Sedimentary and palaeotectonic evolution of some Permian continental basins in the central Southern Alps, Italy.

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ABSTRACT

The authors have dealt with the sedimentary and palaeotectonic evolution of some selected Permian continental basins located in the central South-Alpine domain, immediately to the west and east of the Giudicarie Line. In this area the Permian System can be divided into two well differentiated tectono-sedimentary cycles separated by a marked unconformity.

The first one (generally spanning late Early Permian to Ufimian times) consists of lacustrine and alluvial fan deposits (Collio Fm, Tregiovo Fm, etc.) as well as of volcanics, both infilling intermontane grabens or half-grabens separated by metamorphic and igneous highs. The boundary faults generally have SSW-NNE and E-W trends and often coincide with long-lived tectonic lineaments reactivated as late as the Alpine orogeny (such as the Trompia Line, Valsugana L., Giudicarie L., etcétera).

The second cycle (Late Permian, from the Tatarian (?) to the P/T boundary or almost) is represented by fluvial clastics (Verrucano Lombardo and Val Gardena Sandstone) and, only to the east of the Adige Valley, by sulphate evaporites to the shallow marine carbonate succession of the Bellerophon Fm. These deposits form a widespread blanket which covers both the basins of the first cycle and the surrounding highs. The continuity of tectonic control is documented by strong changes in thickness (from a few tens of metres on the Adige-Giudicarie highs to several hundreds of metres in the depocentral areas, such as Cadore-Comelico).

A reorganisation of the Permian tectonics occurs at the boundary between the

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two cycles, which is probably correlatable to the "Middle" Permian tectonics of Hercynian Europe (i.e. post-Saalian, Altmark, Palatine movements). The new configuration is attested to the different geometry of the rock bodies pertaining to both cycles as well as to the frequent switching of depocentres (structural highs of the first cycle sometimes acted as strongly subsiding areas during the second one).

Key-words: Permian, Collio Basin, Tione Basin, Tregiovo Basin, sedimentary evolution, palaeotectonics, lower cycle, upper cycle, Southern Alps, Italy.

RESUMEN

Este trabajo describe la evolución sedimentaría y paleotectónica de algunas cuencas sedimentarías pérmicas del área suralpina central, localizadas al oeste y al este de la Línea de Giudicarie (Italia).

La sucesión pérmica de los Alpes meridionales, comprende dos ciclos tecto-sedimentarios mayores, separados por una clara discordancia.

En el sector considerado, el ciclo inferior (correspondiente al intervalo Pérmico inferior-Ufemiense) está constituido por depósitos fluvio-lacustres (Fm Collio, Fm Tregiovo, etc.) asociados a vulcanismo, generalmente de tipo ácido. Estos materiales constituyen el relleno de «grabens» o «semigrabens», separados por altos estructurales. Las fallas limitantes tienen, en general, una dirección SSO-NNE y E-O, y a menudo coinciden con antiguas zonas de fractura, reactivadas al final de la orogenia alpina (Linea del Val Trompia, L. de Valsugana, L. de Giudicarie, etcétera).

El segundo ciclo (Pérmico superior, desde el Tartaniense (?) al límite P/T o cercano a él) está representado por sedimentos fluviales (Areniscas de Verrucano Lombardo y Val Gardena). Tan sólo al este del valle Adige, existen evaporitas y carbonatos marinos de la Fm Bellerophon. Los depósitos del segundo ciclo forman un cuerpo continuo lateralmente, que recubre tanto las cuencas del primer ciclo como los umbrales que existian durante el mismo. La persistencia de una tectónica distensiva está registrada por la existencia de importantes variaciones de espesor (desde algunas decenas de metros en los umbrales de Adige-Giudicarie, hasta cientos de metros en las áreas de depocentro, como la de Cadore-Comelico).

El límite con el segundo ciclo está caracterizado por una reorganización de la tectónica del Pérmico, probablemente correlacionable con algún movimiento del Pérmico medio de la Europa hercínica (movimientos post-saálicos, Altmark o palatinos). La nueva confirmación queda reflejada tanto por la diferente geometría de los cuerpos rocosos de ambos ciclos, como por la frecuente variación de los depocentros (los altos estructurales del primer ciclo, a veces actúan como áreas de gran subsidencia durante el segundo).

Palabras clave: Pérmico, Cuenca del Collio, Cuenca del Tione, Cuenca de

Tregiovo, evolución sedimentaria, paleotectónica, ciclo inferior, ciclo superior, Alpes meridionales, Italia.

RIASSUNTO

Il presente lavoro descrive l'evoluzione sedimentaria e paleotettonica di alcuni bacini continentali permiani del Sudalpino centrale, localizzati immediatamente ad ovest e ad est della Linea delle Giudicarie.

La successione permiana delle Alpi Meridionali comprende due cicli tettono-sedimentari maggiori, separati da una chiara discordanza.

Nel settore considerato, il ciclo inferiore (databile in buona parte all'intervallo Artinskiano-Ufimiano) consiste di depositi fluvio-lacustri (Fm di Collio, Fm di Tregiovo, ecc.) associati a vulcaniti generalmente acide e quasi; questi materiali costituiscono il riempimento di graben, in qualche caso asimmetrici, separati da alti strutturali. Le faglie bordiere hanno in genere direzioni SSW-NNE e E-W, e spesso coincidono con lineamenti ancestrali più volte riattivati fino all'orogenesi alpina (Linea della Val Trompia, L. della Valsugana, L. delle Giudicarie, ecc.).

Il secondo ciclo (Permiano Superiore *s.l.*, dal Tatariano (?) sino al limite superiore o quasi del Periodo) è rappresentato da sedimenti fluviali e, ad est della Val d'Adige, dalle evaporiti solfatiche e dai carbonati marini della Fm a Bellerophon. I depositi del secondo ciclo formano un corpo lateralmente continuo che ricopre sia i bacini che gli alti del ciclo precedente. La persistenza di una tettonica distensiva è documentata da vistose variazioni di spessore (da poche decine di metri in alcuni settori dell'alto dell'Adige-Brenta a parecchie centinaia di metri nel depocentro cadorino).

Il limite tra i due cicli è caratterizzato da una riorganizzazione della tettonica permiana, probabilmente correlabile agli eventi Medio-Permiani dell'Europa Ercinica (movimenti post-Saaliani, di Altmark, o Palatini), e documentata sia dalla diversa geometria dei corpi appartenenti ai due cicli, sia dalla disattivazione di alcune linee e dall'inversione o nascita di altre.

Parole chiave: Permiano, Bacino di Collio, Bacino di Tione, Bacino di Tregiovo, evoluzione sedimentaria, paleotettonica, ciclo inferiore, ciclo superiore, Alpi Meridionali, Italia.

INTRODUCTION

The Permian System of the Southern Alps can be divided into two main very distinct tectono-sedimentary cycles, separated by a marked unconformity (ITALIAN IGCP 203 GROUP, ed., 1986). (Fig. 1).

The lower cycle (I) is represented by volcanics and subordinate alluvial-lacustrine deposits, locally associated within intermontane basins, in most of the Southern Alps

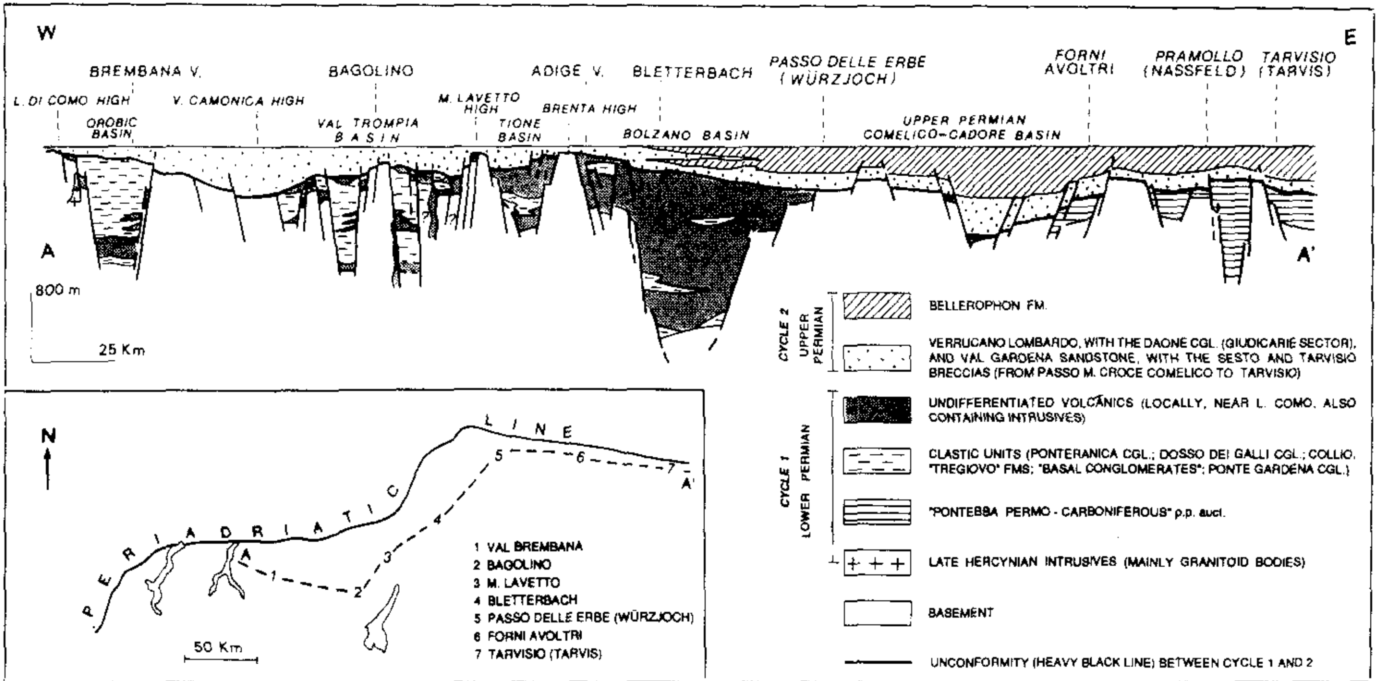


Fig. 1.—Diagrammatic and simplified non-palinspastic cross-section (see trace on the inset map) through the Permian of the Southern Alps. Datum-line: base of the Werfen Formation (=Servino Fm in Lombardy). (After Cassinis *et al.*, 1988).

