Guidebook: Geological excursion through the Alps (München – Belluno)
11. – 25. July 2008

Guides:
Bernd Lammerer & Petra Veselá

Guest guide (day 1):
Uli Haas (LFU)

Participants

Aubele Katharina - Baran Ramona - Carena Sara - Friedrich Anke - Rieger Stefanie - Vesela Petra
Elkhashab Mohamed - Flerit Frederic - Kübler Simon - Lammerer Bernd - Meyer, Rolf - Pohl, Stefan – Söllner Frank - Wan Bo
part time: Guest Bernhard - Suppe John - Melbourne Tim

Departure: 11. July: 08.^{00} at the parking court of Institute; **Return:** 25. July 19.^{00}

The excursion runs roughly along the Transalp profile, where in 1999 – 2002 geophysical studies had been carried out (Vibroseismics, explosion seismics, receiver function studies, tomographic studies, gravimetry). Therefore, we can compare surface and deep structures.

Accomodations in mountain huts or youth hostels. Longer walks in rocky areas included. Driving with busses of the University car pool.

Program
(may be modified depending on weather conditions):

Fri. 11. 7. By car: München - Frasdorf – Spitzingsee. Ascent by cable car to the Taubensteinhaus – walk to the Rotwand and Rotwandhaus 1737 m
Helvetic zone: Eocene l*ithothamnia* limestones, slump structures and *nummulite* marls in the Rohrdorf concrete quarry; millstone quarry; Synclinorium of the Northern Calcareous Alps, Triassic -Jurassic reef and basin sediments. Guide: Dr. U. Haas (Landesamt f. Umwelt).
Accomodation: Rotwandhaus: Peter Weihrer, fone: 08026 / 7683; fax: 08026 / 7683

Sat. 12. 7. Descent and walk through the Valepp valley to Kaiserhaus (~20 km): Cross section through the Northern Calcareous Alps; the Wamberg Anticline, late Triassic neptunian dikes, submarine slumps in the Lower Jurassic coloured Limestones and cherts, Aptycha marls, Guffert thrust over Cretaceous sediments, two Late Cretaceous basins (Gosaubecken) with terrigene clastics, fluvial conglomerates, and marine strata, Cretaceous folds in the Wetterstein limestone.
Accomodation: Kaiserhaus Telefon 0043-5331-5271 (Wirt: G.J. Mitteregger).
***Bad* weather alternative:** by car from Spitzingsee to Kaiserhaus, from there walk to Kaiserklamm

Sun. 13. 7. Kaiserhaus – Brandenberg – Kramsach - Wattens – Lizumer Hütte 2019 m (Ü):
by car: Brandenberg Gosau sediments, of the southern Gosau basin with rudist reefs und Actaeonella limestones, Inntal-Tertiary. **Afternoon**: ascent through the Quarzphyllite zone (2 h) to the Lizumer Hütte.
Accomodation Lizumer Hütte Telefon +43/5224/52111 (valley number**)** +43/5223/56209, Telefon Mobil + 43/664/2308516; fax (hut) +43/5224/52111; Email info@lizumerhuette.at

Mon. 14. 7. walk in the surrounding of the Lizumer Hütte (Ü) and Reckner (2886 m)**:** Tarntal Mesozoic, high pressure metamorphism, Reckner serpentinite – Hippold – Breccianappe, coloured Mélange zone. Guide: P. Veselá, B. Lammerer; **Accomodation Lizumer Hütte**

Tue. 15. 7. walk Lizumer Hütte – Junssee – Geier 2.857m to Tuxer Joch Haus 2.313m, (06:^{30} h), Geyer serpentinite, Mylonites, contact Austroalpine nappes to Penninic nappes, Triassis slices as thrust horizon markers. Guide: P. Veselá, B. Lammerer. **Accomodation Tuxer Joch Haus** telefone: 05287 87216 (Info & Fax: 05285 64555). ***Bad* weather alternative:** by car to Hintertux, by cable car to Tuxer Joch, geology close to hut.

Wed. 16. 7. Tuxer Joch - Tuxerferner – Spannaglhaus 2531 m, (Ü): walk through Penninc nappes, ductile folding and backfolding, Zentralgneis thrust over Hochstegen limestone, deformed conglomerates. Guide: P. Veselá, B. Lammerer, **Accomodation Spannaglhaus** fone +43/5287/87707; Fax +43/5287/86162

Do. 17. 7. Descent to Hintertux, by car to Jenbach – Innsbruck – Brenner – Pfitsch Valley: Brenner fault, Pfitsch landslide, Aigerbach formation. Guide: P. Veselá, B. Lammerer
Accomodation Pfitscher Joch Haus (Sepp Volgger) fone 0039 0472 630119

Fr. 18. 7. around Pfitscher Joch Haus (Ü): Zentralgneis – old roof rocks, Greiner shear zone, Granite porphyry dike, prolate amphibolites, conglomerates (prolate and oblate), Metarhyolite, metamorphic playa sediments, Aigerbach syncline. Guide: P. Veselá, B. Lammerer, **Accomodation Pfitscher Joch Haus**

Sa. 19. 7. by car to Kematen, ascent Burgum - Sterzinger Hütte – Sandjoch 2642 – Brixener Hütte 2307 m (Ü): 6 h walk throug Bündnerschiefer, prasinites and serpentinites (with large zirkon cryistals), **Accomodation Brixener Hütte** Fam. Oberhofer Tel. 047254 71 71 , Telefon Hütte: 0472 54 71 31. ***Bad* weather alternative:** by car to *Vals – Ochsensprung, 2 h ascent to Brixener Hütte).*

So. 20. 7. Ochsensprung – Vals – Jugendherberge Brixen, (Ü): Contact Tauern window - old crystalline gneisses with alpidic dikes – Rensengranite – Pustertal line, Brixen granite.
Accomodation Jugendherberge Brixen Brunogasse 2, I-39042 Brixen Tel. +39 0472 279 999, Fax +39 0472 279 998, E-Mail: brixen@jugendherberge.it

Mo. 21. 7. Brixen – Waidbruck – Kastelruth – Pordoi Joch: transgressive contact quartzphyllite – Waidbruck conglomerate, Bozen Quarzporphyry, Geologic trail to Seiser Alm, Werfener and Buchensteiner formations, Reef – basin relations, Triassic volcanism From Pordoi Pass ascent with cable car to Cima Pordoi, walk to Boe Hütte 2873m (1 hour) **Accomodation Boe Hütte fone 0039 0462 847303**

