passage from the alluvial braided river plain, gradually interfingering with coastal marine, often evaporitic sediments, to more open marine, but never in very deep situations. This general panorama lasted for at least 30 My, from the latest Middle Permian to the beginning of the Middle Triassic. Minor tectonic movements affected this picture locally. Different settings, in different geodynamic scenarios, developed in western Sicily and in the Lagonegro area in Basilicata. They will be discussed separately.

The wide, passive margin

The preserved outcrops are in the Southern Alps where remnants of the passive margin extend over several hundreds of km (Fig. 7). Elsewhere, the Austroalpine nappes or the Northern or Central Apennines were still sites of erosion during this timelag and usually were reached later by sedimentation. Only locally thin veneers of sediments are preserved, as in Tuscany or Sardinia.

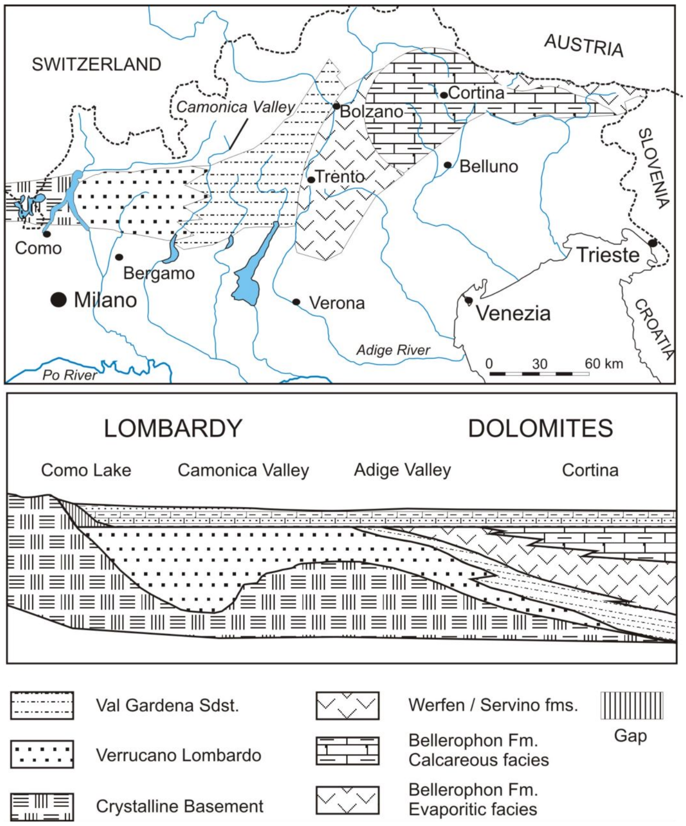
Figure 7. Wordian map.



Palaeogeographic map of the Wordian (Middle Permian) (from Dercourt *et al.*, 2000, reduced and modified).

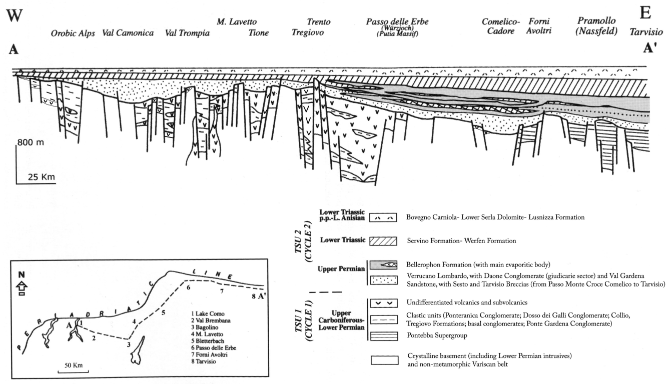
Toward the very end of the Middle Permian and at the beginning of the Late Permian, erosion of the Variscan mountains provided clastic material feeding the wide fan of the Verrucano Lombardo (deposed mostly in a braided river setting) vs. Arenarie di Val Gardena (deposed mostly as meander alluvial plain). The original reconstruction of Assereto *et al.* (1973) is still valid with minor improvements (Cassinis *et al.*, 2008) (Figs. 8, 9). The climate was monsoon-like, with a wet season allowing river drainage and a dry season with marked oxic conditions; hence, the typical reddish colour of sediments. This caused sediments barren of fossils, but there are a few places where for short periods, marine-life ingression is mixed with the alluvial plain sediments. Tetrapod tracks and footprints may be locally common (Avanzini *et al.*, 2008).

Figure 8. The Early Triassic transgression.



Paleogeologic map of the basal surface on which the Lower Triassic sediments transgressed westwards (top). The progressive encroachment of the marine sediments on the wide continental margin from the latest Middle Permian to Early Triassic (bottom). (From Assereto *et al.*, 1973, redrawn and modified).

Figure 9. W-E transect for Permian to Lower Triassic.



Updated interpretation of the structural pattern accommodating the Permian to Lower Triassic sediments and volcanics along the same alignment of the Assereto *et al.* (1973) original scheme, here reported in Fig. 8. (From Perotti, 2010).

During the passive margin stage, several sedimentary sequences are superposed with the common feature that the next sequence aggrades inland more than the previous, usually for some tens of km. Therefore, while the passage from Arenarie di Val Gardena to Verrucano is roughly at the Adige Valley, the evaporitic to marginal sediments of the Formazione a Bellerophon arrive to the west of it, for at least 20 km. And eventually the Werfen/Servino cycles may arrive with marine facies until central Lombardy.

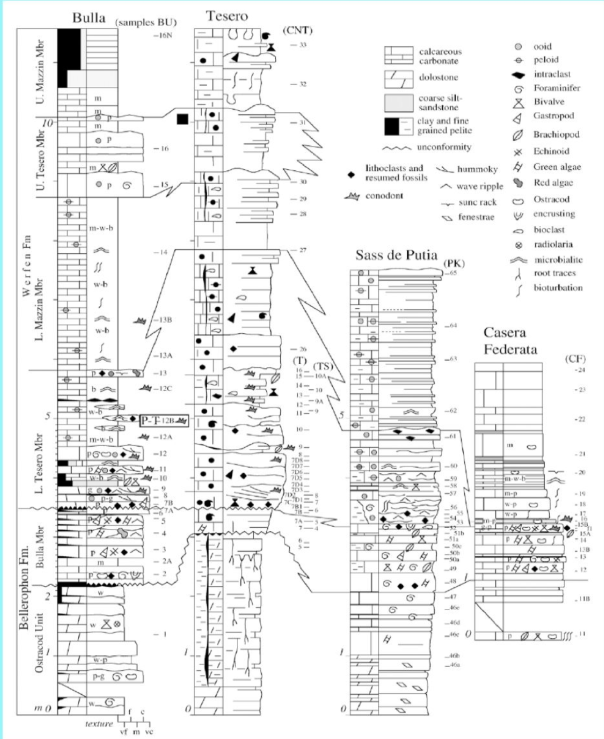
The marine strata are mostly represented by the Bellerophon Fm. It has been classically subdivided into two parts (Massari et al, 1988; Massari and Neri, 1997). In the lower part, “the encroachment of the transgression resulted in fluvial to terminal-fan settings, still dominating in the westernmost areas, graded first into coastal sabkhas and then into a hyperhaline lagoon in which a subtidal evaporitic complex was laid down” (Massari and Neri, 1997).

In the upper part, a low-gradient, homoclinal carbonate ramp replaced the previous evaporitic basin.

Deposition took place in a low-energy, low-gradient ramp without large-scale circulation and hence, without open marine biota. For an exhaustive sedimentological analysis of the couple Val Gardena Sandstone/Bellerophon Fm., refer to Massari and Neri (1997).

The topmost part of the Bellerophon Fm., along with its passage to the basal layers of the overlying Werfen Fm., has been actively studied in the last 25 years because it contains the Permian/Triassic boundary. The last few meters of the Bellerophon Fm. contains a fully marine fauna and flora, even if still in proximal shelfal conditions. The sections of Tesero and Bulla have been considered as auxiliary sections for the global definition of the boundary. Sedimentology (Farabegoli *et al.*, 2007), sequence stratigraphy (Neri and Stefani, 1998), chemiostratigraphy (Kearsey *et al.*, 2009), magnetostratigaphy (Scholger *et al.*, 2000), marine biota (Posenato, 2009) including foraminifera (Groves *et al.* 2007), conodonts (Farabegoli *et al.*, 2007), ostracods (Crasquin et al, 2008), and brachiopods (Posenato, 1998, 2001; Chen, 2006) were studied in detail (Fig. 10).

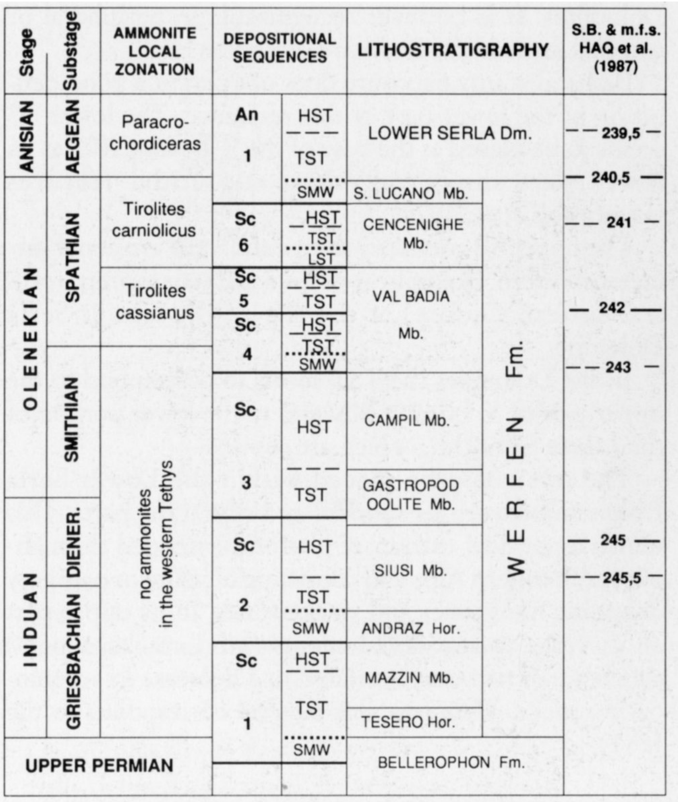
Figure 10. The Permo/Triassic boundary interval.



The Permo/Triassic boundary interval has been studied in much detail in the western Dolomites, where auxiliary section for the GSSP has been described (from Farabegoli *et al.*, 2007, modified).

The Werfen/Servino lithosomes form a complex pattern of mixed silicoclastic/carbonate sediments, deposed on the structural platform with a fairly high subsidence rate because especially the Werfen Fm. may reach 100m/My of non-decompacted sediments. Since 1960, a number of subunits have been proposed, now reaching a total of nine (Broglio Loriga *et al.*, 1982; De Zanche *et al.*, 1993) (Fig. 11). They depict a complex pattern of shallow-water carbonate and fine siliciclastics. Noteworthy is the abundance of oolitic grainstone, linked to the prevailing inorganic precipitation of carbonates when the biotic crisis at the P/T boundary reduced the organic ability to fix the carbonates.

Figure 11. Internal subdivisions of the Werfen Formation.

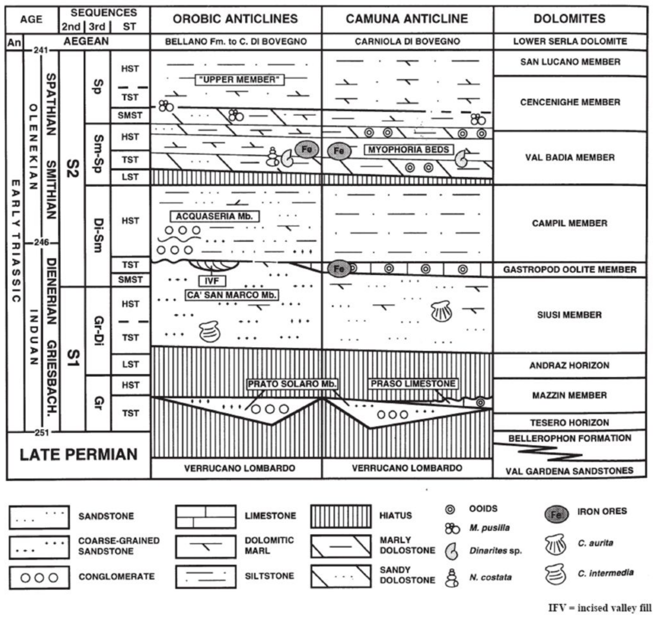


The subdivisions of the Werfen Formation in Dolomites and Carnia according to De Zanche *et al.* (1993), with sequential interpretation.

The environment interpretation identifies a wide tidal flat on which a shallow-water shelf ingresses with hybrid sedimentation, carbonatic and distal silicoclastic. Locally and prevailing in the Tesero and Gastropod Oolite mbs, there are shoals with oolitic bars.

The good exposures of the Dolomites, and in minor extent in Carnia, are not replicated in Lombardy. Here, the rocks of the Lower Triassic are often disrupted at the base of the thrust sheets and their thickness is much reduced and internal gaps are more frequent. Sciunnach *et al.* (1999) (Fig. 12) made an attempt to extend the subdivisions of the Dolomites to overcome the traditional subdivision of the Servino Fm., which was separating a lower part, mostly silicoclastic, from an upper part, mostly carbonatic. The Servino is a traditional name originating from the mining terminology (Brocchi, 1808; Sciunnach in Cita *et al.*, 2007). Due to its content rich in barite and siderite it has been mined for iron since Roman times.

Figure 12. Subdivision of the Servino Fm. in Lombardian Alps.



Subdivision of the Servino Fm. in Lombardian Alps with correlation to the Werfen subdivision in Dolomites and Carnia (from Sciunnach *et al.*, 1999).

The Permian of Sicily

For more than a century, carbonate blocks have been known in the valley of the River Sosio in Western Sicily, containing a very rich and well-preserved macro and microfauna of Permian age, mostly Middle Permian (Gemmellaro, 1887, 1888 a,b, 1889, 1890). More recent research has dealt with the palaeontology of conodonts, radiolarians, ostracods, palynomorphs, and stratigraphic and sedimentological interpretations (Mascle, 1979; Catalano *et al.*, 1991, 1992; Flügel *et al.*, 1991; Kozur, 1991a,b; Gullo, 1993; Kozur *et al.*, 1996; Jenny-Deshusses *et al.*, 2000; and Carcione, 2007; among others). Outcrops are highly disrupted, and superficial sliding is frequent in the softest units. The depositional scenario that resulted from these studies is still debated.

The shallow-water carbonate blocks like “Pietra di Salomone” or “Pietra del Passo di Burgio” no doubt contain fossils of Permian age and are considered as resedimented blocks. Similar rocks are known in outcrops at Jebel Tebaga in S. Tunisia (Khessibi, 1985; Angiolini *et al.*, 2008; and ref. therein) and are penetrated by commercial boreholes in Tunisia. The fine siliclastics and the red and grey shales were thought to be autochtonous and thus still Permian, including evidence from the Early, Middle and Late Permian ages. The same should hold true for marls, red shales and cherty, nodular limestone of Lower and Middle Triassic age. A tentative succession from Permian to the base of the Upper Triassic was proposed by Gullo (1993), identifying seven litho units. This interpretation was shared and stressed by Di Stefano and Gullo (1997).

In contrast, there were others who claimed that most of the stuff is to be included in the Lercara Formation of Triassic age (Cirilli *et al.*, 1990). Both olistholits and fine clastics should be reworked and embedded in this unit. Recently, Carcione (2007) in her Ph.D. thesis reached the conclusion that all the rocks with evidence from Permian to Middle Triassic ages are resedimented and should be included in the Lercara Formation, which was deposited during the Middle Triassic/early Carnian. Therefore, in this interpretation, even if there is paleontological evidence for Permian or earliest Triassic deep-water organisms, they all are reworked in the Lercara Fm. However, this interpretation casts doubt. For instance, if some ostracod assemblages should be the product of reworking, how can their very fine ornamentation be preserved in a grain-by-grain reworking (Crasquin *et al.*, 2008)?.

For palaeogeographic reconstructions, autochthonous or reworked have a minor importance. As a matter of fact, since the Middle Permian a fairly deep trench bordered by a shallow-water carbonate platform was open in that area. Because it includes deep-water fauna of Middle and Late Permian age with some Tethyan affinity, the interpretation was advanced that a deep-water branch of the Tethys was already established in that area during the Permian (Catalano *et al.*, 1991).

Similar meaning may have the Abriola shallow-water blocks embedded in the Monte Facito Fm. (Basilicata) (Donzelli & Crescenti, 1970; Ciarapica *et al.*, 1986; Panzanelli Fratoni, 1991). Recently, Passeri and Ciarapica (2010) wrote that “the calcirudites with fusulinids are known only as scattered boulders and pebbles in tectonic *mélange* and debris. These boulders are interpreted as tectonic shavings coming from *mélanges* and reworked in the postorogenic debris flow. They are the only witness of the Permian in the Southern Apennines.”

The Western Termination of the Tethys Seaways

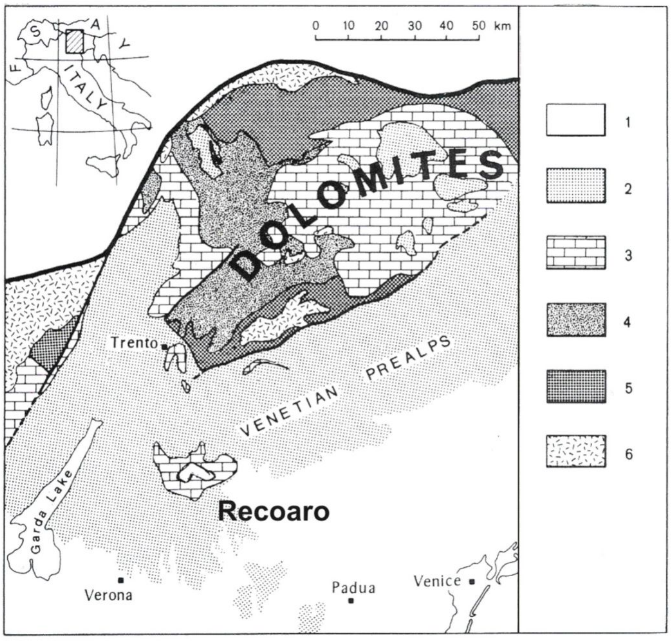
Sedimentation during the time interval from the end of the Lower Triassic till the Carnian/Norian boundary occurred in a complex geodynamic scenario. The Southern Alps are the site where these phenomena are better preserved and exposed. The unique landscape of the Dolomites in particular led recently to recognition of these mountains as World Heritage from UNESCO.

The southernmost Apennines and Sicily had a rather different setting and will shortly be discussed separately.

The Southern Alps

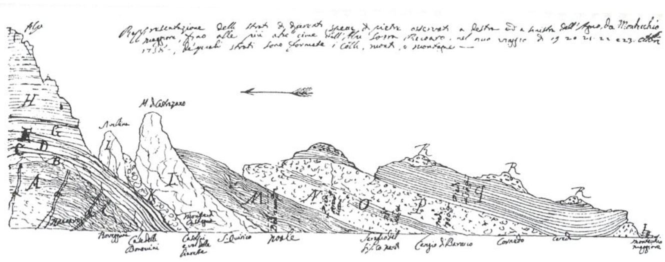
The Triassic of the Dolomites has been a key reference for the Triassic for more than a century, and some of its features, like the concept of intefingering of facies, were first proposed on actual occurrence from the Dolomites (Mojsisovics, 1879). The great advantage of the Dolomites is the relatively low shortening and deformation during the Alpine Orogeny (Fig. 13). Other areas have importance in the history of science, like the section of Recoaro, first drafted by Arduino (1760) (Fig. 14). Lombardy and the Carnic Alps are also significant, even if alpine tectonics may locally mask a detailed analysis. After 150 years of stratigraphic studies, the terminology is very complex and a reader unfamiliar with the area may find it difficult. This is due first to the actual complexity of the stratigraphic record and also to the fact that the area of the Southern Alps was initially ruled by different states (Italy and Austria). To follow, in detail, the stratigraphy of the Anisian to Carnian in the Southern Alps would require tens of pages.

Figure 13. Historical areas.



The Dolomites and the Recoaro area have also an historical interest in the history of stratigraphy and of the Triassic researches. 1. Alluvial deposits. 2. Jurassic to Cenozoic deposits. 3. Triassic successions. 4. Permian ignimbrites and sedimentary successions. 5. Variscan intrusives. 6. Variscan metamorphics. The Dolomites are bounded to the north by the Insubric Lineament. (From Bosellini and Rossi, 1967, modified).

Figure 14. Recoaro area.



The drawing of Giovanni Arduino (1760) through the Valle dell'Agno in the Recoaro area. The calcareous peaks on the left side correspond to the Middle Triassic Spitz Lmst. From Stegagno (1929).

To summarize and search for some common features, I would stress the following common points:

1. High subsidence rate, mostly compensated by high carbonate productivity, often result in very thick successions.

2. Subsidence was controlled by active tectonic movements, mostly extensional or transtentional.

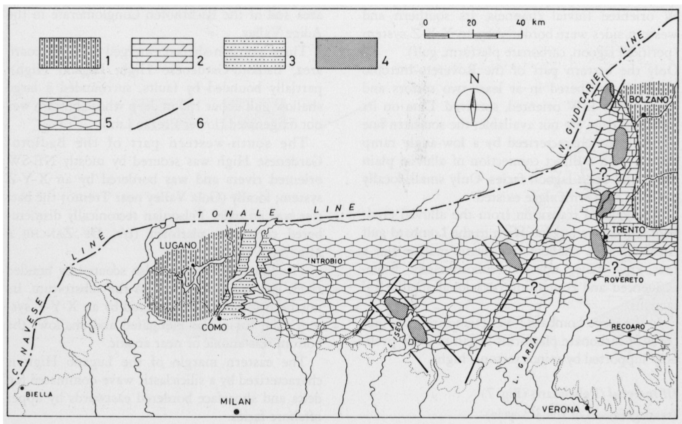
3. Volcanic activity was significant from the late Anisian until most of the Carnian, with migration of the effusive centres and changes through the time of the geochemical signature. The overall trend is calc-alkaline.

The time interval may be subdivided in four parts.

The Anisian

This interval roughly spans from the earliest Anisian until the beginning of the late Anisian. The age of the base is poorly constrained, lacking significant fossils, while the top is better defined. As a whole, the trend was toward a general aggradation of more frankly marine facies on the previous marginal to evaporitic sediments (Carniola di Bovegno in Lombardy, Lower Serla Dolomite in Dolomites, and Lusnizza Fm. in Carnia). Reliable age control is possible only with the middle Anisian (Pelsonian in the Tethyan substage terminology). Mixed carbonatic/very-fine siliciclastic ramps were a typical setting for the initial steps of the transgression, while thick carbonate banks first appeared in the geological record. These banks reached a thickness up to 300–400 m, mostly built by algal activity. They were still fairly isolated in the bays. Among the better preserved are the Camorelli Bank in Lombardy (Gaetani and Gorza, 1989; Berra *et al.*, 2005), M. Guglielmo (Falletti and Ivanova, 2003), Dosso dei Morti in Trento Province (Gaetani, 1969; Unland, 1975), and M. Rite in Venetian Dolomites (Stefani *et al.*, 2010) (Fig. 15).

