Field trip to the Dolomites and Southern Alps 8. – 14. 9. 2011

***Bernd Lammerer[1], Rainer Brandner[2], Lorenz Keim[3], Ludwig Masch[1]**
& Siegfried Siegesmund[4]*

[1] University of Munich (LMU); [2] University of Innsbruck; [3] Geologic Survey Bolzano; [4] University of Göttingen

Participants:

Bebiolka, Anke, Hannover	anke.bebiolka@bgr.de
Dogra, N.N. Kurukshetra IN	nndogra@rediffmail.com
Heim, Sabine, Aachen	heim@lek.rwth-aachen.de
Hinderer, Matthias, Darmstadt	hinderer@geo.tu-darmstadt.de
Hörfarter, Christine Wien	Christine.Hoerfarter@geologie.ac.at
Hottenrott, Martin, Wiesbaden	martin.hottenrott@hlug.hessen.de
Rehlinger, Myriam Roodt LU	myriam.rehlinger@education.lu
Stähler, Simon, München	staehler@geophysik.uni-muenchen.de
Tauchert, Wolfgang, München	wtauchert@t-online.de
Uffmann, Anna Kathrin, Aachen	uffmann@lek.rwth-aachen.de
Wagner, Jean-Frank, Trier	wagnerf@ni-trier.de
Weber, Hellmar, Schwäb. Hall	Hellmar.Weber@t-online.de

Students:

Conradin, Philip, LMU	philip.conradin@gmx.de
Fina, Andreas, LMU	Andreasfina@gmx.de
Garnish, Jenny, LMU	jennyag@gmail.com
Klausner, Theresa, LMU	Theresa@Klausner.de
Kittelmann, Andre, LMU	Shogun089@gmx.net
Mages, Viola München DE	viola.mages@mytum.de*

Meeting:
Sunday 21. 8. 2011 at 08.15 h in Munich, Luisenstrasse 37, in front of the Institute building.

Equipment: identity card, money for food and drinks (not included); Mountain boots and clothes, backpack, rain-, coldness-, sun- and wind- protection, hammer, hand lens, emergency pack, personal medication.

Weather may be warm and sunny or cold and rainy; in high altitudes even snowfall is possible**.**

Program

8. 9. Munich – Brenner – Waidbruck – Kastelruth – Pufels (265 km, Hotel Mesavia, accommodation) Program: Basal series of the Dolomites: Permian to Middle Triassic geodynamic and stratigraphic evolution, Permian/Triassic Boundary standard section.

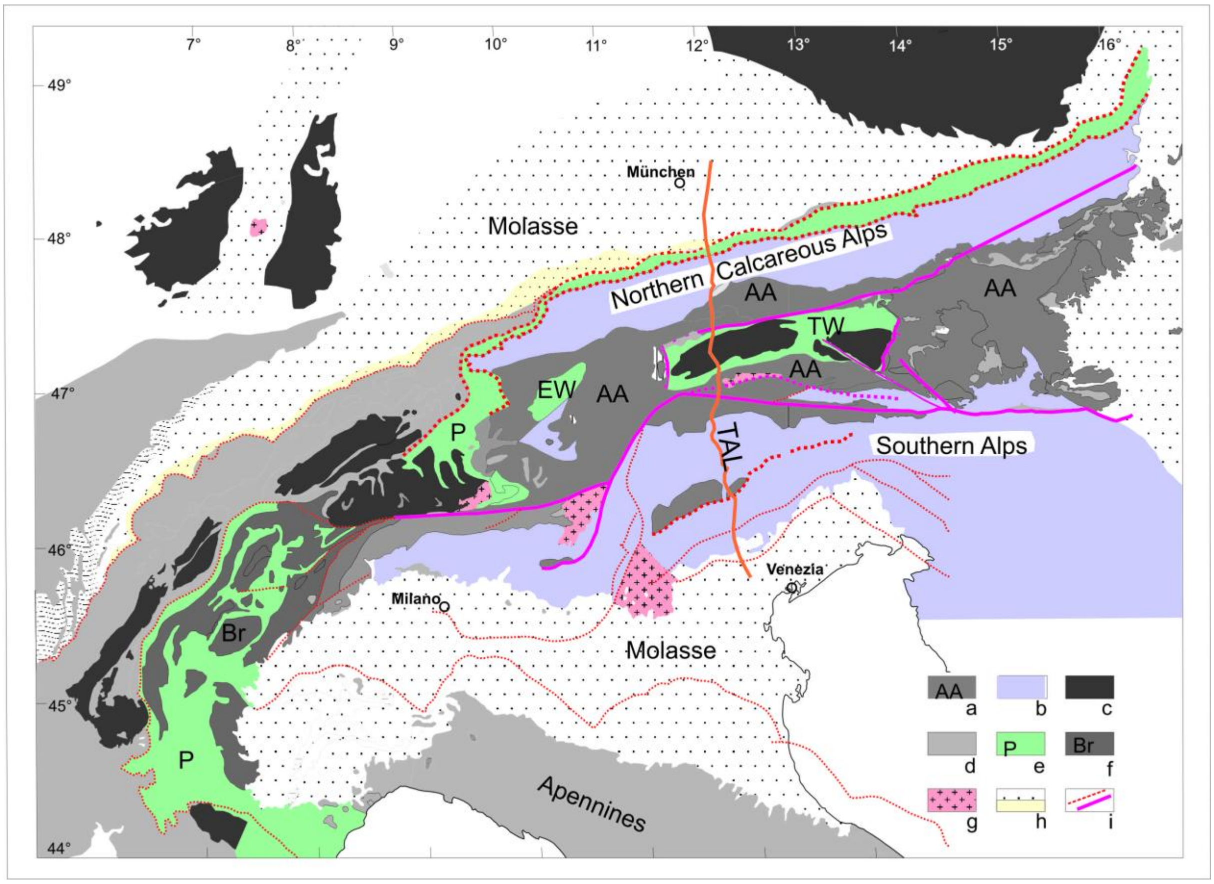
9.9. Pufels - Seiser Alm – Molignon – Roßzähne – Pufels (10 km Hotel Mesavia, accommodation)
Program: Reef – basin – interaction, Middle Triassic magmatism.

10.9. Pufels – Grödner Joch (23 km) – Sellajoch (9 km) – walk to Rodella (1,8 km) – Sellajoch – Pordoi Pass (14 km, Hotel Col di Lana, accommodation) Program: Clinoform geometries and their alpine deformation at the Grödner Joch; Triassic extensional *vs*. alpine compressional tectonics of the Rodella imbricate zone; sequences of basinal sediments (Wengen/Cassian beds) at the Sellajoch.

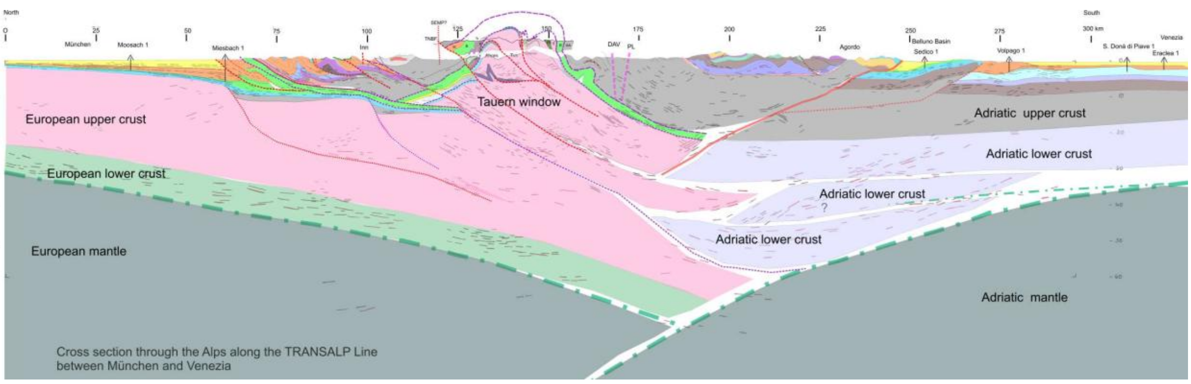
11.9. Sella – from the Pordo Pass to the Sass Pordoi (2950 m) by cable lift – walk to Piz Boè (3152 m) (whole day walk in Alpine topography) – Pordoi Pass – (Hotel Col di Lana, accommodation)
Program: Sella atoll-reef geometry, Upper Triassic to Cretaceous stratigraphy, top of a fold and thrust belt, Alpine and Dinaric tectonics.

12. 9. PORDOI – PREDAZZO (40 KM) – ROVERETO – LAGO DI LEDRO – RIFUGIO AL FAGGIO (ACCOMMODATION) PROGRAM: Triassic monzonitic (type locality!) and granitic intrusions into limestones, Predazzo geological Museum (Neptunists – Plutonists discussion was decided here!); Jurassic Trento platform and Dinosaur tracks in intratidal carbonates at Rovereto.

13. 9. Val Concei – Bocca di Trat – Mazza di Pichea – Tofino – Rifugio al Faggio (accommodation)
Program: Transition Trento platform - Lombardian Basin, slumps and turbidites in limestones indicating deepening of the basin, Neogene folds and thrusts parallel to the Judicaria fault.
14.9. Val Concei – Trento – Brenner – Innsbruck – Garmisch – Munich 400 km
Program: Glacial morphology and formation of the Lake Garda, landslides of the Sarca Valley. Arrival in Munich in the afternoon.



Tectonic map of the Alps. a = Austroalpine basement nappes (AA) and South Alpine basement; b = Austroalpine cover nappes and South Alpine cover; c= European basement; d = European cover nappes; e = oceanic napps and ophiolites of the Piemontese – Valais Oceans (P); f = Briaconnais terrane (Br); g = Tertiary intrusives and volcanics; h = molasse sediments, in yellow: folded; i = solid: strike slip faults, dotted: thrusts; EW = Engadine Window; TW = Tauern Window; TAL = TRANSALP – Line.



Cross section along the TRANSALP Line. The Eastern Alps are characterized here by a thin skinned wedge in the north (left) and a thick-skinned wedge to the south and the imbricate and upthrust Tauern Window in the center. Lower crustal wedges led to thickening of the South Alpine crust. The actual dip of the Adriatic mantle is to the north-east.

GEOLOGY OF THE WESTERN DOLOMITES

by

Rainer Brandner & Lorenz Keim

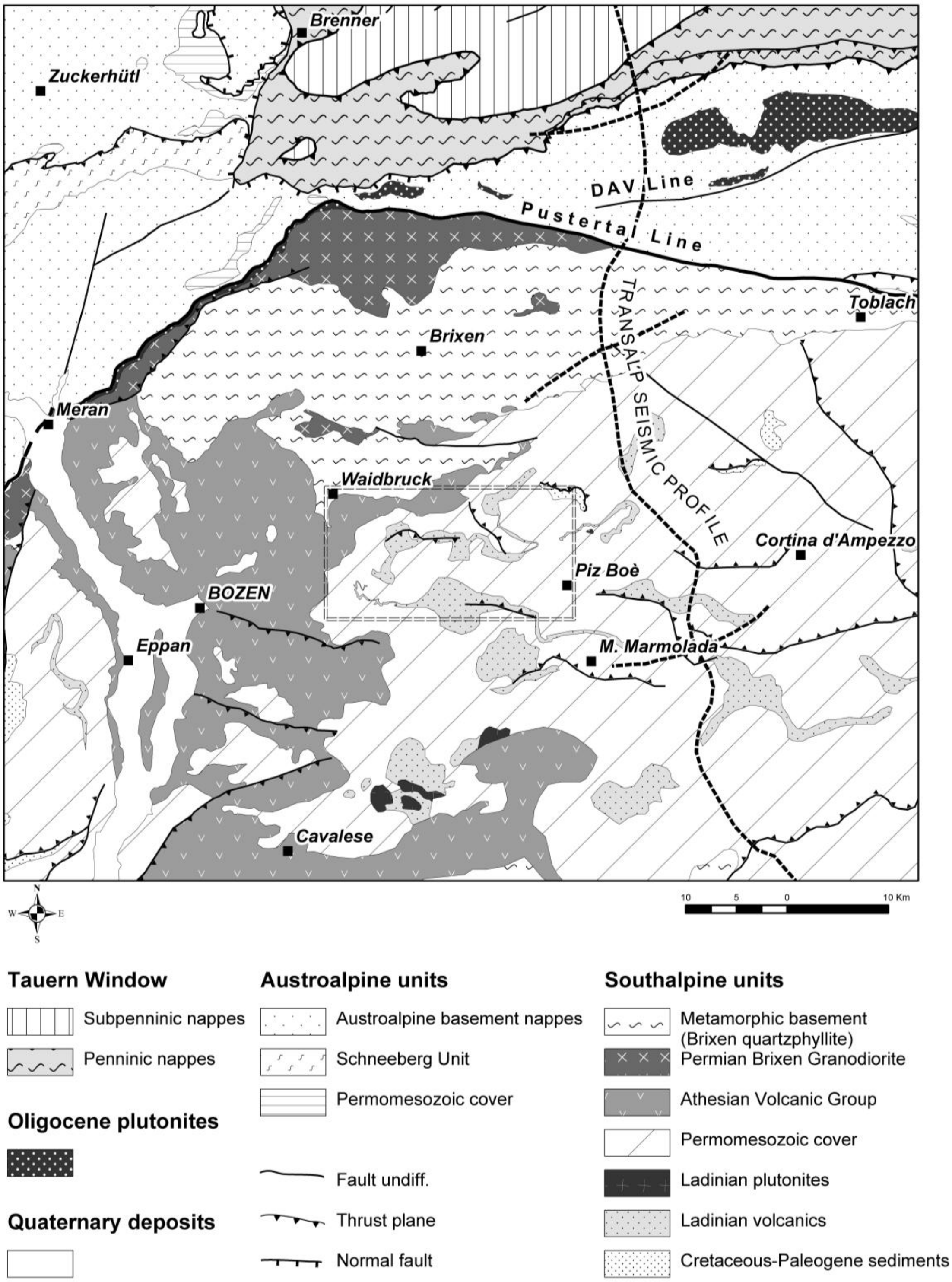


Fig. 1 Regional geological overview with location of the excursion area in the Dolomites (rectangular).

DAY 1
The Permian volcanic event and the upper Permian to lower Triassic stratigraphic succession

Excursion route
Morning: From Waidbruck/Ponte Gardena along the road to Kastelruth/Castelrotto
Afternoon: road section along the abandoned road to Pufels/Bulla

Stop 1.1 – 1.3: The Permian volcanic succession
Stop 1.4 – The Permian/Triassic Boundary
Stop 1.5 – Supratidal/subtidal facies of the Werfen Formation
Stop 1.6 – Seis/Campill Member: enhanced siliciclastic input – a climate signal
Stop 1.7 – The Pufels/Bulla overthrust

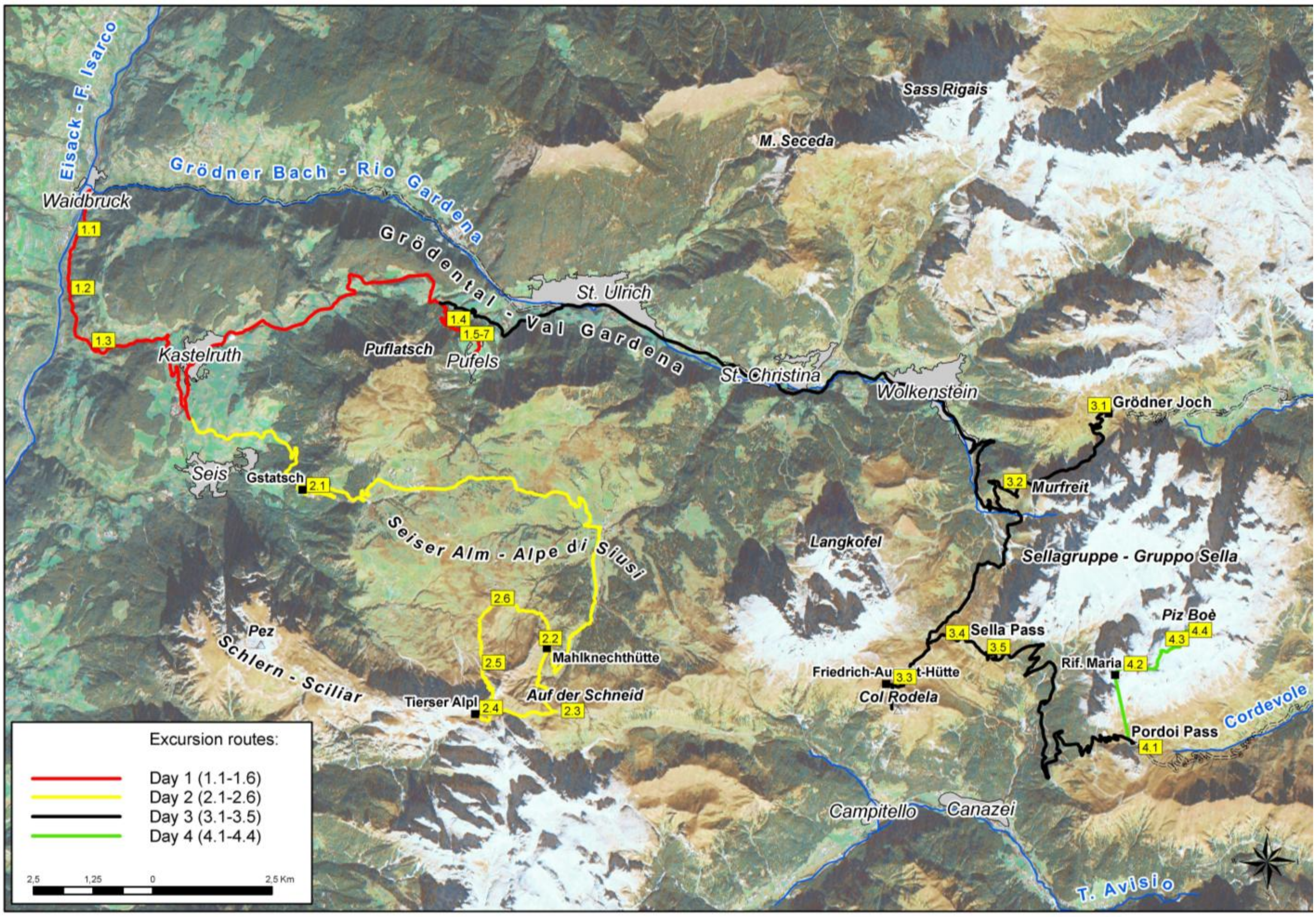


Fig. 2
Satellite image of the Dolomites with location of the four-day excursion routes.