Fig. 1.—Corte transversal, no palimpástico, esquemático y simplificado, a través del Pérmico de los Alpes meridionales. Línea de referencia: base de la Formación Werfen (=Fm. Servino en Lombardia). (Según Cassinis *et al.*, 1988).

as well as by paralic-marine terrigenous to carbonate sequences in the Carnia area.

The upper cycle (2) consists of widespread clastic fluvial sediments and, only east of the Adige Valley, of the evaporitic - carbonate succession of the Bellerophon Formation.

Recent research, in collaboration with J. Doubinger from Strasbourg, have led to more accurate dating of both cycles in the central South-Alpine domain (see Cassinis & Neri, 1990). According to palynological data, the Collio and Tregiovo Formations, included in Cycle 1, may be attributed to the late Early Permian and probably, above all with regard to Tregiovo Fm, also to the earliest Late Permian. Following the Cis-Uralian standard geological scale, their depositional range seems

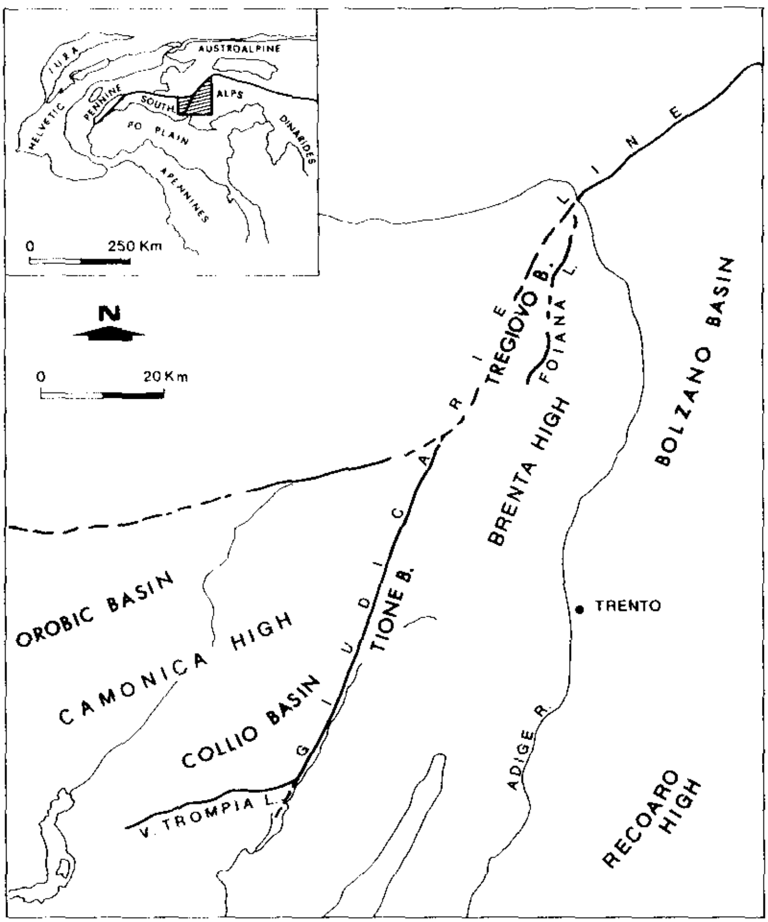
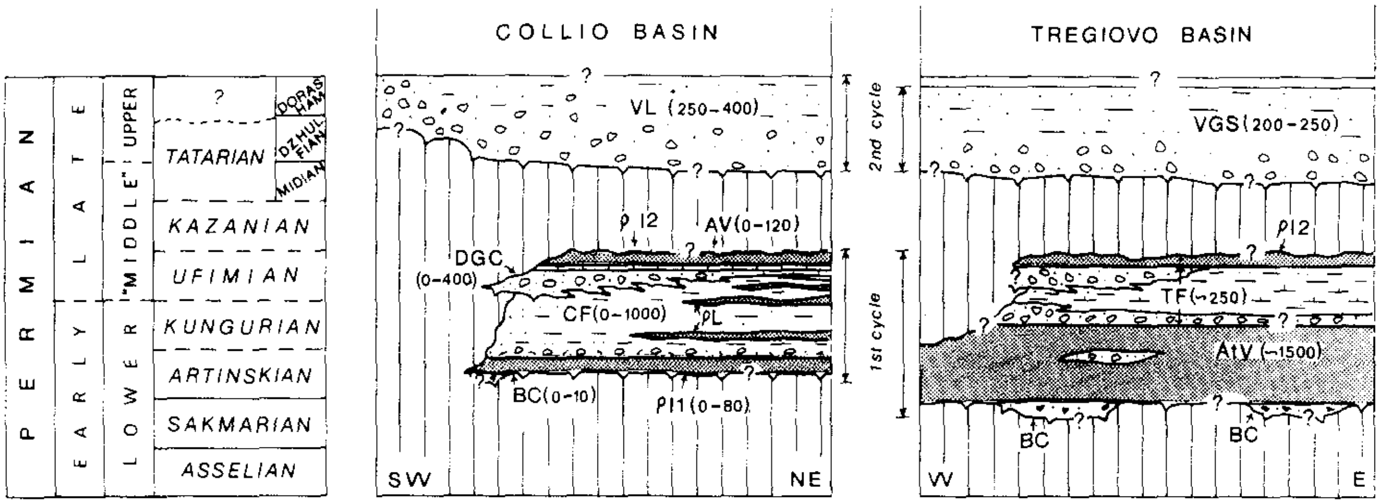


Fig. 2.—Location of the Permian Collio, Tione and Tregiovo basins on both sides of the Giudicarie Line, central Southern Alps, in relation to other basins and to structural highs.

Fig. 2.—Situación de las cuencas pérmicas de Collio, Tione y Tregiovo, a ambos lados de la línea Giudicarie, y su relación con las otras cuencas y los umbrales estructurales.



CONGLOMERATE (VERRUCANO LOMBARDO: **VL**; DOSSO DEI GALLI CGL: **DGC**; BASAL AND, LOCALLY, UPPER PARTS OF THE COLLIO AND TREGIOVO FMS)

SANDSTONE (VERRUCANO LOMBARDO: VL; VAL GARDENA = GRÖDEN SANDSTONE: **VGS**; LOCALLY, UPPER PARTS OF THE COLLIO AND TREGIOVO FMS)

GENERALLY SHALE-SANDSTONE (COLLIO FM: **CF**; TREGIOVO FM: **TF**)

UNDIFFERENTIATED VOLCANICS *(COLLIO BASIN* = UPPER RHYOLITIC IGNIMBRITES: **ρl2**; LAVA-FLOWS: **ρL**; TUFFS BELOW CF; BASAL RHYOLITIC IGNIMBRITES: ρl1. *TREGIOVO BASIN* = UPPER RHYOLITIC IGNIMBRITES: **ρl2**; ATHESIAN VOLCANICS: **AtV** (INCLUDING AT THE TOP RHYOLITIC IGNIMBRITES IN THE TREGIOVO BASIN AREA)

CONGLOMERATE AND BRECCIA (BASAL CONGLOMERATE: **BC**)

UNCONFORMITY

EROSION SURFACE

STRATIGRAPHIC GAP

to span Artinskian to Ufimian times (Figs. 2 and 3). If we refer to the European continental stratigraphy, the above units could be correlated to the medium and higher levels of the Saxonian or the Upper Rotliegend. Biostratigraphic papers, containing a list and description of the palynological assemblages, are in preparation by J. Doubinger.

From all the geological data, also including regions extraneous to the one considered, the beginning of Cycle 2 must be located in the Late Permian; the age of its base (which may be diachronous) is still undefined.

The dating of the unconformity between the two Permian cycles is therefore not yet known with precision; however, it should be within the «Middle» Permian, where it is probably younger than Ufimian and older than Tatarian. The validity of this dating unfortunately meets with a serious obstacle: the scarce stability of the existing geological time- scales, above all with regard to the Early/ Late Permian transition', due to the paucity of data as well as to their problematic and often imprecise correlation.

LOWER CYCLE

The products, both sedimentary and volcanic, of Cycle 1 (Fig. 1) have been laid down within fault-bounded intermontane basins essentially separated by basement highs. These basins are characterized by quite a similar tectono-sedimentary evolution, which will be described here with reference to some selected examples, viz. the better known Collio, Tione and Tregiovo basins, located in the area between eastern Lombardy and south-western Trentino-Alto Adige (Fig. 2).

