5th Day

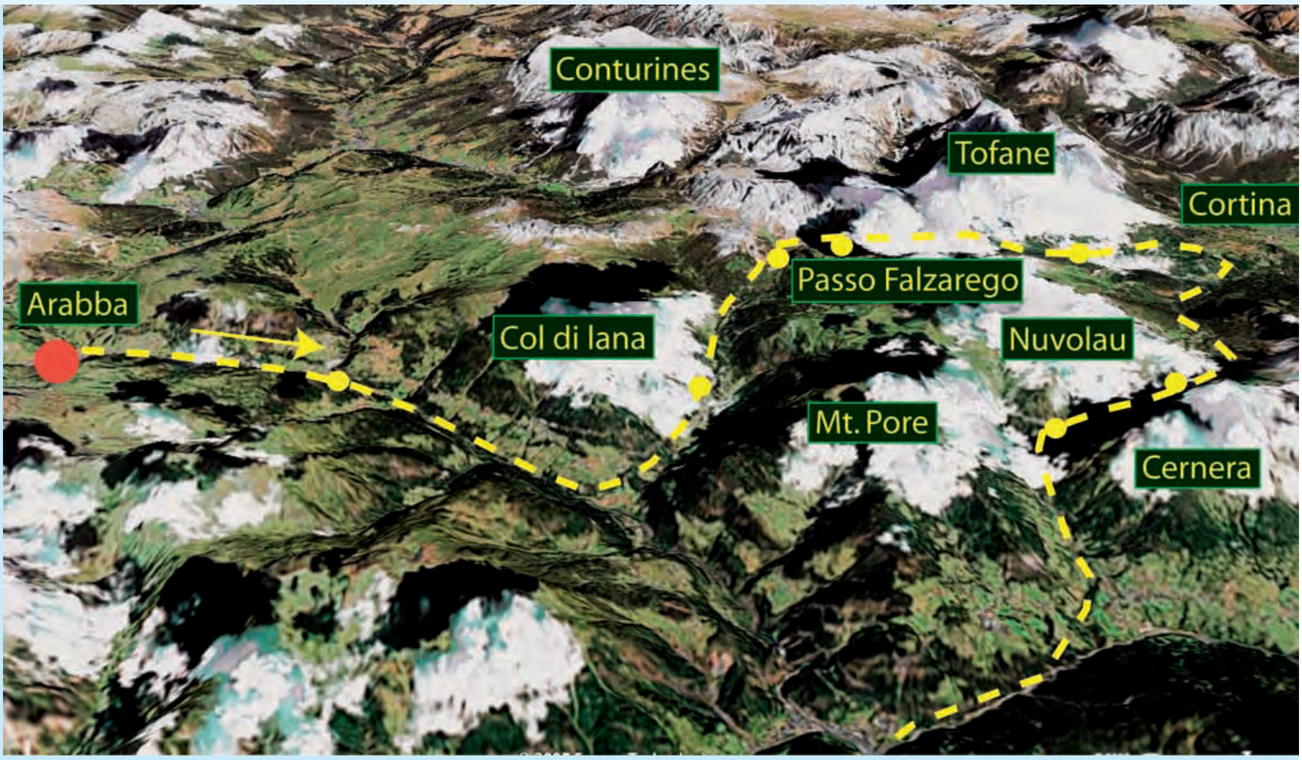


Fig. 5.0 - Itinerary: Passo di Campolongo, Passo Falzarego, Passo Giau, Agordo.

Subject: Tectonics-stratigraphy relationship, Mesozoic extension and inversion structures

In the Middle Triassic of the Dolomites, extensional tectonics and local compressional effects coexisted. This can be explained by the occurrence of a transtensional regime with local transpressional effects. Near Arabba, both aspects can be observed in the field: the Livinè Line (a Middle Triassic thrust fault en-echelon with the transcurrent faults) and the Varda Line (an Upper Ladinian extensional fault). The Dolomites are characterised by extensional synsedimentary structures excellently exposed and preserved from the Alpine shortening. The extensional faults are characterised by a quite stable N-S trend, as in the whole Tethyan, African and North Atlantic domain, suggesting a global significance for such a regularity. The age is variable from Upper Permian to Scythian, to Ladinian, Carnian and Jurassic. The spacing between the main normal faults is quite regular. A major subsidence step reported in literature at least for the Liassic is located in Val Badia, between the Puez Massif to the west (without Calcari Grigi Fm in the stratigraphic sequence) and the Fanes massif to the east (characterised by several hundred meters of Calcari Grigi Fm). This extensional zone is the border between the Trento Platform and the Belluno Basin and was inverted and resheared as a ramp by later WSW-vergent thrust faults. The interference between paleostructures and tectonics can be excellently studied also at the Falzarego Pass. Here, in the hangingwall of the Falzarego thrust, a Carnian graben was cut passively since it is characterised by high angle extensional faults at approximately 90° with respect to the direction of compression. Moreover, the margin of the

Lagazuoi carbonate platform influenced the thin-skin geometry of the thrust that forms a lateral ramp where the carbonate platform terminates. During this day we will study various structures formed by the tectonic interference between the earlier WSW-verging thrusts and the younger SE-verging thrust.
Moreover, we will cross the belt towards the foreland, crossing the Valsugana thrust (cropping out just after Agordo), the Belluno thrust and the frontal triangle structure. In previous stages of the belt, the Belluno Line was likely the front of the belt and could have been itself a triangle zone, similar to that now observed at the northern margin of the Venetian plain.

In the Mesozoic, the regularity of extensional faults and transfer zones suggests the occurrence of a relative flow between lithosphere and sub-lithospheric mantle. Lateral heterogeneities and distribution and shape of lithospheric anisotropies control the subductions and, therefore, the geometry and evolution of mountain chains. Consequently, from the geometry of mountain belts it is possible to reconstruct the zones of thinned lithosphere (i.e., the Mesozoic basinal areas). These informations are of fundamental importance when reconstructing the paleogeography of the Mediterranean area.

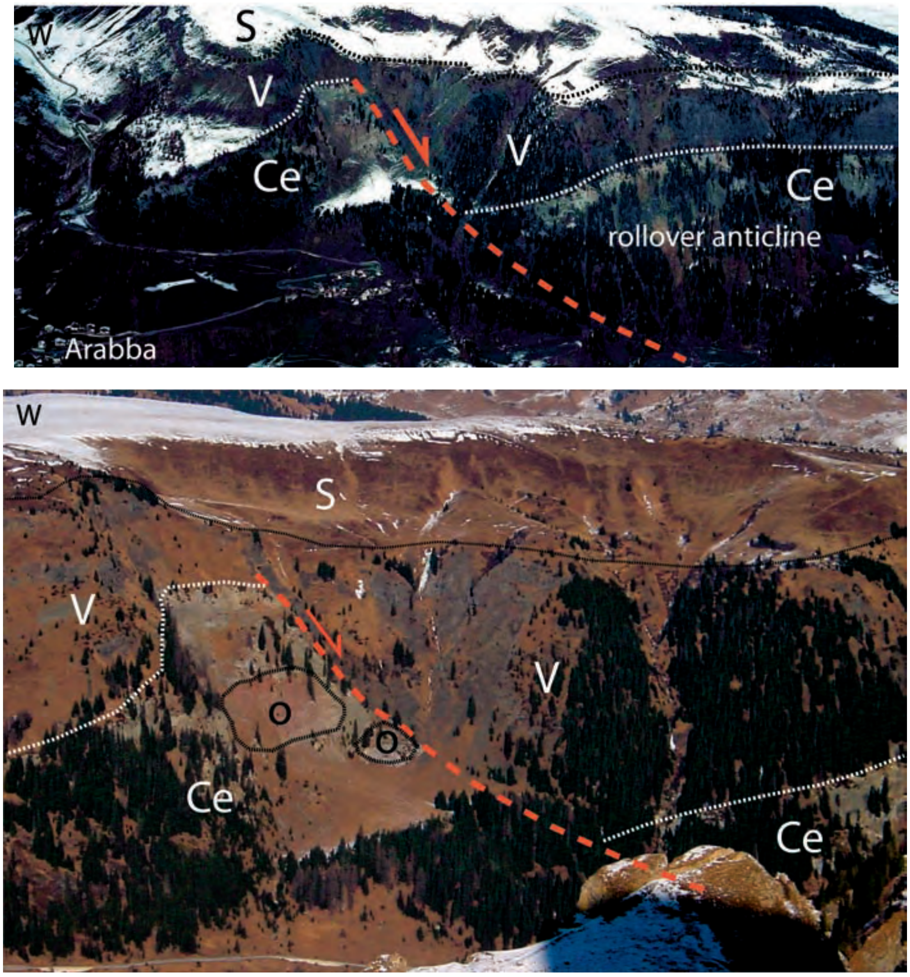


Fig. 5.1 - Distal (above) and closer (below) view of the Varda Line, a N-S synsedimentary extensional fault of upper Ladinian age, near the village of Varda, close to Arabba, Central Dolomites. The throw is evidenced by the greyish formation of the Caotico Eterogeneo (Ce), a conglomerate with poligenic clasts of volcaniclastic and of sedimentary (including large olistholiths (o) of the Werfen Fm and Marmolada Limestone) origin. A gentle rollover anticline occurs in the hangingwall, downthrown to the right, of the fault. The volcanoclastic sandstones (V) of the Upper Ladinian (Fernazza Hyaloclastites, Wengen group) seal the fault with 150 m of thickness to the right and 30-40 m in the footwall. S, Carnian San Cassiano Fm.

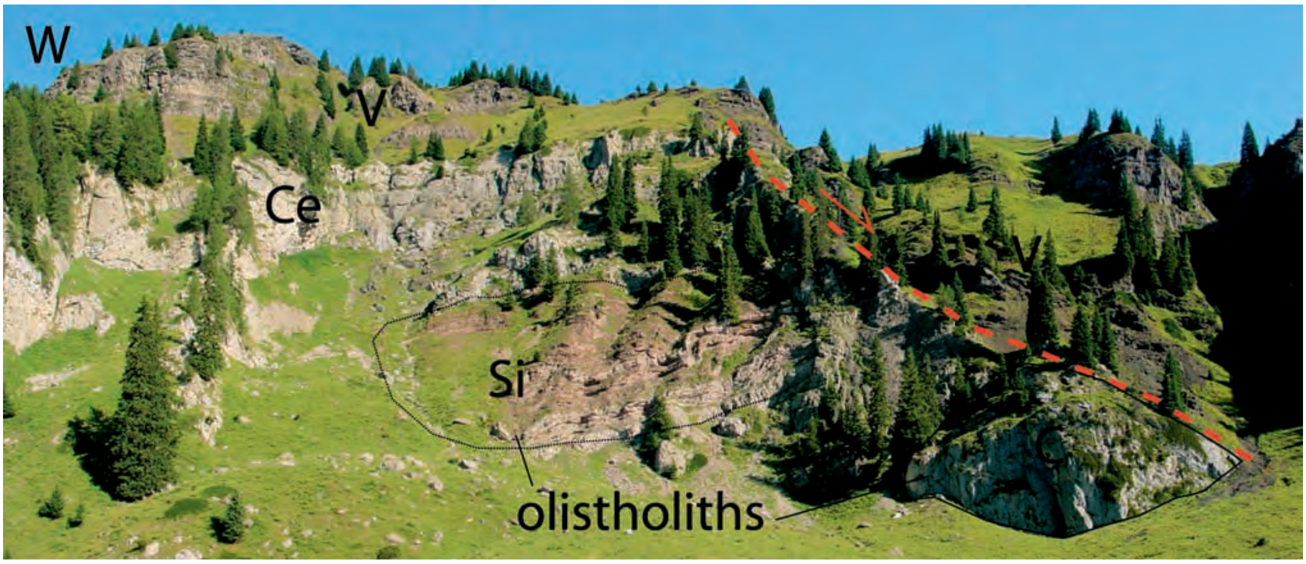


Fig. 5.2 - Detail of the previous figure, where several tens of meters wide olithosliths outcrop in the footwall of a synsedimentary normal fault. The biggest olistholith is made of Siusi Mb (Si) of the Werfen Fm, and Marmolada Limestone (C) included in the Caotico Eterogeneo (Ce). The volcanoclastic Wengen Fm (V) are thicker than 150 m in the hangingwall of the fault, and thinner than 50 m in the footwall indicating the Ladinian growth nature of the listric normal fault.

Fig. 5.3 - The Livinè Thrust in the Livinallongo Valley, 4 km east of Arabba. Legend, in the footwall, channelized breccias of the Late Anisian Moena Fm (Mo) over the Morbiac Lm (Mr); in the hangingwall, Scythian Werfen Fm, Siusi Mb (Si), and Andraz horizon (A).