Figure 15. Middle Anisian palaeogeography.



Paleogeography (non palinspastic) of the middle Anisian (Pelsonian) in western and central Southern Alps (from De Zanche and Farabegoli, 1988, modified). 1. Emergent areas. 2. Carbonate peritidal lagoon. 3. Siliciclastic flats with calcareous interlayers. 4. Carbonate banks . 5. Carbonate embayements with fine terrigenous input. 6. Triassic synsedimentary fault.

Another common feature was the presence of several conglomeratic horizons, testifying to local emersion and erosion episodes of the underlying Lower Triassic/Permian successions, like the Bellano Fm. in Lombardy (Gaetani, 1982; De Zanche and Farabegoli, 1983) and the well-known successions of conglomerate bodies around the margin between the Western and Eastern Dolomites —i.e., the Voltago and Piz da Peres conglomerates (Bosellini, 1967; Brandner and Bechstaedt, 1970; De Zanche and Farabegoli, 1988, Neri and Stefani, 1998; Stefani *et al.*, 2010).

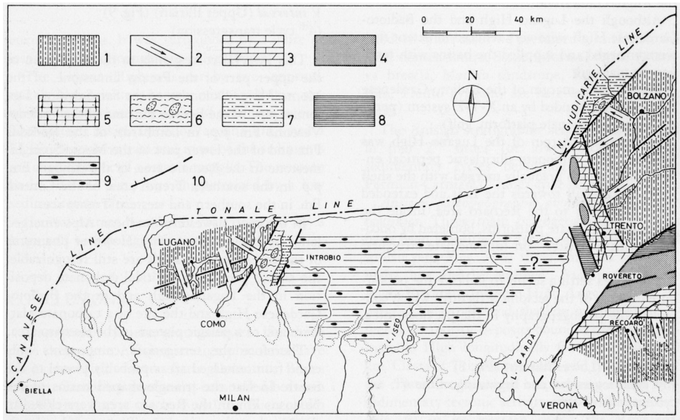
Extensional movements were locally active, forming scarps linked to faults. From the rifted shoulders, conglomeratic fans expanded in the nearby areas. Figure 14 illustrates the complex geological pattern of this first part of the development in the western Southern Alps.

During this time interval, no volcanic activity is proved.

Late Anisian-Ladinian

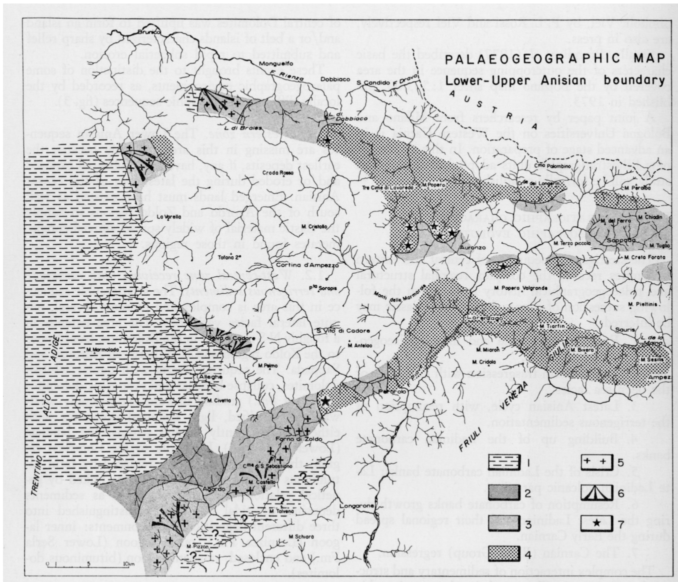
At about the middle–late Anisian boundary, a major differentiation occurred, with identification of areas that had a more proximal setting, emergent or with less subsiding during this time interval, and areas more subsiding in which deeper deposition prevailed. The active faulting occurred along lineaments that suggest the formations of sphaenocasm. Sinistral transtentional movements were also identified (Doglioni, 1987). In Lombardy, the Lario-Ceresio areas had another positive pulse (Fig. 16). The Western Dolomites and the Carnian Ridge emerged and were eroded down until the Upper Permian formations. The Richthofen Conglomerate and the Ugovizza Breccia are among the most significant products of this event (Figs. 17 and 18). The Eastern Dolomites instead were more basinal-prone and received the material eroded to the west and to the north (Fig. 19).

Figure 16. Base of Upper Anisian paleogeography.



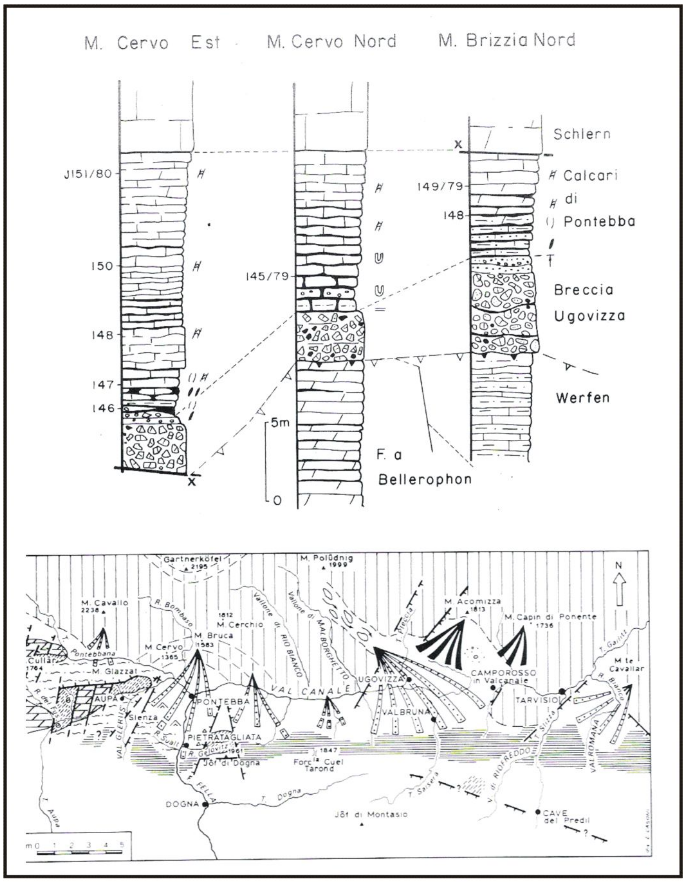
Paleogeographic map (not palinspastic) of the base of upper Anisian. The topographic relief was rejuvenated and new areas emerged, feeding the nearby sea embayments with new terrigenous material (From De Zanche and Farabegoli, 1988). 1. Emergent areas. 2. Fluvial distributory channels. 3. Algal carbonate lagoon. 4. Carbonate platform. 5: Dismembered carbonate platform. 6. Siliciclastic fan-delta- 7. Siliciclatic offshore. 8. Anoxic shallow basin. 9. pelagic shelf (Prezzo Limestone) with alternating carbonate-clayey sedimentation.

Figure 17. Upper Anisian paleogeography in Dolomites.



Paleogeographic map (non palinspastic) for the middle-upper Anisian in Dolomites. Note the alignment of the emergent areas and depressions, forming a rhombochasm. This suggests the direction of the strain in W-E direction. 1. Emergent land. 2. Slow subsiding areas. 3. Areas with higher subsidence, that will later became basin. 4. Carbonate bank. 5. Extension of conglomeratic and sandy bodies. 6. Main alluvial fans. 7. Ore deposits. (From Assereto *et al.*, 1977).

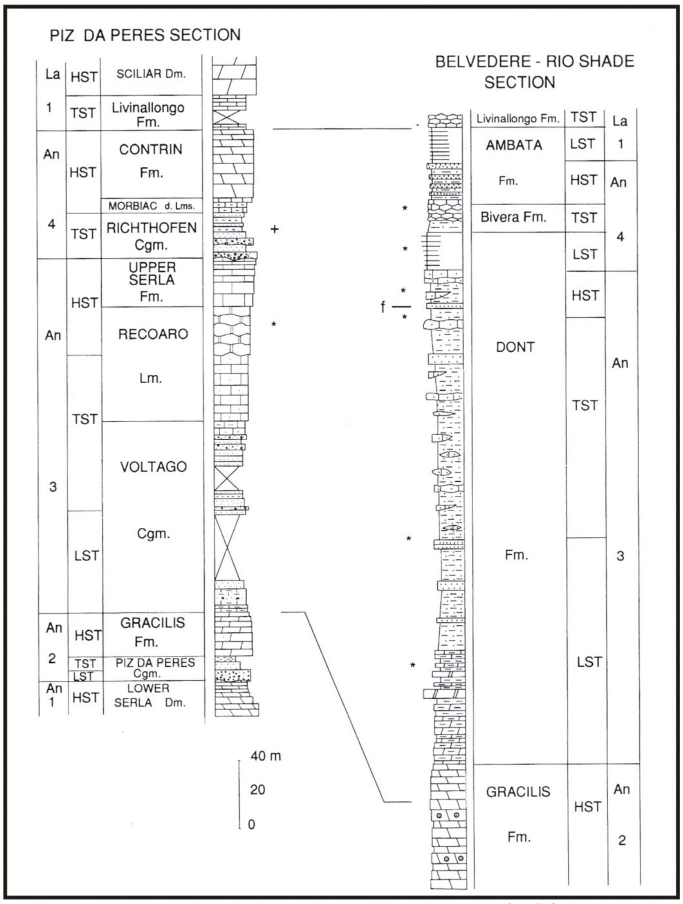
Figure 18. Ugovizza Breccia.



A. Logs measured on the "Palaeocarnic Ridge" (Dorsale paleocarnica) showing the depth of the erosion before the deposition of the Ugovizza Breccia (from Fois and Jadoul, 1983).

B. Partly palinspastic reconstruction of the fluvial channels and fans along which the Ugovizza Breccia was transported and deposited to the S of the Palaeocarnic Ridge (from Farabegoli *et al.*, 1985).

Figure 19. Relationship basin/paleohigh.

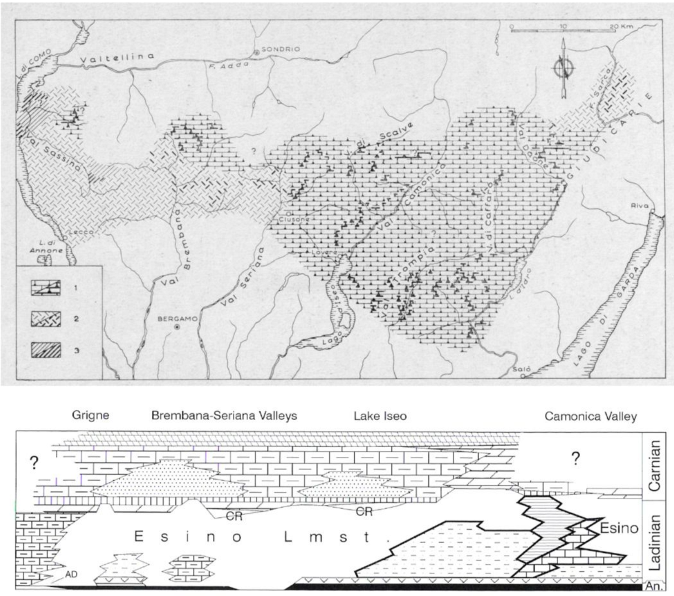


An example of the relationships between paleohigh and basin in the Anisian of the Northern Dolomites, Braies area. (From De Zanche *et al.*, 1993).

Toward the end of the Anisian, the subsidence rate increased on most of the Southern Alps. As a result, areas that were emergent or in a shallow-water setting became the preferential sites for the growing of carbonate platforms. Deeper areas continued their basinal trend. This is the right situation that makes the landscape of Western Dolomites classical, with steep walls in the massive limestone or dolostone units, dominating gentle green slopes made by the softer, bedded limestone, marly, and shaly units. Due to the minor alpine shortening suffered by the Dolomites, interfingerings in the original settings are preserved, and since Mojsisovics (1879) are amongst the most studied examples of these phenomena (Fig. 20). A similar setting was also present in Lombardy and Carnia, but the more severe alpine tectonics disrupted the original relationships and the softer basinal units often form the sole of the thrusts. In Lombardy, a good example may be observed in the Grigna Mountains, where the upper

Anisian-Ladinian carbonate platform of the Esino Fm. is well preserved and its margin may be studied (Landra *et al.*, 2000) (Fig. 21). Margins typically prograded on the basin only a few hundreds of metres because they were facing deep troughs and productivity was insufficient to fill the deep and subsident basin. Therefore, slope inclination of the margins has grown high, often up to 30 degrees (Fig. 22).

Figure 20. Lower Ladinian Palaeogeography.



Palaeogeography of the lower Ladinian in Lombardy and western Trento area.

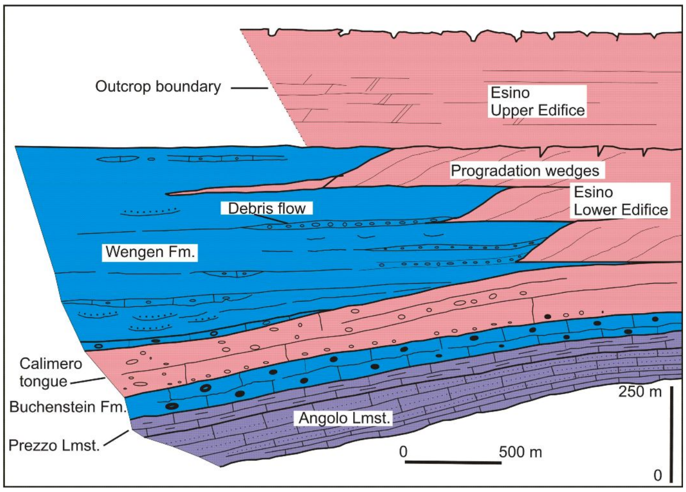
Top. The classic map, non palinspastic, of Assereto and Casati (1965). 1. Cherty well bedded limestone of open marine environment (Buchenstein Fm.). 2. Light limestone and dolostone of carbonate platform (Esino Fm.). 3. Dark grey thin bedded limestone, restricted environment (Perledo-Varenna Fm.).

Bottom. W-E cross section with the relationship between platform and basins. (From Balini *et al.*, 2000).

Figure 21. The margin of the Grigna Settentrionale carbonate platform.

The Esino Fm. builds the walls in which the clinoforms merge to the SE (from left to right in the picture) to eventually interfinger with the basinal units of Buchenstein and Wengen fms. (Photo M. Gaetani).

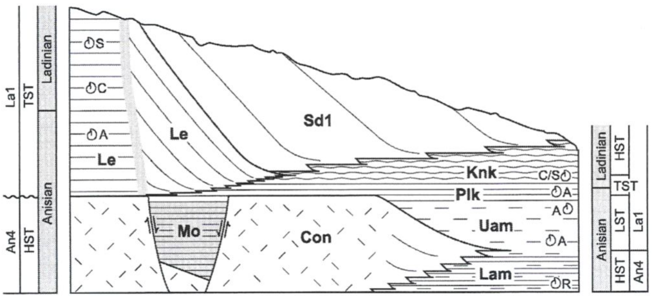
Figure 22. Platform vs basin relationship.



Example of complex interfingering between carbonate platform and basin; north side of the Prabello through (Grigna Settentrionale) (redrawn and modified from Gaetani *et al.*, 1998). The Angolo + Prezzo lmsts. represent a bay environment, deepening during the upper Anisian. The Buchenstein + Wengen fms. represent the basin on which the Esino platforms prograded. The Calimero tongue was partly a progradation and partly a huge megabreccia body, entirely consisting of carbonate debris.

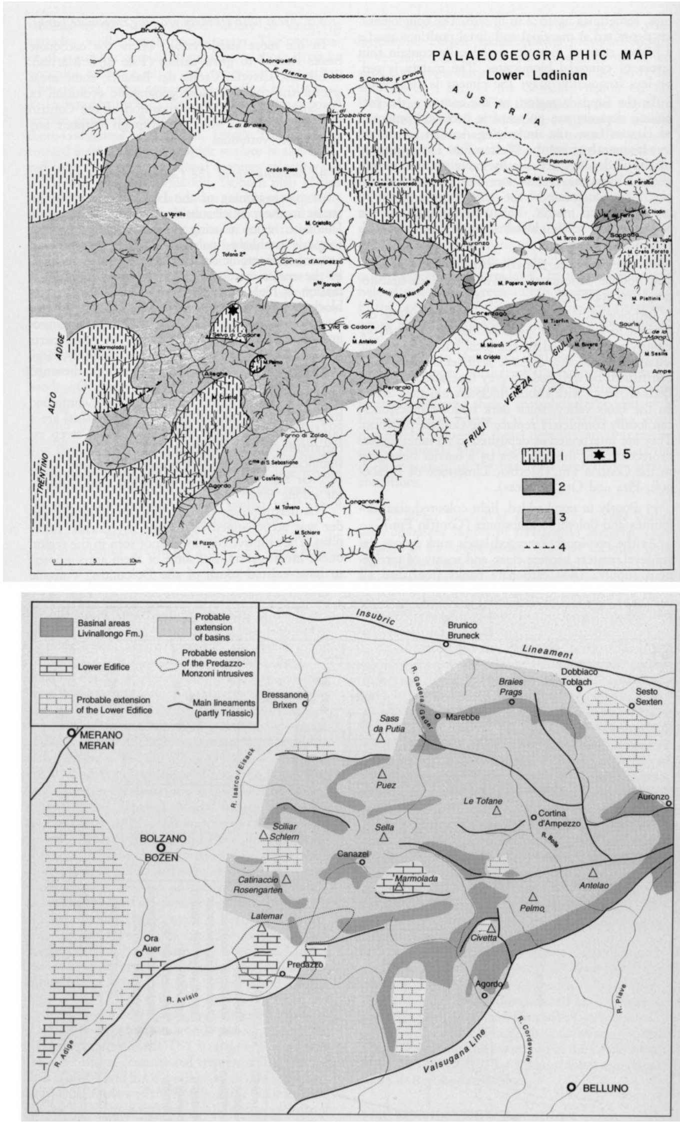
In the Dolomites are the best-studied examples and the literature on this topic is very ample (Bosellini and Rossi, 1974; Gaetani *et al.*, 1981; De Zanche *et al.*, 1995; Gianolla *et al.*, 1998; Maurer, 2000; Blendinger, 2001; Keim and Brandner, 2001; Caputo and Stefani, 2002; Bosellini *et al.*, 2003; Stefani *et al.*, 2010; among others) (Fig. 23). Due to the pervasive diagenetic dolomitization, often microfacies of the margins are not preserved, but study of the blocks fallen along the slope and embedded in the basinal rocks may allow comprehension of the organism communities building the banks and platforms. A basic feature is the scanty presence of corals. The platforms are mostly the product of algal and microproblematic activity, like *Tubiphytes*. Early cementation is the device that allowed the formation of growing steeper slopes. For full discussion on this point, see Stefani *et al.* (2010) (Fig. 24).

Figure 23. Style of interfingering.



The style of interfingering in the lower edifices in western Dolomites. Especially in the Latemar Group, the presence of ammonoids also on the platform allowed to better constrain the parallelization platform/basin (from Manfrin *et al.*, 2005 modified).

Figure 24. Palaeogeography at the Anisian/Ladinian boundary.



The distribution (not palinspastic) of platforms and basin in Dolomites around the Anisian/Ladinian boundary.

Top. 1. Carbonate platforms, 2. pelagic plateau or carbonate banks sunken in the lower Ladinian; 3. Basins. 4. Alpine faults truncating carbonate banks. 5. Ore deposits. (From Assereto *et al.*, 1977).

Bottom. The extension of the lower edifice of the carbonate platforms. (From De Zanche *et al.* 1995).

From a palaeogeographic point of view, a wide and deep embayment flanked by carbonate platforms developed in the Cadore area of the Eastern Dolomites. It was open to the south because it received the turbiditic currents with reworked volcanics and siliciclastic material of the Zoppè Sandstone (Viel, 1979). Wide lobes of this major basin penetrated westwards, separating the carbonate banks or protruding platforms from the persistent shallow-water area with carbonate production in the westernmost part of the Dolomites (Fig. 25).

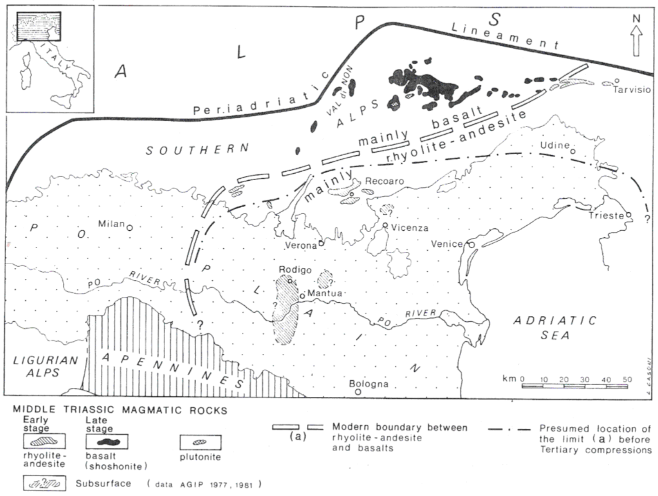
Figure 25. The slope of the Cernera Bank.

An example of the slope of the Anisian/Ladinian carbonate bank. The Cernera margin toward the North. Note the angular unconformity sealing the paleoslope indicating the original steepness of the bank margin. (Photo M. Gaetani).

Some of these margins are interpreted as being guided by active faults (Doglioni, 1987).

Associated with the increasing of the crustal instability is the first onset of the volcanism. Most typical for this time are tuffs and in general explosive products in outcrop. Rarer are the feeding dykes and magmatic bodies. They are cropping out in Eastern Lombardy (Cassinis and Zezza, 1982) and in the Recoaro area (Barbieri *et al.*, 1980). The most typical products are the so-called "Pietra Verde" consisting of green tuffs with lapillistone, frequently reworked and displaced in the deepest part of the basin by turbidity currents. Being present from western Lombardy and Ticino until the Carnia, they reach a maximum thickness of some hundreds of m in the basin of the Eastern Dolomites, reworked and accumulated from the sources situated to the south (Bosellini *et al.*, 2003). The Recoaro area was a site for the effusion, but other sources should be situated below the Venetian plain and detected by commercial boreholes (Brusca *et al.*, 1982; Castellarin *et al.*, 1988) (Fig. 26).

Figure 26. Magmatism in Southern Alps.



