Field Trip Guide Book - P54

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August 20-28, 2004

Volume n° 5 - from P37 to P54

32nd INTERNATIONAL GEOLOGICAL CONGRESS

STRUCTURE OF THE ITALIAN DOLOMITES, PARTIALLY ALONG THE SOUTHERN SECTOR OF THE TRANSALP SEISMIC PROFILE

Leaders: A. Castellarin, L. Cantelli,
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Post-Congress **P54**

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Front cover:
Panoramic view of the Rosengarten
(Catinaccio)

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Scientific Focus

The field trip is devoted to the sedimentary, magmatic and structural evolution of the eastern Southern Alps which will be analysed and shown across a section from the Venetian Plain (to the S) to the western core of the Italian Dolomites (to the N). In its second part the field trip routes approximate the Main Line of the Transalp seismic reflection Profile. This field trip, across the spectacular scenarios of the Italian Dolomites, is a stimulating opportunity in order to visit and to analyse one of the most classical zone for the Geology of the Southern Alps whose reconstruction in depth is now improved by the new seismic images provided by the Transalp seismic Profile.

Geological setting of the Dolomites, Southern Alps

The Southern Alps correspond to the structural belt located S of the eastern side of the Periadriatic Lineament (Pustertal and Gailtal Lines) (Figs.1, 2, see also Figure 32). This belt is affected by intense backthrusting which forms the orogenic structure of the Alps verging to the S (Africa-verging belt) opposite to the tectonic polarity of the Northern Alpine chain verging to the N (Europa verging orogenic chain), located to the N of the Periadriatic Lineament. The pre-Alpine Hercynian (or Variscan) orogenic evolution is well recognized and documented both in the non metamorphic Palaeozoic (Carnic Alps) and in the metamorphic basement rocks of the Southern Alps (Selli, 1963; Vai and Cocozza, 1986; Zanferrari and Poli, 1992). These basement rocks include huge granodiorite intrusions (Brixen, Cima d'Asta, etc.) similar in age to the early Permian volcanics of the Bolzano-Trento Provinces (ignimbrite plateau) and mostly located along the Insubric Lineament (C.N.R., 1990, Sheet N.1).

The post Upper Carboniferous magmatic history of the Alps is consistent with their structural and kinematical evolution. The early continental rifting evolution is documented by extensional tectonics and huge magmatic activities occurred during Lower Permian and Middle Triassic Times (Dal Piaz, 1993; Selli, 1998) whereas the further Norian-Liassic rifting evolution is well testified by the strong extensional tectonics controlling the carbonate platform-basin systems in the whole Southern Alps (see f. i.: Bertotti et al., 1993). The drifting evolution, related to the spreading centre of the Tethys, is coherent with the progressive drowning of the southern continental margin well evidenced by the transgressive condensed sequences the Mid Jurassic (about 157 Ma) to the late Early Cretaceous (≅115 Ma) (see f. i.: Bertotti et al., 1993, Winterer and Bosellini, 1981). At the end of the Early Cretaceous started the continental margin convergence (Coward and Dietrich., 1989; Roure et al., 1990; Dal Piaz, 1995). The convergence evolution of the Alps include the Upper Cretaceous pre collisional (eo-Alpine), the Eocene collisional (meso-Alpine) and the Paleogene-Neogene post collisional (neo-Alpine) compressional events (Trümpy, 1973). The pre-collisional-collisional events have no structural evidence in the Venetian Southern Alps. They are indicated only by the Upper Cretaceous drastic change in the marine sedimentation with strong siliciclastic input of Flysch deposits in the basinal areas which are present also in the Dolomites (Ra Stua and Antruille). The Lower Eocene siliciclastic Flysch of the Friuli to the Belluno zones is mostly the distant marker of the meso-Alpine compressional event affecting the external Dinaric orogenic domain rather than the Eastern Alps (C.N.R., 1990, Sheets N.1,2) (see later).

The stop in the oceanic subduction, subsequent to the continental collision, produced a rapid Palaeogene geothermal rise under the orogenic eo- to meso-Alpine chain and concomitant extensional uplifting. Magmatic processes produced large emplacement of acidic intrusive bodies (mainly granodiorites and tonalites) outcropping along the Insubric borders of the Alps (Bergell-, Adamello-, Riesenferner- and others intrusive masses) (Dal Piaz, 1986; Laubscher, 1986; C.N.R., 1990). The sector located to the S, in the Venetian foreland, were affected by lava flows of alkaline basalts and their sub-volcanic differentiates (Mts Lessini and Euganei hills) (Zampieri, 1995).

The Permian - Triassic magmatic events

The post-Hercynian, late Palaeozoic and Mesozoic magmatic and tectonic evolution of the E-Southern Alps intensely controlled the further mainly Tertiary structural inversion. Important examples are the Lower Permian extensive magmatic occurrences and the less expanded Mid Triassic ones, largely superposed each other in the Dolomites. These events concurred to origin a more rigid post magmatic upper crust in these areas and to reinforce this sector, less intensely affected by further superficial tectonic

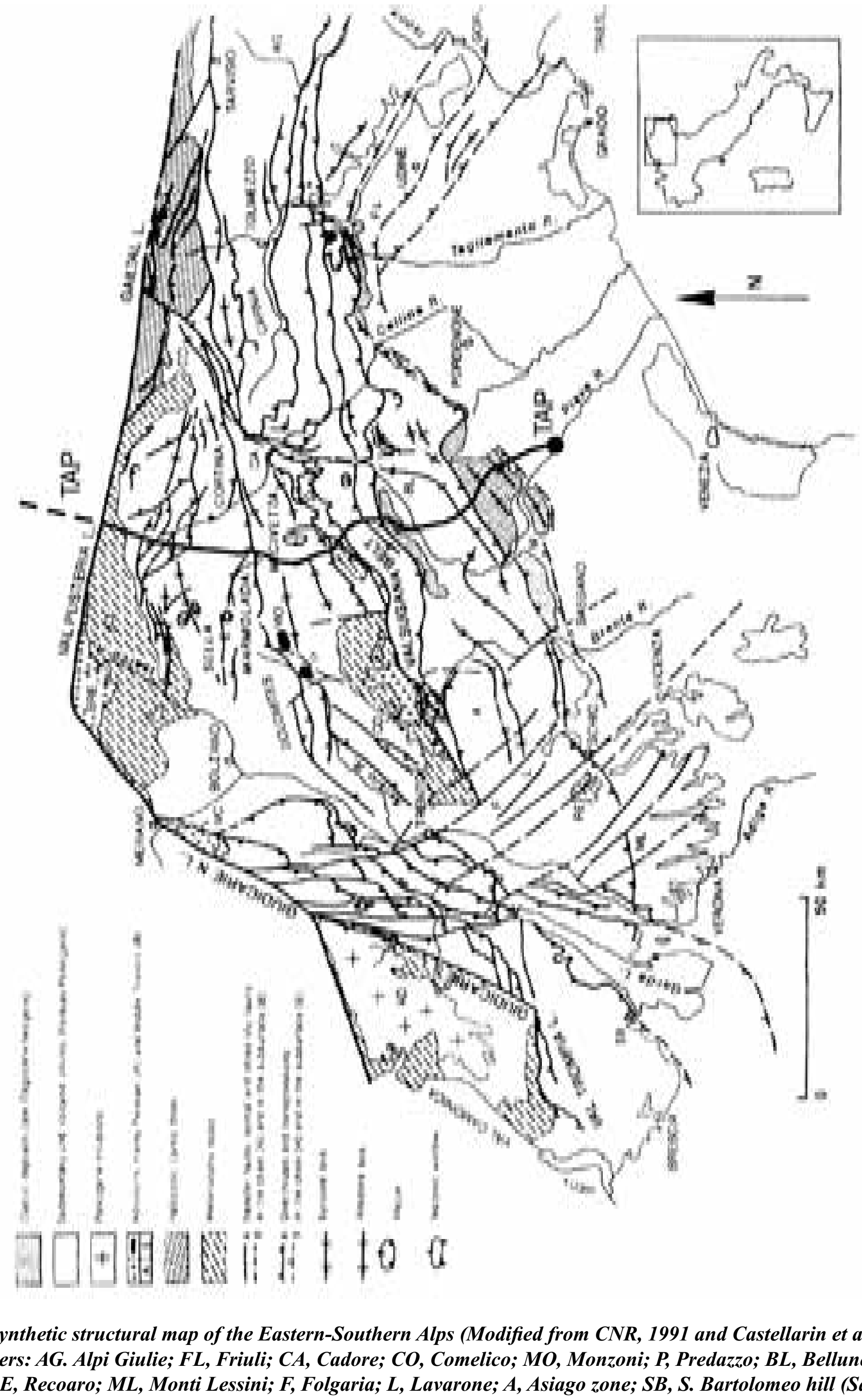


Figure 1 - Synthetic structural map of the Eastern-Southern Alps (Modified from CNR, 1991 and Castellarin et al., 1998b). Letters: AG. Alpi Giulie; FL, Friuli; CA, Cadore; CO, Comelico; MO, Monzoni; P, Predazzo; BL, Belluno; M, Montello; RE, Recoaro; ML, Monti Lessini; F, Folgaria; L, Lavarone; A, Asiago zone; SB, S. Bartolomeo hill (Salò, L. Garda); MC, Monte Croce; BRE, Bressanone, Ivigna; CD, Cima d'Asta; AD, Adamello; Orobie, Grigna and Presolana (Bergano Province, Lombardy) see PA (Pre Adamello Belt) in Figure 2. TAP, Transalp profile (Italian sector). Modified from Castellarin et al. 1998c

deformations (Castellarin and Vai, 1982). Intense structural deformations, on the contrary, occurred in the eastern contiguous sectors (Cadore, Carnia) where the magmatic bodies are much more restricted, or absent. Furthermore, this more rigid block is, apparently, the part of the Southern Alpine belt more extensively pierced (indented) in the Northern Alpine structure along the N Giudicarie Line (Figs. 1, 2).

The Lower Permian magmatism is represented by the volcanic porphyry plateau of the Bolzano province (Bozener Porphyrplatte Auct.) covering an area of more than 2,000 km2 and by several magma intrusions (Cima d'Asta, Bressanone-Chiusa, Ivigna e M. Croce) (Figure 2, CD, BRE, MC). These magmatic products display typical calc-alkaline evolutional trends with geo-chemical and isotopic composition consistent with the interaction of different magmas coming both from the upper mantle and the lowermost crust (Barth et al., 1993).

The Mid Triassic magmatic occurrences in the Eastern Alps produced rhyolites/andesites (Recoaro, Tarvisio) and shoshonitic basalts in the Dolomites where there are also rare shallow intrusive equivalents (M.ts Monzoni) with differentiated products (Predazzo) (Figure 2, MO, P). All of these magmatics correspond to calc-alkaline suites well defined and

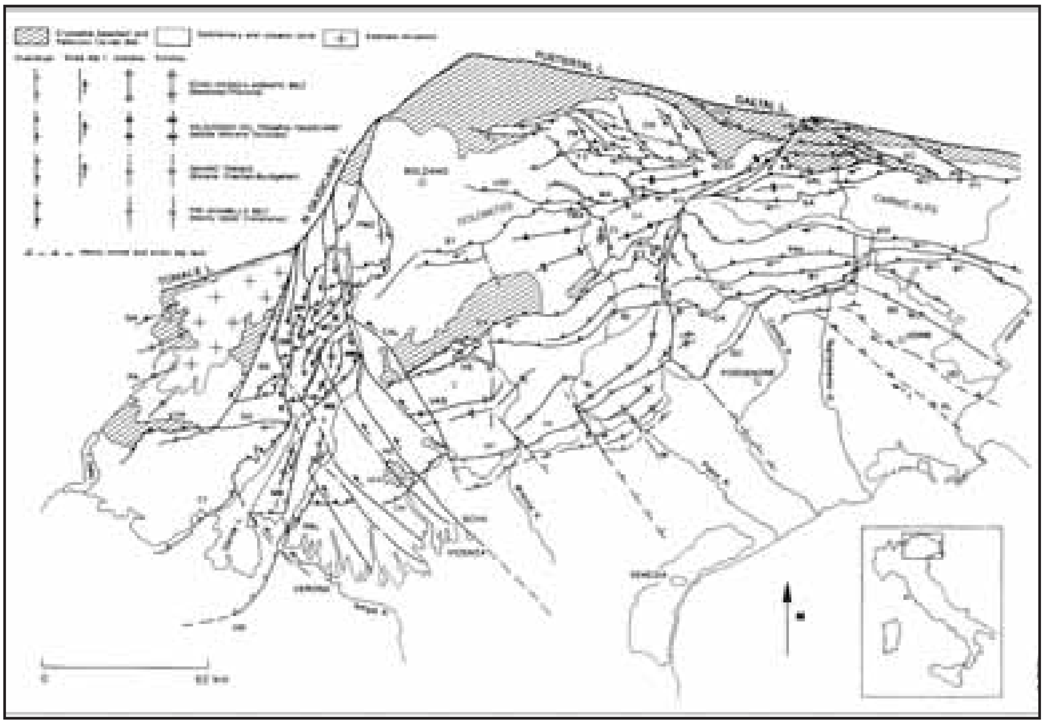


Figure 2 - Structural interpretation of the Eastern Southern Alps (modified from Castellarin et al., 1998c). Denomination of the structures: L.: tectonic line, lineament overthrusting, transfer faults. S.: local structural system. B.: structural belt. Palmanova L. (PL); Udine L. (UD); Bernadia L. (BE); Sacile L. (SC); Bassano-Valdobbiadene-Montello L. (BVM); Caneva L. (CA); Pinedo-Avasinis L. (PAV); Barcis-Taro Selo L. (BT); Alto Tagliamento L.-Fella L. (ATF); Sauris L. (SA); Val Pesarina-Lozzo L. (VPL); Pontebba-Tarvisio L. (PT); Poludnig L. (PG); M. Zermula-M. Cavallo L. (ZC); Forni Avoltri-Ravascletto L. (FR); Croce di Comelico-Val Visdende L. (CCV); S. Candido-S. Stefano di Cadore L. (SCST); Val Bordaglia L. (VB); Dolomiti di Sesto S. (DS); Funes L. (FU); Falzarego L. (FZ); M. Parei-Col Becchei-Fanes S. (PB); Stava-Collaccio L. (ST); Marmolada-Antelao L. (MA); "Giunzione Cadorina" (GA); Valsugana S. (VV); Val di Sella L. (VS); Colombarone klippe (C); Belluno L. (BL); Civetta L. (CI); Duron-Fedaia L. (VDF); Foiana-Mezzocorona S. (FMZ); Trento-Cles L. (TC); Calisio L. (CAL); Val d'Astico L. (VAS); Schio-Vicenza L. (SCHV); Castel Malera klippe (MA); Rovereto-Riva-Arco transfer zone (R); Recoaro zone (RE); Cima Marana L. (CM); "Flessura Pedemontana" (FP); M. Pastelllo-Ala L. (PAL); Volta Mantovana L. (VM); Doss del Vento L. (DV); Tremosine-Tignale-Costa L. (TT); Giudicarie S. L. (GS); Val Trompia L. (VTP); Brenta Group S. (BR); Ballino L. (B); M. Baldo-M. Stivo-M. Bondone L. (MB); Sarca-Paganella L. (S); Molveno L. (MO); Pre Adamello Belt (PA); Gallinera L. (GA). Modified from Castellarin et al. 1998c.

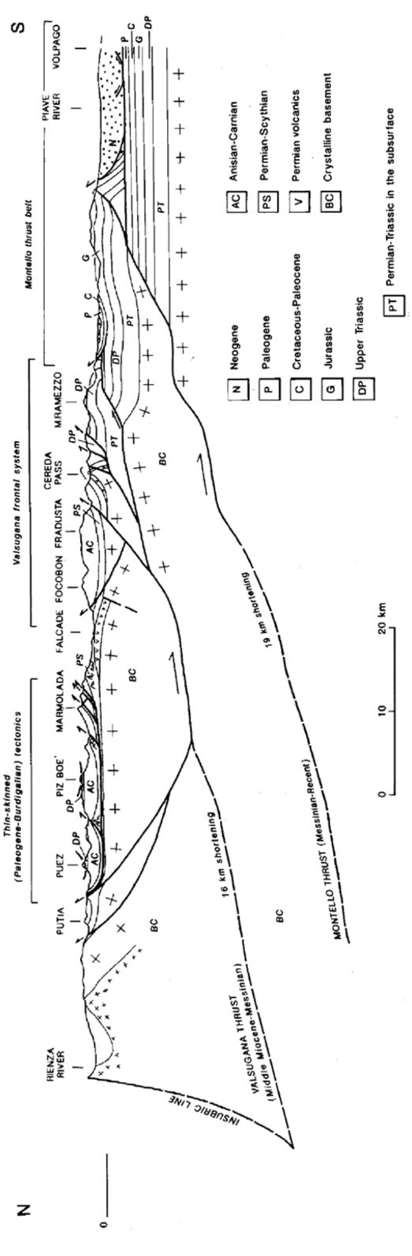


Figure 3 - Geological section through the eastern Southern Alps (from Castellarin et al., 1998c) along a trace close to the Transalp Profile: compare to the section of the Figure 36.

tested in several sectors of the Southern Alps (see f. i., Castellarin et al., 1988). New stratigraphic and structural data (Castellarin et al., 1998a) indicate that the tectonic control related to these magmatic activities can be referred to extensional crustal conditions as documented by the sin- and post magmatic normal faults, recognized in the Dolomites. The compressional tectonic associations (folding, minor and local overthrusts and strike-slip faults) previously thought to be linked to the Middle Triassic tectonic-magmatic events (Castellarin and Vai, 1982; Castellarin et al., 1988, see also Doglioni, 1984) are now considered as strong diapiric anticlines of the upper Permian evaporites originating submarine unstable strong relieves producing huge slide masses, chaotic assemblages ("agglomerati") and gravity deformations (see explanations on origin and effects of the Mid Triassic diapiric anticlines on pag. 7-12); these diapiric activities were trigged by the Mid Triassic magmatic event coupled by extensional tectonics (Castellarin et al., 1998a). Moreover, several true compressional structures (considered Mid Triassic in previous works) are largely consistent with the neo-Alpine compressional events.

