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Remarks on the Permian-Triassic transition in Central and Eastern Lombardy (Southern Alps, Italy)

Apuntes sobre el tránsito Pérmico-Triásico en Lombardía central y oriental (Alpes Meridionales, Italia)

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Abstract

The main lithological and petrographical characteristics of the Permian-Lower Triassic Orobic and Brescian successions in central and eastern Lombardy are briefly recorded, especially with regard to the units cropping out below and above the P-T boundary. The lower formation is represented by the Verrucano Lombardo, which consists of continental, fluvial red clastics, barren of fossils, generally Late Permian (Lopingian) in age, whereas the overlying Servino Formation, which is represented by well-bedded clastic and carbonate polychrome sediments, generally rich in fossils, pertains to the Early Triassic (Induan-Olenekian).

The sequences of the two above-mentioned areas differ at least in part, as proof of their regional division, probably because of an inherited paleotopography and syntectonic activity. Taking into account the units bracketing the P-T boundary, which represents the real topic of this work, the Verrucano Lombardo of the Orobic Alps is paraconformably covered by the conglomerates and sandstones of the Prato Solaro Member in the lower part of the Servino Formation, cropping out extensively, although discontinuously, from the eastern side of Lake Como to the upper Scalve Valley in the Camonica region. The shape of some quartz rock fragments, derived from the Variscan crystalline basement and its Upper Carboniferous siliciclastic cover, has been interpreted as due to relatively coeval aeolian activity, and testifies to an arid climatic "event" probably late Dienerian-early Smithian in age.

In contrast, in the Brescia province, the onset of the Servino is made up of wave and current rippled, fine clastics, 1-2 m thick, and a typical horizon of oolitic dolostones ("Praso Limestone" *Auct.*), continuous from the lower Camonica Valley to the western Trentino. This unit could laterally correlate towards east, in the eastern South-Alpine segment, with the famous oolitic Tesero Member at the base of the Werfen Formation of the Dolomitic and Carnic Alps. In the Brescian Prealps, the above oolitic deposits crop out below some *Claraia* beds yielding forms common to those present in the Siusi Member of the Dolomites, generally attributed to late Griesbachian-early Dienerian times. Their age could be ascribed to a slightly older Griesbachian, i.e. to early Induan.

Therefore, the P-T boundary in central and eastern Lombardy seems substantially located between the final part of the Permian and the very base of the respective Triassic successions, temporally and spatially ranging in different ways and generally affected by non-depositional and perhaps tectonic processes. In our opinion, however, the duration of the gap, based on correlations with the well-documented stratigraphical studies recently carried out in the nearby Dolomitic area and other European regions, should be considered as slightly longer than previously recognized: the maximum gap could be estimated at about 3-4 Ma. As a consequence, we thus point out that the Servino Formation of the Brescian Alps rests, itself, paraconformably on the Verrucano Lombardo red beds, even if the P-T gap was probably less for correlation with the well-known Dolomites sections.

At the end of the paper, for a more comprehensible understanding of the late- to post-Variscan geological scenario, is a tentative synthesis of the regional evolution.

Keywords: Permian, Lower Triassic, P-T boundary, central and eastern Lombardy, geodynamic evolution.

Resumen

Se resumen las principales características litológicas y petrológicas de las sucesiones Oróbica y Bresciana del Pérmico y Triásico Inferior del este de Lombardía, especialmente las referidas a aquellas unidades que afloran por encima y por debajo del límite P-T. La formación inferior está representada por el "Verrucano Lombardo", que está constituido de sedimentos continentales clásticos de color rojo, de origen fluvial y sin fósiles y que muestran generalmente una edad Pérmico Superior (Lopingiense), mientras que la unidad inmediatamente superior, Formación Servino, representada por sedimentos bien estratificados, clásticos y carbonáticos, con abundantes fósiles y diferentes colores, es de edad Triásico Inferior (Induense-Olenekian).

Las sucesiones de las dos áreas arriba mencionadas difieren entre sí, debido, entre otros motivos, a aquellos ligados a las características paleogeográficas y tectónicas propias de las zonas en las que afloran. El Verrucano Lombardo, en los afloramientos de los Alpes Oróbicos, que aflora extensivamente aunque de forma discontinua desde la parte este del lago Como hasta la parte alta del valle Scalve, en la región Carmónica, se sitúa, mediante una paraconformidad, bajo los conglomerados y areniscas del Miembro Prato Solaro, pertenecientes a la parte inferior de la Formación Servino. La forma de algunos fragmentos de roca, derivados del basamento cristalino varisco, así como los sedimentos siliciclásticos del Carbonífero Superior que los cubren, han sido relacionadas con una actividad de tipo eólica, testificando un evento climático de tipo árido, probablemente de edad Dieneriense superior-Smithiense inferior.

En contreste, en la provincia de Brescia, la Formación Servino está constituida por sedimentos clásticos con ripples de oscilación y corriente, de tamaño de grano fino, constituyendo un espesor de 1-2 m y un nivel típico de dolomías oolíticas ("Praso Limestone" *Auct*.), que aparece desde la parte inferior del valle de Camonica hasta el oeste Trentino. Hacia el oeste, en el segmento este de los Alpes Meridionales, esta unidad podría correlacionarse lateralmente con el Miembro Tesero, de carácter oolítico, de la base de la Formación Werfen de los Alpes Dolomíticos y Cárnicos. En los Prealpes Brescianos, los depósitos oolíticos anteriormente mencionados afloran por debajo de algunas capas con *Claraia*, mostrando formas parecidas a las existentes del actual Miembro Siusi de los Dolomitas, generalmente atribuidos a una edad Griesbachiense-Dineriense inferior. Su edad podría ser ligeramente anterior a Griesbachiense, i.e. Induense inferior.

Así, el límite P-T en el centro y este de Lombardía, estaría básicamente estar localizado entre la parte final de los sedimentos considerados pérmicos y aquellos de la parte más baja de los considerados Triásico Inferior, aunque con ciertas variaciones temporales y espaciales, variando en función de los procesos no deposicionales y, posiblemente, tectónicos. En nuestra opinión y, basándonos en correlaciones bien documentadas estudios estratigráficos llevados a cabo en los Dolomitas y en otras regiones europeas, la prolongación en el tiempo de esta etapa en la que falta registro sedimentario podría ser considerada como ligeramente más larga de lo inicialmente reconocido: esta etapa podría ser considerada en torno a 3-4 Ma. Como consecuencia, consideramos que la Formación Servino de los Alpes Brescianos, como tal, paraconformable sobre las capas rojas del Verrucano Lombardo incluso aunque el vacío sedimentario de la transición P-T en esta zona fuese menor que el de la zona correlacionable y bien conocida de las secciones de los Dolomitas.

Palabras clave: Pérmico, Triásico Inferior, límite P-T, centro y este de Lombardía, evolución geodinámica.

1. Introduction

This research aims at investigating the Permian-Triassic boundary (PTB) in central and eastern Lombardy, since previous knowledge has been limited by the lack of or the inadequate presence of paleontological records. Only after the Second World War did it attract the attention of geologists from Pavia and Ferrara, mainly looking for a correlation with the famous "Tesero Horizon" at the base of the Lower Triassic Werfen Formation in the eastern Southern Alps, which has been the topic of a great number of studies since its stratigraphic introduction by Bosellini in 1964. In later times, further investigations by researchers on both the shores of Lake Como and to the east centred on the Permo-Triassic Verrucano Lombardo and Servino formations, and highlighted the

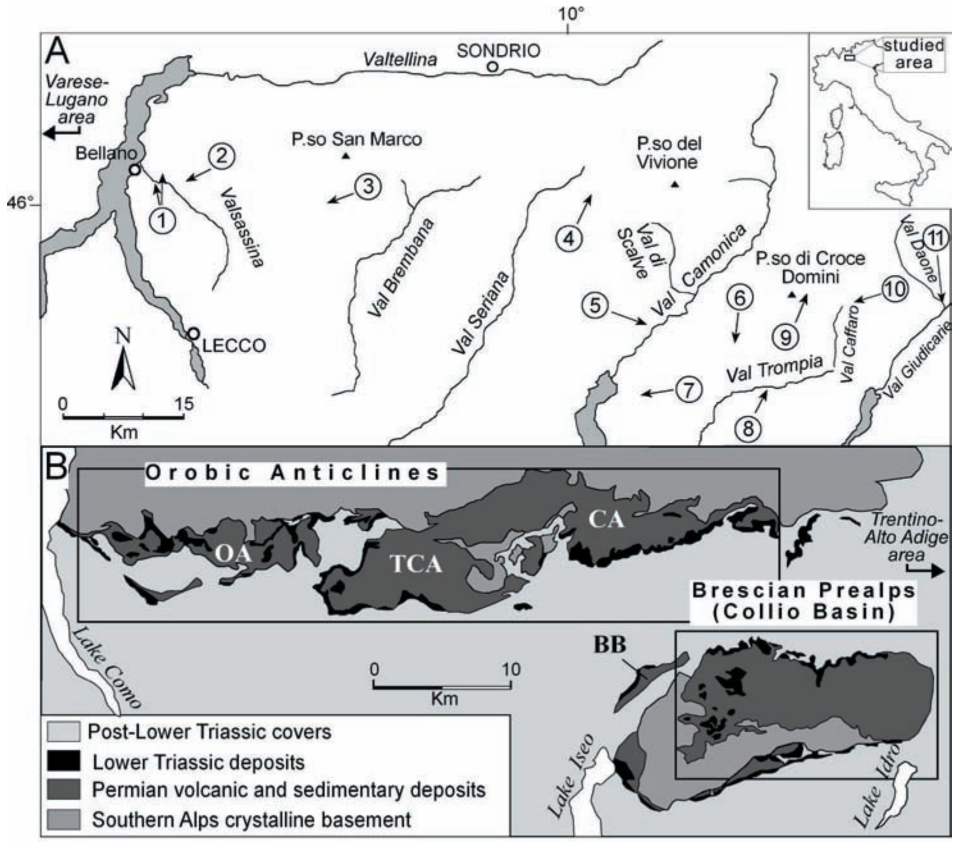

Fig. 1.- A. Location of the main outcrops of the Permian-Triassic transitional sequences cited in the text. 1: Val Muggiasca (Prato Solaro type-section and reference section of the nearby Val dei Mulini); 2: Alpe d'Oro; 3: Piani dell'Avaro; 4: Manina Mine (Val di Scalve); 5: Anfurro area; 6: Val Rondeneto (M.te Muffetto area); 7: M.te Guglielmo sections (Pontasio-Gale-Muraccone); 8: Val Fontanelle (upper Val Trompia); 9: P.so di Croce Domini-M.te Gera; 10: Passo Valdì (upper Val Caffaro); 11: Praso (Val Daone, in the western Trentino region). B. Simplified geological sketch of the investigated Lombardy region. It includes northward, between Lake Como and the Camonica Valley, the Orobic Anticlines which are known, from west to east, as Orobic Anticline *sensu stricto* (OA), Trabuchello-Cabianca Anticline (TCA) and Cedegolo Anticline (CA). Whereas, toward southeast, in the Brescian Prealps, research was centred on the Collio Basin area and its Permo-Triassic cover. BB indicates the small Early Permian volcano-sedimentary basin of Boario Terme, in lower Val Camonica, running along the westernmost margin of the above-mentioned main basin.

Fig.1.- A. Localización de las principales secuencias de las series de transición del Pérmico-Triásico citadas en el texto. 1: Val Muggiasca (sección tipo de Prato Solaro y sección referencia de los alrededores de Val dei Mulini); 2: Alpe d´Oro; 3 Piani dell´Avaro; 4: Manina Mine (Val di Scalve); 5: Anfurro area; 6: Val Rondeneto (área de Mount Muffetto); 7: Secciones del Mount Gugliemo (Pontasio-Gale-Muraccone); 8: Val Fontanelle (parte superior de Val Trompia); 9: P.so di Croce Domini-M.te Gera; 10: Passo Valdì (parte superior de Val Caffaro); 11: Praso (Val Daone, en el oeste de la región de Trento). B. Esquema geológico simplificado de la región investigada de Lombardía. Incluye hacia el norte, entre el lago Como y el Valle Camonica, los anticlinales de Orobic, los cuales son conocidos, de este a oeste, como el Anticlinal Oróbico (*sensu stricto*) (OA), anticlinal de Trabuchello-Cabianca (TCA) y anticlinal Cedegolo (CA). Por otro lado, hacia el sureste, en los Prealpes Brescianos, diferentes investigaciones han sido centradas en la Cuenca de Collio y su cobertera Permo-Triásica. BB indica la pequeña cuenca volcanosedimentaria del Pérmico Inferior de Boario Terme, en la parte inferior de Val Camonica, orientada a través del margen más occidental de la cuenca principal arriba mencionada.

importance of this chronostratigraphic interval essentially based on petrographic detrital modes. Our overview regards some selected sections from the literature and subjects them again to study in the light of wider research and correlation. Locations of the main visited PTB sections are reported in Fig.1. Furthermore, this work is accompanied by a general view of the late-Variscan volcanic and sedimentary evolution in order to understand better the key-significance of this geological period, heralding the Alpine Era.

2. Stratigraphic framework

2.1. Permian

The South Alpine Permian can be clearly subdivided into two major well-differentiated tectonosedimentary cycles, separated by a marked unconformity and a gap of as-yet-uncertain duration (Italian IGCP 203 Group, 1986; Cassinis *et al*., 1988; Figs. 2 and 5).