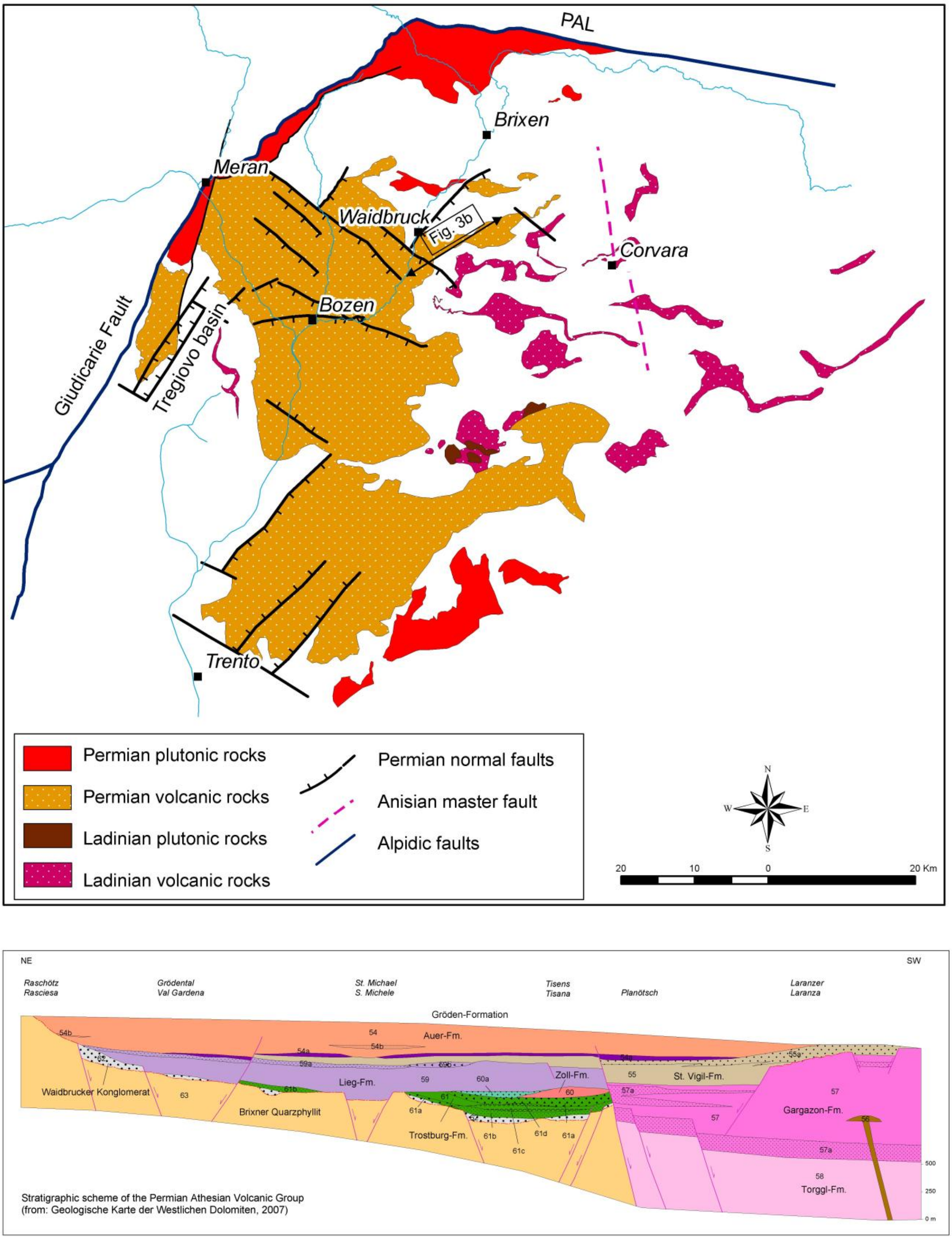


Fig. 3
(a) Distribution of present-day Permian and Ladinian plutonic and volcanic rocks. The formation of Permian volcanites seems to be connected to synvolcanic extensional tectonics with NW-SE and NE-SW trending faults with half graben geometries. This configuration of the Permian faults could be related to an overall sinistral megashear related to the beginning opening of the Neo-Tethyan Ocean in the Far East. Data on the Permian faults are based on own field mapping, Carta Geologica

d’Italia (2007, sheet “Appiano-Eppan”), Carta Geologica d’Italia (2010, sheet “Merano-Meran”) and Morelli, C. (pers. comm., 2011).

The Ladinian magmatites in the Dolomites are located close to the Pemian ones – thus a genetic connection, i. e. a similar uplifted position of the mantle as in the Permian, could be taken into account. The Anisian master fault as an example, should point to the fact of the inheritance of the Permian fault pattern in the Triassic and Jurassic.

(b) Schematic lithostratigraphic model of the Permian Athesian Volcanic Group east of the Eisack valley, based on Geologische Karte der Westlichen Dolomiten 1:25.000 (2007) and Brandner et al. (2007). The location of the schematic section is shown in Fig. 3a.

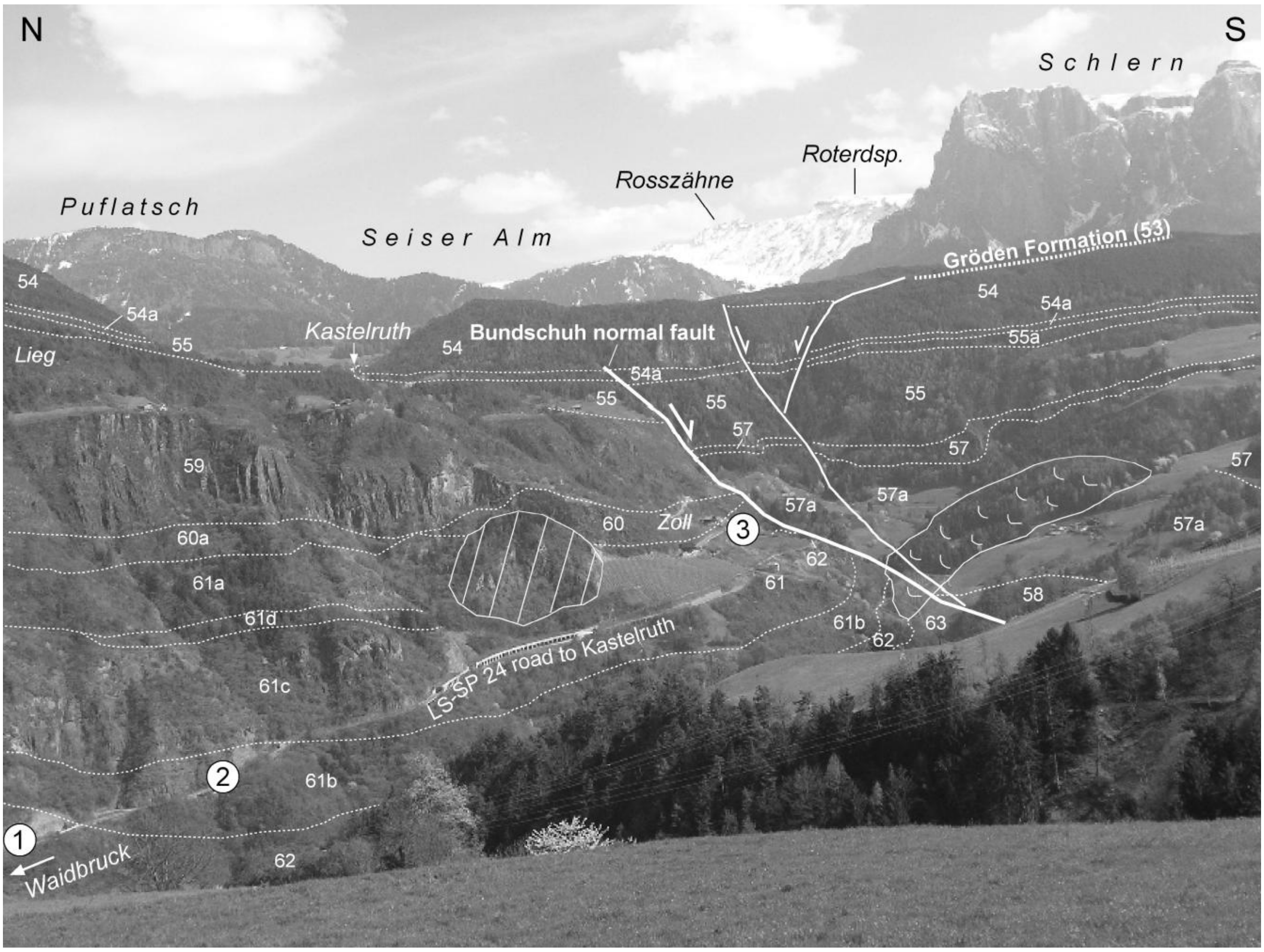


Fig. 4

Panoramic view of the Permian volcanites between Waidbruck/Ponte Gardena and Kastelruth/Castelrotto. A major upper Permian synvolcanic, WNW-ESE running, steep normal fault between Bundschuh-Planötsch is present. This fault is also responsible for the abrupt thickness change of the epiclastic sediments of the St. Vigil Fm. Numbers correspond to the facies model of Fig. 3b. (after Brandner et al., 2007).

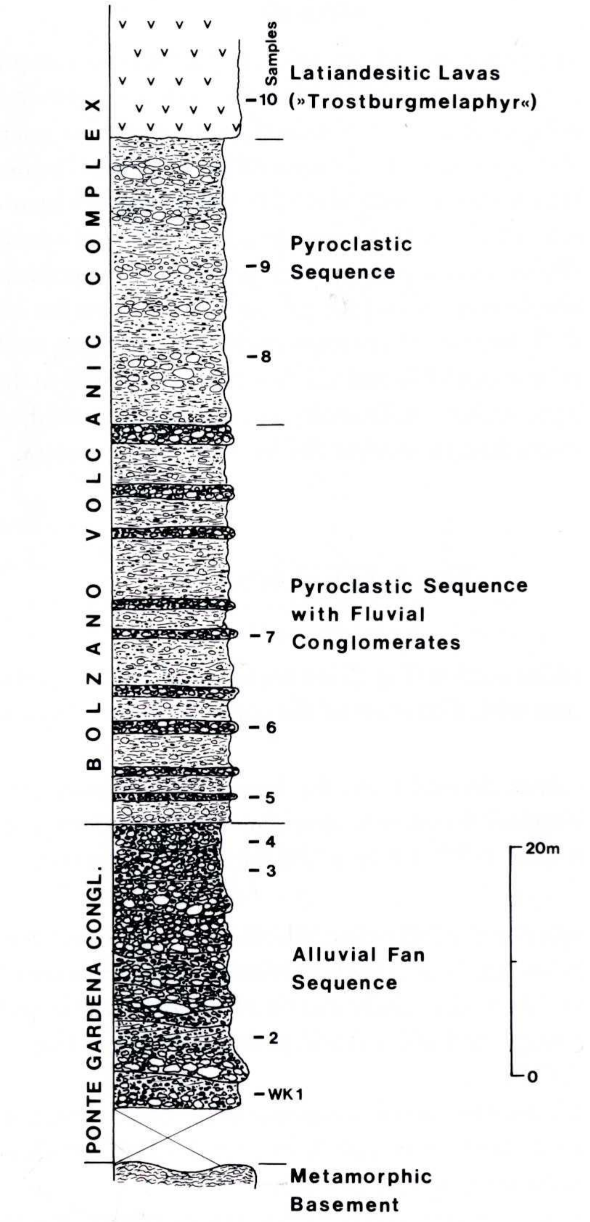


Fig. 5
Measured section of the Ponte Gardena (Waidbruck) Conglomerate and the lower part of the volcanic sequence along the road form Waidbruck to Kastelruth, after Krainer (1989). Reworked clasts of the Ponte Gardena (Waidbruck) Conglomerate consist essentially of quartz phyllite of the underlying metamorphic Basement. Upsection, theses conglomerates are gradually replaced by conglomerates and sandstones with abundant and well rounded volcanic clasts.

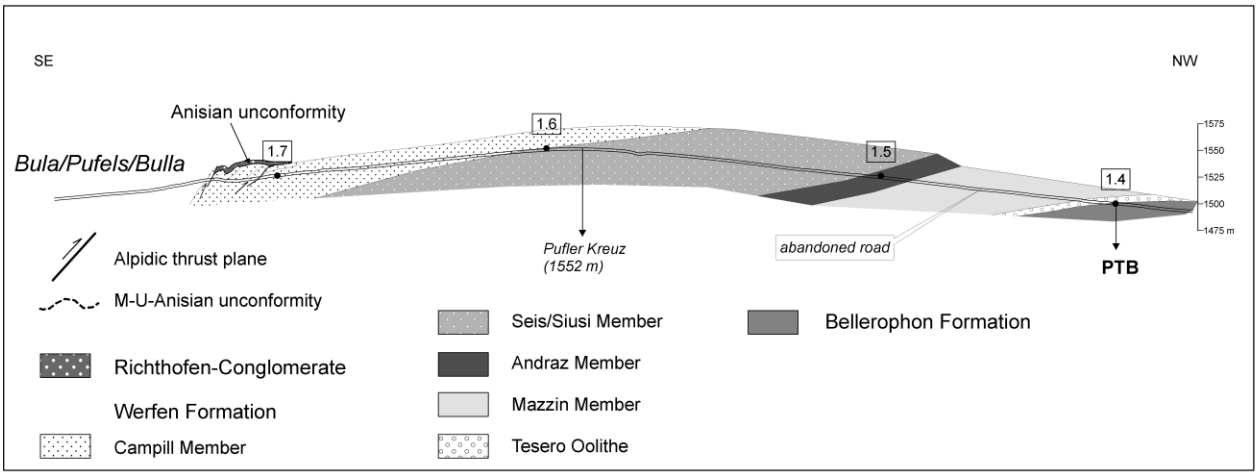


Fig. 6
Geological cross section along the abandoned road to Pufels/Bulla with location of the single excursion stops. PTB = Permian-Triassic Boundary (after Brandner et al., 2009).

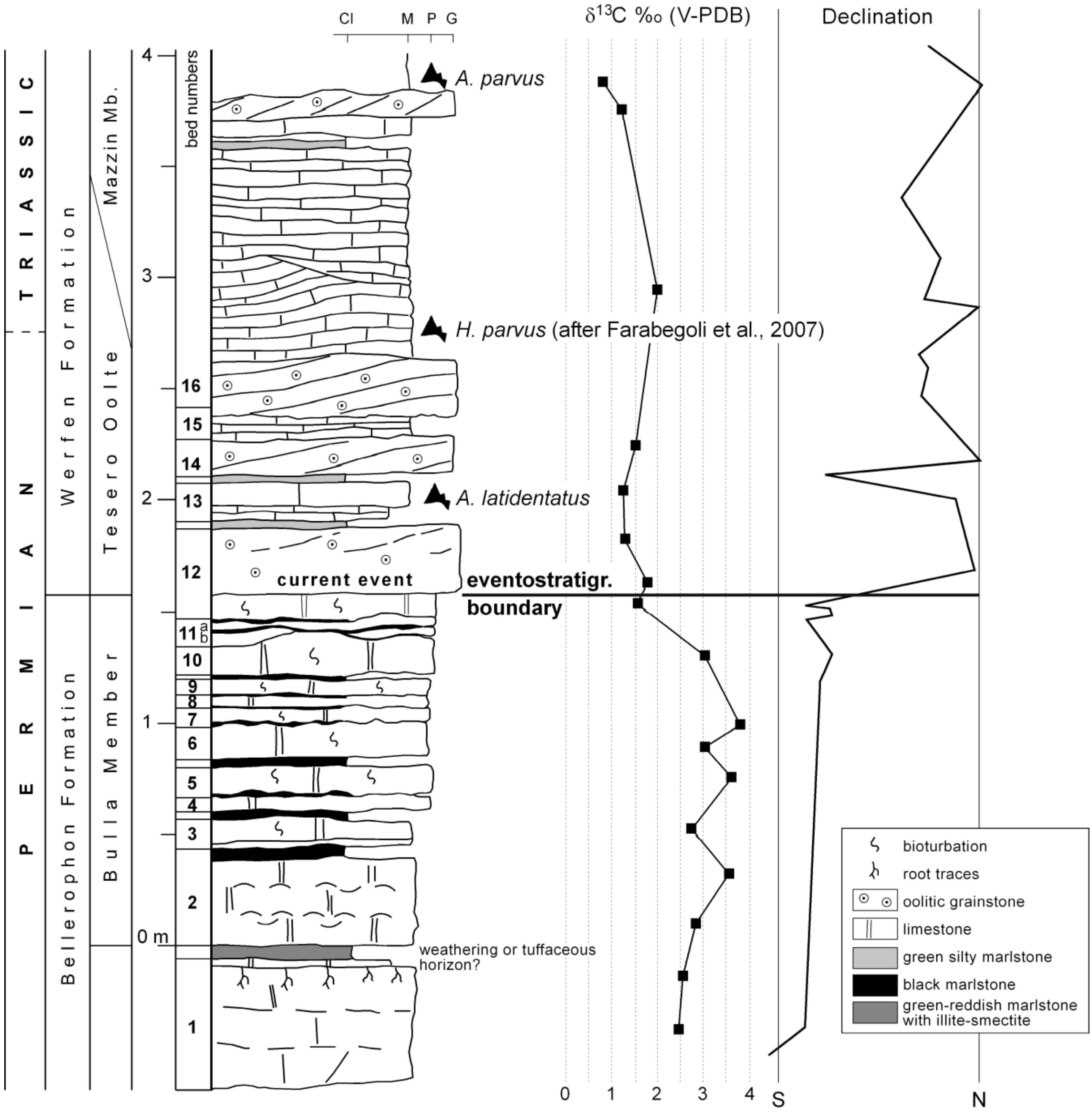


Fig. 7a

The Perm-Triassic Boundary: **(a)** detailed measured section of the PTB with litho-, bio-, chemo- and magnetostratigraphy. Conodonts and position of the PTB after Mostler (1982) and Farabegoli et al. (2007), magnetic declination after Scholger et al. (2000);

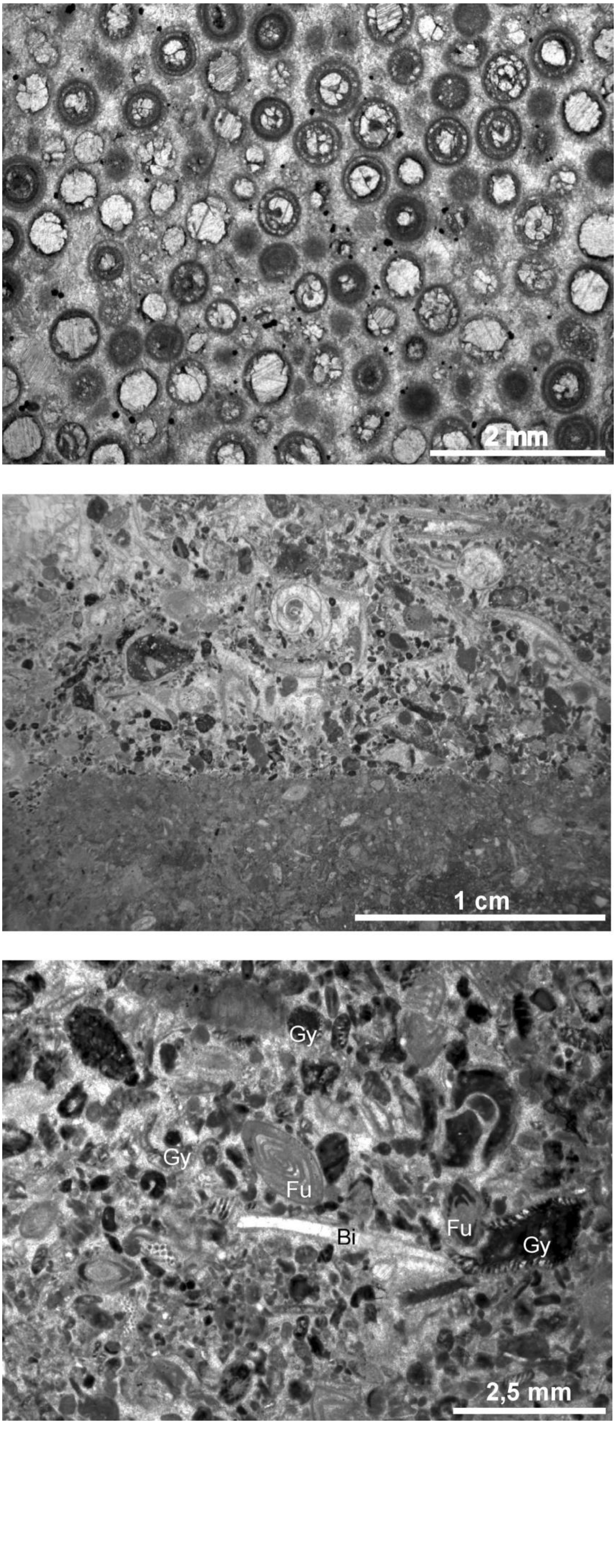


Fig 7b

Three thin-section photomicrographs from the uppermost Bellerophon Formation and the lowermost Werfen Formation. The lower thin section shows a fossil rich, skeletal packstone with typical fusulinids (Fu), red (gymnocods, Gy) algae and bivalves (Bi). In the middle thin section we see a variably sharp contact between the fossiliferous packstone to a grainstone along a firm ground. An increase of hydrodynamic energy is documented by outwash of mud and reworking of intraclastic grains. Only a part of the grains is reworked (e. g. fusulinids). Contrary to Farabegoli et al. (2007) we do not see evidence for subaerial exposure. The uppermost image shows a typical oolitic grainstone from the Tesero Oolite (after Brandner et al., 2009).