The structural systems of the Southern Alps

The Insubric or Periadriatic Lineament

The Insubric Lineament (IL) of the Pustertal and Gailtal zones is a very strong tectonic separation between the S verging thrust belt of the Southern Alps, unaffected by Alpine metamorphism (Africa verging orogenic Chain) and the metamorphic nappe building of the Alps characterized by strong tectonic polarity to the N (Europa verging orogenic chain) (Dal Piaz 1934; 1942; Laubscher, 1974; 1986; Lammerer and Weger, 1998, etc.). The IL is a very sharp structural divide of the two facing sectors of the Alps. The lack in their N-S continuity is also enhanced by the E-W dextral strike slip displacement affecting the IL (for an update review of the problem see f.i. Viola et al., 2001). About its geometry, the sub-vertical setting is prevailing at the surface.

Pre Adamello Structural belt

The pre-Adamello structural belt is characterized by S vergent ENE-WSE trending thrusts with large crystalline basement implications; the superposition of the big fold ramps produced severe deformations and shortening in the western Southern Alps (Orobic, Presolana and Grigna mountain groups)

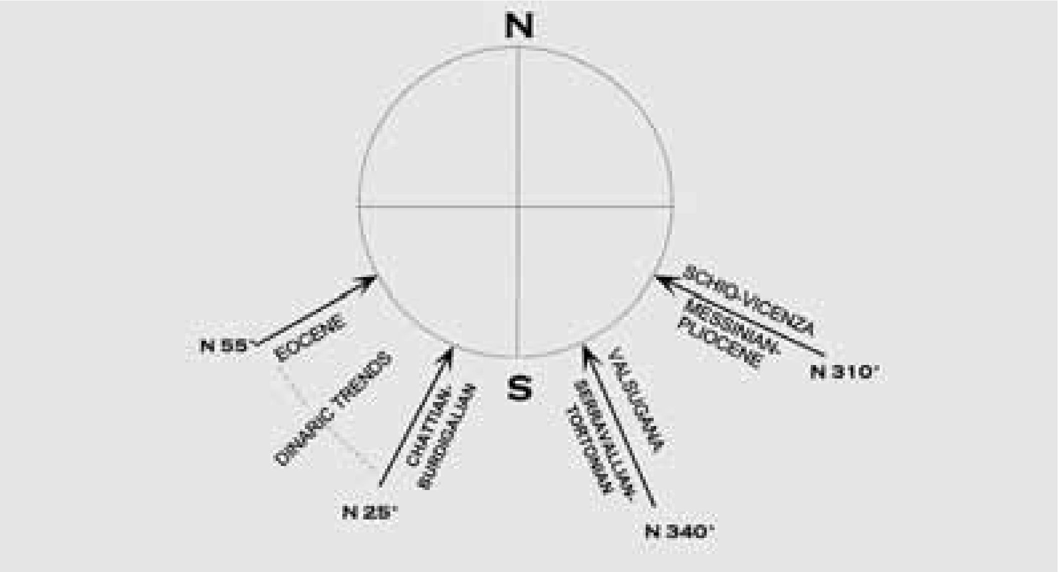


Figure 4 - Present azimuthal direction of the main paleo stress (compressional) axes of the eastern-Southern Alps polyphase structural systems. Chattian-Burdigalian and Messinian-Pliocene (Schio-Vicenza) compressions correspond to the Insubric phase and to Adriatic events in the text respectively (from Castellarin et al., 1998c).

(Laubscher, 1985). This structural system extends to the E in Val Camonica up to the western sector of the Adamello intrusions which clearly post date the tectonic deformation of the system (Brack, 1986). This belt has to be considered eo-Alpine in age (Late Cretaeous) (Doglioni and Bosellini, 1988; Bersezio and Fornaciari, 1988) and has not been recognized E of the S-Giudicarie fault (Figure 2, PA,GA).

Dinaric Structural Trends
(Eocene - Chattian/Burdigalian)

The Dinaric structural trends include two structural systems of similar orientation but of different age. Prominent SW verging, NW-SE trending thrusts, are located on the NW continuation of the external Dinaric orogenic chains (Figs. 1,2) in the Alpi Giulie and Friuli. To the N-NE (Carnia, Comelico) compressional deformations severely affected the crystalline basement of the frontal ramps. These deformations must be expanded to the SW involving the Mesozoic covers of the Dolomites as previously proposed (Doglioni and Bosellini, 1988; Doglioni, 1987). Stratigraphic and structural data, indicate that this tectonic system can be related to the meso-Alpine compressional event (Eocene). Generally, these structures were strongly remobilised during the neo-Alpine evolution in particular by the Insubric or Helvetic compressional events having similar contractional axes and Chattian-Burdigalian ages (Figs. 3, 4) (see f. i.: Picotti et al., 1997; Castellarin et al., 1998c). Due to the similarities in the structural trends and styles the two systems are not easy to be distinguished in the Dolomites where, generally, Tertiary marine deposits have been eroded.

Valsugana Structural System

The Valsugana structural system is largely developed in the whole S-Alpine domain and displays morpho-structural prominence in the eastern part of the belt (Figs. 2, VV). The structural system is characterized by SSE (S) verging and ENE-WSW (E-W) trending thrusts particularly intense in the Valsugana zone where the crystalline basement rocks are largely involved in the frontal ramp, overthrusting a still preserved sintectonic deformed post-Langhian clastic wedge, mostly composed by sequences of Serravallian and Tortonian age (Castellarin et al., 1992; 1998c; Selli, 1998). The intense activity of this compressional event is documented both by stratigraphic-structural data and by fission tracks studies which indicate uplifting in the hanging wall of the Valsugana overthrust of approximately 4 km between 12 and 8 Ma B.P. (Dunkl et al., 1996; Zattin et al., 2003). Detailed macro- and meso-structural analysis indicate that the paleo-stress field is homogeneously NNW-SSE (N-S) oriented in the whole belt, with an

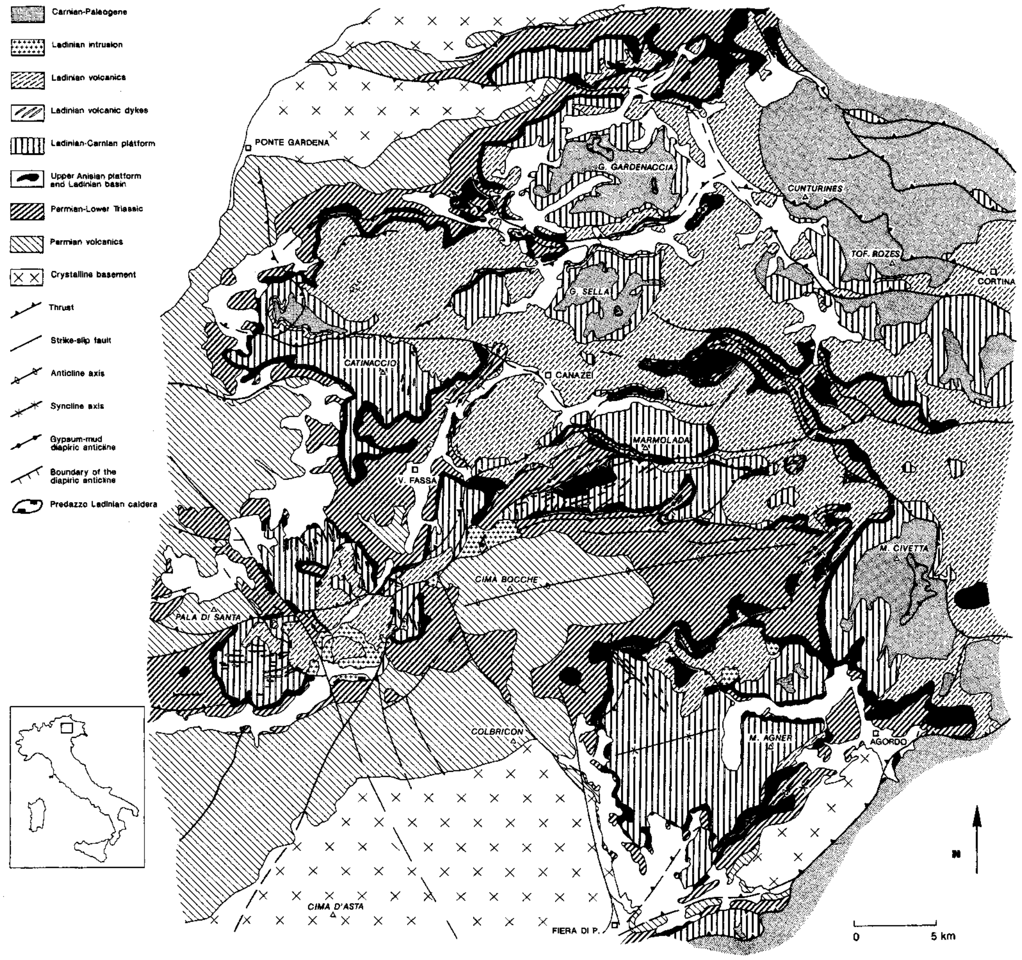


Figure 5 - Schematic structural map of the Western Dolomites (modified from Leonardi , 1968). From Castellarin et al., 1998a.

average value of N 340° (Figure 4) (Castellarin et al., 1992; Caputo, 1996; Picotti et al., 1995; 1997; Selli, 1998).

The Valsugana structural system expand largely to the E with strong overthrusts of the Belluno Dolomites (Figure 2, VV, Figure 3) with their continuation to the E in the Carnic Alps (Figure 2, SA, ATF). In the northern zone of the Piave River, the Dinaric NO-SE trending thrusts are cut by the younger ENE-WSW trending Valsugana main tectonic elements to form a typical structural crossing, previously indicated as Cadore junction ("Giunzione Cadorina") (Largaiolli and Semenza, 1966) (Figure 2, GA). Good images of the Valsugana structural system are visible in the vibroseismic section, N of Belluno and at Agordo such as the Belluno and Valsugana low middle angle overthrusts within the upper crustal zone, 10-15 km in depth (see later , stops of the last day of this excursion).

Bassano-Montello-Friuli structural belt

The Bassano-Montello (M)-Friuli (FL) structural belt (Figs. 1, 2, 3) is located E of the Schio-Vicenza (SCHV) and Val d'Astico (VAS) transfer faults (Figure 2) and include a wide belt from the Belluno (BL) depression ("Vallone Bellunese") (Figure 2), to

the N, to the border of the Venetian Plain (the “foothill flexure” by Barbieri, 1987, FP of Figure 2), to the S. The belt is dominated by prominent NE-SW trending, SE verging folds and thrust associations that deform and partly override the thick sintectonic clastic successions of the foot hill (Figure 1). This sintectonic wedge is composed by prevailing clastic deposits with conglomerates of late Tortonian and mostly Messinian age thick over 2 kms (Montello-Friuli) which are locally capped by deformed Pliocene clays (at Cornuda, Montello, M, Figure 1) (Massari et al., 1986). The paleo-stress directions obtained by mesostructural analysis are oriented NW-SE with prevailing value between N 300° and N 330° (Castellarin and Cantelli, 2000) (Figure 4). Underneath the ramp anticline of the Flessura Pedemontana-Passo di S. Boldo, the low to middle angle N dipping overthrust bordering to the N the Montello structure (including the Neogene clastic wedge) is clearly visible in the Transalp seismic section up to depth of 10-12 km (see later , stops of the last day of this excursion).

The ages of the structural accretions and deformations of this structural belt are well controlled by the sintectonic clastic sequences and can be related mostly to the Messinian-Pliocene and to the Pleistocene. These structures are the youngest in the whole Alpine orogenic Chain and can be related to the late post-collisional neo-Alpine evolution of the Adriatic compressional events, strongly affecting the Apennines.

Notes on the regional kinematics

In the Carnia and Friuli, the tectonic activity which produced the present seismicity has been attributed to compressions oriented about N-S, recognized by focal mechanisms (aftershocks of the 1976 Friuli earthquake: Slejko et al., 1987; see also Anderson and Jackson, 1987 and Carulli et al., 1990). However, in the zone between Cellina and Tagliamento Rivers (Figure1) across the hills and at the border of the Plain, prominent E-W folds (enclosing the Messinian thick conglomerates) are largely developed and they are considered to affect also the subsurface of the Plain of the Tagliamento river (Amato et al., 1976). This structural setting could be originated by particular mechanical conditions of this area due to anomalous crustal block motions (Venturini, 1990; Bressan et al., 2003). Alternant about NW-SE and N-S compression during late Pliocene-Pleistocene have been suggested by structural analysis, in this area (Caputo et al., 2003), where the focal mechanism reconstructions of the seismic events, occurred during the two last decades, indicate compressions oriented between NNE And NNW (Bressan et al. 2003).

The extensional tectonics is well represented in the eastern S-Alps generally by minor structural systems of normal faults originated during the uplifting of the chain, subsequent to the greatest compressional events. Several main normal to listric faults correspond to Mesozoic structures mostly of the previous Norian-Liassic continental rifting which were not (or only partly) inverted during the compressional evolution.

As to the regional frame of the neo-Alpine compressional tectonics, the detailed studies carried out on

the magnetic evolution of the Central Atlantic indicate that the post collisional convergence between the African and European plates, referred to the eastern Southern Alps, is of the order of 150-200 km in the last 26 Ma (Mazzoli and Helman, 1994): the motion of the African plate to the N (referred to Iblei, Sicily) occurred according to the following kinematical conditions: displacement to the NE between 26 and 16,22 Ma (Chattian-Burdigalian); toward the NNW between 16,22 and 7,9 Ma (Burdigalian-Tortonian) and toward the WNW, from 7,9 Ma onwards. These kinematical conditions and their chronological development are coherent with the compressional evolution of the three superposed thrusts systems recognized in the polyphase structure of the Eastern Southern Alps here outlined (Figs. 1,2).

Description of the field trip itinerary and of the stops in the Western Dolomites.

The field trip is planned across the western central sector of the Italian Dolomites inside one of the best landscape of the most famous Mountain groups in the eastern Southern Alps such as the Catinaccio (Rosengarden), the Sassolungo-Sassopiatto (Langkofel-Plattkofel), the Sella and Marmolada massives whose peaks are higher than 3000 m: the highest one, the Punta Penia (3343 m) belongs to the Marmolada group. Spectacular high subvertical wall, mountain crest and tops was and are also now an invincible attraction not only for climbers but also for every kind of people, fond of mountain milieu both in summer and in winter. These beautiful landscapes of this part of the Dolomites is provided by the stratigraphic succession composed by extensive Triassic Dolomite units generally divided into two principal parts by one extensive and thick volcanic interval. The stratigraphic units outcropping in this area of the Dolomites include also several other units predating and also postdating the Middle-Upper Triassic, as indicated in the synthetic map in the cover of this book and in Figure 5. The first two days of field trip are dedicated to the present setting of this classical zone of the Alps, throughout his stratigraphic and tectonic evolution reconstructed by geological data.

Saturday 28 (or Sunday 29) August, 2004:

departure from Florence to the Dolomites in the early afternoon of 27,or 28 August 2004 by train (reserved car) or bus to Bolzano . Continuation of the trip to Passo di Costalunga via Eggen Tal (bus). Overnight in Hotel at Nuova Levante or at Frommer Alm

DAY 1

Introduction to the stratigraphy and to the structural setting of the Western Dolomites.

Stop 1:

350 m W of Passo di Costalunga (Karer Pass main road) in the meadows facing to the N the Catinaccio (Rosengarten): explanation of the Stratigraphy of the Western Dolomites (Figg.6)).Panoramic view of the Mid Triassic Rosengarten buildup in particular : in the basal part of the relief, a tabular some 60-80m thick dolostone shelf carbonate lithosome (Contrin Fm.), late Anisian in age, forms the base of the overlying thin bedded basinal mainly early Ladinian limestones (the Livinallongo Fm.), thickening to the E up to 50-60 m and disappearing to the W in about 4 km. This unit is overlie by Mid Triassic carbonate buildup

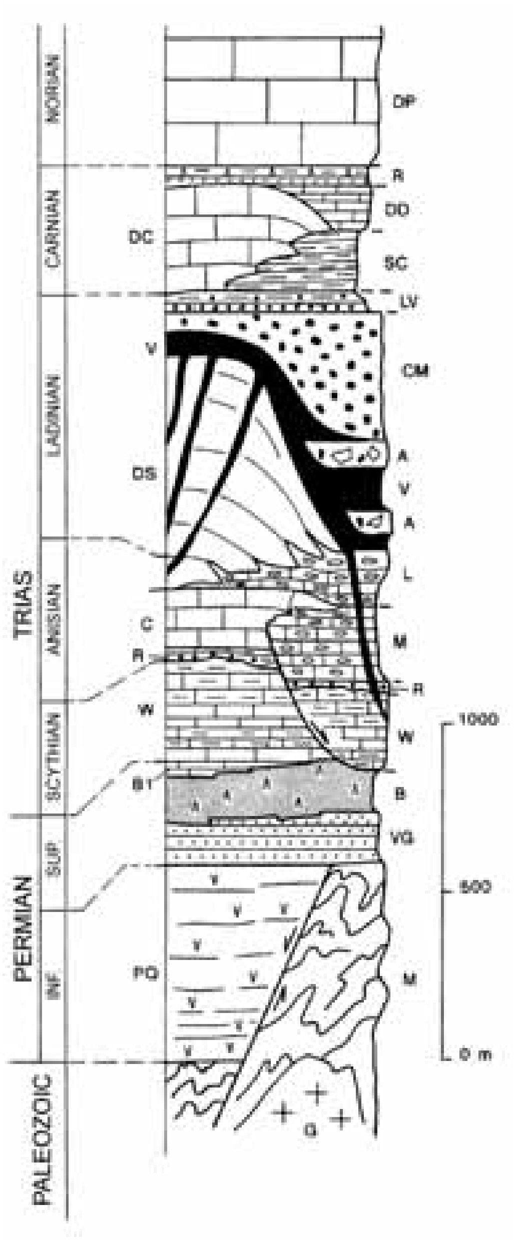


Figure 6 - Synthetic stratigraphy of the pre-Jurassic succession of the Western Dolomites. Letters: M, metamorphic rocks of the crystalline basement (Pre-Permian); G, Granodiorite intrusions (Early Permian); PQ, volcanics (quartz porphyry) (Early Permian); VG, Val Gardena sandstone Fm (Late Permian); B, B1, Bellerophon Fm(Late Permian): evaporitic (B) and shelf carbonate (B1) facies(late Permian); Werfen Fm (Early Triassic); R, Richthofen conglomerate Fm (Early Mid Triassic); C, Contrin Dolomite Fm (Anisian); M, Moena Fm (Anisian); L, Livinallongo Fm (Anisian-Ladinian); DS (PL), Sciliar Dolomite Fm (Ladinian carbonate Platform or buildup) (Anisian-Ladinian); V, volcanics (basalt) and sub-volcanics (basaltic dyke) (Late Ladinian); A, chaotic assemblage ("Agglomerate"); CM, Marmolada conglomerate Fm (Late Ladinian); LV, La Valle Fm (or Wengen Fm) (Late Ladinian); SC, San Cassiano Fm (Carnian); DC, Cassian Dolomite Fm (Carnico); DD, Dürrenstein Dolomite Fm (Carnico); Raiblian beds Fm (Carnico); DP,Dolomia Principale (Norico). From Castellarin et al., 1998a.

of the Sciliar dolomite Fm (late Anisian-Ladinian) forming the high and steep walls of the Group which are coeval to the basinal deposits as documented by their stratigraphic relationships. The carbonate shelf deposits, in fact, display clinoform bedding dipping to the W about 30°, inside a thick succession (hundred of m to about one Km, according to the outcrops extension). They correspond to the slopes of the buildup progradation toward the basinal domain where they interfinger with the deep water deposits of the Livinallongo Fm (Figure 7, 8). The basal part of the sequence, badly exposed, in the discontinuous outcrops underneath the cliffs and inside the meadows include the clastics of the Richthofen Conglomerate (basal part of the late Anisian), the shelf carbonates alternated to polychrome, mostly red silty sandstones of the Werfen Fm (Early Triassic) and, in the lowest part of the slope, the Upper Permian evaporites of the Bellerophon Fm(Figure 5).