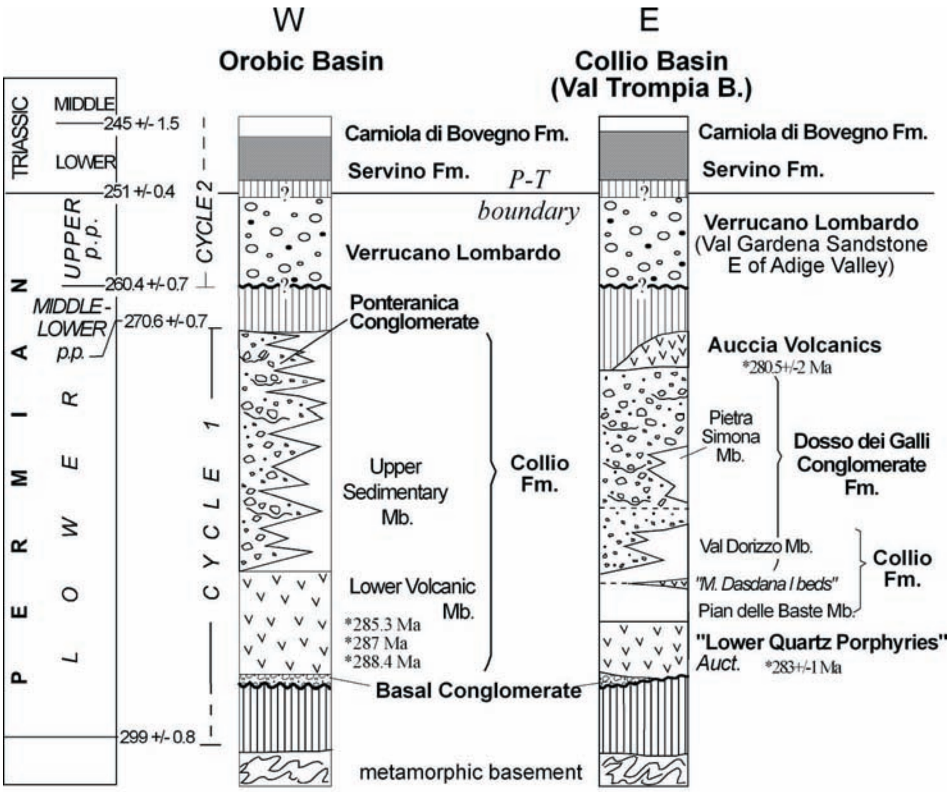

Fig. 2.- Pre-Permian to Lower Triassic representative stratigraphic logs of the Orobic and Val Trompia volcano-sedimentary deposits and their cover, in central and eastern Lombardy respectively. Vertical distances are not time or thickness-related. Geologic time scale from Gradstein *et al.* (2004).

Fig. 2.- Secciones estratigráficas representativas del pre-Pérmico-Triásico Inferior de los depósitos volcanosedimentarios y de los materiales de la cobertera de éstos del Anticlinal Oróbico y Val Trompia, en la zona central y este respectivamente de Lombardía. No hay relación tiempo-espesor en la vertical. La escala del tiempo geológico es de Gradstein *et al.* (2004).

2.1.1. Lower Cycle

In Lombardy, the lower cycle (cycle 1), up to 1500 m-thick, is made up of acidic to intermediate volcanics and alluvial to lacustrine continental deposits (Collio Formation, Ponteranica and Dosso dei Galli Conglomerates, and other lithosomes), both infilling intramontane fault-bounded subsiding basins isolated from each other by metamorphic and igneous structural highs. The boundary paleofaults normally show SSW-NNE and W-E trends, and often coincide with important Alpine tectonic lineaments (such as the Val Trompia, Giudicarie and Insubric lines; Fig. 3). In addition, in the western and central sectors of the investigated region, conglomerates, sandstones and finer-grained siliciclastic products (known under the general name of "Basal Conglomerate") crop out underneath the above deposits, but in non-time-equivalent position, extending from the Late Carboniferous to Early Permian, and could be also ascribed to another independent cycle. During this period the climate was warm and moderately semi-arid (Dal Cin, 1972), with alternating wet and dry periods.

In the Orobic Anticline *stricto sensu* (Figs. 1B, 2 and 4.B), the Lower Permian sandstones of the Collio Formation and Ponteranica Conglomerate can be classified as volcanic arenites (average detrital modes: Q = 10±5, F = 20±7, L = 70±8), and further petrographical data from the Basal Conglomerate are reported in a thorough and extensive work of Sciunnach (2001b), to which we refer for further details. In the Brescian Prealps (Fig. 1B) also, along and around the Maniva-Croce Domini road which crosses the local Paleozoic to Lower Triassic massif, a petrographical and mineralogical study of the Lower Permian Collio Formation (Cassinis *et al*., 1978; Figs. 2 and 4.A) records, in the varicoloured shales of the lower Pian delle Baste Member, a stable mineralogical association of illite-chlorite and some poor flakes of kaolinite; the alternating sandstones and siltstones prevalently consist, after Folk's systematics (1968), of arkose and lithic arkose, due to the presence of abundant feldspars (albite-oligoclase), locally rimmed by neogenic albite. Upwards, the thin detrital rocks (represented again by sandstones and siltstones), which rest conformably on the volcaniclastic mass-flow deposits of the so-called "M. Dasdana I Beds" (Breitkreuz *et al*., 2001), are characterized by immature sediments, where the feldspars prevail over the lithics. The mineralogical composition of the associated pelites consists, as in the underlying member, of dominant illite. In contrast, the siliciclastic deposits which mark the onset of the Dosso dei Galli Conglomerate Fm. are made up of lithic sandstones and conglomerates with mineralogical-petrographical features clearly different from the previous units. In fact, they include for the first time conspicuous metamorphic and volcanic rock-fragments, also of large size. As a consequence, this event appears clearly connected with a pronounced erosion of uplifted source areas, essentially represented by the Variscan crystalline basement.

Paleontological investigations of the macro- and microflora, and tetrapod footprints, indicate that the aforementioned older cycle/cycles began locally in the Westphalian but developed generally during Early Permian times (Geinitz, 1869; Venzo and Maglia, 1947; Jongmans, 1960; Remy and Remy, 1978; Ceoloni *et al.*, 1987; Conti *et al.*, 1991; Cassinis and Doubinger, 1992; Nicosia *et al.*, 2001). Radiometric ages for a large number of igneous, extrusive and intrusive bodies also agree, generally, with the above dating (Cadel, 1986; De Capitani *et al.*, 1988, 1994; Thöni *et al.*, 1992; Schaltegger and Brack, 1999).

2.1.2. Upper Cycle

The Permian upper cycle (cycle 2), from few tens of metres to nearly 600 m-thick (Perotti and Siletto, 1996), consists in central and eastern Lombardy of the Verrucano Lombardo fluvial red clastics, which form a widespread blanket from Lake Como to the western Trentino, covering both the basins of the lower cycle/s and the surrounding highs. However, east of the Camonica Valley, the Verrucano Lombardo is represented in continuity by continental wine-red sandy-silty rocks which, on the whole, might be interpreted as a progressive facial change towards the well-known Val Gardena Sandstone of the Dolomites. Generally these sediments, compared with the products of cycle 1, appear more widely distributed even if less thick.

Compositional analyses of the Verrucano Lombardo (Fig. 4.B) document gradual attenuation of the relief, with dissection of the Lower Permian volcanic plateaux and, subordinately, unroofing of Variscan basement rocks and their local "aporphyric" siliciclastic cover (Cassinis, 1968a; Fontana and Zuffa, 1983; Sciunnach *et al.*, 1996; Garzanti *et al.*, 2003). According to Sciunnach *et al.* (1996), in the Orobic Alps the abrupt change from this lithic petrofacies P1 to the quartzo-lithic petrofacies P2, observed in the Inferno Valley (Valtellina, Fig. 1A for location), records a significant hiatus; in fact, at the base of this second petrological interval, the appearance of arenaceous rock fragments (very fine-grained quartzarenites lacking in volcanic lithics, similar to those typical of the "Basal Conglomerate"), and a much higher quartz content suggest wider dissection of the underlying volcanic plateaux, with erosion reaching into the Upper Carboniferous siliciclastics and the deeper-seated crystalline basement.

Further to the east, at the Passo San Marco area (Fig. 1A), feldspar increases in the upper part of the Verrucano Lombardo (Sciunnach *et al.*, 1996; Garzanti *et al.*, 2003). According to the same authors, this trend probably points to progressive local erosion of granitoid rocks, rather than climatic causes, since feldspar abundance was not observed in other sections of the Orobic Alps.

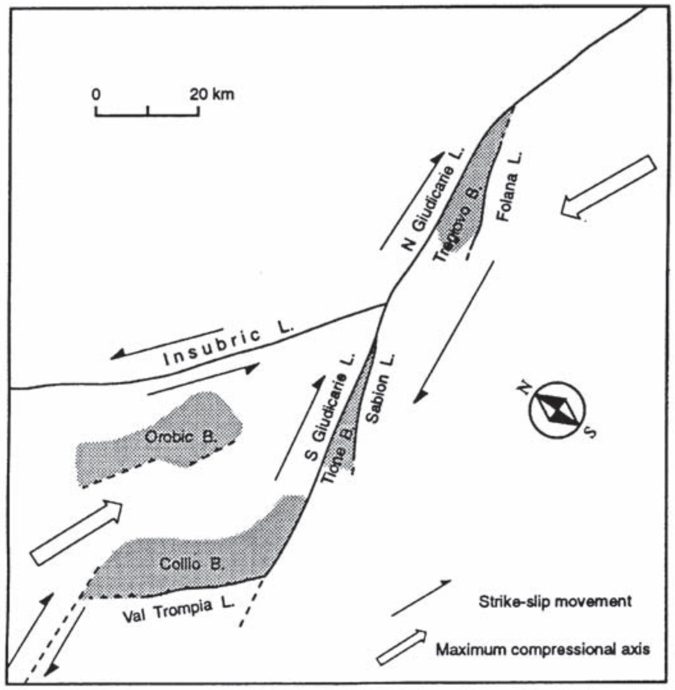

Fig. 3.- Interpretative schematic model showing the Late Variscan tectonic setting of the region examined, in the central Southern Alps, before deposition of the Upper Permian Verrucano Lombardo-Val Gardena continental red beds. The north-south orientation of that tectonic framework during Permian times is also shown. (From Cassinis *et al.*, 1997b).

Fig. 3.- Modelo esquemático interpretativo mostrando la tectónica tardivarisca de la zona estudiada, en la zona centro y sur de los Alpes, previa a la deposición de los sedimentos rojos continentales del Pérmico Superior Verrucano-Val Gardena. Se muestra también la orientación N-S de esta estructura tectónica durante el Pérmico.

Detrital modes of some selected samples collected in the same unit by Fontana and Zuffa (1983) are consistent with the petrofacies P2 (Valsassina) or P1+P2 (Pizzo della Nebbia and Val Sanguigno in the Valtellina-Brembana-Seriana central sector of the Orobic Alps; Fig. 1A for location). Sandstones much richer in feldspar (F>20) crop out, in the Brescian Prealps, around the Passo di Croce Domini area (Cassinis, 1968a; Sciunnach *et al.*, 1996; Fig. 1A for location); in the easternmost Val Gardena Sandstone (where the rock-fragments are invariably <35), they dominate in the western Dolomites (Butterloch gorge, near Cavalese in Val di Fiemme) and become exclusive, towards the east, from Cadore to Friuli (Sciunnach *et al.*, 1996).

During the Verrucano Lombardo sedimentation, the climate was characterized by semi-arid to arid conditions (Massari *et al.*, 1988; Ori, 1988), presumably in subtropical paleolatitudes.

Given the lack of fossils, the age of the Verrucano Lombardo is still subject to uncertainty and discussion. However, as the unit generally rests over Lower Perm-

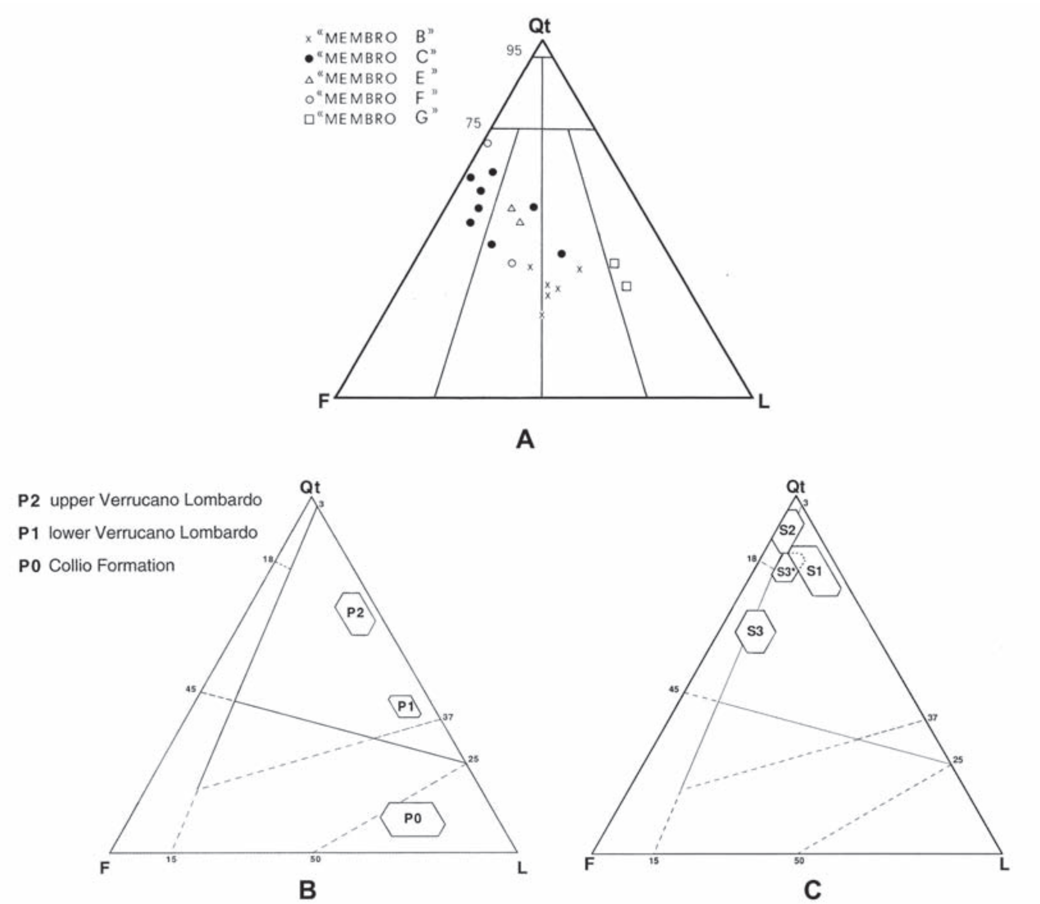

Fig. 4.- QLF detrital modes: A - after Folk (1968), for the Collio Fm. in Val Trompia (from Cassinis *et al*., 1978, modified); B - after Dickinson *et al*. (1983), for the Collio Fm. - Ponteranica Cgl. (petrofacies PO), Verrucano Lombardo Fm. (petrofacies P1 and P2), and C – the Servino Fm. (petrofacies S1 to S3) in Orobic Alps. (B, from Sciunnach, 2001a and C, from Sciunnach *et al*., 1996, both the drawings modified).