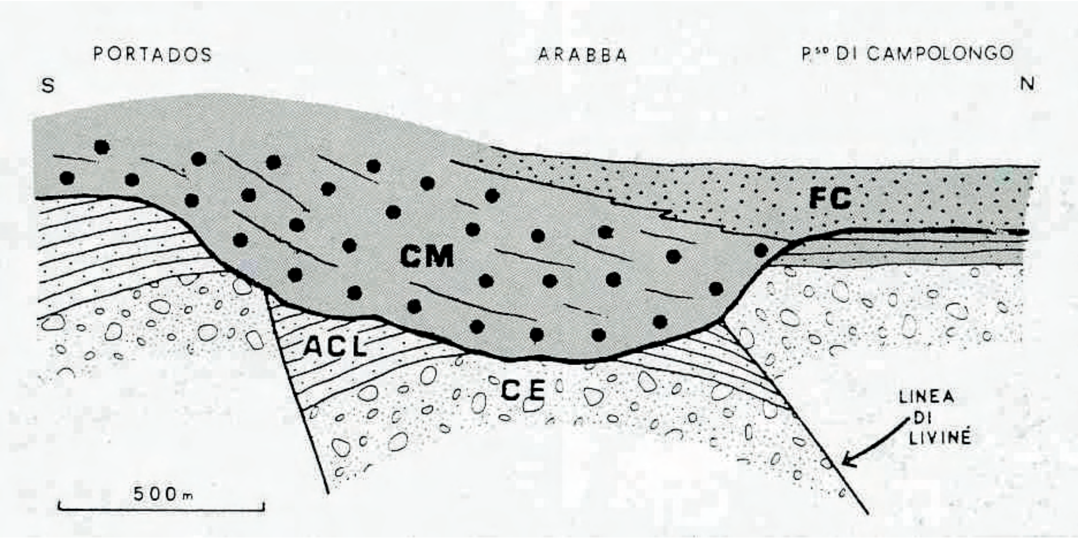


Fig. 5.4 - N-S geological section reconstructed at the Upper Ladinian-Lower Carnian for the Arabba area. The Marmolada Conglomerate (CM) seals an irregular morphology and middle Triassic faults (e.g., the transpressional Livinè Line). The conglomerates pass laterally to sandstones (FC) stratigraphically located at the bottom of the San Cassiano Fm. CE, Caotico Eterogeneo; ACL, Volcaniclastic sandstones, Fernazza Hyaloclastites. Notice that the N 70°-130° trending transpressional structures, as the Livinè Line, coexist with coeval extensional structures trending N-S.

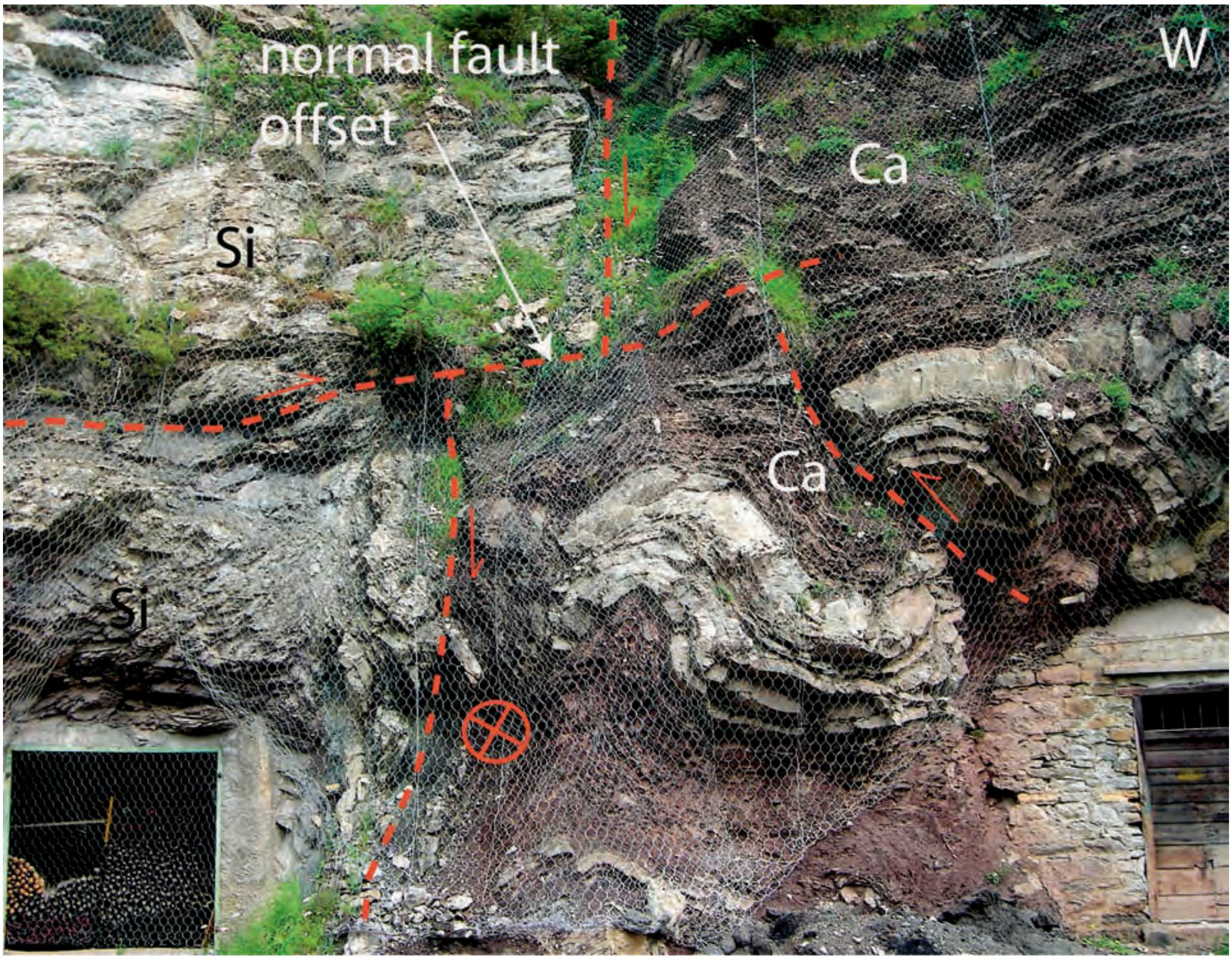


Fig. 5.5 - A N-S trending normal fault in the Werfen Fm (Scythian), sealed by Upper Anisian sequences (not visible in the picture) has been cross-cut and folded by a later E-verging thrust, and the whole visible rocks have been squeezed and buckled. It appears as a meso-scale example of inversion tectonics such as those observed in the North Sea. The N-S pre-existing normal fault has been re-sheared also by left-lateral strike-slip motion during alpine compression. Si, Siusi Mb; Ca, Campil Mb. 1 km west of Andraz.

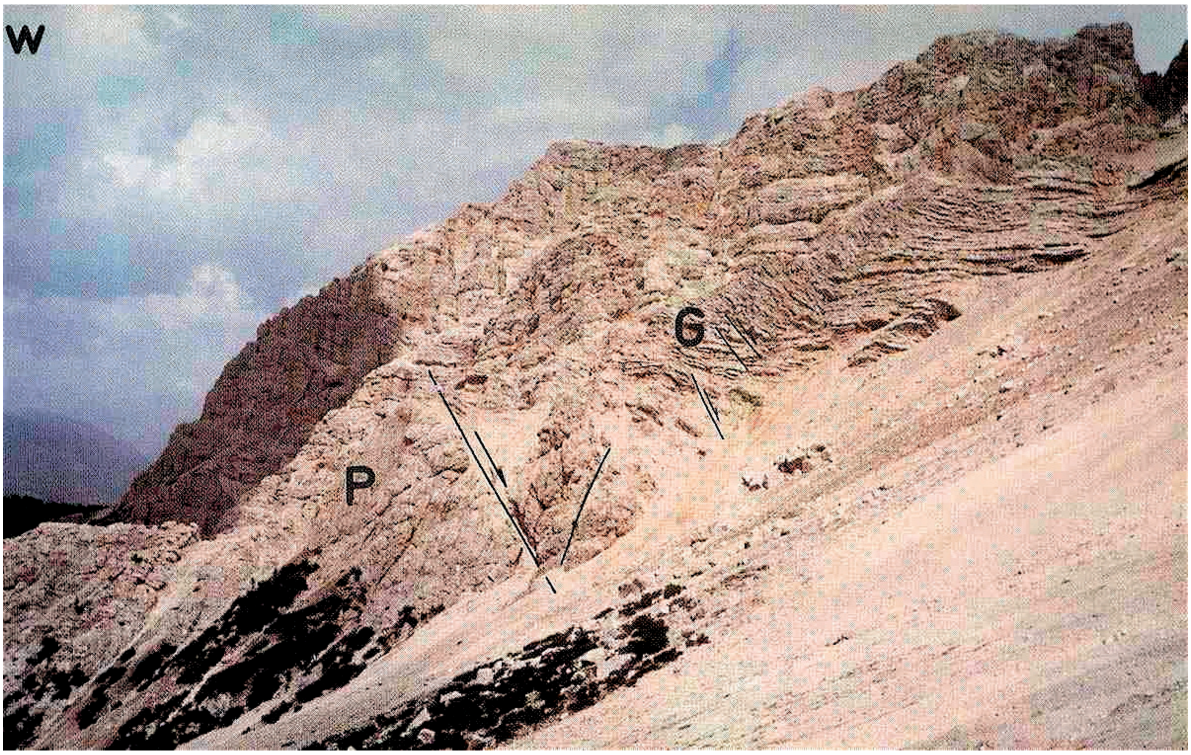


Fig. 5.6 - N10°W trending extensional fault cropping out on the western flank of the Lavarella mountain. Right of the fault, the fan shape of the Calcari Grigi (G) suggests a growth geometry. In the footwall of the fault it occurs the Dolomia Principale (P).

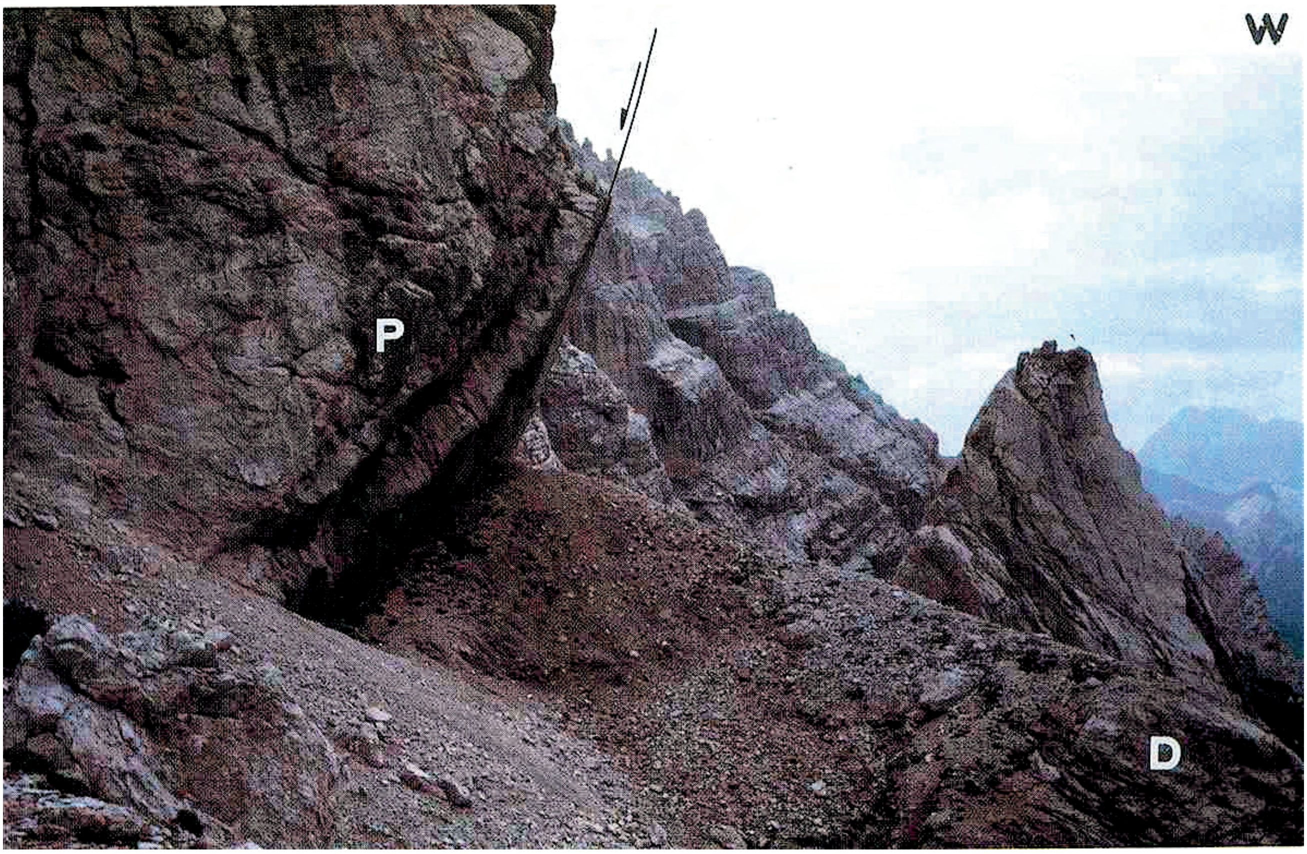


Fig. 5.7 - Detail of the extensional fault of Fig. 5.6, as cropping out to the south. The Dolomia Principale (P) is in the hangingwall and Carnian marls and Cassian Dolomite (D) in the footwall. The slickenlines on the fault surface are subvertical. The fault dips to the east (left) and is underlined by a thin reddish-blackish oxidised crust.