Fig. 3.—Chronostratigraphic schemes as applied to the Permian continental basins examined. Thicknesses are approximate. The stratigraphic classification, not drawn to any scale, is based on data taken from several documents of International Working Groups, which are included in Newsletters of SCPS (Permophiles, N° 12-16, 1987-90), as well as of other scientists; it largely reflects the Cis-Ural/Russ.platform standard scale (only the interval from Tatarian up to the top Permian additionally shows, on the right, the USSR Tethyan subdivision, according to Kotljar, 1989 and in Nakazawa, 1990). Both two-fold and three-fold subdivision of the Permian are reported.

Fig. 3.—Esquema cronoestratigráfico, utilizado en las cuencas continentales pérmicas estudiadas. La clasificación estratigráfica (no a escala), se basa en datos de diversos documentos de Grupos Internacionales de Trabajo, incluidos en los boletines de información del SCPS (Permophiles, n° 12-16, 1987-90), así como de diversos investigadores. Esta clasificación refleja en gran parte la escala tipo de la plataforma Cis-Ural/Rus. (tan solo en el intervalo Tatariense- parte superior del Pérmico, se expresa además, a la derecha, la subdivisión rusa para el Tethys, según Kotljar, 1989 y Nakazawa, 1990). Se indican aquí tanto la subdivisión Pérmica doble como la triple.

Collio Basin (Fig. 4)

This is the westernmost of the basins mentioned above. To the south and east it surrounds the Adamello Tertiary magmatic intrusion from the lower Camonica Valley to the Giudicarie Line, with an approximately E-W orientation changing to a NNE-SSW direction along the western side of the Giudicarie Line. This structural disposition, although accentuated by the Alpine tectonics, probably reflects the original geometry of the basin.

The basin was originated as a result of collapse associated with a strong volcanicity, following the Hercynian orogenesis, that gave rise to a rhyolitic ignimbrite plastron and tuff cover resting unconformably on the metamorphic basement. Locally, however, some thin bands and wedges of Basal Conglomerate occur in between the above volcanics and metamorphic complex. Generally these deposits, rich in lithic basament fragments, are found on the Permian mountain ridge that from the upper Trompia Valley, through Mt. Muffetto, continues into the

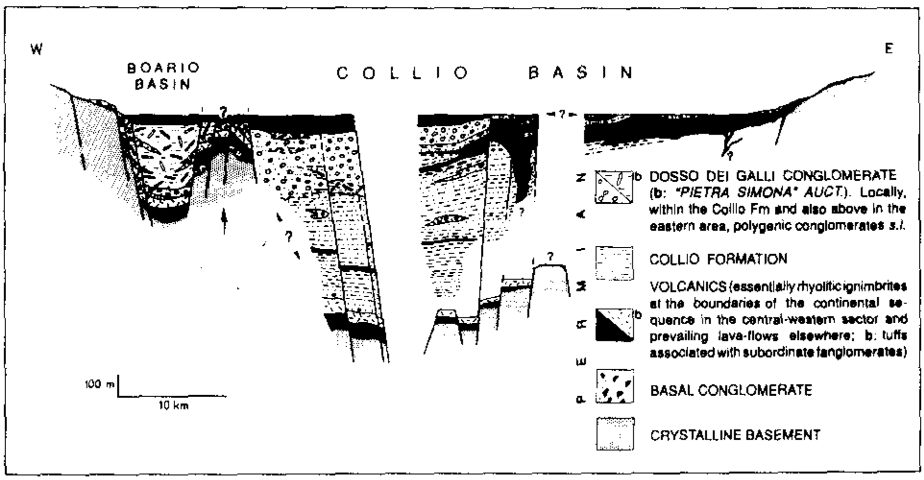


Fig. 4.—Tentative W-E cross-section through the late-Hercynian Boario and Collio Basins (Permian lower cycle) between the Camonica and Chiese valleys. This discontinuous non-palinspastic reconstruction shows both an intense coeval dislocation of the whole area in minor structural highs and lows, giving rise to notable variations in thickness and lithology, and the occurrence of magmatic resurgence sites in the eastern sector (Caffaro - Giudicarie). (After Cassinis, 1985, modified).

Fig. 4.—Corte idealizado, con dirección oeste-este, a través de las cuencas tardi-hercínicas de Boario y Collio (ciclo inferior pérmico) entre los valles de Camonica y Chiese. Esta reconstrucción discontinua, no-palimpástica, presenta por una parte una dislocación coetánea de todo el área en umbrales y surcos estructurales menores, dando lugar a variaciones importantes de espesor y litología, así como a la existencia de una reactivación magmática en el sector oriental (Caffaro-Giudicarie). (Modificado de Cassinis, 1985).

Camonica Valley. Their age is still uncertain, but probably belongs to the Early Permian.

The incipient deformations of the Collio Basin were accompanied by some reddish clastic lenses, mainly of current-reworked volcanic detritus, within and on top of the tuffs (Fig. 5).

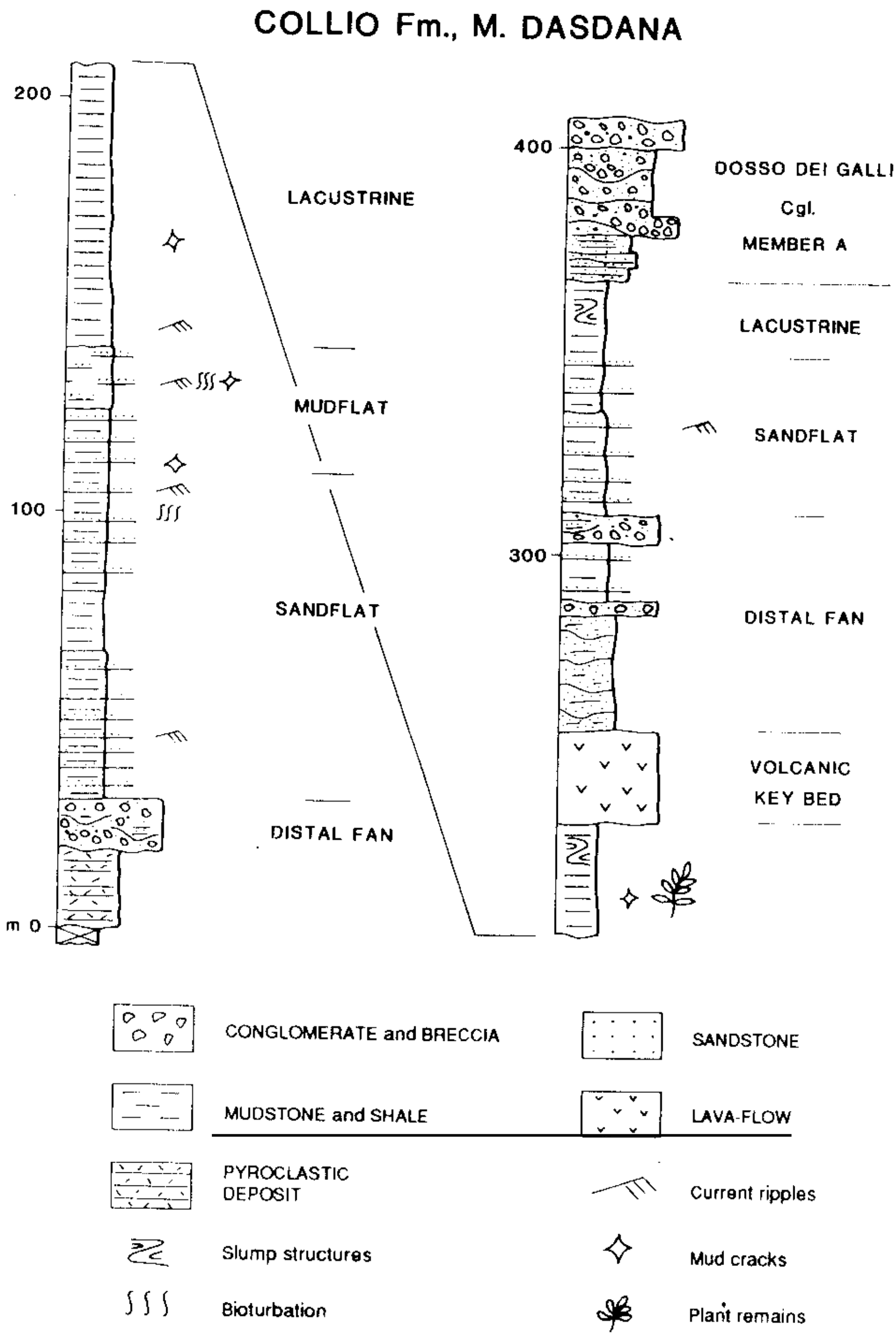
According to Ori, Dalla and Cassinis (1988), alluvial fan to lacustrine sediments form the bulk of the overlying Collio Formation which consists of fanglomerates, sandstones and shales (Fig. 5). Shale deposits prevail in the central parts of the basin, whereas sandstones and conglomerates are more frequent in the marginal and other tectonically active areas. Fanglomerates include conglomerates, without clear organisation, pebbly sandstones and pebbly mudstones. The lack of organisation and virtual absence of erosional bases indicate mass-flow as the principal sedimentary process. The fanglomerates pass into flat-bedded reddish-green sandstones. Parallel lamination, small scale (ripple) cross-lamination, normal grading and rain-drop marks are the most common sedimentary structures. These structures, coupled with the associated fanglomerates, can be related to a sand flat environment in the distal part of alluvial fans. By sand flat, we suggest that this area was dominated by unchannelised sheet flood deposits.

Shaly facies may include very thin fine-sandstone layers, which show parallel and ripple-cross lamination. Mud-cracks and rain-drop prints are common structures. Shales are black and contain an abundant quantity of organic matter, leaves and other plant remains. This facies represents low energy mudflat to distal lacustrine environments. Moreover, the above sedimentary structures suggest that the basin was never very deep and was very often subaerial.