Fig. 4.- Valores detríticos QLF: A - basado en Folk (1968), para la Formación Collio en Val Trompia (modificado de Cassinis *et al*., 1978); B- Basado en Dickinson *et al*., (1983), para la Formación Collio – Conglomerados Ponteranica (petrofacies PO), Formación Verrucano Lombardo (petrofacies P1 y P2), y C- La Formación Servino (petrofacies S1 y S3) en los Alpes Oróbicos. (Datos de B obtenidos de Sciunnach, 2001a, y los de C obtenidos de Sciunnach *et al*., 1996, ambos con los dibujos modificados).

ian volcanic and sedimentary deposits and below Lower Triassic fossiliferous marine sediments, attribution to the Upper Permian is clearly plausible (Fig. 5). Owing to the age outlined for the previous lower cycle (generally related to a Sakmarian-Artinskian interval), and due to correlation with the more indicative lateral sections of the Trentino-Alto Adige, the Verrucano Lombardo probably developed diachronously during Late Tatarian times, reaching up (or almost) to the Permian-Triassic boundary. However, from Lake Como to the Giudicarie region, the presence of a P-T boundary is not yet supported from paleontological data.

According to Massari *et al*. (1994) and to Massari and Neri (1997), this second Upper Permian cycle continues up to the Lower Triassic (Induan-Olenekian) and slightly younger units. As already indicated, the contact with the previous cycle 1 is marked by a stratigraphic gap of unknown duration, probably extending into Middle Permian (Guadalupian) times. The gap, which is well documented by extensive erosion surfaces and palaeosol profiles, could be tentatively estimated as spanning approximately 14 to 25 Ma in various places. This time-interval is consistent with the marked evolutionary changes recorded in the tetrapod footprints of the Southern Alpine Lower and Upper Permian sedimentary deposits.

2.2. Lower Triassic

On the top, the Verrucano Lombardo continental red beds are followed by shallow-marine sediments of the Servino Formation, Early Triassic in age. The so-called "Servino" is the Lombardian equivalent of the Werfen Formation (Fig. 5), representing the Lower Triassic deposits in the eastern Southern Alps (as well as, with different regional names but with substantially similar fossil assemblages, facies pattern and sedimentary evolution, a large part of Alpine Europe) (Broglio Loriga *et al*., 1990).

The Servino Formation generally consists of mixed or alternating terrigenous and carbonate deposits laid down in depositional settings ranging from the offshore portion of a wave-dominated shelf to supratidal mud-flats. Thickness is variable, ranging from approximately 120 to 200 m or more; it decreases rapidly along the western shore of Lake Como, where the unit is reduced to discontinuous lenses west of Acquaseria (Sciunnach *et al*., 1996), and changes abruptly in the Trento region across the Giudicarie Line, probably due to previous Permian paleotopography, increasing towards the east in the Dolomitic Alps.

Orobic Anticlines

The base of the Servino Formation is characterized from Lake Como to the Manina mine section by discontinuous oligomict conglomerates, breccias and sandstones (Prato Solaro Member; Sciunnach *et al*., 1996, 1999b), which lack extensively towards the southeast, in the Brescian Prealps and nearby, where the basal Servino is represented by quartzarenites and other lithotypes (Cassinis, 1968b; De Donatis and Falletti, 1999), which will be described below (Figs. 1 and 6).

The middle part of the formation consists of mature quartzose sandstones. It yielded in only one place of the western Orobic Alps, about 7 m above its base, many specimens of the bivalve *Claraia*, which led Posenato *et al.* (1996) to relate the first Triassic marine transgression, in this area, to an age presumably ranging from the latest Griesbachian to the early Dienerian. The chronostratigraphic meaning of these fossils will be discussed farther herein. In the upper part of the Servino Formation, which is represented by bioclastic yellowish carbonates and green to reddish carbonatic pelites, occurrence of the ammonoids *Dinarites* and *Tirolites*, and the foraminifers *Meandrospira pusilla*, *Glomospira* and *Glomospirella* indicates a Spathian age (Sciunnach *et al*., 1996: p.33).

QFL detrital modes for the Servino Formation display three distinct petrofacies (Sciunnach *et al*., 1996; Garzanti *et al*., 2003). The petrological interval S1 corresponds to the Prato Solaro Member of the Servino Formation and is essentially made up of sublitharenites (Fig. 4.C). It is markedly enriched in detrital quartz at the expense of lithic grains. Metamorphic pebbles (identified as Gneiss Chiari in the Prato Solaro and Comasira sections, both in Fig. 1A.1) occur at the very base of the Member. Further details may be taken from the above-cited works. In essence, this geological step represents the conclusive geodynamic evolution of the previous Verrucano Lombardo depositional stage. However, the Prato Solaro Member does not crop out everywhere with its typical features and, as already indicated, it is also locally (*e.g.* at Ca' San Marco) lacking. In contrast, petrofacies S2, with a further increase in detrital quartz, and petrofacies S3 exibit subarkosic and arkosic trends respectively (Fig. 4.C).

Between Lake Como and Brembana Valley (Fig. 1A) the conglomeratic basal beds of the Prato Solaro member yielded to the authors of this paper many ventifacts: wind worn phenoclasts (Fig. 7). They are mainly quartz pebbles, having already acquired a certain roundness, during fluvial transportation, before their fashioning (ridges and facets, pits) by aeolian sand blasting. At Alpe d'Oro they were not largely dispersed, indicating that their last reworking was rather short. Such an interpretation is evidenced everywhere by the good preservation of the secondary ridges and of the polarity expressed by smooth upper and rough lower faces. They testify for a clearly arid climate in the depositional area just before the first Triassic transgression (Durand, 1972; Smith and Edwards, 1991; Durand, 2006).

Brescian Prealps

The Servino Formation of eastern Lombardy, between the Camonica and Caffaro Valleys, crops out prevalently in the Brescian Prealps, south of the Alpine Adamello intrusion. Generally it is well exposed along the Fontanelle Valley, near Collio in upper Val Trompia (Figs. 1A for location, 6 and 8). The basal part, resting on the Verrucano Lombardo continental red beds, consists of wave-rippled thin clastics, 3-4 m-thick, which are overlain by metre-thick layers of yellowish oolitic dolostones alternating with siltstones (marked as "PD Hor." in the the small columns 8-10 of Fig. 6; Fig. 9.I). This oolitic unit (named improperly, for its composition, as "Calcare di Praso") can be recognized in many parts of the investigated area and can be followed and also locally mapped to the eastern side of the Rendena Valley, in western Trentino. The lower and upper contacts of this member were interpreted as erosional (Cassinis *et al*., 1990: Fig. 8, and 1993: surface 2 in the logs III and IV of Fig. 9). A grey to bluish well-bedded unit, with marls, siltstones, thin sandstones and dolomitic calcarenites, containing *Claraia aurita* (Hauer) and foraminifers of the *Rectecornuspira-Cyclogira* group, occurs above. These strata may be interpreted, according to Neri (*in* Cassinis *et al*., 1990), as a lithostratigraphic equivalent of the Siusi Member in the Werfen Formation of the Dolomites, and thus ascribed to a latest Griesbachian-early Dienerian age. In this context, we wish also to point out that Yin (1985) related the acme zone of *Claraia aurita* (Hauer) in the Western Tethys (Alps) essentially to a Dienerian interval.

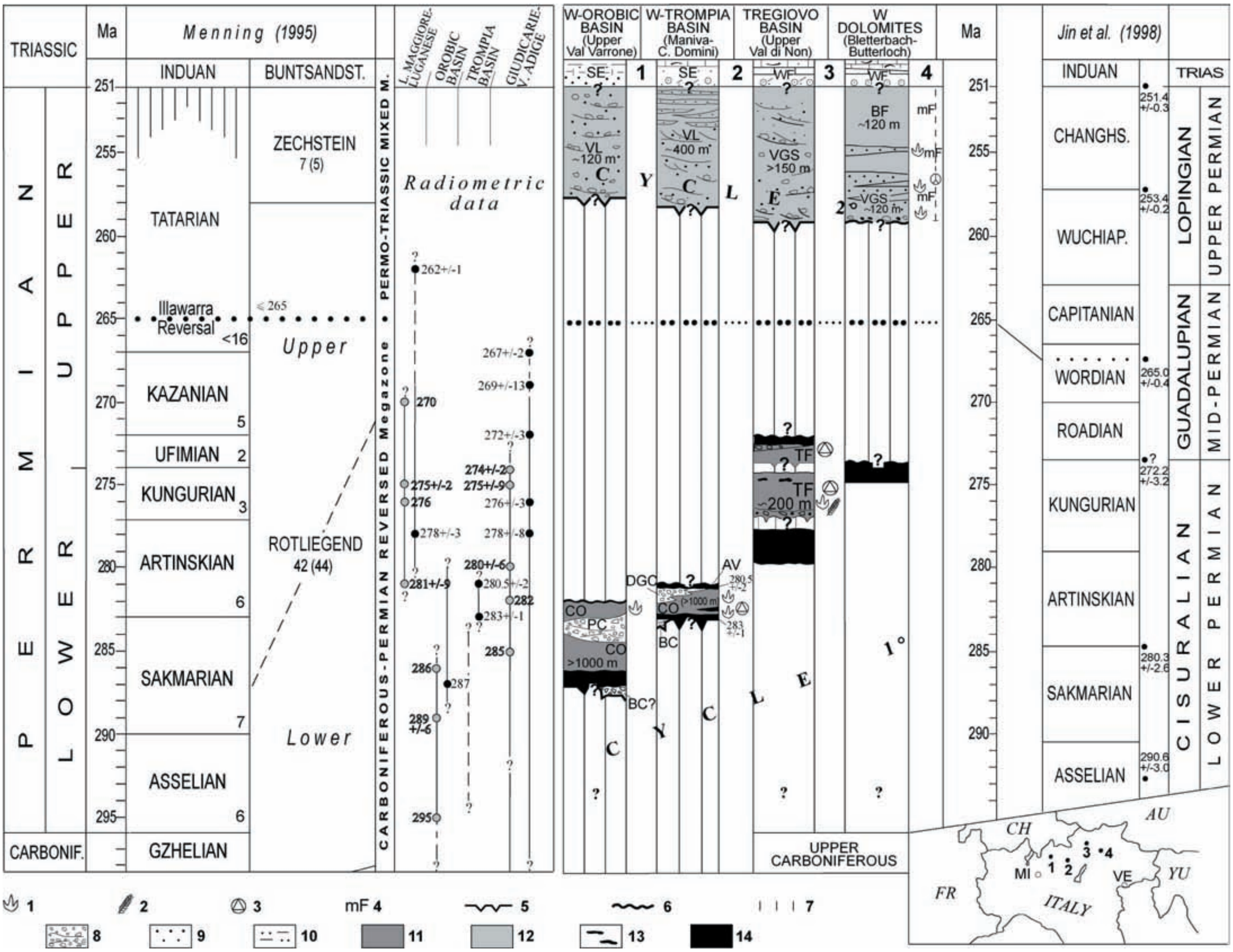

Fig. 5.- Permian simplified stratigraphic successions (localities shown on the inset map) from the Southern Alps, between Lake Como and the western Dolomites. Westward, the lower part (Cycle 1) consists of continental volcanics and alluvial-lacustrine sediments, while the upper part (Cycle 2) is made up of fluvial red beds, which, to the east of the Adige Valley (column 4), grade laterally and upwardly to sulphate evaporites and shallow-marine sediments. Sections 3 and 4 are incomplete below, because the corresponding volcanic and sedimentary succession is still lacking in careful investigations. The Val Trompia section shows two radiometric data, recently obtained by Shaltegger and Brack (1999). *Lithostratigraphic units*: abbreviations (from bottom) – Lombardy, **BC**: Basal Conglomerate, **CO**: Collio Formation, **PC**: Ponteranica Conglomerate; **DGC**: Dosso dei Galli Conglomerate, **AV**: Auccia Volcanics, **VL**: Verrucano Lombardo, **SE**: Servino Formation – Trentino-Alto Adige, **TF**: Tregiovo Formation, **VGS**: Val Gardena Sandstone, **BF**: Bellerophon Formation, **WF**: Werfen Formation. *Fossils* – **1**: Tetrapod footprints, **2**: Plant remains, **3**: Palynomorphs, **4**: Marine fossils. *Other symbols* – **5**: Unconformity, **6**: Erosion surface, **7**; Stratigraphic gap. *Lithology* – **8**: Conglomerates and breccias, **9**: Sandstones and conglomerates, **10**: Pelites and sandstones, **11**: Lower Permian sediments of Cycle 1 (dark-grey colour), **12**: Upper Permian deposits of Cycle 2 alternating, without symbols, with sulphate evaporites to shallow-marine sediments (light-grey colour), **13**: Cherty nodules, **14**: Undifferentiated volcanic rocks of cycle 1 (black colour). Geologic time scales from Menning (1995) and Jin *et al.* (1998). This scheme besides the subdivisions of the first author also includes a large number of radiometric data (in Ma) on intrusive (light-grey dotted) and volcanic (black) rocks generally cropping out between Lake Maggiore and the Val d'Adige region; the respective vertical lines indicate the assumed duration of the igneous activity in each area, whereas the dashed lines correspond to presumed or discontinuous manifestations. (After Cassinis *et al*., 2002, modified).

