Rivista Italiana di Paleontologia e Stratigrafia	volume 107	numero 1	pagine 47-68	Aprile 2001

THE LOWER PERMIAN IN THE OROBIC ANTICLINE (SOUTHERN ALPS, LOMBARDY): A REVIEW BASED ON NEW STRATIGRAPHIC AND PETROGRAPHIC DATA

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Received September 5, 2000; accepted January 31, 2001

Key-words: Southern Alps, Permian, geological mapping, volcanic successions, sandstone petrography, chronostratigraphy.

Riassunto. Un rilevamento geologico di facies, eseguito in scala 1:10 000 nel Permiano Inferiore dell'Anticlinale Orobica nell'ambito del Progetto CARG, ha consentito di ricostruire l'architettura del bacino e di pervenire ad una suddivisione della successione stratigrafica meglio documentata rispetto al quadro disponibile dalla letteratura. All'eruzione parossistica di benmoreiti nel membro vulcanico della Formazione di Collio seguì un'attività vulcanica sinsedimentaria di tipo polimodale (comprendente lave mugearitiche e tufi riolitici), concomitante con la deposizione del soprastante membro arenaceo-vulcanoclastico. Dopo la progradazione delle facies di delta-conoide prossimale del Conglomerato del Ponteranica, una possibile ingressione marina è suggerita da rari Foraminiferi nel membro arenaceo-pelitico sommitale della Formazione di Collio.

L'evoluzione del magmatismo ben si inquadra in uno scenario paleogeodinamico di trascorrenza crostale; l'assenza di rioliti nel membro vulcanico induce a ritenere che l'attività vulcanica al margine occidentale del Bacino del Collio (Anticlinale Orobica) fosse distinta e/o non coeva rispetto al settore centro-occidentale (dall'Anticlinale di Trabuchello-Cabianca all'Anticlinale Camuna).

La petrografia delle arenarie, che indica una soverchiante provenienza da aree sorgenti neovulcaniche, è assai uniforme in senso sia verticale, sia laterale, e suggerisce alti tassi di sedimentazione per la Formazione di Collio, in accordo con la breve finestra-tempo recentemente assegnata a questa unità da datazioni radiometriche ottenute in Anticlinale Camuna. La differenza di composizione tra le arenarie delle Anticlinali Orobica e Camuna è un altro elemento a sfavore della continuità fisica del Bacino del Collio.

Abstract. Facies mapping at the 1:10 000 scale of the Lower Permian in the Orobic Anticline, carried out in the framework of the CARG Project, allowed reconstruction of the basin architecture and refined subdivision of the stratigraphic succession with respect to the available framework. Paroxysmal effusion of benmoreites in the lower volcanic member of the Collio Formation was followed by a synsedimentary, polymodal volcanic activity (mugearite flows to rhyolite tuffs) during deposition of the overlying arenaceous-volcaniclastic member. After progradation of the Ponteranica Conglomerate proximal fan-delta facies, a possible marine transgression is suggested by rare foraminifers, newly-found in the upper arenaceous-pelitic member of the Collio Formation.

Magmatic evolution fits into a palaeogeodynamic scenario of continental wrenching; lack of rhyolites in the lower volcanic member points to distinct and/or non-coeval volcanic activity at the western edge of the Collio Basin (Orobic Anticline) with respect to the central-eastern sector (Trabuchello-Cabianca to Camuna Anticlines).

Sandstone petrography, indicating provenance from overwhelming neovolcanic sources, is fairly uniform both vertically and laterally, and thus suggests high sedimentation rates for the Collio Formation, in agreement with the short time span recently assigned to this unit by radiometric data from the Camuna Anticline. Different sandstone composition in the Orobic and Camuna Anticlines is another line of evidence against physical continuity of the Collio Basin.

Introduction.

The Italian program for geological mapping at the 1: 50 000 scale (CARG Project: Catenacci 1995) can be seen as an opportunity to reconsider both the lithostratigraphic framework and the tectonic evolution of the Lombardy Southern Alps. A prominent structural feature of the Southalpine range is represented by the Orobic Anticlines, an alignment of three E-W trending anticlinoria named Orobic stricto sensu, Trabuchello-Cabianca and Cedegolo, west to east (Fig. 1); in each anticlinorium, a volcanic to sedimentary succession spanning the Upper Carboniferous to the lowermost Anisian non-conformably overlies the Hercynian crystalline basement. The most important part of this succession in terms of volume, economic interest and palaeotectonic significance is surely the Lower Permian (Collio Formation and heteropic conglomerates: Fig. 2), deposited in strongly subsiding, fault-bounded continental basins and containing uranium minerals in the Novazza-Val Vedello district (Cadel 1986; Cadel et al. 1987). Mapping of this series should rely on a detailed stratigraphic framework, that however has turned out difficult to establish all over the outcrop area, mostly due to 1) strong lateral variations of facies and thickness of the clastic bodies, 2) scarcity of time-diagnostic fossils and

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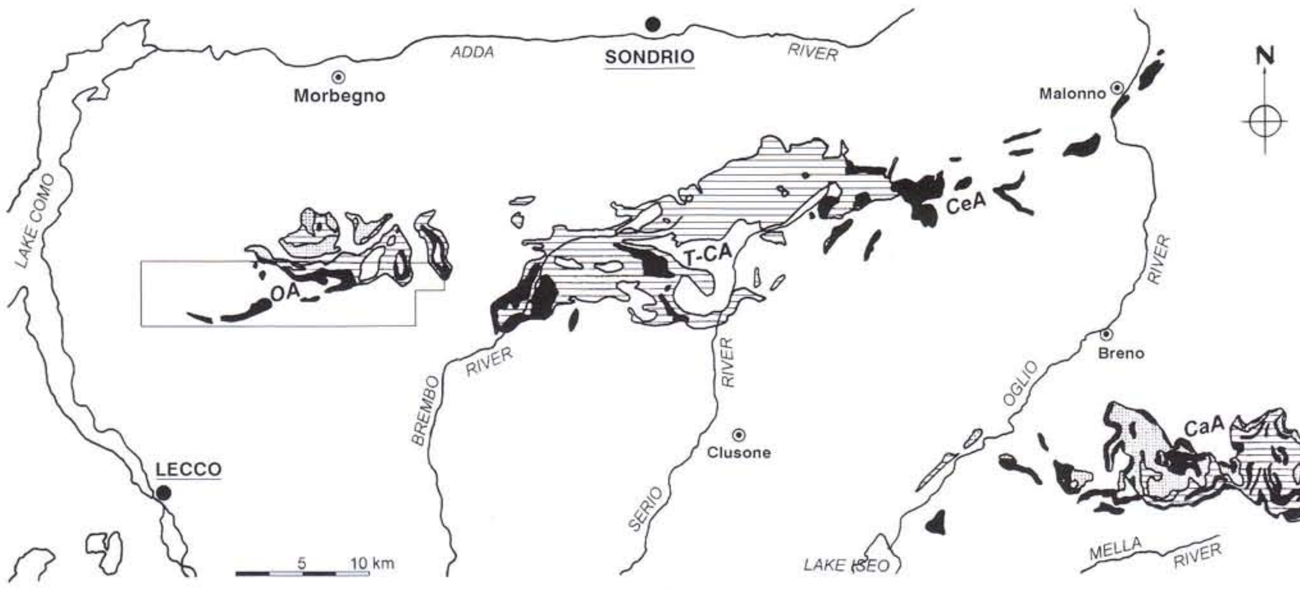


Fig. 1 - Location of the Lower Permian outcrops in the Lombardy Southern Alps (simplified after Montrasio 1990): solid, horizontally stripped and dotted areas correspond, respectively, to volcanic, arenaceous-pelitic and conglomeratic facies. OA = Orobic Anticline, T-CA = Trabuchello-Cabianca Anticline, CeA = Cedegolo Anticline, CaA = Camuna Anticline. The box includes the area of Fig. 3.

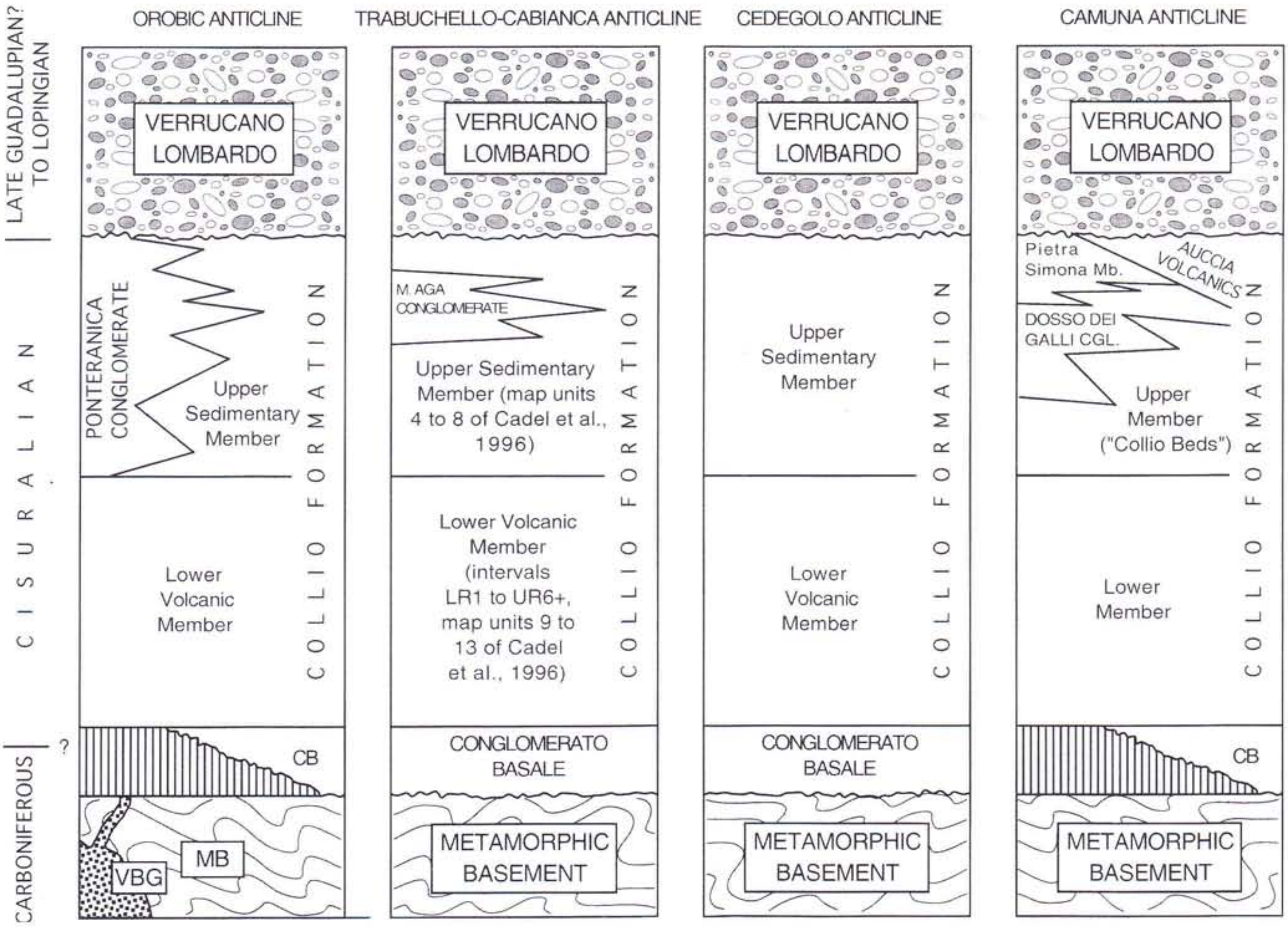


Fig. 2 - Available stratigraphic framework for the Lower Permian in the Orobic to Camuna Anticlines (mostly after Dozy 1935; Casati & Gnaccolini 1967; Cassinis et al. 1988; Cadel et al. 1996). Formations are in all capitals, members in capital/small letters. VBG = Val Biandino Granodiorite and associated post-Variscan plutons. Age constraints after Fig. 10 and related discussion in text.

marker beds, 3) intense Alpine deformation. The type areas and best exposures of the Collio Formation occur in the Camuna Anticline (Fig. 1); the present paper is focused on stratigraphic and petrographic results obtained on the Lower Permian of the Orobic Anticline during field and laboratory work carried out in the framework of the geological mapping of the forthcoming sheet 076 "Lecco" of the new 1: 50 000 geological map of Italy.

Geological framework.

The Orobic Anticline ("Val Stabina Anticline" of Porro 1932; "Mezzoldo Unit" of Schönborn 1992) extends for about 25 km west to east, from the Taceno district in Valsassina (Sciunnach et al. 2000 and ref. therein) to the Monte Pegherolo carbonate ridge in the Brembana Valley (Casati & Gnaccolini 1967), peaking in altitude with the Pizzo dei Tre Signori (2554 m a.s.l.). At the core of the fold, the Hercynian crystalline basement is exposed in the Valsassina, Ornica, Caprile (or Valmoresca) and Mezzoldo "windows". The metamorphic basement consists of metapelites and metapsammites (phyllites, micaschists and paragneisses with minor quartzites, amphibolites and marbles) in greenschist facies ("Gneiss di Morbegno" Auct.); relics of higher-grade parageneses (kyanite, staurolite; Cadel et al. 1996) are locally preserved. Leucocratic orthogneisses ("Gneiss Chiari di Corno Stella") are commonly found at the non-conformable contact with the sedimentary succession (Boriani & Colombo 1979). In Valsassina, the metamorphic basement is intruded by late Hercynian plutons, commonly known as Val Biandino Granodiorite (Pasquaré 1967) and V.le Biagio Granite (De Sitter & De Sitter-Koomans 1949). Radiometric ages (Thöni et al. 1992 and ref. therein) constrain these intrusions as largely Early Permian. A swarm of roughly parallel·stocks and dykes, striking about 60° N and thus matching a Permian tectonic trend widespread in the Orobic Alps (Cadel 1986), represents the typical outcrop pattern (Fig. 3).

The oldest sedimentary unit, non-conformably overlying the crystalline basement, is the Conglomerato Basale, up to160 m-thick in the Trabuchello-Cabianca Anticline (Cadel et al. 1996) but very poorly exposed in the Orobic Anticline.

At least three lithofacies within the Conglomerato Basale are easily recognised in the field:

1) "aporphyric" phyllarenitic conglomerates, with subangular metamorphic pebbles prevailing over quartzite pebbles and commonly supported by a coarse-grained, poorly-sorted micaceous sandy matrix. Deposition occurred in talus cones to proximal alluvial fans;

2) "aporphyric" quartzose orthoconglomerates, paraconglomerates and very coarse-grained sandstones with sparse granules and pebbles ("typical" facies), in poorly distinct layers 10 to over 100 cm-thick, commonly with imbricated pebbly lags at their base (estimated pebble composition: milky quartz = 90-99%, metamorphic rocks = 1-10%, volcanic rocks = tr.). Deposition in alluvial fans and high-energy braided streams is indicated;

3) strongly bioturbated siltstones to medium-grained sandstones, wine red in colour and rich in detrital mica flakes, ("Pietra Simona-like" facies, although much older). This finer-grained facies, seemingly deposited by floods in overbank settings, supports the inference that the described facies are remnants of a vast, articulated alluvial system, dissected by subsequent erosion; typical channel lag to meander plain facies are lacking.

Compositionally similar clastics, non-conformably overlying the metamorphic basement west of Lake Como (Manno, Alpe Logone, Bocchetta di San Bernardo, Bedero, Invorio) are ascribed to late Westphalian to possibly early Stephanian times due to plant remains (Venzo & Maglia 1947; Jongmans 1960); however, an early Cisuralian age (Asselian to Sakmarian) for the unfossiliferous Conglomerato Basale cannot be ruled out due to stratigraphic position.

In the Orobic Anticline, the only outcrops of Conglomerato Basale are found at Cima dei Siltri and Monte Arele (Casati & Gnaccolini 1967), north of the Monte Pegherolo ridge and well outside the study area. Thus, in the present paper this unit will be discussed only marginally. That possibly huge volumes of Conglomerato Basale were erased along the tectonic surface displacing the base of the Collio Formation (see below) is destined to remain an undemonstrated assumption.