Di. 22. 7. Ascent to Piz Boe 3152m - Rifugio Passo San Nicolo 2340 m
"Gipfelfaltung" peak-folds and thrusts of the Sella, descent to Pordoi, by car to Valle San Nicolo, ascent to Passo San Nicolo. Afternoon: ascent to the psso. San Nicolo: Spectacular folded Bellerophon formation (Permian), Triassic volcanism, Marmolada overthrust **Accomodation Rifugio Passo San Nicolo** Tel: 0462/763269

Mi. 23. 7. by car to Moena, Passo Pellegrino, Cencenighe, to Agordo Triassic volcanism monzonite type locality, contac tmetamorphism of Predazzo (famous because of the dispute between plutonists and neptunists), Val Sugana thrusts and copper ore deposits; Cambrian phyllites
Accomodation Youth hostel Le Miniere - 32020 Rivamonte Agordino (BL); Cell. 329/2105989; E-mail: ostelloimperina@dolomitipark.it

Do. 24. 7. Mas – Bolago – Tisoi - Agordo (Ü): southern Molasse, condensed strata with sharc teeth, frontal monocline, Val Medon: Triassic – Jurassic formations of the Southern Alps, southalpine flysch **Accomodation Youth hostel Le Miniere**

Fr. 25. 7. Passo San Boldo - Belluno – Longarone (Vajont reservoir) – Cortina – Felbertauern – Kitzbühel – München: Montello frontal thrust and flexure, folded Tertiary, Vaiont landslide – **back to Munich.**

Geologic overview

The excursion runs roughly along the TRANSALP seismic section, which is located between München and Pordenone at the greatest width of the Eastern Alps where minimal tectonic deformation could be expected and hence the clearest seismic and tectonic picture.

Geologic setting *
The Eastern Alps represent a double-vergent orogen, which was formed by the collision of the European plate in a lower tectonic position and the Adriatic microplate in an upper tectonic position. In contrast to the Western Alps, the Eastern Alps are widely covered by cold and rigid crystalline and cover rock nappes (Austroalpine nappes, e.g., the Northern Calcareous Alps, the Greywacke zone and the Ötztal crystalline nappe) which originated from the Adriatic microplate and camouflage deeper structures. Only the Tauern window allows a deeper look down to the Penninic ocean units of Bündnerschiefer and ophiolites and, finally, to the cover and basement of the European plate. Jurassic marbles cover Variscan granitic sills and Palaeozoic or Precambrian paragneisses and amphibolites. Major tectonic units in this section include from north to south:

(I) The stable European continental basement and its Post-Variscan cover are unconformably overlain after the Upper Eocene by the classical wedge-shaped peripheral foreland Molasse basin. Molasse sediments are folded and thrust close to the Alpine front and show considerable fluid overpressure (up to 2.0) (after Lemcke 1973).

(II) The Helvetic nappe complex is a small zone of Mesozoic to Eocene cover rocks detached from the stable European plate.

(III) The Rhenodanubian Flysch nappe constitutes Early Cretaceous to Upper Eocene turbiditic sequences, which developed along the front of the approaching Austroalpine nappes within the Penninic ocean basin.

(IV) The Austroalpine nappe complex comprises a mainly Variscan basement and Late Carboniferous to early Late Cretaceous cover successions . Internal and deep Austroalpine nappes were ductilely deformed and variably metamorphosed during the mid-Cretaceous, Eo- Alpine orogeny, which is characterized by a basically WNW-transport of units (Ratschbacher, 1986). Its cover units were accumulated in the Northern Calcareous Alps which are still juxtaposed to the Graywacke zone, which is considered as the former basement of at least part of the NCA .

(V) In the central Eastern Alps and structurally below the Austroalpine nappe complex, the Tauern window exposes the Mesozoic Penninic ophiolite (Glockner nappe) and

(VI) The Venediger nappe complex (or Central Gneiss unit), a basement-cover complex. The Penninic ophiolite and the Central Gneiss unit are affected by Paleogene metamorphism and nappe stacking (Kurz et al., 1998 for review) and subsequent Neogene shortening with E–W elongated structural domes. The Periadriatic fault, a major regional dextral strike-slip fault to the south of the Tauern Window is decorated with Late Eocene–Oligocene plutons (Schmid et al., 1989). It separates the Austroalpine nappe complex to the south and separates it from the

(VII) Southern Alps (or Southalpine unit) with the Dolomite Mountains as the most prominent feature. The Southalpine unit is a basement-cover nappe complex with basically southward vergency, which is in contrast to northward transport of the all units exposed to the north of this fault. Another distinct feature is the missing metamorphic overprint of the Southalpine unit (Frey et al., 1999).

(VIII) The Southalpine unit is thrust over the Neogene–Quaternary Venetian platform, which is a foreland basin overlying the undeformed Adriatic microplate.

* modified after: Ewald Lüschen , Daniela Borrini, Helmut Gebrande, Bernd Lammerer, Karl Millahn, Franz Neubauer, Rinaldo Nicolich: TRANSALP—deep crustal Vibroseis and explosive seismic profiling in the Eastern Alps Tectonophysics 2006, 9-38.

The Eastern Alps in its present structure are the result of Late Eocene to Neogene collision of the stable European plate with the Austroalpine and Southalpine nappe complexes after Mid-Eocene completion of southward subduction of the Penninic ocean in between (for plate tectonic scenarios, see Stampfli and Mosar, 1999). The arrangement of these units clearly demonstrates the double-vergent nature of the orogen with initial northward accretion and accumulation of nappes, and subsequent south-ward directed, still ongoing transport. During Late Oligocene and Neogene, central sectors of the orogenic edifice were affected by strong shortening and exhumation of units exposed within the Tauern window.

Shortening also created a system of ca. orogen-parallel strike-slip faults including the dextral Periadriatic fault in the south and a sinistral wrench corridor along southern margins of the Northern Calcareous Alps, which also include the Inn valley fault crossing the TRANSALP section. The effect of this fault system was the lateral extrusion of central sectors of the Eastern Alps. The system was driven by indentation of the apparently rigid Southalpine unit into weak central sectors of the Eastern Alps, the Penninic units and overlying Austroalpine nappe complex (Ratschbacher et al., 1991 and references therein). The effect of indentation, associated shortening, generation of the strike-slip fault systems and its possible linkage with late-stage exhumation of the Tauern window were principal reasons for selection of the TRANSALP section.