Fig. 5.- Sucesiones estratigráficas simplificadas del Pérmico (las localidades están marcadas en el recuadro del mapa) de los Alpes meridionales, entre el Lago de Como y la zona oeste de los Dolomitas. Hacia el oeste, la parte inferior (Ciclo 1) consiste en sedimentos continentales volcánicos y aluvial-lacustre, mientras que la parte superior (Ciclo 2) está constituido por rocas rojas de origen fluvial, las cuales, hacia el este del Valle de Adige (columna 4), gradan lateralmente y hacia arriba a sedimentos marinos someros y evaporitas. Las secciones 3 y 4 están incompletas debido a que las sucesiones volcánicas y sedimentarias correspondientes carecen todavía de un estudio en detalle. La sección de Val Trompia muestra dos datos radiométricos obtenidos recientemente por Shaltegger y Brack (1999). *Unidades litoestratigráficas*: Abreviaciones (desde la base): *Zona de Lombardía*- **BC**: Conglomerado Basal, **CO**: Formación Collio; **PC**: Conglomerado de Ponteranica; **DGC**: Conglomerado Dosso dei Galli; **AV**: Volcánicos de Auccia; **VL**: Verrucano Lombardo; **SE**: Formación Servino. *Zona Trentino-Alto Adidge*- **TF**: Formación Tregiovo; **VGS**: Arenisca de Val Gárdena; **BF**: Formación Bellerophon; **WF**: Formación Werfen. *Fósiles*- **1**: Huellas de tetrápodos; **2**- Restos de plantas; **3**: Palinomorfos; **4**: Fósiles marinos. *Otros símbolos*: **5**: discordancia; **6**: superficie erosiva; **7**: Gap

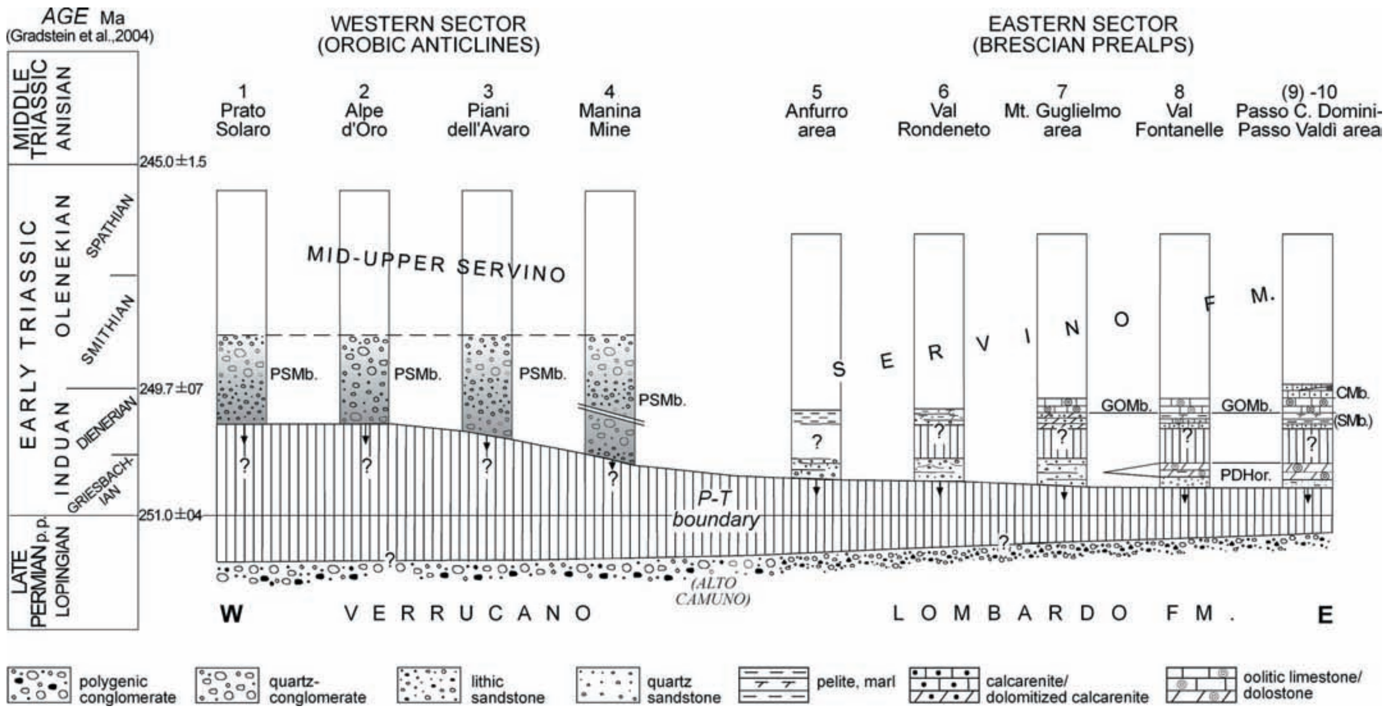

Fig. 6.- Chronostratigraphic scheme as applied to some selected and simplified stratigraphic sections at the transition between the Upper Permian Verrucano Lombardo and the Lower Triassic Servino formations in central and eastern Lombardy, from Lake Como to Val Caffaro (W of the Chiese Valley). The sections n. 4 of the Manina Mine and n. 7 of the M. Guglielmo areas are taken from Sciunnach *et al.* (1999a) and De Donatis and Falletti (1999) respectively. A greyish pattern points out the sections of the Prato Solaro Member including the ventifacts represented in Fig. 7. Localities in Fig.1A. *Symbols* (from W to E), all pertaining to the Servino Formation: **PSMb**., Prato Solaro Member; **GOMb**., Gastropod Member; **PD Hor**., Praso Dolostone Horizon (also named "Praso Member" or, improperly, "Praso Limestone"); (**SMb**.), unit probably correlatable with the Siusi Member of the Werfen Formation, cropping out in eastern Southern Alps; **CMb.**, corresponding to the Campil Member of the Werfen Formation. Vertical distances are not time or thickness-related. Geologic time scale 2004 from Gradstein *et al*., 2004.

Fig. 6.- Esquema cronoestratigráfico aplicado a algunas secciones estratigráficas simplificadas en la transición entre las Formaciones Verrucano Lombardo (Pérmico Superior) y Servino (Triásico Inferior) en el centro y este de Lombardía, desde el Lago de Como hasta el Val Caffaro (oeste del Valle de Chiese). La sección número 4, perteneciente a la Mina Manina y la número 7, de la zona del Monte Gugliemo, han sido tomadas de Sciunnach *et al*. (1999a) y de De Donatis y Falletti (1999) respectivamente. Las secciones del Miembro Prato Solaro están indicadas en gris, incluyendo los *ventifacts* mostrados en la Fig. 7. Las localidades son las indicadas en la figura 1. *Símbolos*- (de W a E), todos pertenecen a la Formación Servino: **PSMb**: Prato Solaro Member; **GOMb**: Gastropod Member; **PD Hor**: Praso Dolostone Horizon (tambien denominado "Prado Member" o, impropiamente, "Caliza de Praso"); **SMb**: Unidad probablemente correlacionable con el Miembro Siusi de la Formación Werfen, aflorando en el este de los Alpes Meridionales; **CMb**: Corresponde al Miembro Campil, de la Formación Werfen. La escala vertical no indica una relación de tiempo-espesor. La escala geológica de los tiempos ha sido obtenida de Gradstein *et al.* (2004).

Upwards follows the so-called "Gastropod Oolite" member (indicated as "GO Mb." in the columns 7-10 of Fig. 6; Fig. 9.E), which represents the most typical facies of the Servino Formation in eastern Lombardy. It is made up of lenticular bedded, cm- to dm-thick, locally dolomitized oolitic coquinoid limestones, passing laterally to red calcarenites and mudrocks. The unit is practically unknown west of the Camonica Valley, along the eastern outcrops of the Orobic Anticlines (CA: Cedegolo anticline). Pelitic (marls, marly siltstones) sets alternating with fine-grained sandstones forming thin wave-ripple beds or lenses, of red colour, crop out above. Some dm-thick oolitic calcarenites (storm layers) occur in the lower part. This unit, which shows an overall fining-upwards trend suggesting a lagoonal to muddy tidal-flat setting, can be correlated with the Campil Member of the Dolomites (Neri in Italian IGCP 203 Group 1986, pp. 162-163; Cassinis *et al*., 1990; Twitchett, 1999; Fig. 6.10 of

(continues from previous page)
estratigráfico. *Litología*- **8**: Conglomerados y Brechas; **9**: Areniscas y conglomerados; **10**: Pelitas y areniscas; **11**: Sedimentos del Ciclo 1 del Pérmico Inferior (color gris oscuro); **12**: Sedimentos del Ciclo 2 del Pérmico Superior alternando (sin símbolos) con evaporitas y sedimentos marinos someros (color gris claro); **13**: Nódulos de chert; **14**: Rocas volcánicas indiferenciadas del Ciclo 1 (color negro). Escala de tiempos geológicos obtenida de Menning (1985) y Jin *et al*. (1998). El esquema de este primer autor incluye también abundantes datos radiométricos (en Ma) en rocas intrusivas (puntos gris claro) y volcánicos (negros) de rocas que afloran principalmente entre el Lago Mayor y la zona de Val d´Adige; las líneas verticales respectivas indican la duración que se asume de la actividad ígnea de cada área, mientras que las líneas discontinuas corresponden a manifestaciones estimadas o discontinuas. (Modificado de Cassinis *et al.*, 2002).

this paper: CMb.). The overlying "*Myophoria* beds" *Auct*. (Fig. 9.F and H) consist of grey and bioturbated marly and silty limestones with intercalations, dm-m thick, of bioclastic and oolitic calcarenites. Fossils are represented by *Natiria costata*, *Neoschizodus ovatus*, and so on; *Dinarites* spp. and other Spathian fossils (*Turbo rectecostatus*, Bakevellidae, etc.) also occur in other parts of the Brescian province, such as in the Passo di Croce Domini and Passo Valdì sections (Figs. 1A.9-10 for location and 6.9-10; Fig. 9.G), where the foraminifer *Meandrospira pusilla* was displayed at the transitional beds with the overlying member. The already named Val Fontanelle section ends with pelitic rocks (marls and siltstones) of grey, green and red colour, and subordinate intercalations of thin sandstone and carbonate rocks. Upwards, this uppermost member is delimited by the yellowish Carniola di Bovegno (Fig. 2), ?Upper Scythian to Lower Anisian in age.

In the Brescian Alps and surroundings, between the Trompia and Camonica Valleys (Fig. 1A), the Servino Formation is locally a well-known host rock for iron ore, exploited by mining works for many centuries until the last two decades. Mineralization occurs at different levels, as typical strata-bound deposits and in vein-type discordant bodies, generally characterized by manganesiferous siderite and subordinate barytes and sulphides (Rodeghiero and Zuffardi, 1985, 1988; Cassinis *et al*., 1997a). In particular, the mineralization events appear to be connected with well-defined tectonically active zones, marked by fractures and paleofaults cutting the crystalline basement, the Permian and Lower Triassic rocks, the latter sutured by the ore-bodies present in the Servino Fm. In this context the Val Trompia lineament, which was a southern boundary-fault of the Lower Permian Collio Basin (Fig. 3), can be considered as a significant example. Therefore, the distribution of the Servino iron-bodies seems to have been strictly conditioned by the Permian paleotopography (Cassinis, 1985; De Donatis *et al*., 1991; Cassinis *et al*., 1997a; De Donatis and Falletti, 1999).

3. Permian-Triassic Boundary

Several studies have been carried out on the P-T boundary in the eastern Southern Alps (especially in the Dolomites) both from chronostratigraphical and sedimentological viewpoints. They essentially arose from the Field Conference on the "Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys", held in Brescia in 1986, which led to a historical review by Broglio Loriga and Cassinis (1992) and to a large number of Italian and other investigations, based on the macro- and microfloras, tetrapod footprints and marine fossil fauna from the cited time interval. In contrast, very few data are available on the P-T boundary of Lombardy. Exceptions are due to the research regionally carried out by Cassinis (1968b), Assereto *et al.* (1973), Cassinis *et al.* (1993), Sciunnach *et al*. (1996, 1999a) and De Donatis and Falletti (1999).

Therefore, in this context, an outline of the P-T transitional sections selected by the writers in the Lombardy study areas is required. This aims to elucidate some coeval geological events, as well as to confirm again the presence of a gap and, possibly, to evaluate its chronological range.

Orobic Alps

Along the Orobic Anticlines, between the Verrucano Lombardo red beds and the Servino Formation, Sciunnach *et al.* (1996) pointed out the presence of pinkish quartzose conglomerates to sublitharenites and white subarkoses from northern Valsassina to northwestern Brembana Valley (Valtorta area) and, further to the east, in western Scalve Valley (Manina mine section) (Figs. 1A.1-4, for location, and 6.1-4; Figs. 7.a-j and 10.A-F). This unit was mentioned by previous authors (Merla, 1933; Gaetani *et al*., 1987; Dallagiovanna *et al*., 1987; Schönborn and Laubscher, 1987; Schönborn, 1992; Schönborn and Schumaker, 1994) under different names (such as the Alpe d'Oro quartzites; Figs. 1A.2, for location, and 6.2; Fig. 7.b-e and i.j), but was formally defined by Sciunnach *et al*. (1996), owing to problems of nomenclature and exposure, as the "Prato Solaro Member" from a locality of the Muggiasca Valley where the member is complete and well-exposed along the S.P. 62 roadcut, below the Prato Solaro hamlet (below Parlasco) (Figs. 1A.1 and 6.1). The type-section may be estimated as about 30- 40 m thick. The basal contact with the Verrucano Lombardo is paraconformable and includes locally metamorphic ("milky" polycrystalline quartz, gneisses) and sedimentary pebbles of presumed Late Carboniferous age. Later on, lithological data were also provided from the nearby Mulini Valley section (Sciunnach *et al*., 1999b).

The wind worn pebbles (ventifacts) found in the lowermost beds of the Prato Solaro Mb., on the type-section and elsewhere in Orobic Alps, evoke those recorded in the Early Triassic from many other places of Germany, England, France, Spain, Sardinia and Bulgaria. These latter can be related to an episode of maximum aridity developed probably in late Dienerian-early Smithian times (Durand, 2006; Bourquin *et al.*, this volume).