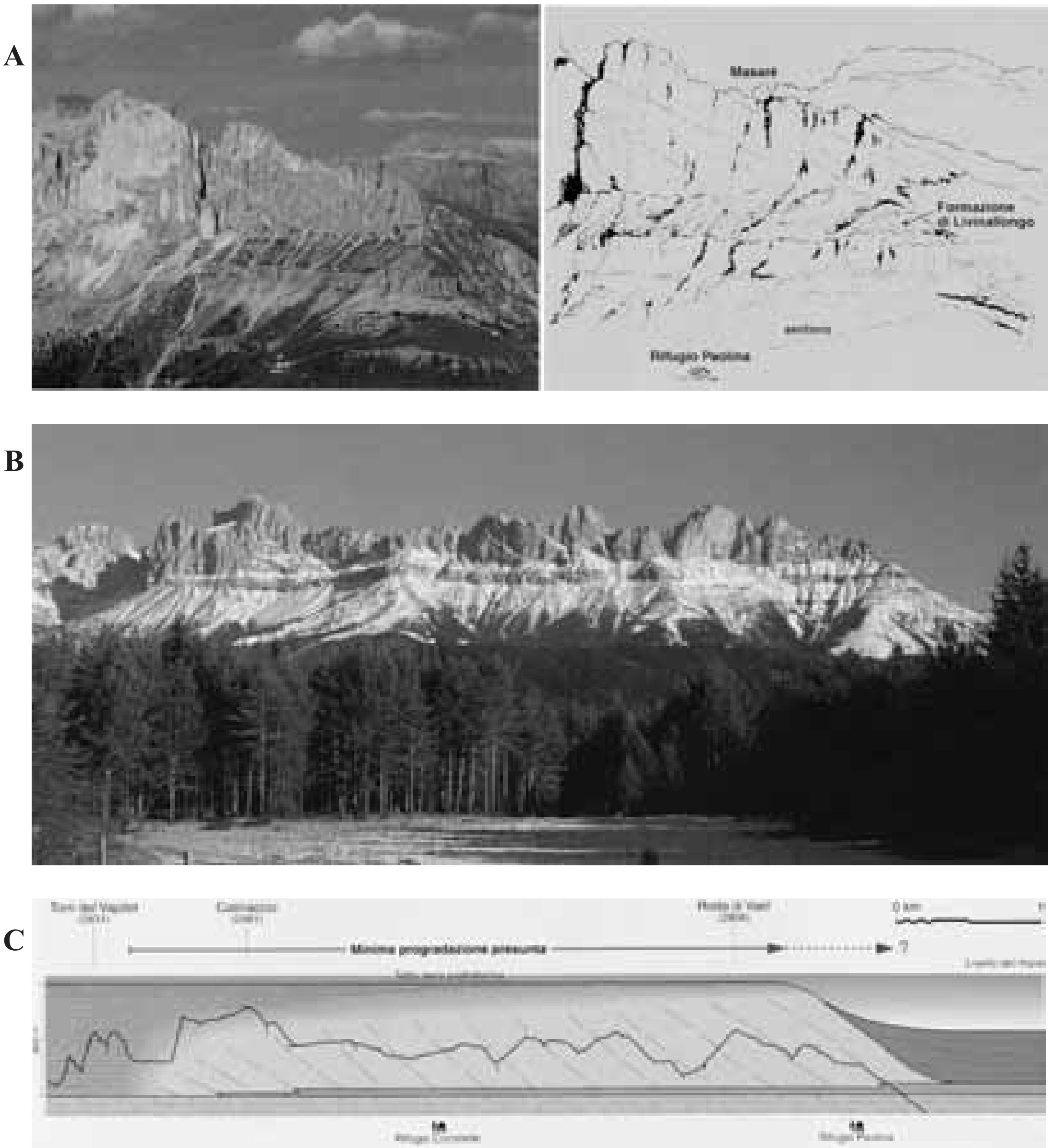
Stop 2:

at the northern border of the lake Carezza (Karen). Panoramic view of the Latemar mountain Group where a thick sequence of the Sciliar Dolomite Fm with clinoform bedding, due to lateral progradation of the platform, are visible. To be noted the internal part of the carbonate body where the join the sub-horizontal bedding superposition of the aggraded buildup (Figure8). Note the location of the small lake confined inside morenic ribbons, covered, to the S, by detrital and blocky slides.

The field trip descends the road from the Passo di Costalunga to Vigo di Vassa attaining, in the vicinity of Campitello di Fassa, the departure point (altitude circa 1450 m) of the cableway to Col Rodella peak (2387 m).

Stop 3:

at base of the cableway to the Col Rodella. See the preparatory description on the Mid Triassic diapirism of the second day field trip (pag. 8-9) for better



Figs. 7 A, B, C - Rosengarten (Catinaccio) W side: Roda di Vael and Masaré peaks: relationships between the Mid Triassic shelf carbonate (Sciliar DolomiteFm) and the basinal coeval deposits (Livinallongo Fm). To be noted the clinoform thick beds of the the Sciliar Fm corresponding to the shelf slopes joining the tabular beds of the Livinallongo Fm in the basinal zone according to typical progradation geometries (Figure 7 A); panoramic view of the Rosengarten (Catinaccio) W side (Figure 7 B) and graphic synthetic reconstruction of the relationships between the different parts of the carbonate buildup and the basinal deposits documenting, in some 5 km, the minimal N to S progradation of the carbonate platform (Figure 7 C). In the same scheme(Figure 7 C) a reconstruction of the carbonate edifice zones missing, due to erosion, is also proposed. From Bosellini, 1996.

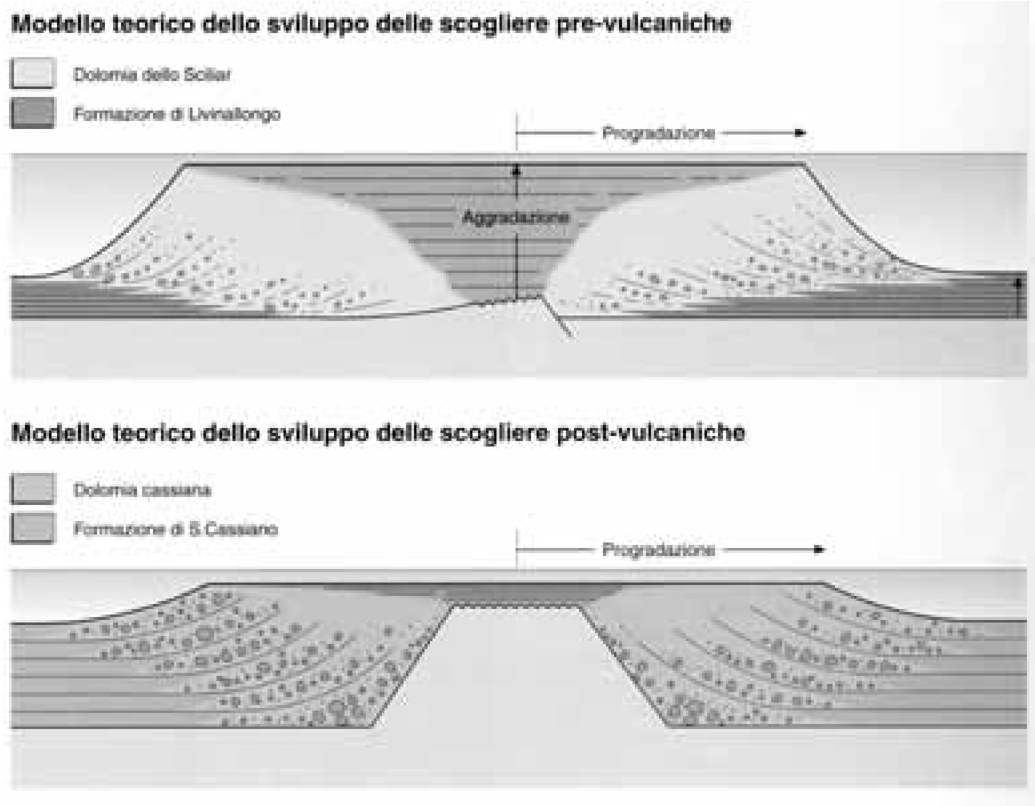


Figure 8 - Synthetic schemes illustrating different models controlling the relationships between carbonate shelf edifices during the mid Triassic time : in particular the Anisian-Ladinian buildups pre-dating the volcanic events and those (mostly Carnian) postdating the Volcanism. In the second case the progradation is strongly greater than aggradation due to the lower rate in subsidence. From Bosellini,1996

understanding the explanation of the structural setting of the Col Rodella (Figg. 9, 10A, 10B, 10C). The N-S section across this relief is synthetically represented in the section of Figure10C showing the complicate structure of this zone where four "tectonic" sheets of Permian-Mid Triassic sequences are superposed. This structure affects only the local sequences pre dating the end of Mid Triassic. In fact the whole structure is sealed by the late Ladinian clastics of the Conglomerate of the Marmolada Fm disappearing in the stratigraphic sequence overlying this unit. Furthermore the tectonic sheets are associated to chaotic assemblages ("Agglomerates") which, in the more recent studies are considered originated by submarine slides (debris flow). In the Col Rodella structural zone thin flakes of this rocks separate, in some place, the superposed Permian -Triassic sheets. On the contrary, the "Agglomerates" occupies a wide extent of the eastern slope of the Col Rodella relief: here the lateral E-continuity of the of Permian-Mid Triassic slabs superposition is also interrupted (Figg. 10A, 10B). The "Agglomerates" form a wide and thick body N to Canazei village continuing to the E (northern side of Buffaure mountain group, in the vicinity of Penia and Alba villages). They are considered as huge to giant (up to several hundred m thick) submarine slide masses detached from the limbs of the Mid Triassic diapiric structures (Figs.9,10B,10C) (see also later: "Mid Triassic diapirism..", Day 2 .on pag. 4).

Stop 4:

at the cableway arrival station of the Col Rodella peak.

Analysis of the Sciliar Dolostone huge slide masse forming the summit of the Col Rodella (Figs.10D1,2):

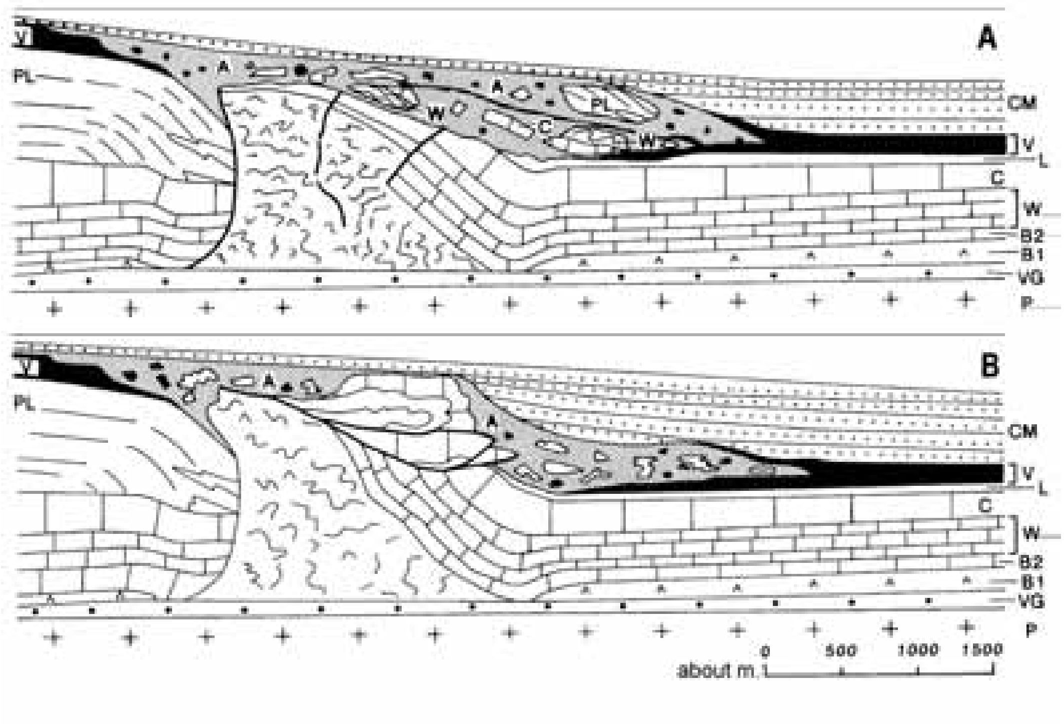


Figure 9 - General interpretation of the geometric and structural relationships between Mid Triassic diapiric anticline and chaotic assemblages ("Agglomerates"). The late Permian evaporites is assumed to intrude close to the carbonate buildup border. In the section A the huge slide produced prevailing dismembering and fragmentation of the detached masses, generating chaotic assemblages similar to sedimentary mélanges. In the section B the rock detachment produced gravitational superposition of great slabs: this scheme is suitable to the structural setting of the Col Rodella (see Figure 10 C). Letters: P, Lower Permian Volcanics; PL, Ladinian buildup; other letters as in Figure6. From Castellarin et al.,1998a

Figure 10 A - Panoramic view of the Col Rodella. Letters as in Figure 6 and 9.

dolomicrites and dolosparites are mainly formed by dolomitic breccias (Figure10D2)inside an hectometric sequences of metric to decametric clinoform bedding. Pelagic micritic soft clasts (inside the breccias) and thin (mm, cm) discontinuous laminated intercalations covering the dolomite metric beds, are presenting at the W side of the outcrops about 20 m below the cableway arrival point . The sequence can be interpreted as coming from a slope basal part of a Ladinian buildup. In fact, the top of the Sciliar

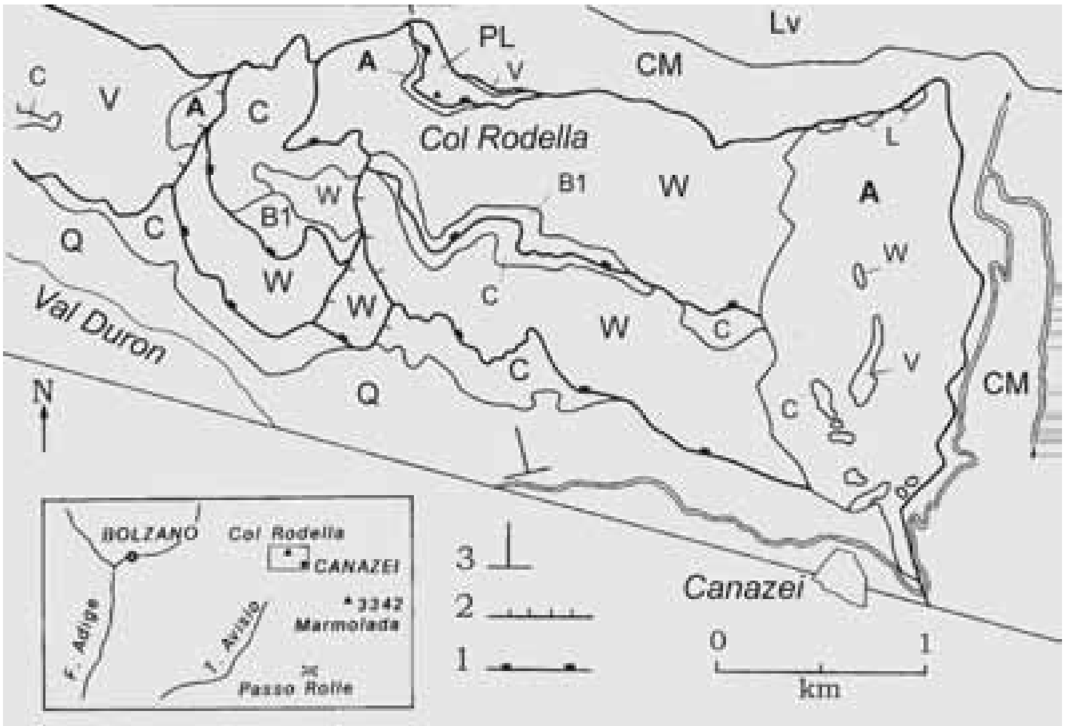


Figure 10 B - Very simplified geological map of the Col Rodella and surrounding zones (modified from unpublished map by Eugenio Del Pero). Letters as in Figs. 6,9; B1, Bellerophon Fm, carbonate shelf "badiota" facies; Lv, LaValle or Wengen Fm; Q, Quaternary cover. Numbers: 1, contact between superposed slab; 2, extensional fault; 3, trace of the geological section of Figure 10C (central part).

