3rd Day

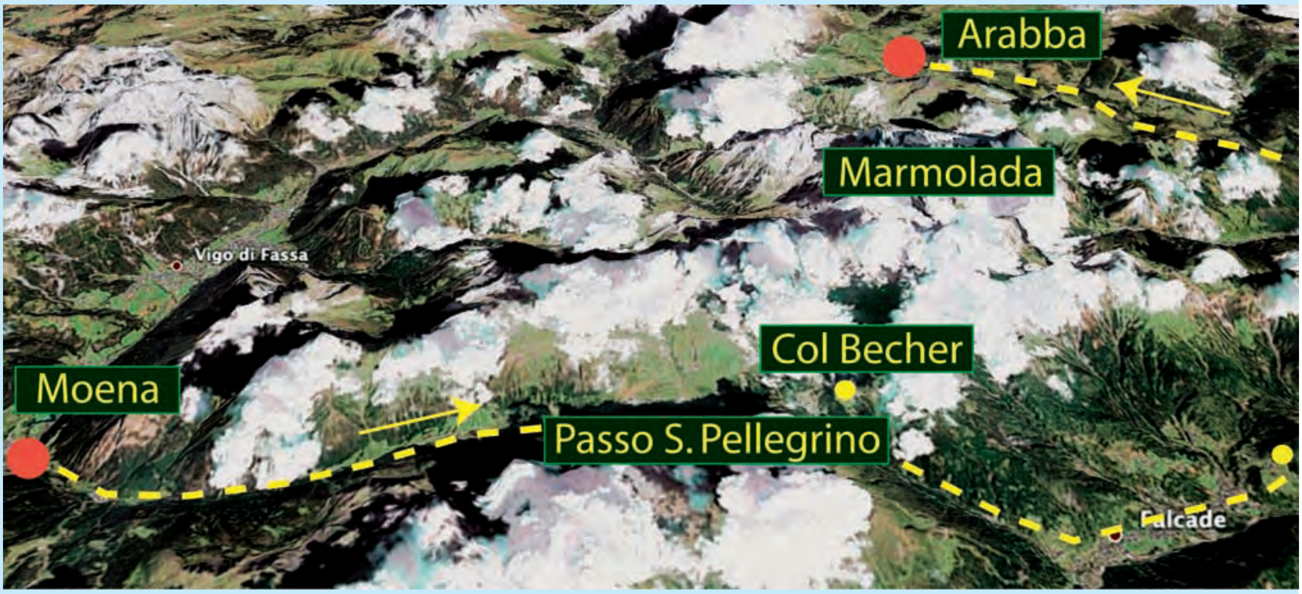


Fig. 3.0 - Itinerary: Moena, Passo S. Pellegrino, Avoscan, Arabba

Subject: Transpressional Triassic tectonics and related diapiric structures

The Dolomites are crossed by an important structural alignement involving the basement oriented N70°-90°E consisting, from west to east by: the Stava Line, the Trodena Line, the Cima di Bocche anticline and the fault system that truncates the anticline to the north and continues, with the same orientation, towards the eastern Dolomites. This alignement is cut by the Ladinian intrusive bodies of Predazzo-Monzoni and deforms all the succession up to the Lower-Middle Ladinian, thus suggesting a Middle Triassic age. Volcanic dykes cutting folds and upper Ladinian volcaniclastic conglomerates unconformably deposited on folds and thrusts confirm the Triassic age of an important deformation phase in the Dolomites. The alignement is characterized by high angle to subvertical faults with both normal and reverse kinematics. Additional structures related to this tectonic phase are en-echelon thrust faults (Costabella, Marmolada, Col Rodella and Livinallongo valley) and diapiric structures triggered by transpressional tectonics within the basin with, at the core, the evaporitic facies of the Permian Bellerophon Fm piercing the sedimentary cover right above the structural alignement cutting the basement. The most significative structures are located in the Col Becher, Val San Nicolò, Passo Selle and Avoscan areas. The flower structures along the Stava Line-northern flank of the Cima Bocche anticline alignement and various other en-echelon structures indicate a transpressive sinistral motion. Along the alignement, narrow and elongated depressions limi-

ted by high angle reverse faults (e.g., Passo San Pellegrino) can be observed, together with long and narrow uplifted blocks (Monte Rocca). Both these structures are referred to strike-slip zones. In the Triassic rocks of the Dolomites, extensional syn-sedimentary faults oriented N-S coexisting with above described strike slip tectonics can be also observed. These extensional tectonics are consistent with the occurrence of 1-2 km thick carbonate platforms of Middle-Upper Triassic age that required a comparable subsidence for their deposition. This amount of subsidence cannot be accommodated in a compressional or transpressional environment. The transpressional structures, morever, are localized to very limited areas and are confined to the north and to the south by sinistral transpressional shear zones oriented N70°-90°E.
This favors an interpretation of such compressional areas as local push-ups. The geological significance of these tectonics has been long disputed through the years. A first interpretation suggests the development of an aborted rift to explain the considerable Middle Triassic subsidence and its cessation in the Upper Triassic (BECHSTADT *et alii*, 1977).
A second hypothesis explains the Middle Triassic compressional structures and the calcalcaline shoshonitic magmatism with the existence of a Middle Triassic subduction zone (CASTELLARIN *et alii*, 1979). A further scenario suggests a continuous rifting from Permian to Lower Cretaceous, with a strong continental extensional crisis in the Middle Triassic. The cause of this rifting (either backarc extension or linear Atlantic-type rifting) is unclear. According to some researchers, the calcalcaline chemistry of the Triassic magmatism could reflect an Hercynian inheritance in the mantle. It remains open the possibility of a west-dipping subduction (localized in the area of Hungary?) generating calcalcaline magmatism, backarc extension and local transpressional zones. A present-day example is the Tyrrhenian Basin, where, at the eastward margin, local transpressional structures have been described.

Fig. 3.1 - View towards the west of the northern flank of the Cima Bocche (the mountain in the left part of the picture) anticline, characterized by the outcrop at its hinge of Permian porphyroids (PP). The fold is truncated along its northern flank by N70°E reverse subvertical faults belonging to the Stava Line-Cima Bocche anticline structural system. In the foreground, Passo San Pellegrino (where Permian porphyrites and minor Gardena Sandstone rocks crop out) is located in the structural depression. In the background, along the alignement, Passo Feudo (Fig. 3.2) can be observed. The Upper Ladinian Monzoni intrusives (M) were emplaced along the sinistral transpressional alignement. These can be recognized by the dark color, and crop out to the right of Passo San Pellegrino, confirming the Middle Triassic age of structures in this area.

Fig. 3.2 - Passo Feudo, along the Stava Line, west of Predazzo. A latitic-basaltic dyke (V) of upper Ladinian age cuts chevron faults developed in the dark limestones of the Upper Anisian Moena Fm (Mo), dating to the Middle Triassic the age of deformation.

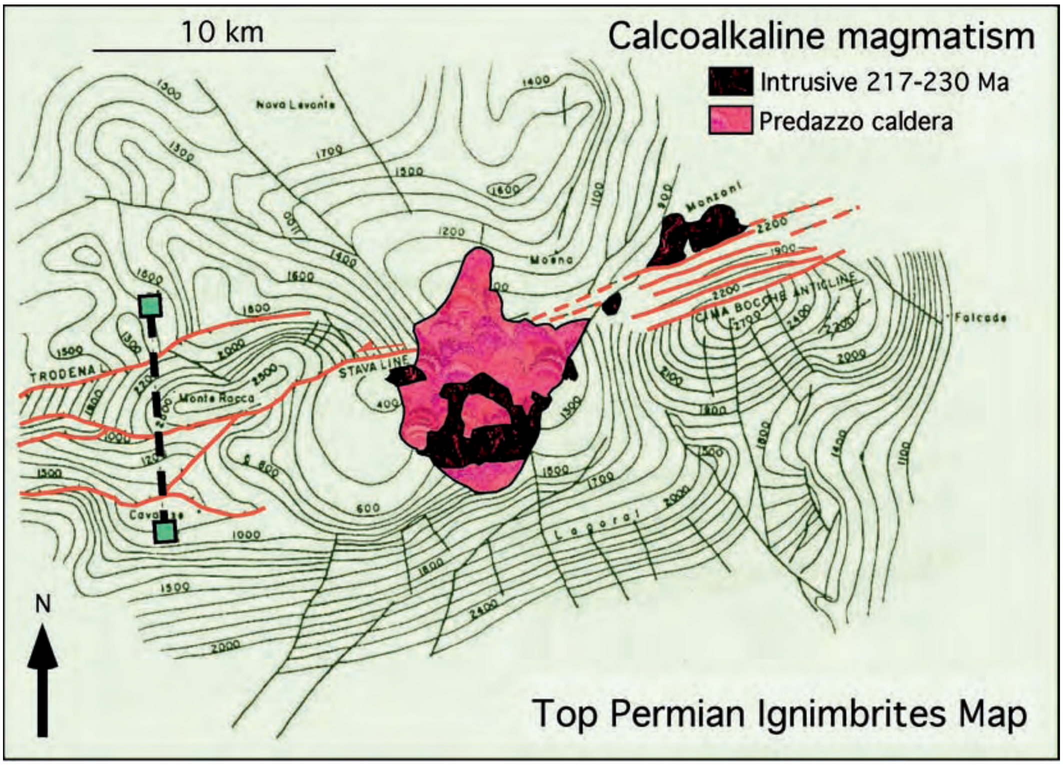


Fig. 3.3 - Morphological map of the basement (top of the Permian porphyrites) in the central-western Dolomites. The contour lines (every 100 m) are referred to the mean sea level. Notice that the northern flank of the Cima Bocche anticline is truncated by a fault system that seems to continue, to the west, in the Trodena and Stava Lines (Monte Rocca structure, Fig. 3.4). The motion along the alignement is sinistral transpressive. The Upper Ladinian-Lower Carnian(?) plutonic bodies and the Predazzo caldera cut, and therefore date this N70°E alignement (Stava Line-northern flank of the Cima Bocche anticline) that deformed sedimentary rocks up to the upper Ladinian. Notice that volcanism also developed along the alignement. In the left part of the figure, the opposite vergence of the Stava and Trodena Lines can be observed. Such opposite vergence has been interpreted as the result of a flower structure. The thick dashed line is the trace of Fig. 3.4).

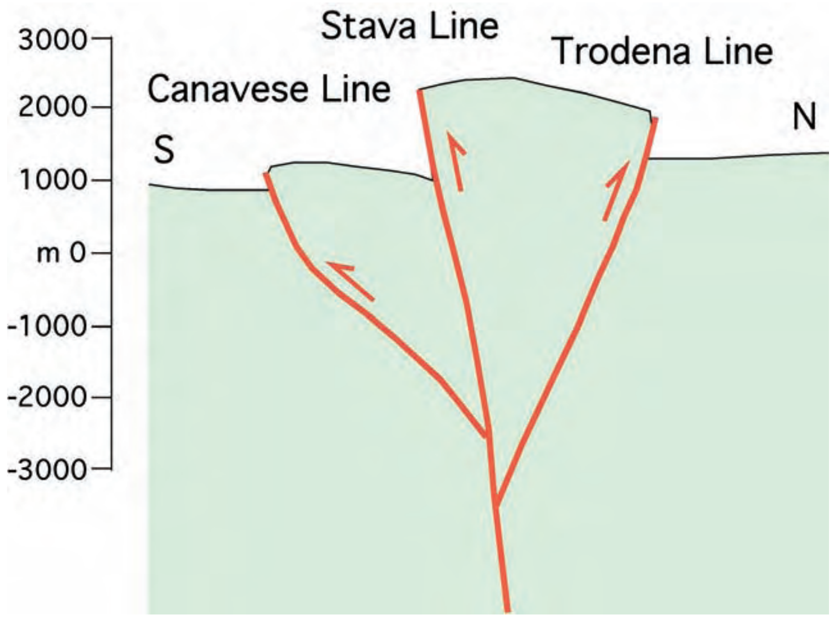


Fig. 3.4 - Approximately N-S sketch profile across the undifferentiated basement (including the Permian porphyrites) about 12 km west of Predazzo: the Monte Rocca structure is a positive flower structure, triggered by sinistral transpression along the Triassic N70E° Dolomitic alignement.