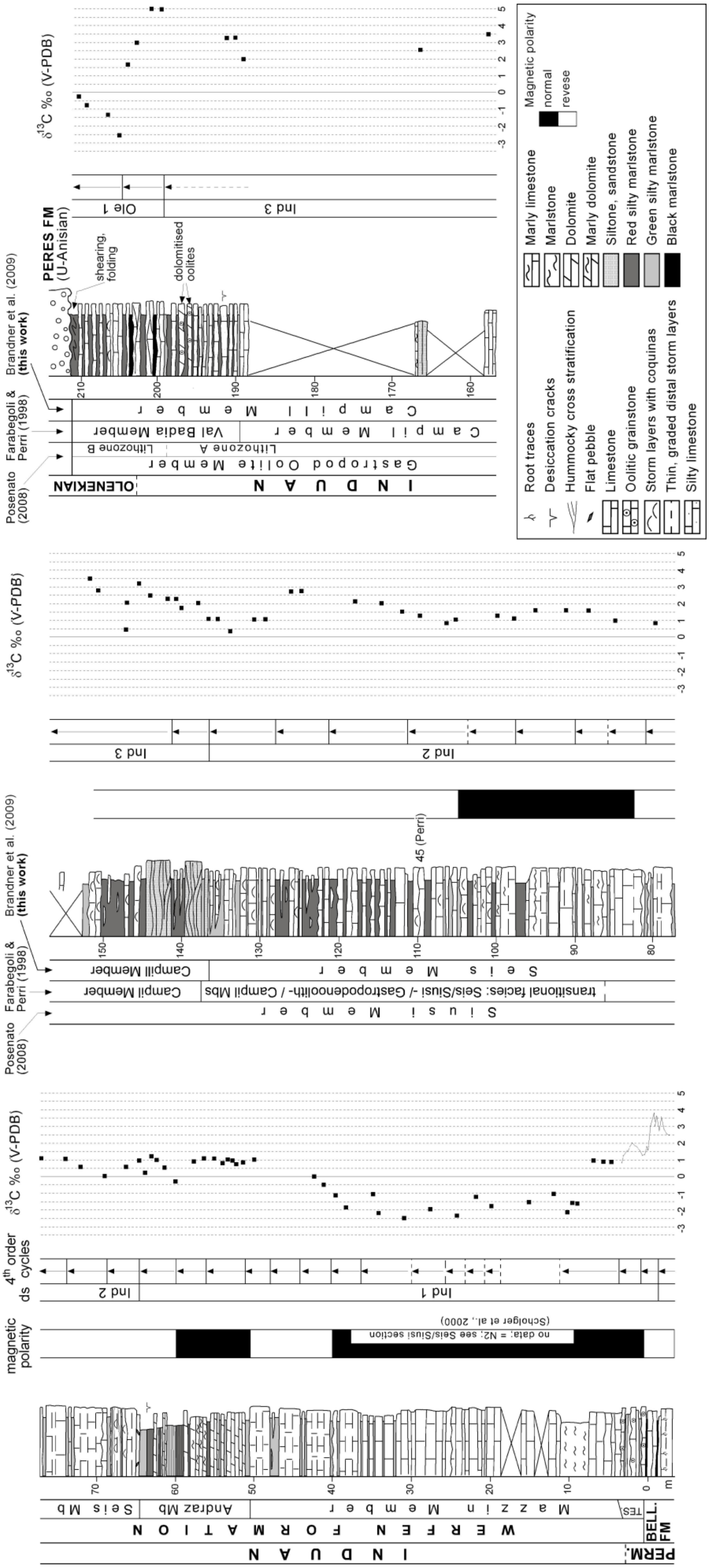


Fig. 8
Measured section through the Werfen Formation along the abandoned road to Pufels/Bulla. The top of the section shows alpine ramp folds which can be restored bed by bed. Upper Anisian conglomerates unconformably overlie the lower part of the Campill Member recording upper Anisian uplift and erosion (after Brandner et al., 2009).

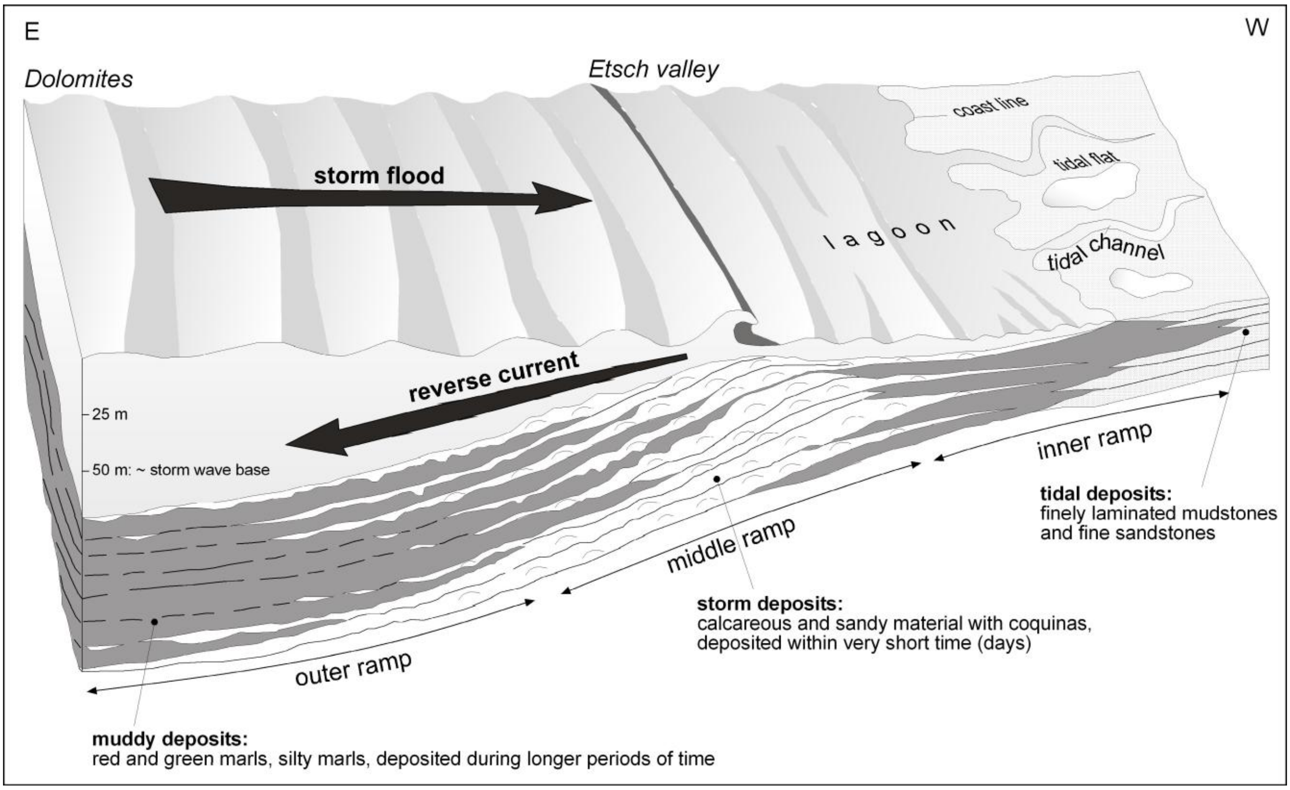


Fig. 9
Schematic model for the deposition of the Werfen Formation on an east-dipping ramp. Sedimentation is essentially controlled by storms; the coast line is supposed to be far in the west near the Como Lake. Mud deposits, now red and green marls, alternate with layers of sand with bivalve and gastropod shells. Each limestone bed is the product of a storm event and is deposited within some days. Storms generate energy-rich, seafloor-touching waves, which, especially in the coastal zone, are eroding and swirling up the mud and sand on the seafloor. Consequently, bivalve and gastropod shells are washed out and enriched separately forming coquina beds (see Fig. 10) (after Brandner & Keim, 2011).

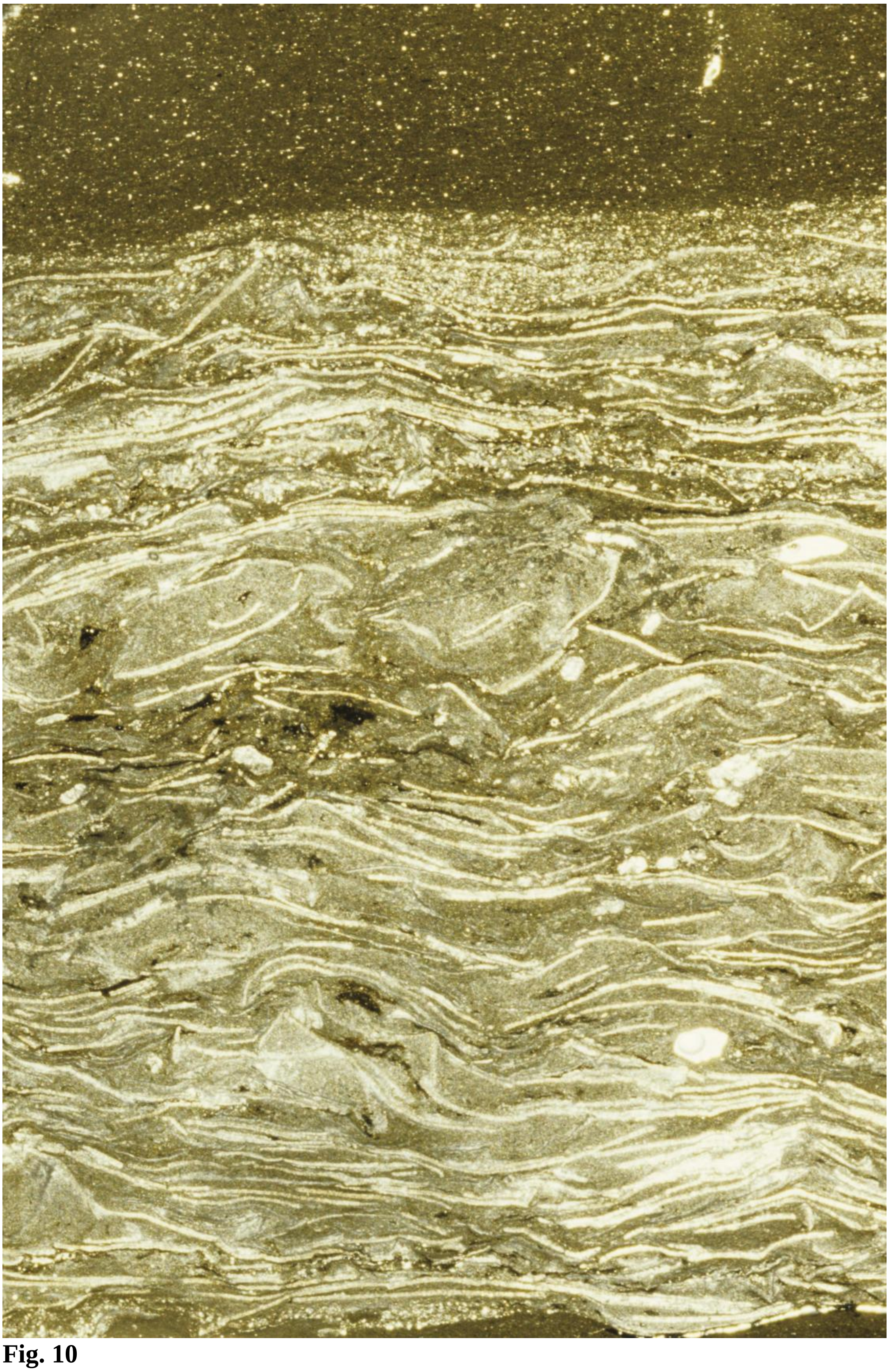


Fig. 10
Thin section photomicrographs of typical tempestites with graded beds and coquinas with *Claraia clarai* (after Brandner & Keim, 2011).

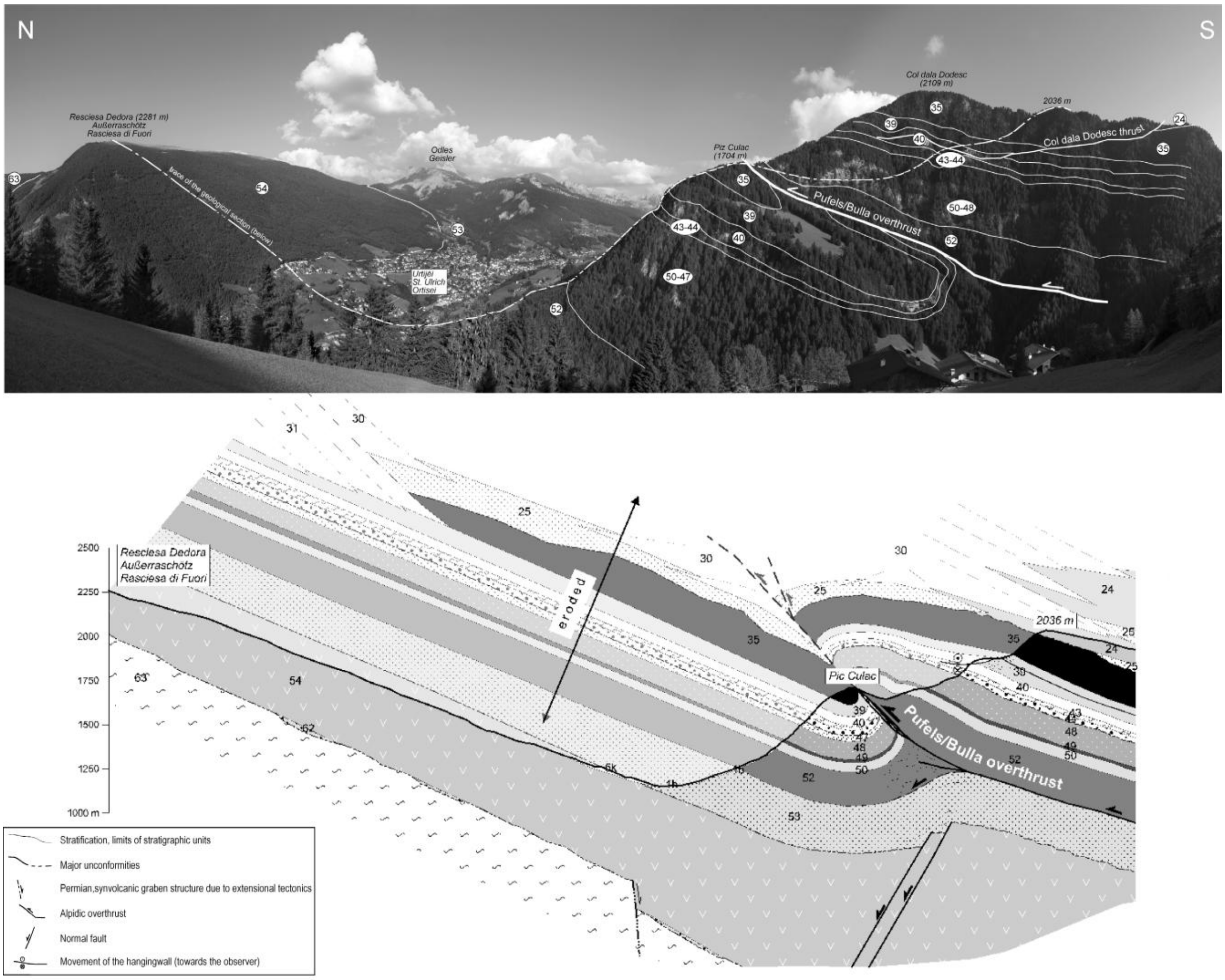


Fig. 11
Geological cross section of the N-vergent Pufels/Bulla overthrust, which developed from the sheared syncline at Piz Culac. The virtual extension of the cross section in the air shows the south dipping clinoforms of the Geisler/Odles on the upper left side. 63 = Southalpine metamorphic Basement, 62 = Waidbruck Conglomerate., 54 = ignimbrites undifferentiated of the Athesian Volcanic Group, 53 = Gröden Fm, 52 = Bellerophon Fm, 50 = Mazzin Mb, 49 = Andraz Mb, 48 = Seis/Siusi Mb, 47 = Campill Mb, 44 = Peres Fm (Voltago/Richthofen Conglomerate), 43 = Morbiac Fm, 40 = Contrin Fm, 39 = Buchenstein Fm, 35 = lavas, 25 = Wengen Fm, 24 = St. Cassian Fm (after Brandner & Keim, 2011, based on Geologische Karte der Westlichen Dolomiten 1:25.000 (2007)).

DAY 2

Middle and Upper Triassic successions at the NE margin of the Schlern/Sciliar platform and in the Seiser Alm/Alpe di Siusi basin

Exkursion route

From Bula/Pufels to Seiser Alm/Alpe di Siusi to the Mahlknechthütte/Rif. Molignon by bus, then hiking to the Mahlknecht cliff, walk to Auf der Schneid/Cresta Alpe di Siusi, walk to Tierser Alpl Hütte, Rosszahnscharte/Forcella di Denti di Terra Rossa, walk down to the Wiedner Woadn and back to Mahlknechthütte.