Interstratified with the above terrigenous deposits, there are one or more volcanic bodies generally interpreted as rhyolitic lavas (Peyronel Pagliani, 1965; Cassinis, Origoni Giobbi & Peyronel Pagliani, 1975) (Fig. 5). Their source area is located to the east of the Caffaro Valley, where subvolcanic bodies and a thicker volcanic sequence crop out (Cassinis, 1988). These bodies become suddenly thinner westwards, so that only some of them can be followed through the basin and used as "key beds". These igneous products testify to good continuity of marginal volcanism during the deposition of the Collio Formation.

Between the Trompia and Caffaro Valleys the sedimentary «Collio» is generally organised in two sequences starting upwards from each of the two mentioned volcanic units. Each sequence shows a general upwards decrease in grain size and bed thickness passing from distal fan to shallow lacustrine facies (Ori *et al.*, 1988). These sequences may be the product of two major tectonic movements.

The Dosso dei Galli Conglomerate Formation follows above. It overlies and grades laterally into the upper part of the «Collio». This new unit, the thickness of


COLLIO Fm., M. DASDANA
200
100
m 0
LACUSTRINE
MUDFLAT
SANDFLAT
DISTAL FAN
400
300
DOSSO DEI GALLI
Cgl.
MEMBER A
LACUSTRINE
SANDFLAT
DISTAL FAN
VOLCANIC
KEY BED
CONGLOMERATE and BRECCIA
SANDSTONE
MUDSTONE and SHALE
LAVA-FLOW
PYROCLASTIC
DEPOSIT
Current ripples
Slump structures
Mud cracks
Bioturbation
Plant remains

which ranges from 0 to 450 m, is made up of alluvial fan deposits which can be divided into two members. According to Ori *et al.* (1988), the lower member (A) consists of coarsening upwards sequences locally interfingering with lacustrine deposits («Collio») or stacked one above the other. These C.U. sequences show three main facies. The underlying deposits are made up of sandstone beds with normal grading, parallel and cross-lamination. Above follow fine conglomerate to coarse sandstone lenses, still containing the same sedimentary structures. The uppermost deposits are composed of coarse-grained red-grey-green unsorted conglomerates with ill-defined stratification. (Fig. 6).

The above general sequence represents the progradation of an alluvial fan. The upper conglomerates correspond to proximal debris flow deposits that pass downstream into channeled tongues due to traction and turbulent currents. In the more distal part, sheet flow sandstones interfinger with lacustrine shales of the Collio Formation (Ori *et al.*, 1988).

The upper member (B) is composed of thick unsorted conglomerates interbedded with coarse sandstones, both reddish in colour (Fig. 7). This unit represents the most proximal part of the progradational alluvial fan system.

Another unit known as «Membro della Pietra Simona» (Assereto & Casati, 1965; Cassinis, 1966a, 1966b), which in the Trompia-Caffaro area is normally developed below member B, consists of intensively bioturbated sandy-shaly red beds and can be interpreted as areas lateral to the main alluvial fan lobes or to inactive areas on the fans (Fig. 7).

According to Ori and Dalla (see Ori *et al.*, 1988), the top of the Dosso dei Galli Conglomerate is marked by an erosional surface, only visible where it is superimposed by the Auccia Volcanics. The erosion was probably due to the normal (autocyclic) evolution of the alluvial fan systems .

Clast composition in the Dosso dei Galli Conglomerate reflects the source area, which palaeocurrents show to have lain to the south-southwest. Upwards, metamorphic pebbles generally replace volcanic detritus. In the Caffaro Valley and towards the Lower Giudicarie some conglomerates are practically monomict , being almost entirely composed of volcanic lithologies. These bodies, which are generally thinner

Fig. 5.—Litholog, with sedimentological interpretation, of the Collio Formation on the eastern side of Mt. Dasdana. At the bottom of the section crop out stratified tuffs and a widespread basal conglomerate and sandstone deposit starting the sedimentary history ot the local basin. For more details see explanation in the text. (After Ori *et al.*, 1988).

Fig. 5.—Columna litológica e interpretación sedimentológica de la Formación Collio en el área oriental del Monte Dasdana. En la base afloran tobas estratificadas así como un depósito basal de conglomerados y areniscas, que representan el comienzo de la historia sedimentaría de esta cuenca local. Para más detalles, ver explicación en el texto. (Según Ori *et al.*, 1988).

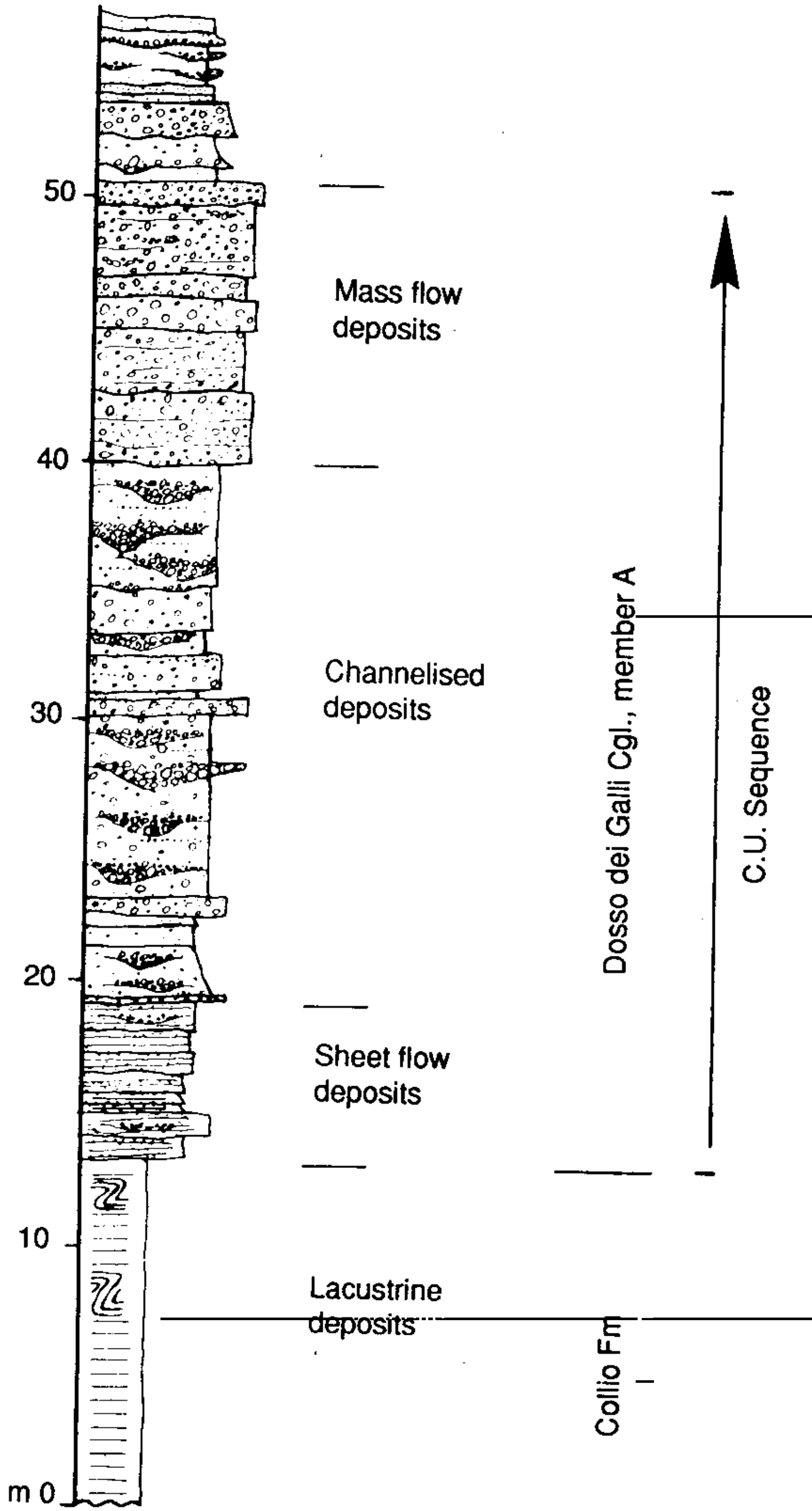


Fig. 6.—Section of the lowermost prograding body of the Dosso dei Galli Conglomerate (Mt. Colombine). Legend in Fig. 5. The general C.U. sequence of the formation is explained in the text. (After Ori *et al.*, 1988).

Fig. 6.—Corte del cuerpo progradante más inferior del conglomerado Dosso dei Galli (Mt. Colombine). Leyenda en la Fig. 5. La secuencia general de la formación granocreciente, viene explicada en el texto. (Según Ori *et al.*, 1988).

than the preceding ones in the Trompia Valley, can be interpreted as the product of volcanic rocks located in the eastern marginal area of the Collio Trough, and eroded and brought in from the east.