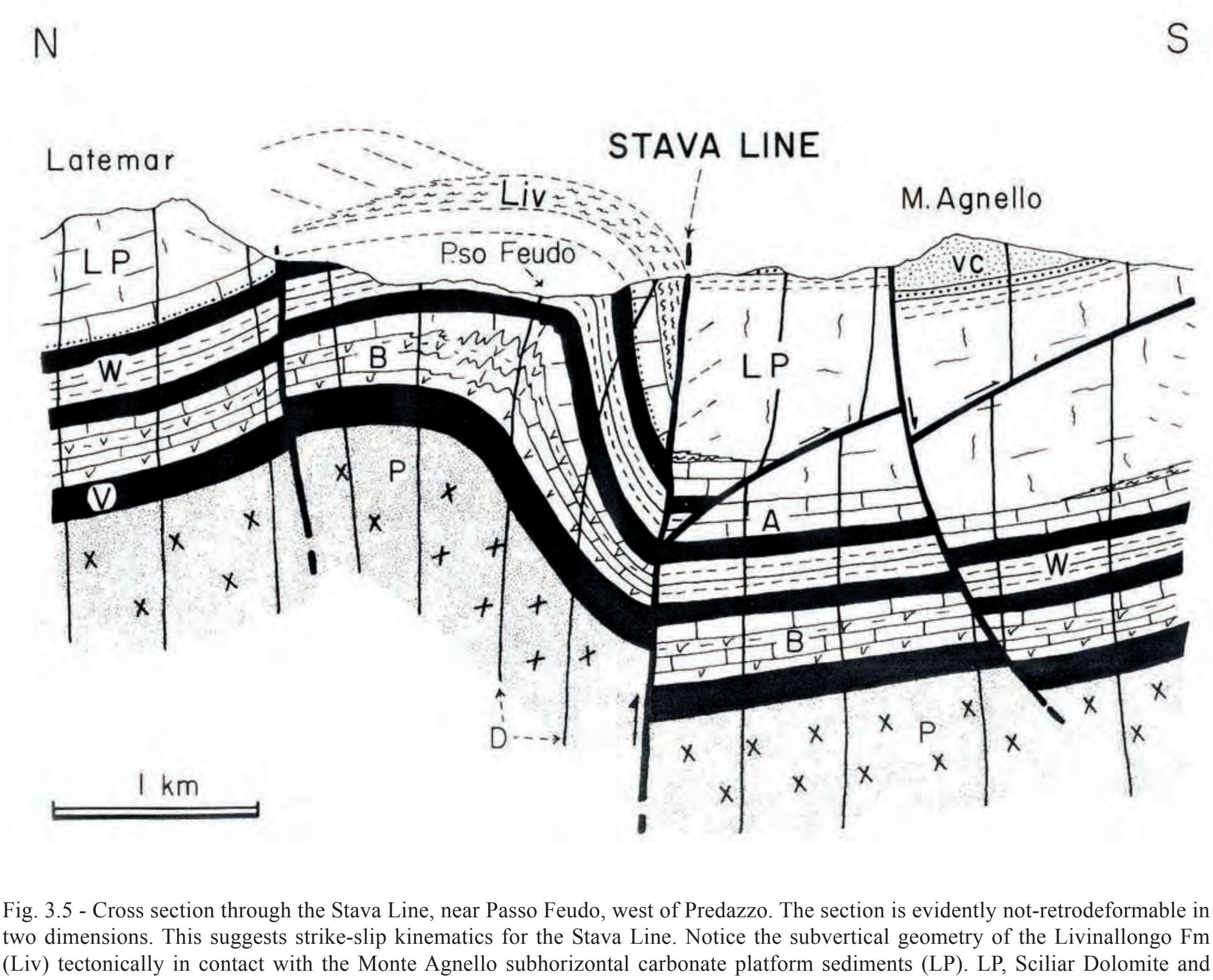


Fig. 3.5 - Cross section through the Stava Line, near Passo Feudo, west of Predazzo. The section is evidently not-retrodeformable in two dimensions. This suggests strike-slip kinematics for the Stava Line. Notice the subvertical geometry of the Livinallongo Fm (Liv) tectonically in contact with the Monte Agnello subhorizontal carbonate platform sediments (LP). LP, Sciliar Dolomite and Latemar Limestone (Ladinian); Liv, Livinallongo Fm (coeval Ladinian basinal facies); D, Ladinian volcanic dykes; VC, Upper Ladinian lavas and volcaniclastic deposits; A, Upper Anisian: Moena Fm north of the Stava Line, Contrin Fm and Serla Dolomite south of the line; W, Scythian Werfen Fm; B, Upper Permian Bellerophon Fm; V, Upper Permian Gardena Sandstone; P, Permian Ignimbrites. Numerous volcanic dykes are not represented.

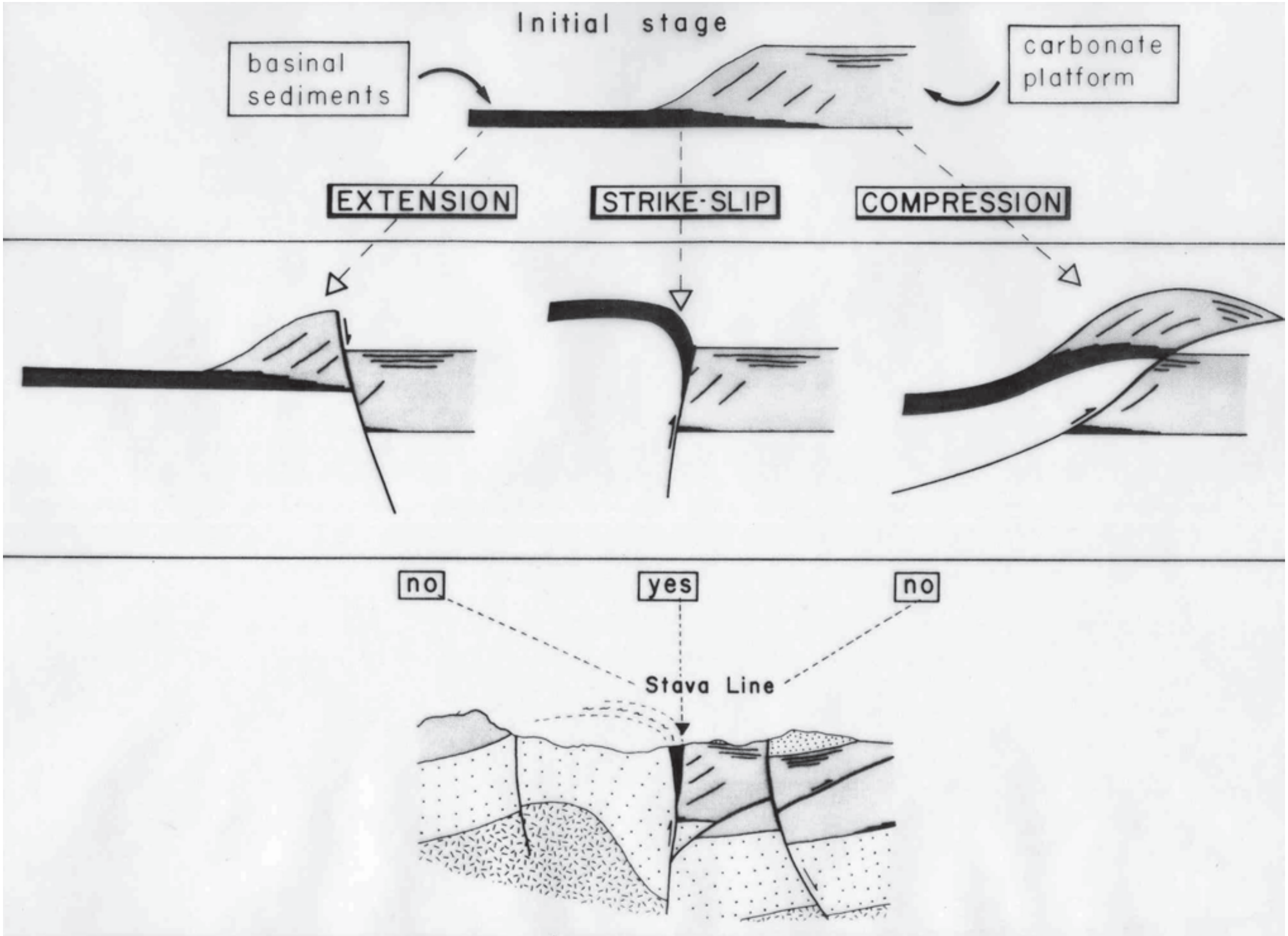


Fig. 3.6 - Scheme illustrating that both extensional and compressional deformation affecting a platform-basin system can be retro-deformed, contrary to strike-slip motions, as seen for the Stava Line, near Passo Feudo (Fig. 3.5). Notice that in the strike-slip panel the toe wedge of the carbonate platform is missing.

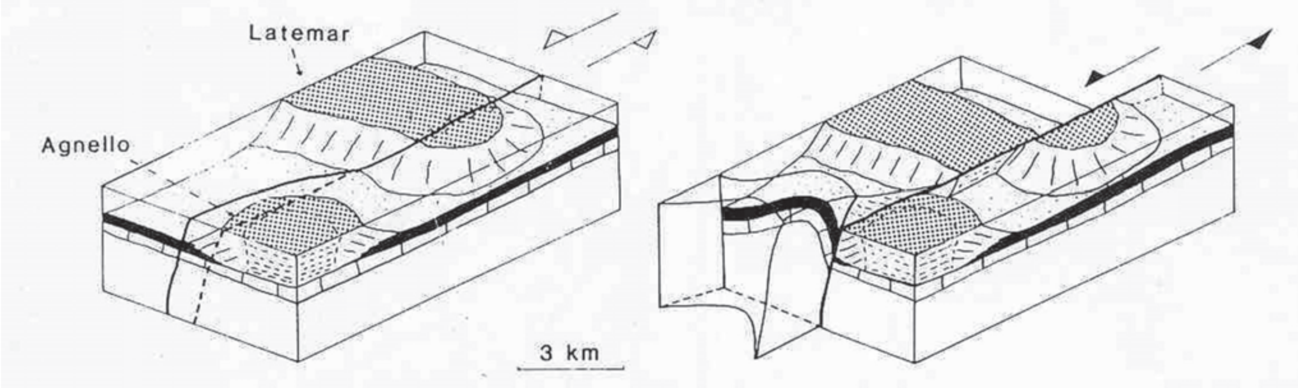


Fig. 3.7 - Reconstruction of the Monte Agnello and Latemar carbonate platforms before the strike-slip motion occurred along the Stava Line and of the volcanic event that cut the Stava tectonic alignement. North is to the left.