Stop 2.1 – Gasthof Gstatsch: panoramic overview and general Triassic stratigraphy
Stop 2.2 – Mahlknechthütte/Rif. Molignon: volcanics vs. carbonate slope deposits
Stop 2.3 – Auf der Schneid/Cresta di Siusi: panoramic overview, sequence stratigraphy
Stop 2.4 – Tierser Alpl Hütte and Rosszahn Scharte: megabreccia formation
Stop 2.5 –Wiedner Woadn: interfingering of carbonate slope deposits and volcaniclastics

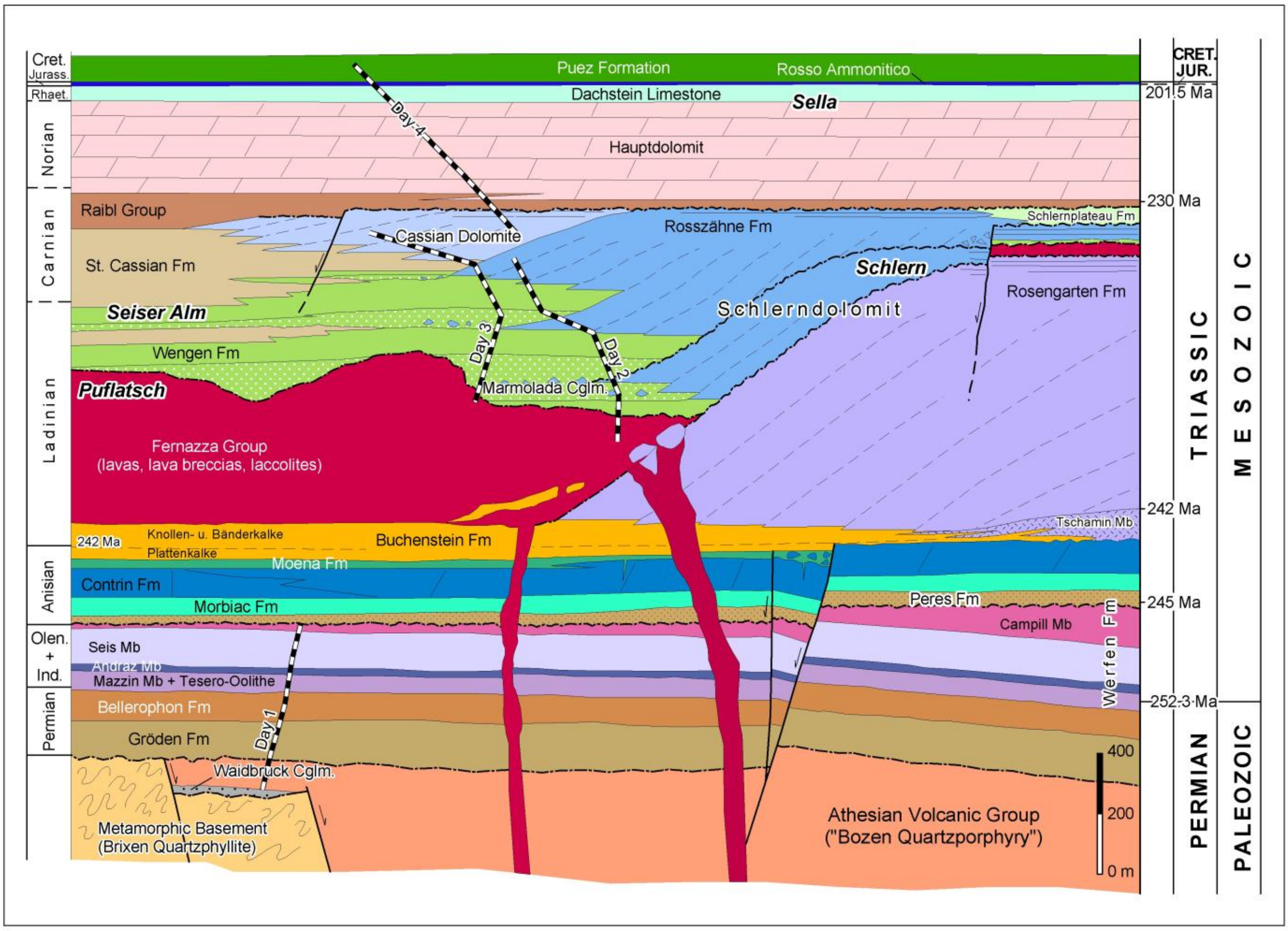


Fig. 12
(a) Lithostratigraphic model for the Permo-Mesozoic succession of the Western Dolomites (modified after Brandner et al., 2007); **(b)** chronostratigraphic framework for the Triassic succession of the western Dolomites. LPV, MPV, UPV = Lower, middle and upper Pietra Verde (see Brack et al., 2005). Radiometric ages are taken from Mundil et al. (2010).

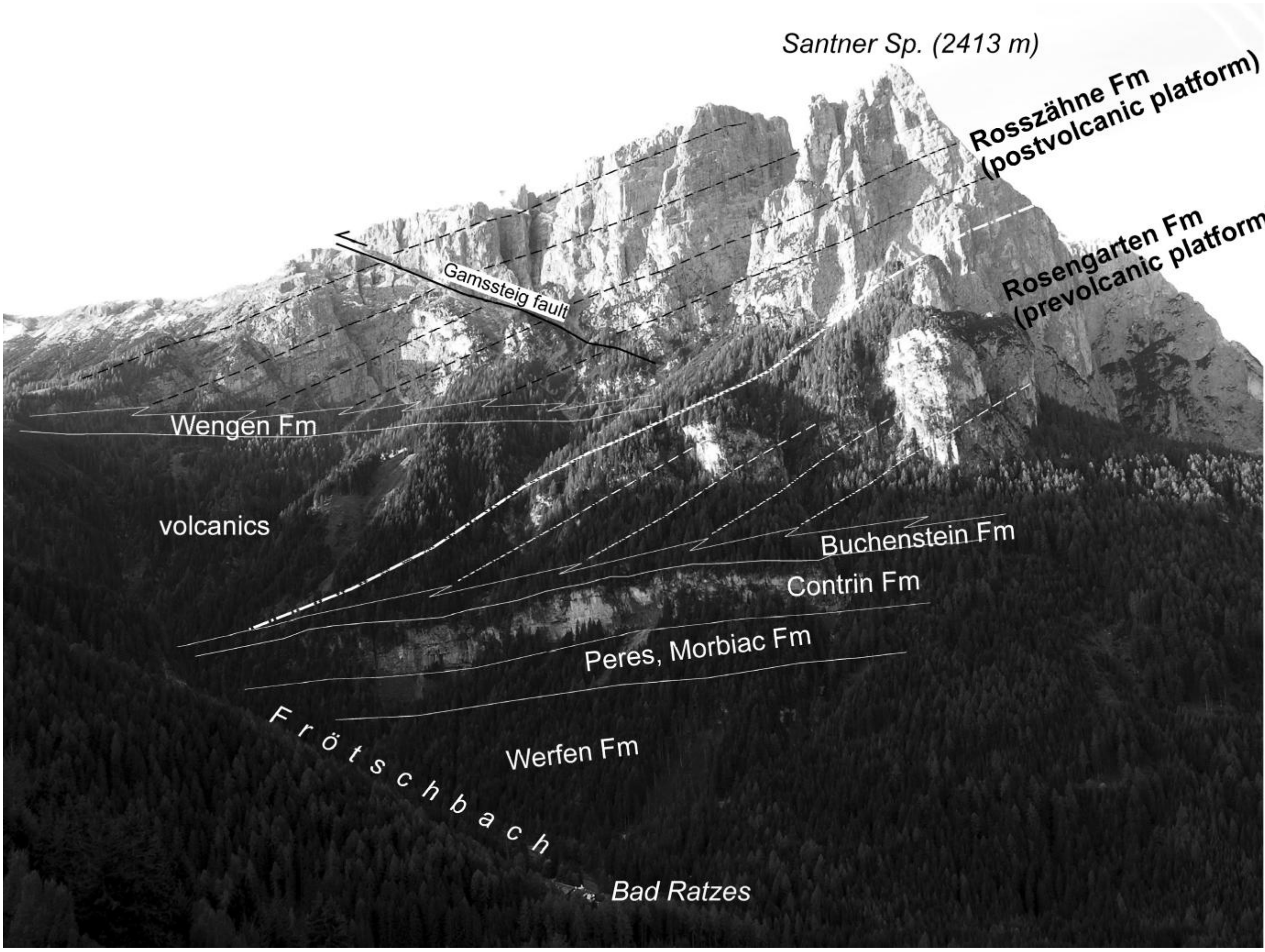


Fig. 13
Panoramic view on the north-eastern flank of the Schlern showing the excellently preserved, seismic-scale platform-to-basin transition of the Anisian to Ladinain carbonate platform. Depostitional sequences are bordered by 3rd order unconformities (stippled lines). Wf = Werfen Fm, Pe = Peres Fm, Mo = Morbiac Fm, Co = Contrin Fm, Bu = Buchenstein Fm, Ro = Rosengarten Fm, Ro/t = topsets of the Rosengarten Fm, V = volcanics (Fernazza Group), We = Wengen Fm, Rz = Rosszähne Fm, Rz/t = topsets of the Rosszähne Fm, Mc = Marmolada Conglomerate, Hd = Hauptdolomit (after Brandner et al., 2007).

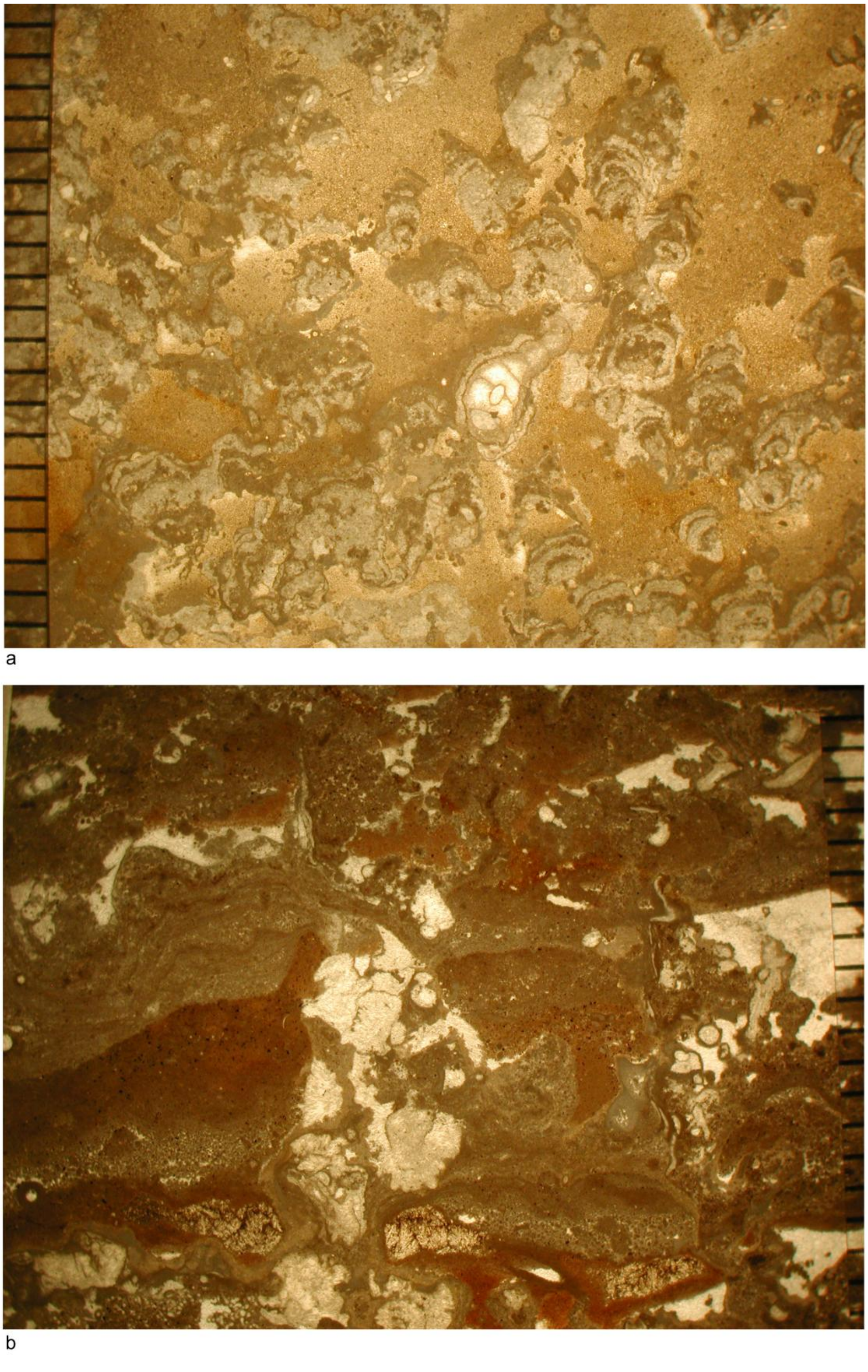


Fig. 14
Thin section photomicrographs of Cipit boulders from the Mahlknechtwand: **(a)** Thrombolitic boundstone with Tubiphytes and microbial encrustations and large cavities filled with internal sediment; **(b)** Boundstone with clotted peloidal micrite, festooned crusts, Tubiphytes, botryoidal cements and various generations of tilted geopetal sediment infills. Scale in mm.

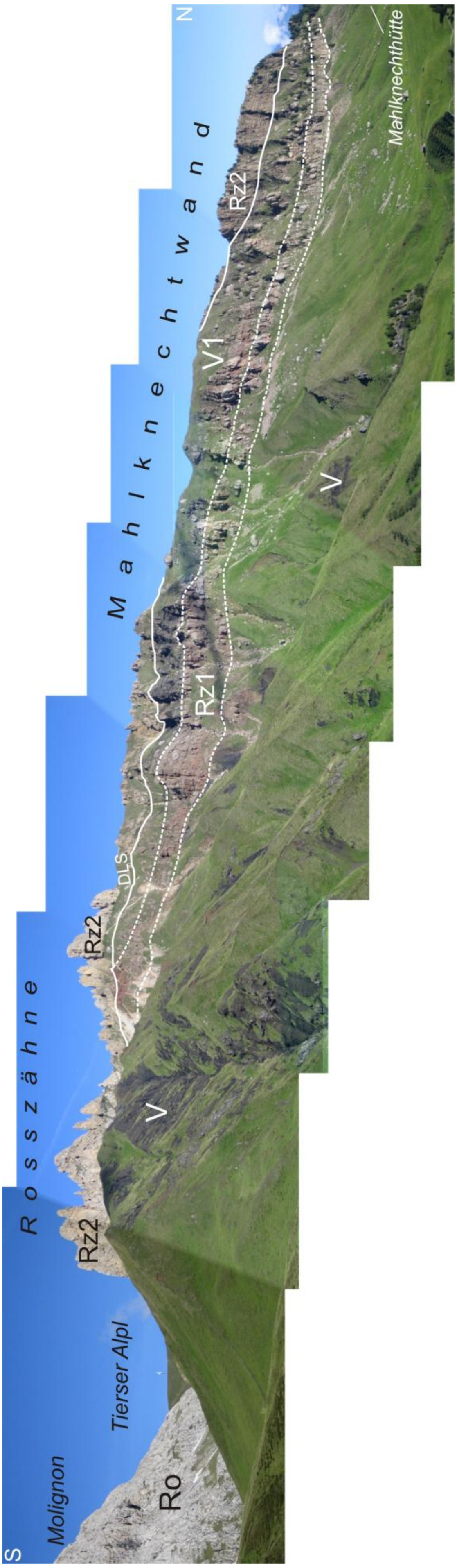


Fig. 15
Panoramic view from "Auf der Schneid" (Cresta di Siusi) to the Rosszähne and Mahlknechtwall showing the interfingering between the prograding reef slope deposits of the Rosszähne Fm (Rz1, 2) and volcaniclastic sandstones and conglomerates (V1). The wedging-out of the volcaniclastics onto the upper carbonate slope (= onlap) as well as the above following downlap surface (DLS) of the reef tongue 2 are clearly visible. The natural cut of the Mahlknechtwand runs obliquely to the depositional dip of the clinoforms, therefore the true dip-angle is steeper. V = volcanics (Fernazza Group) which cover the paleo-slope of the pre-volcanic Rosengarten Fm (Ro) to the south of the Tierser Alpl. (after Brandner et al., 2007)

Fig. 16
Outcrop photo of steeply N-dipping clinoforms west of the Rosszahn Scharte with typical slope breccia tongues.

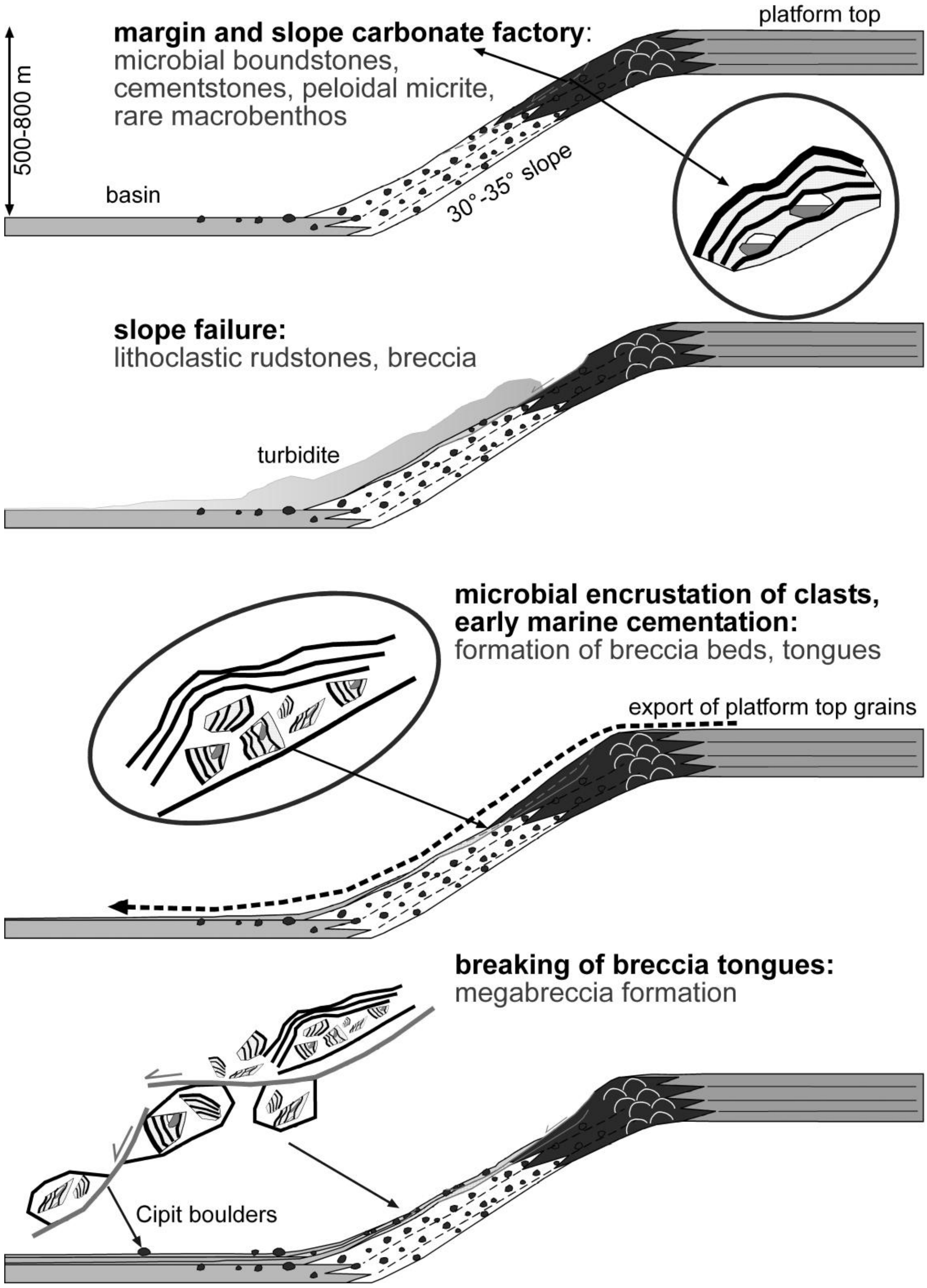


Fig. 17
Schematic model for steeply dipping, prograding carbonate slopes. The formation of breccias and megabreccias on the slope requires multiple interactions of platform shedding, *in situ* carbonate precipitation and microbial encrustation, geopetal infill, early cementation, breaking of already hardened sediments by gravitational mass-movements triggered by oversteepening or seismic shocks, renewed encrustation and cementation, etc. The clinostratification corresponds partially to discrete submarine shear planes.