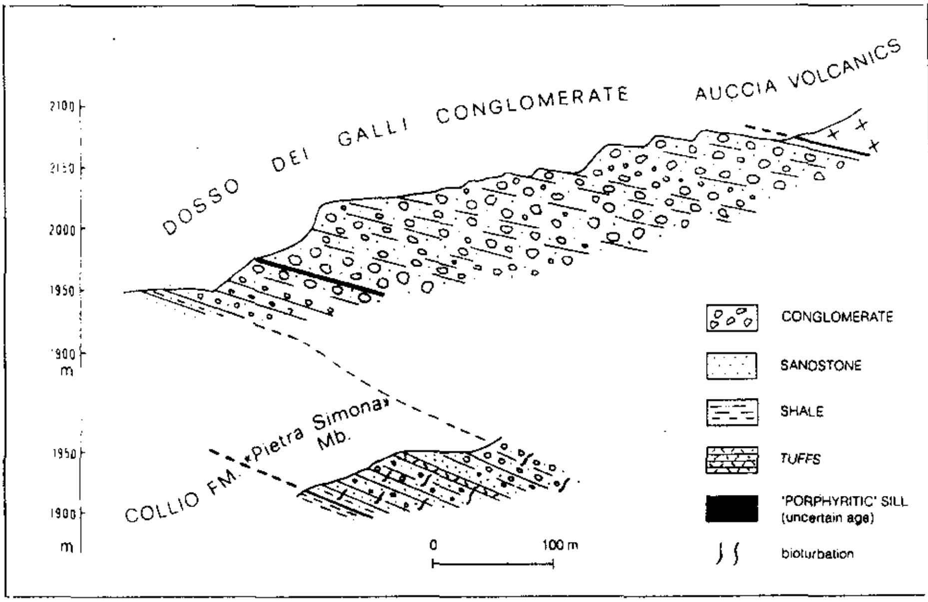


Fig. 7.—Geological cross-section of the Dosso dei Galli Conglomerate in the valley of the Malghe Dasdana Corna. (After Cassinis, 1969, modified).
Fig. 7.—Corte transversal del conglomerado Dosso dei Galli en el valle de Malghe Dasdana Corna. (Modificado de Cassinis, 1969).

The Auccia Volcanics, ranging from 0 to 140 m, represent the conclusion of effusive activity in the basin (Fig. 8). They mainly consist of violet rhyolitic ignimbrites (Peyronel Pagliani & Clerici Risari, 1973), like the volcanic body underlying the Collio Formation. Locally, as in the Mt. Crestoso area, the lack of the Auccia Volcanics is apparently related ,at least in part , to erosion by the overlying fluvial deposits of the Verrucano Lombardo.

In conclusion, the Collio Basin in W-E cross section is asymmetric, with a typical half-graben shape represented by a steep margin on the eastern side and a more gentle slope on the western margin (Ori & Dalla, 1984). The eastern border (towards the Giudicarie Line) is a site of volcanic activity, whereas the western margin, not volcanic, is a source area of detritus, as is proved by the thickness of alluvial fan deposits. Furthermore, a southern source is inferred from palaeocurrents measured from ripple-marks in the Collio Formation.

The western side of the basin dips towards the depocentre area matched with

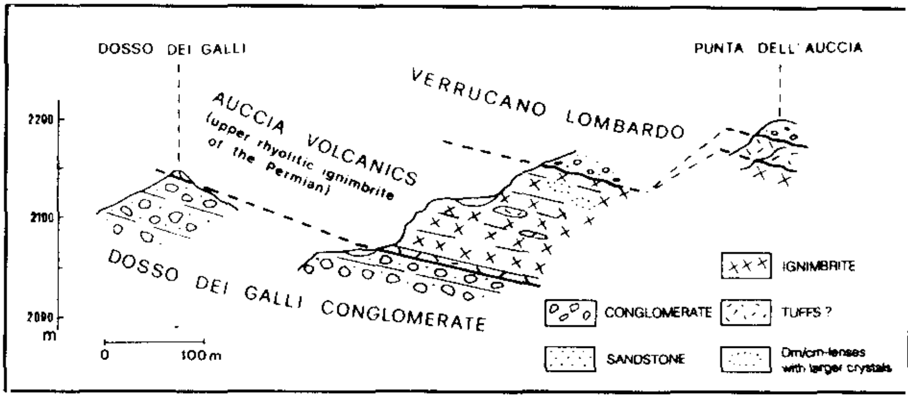


Fig. 8.—Geological cross-section of the Auccia Volcanics in the area between Dosso dei Galli and Giogo della Bala, below and above the Maniva-Croce Domini road. (After Cassinis, 1968, modified).
Fig. 8.—Corte transversal de los materiales volcánicos Auccia en el área entre Dosso dei Galli y Giogo della Bala, por debajo y por encima de la carretera de Maniva a Croce Domini. (Modificado de Cassinis, 1968).

some synsedimentary faults (Cassinis, 1964, 1966 b, 1985). Slumping events were provoked by slope instability and faulting. In the Collio Formation, alluvial fan deposits are concentrated above the most extensive volcanic bodies that reached the western slope of the basin. This fact suggests a pronounced uplift of the western area (and probably elsewhere) induced by tectonism and related magmatism.

The erosion-deposition relationships are practically the same in the Dosso dei Galli Conglomerate (Ori *et al.*, 1988), since in the Mt. Crestoso area the unit only consists of member B that erosionally rests on the «Collio». Downdip the boundary becomes an interfingering between the lower member A and the underlying formation. As shown in Fig. 3, the beginning of progradation corresponded to a major break in the history of the basin.

Tione Basin (Fig. 9)

Owing to the non gradual, often also sudden lateral facies and thickness variations of the materials contained therein, the presence of a late- Hercynian trough clearly stands out in an area to the SW of the Brenta Group. Here, north of Bondo, this depression corresponds to a subsiding sector delimited by structural highs, formed during the Early Permian and named «Tione Basin» (Cassinis *et al.*, 1982).

The boundary faults were also active throughout Triassic times and were reactivated again during the Alpine orogenesis, taking on aspects different from original ones (see also Peloso & Vercesi, 1982).

The Tione Basin contains acidic volcanics with occasional terrigenous intercalations similar to the «Collio» sediments. The thickness of the total succession is up to 600-700 m. The basin shows a rectangular shape oriented SSW-NNE, and therefore a Giudicarie trend not too dissimilar to the one observed in the NE part of the «Collio» cropping out to the south.

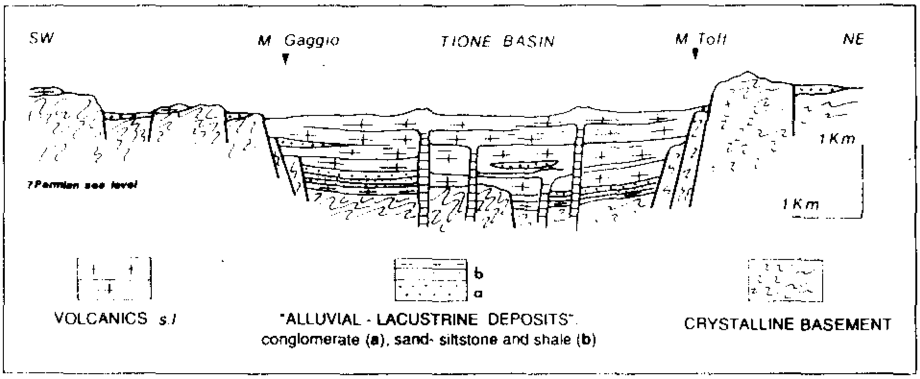


Fig. 9.—Idealised SW-NE Permian cross-section through the Tione Basin (lower cycle), in western Trentino. (After Cassinis *et al.*, 1982, modified).
Fig. 9.—Corte idealizado, en la zona occidental de Trentino, del Pérmico de la cuenca de Tione (ciclo inferior), con dirección SO-NE. (Modificado de Cassinis *et al.*, 1982).

According to Cassinis *et al.* (1982), a steep margin with an approximate E-W direction represents the southern boundary of the trough in the Tione area. The eastern boundary runs along or immediately west of the Sabion Line, where the Permian System is only represented by the Verrucano Lombardo. Thus, the present area in front of the Mt. Sabion overthrust was located on the eastern side of the basin, giving rise to a structural high along a wide escarpment. The northern and eastern limits are difficult to define owing to a general lack of outcrops. Towards the north it is possible to suggest that the late-Hercynian intrusive mass of Mt. Sabion was part of a high and that this represented the northern boundary of the basin. To the west the trough may have continued beyond the South Giudicarie Line *auct.* because, in so far as this line can be followed clearly (e.g. in the surroundings of Tione), the contact between the Permian outcrops and the metamorphic basement is tectonic. However, on general grounds, the area now occupied by the Adamello pluton seems to have essentially corresponded to a structural high (Cassinis, 1985).

In conclusion, the above data allow the supposition that the Tione depression was mostly characterised by magmatic activity coupled with tectonic movements, lateral or close to the Athesian megacaldera present to the east. During quiet tectono-volcanic times conglomerates and finer deposits were laid down. Unfortunately, owing to the rich vegetation and numerous faults in the area examined, it has not yet been possible to recognise the exact geometric relationships. Generally, these sedimentary bodies would seem to occupy different parts of the Permian succession.

Tregiovo Basin (Fig. 10)
(with notes on the surrounding Athesian volcanics)

The Tregiovo basin is a fault-bounded small trough located at the western border of the the so-called «Athesian volcanic platform», which may be regarded as a megacaldera infilled by a very thick effusive sequence known as «Atesine» volcanics or «Bozener Quartzporphyr». This major volcanic «basin» is limited to the west by the Giudicarie Line, to the south by the Valsugana Line, to the north approximately by the Funes Line; the eastern margin is determined by a N-S tectonic alignment running a little west of the Badia and Cismon valleys; its northern segment corresponds to the «Würz Joch Ridge» of Wopfner(1984).