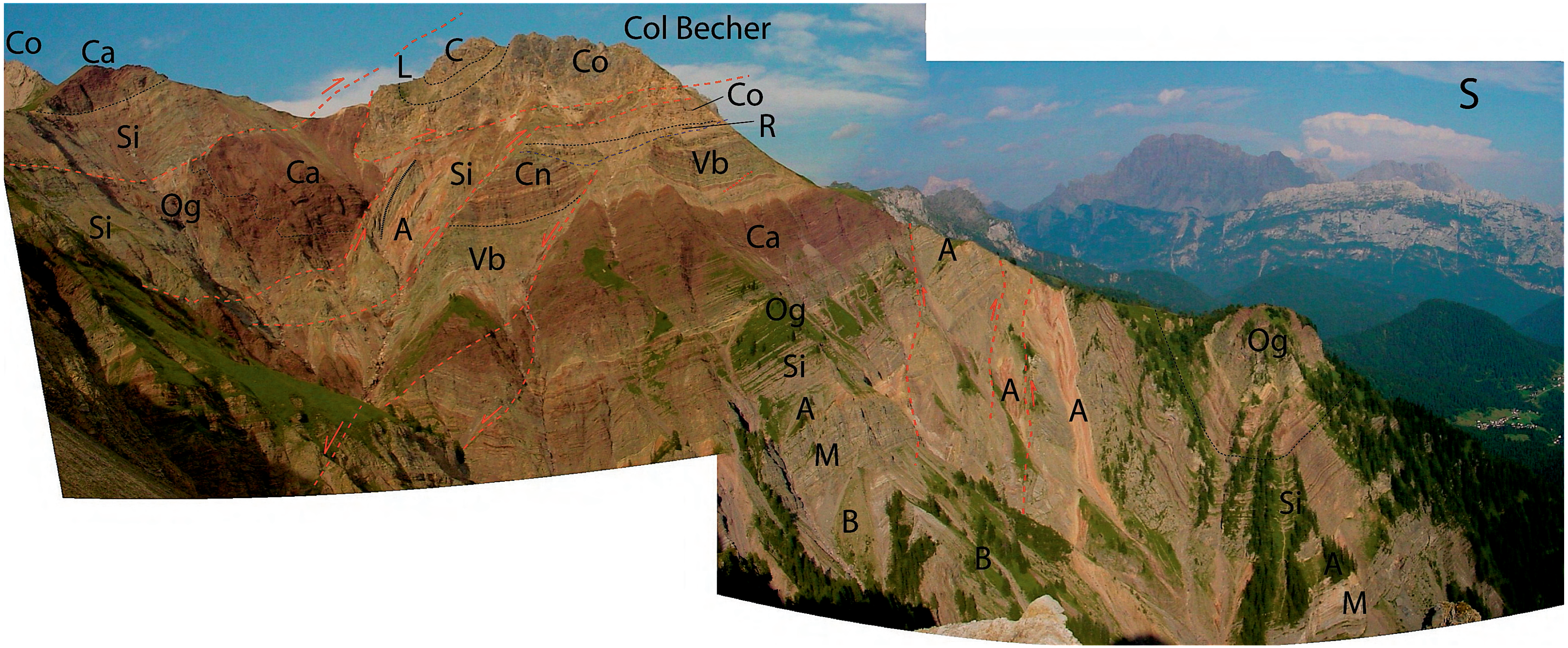


Fig. 3.8 - The Col Becher is one of the most impressive and original outcrops of the Dolomites from a structural geology point of view, near the San Pellegrino Pass. The picture was taken from the west. A diapiric structure triggered by the Bellerophon Fm evaporites (not cropping out) intrudes the Werfen Fm. Legend, Ladinian: C, Marmolada Limestone; L, Livinallongo Fm; Upper Anisian: Co, Contrin Fm; R, Richthofen Conglomerate; Scythian: Werfen Fm: Cn, Cencenighe Mb; Vb, Val Badia Mb; Ca, Campil Member; Og, Gastropod Oolite; Si, Siusi Mb; A, Andraz horizon; M Mazzin Mb. Late Permian: B, Bellerophon Fm. The piercing structure (where A is uplifted on the left side of the picture) is truncated by a thrust sheet of younger (Anisian-Ladinian) formations. The thrust fault was later folded (left of Col Becher). An extensional or transtensional Anisian fault, older than the above described deformation, was sutured by the Upper Anisian Richthofen Conglomerate (R). The following deformation phases can be thus recognized: 1) extensional or transtensional Anisian fault; 2) Diapir development, possibly triggered by deep seated basement involving N70°E left-lateral transtensional/transpressional faults; 3) truncation of the upper part of the diapiric structure by the Col Becher thrust fault; 4) folding of the thrust fault. The Upper Ladinian age of the diapiric structure is suggested by analogy with similar structures (e.g., Passo Serle, in the San Nicolò Valley) that present folds and faults cut by Ladinian magmatism and, at places, eroded and overlain unconformably by submarine landslides of the Caotico eterogeneo and by Upper Ladinian volcaniclastic deposits. Moreover, the structure is localized along the Stava-Cima Bocche Line that is, as already mentioned, cut by Middle Triassic volcanism. Compare with the map and sections of Fig. 3.12 and 3.13.

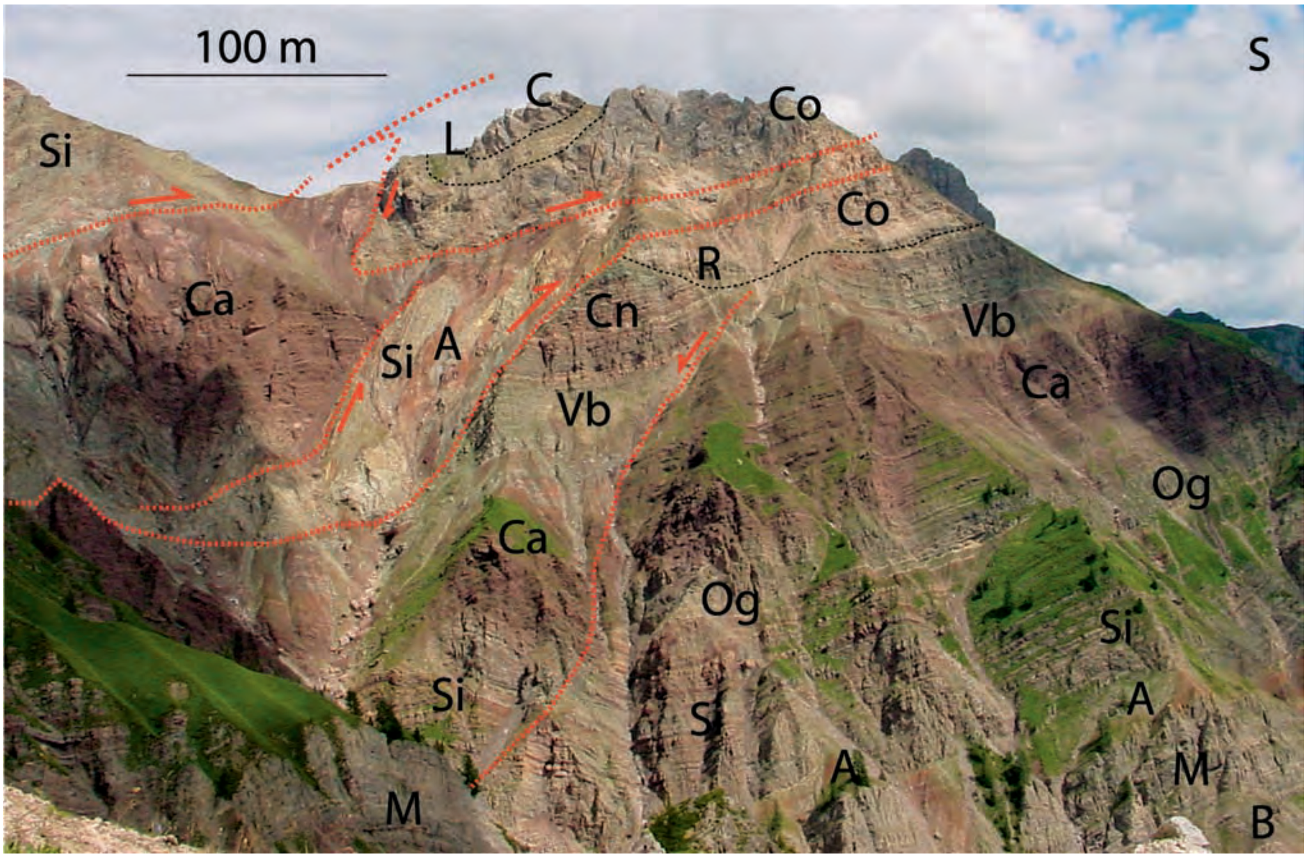


Fig. 3.9 - Detail beneath the Col Becher. The piercing "diapiric" structure has been decapitated by the upper thrust, which has later been folded. In the center is also visible the Anisian transtensional fault sealed by the Richthofen Conglomerate. Legend, Ladinian: C, Marmolada Limestone; L, Livinallongo Fm; Upper Anisian: Co, Contrin Fm; R, Richthofen Conglomerate; Scythian: Werfen Fm: Cn, Cencenighe Mb; Vb, Val Badia Mb; Ca, Campil Mb; Og, Gastropod Oolite; Si, Siusi Mb; A, Andraz horizon; M, Mazzin Mb. Late Permian: B, Bellerophon Fm).

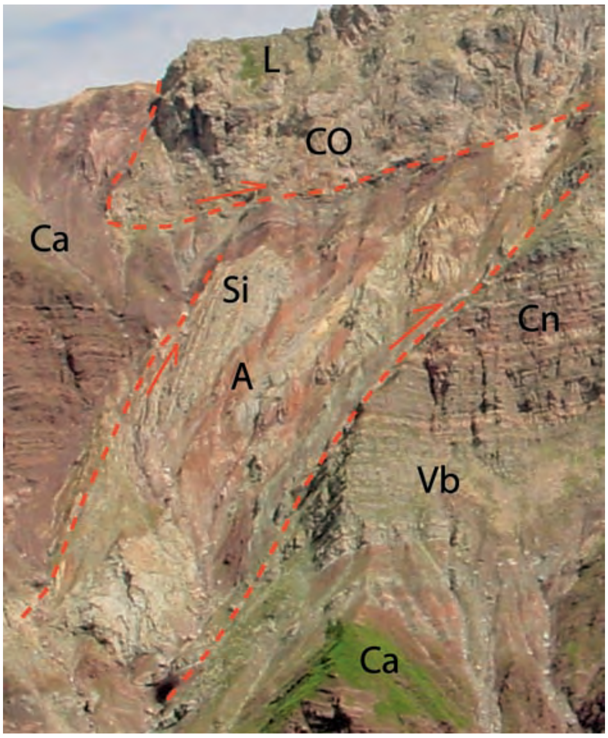


Fig. 3.10 - Detail of the previous panoramic view, with the "diapiric" intrusion of disrupted Werfen Fm, bounded by two faults cross-cut by the upper thrust of the Col Becher. In the core of the intrusion can be inferred the evaporitic Bellerophon Fm. Legend: L, Livinallongo Fm; Co, Contrin Fm; Cn, Cencenighe Mb; Vb, Val Badia Mb; Ca, Campil Mb; Si, Siusi Mb; A, Andraz horizon.