Nevertheless, according to Sciunnach *et al.* (1996), most of the texturally submature to mature sediments of the Prato Solaro Member were deposited in a fan-delta setting, where marine transgression would be proved by

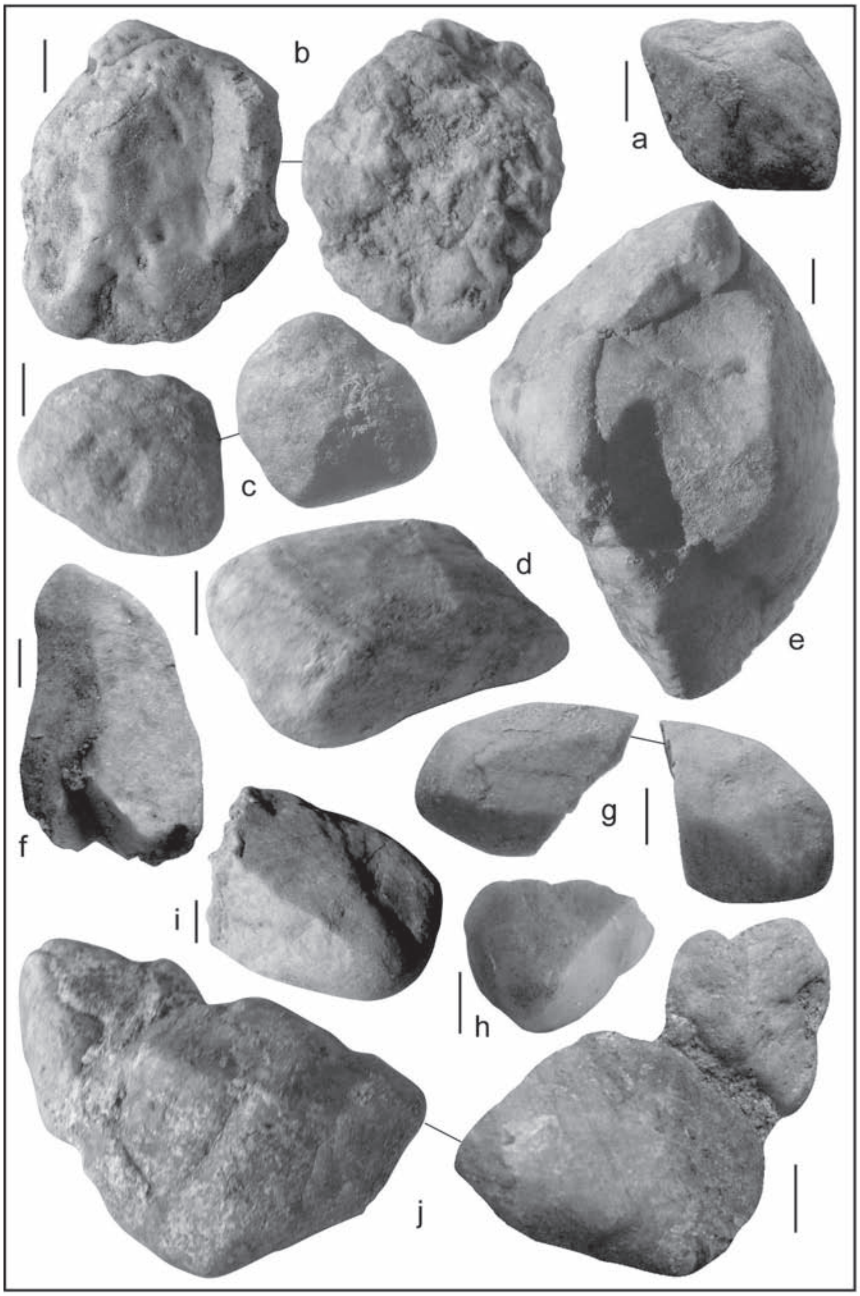

Fig. 7.- Photographs of several types of ventifacts found in the Prato Solaro Member: Piani dell'Avaro (a), Alpe d'Oro (b,c,d,e,i,j), Val Muggiasca (f,g,h). Scale bar: 1 cm. a) Upper side. b) Left: upper side, right: mower side. c) Bifacial type. d) Upper side. e) Upper side. f) Broken, bifacial type. g) Broken, left: lower side, right: upper side. h) Broken, upper side. i) Broken, upper side. j) Left: upper side, right: lower side.

Fig. 7.- Imágenes de diferentes tipos de ventifactos encontrados en el Miembro Prato Solaro: Piani dell´Avaro (a), Alpe d´Oro (b-j), Val Muggiasca (f-h). Barra de escala- 1cm. a) Lado superior. b) Izquierda: lado superior, derecha: lado inferior. c) tipo Bifacial. d) lado superior, e) lado superior, f) tipo bifacial fracturado; g) fracturado, izquierda: lado inferior, derecha: lado superior; h) fracturado, lado superior. i) fracturado, lado superior. j) izquierda: lado superior, derecha: lado inferior.

wave rippled mature subarkoses and the presence (Merla, 1933) of the bivalves *Neoschizodus laevigatus* (Goldfuss) and *Unionites canalensis* (Catullo) which, according again to Sciunnach *et al.* (1996: p.32), generally indicate an early to mid-Griesbachian age. Actually these two cosmopolitan taxa range on the entire Early Triassic, and the first one even until the Ladinian in the Germanic Basin.

As regards the *Claraia* beds found less than 5 km SE from the Prato Solaro Member type-section, in the lower part of the overlying Ca' San Marco Member, but only about 8 m above the basement, there is some discrepancy between their latest Griesbachian - early Dienerian age proposed by Posenato *et al.* (1996) and the age proposed above for the ventifact beds. This problem deserves further studies, but it should however be noticed that, as pointed out by Posenato *et al.,* these *Claraia* beds of the Valsassina "do not yield any of the index-species of the Dolomites" – all specimens were referred to *C. intermedia* (Bittner) – and thus had to be dated on the basis of correlations with Iranian sequences. *Claraia* can display a very high genetic plasticity (Broglio Loriga *et al.*, 1983) and is also clearly facies dependent, proliferating in stressing, mainly dysaerobic, settings (Wignall and Hallam, 1992), which reduces its chronostratigraphic value. So, it must be emphasized that Yin (1985) distinguishes only two *Claraia* zones useful at the world scale within the Early Triassic, among which the second (*Claraia aurita - C. stachei - Eumorphotis multiformis* Zone), that

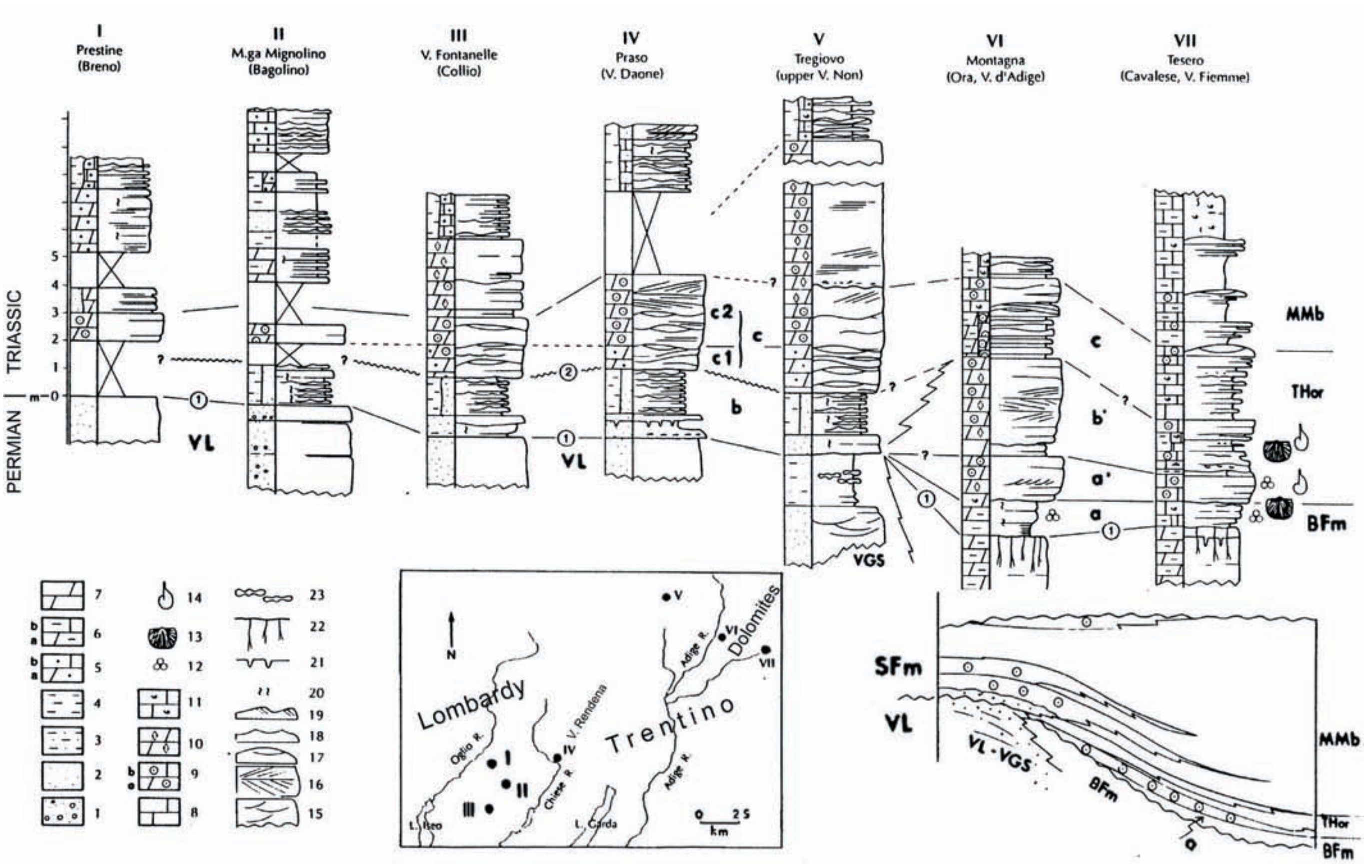

Fig. 8.- Correlation chart of some stratigraphic sections including the P-T boundary from eastern Lombardy to western Trentino-Alto Adige (from Cassinis *et al*., 1993). *Legend*: **1**, coarse sandstone and microconglomerates; **2**, sandstone; **3**, pelite; **4**, marl; **5**, arenaceous dolomite (a) and limestone (b); **6**, marly dolomite (a) and limestone (b); **7**, dolomite; **8**, micritic limestone; **9**, oolitic dolomite (a) and limestone (b); **10**, dolomitized calcarenite; **11**, bioclastic limestone; **12**, Permian foraminifers; **13**, Permian brachiopods; **14**, *Bellerophon vaceki*; **15**, trough cross-bedding; **16**, herringbone; **17**, hummocky; **18**, wave ripple; **19**, current ripple; **20**, bioturbation; **21**, mud cracks; **22**, root traces; **23**, caliche. *Additional symbols*: **VL**, Verrucano Lombardo; **VGS**, Val Gardena Sandstone; **BFm**, Bellerophon Formation; **SFm**, Servino Formation; **THor**, Tesero Horizon; **MMb**, Mazzin Member. Other letters and numbers refer to sedimentary units described in the text.

Fig. 8.- Correlación entre algunas de las secciones estratigráficas que incluyen el límite P-T desde el este de Lombardía hasta el oeste del Trentino-Alto Adidge (obtenido de Cassinis *et al*., 1993). *Leyenda*- **1**: arenisca de grano grueso y microconglomerados; **2**: areniscas; **3**: pelitas; **4**: margas; **5**: dolomía arenosa (a) y caliza (b); **6**: dolomía margosa (a) y caliza (b); **7**: dolomía; **8**: caliza micrítica; **9**: dolomía oolítica (a) y caliza (b); **10**: calcarenita dolomítica; **11**: caliza bioclástica; **12**: foraminíferos pérmicos; **13**: braquiópodos Pérmicos; **14**: *Bellerophon vaceki*; **15**: estratificación cruzada de surco; **16**: herringbone; **17**: hummocky; **18**: ripples de oscilación; **19**: ripples de corriente, **20**: bioturbación; **21**: mud cracks; **22**: raíces; **23**: caliche. Símbolos adicionales- **VL**: Verrucano Lombardo; **VGS**: Arenisca de Val Gárdena; BFm: Formación Bellerophon; SFm: Formación Servino; T Hor: Horizonte Tesero; MMb: Miembro Mazzin. El resto de las letras y los números que se refieren a las unidades sedimentarias están descritas en el texto.

include *C. intermedia*, ranges from the late Griesbachian up to the Smithian.

Towards the east, however, in contrast with the aforementioned geometry, the top of the Verrucano Lombardo at Ca' San Marco is unconformably onlapped at a low angle by the middle Servino (Garzanti, 1990). A slightly angular contact between the Upper Permian Verrucano Lombardo and the overlying Prato Solaro Member of the Servino Formation has been also supposed locally by the authors of this paper in the Piani dell'Avaro area (above Cusio, in the upper Brembana Valley) (Fig. 1A.3, for location, Figs. 6.3, 7.a, 10A and 10B).

Further to the east, the Manina mine section (Figs. 1A.4 and 6.4) - confined to the Cedegolo Anticline, in western Scalve Valley - is characterized again by the Prato Solaro Member (Sciunnach *et al*., 1999a).