References

Behrmann, J.H., Tanner, D.C., 2005. Structural synthesis of the Northern Calcareous Alps, TRANSALP segment. Tectonophysics 414, 225–240.

Bleibinhaus, F., Gebrande, H., 2005. Crustal structure of the Eastern Alps along the TRANSALP profile from wide-angle seismic tomography. Tectonophysics 414, 51–69.

Castellarin, A., Nicolich, R., Fantoni, R., Cantelli, L., Sella, M., Selli, L., 2005. Structure of the lithosphere beneath the Eastern Alps (southern sector of the TRANSALP transect). Tectonophysics 414, 259–282.

Frey, M., Desmons, J., Neubauer, F., 1999. The new metamorphic maps of the Alps: introduction. Schweiz. Mineral. Petrogr. Mitt. 79, 1– 4. Geologische Bundesanstalt, 1980. Geologische Karte der Republik Österreich und der Nachbargebiete: 3. Unveränderter Nachdruck, 1:500 000, Wien.

Kurz, W., Neubauer, F., Genser, J., Dachs, E., 1998. Alpine geodynamic evolution of passive and active continental margin sequences in the Tauern Window (eastern Alps, Austria, Italy). Geol. Rundsch. 87, 225–242.

Lammerer, B., Weger, M., 1998. Footwall uplift in an orogenic wedge: the Tauern Window in the Eastern Alps of Europe. Tectonophysics 285, 213– 230.

Lippitsch, R., Kissling, E., Ansorge, J., 2003. Upper mantle structure beneath the Alpine orogen from high-resolution teleseismic tomography. J. Geophys. Res. 108, doi:10.1029/2002JB002016.

Lüschen, E., Lammerer, B., Gebrande, H., Millahn, K., Nicolich, R., TRANSALP Working Group, 2004. Orogenic structure of the Eastern Alps, Europe, from TRANSALP deep seismic reflection profiling. Tectonophysics 388, 85–102.

Mancktelow, N.S., Stöckli, D.F., Grollimund, B., Müller, W., Fügenschuh, B., Viola, G., Seward, D., Villa, I.M., 2001. The DAV and Periadriatic fault systems in the Eastern Alps south of the Tauern Window. Int. J. Earth Sci. 90, 593–622.

Pfiffner, O.A., Lehner, P., Heitzmann, P., Mueller, St., Steck, A. (Eds.), 1997. Results of NRP20—Deep Structure of the Alps. Birkhäuser Verlag, Basel.

Ratschbacher, L., 1986. Kinematics of Austro-Alpine cover nappes: changing translation path due to transpression. Tectonophysics 125, 335–356.

Ratschbacher, L., Frisch, W., Linzer, G., Merle, O., 1991. Lateral extrusion in the Eastern Alps: Part 2. structural analysis. Tectonics 10, 257–271.

Rosenberg, C.L., Brun, J.-P., Gapais, D., 2004. Indentation model of the Eastern Alps and the origin of the Tauern Window. Geology 32, 997–1000.

Roure, F., Heitzmann, P., Polino, R. (Eds.), 1990: Deep structure of the Alps. Me´m. Soc. ge´ol. Fr.156, Paris; Me´m. Soc. ge´ol. Suisse 1, Zu¨ rich; Vol. spec. Soc. Geol. It. 1, Roma. 367 pp.

Scarascia, S., Cassinis, R., 1997. Crustal structures in the centraleastern Alpine sector: a revision of the available DSS data. Tectonophysics 271, 157– 188.

Schmid, S.M., Aebli, H.R., Heller, F., Zingg, A., 1989. The role of the Periadriatic line in the tectonic evolution of the Alps. In: Coward, E. Lu¨schen et al. / Tectonophysics 414 (2006) 9–38 37

Stampfli, G.M., Mosar, J., 1999. The making and becoming of Apulia. Mem. Sci. Geol. 51, 141– 154.

TRANSALP Working Group, 2002. First deep seismic images of the Eastern Alps reveal giant crustal wedges and transcrustal ramps. Geophys. Res. Lett. 29, doi:10.1029/2002GL014911.

The main tectonic units*

*** adapted from: * A. Castellarin, L. Cantelli (Universita' di Bologna) L. Bertelli, , R. Fantoni, M. Sella, D. Borrini (ENI-AGIP, Milano); K. Millhan (Montanuniversitaet Leoben), F.Neubauer (Universitaet Salzburg); H.Gebrande, E. Lueschen, B.Lammerer (Universitaet Muenchen); A. Mazzotti (Universita' di Milano), M. Bernabini (Universita' di Roma); O. Oncken, M. Stiller (GeoForschungsZentrum Potsdam); R. Nicolich (Universita' di Trieste): CROP ATLAS-Trasansalp Working Group*The TRANSALP seismic Profile and the CROP 1-ASubproject**

THE SOUTHERN ALPS

The Eastern Southern Alps correspond to the structural belt located S of the eastern side of the Periadriatic Lineament (Pustertal and Gailtal Lines). This belt is affected by intense back-thrusting which forms the orogenic structure of the Alps verging to the S (Africa-verging belt) opposite to the tectonic polarity of the Northern Alpine chain verging to the N (Europa verging orogenic chain), located to the N of the Periadriatic Lineament. The Southern Alps are considered to be still in structural continuity with the northern border of the Adria microplate, a largely prevailing lithospheric domain of the Alpine belts belonging to the African Promontory (D'Argenio et al.,1980; Channel et al., 1979; Vai, 1994). The African Promontory was incorporated in the Africa NE border during the Late Precambrian time mostly as consequence of the Pan African or Cadomian orogenic events, from 750 to 550 Ma BP, deformations affecting also rock systems of older age (Khain, 1977). These basement rocks underwent the subsequent tectonic evolution. During the Ordovician the "porphyroid thermal event", also indicated as "caledonian" event, is not yet clearly understood and may correspond to an early extensional episode of the continental rifting predating the Hercynian orogenic events (Vai, 1991). The Hercynian or Variscan orogenic evolution is well recognized and documented both in the non metamorphic Paleozoic (Carnic Alps) and in the metamorphic basement rocks of the Southern Alps (Selli, 1963; Vai and Cocozza, 1986; Zanferrari and Poli, 1992). These basement rocks include huge magmatic intrusions sometimes pre dating and mostly post dating the Hercynian orogenic events such as the rare acidic intrusion of Ordovician emplacements (446 ± 18 Ma) (Assunta well, AGIP, 1977; Pieri and Groppi, 1981) and the widespread granodioritic intrusions (Brixen, Cima d'Asta, etc.) mostly located along the Insubric Lineament, penecontemporaneous to the early Permian ignimbritic plateau of the Bolzano-Trento Provinces (C.N.R., 1990, Sheet N.1).