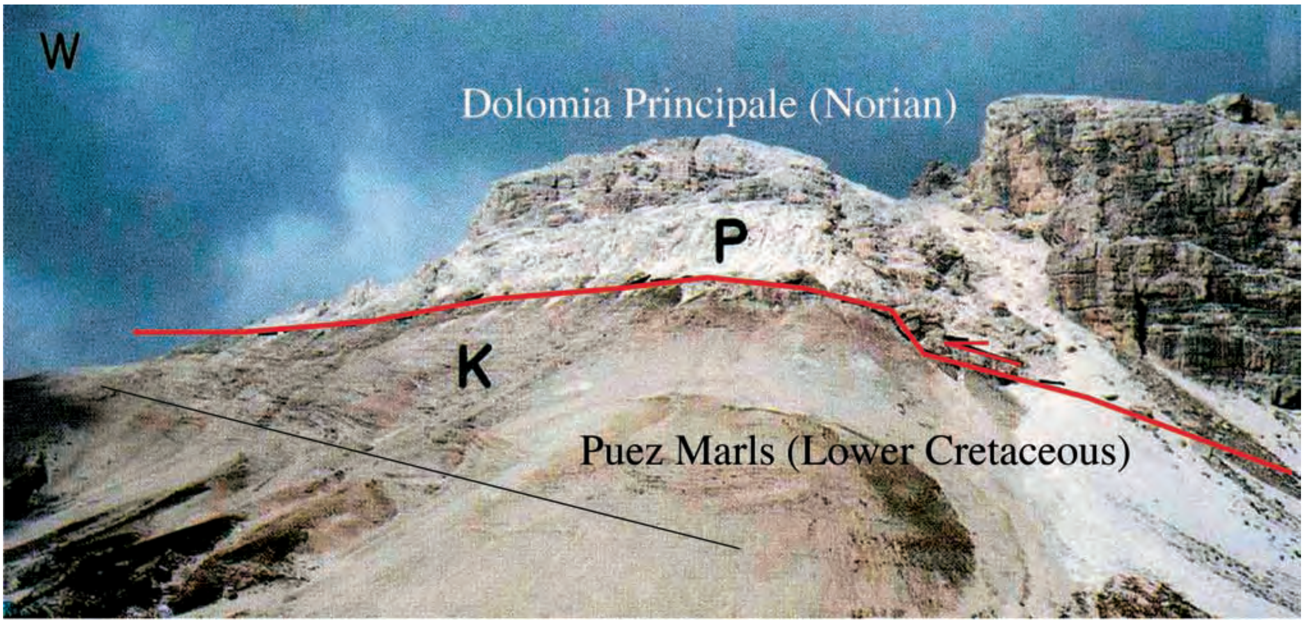


Fig. 5.8 - The Puez thrust, described very well by ACCORDI already in 1955. In the hangingwall the Norian Dolomia Principale (P) and in the footwall the Cretaceous Puez Marls (K), extremely laminated and affected by minor fault planes close to the main thrust fault. The thrust is W-SW vergent (to the left). It is noteworthy that the thrust plane is gently tilted, with a dip towards the south. The Southalpine N-vergent Funes thrust fault (not visible here), with a ramp geometry in the basement, tilted the Paleogene WSW-verging structures.

Fig. 5.9 - Altipiano del Puez, with Cretaceous Puez Marls (K) preserved by a very small klippe of Dolomia Principale (P) in the hangingwall of the thrust. Notice the absence of the Liassic Calcari Grigi in the stratigraphy.

Fig. 5.10 - Conturines and Lavarella massifs. S, San Cassiano Fm; D, Cassian Dolomite; R, Raibl Fm; DP, Dolomia Principale; G, Calcari Grigi. The two thrusts cross-cut a pre-existing N-S trending normal fault.

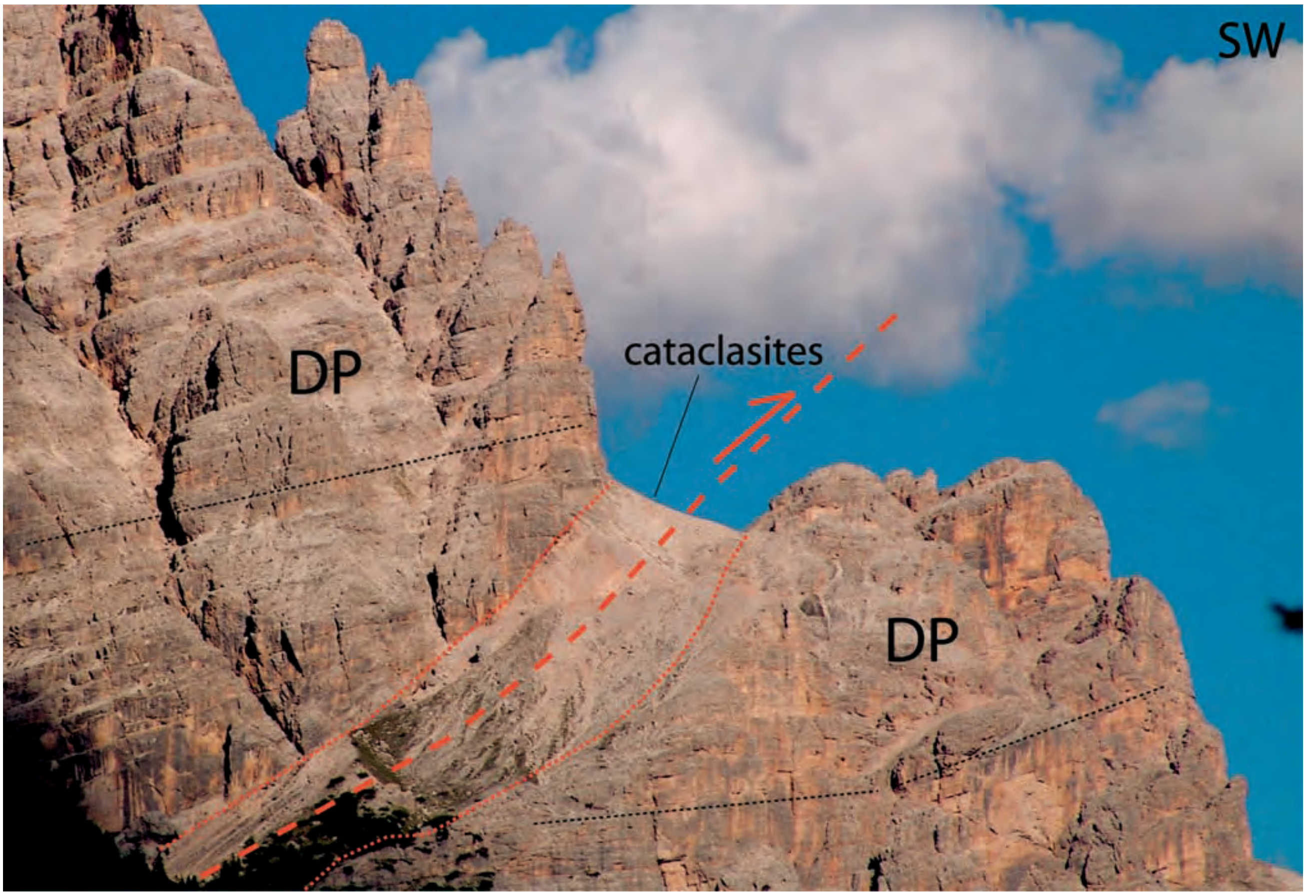


Fig. 5.11 - Detail of the Conturines Thrust viewed from Valparola. Note the footwall and hangingwall cutoff, and the 30-40 m thick cataclasites forming the gentle slope of the fault debris. The hangingwall cutoff indicates reduced shortening, limited to the thrust ramp. DP, Dolomia Principale.

Fig. 5.12 - Detail of the central part of the figure 5.10. A relict of the lower slope of a prograding Carnian Cassian Dolomite (D) over the basin of the San Cassiano Fm (S) is crosscut by a normal fault which has been in turn offset by the two thrusts. Conturines Massif.

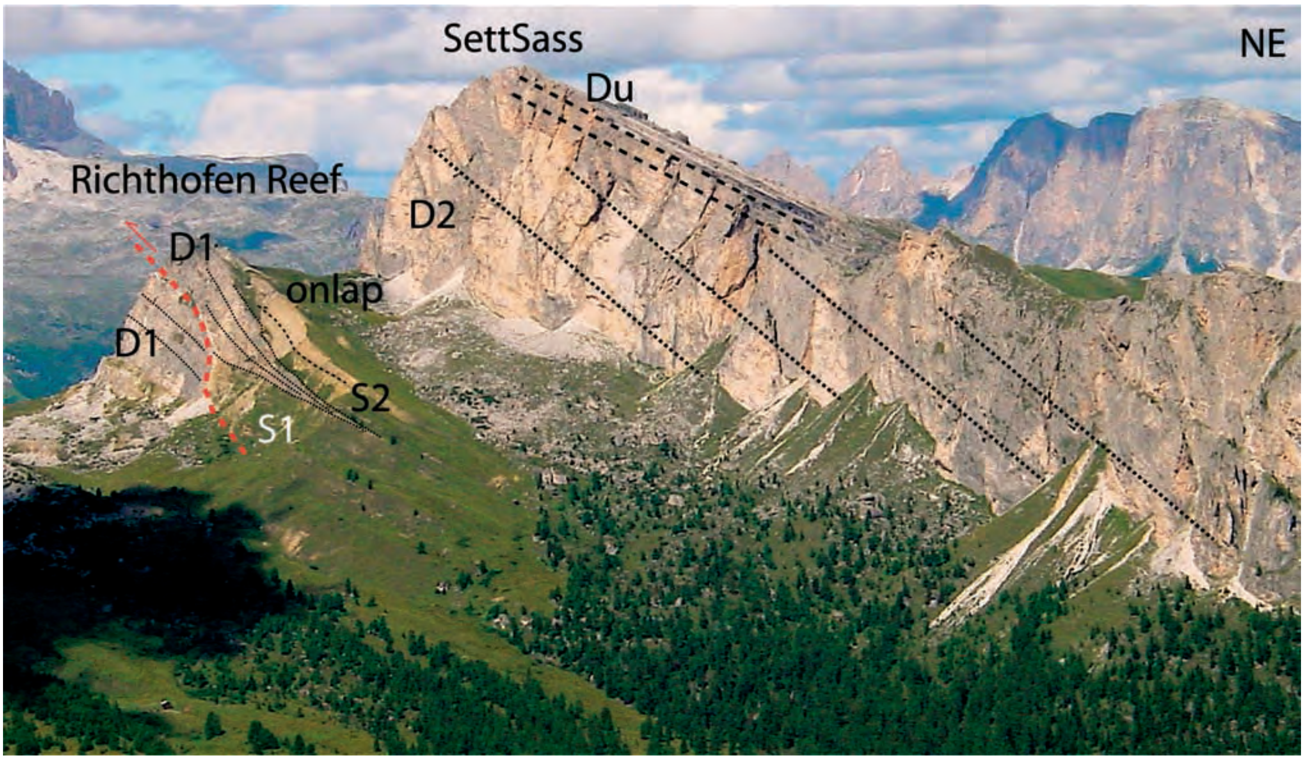


Fig. 5.13 - The Richthofen Reef to the left and the Settsass to the right, respectively formed by the Lower (D1) and Upper (D2) Cassian Dolomite, testifying two third order Carnian cycles. The two dolomites should represent the relative highstand phases, prograding onto the adjacent basin of the Lower (S1) and Upper (S2) San Cassiano Fm. At the sequence boundary, the San Cassiano Fm onlaps the mega-breccias of the Lower Cassian Dolomite. The thrusting thickened the Richthofen Reef. Du, Dürrenstein Dolomite.

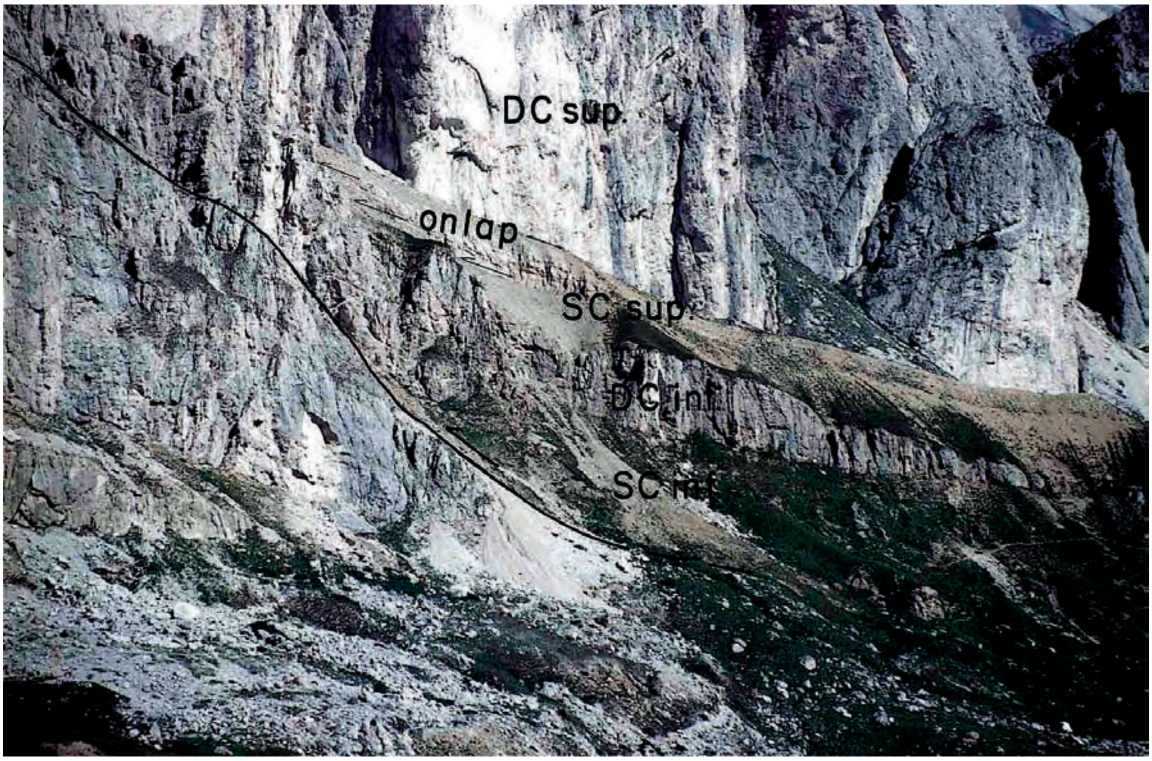


Fig. 5.14 - Detail of the Richthofen Reef. DC sup., Upper Cassian Dolomite; SC sup., Upper San Cassiano Fm; DC inf, Lower Cassian Dolomite; SC inf., Lower San Cassiano Fm.