DAY 3
Geology of the Sella platform and the Col Rodela area

Excursion route
During the excursion, we will approach the Sella from the Gardena Valley and continue in a counter-clockwise direction. From the Gardena Pass we will pass the Sella Pass, then walk to Col Rodela, turn back to the Sella Pass, and proceed to the Pordoi Pass.

Stop 3.1: Grödnerjoch: lower slope megabreccias and their alpine deformation
Stop 3.2: Hotel Gerhard, Grödnerjoch road: antiformal deformation of the succession
Stop 3.3: August-Friedrich-Hütte: stratigraphy and multiple tectonics of the Col Rodela area
Stop 3.4: Sella Pass: facies interfingering of the basinal deposits (Wengen/St. Cassian Fm)
Stop 3.5: road curve just below the Sella Pass: seismic-scale cross section of the Sella atoll

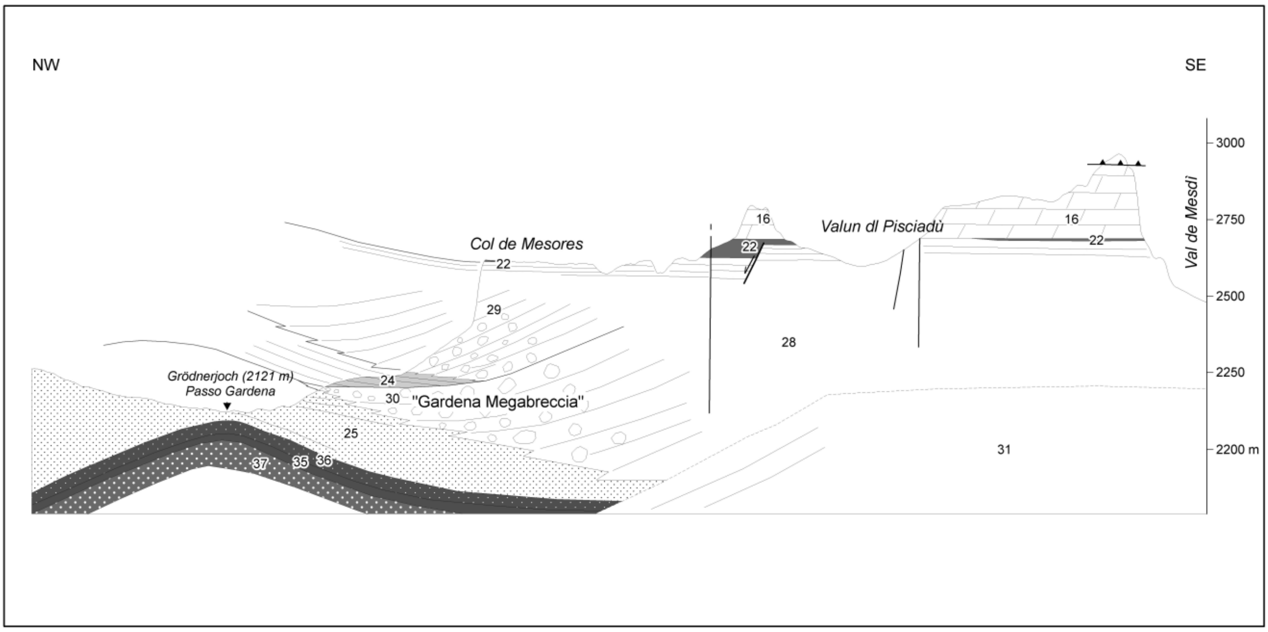


Fig. 18
The geological situation at Grödner Joch/Passo Gardena: **(a)** The geological cross section illustrates the antiformal deformed lower slope megabreccias (“Gardena megabreccia”) and basinal deposits during alpine tectonics along the E-W trending Plan-Grödner Joch/Passo Gardena anticline; **(b)** close up view of the “Gardena megabreccia” (= Rosszähne Fm) wedging out in the basinal sediments of the Wengen Formation. See text for explanation. 37 = “Caotico eterogeneo”, 35 = lava, 37 = Hyaloclastites, 31 = pre-volcanic Schlerndolomite (Rosengarten Fm), 30 = post-volcanic Schlerndolomite (Rosszähne Fm), 29 = Cassian Dolomite, 28 = Selladolomite Subgroup (post-volcanic platform carbonates undiff.), 25 = Wengen Fm, 24 = St. Cassian Fm, 22 = Pordoi Fm (“Raibl beds”), 16 = Hauptdolomit/Dolomia Principale.

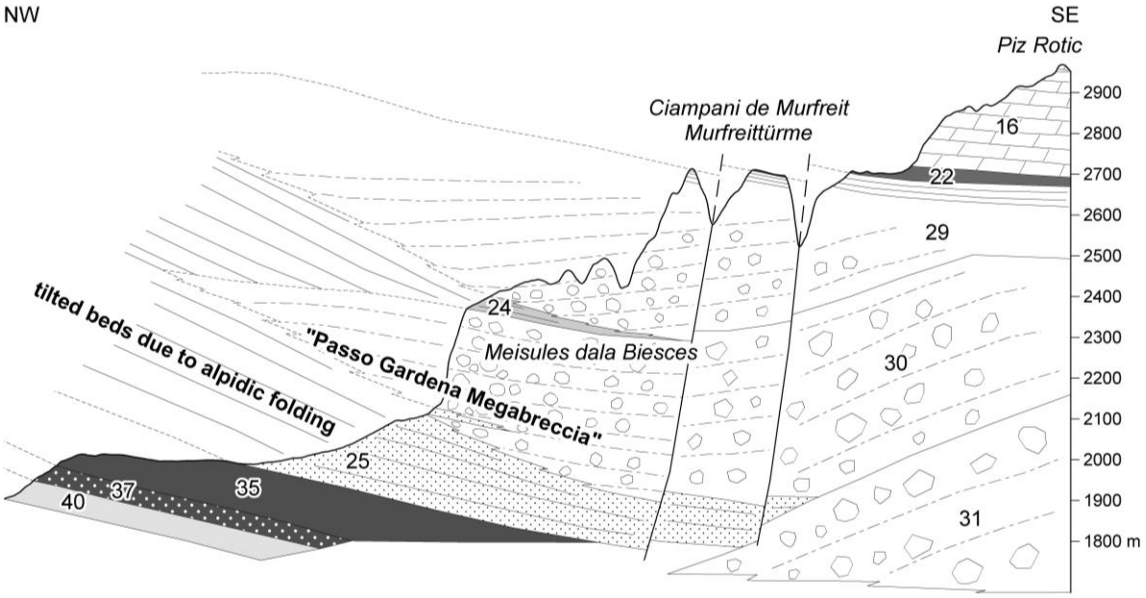


Fig. 19
Geological cross section at Campani de Murfreit. Here the alpine antiformal deformation of the entire stratigraphic succession up to the Norian Hauptdolomite is clearly visible. 40 = Contrin Fm, for the remaining legend see Fig. 18.

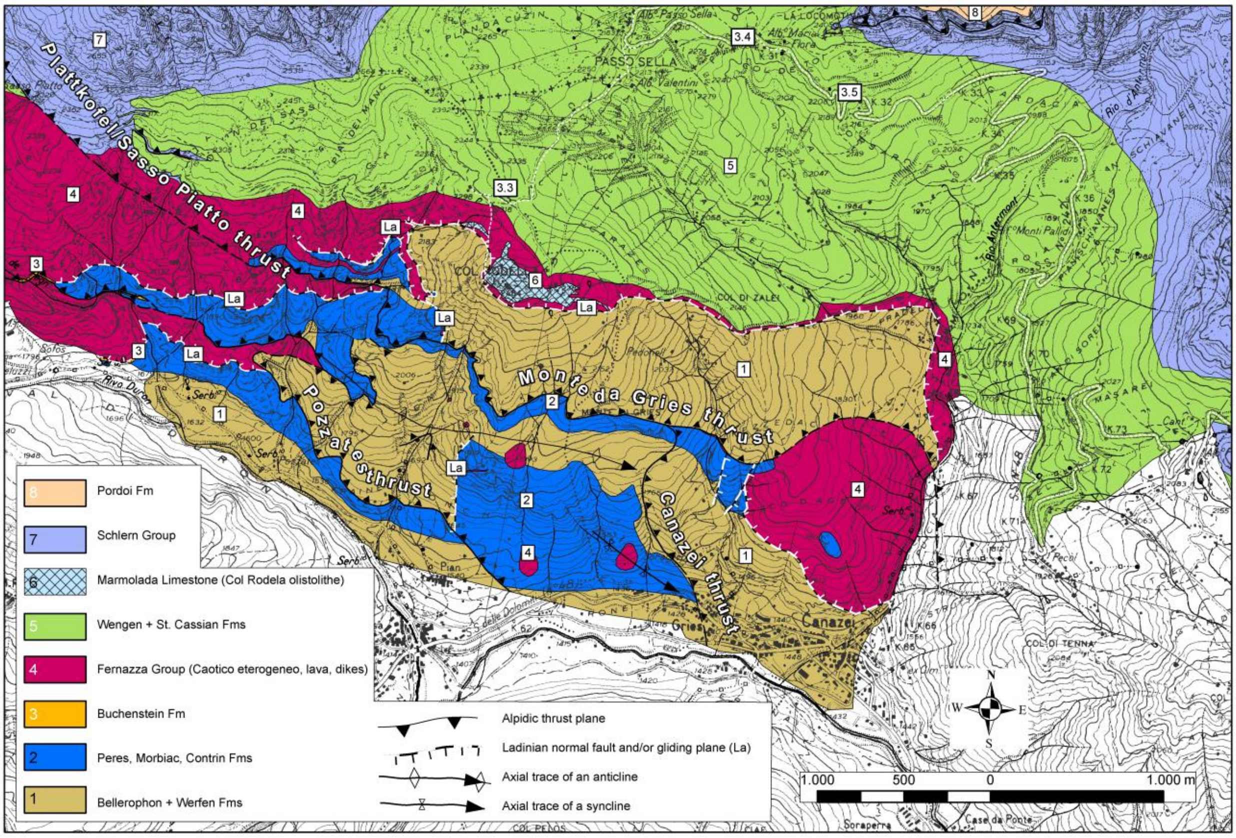


Fig. 20
Simplified tectonic map of the area between Canazei (Val di Fassa) and Col Rodela, based on the Geologische Karte der Westlichen Dolomiten 1:25.000 (2007). The tectonic repetition of the stratigraphic succession is caused by a two-phased alpine, i.e. early and late Dinaric deformation.

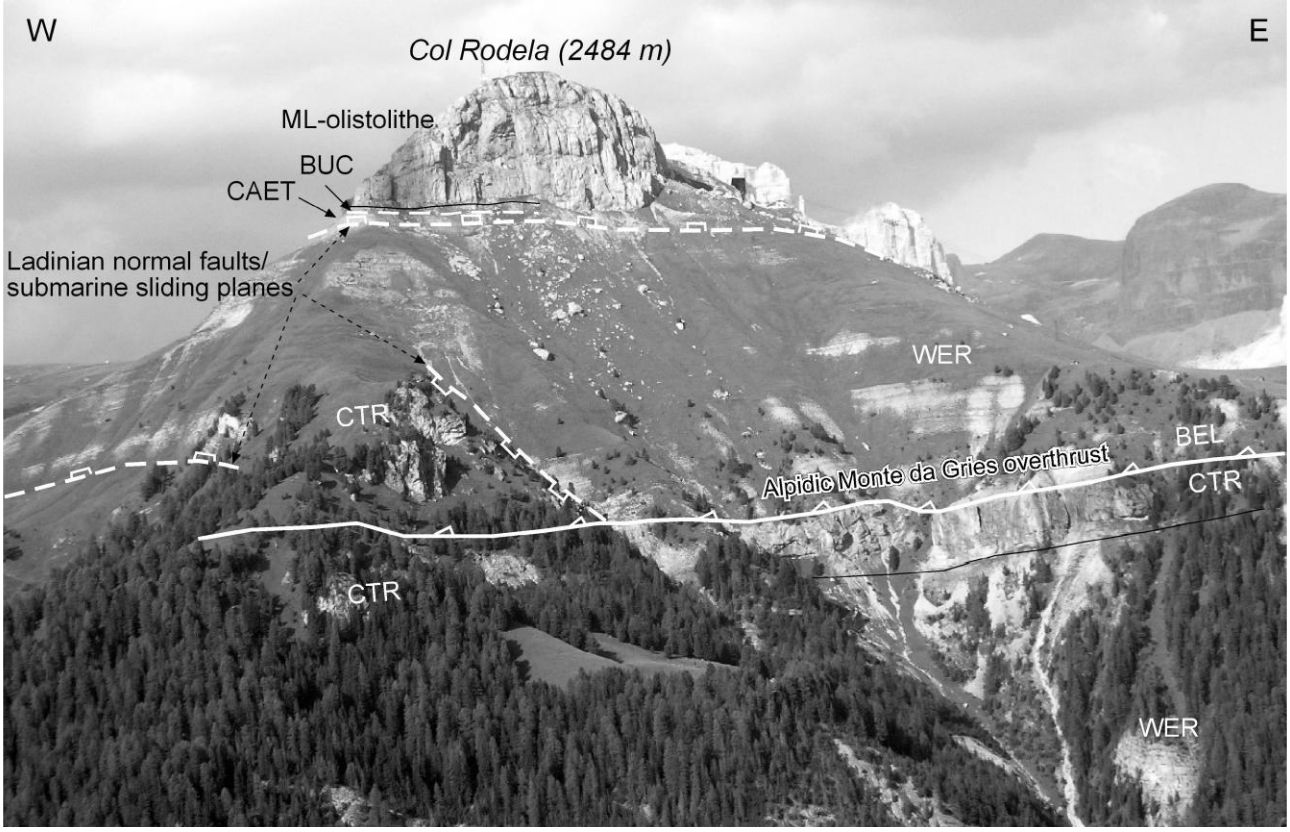


Fig. 21
Panoramic view of the southern flank of Col Rodela with outline of the most important tectonic structures. BEL = Bellerophon Fm, WER = Werfen Fm, CTR = Contrin Fm, CAET = "Caotico eterogeneo", BUC = Buchenstein Fm, ML = Marmolada Limestone (olistolithe).

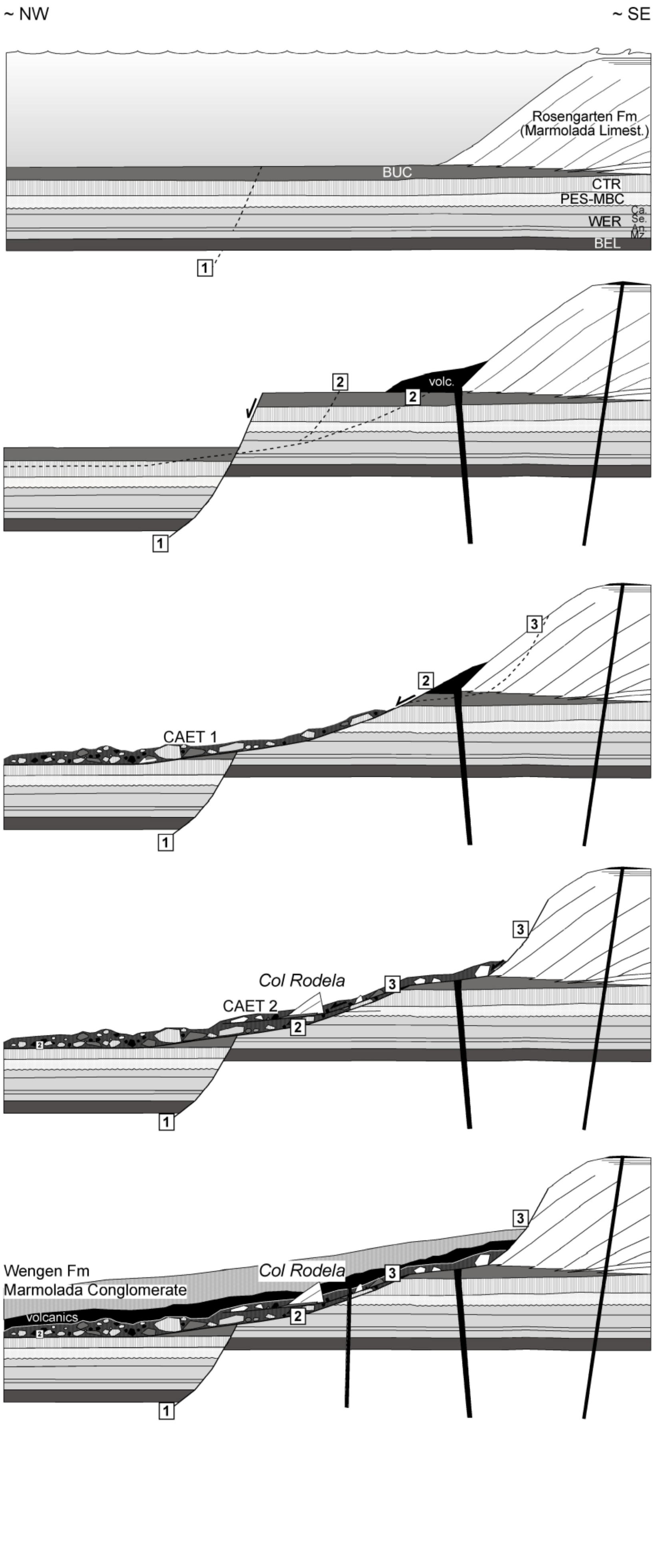


Fig. 22
Schematic model for the development of the “Caotico eterogeneo” for the area of Col Rodela during the Late Ladinian. The formation of breccias and megabreccias with reworking of sediments down to the Werfen Fm requires a multiple extensional tectonics with steep and flat lying normal faults and/or gliding planes in connection with the volcanic activity. The breccias and megabreccias resulted essentially from submarine mass flow deposits. The presence of Ladinian normal faults combined with a complex stratigraphic succession of the “Caotico eterogeneo” with local olistolithes complicates the interpretation of the succession at the southern flank of Col Rodela. Alpidic thrust planes cut through diverse stratigraphic levels and younger rocks, which were downfaulted during the late Ladinian, may thrust over older rocks during the alpine (Dinaric) deformation.