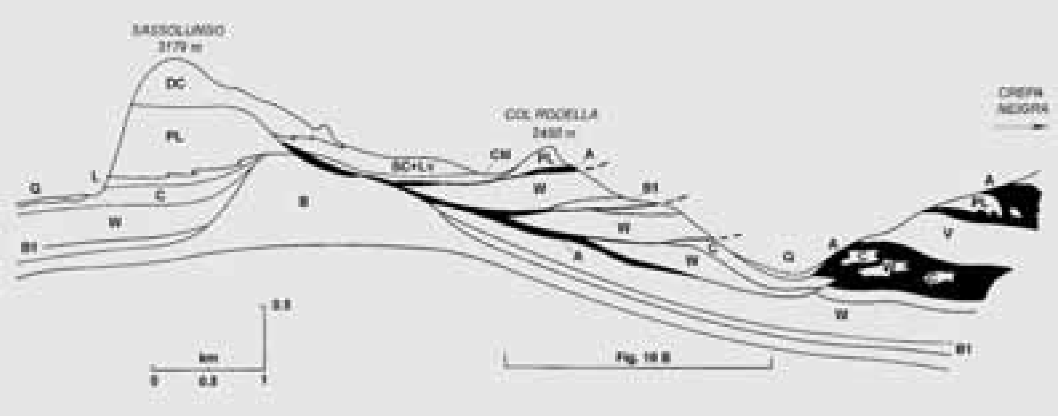
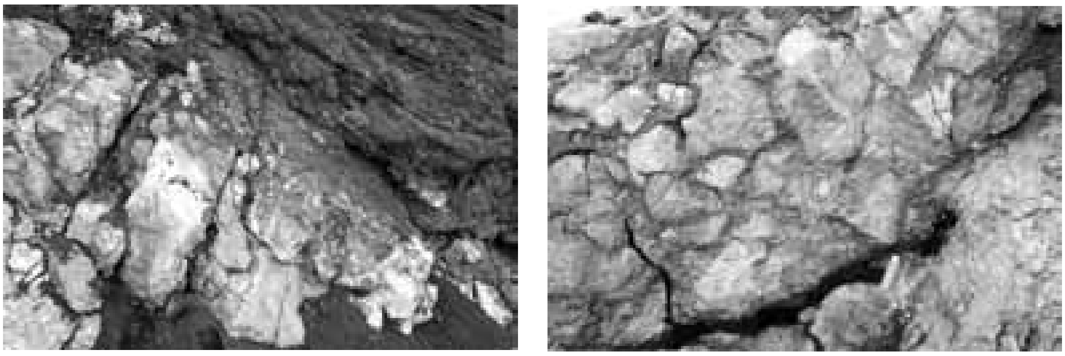
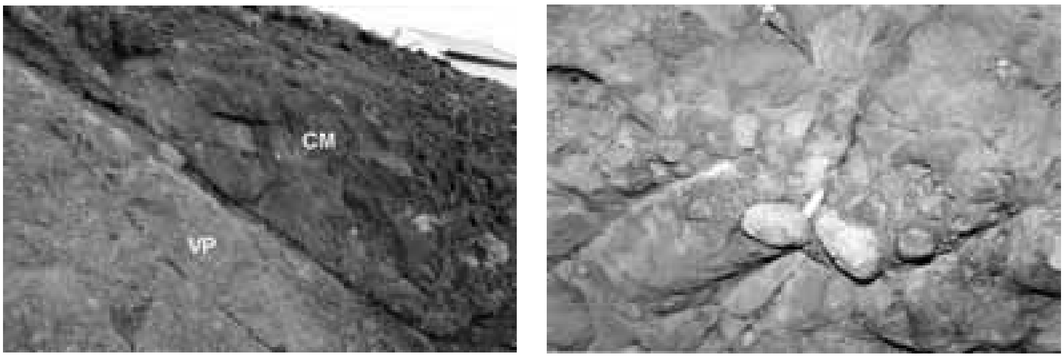


Figure 10 C - Geological section across the Col Rodella between the Sassolungo (Langberg) (to the N) and the Buffaure massif (to the S). The superposition of several Permian-Triassic slabs, previously referred to Mid Triassic or Neogene compressional duplication, are here related to gravitational Mid Triassic huge slides discharged from the S limb of a prominent diapiric anticline (modified from unpublished section by Eugenio Del Pero). Letters as in Figs. 6 , 9, 10B.



Figures 10 D1-2 - Col Rodella: arrival site of the cableway.
Contact of the pillows breccias on the carbonate breccias of the Ladinian platform (Sciliar Dolomite Fm). Note the unconformity marked by dark crust (hard ground) along the irregular contact sealing the underlying dolomite breccias (Figure 10 D1). The structure of the underlying carbonate breccias is evidenced by the matrix septa (Figure 10 D2).



Figures 10 D3-4 - Col Rodella: arrival site of the cableway. Contact between the pillow breccias (VP) and the overlying conglomerates (Marmolada Conglomerate Fm) (CM) which discordantly onlap the breccias (Figure 10 D3) and include great round pebble of basic volcanics (Figure 10 D4).

Figure 10 E1-2 - Grohmann tower, south lower slope : transition between the San Cassiano Fm and the Cassian Dolomite Fm, marked by thin beds of calciturbidites, isolate carbonate blocks (olistolithes) (Figure E 1) and breccias bodies (Figure E 2) close to the contact.

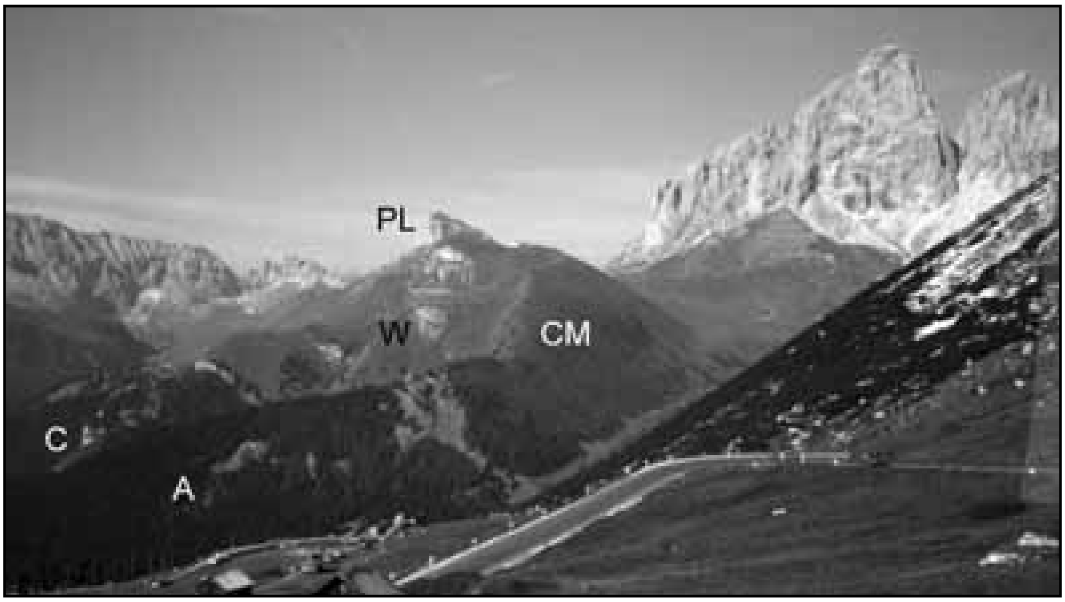


Figure 10 F - Panoramic view of the Col Rodella from the road bents (altitude about 2000 m) to Passo Pordoi. To be noted the homoclinal setting of the Marmolada conglomerate (CM) discordantly covering and sealing underlying the chaotic assemblages (Agglomerates) (A) and the pile of superposed Permian-Triassic slab (W). Letters as in Figs. 6, 9.

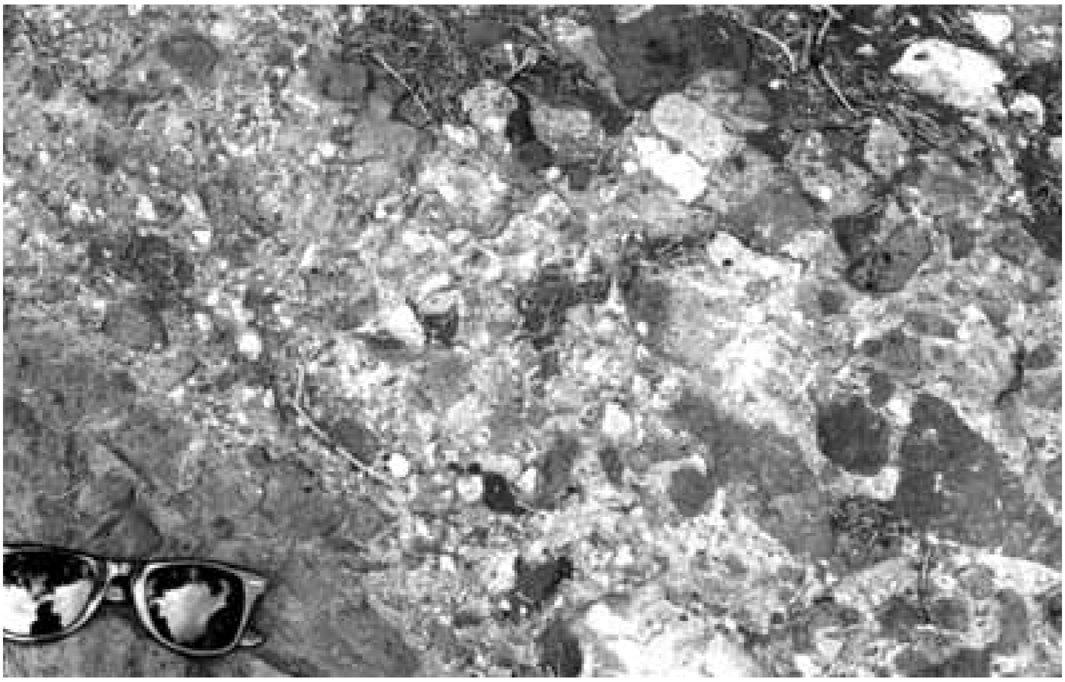


Figure 11 - Road leading to Passo Pordoi: surrounding of "Lupo Bianco"(altitude about 1715 m) along the forest track (about 100m to the W). Chaotic assemblage displaying texture and structure looking like sedimentary mélanges. They enclose clasts and blocks (cm,dm) of basaltic lava flow, micritic limestones and cherts (Livinallongo Fm), and rare sandstones (Werfen Fm). The matrix is composed mostly by carbonate mud and clayey volcanics (?ialoclastites).

dolostone is covered by late Ladinian pillows breccias (shoshonitic basalt) (Figure 10 D2), about 40 m thick, including rare complete pillows. A low angular unconformity separates the two units. One stronger basal discontinuity marks the contact with the overlying volcano-clastic succession of the Marmolada Conglomerate Fm (50- 60 m thick) (Figure 10 D3) composed by coarse basaltic rounded pebbles (up to 20-30 cm) (Figure10 D4) of turbiditic fan delta deposition passing to the volcanic sandstones (with a minor carbonate component) of the Wengen Fm. Conglomerates of this unit seals the chaotic mélange in the W slope of the Col Rodella up to the vicinity of Canazei village thus documenting both the Mid Triassic age of the superposition of the Permian-Triassic slabs (Figure10 C) denying significant Neogene thrust duplication in the Col Rodella structure (see also Figure10E).

Stop 5:

along the way in front of the Sassolungo Group toward the base of the Grohmann peak about 400m and more from the cableway arrival.

To be observed the spectacular panoramic views of the stratigraphic and structural setting of the Sassolungo and Sella Groups. To be noted the tabular structure of this area, only gently affected by Alpine tectonic deformations; furthermore large expositions of the local stratigraphic successions are present: here the thick clinoform beds of the Dolomia cassiana Fm (latest Ladinian-early Carnian) interfinger the basinal deposits of the uppermost part of the Wengen and mostly of the S.Cassiano Fm (early Carnian). At the basal side of the Grohmann peak to be noted the passage between the basinal S. Cassiano Fm and the overlying Cassian Dolomite Fm. This transitional sequences includes canalized caciturbidites, carbonate mega-breccias and isolate olistolithes (Figure10 F1,2). The field trip continues from the Col Rodella top to Val di Fassa (Campitello) by cableway and to Canazei along the national road to Passo Pordoi (by bus).

Stop 6:

at the "Lupo bianco" Hotel (locality: Pian de Frataces). Following the forest way to the S for hundred m (with small differences in altitude). Several outcrops of chaotic assemblages are visible. To be noted the varieties of the enclosed lithological units with giant olistolithes of Werfen Fm, and Contrin Dolomite Fm inside a sedimentary mélange of soft basinal sediments (Livinallongo Fm) and volcanics (Pillow breccias and ialoclastites) (Fig 11).

After the conclusion of the observations, the fild trip attains (by bus) Pozza di Fassa and Meida for the dinner and the overnight.

DAY 2

Geology of the Mid Triassic upper Permian diapiric structure of the Valle di S. Nicolò; neo Alpine tectonic structure of the Marmolada Group.The excursion target is the S.Nicolò Pass zone (altitude, 2340 m): start point Meida, the bus rises the road along the S. Nicolò Valley up to Ciampié (1820 m), small shuttle cars are available up to valley head (about 2000m) to reach the steeper way: continuation of the excursion on foot.

Mid Triassic diapirism of upper Permian evaporites in the Western Dolomites (Introduction)

The Mid Triassic diapiric anticlines of the Western Dolomites are considered the basic structures triggering static instability of the sedimentary and volcanic successions overlying the Permian evaporites of anticlines and diapirs. Huge strata and rock detachment, disruption and fragmentation along the limbs of these structures provided deep marine gravitational accumulation within the border of the basinal areas: in fact great volumes of chaotic assemblages and slide masses of the so called "Agglomerates" are well documented in this zone of the W Dolomites (Figs. 9, 11, 13). Formerly, the most part of these rocks were considered as intra diatreme volcanic products due to the submarine explosive eruptions (Leonardi, 1968).

The Permian evaporitic sequence

The succession of the Permian evaporites of the Bellerophon Fm correspond to the lower interval of this unit, about 100-150 m thick. This has been called "facies fiemmazza" in the classic study (see f. i.: Leonardi,1968). The evaporitic succession is made up of an irregular alternation of dark pelite, limestone, mostly evaporitic dolomite and provides levels of sulphates in nodules (if they are present in the primary structures and have not been re-mobilized). They refer to typical coastal Sabkha conditions in which nodular production of gypsum occurred. (Bosellini and Hardie, 1973). Pelites are prevalent at approximately 60% while carbonate (10%) and sulphates (30%) make up approximately the other 40% of the whole succession. It is necessary to note that the value of the above noted pelite seems underestimated in comparison to the real quantity present inside the anticlinal diapiric nuclei where these rocks can exceed values of 70% of their total volume. One must consider that inside the diapiric intrusions, the pelites are probably selectively concentrated if compared to the other components of the succession. As a group, they are probably lighter, with more plastic and therefore more mobile behaviour inside the evaporitic multi-layer. Moreover it is assumed that the primary sulphates, especially gypsum, were made by hydrated phases and that the primary conditions were maintained until the thermal event. This was concurrent with the onset of the basaltic magmatic event (shoshonites) of the late Ladinian.

Mechanical remarks on the origin of the diapiric anticlines.

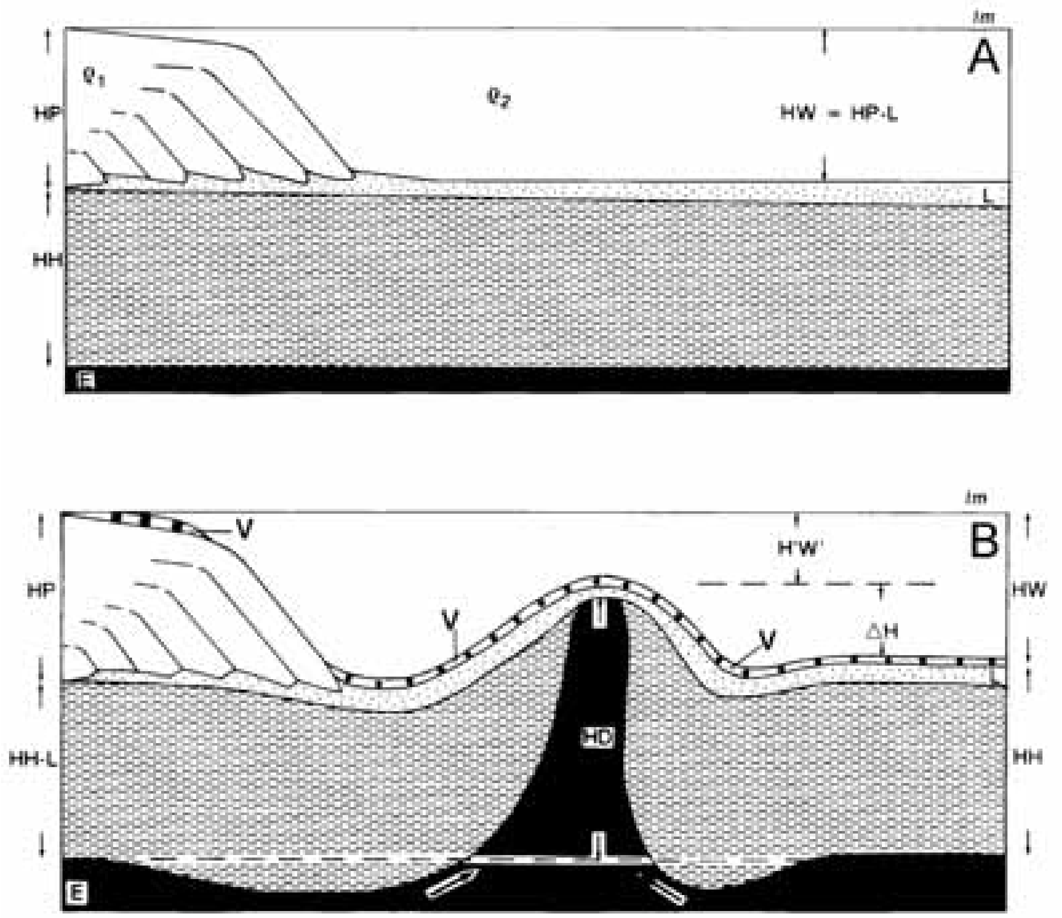
The late Ladinian diapiric anticlines of the Dolomites are interpreted as a consequence of a loading differential (approximately 10.25 MPa) exerted on the Permian evaporites located between the Ladinian shelf carbonate buildup (Sciliar Dolomite) and the adjoining coeval basinal deposits (Livinallongo Fm) whose difference in thickness is equal or over 700 m (Figs. 12, 13). The principal cause of instability within the evaporite multi-layer is assumed to have been produced by the largely widespread former hydrate sulphates (gypsum) which maintained temperatures below the inversion phase to anhydrite (approximately 60 degrees Celsius) until the late Ladinian. In fact, at a depth corresponding to the 1500 m of overlying succession thickness and with a normal thermal gradient (30 degrees C°/km or less, due to the submarine conditions) the Permian evaporites, during Ladinian time were heated to 40-50 degrees Celsius, insufficient to produce the phase inversion (Figure14B). During the Late Ladinian thermal event in connection with the volcanic occurrences (mostly shoshonitic basaltic flows), the temperature within the evaporites must have been increased to even larger values over the phase inversion of the semi-hydrate sulphate (bassanite) and anhydrite, thus triggering diapiric processes (Figure 14A). In fact, large amounts of water coming from the dehydration of sulphates had to be supplied to the pelitic rocks of the evaporite multi-layer, wherein most of the over pressured fluids were trapped. The intrusive raising of the diapiric structures were provided, mostly, by the pelitic sediments. In fact, they represent the dominant or prevailing lithological component of the intruded evaporites. Due to their over pressured fluid content, their low density, and their ductile mechanical behaviour (Figs. 15, 16,17A,B) the pelites could best utilized the loading differential to trigger the diapiric intrusions. In such conditions the denser anhydrites, passively rose up inside the diapiric bodies (Figure 17A). Further more, the mobile mechanical behaviour of the sulphates, due to their very low shear resistance, is testified by their internal sheath fold structure (Figure 16). The Late Anisian fracturing and block faulting and the Late Ladinian reactivation of extensional tectonics enhanced and in some cases controlled the rise of the diapiric structures.