The magmatic rock distribution in the Southern Alps during the Middle Triassic and the Carnian. Note that volcaniclastics fed alluvial and submarine fans also in central Lombardy and the tephra arrived to the western Lombardy (From Castellarin *et al.*, 1988, modified).

The late Ladinian

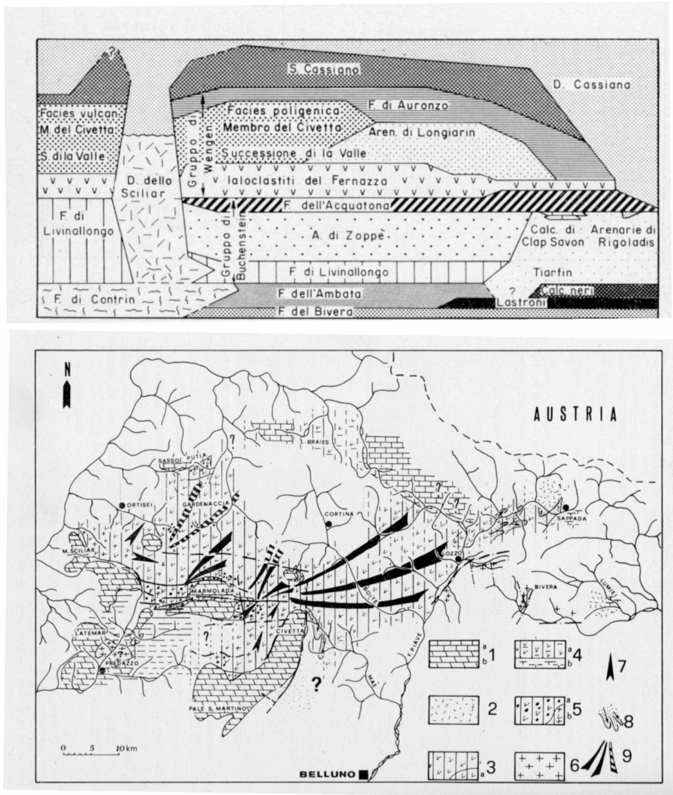
During the upper part of the Ladinian, two main settings developed in the Southern Alps. In Lombardy and Carnia, a development of the carbonate platforms coupled to basins continued. Often no distinction with the platform may be made and consequently, from the nomenclatural point of view, a single term like Esino or Schlern is adopted for the whole platform (Gaetani *et al.*, 1992; Jadoul *et al.*, 1993; Jadoul and Nicora, 1986). In the basins the major difference in comparison to the lower Ladinian was the passage from the cherty limestone of the Buchenstein Fm. to more silty units, fed mostly from the south (Brusca *et al.*, 1982).

In the Dolomites, by contrast, geologic evolution and setting are more complicated, with the most important event being the intrusion of a magmatic dome in the area of Predazzo (Doglioni, 1983; Castellarin *et al.*, 1988). An aureole of dykes is spread all around, cutting the carbonate platform bodies as in the Latemar Group (Fig. 27). Other volcanic activity occurred in the south, under the Venetian and Po plains. Doming stopped the growth of the platforms in the Western Dolomites, and most of them emerged or, due to the reduced accommodation, resulted in less thick carbonate bodies. Dismantling of the volcanic products generously fed the basins with chaotic accumulations, conglomerates, and more organized turbiditic bodies (Viel, 1979) (Fig. 28). Gradually, the paroxistic magmatic activity stopped and the carbonate platforms that continued to grow far from the polluting centres recovered (Fig. 29).

Figure 27. Volcanic dykes in the Latemar.

In the Latemar Group, the volcanic dike dissect the carbonatic platform. Saddle to the north-west of the Cornon del Latemar. (Photo M. Gaetani).

Figure 28. Volcanics in Dolomites.



The dismantling of the volcanics in the western Dolomites brought a great amount of material in the basin of eastern Dolomites. Top. Relationships between the major units. Bottom. Paleogeographic (not palinspastic) map the major submarine fans. (From Viel, 1979).

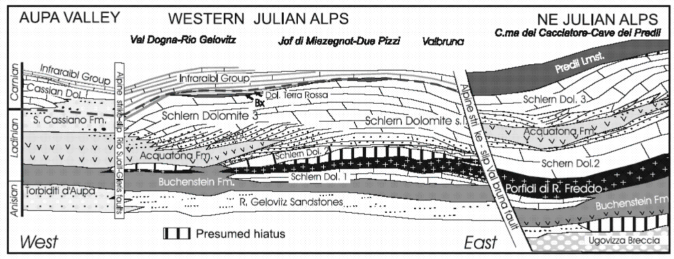
Figure 29. Recovering of the carbonate platform.

With the demise of the volcanic activity and filling of large part the basins, the carbonate platforms were able to prograde and a new set of platform established since the latest Ladinian through part of the Carnian. The Lastoni di Formin Cassian platform prograded on the volcaniclastics of the Wengen Group. (Photo M. Gaetani).

Magmatic products moved from the mainly rhyolite-andesitic signature to a basaltic shoshonitic nature. The calc-alkaline trend toward more basic products is coupled with a shifting of effusion centres to the NNW in present coordinates (Castellarin *et al.*, 1988) (Fig. 26). The shifting in time and space of the volcanic sources suggests the existence of a source moving deeper toward the NW. Several geochemical indexes point to a volcanic arc of basalts for the upper Ladinian magmas. To discuss the general geodynamic scenario is out of the scope of the present review, but it should be stressed that up to now a very convincing reconstruction has yet to be proposed because of contradictory evidence affecting the general settings of the margins of Adria and the Balkan areas. The system Palaeo-Tethys vs. Neo-Tethys is better understood eastwards (see Barrier and Vrielynck, 2008). Details on the pivotal point(s) to the margin of Adria are instead controversial.

In Carnia, the Alpine tectonics dismembered the original paleogeographic pattern. However, a basinal area may be recognized to the west, while the carbonate platform was persistent to the east (Jadoul and Nicora, 1985; Jadoul *et al.*, 2002) (Fig. 30).

Figure 30. Ladinian units in Carnia.



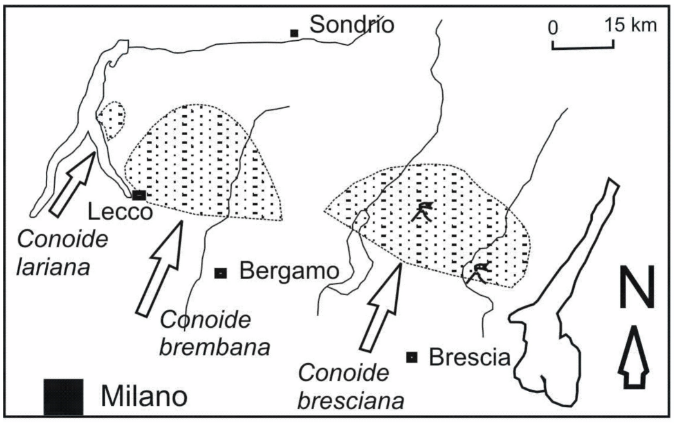
Stratigraphic scheme for the Ladinian units in Carnia region. The deeper areas are developed to the west. (From Jadoul *et al.* 2002).

The Carnian

The last act of the very complex evolution of the Southern Alps during the time interval under examination was characterized by gradual reduction in tectonic activity and subsidence rate. The volcanism was no more active in the Dolomites, but moved to the SW, with a volcanic arc located to the south of the Lombardian Prealps, and with a few apparatuses cropping out near Brescia. This last cycle started after the global eustatic sea-level lowering, which occurred during the topmost Ladinian.

In Lombardy, veneers of peritidal/subtidal, mostly micritic carbonates, are spread over large parts of the area, except for a few basins that are not completely filled by the fine clastics of the Wengen Fm., as in Valcamonica and Giudicarie (Balini *et al.*, 2000). In the southern parts of the outcrops and below the sole of the alpine thrust sheets, these carbonatic bodies were cut and covered by a volcanic arc, spread from Lecco to Recoaro for some 150 km, whose material was dismantled and transported northwards to form three major aprons (Val Sabbia Sandstone) (Fig. 31).

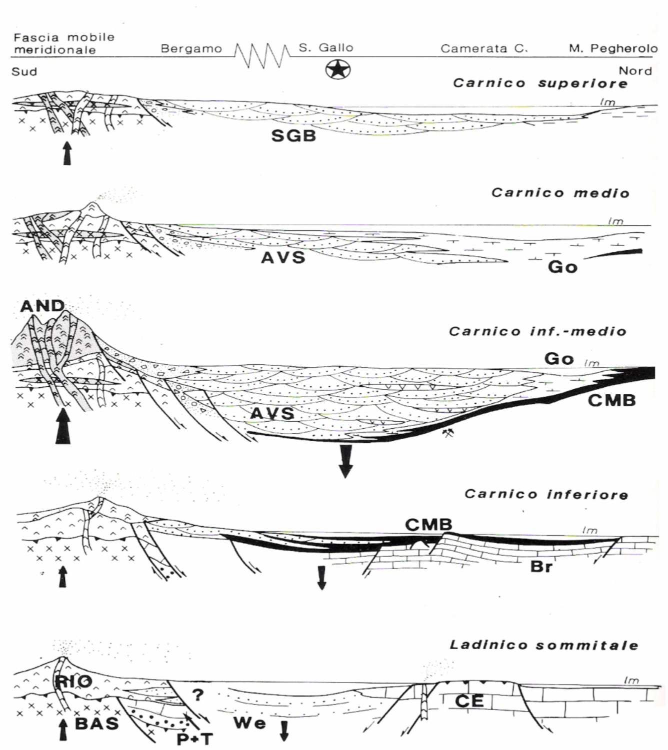
Figure 31. The Valsabbia volcaniclastic fans.



The volcaniclastics originating from the dismantling of the volcanic arc situated to the SW of the present Bergamo and Brescia Prealps, formed three major subaerial fans, submarine in their distal part. In the Brescia province also some volcanic apparatuses are preserved (From Garzanti and Pagni Frette, 1991, redrawn). Not palinspastic.

The aprons were partially submarine to the north, where they interfingered with the lagoon of the Gorno Fm. (grey, dark, marly limestone with oligotypic mollusc fauna) (Fig. 32). In turn, the lagoon interfingered with the peritidal carbonates of the Breno Fm. The geochemical signature suggests linking these volcanics to a back arc magmatism (Garzanti, 1985; Cassinis *et al.*, 2008). After a last pulse of volcanic eruptions late in the Carnian, a wide, mixed evaporitic, flat with red and green shale, covered the whole area, in a setting of playas with a low subsidence rate.

Figure 32. Evolution of the Carnian back-arc.



Evolution of the Carnian back-arc in Central Lombardy along a N-S transect. To the North of Bergamo data from outcrops. To the South, the interpretation is based on few borehole and mainly on clastic analysis of the terrigenous fans. (From Garzanti and Jadoul, 1985).

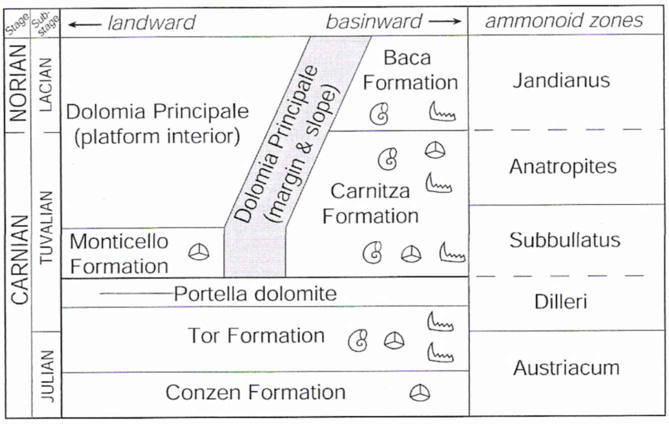
In the Dolomites, the situation was still more complex. When the volcanic activity was over, carbonatic bodies recovered on the previously non-emergent areas of the Western Dolomites and to the northern fringe of the Eastern Dolomites. Reef builders evolved to more diversified patterns, with colonial scleractinians making their first important appearance together with calcareous sponges (Dieci *et al.*, 1970; Zardini, 1973, 1978). Algae and sponges also became important. Where subsidence persisted at a higher level, several superposed tongues of the platforms prograded toward the basin. Since the basins had been previously largely filled by volcanogenic material, progradation was easier, and the platforms progressively merged (Cassian 1 and 2 platforms). Stefani *et al.* (2010) examined in detail the climatic control of the evolution, stressing the importance of the arid-to-moist climatic oscillations. The increasing influence of moist episodes helped in producing siliciclastics that reached the smaller remaining basins. Carbonate productivity still formed carbonate ramps and coral patch reefs that sealed the succession in the Eastern Dolomites before the emersion of the area, producing a flat topography (Stefani *et al.*, 2010). Red silty-to-shaly units mark the end of the complex cycles characterizing the Dolomites (Fig. 33).

Figure 33. Red shales sealing the sedimentary cycle.

The end of the cycle is marked by red siltstone and shale, with few dolostone intercalations. Moiazza Group, loc. Col dell'Orso, Belluno Province (Photo M. Gaetani).

In Carnia, the persistent carbonate platform, often dolomitized, had its maximum development toward the top of the Ladinian. This platform was dismembered by syngenetic movements in the earliest Carnian (dating is uncertain) (Jadoul and Nicora, 1985; Krainer and Lutz, 1995). Isolated small basins, fed by the micrite produced on the still-living carbonate banks, remained in a few areas (Malborghetto). Later, most of the area was covered by lagoonal micrite and clays. The classical succession of Cave del Predil/Raibl is within this interval (De Zanche *et al.*, 2000; Gianolla *et al.*, 2003). Also in that region, the demise of the reef-builder communities and consequent crisis in the carbonate productivity led to almost a filling of the previous basins. What is peculiar to the Tarvisio area is the possibility of fairly good dating of the demise of the previous settings and the ongoing of a new style of carbonate production and general setting (Gianolla *et al.*, 2003). The ongoing of the Dolomia Principale type of platforms and peritidal flats may be dated to the late Carnian, while on most of the Southern Alps dating is poor or emergent areas with playas were dominating (Fig. 34).

Figure 34. Transition to the new story.



In the Raibl area it is possible to date the onsetting of the Dolomia Principale, in the latest Carnian (From Gianolla *et al.*, 2003, modified).

The Ionian Triassic

In Southern Italy, in the area of the seaway that had already opened in the Permian, a different evolution occurred. Two regions are significant.

Sicily

In western Sicily, a succession of troughs and swells has been recognized since the 1960s. Studies were done first by petroleum geologists (Schmidt di Friedberg, 1960), with academic studies following (Mascle, 1967; Catalano and d'Argenio, 1978; Montanari, 1987; Catalano *et al.*, 1991, 1992). From north to south in the present orientation they are: Panormide Platform/Imerese Basin/Trapanese Swell/Sicanian Basin/Sciacca Swell/Iblean Platform. Full separation of these paleogeographic elements has occurred since the latest Carnian (Di Stefano, 1990). The stratigraphy and sedimentology of the Triassic sediments in these paleogeographic and structural elements have been thoroughly discussed in several papers (Di Stefano, 1990; Catalano *et al.*, 1992, Bellanca *et al.*, 1995; Gullo, 1996; among others).

As previously mentioned, the Lercara Formation contains intrabasinal (carbonate and shales) and extrabasinal components (clayey sandstones, quartz, and feldspars). Among the numerous group of fossils there is evidence for many Permian stages and Early Triassic to Anisian in the Triassic (Gullo,1993; Carcione, 2007).

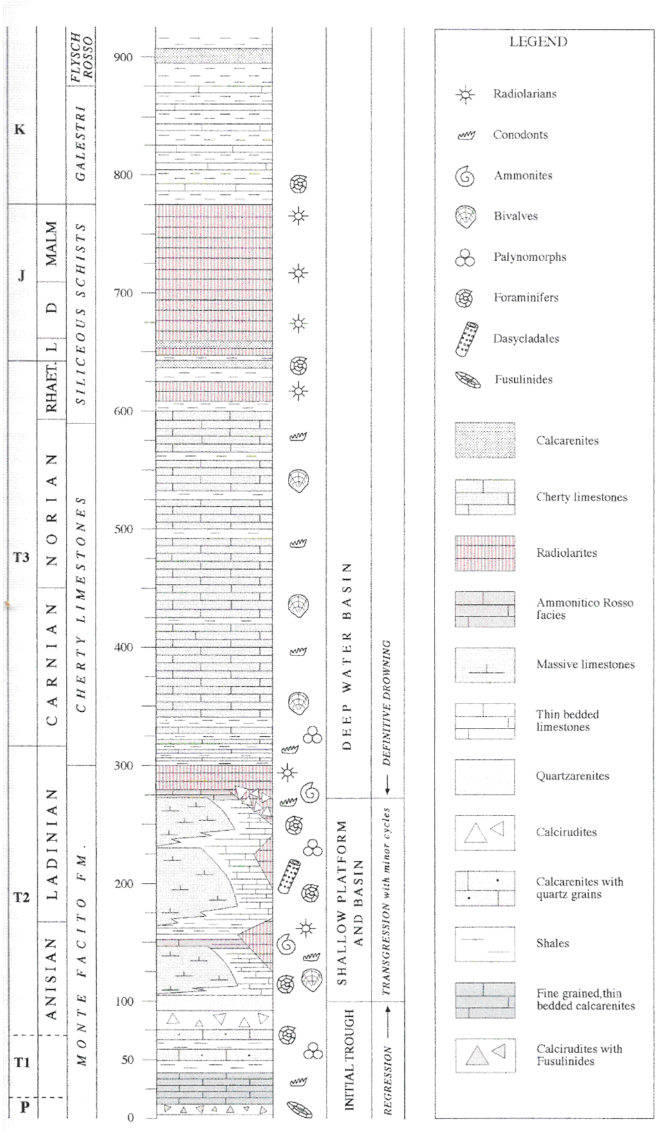
On these rocks lays, with tectonic contact, the Mufara Fm., which is in turn overlain, mostly with tectonic contact, by the cherty limestones of the late Carnian-Rhaetian age. The Mufara Fm. consists of fine siliciclastics, marls, and shales, with calcarenite intercalations (Di Stefano, 1990; Distefano et al., 1998; Carrillat and Martini, 2009). It is known in the Panormide, Imerese, and Sicano domains, where it is bounded to the Carnian, while in the Trapanese domain it is late Ladinian/early Carnian in age (Buratti and Carrillat, 2002; Carillat and Martini, 2009). It is also known near Catania at M. Judica (Lentini, 1974). The carbonate debris intercalated within the Mufara Fm. should indicate that the carbonate skeletal grains derive from coralline sponge and Spongiostromata patch reef communities located on a distally steepened shelf or ramp (Carillat and Martini, 2009).

During the late Carnian, terrigenous sedimentation was over on the entire basinal areas of Sicily, and sedimentation was dominated by calcilutites, resulting in a well-bedded mudstone with cherts, rich in halobiids, conodonts, radiolarians, and a few ammonoids. Due to its rich fossil content and physical stratigraphy (palaeomagnetism and isotope stratigraphy), the Pizzo Mondello section is presently proposed as the GSSP of the Carnian/Norian boundary (Nicora *et al.*, 2007). On the carbonate platforms and in the slope breccias, nice reef-builder organisms are described (Senowbari-Daryan *et al.*, 1982).

Lagonegro

Severe deformations affect the Triassic succession of the Lagonegro area in the Basilicata region, especially its lower part. However, since the first synthesis of Scandone (1967), detailed field researches have reconstructed the succession (Ciarapica *et al.*, 1990; Panzanelli Fratoni, 1991; Ciarapica and Passeri, 2005; and ref. therein). The basal unit is represented by the Monte Facito Fm., a comprehensive unit including up to 10 different lithofacies (Passeri and Ciarapica, 2010). Besides the shallow-water blocks with Permian microfauna, it records deeper-water evidence (shales and calcarenites) for part of the Lower Triassic, and also both shallow-water massive carbonates and shales and radiolarites, which are assumed to be lateral equivalents during most of the Middle Triassic. Toward the top of the Ladinian, a general drowning spread the radiolarites over the whole area, sealing the previously more-articulated setting (Fig. 35). With the beginning of the Late Triassic, an homogeneous sedimentation dominated by thin-bedded, light cherty limestones continued, with an average sedimentation rate (non-decompacted) around 10–20 m/My. Limy sedimentation went to an end toward the top of the Triassic, when siliceous shales, with occasional layers of calcarenites, prevailed, forming the record for the whole successive Jurassic.

Figure 35. Comprehensive successions of the Lagonegro area.



Note the definite down-warping toward the end of the Ladinian. The pelagic conditions will persist for the whole Upper Triassic and Jurassic. (From Ciarapica and Passeri, 2005, simplified).

Discussion

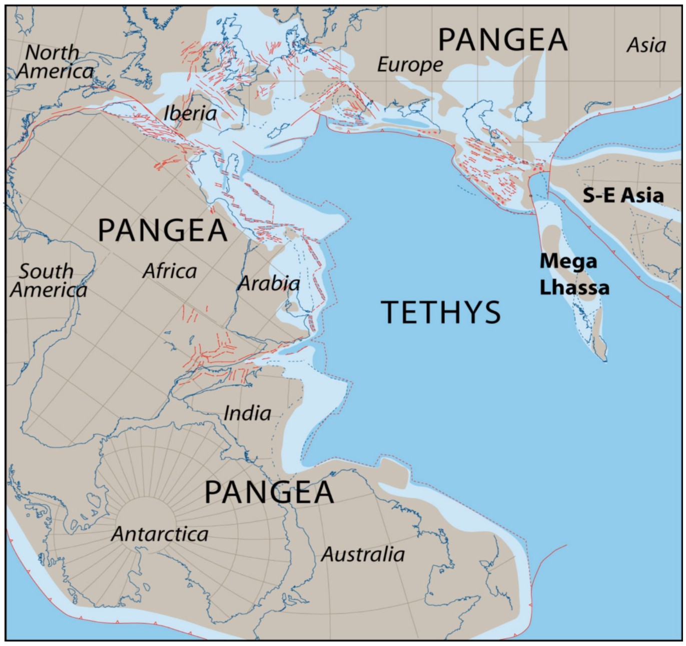
There is no doubt that since the Permian a deep marine trench was open in Southern Italy, bordered by carbonate reefs and banks. Fine siliciclastics fed the trench in which landslides repeatedly displaced fragments of the shallow-water carbonates. This setting continued at least up to the Ladinian, both in Sicily and in the Lagonegro area. Syntectonic activity decreased in the Ladinian, ending in the Lagonegro, while it continued in Sicily, though gradually reducing, during the early Carnian. With the late Carnian it was over also in Sicily and steady pelagic carbonate/cherty sedimentation spread everywhere in the basins. The rather high sedimentation rate suggests the importance of the nearby carbonate platforms as producers of micrite to be exported in the basins, even if the evolution of the first coccolitophorides algae may add a significant new producer to the carbonate factory, within the pelagic context itself, since the Ladinian-Carnian (Erba, 2006).