The Collio Formation (up to 1250 m-thick in the Orobic Anticline) overlies either the Conglomerato Basale or, more commonly, the crystalline basement. In the former case the boundary is sharp and paraconformable; in the latter, it typically corresponds to a blanket of black cataclasites, up to a few metres-thick, yielding abundant tourmaline (Zhang et al. 1994). In the three Orobic Anticlines, the Collio Formation is usually subdivided into a lower member, in which volcanic products prevail by far over sedimentary rocks ("Volcanic Member" Auct.), and an upper member, mainly consisting of clastic sedimentary rocks with volcanic intercalations ("Sedimentary Member" Auct., "Arenaceous-shaley Member" Auct.); both members have to be regarded as informal lithostratigraphic units. At the western and eastern boundaries of the outcrop area, the "Sedimentary Member" passes laterally and upsection to conglomerate wedges (Ponteranica and Dosso dei Galli Conglomerates, respectively) that are instead formal lithostratigraphic units of formation rank. To the east, the Dosso dei Galli Conglomerate (which includes the Pietra Simona Member) is sealed by the Auccia Volcanics, in turn overlain with angular unconformity by the Verrucano Lombardo redbeds (Fig. 2). Strong lateral variability of facies and local incompleteness of the stratigraphic succession are probably due to syndepositional uplift of fault-bounded blocks and erosion in continental setting. These factors cause the Collio Formation, along with the above-mentioned associated units, to be perceived by most field geologists simply as the stratal package bracketed between the crystalline basement ± the Basal Conglomerate at the base and the Verrucano Lombardo at the top. Under this respect, the whole Lower Permian may be regarded as an unconformity-bounded allostratigraphic unit of group rank.

Sedimentary structures and the few fossils (largely plant remains and tetrapod footprints) document deposition in endorheic lacustrine basins in the Camuna (Cassinis 1966) and Trabuchello-Cabianca Anticlines (Cassinis et al. 1986). Sandier facies and minor pelites are exposed in the Orobic Anticline, pointing to prevailing distal fan-delta environments. Strongly variable facies and thickness can be seen as the result of syntectonic deposition on the hanging walls of fault-controlled basins, accommodating the clastic sediments from footwall-sourced fans; this architecture indicates that the vertical slip rate of the faults outpaced regional subsidence (Doglioni et al. 1998). Tectonic deformation probably started already in the Permian and peaked during the Alpine Orogeny; it results in large-scale, open folds and widespread faults, as well as in pervasive fracture to slaty cleavages developed in volcanic to coarse clastic and pelitic rock types, respectively. Small-scale polyharmonic folds are common in sand-mud couplets, and recumbent to isoclinal folds - transposing the sedimentary bedding - occur in all the sedimentary facies.

The Verrucano Lombardo, ranging in thickness from 150 to nearly 450 m over most of its outcrop area (Assereto & Casati 1965), consists of pebble ortho- and paraconglomerates, coarse-grained sandstones and micaceous siltstones commonly arranged in decametric FU-cyclothems; rounded volcanic pebbles are roughly as abundant as subangular quartzite pebbles, whereas metamorphic pebbles are very rare. In Valsassina, angular cobbles of Gneiss Chiari are however observed; rare granophyre pebbles might have been derived from subvolcanic acidic rocks similar to the those presently exposed at Cuasso al Monte (Buletti 1985), but their local concentration might even suggest provenance from local sources nearby.

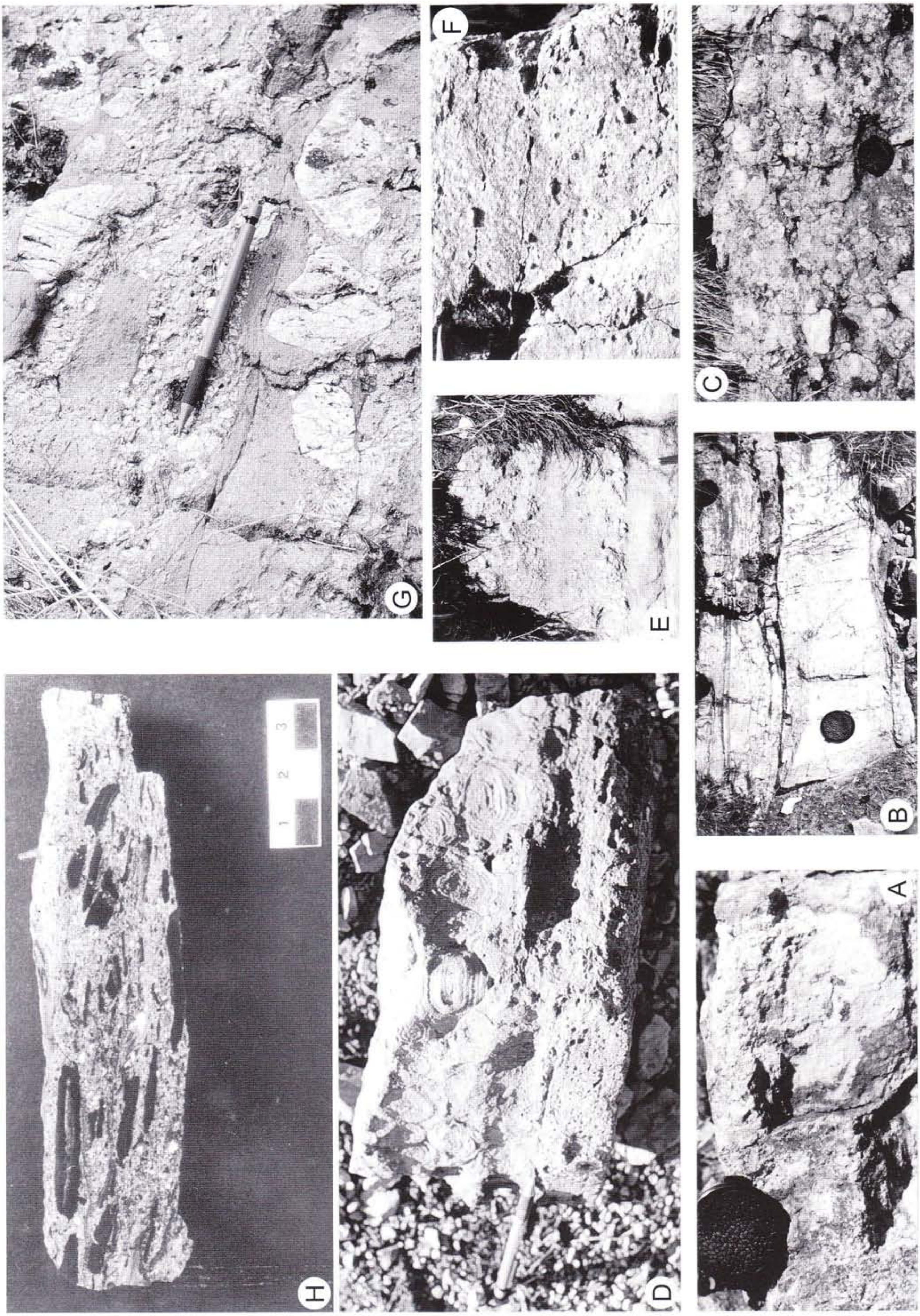
Colour of all the grain size fractions is typically wine red; greenish reduction spots are observed only locally. The Verrucano Lombardo was deposited in a vast braidplain, passing - east of the Giudicarie Line - to the Val Gardena Sandstone floodplain (Massari et al. 1994). Both the non-conformable contacts on the crystalline basement observed west of Introbio (Garzanti & Sciunnach 1997; Sciunnach 2001) and the angular unconformity with the Collio Formation (Casati & Gnaccolini 1967) document a prolonged hiatus before deposition of the Verrucano Lombardo and a major shift in the subsidence patterns, seemingly passing from tectonically-driven and localised to thermo-tectonically driven and widespread (Cassinis et al. 1988); the described architecture indicates that regional subsidence outpaced the vertical slip rate of normal faults (Doglioni et al. 1998). Oxidation and pedogenesis are reported from both basement rocks (Sciunnach 2001) and Collio sediments (Cadel et al. 1996) underlying the Verrucano Lombardo redbeds. An intraformational hiatus, not easily perceived in the field, is suggested by the abrupt compositional shift in sandstone composition from Petrofacies P1 to P2 (Sciunnach et al. 1996).

Methods of study.

Facies mapping. In the framework of the CARG Project, an area of about 75 km^2 was mapped at the 1:10.000 scale in the southern Orobic Anticline (Fig. 3). Since the stratigraphic reference framework (Casati & Gnaccolini 1967) considered only two subdivisions in the Collio Formation (a volcanic lower member and a sedimentary upper member), contrasting with much more detailed subdivisions obtained in the adjacent Trabuchello-Cabianca Anticline (Cadel et al. 1996), a preliminary facies mapping has been carried out, aimed at defining a sufficient number of mappable stratigraphic intervals. The complex problems of stratigraphic nomenclature posed by the Lower Permian in the Southern Alps are beyond the scope of this paper; the rank of the Collio Formation, although needing reconsideration, will not be questioned, and all the lithostratigraphic names here proposed have to be regarded as informal.

Six lithofacies, systematically recognised in the Lower Permian of the Orobic Anticline, are described here below (volcanic lithofacies V1 to V3 and sedimentary lithofacies S1 to S3). A similar, but wider, spectrum of facies is proposed in Forcella et al. (2001) for all the three Orobic Anticlines.

Fig. 4 - Selected facies of the Lower Permian volcanics and clastics in the Orobic Anticline. Volcanic member of the Collio Formation: A) welded lapillistone in which only subtle variations in grain size and degree of welding hint at the original plane bedding (V1 facies, Cedrino Pass); B) laminated welded tuff (V1 facies, Pizzo di Giovanni); C) intraformational volcanic breccia (V1 facies, Pizzo di Giovanni); D) welded accretionary lapilli (V1 facies, Biandino Valley - photo by M.P. Confalonieri); E) graded pyroclastic to epiclastic deposit (V2 facies, Pizzo di Giovanni). Lower Permian clastics: F) volcaniclastic paraconglomerate (S1 facies, Cusio - hammer head on the left for scale); G) Ponteranica Conglomerate (S3 facies, Biandino Valley - photo by M.P. Confalonieri); H) medium-grained sandstone with abundant flattened and imbricated mudclasts (S2 facies, Pizzo di Giovanni).


A
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V1 - Intermediate to acidic welded tuffs and lapillistones, with variable amount of porphyrocrysts and degree of welding (Fig. 4A) up to massive porphyries, ranging in colour from whitish to deep red to brownish-green; comparatively rare ignimbrites, displaying pumiceous lithics and sheared *fiamme*, do however occur. This facies was meant to include also intraformational breccias (Fig. 4C) consisting of 100% angular blocks welded in an aphanitic matrix ("block- and ash-flow deposits" *sensu* Cas & Wright 1987), commonly too thin to be mapped at the 1:10.000 scale. A rough bedding underlined by thin tuffaceous interlayers (Fig. 4B) is locally observed, but in general is pervasively overprinted by the Alpine cleavage.

V2 - Volcaniclastic breccias and arenites to reworked tuffs ("epiclastics"; Fisher 1961) with poorly-sorted, angular lapilli exclusively volcanic in origin embedded in a "salt-and-pepper" sandy matrix (Fig. 4E); abundant plagioclase is recognised in the arenites.

V3 - Massive, mostly basic lava flows, deep green to almost black in colour. Black femics and saussurritised pale green plagioclase are locally observed; amygdalar vacuoles are widespread.

S1 - Medium- to coarse-grained, grey to pink volcanic arenites, displaying abundant fresh detrital feldspar and scattered white mica flakes, locally concentrated on the bedding planes in the finer-grained fraction. Layers are up to several tens of cm-thick, mostly homogeneous in grain size but locally displaying a rough grading, either normal or inverse. Subordinate intercalations of pelites, pyroclastics and conglomerates occur (Fig. 4F).

S2 - Prevailing fine- to medium-grained, dark grey volcanic arenites, in layers a few cm to less than 20 cm-thick, fining upwards to black pelites rich in white mica flakes (sand/mud ratio > 1). A variety of sedimentary structures (channelised beds underlined by clay chips at their base, normally graded beds, parallel and low-angle lamination, climbing and load-casted ripples, lenticular bedding, slumpings, convolute lamination, load structures evolving to balls and pillows) is displayed (Fig. 4H).

S3 - Pebble to cobble conglomerates, alternating to coarse-grained pebbly sandstones, deposited in proximal alluvial fans (Fig. 4G). In the Pizzo dei Tre Signori area this facies was formally introduced as a distinct unit, occupying a definite stratigraphic position (Ponteranica Conglomerate; Casati & Gnaccolini 1965), whereas in the Trabuchello-Cabianca Anticline the term "Monte Aga Conglomerate" has been recently introduced (Cadel et al. 1996).

The stacking pattern of facies observed in the field suggested their lumping into three mapping units: a volcanic member, in which facies V1 is exclusive, an arenaceous-volcaniclastic member, enclosing all facies except S3, and an upper arenaceous-pelitic member, in which facies S2 is exclusive. These mapping units, exposed all over the study area and easily identified even under poor exposure, correspond to the whole Collio Formation as described in the previous literature; facies S3 corresponds to the Ponteranica Conglomerate.

Geochemistry. Major element geochemical analyses on volcanic rocks where carried out on powder discs using an automatic Philips PW 1400 X-Ray fluorescence spectrometer. The results were corrected according to a wide range of international and natural geostandards; at least five standards were used for each selected element. Loss on ignition was determined on powders kept at 1000 °C overnight. Both WDS (kV = 15.0, nA ~ 300, livetime = 40÷80 seconds, natural amphibole and rhodonite as standards) and EDS (kV = 20.0, nA = 300÷350, livetime = 50 seconds, international standards and metallic cobalt for calibration) microprobe analyses were carried out on a polished thin section of the basal cataclasite.

Sandstone petrography. 300 points were counted on each standard thin section, and point-counting data were recalculated following the Gazzi-Dickinson method (Dickinson 1970; 1985). Grain size was semi-quantitatively evaluated according to Garzanti et al. (2001).

The Pradini Valley section revisited.

Tectonic basal contacts on the crystalline basement, severe Alpine deformation and poor exposure of its sedimentary upper part, commonly hamper a precise thickness estimate of the Collio Formation from base to top. One of the very few places where a continuous section is exposed is the Pradini Valley talweg (Fig. 5), on the southern slope of the Pizzo dei Tre Signori and on the northern limb of the Orobic Anticline (base of section at 1490 m a.s.l., Gauss-Boaga co-ordinates 5 093 920 - 1 541 220). This section, 976.5 m-thick, was first measured and described in Casati & Gnaccolini (1967). In the present paper, their interval 1 is split into intervals 1-8. Twenty-five samples were collected for petrographic and geochemical analyses from the measured section.

The composite section of the Zatto-Monte Cavallo Valleys north of Mezzoldo (Casati & Gnaccolini 1967) can be useful for comparison. In both sections, however, the basal contact with the basement is tectonised and the thickness of interval 1 has to be regarded as a minimum value.

The recognised levels are, top to bottom:

- Verrucano Lombardo. Orthoconglomerates and paraconglomerates supported by very coarse sand matrix, in amalgamated beds with pebbly lags at their base; angular boulders of Collio sedimentary rocks, up to 30 cm in length, are observed at the very base. Sample VP 20 (0.4 m above the base).

- Collio Formation.

20) Interbedded fine to medium-grained sandstones and pelites, reddish in the lower part, greenish to dark grey upwards, with parallel to cross- and trough-bedding, abundant mudclasts and load structures. Thin intercalations of black pelites are common; sandstones are more abundant at the base. Symmetrical ripples are observed 5 m below the top. Samples VP 17 (3 m above the base), VP 18 (30 m below the top), VP 19 (0.4 m below the top) (196 m);

- Ponteranica Conglomerate.

19) Grey-greenish orthoconglomerates, paraconglomerates and pebbly sandstones, roughly bedded to massive, with volcanic and subordinately metamorphic pebbles, up to 25 cm in size. Samples VP 15 (75 m above the base), VP 16 at the top (185 m);

- Collio Formation.