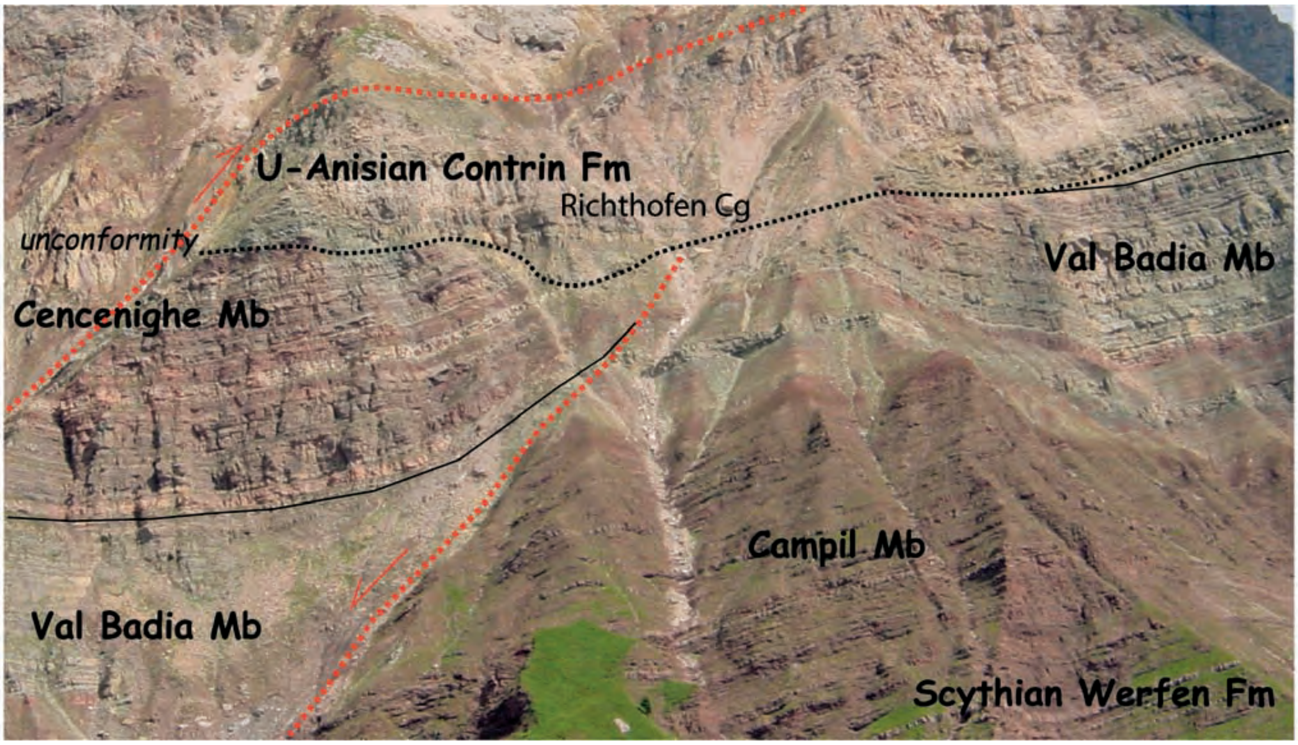


Fig. 3.11 - Detail of the Col Becher structure: the Anisian fault lowered the Cencenighe Mb of the Werfen Fm, now in contact with the Campil Mb (dark red) in the footwall. The Richtofen Conglomerate and the Upper Anisian Contrin Fm unconformably overlie the erosional surface that leveled the extensional structure. Notice, in the Cencenighe Mb of the hanging wall a drag fold associated to the normal or transtensional fault. Above, the Col Becher thrust fault with reddish siltstones of the Werfen Fm overriding the Anisian dolomites. C, Campill Mb; V, Val Badia Mb; E, Cencenighe Mb; R, Richthofen Conglomerate; CO, Contrin Fm. See also the map and the sections in the following figures.

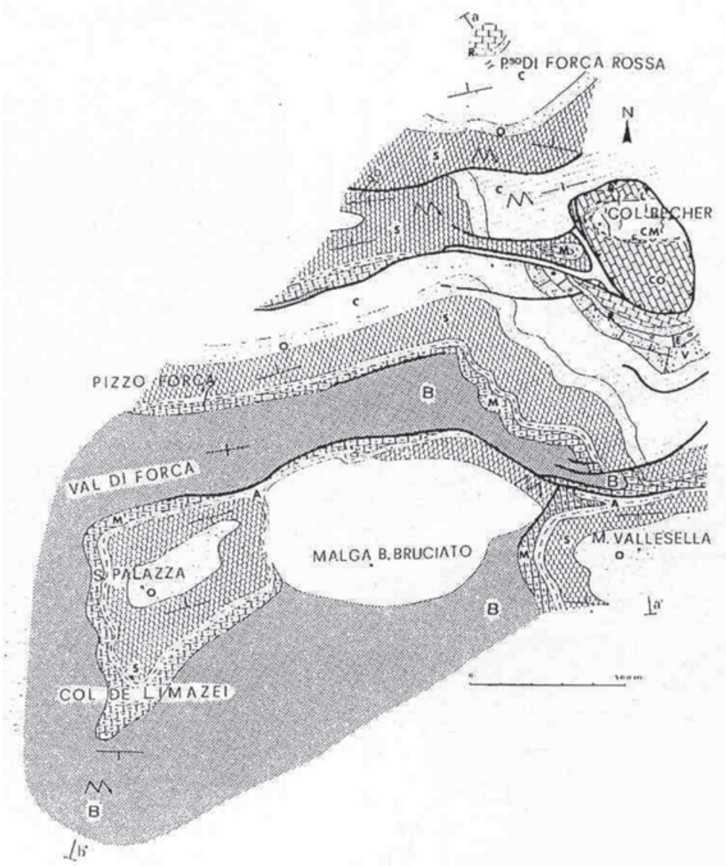


Fig. 3.12 - Geological map of the Col Becher structure. The top of Col Becher is a small klippe. Other diapiric structures occur north of the Vallesella syncline, in structural continuity with the Val di Forca diapiric anticline, and at Col de Limazei, to the southwest. B, Bellerophon Fm; M, Mazzin Mb; A, Andraz horizon; S, Siusi Member; O, Gastropod Oolite; C, Campil Mb; V, Val Badia Mb; E, Cencenighe Mb; R, Richthofen Conglomerate; Co, Contrin Fm; L, Livinallongo Fm; CM, Marmolada Limestone.

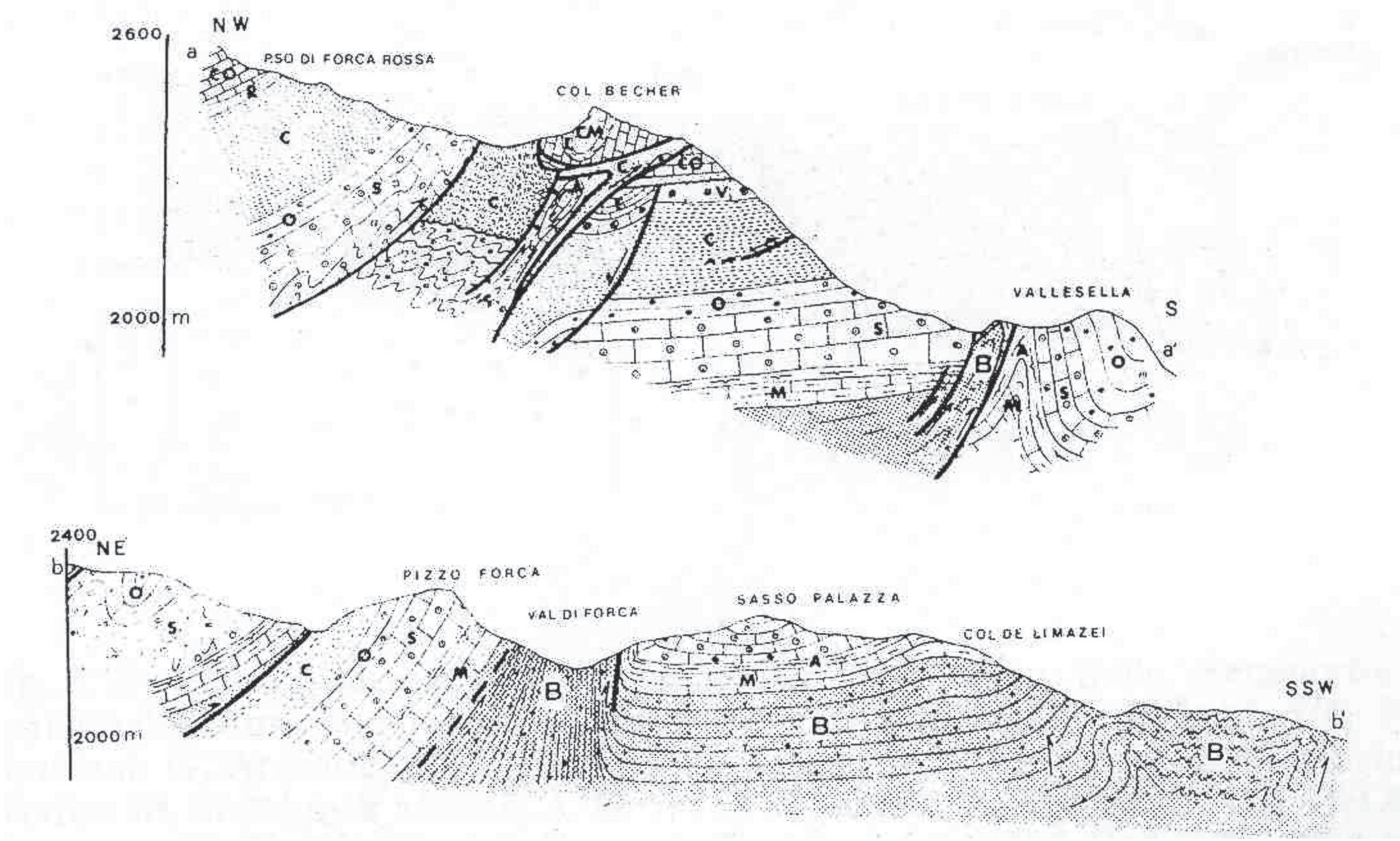


Fig. 3.13 - Geological cross-sections of the Col Becher area. B, Bellerophon Fm; M, Mazzin Mb; A, Andraz horizon; S, Siusi Mb; O, Gastropod Oolite; C, Campil Mb; V, Val Badia Mb; E, Cencenighe Mb; R, Richthofen Conglomerate; Co, Contrin Fm; L, Livinallongo Fm; CM, Marmolada Limestone.