The post Upper Carboniferous magmatic history of the Alps is consistent with their structural and kinematic evolution. The early continental rifting evolution is documented by extensional tectonics and huge magmatic activities occurred during Lower Permian and Middle Trassic Times (Dal Piaz, 1993; Selli, 1998; Castellarin et al., 1998a;), whereas the further Norian-Liassic rifting evolution is well documented by the strong extensional tectonics controlling the carbonate platform-basin systems in the whole Southern Alps (Bernoulli, 1964; Bosellini, 1973; Bertotti et al., 1993). The drifting evolution, related to the spreading center of the Tethys, is consistent with the progressive drowing of the southern continental margin well documented by the transgressive megasequence of the successions from the Mid Jurassic (about 157 Ma) to the late Early Cretaceous (≅115 Ma) (Winterer and Bosellini, 1981) which are the distant equivalent of the Ligurian sequence capping the Tethyan oceanic basement (Steinman, 1927).

At the end of the Early Cretaceous a basic change occurred in the kinematics of the plates which inverted their motion: with the beginning of the continental margin convergence (see f. i.: Coward and Dietrich., 1989; Roure et al., 1990a; Dal Piaz, 1995). The convergence evolution of the Alps include the Upper Cretaceous pre collisional (eo-Alpine), the Eocene collisional (meso-Alpine) and the Paleogene-Neogene post collisional (neo-Alpine) compressional events (Trümpy, 1973). The pre-collisional-collisional events have no structural evidence in the Venetian Southern Alps. They are indicated only by the Upper Cretaceous drastic change in the marine sedimentation with strong siliciclastic input in the basinal areas close to the uplifted orogenic chain such as the thick successions of Flysch deposits in the Judicaria zone (Insubric Flysch), in the Dolomites (Ra Stua and Antruille), Carnian (Val di Resia), and Julian Alps (Slovenia) (Castellarin, 1977). The Lower Eocene siliciclastic Flysch of the Friuli to the Belluno zones is mostly a distant marker of the meso-Alpine compressional event affecting the external Dinaric orogenic domain rather than the Eastern Alps (C.N.R., 1990, Sheets N.1,2). Nevertheless, intense Eocene tectonic deformations related to this compressional events affected the Carnic Alps and the E sector of the Dolomites (Doglioni and Bosellini, 1988; Carulli et al., 1982), generally rearranged by the further Cattian-Burdigalian nearly coaxial compressions (see later).

The stop in the oceanic subduction, subsequent to the continental collision, produced a rapid Paleogene geothermal rise under the orogenic eo- to meso-Alpine chain and consequent extensional uplifting. Magmatic processes produced large emplacement of acidic intrusive bodies (mainly granodiorities and tonalites) occurring along the Insubric border of the Alps (Bergell-, Adamello-, Riesenferner- and others intrusive masses) (Dal Piaz, 1986; Laubscher, 1986; C.N.R., 1990). The sector affected by the maximum stretching in the back-foreland lithosphere, to the S, underwent widespread lava flows of alkaline basalts and their subvolcanic differentiates (Mounts Lessini and Euganei Hills) (Barbieri and Zampieri, 1992; Zampieri, 1995).

The Permian – Triassic magmatic events

The post-Hercynian, late Paleozoic and Mesozoic magmatic and tectonic evolution of the E-Southern Alps intensely controlled the further mainly Tertiary structural inversion. Important examples are the Lower Permian extensive magmatic occurrences and the less expanded Mid Triassic ones, largely superposed each other in the Dolomites. These events concurred to origin a more rigid post magmatic upper crust in these areas and to reinforce this sector, less intensely affected by further surficial tectonic deformations (Castellarin and Vai, 1986). Intense structural deformations, on the contrary, occurred in the eastern contiguous sectors (Cadore, Carnia) where the magmatic bodies are much more restricted, or absent. Furthermore, this more rigid block is, apparently, the part of the Southern Alpine belt more extensively pierced (indented) in the Northern Alpine structure along the N Giudicarie Line.

The Lower Permian magmatism is represented by the volcanic porphyric plateau of the Bolzano province (Bozener Porphyrplatte Auct.) covering an area of more than 2,000 km² and by several plutons (Cima d'Asta, Bressanone-Chiusa, Ivigna and M. Croce). These magmatic products display typical calco-alkaline evolutive trends with geochemical and isotopic composition consistent with the interaction of different magmas coming both from the upper mantle and the lowermost crust (Barth et al., 1993). The volcanic succession is generally formed by the lower andesitic-dacitic interval (including lava flows and lava domes) followed by the upper group of mainly rhyolitic ignimbrites and piroclastic flows (D'Amico, 1979). Recent stratigraphic and structural analysis documented that the volcanic activity was controlled by extensional tectonics which produced drastic changes in the thickness of the volcanic covers from few hundred m to more than 2 km, in short distances. Calderic collapses enhanced the tectonic depressions which migrates in time as the volcanic activities expanded and enlarged to the E (Selli, 1998).

The magmatic occurrences in the Eastern Alps produced rhyolites/andesites (Recoaro, Tarvisio) and shoshonitic basalts in the Dolomites where there are also rare shallow intrusive equivalents (M.^{ts} Monzoni) with differentiated products (Predazzo). All of these magmatics correspond to calc-alkaline suites well defined and tested in several sectors of the Southern Alps (see f. i., Castellarin et al., 1988). New stratigraphic and structural data (Castellarin et al., 1998a) indicate that the tectonic control related to these magmatic activities can be referred to extentional crustal conditions as docomented by the syn- and post magmatic normal faults, recognized in the Dolomites. The compressional tectonic associations (folding, local overthrusts and strike-slip tectonics) previously thought to be linked to the Middle Triassic tectonic-magmatic events (Castellarin and Vai, 1982; Castellarin et al., 1988, see also Doglioni, 1984) are now considered as strong diapiric anticlines of the upper Permian evaporites originating submarine unstable strong relieves producing huge slided masses, cahotic assemblages (“agglomerati”) and gravity deformations; these diapiric activities were trigged by the Mid Triassic magmatic event coupled by extensional tectonics (Castellarin et al., 1998a). Moreover, several true compressional structures (wrongly considered Mid Triassic in previous works) are largely consistent with the neo-Alpine compressional events.