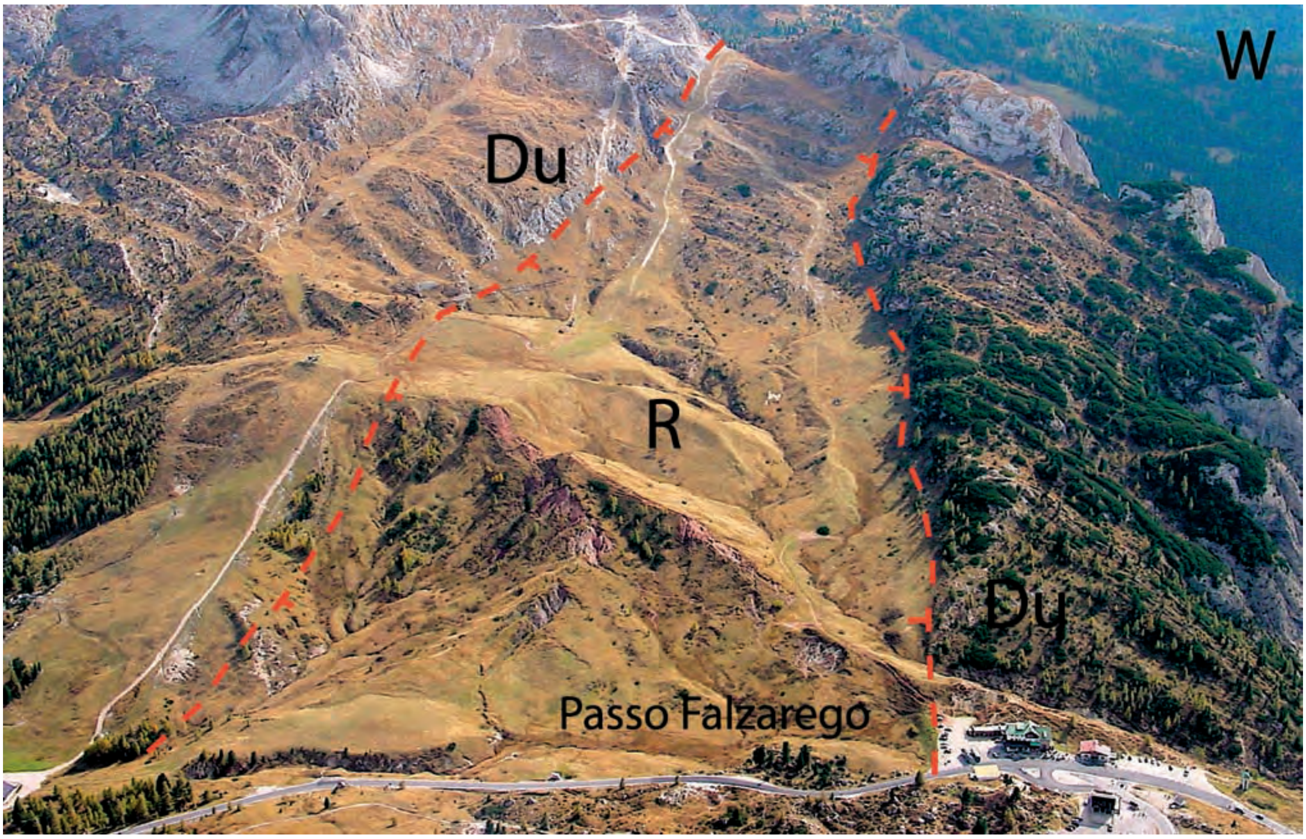


Fig. 5.15 - N-S-trending graben at Falzarego Pass. As typically occurs, normal faults are not stright planes, but are rather undulated. The axis of the graben is tilted to northeast because is in the hangingwall of a SW-directed thrust. R, Raibl Fm; Du, Dürrenstein Dolomite. The Raibl Fm is thicker within the graben, indicating a Late Carnian age of the structure.

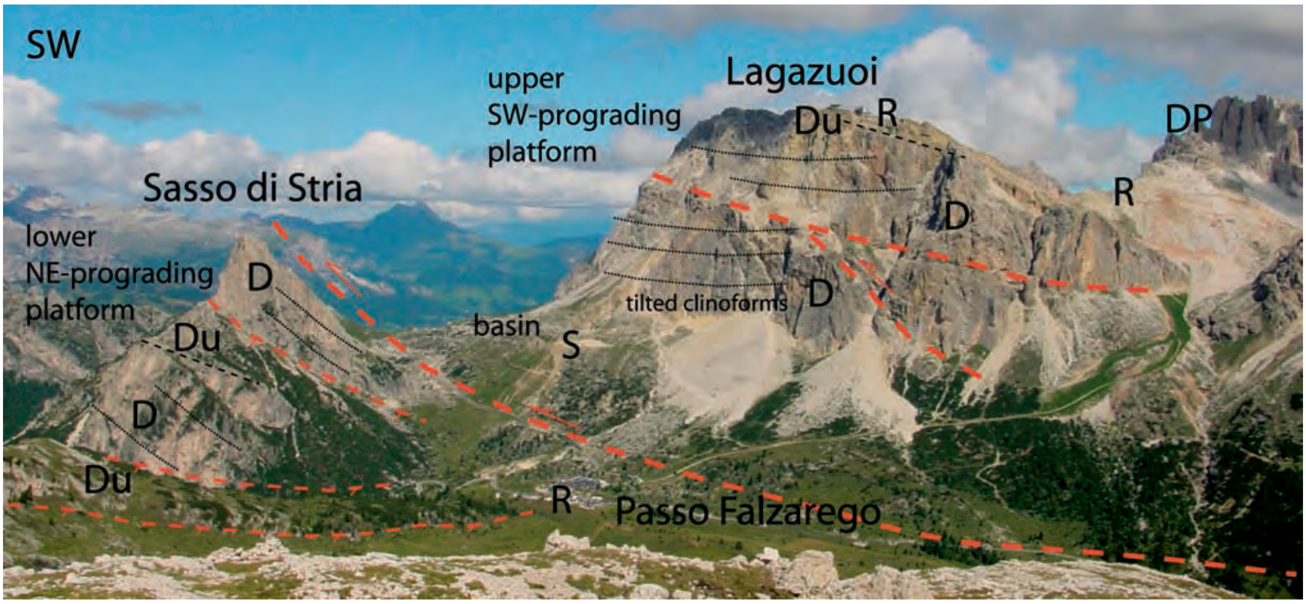


Fig. 5.16 - Two independent, opposite prograding Carnian carbonate platforms of Cassian Dolomite (D) were juxtaposed with the sandwiched intervening basin of the San Cassiano Fm (S). The lagoonal deposit of the Dürrenstein Dolomite (Du), overlain by the shallow water Raibl Fm (R) are visibly duplicated at the top of Lagazuoi Massif. DP, Norian Dolomia Principale. The thin-skinned tectonics of the Falzarego thrust was controlled by the shape of the Lagazuoi carbonate platform. The lateral ramp developed where the carbonate platform terminates and the frontal ramp followed the escarpment of the Sasso di Stria platform. Pre-existing Mesozoic (?) normal faults are well visible in the footwall.

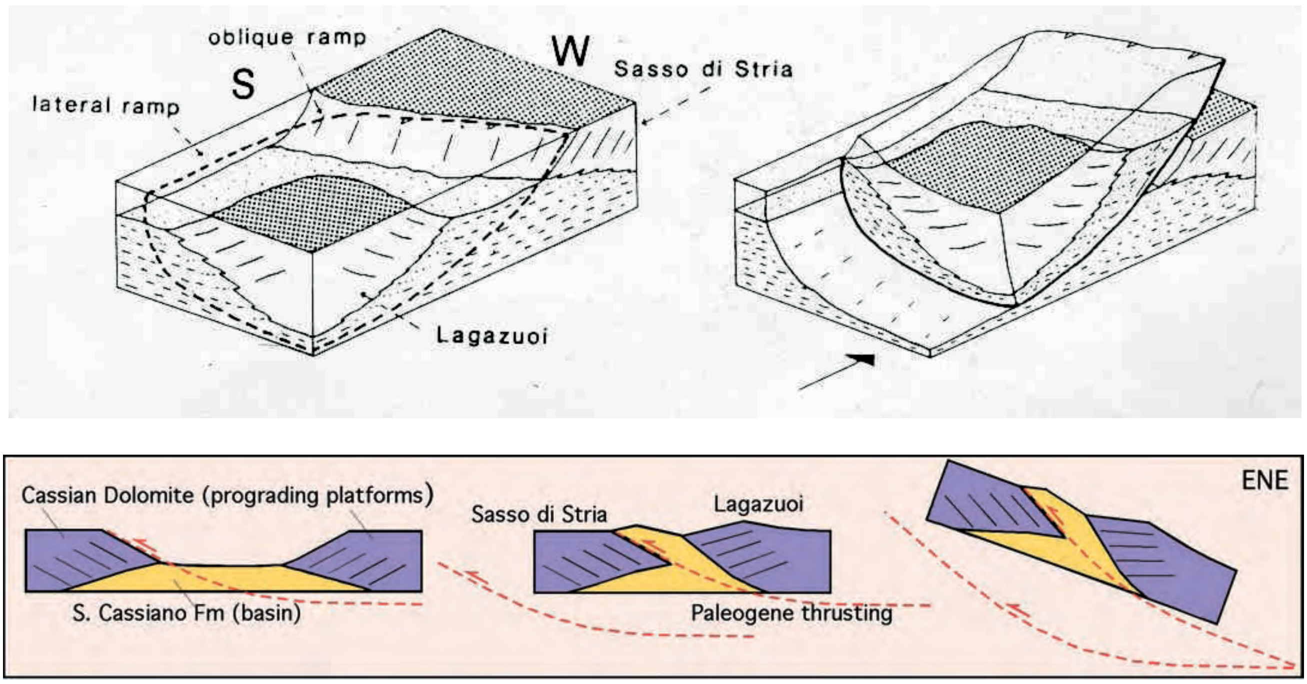


Fig. 5.17 - Sketches of the Falzarego thrust where the Lagazuoi Carbonate platform overrode the Sasso di Stria Platform. The geometry of the upper platform determined the undulation (frontal and lateral ramp) of the Falzarego Thrust. Upper panel viewed from NE, lower panel from S.

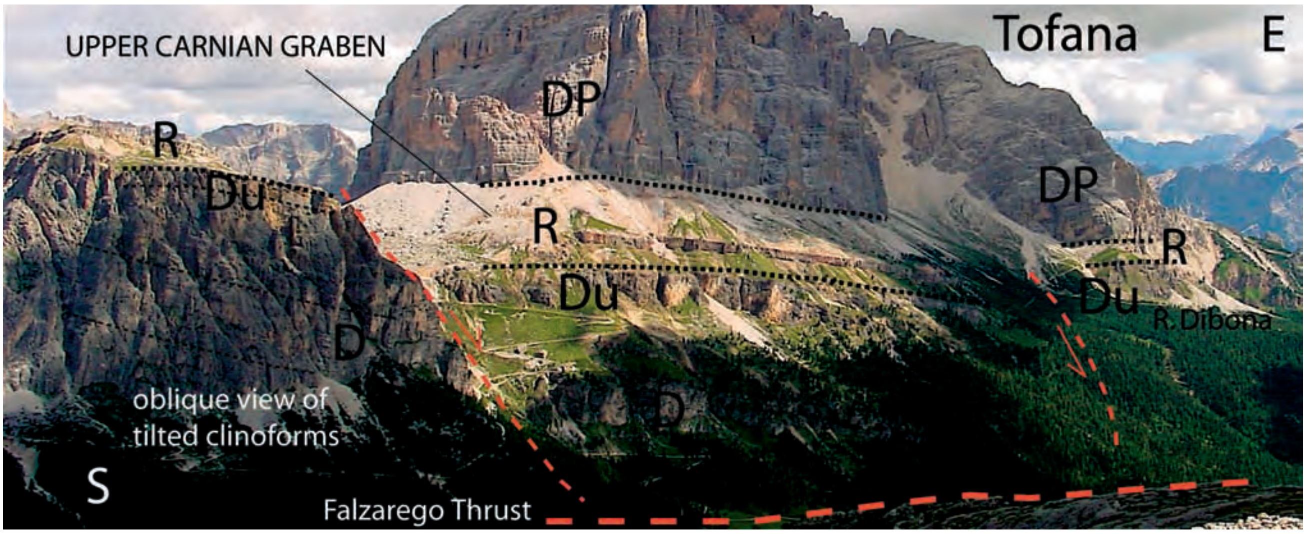


Fig. 5.18 - Southern cliff of the Lagazuoi and Tofane massifs, along the valley from the Passo Falzarego to Cortina. DP, Norian Dolomia Principale; R, Upper Carnian Raibl Fm; Du, Carnian Dürrenstein Dolomite; D, Lower Carnian Cassian Dolomite; S, San Cassiano Fm. See the thicker Raibl Fm in the center with respect to the same formation to the right in the footwall of the normal fault, indicating a syndepositional Late Carnian origin of the graben. See also the drawing in the following figure from a more perpendicular view.