The geodynamic interpretation may suggest that during the interval—Permian to Middle Triassic—the trenches were activated by the rifting tectonics, and later, in the Late Triassic, the thermal subsidence was the greatest driving force. Reconstructions of the Ionian Sea (Catalano *et al.*, 2001; Finetti, 2005b) suggest that the main trench was continuing below what is now the Calabrian arc, while the basin and swell system of Sicily was a lateral branch connected to the main basin.

Propagation of the Atlantic Rifting

Around the Carnian-Norian boundary, a totally new setting was emerging at the northwestern margin of Adria (Fig. 36). A rifting was starting in the Central Atlantic in the Ladinian-Carnian, according to ages obtained in the Moroccan rifted basins (Baudon *et al.*, 2009), eventually giving way to the large basalt outpouring of the Central Atlantic Magmatic Province (CAMP) (Marzoli *et al.*, 1999; Cirilli *et al.*, 2009). This rifting system propagated eastwards and controlled the structural evolution and sedimentation, both in the Southern Alps and the Apennines, in the time interval Norian to Middle Jurassic. We may divide this interval into three parts: first, a Late Triassic section, followed by an Hettangian-basal Toarcian step, and then a third phase Toarcian-Aalenian in age. It is important to note that rifting and later the opening of an oceanic seaway contoured Adria around its northern margin, instead to join directly the already opened Ionian trench, and the Sicilian basins. Should this rifting have directly joined the Ionian trench, this last should have reached a much larger width than the actual 330 km calculated by Catalano *et al.* (2001). Also, if Ionian was already an ocean, why the propagating rifting didn't joined the already existing weakness in the crust?

Figure 36. Central Atlantic rifting.



The rifting in the place of the future Central Atlantic Ocean started to propagate eastwards during the Norian, turning around Adria, still an African Promontory. (From Barrier and Vrielynck, 2008).

The Late Triassic first stage of rifting

I will discuss only the Southern Alps evidence because of their better-preserved relationships. For a review of the Apenninic evolution during this time refer to Ciarapica (2007). The new cycle started everywhere with deposition of the Dolomia Principale, a very thick composite unit, consisting of thick-bedded peritidal dolostone mainly deposed under arid conditions due to the tropical latitudes in which Adria was laying at that time. This wide peritidal platform might have a modern counterpart on the Arabic side of the Gulf. Dolomitization was due to early diagenesis and represents a huge sequestration of Mg from the sea waters, the last massive Mg storage in the Earth's history. The Dolomia Principale facies (the Haupt Dolomit of German authors) extends from the Betic Range in Spain as far as the Himalayas (India and Tibet). It might also be considered a typical Tethyan facies. However, the subsidence patterns in the Southern Alps are already driven by rifting linked to the Central Atlantic rifting. In fact, in Lombardy the most subsiding areas are the same as the Early Jurassic. The subsidence rate may be 1:3, paleohighs vs. troughs, with rates exceeding 100 m/My in the basins. In the more subsiding areas, significant facies differentiation occurred in the middle/upper part of the Dolomia Principale, when slightly deeper basins individuated within the carbonate platforms (Aralalta Group). Thin-bedded mudstone with interbedded calciruditic and calcarenitic layers formed at the bottom of basins often in disoxic to anoxic conditions. This allowed the preservation of a unique vertebrate fauna, mostly with fishes, but including the more ancient pterosaurians (Fig. 37). On the shoulders of the basins, the peritidal carbonates continued to develop, even with a lower sedimentation rate (Fig. 38). The platform margins are sometimes preserved with a rim built mostly by encrusting algae and microbialite, after a significant demise of the coral frame builders. Slopes may be locally preserved as in Lombardy (S. Martino di Griante: Gaetani *et al.*, 1987; Artavaggio: Jadoul, 1986; Jadoul *et al.*, 1992) and in Carnia (Cave del Predil: De Zanche *et al.*, 2000). The same pattern with interplatform anoxic to disoxic basins has been also recognized in Friuli (Scotti *et al.*, 2002) where the Dolomia di Forni, the lateral equivalent of the Dolomia Principale, also contains significant terrestrial vertebrate fauna, including pterosaurians (Dalla Vecchia, 2002) (Fig. 39).

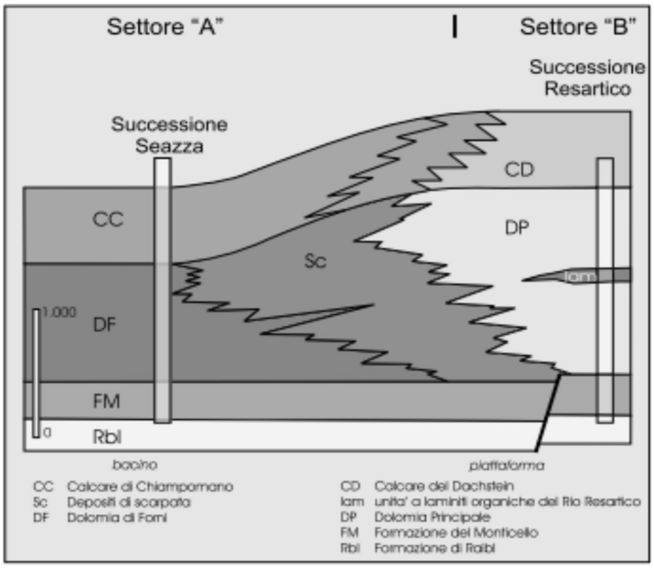
Figure 37. Early flying reptile.

Eudimorphodon ranzii, a flying reptile from the Zorzino Limestone (middle Norian), one of the most ancient flying reptiles so far known.

Figure 38. Upper Triassic-Lower Jurassic succession.

The Norian - Sinemurian succession near Cadenabbia (Como Lake). To the right the Dolomia Principale is overlain by the softer shale, marl and limestone succession of the upper Norian-Rhaetian, in turn overlain by the cornice formed by the Albenza Fm. (formerly *Conchodon* Dolomite) of Hettangian age. The prairies of the Calbiga Mnt., on the upper left, cover Moltrasio Limestone, the major infilling of the Generoso Trough. (Photo M. Gaetani).

Figure 39. Platform vs basin.

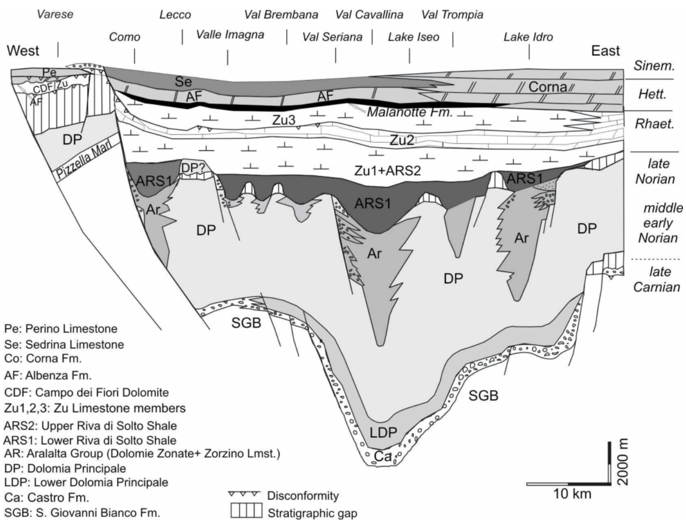


Relationships between the plaform (Dolomia Principale + Calcare del Dachstein) and the basinal facies (Dolomia di Forni + Calcare di Chiampomano). (From Scotti *et al.*, 2002)

Toward the end of the middle Norian, a new pulse in the rifting, coupled with an increase of humidity because of the drifting of Africa northwards—thus pushing Adria toward more temperate latitudes (Muttoni *et al.*, 2005)—

caused the input in the basins of a huge amount of clay. It resulted in the deposition of the Argillite di Riva di Solto Formation (Fig. 40). The high accommodation rate was allowed by the extensional regime, continuing the separation of basins from the swells, allowed by direct syngenetic faults (Jadoul *et al.*, 2008). The amount of clay is much reduced in Friuli and absent in the Dolomites, even if in the eastern Dolomites the thickness of the Dolomia Principale is very high (up to 2000 m) but encompasses the whole Norian and probably the Rhaetian (Fig. 41). With the beginning of the Rhaetian, this first rifting episode gradually vanished, and the Calcare di Zu Fm., a mixed shale/mudstone unit, extended in Lombardy also on some of the swells not previously attained by the clays of the Riva di Solto (Fig. 40). The gradual decrease of the clay input allowed the recovering of colonial corals forming one or two fairly continuous banks (Fantini Sestini, 1990). Recent findings of conodonts allow dating more precise than was previously possible (Rigo *et al.*, 2009; Muttoni *et al.*, 2010). By the end of the Triassic, this first rifting pulse was over, and the Triassic/Jurassic boundary may be recognized only in central Lombardy (Jadoul *et al.*, 2008). Due to the biocalcification crisis, fossils are scanty and the boundary is recognized on a palynological basis (Galli *et al.*, 2007).

Figure 40. Norian to Hettangian in Lombardy.



Stratigraphic scheme for the Norian to Hettangian in the central part of the Lombardian Basin. The scheme considers both thickness and time, thus also the gaps have a temporal expression. (From Jadoul *et al.*, 2008).

Figure 41. Peritidal cycles in the Dolomia Principale.

The dolostones of the Dolomia Principale form typical peritidal cycles. Upper walls of the Cima Ovest di Lavaredo. (Photo M. Gaetani).

In the eastern Lombardy and western Trento area, the clay input was reduced, and only the Calcare di Zu and local equivalents developed, overlying the Dolomia Principale. In the Dolomites this unit may be very reduced in thickness—200 m in the Sella group—(Bosellini, 1967). No equivalent of the shaly Norian-Rhaetian units are known here (Fig. 42). To the east in Carnian and Julian Alps, a more calcareous unit interfingers or overlies the Dolomia Principale, the Dachstein Limestone (De Zanche *et al.*, 2000; Piano and Carulli, 2002).

Figure 42. The wall of the walls.

The Dolomia Principale is overlain by the Liassic limestone of the Calcari Grigi, without any erosional ledge corresponding to Upper Triassic clay input. The Calcari Grigi start where the wall became fully vertical. West wall of the Civetta Mnt. (Belluno Province). The wooded wall in front is made of the Middle Triassic Sciliar Dolomite.(Photo M. Gaetani).

The Late Triassic palaeogeography partly reproduces settings previously already present, as some basins were active where they were already in the Middle Triassic in central Lombardy. However, palaeogeography mainly evolves along new lineaments, prevailing N-S oriented. The W-E orientation of the depositional features in Lombardy and in Carnia, and to a minor extent in the Venetian Alps, is not continued, and the new orientation suggests the linking to an extensional area active to the north and to the west. Bertotti *et al.* (1993) evaluated in detail the amount of extension originated from this stretching.

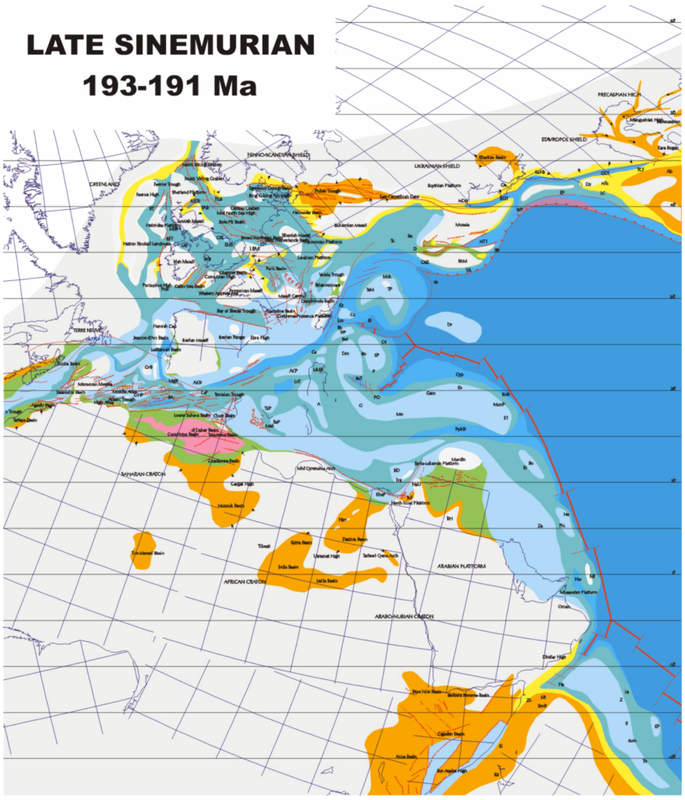
The Early Jurassic, second phase of rifting

After the pioneering Ph.D. theses of F. Wiedenmayer (1963) and D. Bernoulli (1964), and subsequent papers (Bosellini, 1973; Gaetani, 1975; Bernoulli *et al.*, 1979; Winterer and Bosellini, 1981; Weissert and Bernoulli, 1985; Sarti *et al.*, 1992; Bertotti *et al.*, 1993; among others) it appeared possible to describe the Jurassic evolution of the Southern Alps in terms of a passive margin facing a rifting and subsequently spreading oceanic area positioned to the west and to the NW.

In the Central Apennines especially, similar facies are present with timing in rifting and drowning comparable to the Southern Alps (Bosellini, 1973) indicating that also in that area the evolution of the passive margin may be studied, even if geometrical relationships are less preserved.

In the Southern Alps, fragments of the rim of the passive margin are poorly exposed in the Canavese area (Sturani, 1973). Better exposures are in the Swiss Alps (Trümpy 1960; Weissert and Bernoulli, 1985; Manatschal and Bernoulli, 1999) or more scanty in the Ligurids nappes (Marroni and Pandolfi, 2007) (Fig. 43).

Figure 43. Palaeogeographic map of the upper Sinemurian.

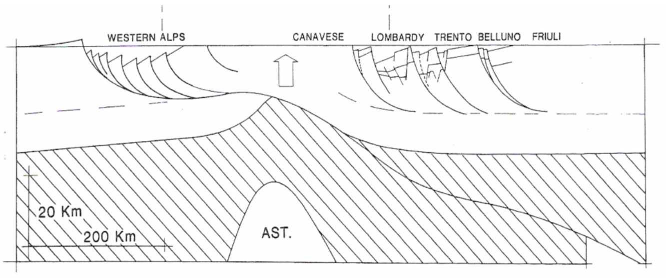


(From Dercourt *et al.*, 2000)

Moving from west to east, five main paleogeographic elements may be distinguished: the Canavese and Biella Zone, the Lombardian Basin, the Trento Plateau, the Belluno Basin, and the Friuli Platform. The basins are activated by direct faults mainly along a pattern of half-graben system, with the more subsiding part to the west, suggesting that the evolution of the margin was according to the "simple shear" model (Sarti *et al.*, 1992) (Fig.

44). However, Bertotti *et al.* (1993) consider that there are not yet sufficient data to support this interpretation.

Figure 44. Simple shear extension.



The Adria margin evolved according to the "simple shear" model in the Sarti *et al.* (1992) interpretation, along a half-graben system in the Southern Alps.

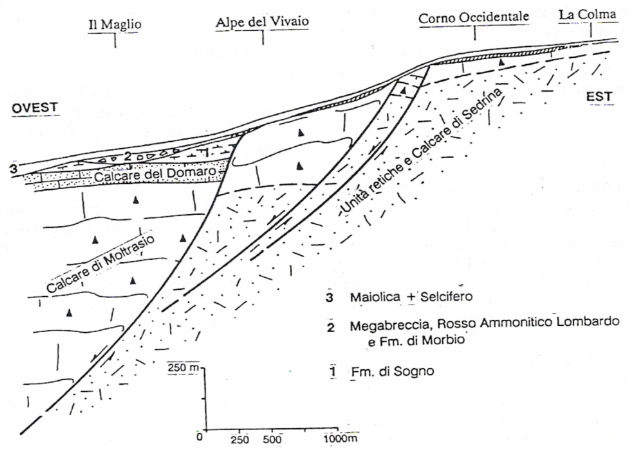
The successions of the Canavese/Biella Zone are reduced in thickness and poorly exposed. Its hinge with the Lombardian Basin is fixed at the Gozzano High. Within the Lombardian Basin itself, starting with the late Hettangian or the early Sinemurian, a number of troughs and swells or paleohighs were individuated. West to east, they are: M. Nudo Trough/Arbostora High/Generoso Trough/Corni di Canzo Swell/Albenza Trough/M. Cavallo-Zandobbio High/Sebino Trough/Botticino Dome. They end against the Trento Plateau with the Garda Escarpment. Due to the outcrops aligned along a belt roughly W-E oriented, the N-S relationships are lesser known. Troughs are some 20–30 km wide and swells or palaeohighs are a few km in width. Because the carbonatic backbone of the paleohighs acted as a trap and reservoir for hydrocarbons originating from the Middle Triassic and Norian anoxic basins, these features were economically investigated under the Po plain (Pieri and Mattavelli, 1986; Consonni *et al.*, 2010; and ref. therein). The NNE-SSW trend was confirmed, but also W-E trends are present (e.g., Bertotti, 1991), suggesting that the extension occurred along a rhombic pattern.

The infilling of the troughs may be over 3000 m in non-decompacted thickness, as in the Generoso Trough, in a time spanning the late Hettangian to the early Pliensbachian—i.e., about 250 m/My. For discussion on compaction and thermal history, refer to Bertotti (2001). The Moltrasio Limestone forms most of this infilling and consists of alternating grey, dark, marly limestone and marls, frequently with chert nodules, lenses, and bands (Fig. 45). Internal subdivisions are not obvious because of alpine tectonics disrupting monotonous successions and the soil-prone nature of the rocks. Tentatively, we may recognize a lower part more calcareous with abundant cherts; an intermediate part with thicker bedding, often clearly gradated with distal turbidites and more rich in clay; and an upper part in which the infilling by density current gradually decreases, as well as its clay content. Cherts are always present, but with a discontinuous and irregular distribution. Near the margin of the troughs, activated by syngenetic normal faults (Fig. 46), breccias and more coarse reworked material may be present. Decametric-thick slumpings are also observed. The Moltrasio Limestone may form 70–80% of the whole Jurassic succession. The origin of these sediments is not fully obvious. The clay may originate from the nearby emerging lands on the European continent, where the landscape was dominated by old and mature forms, rich in soils. The ongoing general transgression due to the increasing sea level (Hallam, 2001) may have provided such an amount of clay, eroded by the advancing seas on the peneplaned Variscan continent. More difficult is to search for the origin of the micrite. Bottom production should have been almost nonexistent, and calcareous phytoplankton was increasing in density and diversity (Erba, 2006), but it was not sufficient to account for such an imposing amount of micrite. The only viable source is the micrite exported in suspension from more distant shallow-water carbonate platforms, not from the near paleohighs, which are too small and partly already below the photic zone. The chert originates from the diagenesis of silica-sponge spicula and to a lesser extent of radiolarians.

Figure 45. Moltrasio Limestone.

In the middle part of the Moltrasio Limestone in the Generoso Trough, distal turbidites and m-thick slumping are very frequent. (Photo M. Gaetani).

Figure 46. Syngenetic faults between paleohigh and basin.



Sketch of the western slope of the Corni di Canzo Swell. Situation at the end of Lower Jurassic. (From Gaetani and Erba, 1990).

During the Pliensbachian, the accelerated infilling gradually decreased, and sedimentation was prevalently calcareous, with a reduced amount of clay, and also often less rich in silex. Micrite from nannoplankton became important (Cobianchi, 1992).

Because of quarries, some of them still active, the paleohigh of Arzo in the Arbostora complex is the better studied (Wiedenmayer, 1963). Very reduced sedimentations, gaps, and fissure fillings are the rule.

Moving eastward, through drowning occurred later, starting in the Sinemurian or even later, as on the Botticino Dome. The margin of the Lombardian Basin and the evolution of the Garda Escarpment have been studied in detail by Castellarin (1972) and later reconsidered by Picotti and Cobianchi (1996).

The Trento Plateau, some 60 km wide, remained under shallow-water conditions with carbonatic sedimentation during the interval Hettangian–earliest Toarcian. The Calcari Grigi di Noriglio Fm. represents this interval, and it was subdivided into three members (Bosellini and Broglio Loriga, 1971). Only toward the margin in the direction of the Lombardian Basin did an oolitic body develop (Massone Oolite). The general trend is from the peritidal platform in the lower part to oolitic shoals in the middle and lagoonal facies upwards (Masetti *et al.*, 1998; Clari and Masetti, 2002). The total thickness hardly reaches 500 m. (Fig. 47).

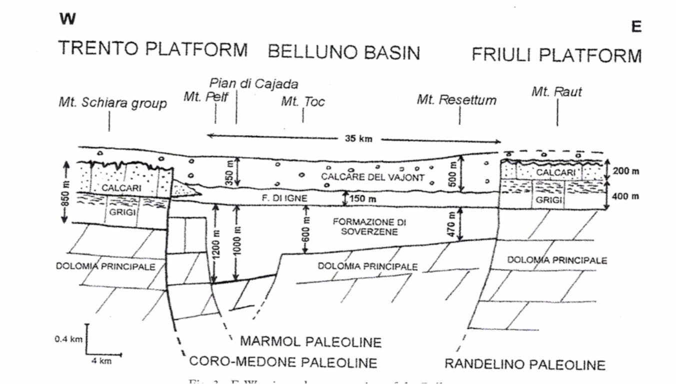
Figure 47. The Calcari Grigi Formation.

The Calcari Grigi Formation represents the peritidal carbonate complex that developed during the lowermost Jurassic (Hettangian to Pliensbachian) on the Trento Plateau. It was a potential source for the micrite exported in the nearby basins. Fanes Altopiano (Photo M. Gaetani).

In the lower part, layer surfaces revealed an enormous number of dinosaur tracks (Avanzini *et al.*, 1997; Leonardi and Mietto, 2000). The upper member (Rotzo Member) is instead very typical for the spread and diversified *Lithiotis* facies (Accorsi Benini and Broglio Loriga, 1977; Accorsi Benini, 1979).

The next paleogeographic main element eastwards is the Belluno Basin, described as an ancient analogue of the “Tongue of the Ocean” (Bosellini *et al.*, 1981). Its drowning occurred in the early Sinemurian. It acted during this phase mostly as a starved basin (Soverzene Fm., 400–1200 m thick; Sarti *et al.*, 1992), fed by the micrite and locally coarser clasts originating from the nearby carbonate platforms. The Belluno Basin joined the Slovenian Basin (Cousin, 1973; Buser, 1987), contouring the Friuli Platform, which is the last main paleogeographic element. During the Early Jurassic, the Belluno Basin widened in successive steps at its western margin, extending for an additional 20 km at the expense of the Trento Plateau (Clari and Masetti, 2002; Carulli *et al.*, 2002) (Fig. 48).

Figure 48. Platform vs basin in Carnia.