Stop 1:

S. Nicolò valley road (altitude 2000 m):

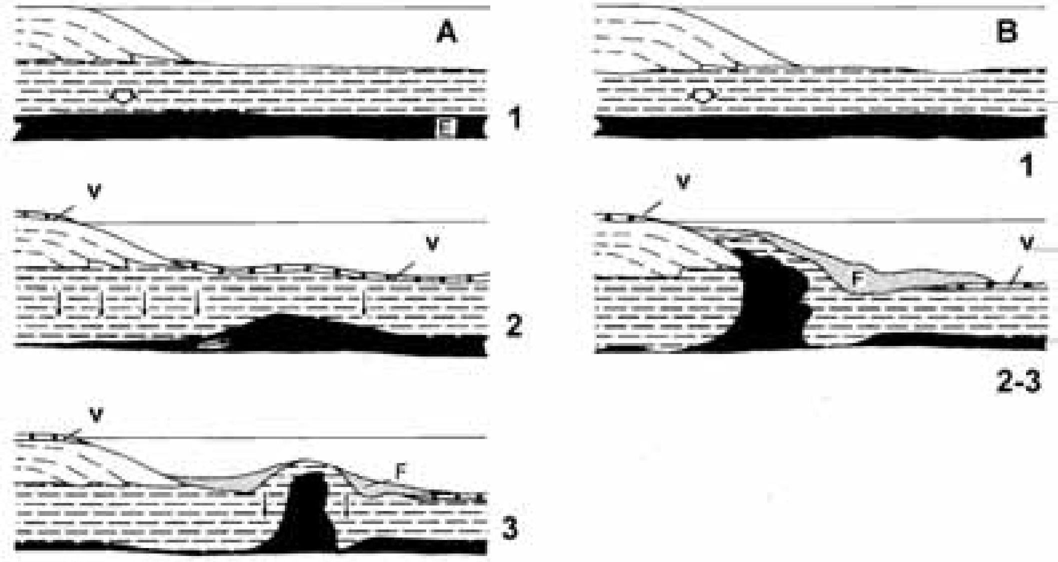
To the W: panoramic view of the Ladinian carbonate shelf edge at Maerins Mt. (west side of the S. Nicolò Valley). The thick clinoform beds of the Sciliar Dolomite dip to the N and are onlapped by basinal volcanics (ialoclastites, pillow-breccias and p.-lavas) of the SW border of the Buffaure mountain Group, were these kinds of volcanics are dominant with huge thickness and volumes (Figure 18). In the Valley of S. Nicolò zones and the adjacent Buffaure Group, during the Ladinian, deep water sedimentary conditions developed. This area was located along the border of the carbonate shelf buildup of the Costabella Mountain Group.

To the E and NE: panoramic view of the S. Nicolò diapiric anticline (Figs.19A, 19B) an ENE trending structure, some 7-8 Km long and more than 2 km wide, dominated by the strong diapiric intrusion of the upper Permian evaporites of the Bellerophon Fm (see previous pages).



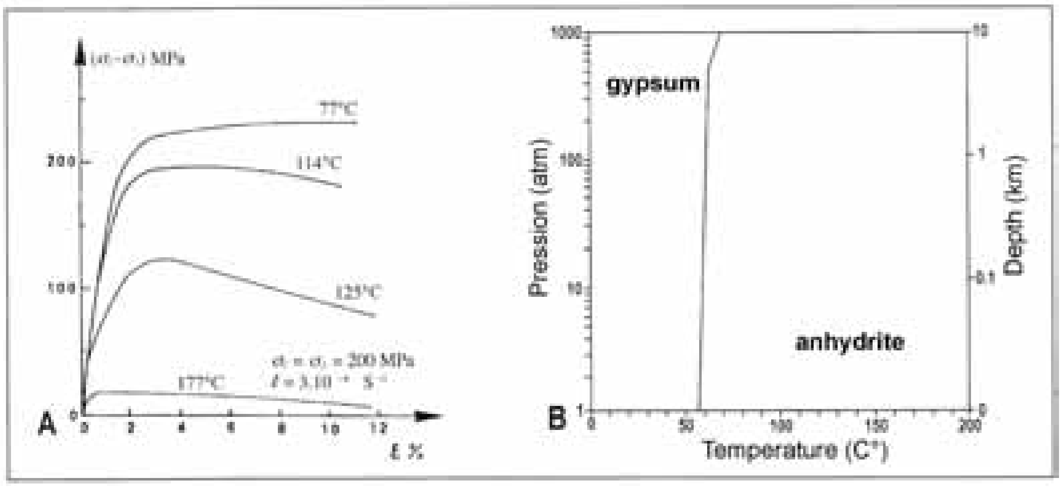
Figs.12 A, B - Relationships between Sciliar Dolomite buildup and the Livinallongo Fm basinal deposits predating the diapiric intrusion (12A). Simplified geometries of a diapiric anticline where the difference in overburden is provided by the difference in density of Sciliar Dolomite ($\rho1$) and sea water ($\rho2$) (12B). Letters: E, Permian evaporites; HH, stratigraphic units overlying the evaporites; HP, Sciliar carbonate platform succession (about 800m thick including volcanics); L, Livinallongo Fm (about 100 m thick including volcanics); V, volcanics (Figure12 B); HW(= HP-L) depth of the basinal zone; average density of the Sciliar Dolomite (assumed value of some 2,5 gr/cm3); density of sea water (assumed value of 1,035); HD, height of the diapiric structure (from evaporite source to top); H, height of the diapiric top (from the sea bottom); HH-L, interval of common units across the basin; overburden differential = (HP-L) . $\rho1$ - HW . $\rho2$ = 102,55 Bars (10,25 MPa). Modified from Castellarin et al.,1998b.

- The structure, in its nucleus, is strongly complicated by thin wedges and blades of the evaporitic multilayer, by vertical shear planes and faults inside a serrate system of chevron and cuspate folds (Figs. 15, 17A,B, 20, 23A,B).
- Fold are crossed by tabular late Ladinian basaltic dikes (Figs. 21A, B, C and 22A, B) post dating the folds, but in few cases basaltic irregular lenses, up to one m thick, appear to be involved in the hinge deformations of the folds (Figs. 23A, 23B). thus indicating that this structures were similar in age to the sub-volcanic bodies and were originated during late Ladinian time as confirmed by the deformations inside the anticline which involve the whole carbonate Mid Triassic sequences.
-The NW limb of the anticline displays thick volumes of chaotic assemblage due to submarine mass slides (debris flow) (“Agglomerates”) equivalent to the ones of the Col Rodella (see the previous day excursion). These rocks are discordantly superposed to the early Triassic sequence of the Werfen Fm including giant blocks (10 to 100 m wide and more) of Anisian



Figs. 13 A, B - Simplified schemes illustrating diapiric intrusions rising externally to the carbonate edifice (A) and along, or inside the platform edge (B). Letters: E, Permian evaporites; V, volcanics; F, slide deposits ("Agglomerates"). Modified from Castellarin et al.,1998b.

carbonate shelf dolostones (Contrin Dolomite) associated to dismembered strata of the Richthofen Conglomerates, Werfen Fm and volcanics (Figure 19B, sect. I). Thick (30-50 m) pillow lavas flows are unconformable superposed to the chaotic debris flow body. These units seal the NW top limb of the diapiric anticline and the meso-structural assemblages therein included, documenting they postdate their nucleation. The diapiric anticline is bounded by high to middle angle normal faults well documented both in the SSE side at the basal part of the Col Ombert (Figure 21C) and in the opposite WNW limb close to the Marmolade, Sasso Bianco zone (Figure 24).



Figs. 14 A, B - Strain curves of Gypsum sample under different temperature conditions and constant confining pressure (200 MPa) (Heard & Rubey,1966 in Mercier & Viergely,1995) (Figure 14 A). Inversion phases curve of the CaSO4.H2O (Anhydrite and Gypsum) (Blount & Dickson, 1973) (Figure 14 B).

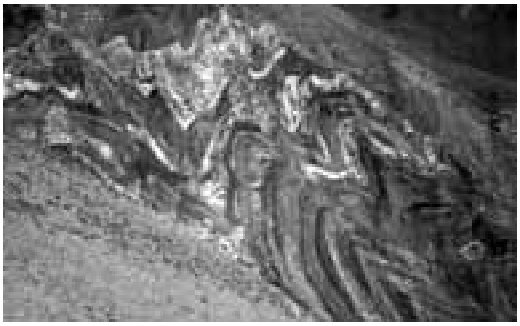


Figure 15 - Serrate folds affecting the Permian evaporites of the S.Nicolò diapiric anticline at Marmolade locality. To be noted the thickening of gypsum beds (white) in the hinge of the folds and their boudinage structure testifying ductile behaviour of sulphate deformations.

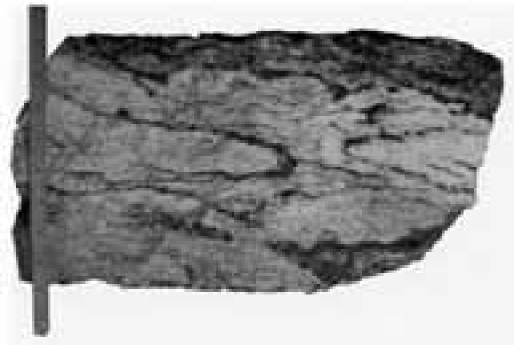
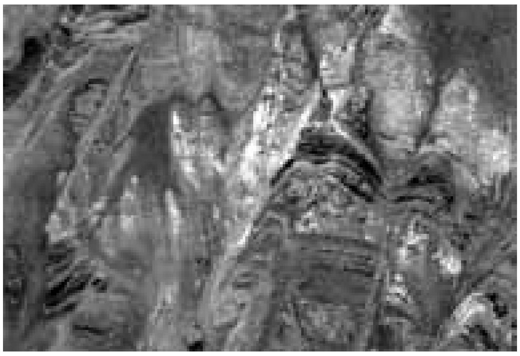


Figure 16 - Permian evaporites gypsum sample of the core of the S.Nicolò diapiric anticline. The sample displays micro and meso scale sheath folds: pelite thin transposed films mark the foliate structure of the rock.



Figs. 17 A, B - Permian evaporites folds of the nucleus of the S.Nicolò diapiric anticline. The pelitic components are largely prevailing versus the sulphates and show strong ductile behaviour, up to a nearly fluid mobility within the structure (Figure 17 B). The gypsum coarse and thick lens in the hinge of the folds are laterally truncated suggesting a passive upward rise inside the pelite masses (Figure 17A).

Figure 18A - Panoramic view on the western sector of the S. Nicolò Valley: the Sciliar carbonate shelf edge of the Maerins local peak shows clinoform bedding to the N onlapped by the volcanics (pillow lavas, p. breccias and ialoclastites) of the Buffaure Group

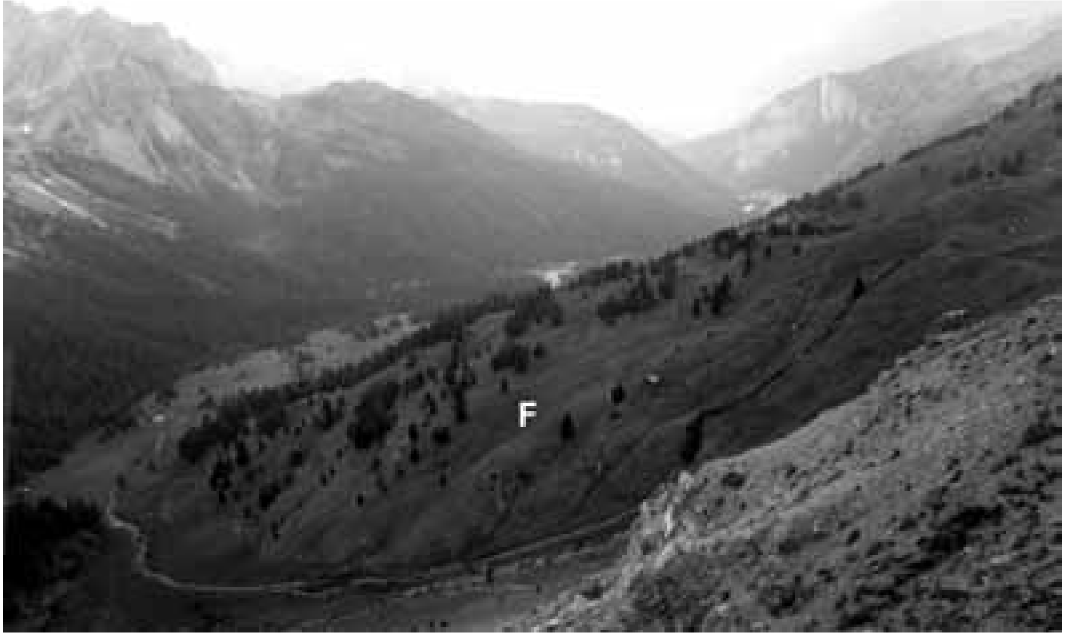


Figure 18B - Panoramic view of the S. Nicolò valley head from the mule track (altitude about 2200 m): a recent, fan sized, big slide, very likely due to deep seated detachment inside the present slope, can be observed

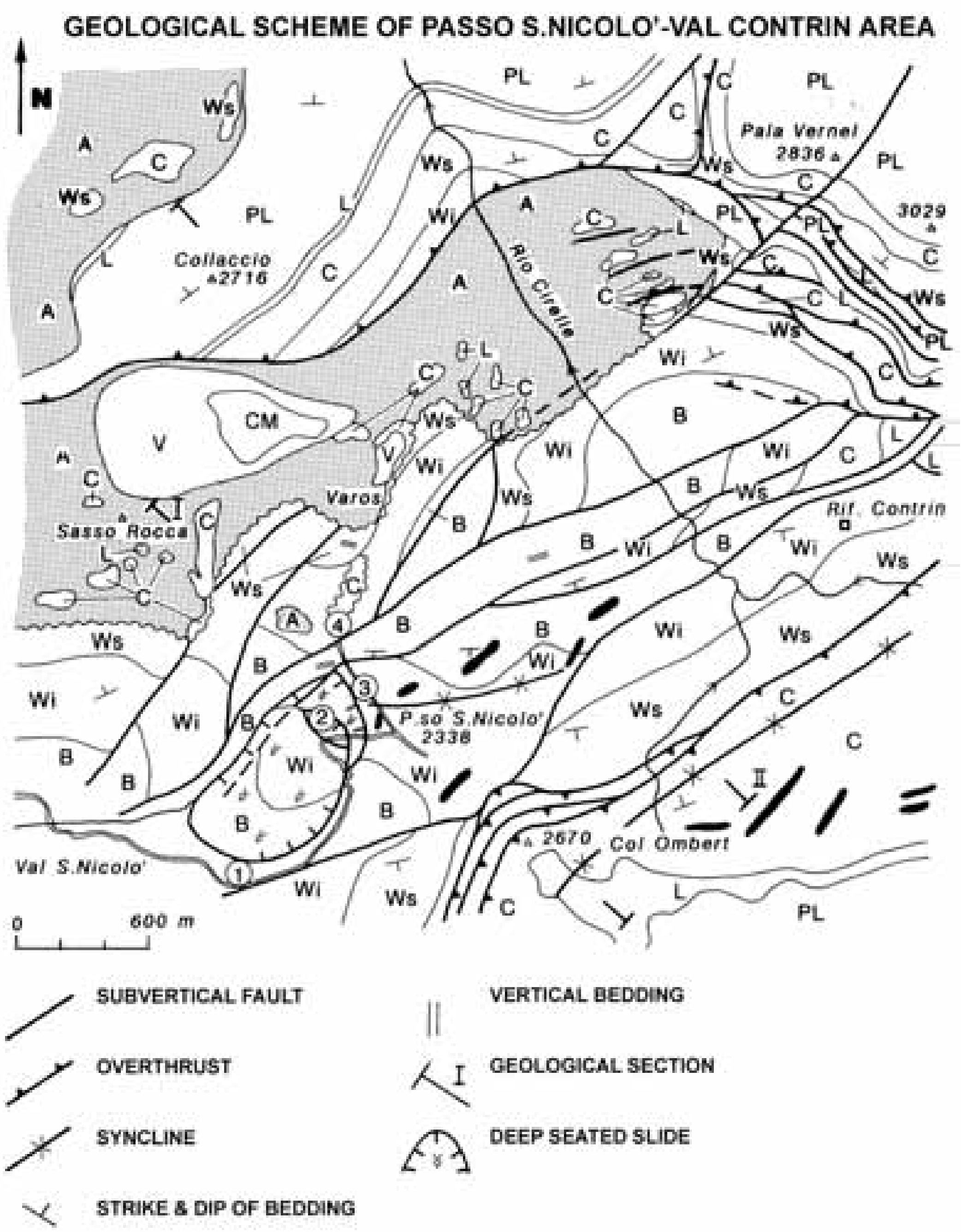
Stop 2:

Mule-track to the Pass at the altitude of 2260 m, about 100 m W of the Track. Panoramic view of the folds strongly affecting the upper Permian evaporites of the innermost part of the anticline core (outcrops along the steep slope of the Marmolade zone). The outcrops display characters of a serrate fold system strongly complicated by thin wedges and blades of the evaporitic multilayer rising inside the system of chevron and cuspate folds. These structures are formed mostly by pelitic sediments representing the dominant or prevailing lithological component of the intruded evaporites (Figs. 17A, 17B, 20,). White, thin flakes and lenses of anhydrite, along the steep and long limbs of the folds, are normally thickened in their hinge assuming the characters of intensely remobilized and transposed foliate rocks (Figs.15, 16 17A,B, 20, 23A, 23B). Basaltic dykes are not easy visible from the stop and are well exposed in the opposite nearly inaccessible side of the minor valley near the stop (Figs. 22A,B,C, 23A, 23B).