The volcanic sequence of this megacaldera may reach a thickness of about 2000 m and shows a quite complex vertical evolution from basal andesitic lavas to upper rhyolitic ignimbrites, through dacitic- rhyodacitic lavas and ignimbrites (for recent reviews see D'Amico, 1979, 1986). According to D'Amico (1986) and Bargossi and D'Amico (1989) the magmatic association is clearly calk- alkaline. In D'Amico *et al.* (1980), and D'Amico and Del Moro (1988) radiometric ages relative to a great part of this sequence range from about 272 Ma (both lower and upper rhyodacitic ignimbrites) to 267 Ma (upper rhyolitic ignimbrites).

Synvolcanic tectonic activity has been documented (e.g. Brondi *et al.*, 1970, 1976; Bargossi, D' Amico & Scipioni, 1983), resulting in lateral changes in thickness and in the petrographic association of the effusive succession. Intravolcanic sedimentary clastic bodies (conglomerate and sandstone) may occur within the megacaldera; they represent the infillings of small fault-controlled basins.

The Tregiovo Formation is only one of such clastic intercalations, although it is probably the most important one, due to its stratigraphic position near the end of the volcanic manifestations. Rich fossil assemblages (plant remains, palynomorphs, tetrapod footprints) permit its correlation with other Alpine and extra-Alpine Permian continental basins.

The Tregiovo Fm is inserted in the uppermost part of the Monte Luco volcanic succession, cropping out along a NNE-SSE strike between the Giudicarie and Foiana Lines. This succession (Bargossi & D'Amico, 1989) consists of a "Lower Group" composed of conglomerates with pebbles derived from the metamorphic basement and basal effusive products, intercalated with rhyodacitic to rhyolitic lava flows and covered by thick (800 m) rhyodacitic lavas. The "Upper Group" is mainly represented by rhyodacitic to rhyolitic ignimbrites. The peculiarity of the Lower Group, lacking in andesitic products and rich in rhyodacitic lavas (which are quite scarce in the true Athesian area) leads Bargossi and D'Amico (1989) to propose a tectonic separation of the Mt. Luco district from the Athesian one, which only ceased during the deposition of the Upper Group.

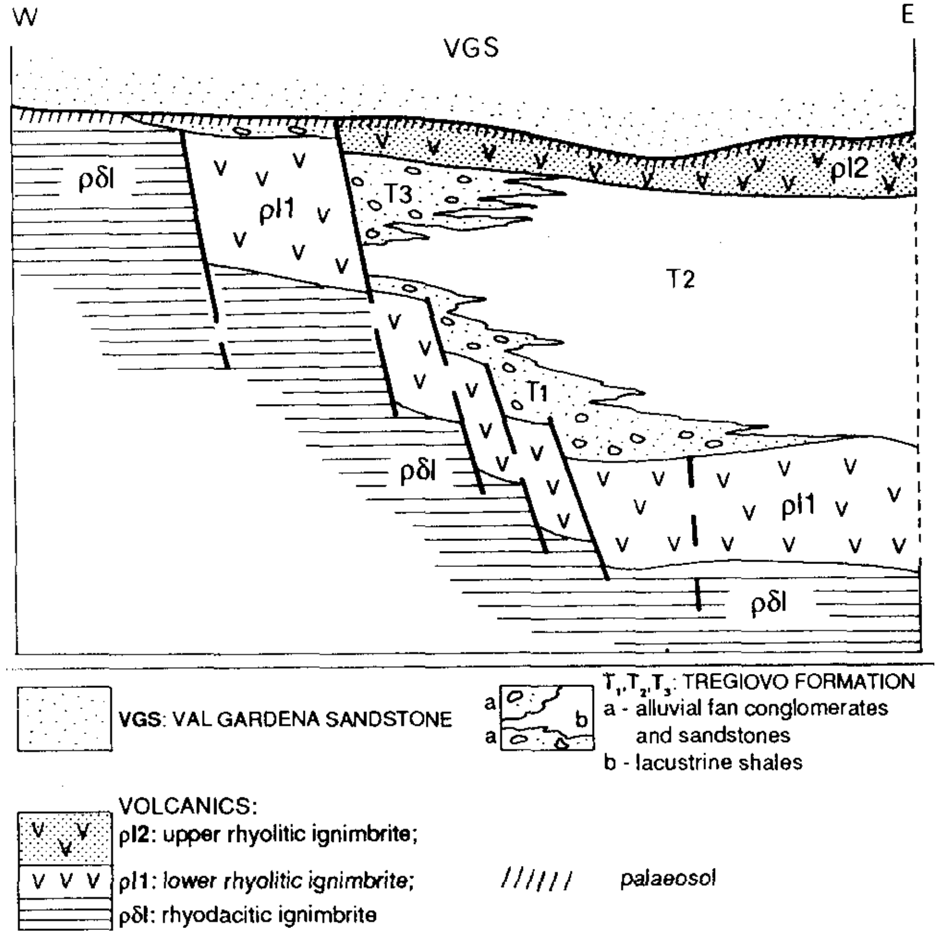


Fig. 10.—Idealised W-E Permian cross-section through western part of the Tregiovo Basin, Bolzano/Trento provinces. (After Cassinis & Neri, 1990).
Fig. 10.—Corte idealizado, en las provincias de Bolzano/Trento, del Pérmico de la zona occidental de la cuenca de Tregiovo, con dirección O-E. (Según Cassinis & Neri, 1990).

The Tregiovo Fm was deposited along the south-eastern border of the mentioned volcanic district, between Tregiovo and Lauregno, within a tectonically depressed N-S trending belt. It is limited at the base and the top by two rhyolitic ignimbrite units (Giannotti, 1963; Ulcigrai, 1969; Bargossi *et al.*, 1983; Bargossi & D'Amico, 1989).The occurrence of the upper ignimbrite unit is denied by Mostler (1966), Klau and Mostler (1983) and Astl and Brezina (1986), according to whom the «Tregiovo» is directly overlain by the Val Gardena Sandstone. However, recent field work by the present authors also supports the existence of a volcanic unit, a few tens of metres thick, intercalated between the Tregiovo beds and the overlying Val Gardena Sandstone (localities: Miauneri, Pertmeri). The upper part of the ignimbritic unit displays an intense pedogenic alteration before the deposition of the Val Gardena clastics. Also the Rio Pescara section, from which Astl and Brezina (1986) describe a Tregiovo-Gardena stratigraphic contact, confirms this conclusion. In fact, the contact examined by these authors is tectonised; laterally the Val Gardena Sandstone is clearly underlain by a volcanic body (kindly interpreted by L. Cortesogno from Genova University as a rhyolitic ignimbrite, pers. com.), of unknown thickness as only the top (about 2 m) emerges from the water.

The Tregiovo Formation may be divided into three informal members (Fig. 10).

1) The lower one (40-50 m) is made up of unsorted sand- to clast- supported conglomerates with angular to poorly rounded volcanic pebbles (from a few cm to some dm in size). Only towards the top this unit evolves to coarse sandstone with scarce trough cross- bedding and parallel lamination, with ruditic pockets and lenses. The prevailing depositional mechanism seems to have been mass-flow. It follows that the sedimentary setting may be interpreted as a proximal alluvial fan at the foot of fault- controlled scarps. The upper part of the member records mid- to distal alluvial fan facies, dominated by channelised to unchannelised stream flows.

2) The second member (80-100? m) represents the classical facies of the Tregiovo beds, consisting of thin-bedded, platy dark grey to black mudstone with mm-cm thick "varve-like" intercalations made up of siltstone or very fine sandstone. A carbonate fraction is very common throughout these beds and may be locally dominant. Silicification and silicified concretions occur at different levels. The sedimentary structures are characterized by normal grading, parallel lamination and, more rarely, ripples and mud-cracks. The fossil contents include plant remains, ostracods, conchostracans; several horizons with «lacertoid» tetrapod footprints have been recently discovered and sampled by M.A. Conti, N. Mariotti, U. Nicosia (University of Rome) and P. Mietto (University of Padova) in the lower part of the unit.

No clearly apparent internal organization into facies sequences seems to exist within this monotonous succession. The sedimentary environment can be referred to a shallow, low-energy lacustrine setting characterised by frequent episodes of subaerial exposure.

3) The upper member is documented by a few outcrops separated by wide unexposed areas. Thus, due to this condition and the intense Alpine tectonics affecting the sector in question, it is difficult to reconstruct its vertical sequence and thickness.

The lower part is represented by shaly-silty mudstone with sandy intercalations ranging in thickness from a few cm to about 20-40 cm. These lithofacies are organised into thickening- and coarsening-upward (C.U.) sequences, 4-5 m thick, in which the mud fraction is dominant.

Some outcrops attributable to the mid-upper part of the member are still characterised by a similar facies organisation, with a distinct increase in the sand/mud ratio; the sandstone layers are platy. Following a C.U. trend, these facies are capped by a massive coarse sandstone body, of ill-defined thickness (over 10 m ?), strongly disturbed by tectonics.

Member 3 probably records the repeated progradation phases of distal alluvial fan «sheet sands» (such as those described by Ori *et al.*, 1988, in the typical «Collio» area) towards the basin centre. Upwards, more proximal facies return.

According to the stratigraphic column of Klau and Mostler (1983), the top part of the member is represented by mass-flow conglomeratic deposits pertaining to proximal alluvial fans (not observed in the field by the writers).