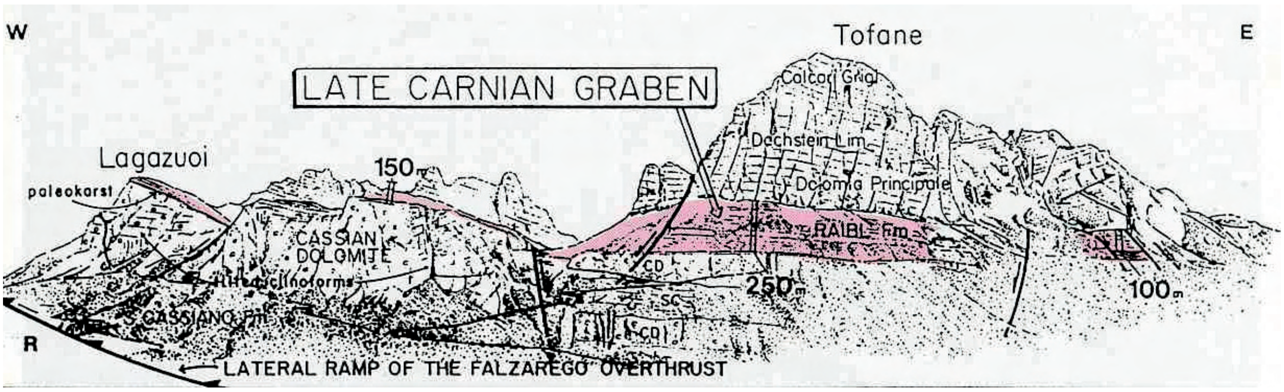


Fig. 5.19 - An Upper-Carnian graben, syn-Raibl Fm, is preserved in the hangingwall of the Falzarego thrust. Its occurrence is evidenced by the sudden changes of sedimentary thicknesses between the adjacent horsts and the graben (after Doglioni *et alii*, 1989b).

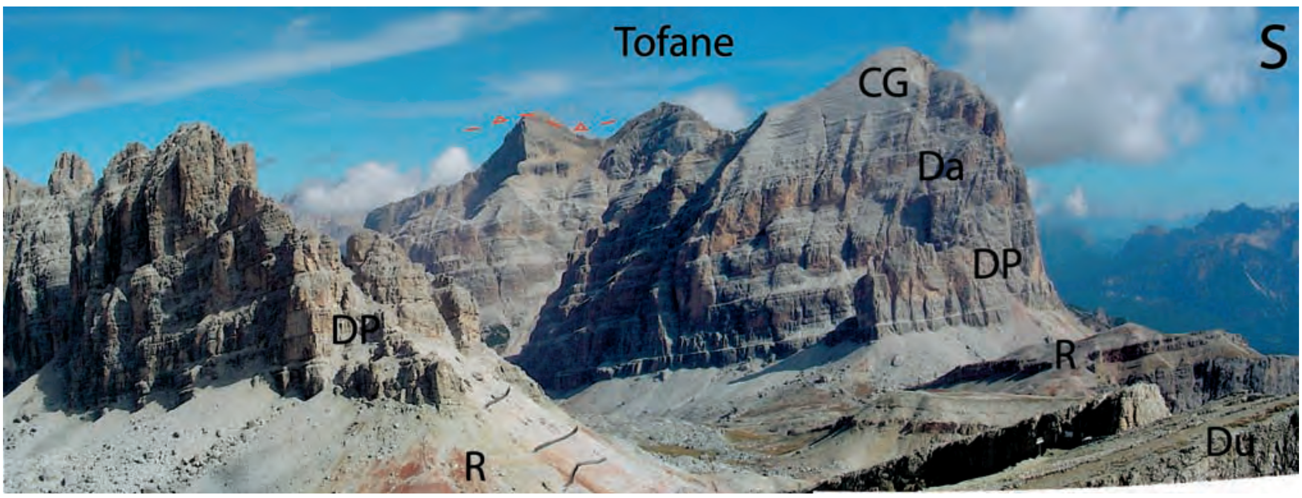


Fig. 5.20 - View from the Lagazuoi toward the Tofane. The earlier WSW-verging thrust of the Tofana III has been tilted by the northern general dip related to the deeper ramp of the Falzarego Thrust. CG, Calcari Grigi; Da, Dachstein Lm; DP, Dolomia Principale; R, Raibl Fm; Du, Dürrenstein Dolomite.

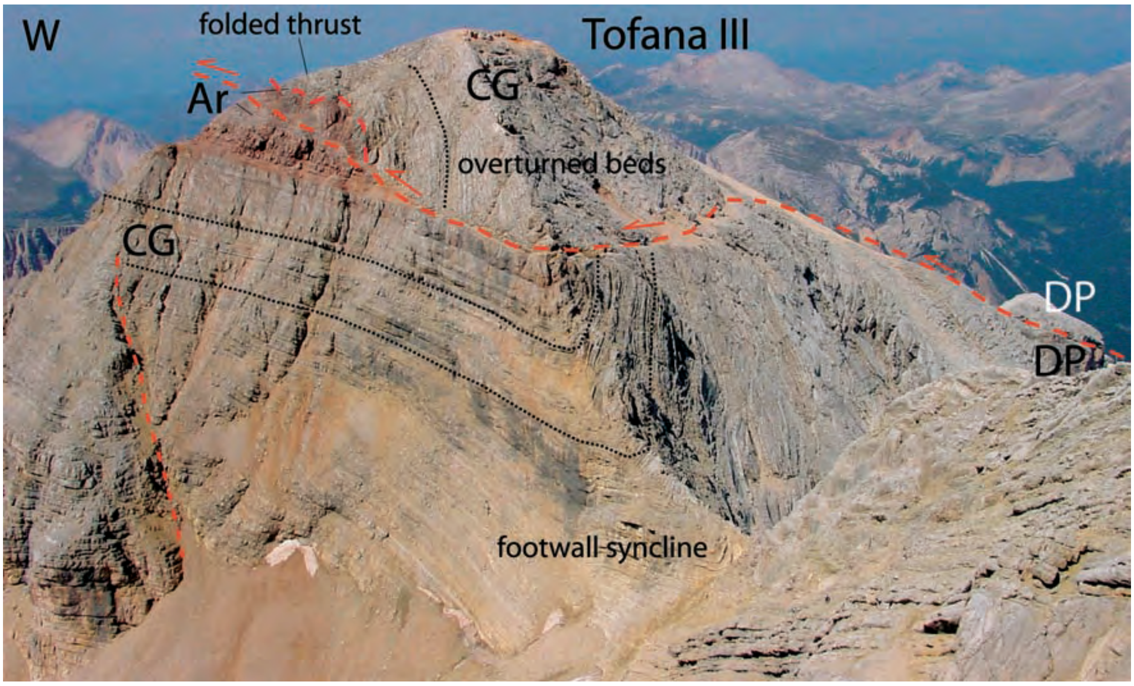


Fig. 5.21 - The W-vergent thrust of the Tofana III. Notice the transition from ramp to flat and the occurrence of an antiformal stack duplex, with the Calcari Grigi (CG) in the hangingwall, and the Ammonitico Rosso (Ar) in the footwall and in the duplex horse. In the footwall of the main thrust, a vertical flank of a syncline occurs. This suggests that a fault-propagation fold was later truncated along the elongated limb and was later deformed by fault-bend folding. The flat developed along the horizontal flank of the syncline (to the left). To the right, the ramp is visible at the base of a klippe in the Dolomia Principale (DP).

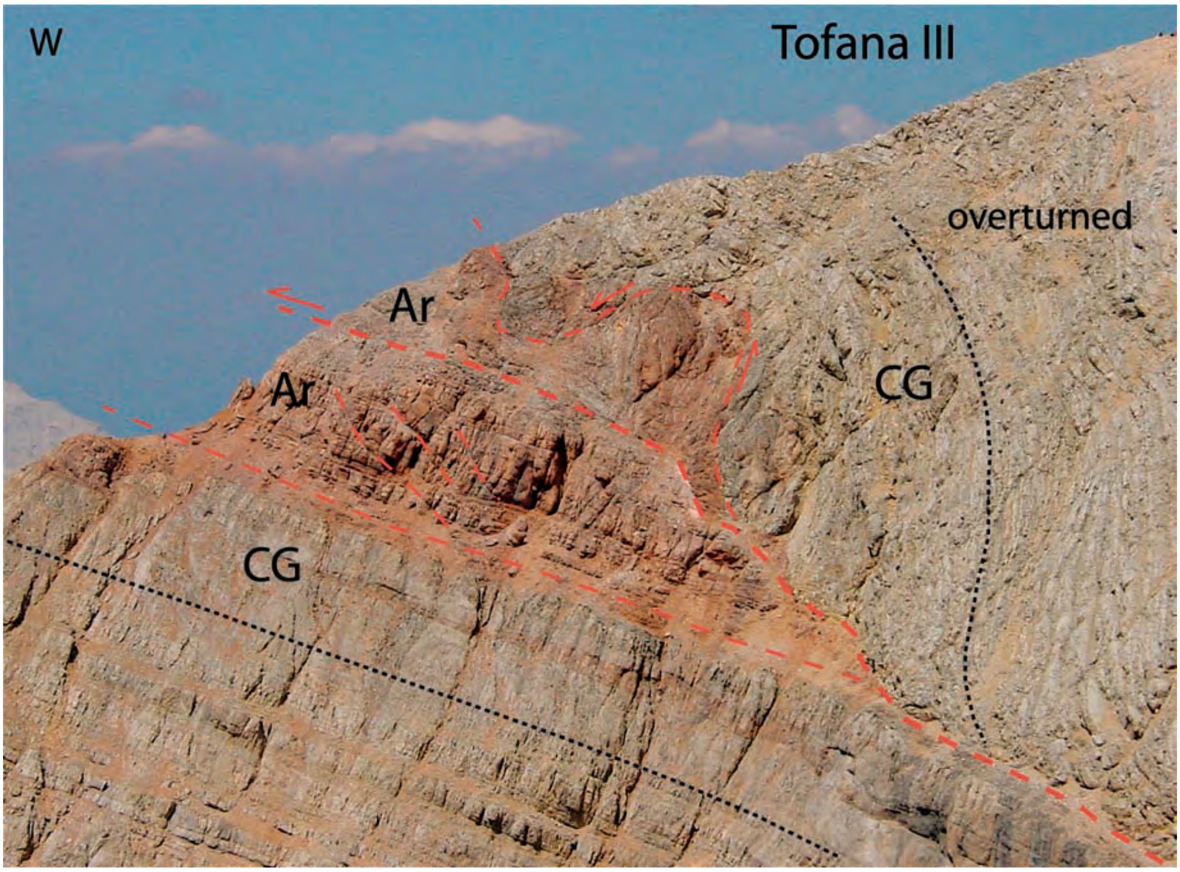


Fig. 5.22 - Detail of the Tofana III Thrust with an antiformal stack where the upper fault plane has been folded and passively transported. Ar, Ammonitco Rosso; CG, Calcari Grigi.

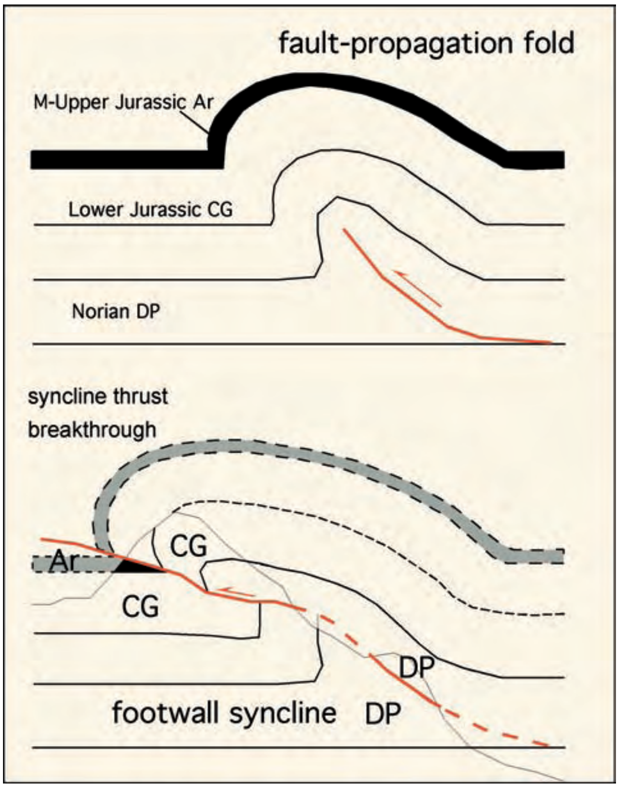


Fig. 5.23 - Kinematic sketch of the Tofana III evolution.

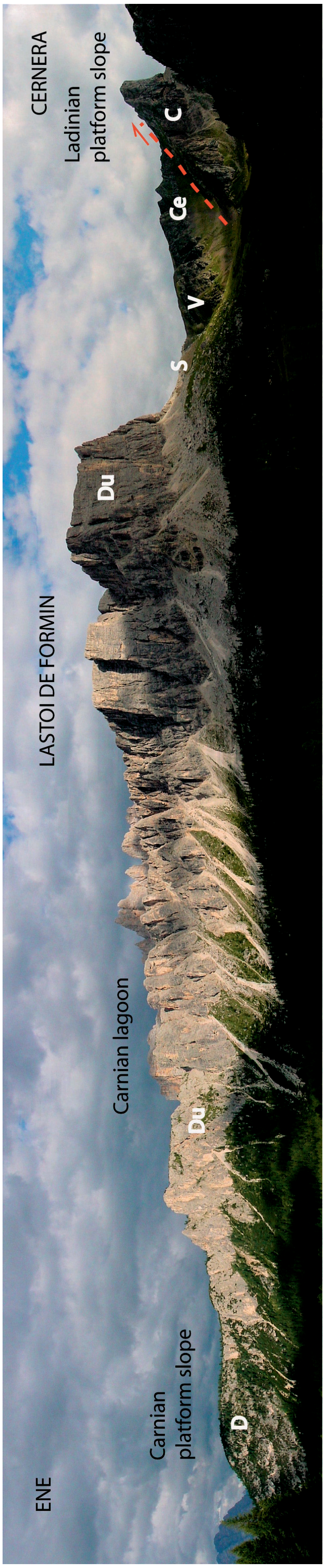


Fig. 5.24 - The famous section between the Lastoi de Formin and the Cernera Group, where the Upper Ladinian volcaniclastic deposits onlap on the platform escarpment, in the right side of the picture. The contact was later weakly reactivated by a W-vergent thrust fault (see next figure). The Carnian carbonate platform prograding margin of the Cassian Dolomite (D) in the left passes to the internal lagoonal facies of the Dürrenstein Dolomite (Du). S, San Cassiano Fm; V, volcaniclastic deposits; Ce, Caotico Eterogeneo; C, Marmolada Limestone.