The relationships between the Friuli Platform and the Belluno Basin in western Carnia. (From Carulli *et al.*, 2002).

On the Friuli Platform, shallow-water carbonate sedimentation continued through all of this time. The shelf edge is activated by normal faults and partly rimmed by oolitic shoals. The uppermost Triassic and the Lower Jurassic are represented by mostly undolomitized facies, referred to as the Dachstein Limestone and the Calcari Grigi (Carulli *et al.*, 2002). In the core of the platform, successions are very reduced in thickness and are still partly dolomitized in the Lower Jurassic beds: the rimmed platform includes a lagoon, in which isolated coal seams and pelletal wackestone are present (Venturini, 2002). Boreholes revealed that the Friuli Platform is dissected by a deeper area since the Pliensbachian, the Friuli Basin (Cati *et al.*, 1987).

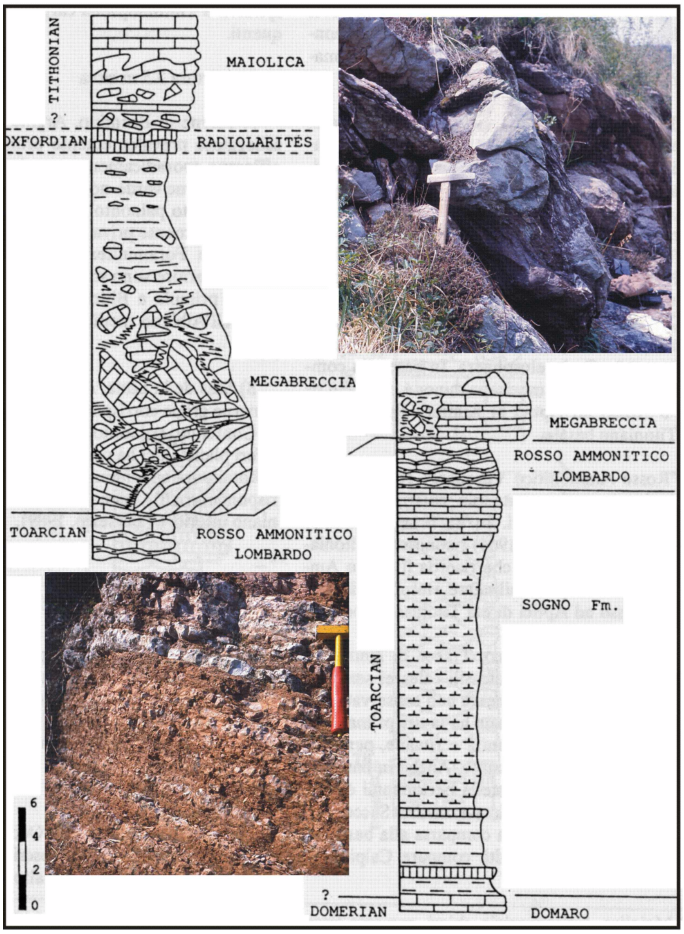
The Toarcian-Aalenian last step of rifting

The continuous crustal extension acting for at least 35 My had already sufficiently widened the seaway which, during the Middle Jurassic, will provide the floor of the Ligurian-Piedmont Ocean. This is also evidenced by the presence of the Toarcian Oceanic Anoxic Event (T-OAE) in the deeper part of the basins (Erba and Casellato, 2010).

During this final step of the rifting, the Lombardian Basin continued to deepen. Accomodation being only partially compensated by sedimentation, the basin became progressively starved. The Trento Plateau became the site for oolitic shoals and more open carbonate facies, even if not too deep. The Belluno Basin also was affected by the Anoxic Event, but its sedimentation was characterised also by resedimentation of significant volumes of shallow-water carbonates originating from the Friuli Platform, which continued to remain in shallow-water conditions.

In the Lombardian Basin, it is possible to date the onsetting of this third step, within the Tenuicostatum Zone of the lowermost Toarcian. The mudstone/wackestone with some minor quartz and muscovite clasts of the top of the Domaro Limestone are abruptly substituted by grey and brown marls eventually ending in the black shales of the T-OAE (Jenkins, 2003). The level, known also as the “Fish Level”, is usually less than 1 m thick but may reach more than 10 m in the most expanded sections. The T-AOE is preserved only in the deepest depressions. The best section is the Colle di Sogno (Tintori, 1977; Gaetani and Poliani, 1978). The expansion of an enormous amount of basalts in the Karoo-Ferrar Province (Jenkyns, 2003) would have introduced in the oceanic-atmospheric system a huge amount of CO_2. The destabilization of the previous equilibrium also would have caused, among other things, an enormous increase of the primary productivity in organic matter (Erba, 2004). With the decreasing of the volcanogenic CO_2, oceanic conditions returned to more oxic and sedimentation was characterized by two types of facies. One is represented by condensed red mudstone nodules embedded in a marly matrix (Rosso Ammonitico Lombardo—a few tens of m thick), locally rich in ammonite moulds. The second is a cyclic coupling of grey marls and marly limestone, presumably astronomically controlled in their deposition (Sogno Formation, up to 145 m thick). Near the swells and paleohighs, sedimentation on the slopes is evidenced by fluidal textures in the Rosso Ammonitico and rarer breccia bodies. A major syntectonic event is recorded in the Generoso Trough, where a huge landslide occurred during the Aalenian, when rock slabs including rocks from the upper Pliensbachian until the Toarcian became embedded as boulders up to several m wide in the slumped material (Gaetani and Erba, 1990) (Fig. 49).

Figure 49. The Aalenian last major slumping.



At the foot of the slope of the Corni di Canzo Swell, a huge accumulation of slumped material cut deep into the Toarcian Rosso Ammonitico Lombardo. The slope persisted through the whole Jurassic and resedimented cobbles are included in the Rosso ad Aptici and the Maiolica. (From Gaetani & Erba, 1990) (Photos M. Gaetani).

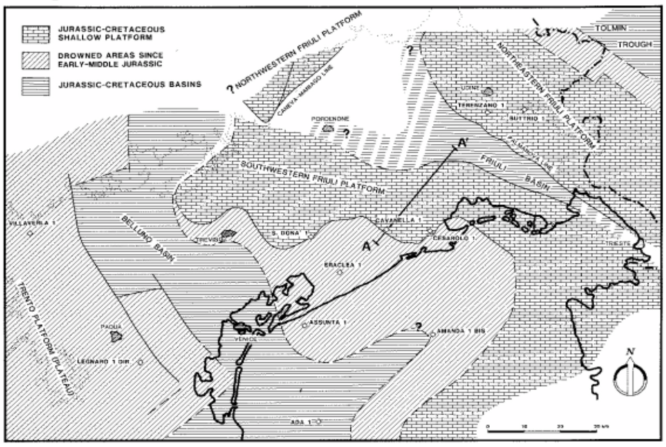
Carbonate deposition gradually ended with the lowest Bajocian, and residual red clays carpeted the bottom of the Lombardian Basin.

On the Trento Plateau, as a consequence of the drowning, environments moved from the restricted lagoons of the Rotzo Member of Calcari Grigi to the open shoals of the Oolite di S.Vigilio and its marginal facies. toward the Lombardian Basin, it may reach 200 m in thickness, dying out toward the core of the plateau. It consists of poorly stratified oolitic and encrinitic grainstone with festooned cross-lamination. The emerging surface is characterized by ferruginous crust and hard ground with pelagic stromatolites (Massari, 1979).

In the Belluno Basin, there are partly reproduced facies already met in the Lombardian Basin. The Igne Formation, with cyclic grey marls and marly mudstone recalls the Sogno Fm., containing the early Toarcian Anoxic Event, recorded by discontinuous levels of black shales. Layers with marly Rosso Ammonitico are also present.

On the Friuli Platform, the rim was made of oolitic shoals, while toward the centre of the platform, peritidal dolomitized layers occasionally occurred. But this interval seems to be poorly documented or already included in the base of the Cellina Limestone (Venturini, 2002). The deeper area internal to the platform detected through boreholes persisted in being active (Fig. 50).

Figure 50. Friuli Platform.

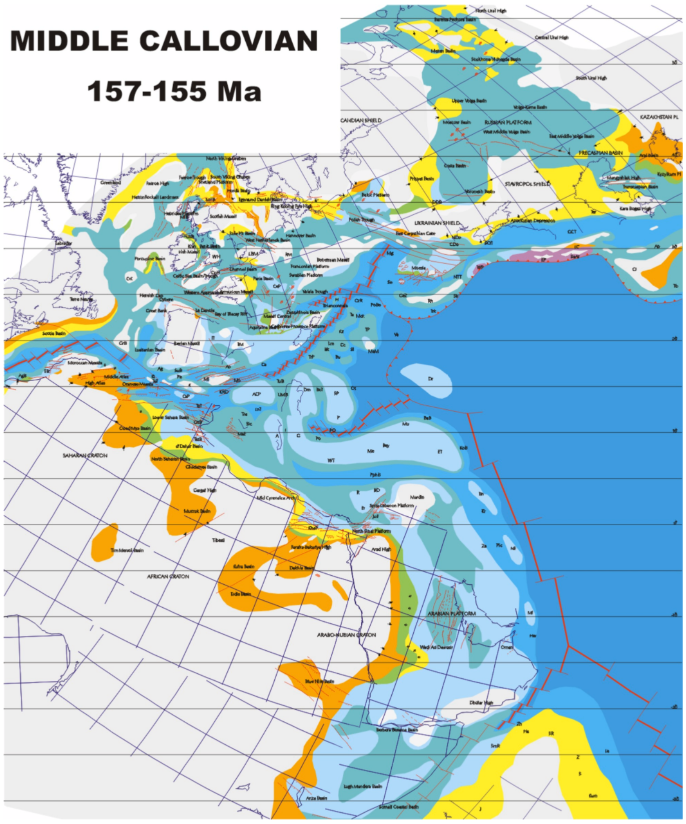


The Friuli Platform appears to be dissected by an internal deeper area since the Pliensbachian. The other parts of the platform remained in shallow-water condition through the whole Mesozoic. (From Cati *et al.*, 1987).

The Thermal Subsidence Stage of the Margin

The subsidence driven by the tectonic extension of the rifting was gradually over, and since the Bajocian for the remaining Jurassic and the initial part of the Cretaceous the subsidence seems to be driven by the thermal cooling of the margin crust of Adria. The rifting of the Central Atlantic was gradually replaced by the drifting. The same occurred out of the Adria margin, giving birth to the Ligurian-Piedmont Ocean, a branch linking the Atlantic with the Tethys (Fig. 51). According to Bertotti *et al.* (1993) the W-E section from Canavese to the eastern tip of the Trento Plateau stirred from 237 km to 290 km, because of the extension. Because of the continuous deepening, the shallow-water carbonate factories moved away from the Lombardian Basin. Also on the Trento Plateau reduced productivity is recorded. The Belluno Basin instead continued to be fed by sediment-transferring processes from the Friuli Platform, which remained in a shallow-water condition.

Figure 51. Palaeogeographic map of the Callovian.



(From Dercourt *et al.*, 2000).

The Lombardian Basin entered therefore into a phase of pronounced starvation, enhanced by the subsidence that brought the bottom below the Carbonate Compensation Depth (CCD) (Fig. 52). The carbonate biogenic rain was dissolved, as evidenced by the red, marly shale veneer, carpeting the top of the previous formations in the troughs (Erba and Gaetani, 1990; Erba and Casellato, 2010). This trend should have continued for a long time, if a massive input of siliceous mud had not changed the sedimentation dramatically. Following Winterer and Bosellini (1981), it was considered that the siliceous sedimentation dominating for about 20 My, from the late Bajocian to the Kimmeridgian (Baumgartner, 1987; Baumgartner *et al.*, 1995) was the residual deposit under the CCD. Winterer (1998), reviewing the paleodepths in the

Mediterraneam Jurassic, stated that radiolarian cherts are the product of massive bioproductivity. Muttoni *et al.* (2005) pointed out that, as today, the siliceous muds in the oceanic waters should be preserved only in the equatorial upwellings because of overproduction. Palaeomagnetics performed in the Selcifero Group of central Lombardy showed that the margin of Adria, following the loop of Africa with a southwards rotation of some 10°, was once more about 10°N latitude during the Middle Jurassic, in the more favourable conditions for massive bioproductivity of radiolarians (Muttoni *et al.*, 2005).

Figure 52. The Jurassic succession in Lombardy.

In the overturned section of M. Mudarga (western side of the Albenza Plateau) almost all the Jurassic succession is exposed. The upper part of the Moltrasio Limestone (Sinemurian-lower Pliensbachian) is followed by the Domaro Limestone (upper Pliensbachian till very base of Toarcian). The "reds" includes the Rosso Ammonitico Lombardo and the Selcifero Group (Toarcian – lower Tithonian). The Maiolica Fm. extends from the upper Tithonian to the Barremian. (Photo M. Gaetani).

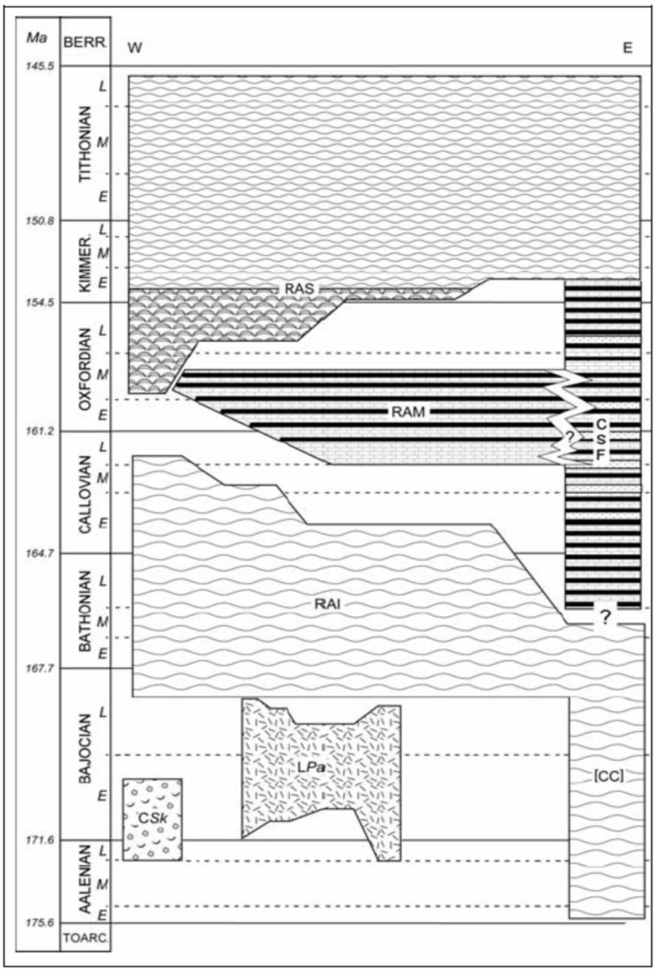
From the Kimmeridgian upwards, the amount of carbonate fraction in the sediments gradually increased. Most typical is the Rosso ad Aptici Fm., in which only the originally calcitic gnawings of ammonites are preserved and not their aragonitic shells. This was traditionally interpreted as the gradual deepening of the CCD (Gaetani, 1975; Winterer and Bosellini, 1981). Muttoni *et al.* (2005) instead showed that the return toward more high latitudes of Adria brought the margin toward trofic conditions more favourable to the calcareous than to the siliceous phytoplankton. Bottom positive movements or significant changing of the CCD should thus not be responsible for the recovery of the carbonatic sedimentation, but rather the latitudinal moving of plates, controlling bioproductivity. The full recovery occurred with the upper Tithonian, when the whitish, well-layered mudstone of the Maiolica Fm. spread over the whole Lombardian Basin (Chiari *et al.*, 2007; Casellato, 2010) (Fig. 53).

Figure 53. Maiolica cherts.

The nonnococco ooze forming the Maiolica, may be locally enriched in chert, originating from the locally abundant radiolarians.

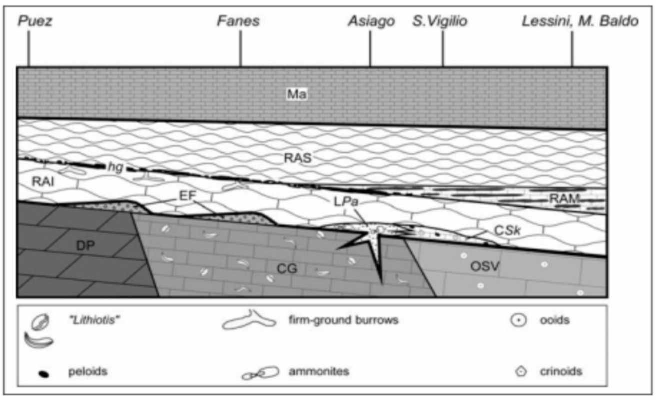
On the Trento Plateau, this was the time of deposition for a well-known facies, the Rosso Ammonitico (in the Anglo-saxon literature curiously spelled *Ammonitico Rosso*). Polished stones from the quarries of the Venetian Prealps were largely used in churches and manors throughout Italy and elsewhere. Due to the mixing of facies and lithostratigraphic terms, Martire *et al.* (2006) proposed to define the formation as Rosso Ammonitico Veronese. In their review, they identified several members from upper Aalenian to Tithonian (Fig. 54). They include in the formation also the "Lumachella a *Posidonia* *alpina* Member" (Sturani, 1971), consisting of coarse-grained grainstone packed with thin-shelled bivalves, poor in micrite and with thick rims of isopachous cement (Martire *et al.*, 2006). Most typical is the Rosso Ammonitico facies, subdivided in three members—lower, middle, and upper. The lower member is an amalgamated pseudonodular, pink packstone-mudstone, apparently massive in outcrop (age: late Bajocian to lowermost late Callovian). It thins out northwards, where it lies directly on the Dolomia Principale (Fig. 55). The middle member, a few m thick, consists of thin-bedded nodular limestone with red chert nodules and beds (age: late Callovian to middle Oxfordian). toward the Belluno Basin, this member interfingers with a grey, cherty limestone, including resedimented ooidal and peloidal grainstone, which forms the Calcare Selcifero di Fonzaso (Beccaro *et al.*, 2008). The Rosso Ammonitico Superiore consists of nodular, marly limestone with a knobby, weathering surface (age: middle Oxfordian to late Tithonian). toward the top, the formation gradually loses its pink colour and passes to the whitish, thin-bedded wackestone of the Maiolica Fm. (Biancone Fm. in the local terminology). This member reaches the thickness of about 15 m in its type-section, while on the whole the total thickness of the formation is about 30 m. The Rosso Ammonitico Veronese therefore has a sedimentation rate around 1 m/My, with frequent gaps and indurated surfaces. Winterer (1998) made an exercise to estimate the depth of deposition in the Middle and Upper Jurassic on the Trento Plateau and produced a figure around 100 m in depth at the beginning of the Rosso Ammonitico Veronese, reaching about 400 m at the end with the Maiolica deposition. These figures account for a sea floor initially swept by currents forming the *Posidonia alpina* lumachelle, followed by a deeper floor reached by planktonic carbonatic rain, partly dissolved during the long time resting before burial. The cherts of the middle member record the blossom of radiolarians during the southern loop of Adria during the Middle Jurassic.

Figure 54. Rosso Ammonitico Veronese.



The stratigraphic scheme of the Rosso Ammonitico Veronese on the Trento Plateau (From Martire *et al.*, 2006).

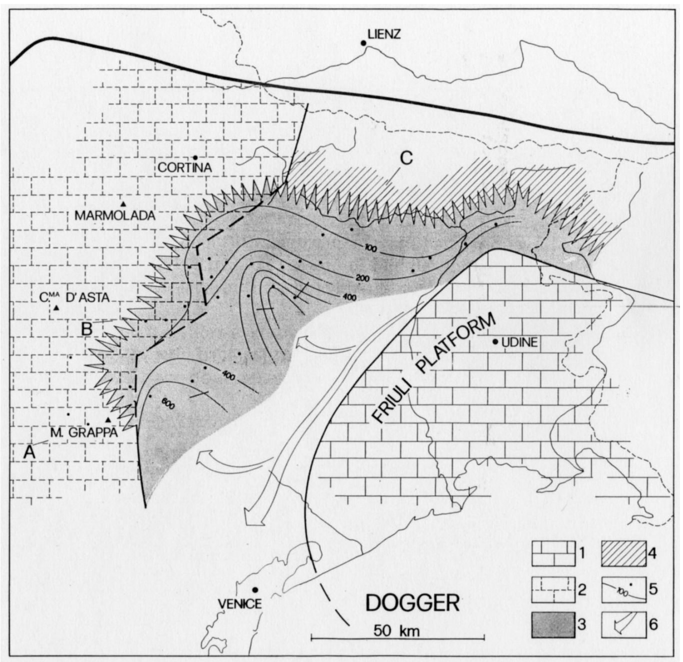
Figure 55. The Rosso Ammonitico Veronese onlaps.



The Rosso Ammonitico Veronese onlaps northwards on progressively older units. (From Martire *et al.*, 2006).

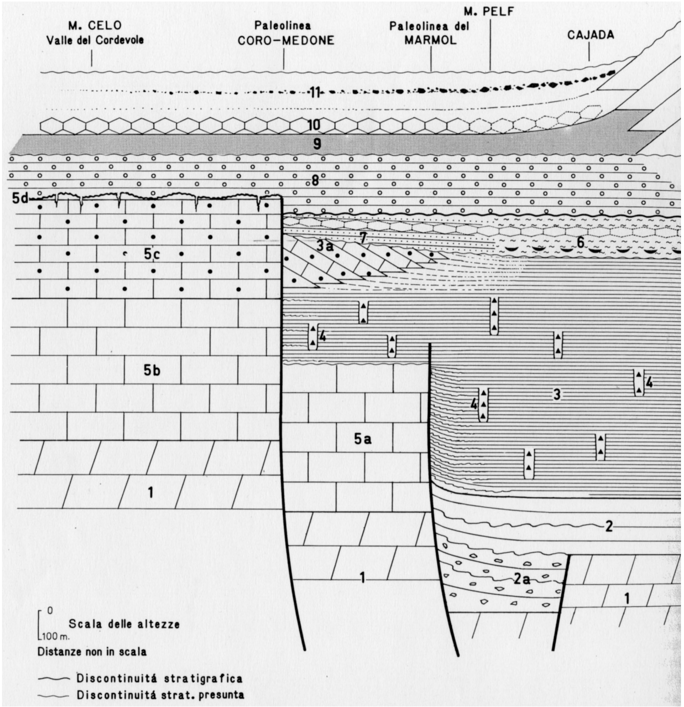
The Belluno Basin records the unusual feature of a thick unit, the Vaiont Limestone—up to 500 m thick, consisting of oolitic and skeletal grainstone. This typical shallow-water facies is interbedded in a pelagic sequence. Bosellini and Masetti (1972) first recognized the resedimented nature of the oolites, originating from the nearby Friuli Platform, and forming a wide apron infilling this Jurassic “Tongue of the Ocean” (Bosellini *et al.*, 1981) (Fig. 56) (age: late Bajocian to Bathonian; Clari and Masetti, 2002). When oolitic resedimentation was over, pelagic sedimentation resumed with cherty mudstone and interbedded turbiditic layers of the Fonzaso Fm. Its age, from Callovian to early Kimmeridgian, matches the radiolarian blossom, already discussed within the Lombardian Basin. The deep-sea sedimentation graded into a facies similar to the upper member of the Rosso Ammonitico Veronese, then it passed gradually, toward the end of the Tithonian, to the Maiolica whitish mudstones (Fig. 57).