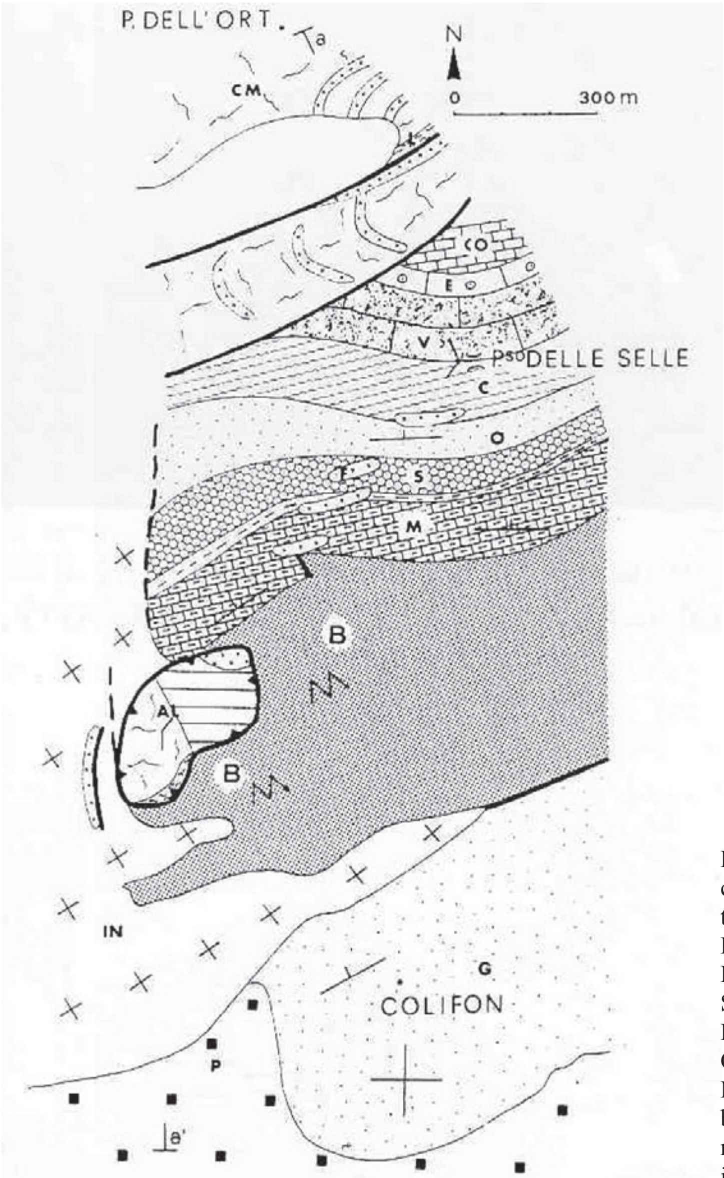
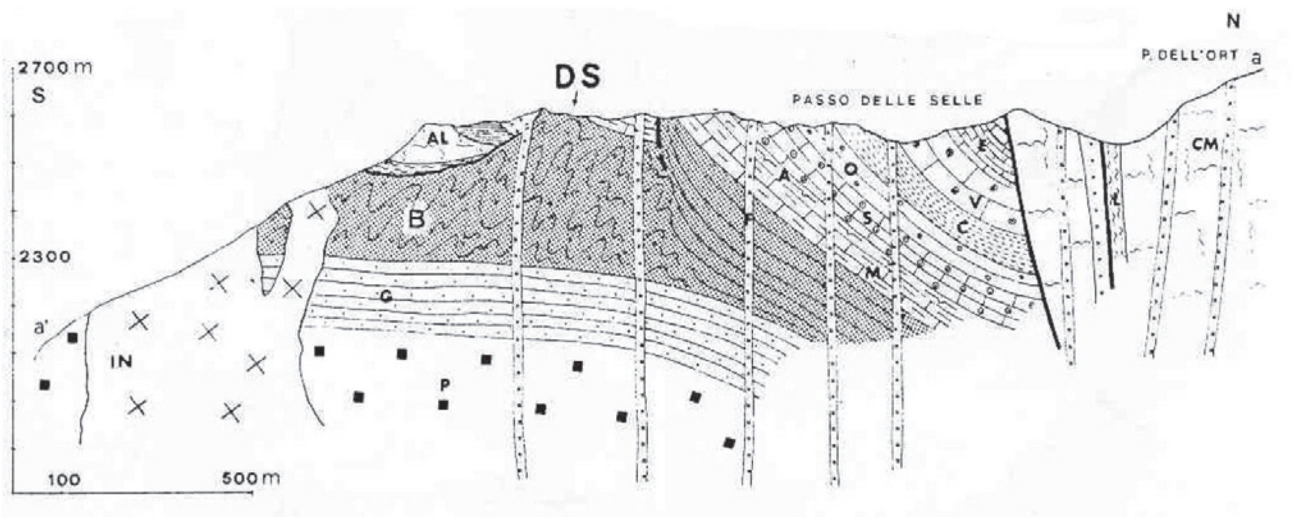


Fig. 3.14 - Geological map and section of the diapiric anticline of Passo Selle, metamorphosed by the contact with the monzonitic intrusion, northwest of Passo San Pellegrino. P, Permian porphyrites; G, Gardena Sandstone; B, Bellerophon Fm; M, Mazzin Mb; A, Andraz horizon; S, Siusi Mb; O, Gastropod Oolite; C, Campil Mb; V, Val Badia Mb; E, Cencenighe Mb; R, Richthofen Conglomerate; CO, Contrin Fm; L, Livinallongo Fm; CM, Marmolada Limestone; AL, allochthonous carbonatic block of Latemar or Marmolada Limestone, thrusted and metamorphosed; F, latit-basaltic dykes; IN, monzonitic intrusion; DS, diapiric structure.



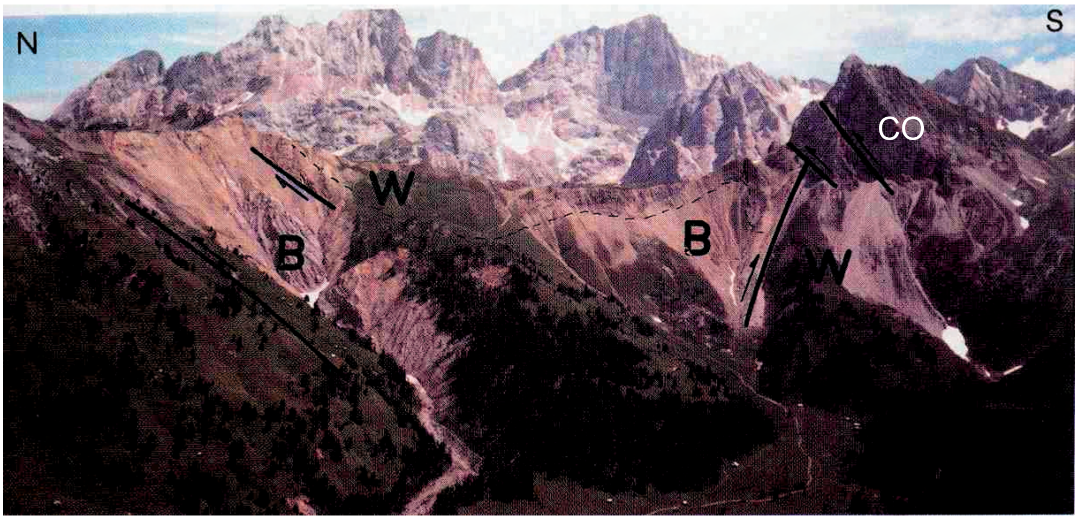


Fig. 3.15 - Diapiric anticline of Val San Nicolò, a lateral valley of Val di Fassa. View from the west. B, Bellerophon Fm; W, Werfen Fm; CO, Anisian carbonates. See the map and section of Fig. 3.16.

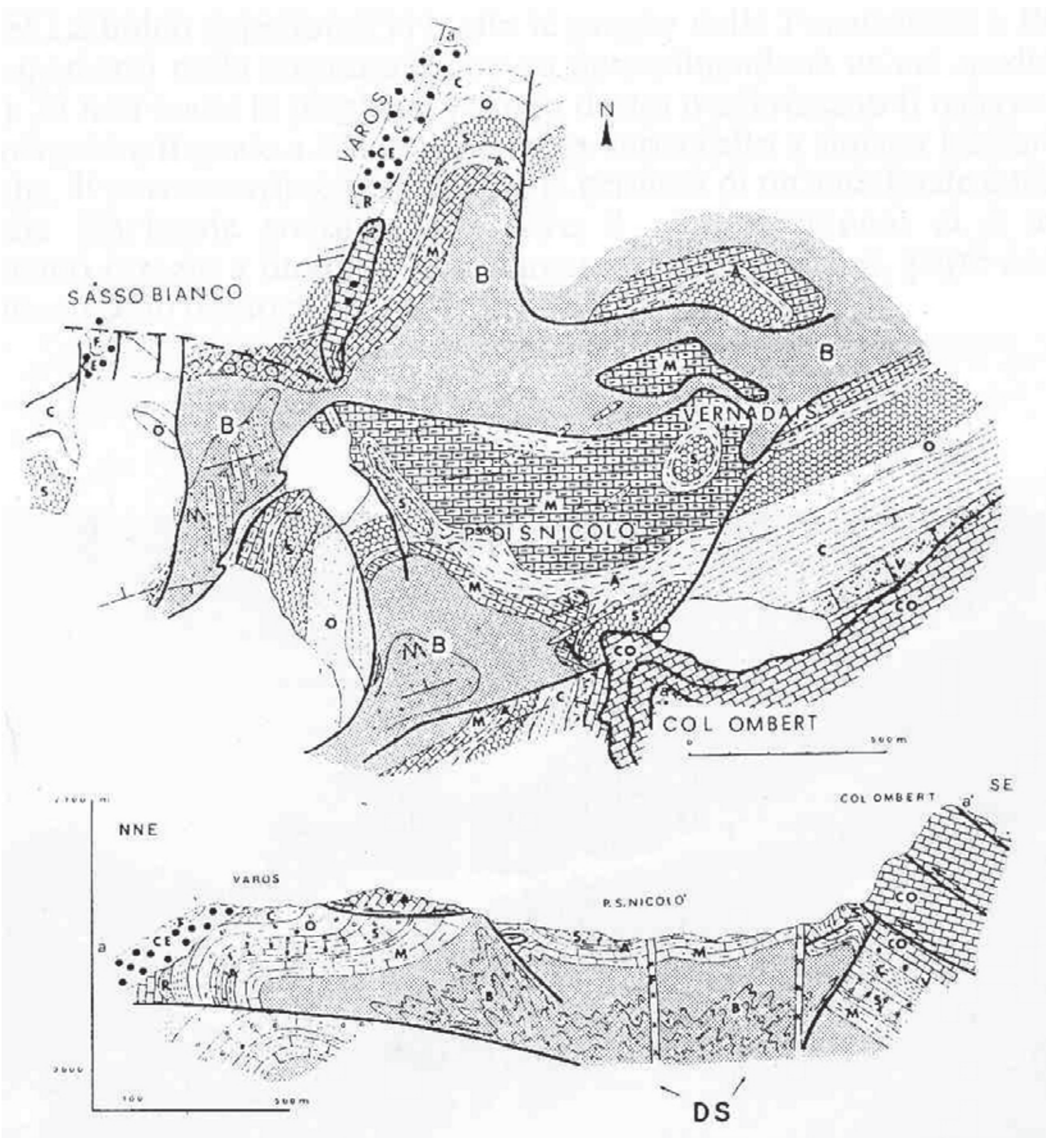


Fig. 3.16 - Geological map and cross section of the double vergent diapiric anticline of Val San Nicolò. B, Bellerophon Fm; M, Mazzin Mb; A, Andraz horizon; S, Siusi Mb; O, Gastropod Oolite; C, Campil Mb; V, Val Badia Mb; E, Cencenighe Mb; R, Richthofen Conglomerate; CO, Moena Fm, Contrin Fm; F, latitic-basaltic dykes, diatrems and subvulcanic bodies; CE, Caotico eterogeneo; DS, diapiric structure.