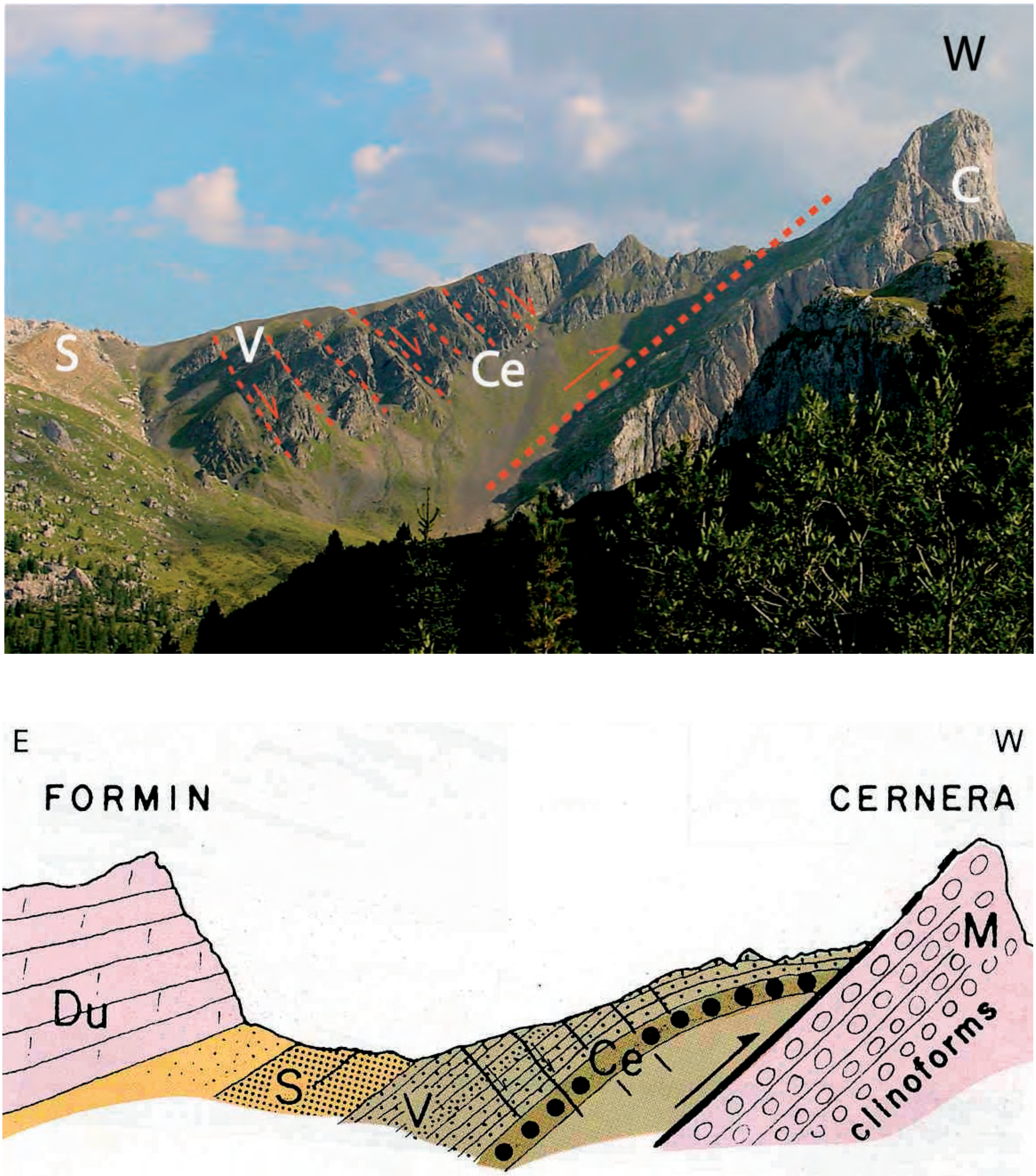


Fig. 5.25 - The Cernera Ladinian Carbonate platform slope of the Marmolada Limestone (C in upper panel and M in lower panel), originally onlapped by volcanoclastic rocks (V) and the Caotico Eterogeneo (Ce), has been partly inverted by a thrust. An open fold, and small-scale, regularly spaced normal faults affected the volcanic rocks in the hangingwall. S, Carnian San Cassiano Fm; Du, Dürrenstein Dolomite.

Fig. 5.26 - Detail of the central part of figure 5.24. The interior of the Lastoi de Formin lagoonal facies of the Carnian Dürrestein Dolomite is cross-cut by a set of normal faults with a domino array, possibly related to the Norian-Jurassic rifting.

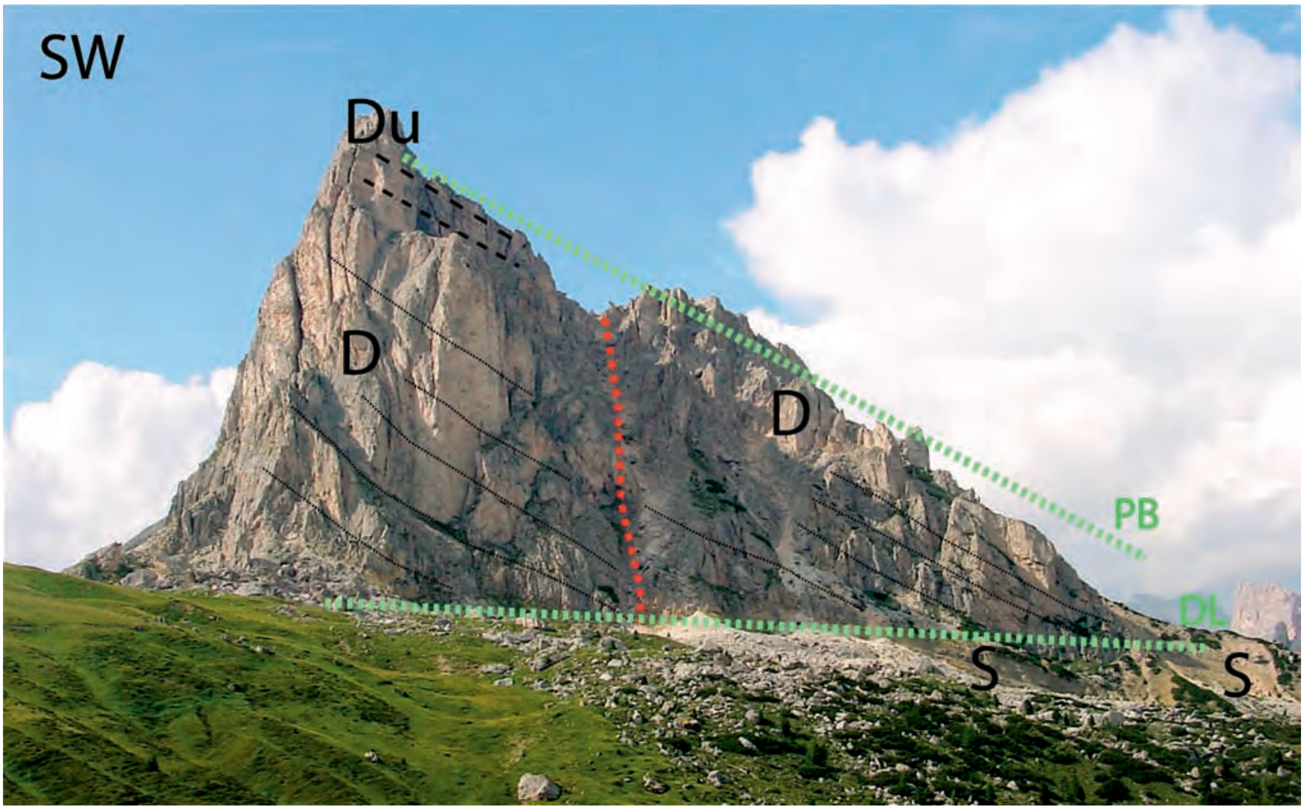


Fig. 5.27 - The Gusela del Nuvolao, near Passo Giau. Some 20°-25° of the present day clinoforms dip are due to an underlying ramp of a W-vergent thrust fault. Retrodeforming the Cassian Dolomite (D) prograding onto the San Cassiano Fm (S), a convergent geometry between the platform break (PB) and the downlap (DL) surfaces can be observed. This suggests a decrease of bathymetry in the basin facing the platform. Near the peak, the Dürrenstein Dolomite (Du) crops out. Minor faults complicate the structure.

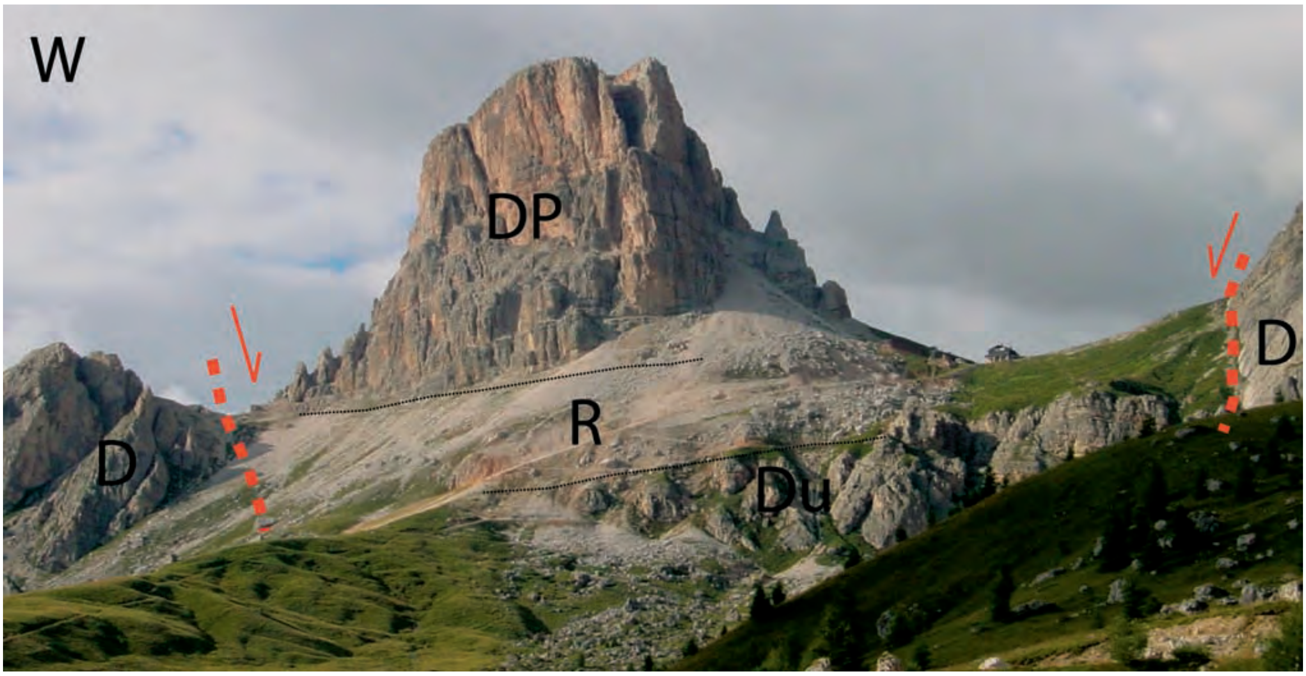


Fig. 5.28 - The Averau graben, again oriented roughly N-S, in the vicinity of the Giau Pass. D, Cassian Dolomite; Du, Dürrenstein Dolomite; R, Raibl Fm; DP, Dolomia Principale. Here extensional tectonics is post-Norian (Liassic?).