18) Greenish sandstones, locally containing abundant volcanic pebbles, alternating to parallel-laminated pelites and greenish tuffs

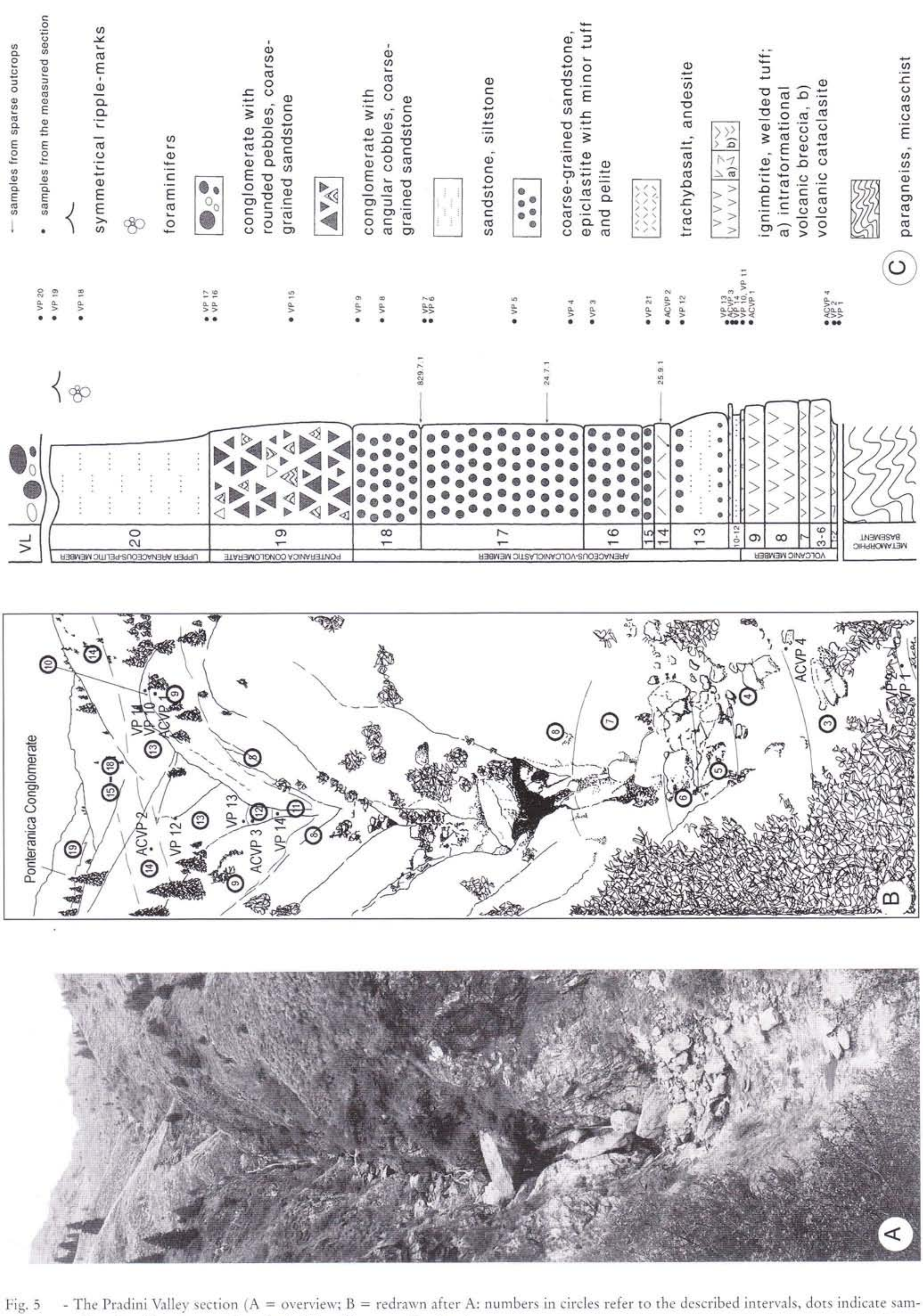

Fig. 5 - The Pradini Valley section (A = overview; B = redrawn after A: numbers in circles refer to the described intervals, dots indicate sampling sites; C = measured section). VL = Verrucano Lombardo.

with inversely-graded pumiceous lapilli. Water-escape structures are common in sand-mud couplets. Samples VP 8 (25 m below the top), VP 9 at the top (86 m);

17) Grey sandstones with black pelite veneers, commonly displaying parallel to cross-lamination and containing abundant mud-clasts, with thin tuffaceous intercalations. Samples VP 4 (15 m above the base), VP 5 (85 m above the base), VP 6 (0.3 m below the top), VP 7 at the top (203 m);

16) Greenish sandstones, frequently purple and reddish in the lower part, passing to parallel-laminated pebbly sandstones with scoured base or less commonly to conglomerates yielding volcanic pebbles; up to 15 cm-thick intercalations of purple tuffs also occur. Both normally and inversely graded beds are common. Sample VP 3 (5 m below the top) (73.5 m);

15) Reddish sandstones, pebbly sandstones, tuffs and volcanic breccias. Sample VP 21 at the top (14.5 m);

14) Deep green, massive lava flows, with plagioclase microliths and sparse amygdalar cavities filled by carbonate crystals. Basal contact on the underlying sandstones is sharp and mildly erosional; up to 0.7 m above the base, the lavas are fractured, vuggy and somehow foliated parallel to bedding. Sample ACVP 2 (4 m above the base) (20 m);

13) Grey sandstones, locally pebbly and coarse-grained, in beds 1 to 20 cm-thick (mode = 6 cm) alternating to black pelite veneers, commonly with parallel lamination. Fractured microconglomerates, 10 cm-thick, at the very base. Samples VP 13 (0.6 m above the base), VP 12 (10 m below the top) (71 m);

12) Red to purple porphyries. Sample ACVP 3 from the middle part (5 m);

11) Grey to brownish sandstones and tuffs rich in plagioclase ("salt-and-pepper"). Sample VP 14 at the top (9.5 m);

10) Red to purple pyroclastic breccia. Samples VP 10 (2.5 m above the base), VP 11 (1.5 m below the top) (6 m);

9) Red to purple porphyries. Sample ACVP1 (4.3 m below the top) (26 m);

8) Cliff-forming whitish to whitish-grey volcanics (40.6 m);

7) White to pink porphyries, with sparse tuffaceous intercalations and unfolded quartz veins (15.5 m);

6) Pinkish to reddish bedded porphyries with cavities filled by white dolomite (3.8 m);

5) Fine-grained, pseudonodular porphyries alternating with welded tuffs in up to 2 cm-thick beds (5.3 m);

4) Welded tuffs with folded quartz veins (6 m);

3) Aphyric welded tuffs ranging in colour from light grey to pinkish to greenish, in thick, poorly distinct beds, intensely folded and cleaved. Sample ACVP 4 at the top (5.6 m);

2) Black cataclasite including thin slivers of tectonised volcanics. Sample VP 2 at the top (2 m);

1) Tectonised volcanics, injected by black cataclasite veins, encasing amygdaloid basement blocks up to 60 cm in diameter. Sample VP 1 at the base (2.2 m);

- metamorphic basement. Muscovite paragneisses with quartz rods, injected by subparallel veins of black cataclasites in the topmost 2 metres.

Petrography and geochemistry of the Collio volcanics.

Four major element geochemical analyses were carried out on samples from the Pradini Valley section (Tab. 1). Samples from both the base (interval 3, sample ACVP 4) and top (interval 9, sample ACVP 1) of the lower volcanic member, over 110 m-thick, can be classified as intermediate, Na-alkaline volcanics (benmoreites), yielding relatively high Al and low Mg content. Proximal stratigraphic position of sample ACVP 4 to the basal cataclasites results in a stronger alteration, testified by high I.L. values, but not in a severe disruption of the original texture. Similar geochemistry of the two samples does not allow to recognise differentiation trends, from base to top, within the thick volcanic succession extending from intervals 3 to 9.

	ACVP4	ACVP1	ACVP3	ACVP2
SiO_2	58,35	55,25	66,85	50,35
TiO_2	0,84	1,10	0,85	2,03
$Al2O_3$	16,20	20,19	16,40	18,02
FeO_{tot}	5,70	6,12	6,49	10,02
MnO	0,26	0,28	0,05	0,14
MgO	5,90	2,25	0,55	4,44
CaO	3,99	3,80	0,43	7,93
Na_2O	5,67	6,11	3,89	5,07
K_2O	2,42	4,21	3,61	0,95
P_2O_5	0,24	0,23	0,18	0,53
I.L.	10,93	6,41	2,00	8,53
Tot	99,57	99,54	99,30	99,48

Tab. 1 - Geochemistry of the Collio volcanics in the Pradini Valley section; samples are listed in stratigraphic order. I.L. = ignition loss.

The lower volcanic member is capped by a pyroclastic breccia (interval 10) where deeply altered and resorpted plagioclase phenocrysts are hardly distinguished from the felsitic to aphanitic groundmass of individual clasts.

Upsection, porphyries in thinner layers (ACVP 3) alternating to volcanic arenites (interval 12), can be classified as acidic, high-K calc-alkaline volcanics (dacites) with low Mg content. The silica excess due to quartz veins might explain the shifting of this sample away from the Na-alkaline suite.

Next, interval 14 consists of a 40 m-thick mugearite lava flow (ACVP 2, 25.9.1). These basic volcanics, belonging to the Na-alkaline suite, yielded high Al and Ti and low Mg content; in thin section, they display a homogeneous intersertal texture, where felted plagioclase laths (250 μm on the average) are enclosed in an altered matrix consisting of chlorite and ferroan dolomite (Fig. 6C). In outcrop, no evidence has been found of subaqueous deposition of the andesitic lavas (breccias to pillow-structures); contact on the underlying sediments is sharp, mildly erosional, and underlined by flow textures and cavities. Still upsection, thin tuffaceous beds, in which quartz, plagioclase and commonly spherulitic felsitic fragments are enclosed in an aphyric matrix, are intercalated to the prevailing sandstones and pelites (sample VP 4; intervals 15-18).

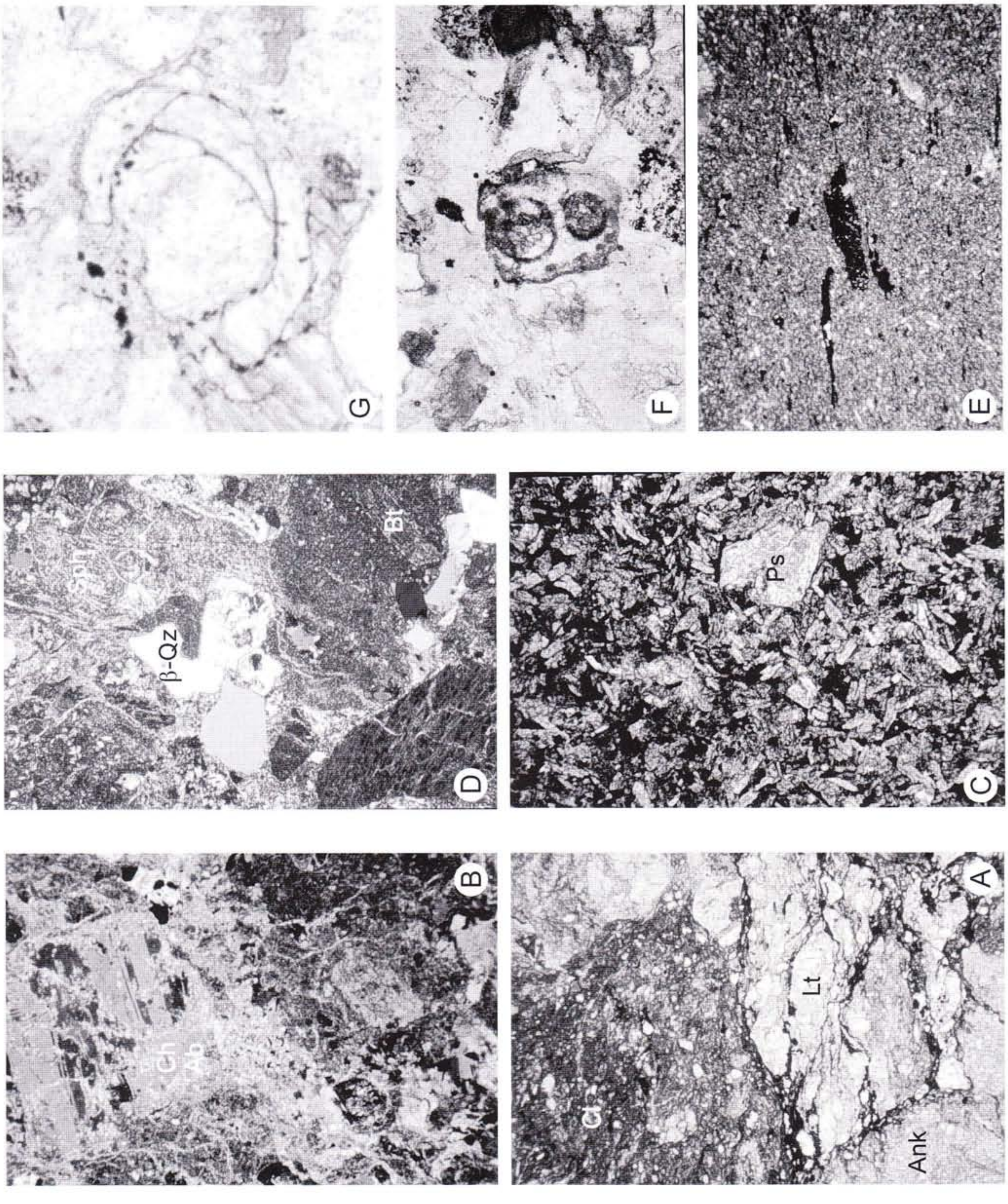

Fig. 6 - Representative photomicrographs of facies described in the Pradini Valley section. A = basal cataclasite, with a clayey matrix (Cl, largely consisting of illite) encasing tectosilicate lithons with felsitic texture (Lt) partly replaced by ankerite patches (Ank) grown in oversized secondary pores (VP2; plane polarised light, 27x); B = weathered intermediate welded tuff (benmoreite; facies V1) displaying feldspar phenocrysts locally transformed into chessboard-albite (ChAb) (ACVP1; cross-polarised light, 27x); C = sericitised lava flow (mugearite; facies V3) with a plagioclase lathwork encasing large calcite-chlorite pseudomorphs (Ps) after femic phenocrysts (amphiboles?) (ACVP2; cross-polarised light, 27x); D = very coarse-grained, moderately sorted volcanic arenite (Ponteranica Conglomerate; facies S3) rich in volcanic lithics displaying spherulitic textures (Sph) and containing embayed quartz (β-Qz) as well as leached biotite (Bt) phenocrysts (VP 15; cross-polarised light, 27x); E = black shale (facies S2) including imbricated carbon-rich chips (VP 7; cross-polarised light, 25x); F, G = bioclasts in a medium-grained, moderately sorted volcanic arenite (VP 18; plane polarised light); F = small gastropod fragment, 124x; G = foraminifer fragment (cf. *Hemigordius* sp.; det. by R. Rettori), 260x.

Tab. 2

	1	2	3	4
SiO_2	0,33	0,33	0,17	48,64
TiO_2	0,13	0,13	0,01	0,37
Al_2O_3	0,11	0,10	0,08	27,79
FeO	10,33	10,32	13,08	5,36
MnO	0,73	0,73	0,98	0,01
MgO	15,79	15,78	16,24	4,16
CaO	28,50	28,47	28,69	0,21
Na_2O	1,46	1,51	1,64	1,19
K_2O	0,03	0,03	0,02	3,04
CO_2*	42,59	42,60	39,09	0,00
H_2O*	0,00	0,00	0,00	9,23
Tot**	100,00	100,00	100,00	100,00

Tab. 2 - Geochemistry of the basal cataclasite of the volcanic member of the Collio Formation (sample VP 2, Pradini Valley section). 1-3: EDS analyses of ankerite patches; 4: WDS analysis of illite in the matrix. * = Content of oxides not detected at the EDS-WDS microprobes, calculated to obtain a theoretical 100% total (**).