The structural systems of the eastern Southern Alps

PRE ADAMELLO STRUCTURAL BELT

The pre-Adamello structural belt is characterized by S vergent ENE-WSE trending thrusts with large crystalline basement implications; the superposition of the big fold ramps produced severe deformations and shortening in the Orobic, Presolana and Grigna zones (Laubscher, 1985). This structural system extends to the E in Val Camonica up to the western sector of the Adamello pluton which clearly post date the tectonic deformation of the system (Brack, 1986). This belt has to be considered eo-Alpine in age (Late Cretaeous) (Doglioni and Bosellini, 1988; Bersezio and Fornaciari, 1988) and has not been recognized E of the S-Giudicarie fault.

DINARIC STRUCTURAL TRENDS

The Dinaric structural trends include two structural systems of similar orientation but of different age.

Eocene structural system

The Eocene structural system is largely developped in the easternmost sector of the E-Southern Alps with prominent SW vergent, NW-SE trending thrusts, located on the NW continuation of the external Dinaric orogenic chains (Figs. 2, 3). These structures are typical of the Alpi Giulie and Friuli. They also severly affected the Carnic Alps and the Cadore where the Dinaric deformations were drastically rearranged by the subsequent Alpine compressions (mostly by the Valsugana event). The implication of the Paleozoic and the crystalline basement (Carnia, Comelico) in the internal frontal ramps indicate that these deformations must be expanded to the SW to involve the Mesozoic and Tertiary covers of the Dolomites as previously proposed (Doglioni and Bosellini, 1988; Doglioni, 1987). The Eocene age (early Mid Eocene) of the conglomerates discordantly superposed on the folded latest Triassic carbonates in the Tolmezzo zone (Carnia) (Carulli et al., 1982), together with other stratigraphic and structural data, indicate that this structural system can be related to the meso-Alpine compressional event (Eocene).

Chattian-Burdigalian system

NW-SE (WNW-ESE) verging thrusts are well documented by the syntectonic clastic wedges buried in the Udine plain (Pieri and Groppi, 1981). Similar stratigraphic constraints of several localities in the East (Friuli, Montello, Belluno) (Massari, 1990) and the Lake Garda zone (Luciani, 1989) well document the ages of these associations. The best correlations are established with the structural system located in Lombardy, that has affected the syntectonic wedges of the Gonfolite clastic succession (Roure et al., 1990b); this structural system has also been well recognized in the pre-Alpine zone between Brescia and Bergamo (Picotti et al., 1997). These deformations may be related to the neo-Alpine post collisional deformations of the compressional Insubric or Elvetic event. During these compressions in the Dolomites, the previous Eocene thrusts were strongly reactivated and a new frontal system was expanded to the SW to attain the central Dolomites. According to Caputo (1996) in the Eastern Dolomites the two Dinaric associations can be distinguished by the difference in the axial trend. The early system (Eocene) should be connected to NE-SW compressions, whereas for the late one, NNE-SSE compressions are proposed.

VALSUGANA STRUCTURAL SYSTEM

The Valsugana structural system is largely developed in the whole S-Alpine domain and displays morphostructural prominence in the eastern part of the belt. The structural system is characterized by SSE (S) verging and ENE-WSW (E-W) trending thrusts particularly intense in the Valsugana zone where the crystalline basement rocks are largely involved in the frontal ramp, overthrusting a still preserved syntectonic deformed post-Langhian clastic wedge, mostly composed by sequences of Serravallian and Tortonian age (Castellarin et al., 1992; Selli, 1998). The intense activity of this compressional event is documented both by stratigraphic-structural data and by fission tracks studies which indicate uplifting in the hanging wall of the Valsugana overthrust of approximately 4 km between 12 and 8 Ma B.P. (Dunkl et al., 1996). Detailed macro- and meso-structural analysis indicate that the paleostress field is homogeneously NNW-SSE (N-S) oriented in the whole belt, with an average value of N 340° (Castellarin et al., 1992; Cantelli and Castellarin, 1994; Prosser and Selli, 1991; Picotti et al., 1995, 1997; Selli, 1998). In the sector of the Giudicarie (including Lake Garda and Adige River to the E) the system is dominated by several very long NNE-SSW (NE-SW) sinistral lateral ramps that join short and generally narrow ENE-WSW (E-W) trending fold ramps (Picotti et al., 1995). The Giudicarie belt of deformations (of the Valsugana structural system) is connected to the Valsugana overthrust to the E by the NNW-SSE (N-S) trending Trento-Cles and Calisio-Val d'Astico transfer fault (Selli, 1998). The Giudicarie system underwent further deformations due to late WNW (NW) compressions which have been differently interpreted (compare Castellarin et al., 1998b with Castellarin et al., 1992).

The Valsugana strucutral system expand largely to the E with strong overthrusts of the Belluno Dolomites whith their intense Carnic continuations. In the northern zone of the Piave River, the Dinaric NO-SE trending thrusts are cut by the younger ENE-WSW trending Valsugana main tectonic elements to form a typical structural crossing, previously indicated as Cadore junction ("Giunzione Cadorina") (Largaiolli and Semenza, 1966). Good images of the Valsugana structural system are visible in the vibroseismic section, N of Belluno and at Agordo (the Belluno and Valsugana low middle angle overthrusts within the upper crustal zone up to 10-15 km in depth)