Brescian Prealps

East of the Orobic Alps, around the southern border of the Adamello magmatic intrusion of Palaeogene age (42-30 Ma, according to Del Moro *et al*., 1986), Upper Permian to Lower Triassic rocks occur extensively from the Camonica to the Giudicarie Valleys (Fig. 1A for location). However, in recent years, only the latter outcrops have been the topic of comprehensive stratigraphical

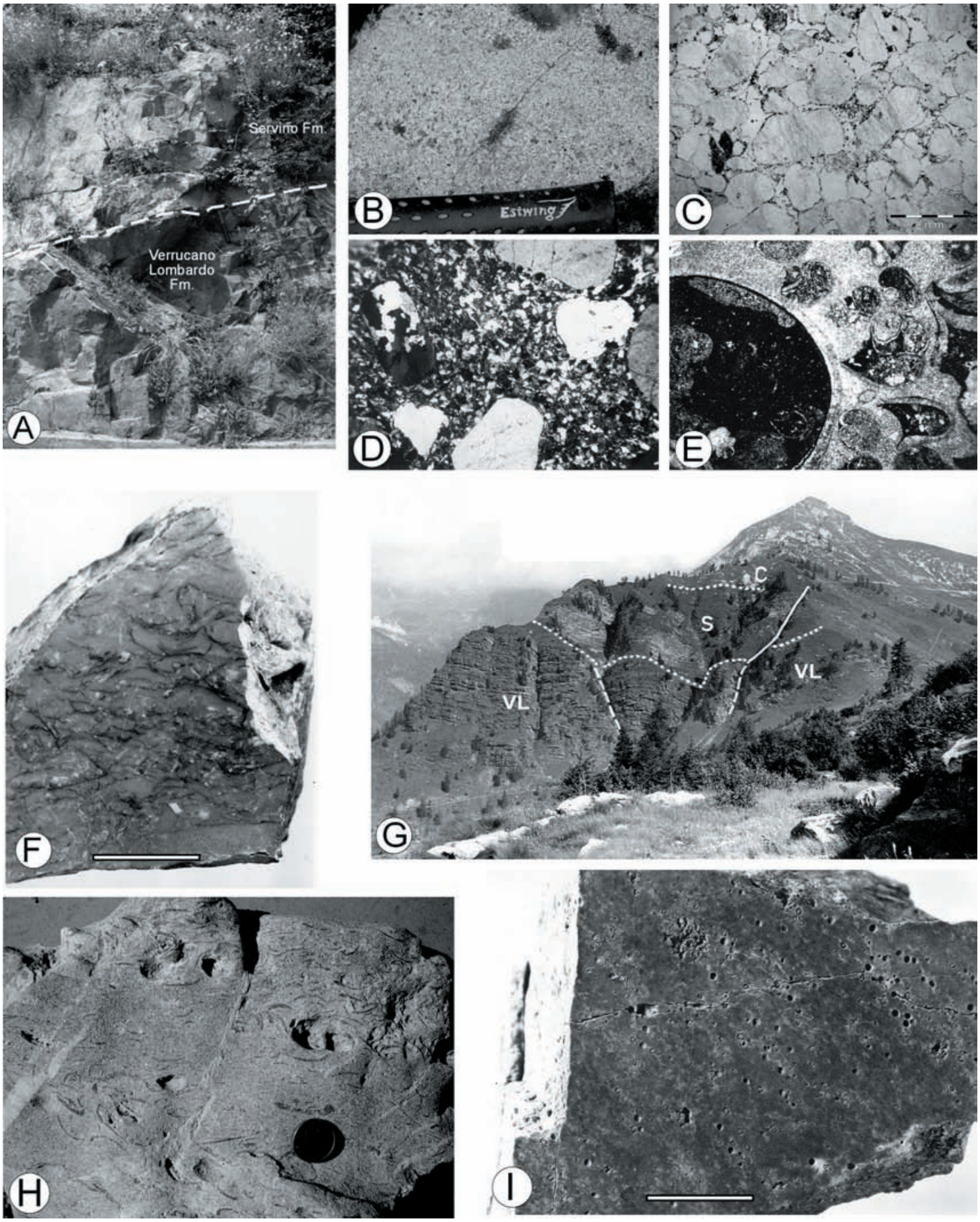

Fig. 9.- Selected pictures from the lower Val Camonica to upper Val Caffaro, in proximity of the Lombardy-Trentino border. See Figs.1A and 6 for reference. **A**. The P-T boundary at Anfurro; **B**. Coarse pinkish quartzarenite at the Anfurro section; **C**. As B lithology, in photomicrographs with plane-polarized light; **D**. Medium-to-coarse grained litharenite with abundant matrix from the base of the Pass Valdì section. Cross-polarized light 37x; **E**. Photomicrograph of the so-called "Gastropod Oolite"*Auct*. from Valdì Pass. Cross-polarized light, 37x; **F**. Polished section of a sample from the "*Myophoria* beds" *Auct.* cropping out in the Servino of Valdì section. Scale bar 5 cm; **G**. Panoramic view of Mt. Valdì: VL: Verrucano Lombardo Fm., S: Servino Fm., C: Carniola di Bovegno Fm. The local succession is cut by subordinate faults (continuous white lines); **H**. *Myophoria* bearing sample from the Pass Valdì section. Coin for scale.; **I**. Praso oolitic dolostone. Scale bar 5 cm.

Fig. 9.- Figuras seleccionadas de la parte inferior de Val Camonica a la superior de Val Caffaro, en la proximidad de la frontera Lombardo-Trentino. Ver las figuras 1 y 6 para referencias. **A**: Límite P-T en Anfurro; **B**: Cuarzoarenita rosacea de grano grueso de la sección de Anfurro. **C**: Igual litología que B, utilizando fotomicrografías con luz polarizada. **D**: Litoarenita de grano medio-grueso con abundante matriz, en la base de la sección de Pass Valdì. Luz polarizada 37X. **E**: Fotomicografía del también llamado "Oolito de Gasterópodos" *Auct.* De Valdì Pass. Luz polarizada 37X; **F**: sección pulida de una muestra de las "Capas de *Myophoria*" *Auct.* Aflorando en la sección de Servino de Valdì. Escala 5 cm. **G**: Vista panorámica del monte Valdì: VL- Formación Verrucano Lombardo; S: Formación Servino; C: Formación Carniola di Bovegno. La sucesión local está cortada por fallas subordinadas (líneas blancas continuas); **H**: *Myophoria* de una muestra de la sección de Valdì. Moneda de escala; **I**: Dolomía oolítica de Praso. Escala 5 cm.

and sedimentological research (De Donatis and Falletti, 1999), which was locally integrated with previous data (Cassinis, 1968b; Cassinis *et al*., 1990, 1993). In general, the former authors confirmed for the Servino of the investigated area the presence of six lithostratigraphic units, similar to those already described above, in Val Fontanelle. Only the basal part of the formation shows somewhat different features, which can be summarized in the area between Anfurro and Monte Guglielmo (i.e. in the southwestern corner of the Camonica Valley) as represented, according to De Donatis and Falletti (1999), by quartzarenites, bioclastic and oolitic arenites, sandstones and siltstones with wave-ripples, forming cm- to dm-thick beds locally alternating with burrowed pelites (Figs. 1A.5, 1A.7, for location, and 6.5, 6.7; Fig. 9.A-C). The Servino Formation is clearly visible also in the Rondeneto Valley, near M. Muffetto (Figs. 1A.6 and 6.6; Fig. 10.G and H), where the basal part, which rests paraconformably on the Verrucano Lombardo continental red beds locally through a surface bearing dolomitic nodules of probably pedogenetic origin, may be interpreted as deposited in fluvial and coastal environments, bordered by mud-dominated areas. This unit marks the inception of the Early Triassic transgression and excludes indirectly the continuity of the Prato Solaro Member to the south of the Orobic Anticlines. The age of this geological event is not clearly documented by paleontological evidence. However, the correlation by De Donatis and Falletti (1999) of these first local deposits with those observed at the base of the Val Fontanelle section could support the same age for both the respective units, which, from the already above-cited presence in the latter of latest Griesbachian-early Dienerian pelecypods, should be probably ascribed to a slightly earlier Triassic interval.

As regards the interpretation of the P-T boundary in the Brescian Alps, however, another problem arises from the chronostratigrafic classification of the Praso oolitic horizon at the base of the Servino Formation, which is very reduced but widespread in the investigated area (Cassinis *et al*., 1993) and, as already recorded in this paper, also in the nearby Trento region, where it can be followed up to the Upper Rendena Valley, east of Massimeno (Malghe Movlina). As recognized in the well-exposed Pass Valdì section by Cassinis (1968b), the very base of the Servino consists of a thin horizon made up of grey sandstone covered by a m-thick oolitic unit which can be correlated to the Tesero Member of the Werfen Formation of the Dolomites (Cassinis *et al*., 1993) (Figs. 1A.8-11 for location; 6.8-10; 8.I-IV; Fig. 9.I). In more detail, according to Neri, red to grey medium- to coarse-grained sandstones, which represent the top of the Verrucano Lombardo, are overlain by a unit ("b"), 1-2 m thick, consisting of pelites alternating with fine sandstones; wave- and current ripples are the dominant structures (Fig. 8 in this paper), and depending on the amount of pelite, the stratification pattern may be represented by wavy or flaser bedding.

In the Praso section (Val Daone, Trento: Figs. 1A.11, location, and 8.IV), the base of this unit is marked by a "lag" of breccia including pelite clasts. Bioturbation, mainly represented by vertical burrows, may occur, while no significant fossil have been found until now.

The depositional setting of unit "b" may be referred to a marginal marine setting, probably to coastal lagoons bordered by muddy tidal flats; moreover, unit "b" may be regarded as the record of the first stages of the early Scythian transgression, responsible for the superposition of "paralic" deposits on the continental, fluviatile Verrucano Lombardo.

According again to Neri (*in* Cassinis *et al*., 1993; Fig. 8 of this paper), unit "b" is overlain by sandstones with carbonate cement and sandy dolostones ("c1"), forming a body ranging in thickness from a few decimetres to about 1-1.5 m, with amalgamated hummocky cross-lamination, suggesting a shallow shelf (shoreface) depositional setting. The body "c1" grades upwards into a dolomitized oolitic unit ("c2"), exhibiting both hummocky structures and bidirectional cross-bedding (indicative of tidal control) (Fig. 8). The "c2" oolite may be correlated to the Tesero Member on a simple lithostratigraphic basis. Surface 2 in Fig. 8, separating the "paralic" unit "b" from the fully marine (shoreface) base of unit "c", is obviously characterized by a jump in facies and may be regarded as a shoreface ravinement surface generated during the westward shifting of the transgression. It is at least a moderately heterochronous surface, younger to the west and older to the east.

Following upwards are fine-grained clastic sediments, mixed or alternating with carbonate rocks, dolomitized, and yielding pelecypods and subordinate gastropods.

Due to the lack of paleontological data, the age of the above units is yet unknown. However, on the basis of their stratigraphic position and wider correlation, attribution to an Induan-early Olenekian time interval could be generally justified.

Concluding Remarks. From the aforementioned review, the Permian-Triassic boundary in central and eastern Lombardy is extensively marked by a hiatus, which is of as-yet-uncertain duration (Fig. 2). In fact, the first Lower Triassic transgressive marine deposits of the Servino Formation rest undoubtedly paraconformably, or locally (Ca' San Marco, Piani dell'Avaro? and in other places) also unconformably, on the underlying Upper Permian continental fluvial red beds of Verrucano Lombardo, but the major problem is to date the temporal distribution of this gap.

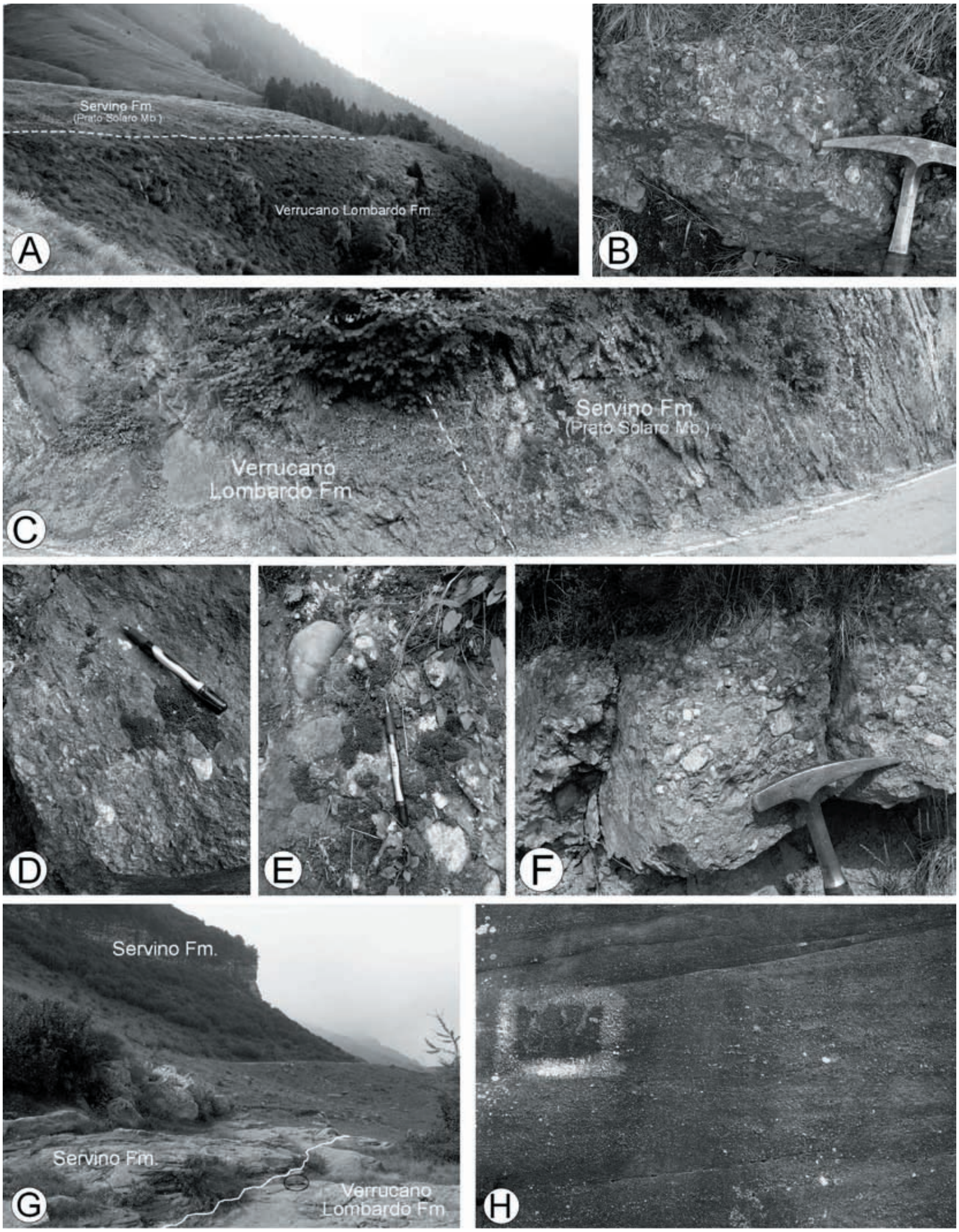

Fig. 10.- Selected pictures from the Muggiasca (Valsassina) to Camonica Valleys. See Figs. 1A and 6 for reference. **A.** Piani dell'Avaro (Val Brembana): locally, a slight angular unconformity seems to separate the Upper Permian Verrucano Lombardo Fm. and the Lower Triassic Servino Fm.; **B.** Close-up of pebble quartz conglomerates at Piani dell'Avaro; **C.** The Prato Solaro type-section; **D.** Close-up of Verrucano Lombardo conglomerates at the P-T boundary in the Prato Solaro type-section; **E**. Detail of coarse-grained quartz conglomerates of Prato Solaro Mb. at the type-section; **F**. Quartz-conglomerates of the Servino Fm. at the Alpe d'Oro locality (Pian delle Betulle); **G**. Verrucano Lombardo Fm. and Servino Fm. in Val Rondeneto, near M. Muffetto (lower Camonica Valley); **H**. Detail of Servino cross-bedded quartz-sandstones at Val Rondeneto.