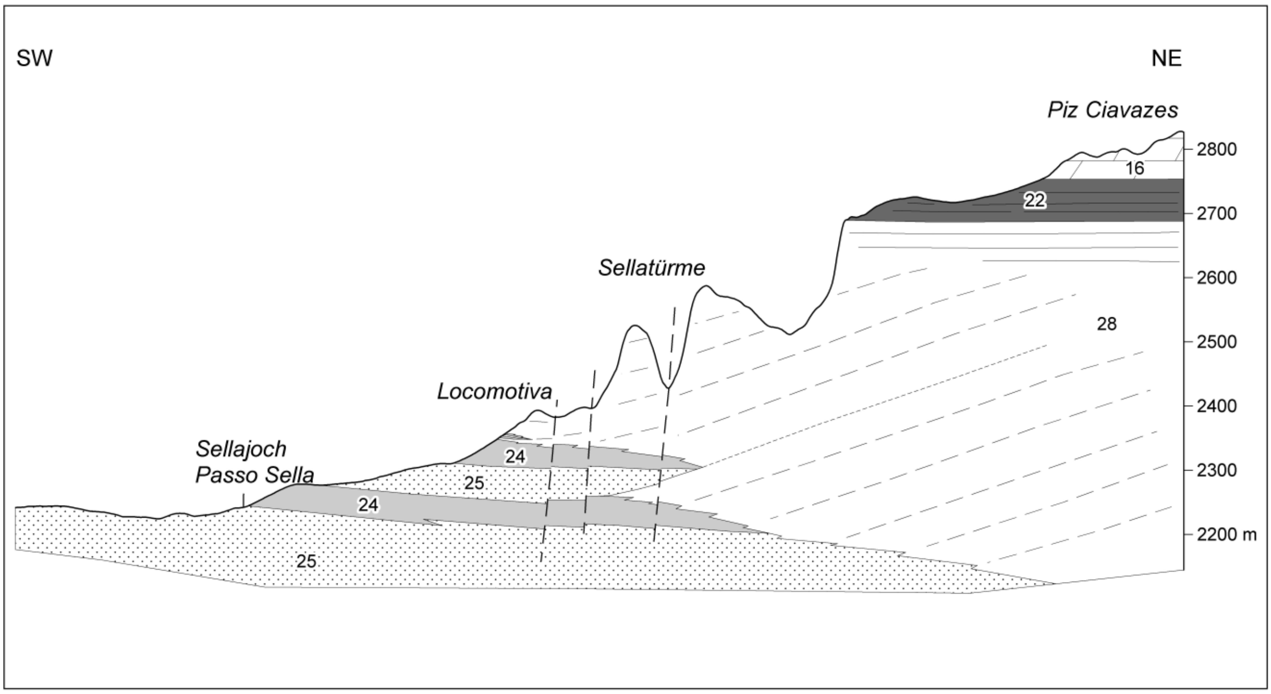


Fig. 23
Interpretative cross section between Piz Ciavaces and Passo Sella. The subdivision of the platform and slope deposits into the Rosszähne Fm and Cassian Dolomite, such as at the Grödner Joch/Passo Gardena, is not possible here. Therefore the term Selladolomite-Subgroup is used. The two-fold repetition of the Wengen and St. Cassian Fms originates from the different input of carbonate *vs*. volcaniclastic material into the basin. 25 = Wengen Fm (incl. Marmolada Conglomerate), 24 = St. Cassian Fm, 28 = Selladolomite Subgroup, 22 = Pordoi Fm, 16 = Hauptdolomit/Dolomia Principale.

DAY 4
Stratigraphy and tectonics at the southern side of the Sella Group

Excursion route
This day is dedicated first to the general geology at the Pordoi Pass itself and secondly to the tectonic deformation at the summit Piz Boè (3152 m). From Pordoi Pass we ascent to Sas Pordoi by cable car, walk to the Piz Boè (3152 m), and turn back to Sas Pordoi und descend by cable car. The Sass Pordoi and Piz Boè offer one of the most spectacular panoramic views over the entire Dolomites.

Stop 4.1: Pordoi Pass: a seaway between two prograding carbonate platforms
Stop 4.2: Sas Pordoi-Piz Boè: spectacular panoramic view and walk over peritidal deposits
Stop 4.3: Southern flank at Piz Boè: the W-vergent summit thrusts
Stop 4.4: Piz Boè (3152 m): the summit – panorama, discussion, sunset…

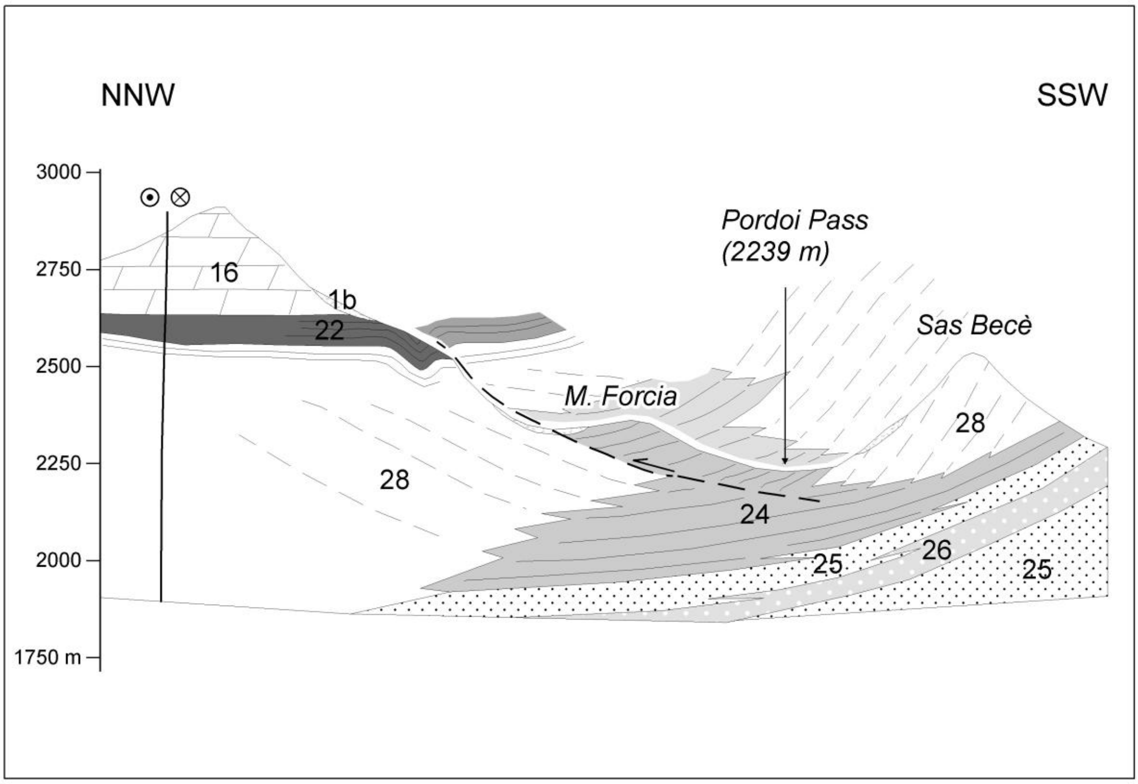


Fig. 24
Interpretative N-S cross section across Passo Pordoi. See text for explanation. 25 = Wengen Fm (incl. Marmolada Conglomerate), 24 = St. Cassian Fm, 28 = Selladolomite Subgroup, 22 = Pordoi Fm, 16 = Hauptdolomit/Dolomia Principale, 1b = talus deposits.

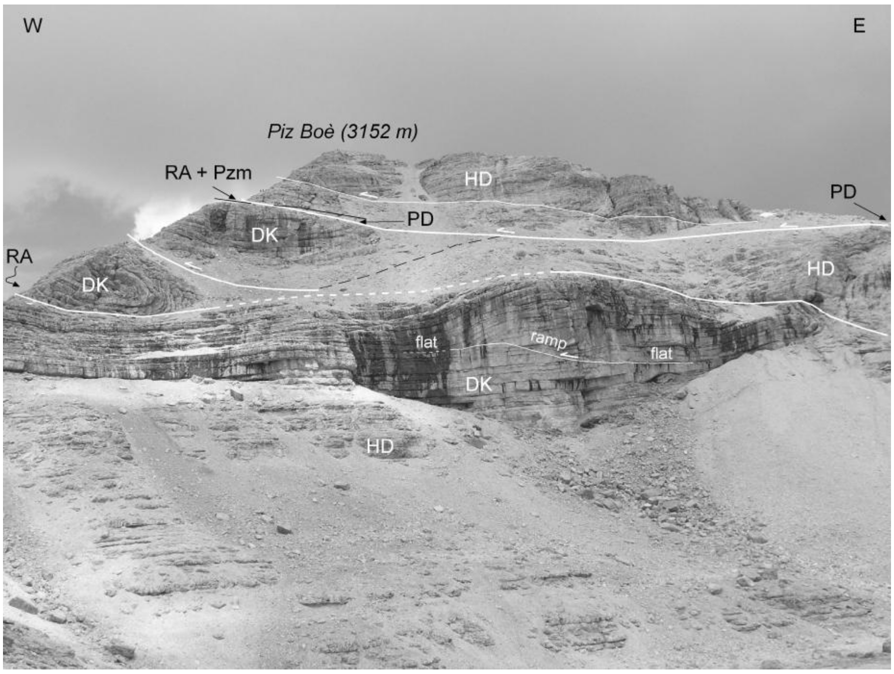


Fig. 25
Foto and line drawings of the southern flank at Piz Boè showing a stack of W vergent thrust slices. PD = Pordoi Fm, HD = Hauptdolomite, DK = Dachstein Limestone, RA = Rosso Ammonitico, Pzm = Puez Marls.

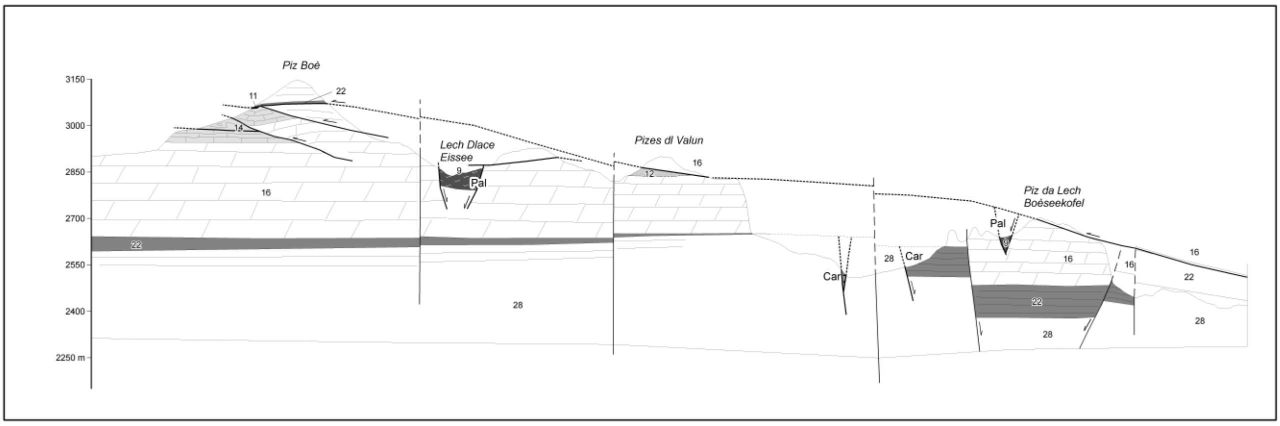


Fig. 26
Geologic cross section of the Piz Boè-Piz da Lech overthrust sub-parallel to the Dinaric NE-SW directed compression. The footwall is dissected by numerous steeply dipping normal faults of Carnian (Car) and late Cretaceous?-Paleogene (Pal) age with the formation of graben structures. Note the strong thickness variation of the Carnian Pordoi Fm ("Raibl beds"). At Pizes dl Valun the thickness of the Hauptdolomit/Dolomia Principale is distinctly reduced due to an erosional surface of probably Jurassic age. Based on this cross section the transport width of the uppermost slice of Hauptdolomit from the eastern side of Piz da Lech to Piz Boè is at least 3 km.
28 = Selladolomite Subgroup (= Cassian Dolomite in the present case), 22 = Pordoi Fm, 23 = breccias (Pordoi Fm), 16 = Hauptdolomit/Dolomia Principale, 14 = Dachstein Limestone, 12 = Gardenacia Fm (breccias, dolosparites), 11 = Rosso Ammonitico, 9 = Puez Marls.

DAY 5

Middle Triassic plutons of Predazzo and its contact aureole; dinosaur tracksite of Rovereto; glacier mills (moulins) of Nago

Excursion route: From Passo Pordoi to Predazzo (40 km), Rovereto (100 km) and the Val di Concei (42 km)

Stop 5.1 – 5.3 The Middle Triassic plutons of Predazzo and its contact aureole
Stop 5.4 – The dinosaur tracksite of Rovereto
Stop 5.5 – The glacier mills (Moulins) of Nago and glacial history
Stop 5.6 – Molino di Ledro: History of a hanging valley and the Garda Valley

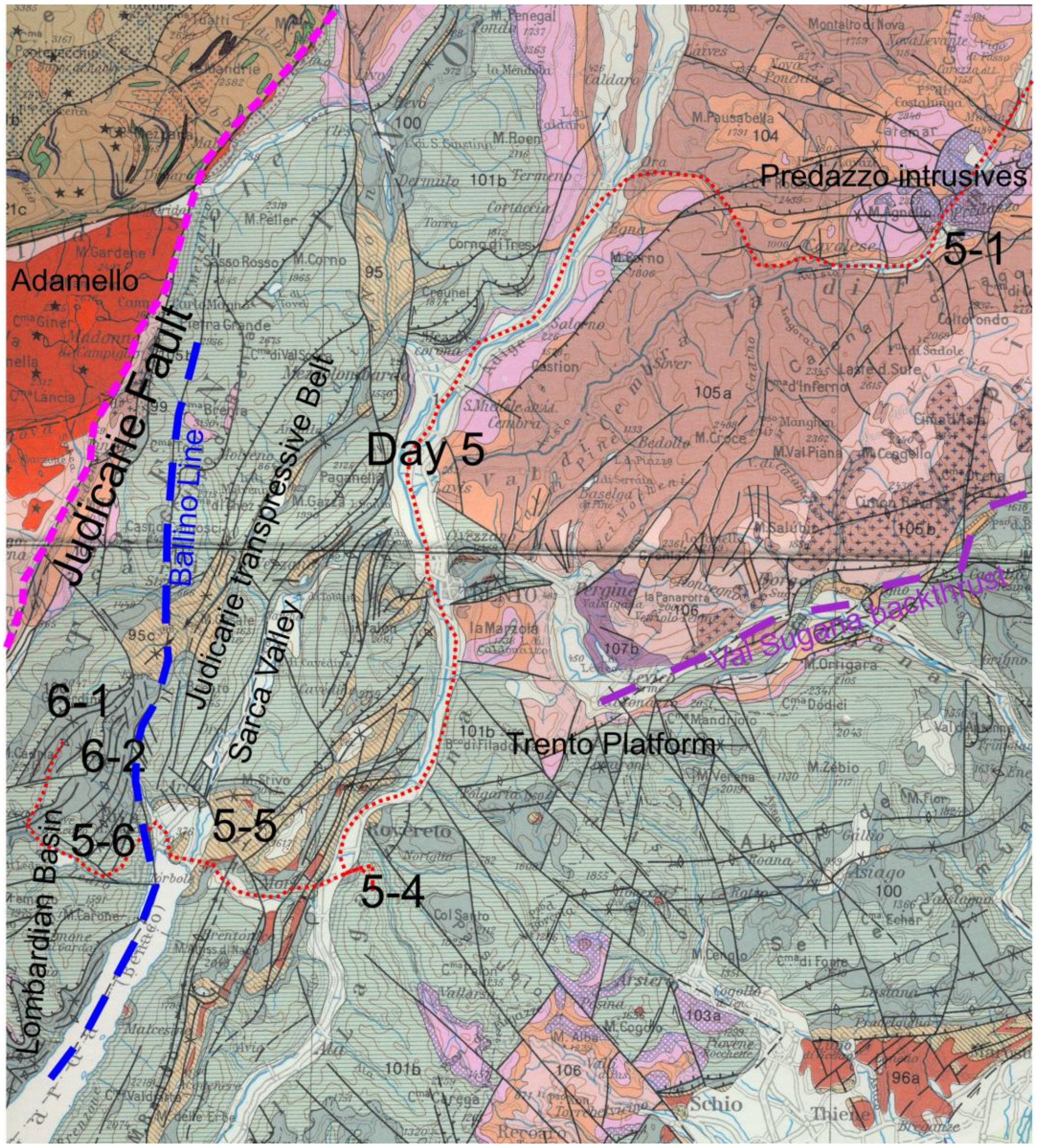


Fig. 5-1: Excursion route of Day 5 and 6.
Geology from Structural model of Italy, 1:500.000 CNR, 1983

Stop 5.1: Bridge north of Predazzo: 46° 19´53´´ N; 11° 36´15´´ E

The Middle Triassic monzonitic intrusion of Predazzo and its thermometamorphic aureole, W. Dolomites, Northern Italy.

The intensive Ladinian magmatism of the Dolomites with volcanics and dikes comprises also the two small (4 x 5,5 and 5 x 2 km) intrusions of Predazzo and Monzoni. In 1820 Marzari-Pencati discovered on the Canzoccoli slope SW of Predazzo magmatic rocks cross-cutting the Permian and Triassic platform carbonates. This convincing field evidence briefly contributed to the settling of the dispute between plutonists and neptunists in favour of a melt origin of the magmatic rocks. The Predazzo intrusion forms two mappable features: an outer ring of monzonitic rocks and an inner halfring of granite (Vardabasso, 1930). The monzonitic rocks comprise according to Lucchini, Rossi & Simboli (1982): monzodiorite, monzonite as the principal rocktypes and monzogabbro, diorite, gabbro, olivine-gabbro, clinopyroxenite in smaller fractions. Textures, rock and mineral compositions establish these series to be the result of low pressure fractionation and cumulation processes as was shown for the Monzoni intrusive complex by Masch & Huckenholz (1993) and Bonadiman et al. (1994). The rocks of both intrusives fit well into the calc-alkalic and shoshonitic geochemical pattern of the Ladinian volcanics (Petersen et al., 1980). The Predazzo intrusion complex was dated by Rb/Sr to 217-230 my, and by U/Pb by Mundit et al. (1996) and 40Ar/39Ar (Laurenzi & Visona, 1996) to 232-238 my, these ages fit well to the upper Ladinian-Lower Carnian stratigraphic age of the volcanics.