BASSANO-MONTELLO-FRIULI STRUCTURAL BELT

The Bassano-Montello (M)-Friuli (FL) structural belt is located E of the Schio-Vicenza (SCHV) and Val d'Astico transfer faults and include a wide belt from the Belluno depression ("Vallone Bellunese")(to the N, to the border of the Venetian Plain (the "foot-hill flexure" by Barbieri, 1987, to the S. The belt is dominated by prominent NE-SW trending, SE verging folds and thrust associations that deform and partly override the thick syntectonic clastic successions of the foot hill. This syntectonic wedge is composed by prevailing clastic deposits with conglomerates of late Tortonian and mostly Messinian age thick over 2 kms (Montello-Friuli) which are locally capped by deformed Pliocene clays (at Cornuda, Montello, (Massari et al., 1986). The paleostress directions obtained by meso-structural analysis (Cantelli and Castellarin, 1994) are oriented NW-SE with prevailing value between N 300° and N 330° (Castellarin and Cantelli, 2000). The ages of the structural accretions and deformations of this structural belt are well controlled by the syntectonic clastic sequences and can be related mostly to the Messinian, Pliocene up to the Pleistocene. In the seismic section the low to midle angle N dipping overthrust of the Flessura Pedemontana-Passo di S. Boldo ramp anticline on the Montello clastic wedge is clearly visible up to depth of 10-12 km In spite of the different structural pertinance and opposite polarity this Alpine stuctural belt is an acretionary time equivalent of the frontal Apennines, buried beneath the Po Plain and Adriatic Sea. These structures can be related to the late post-collisional neo-Alpine evolution of the Adriatic-Po Plain compressional events. In the E (Friuli and Carnia) strong reactivations of the previous structures, mostly in the frontal zones, occurred (Venturini, 1990; see also Zanferrari et al., 1982). The Eastern Dolomites were affected by conjugate system of strike slip faults during this deformational interval (Caputo, 1996).The large overthrusts of the Valsugana are also involved in the reactivation of the Adriatic compressions,

as documented by the Val di Sella back-thrust. This structure disconnected the in-sequence propagation of the thin skinned frontal zone of the Valsugana system (M. Colombarone klippe,; Barbieri and Zampieri, 1992) presently uplifted about 2 km in the hanging wall of the Val di Sella back-thrust (Selli, 1998). The effects of the Adriatic compressions were transfered also to the contiguous western sector SW and W of the Schio-Vicenza and Val d'Astico transfer faults (Castellarin and Cantelli, 2000).
Moreover it is worth remembering that the northward inflexion of the Adriatic Lithosphere connected to the foredeep sedimentary evolution of the Venetian area (Montello-Friuli) with a Neogene clastic wedge up to 4-5 km in thickness (Massari et al., 1986), is also of great interest to the understanding the lithosphere mechanical behaviour of the Adria Plate at the seismic Profile southern edge, where the seismic acquisition stops.

LATE SOUTHRALPINE STRUCTURAL EVENTS AND REGIONAL KINEMATICS

In the Carnia and Friuli, the tectonic activity which produced the present seismicity has been attributed to N-S compressions recognized by focal mechanisms (aftershocks of the 1976 Friuli earthquake: Slejko et al., 1987; see also Anderson and Jackson, 1987 and Carulli et al., 1990). However, in the zone between Cellina and Tagliamento Rivers across the hills and at the border of the Plain, prominent E-W folds (enclosing the Messinian thick conglomerates) are largely developped and they are considered to also affect the subsurface of the Plain of the Tagliamento river (Amato et al., 1976). In this area the N-S compressions are also documented by unpublished mesostructural local tests. This structural setting could be originated by particular mechanical conditions of this area due to anomalous crustal block motionsor to other causes. Moreover, alternance in N-S and NW-SE compression cannot be excluded during late Pliocene-Pleistocene in this area; the N-S compressions, affected mosly the Friulian foot hill zone of the Taglianmento river (Venturini, personal comunication). Up to date, they are unknown both in the Carnic Alps (Venturini, 1990) and in the Eastern Dolomites (Caputo, 1996). The extensional tectonics are well represented in the eastern S-Alps generally by minor structural systems of normal faults subsequent to the compressional events and originated during the uplifting of the orogenic chain. Several main normal to listric faults correspond to Mesozoic structures mostly of the previous Norian-Liassic continental rifting which were not (or only partly) inverted during the compressional evolution.
As to the regional frame of the neo-Alpine compressional tectonics, the detailed studies carried out on the magnetic evolution of the Central Atlantic indicate that the post collisional convergence between the African and European plates, referred to the eastern Southern Alps, is of the order of 150-200 km in the last 26 Ma (Mazzoli and Helman, 1994): the motion of the African plate to the N (referred to Iblei, Sicily) occurred according to the following kinematic conditions: displacement to the NE between 26 and 16,22 Ma (Chattian-Burdigalian); toward the NNW between 16,22 and 7,9 Ma (Burdigalian-Tortonian) and toward the WNW, from 7,9 Ma onwards. These kinematic conditions and their chronological development are coherent with the compressional evolution of the three superposed thrusts systems recognized in the polyphase structure of the Eastern Southern Alps here outlined.

THE INSUBRIC LINEAMENT AND THE NORTHERN ALPINE CHAIN

The Insubric or Periadriatic Lineament

The Insubric Lineament (IL) of the Pustertal and Gailtal zones is a very strong tectonic separation between the S verging thrust belt of the Southern Alps, unaffected by Alpine metamorphism (Africa verging orogenic Chain) and the metamorphic nappe building of the Alps characterized by strong tectonic polarity to the N (Europa verging orogenic chain) (Dal Piaz 1934; 1942; Laubscher, 1974; 1986; Roeder and Boegel, 1978, Lammerer and Weger, 1998, etc.).
The IL is a very sharp structural devide of the two facing sectors of the Alps. The lack in their N-S continuity is also enhanced by the significant E-W dextral strike slip dispacement affecting the I.L. (Laubscher, 1974; 1986; Schmid et al., 1989) and other sub- parallel strike slip minor faults. About its geometry in depth, although the subvertical setting is prevailing at the surface, both N and S high-middle angle immersions can be assumed (see later).
The following structural units are present across the Transalp profile trace, N of the Insubric Line (C.N.R., Sheet N.1).

The Tauern Window (TW)

Framed by Austroalpine crystalline nappe units, the Tauern window is exposed in the central Eastern Alps between the Brenner and Katschberg passes to the west and east, and by the Salzach and Aurina valleys to the north and south. Two major complexes compose the window: the deepest exposed parts belong to European basement, which is topped by a thin sheet of cover rocks. These are overthrust by nappes of oceanic lithosphere and metasediments, which remind strikingly of the North Penninic Bündnerschiefer in the Engadine Window.