Figure 56. The “Tongue of the Ocean”.



The Belluno Basin had the size in its outcropping part, like the present Tongue of the Ocean in the Bahama Banks. 1. Platform limestone. 2. Red nodular pelagic limestone (Rosso Ammonitico Veronese). 3. Oolitic turbidites (Vajont Limestone). 4. Siliceous basinal limestone (Fonzaso Fm.) 5. Isopachs (in m). 6. Inferred longshore currents. (From Bosellini *et al.*, 1981).

Figure 57. Belluno Basin.



Stratigraphic scheme for the Belluno Basin. 1. Dolomia Principale. 2. Schiara Dolomite. 2°. Schiara Dolomite, Marmol breccias. 3. Soverzene Formation. 3°. Soverzene Fm. calcarenitic member. 4. Pelf breccia. 5°, b, c, d, members inside the Calcari Grigi Fm. 6. Igne Formation. 6°. Igne Fm. black shale. 6b. Igne Fm. nodular limestone in Rosso Ammonitico facies. 7 Erbandoli calcarenite. 8. Vajont Limestone. 9. Fonzaso Formation. 10. Rosso Ammonitico Veronese. 11. Maiolica. (From Masetti and Bianchin, 1987).

On the Friuli Platform, the oolite factory was fully active to be able to export the huge amount of material transferred into the Belluno Basin to form the Vaiont Fm. During the Oxfordian and early Kimmeridgian, coral and *Ellipsactinia* reef, cropping out in the Cansiglio - M. Cavallo area, bounded the platform (Sartorio, 1987; Cati *et al.*, 1987). After this episode, the margin, formed mainly by sandy shoals, prograded toward the basin. The internal platform facies, spread with mudstone to packstone of the Cellina Limestone, persisted up to the earliest Aptian (Cati *et al.*, 1987; Venturini, 2002). It should be noted that boreholes indicate that inside the Friuli Platform persisted a deeper area oriented NW-SE (Cati *et al.*, 1987).

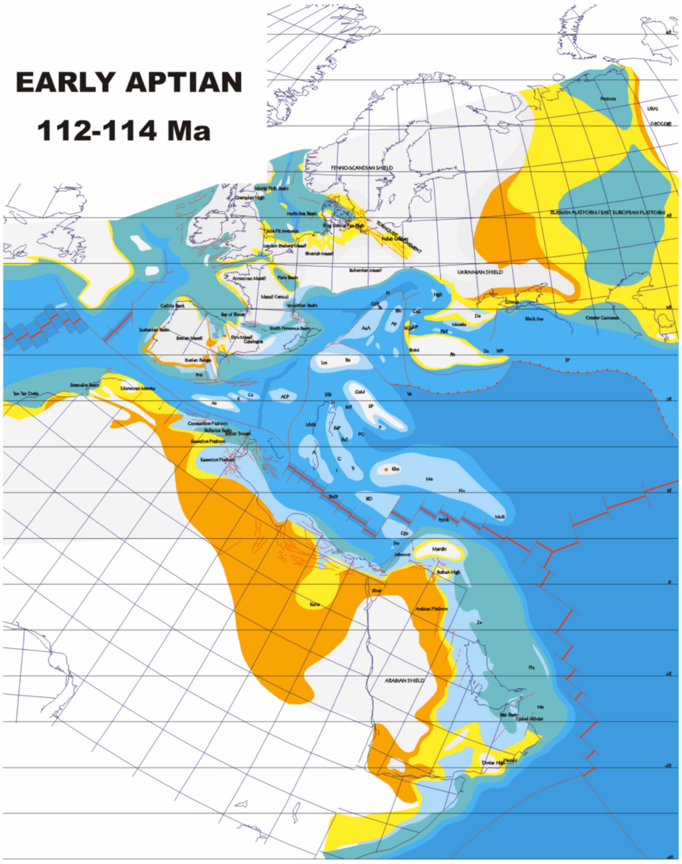
The Convergence of Adria toward Europe

The thermal cooling of the Adria margin would have steadily continued for the successive Cretaceous, being controlled by bioproductivity, climate, O_2p and CO_2p, and oceanic currents, unless new geodynamic events occurred (Figs 58 and 59).

Figure 58. Aptian palaeogeography.

The opening of South Atlantic forced Adria to move northwards to converge and eventually collide with Europe. (from Barrier and Vrielynck, 2008).

Figure 59. Early Aptian palaeogeography.



Also the opening of the eastern Mediterranean forced Adria toward Europe, detaching it from Africa. (From Dercourt *et al.*, 2000).

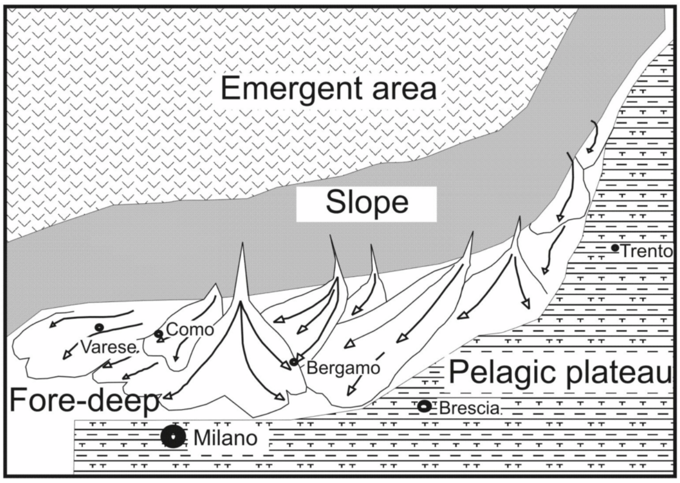
For the lowest part of the Cretaceous, no new significant events affected the margin of Adria. Since the late Tithonian, the deposition of Maiolica spread on the whole southern alpine margin, but not on the Friuli Platform. This was the actual product of the great increase in the coccolith and nannolith productivity (Erba, 2006) that carpeted all the previous paleogeographic elements. However, the sea floor did not become completely flat. Especially in the Lombardian Basin, some positive topographic features persisted, like the Corni di Canzo swell, where only the Tithonian part of the Maiolica is preserved, and slumped material is accumulated in the nearby deeper marginal part of the Generoso Trough. The carbonate productivity had no significant changes until the earliest Aptian (Erba, 2006, and ref. therein). A significant change in carbonate bioproductivity, with fading of nannoliths, shortly preceded the onsetting of the first of the Cretaceous Anoxic Events that characterized this period, from Aptian to early Turonian.

The new geodynamic event that interfered with this pattern was due to the opening of the Southern Atlantic Ocean. The consequent anticlockwise rotation of Africa pushed Adria to rotate northwards, approaching Europe. This convergence gradually closed the Ligurian-Piedmont Ocean, with subduction obliquely dipping below Adria. Therefore, during the Cretaceous, deformations progressively affected also the Southern Alps. During the Early Cretaceous, the deformation did not involve directly the northern Adria margin cropping out in Southern Alps. However, from the Valanginian onwards, clastic sedimentation reached progressively the Austroalpine domain, presently involved in the alpine nappes in Switzerland and Austria (Wagreich *et al.*, 2008).

On the Southern Alps, terrigenous input originating from the emerging reliefs, linked to the ongoing convergence of Adria and Europe, arrived later. In the Lombardian Basin, the Maiolica is overlaid by the Marna di Bruntino (Aptian-Albian), a succession of marls and splintery, varicoloured shales representing the local evidence of the Anoxic Events OAE1 (Erba, 2004). This unit also contains thin layers of quartzitic arenites led in the deep pelagic environment, often totally anoxic, by feeble tractive currents carrying the first silicoclastic sands originating from the emerging areas to the north.

The definitive turning point occurred since the Cenomanian, when also the northern part of the Lombardian Basin was directly involved by folding (Pizzo Camuno folds; Brack, 1981), and clastic sedimentation occurred in the basin, now mostly E-W oriented. The northern shoulder of this newly oriented basin was also affected by deformation (Bersezio and Fornaciari, 1988). With the Upper Cretaceous, the Adria margin was fully involved in the Eo-Alpine orogeny (Doglioni and Bosellini, 1987; Di Giulio, 1996; Boriani and Giobbi, 2004; Montrasio *et al.*, 2005) (Fig. 60).

Figure 60. The early flysch in Lombardy.

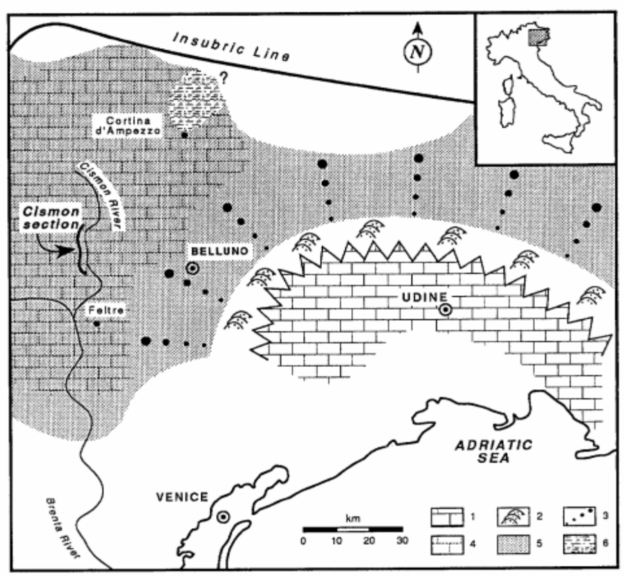


With the emerging of the first relief to the north, a long-shore basin was formed at the foot of the emerging area, in which the turbiditic flows were conveyed. (from Castellarin, 1976, redrawn and modified).

On the Trento Plateau, the Maiolica sedimentation continued, and probably due to the persisting, more elevated sea floor than the surrounding areas, no major silicoclastic input arrived during the Early Cretaceous. Only on the northern margin of the Dolomites in the Val Badia-Ampezzo area (Puez-Ra Stua) some 50–160 m of grey marls, red marly limestone, and occasionally thin quartzarenitic layers crop out above the Maiolica and reddish silty limestones (Cita and Pasquaré, 1959; Baccelle and Lucchi Garavello, 1967; Scudeler Baccelle and Semenza, 1974; Bini *et al.*, 1995; Lukander, 2008). These marls are overlain by a succession in Scaglia facies. Luciani and Cobianchi (1999) distinguished in the Antruiles section a Scaglia Variegata facies of Cenomanian age consisting of burrowed, marly limestone (or sometimes siltstone), marlstone, and calcareous shale, usually black. In turn, they are overlaid by brick-red marl and pink-red pelagic limestone containing in the upper part black, cherty nodules and layers, assigned to the Scaglia Rossa facies (Turonian). Between the two units, a black shale layer is referred to the Bonarelli Level. Bini *et al.* (1995) mention also calcarenite and conglomerate intercalations, but their age assignment to the Santonian-Maastrichtian was not confirmed by Luciani and Cobianchi (1999).

In the Belluno Basin, the whitish mudstone/wackestone of the Maiolica persisted until the Barremian. From the Aptian, the rain of suspension clay, derived from the ongoing deformations and erosions to the north, together with the biogenic micrite, formed the succession of monotonous white and grey calcareous beds; thin, light-green laminated marls; and marly limestone, organized in couplets and bundles (Bellanca *et al.*, 1996). Within this orbital controlled sedimentation are recorded major anoxic events like the Selli and the Bonarelli Beds (Channel *et al.*, 1979; Bellanca *et al.*, 1996; Erba *et al.*, 1999). At the centre of the basin pelagic sedimentation persisted for the remaining Cretaceous. The Belluno Basin remained in pelagic condition, and the coarser clastic material could not arrive, being situated in the shadow of the topographically more elevated Trento Plateau. On the slope toward the Friuli Platform, bioclastic turbidites are instead interbedded in the pelagic succession (Fig. 61). Their thickness increases eastward of the Piave River to form also resedimented bodies up to 400–500 m (Bellanca *et al.*, 1996).

Figure 61. The terrigenous input reached the northern Dolomites.



During the late Early Cretaceous, the Trento Plateau and its extenson in northern Dolomites were reached by the first terrigenous sediments produced to the north by the convergence of Adria toward Europe. Instead the Belluno Basin remained in pelagic aconditions without terrigenous input, in the shadow of the Trento Plateau. (From Bellanca *et al.*, 1996).

On the Friuli Platform, the carbonate sedimentation continued throughout the whole Early Cretaceous (Venturini, 2002). The resedimented material on the margin of the Belluno Basin testifies to rudist banks growing on the platform rim during the Late Cretaceous (Bosellini and Sarti, 1978). On the internal part of the Friuli Platform, carbonate sediments of the Upper Cretaceous reflect a more open platform environment. Accommodation was significantly reduced to eventually emerge since the Campanian (Venturini, 2002).

In conclusion, the external parts of the Adria margin, what is now the Austroalpine and the northwestern part of the Southern Alps, were directly involved in the Eo-alpine Deformation, while the more internal part of the passive margin, like the Umbria-Marche Basin in the central Apennines, were not directly involved in the deformation, instead only receiving a minor amount of clay to produce the typical sediments of the Scaglia facies.

Conclusions

The approximately 200-million-year history of Adria depicts the evolution of a lithospheric slab that had a critical importance in the Europe-Africa relationship. Between the stable Europe, with a thicker continental lithosphere, bounded to the south by the Tornquist-Teyssere fault, and the northern margin of the stable Africa, bounded by the Atlas system of faults, lies a more mobile belt, affected by the Variscan and Alpine orogeneses. The time span considered in this paper covers the interval between these two major deformation events. Adria was basically connected with Africa. During the Permian, it was involved mostly with its northern part in the dextral megashear between Laurasia and Gondwana, which attenuated and eventually ceased during the Middle Permian. When this major transcurrent event was over, Adria remained an African Spur, even if affected by some rifting in Sicily and in the Ionian area. Evidence for a Permian oceanic way, early detaching Adria from Africa is considered not conclusive, and the presence of deep trenches along the rifting activated during the megashear activity are considered as sufficient to explain the deep-water faunal association described in the Permian of Sicily. From the Late Permian to the early Middle Triassic, the Adria margin evolved as a continental passive margin, especially toward the east, facing a branch of the Tethyan Ocean, probably the Palaeo-Tethys. While in the northern and central Apennines the crustal activity during the Middle Triassic to early Norian was attenuated, in the present Southern Alps it was registered as a more intense and complex geodynamic activity, with high subsidence, sedimentary productivity, and significant volcanic activity. Interpretations of these events are not unanimous and should be related to the western terminations of the Palaeo-Tethys Ocean. However, knowledge and interpretation of the belt between Turkey and the Balkan peninsula are far to be clearly understood and beyond the scope of this paper. With the end of the Carnian-early Norian, a new geodynamic event occurred, represented by the Central Atlantic rifting and its eastward propagation contouring the northern margin of Adria. It should be noted that the propagation was not connected to the trenches of Sicily and the Ionian Sea, which had already an attenuated continental crust, but was opened to the north of Adria. The new passive margin was, since the Norian, facing the area that in the Middle Jurassic gave way to the spreading of the Ligurian-Piedmont Ocean. In the Southern Alps and in the Northern and Central Apennines, the passive margin evolution is preserved. In the present paper, this was described mostly for the Southern Alps, where alpine tectonics disrupted the original relationships less. The passive margin evolution registered all of the phases from rifting to spreading until toward the end of the Early Cretaceous, when the opening of the Southern Atlantic Ocean pushed Africa to rotate anticlockwise and approach Europe. The Adria margins first involved in the convergence emerged, and its terrigenous products were deposed in basins, mostly in Lombardy, on the rear of the deformated ridges. Far from the margin under deformation, as in the eastern Southern Alps and central Apennines, carbonate production and deposition continued.

References

Accorsi Benini, C. 1979. Lithioperna, un nuovo genere tra i grandi Lamellibranchi della facies a “Lithiotis”. Morfologia, tassonomia ed analisi funzionale. Bollettino della Società Paleontologica Italiana 18, 221-257.

Accorsi Benini, C. and Broglio Loriga, C. 1977. Lithiotis Gümbel, 1871 e Cochlearites Reis, 1903. Revisione morfologica e tassonomica. Bollettino della Società Paleontologica Italiana 16, 15-60.

Aldinucci, M., Brogi, A., and Spina, A., 2008. Middle-Late Permian sporomorphs from the Farma Formation (Monticiano-Roccastrada Ridge, southern Tuscany); new constraints for the tectono-sedimentary history of the Tuscan domain. Bollettino della Società Geologica Italiana 127; 3, 581-597.

Angiolini, L., Chaouachi, C., Soussi, M., Verna, V., Davydov, V.I., Henderson, C.M., Nicora, A., Rettori, R., and Carabelli, L., 2008. New fossil findings and discovery of conodonts in the Guadalupian of Jebel Tebaga de Medenine: Biostratigraphic implications. Permophiles 51, 10-24.

Assereto, R., Bosellini, A., Fantini Sestini, N., Sweet, W.C., 1973. The Permian-Troassic boundary in Southern Alps (Italy). In A. Logan and L.V.Hills (eds.) – The Permian and Triassic Systems and their Mutual Boundary. Alberta Society Petroleum Geologists, Mem.2, 176-199.

Assereto, R., Brusca, C., Gaetani, M., and Jadoul, F., 1977. The Pb-Zn mineralizations in the Triassic of the Dolomites. Geological history and genetic interpretations. L'Industria Mineraria 28, 6, 34 pp.

Assereto, R. and Casati, P. 1965. Revisione della stratigrafia permo-triassica della Val Camonica meridionale (Lombardia). Rivista Italiana di Paleontologia e Stratigrafia 71, 999-1097

Avanzini, M., Frisia, S., Keppens, E., and Van dem Driessche, K. 1997. A dinosaur tracksite in an Early Jurassic tidal flat in Northern Italy palaeoenvironmental reconstruction from sedimentology and geochemistry. Palaios 12, 538-551.

Avanzini, M., Neri, C., Nicosia, U., and Conti, M. A., 2008. A new Early Permian ichnocoenosis from the "Gruppo Vulcanico Atesino" (Mt. Luco, southern Alps, Italy). Studi Trentini di Scienze Naturali Acta Geologica 83, 231-236.

Baccelle, L. and Lucchi Garavello, A. 1967. Ammoniti dei livelli Cretacei di Ra Stua (Cortina d’Ampezzo). Annali dell’Universita’di Ferrara, IX 4, 117–153.

Balini, M., Germani, D., Nicora, A., and Rizzi, E., 2000. Ladinian/Carnian ammonoids and conodonts from the classic Schilpario-Pizzo Camino area (Lombardy): Revaluation of the biostratigraphic support to Chronostratigraphy and Paleogeography. Rivista Italiana di Paleontologia e Stratigrafia 106, 19-58.

Bargossi, GM., Rottura, A., Vernia, L., Visonà, D., Tand Tranne, CA., 1998. Guida all’escursione sul distretto vulcanico atesino e sulle plutoniti di Bressanone–Chiusa e Cima d’Asta. Memorie Società Geologica Italiana 53, 23–41.

Barrier E. and Vrielynck B. (2008) – Palaeotectonic maps of the Middle East. MEBE Programme. Atlas of 14 maps, CCGM, Paris.

Baudon, C., Fabuel-Perez, I., Redfern, J., 2009. Structural style and evolution of a Late Triassic rift basin in the central High Atlas, Morocco; controls on sediment deposition. Geological Journal 44, 6, 677-691.

Baumgartner, P.O. 1987. Age and genesis of the Tethyan Jurassic Radiolarite. Eclogae geologicae Helvetiae 80(3), 831-879.

Baumgartner, P.O., Martire, L., Gorican, S., O'Dogherty, L., Erba, E. and Pillevuit, A. 1995. New Middle and Upper Jurassic radiolarian assemblages co-occurring with ammonites and nannofossils from the Southern Alps (Northern Italy). In: Baumgartner, P.O. et al. (Eds.), Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: Occurrences, Systematics, Biochronology. Mémoires de Géologie 23, 737-749.

Beccaro P., Diserens M-C., Gorican S., and Martire L. 2008. Callovian radiolarians from the lowermost Calcare Selcifero di Fonzaso at Ponte Serra (Trento Plateau, Southern Alps, Italy). Rivista Italiana di Paleontologia e Stratigrafia 114, 489-504.

Bechstädt, T. and Brandner, R., 1970. Das Anis zwischen St. Vigil und dem Höhlensteintal (Pragser-und Olanger Dolomiten, Süditirol). Festband des Geologischen Institutes, 300-Jahr-Feier Universität Innsbruck, 9-103.

Bellanca, A., Di Stefano, P., and Neri, R. 1995. Sedimentology and isotope geochemistry of Carnian deep-water marl/ limestone deposits from the Sicani Mountains, Sicily: Environmental implications and evidence for a planktonic source of lime mud. Palaeogeography, Palaeoclimatology, Palaeoecology, 114: 111-129.

Bellanca, A., Claps, M., Erba, E., Masetti, D., Neri, R., Premoli Silva, I., and Venezia, F., 1996, Orbitally induced limestone/ marlstone rhythms in the Albian-Cenomanian Cismon section (Venetian region, northern Italy): sedimentology, calcareous and siliceous plankton distribution, elemental and isotope geochemistry. Palaeogeography, Palaeoclimatology, Palaeoecology126, 227–260.

Bernoulli, D., 1964. Zur Geologie des Monte Generoso (Lombardische Alpen). Materiali per la Carta Geologica della Svizzera 118, 1–134.

Bernoulli, D., Caron, C., Homewood, P., Kaelin, O., and van Stuijvenberg, J., 1979. Evolution of continental margins in the Alps. Schweizerische Mineralogische Petrographische Mitteilungen, 59, 165–170.

Bernoulli, D., and Jenkins, H. C., 2009. Ancient oceans and continental margins of the Alpine-Mediterranean Tethys: deciphering clues from Mesozoic pelagic sediments and ophiolites. Sedimentology 56, 149-160.

Berra, F., Jadoul, F., and Anelli, A., 2010. Environmental control on the end of the Dolomia Principale/Hauptdolomit depositional system in the central Alps: Coupling sea-level and climate changes. Palaeogeography, Palaeoclimatology, Palaeoecology 290 (2010) 138–150

Berra, F., Rettori, R., and Bassi, D., 2005. Recovery of carbonate platform production in the Lombardy Basin during the Anisian: paleoecological significance and constrain on paleogeographic evolution. Facies 50, 615-627.