Fig. 10.- Fotos seleccionadas de los valles de Muggiasca (Valsassina) a Camonica. Ver las figuras 1 y 6 para referencias. **A**. Piani dell´Avaro (Val Brembana): una ligera discordancia angular separa el Pérmico Superior de la Formación Verrucano Lombardo del Triásico Inferior de la Formación Servino. **B**: Detalle de los clastos de cuarzo de los conglomerados en Piani dell´Avaro; **C**: Sección tipo de Prato Solaro; **D**: Detalle de los conglomerados del Verrucano Lombardo en el límite P-T en la sección tipo de Prato Solaro. **E**: Detalle de los conglomerados de clastos de cuarzo de tamaño grueso del Miembro Prato Solaro en la sección tipo. **F**: Conglomerados de cuarzo de la Formación Servino en la localidad Alpe d´Oro (Pian delle Betulle). **G**: Formación Verrucano Lombardo y Formación Servino en Val Rondeneto, cerca de M. Muffetto (parte inferior del Valle Camonica). **H**: Detalle de la estratificación cruzada de las cuarzoarenitas en Val Rondeneto.

Our overview, based essentially on the lithostratigraphic record of central and eastern Lombardy (Fig. 6) in a general scenario inclusive of the western sector (Sciunnach *et al*., 1996), displays a large number of discontinuities and sharp changes possibly connected with an inherited paleotopography and more or less coeval tectonic activity, generating lateral and vertical striking contrasts for a well-defined Permian-Triassic boundary. In fact, as already stated, the Upper Permian Verrucano Lombardo, the Lower Permian volcanic and sedimentary units, and the Variscan crystalline basement along with its Permo? - Carboniferous siliciclastic cover, were affected in some places (such as to the west of the Orobic Alps) and in different ways by erosion, which prevents us from knowing the real duration of the debated PTB gap before the overlying unconformable Triassic deposits.

In contrast, the main marine transgression, even if based on some fossils (*Claraia*) occurring towards the east of the Adige Valley (Trento-Bolzano), in the Siusi Member of the Werfen Formation, probably developed between Induan and early Olenekian times. However, in the Brescia and Trento regions, the "Calcare di Praso" (along with the underlying thin clastic unit) seals a hiatus probably shorter than that regarded in the western Orobic Anticline. In conclusion, the PTB gap of central and eastern Lombardy should be interpreted as discontinuous in time and space, generally spanning the latest Permian (top of Lopingian) and not yet a defined part of the Early Triassic.

4. Permian and Early Triassic geodynamic evolution: an overview

As recorded above, significant events mark the geodynamic evolution of the Lombardy Southern Alps from late- to post-Variscan to early Mesozoic times. During the Early Permian, at the end of the Variscan orogenesis, a transtensional geodynamic regime developed along the southern Paleoeuropean border, due to a dextral transform margin between Laurasia and Gondwana (Arthaud and Matte, 1977). The coeval depositional record, represented by calc-alkaline, low- to high-K, intermediate-to-acidic volcanics and alluvial-to-lacustrine deposits, infilling fault-bounded, subsiding, strike-slip or pull-apart basins, was accompanied by widespread granitoids and subordinate gabbros from asthenospheric upwelling and crustal contributions. In more detail, the Collio Basin of the Brescian Alps (Figs. 1B, for location, 2 and 3) can be appropriately interpreted as a pull-apart basin because it has a typical sigmoid shape, which is clearly evident both in the eastern sector, where the basin changes direction, and in the western sector, especially if the latter is considered together with the Boario Basin (BB in Fig. 1B). Thus the Collio Basin seems to originate from the stress field, which interacts between two main Permian right strike-slip faults, *i.e.* the Giudicarie line to the east and another hypothetical parallel fault, the Val Camonica line, to the west (Fig. 3).

During Late Permian to Anisian times, an extensional regime, linked to plate reorganization and likewise to the opening of the Meliata back-arc basin to the east (Ziegler and Stampfli, 2001), gave rise to a second sedimentary cycle, following a stratigraphic gap marked by extensive erosion surfaces and palaeosol profiles, but of as-yet-unknown duration, tentatively estimated at about 15-25 Ma, probably extending into Middle Permian (Guadalupian) times. This "Mid-Permian Episode" (Deroin and Bonin, 2003) was characterized by specific tectonic, magmatic, thermal and basinal features. An angular unconformity can be observed in places. In the Southern Alps, this general structural reorganization was accompanied by a change in the depocentral areas; we may consider this reorganization as a consequence of a larger wavelength extensional regime. However, such a geological event was also assumed by some authors, also in other countries, as due to compressional movements or tilting (Cassinis, 1964; Prost and Becq-Giraudon, 1989; Cadel *et al*., 1996; Cassinis and Perotti, 1997; Sciunnach, 2001b; and so on).

The aforementioned upper cycle consisted of the Middle *p.p.*? - Upper Permian continental, fluvial red beds of Verrucano Lombardo, lacking in volcanic activity, and the Lower Triassic shallow-marine, varicoloured deposits of the Servino Formation. In this context, the former unit gave rise to a widespread blanket over the Lower Permian cyclic deposits and the surrounding metamorphic and igneous structural highs; moreover, if compared with the products of the lower cycle, it generally appears more widely distributed although less thick. The siliciclastic and carbonate sedimentation of the latter unit, linked to a rapid transgression from east, followed a progressive peneplanation of the former irregular topography.

According to Ori (1988) and other authors, during the Verrucano Lombardo deposition the climate was dominated by semi-arid to arid conditions, which persisted throughout the Early Triassic up to the Carniola di Bovegno Formation, which is generally ascribed to latest Spathian-early Anisian times. In this context, the maximum of aridity is recorded by wind-worn quartz pebbles (ventifacts) present in the basal beds of the Servino Formation of the Orobic Alps. On the scale of the West European Plate, such climate indicators, referred to mid-Scythian times, appear as powerful tools for correlations within non-marine formations, devoid of any biostratigraphical marker, that straddle the Permian-Triassic boundary (Durand, 2006). Therefore, in contrast with previous authors, our current research leads us to suggest that the P-T boundary of central and eastern Lombardy is marked by a gap generally running from the top of the Permian (Lopingian *p.p.*) to part of the Scythian (up to early Olenekian locally).

In conclusion, this work displays in the Lombardy stratigraphic record of the Permian to Lower Triassic a significant link between the eastern Trentino-Alto Adige and the western Lugano-Varese regions. In fact, the restored scenario of the South-Alpine segment examined shows a fairly good similarity, as it is generally made up, in the lower part, of continental volcanic and alluvial to lacustrine deposits unconformably capped by the Verrucano Lombardo-Val Gardena Sandstone fluvial red beds, and is marked on the top, again through an unconformity, by the marine sediments of the Lower Triassic Servino and Werfen formations. This rather similar evolution is probably, at least in large part, consistent with the structural setting of the investigated area, widely confined to active tectonic lineaments matching with the present Lake Como and the Giudicarie belt, respectively. This Permian-Triassic regional structure, which separated an uplifted sector (M.Grona-Lugano) to the west from a more subsiding basin (Val d'Adige-Dolomites) to the east, could also explain some geological features of Permian history, such as the presence of different facial deposits and of new gaps (*e.g.* between P1 and P2 petrofacies of Verrucano Lombardo as indicated by Sciunnach *et al.*, 1996, in the Orobic Alps), as well as the presumed slightly younger age of the Lower Triassic Servino Formation, due to the westwards progressive and relatively rapid transgression over a more stable region. Therefore, in this context, we can remark on the particular geodynamic significance of central and eastern Lombardy during the late- and post-Variscan evolution of the Southern Alps.

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References

Arthaud, F., Matte, P. (1977): Late Paleozoic strike-slip faulting in southern Europe and northern Africa: Result of a right-lateral shear zone between the Appalachians and the Urals. *Geological Society of America Bullettin*, 88: 1305-1320.

Assereto, R., Bosellini, A., Fantini Sestini N., Sweet, W.C. (1973): The Permian-Triassic boundary in the Southern Alps (Italy). In: The Permian and Triassic Systems and their mutual boundaries. *Memoir of Canadian Society of Petroleum Geol*ogy, 2: 176-199.

Bosellini, A. (1964): Stratigrafia, petrografia e sedimentologia delle facies carbonatiche al limite Permiano-Trias nelle Dolomiti occidentali. *Memorie del Museo di Storia Naturale Venezia Tridentina*, a. 27 – 28, 15: 106 p.

Bourquin, S., Durand, M., Diez, J.B., Broutin, J. (2007): The Permian-Triassic boundary and Early Triassic sedimentation in Western European basins: an overview. *Journal of Iberian Geology*, 33, 143-162.

Breitkreuz, C., Cassinis, G., Checchia, C., Cortesogno, L., Gaggero, L. (2001): Volcanism and associated sub-lacustrine crystal-rich mass-flow deposits in the Early Permian Collio Basin (Italian Alps). In: G. Cassinis (ed.): Permian continental deposits of Europe and other areas. Regional reports and correlations. *Natura Bresciana, Annali Museo Civico di Scienze Naturali Brescia*, *Monografia* No. 25: 73-81.

Broglio Loriga, C., Cassinis, G. (1992): The Permo-Triassic boundary in the Southern Alps (Italy) and in adjacent Periadriatic regions. In: W.C. Sweet, Z.Y. Yang, J.M Dickins, H.F. Yin (eds): *Permo-Triassic events in the Eastern Tethys*, Cambridge Univ. Press: 78-97.

Broglio Loriga, C., Masetti D., Neri, C. (1983): La Formazione di Werfen (Scitico) delle Dolomiti occidentali: sedimentologia e biostratigrafia. *Rivista Italiana di Paleontologia e Stratigrafia*, 88: 501-598.

Broglio Loriga, C., Gòczàn, F., Haas, J., Lenner, K., Neri, C., Oravecz Scheffer, A., Posenato, R., Szabò, I., Toth Makk, A. (1990): The Lower Triassic Sequences of the Dolomites (Italy) and Transdanubian Mid-mountains (Hungary) and their correlation. *Memorie di Scienze Geologiche*, Padova, 42: 41-103.

Cadel, G. (1986): Geology and uranium mineralization of the Collio basin (Central-Southern Alps, Italy). *Uranium*, 2: 215-240.

Cadel, G., Cosi, M., Pennacchioni, G., Spalla, M.I. (1996): A new map of the Permo-Carboniferous cover and Variscan metamorphic basement in the central Orobic Aps, Southern Alps – Italy: structural and stratigraphical data. *Memorie di Scienze Geologiche*, Padova, 48: 1-53.

Cassinis, G. (1964): Una faglia saaliana nelle Prealpi bresciane e la sua importanza nei riguardi della stratigrafia permiana. *Bollettino della Società Geologica Italiana*, 83: 273-283.

Cassinis, G. (1968a): Sezione stratigrafica delle "arenarie rosse" permiane presso il Passo di Croce Domini (Brescia). *Atti dell'Istituto di Geologia dell'Università di Pavia*, 19: 3-14.

Cassinis, G. (1968b): Studio stratigrafico del "Servino" di Passo Valdì (Trias inferiore dell'Alta Val Caffaro). *Atti dell'Istituto di Geologia dell'Università Pavia*, 19: 15-39.

Cassinis, G. (1985): Il Permiano nel Gruppo dell'Adamello, alla luce delle ricerche sui coevi terreni delle aree contermini. In: Atti del Convegno sul tema: "Il magmatismo tardo alpino nelle Alpi", Padova (13-14 Luglio 1983). *Memorie della Società Geologica Italiana*, 26 (1983, Parte prima): 119-132.

Cassinis, G., Doubinger, J. (1992): Artinskian and Ufimian palynomorph assemblages from the central Southern Alps, Italy, and their stratigraphic regional implications. In: A.E.M. Nairn, V. Koroteev (eds): *Contribution to Eurasian Geology, Intern. Congr. on the Permian System of the World*, Perm, Russia, 1991 - Occasional Publications ESRI, New Series N° 8B, Columbia Univ. of South Carolina, Part I: 9-18.

Cassinis, G., Perotti, C.R. (1997): Tectonics and sedimentation in the western sector of the Permian continental Collio Basin, Southern Alps, Italy. In: Prace Panstwowego Instytutu Geologicznego CLVII, *Proceed. of the XIII Intern. Congr. on the Carboniferous and Permian*, 28th August-2nd September 1995, Kraków, Poland, Part 2: 25-32.

Cassinis, G., Mattavelli, L., Morelli, G.L. (1978): Studio petrografico e mineralogico della Formazione di Collio nel Permiano inferiore dell'alta Val Trompia (Prealpi bresciane). *Memorie di Scienze Geologiche*, Padova, 32: 4-13.

Cassinis, G., Massari, F., Neri, C., Venturini, C. (1988): The continental Permian in the Southern Alps (Italy). A review. *Zeitschrift für Geologische Wissenschaften*, 16: 1117-1126.

Cassinis, G., with the contribution of Frizzo, P., Lualdi, A., Neri, C., Perotti, C.R., Santi, G., Schirolli, P., Stefani, M. (1990): Itinerario n° 3 – Val Trompia. In: M.B. Bianca, R. Gelati, A. Gregnanin (coords): Alpi e Prealpi Lombarde, *Guide Geologiche Regionali*, n.1, BE-MA Editrice, Milano: 291 p.

Cassinis, G., Neri, C., Perotti, C.R. (1993): The Permian and Permian-Triassic Boundary in eastern Lombardy and Western Trentino (Southern Alps, Italy). In: S.G. Lucas, M. Morales (eds): The Nonmarine Triassic. *New Mexico Museum of Natural History and Science Bullettin,* 3: 51-63.

Cassinis, G., Frizzo, P., Moroni, M., Rodeghiero, F. (1997a): Le mineralizzazioni delle Alpi bresciane: aspetti geologico-minerari e metallogenici. Atti della Giornata di Studio:"Le vene delle montagne", Brescia, 24 novembre 1995. *Fondazione Bresciana per la Ricerca Scientifica*: 97-119.