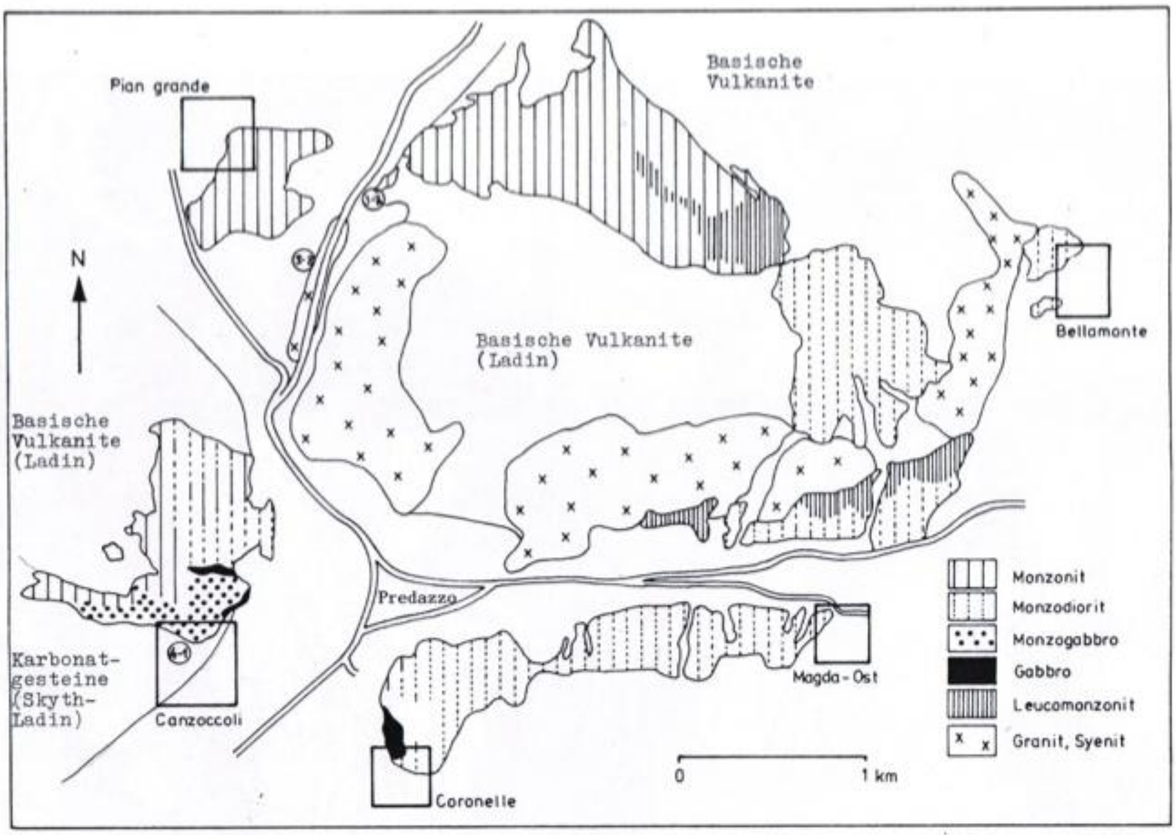


Fig. 5-2a Intrusive rocks around Predazzo (Lucchini & Simboli 1972, Inderst 1987)

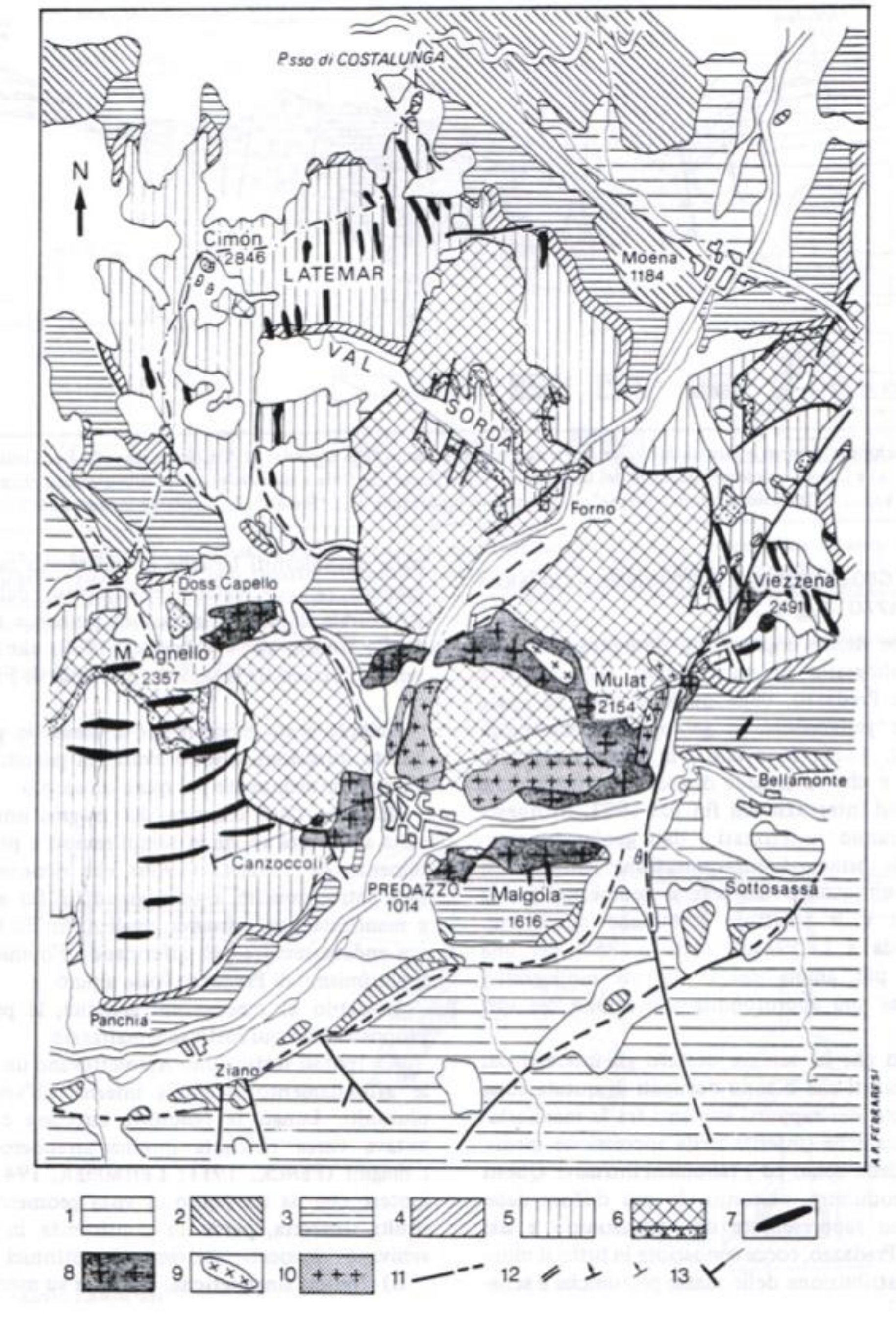


Fig. 5-2b: Geology of the Fassa Valley: 1. Quartz porpyry (Permian); 2. Val Gardena sandstone; 3. Werfen beds: sandstones, conglomerates and limestones (Scythian, Anisico); 4. dolomites and Limestones (Anisian); 5. platform carbonates (Latemar limestone) (Ladinico); 6. explosion breccias and mafic lavas (shoshonitic); 7. dikes; 8. monzonitic intrusives; 9. sienites; 10. granitie 11. faultd; 12. strike and dip; (from Castellarin et al. 1982).

Stop 5- 2 Canzoccoli 46° 18´ 32´´ N; 11° 35´21´´ E;

The shallow Predazzo intrusion caused extensive low pressure (500 bar) and high-temperature (800°C) contact metamorphism on regional sedimentary and volcanic rocks. Best outcrops are in the carbonate rocks at the two localities Canzaccoli and Malgola which show the thermometamorphic assemblages of high-temperature decarbonation reactions. Two rock compositions can be distinguished: the pure dolomites of Anisian Sarl formation and the siliceous carbonates of strata in Scythian Seiser and Campiller formations (Brandner & Mostler, 1982). Pure dolomite reacted to periclase + calcite+ CO_2, periclase is replaced by brucite on cooling, the latter occurs in idiomorphic pseudomorphs, that preserve the cubic symmetry of periclase. Periclase is only preserved in tiny inclusions in calcite (Inderst, 1987, Ferry et al. 2002). In siliceous carbonates the sequence of metamorphic zones involve the formation of tremolite, forsterite, diopside, wollastonite, monticellite, melilite. Endo- and exoskarns with formation of massive plebs of calcsilicates with fassaites, vesuvianites, Ca-garnets are found at the immediate intrusive contact.

Stop 5-3: Geological Museum of Predazzo
It shows fossils and the famous contact minerals from the Predazzo area, and the Guest book of the Nave d´Oro Guesthouse, in which scientists like Alexander von Humboldt and Leopold von Buch have left their signature and where the first International Geological Congress was held in 1903.

Reverences for Predazzo:

Avanzini,M.& Petti, F.M. 2008 Updating the dinosaur tracksites from the Lower Jurassic Calcari Grigi Group (Southern Alps, Northern Italy), Studi Trent. Sci. Nat., Acta Geol., 83 (2008): 289-301 ISSN 0392-0534

Avanzini M., Piubelli D., Mietto P., Roghi G., Romano R. & Masetti, D., 2006 - Lower Jurassic (Hettangian-Sinemurian) Dinosaur Track Megasites, southern Alps, Northern Italy. In: Harris J.D., Kirkland J.I. & Milner A.R.C. (eds), "The Triassic-Jurassic Terrestrial Transition". New Mex. Mus. Nat. Hist. Sci. Bull., 37: 207-216.

Bassetti, M & Borsato, A., 2007 Evoluzione geomorfologica della Bassa Valle dell'Adige dall'Ultimo Massimo Glaciale: sintesi delle conoscenze e riferimenti ad aree limitrofe. Studi Trent. Sci. Nat., Acta Geol., 82 (2005): 31-42

Bonadiman, C.M.; Coltorti & F.Siena (1994) Petrogenesis and T-fO2 estimates of Mt. Monzoni complex (Central Dolomites, Southern Alps): a Triassic shoshonitic intrusion in a transcurrent geodynamic setting. Eur. J. Mineral. 1994, 6, 943-966.

Brandner R. & H. Mostler (1982) Exkursionsführer. Jahrestagung der Österreichischen Geologischen Gesellschaft, Seis am Schlern, Südtirol 1982.

Castellarin, AQ. 1982, Tettonica sinsedimantaria ed associazioni di facies carbonatiche (con principali riferimenti al Giurassico Sudalpino): in Castellarin, A and Vai G.B., Guida alla Geologia del Sudalpino Centro – Orientale, 23-40

Ferrari, A. 1982: Geologia del Monte Giovo (Versante settentrionale del Monte Baldo – Trentino). – In: Castellarin, A and Vai G.B., Guida alla Geologia del Sudalpino Centro – Orientale, 67-77.

Ferry J.M., B.A. Wing, S.C. Penniston-Dorland, D. Rumble III. (2002) The direction of fluid flow during contact metamorphism of siliceous carbonate rocks: new data for the Monzoni and Predazzo aureoles, Northern Italy and a global review. Contr. Mineral. Petrol. 142: 679-699.

Geyer, O.F. 1993, Die Südalpen zwischen Gardasee und Friaul. Sammlung Geologischer Führer Nr. 86; Gebr. Bornträger, Stuttgart, 576 p.

Inderst, B.(1987) Mischkristalle und fluide Phase (H2O-CO2) bei Hochtemperatur-Dekarbonatisierungsreaktionen in zwei Thermoaureolen (Predazzo, Monzoni).215p.Diss. Univ.München.

Laurenzi M.A., Visona, D. (1996) 40Ar/39Ar chronology of Predazzo magmatic complex (Southern Alps, Italy). Geologia delle Dolomiti, 78a Riunione Estiva. Societa Geologica Italiana, Bologna.

Lucchini F., P.L. Rossi &G. Simboli (1982) Il magmatismo triassico dell'area di Predazzo (Alpi Meridionali, Italia).In: A.Castellarin & G.B. Vai(a cura di): Guida alla geologia del Subalpino centro-orientale. Guide geol. reg. S.G.I. 221-229, Bologna.

Marzari Pencati G. (1820) Notizia sopra un granito in massa terziaro sovrapposto al calcare secondario nel fiume Avisio. Supplemento al " Nuovo Osservatorio Veneziano" n. 118-127.

Masch L., Huckenholz H.G. (1993) Der Intrusivkomplex von Monzoni und seine thermometamorphe Aureole. Beih. Eur.J.Mineral. 5, 81-135.

Mundil R., Brack P., Laurenzi M.A. (1996) High resolution U-Pb single zircon age determinations: new constraints on the timing of Middle Triassic magmatism in the Southern Alps, Geologia delle Dolomiti, 78a Riunione Estiva.Societa Geologica Italiana, Bologna.

Oppel, A. 1863_ Über das Vorkommen von jurassischen Posidonomyen Gesteinen in den Alpen.- Zeitschr. deutsch. geol. Ges. 15, 188-217.

Peterson J.S., Morten L., Simboli G., & Lucchini F. (1980) Ree abundances in the Predazzo-Monzoni intrusive complex, Dolomites, North Italy. Riv.Ital. Paleont.Strat., 85, 3-4, 1065-1080.

Scheuber M.: Zur Geologie der Bergsturzmassen im unteren Sarca-Tal; Arb. Inst. Geol. Paläont. Univ. Stuttgart, 1988.

Vardabasso S., (1930) Carta geologica del territorio eruttivo di Predazzo e Monzoni nelle Dolomiti di Fiemme e Fassa. A colori, alla scala 1:25000 "R. Scuola d' Ingegneria", Padova.

The Southern Alps

Stop 5-4: Dinosaur tracks of Rovereto – Lawini di Marco. By car from Predazzo via Cavalese, Segonzano, Trento to Rovereto and Marco to the Parking of the trail of the Lawini di Marco (99 km):

Dinosaur tracks are known in the Trentino from 11 different locations. They are all situated within the early Jurassic grey limestone group the "Calcare Grigi" (Avanzini und Petti 2008). The Calcare Grigi reach more than 400 meters in thickness and its shallow water limestones were deposited under subtidal, intratidal or supratidal conditions on the Trento Platform, which was connected to Gondwana.

From the Trento plateau, large masses of limestone were exported to the Belluno Basin to the East and to the Lombardian Basin to the West. Here, the pelagic limy mudstones interfinger with calcturbidites from the platform (Castellarin, 1982; Avanzini et al. 2006). Deep fissures filled with clastic material and fossils are found along the platform rim (Terlago, Castione, Rifugio Lancia and others). At cCastione, a several meters wide fissure is filled with a lumachella of Bositra buchi (the former Posidonia) (Oppel, 1863; Geyer 1993, Ferrari, 1982).

The largest and most important outcrop is found to the south of Rovereto at the western slope of Monte Zunga near Marco. A bedding plane of ~ 300.000 m² became exposed due to a medieval landslide.

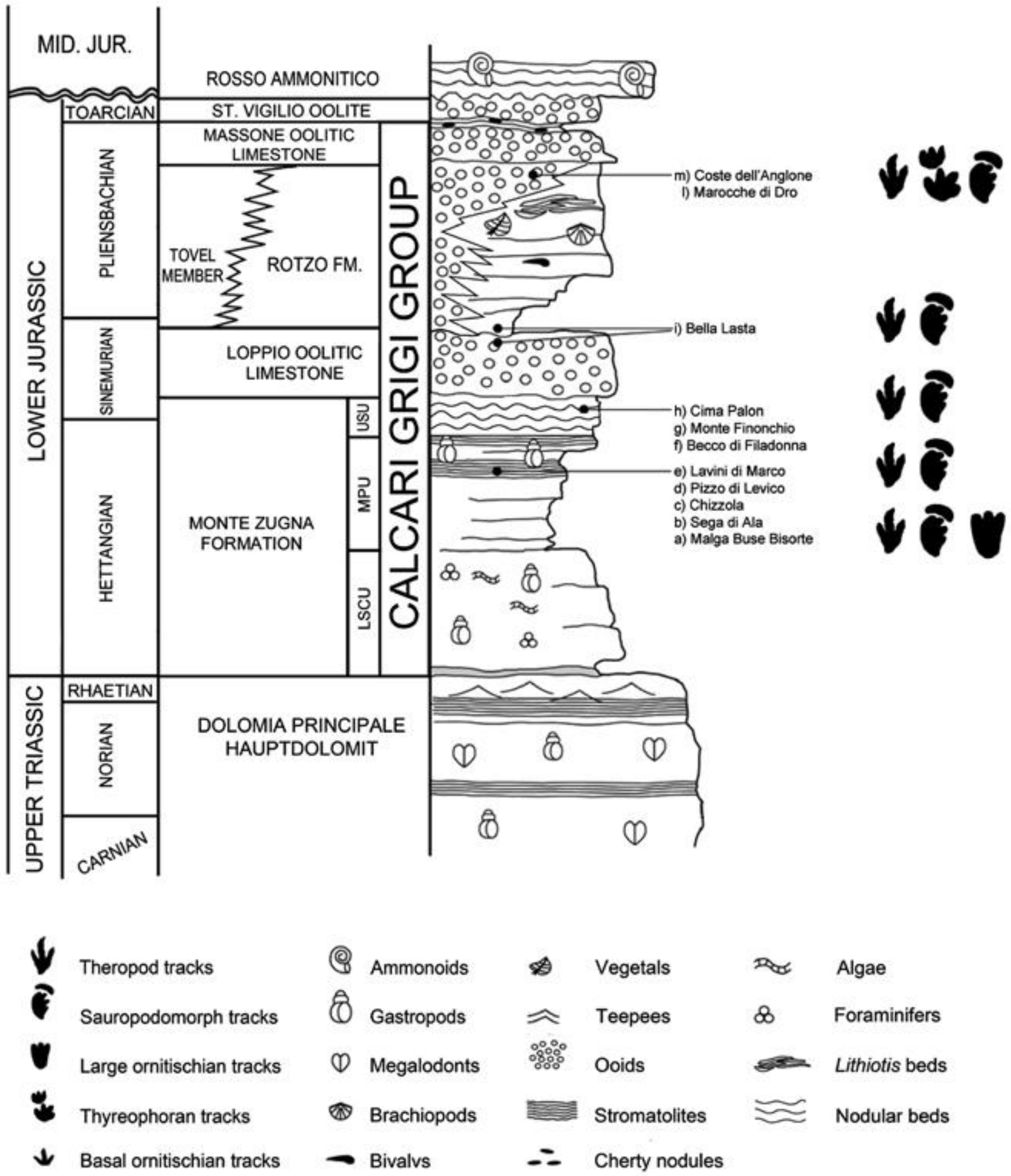


Fig. 5-3. The Calcari Grigi group and its formations and members, (from Avanzini and Petti, 2008).

The Calcare grigi overly the late Triassic dolomia principale formation and encompass the entire Liassic period. The Monte Zunga formation starts with thick-bedded grey subtidal limestones. The thinly bedded intratidal middle part contains most of the tracks and grades into an upper Member, again subtidal in character and scarce tracks.