The basal part of the Tauern window shows Germanic and Helvetic affinities in the sedimentary record similar to the External massivs of the Western Alps. On the other hand, it is ductilely deformed and covered by oceanic nappes like the Penninic zones of the Switzerland. The Helvetic paleogeographic affinities on the one hand, together with the Penninic style of deformation on the other hand caused often confusion with regard to the position of the Tauern window within the Alpine edifice (North Penninic, Briançonnais or Helvetic) - which seems senseless because of its unique situation.

Precambrian to Lower Paleozoic paragneisses, graphitic schists and metabasites (mainly amphibolites) are the oldest rocks of the Tauernwindow. Ultramafics, like antigorite-serpentinites, are less frequent and marbles are found only occasionally. The whole complex is considered as a volcano sedimentary rock suite of oceanic, cordilleran or island arc provenance (Frisch and Neubauer, 1989). In part, it resembles a metamorphosed olisthostrome or a coloured melange. The serpentinites, at least in part, derive from ophicalcitic rocks, marked by considerable amounts of calcsilicatic and carbonatic minerals.

These „old roof rocks“ were intruded by Hercynian plutonites between 309 and 295 Ma. The entire spectrum from ultramafic cumulates to leucogranites occurs with predominance of granodiorites and tonalites (Morteani 1974, Cesare et al. 2002). They form sills („Zentralgneislamellen“) of dekameters thicknesses or lakkolithic bodies of up to 2 or 3 kilometers in thickness (earlier considered as batholiths). A contemporaneous east-west directed stretching affected all rock types leading to a strong structural anisotropy.

Post Hercynian sedimentation starts with metakonglomerates or –breccias and graphitic schists which contain Upper Carboniferous to Lower Permian plant fossils (Franz et al. 1991). Locally, metaquartzporphyries and meta-arkoses (“Porphyrmaterialschiefer”) serve as good marker beds for the Permian. Younger siliciclastic sediments are finer grained and more mature in the upper parts, and grade into white hematite bearing quartzites (former red sandstones “Buntsandstein”). Middle Triassic (Anisian) crinoid-bearing grey dolomites and bedded white and yellow limestones and cargnieuls are overlain by chloritoid schists („Quartenschiefer“), arkoses and quartzites (Keuper facies). The Jurassic strata are supposed to start with black cyanite bearing schists and black marls (Liassic?) and continue with some meters of reddisch sandy limestones (Dogger??).

Rocks older than Malm are only spatially present and fossil record is scarce. The Upper Jurassic Hochstegen marble however is well dated by ammonites and radiolarias. It is present all over the Tauern window but with changing thickness from 20 m up to 300 m – with large uncertainities due to strong internal deformation. In the sedimentary and faunal characteristica it is similar to the Helvetic Quinten limestone of Switzerland and the South German Malm limestones (Kissling, 1992).

Sediments of confirmed Cretaceous age are unknown in the basal part of the Tauern window. Arcosic gneisses (Kaserer serie) on top of the Hochstegen marble were considered as Cretaceous in age due to „sedimentary contacts“ (Frisch 1975). This interpretation was accepted in the following years by many successory workers. In the meantime, severe doubts have come up: zirkons from quartz porphyries at the base of the Kaserer serie gave an U/Pb - age of 284 +2/-3 Ma (Söllner et al. 1991), and Middle Triassic carbonates are embedded within the middle part of Kaserer as thin beds and as thick boudinaged bodies. From this, the Kaserer serie is confirmed to be Permo-Triassic in age and belongs to the basal part of the Penninic nappe system.

The Alpine tectonic history starts with an Eo-Alpine decollement and thrusting. North vergent fault-propagation-folds developed in the sedimentary cover. In part, slices of the crystalline core were also dislocated. This decollement tectonic accompanied the transport of the Penninic nappes over the Tauern. Thrust planes within the ophiolitic nappes are frequently decorated with isolated Triassic dolomite or serpentinite bodies.
In a second stage the entire mass of the Tauern was compressed, leading to internal thrusts and a high amplitude and long wavelength folding which includes the granitoid sills and laccoliths. Two main antiforms (Tux- and Zillertal core) separated by a gneiss and schist synform (Greiner synform) developed which dominate the present structure. Earlier Folds were refolded and mainly along the northern rim of the Tauern upside down – structures formed, as the synformal anticline of the Hoellenstein. As this tectonic phase was accompanied by a penetrative east-west stretching lineation, a transpressive regime was proposed (Lammerer 1988, Lammerer and Weger 1998).
The steep southern limb of the Tauern window is cut by dikes of the periadriatic plutons which virtually had not been rotated to a larger amount. Fügenschuh et al. (1997) suggested therefore, that the main folding was prior to 30 Ma.

The uplift of the Tauern is crucial in the understanding of the East alpine history. Internal deformation cannot explain its present high position. Therefore, a sub- Tauern ramp was proposed earlier, where the Tauern was uplifted by reverse faulting. Exhumation started at the end of Oligocene to the beginning of Miocene (around 20 Ma) with rapid uplift rates of 4 mm/a which decreased to 1 mm/a until 10 Ma. It was followed by very slow uplift of 0.2 mm/a until today (Fügenschuh et al. 1997). On the other hand, recent fine-nivellement measurements come to much higher recent rates (>1mm), which cannot be only a consequence of glacio-isostatic effects.

Northern Calcareous Alps

The Northern Calcareous Alps comprise a stack of Austroalpine nappes which covers most of the north-eastern Alps. They have been detached from its original Hercynian low-grade metamorphic basement and rest in their northern part rootless on Rhenodanubian Flysch or on detached Helvetic units.
To the southeast, the substratum is the Northern Greywacke Zone, a series of Cambro – Ordovician to Devonian fine clastic sediments with minor carbonates and mainly Ordovician bimodal volcanics (e.g. Blasseneck porphyry) and intrusives (gabbros), including rare ultramafics (serpentinite at the Marchbachjoch). To the southwest, the basement is formed by quartzphyllites and phyllonites (Innsbruck, Telfs, Landeck) similar to the Brixen quartzphyllite.
Comparable to the history of the Dolomites, the sedimentary record of the Northern Calcareous Alps starts with Permoscythian siliciclastics (Verrucano, Alpine Buntsandstein, Werfen beds) and evaporites, in part with larger amounts of rock salt (Berchtesgaden, Hallein and many others). Since Anisian time, the platform was drowned and a reef-basin topography developed mainly in Ladinian times (Wetterstein limestone reefs and Partnach marls in the basin).