Cassinis, G., Perotti, C.R., Venturini, C. (1997b): Examples of late Hercynian transtensional tectonics in the Southern Alps (Italy). In: J.M Dickins., Z.Y. Yang, H.F. Yin, S.G. Lucas, S.K. Acharyya (eds): *Late Palaeozoic and Early Mesozoic Circum-Pacific Events and Their Global Correlation*, Cambridge Univ. Press: 41-50.

Cassinis, G., Nicosia, U., Lozovsky, V.R., Gubin Y.M. (2002): A view on the Permian continental stratigraphy of the Southern Alps, Italy, and general correlation with the Permian of Russia. *Permophiles*, 40: 4-16.

Ceoloni, P., Conti, M.A., Mariotti, N. Mietto, P., Nicosia, U. (1987): Tetrapod footprints from Collio Formation (Lombardy, Northern Italy). *Memorie di Scienze Geologiche*, Padova, 39: 213-233.

Conti, M.A., Mariotti, N., Mietto, P., Nicosia, U. (1991): Nuove ricerche sugli icnofossili della Formazione di Collio in Val Trompia (Brescia). *Natura Bresciana, Annali Museo Civico di Scienze Naturali Brescia*, 26: 109-119.

Dal Cin, R. (1972): I conglomerati tardo-paleozoici post-ercinici delle Dolomiti. In: G. Woltetz, G. Rielhl-Herwirsch (eds): Verrucano-Symposium, Wien 1969. *Verhandlungen der Geologischen Bundesanstalt*, Wien: 47-74.

Dallagiovanna, G., Perotti, C.R., Seno, S. (1987): Strutture transpressive in corrispondenza della terminazione occidentale della Linea Orobica (alta Val Muggiasca-Como). In: M. Gaetani, A. Piccio (eds): Atti del Convegno sul tema: "Geologia Lariana" (Varenna, 1-5 Aprile 1986). *Memorie della Società Geologica Italiana*, 32 (1986): 101-112.

De Capitani, L., Delitala, M.C., Liborio, G., Mottana, A., Nicoletti, M., Petrucciani, C. (1988): K-Ar dating of the Val Biandino plutonic complex (Orobic Alps, Italy). *Memorie di Scienze Geologiche*, Padova, 40: 285-294.

De Capitani, L., Delitala, M.C., Liborio, G., Mottana, A., Rodeghiero, F., Thöni, M. (1994): The granitoid rocks of Val Navazze, Val Torgola and Val di Rango (Val Trompia, Lombardy, Italy). *Memorie di Scienze Geologiche*, Padova, 46: 329-343.

De Donatis, S., Falletti, P. (1999): The Early Triassic Servino Formation of the Monte Guglielmo area and relationships with the Servino of Trompia and Camonica Valleys (Brescian Prealps, Lombardy). *Memorie di Scienze Geologiche*, Padova, 51: 91-101.

De Donatis, S., Riganti, A., Rodeghiero, F. (1991): Mineralizzazioni a siderite-barite nella Val Camonica meridionale (Brescia, Lombardia). *Natura Bresciana, Annali Museo Civico di Scienze Naturali Brescia*, 26: 87-100.

Del Moro, A, Pardini, G., Quercioli, C., Vialla, I., Callegari, E. (1986): Rb/Sr and K/Ar chronology of Adamello granitoids, Southern Alps. In: Atti del Convegno sul tema: "Il magmatismo tardo alpino nelle Alpi", Padova (13-14 Luglio 1983). *Memorie della Società Geologica Italiana*, 26 (1983, Parte prima): 285-299.

Deroin, J.P., Bonin, B. (2003): Late Variscan tectonomagmatic activity in Western Europe and surrounding areas: the Mid-Permian Episode. In: F.A. Decandia, G. Cassinis, A. Spina (Guest eds): Special Proceed. of the Scient. Meet. "Late Palaeozoic to Early Mesozoic events of Mediterranean Europe, and additional regional reports", Siena (Italy) 30 Aprile-7 Maggio 2001. *Bollettino della Società Geologica Italiana*, Volume spec. no. 2: 169-184.

Dickinson, W.R., Beard, L.S., Brakenridge, G.R., Evjavec, J.L., Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindberg, F.A., Ryberg, P.T. (1983): Provenance of North American Phanerozoic sandstones in relation to tectonic setting. *Geological Society of America Bullettin*, 94: 222-235.

Durand, M. (1972): Répartition des galets éolisés dans le Buntsandstein moyen lorrain. *Comptes Rendus des Séances de la Société géologique de France*, 5: 214-215.

Durand, M. (2006): The problem of transition from the Permian to the Triassic series in southeastern France: comparison with other Peritethyan regions. In: S.G. Lucas, G. Cassinis and J.W. Schneider (eds.): *Non-marine Permian Biostratigraphy and Biochronology*. Geological Society, London, Special Publications, 265: 281-296.

Folk, R.L. (1968): Petrography of sedimentary rocks. Hemphill's (drower M. Uivers. Station), Austin: 170 p.

Fontana, D., Zuffa, G.G. (1983): Composizione e provenienza delle Arenarie di Val Gardena e del Verrucano Lombardo (Permiano, Alpi). *Memorie della Società Geologica Italiana*, 24 (1982): 43-49.

Gaetani, M., Gianotti, R., Jadoul, F., Ciarapica, G., Cirilli, S., Lualdi, A., Passeri, L., Pellegrini, M., Tannoia, G. (1987): Carbonifero Superiore, Permiano e Triassico nell'area lariana. In: M. Gaetani, A. Piccio (eds): Atti del Convegno sul tema: "Geologia Lariana" (Varenna, 1-5 Aprile 1986). *Memorie della Società Geologica Italiana*, 32 (1986): 5-48.

Garzanti, E. (1990): Le unità terrigene permo-triassiche dell'alta Val Brembana. Excursion guidebook of the congress "*La geologia Italiana degli anni '90*", Milano.

Garzanti, E., Sciunnach, D., Confalonieri, M.P. (2003): Discriminating source rock and environmental control from detrital modes of Permo-Triassic fluvio-deltaic sandstones: I. Southern Alps (Lombardy, Italy). *Memorie Descrittive della Carta Geol. d'Italia*, Istituto Poligrafico e Zecca dello Stato, Roma, 61: 63-82.

Geinitz, H.B. (1869): Über fossile Pflanzenreste aus der Dyas von Val Trompia. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie*, 1869: 456-461, Stuttgart.

Gradstein, F.M., Ogg, J.G., Smith A.G., Bleeker W., Lourens L.J. (2004): International Stratigraphic Chart (ICS). To accompany "A new Geological Time Scale, with special reference to Precambrian and Neogene". *Episodes*, 27, no. 2: 83-100.

Italian IGCP 203 Group (ed.) (1986): Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys. Field Guidebook. Field Conf. SGI-IGCP Project 203, July 1986, Brescia (Italy). Tipolitografia Commerciale Pavese, Pavia:180 p.

Jin, Y., Wang, W., Wang, Y., Cai, C. (1998): Prospects for global correlation of Permian sequences. *Proceedings of the Royal Society of Victoria*, Melbourne, 110, nos.1/2: 73-83.

Jongmans, W. (1960): Die Karbonflora der Schweiz. Mit einem Beitrag von Ritter, E.: Die Karbon-Vorkommen der Schweiz. *Beiträge zur Geologischen Karte der Schweiz*, Neue Folge 108: 1-95, Basel.

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

Massari, F., Conti, M.A., Fontana, D., Helmold, K., Mariotti, N., Neri, C., Nicosia, U., Ori, G.G., Pasini, M., Pittau, P. (1988): The Val Gardena Sandstone and the Bellerophon Formation in the Bletterbach gorge (Alto Adige, Italy): biostratigraphy and sedimentology. *Memorie di Scienze Geologiche*, Padova, 60: 229-273.

Massari, F., Neri, C., Pittau, P., Fontana, D., Stefani, C. (1994): Sedimentology, palynostratigraphy and sequence stratigraphy of continental to shallow-marine rift-related succession: Upper Permian of the eastern Southern Alps (Italy). *Memorie di Scienze Geologiche*, Padova, 46: 119-243.

Menning, M. (1995): A numerical time scale for the Permian and Triassic Periods: an integrated time analysis. In: Scholle, P.A., Peyrit, T.M. and Ulmer Scholle, D.S. (eds,): The Permian of Northern Pangea, Springer Verlag, Vol. 1: 77-97.

Merla, G. (1933): Geologia della Valsassina da Introbbio a Bellano. *Memorie Geologiche e Geografiche di Giotto Dainelli*, Firenze, 4: 44 p.

Nicosia, U., Ronchi, A., Santi, G. (2001): Tetrapod footprints from the Lower Permian of western Orobic Basin (N. Italy). In: G. Cassinis (ed.): Permian continental deposits of Europe and other areas. Regional reports and correlations. *Natura Bresciana, Annali Museo Civico di Scienze Naturali Brescia*, *Monografia* No. 25: 45-50.

Ori, G.G. (1988): The nature of Permian rivers in Southern Alps. In: G. Cassinis (ed.): Proceed. of the Field Conf. on "Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys, and additional regional reports". (Brescia, 4-12 July 1986), Soc. Geol. It. – IGCP Project No. 203. *Memorie della Società Geologica Italiana*, 34 (1986): 155-160.

Perotti, C.R., Siletto, G. B. (1996): Le caratteristiche geometriche dei bacini permiani tra la Val Camonica e la Val Giudicarie (Sudalpino Centrale). *Atti Ticinensi di Scienze della Terra*, Serie speciale, Pavia, 4: 77-86.

Posenato, R., Sciunnach, D., Garzanti, E. (1996): First report of *Claraia* (Bivalvia) in the Servino Formation (Lower Triassic) of the Western Orobic Alps, Italy. *Rivista Italiana di Paleontologia e Stratigrafia*, 102: 201-210.

Prost, A.E., Becq-Giraudon, J.F. (1989): Evidence for mid-Permian compressive tectonics in Western Europe supported by a comparison with the Alleghanian geodynamic evolution. *Tectonophysics*, 169: 333-340.

Remy, W., Remy, R. (1978): Die Flora des Perms im Trompia-Tal und die Grenze Saxon/Thuring in den Alpen. *Argumenta Palaeobotanica*, 5: 57-90.

Rodeghiero, F., Zuffardi, P. (1985): Stratiform and strata-bound siderite and barite deposits of the Central Italian Alps. *Monografie Ser. Mineralium Deposita*, 25: 121-135.

Rodeghiero, F., Zuffardi, P. (1988): Mineralizations in the Permian-Triassic transition zone of Northern Italy. In: G. Cassinis (ed.): Proceed. of the Field Conf. on "Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys, and additional regional reports", Brescia, 4-12 July 1986. *Memorie della Società Geologica Italiana*, 34 (1986): 175-178.

Schaltegger, U., Brack, P. (1999): Short-lived events of extension and volcanism in the Lower Permian of the Southern Alps (Northern Italy, Southern Switzerland). *EUG 1999*, Abstract Vol., D02:4A/02:F1, Strasbourg: 296-297.

Schönborn, G. (1992): Alpine tectonics and kinematic models for the Central Southern Alps. *Memorie di Scienze Geologiche*, Padova, 44: 229-393.

Schönborn, G., Laubscher, H.P. (1987): The suborobic imbrications near Taceno. In: M. Gaetani, A. Piccio.(eds): Atti del Convegno sul tema: "Geologia Lariana" (Varenna, 1-5 Aprile 1986). *Memorie della Società Geologica Italiana*, 32 (1986): 113-121.

Schönborn, G., Schumaker, M.E. (1994): Controls on thrust tectonics along basement-cover detachment. *Schweizerische Mineralogische und Petrogrographische Mitteilungen*, 74: 421-436.

Sciunnach, D. (2001a): Early Permian palaeofaults at the western boundary of the Collio Basin (Valsassina, Lombardy). In: G. Cassinis (ed.): Permian continental deposits of Europe and other areas. Regional reports and correlations. *Natura Bresciana, Annali Museo Civico di Scienze Naturali Brescia*, *Monografia* N° 25: 37-43.

Sciunnach, D. (2001b): 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: 47-68.

Sciunnach, D. Garzanti, E., Confalonieri, M.P. (1996): Stratigraphy and petrography of Upper Permian to Anisian terrigenous wedges (Verrucano Lombardo, Servino and Bellano Formations; Western Southern Alps). *Rivista Italiana di Paleontologia e Stratigrafia,* 102: 27-48.

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

Sciunnach, D., Bassanelli, D., Garzanti, E., Riganti, F. (1999b): New evidence towards a geometrical model for the Taceno district (Taceno-Vendrogno road cut, Western Orobic Alps, Lombardy). *Geologia Insubrica*, 4: 35-47.

Smith, S. A., Edwards, R. A. (1991): Regional sedimentological variations in Lower Triassic fluvial conglomerates (Budleigh Salterton Pebble Beds), southwest England: some implications for palaeogeography and basin evolution. *Geological Journal*, 26: 65-83.

Thöni, M., Mottana, A., Delitala, M.C., De Capitani, L., Liborio, G. (1992): The Val Biandino composite pluton: A late Hercynian intrusion into the South-Alpine metamorphic basement of the Alps (Italy). *Neues Jahrbuch für Mineralogie Monatschefte*, 1992 (12): 545-554.

Twitchett R.J. (1999) – A high resolution biostratigraphy for the Lower Triassic of northern Italy. *Palaeontology Newsletter*, 43 (1988): 19-22,

Wignall, P.B.. Hallam, A. (1992): Anoxia as a cause of the Permian/Triassic mass extinction: facies evidence from northern Italy and the western United States. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 93: 21-46.

Venzo, S., Maglia, L. (1947): Lembi carboniferi trasgressivi sui micascisti alla «fronte sedimentaria sudalpina» del Comasco (Acquaseria di Menaggio-Bocchetta di S. Bernardo) e del Varesotto (Bedero). *Atti della Società Italiana di Scienze Naturali*, Milano, 86: 33-70.

Yin, H.F. (1985): Bivalves near the Permian-Triassic boundary in South China. *Journal of Paleontology*, 59, No.3: 572-600.

Ziegler, P.A., Stampfli, G.M. (2001): Late Palaeozoic-Early Mesozoic plate boundary reorganization: collapse of the Variscan orogen and opening of Neotethys. In: Cassinis, G., ed., Permian continental deposits of Europe and other areas. Regional reports and correlations. *Natura Bresciana, Annali del Museo Civico di Scienze Naturali, Brescia, Monografia* N. 25: 17-34.