Stop 3:

At the Passo di S Nicolò in front of the S slope, mostly sub-vertical, of the Marmolada highest relief a spectacular panoramic view displays the frontal zone of the homonymous major overthrust and other structures (Figs. 25, 26). The general setting can be illustrated as it follows.

- In the basal part of the Gran Vernel peak a recumbent anticline whose reverse limb thrust to the SE is present. This structure located, on the NE trending axe of the S. Nicolò diapiric anticline, include, inside the nucleus, upper Permian evaporites and can be interpreted as an attenuate continuation, over the Contrin Valley, of the same anticline, rearranged and partially displaced by the compressional neo-Alpine events strongly affecting the whole outcropping section of the Marmolada group (Figs. 25, 26).
- On the Werfen Fm and Contrin Dolomite succession of the anticline western limb the contact with the chaotic slide masses of the “Agglomerates” (the so called “Contrin volcanic neck” of previous interpretations) are, in part, still preserved. This slide assemblage, attains here great thickness (over 500) and include, in the apical zone, an hectometric wide slab of Sciliar Dolomite arranged in a 100 m or more thick clinoform sequence, recalling, for its similarities, that in the summit of the Col Rodella peak. This rock body is lined to the NE with the equivalent chaotic masses of the S.Nicolò Pass, Varos and Sasso Bianco (see next stop).
- The Marmolada major duplication, inside the nearly E-W trending structure, is present and visible as


GEOLOGICAL SCHEME OF PASSO S.NICOLO'-VAL CONTRIN AREA

top roof thrust with the associated underlying minor sheets which may correspond to small duplexes. The whole system overrides on the Permian-Scythian uplifted and deformed sequences of the largely previous, late Ladinian, diapiric anticline (Figs. 25, 26). The Marmolada overthrust continuation may be follow to the W along the SE base of the Collaccio relief displaying similar structural patterns in spite of the small differences in the orientation (ENE-WSE). To the E the overthrust can be follow at Malga Ciapela (see on the captions of the Stop 4 of the day after).
- The last observation concern with the apical zone of the massif where local indication of the clinoform bedding inside the Sciliar Dolomite are present. They coherently incline to the Valle di S. Nicolò indicating that this zone, at that time, could correspond to a basinal gulf enclosed among Ladinian carbonate build-ups.

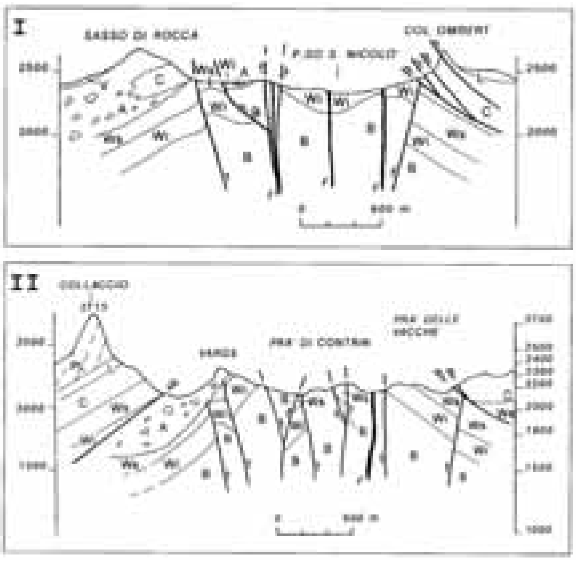


Figure 19A, B - Geological map (A) and sections (B) of the zone of Passo di S. Nicolò-Val Contrin. Letters: CM, Marmolada Conglomerate Fm; A, chaotic assemblages ("Agglomerates") enclosing huge olistolithic masses (C,W,L); V, volcanics; PL, Ladinian carbonate shelf ("Calcare della Marmolada"); L, Livinallongo Fm; C, Anisian succession: Contrin Dolomite Fm, Richthofen Conglomerate Fm and Morbiac Limestone Fm); Ws, Werfen Fm, upper part; Wi, Werfen Fm, lower part up to the "Oolite a Gasteropodi" member included; B, Permian evaporites; F, basaltic dyke; the encircled number refer to the stops. From Castellarin et al.,1998b

Figure 20 - Permian evaporites chevron and cuspate folds in the nucleus of the S.Nicolò diapiric anticline, lower slope of the Marmolade locality. The sulphates (white) mark the thickened hinge of the syncline trough in the central part of the picture.

Stop 4:

At Varos-Forcia Neigra junction of the track, 2440m in altitude, from the Passo di S. Nicolò. Here, the contact between the Werfen Fm of the NW top limb of the diapiric anticline and the overlying chaotic slide assemblages is present and visible. The "Agglomerates" include big blocks of the Contrin Dolostone (at the stop), upper units of the Werfen Fm (Campil red sandstones) and volcanics. This body is better visible some 150-200 m over the stop along the track leading to the Forcia Neigra (Figs. 27 , 28). This zone is close to the giant and spectacular Contrin Dolostone olistolith of the Sasso Bianco locality (Figure 29) about at the same altitude of that at Varos. The "Agglomerates" are closed on top by basaltic Pillows lavas overlain by the Conglomerato della Marmolada volcano-clastic deposits displaying sub vertical setting due to the Neogene Alpine Compressions.

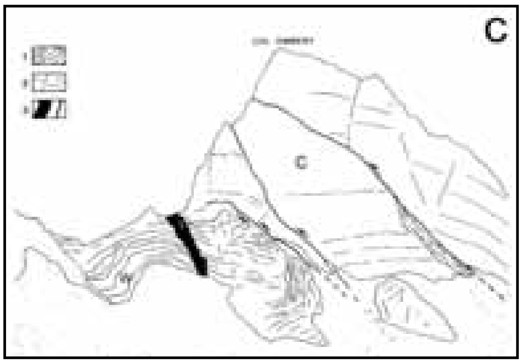


Figure 21 A, B - Panoramic view of the diapiric anticline E limb close to the Col Ombert peak western slope. In Figure 21A, note the extensional style of the contact between the Contrin Dolomite Fm (C) and the Werfen FM (W) whose succession is crosscut by a thick tabular basaltic dyke post-dating the folds due to the discordant relationships between the folds (minor folds) and the basaltic injection (Figure 21B). Normal faults of the Col Ombert lower slope bound the E border of the diapiric anticline as indicated in the graphic scheme (Figure 21 C).

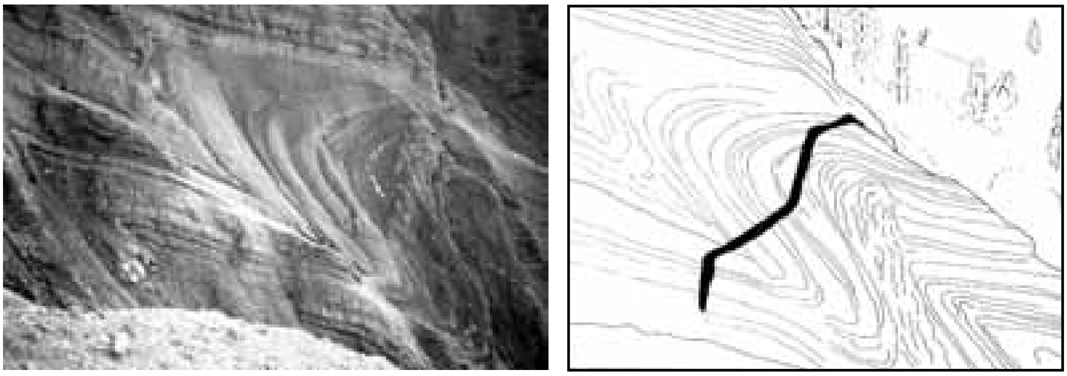


Figure 22 - The recumbent fold (central part of the picture) is crosscut by a tabular basaltic dyke postdating the fold. Basaltic dykes of the zone are connected to the late Ladinian basaltic flows (pillows lavas) on top f the sequence (see Figs. 19A, B).

Figure 23 - Serrate folds of the Permian evaporite inside the nucleus of the S. Nicolò diapiric anticline, Marmolade locality (altitude circa m. 2330). The style of the deformations is similar to that illustrated in the previous Figs. Both pictures show the presence of refolded sub-volcanic nuclea whose basalts predate the folds. Thus, the late Ladinian basalts predate and postdate the folding which, consequently, have to be nearly coeval with the basaltic events.

Figure 24 - Panoramic view on the N-western limb border of the S Nicolò diapiric anticline, where an extensional normal fault separates the Permian evaporites (B) from the beds of the Werfen Fm (W).

Figure 25 - Panoramic view of the spectacular S wall of the Marmolada Group. For more explanation see Figure 6 and follow the description on the text.

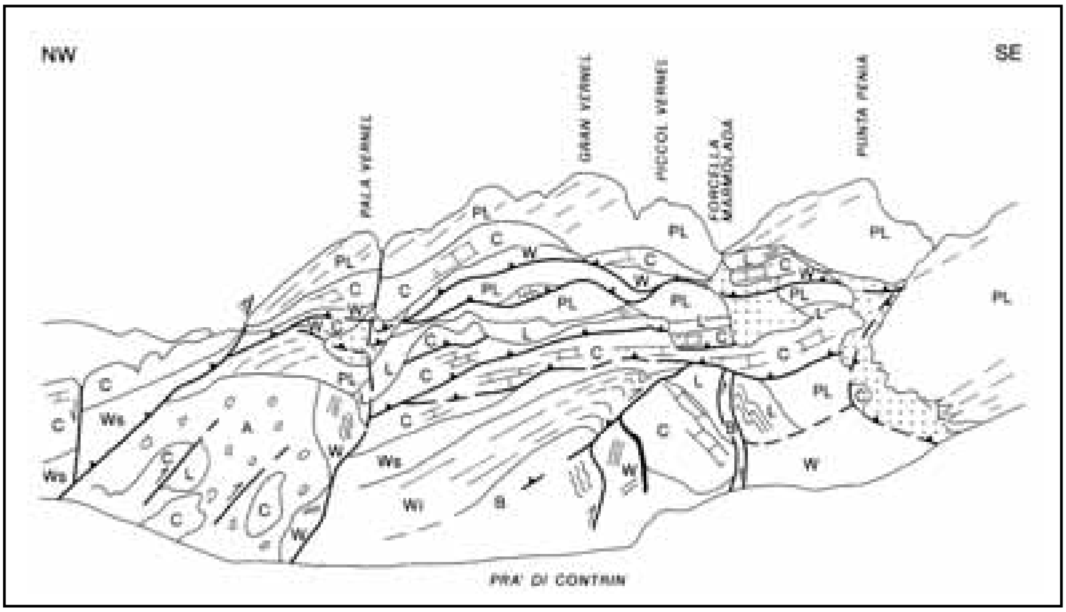


Figure 26 - Southern great wall of Marmolada Group: structural interpretation of the section (graphic scheme). For more precisions see the text.

Figure 27 - N-western border of the S. Nicolò diapiric anticline at the S side of the Varos crest: chaotic assemblages "Agglomerates" overly the Werfen Fm sequence (Wi) on the eroded NW top limb of the structure, cropping out along the track. Great slabs (olistolithes) of Werfen Fm, Contrin Dolomite and volcanics are enclosed.

Figure 28 - Crest of the Varos: chaotic assemblage view from the top of the crest. To be noted the great thickness of the chaotic masses interval and the big sizes of the Contrin Dolomite olistolithes.

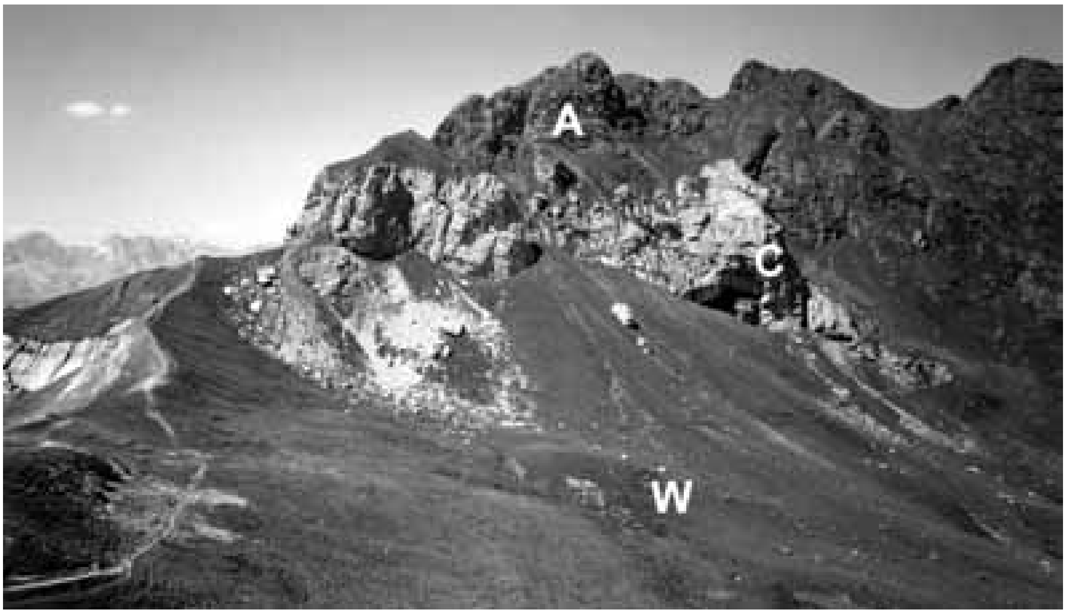
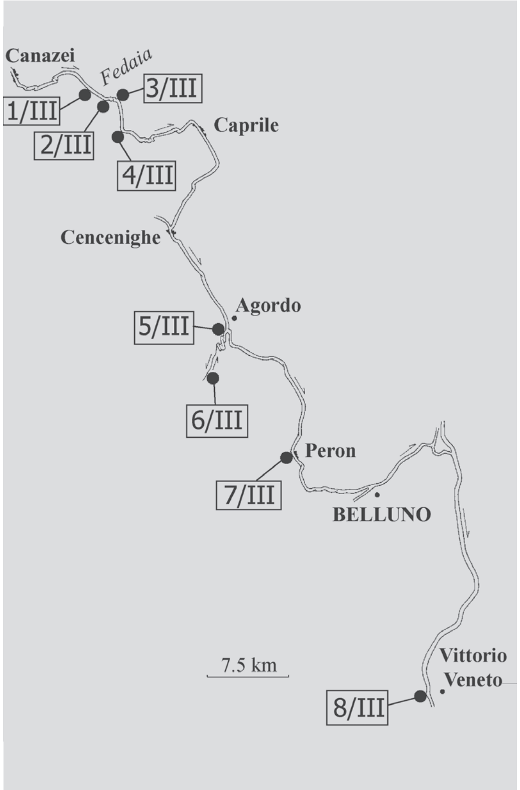


Figure 29 - Contact between the Werfen Fm sequence (to the left) and the chaotic masses (“Agglomerates”) dominated by the giant Contrin Dolomite Olistolithe of the Sas Bianch on the NW limb of the Diapiric anticline. Letters: A , chaotic masses; C, Contrin Dolomite olistolithe; W , Werfen Fm



DAY 3

The excursion is devoted 1) to the completion of the structure of the internal part of the Dolomites around the N and E sides of the Marmolada Massif and 2) to the analysis of the external section of the Southern Alps in a sector where the Transalp seismic Profile is available. From the Marmolada massif E border the field trip continuation is planned going down the Valle del Cordevole, across the belt of the Valsugana thrust zone at Agordo up to the marginal youngest structures of the Montello belt where the Neogene up to “Villafranchian” (Pleistocene) units of the Southern Alps foot hills are strongly folded and deformed.

Stop 1:

At the refuge (Rifugio E. Castiglioni) along the National road to Passo Fedaia: Panoramic view of the Southern slope of this massif in front of the glacier. Explanation of a N-S section across the whole structure. To be noted that the Sciliar Dolomite buildup of the Marmolada massif was bounded by basinal areas both from the S (S. Nicolò valley basinal gulf) and from the N (the Arabba-Livinallongo-Caprile zones). Distribution and thickness of agglomerates and slide masses along the N borders of this buildup may be explained, also in these zones by upper Permian diapiric structures.