At the outcrop of the Lawini di Marco we find stromatolites within the thin marly beds, which point to shallow water in a tropical lagoon, which fell dry during low tides. This is confirmed also by desiccation cracks, which show, that the area could also be exposed for longer periods. The upper part contains oolithic limestones from subtidal dunes or mega ripples in moving water

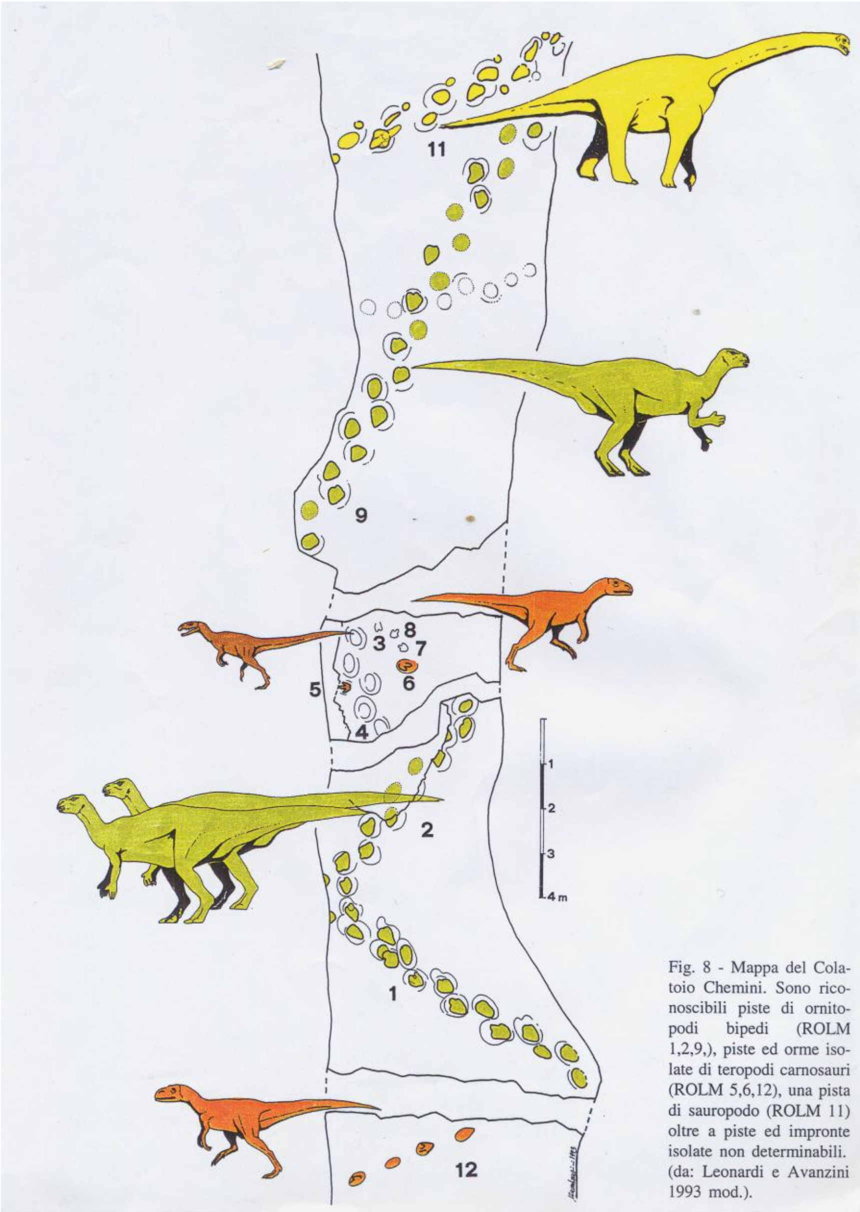


Fig. 5-4. The tracks of ornitopod predator dinosaurs with three toes at ROLM 1,2, and 9 and vegetarian sauropodes with four toes and elefant-like tracks at location ROLM 11 (ROLM = Rovereto Lawini di Marco Location). After Leonardo and Avanzini, 1993).

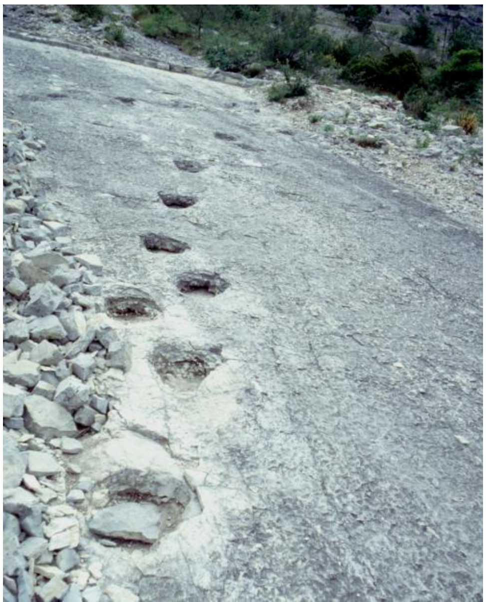


Fig. 5-5. Sauropode track of ROLM 9

Stop 5-5: Marmite dei Giganti of Nago.
From Marco we pass through the Valle di Loppio to the Passo San Giovanni. Under the Loppio Valley, a water tunnel runs over 10 kilometers from Mori near Rovereto to Torbole to feed the Lake of Garda with water from the Adige River and to protect Verona and adjacent areas from inundations. The tunnel was finished in 1959, but as a consequence, the Lago di Loppio lost its water into the tunnel and fell dry. After Loppio, we climb up to the Passo San Giovanni (285 m), which became famous because in 1493 the Venetians transported a fleet by help of 400 bulls over the pass and defeated the fleet of the Milan Visconti. Since that time, the southern part of the Lake of Garda belongs to the Province of Venice.
Parking in Nago. We follow a path through Olive Gardens to the Marmite dei Giganti, large glacier mill potholes within Late Eocene fossil rich limestone. Corals, nummulites, discocylina, algae (dasycladacea), gastropods, bivalvia, serpulae, may be found herein. Here in Nago, a transfluent branch from the Adige glacier flew over the Passo San Giovanni. The topographic relief caused stationary crevasses within the ice and the summer meltwaters fell in vortices at the Ice-rock contact and the sands and rocks modelled the impressive glacier Mill potholes within the limestones.

Fig. 5-5: Marmite dei giganti of Nago, carved into Eocene limestone

DAY 6
In a whole day mountain tour we investigate the margin of the Lombardian basin and it´s filling by calc-turbidites and megabreccias from the Trento platform along the Ballino line escarpment, which formed in the course of the opening of the Alpine Tethys in Liassic times.
Hint: You will need your mountain boots and sun/cold/rain protection, lunch and water!!

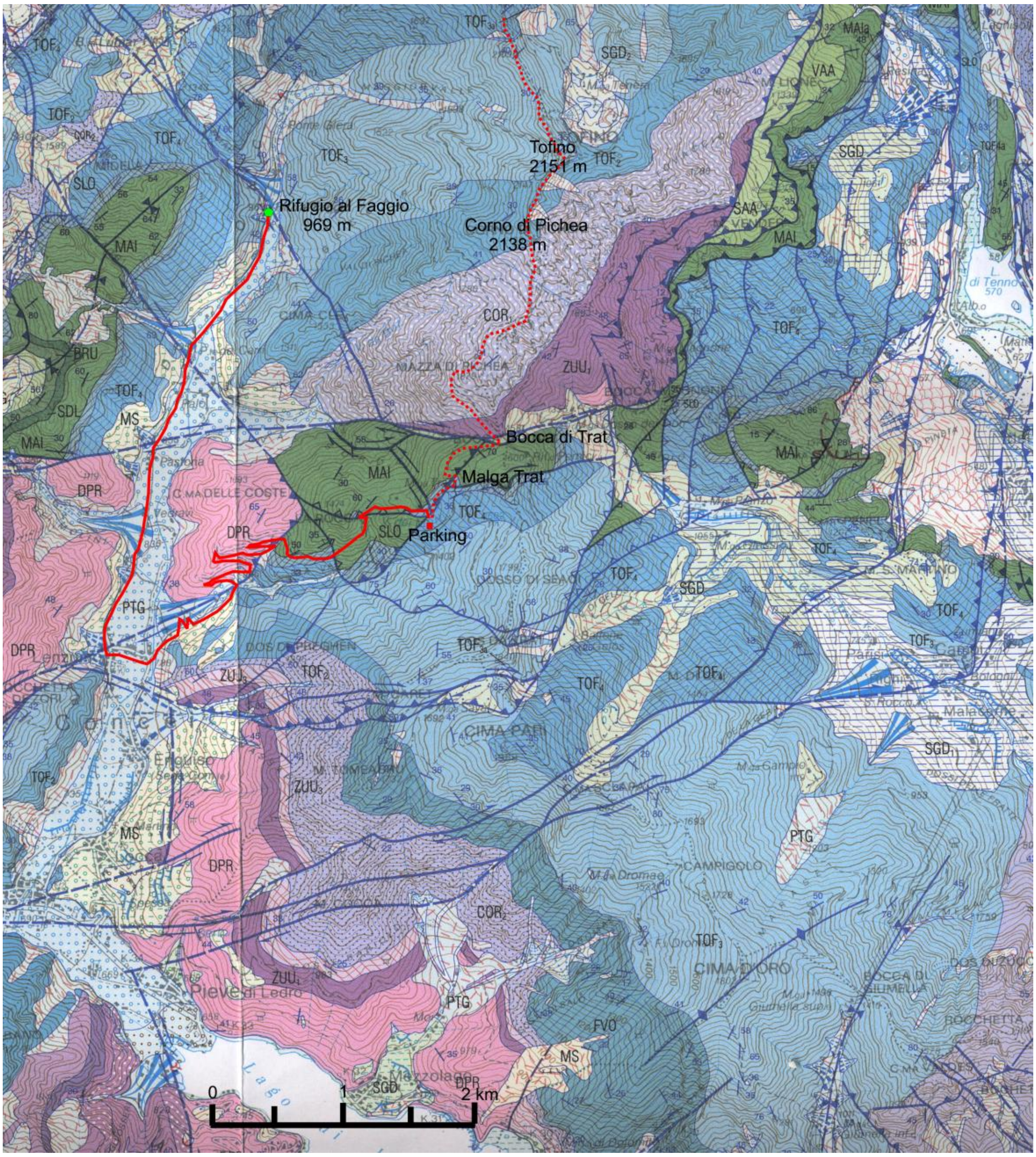


Fig 6-1: Geologic map of Riva, 1 : 50.000 - the Val Concei sector and route of day 5 (solid line = by car; dotted: mountain trail). Explanation of relevant formations: DPR = dolomia principale; ZUU = Calcare di Zu; COR = Corna; TOF = Tofino formation; Mai = Maiolica; (after Carta Geologica d´Italia, 1: 50.000, Foglio 080 Riva del Garda; 2005; Coordinatore: A. Castellarin)
Excursion route: From Rifugio al Faggio to Lenzumo and to Malga Trat (Parking). From here along a small mountain trail to Mazza di Pichea, Tofino to Bocchetta di Slavazi. A whole day mountain trip along the former Austrian-Italian border and war front of 1914-1918.

Stop 6.1: By car to the Malga Trat, ascent on a mountain path to the Mazza di Pichea –Tofino (2151m) and Bocchetta di Slavazi (this is an all day mountain hiking tour, ca. 800 m difference in altitude.).
Description: The route starts in the late Triassic Dolomia principale formation (ascent by car), a light coloured dolomite with stromatolites and storm beds. The road crosses at 1170 meters altitude an east-west striking dextral strike slip fault which continues to the Bocca di Trat where it bends to the north and changes into a thrust fault. To the south of the fault the Early Cretaceous Majolica

formation occurs. Calcareous mudstones with black chert nodules and thin blackshale horizons are well bedded and contain radiolarian and lamellaptychus punctatus. A slump horizon occurs near the base. The contact to the red radiolarites beneath shows a tectonically and by slumps overprinted surface. A breccia of radiolarites indicates a fault scarp nearby. The Maiolica is overlain by red nodular limestone (Ammonitico rosso) and grey Scaglia at the Bocca di Trat.

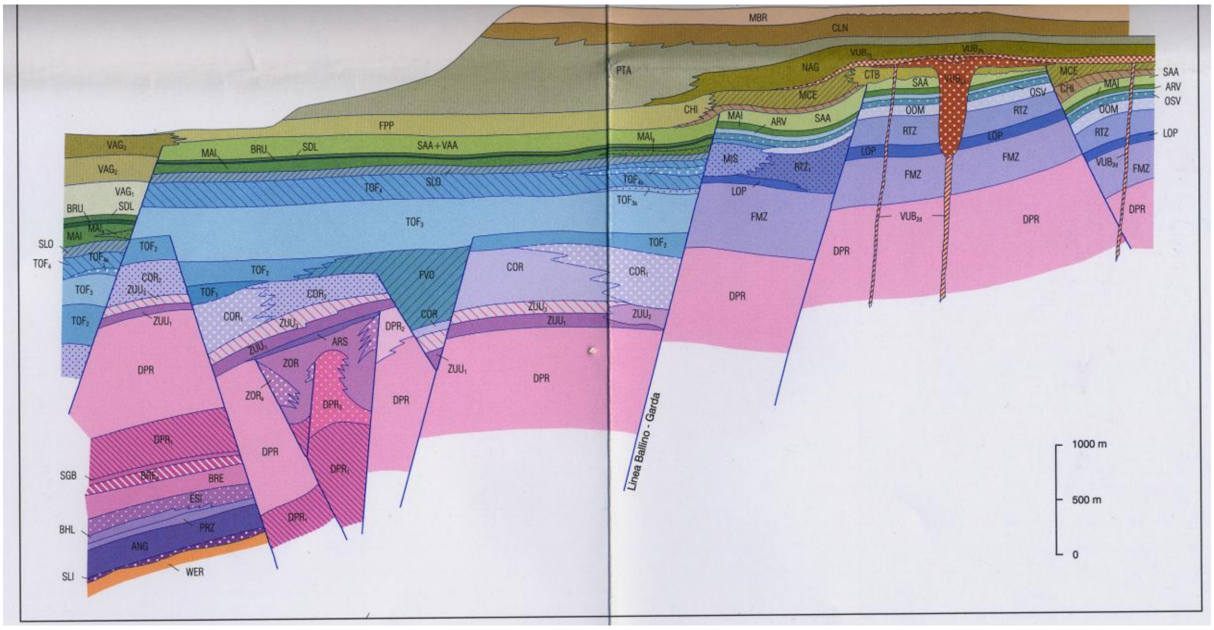


Fig. 6-2: Stratigraphic sceme of the margin of the Lombardian basin and the Trento high. reddish and pink colours: Triassic; blue = Jurassic; green = Cretaceous (after Carta Geologica d´Italia, 1: 50.000, Foglio 080 Riva del Garda; 2005; Coordinatore: A. Castellarin)

Stop 6.2: The ascent to the Mazza di Pichea leads through Corna, a mostly saccharoid whitish and thickbedded dolomite of Early Jurassic age. Some tenth of meters beneath the summit of the Corno di Pichea the rock becomes gradually calcareous and fossil rich (Corals, brachiopods, crinoids). At the crest the Tofino formation starts with well bedded fetid limestones and thicker oolithic turbidites, where the ooids are embedded into calcareous mudstone. They clearly are shed from the shallow water platform to the east.


Fig. 6-3: Mountain trail at Corno di Pichea and the Liassic Tofino formation with turbidites bringing ooids into the basin.

Fig 6-4: Thick coarse grianed calc-turbidites with fossil detritus were brought into the Lombardian basin. On top: Megabreccia.

Fig. 6-5: Megabreccia horizon at the crest north of Tofino with strategic cave from the 1st world war.

Fig. 6-6: Channel eroded into Liassic Tofino formation and filled with coarse fossil detritus.

Stop 6.3: Coming into younger units, submarine slumps become more and more evident and frequent. Coarse fossil debris of mainly crinoids and brachiopods form bottom parts of turbidites and channel fillings. Several horizons of megabreccias up to km³ in size indicate the closeness of the fault scarp of the Ballino line. At the western side of the Val Concei most of these megabreccias and turbidites are not anymore present.
Increasing chert content and, finally, radiolarites indicate successively deeper subsidence of the basin by tectonic processes.

DAY 7
Glacial morphology and history of the Lake Garda, landslides of the Sarca Valley

Excursion route: From Rifugio al Faggio to Molina di Ledro – Pregasina - Sarca – Brennero - Innsbruck - Munich

Stop 7-1: Molina di Ledro Museo Palefitte, glacial history of the Ledro Valley and its Neolithic habitants (optional stop)

Stop 7-2: Pregasina scenic view: We continue trough Torbole and Riva via a large tunnel to Pregasina. From the large Madonna monument, we have a spectacular panoramic view over the Lake, the Monte Baldo Massive and the Judicaria fold and thrust belt.
History of the Lago di Garda: During the Messinian event, when the Mediterranean dried out for a period of 400.000 years, deep V-shaped valleys were cut back into the Alps. The base of the Gardalake lies at -1700 meters at its southern end and near its northern part still ~ 700 meters. After refilling of the Mediterranean, a marine ingression into these fjord-like valleys followed. Delta sediments filled the fjords, but during the great ice ages the Garda-glacier eroded deeply the poorly consolidated sediments. Today, the floor of the Garda Lake is still more than 300 meters beneath sea level.

Fig. 7-1: View from Pregasina northward to (from the left) Monte Misone, the tilted Neogene strata of the Monte Brione between Riva (left) and Torbole (right) in front of the Monte Stivo and Monte Bondone (background to the right).

Stop 7.3: Sarca landslide near Dro: The Holocene is characterized by large landslide episodes, in the Adige and in the Sarca valleys, with different phases around 6500, 4700, 2200 and 1000 cal. years BP (Bassetti, M & Borsato, A. 2007). After overdeepening of the Sarca valley by glaciers, three large landslides came down from the Monte Brento (1544 m) and Monte Casale (1632 m). In total, a volume of ca. 1 km³ dammed the Sarca valley in postglacial times and caused the Cavedine lake. The huge masses of coarse blocks are habitat for many seldom plants and animals (vipers, emerald lizards etc.).

Selected references

Brack, P., Rieber, H. & Nicora, A. & Mundil, R. (2005) The Global boundary Stratotype Section and Point (GSSP) of the Ladinian Stage (Middle Triassic) at Bagolino (Southern Alps, Northern Italy) and its implications for the Triassic time scale. *Episodes*, **28 (4)**, 233-244.

Brandner, R. & Keim, L. (2011) Geotrail Bula – Pufels – Bulla. Amt für Geologie & Baustoffprüfung/Ufficio Geologia e prove materiali, Autonome Provinz Bozen-Südtirol/Provincia Autonoma di Bolzano-Alto Adige, 44 pp.

Brandner, R., Gruber, A. & Keim, L. (2007) Geologie der Westlichen Dolomiten: von der Geburt der Neotethys im Perm zu Karbonatplattformen, Becken und Vulkaniten der Trias. *Geo.Alp*, **4**, 95-121.

Brandner, R., Horaceck, M., Keim, L. & Scholger, R. (2009) The Pufels/Bulla road section: deciphering environmental changes across the Permian-Triassic to the Olenekian by integrated litho-, magneto- and isotope stratigraphy. A field trip guide. *Geo.Alp*, **6**, 116-132.

Carta Geol. d'Italia (2007) ISPRA - Servizio geologico d'Italia, Foglio 026 "Appiano-Eppan", 1:50.000, Roma.

Carta Geol. d'Italia (2010) ISPRA - Servizio geologico d'Italia, Foglio 013 "Merano-Meran", 1:50.000, Roma.

Farabegoli, E., Perri, C. M. & Posenato, R. (2007) Environmental and biotic changes across the Permian-Triassic boundary in western Tethys: The Bulla parastratotype, Italy. *Global and Planetary Change*, **55**, 109-135.

Geologische Karte der Westlichen Dolomiten 1:25.000. (2007), Autonome Provinz Bozen – Südtirol, Amt für Geologie & Baustoffprüfung, Bozen/Kardaun.

Krainer, K. (1989) Composition and evolution of Lower Permian molasse sediments (Ponte Gardena Conglomerate) at the base of the Bolzano Volcanic Complex, Southern Alps (N Italy). *N. Jb. Geol. Paläont. Mh.*, **7**, 400-424, Stuttgart.

Mostler, H. (1982) Bozener Quarzporphyr und Werfener Schichten. In: Mostler, H. (Ed.), Exkursionsführer zur 4. Jahrestagung der Österreichischen Geologischen Gesellschaft, 43-79, Innsbruck.

Mundil, R., Pàlfi, J., Renne, P.R. & Brack, P. (2010) The Triassic timescale: new constraints and a review of geochronological data. In: Lucas, S.G. (ed) The Triassic Timescale. *Geol. Soc. London Spec. Publ.*, **334**, 41-60.

Scholger, R., Mauritsch, H. J. & Brandner, R. (2000) Permian-Triassic boundary magnetostratigraphy from the Southern Alps (Italy). *Earth and Planetary Science Letters*, **176**, 495-508.