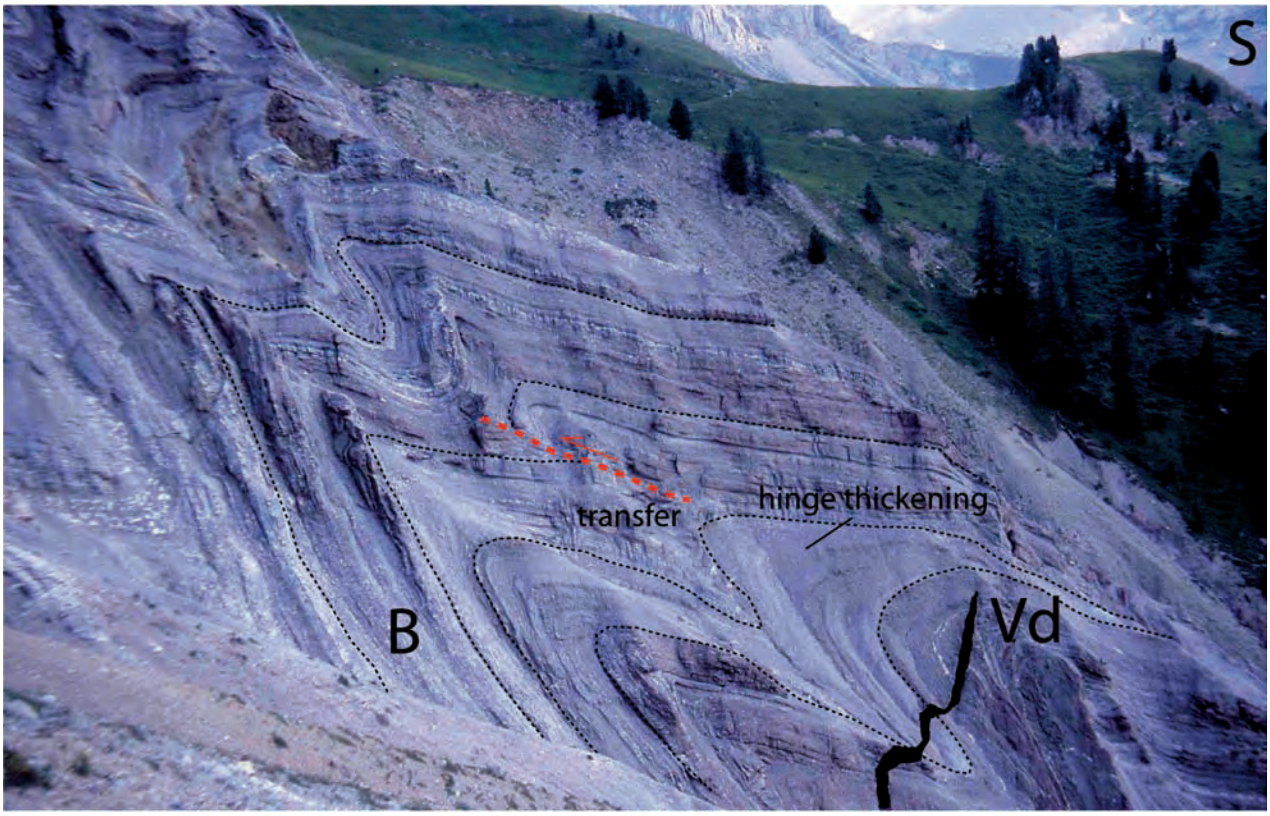


Fig. 3.17 - Northern head of Val San Nicolò. To the right an Upper Ladinian latitic-andesitic dyke (Vd) cuts the folds of the diapiric structure in the Upper Permian Bellerophon Fm (B), constraining their Middle Triassic age (Rossi, 1977). Notice that the folds (right bottom) transfer the shortening to a thrust fault that terminates, leaving the pace to other folds (top left). The thrust fault generates at the hinge of an anticline and terminates at the hinge of an overlying syncline. The two tip lines of the small thrust transfer the shortening into the folds. Where the shortening is accommodated by the thrust fault (due to relatively more competent lithologies; central part of the photo), folds are much less frequent. In the more shaly layers the folds show hinge thickening.

Fig. 3.18 - Synsedimentary syncline filled by nodular limestones of the Livinallongo Fm (L), south of the top of Col Ombert mountain, south of the diapiric structure of Valle di San Nicolò. This structure testifies the Ladinian transpressional tectonics of the central Dolomites. The Contrin Fm (C) is folded with synclinal geometry due to a pop-up structure produced by conjugate thrust faults.

Fig. 3.19 - Detail of the previous structure: the southern limb of the synsedimentary syncline, with onlap geometries within the Livinallongo Fm, characterized by massive calcarenites passing laterally into reddish nodular limestones. The picture was taken north of the Massiccio della Costabella, between Passo Pasche and Col Ombert. Alberto Boz for scale.

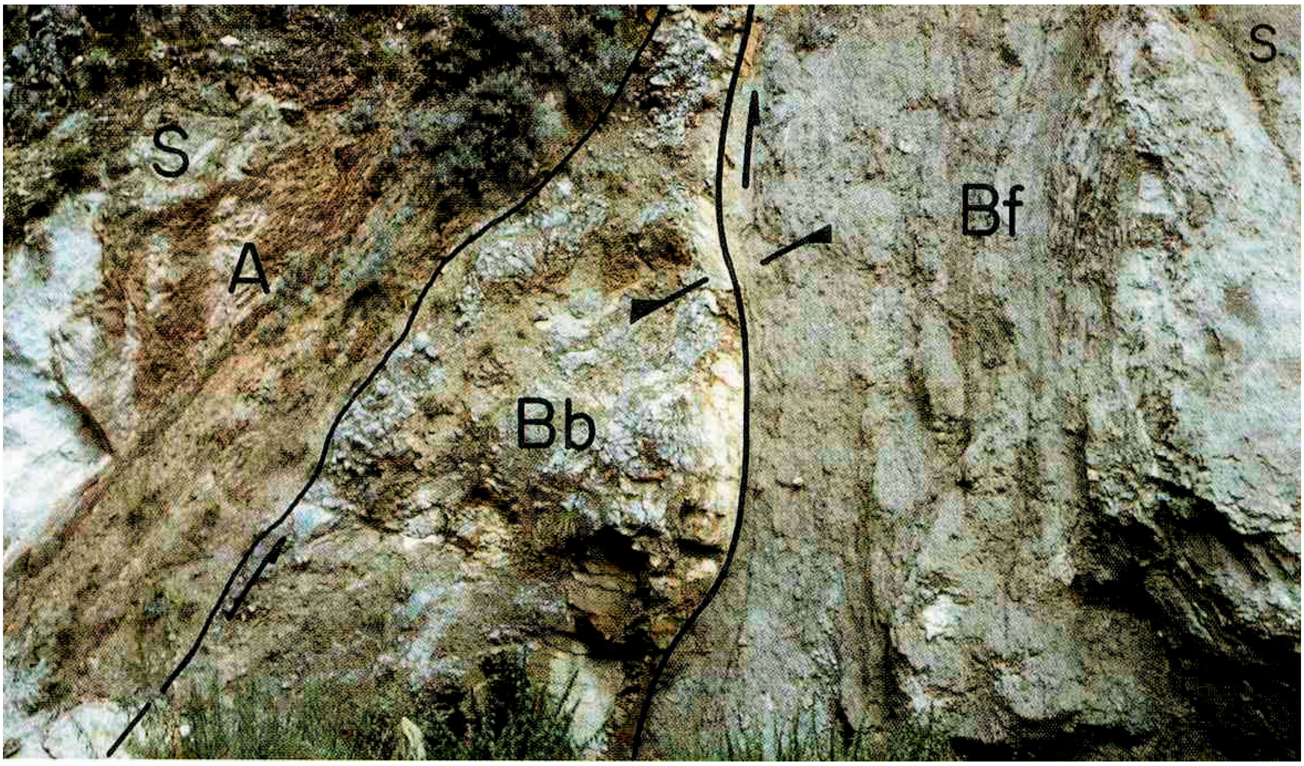


Fig. 3.20 - Detail of the northern flank of the Avoscan (locality Roi, see also the following picture) diapiric anticline. The Bellerophon Fm (Bf) in the “fiammazza” (evaporitic) facies is in tectonic contact with a slice of the same formation with a “badio-ta” (lagoon) facies (Bb). The main movement plane is characterized by both vertical and horizontal slickenlines. (A) Andraz horizon and (S) Siusi Member of the Scythian Werfen Fm.

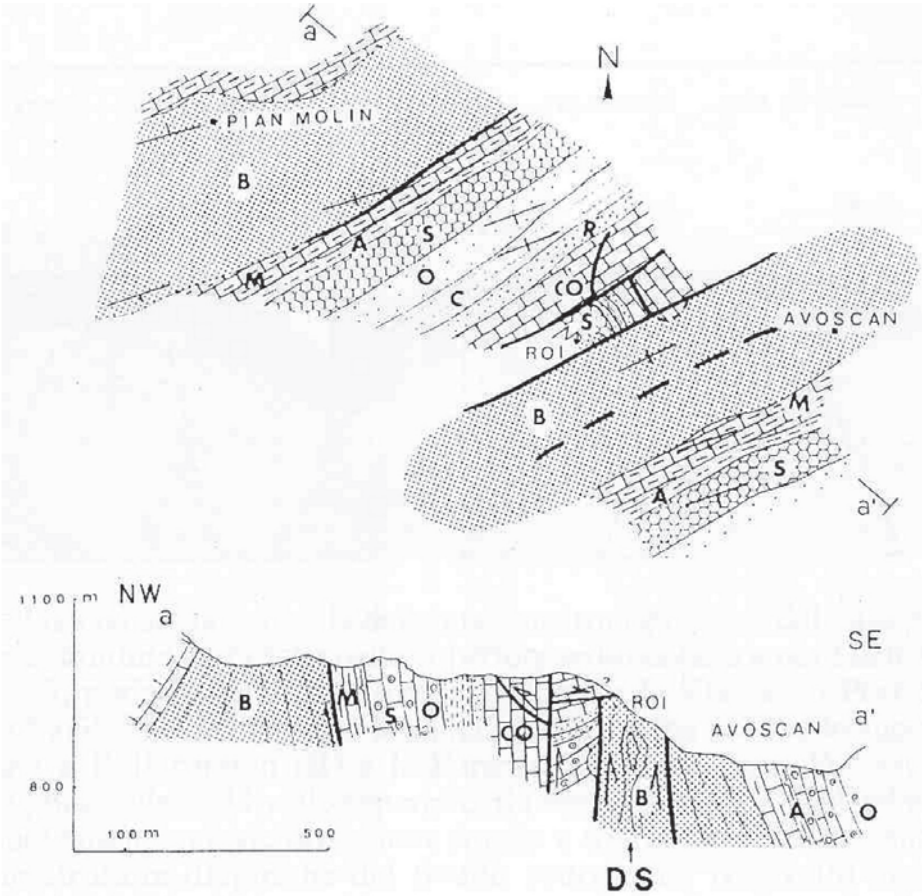


Fig. 3.21 - Geological map and cross section of the Avoscan diapiric anticline, between Cencenighe and Alleghe. B, Bellerophon Fm; Werfen Fm: M, Mazzin Mb; A, Andraz horizon; S, Siusi Mb; O, Gastropod Oolite; C, Campil Mb; R, Richthofen Conglomerate; CO, Contrin Fm; DS, diapiric structure.