Stop 2:

At the Fedaia Pass: panoramic view of the structural and stratigraphic setting with particular attention to the impressive thickness of the volcanic sequences (more than one km) overlying the Sciliar Dlolomite (="Calcare della Marmolada" Auct.). Inside the volcanics, to be noted the thick bodies of mega-breccias at the Crepe Rosse crest inside a n NE-SW trending syncline possibly rearranging a previous late Ladinian listric fault.(Figure 30A,B) The dolomite big clasts inside the breccias display strong alteration, due the Mid Triassic weathering, in sub-aerial conditions of the sourcing carbonate shelf, as documented by micro karst structures and strong red oxidation crusts, affecting the Sciliar Dolomite slide blocks

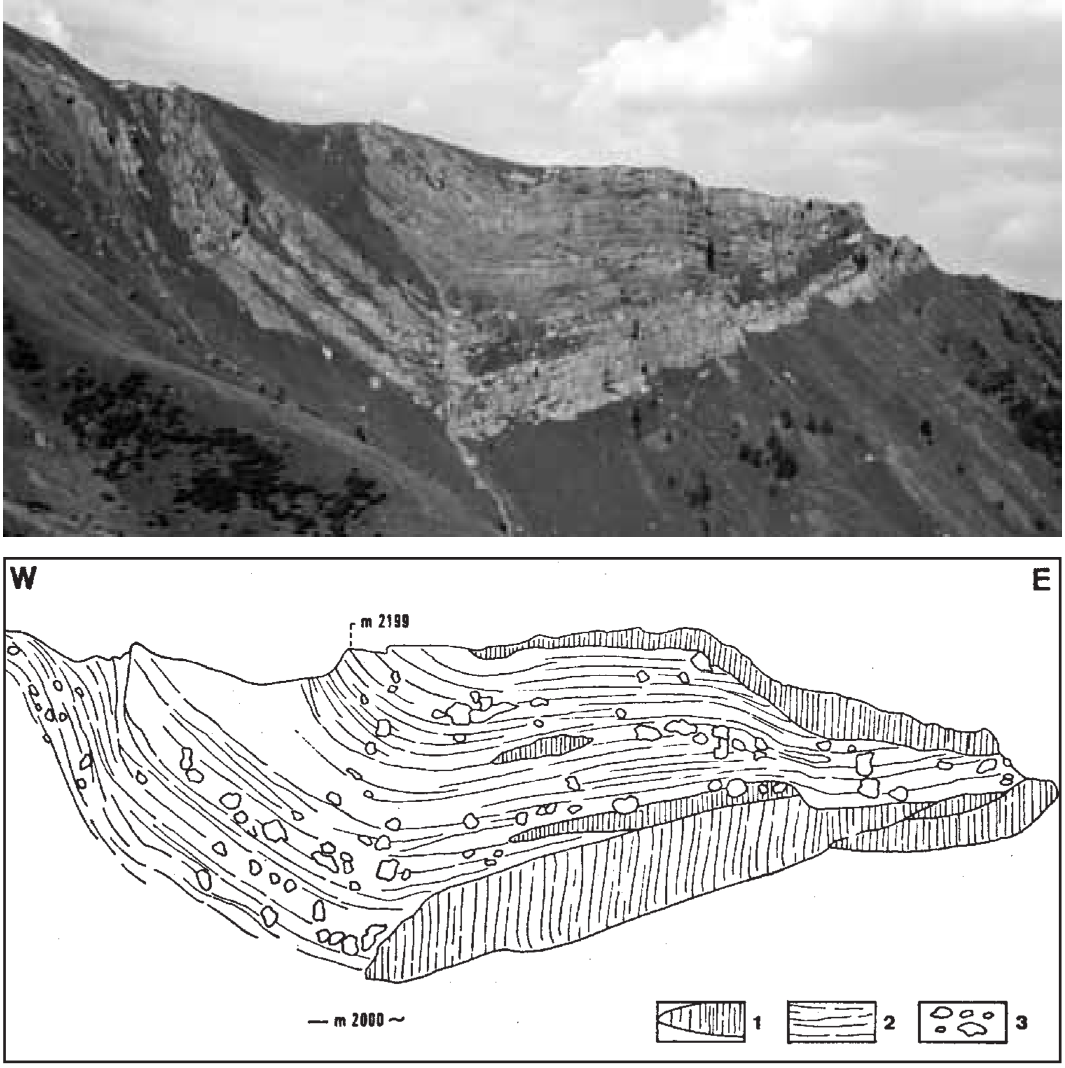


Figure 30A, B - The Crepe Rosse crest view from the Fedaia Pass. The NE- SW trending syncline folds up some 200 m of volcanic sandstones with conglomerates (Marmolada C. Fm) enclosing thick lenses of carbonate megabreccia and abundant isolated olistolithes (Figure 31A) . The geometries of the deposits are indicated in the graphic scheme (Figure 31 B). The interpretation of the structure is not yet solved: Mid Triassic grow fold or Mid Triassic listric grow fault rearranged into a Neogene fold ?? Numbers: 1, E-W section of principal megabreccias lenses corresponding to thick tongues filling about N-S erosional channels; 2, volcanic sandstones and conglomerates; 3, carbonate olistolithes, isolated or in swarm ("Calcare di Cipit").

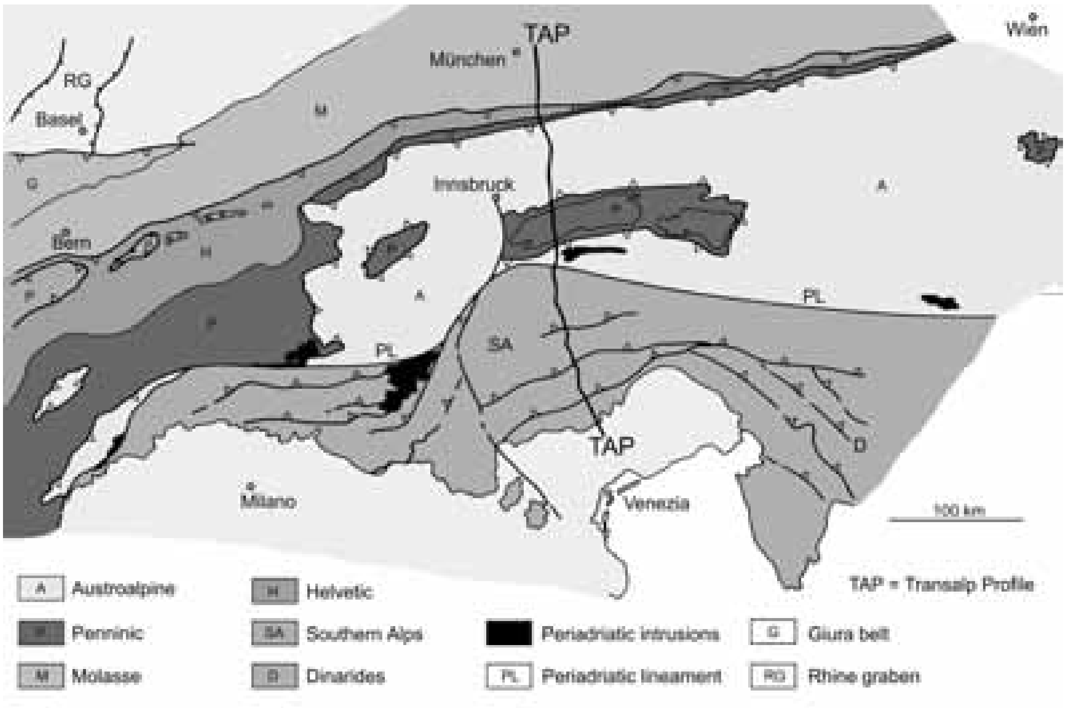


Figure 31 - Simplified structure of the Alps (modified from CNR, 1991, Sheet N.5) and location of the Transalp seismic Profile (TAP).

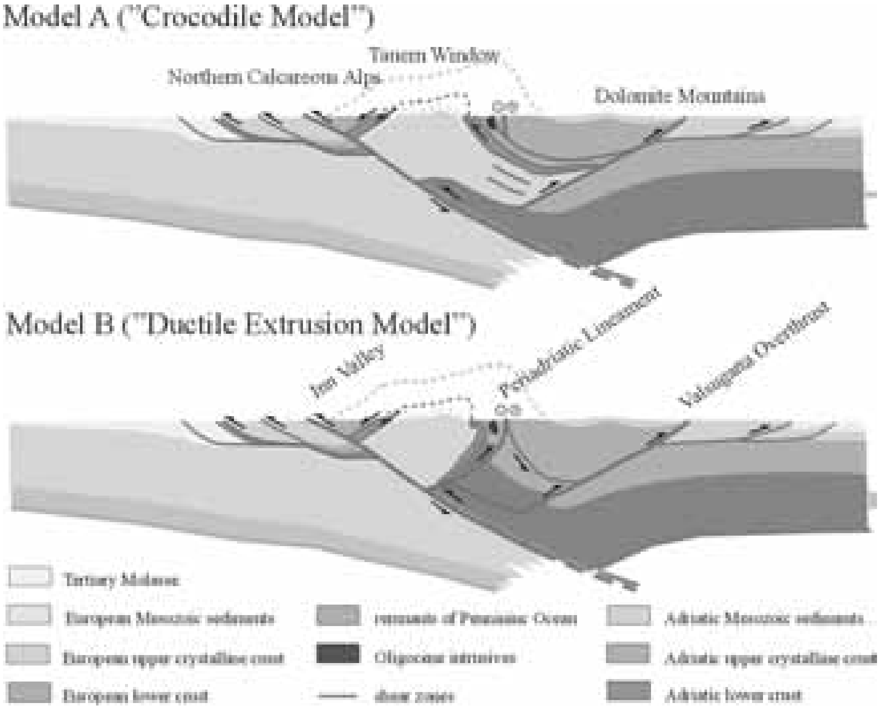


Fig 32 - The main general interpretations of the Transalp Profile (from Transalp Working Group, 2002)

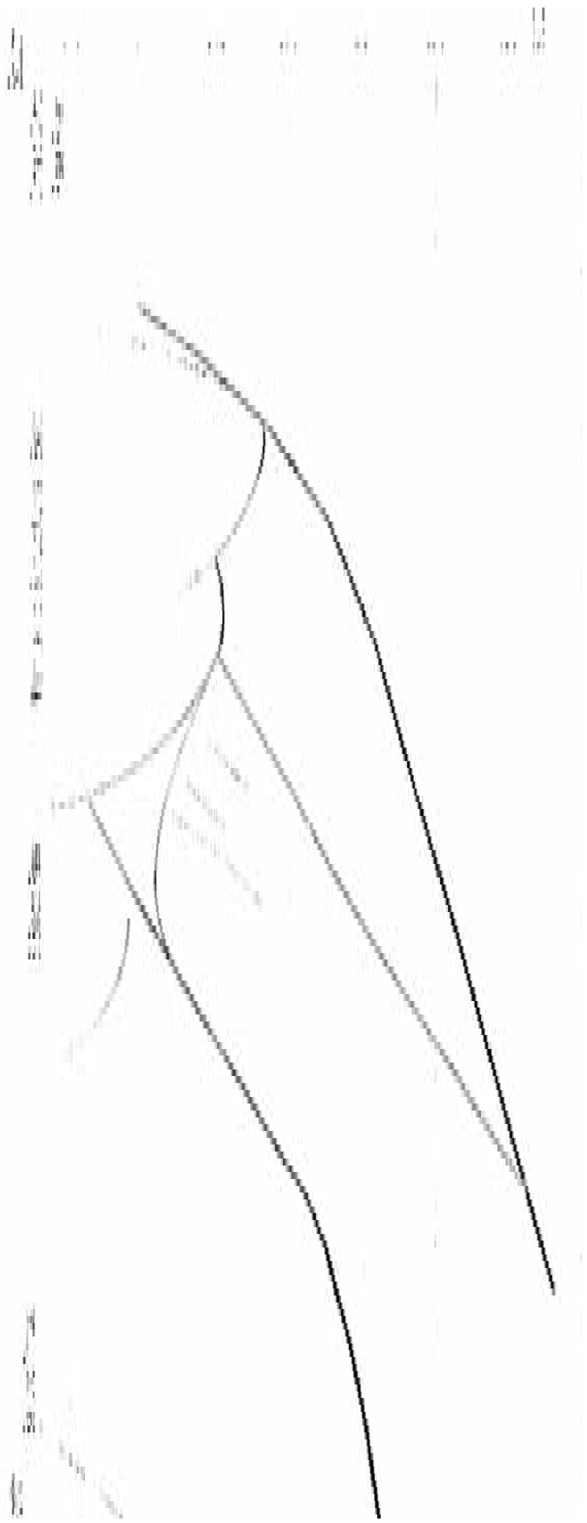


Figure 33 - Interpreted structural style of the Transalp Profile southernmost sector (migrated vibroseis section). For the stratigraphy compare with the subdivisions (numbers) of the geological section, Fig. 24
From Transalp Conference,Trieste, 2003

Stop 3:

Volcanics at “Capanna Bill” : outcrops at the bent of the national road (from the Pass), about 100 m before the ski lift departure to the Padon refuge. To be noted the pillow breccias enclosing some preserved pillows. These volcanites are interpreted onlapping the Sciliar Dolomite of the Marmolada N slope, visible in the opposite side of the valley, close to the outcropping base of the volcanics. The contact is not exposed.

Stop 4:

In the parking place of the cableway station at Malga Ciapela. Panoramic view of the Marmolada overthrust eastern side. To be noted the evident tectonic superposition of the Contrin-Sciliar Dolomite thick body on the late Ladinian volcanics. This structure is the direct eastern continuation of that present at the base of the Grand Vernel peak (see stop n. 3 of the previous day excursion).

From Malga Ciapela onward to the E the overthrust branches into several different units up to the zone of Selva di Cadore. In the zone of Digonera and Caprile these nearly ENE-WSW (E-W) trending system clearly crosscut the previous NO-SE Dinaric orientation. These geometric relationships suggest that the Marmolada structural belt may belong to an early event of the Valsugana compressional phase (referable to Serravallian-Tortonian age) rather than to the older Dinaric evolution as proposed in previous studies .

Figure 34 - Interpreted section on the vibroseis migrated section of the Transalp Profile from Agordo (to the north) to the Venetian plane (to the south). Subsurface data from AGIP (sedico, Volpago, Nervesa wells), Geological data from the official geological maps and unpublished data of the authors. Keys for the numbers: 1: metamorphic basement, non metamorphic covers, 2: Permian, 3: Triassic (undifferentiad), 4: Upper Triassic; 5: Jurassic, 6:Cretaceous (carbonate platforms), 7: Cretaceous (basinal deposits), 8: Eocene Flysch, 9: Neogene Molasses, 10: Marine Pliocene (Cornuda), 11. Plio-Pleistocene-Olocene. From transalp Working Group, 2003

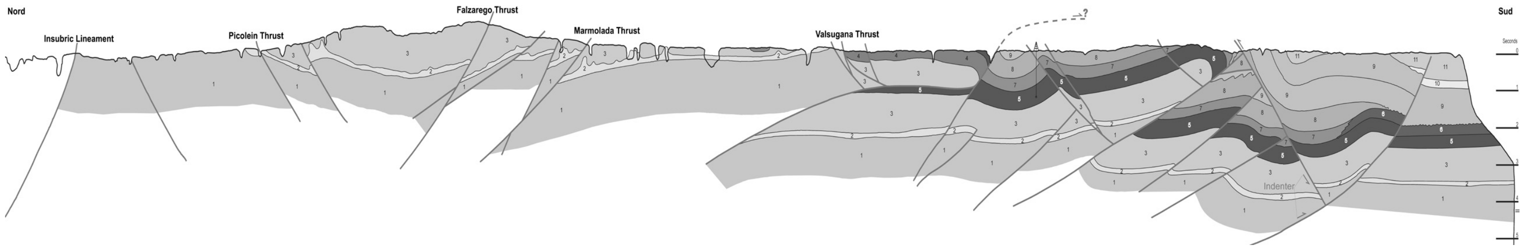


Figure 35 - Interpreted section of the Transalp Profile from the Insubric Lineament (Pustertal) (to the north) and the Venetian plane (to the south). Key of graphic same as in Figure34. From Transalp Working Group, 2003.

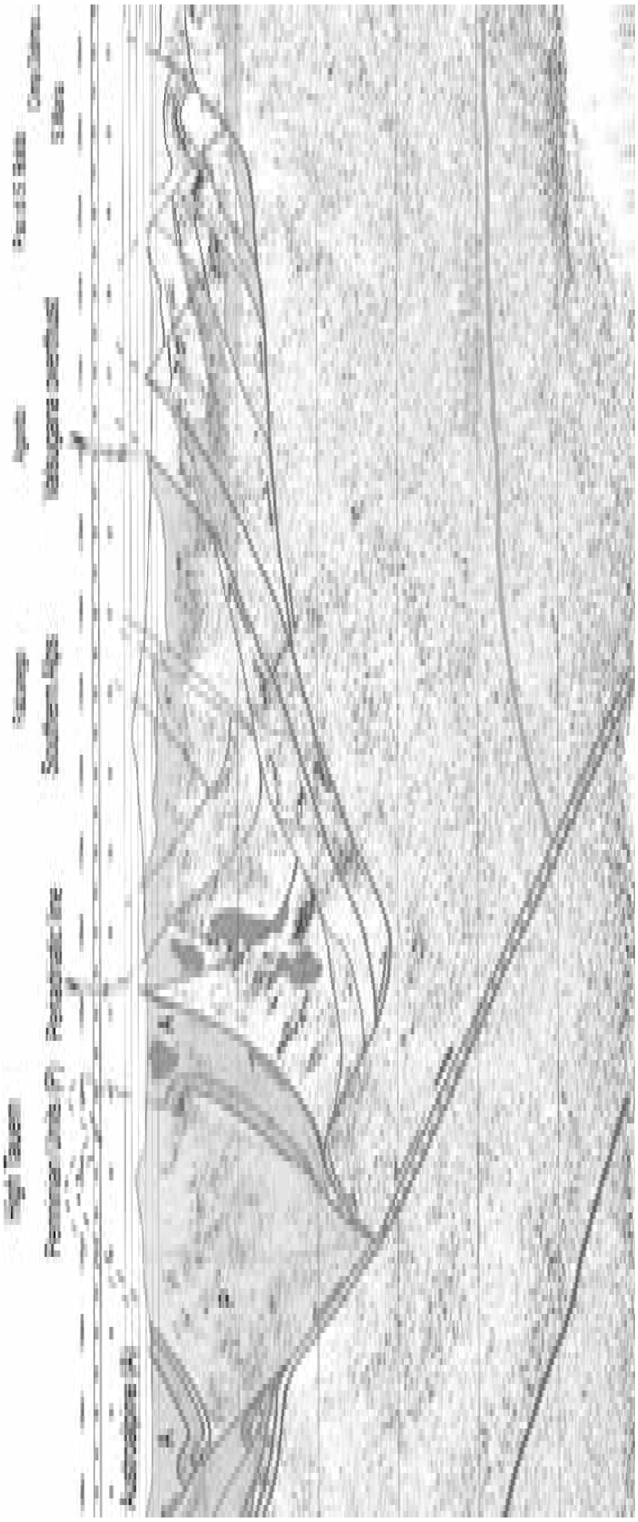


Figure 36 - Simplified general interpretation of the Transalp Profile. From Transalp Working Group, 2003.