Tab. 3 - Petrography of the Lower Permian sandstones. Samples VP 3-VP 21, in stratigraphic order bottom to top, are from the Pradini Valley Section (Fig. 5); the remaining samples, tentatively ordered according to their inferred stratigraphic position, are all from the Orobic Anticline except MA 29 (Trabuchello-Cabianca Anticline). Qs = "common" monocrystalline quartz; Qsbay = embayed monocrystalline quartz (Qs + Qsbay = total monocrystalline quartz); Qp = polycrystalline quartz; Pl = untwinned and unzoned plagioclase; Pltw = twinned plagioclase; Plzon = zoned plagioclase (Pl + Pltw + Plzon = total plagioclase); Af = alkalifeldspars; ChAb = chessboard-albite; Fels = felsitic volcanic rock fragment; Vitr = vitric volcanic rock fragment; Lath = microlitic to lathwork volcanic rock fragment; uVRF = undeterminable volcanic rock fragment; HRF = hypabyssal rock fragment; GRF = granitoid rock fragment; Ortho = orthometamorphic rock fragment; Para = parametamorphic rock fragment; TRF = terrigenous rock fragment; Pseud = pseudomorphic grains and pseudomatrix; HM = heavy minerals and detrital micas; NCI = non-carbonate intrabasinal grains; CI = carbonate intrabasinal grains; Mat = epimatrix; Cem = cement; Aut = authigenic minerals; Tot = total; Q, F, L, C/Q, P/F, V/L parameters after Dickinson (1970); GSZ = grain size (Φ scale); SRT = sorting (MOD = moderate; M/POOR = moderate to poor; V.POOR = very poor).

Tab. 3

Sample	Qs	Qsbay	Qp	Pl	Pltw	Plzon	Af	ChAb	Micr	Fels	Vitr	Lath	uVRF	HRF	GRF	Ortho	Para	TRF	Pseud	HM	NCI	CI	Mat	Cem	Aut	Tot	Q	F	L	C/Q	P/F	V/L	GSZ (Φ)	SRT
MA 29	8,3	tr.	1,0	6,0	2,3	-	2,7	-	-	7,3	1,3	tr.	-	1,0	1,3	-	-	-	21,3	3,3	-	-	38,0	0,3	5,7	100	19,0	23,4	57,6	0,10	0,78	1,00	1,25	M/POOR
31.7.1	6,3	2,0	1,0	7,7	2,0	1,7	1,0	-	-	4,3	1,7	-	3,3	1,3	-	-	0,3	-	38,7	1,0	-	-	27,7	-	-	100	14,8	22,2	63,0	0,13	0,90	1,00	1,75	POOR
1.8.3	6,3	0,3	2,7	5,7	1,7	-	2,3	0,3	-	7,3	15,7	-	2,0	1,0	-	-	-	-	15,3	1,0	1,0	-	27,0	-	10,7	100	18,0	18,5	63,5	0,27	0,74	1,00	2,25	M/POOR
1.8.2	1,0	1,7	-	12,0	5,0	1,0	0,7	0,7	-	6,7	1,7	5,3	0,3	2,0	-	-	-	-	14,3	-	-	-	37,3	0,3	10,0	100	7,0	42,0	51,0	0,00	0,93	1,00	2,25	V. POOR
724.9.2	7,0	1,7	1,0	3,3	2,3	0,3	5,0	-	-	11,0	17,0	0,7	2,7	6,0	2,3	-	1,7	-	10,0	0,3	-	-	18,0	7,0	2,7	100	14,8	19,4	65,8	0,09	0,57	0,96	1,25	M/POOR
13.8.1	9,3	-	4,3	1,0	0,7	-	1,0	-	-	24,7	8,0	1,3	0,7	1,3	0,3	1,7	0,7	-	11,3	0,7	-	-	15,7	2,0	15,3	100	20,6	10,0	69,4	0,32	0,70	0,96	0,00	V. POOR
4.9.3	6,0	1,7	1,7	3,0	4,7	-	2,0	0,3	0,3	14,7	25,7	2,7	6,3	3,7	0,3	0,3	-	1,0	19,3	tr.	-	-	2,0	-	4,3	100	10,2	15,9	73,9	0,18	0,71	0,98	-0,50	M/POOR
4.9.2	7,0	2,3	0,3	1,0	2,7	1,3	0,7	-	-	11,7	20,0	5,7	9,7	3,3	1,3	1,0	-	1,7	11,7	-	tr.	-	15,3	1,0	2,3	100	14,2	10,3	75,5	0,03	0,87	0,95	-1,25	M/POOR
1.8.1	7,3	1,0	0,7	1,3	5,3	1,0	1,3	-	-	11,3	10,7	2,7	11,0	1,0	-	tr.	tr.	-	15,0	0,7	1,7	-	25,3	0,3	2,3	100	14,9	16,5	68,6	0,07	0,85	1,00	1,50	M/POOR
CU 2	5,7	0,7	2,7	2,0	3,7	-	1,7	1,0	-	13,7	21,7	3,3	3,7	2,7	0,3	-	0,7	-	14,3	0,3	-	-	12,7	0,3	9,0	100	12,3	15,0	72,7	0,30	0,68	0,98	0,75	MOD
24.7.1	8,0	-	1,3	4,3	3,0	-	2,0	0,3	-	4,3	22,7	tr.	0,7	1,7	-	-	1,7	0,3	16,7	1,0	tr.	-	4,7	16,7	10,7	100	15,4	19,7	64,9	0,14	0,73	0,95	1,50	MOD
VP 19	2,7	0,3	0,3	2,7	1,3	-	0,3	0,7	-	2,3	7,0	-	1,0	-	-	-	tr.	-	21,7	0,7	-	-	23,3	0,7	35,0	100	10,0	15,0	75,0	0,10	0,80	1,00	1,75	POOR
VP 18	2,0	0,3	0,7	5,3	2,7	-	1,7	-	-	4,7	17,3	-	1,3	0,7	-	-	-	-	11,7	1,0	3,0	tr.	11,3	-	36,3	100	6,7	29,1	64,2	0,22	0,83	1,00	1,75	MOD
VP 17	2,7	1,0	2,0	6,7	6,3	0,3	2,7	-	-	3,0	20,0	2,3	4,3	1,0	0,3	-	0,3	-	17,7	1,0	-	-	19,0	-	9,3	100	8,6	30,8	60,6	0,35	0,77	0,99	1,50	MOD
VP 16	2,7	1,0	-	3,7	1,3	-	0,3	0,3	-	6,7	18,7	2,3	2,7	3,0	-	-	-	-	15,7	2,7	-	-	35,7	-	3,3	100	7,5	12,0	80,5	0,00	0,89	1,00	1,50	V. POOR
VP 15	4,3	1,7	-	3,7	1,3	1,7	4,7	-	-	11,7	29,3	2,0	0,3	3,3	-	1,0	0,7	-	19,0	2,7	-	-	6,7	4,3	1,7	100	8,1	18,6	73,3	0,00	0,56	0,98	-0,50	MOD
VP 9	4,0	0,7	1,0	8,3	2,0	-	2,0	-	-	5,0	17,3	-	-	1,3	-	-	0,7	-	19,3	2,7	-	-	34,3	-	1,3	100	10,2	22,9	66,9	0,18	0,82	0,98	1,50	M/POOR
VP 8	3,3	tr.	1,3	2,3	1,0	0,3	0,7	0,3	-	3,3	18,7	0,3	2,7	1,0	-	-	-	-	11,0	1,0	-	-	51,3	0,7	0,7	100	10,1	10,8	79,1	0,29	0,80	1,00	1,75	POOR
VP 6	2,0	0,3	1,7	2,3	5,3	-	1,0	-	-	4,7	44,3	1,3	1,3	2,0	-	0,7	1,7	0,3	10,3	0,7	-	-	2,7	0,7	16,7	100	5,7	13,1	81,2	0,38	0,83	0,96	1,25	M/POOR
VP 5	2,7	-	1,3	6,7	5,0	-	0,7	1,3	-	3,7	28,7	1,7	0,7	2,0	1,0	-	0,7	-	17,3	1,0	0,3	-	15,7	-	9,7	100	6,4	21,3	72,3	0,38	0,86	0,99	1,25	M/POOR
VP 3	3,7	0,3	0,3	4,0	6,3	-	1,0	-	-	8,7	27,3	3,3	-	1,3	-	-	-	-	11,0	tr.	-	-	26,3	0,7	5,3	100	6,4	18,7	74,9	0,08	0,92	0,99	1,00	M/POOR
VP 21	1,0	0,7	0,3	3,0	4,3	-	0,3	0,3	-	10,0	14,3	3,7	2,7	2,0	-	-	1,0	0,3	27,3	0,3	-	-	3,0	0,3	25,0	100	3,7	15,0	81,3	0,14	0,92	0,98	0,75	POOR
VP 12	2,0	-	0,7	4,3	2,3	-	1,3	-	-	10,7	12,7	0,3	0,3	1,3	-	-	-	-	13,3	0,3	-	-	32,7	0,7	17,0	100	5,4	18,9	75,7	0,25	0,85	1,00	1,25	M/POOR
VP 13	2,0	0,3	-	6,7	5,0	-	0,3	-	-	4,3	10,3	0,3	1,3	2,0	-	-	tr.	-	9,0	1,0	-	-	12,3	-	45;0	100	5,6	28,8	65,6	0,00	0,97	1,00	1,50	POOR
VP 14	0,3	0,3	0,3	5,3	4,3	0,7	1,3	-	-	8,7	11,3	1,3	-	1,7	-	-	-	-	17,7	0,3	-	-	16,3	2,3	27,7	100	2,1	27,7	70,2	0,33	0,87	1,00	1,25	POOR

EDS and WDS analyses were carried out on the basal cataclasite (VP 2), indicating the clayey composition (illite) for the dark, aphanitic matrix encasing volcanic lithons (Fig. 6A), as well as the occurrence of large patches of nearly stoichiometric ankerite (Tab. 2), but failing to reveal tourmalinisation (compare with Zhang et al. 1994).

Petrography of the Lower Permian sandstones.

All the studied sandstone samples from the Collio Formation (n = 19) and the Ponteranica Conglomerate (n = 6) can be classified as mostly medium-grained, moderately to very poorly-sorted volcanic arenites (average detrital modes: Q = 10±5, F = 20±7, L = 70±8; Tab. 3) and can thus be described comprehensively. Moderately sorted sandstones are medium- to very coarse-grained.

Quartz is mainly monocrystalline, although polycrystalline grains are also common (C/Q = 0.17±0.13); embayed pseudo-hexagonal crystals of volcanic origin (Fig. 6D) represent nearly 20% of total monocrystalline quartz. Polycrystalline grains display sutured boundaries, elongated and isooriented crystallites and common phyllosilicate inclusions, suggesting a mostly metamorphic origin.

Feldspars comprise prevailing plagioclase and subordinate alkalifeldspar (P/F = 0.81±0.11). Plagioclase commonly occurs in fresh, angular to subangular grains preserving twinning (38.0±20.0% on total plagioclase) and zoning (10.5±7.0%), thus hinting at provenance from neovolcanic rocks (Zuffa 1985) exposed not far from the basin. Among alkalifeldspars, chessboard albite is widespread, also pointing to a volcanic source; microcline is instead negligible. Pervasively sericitised feldspars are found only in deeply diagenised samples, where epimatrix (Dickinson 1970) cross-cuts the boundaries of unstable grains. Volcanic lithics are mostly vitric (17.0±10.0% of rock volume), but also fragments of felsite (8.0±5.0%) and microlitic lava (2.5±1.5%) are common (Fig. 6D). Hypabyssal lithics derived from subvolcanic rocks are also widespread (2.0±1.0% of rock volume), whereas granitoid rock fragments are scanty. In general, parametamorphic lithics prevail over gneissic rock fragments, that are instead more abundant in the coarser-grained samples (r = 0.706, sign. lev. < 0.1%). Sandstone to pelite fragments occur, whereas the absence of carbonate lithic grains fails to support cannibalism of carbonate crusts as an important process (Cassinis et al. 1986). The abundance of pseudomorphic grains and mostly volcanic pseudomatrix (Dickinson 1970; 16.5±6.5% of rock volume) hampers assessment of the original sand composition, that may be misinterpreted if pseudomatrix is overlooked. Accessory minerals comprise prevailing mica flakes (muscovite to paragonite and "leached" biotite) and subordinate zircon, apatite, rutile, tourmaline and sphene. Intraformational oversized mudclasts (up to 3% of rock volume) locally display slaty cleavages as an effect of post-depositional anchimetamorphism. Sparse phosphate nodules are observed only in sample VP 18, where rare bioclasts (foraminifers and small gastropods) also occur. Epimatrix, including celadonite, is abundant (20.5±13.0% of rock volume) and so intensely recrystallised that phyllosilicate flakes commonly cross-cut grain boundaries. Early diagenetic quartzose to feldspathic cement is minor (2.5% of rock volume on the average), consistent with poor sand sorting (Winn et al. 1984): maximum abundance is recorded in moderately-sorted sandstones. Poor preservation of primary pores under rapid burial and sediment compaction is also indicated. Quartz veins and ferroan dolomite patches are widespread (13.0±12.5% of rock volume); precipitation of these authigenic carbonates in secondary pores should have occurred during burial diagenesis, through the leaching of Ca and Mg ions from the volcanic detritus. The adjoining Triassic dolostones and limestones, lying in tectonic contact with the Orobic Anticline along the Valtorta Line (Fig. 3), are unlikely to have pervasively fed with carbonate the Permian succession, that had already experienced strong compaction and porosity loss at depth; moreover, an Alpine age for the precipitation of the authigenic ferroan dolomite would not explain why the overlying Verrucano Lombardo is almost carbonate-free (Sciunnach et al. 1996).

Composition of the Lower Permian sandstones is consistent with provenance of detritus from overwhelming volcanic sources, along with a subordinate input from the Hercynian crystalline basement (metamorphic and granitoid rocks) and minor supply from older clastic units (e.g., Conglomerato Basale). Total quartz, gradually increasing upwards in the Pradini Valley section (r = 0.713, sign. lev. < 1%), records a stepwise increase passing from interval 17 to 18. However, this petrographic signal is in general too gradual to allow discrimination of petrologic intervals within the Lower Permian sandstones, that cluster into a single Petrofacies P0 (Fig. 7). Since the pioneering work of Dickinson & Rich (1972), petrologic intervals identified by means of peculiar petrofacies have been successfully employed as correlation tools in sterile clastic successions (Zuffa et al. 1995 and ref. therein).

Despite marked lateral variability of facies and wide grain size range of the analysed samples, composition of the Lower Permian sandstones is remarkably uniform in both the Orobic and the Trabuchello-Cabianca Anticlines, that is, over an area extending for over 35 km west to east (Sciunnach et al. 1999a). In the Camuna Anticline, arkosic and more quartzose compositions are instead reported (Cassinis et al. 1978), suggesting greater contribution from unroofed basement rocks.

Stratigraphy of the Lower Permian in the Orobic Anticline.

The vertical organisation of facies recognised all over the study area allowed construction of a refined stratigraphic framework for the Lower Permian in the Orobic Anticline (Fig. 8). Each of the lithostratigraphic units listed below in ascending stratigraphic order, except the Ponteranica Conglomerate, needs to be regarded as an informal member of local significance, but also reflects a distinct stage of volcanic activity vs. sedimentation.

1. Volcanic member of the Collio Formation.

1a. In the lower part, observed in all sections, welded tuffs and lapillistones (whitish in colour in the lower part, reddish at the top probably due to oxidation in continental setting) are associated to porphyric ign-

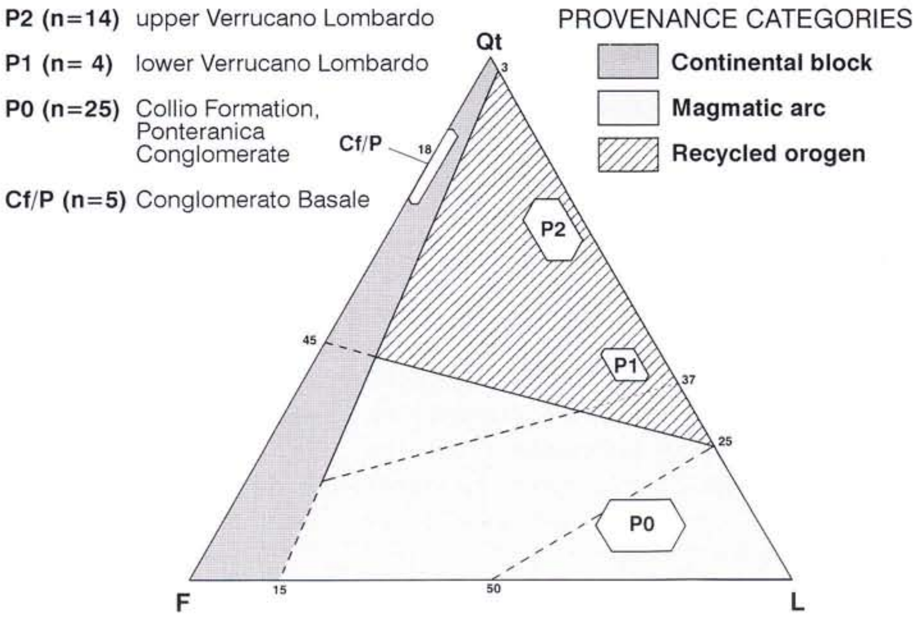

Fig. 7 - QtFL diagram (Dickinson 1985) for the Lower Permian sandstones of the Orobic Anticline (Petrofacies P0) compared to the Carboniferous-lowermost Permian? Conglomerato Basale (Petrofacies Cf/P) and to the largely Upper Permian Verrucano Lombardo sandstones (Petrofacies P1, P2). Modified after Sciunnach et al. (1999a). Polygons are one standard deviation each side of the mean; n = number of samples.

imbrites, dark bedded tuffs and graded pyroclastic flows. Massive aphyric volcanics with a dark-green glassy paste, in bodies of poorly-defined geometry, locally occur. Accretionary lapilli (Moore & Peck 1962) were found in cobbles from the Collio volcanics in the Biandino Valley (Fig. 4D; Confalonieri 1993). These constituents are particularly common - although not exclusive - in pyroclastic flow deposits and are reliable indicators of subaerial eruption (Cas & Wright 1987).