Bersezio, R. and Fornaciari, M. 1988. Geometria e caratteri stratigrafici della sequenza cenomaniana nel Bacino Lombardo (Alpi Meridionali). Rivista Italiana di Paleontologia e Stratigrafia 94, 425–454.

Bertotti, G., 1991. Early Mesozoic extension and alpine shortening in Western Southern Alps: the geology of the area between Lugano and Menaggio (Lombardy, North Italy). Memorie di Scienze Geologiche 43, 17-123.

Bertotti, G., 2001. Subsidence, deformation, thermal and mechanical evolution of the Mesozoic South-Alpine rifted margin: An analogue for Atlantic-type margins. In: Non-volcanic rifting of continental margins: a comparison of evidence from land and sea. In Wilson, R.C.L., Whitmarsh, R.B., Taylor, B., and Froitzheim, (Eds) Geol. Soc., London, Sp. Publ. 187, 125-141.

Bertotti, G., Picotti, V., Bernoulli, D. and Castellarin, A., 1993. From rifting to drifting: tectonic evolution of the South-Alpine upper crust from the Triassic to the early Cretaceous. Sedimentary Geology, 86, 53-76.

Bini, A., Meneghel, M., Mietto, P., Sauro, U., and Siorpaes, C., 1995. Altopiani ampezzani: geologia, geomorfologia, speleologia, 156 pp. (La Grafica, Padova).

Blendinger, W., Brack, P., Noborg, A.K., and Wulff-Pedersen, E., 2004. Three-dimensional modelling of an isolated carbonate buildup (Triassic, Dolomites, Italy). Sedimentology 51, 297-314.

Boriani, A. and Giobbi, E., 2004. Does the basement of western southern Alps display a tilted section through the continental crust? A review and discussion. Periodico di Mineralogia, volume , 5-22.

Bosellini, A., 1967. La tematica deposizionale della Dolomia Principale. (Dolomiti e Prealpi Venete). Bollettino della Società Geologica Italiana 86,113-169.

Bosellini, A., 1968. Paleogeologia pre-anisica delle Dolomiti centro-settentrionali. Memorie Accademia Nazionale Lincei, classe Scienze fisiche, matematiche e naturali, s. 8, 9, 1-33.

Bosellini, A., 1973. Modello Geodinamico e Paleotettonico delle Alpi Meridionali durante il Giurassico – Cretaceo. Sue possibili applicazioni agli Appennini. In Accordi, B. (Ed.) - Moderne vedute sulla geologia dell'Appennino. Accademia Nazionale dei Lincei, Atti Convegni, 183, 163-205.

Bosellini, A., and Broglio Loriga, C., 1971. I "Calcari Grigi" di Rotzo (Giurassico inferiore, Altopiano di Asiago) e loro inquadramento nella paleogeografia ed evoluzione tettono-sedimentaria delle Prealpi venete. Annali dell'Università di Ferrara 5, 1-61.

Bosellini, A., Masetti, D., and Sarti, M. 1981. A Jurassic "Tongue of the Ocean" infilled with oolitic sands: the Belluno Trough, Venetian Alps, Italy. Marine Geology 44, 59-95.

Bosellini, A., and Rossi, D., 1974. Triassic Caarbonate Buildups of the Dolomites, Northern Italy. Society of Economic Paleontologists and Mineralogists, Special Publication 18, 209-233.

Bosellini, A. and Sarti, M. 1978. Geologia del Gruppo del M.Cuar –M. Covria (Prealpi Carniche). Giornale di Geologia 43, 47-88.

Brack, P., 1981. Structures in the southwestern border of the Adamello intrusion (Alpi bresciane, Italy). Schweizrische Mineralogische Petrographische Mitteilungen 61, 37-50.

Brocchi, G.B., 1808. Trattato Mineralogico e Chimico sulle miniere di ferro del Dipartimento del Mella con l'esposizione della costituzione fisica delle montagne metallifere della Val Trompia. 2 voll. di 296 e 352 pp., Tip. Bettoni, Brescia.

Broglio Loriga, C., Masetti, D., Neri, C., 1982. La Formazione di Werfen (Scitico) delle Dolomiti Occidentali: sedimentologia e biostratigrafia. Rivista Italiana di Paleontologia e Stratigrafia 88/4, 501-598.

Brusca C., Gaetani M., Jadoul F., and Viel G., 1982. Paleogeografia ladino-carnica e metallogenesi del Sudalpino. Memorie della Società Geologica Italiana 22, 65-82.

Buratti, N. and Carrillat, A. 2002. Palynostratigraphy of the Mufara Formation (Middle-Upper Triassic, Sicily). Rivista Italiana di Paleontologia e Stratigrafia 108; 1, 101-117.

Buser, S., 1989. Development of the Dinaric and Julian carbonate platforms and the intermediate Slovenian basin (NW-Yugoslavia). In: Carulli, G.B., Cucchi, F. and Radrizzani, C.P. (Eds) - Evolution of the Karstic carbonate platform: relation with otherperiadriatic carbonate platforrns. Memorie Società Geologica Italiana 40, 313-320.

Carcione, L., 2007. Sedimentology, biostratigraphy and mineralogy of the Lercara Formation (Triassic, Sicily) and its palaeogeographic implications. Terre and Environnement. 68; 247 pp. Ph.D. Thesis, Genève.

Carrillat, A. and Martini, R., 2009. Palaeoenvironmental reconstruction of the Mufara Formation (Upper Triassic, Sicily); high resolution sedimentology, biostratigraphy and sea-level changes. Palaeogeography, Palaeoclimatology, Palaeoecology 283; 1-2, 60-76.

Carulli, G.B., Cozzi, A., Masetti, A. Penarcic, E., Podda, F., and Ponton, M., 2002. Middle Triassic-Early Jurassic extensional tectonics in the Carnian Prealps (eastern Southern Alps, N.E. Italy). Memorie di Scienze Geologiche, 54, 151-154.

Casellato, C. E., 2010. Calcareous nannofossil biostratigraphy of Upper Callovian-Lower Berriasian successions from Southern Alps, North Italy. Rivista Italiana di Paleontologia e Stratigrafia, 116/3, in press.

Cassinis, G., 2008 (Ed.) Stratigraphy and palaeogeography of late and post-Hercynian basins in the Southern Alps, Tuscany and Sardinia (Italy); in memory of Francesco Antonio Decandia. Bollettino della Società Geologica Italiana 127; 3.

Cassinis, G., Cortesogno, L., Gaggero, L., Perotti, C. and Ronchi, A., 2007. Volcanic products from the Early Permian Collio Basin (southern Alps) and their geodynamic implications. Periodico Mineralogia 76, 25- 47.

Cassinis, G. and Perotti, C., 2007. A stratigraphic and tectonic review of the Italian Southern Alpine Permian. Palaeoworld 16, 140- 172.

Cassinis G., Cortesogno L., Gaggero L , Perotti C.R. and Buzzi L., 2008. Permian to Triassic geodynamic and magmatic evolution of the Brescian Prealps (eastern Lombardy, Italy). Bollettino della Società Geologica Italiana 127, 501-518.

Cassinis, G., Perotti, C., Ronchi A., and Santi G., 2009. Data and Hypotheses from Carboniferous to Triassic Continental Deposits of Italy, Based on the 1999-2006 Brescia and Siena Meetings. Permophiles, 51, 50-62.

Cassinis, G. and Zezza, U., 1982. Dati geologici e petrografici sui prodotti del magmtismo triassico nelle Prealpi Bresciane. In: A., Castellarin and G.B. , Vai, (Eds.) Guida alla Geologia del Sudalpino Centro-Orientale. Guide Geologiche Regionali, Società Geologica Italiana, 157-171.

Castellarin, A., 1972. Evoluzione paleotettonica sinsedimentaria del limite tra la “Piattaforma Veneta” e “Bacino Lombardo”, a Nord di Riva del Garda. Giornale di Geologia 38/2, 11-212.

Castellarin, A., 1976. Ipotesi paleogeografia sul bacino del flysch Sudalpino cretacico. Bollettino della Società Geologica Italiana 95, 501-511.

Castellarin, A., Lucchini, F., Rossi, P.L., Selli, L., and Simboli, G. 1988. The Middle Triassic magmatic-tectonic arc development in the Southern Alps. Tectonophysics, 146, 79-89.

Catalano, R. and D'Argenio, B., 1982. Guida alla Geologia della Sicilia occidentale. SocietàGeologica Italiana, Guide Geologiche Regionali 155 pp.

Catalano, R., D'Argenio, B., Montanari, L., Renda, P., Abate, B., Monteleone, S., Macaluso,T., Pipitone, C., Di Stefano, E., Lo Cicero, G., Di Stefano, P., and Agnesi, V., 1978. Contributi alla conoscenza della struttura della Sicilia occidentale. 1) Il profilo Palermo-Sciacca.Memorie Società Geologica Italiana 19, 485–493.

Catalano, R., Di Stefano, P. and Kozur, H., 1991. Permian Circumpacific deep-water faunas from the Western Tethys (Sicily, Italy) – new evidence for the position of the Permian Tethys. Palaeogeography, Palaeoclimatology, Palaeoecology 87, 75-108:

Catalano, R., Di Stefano, P. and Kozur, H., 1992. New data on Permian and Triassic stratigraphy of Western Sicily. Neues Jahrbuch Geologische Palaeontologische Abhandlungen 184, 25-61.

Catalano, R., Di Stefano, P. and Vitale, F.P. 1995. Structural trends and palaeogeography of the central and western Sicily belt: new insights. Terra Nova, 7: 189-199.

Catalano, R; Doglioni, C.; Merlini, S., 2001. On the Mesozoic Ionian Basin. Geophysical Journal International 144; 1, 49-64.

Cati, A., Sartorio, D., Venturini, S. 1987. Carbonate platform in the subsurface of the Northern Adriatic area. Memorie della Società Geologica Italiana 40, 295-308.

Channel, J. E. T, Lowrie,W., and Medizza, F., 1979. Middle and Early Cretaceous magnetic stratigraphy from the Cismon section, Northern Italy: Earth and Planetary Science Letters 42, 153–166.

Chen, Z.-Q., Kaiho, K., George, A. D., and Tong, J., 2006. Survival brachiopod faunas of the end-Permian mass extinction from the southern Alps (Italy) and south China. Geological Magazine 143, 3, 301-327.

Chiari, M., Cobianchi, M., and Picotti, V., 2007. Integrated stratigraphy (radiolarians and calcareous nannofossils) of the Middle to Upper Jurassic Alpine radiolarites (Lombardian Basin, Italy): Constraints to their genetic interpretation. Palaeogeography, Palaeoclimatology, Palaeoecology 249, 233-270.

Ciarapica, G., 2007. Regional and global changes around the the Triassic-Jurassic boundary reflected in the late Norian-Hettamgian history of the Apennine basins. Palaeogeography, Palaeoclimatology, Palaeoecology 244, 34-51.

Ciarapica, G., Cirilli, S., Panzanelli Fratoni, R., Passeri, L. and Zaninetti, L. 1990. The Monte Facito Formation (Southern Apennines). Bollettino della Società Geologica Italiana 109, 135-142.

Ciarapica, G. and Passeri, L., 2005. Ionian Tethydes in the Southern Apennines. In Finetti, I.R. (ed.) CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy, 209-224. Elsevier.

Cirilli, S., Marzoli, A.., Tanner, L., Bertrand, H., Buratti, N., Jourdan, F.,Bellieni, G., Kontak, D., and Renne, P.R., 2009. Latest Triassic onset of the Central Atlantic magmatic province (CAMP) volcanism in the Fundy Basin (Nova Scotia); new stratigraphic constraints. Earth and Planetary Science Letters 286, 3-4, 514-525.

Cirilli, S., Montanari, L., and Panzanelli Fratoni, R., 1990. Palynomorphs from the Lercara Formation (Sicily): new biostratigraphic data. Bollettino della Società Geologica Italiana 109, 123-133.

Cirilli, S., Pirini Radrizzani, C., Ponton, M., and Radrizzani, S. 1997. Stratigraphical and palaeoenvironmental analysis of the Permian-Triassic transition in Badia Valley (Southern Aps, Italy). Palaeogeography, Palaeoclimatology, Palaeoecology 138, 85-113.

Cita Sironi M.B., Abbate E., Aldighieri B., Balini M., Conti M.A., Falorni P., Germani D., Groppelli G., Manetti P., Pampaloni M.L., Petti F.M. and R.M. Pichezzi, 2007. Carta Geologica d'Italia 1: 50.000, Catalogo delle Formazioni – unità tradizionali(1)». Quaderni APAT, ser. III, 7/VI, 342 pp., Roma.

Cita, M.B. and Pasquaré, G., 1959. Osservazioni micropaleontologiche sul Cretaceo delle Dolomiti. Rivista Italiana di Paleontologia e Stratigrafia 65, 385-443.

Clari, P. and Masetti, D., 2002. The Trento Ridge and the Belluno Basin. In: Santantonio,M., Ed., General Field Trip Guidebook, VI International Symposium on the Jurassic System, 12-22 September 2002: 271 -315, Palermo.

Cobianchi, M., 1992. Sinemurian–Early Bajocian calcareous nannofossil biostratigraphy of the Lombardy Basin (Southern Calcareous Alps). Atti Ticinensi di Scienze della Terra 35, 61–106.

Consonni, A., Ronchi, P., Geloni, C., Battistelli, A., Grigo, D., Biagi, S., Gherardi, F., and Gianelli, G., 2010. Application of numerical modelling to a case of compaction-driven dolomitization: a Jurassic palaeohigh in the Po Plain, Italy. Sedimentology 57, 209-231.

Cousin, M., 1973. Le sillon slovène: les formations triasiques, jurassiques et neocomiennes au Nord - Est de Tolmin (Slovénie occ., Alpes mer.) et leurs affinités dinariques. Bulletin de la Société Géologique de France (7), XV, 326-339.

Crasquin, S., Carcione, L..and Martini, R., 2008. Permian ostracods from the Lercara Formation (Middle Triassic-Carnian?), Sicily, Italy. Palaeontology 51, 537-560.

Crasquin, S., Perri M. C.., Nicora A., and De Wever P., 2008. Ostracods across the Permian-Triassic boundary in western Tethys; the Bulla parastratotype (southern Alps, Italy). Rivista Italiana di Paleontologia e Stratigrafia 114; 2, 233-262.

Dalla Vecchia, F., 2002.Terrestrial reptiles in the Norian of the Carnian Pre-Alps(Friuli, NE Italy): paleoenvironmental implications. Memorie della Società Geologica Italiana 57, 101-106.

Dercourt J., Gaetani M., Vrielynck B., Barrier E., Biju-Duval B., Brunet M.F., Cadet J.P., Crasquin S.,and Sandulescu, M., 2000. Atlas Peri-Tethys,. Palaeogeogeographic maps. 24 maps and explanatory notes: I-XX, 1-269. CCGM/CGMW, Paris.

De Vecchi, Gp., and Sedea, R., 1983. Il vulcanismo medio-triassico nelle Prealpi Vicentine (Italia Sett.). Memorie di Scienze Geologiche 36, 149-169.

De Zanche, V. and Farabegoli, E., 1983. Anisian stratigraphy in the Northern Grigna area (Lake Como, Italy)., 36, 283-291.

De Zanche, V. and Farabegoli, E., 1988. Anisian paleogeographic evolution in the Central-western Southern Alps. Memorie di Scienze Geologiche, 40, 399-411.

De Zanche, V., Gianolla,P., Mietto, P., Siorpaes, C., and Vail, P.R., 1993. Triassic sequence stratigraphy in the Dolomites (Italy). Memorie di Scienze Geologiche 45, 1-27.

De Zanche, V., Gianolla, P., Manfrin S., Mietto, P., and Roghi , G., 1995. A Middle Triassic back-stepping carbonate platform in the Dolomites: sequence stratigraphy and biostratigraphic stratigraphy. Memorie di Scienze Geologiche 47, 135 -155.

De Zanche, V., Gianolla, P., and Roghi , G., 2000. Carnian stratigraphy in the Raibl/Cave del Predil area (Julian Alps, Italy). Eclogae Geologicae Helvetiae 93, 331-347.

Dieci, G., Antonacci, A., and Zardini, R., 1970. Le spugne cassiane (trias medio-superiore) della regione dolomitica attorno a Cortina d'Ampezzo. Bollettino della Società Paleontologica Italiana 7; 2, 94-155.

Di Giulio, A., 1996. Eo-Alpine geodynamics; an integrated approach. Bollettino della Società Geologica Italiana 115, 649-671.

Di Stefano, P., 1990. The Triassic of Sicily and Southern Apennines. Bollettino della Società Geologica Italiana 109, 21-37.

Di Stefano, P., Alessi, A. and Gullo, M., 1998. Mesozoic and Paleogene megabreccias in Southern Sicily.: new data on the Triassic palaeomargin of the Siculo-Tunisian Platform. Facies, 34: 101-122.

Di Stefano, P. and Gullo, M., 1997. Permian deposits of Sicily: a review. Geodiversitas, 19/2, 193-202.

Doglioni, C., 1983. Duomo medio-triassico nelle Dolomiti. Rendiconti Società Geologica Italiana 6, 13-16.

Doglioni, C., 1987. Tectonics of the Dolomites (Southern Alps, Northern Italy). Journal of Structural Geology 9, 181-193.

Doglioni, C. and Bosellini, A., 1987. Eoalpine and Mesoalpine tectonics in the Southern Alps. Geol. Rundsch. 76 (3), 735–754.

Donzelli, G. and Crescenti, U., 1970. Segnalazione di una microbiofacies permiana, probabilmente rimaneggiata, nella Formazione di M. Facito (Lucania Occidentale). Bollettino della Società dei Naturalisti in Napoli 79, 13-19.

Erba, E., 2004. Calcareous nannofossils and Mesozoic oceanic anoxic events. Marine Micropaleontology 52, 85-106.

Erba, E., 2006. The first 150 million years history of the calcareous nannoplancton: biosphere-geosphere interactions. Palaeogeography, Palaeoclimatology, Palaeoecology 232, 237-250.

Erba, E. and Cesellato, M.C., 2010. Paleoceanografia del Giurassico nella Tetide occidentale: l'archivio geologico del Bacino Lombardo. Atti del Convegno: Una Nuova Geologia per la Lombardia, Istituto Lombardo 457, 115-140.

Falletti, P. and Ivanova, D., 2003. Monte Guglielmo Limestone; a middle-late Anisian carbonate platform in central southern Alps; Italy. Monte Guglielmo Limestone; a middle-late Anisian carbonate platform in central southern Alps; Italy. Atti Ticinensi di Scienze della Terra 44; 75-83.

Fantini Sestini, N., 1990. I coralli del Calcare di Zu (Triassico superiore) della Lombardia (Italia); nuove segnalazioni. Rivista Italiana di Paleontologia e Stratigrafia 96/1: 103-110.

Farabegoli, E., Jadoul, F., and Martines, M. 1985. Stratigrafia e paleogeografia anisiche delle Alpi Giulie occidentali (Alpi Meridionali –Italia). Rivista Italiana di Paleontologia e Stratigrafia 91, 147-196.

Farabegoli, E., Perri, M. C., and Posenato, R., 2007. Environmental and biotic changes across the Permian-Triassic boundary in western Tethys; the Bulla parastratotype, Italy. Global and Planetary Change 55, 1-3, 109-135;.

Finetti, I.C., 2005a. Understanding the Ionides and their Geodynamics. In Finetti, I.R. (ed.) CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy, 197-207. Elsevier.

Finetti, I.C., 2005b. Geodynamic Evolution of the Mediterranean Region from the Permo-Triassic Ionian opening to the present, constrained by New Lithospheric CROP Seismic Data. In Finetti, I.R. (ed.) CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy, 767-776. Elsevier.

Fois, E. and Gaetani, M., 1980. The northern margin of the Civetta buildup. Evolution during the Ladinian and the Carnian. Rivista Italiana di Paleontologia e Stratigrafia 86, 469-542.

Fois, E. and Jadoul, F., 1983. La Dorsale Paleocarnica anisica di Pontebba. Rivista Italiana di Paleontologia e Stratigrafia 89, 3-30.

Forke, H.C., 2002. Biostratigraphic subdivision and correlation of uppermost Carboniferous/Lower Permian sediments in the southern Alps; fusulinoidean and conodont faunas from the Carnic Alps (Austria/Italy), Karavanke Mountains (Slovenia), and Southern Urals (Russia). Facies 47, 201-275.

Gaetani, M., 1975. Jurassic stratigraphy of the Southern Alps: a rewiew. In: C. Squyres (Ed.): «Geology of Italy». Earth Sc. Soc. Libyan Arab Rep., 377– 402, Tripoli.

Gaetani, M., 1982. Osservazioni stratigrafiche e strutturali sulla Galleria SS 36 Bellano-Varenna. Rivista Italiana di Paleontologia e Stratigrafia 88, 1-10.

Gaetani, M. and Gorza, M., 1989. The Anisian Camorelli carbonate bank. (Lombardy, Southern Alps). Facies 21, 41-56.

Gaetani, M., and Jadoul, F., 1987. Controllo ancestrale sui principali lineamenti strutturali delle Prealpi Lombarde Centrali. Rendiconti Società Geologica Italiana 10, 21-24.

Gaetani, M., Fois, E., Jadoul, F., and Nicora, A., 1981. Nature and evolution of the Middle Triassic carbonate buildups in the Dolomites (Italy). Marine Geology 44, 25-57.

Gaetani, M. and Erba, E. 1990.. Il Bacino Lombardo: un sistema paleoalto/fossa in un margine continentale passivo durante il Giurassico. 75° Congresso nazionale S.G.I. Guida alle escursioni pre-Congresso, Escursione A3.

Gaetani, M., Gianotti, R., Jadoul, F., Ciarapica, G., Birilli, S., Lualdi, A., Passeri, L.M., Pellegrini, M., Tannoia, G., 1987. Carbonifero superiore, Permiano e Triassico nell'area lariana. Memorie della Società Geologica Italiana 32, 5-48.

Gaetani, M., Gnaccolini, M., Jadoul, F., and Garzanti, E., 1998. Multicyclic sequence stratigraphy in the Triassic of Western Southern Alps. Society of Economic Paleontologists and Mineralogists, Special Publication 58, 708 -720.

Gaetani, M., Gnaccolini, M., Poliani, G., Grignani, D., and Gorza, M., Martellini, L., 1992. An anoxic intraplatform basin in the Middle Triassic of Lombardy (Southern Alps, Italy): Anatomy of a hydrocarbon source. Rivista Italiana di Paleontologia e Stratigrafia 97, 312-345.

Gaetani, M. and Poliani, G., 1978. Il Toarciano e il Giurassico medio in Albenza (Bergamo). Rivista Italiana di Paleontologia e Stratigrafia 84, 349–382.