Member 3 has not been observed all over the Tregiovo Basin. For example, the upper part of the Tregiovo Formation near Lauregno (Pertmeri) consists of shaly «varve-like» facies of member 2; these contain some horizons, 0.5-1 m thick, made up of flat pebble breccias with clasts derived from the same lacustrine facies; there are also slumped or debris-flow levels with plastically deformed slabs more than 1 m large, also derived from the «shaly» Tregiovo beds. Most probably these represent the response to a reactivation of the boundary faults, which are also responsible for the progradation of the marginal alluvial fan lobes.

On the basis of the stratigraphic features described above, the structural evolution of the Tregiovo Basin can be summarised as follows:

a) initial block-faulting leading to the collapse of the basin and to the deposition of the scarp-foot conglomerates of member 1;

b) a tectonically quiet time in which the monotonous muddy lacustrine facies (member 2) was deposited;

c) a reactivation of synsedimentary tectonics, producing the basinward progradation of the marginal alluvial fan coarse clastics and episodes of gravitational resedimentation within the basin;

d) finally, the extrusion of the last volcanic products (upper rhyolitic ignimbrite) capping the sedimentary succession.

UPPER CYCLE

In the central-eastern South-Alpine area the second cycle (Fig. 1) consists of the following units (from the base upwards):

a) basal conglomerates, sometimes distinguished as independent lithostratigraphic units (Val Daone Conglomerate, Sesto Conglomerate, Tarvisio Breccia); they rest unconformably on a substrate formed within the investigated area by the products of the first Permian cycle as well as by the Hercynian metamorphic basement;

b) continental clastic Verrucano Lombardo-Val Gardena Sandstone, representing the same lithosome known with different names in Lombardy and in the area east of the Adige Valley;

c) Bellerophon Formation, deposited only in the area east of the Adige Valley and consisting of a very complex array of lithofacies ranging from sulphate evaporite and marly-silty dolomite deposited in a coastal sabkha environment to shallow marine fossiliferous limestone; it interfingers with and laterally replaces part of the Val Gardena Sandstone.

Unlike the deposits of the lower cycle, those of the second one form a continuous, widespread body in a large sector of the Southern Alps, extending from the eastern border of the Monte Generoso- Como High (Cassinis *et al.*, 1988) to the Carnic Alps and, further to the east, to Yugoslavia. They are separated from the generally Lower Permian units by a pronounced unconformity, related to an overall reorganisation of the synsedimentary tectonics which will be discussed in detail in the next section. At the top they are overlain by the marine Lower Triassic sediments pertaining to the Servino (Lombardy) and Werfen (eastern Southern Alps) formations.

As regards the «basal conglomerates» the age, stratigraphic setting and geological meaning of these bodies, interpreted as alluvial fan lobes deposited at the foot of fault-controlled scarps, have long been debated. Some authors placed them at the end of the first cycle. The Sesto Conglomerate and Tarvisio Breccia, considered by Kahler (1986), Flügel (1986), Flügel and Kraus (1988) as Cisjanskian in age, have been interpreted by these authors as almost isochronous bodies resulting from the tectonic uplift and disintegration of the Lower Permian carbonate platforms at the end of their depositional history.

However, according to the Italian IGCP 203 Group (1986), Cassinis *et al.* (1988), Venturini (1990), they represent the lowermost deposits of the second Permian cycle; their age probably changes from place to place, due to synsedimentary tectonics and the palaeostructural setting. In this interpretation they grade upwards into the braided stream deposits of the Val Gardena Sandstone without any appreciable time gap.

The sedimentary evolution of the units pertaining to the second cycle has been described in detail by several workers (e.g. Bosellini & Dal Cin, 1968; Bosellini & Hardie, 1973; Italian IGCP 203 Group, 1986; Ori *et al.*, 1988; Ori, 1988; Massari *et al.*, 1988; Broglio Loriga *et al.*, 1988; Noé, 1988).

Altogether, the Verrucano Lombardo - Val Gardena Sandstone and the Bellerophon Formation constitute a major fining-upwards transgressive sequence, slowly evolving from coarse, piedmont clastics at the base to shallow marine fossiliferous limestone at the top .

The base of this sequence is represented by mud- to clast- supported conglomerates, frequently unchannelised and interbedded with variable amounts of mudstone, usually rich in pedogenic structures such as deeply-reaching desiccation cracks and calcrete horizons; these facies are interpreted in terms of an alluvial fan.

This unit is overlain by red to grey sandstones and gravels forming cross-cutting lenticular channel fills in which the dominant depositional structures are represented by trough cross-bedding (braided stream deposits); it evolves upwards into a meandering river setting, characterised by the vertical stacking of a number of point-bar sequences with a lateral accretion pattern (epsilon cross-bedding).

The fluvial sequence is capped by a mud- dominated unit with sparse ribbon channels and sheet sands; these deposits are interpreted as the record of terminal fan systems encroaching onto the coastal plain. According to Ori (1988) the Permian rivers of the Southern Alps were exotic in nature; flowing across a semiarid-arid plain they were affected by a progressive loss of water due to evaporation and infiltration, until they became unable to cut channels. Before reaching the sea, they vanished in coastal terminal fans.

East of the Adige Valley, the red clastics are gradually covered by the marginal marine sediments of the lower part of the Bellerophon Fm, representative of various coastal settings and patterns of sedimentation. At the base of this formation, the prominent depositional theme is the «sabkha cycle» described by Bosellini and Hardie (1973), characterised by a shallowing-upwards trend evolving from subtidal dolomite to chicken-wire gypsum of the supratidal portion of the sabhka. Following an overall transgressive trend, the marginal marine deposits are replaced upsection by shallow water limestone, with rich faunal and floral remains (forams, calcareous algae, bivalves, gastropods, nautiloids; see Broglio Loriga *et al.*, 1988 for a review). Such an ideal transgressive sequence may be divided into a number of minor transgressive-regressive cycles, which may be interpreted as eustatically controlled 3rd order depositional sequences, although their vertical evolution and facies organisation is also strongly influenced by synsedimentary tectonics. As a result, clastic, evaporite and carbonate repeatedly interfinger. Three depositional sequences have been recognized within Cycle 2 in the western Dolomites (Farabegoli & Viel, 1982;

Massari *et al.*, 1988; Neri & Massari, 1990). Four sequences are recorded in the Carnic Alps where a basal sequence occours, apparently inexistent west of the Comelico region.

Although synsedimentary tectonics were still active, Cycle 2 seems to testify, from the base upwards, to a progressive flattening of the palaeotopography, inherited as well as due to new fault movements (reactivation and new formation may be involved). At the end of the Permian the depositional area extended all over the Southern Alps east of the Mt. Generoso High. It was characterised by a very low relief with wide facies belts which graded into each other laterally. On this flat land the «Werfen transgression», more or less coinciding with the Permian/Triassic boundary, encroached. This generated a fast shift of the coastline towards western Lombardy.

The geometry, thickness and facies pattern of the deposits of Cycle 2 give some indications about the "Middle" Permian reorganisation of structural trends.

The most subsident areas were represented by:

a) eastern Lombardy, where the Verrucano Lombardo reaches a maximum thickness of about 500 m, even on previous Early Permian highs, such as the Val Camonica Ridge;

b) the eastern sector of the Southern Alps: part of the Western Dolomites, i. e. Mt. Putia, with a thickness of more than 500 m; the Cadore-Comelico area, where a thickness of ca. 800 m is reached locally; part of Carnia, i. e. the Paularo area. It is noted that in the Cadore-Comelico depocentre the succession directly overlies the metamorphic basement, which was a relative high during Cycle 1.

These two main depocentres were separated by a prominent N-S trending ancient high located between the Adige Valley and the Giudicarie Line (Adige-Brenta Ridge), which is subdivided into minor lows and highs, with thicknesses ranging from 50 m to about 150- 200 m. Other important highs were represented by the area south of the Valsugana Line (thickness of the Upper Permian deposits not in excess of 100 m), which also acted as a high during Cycle 1, and by some sectors of NE Carnia (Pramollo, etc.; see Venturini, 1986, 1990). Moreover, the palaeocurrent pattern of the Val Gardena Sandstone, with frequent S- directed transport, seems to suggest the existence of a northern Insubric high.

THE UNCONFORMITY BETWEEN LOWER AND UPPER CYCLES

As stated in the previous pages, the boundary between the two Permian cycles is marked by an unconformity (Figs. 1 and 3), in all probability due to the Mid-Permian tectonic event. It results in the superposition of the widespread fluvial

Verrucano Lombardo-Val Gardena Sandstone lithosome onto the more localised lacustrine-alluvial fan sediments and subaerial volcanics infilling the «taphrogenic» basins of Cycle 1.

Cycle 2 is characterised by a general reorganisation of the tectonic lines responsible for the palaeotopography and the subsidence pattern. Several important faults which controlled the palaeogeography of Cycle 1 were deactivated (e. g. Funes Line, probably Val Trompia Line, etc.); others were reactivated with a different structural behaviour, determining the shift of depocentres. Some examples are given at the end of the preceding section.

The time gap associated with this unconformity is still not fully known, due to the fact that the standard classification of this geological interval has not yet been clearly defined and to the low resolution and general paucity of the fossil record (mainly restricted to palynomorphs) in the lower part of the Val Gardena Sandstone. However, the base of Cycle 2 seems diachronous, being older in Carnia than in the Dolomites; moreover, within a single area, the age also depends on the structural setting, the onset of sedimentation being usually later on palaeohighs.

Palynological dating of the top of Cycle 1, due to J. Doubinger (in Cassinis & Neri, 1990), indicates that the age of the unconformity has to be later than the earliest «Middle» Permian (according to the three-fold subdivision of the Period), and probably older than Tatarian (although no certain data are available about the time of the basal sequence of Cycle 2 from Carnia, believed to be the oldest deposits of the upper cycle) (Fig. 2).