1b. In the upper part, observed only under favourable outcrop conditions and seemingly discontinuous, intraformational volcanic breccias, consisting for nearly 100% of volcanic clasts, display highly variable thickness. This mapping unit corresponds to intervals 1-10 of the Pradini Valley section (thickness = 113 m; 1a = 107 m, 1b = 6 m), to intervals 1-8 of the Zatto Valley section (thickness = 178 m; 1a = 81.5 m, 1b = 96.5 m) and invariably displays a V1 facies; thickness possibly exceeds 250 m in the Ornica area.

The basal volcanic succession (1a) was probably deposited at very high accumulation rates during a stage of paroxysmal volcanic activity possibly lasting just a few thousand years; the topmost volcaniclastic breccias (1b) are likely to have been accumulated during catastrophic intracalderic collapses. A very short time span for the whole member would be consistent with both the homogeneous geochemistry of the welded tuffs from base to top and the inconspicuous non-volcanic clasts in the overlying breccias.

2. Arenaceous-volcaniclastic member of the Collio Formation.

Prevailing coarse-grained arenites with minor pelites, alternating to epiclastics, commonly welded tuffs, and basic lava flows. Basal contact on the underlying member is paraconformable in the Pradini Valley section, although a regional unconformity is suggested in map view. Volcanism occurred episodically and alternated to prolonged stages of volcanic quiescence during which clastic sedimentation took place. This member can be further subdivided, easily in continuous sections but hardly where outcrops are sparse, in two parts:

2a. Prevailing fine-grained, thin-bedded sandstones with subordinate siltstones and rare conglomerates: all rock types are typically dark grey in colour. This lower part corresponds to intervals 11-13 of the Pradini Valley section (thickness = 85.5 m), to intervals 9-13 of the Zatto valley section (thickness = 76.5 m) and includes facies S1, S2.

2b. Prevailing fine-grained, thin-bedded grey sandstones alternate with greenish tuffs, epiclastics, lava flows, ignimbrites and black siltstones (Fig. 6E); inversely-graded pumiceous pyroclastic flows are particularly well preserved on the southern slope of the Pizzo dei Tre Signori. This lithozone corresponds to intervals 14-18 of the Pradini Valley section (thickness = 397 m), to intervals 14-20 of the Zatto Valley section (thickness = 295.2 m) and includes facies V1, V2, V3, S1 and S2.

A fossiliferous horizon was found on the Averara-Valmoresca road cut (689.6 m a.s.l.). Deformed composite moulds of smooth-shelled bivalves (Fig. 9) were collected from a grey to brownish, fine-grained micaceous sandstone overlain by a thin interval of welded tuff; a tectonic contact with the Verrucano Lombardo shortly follows upwards.

This member was deposited as a whole in a rapidly subsiding, newly-formed sedimentary basin. Occurrence of both massive, structureless deposits of granular sediment and plane bed, horizontally-laminated deposits, documents either subaerial (sheetfloods) or subaqueous (slurry mass flows) fan-delta processes. Dacitic volcanics in the lower part seem to suggest

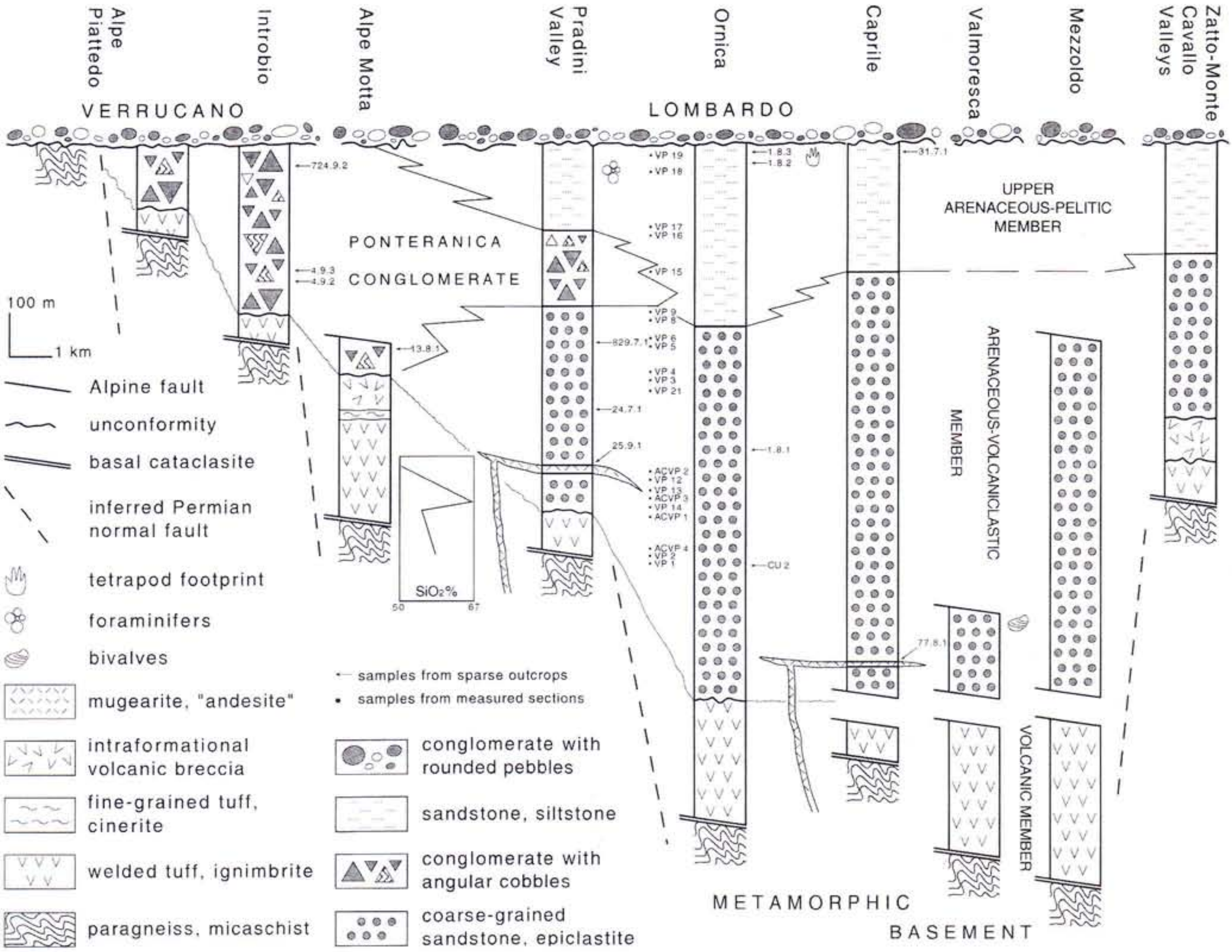

Fig. 8 - Stratigraphic framework for the Collio Formation in the Orobic Anticline, as obtained from correlation of measured sections (the Pradini Valley section near Valtorta and the Monte Cavallo-Zatto Valleys near Mezzoldo) and 8 stratimetric logs. Localisation of the major inferred Permian normal faults, as well as thickness of the volcanic and sedimentary basin fill, tend to indicate the Ornica area as a depocentre. Box displaying SiO_2 content refers to samples ACVP1-4.

magma differentiation with respect to the underlying volcanic member, although basic lava flows, up to 20 m-thick and found 92 m above the base of the member in the Pradini Valley section, shortly mark an inversion of the trend. Similar small "andesite" flows are reported from the lower part of the "Sedimentary Member" of the Collio Formation also in the Trabuchello-Cabianca Anticline (Cadel et al. 1987). The arenaceous-volcaniclastic member is likely to have been deposited at variable accumulation rates (higher under episodic volcanic input, lower when clastic rocks were deposited during stages of volcanic quiescence).

3. Ponteranica Conglomerate (Casati & Gnaccolini 1965; 1967).

Sandstones and pelites of the "Sedimentary Member" pass laterally to conglomerates of similar composition: volcanic clasts (75÷80%) prevail in fact over metamorphic rock fragments (10÷15%) and milky quartz (5÷10%). Mostly poorly-sorted, pebbly to cobbly conglomerates alternate to coarse-grained sandstones in thick, poorly-defined beds. A proximal fan-delta environment is indicated. Colour, ranging from purple to pinkish to deep green due to variable oxidising conditions, is invariably purple west of the Camisolo ridge, suggesting emergence of the fan-delta, that was instead in part or episodically submerged to the east. Three-dimensionally and exceptionally well-preserved plant remains are found north of the study area, although at present they do not provide biostratigraphic information (Kerp et al. 1996). This mapping unit corresponds to interval 19 of the Pradini Valley section (thickness = 185 m) and to facies S3.

Composition of coarse-grained sandstones intercalated to the conglomeratic red beds of the Acquaduro Valley, south-east of Introbio (Fig. 3), is consistent with the Lower Permian petrofacies P0 (Sciunnach et al.

1999a; Sciunnach 2001). These red beds, displaying lower textural maturity and mineralogical stability than the Verrucano Lombardo, are thus correlated with the Ponteranica Conglomerate, and are restored to the western edge of a clastic wedge that pinches out towards a structural high (Sciunnach 2001). They are in turn sealed by a continuous blanket of Verrucano Lombardo red beds, not always obviously discriminated: criteria originally proposed in Casati & Gnaccolini (1965) have been integrated with further observations in Tab. 4.

These previously unrecognised outcrops of Ponteranica Conglomerate correspond to the cobble conglomerates displaying crystalline components and a matrix "classified as subangular coarse sandstone or fine conglomerate" described by Schönborn (1992) in the Introbio area. There, the Ponteranica Conglomerate overlies intraformational breccias "consisting completely of volcanics" (Schönborn 1992) ascribed herein to the volcanic member of the Collio Formation (1b), as are the underlying bedded cinerites, up to about 20 m-thick in the Acquaduro Valley (Fig. 8) and mentioned in Gaetani et al. (1987) as a sedimentary facies of the Collio Formation.

As a whole, the Ponteranica Conglomerate records a stage of fan progradation at the end of volcanic activity in the Orobic Anticline area.

4. Upper arenaceous-pelitic member of the Collio Formation.

Prevailing grey to greenish sandstones, largely medium to fine-grained and rich in sedimentary structures, are interpreted as deposited in perennial lake basins (Cassinis et al. 1986; Cadel et al. 1996). Tetrapod footprints were observed in the Scioc Valley (Ornica), from where they had been reported also in Casati & Gnaccolini (1967; plate 8, figs. 1,2), a few metres below the unconformable contact with the Verrucano Lombardo. Recently, tetrapod footprints from the same stratigraphic level have been found in the Inferno Lake surroundings, about 2 km north of the study area (Santi & Krieger 2000). Rare foraminifers with calcareous tests (Miliolacea) and small gastropod fragments are reported here for the first time from the upper part of the Pradini Valley section (Fig. 6F, G). This mapping unit corresponds to interval 20 of the Pradini Valley section (thickness = 196 m), to interval 21 of the Zatto Valley (thickness = 246 m) and to facies S2; it is heteropic, at least in part, with the Ponteranica Conglomerate and appears to have been deposited at lower sedimentation rates at the end of the volcanic activity. Clastic input seemingly outpaced subsidence, as suggested by progressive infilling of the lake basin and reduction of the water body documented by footprints and mud-cracks towards the top.

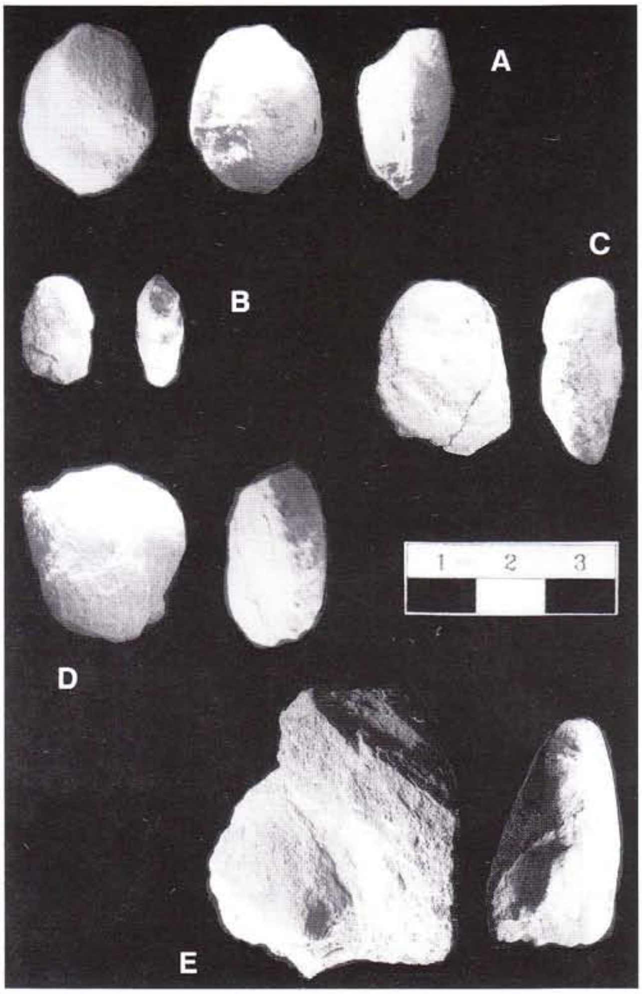

Fig. 9 - Deformed composite moulds of smooth-shelled bivalves, Averara. Moulds A, C seem comparable to the genus *Anthraconauta* (Paproth 1966), whereas nearly equilateral moulds B, D, E resemble the undetermined fresh-water bivalves pictured by Berruti (1967). Scale bar in cm.

Discussion.

Magmatic evolution.

Geochemical analyses of the Collio volcanics in the study area indicate a benmoreitic composition for the lower pyroclastic flow deposits, evolving to a more differentiated (dacitic) composition in the lowermost arenaceous-volcaniclastic member. These magmatic products are however abruptly followed upsection by mugearite lava flows and rhyolite tuffs. In the Trabuchello-Cabianca and Camuna Anticlines, prevailing rhyolites and subordinate "andesites" are reported (Peyronel Pagliani 1965; Cadel 1986), although intermediate alkaline volcanics also occur (Cortesogno et al. 1998).

In general, Early Permian magmatism in the Southern Alps displays a prevalent calc-alkaline signature, although a subduction context can be ruled out based on the regional tectonic scenario. Partial melting is likely to have occurred at the mantle/crust transition (Corteso-

		PONTERANICA CONGLOMERATE	VERRUCANO LOMBARDO
CONGLOMERATE	composition	volcanic ≈ 75%, metamorphic ≈ 15%, quartz ≈ 10%	quartz 40÷70%, volcanic 30÷60%, metamorphic < 1%
	grain size	average 10÷20 cm, maximum 60 cm	average 4÷10 cm, maximum 20 cm
	sorting	poor to very poor	moderate to poor
	roundness	angular to subrounded	subangular to rounded
	colour	violet to pink to deep green	wine red (greenish on reduction)
SANDSTONE	detrital modes	Q10÷20 F10÷20 L70÷80	Q35÷68 F5÷15 L20÷60
	composite vs. tot. quartz	0.00 ÷ 0.32	0.38 ÷ 0.50
	plagioclase vs. tot. feldspar	0.55 ÷ 0.90	0.25 ÷ 0.30
	sorting	moderate to very poor	moderate
	roundness	angular to subangular	subangular to subrounded
	colour	grey to deep green	wine red (greenish on reduction)
PELITE	occurrence	negligible	cyclical

Tab. 4 - Distinctive facies characters of the Ponteranica Conglomerate vs. Verrucano Lombardo.

gno et al. 1998). Self-limiting magmatic stoping of the continental crust, resulting in both mixing and mingling of different magmas, as well as in their high Al content, occurred during the ascent of magmas stored at different lithospheric levels; their local underplating - consistent with the low Mg content in the studied samples - caused a variable degree of differentiation even among plutons and volcanic centres close either in space or time.