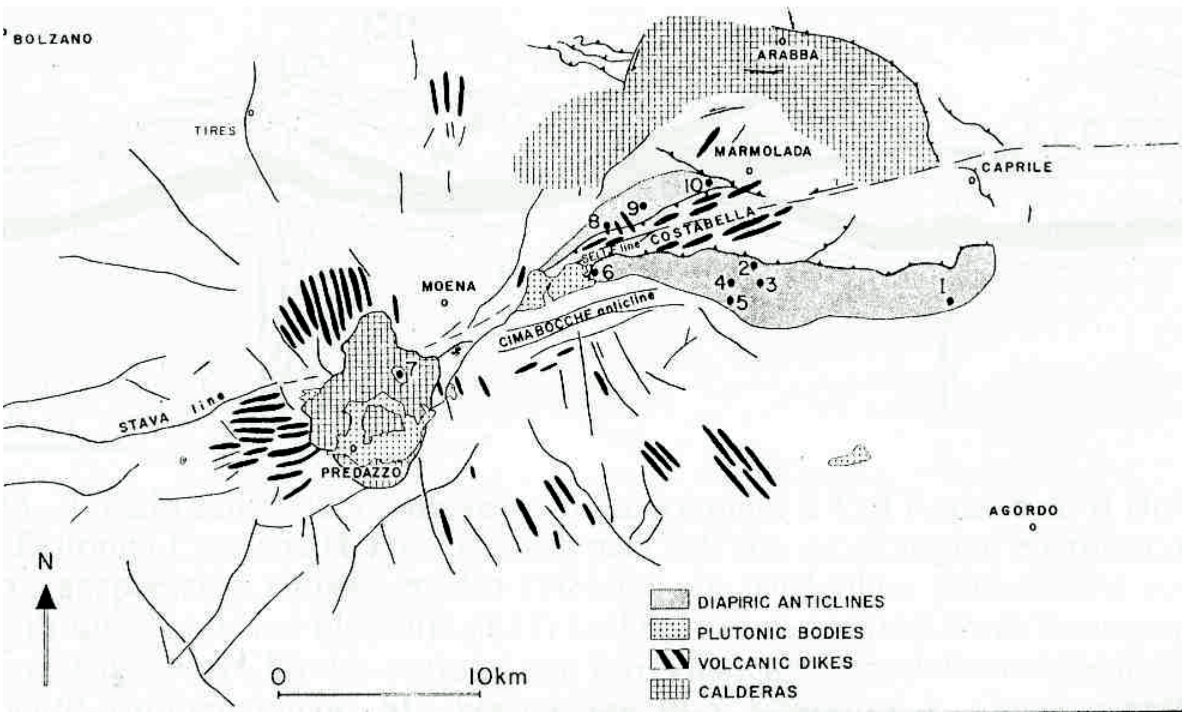


Fig. 3.22 - Structural scheme of the Ladinian tectonics of the Dolomites. The following tectonic phases can be distinguished: 1) development of the (numbered) diapiric anticlines along the N70°E-trending transpressional Stava-Cima Bocche alignement; 2) truncation of the diapiric structures by the thrust faults of Costabella, characterized by opposite vergence, a feature typical of flower structures, and by the en-echelon thrusts of Marmolada and Col Rodella; 3) development of extensional faults with radial pattern around the Predazzo and Monzoni magmatic centers; such faults possibly accommodated with a dome shape the magma upraise and the emplacement of the radial dykes.

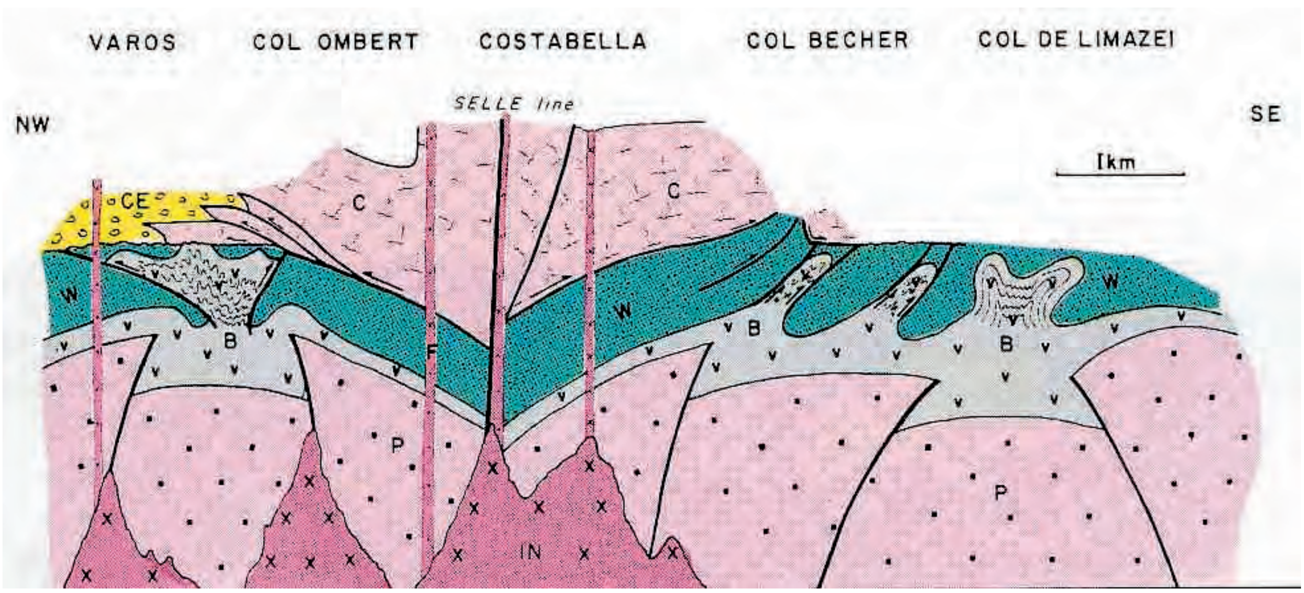


Fig. 3.23 - Relationship between the transpressional deformation of the basement P (top of the Permian Ignimbrites) and the diapiric structures in the sedimentary cover to the north of the Cima Bocche anticline. Notice the following three different structural levels: (1) at their bottom the ignimbrites suffered brittle deformation that triggered the diapiric anticlines in the above layer (2), where the Bellerophon Fm (B) and the Werfen Fm (W) show a more ductile deformation; in the uppermost level (3) the Anisian and Ladinian carbonates (C) display again brittle deformation and are thrust over the diapiric anticlines of the middle layer, truncating them at their top. In the structural highs of the diapiric anticlines, a Ladinian (Varos) erosional surface, unconformably overlain by a volcaniclastic conglomerate (CE, Caotico eterogeneo) is at places observed. The monzonitic intrusion (IN) fossilized the deformation.

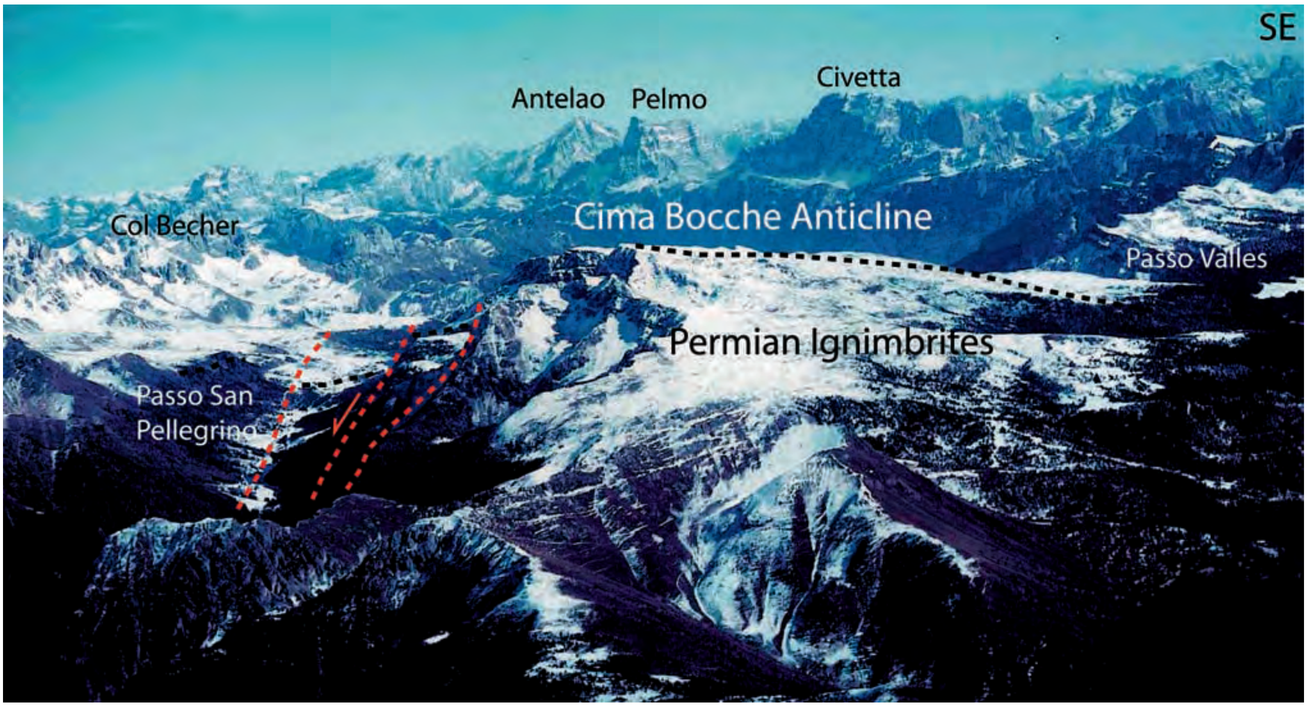


Fig. 3.24 - The Cima Bocche Anticline involves the basement and the overlying Permian Ignimbrites. Its northern limb is truncated by few subvertical N70-90° trending, possibly left-lateral strike-slip faults along the Passo San Pellegrino.

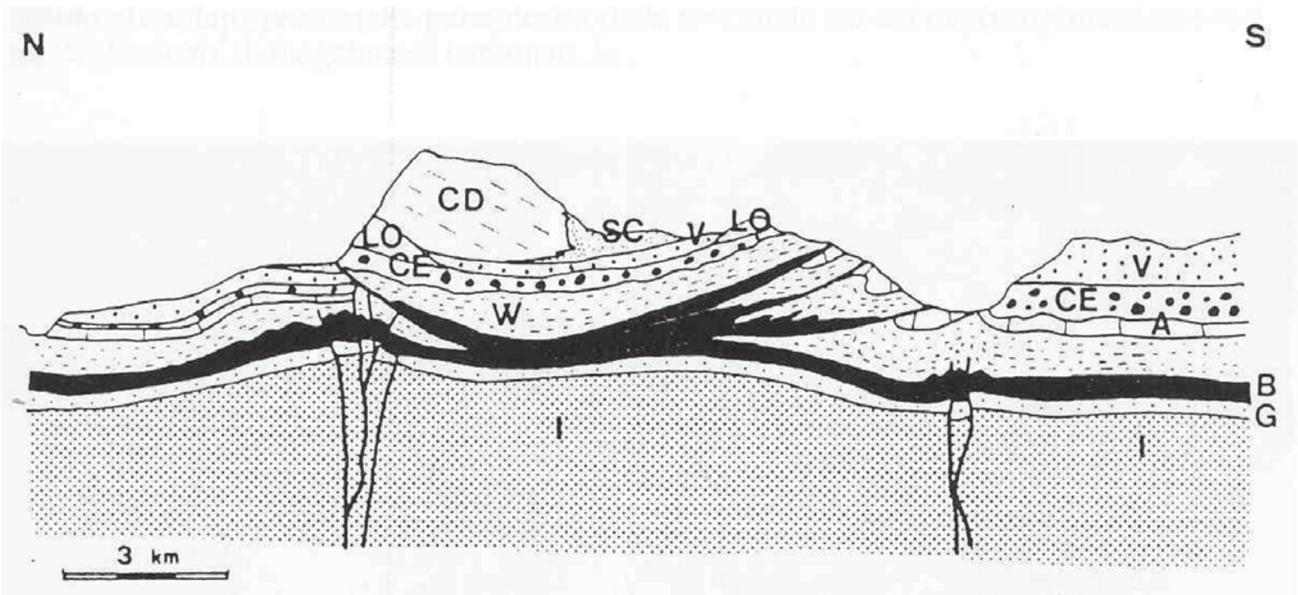


Fig. 3.25 - Schematic profile through the Sassolungo, Col Rodella and Buffaure massifs. The Cassian Dolomite (CD) developed on the morphological and structural high generated by a sinistral transpressional push-up of Middle Triassic age. In particular, the push-up nucleated beneath a giant olistolite (LO) included in the marine landslide deposits of the Caotico eterogeneo (CE). The section is not retrodeformable due to the strong out-of-section component of deformation. SC: San Cassiano Fm; V, Marmolada Conglomerate, volcaniclastic deposits and lavas; A, Livinallongo and Contrin Fms.; W, Werfen Fm; B, Bellerophon Fm; G, Gardena Sandstone; I, Ignimbrites, Permian rhyolites and crystalline basement. The main detachments are located in the Bellerophon Fm. Notice the two transpressional systems to the north and to the south, respectively the westward prosecutions of the Passo Gardena and Passo Fedaia alignments. South of Val di Fassa (right in the drawing), the Buffaure massif represented a sort of small foredeep basin for the push-up structure developed between the two transpressional belts. Here the volcaniclastic deposits are much thicker (800-1000 m) with respect to the 100-200 m thick volcaniclastic sediments in the push-up zone (Sassolungo and Col Rodella Massifs).