Thus the unconformity in question is more recent than the main Saalian «phase». Probably it is to be correlated to post-Saalian events, such as the first Altmark movements of Hoffmann, Kamps and Schneider (1989), probably corresponding to the «Palatine phase» *sensu* Kozur (1980).

In the Southern Alps this event took place at the end of the Permian volcanism, i. e. of the lower cycle, although some authors (Cadel, 1986; Dickins, 1988) note the occurrence of minor igneous products in the lower part of the upper cycle.

CONCLUDING REMARKS

In this work we have discussed the history of some continental basins in the Southern Alps. Two tectono-sedimentary cycles have been documented.

1) Cycle 1

1.1. The depositional history and the structural evolution of the products of this cycle may be described with reference to the Collio Basin, the best known and most remarkable example among those considered. The structural organisation of the Tregiovo Basin is substantially similar, albeit on a smaller scale. Other basins supply less clear evidence.

The main evolutionary stages of the Collio Basin can be summarised as follows (Ori *et al.*, 1988) (Fig. 11):

a) Extensive volcanic activity produced a basal ignimbritic body draping the crystalline basement.

b) Block-faulting, which also controlled the volcanicity, led to the formation of an half-graben; main faults roughly correspond to the Giudicarie Line (east) and to the Val Trompia Line (south). Alluvial fans, on the basin margin, and lacustrine

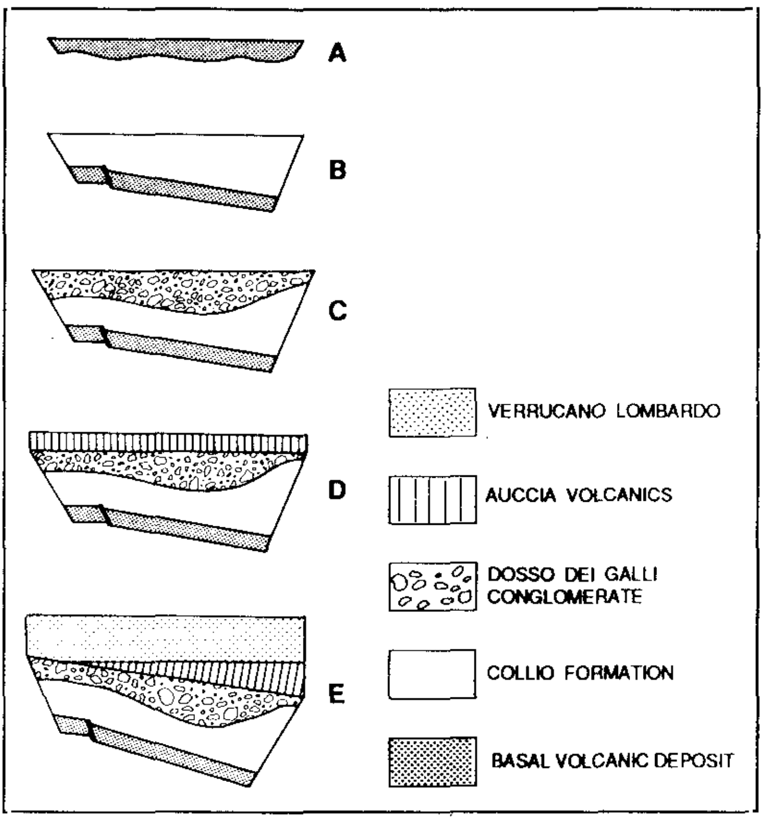


Fig. 11.—Major evolutionary stages of Permian volcanic-sedimentary deposition in the Collio Basin. Explanation in the text for more details. (After Ori *et al.*, 1988).
Fig. 11.—Principales etapas evolutivas de la sedimentación volcanoclástica pérmica en la cuenca Collio. Para más detalle ver explicación en el texto. (Según Ori *et al.*, 1988).

deposits (Collio Fm) were both laid down at this stage. Volcanic activity (lava flows, dikes, tuffs) was still in force on the steep eastern margin of the basin.

c) As a result of major tectonic effects (uplift of the basin margin), marginal alluvial fan systems prograded into the basin, progressively filling it up (Dosso dei Galli Conglomerate).

d) The sedimentary history of the basin is closed by the outpouring of the last volcanic products, represented by the rhyolitic ignimbrites and other minor effusive manifestations known as «Auccia Volcanics».

e) After stage d), the whole succession underwent a phase of tectonic deformation and subsequent erosion, resulting in an unconformity (locally angular) between the Auccia Volcanics and the overlying Verrucano Lombardo. Frequently, thick palaeosols are developed at the top of the deposits of the lower cycle during this phase.

1.2. As discussed in the previous pages, the main faults controlling the basin margins and the volcanic districts in the different parts of the overall area fall into two major groups. The first, from NNE- SSW to N-S trending, is substantially parallel to the Giudicarie Line. The second is directed about E-W, and the main faults approximately coincide with or are parallel to the present Val Trompia Line, Valsugana Line, Tonale and Pusteria segments of the Periadriatic Lineament, etc.

Thus the quoted lines seem to represent ancestral fault lineaments which have been repeatedly reactivated until the Alpine orogenesis. The Hercynian structural grain, therefore, has played an important role on the future Mesozoic and Tertiary reorganisation.

2) **Cycle 2**

The Mid-Upper Permian clastics forming the basal part of this cycle is very widely distributed geographically; they also extend outside the Southern Alps (Slovenia, etc.), overlying the Lower Permian marine sediments (Trogkofel Group) which crop out in Carnia and in the Karawanken Mts. This suggests a regional relative uplift due to the previously discussed «Mid-Permian» tectonics, accompanied by an overall regression.

The following depositional history of the sedimentary succession pertaining to Cycle 2 is characterised by a general transgressive trend which led the coastline to reach the Adige Valley at the end of the Permian. This may be interpreted as the response to a general peneplanation concomitant to a continuing regional subsidence, induced by tensional tectonics. The whole succession may be further divided into some third order cycles, resulting in the repeated interfingering of continental red beds (Val Gardena Sandstone) and marginal to fully marine units (Bellerophon Fm).

The evolution of these cycles is controlled by eustatic fluctuations (Neri & Massari, 1990) as well as being influenced by persistent tectonic activity. In fact, the latter determined the position of palaeohighs (with reduced, mainly continental successions) and strongly subsiding areas.

3) **Geodynamic setting**

The geodynamic setting of the basins examined is still controversial, as it belongs to the more general and still debated interpretation of the «Late» and/or «Post»-Hercynian events of the whole European area. The data supplied from the Permian sedimentary and volcanic successions of the central Southern Alps underline the following facts.

3.1. The structural evolution of the basins is controlled by tensional tectonics, as supported by many authors (e.g. Cassinis *et al.*, 1980). This has been interpreted as the response to simple crustal extension (Wopfner, 1984), or as due to transtensional movements in a general strike-slip context. The latter interpretation, advanced for the Southern Alps by Venturini (1983), Cadel (1986), Massari (1988) and others, is gaining force since it may explain the coexistence of distensive and compressional effects (which may control the repeated reactivations of the paleohighs), the abrupt shifting of depocentres, the frequently observed inversion of the highs into subsiding areas and *viceversa*. The strike-slip interpretation fits in with the Permo-Carboniferous reconstructions of Arthaud and Matte (1977), Ziegler (1982, 1988) and others, which affirm the existence of a widespread zone of dextral megashear between the Atlas and the Tornquist Line.

3.2. According to most authors (e.g. Bargossi & D'Amico, 1989) the central South-Alpine Permian volcanics are mainly calk-alkaline in nature. The common alkaline character shown by the essentially rhyolitic volcanic and subvolcanic bodies cropping out in the Collio Basin (between the Daone and Trompia Valleys) as well as in the Tione Basin (lower Rendena Valley) seems referable to an intense deuteric hydrothermal-pneumatholitic alteration (Peyronel Pagliani, 1965; Peyronel Pagliani & Clerici Risari, 1973; Cassinis *et al.*, 1975; Origoni Giobbi, Peyronel Pagliani & Zanchini Camerini, 1979), even if, according to the latter authors, the present chemical composition should be very close to that of the primary magmatic melt.

A number of models have been proposed for the causes of melting and volcanic chronological distribution in the light of different geodynamic interpretations used to explain the Hercynian orogeny and the following related events. Most of these models involve type A subduction (Vai *et al.*, 1984; etc.) or type B (Stille & Buletti, 1987; Mercolli & Oberhänsli, 1988; Di Battistini *et al.*, 1990), during Late Palaeozoic times.

Cabella *et al.* (1988) pointed out the problem arising from the very long time span which separated Hercynian tectogenesis from the beginning of the volcanic activity. Indeed, one should remember that the area investigated shows the age of the Hercynian metamorphic events is to be around 350-315 Ma, according to Del Moro, Sassi and Zirpoli (1980, 1984) and others, while plutonism and volcanism are respectively assigned to about 295-274 Ma and 272-267 Ma, on the basis of data given by Borsi, Ferrara and Tongiorgi (1966), Borsi, Del Moro and Ferrara (1972), Borsi, D'amico and Del Moro (1974), D'Amico et al. (1980), D'Amico and Del Moro (1988, and personal communication of the latter author). Cabella *et al.* (1988) suggested an alternative view based on a post-orogenic genesis of the magma, probably linked to mantle diapirism. The emplacement of the igneous bodies may be connected with the transition between the compressional to the distensive phase which characterised late- to post- Hercynian times.

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