A system of "leaky" wrench faults, cutting through the whole lithosphere and marking a transcurrent plate boundary, is the most likely tectonic setting for magmatism (Massari 1988; Rottura et al. 1997). Both the distribution of the volcanic districts and the geometry of single plutons, in which subparallel stocks and dyke swarms prevail over central necks (e.g. Val Biandino), are consistent with a fissure-guided rather than central magmatism. Linear cauldron boundaries, striking approximately 60° N, have been reported from the Novazza-Val Vedello district (Cadel 1986 and ref. therein).

Other tectono-magmatic models are less viable. Rising and partial melting of the asthenosphere related to an aborted rifting does not match the close time relationships between regional faulting and volcanism (Favre & Stampfli 1992; Breitkreutz & Kennedy 1999), as well as the wide range of aluminous magmatic products deriving from the lithospheric mantle, although it might explain the "Texan long-horn" cross-sectional pattern characterising the Permian basin fills in the Southern Alps (Cassinis et al. 1988). A mantle plume source finds no actualistic analogue because magmatism is scattered over an exceedingly wide area; however, it might account at least in part for the rapid uplift of the Hercynian range and widespread volcanism shortly pre-dating normal faulting. The cauldron subsidence model is clearly insufficient to account for the geometry of volcanic bodies at basin scale, although it can be successful to justify the geometric relationships between volcanics and epiclastics at a more local scale (Cadel 1986; Cadel et al. 1996).

The magmatic evolution recorded by the Collio Formation in the Orobic Anticline can be framed in a two-step regional trend of volcanic activity:

1. paroxysmal eruption of lithospheric mantle magmas enriched in Al and alkalis by crustal contamination, finding their way to the surface through "leaky" wrench faults;

2. isotherm upwelling, enhanced by stretching and unloading of the upper crust, causing the ascent of deeper-seated, less differentiated magmas; emplacement of basic lava flows, coupled with ongoing eruption of residual acidic magmas, seemingly determined a late stage of "rift-like" bimodal volcanism.

The hypothesis according to which the Valsassina intrusions would represent the magma chambers of the Collio volcanics (Merla 1933; Cadel 1986), although reasonable, is not supported by outcrop evidence. A review of the geochemical data available in the literature on the Val Biandino plutonic complex (De Capitani 1982; De Capitani & Liborio 1988) and the Collio volcanics (Origoni Giobbi et al. 1981; Cadel 1986; Cortesogno et al. 1998) fails to support derivation of the two magmatic bodies from a common parent magma. Substantial lack of rhyolites in the volcanic member of the Orobic Anticline is a first line of evidence against physical continuity of the Collio basal volcanics; rhyolites are in fact the dominant volcanic rock type in the Trabuchello-Cabianca (Cadel 1986) and Camuna Anticlines (Peyronel Pagliani 1965).

Sedimentary cycles.

The Upper Paleozoic succession of the Southern Alps can be subdivided into three sedimentary cycles, corresponding to distinct lithostratigraphic units bounded - either at the base or top - by major unconformities (Conglomerato Basale, Collio Formation and Verrucano Lombardo) as well as documenting different palaeotectonic and palaeogeographic scenarios (Sciunnach et al. 1999a). The subdivision into just two cycles (Conglomerato Basale + Collio Formation vs. Verrucano Lombardo: Cassinis et al. 1988) seems insufficient to explain the strong differences between the Conglomerato Basale phyllarenitic subarkoses and quartz conglomerates, deposited in a complex alluvial system including talus cone to floodplain facies and fed by crystalline sources, and the Collio Formation volcaniclastics, deposited in confined lacustrine basins under active tectonic control and fed by the newly-emplaced volcanic succession.

Basal cataclasite.

Major interpretation problems are posed by the belt, locally over four metres-thick, of black cataclasites marking the tectonic boundary between the crystalline basement and the Collio volcanics. Similar fault contacts are not observed anywhere at the basement/Conglomerato Basale, Conglomerato Basale/Collio volcanics or basement/Verrucano Lombardo contacts. To date no conclusive evidence has been produced to obtain an estimate of the offset along this cataclastic surface, which has long been disputed (Dozy 1935; Casati 1968). An Alpine displacement, although more or less implicitly admitted by Wennekers (1932), Casati & Gnaccolini (1967) and Casati (1968), is at odds with the stratigraphic relationships observed between Introbio and Primaluna (Valsassina), where the cataclastic belt is unconformably sealed by the Verrucano Lombardo (Figs. 3, 8) and does not continue into major faults around the basement/Verrucano Lombardo boundary. Tourmalinisation of the basal cataclasites in the Trabuchello-Cabianca Anticline has been explained in terms of penecontemporaneous metasomatism of the Collio sediments (Zhang et al. 1994). Tourmaline was also found in fault rocks pre-dating the Verrucano Lombardo in Valsassina (Sciunnach 2001). In the Novazza-Val Vedello district, fault zones sealed by the Verrucano Lombardo were mineralised during the Late Permian (Origoni Giobbi et al. 1981; Cadel 1986), and grains of tourmaline-bearing cataclasite occur in the very first Verrucano Lombardo beds in the Pizzo dei Tre Signori area.

All these lines of evidence constrain the age of cataclastic deformation as Artinskian (age of the younger deformed rocks: see the chronostratigraphy paragraph below) to Middle?-Upper Permian (age of the older undeformed rocks), and suggest that faulting was associated with a major phase of metasomatic mineralization of the host rocks.

Basin history.

The lower volcanic member, regionally forming a morphologic plateau (Cadel 1986; Cadel et al. 1996), extended well outside the boundaries of the tectonic troughs accommodating the Collio sediments. It is nearly 400 m-thick in the Monza 1 AGIP well (Casati & Poliani 1986), located today about 50 km south of the Collio Basin. This distance can be restored to a total 130 km to the south according to the values of Alpine shortening suggested by Schönborn (1992). Under this respect, the volume (150 km^3) and surface (600 km^2) estimates for the lower Collio Formation volcanic plateau reported by Cadel (1986) are likely to represent minimum figures.

Thickness of the overlying intraformational breccias (1b), capping at various places the volcanic facies (1a), strongly varies (6 to nearly 100 m between the Pradini Valley and Zatto Valley sections) as an effect of deposition in small fault-controlled basins. These breccias can be interpreted as coeval with both the end of the early stage of paroxysmal volcanism, and the major phase of widespread normal faulting of the Lower Permian volcanic plateau, which created the endorheic basins accommodating the subaqueous and much finer-grained sediments of the arenaceous-volcaniclastic member. At that time, the volcanic caps of the uplifted footwalls were intensely eroded.

The thickest basin fill, set in a rough palaeomorphology controlled by block-faulting, corresponds to the arenaceous-volcaniclastic member. Sharp superposition on facies 1b of fine-grained sandstones and mudrocks (2a), yielding bivalve remains near Averara, seemingly points to momentarily reduced clastic input and/or to the spreading of shallow basin floors. Later (2b), a tectonic subsidence exceeding 100 m/My was matched by deposition of a thick pile of coarser-grained, subaerial to subaqueous mass flow volcaniclastics. Ongoing volcanism is suggested by a bimodal, "rift-like" association fostered by lithospheric thinning through the active wrench faults, also causing extensive erosion of the hanging-wall source areas. Contrasting sandstone composition in the Orobic and Camuna Anticlines is a second line of evidence against physical continuity of the Collio Basin, although it may be accounted for also by deeper dissection of the eastern basement highs and/or lesser contribution from the volcanic plateaux exposed there.

The Ponteranica Conglomerate, as well as the coeval coarse-grained clastics from other localities of the Orobic Alps, marks a stage of progradation of immature, cobbly facies, deposited in fan-delta setting at least partly below lake level. Whether this event was triggered by climatic trends (increased rainfall) or renewed tectonic activity (relative uplift of source areas) can be only tentatively inferred. Preservation of fresh feldspar in the interbedded sandstones is at odds with a humid climate, whereas the invariably positive - although very low - correlation coefficients of polycrystalline quartz and alkalifeldspar, as well as of granitoid and orthogneissic rock fragments, vs. stratigraphy ($r = 0.081 \div 0.170$, sign. lev. $> 10\%$) hint at unroofing of basement rocks. The second line of evidence, however, is not unequivocal because all the mentioned grain types - with the possible exception of alkalifeldspar - are originally coarse-grained

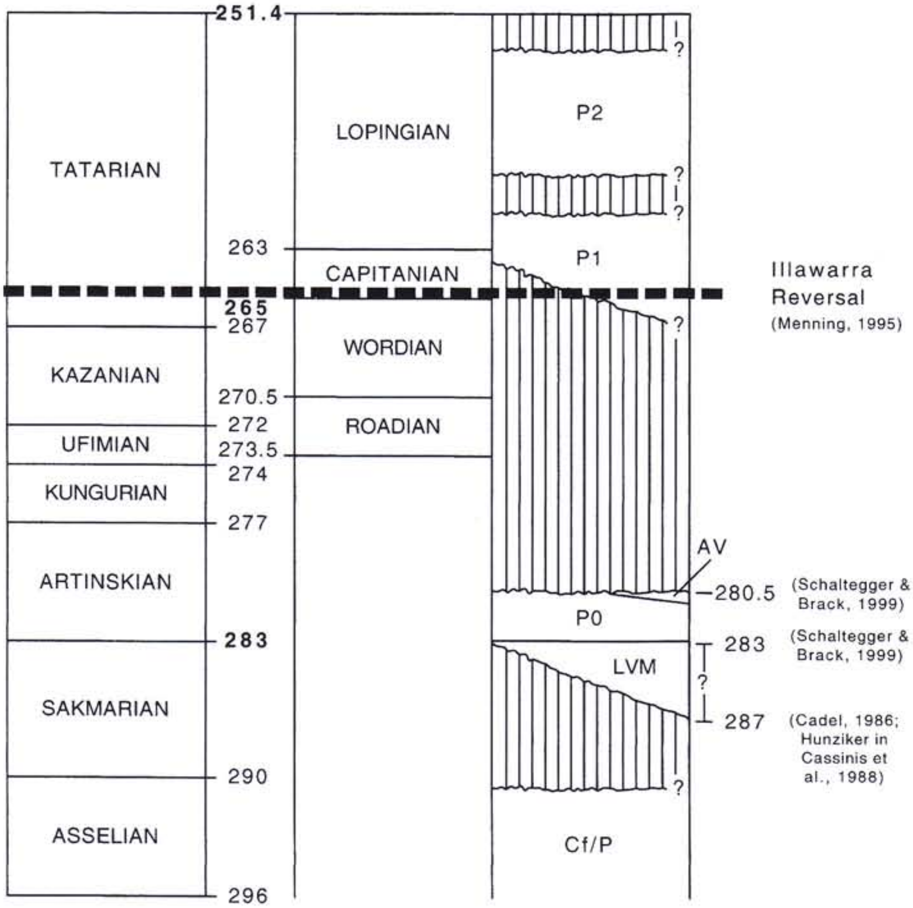

Fig. 10 - Compilation of the available geochronological and magnetostratigraphic data for the Permian of the Orobic to Camuna Anticlines. Time scale after Menning (1995); petrologic intervals (Dickinson & Rich 1972) as in Fig. 7 are displayed instead of lithostratigraphic units. LVM = lower volcanic member of the Collio Formation; AV = Auccia Volcanics.

and their abundance is positively correlated with grain size; correlation coefficients range from 0.089 (polycrystalline quartz; sign. lev. > 10%) to 0.706 (orthogneissic rock fragments; sign. lev. < 0.1%). Volcanic activity seemingly ceased at this stage, as suggested by the lack of volcanic intercalations.

During deposition of the finer-grained upper arenaceous-pelitic member, subsidence was more widespread and reduced, as documented by fairly constant stratigraphic thickness; this is consistent with ceasing normal fault activity. Occurrence of tetrapod footprints, as well as of shallow-water sedimentary structures (wave ripples, clay chips) in the upper part of the member suggests progressive infilling of the lake basin and reduction of the water body even under reduced clastic input. Preservation of abundant fresh detrital feldspars is consistent with both short transport and arid climate. Arid climates would also explain the occurrence of ferroan carbonate layers, crusts and nodules, interpreted as pseudomorphs after evaporites, in the upper "Sedimentary Member" of the Trabuchello-Cabianca and Cedegolo Anticlines (Cassinis et al. 1986). There, conspicuous footprints are found approximately at the same stratigraphic level as the ferroan carbonate and Ca-sulphate lenses (Forcella et al. 2001).

An alternative explanation might be the encroachment of coastal environments onto the former lake basin. Actually, a marine transgression in the Collio Basin would explain both reduced clastic input and finer grain size of the clastic sediments, as well as the remarkable input of Ca and SO_4 ions, deposited as evaporites in sabkha settings. The occurrence of benthic foraminifers is the most important line of evidence supporting the marine transgression model, which, on the other hand, is not indicated by any significant change in sandstone modes and is poorly documented by sedimentary structures (symmetrical ripple-marks may occur in lacustrine as well as in shallow-marine settings). The marine transgression model, if correct, would imply that 1) the Collio basin was not only a hypersaline, but also a coastal lake; it was eventually reached by an at least temporary seaway as a result of either a pronounced eustatic rise or rapid subsidence/erosion of its damming ridge, and 2) altitude of the late Collio lake level cannot have exceeded the amplitude of a first-order sea-level rise, that is, about 100 m.

The hiatus at the top of the Collio Formation may be as long as 10 My (see below). This angular unconformity has been traditionally interpreted as documenting the effects of active tectonics in terms of strike-slip faulting, intraplate wrenching, and inversion of the Late Carboniferous-Early Permian basins (Cadel et al. 1996). Critical revision of the apparent tilting directions of the Collio Formation with respect to the overlying Verrucano Lombardo might suggest that folding, and not simple tilting, occurred at this stage (Cadel et al. 1996).

Permian chronostratigraphy in the Orobic Alps: a review.

A largely Early Permian (Autunian) age for the Collio sediments is indicated by macrofloral remains (Cassinis 1966; Casati & Gnaccolini,1967; Remy & Remy 1978). U/Pb zircon ages from the lower volcanics range from 280÷287 (Cadel 1986) to 283±1 My (Schaltegger & Brack 1999). Rb/Sr and K/Ar ages from the basal volcanics are 287 My (J.K. Hunziker, unpublished data in Cassinis et al. 1988). Palynomorphs from the Collio sediments are ascribed to the Artinskian-Roadian (Cassinis & Doubinger 1991). U/Pb zircon ages of 280.5±2 My were obtained from the overlying Auccia volcanics (Schaltegger & Brack 1999). All of these age constraints fit in the time scale of Menning (1995), placing the Sakmarian/Artinskian boundary at 283 My (Fig. 10). If so, the whole Collio Formation should have been deposited in the latest Sakmarian (Tastubian) to mid-Artinskian, during a time span possibly as short as 5 My or less. Slightly older ages (Cadel 1986; Cassinis et al. 1988) might partly reflect a polyphase cooling history of the late hercynian magmas, resulting in inherited zircon cores.

Very high sedimentation rates for the Collio clastics are consistent with the single petrofacies characterising a complete sandstone section, commonly exceeding 800 m in thickness, independent of facies variations and grain size. Each petrofacies reflects in fact a peculiar, temporary balance of interplaying factors such as source rocks, tectonic context, climate, sedimentary processes and drainage patterns (Johnsson 1993). Such an equilibrium is unlikely to last for more than some My, because significant variations of just one of the factors mentioned above (e.g., unroofing of basement rocks; block-faulting; increasing rainfall; relative sea-level rise; river captures) may cause conspicuous and systematic changes in sand mineralogy. Concurrent variations of two or more factors are unlikely to compensate, and will rather result in a new temporary equilibrium.