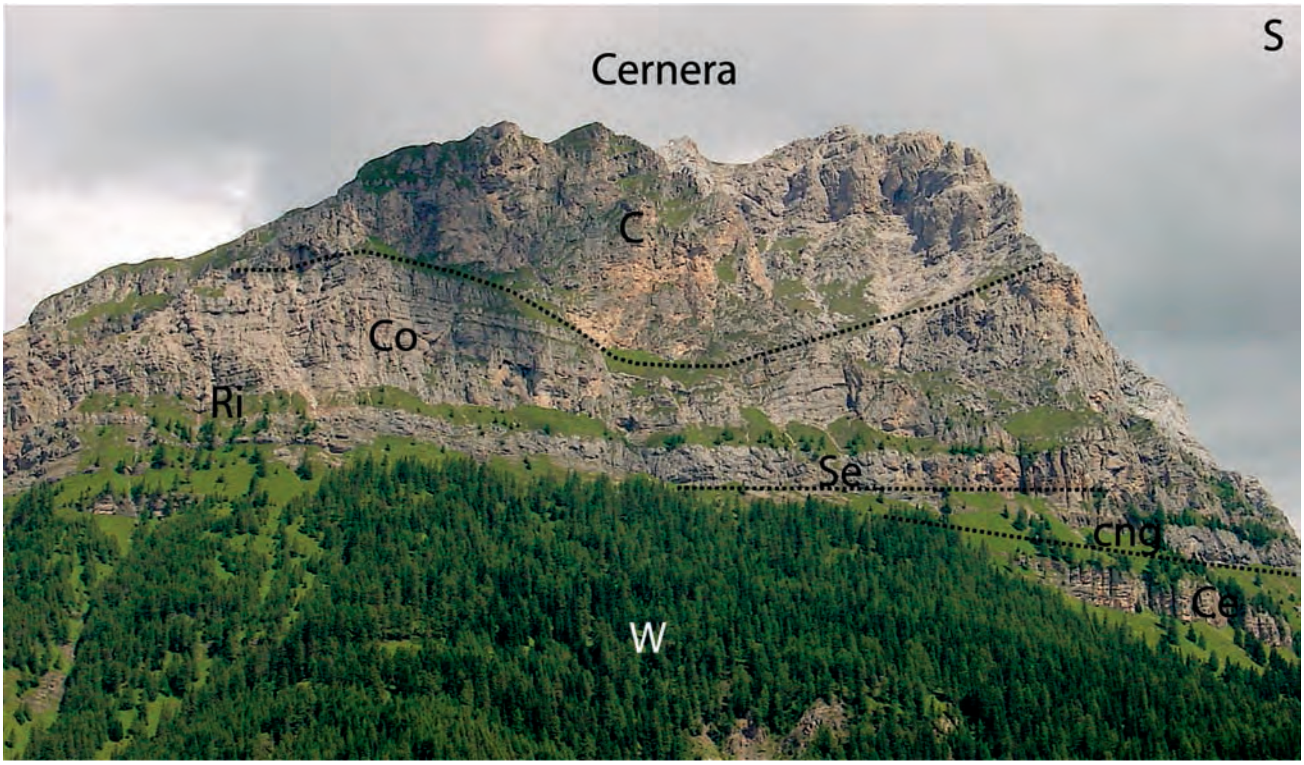


Fig. 5.29 - A channel in the Upper Anisian shallow platform facies of the Contrin Fm (Co) is filled by megabreccias of the Marmolada Limestone (C). Below, the fluvial Richthofen Conglomerate (Ri) overlies the Lower Anisian Serla Dolomite (Se) and a conglomerate (cng), which are sealing an unconformity with the underlying tilted Werfen Fm (W) and its upper Cencenighe Mb (Ce). View of the Mt. Cernera from the Fiorentina Valley.

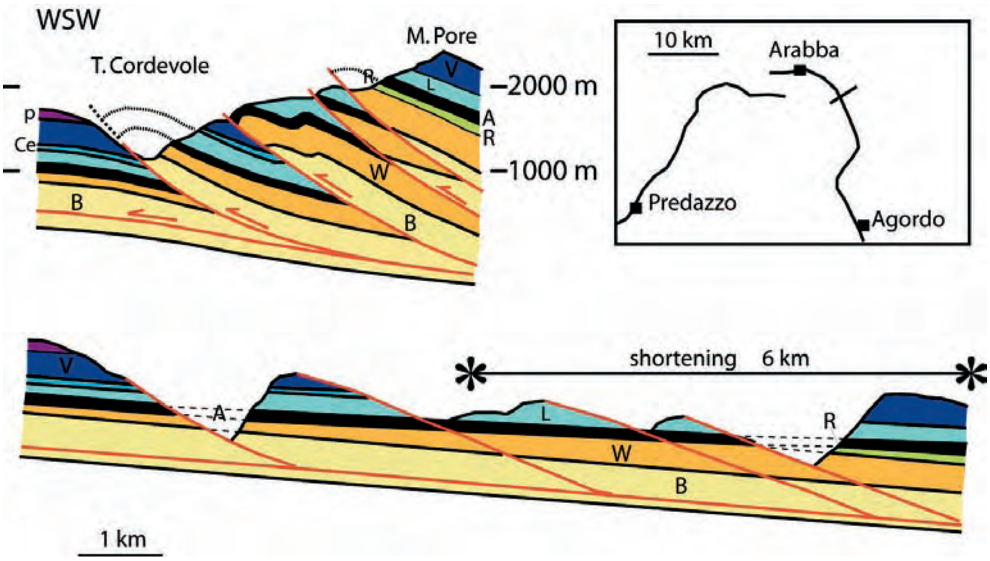


Fig. 5.30 - Balanced cross-section of a frontal segment of the earlier WSW-verging thusting, between the Pore and Digonera mountains. The imbricated fan structure is detached along the Permian evaporites of the Bellerophon Fm (B). The shortening calculated from the retrodeformation is about 6 km. The various thrust units are characterized by different sediment thicknesses. For example, the Werfen Fm (W) thickens towards the east, since the intensity of the Anisian erosion diminishes eastward. Also the Richthofen Conglomerate (R) thickens towards the east. A, Anisian Carbonates (Contrin Fm), with facies variations along the section; L, Livinallongo Fm and Zoppè Sandstones; V, Volcaniclastic sandstones, with, at their base, intercalated levels of Caotico Eterogeneo; P, Pillow lavas.

Fig. 5.31 - The WSW-vergent thrust near Digonera, along the road to Laste. It is the most external thrust plane of the previous section. In the hangingwall of the main thrust fault: S, Siusi Mb; A, Andraz Horizon: M, Mazzin Mb (Werfen Fm, Scythian). In the footwall: V, Volcaniclastic sandstones (Ladinian). The contacts among the levels of the Werfen Fm were resheared to form an antiformal stack duplex. The Mazzin Mb and the Andraz Horizon are strongly foliated by S-C structures. Intense pressure solution, diminishing away from the main fault plane, can be observed in the outcrop. At regional scale, the fault plane can be connected to the Sella and Civetta thrusts klippen (see next figure).

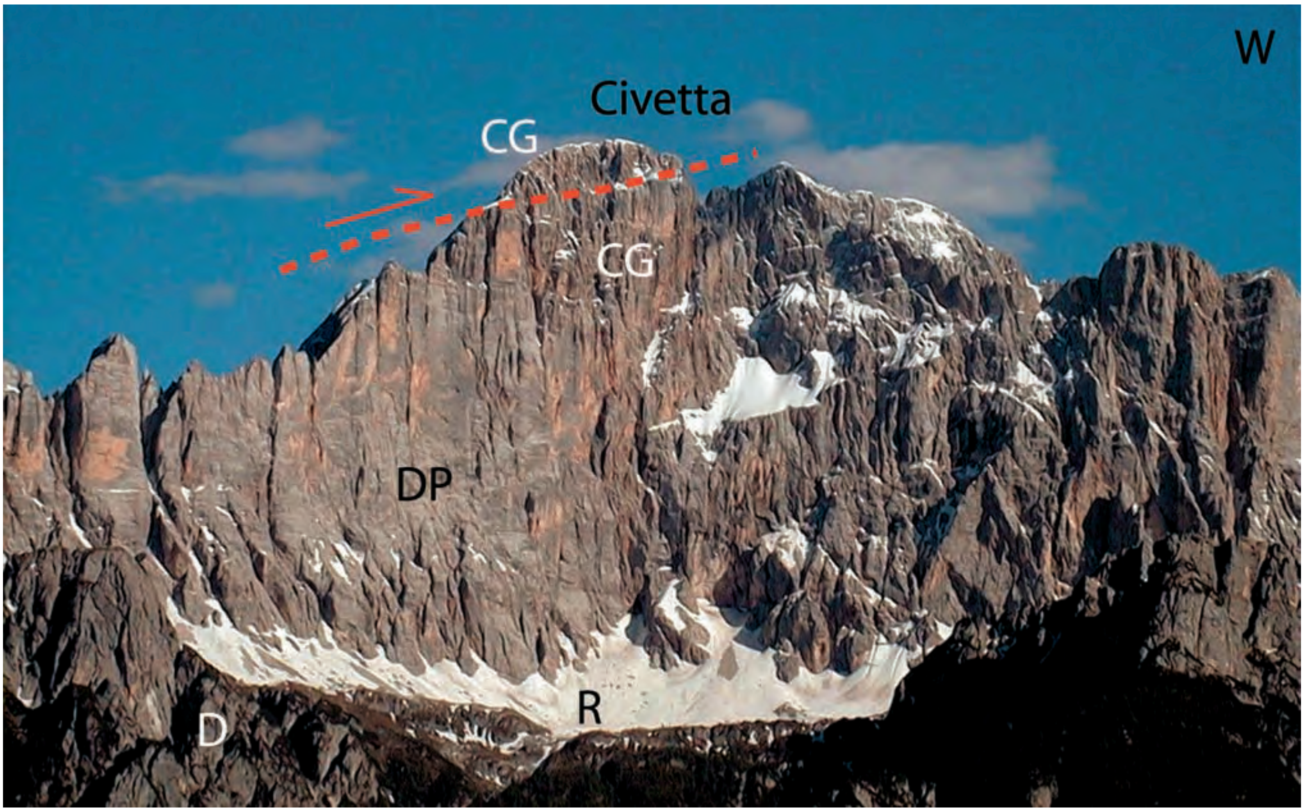


Fig. 5.32 - Northern cliff of the Civetta Massif. Note the klippe at the top. Moreover the thickness of the Dolomia Principale is about twice (>500 m) than at the Piz Boè (250 m), indicating Norian synsedimentary tectonics. CG, Calcari Grigi; DP, Dolomia Principale; R, Raibl Fm; D, Cassian Dolomite.

Fig. 5.33 - The fault of the Digonera dam. It is a S-vergent Southalpine thrust fault (compare with Fig. 5.35) with the Werfen Fm in the hangingwall and Ladinian volcaniclastic sandstones in the footwall. Note the chevron folds in the thinly bedded rocks of the hangingwall. The thrust displaces W-vergent paleostructures.

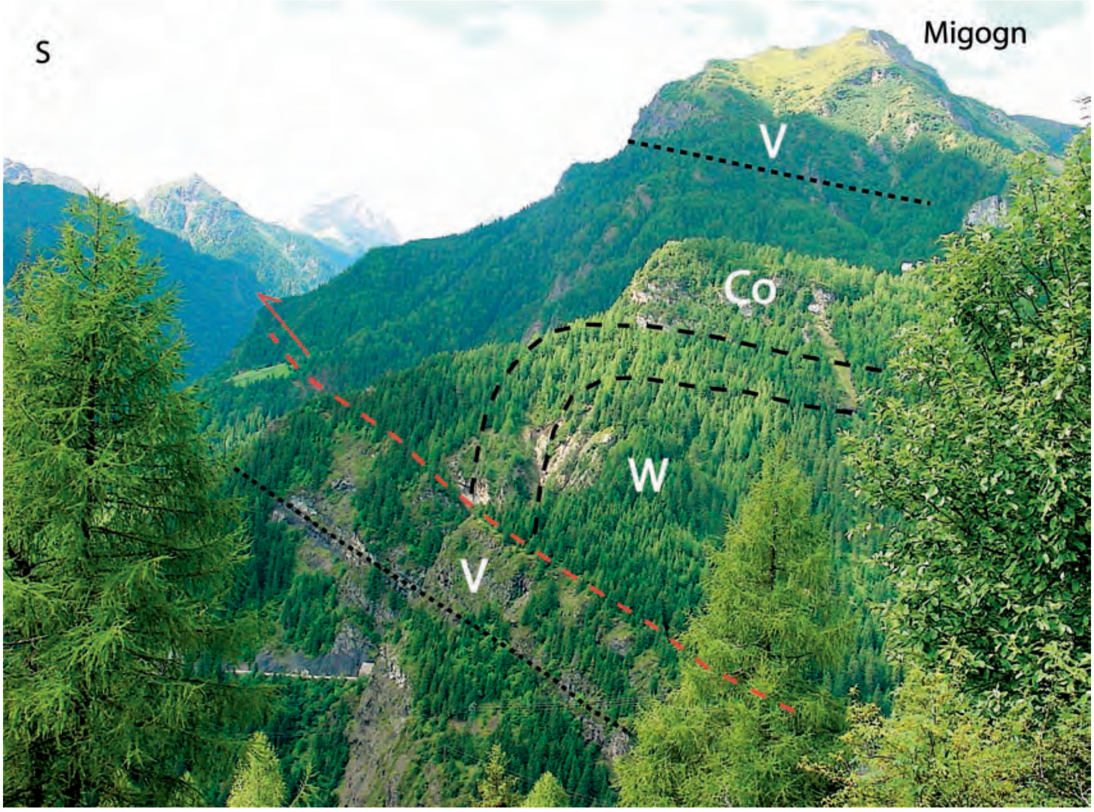


Fig. 5.34 - The Digonera thrust, the same of the dam of the previous figure, seen from the other side of the valley, from the road from Caprile to Selva di Cadore. The hangingwall fold with the vertical forelimb indicates a fault-propagation fold origin. V, Ladinian volcanoclastic sandstones; Co, Upper Anisian Contrin Fm; W, Scythian Werfen Fm.

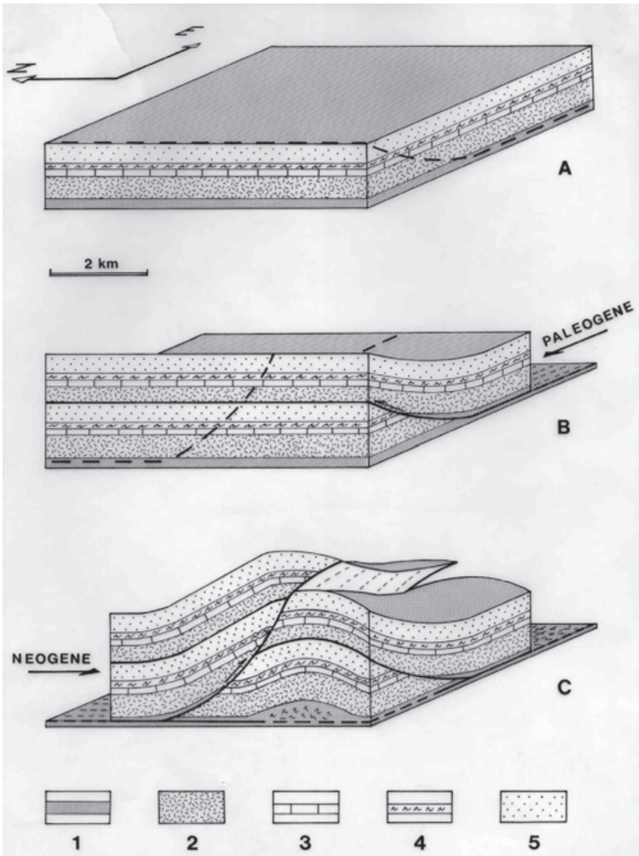


Fig. 5.35 - In the Caprile zone, the interference between the W-vergent Paleogene Dinaric structures and the S-vergent Neogene Southalpine faults, that cut and folded the earlier WSW-verging structures, can be observed. 1, Bellerophon Fm; 2, Werfen Fm; 3, Contrin Fm; 4, Livinallongo Fm; 5, volcaniclastic deposits.