Fig. 3.26 - The Crepe Rosse synsedimentary syncline (located near Passo Fedaia) developed right to the south of the Triassic sinistral transpressional alignement of the Fedaia Lake, that is here buried. Notice the onlaps, expecially on the right flank of the syncline, of both volcaniclastic deposits and the interfingering carbonatic megabreccias.

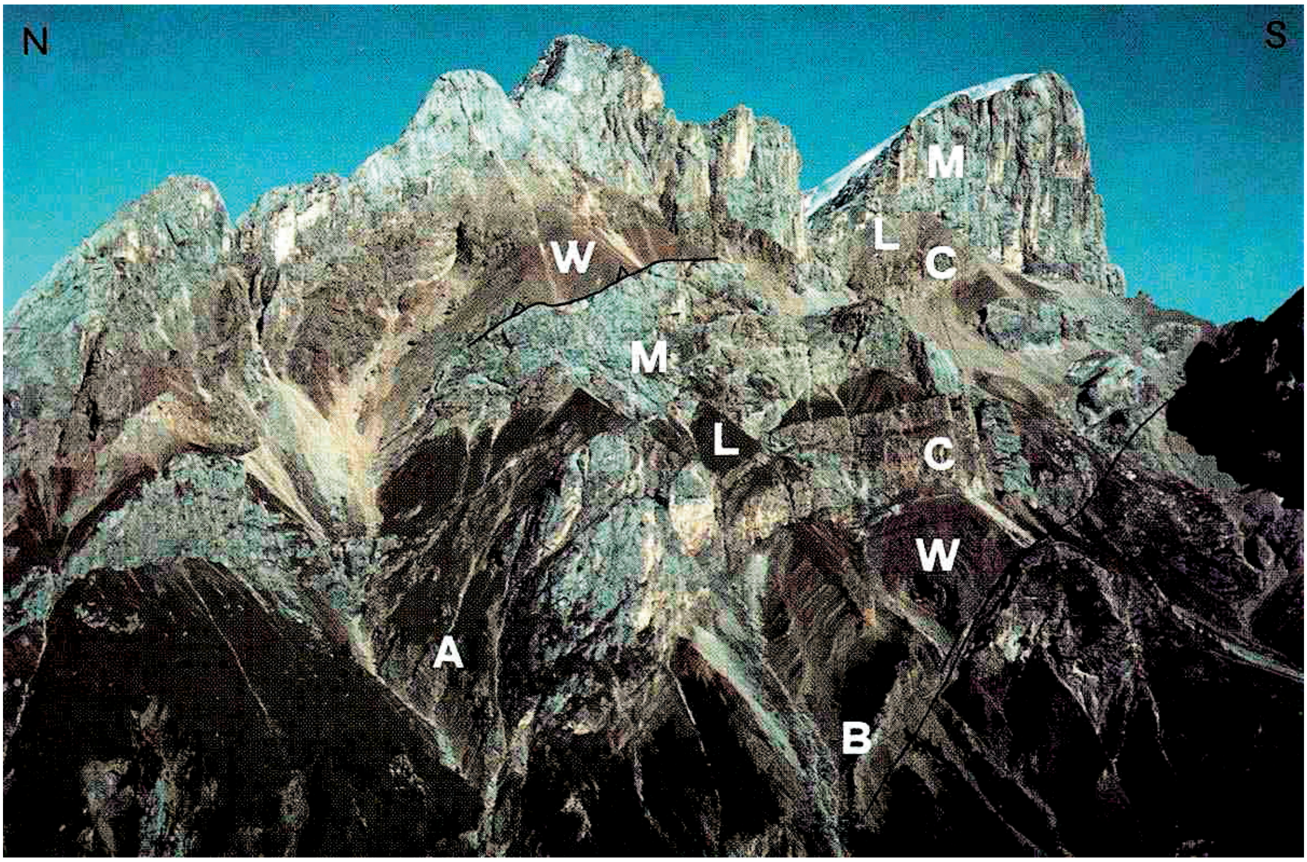


Fig. 3.27 - The southern cliff of the Marmolada massif is extremely complicated by SW-vergent thrusts. B, Bellerophon Fm; W, Werfen Fm; C, Contrin Fm; L, Livinallongo Fm; M, Marmolada Limestone; A, Caotico eterogeneo.

Fig. 3.28 - Northern slope of the Marmolada Ladinian carbonate platform (left), onlapped by Upper Ladinian volcanic and volcaniclastic rocks of the Padon ridge (right). North to the right, looking west. In the valley the Fedaia lake. Cristina Bagolan and Virginio Doglioni for scale.

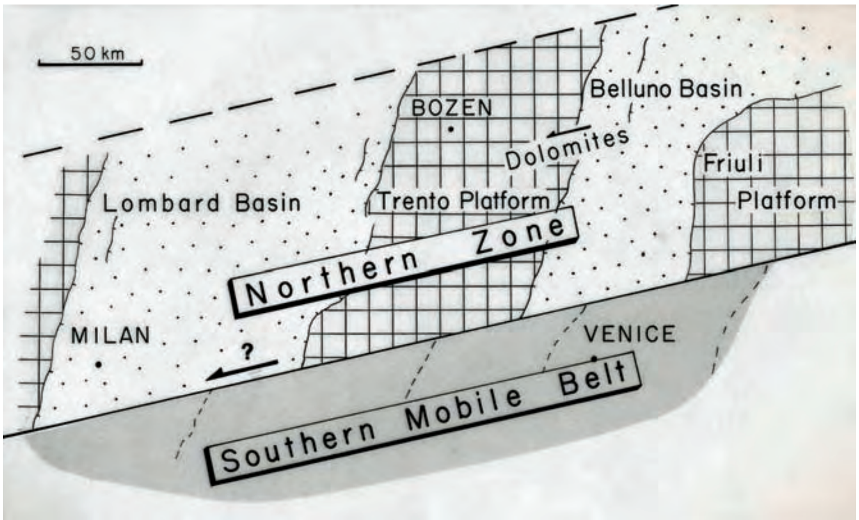


Fig. 3.29 - Schematic geological map of the Southern Alps at the Ladinian. Notice the en-echelon distribution of basins and structural highs with respect to the border between the Northern Zone and the Southern Mobile Belt (sensu Brusca, 1981). The distribution suggests a sinistral shear. In the Northern Zone both carbonate platforms and basins developed (with higher sedimentary thicknesses in the basins), whereas in the Southern Mobile Belt the basement was cropping out (Pieri & Groppi, 1981; Brusca *et alii*, 1981; De Zanche & Mietto, 1984; Garzanti, 1985).

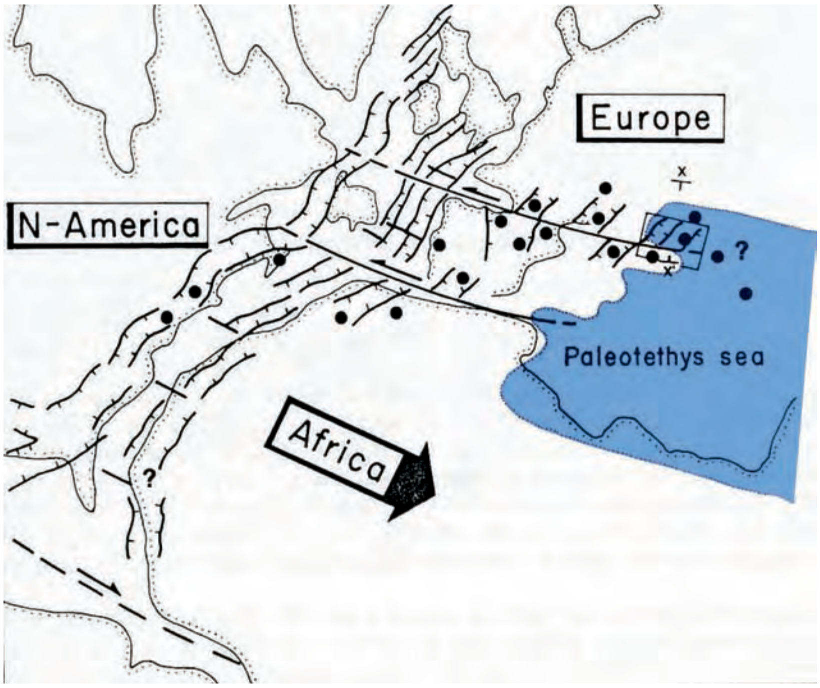


Fig. 3.30 - Upper-Middle Triassic geodynamic reconstruction (modified after Bernoulli & Lemoine, 1980, Brandner, 1984, Masson & Miles, 1986). Notice the sinistral relative motion between Africa and Europe, coeval to the Atlantic rift. The magmatic centers (black dots) are localized within rift zones and transform zones characterized by mainly transtensional kinematics (e.g., Terranova-Azores-Gibraltar; Pyrenees). X-X' is the trace of the section of the following figure and the rectangle indicates the approximate position of the previous figure.

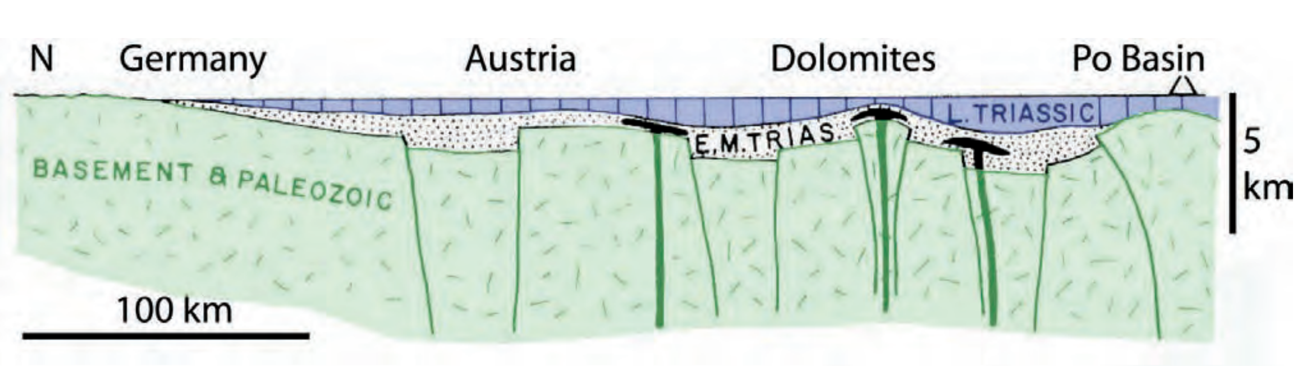


Fig. 3.31 - Idealized section through Europe and the Po Plain in the Upper Triassic. Notice the occurrence of a structural high under the Po Plain. Several positive (i.e., transpressional) flower structures (e.g., Dolomites) occur within an area prevalently characterized by subsidence (transtension).