In the Upper Permian to Carnian succession of the Southern Alps, the estimated lifetime of each petrofacies is about 4±1 My on the average. Two petrofacies are recognised in fact in the Upper Permian, three in the Lower Triassic, three in the Anisian (Sciunnach et al. 1996) and three to five in the Carnian (Garzanti et al. 2001). A similar duration for petrologic interval P0 would match the time constraints indicated in Schaltegger & Brack (1999).

A major unanswered question is the duration of the hiatus marking the Collio Formation/Verrucano Lombardo boundary. The supposed latest Permian age of the Verrucano Lombardo, tentatively confined to the Lopingian in recent works (e.g., Cassinis & Neri 1999), seemingly contrasts with:

1. reported occurrence of the Illawarra reversal within the roughly coeval Val Gardena sandstones of the eastern Southern Alps (Dachroth 1976; Mauritsch & Becke 1983; Dachroth 1988). This major palaeomagnetic event occurred during the early Tatarian (Khramov 1963; Gialanella et al. 1997), the base of which has been extended to ages as old as 267 My, and - accordingly - around the Wordian/Capitanian boundary in the new Permian time scales (Menning 1995; Menning & Jin 1998; Glenister et al. 1999).

2. occurrence of a hiatus at the boundary with the Lower Triassic Servino Formation, documented by another, abrupt increase in mineralogical stability and textural maturity from Petrofacies P2 to Petrofacies S1 (Sciunnach et al. 1996), as well as by progressive onlap of tidal flat facies onto the Verrucano Lombardo continental floodplain (Sciunnach et al. 1999b). Such a hiatus is likely to be confined almost entirely to the uppermost Permian, as suggested by facies correlation of the Praso oolitic limestone of eastern Lombardy with the Tesero Horizon of the Dolomites (Cassinis et al. 1993), and by the occurrence of *Claraia* bivalves of latest Griesbachian-early Dienerian age in the Ca' San Marco Member of the Servino Formation (Posenato et al. 1996; Sciunnach et al. 1999b).

A further line of evidence - although less conclusive - is the occurrence of an intraformational hiatus within the Verrucano Lombardo, documented by the sharp increase in mineralogical stability from Petrofacies P1 to Petrofacies P2 (Sciunnach et al. 1996).

The tectonic event documented by the angular unconformity between the Collio Formation and the Verrucano Lombardo has long been considered coeval with the Saalian "phase". Actually, not only regional correlation of tectonic phases is a questionable stillean concept (Sengör 1990), but in this case poses also timing problems. The Saalian "phase" was in fact originally ascribed to the hiatus between the lower and upper Rotliegendes. Such a hiatus, according to recent Permian time scales, would fall around the Asselian-Sakmarian, probably before the Collio Formation started to be deposited. The hiatus between the Collio Formation and the Verrucano Lombardo (Kungurian-Wordian) would rather correlate with a major unconformity within the upper Rotliegendes, recognised between the Müritz and Havel-Elbe subgroups and spanning a time interval of 8 to 20 My (Ufimian to Kazanian after Menning 1995; Kungurian to Kazanian after Pokorski 1997; Kiersnowski 1997). This event surely coincides in time with the end of the Early Permian volcanism (thin volcanic intercalations in the lower Verrucano Lombardo are reported only by Cadel 1986) and with a major shift in the subsidence patterns, from localised to regional. Moreover, it might correspond to a stage of widespread fault-bound mineralization of the Lower Permian rocks.

Conclusions.

1. Field mapping at the 1:10 000 scale of the Lower Permian in the Orobic Anticline allowed recognition of systematically superposed facies, better defined subdivision of the stratigraphic succession with respect to the available framework, and reconstruction of the basin architecture, including inferred location of the depocentre and of the major master faults. Easily-recognised mapping units also correspond to distinct, subsequent stages of volcanic activity vs. tectonic subsidence and sedimentation patterns.

2. Geochemistry of the volcanic rocks, prevailing in the lower part of the Collio Formation, is highly variable along section. Early paroxysmal effusion of intermediate welded tuffs (benmoreites) was followed by a synsedimentary, polymodal volcanic activity characterised by both differentiated (dacites to rhyolites) and primitive products (mugearite flows). Such an evolution seemingly contrasts with features of the Early Permian volcanism in the Trabuchello-Cabianca and Camuna Anticlines, where "andesites" are found at the base of the volcanic plateau, and rhyodacites to rhyolites prevail by far over other volcanic rock types. Seemingly, the volcanic centres feeding the western edge of the Collio Basin were thus distinct and/or non-coeval with those in the central-eastern sector; occurrence of rare clasts of intermediate volcanics in the lowermost rhyolites of the Novazza-Val Vedello district (G. Cadel, pers. comm. 2001) may suggest that the volcanic member of the Orobic Anticline (intervals 1-9 of the Pradini Valley section) was older.

3. Petrography of sandstones, fairly uniform both vertically and laterally, invariably falls in the "volcanic arc" field of Dickinson (1985). This does not imply, of course, that the Collio clastics were derived strictly from a volcanic arc, but surely from an overwhelming neovolcanic source (Zuffa 1985), represented by the Lower Permian volcanic plateaux. Homogeneous petrography of a clastic succession approaching 1000 m in thickness, independent of strong variability in sandstone facies and grain size, contrasts with the number of petrofacies recognised in the overlying and thinner clastic units of Late Permian to Carnian age, and suggests high sedimentation rates for the Collio Formation, in agreement with the short time span recently assigned to this unit by radiometric data obtained in the Camuna Anticline (Schaltegger & Brack 1999). Unfortunately, to date any biostratigraphic control on radiometric ages has been hampered by the poor fossil content of the unit and by the scarce biostratigraphic value of the discovered taxa. The remarkable difference in sandstone composition between the Orobic and Camuna Anticlines (Cassinis et al. 1978) is another line of evidence against physical continuity of the Collio Basin.

4. Facies architecture, geochemistry of the magmatic products and sedimentary evolution fit into a palaeogeodynamic scenario of continental wrenching (Arthaud & Matte 1977). By Sakmarian-Artinskian times the Hercynian orogen was being disrupted by transtensional faults bounding strongly subsiding continental basins. The major faults were "leaky" (Massari 1988) and drove to the surface calc-alkaline magmas produced by partial melting of a lithospheric mantle metasomatised by the Hercynian subduction (Cortesogno et al. 1998). Stretching and unloading of the continental crust in wrench settings also favoured a later, limited upwelling of less differentiated magmatic products.

5. An entirely continental setting for the upper Collio Formation in the Orobic Anticline can be questioned in the light of the discovery of calcareous foraminifers (Miliolacea) 30 m below the Collio/Verrucano unconformity, in beds deposited under reducing conditions and displaying symmetrical wave ripples. Foraminifers adapted to normal salinity actually fit in the salt lake model (Cassinis et al. 1986), but they do require an at least temporary seaway. A marine transgression at this stage is poorly supported by other sedimentary evidence and is at odds with all the palaeogeographic reconstructions proposed to date, although coeval fusulinid limestones are found in the surrounding areas of the Carnic Alps (Trogkofel Group), the northern Adriatic offshore (Amanda 1bis well: Sartorio & Venturini 1988), and Tuscany (Kalher & Kalher 1969; Engelbrecht et al. 1988). Perhaps the present-day Salton Sea (an intramontane salt lake, confined to a tectonic depression controlled by the San Andreas strike-slip fault system, and separated from the California Gulf by the Colorado River delta) might represent a good actualistic analogue for the late Collio Basin.

Acknoledgements.

Much of the field work was carried out with G.B. Siletto, A. Piccin and students (U. Acerboni, D. Milani, M. Milesi, M. Maggioni, F. Pozza, M. Ricotti, M. Rota). The author is deeply indebted to M.P. Confalonieri for help during some field trips, to A. Gregnanin for providing and discussing the geochemical data, and to F. Massari and M. Menning for providing rare bibliography. Useful discussions with C. Breitkreutz, G. Cassinis, F. Forcella, G. Gosso, R. Rettori and L.A. Ronchi are also acknowledged. Technical assistance was provided by D. Biondelli (WDS microanalysis), R. Crespi (photomicrographs), C. Malinverno (thin sections), G. Manarolla (fossil preparation), S. Renesto (fossil photographs) and A. Rizzi (EDS microanalysis). An earlier draft of the manuscript has been remarkably improved by the constructive criticism of G. Cadel, M. Gaetani and E. Garzanti. Field and laboratory work supported by CARG grants. Project MURST-1999 "L'eredità litosferica mesozoica tetidea nei processi subduttivi e collisionali del Mediterraneo centro-orientale".

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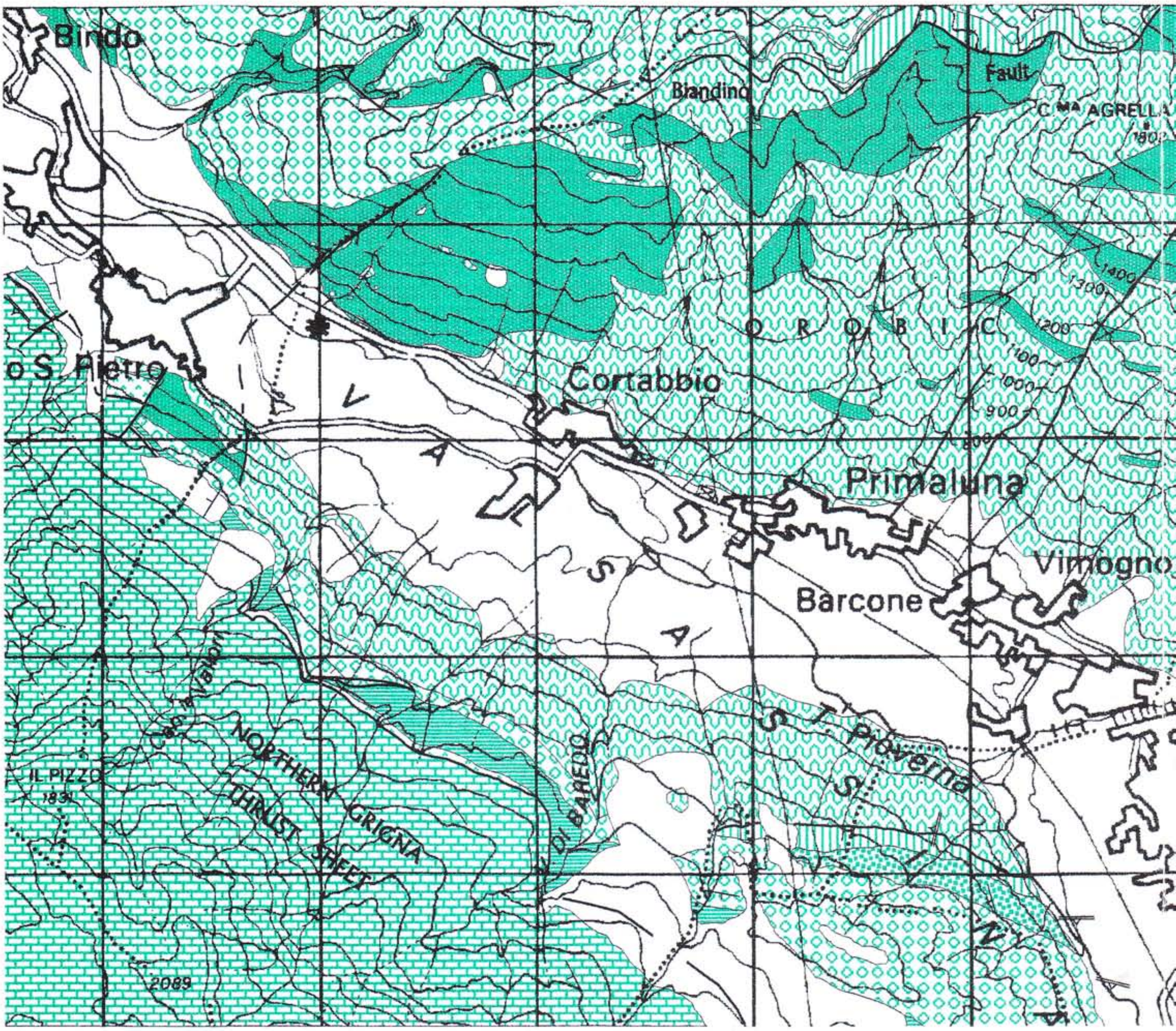

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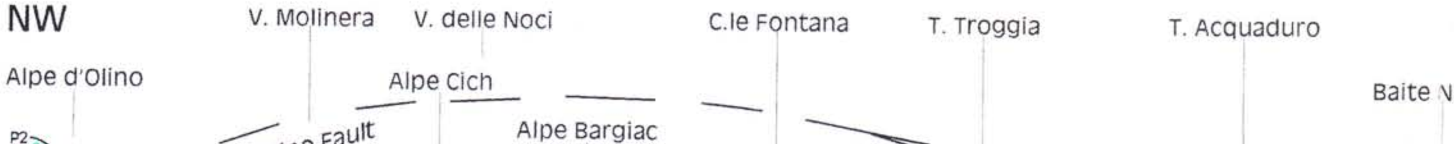