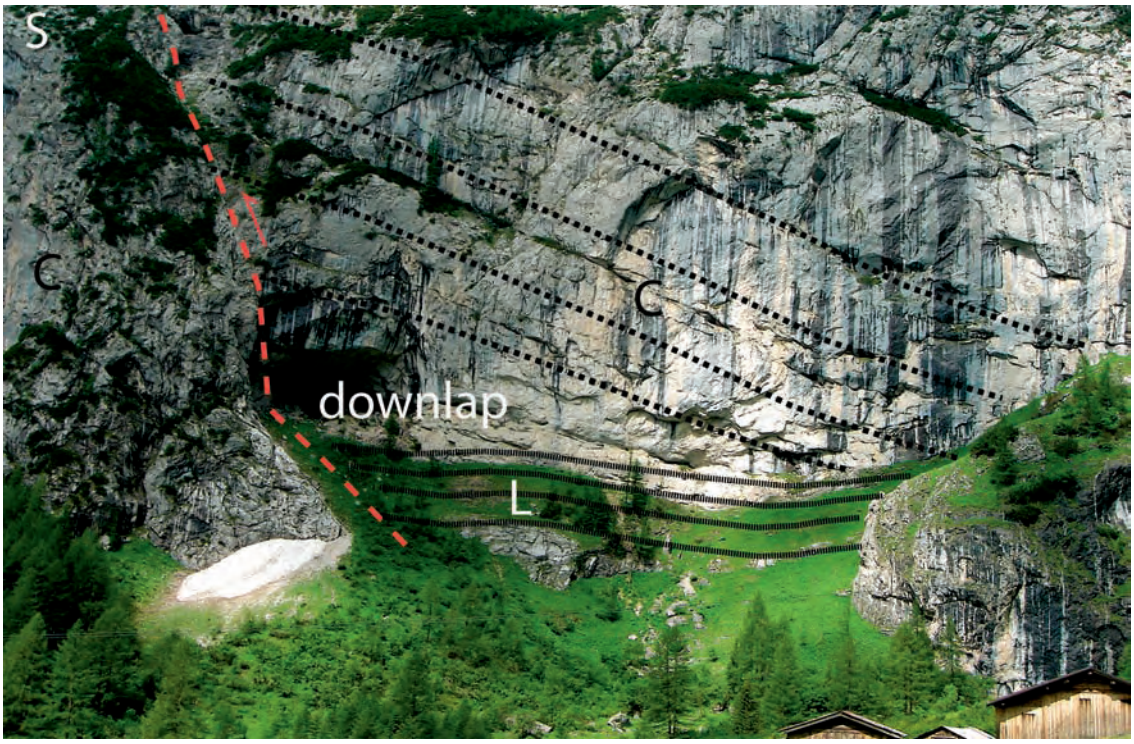
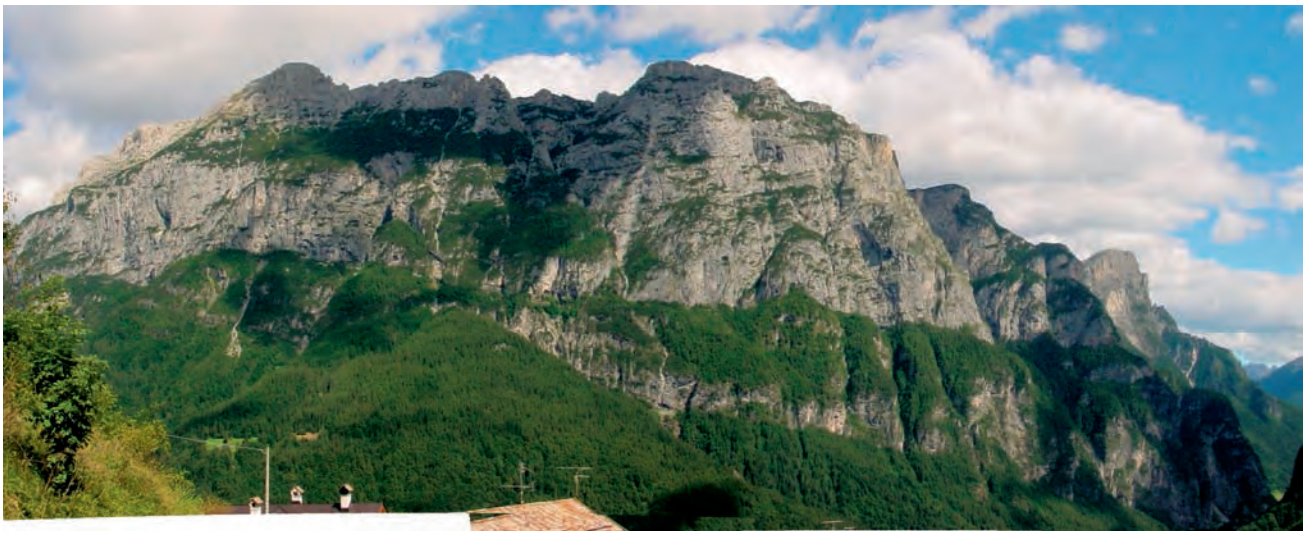


Fig. 5.36 - Downlap of the Ladinian megabreccias of the Marmolada Limestone (C) over the basinal equivalent of the Livinallongo Fm (L). Road from Malga Ciapela to Fedaia Pass.

Fig. 5.37 - Fault-propagation fold in the Dolomia Principale along the Cordevole Valley, south of Agordo. The axial plane is marked by a fracture. The thrust fault shows an undulated trajectory and spaced Riedel planes generate a weak foliation in the hangingwall. The structure is N-vergent and represents a backthrust of the Belluno Thrust.



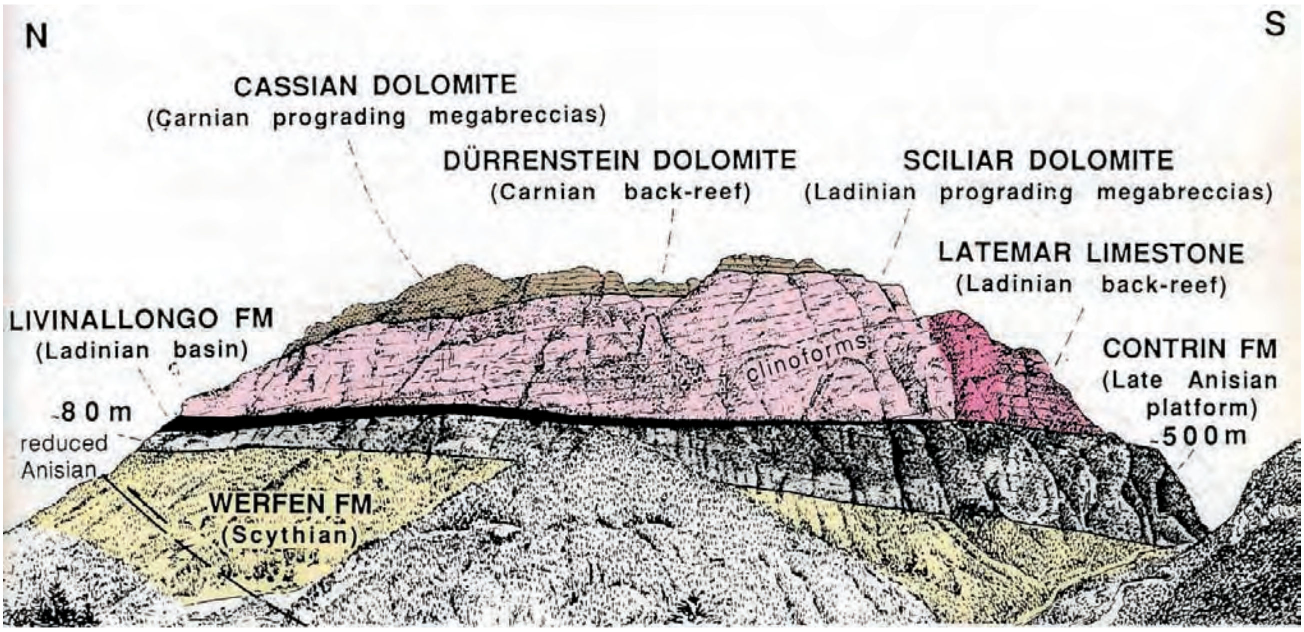


Fig. 5.38 - Natural section along the western flank of the Civetta Group, Monte Alto di Pelsa. View from the west, above Cencenighe. Notice the marked lateral variation of the thickness of the various formations, such as the thinning of the Livinallongo Fm towards the south, the southward thickening of the tilted and truncated underlying Anisian carbonates, and the Ladinian Platform prograding toward the north. It is a noteworthy example of field "seismic section".

Fig. 5.39 - Detachment fold in the Cencenighe Mb of the Werfen Fm. The symmetric buckle fold is decoupled in a siltstone-shaly layer where the thickness of beds changes. The overlying thinner strata allow easier flexural slip than the underlying thicker more competent beds. The outcrop is 5 m wide, along the road cut 2 km west of Cencenighe.

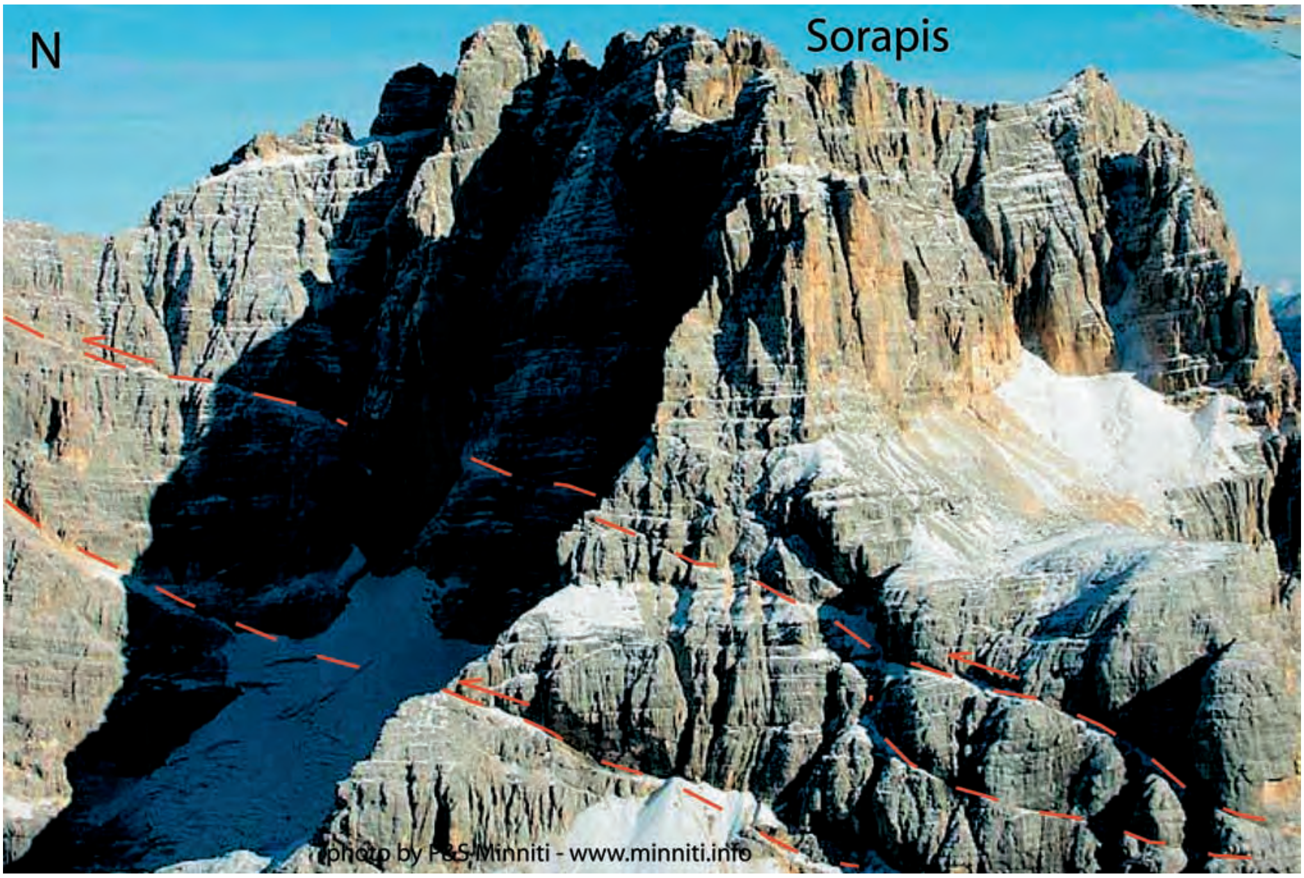


Fig. 5.40 - Ramp geometries in the Sorapis backthrust affecting the Dolomia Principale (photo by Minniti).