Galli, M.T., Jadoul, F., Bernasconi, S.M., Cirilli, S., and Weissert, H. , 2007. Stratigraphy and palaeoenvironmental analysis of the Triassic-Jurassic transition in the Western Southern Alps. Palaeogeography, Palaeoclimatology, Palaeoecology 244, 52-70.

Garzanti, E., 1985. The sandstone memory of te evolution of a Triassic volcanic arc in The Southern Alps, Italy. Sedimentology 32, 423-433.

Garzanti, E. and Jadoul, F., 1985. Stratigrafia e paleogeografia del Carnico lombardo (sondaggio S. Gallo, Valle Brembana). Rivista Italiana di Paleontologia e Stratigrafia 91, 295-320.

Garzanti, E. and Pagni Frette, M., 1991. Il Carnico di Lierna (Como): stratigrafia e paleogeografia. Rivista Italiana di Paleontologia e Stratigrafia 96 (1990),407–426, Gemmellaro, G.G., 1887. La fauna dei calcari con Fusulina della valle del fiume Sosio nella provincia di Palermo. Fasc. 1. Cephalopoda; Ammonoidea. Giornale delle Scienze Naturali Economiche, 19, 1-106, Palermo.

Gemmellaro, G.G., 1888a. La fauna dei calcari con Fusulina della valle del fiume Sosio nella provincia di Palermo. Fasc. 1, Appendice 1: Ammonoidea. Giornale delle Scienze Naturali Economiche, 20, 1-26, Palermo

Gemmellaro, G.G., 1888b. La fauna dei calcari con Fusulina della valle del fiume Sosio nella provincia di Palermo. Fasc. 2. Cephalopoda. Nautiloidea. Gastropoda. Giornale delle Scienze Naturali Economiche, 20, 97-182, Palermo

Gemmellaro, G.G., 1889. La fauna dei calcari con Fusulina della valle del fiume Sosio nella provincia di Palermo. Fasc. 2. Cephalopoda. Nautiloidea. Gastropoda. Giornale delle Scienze Naturali Economiche, 20, 97-182, Palermo

Gianolla, P., De Zanche, V. Roghi, G., 2003. An Upper Tuvalian (Triassic Platform-Basin System in the Julian Alps: the Start-up of the Dolomia Principale (Southern Alps, Italy). Facies 49,135-150.

Groves, J.R., Rettori, R., Payne, J. L., Boyce, M.D., and Altiner, D., 2007. End-Permian mass extinction of lagenide foraminifers in the southern Alps (northern Italy). Journal of Paleontology 81, 3, 415-434.

Gullo, M., 1993. Studi stratigrafici sul Permiano ed il Trias pelagico della Sicilia Occidentale, Tesi di Dottorato, Consorzio tra le Università degli studi di Napoli e Palermo, 203 pp. Unpublished.

Gullo, M. 1996. Conodont biostratigraphy of uppermost Triassic deep-water calcilutites from Pizzo Mondello (Sicani Mountains): Evidence for Rhaetian pelagites in Sicily. Palaeogeography, Palaeoclimatology, Palaeoecology 126, 309-323..

Hallam, A., 2001. A review of the broad pattern of Jurassic sea-level changes and their possible causes in the light of the current knowledge. Palaeogeography, Palaeoclimatology, Palaeoecology 167, 23-37.

Henk, A., Leander, F., Teufel, S., and Oncken O., 1997. Magmatic underplating, extension and crustal reequilibration: Insights from a cross-section through the Ivrea Zone and Strona-Ceneri Zone, Northern Italy. Journal of Geology, 105, 367–377.

Irving, E. 1977. Drift of the major continental blocks since the Devonian. Nature 270, 304–309.

Kearsey, T., Twitchett, R. J., Price, G.D., and Grimes, S.T., 2009. Isotope excursions and palaeotemperature estimates from the Permian/Triassic boundary in the Southern Alps (Italy). Palaeogeography, Palaeoclimatology, Palaeoecology 279, 1-2, 29-40;.

Keim, L. and Brandner, R., 2002. Facies interfingering and synsedimentary tectonics on late Ladinian-early Carnian carbonate platforms (Dolomites, Italy). International Journal of Earth Sciences 90, 813-830.

Khessibi, M., 1985. Etude sedimentologique des affleurements permiens du Djebel Tabaga de Medenine (sud Tunisien). Bulletin du Centre de Recherche, Exploration et Production Elf-Aquitaine 9, 427-464.

Kozur, H., 1991a. Permian deep-water ostracods from Sicily (Italy). Part 1. Taxonomy. Geologisches und palaeontologisches Mitteilungen Innsbruck 3, 1-24.

Kozur, H., 1991b. Permian deep-water ostracods from Sicily (Italy). Part 2. Biofacial evaluation and remarks to the Silurian to the Triassic paleopsychrosphaeric ostracods. Geologisches und palaeontologisches Mitteilungen Innsbruck, 3, 25-38.

Krainer, K. and Lutz, D. 1995., Middle Triassic Evolution and Stratigraphy in the Carnic Alps (Austria). Facies 33, 167-184.

Jadoul, F. , 1986. Stratigrafia e paleogeografia del Norico nelle Prealpi Bergamasche occidentali. Rivista Italiana di Paleontologia e Stratigrafia 91, 479–512.

Jadoul, F. and Galli, M.T., 2008. The Hettangian shallow water carbonates after the Triassic/Jurassic biocalcification crisis: the Albenza Formation in the western southern Alps. Rivista Italiana di Paleontologia e Stratigrafia 114, 453-470.

Jadoul, F. and Nicora, A. 1986. Stratigrafia e paleogeografia ladino-carnica delle Alpi Carniche orientali (versante nord della Val Canale, Friuli) Rivista Italiana di Paleontologia e Stratigrafia 92, 201-238.

Jadoul, F., Nicora, A., Ortensi, A., and Pohar, C. 2002. Ladinian stratigraphy and paleogeography of the Southern Val Canale (Pontebbano-Tarvisiano, Julian Alps, Italy). Memorie Società Geologica Italiana 57/1, 29-43.

Jadoul, F., Berra, F. and Frisia, S., 1992. Stratigraphic and paleogeographic evolution of a carbonate platform in an extensional tectonic regime: the example of the Dolomia Principale in Lombardy (Italy). Rivista Italiana di Paleontologia e Stratigrafia 98, 29–44.

Jenkyns, H.C. 2003. Evidence for rapid climate change in the Mesozoic–Palaeogene greenhouse world. Philosophical Transaction Royal Society A, 361, 1885– 1916.

Jenny-Deshusses, C., Martini, R. and Zaninetti, L. 2000. Decouverte du foraminifère Colaniella Likharev dans le Permien superieur de la vallée du Sosio (Sicile): First occurrence of the foraminifer Colaniella Likharev in the Upper Permian from the Sosio Valley (Sicily). Comptes Rendus de l’Academie des Sciences - Series IIA - Earth and Planetary Science, 330: 799-804.

Landra, G., Longoni, R., and Fantoni R., 2000. Seismic models of two middle Triassic carbonate platforms from the Southern Alps. Memorie di Scienze Geologiche 52, 1, 139-163.

Lentini, F., 1974. Caratteri stratigrafici e strutturali della zona di Monte Judica (Sicilia Orientale). Rivista Mineraria Siciliana 145–147, 71–96.

Leonardi, G. and Mietto, P. 2000. I dinosauri in Italia. Le orme giurassiche dei Lavini di Marco (Trentino) e gli altri resti fossili italiani. Accademia Editoriale Pisa, pp.

Luciani, V. and Cobianchi, M. 1999. The Bonarelli Level and other black shales in the Cenomanian-Turonian of the northeastern Dolomites (Italy): calcareous nannofossil and foraminiferal data. Cretaceous Research 20, 135–167.

Lukeneder, A. 2008. Corals and ammonoids – connecting an incompatible connection (Cretaceous, Italy). Berichte der Geologischen Bundesanstalt 74, 52-53.

Manatschal, R. and Bernoulli, D. 1999. Architecture and tectonic evolution of non-volcanic margins: present-day Galicia and ancient Adria. Tectonics 18, 1099-1119.

Manfrin, S. Mietto, P., and Preto, N., 2005. Ammonoid biostratigraphy of the Middle Triassic Latemat platform (Dolomites, Italy) and its correlation with Nevada and Canada. Geobios 38, 477-504.

Marroni, M. and Pandolfi, L. 2007. The architecture o an incipient ocean basin: a tentative reconstruction of the Jurassic Liguria-Piemonte basin along the Northern Apennines - Alpine Corsica transect. International Journal of Earth Sciences 96, 1059-1078.

Martini, R., Zaninetti, L., Abate, B., Renda, P., Doubinger, J., Rauscher, R. and Vrielynck, B. 1991. Sédimentologie et Biostratigraphie de la Formation Triasique Mufara (Sicile occidentale): Foraminifères, conodontes, palynomorphes. Rivista Italiana di Paleontologia e Stratigrafia 97, 131-152.

Martire, L., Clari, P.,Lozar, F. and Pavia, G., 2006. The Rosso Ammonitico Veronese(Middle-Upper Jurassic of the Trento Plateau): a proposal of lithostratigraphic ordering and formalization. Rivista Italiana di Paleontologia e Stratigrafia, 112, 227-250.

Mascle, G., 1979. Etude géologique des Monti Sicani. Rivista Italiana di Paleontologia e Stratigrafia, Memorie 16, 431 pp.

Masetti, D., Claps, M. Giacometti, A., Lodi, P., and Pignatti, P, 1998. I Calcari Grigi della Piattaforma di Trento (Lias Inferiore e Medio, Prealpi Venete). Atti Ticinensi di Scienze della Terra 40, 139-183.

Massari, F., Conti, M.A., Fontana, D., Helmod, K., Mariotti, N., Nicosia, U., Ori, G.G., Pasini M., and Pittau, P., 1988. The Val Gardena Sandstones and Bellerophon Formation in the Bletterbach Gorge (Alto Adige, Italy: biostratigraphy and sedimentology. Memorie di Scienze Geologiche 40, 229-273,

Massari, F; and Neri,C., 1997. The infill of a supradetachment(?) basin; the continental to shallow-marine Upper Permian succession in the Dolomites and Carnia (Italy). Sedimentary Geology 110, 3-4, 181-221.

Matte, Ph., 1986. La chaine varisique parmi les chaines paléozoiques péri-atalantiques, modèle d'evolution et position dees grandes block coninenteaux au Permo-Carbonifère. Bulletin de la Societè Géologique de France 8, 2,1, 9-24.

Maurer, F., 2000. Growth mode of Middle Triassic carbonate platforms in the Western Dolomites (Southern Alps, Italy). Sedimentary Geology 134, 275-286.

Montanari, L., 1987. Lineamenti stratigrafico-paleogeografici della Sicilia durante il ciclo alpino. Memorie della Società Geologica Italiana 38, 361-406.

Montanari, L. and Panzanelli Fratoni, R., 1990. A comparison between the Lercara Formation (Sicily) and the Monte Facito Formation (Southern Apennines). Bollettino della Società Geologica Italiana 109, 115-121.

Montrasio, A., Nicolich, R., Sciesa, E., 2003. The profile "CROP Alpi Centrali". Memorie Descrittive della Carta Geologica d'Italia. 62; 96-105;

Muttoni, G., Erba, E., Kent, D.V. and Bachtasde, V., 2005. Mesozoic Alpine facies deposition as a result of past latitudinal plate motion Nature, 434: 59–63.

Muttoni, G., Garzanti, E., Alfonsi, L., Cirilli, S., Germani, D., Lowrie, W., 2001. Motion of Africa and Adria since the Permian; paleomagnetic and paleoclimatic constraints from northern Libya. Earth and Planetary Science Letters 192; 2, 159-174.

Muttoni, G., Kent, D.V., Garzanti, E., Brack, P., Abrahamsen, N. and Gaetani, M., 2003. Early Permian Pangea 'B' to Late Permian Pangea 'A'. Earth and Planetary Science Letters 215, 379-394.

Muttoni, G., Kent, D.V., Jadoul, F., Olsen, P.E., Rigo, M., Galli, M.T., and Nicora A., 2010. Rhaetian magnetobiostratigraphy from the Southern Alps (Italy): Constraints on Triassic chronology. Palaeogeography, Palaeoclimatology, Palaeoecology 285: 1-16.

Muttoni, M., Kent, D.V., Meço, S., Balini, M., Nicora, A., Rettori, R., Gaetani, M. and Krystyn, L., 1999. Towards a better definition of the Middle Triassic magnetostratigraphy and biostratigraphy in the Tethys Realm. Earth Planetary Science Letters 164, 285-302.

Marzoli, A., Renne, P.R., Piccirillo, E.M., Ernesto, M., Belliemi, G., De Min, E., 1999. Extensive 200-Million-Year-Old Continental Flood Basalts of the Central Atlantic Magmatic Province. Science, 284, 616-618.

Masetti, D. and Bianchin, G. 1987. Geologia del Gruppo della Schiara (Dolomiti bellunesi). Memorie di Scienze Geologiche 39, 187-212.

Nicora, A., Balini, M., Bellanca, A., Bertinelli, A., Bowring, S.A., Di Stefano, P., Dumitrica, P, Guaiumi, C., Gullo, M., Hungerbueleher A., Levera, M., Mazza M., McRoberts, C.A, Mattoni, G, Preto, N., and Rigo, M., 2007. The Carnian/ Norian boundary interval at Pizzo Mondello (Sicani Mountains, Sicily) and its bearing for the definition of the GSSP of the Norian Stage. Albertiana 36, 102-129.

Pandeli, E., Dominici, S., Degl'Innocenti, V., Cioppi, E., and Tangocci, F., 2008. Marine fossils in the Late Carboniferous metasediments of the Pisani Mountains (Tuscany, Italy). Bollettino della Società Geologica Italiana 127,3, 559-565.

Panzanelli Fratoni, R., 1991. Analisi stratigrafica della Formazone del M. Facito Auctt. (serie di Lagonegro-Appennino meridionale) Tesi di dottorato, Università degli studi di Perugina, 215 pp., unpublished.

Passeri, L. and Ciarapica, G., 2010. Le litofacies permiane e triassiche della formazione di M. Facito auctt. nell'area di M. Facito (successione di Lagonegro, Appennino meridionale). Italian Journal of Geosciences 129/ 1: 00-00, 10.3301/IJG.2009.03

Piano, C. and Carulli, G.B., 2002. Sedimentazione e tettonica giurassica nella successione del Gruppo del Monte Verzegnis (Prealpi Carniche nord-orientali). Memorie della Società Geologica Italiana 57, 15-122.

Picotti, V. and Cobianchi, M., 1996. Jurassic periplatform sequences of the Eastern Lombardian basin (Southern Alps). The deep-see records of the tectonic evolution, growth and demise history of a carbonate platform. Memorie di Scienze Geologiche 48, 171-219.

Pieri, M. and Mattavelli. L., 1986. Geologic framework of Italian Petroleum Resources. American Associaton Petroleum geologists Bulletin 70, 103-130.

Posenato, R., 1998. The gen. Comelicania Frech, 1901 (Brachiopoda) from the Southern Alps: morphology and classification. Rivista Italiana di Paleontologia e Stratigrafia 104, 43-68.

Posenato, R., 2001. The athyridoids of the transitional beds between Bellerophon and Werfen Formations (uppermost Permian, Southern Alps, Italy). Rivista Italiana di Paleonologia e Stratigrafia 107, 197-226.

Posenato, R., 2009. Survival patterns of macrobenthic marine assemblages during the end-Permian mass extinction in the western Tethys (Dolomites, Italy). Palaeogeography, Palaeoclimatology, Palaeoecology 280, 1-2, 150-167.

Rigo, M., Galli, M.T., and Jadoul, F., 2009. Late Triassic biostratigraphic constraints in the Imagna Valley (western Bergamasc Alps, Italy). Albertiana 37, 39-42.

Roghi, G., 2004. Palynological investigations in the Carnian of the Cave del Predil area (Julian Alps, NE Italy). Review of Palaeobotany and Palynology 132, 1-2, 1-35;

Ronchi, A., Sarria, E. and Broutin, J., 2008. The “Autuniano Sardo”: basic features for a correlation through the Western Mediterranean and Paleoeurope. In: Cassinis, G. (Guest ed.), Special Section: Stratigraphy and palaeogeography of late and post-Hercynian basins in the Southern Alps, Tuscany and Sardinia (Italy). Bollettino della Società Geologica Italiana 127, 655-681.

Sartorio, D., 1987. Reef and open episodes on a carbonate platform margin from Malm to Cenomanian: the Cansiglio example (Southern Alps). Memorie della Società Geologica Italiana 40, 91-97.

Sarti, M., Bosellini, A., and Winterer, E. L., 1992. Basin Geometry and Architecture of a Tethyan Passive Margin, Southern Alps, Italy: Implications for Rifting Mechanism. AAPG Memoirs 53, 241- 258.

Scandone, P., 1967. Studi di geologia lucana: la serie calcareo-silico-marnosa e i suoi rapporti con l'Appennino calcareo. Bollettino della Società dei Naturalisti in Napoli 76, 1-175.

Scholger, R., Mauritsch, H. J., and Brandner, R., 2000. Permian-Triassic boundary magnetostratigraphy from the Southern Alps (Italy). Earth and Planetary Science Letters 176, 3-4, 495-508.

Schmidt di Friedberg, P., Barbieri, F., and Giannini, C., 1960. La geologia del gruppo montuoso delleMadonie (Sicilia centro-settentrionale). Bollettino Servizio Geologico Italiano 81, 73–140.

Sciunnach, D., 2001a. The Lower Permian in the Orobic Anticline (southern Alps, Lombardy); a review based on new stratigraphic and petrographic data. Rivista Italiana di Paleontologia e Stratigrafia 107, 1, 47-68.

Sciunnach, D., 2001b. Benthic foraminifera from the upper Collio Formation (Lower Permian, Lombardy Southern Alps): implications for the palaeography of the peri-Tethyan area. Terra Nova 13, 150–155.

Sciunnach, D., Garzanti, E., Posenato, R., and Rodeghiero, F., 1999. Stratigraphy of the Servino Formation (Lombardy, southern Alps): towards a refined correlation with the Werfen Formation of the Dolomites. Memorie di Scienze Geologiche 51, 103–118.

Scotti, P., Fantoni, R., Podda, F., and Ponton, M., 2002. Depositi norici di ambiente anossico nelle Prealpi Friulane (Italia nord-orientale). Memorie della Società Geologica Italiana 57, 65-78.

Scudeler Baccelle, L. and Semenza, E., 1974. Flysch terrigeno con strutture contornitiche nel Cretaceo delle Dolomiti ampezzane. Caratteristiche sedimentologiche e significato geodinamico. Annali dell'Universita' di Ferrara, IX 5, 165–219.

Senowbari-Darian, B., Schaefer, P., and Abate, B., 1982. Obertriadische Riffe und Riffeorganismen in Sizilien. Facies 6, 165-184.

Stampfli, G.M., 2005. PlateTectonics of the Apulia-Adria Microcontinents. In Finetti, I.R. (ed.) CROP PROJECT: Deep Seismic Exploration of the Central Mediterranean and Italy, 747-766. Elsevier.

Stegagno, G., 1929. Il veronese Giovanni Arduino e il suo contributo al progresso della Scienza Geologica. 42 pp., Verona.

Stefani, M., Furin, S., and Gianolla, P., 2010. The changing environmental framework and depositional dynamics of the Triassic carbonate platform from the Dolomites. Palaeogeography, Palaeoclimatology, Palaeoecology 290, 43-57. 10.1016/j.palaeo.2010.02.018

Sturani, C., 1971. Ammonites and stratigraphy of the Posidonia alpina beds in the Venetian Alps (Middle Jurassic, mainly Bajocian). Memorie dell'Istituto di Geologia e Mineralogia dell'Università di Padova 28, 1-190.

Sturani, C., 1973. Considerazioni sui rapporti tra Appennino Settentrionale e Alpi Occidentali. In Accordi, B. (Ed.) - Moderne vedute sulla geologia dell'Appennino. Accademia Nazionale dei Lincei, Atti Convegni, 183, 119-142.

Tintori, A. 1977. Toarcian fishes from Lombardian Basin. Bollettino della Società Paleontologica Italiana 16(2), 143-152.

Trümpy, R., 1960. Paleotectonic evolution of the central and western Alps, Bulletin of the Geological Society of America 71 ,843–908.

Unland, W., 1975. Sedimentary and diagenetic environments of the Dosso dei Morti-Limestone/Giudicarie (Lower and Middle Anisian;Italy). Neues Jahrbuch Geologische Palaeontologische Monatshefte 1, 54-64.

Vai, GB., 1994. Crustal evolution and basement elements in the Italian area: palaeogeography and characterization. Bollettino di Geofisica Teorica ed Applicata 36, 411-434.

Venturini, C.and Spalletta, C., 1998. Remarks on the Paleozoic stratigraphy and the Hercynian tectonics of the Palaeocarnic chain (Southern Alps). Giornale di Geologia 60, Spec Issue, ECOS VII Southern Alps Field Trip Guidebook, 69–88.

Venturini, S. 2002. Il pozzo Cargnacco 1: un punto di taratura stratigrafica nella pianura friulana. Memorie della Società Geologica Italiana 57, 11-18.

Viel, G., 1979. Litostratigrafia ladinica: una revisione. Ricostruzione paleogeografia e paleostrutturale dell'area dolomitico cadorina (Alpi Meridionali). Rivista Italiana di Paleontologia e Stratigrafia, 85, 85-125 and 297-352.

Wagreich, M., Lukeneder, A., Egger, H., 2008. Cretaceous History of Austria. Berichte der Geologischen Bundesanstalt, 74, 12-30.

Weissert, H. and Bernoulli, D., 1985. A transform margin in the Mesozoic Tethys: evidence from the Swiss Alps. Geologiche Rundschau 74/3, 665-679.

Wiedenmayer, F., 1963. Obere Trias bis mittlerer Lias zwischen Saltrio and Tremona (Lombardische Alpen): die Wechselbeziehungen zwischen Stratigraphie, Sedimentologie und syngenetischer Tektonik. Eclogae Geologicae Helvetiae 56/2, 529-640.

Winterer, E.L., 1998. Paleobathymetry of Mediteranean Tethyan Jurassic pelagic sediments. Memorie della Società Geologica Italiana, 53, 97-131.

Winterer, E.L. and Bosellini, A., 1981. Subsidence and sedimentation on Jurassic Passive Continental Margin, Southern Alps, Italy. American Association Petroleum Geologists, Bulletin, 65, 394-421.

Zardini, R., 1973. Geologia e fossili attorno a Cortina d'Ampezzo. 26 pp. Ed. Ghedina.

Zardini, R., 1978. Fossili Cassiani (Trias Medio-Superiore): atlante dei gasteropodi della formazione di S. Cassiano raccolti nella regione dolomitica attorno a Cortina d'Ampezzo. - Cortina d'Ampezzo. 58 p., Ed. Ghedina.