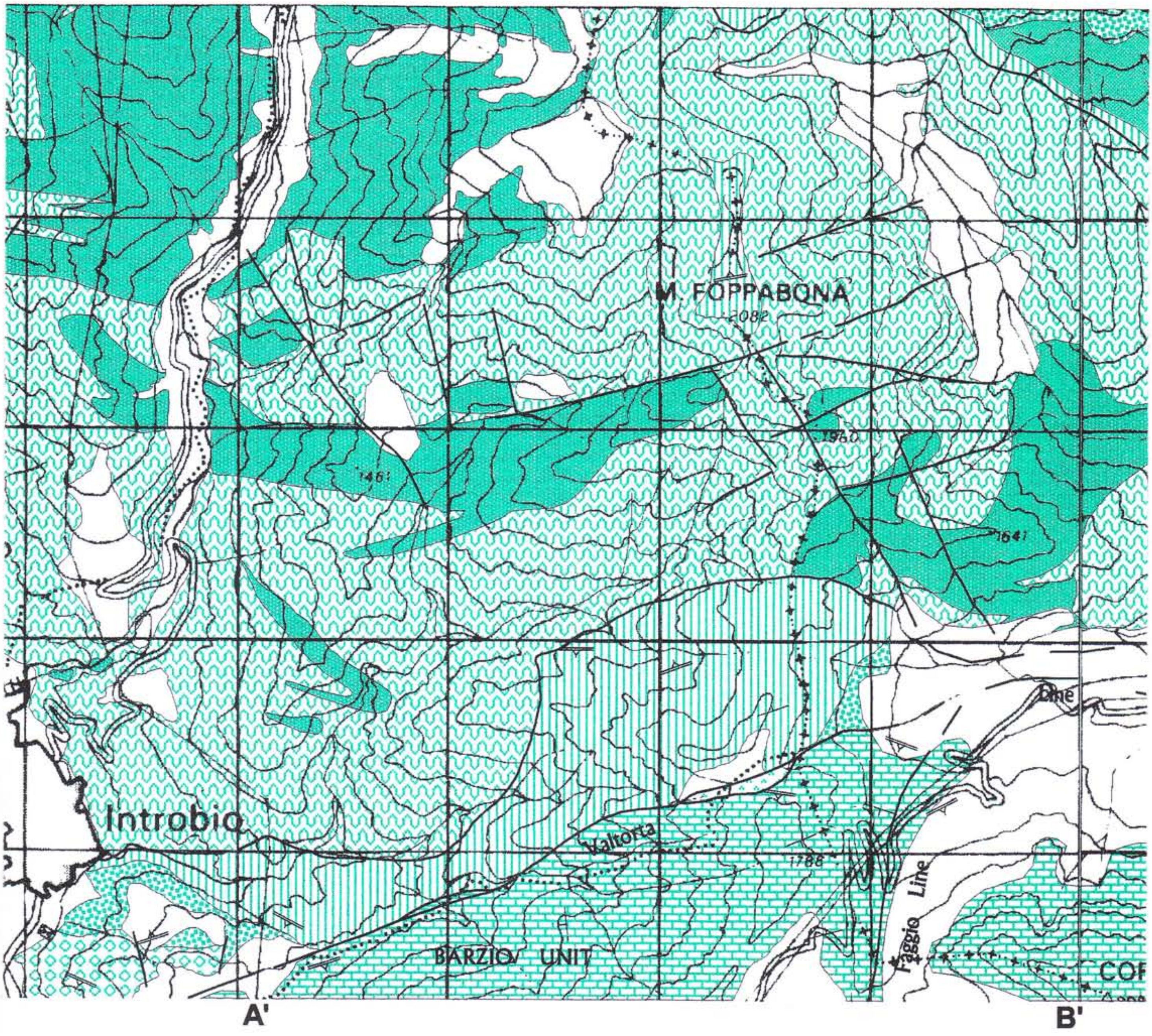
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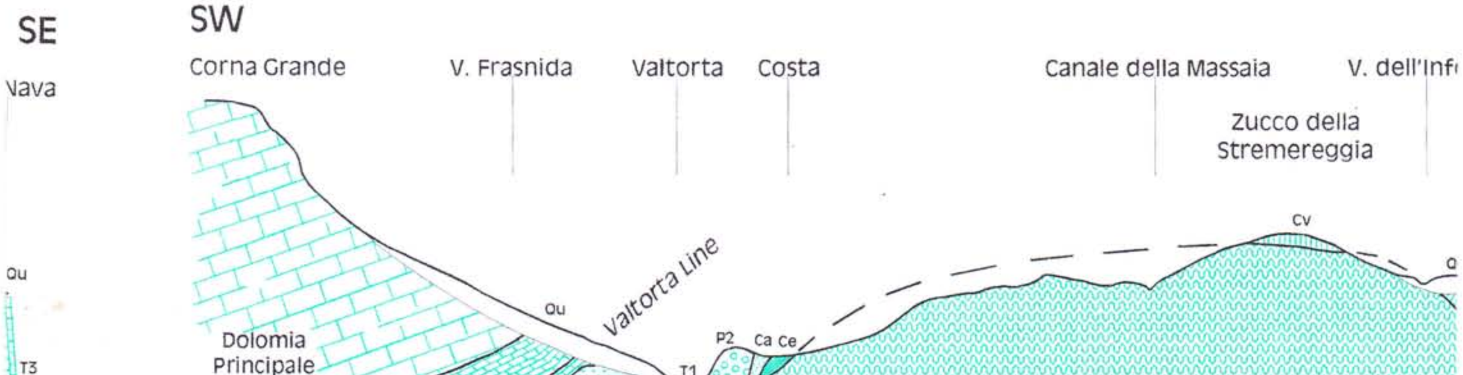
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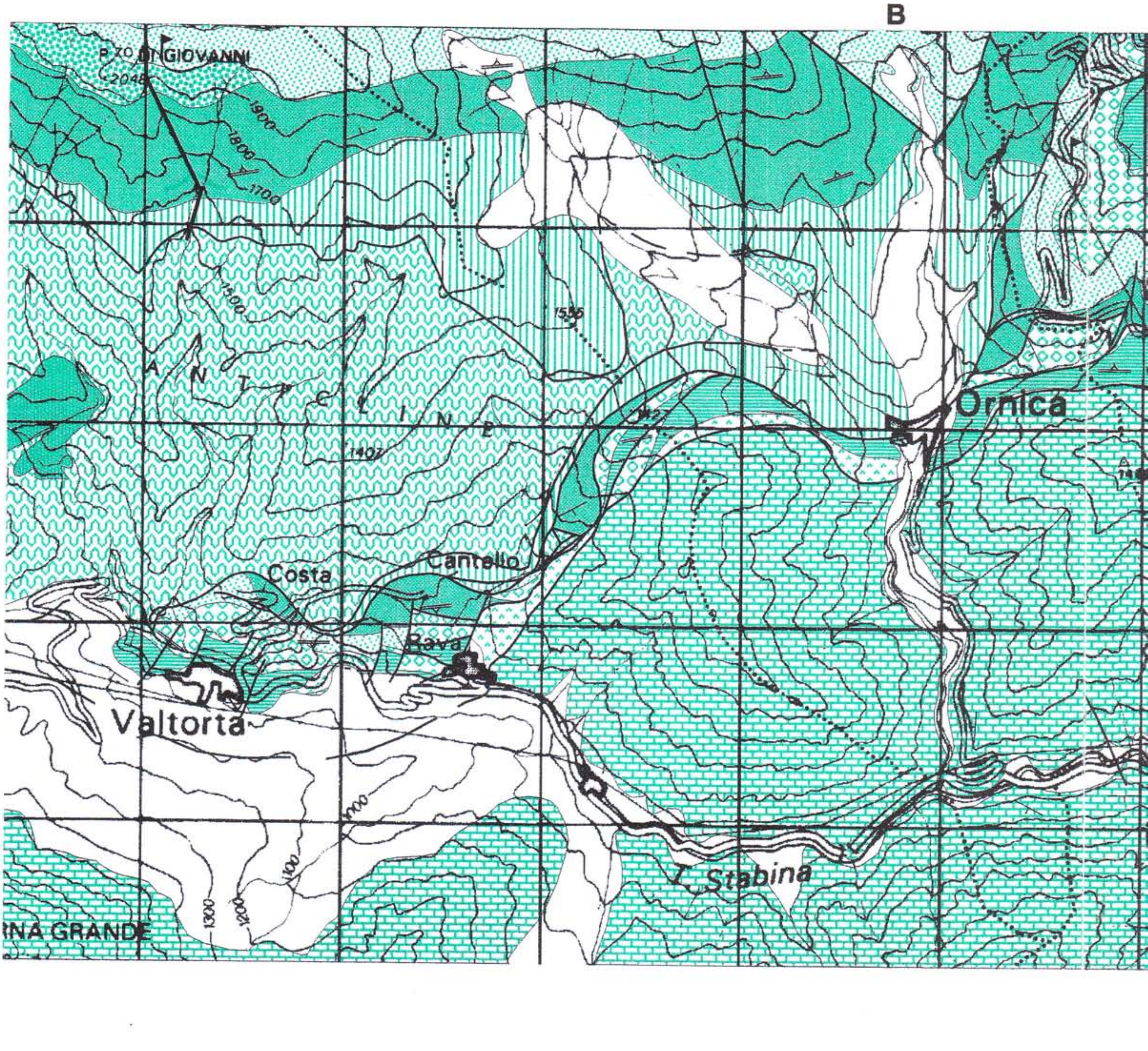
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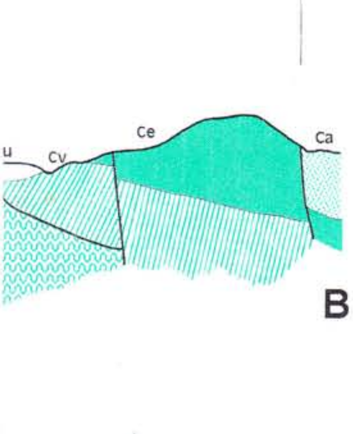
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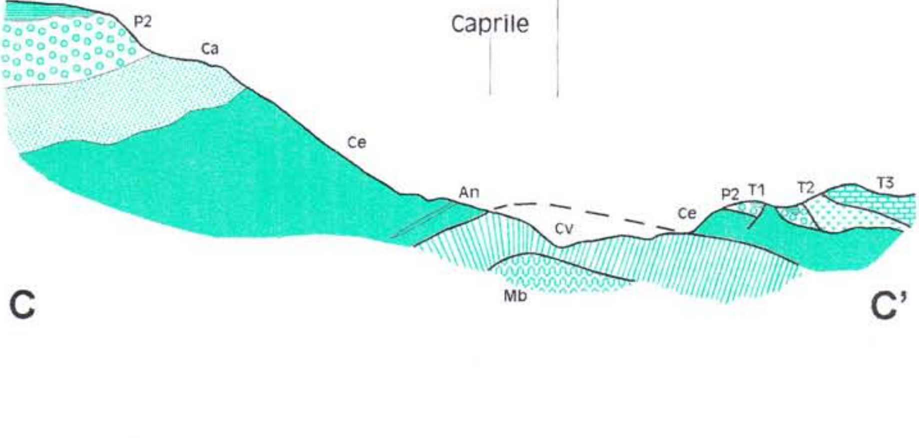
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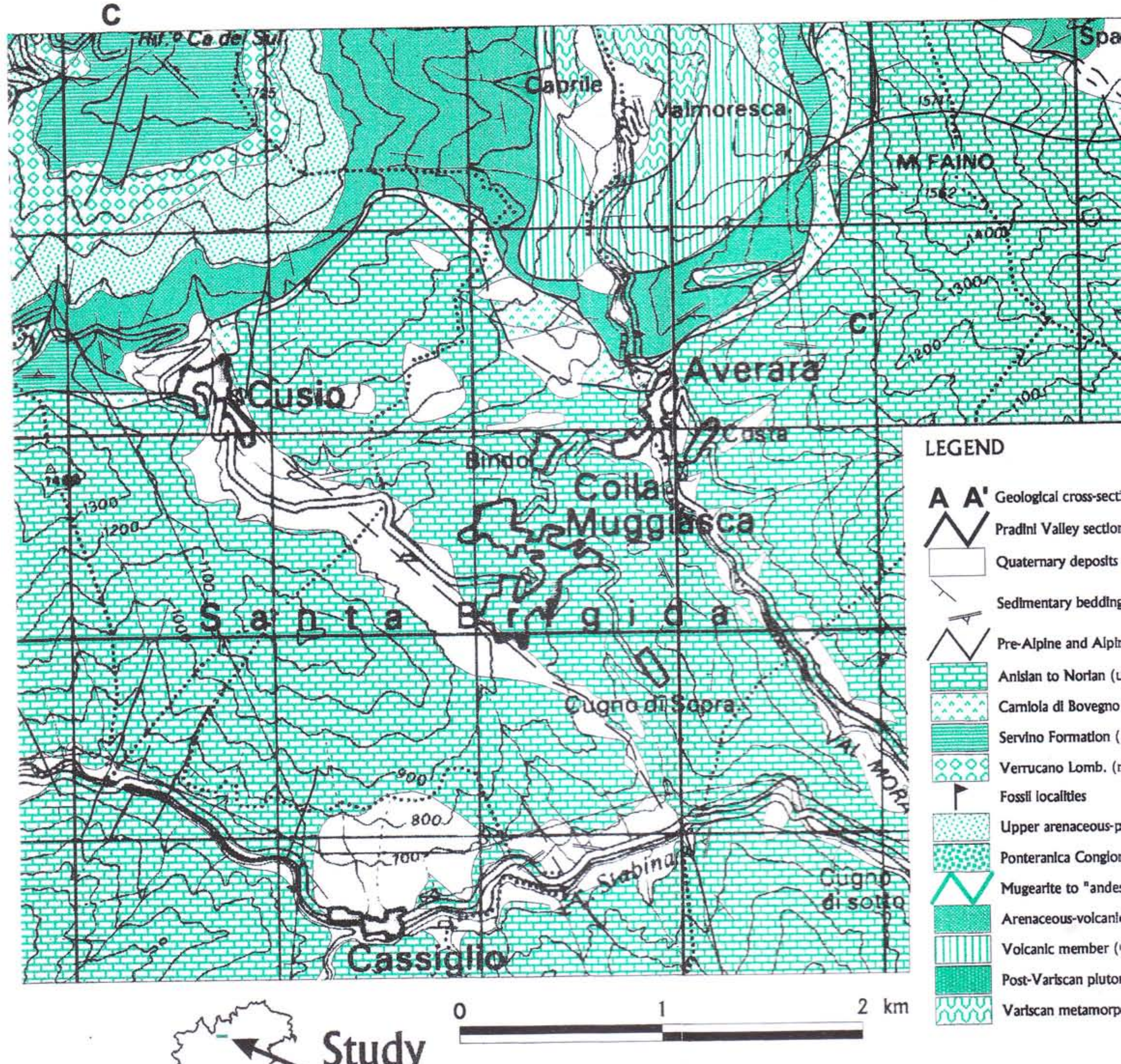

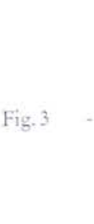

Geological map of the Orobi
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Fig. 3 - Geological map of the Orobic Anticline in the framework of the forthcomin
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Scale of the geological cross-sections is the same as the map, with no vertical
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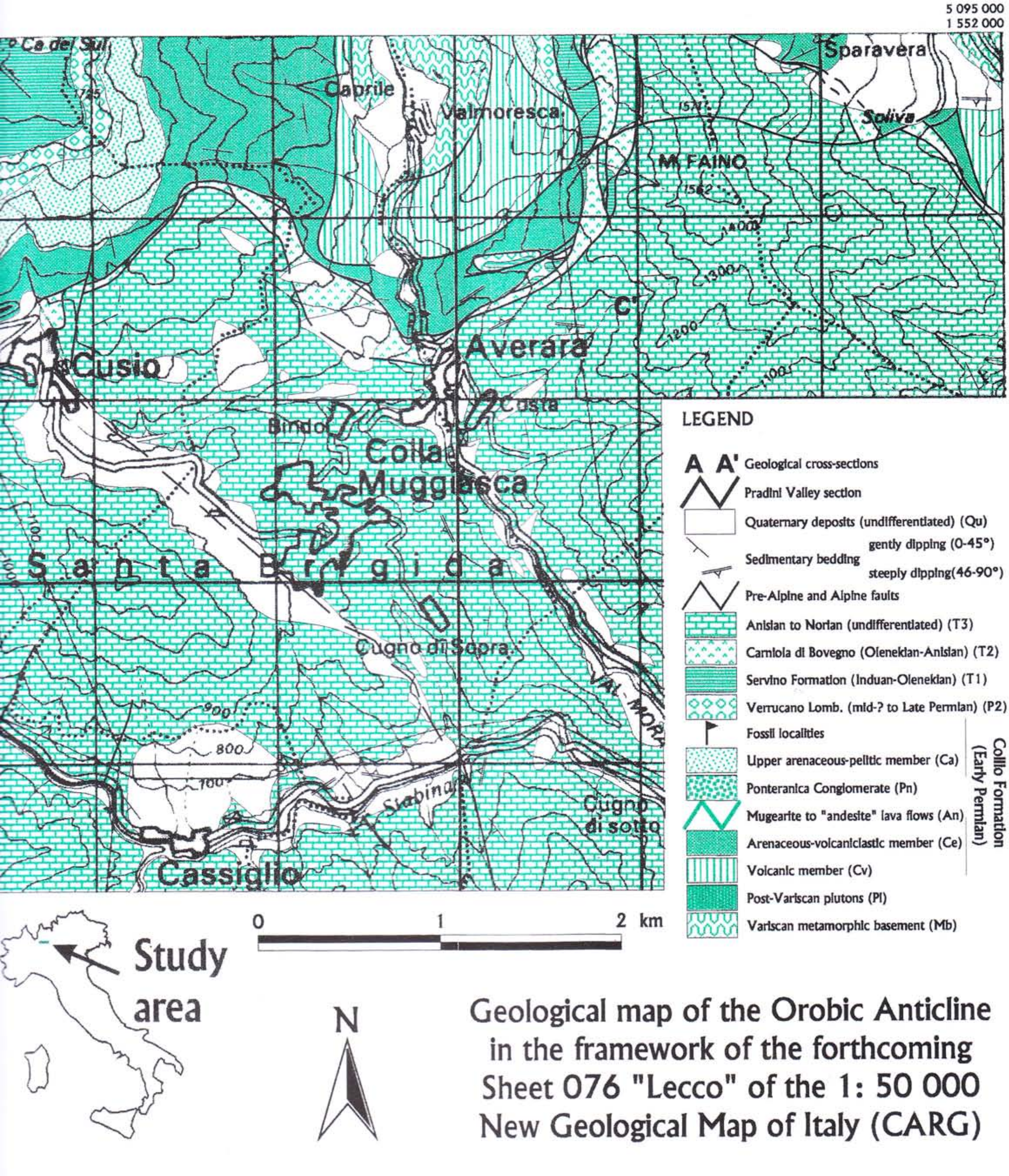

Fig. 3 - Geological map of the Orobic Anticline in the framework of the forthcoming Sheet 076 "Lecco" of the new 1: 50 000 geological map of Italy. Gauss-Boaga co-ordinates are given for the NE and SW corners. Scale of the geological cross-sections is the same as the map, with no vertical exaggeration. Topographic base from the 1:50.000 Carta Tecnica Regionale (Sheets B4, C4).