Introduction to the second part of DAY 3 excursion

THE TECTONIC CRUSTAL STILE OF THE DOLOMITES IN THE FRAME OF THE TRANSALP REFLEXION SEISMIC PROFILE ACROSS THE EASTERN ALPS, SOUTHERN SECTOR

This part of the trip is dedicated to the cross section of the external sector of the Southern Alps along the Transalp seismic reflection Profile (Figs.1 and 31). The aim is to provide a general picture of the structural styles and geometries through the most prominent upper crustal tectonic elements in this crucial sector of the Eastern Alps. Transalp seismic Profile investigations developed deep structural researches on the whole collided orogene, from the Bavarian Molasse to the Venetian Plain. Two general interpretative models of the Eastern Alps, supported by seismic and geological data, have been obtained by the Transalp Working Group. Both models (Figure32) are expression of collisional plate convergence producing strong mechanical interaction of the two facing European and African continental margins as documented by giant lithosphere wedging processes recognizable in the seismic images. Double or single mechanical indentations have been proposed according to the "Crocodile "(A) and the "Extrusion"(B) models (Transalp Working Group, 2002; 2003). In this synthetic review of the essential structure of the Southern Alps along the Transalp Profile, we refer to the model B which seem better suitable to the geological, structural and seismic data which are summarized in the following description.

The upper crustal interpretation of the S part of the Transalp profile (Figure 1) is here examined from S to N, on the base of the principal seismic results of the Project (Transalp Conference Volume, 2003):

a) The more external Venetian-Adriatic Foreland displays only gentle flexural inflexion, toward the N mostly developed during Serravallian to Messinian clastic deposition (Fantoni et al., 2001).

b) To the N, over the foot hill border, strong compressional deformations affected the S. Maria di Feletto anticline (a lateral equivalent of the Montello anticline) and the adjacent Solighetto syncline (Montello structural system) where the Messinian ("Pontico") and the Plio-Pleistocene ("Villafranchiano") mostly conglomeratic succession (Venzo, 1977), thick over 2 km, are strongly involved in the tectonic deformations. The S. Maria di Feletto frontal thrust controlled the Plio-Pleistocene external clastic sedimentary prism as indicated by the seismic images (Figure 33, 34). **c**) Along the N side of the Solighetto syncline, the Flessura Pedemontana appears as a strong S-verging overthrust inside a triangular zone where the Montello structure backthrust corresponds to the N dipping upper surface of an indented tectonic wedge, responsible both for the strong rising and vertical setting of the Solighetto syncline N limb and for the buried truncation of the Flessura Pedemontana overthrust (Figs. 33, 34). The total upper crustal shortening in this southernmost sector of the profile (**a**-**c**) is of some 15-20 km mostly produced by the Messinian - Pliocene and Pleistocene N-Adriatic compressions to the NW (Figs. 33, 34).

d) Towards the N, the Linea di Belluno (near Peron) produced a strong morpho- structural relief with a scarce continuity in depth inside the seismostratigraphic units corresponding to the metamorphic basement sequences. At Agordo, the Valsugana overthrust may be structurally solved as a km-thick wedge indentation to the S of metamorphic rocks where the non metamorphic sedimentary cover appears back thrust to the N over the basement units (Figs. 34, 35).. If the Valsugana structure expands to the S, along the upper Permian evaporites basal contact, as a flat blind sole thrust, joining the Linea di Belluno frontal zone, as shown in Figure 35, upper crustal shortenings should be very strong and could attain 20 km or more. If, on the contrary, the two structures were cinematically independent the alternative is illustrated in the Figure 36 and the total shortening in this area (d) should be smaller with an amount of some 10-12 km. The described structural setting originated mostly during the Serravallian and Tortonian compressional Valsugana event(Figure 4) with possible further reactivations (see f. i. Castellarin et al., 1992, Castellarin and Cantelli, 2000).

e) In the sector located to the N of the synclinorium, between Agordo and Piccolein, the more prominent structures are the Marmolada-Caprile and the Falzarego S-vergent thrusts and, along the northern border of the "Synclinorium", the N-vergent thrusts of the Piccolein zone ("Linea di Funes") (Figs. 35, 36). The Marmolada S vergent thrust zone postdates and cross cuts the previous NW trending structures of the Digonera and Selva di Cadore thrust system. The structural complications in this zone are due mostly to the non coaxial polyphase tectonics where the Dinaric trends (Figure 4), referable to the Insubric (Chattian-Burdigalian or older ?Eocene events), are strongly rearranged by later compressions (Valsugana and/or younger) (Doglioni, 1987). Furthermore the structural styles in such area have been intensely controlled by the diapiric intrusions of the upper Permian evaporites some of which emplaced since Mid Triassic time. These stratigraphic and tectonic complications cause difficulties in reconstructing the structural evolution of this area. Nevertheless, the Dinaric W and SW verging thrust system displays mostly oblique trends to the Transalp Profile, with possible reduced effects in the N-S upper crustal shortenings. Moreover the strong internal deformations of the phyllite metamorphic belt, between the Dolomite Synclinorium N border and the IL, are mostly pre-Alpine, except for the few minor N- verging thrusts inside the northern belt of the Dolomites between Piccolein and the IL. Summarizing, the upper crustal shortening of this area (**d**) may be indicated in some 5 km.

Description of the Stops

Stop 5:

Agordo, south neighbours at the bridge crossing the river Cordevole along the road leading to Gosaldo: outcrops of phyllites, rich in quartzite nodules of the crystalline basement. These rocks are close to the tectonic contact with upper Triassic dolostones of the Dolomia Principale Fm cropping out in the steep slope S of the bridge (opposite side of the valley). Going up the road to Gosaldo village inside the basemet rocks, to be noted the prevailing homoclinal lying of the phyllite schistosity planes along E NE (NE) directions middle to high angle dipping to N (NW).

Stop 6:

at Forcella Franche the contact between the basement crystalline rocks and the Dolomia Principale Fm is not visible but here the two units are very close. In fact at the quarry, where, in the past, the Quaternary loose clastic deposits have been exploited, the dolostones are strongly brecciate to cataclastic. The detrital deposits on the slopes, in front and near the quarry are formed of grains and clasts of a dolomite fault rocks suggesting they come from the overthrust contact zone. The geometric setting in a N-S section of this locality suggests a tectonic superposition of the crystalline basement unit on the upper Triassic carbonate sequences, with geometries similar to those recognized in the zones located to o the W (Passo Cereda- Passo d. Brocon) as illustrated in the Fig 37 . Nevertheless, this interpretation appears to be unsuitable in the thrust contact area, along the national road, where the dolomite succession, close to the thrust, displays steep inclination to the S up to vertical setting. Furthermore the Transalp seismic images along the same trace (the main line of the Profile) indicate wedging of the seismo-stratigraphic reflectors related to the crystalline basement inside the sedimentary cover. This setting is illustrated in the Figs. 34, 35 and summarized on previous description (point **d**). Along the eastern continuation of the the Vasugana thrust belt, in the zone located to the E of the river Cordevole, the crystalline basement rocks are no more cropping out inside the hanging wall of the overthrust which branches in a wider system of structures S of Passo Duran toward E-ENE . This change in the tectonic style of the Valsugana thrust belt may be related to the strong stratigraphic variations (strong increasing in the thickness of the Triassic basinal deposits).

Stop 7:

At Peron about 200 m N of the “Pizzeria”: to be noted the morpho-structural setting of the “Linea di Belluno” and its western equivalents. The structure correspond to a big ramp fold frontally arranged in a steep slope some hundred m high, where the early to late Jurassic carbonate beds are vertical or high angle dipping to the S. These units are overthrust on Tertiary sequences, but the contact is not visible. The morpho-structure of the Linea di Belluno continues for some km to the W with high crests of sub-vertical carbonate Jurassic beds. Sandstone deposits of the basal part of the Venetian Molasse (Chattian- early Miocene) form the N limb of the syncline along the border of the thrust: outcrops some hundred m S of the village Peron.

The Belluno thrust can be interpreted according to the geometries previously indicated (on point **d)** as sedimentary cover décollements in continuity with the Valsugana thrust at Agordo, as shown in Figure 35 or alternatively, as independent structure affecting the crystalline basement (see Figure 36).

Stop 8:

Vittorio Veneto, at the park zone by the highway from Belluno to Venezia, 300 m after the exit of the tunnel (Mt. Alto). Panoramic view on the Neogene Venetian Molasse deposits. Note the general subvertical thick beds of the upper Miocene (mostly Messinian) sandstones and conglomerates, thick over 2 Km in the area of Vittorio Veneto and within the Montello structural belt (Figs. 34, 35, 36). This belt, between the Flessura Pedemontana triangular zone (to the N) and the foot hill frontal thrust (to the S) (see previous description: points **b**, **c)** was strongly deformed by Pliocene-Pleistocene NW compressions of the Adriatic events (Figs. 34, 35, 36). To the W, at Cornuda village, the Montello Molasse sequence include marine early-mid Pliocene dark grey silty clays, followed by "Villafranchian" (late Pliocene-Pleistocene) conglomerates steeply inclined to the S (Venzo 1977). The conglomerates display internal deformations documented by compressional micro- and meso-structures (pressure solutions pits and grooves on the of carbonate pebble surfaces).

General conclusive remarks

According to the different geometric interpretations, the Southern Alps upper crustal total shortening along the Transalp Profile ranges between about 30 and 45 km in amplitude with corresponding percentage values between circa 20 % and 27 %. Significant compressional deformations older than those responsible for the Dinaric structural trends (Chattian-Burdigalian or (?)mid-late Eocene) have not been recognized in the Transalp Profile southern sector zone.

The relevance of the Adriatic upper crustal evolution points to the late post collisional change in the tectonic growth of the Eastern Alps orogenic chain (Castellarin and Vai, 1981). In fact, from the middle-late Miocene (Serravallian-Tortonian) onward, the tectonic accretion was interrupted in the N frontal zone of the Eastern and Central Alps as documented by the Molasse basin evolution (see f. i. Pfiffner et al.1997; Steininger et al. 1986). On the contrary in the E border of the Southern Alps (Montello-Friuli thrust belt) the S verging structural accretion strongly continued during the Messinian and Pliocene, up to the Pleistocene. This structural evolution may be referred to the deep under-thrusting and wedge indentation of the Adriatic lithosphere underneath the southern side of the Eastern Alp structure, consequent to post Tortonian Adriatic Microplate displacement to the NNW (NW). The upper crustal settings, recognized in the southern sector of the seismic profile, shown in Figure 36, is consistent with similar mechanical and kinematical evolution of the Southern Alps lithosphere.

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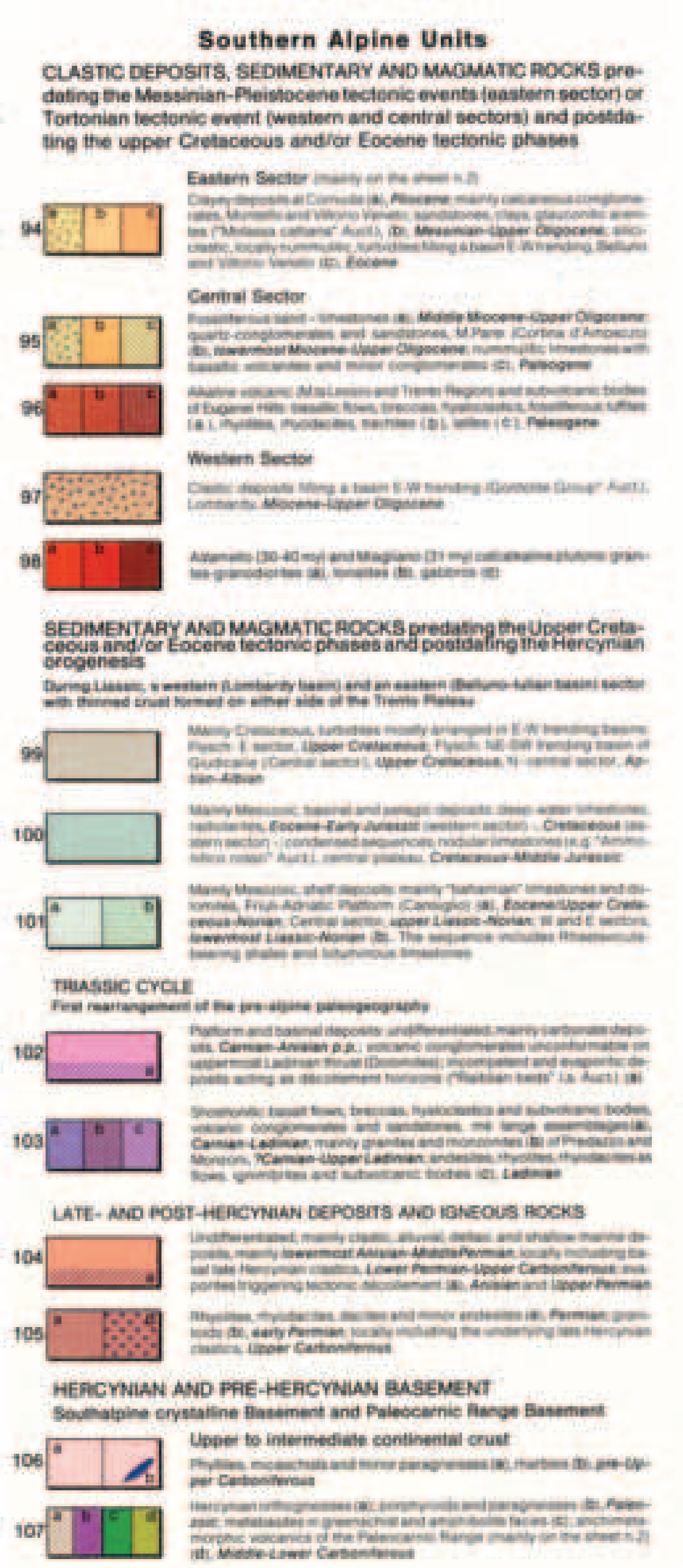

Southern Alpine Units

CLASTIC DEPOSITS, SEDIMENTARY AND MAGMATIC ROCKS predating the Messinian-Pleistocene tectonic events (eastern sector) or Tortonian tectonic event (western and central sectors) and postdating the upper Cretaceous and/or Eocene tectonic phases

Eastern Sector (mainly on the sheet n.2)

94	Clayey deposits at Cornuda (a), **Pliocene**; mainly calcareous conglomerates, Montello and Vittorio Veneto; sandstones, clays, glauconitic arenites ("Molassa cattiana" Auct.), (b), **Messinian-Upper Oligocene**; siliciclastic, locally nummulitic, turbidites filling a basin E-W-trending, Belluno and Vittorio Veneto (c), **Eocene**

Central Sector

95	Fossiliferous sand - limestones (a), **Middle Miocene-Upper Oligocene**; quartz-conglomerates and sandstones, M.Parei (Cortina d'Ampezzo) (b), **lowermost Miocene-Upper Oligocene**; nummulitic limestones with basaltic volcanites and minor conglomerates (c), **Paleogene**
96	Alkaline volcanic (M.ti Lessini and Trento Region) and subvolcanic bodies of Euganei Hills: basaltic flows, breccias, hyaloclastics, fossiliferous tuffites (a), rhyolites, rhyodacites, trachites (b), latites (c), **Paleogene**

Western Sector

97	Clastic deposits filling a basin E-W trending ("Gonfolite Group" Auct.), Lombardy, **Miocene-Upper Oligocene**
98	Adamello (30-40 my) and [illegible] (31 my) calcalkaline plutonic: granites-granodiorites (a), tonalites (b), gabbros (c)

SEDIMENTARY AND MAGMATIC ROCKS predating the Upper Cretaceous and/or Eocene tectonic phases and postdating the Hercynian orogenesis

During Liassic, a western (Lombardy basin) and an eastern (Belluno-Julian basin) sector with thinned crust formed on either side of the Trento Plateau

99	Mainly Cretaceous, turbidites mostly arranged in E-W trending basins: Flysch, E sector, **Upper Cretaceous**; Flysch, NE-SW trending basin of Giudicarie (Central sector), **Upper Cretaceous**; N - central sector, **Aptian-Albian**
100	Mainly Mesozoic, basinal and pelagic deposits: deep-water limestones, radiolarites, **Eocene-Early Jurassic** (western sector) - **Cretaceous** (eastern sector) - (condensed sequences, nodular limestones (e.g. "Ammonitico rosso" Auct.), central plateau, **Cretaceous-Middle Jurassic**
101	Mainly Mesozoic, shelf deposits mainly "bahamian" limestones and dolomites, Friuli-Adriatic Platform (Carsugico) (a), **Eocene-Upper Cretaceous-Norian**; Central sector, **upper Liassic-Norian**; W and E sectors, **lowermost Liassic-Norian** (b). The sequence includes Rhaetavicula-bearing shales and bituminous limestones

TRIASSIC CYCLE

First rearrangement of the pre-alpine paleogeography

102	Platform and basinal deposits undifferentiated, mainly carbonate deposits, **Carnian-Anisian p.p.**; volcanic conglomerates unconformable on uppermost Ladinian thrust (Dolomites); incompetent and evaporitic deposits acting as décollement horizons ("Raiblian beds" Auct.) (a)
103	Shoshonitic basalt flows, breccias, hyaloclastics and subvolcanic bodies, volcanic conglomerates and sandstones, in large assemblages (a), **Carnian-Ladinian**; mainly granites and monzonites (b) of Predazzo and Monzoni, **?Carnian-Upper Ladinian**; andesites, rhyolites, rhyodacites as flows, ignimbrites and subvolcanic bodies (c), **Ladinian**

LATE- AND POST-HERCYNIAN DEPOSITS AND IGNEOUS ROCKS

104	Undifferentiated, mainly clastic, alluvial, deltaic and shallow marine deposits, mainly **lowermost Anisian-Middle Permian**, locally including basal late Hercynian clastics, **Lower Permian-Upper Carboniferous**; evaporites triggering tectonic décollement (a), **Anisian** and **Upper Permian**
105	Rhyolites, rhyodacites, dacites and minor andesites (a), **Permian**; granitoids (b), **early Permian**, locally including the underlying late Hercynian clastics, **Upper Carboniferous**

HERCYNIAN AND PRE-HERCYNIAN BASEMENT

Southalpine crystalline Basement and Paleocarnic Range Basement

Upper to intermediate continental crust

106	Phyllites, micaschists and minor paragneisses (a), marbles (b), **pre-Upper Carboniferous**
107	Hercynian orthogneisses (a); porphyroids and paragneisses (b), **Paleozoic**; metabasites in greenschist and amphibolite facies (c); anchimetamorphic volcanics of the Paleocarnic Range (mainly on the sheet n.2) (d), **Middle-Lower Carboniferous**

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FIELD TRIP MAP

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