Due to a Karnian sea level drop, again siliciclastics with subordinate coal seams and evaporites were deposited. Cellular dolomites and limestones at the surface are represented by kilometer-thick dolomite-anhydrite series in the drilling of Vorderriss 1 (Bachmann and Müller, 1981). The Norian Hauptdolomit, identical to the dolomia principale of the Southern Alps, covers uniformly the older topography. Isolated basins are filled with oil shales and slump units (Brandner and Poleschinski, 1986). The basin-platform topography is accentuated in Lower and Middle Jurassic times, where some basins sink under the CCD and slumping and turbidites along the basin margins are frequent.

First compressive movements started in the Upper Jurassic (Gawlick et al. 1999) and had a first climax during the Lower Cretaceous: the Cenomanian and Gosau group sediments cover already folded Triassic rocks, which are locally eroded down to the Ladinian Wetterstein limestone. The tectonic setting of the Gosau group is under debate: ongoing compression, strike slip, oblique subduction and tectonic erosion of the crystalline basement followed by strong subsidence under the CCD (discussion in: Wagreich 1995).

The sector of the TRANSALP profile is dominated by the Lechtal nappe. The higher Inntal nappe ends some kilometres to the west, the lower Allgäu nappe is very thin, imbricated and barely visible in the seismic section. Two prominent anticlines are thrust over synclinal areas: the Thiersee thrust more to the south and the Wamberg anticline, which compresses the "Bavarian synclinorium" into narrow folds around the Lake of Spitzing. At least the Thiersee thrust is younger than Lower Cretaceous, as Neocomian marls are involved into the movements.

To the north, the NCA end in a complex orogenic front with small scale nappes and slices (Schuppenzone) against the Rhenodanubian Flysch and a small dissected band of Helvetic outcrops, which are steeply thrust onto folded Molasse.

The Bavarian Molasse Basin

The Molasse sedimentary basin accompanies the northern Alpine front from Genève until Vienna over a distance of 800 km. The basin resembles a broad triangle in map view, with an apex at Regensburg, where the Molasse reaches with 130 km its greatest width in north-south direction. The north-eastern border against the Bohemian Massive is marked by a southeast trending steeply dipping Mesozoic fault (active during Upper Jurassic and Cretaceous) with a minimal throw of ~2 kilometres. Covered by Molasse sediments, a further step in the basement (south-western block 1 km down) near Landshut parallels this fault. The north-western limit of the Molasse along the emergent Jurassic strata of the Swabonian – Franconian Jura Mountains is marked by a cliff line of the Miocene Molasse sea cut into Upper Jurassic reefal or platform limestones. A belt of folded and imbricated Molasse sediments accompanies the Alpine front (folded Molasse). To the south, the Molasse trough is overthrust by Helvetic nappes (the own substratum units), Flysch nappes (Rhenodanubian Flysch) and Austroalpine nappes (Northern Calcareous Alps).

The Molasse basin is underlain by Hercynian granites and gneisses which are known from several drillings. Locally, Permo-Carboniferous and Triassic (drilling of Giftthal 1) siliciclastics with coal seams and evaporites occur in graben-, halfgraben- or pull-apart- structures (e.g. Schaffhausen trough). With exception of local horst positions, the entire region was drowned in Middle Jurassic times, and shallow marine shelf sediments of a mixed carbonate – siliciclastic character were deposited with a total thickness of up to 1 km ending with Lower Eocene sandy marls.

An erosional surface with lateritic paleosoils marks the break to the molasse type sedimentation, which started in Upper Eocene with flysch-like turbiditic sequences in the very southern areas (North Helvetic flysch) and marine globigerina marls, lithothamnia limestones and fish shales in other areas. Marly and shalely sediments with sandy and turbiditic interlayers followed. Conditions remained marine throughout the Lower Oligocene (Lower Marine Molasse). Triggered by a world - wide sea level fall, terrestrial influences proceeded from west to east, and brackish to freshwater sediments covered the western sector of the basin (Lower Freshwater Molasse). Siliciclastics of mainly Alpine provenance were deposited, in part also from the Bohemian Massive („glass-sands“).
Coal measures within delta type sequences had been exploited for centuries until 1971. The eastern part of the basin, however, remained marine during this time span. Widespread erosion affected the whole area during the Lower Miocene. Marine conditions came back in the Middle Miocene (Upper Marine Molasse) for only a short time span, which left mainly marly and sandy deposits. These were soon replaced by freshwater deposits (Upper Freshwater Molasse).

The mixed marine, brackish or fluvial sedimentary filling of the Molasse basin is a consequence of world wide sea level changes and contemporaneous basin subsidence throughout the Tertiary.

Due to extensive hydrocarbon exploration, the geometry and sedimentary history of the molasse basin is well known. The sediment apron thickens from a few meters in the north up to more than 5 km along the Alpine margin, and reaching 8 km under the nappe front of the NCA. The geometry clearly approaches that of a flexural basin (Roeder & Bachmann, 1996).

The folded molasse at the south rim of the basin includes 1 to 4 synclines, separated by thrusts. Anticlines are generally missing or cut. An elevated pore fluid pressure, which reaches locally superlithostatic values, is typical for this zone. It decreases with distance to the Alpine nappe front but is still present in the southern part of the unfolded molasse (Müller & Nieberding, 1996).
Oil traps in the foreland molasse are mostly bound to the footwall block of north dipping antithetic faults with throws of some tenth or hundred meters. Some 60 small oil and gas fields have been detected so far.

Conclusive remarks on the axial zone of the Eastern Alps

Lithospheric stuctural relationships of the the two facing sectors of the Alps across the Insubric Lineament correspond to the more complex probleme of the whole Transalp profile. N of the IL, the European units of the Central Gneiss Zone with their tectonic cover of oceanic meta-sediments and ophiolites were affected by strong ductile deformations, dominated by vertical narrow folds where the gneiss are largely prevailing (Lammerer and Weger, 1998). These units underwent very intense shortening and uplifting, rising up and/or exhuming for 30-35 km in the last 40 Ma (mostly in early-mid Miocene times, between 20 and 15 Ma) as documented by the 10-KBars decompressional P-T path evolution recognized for the same interval (Von Blanckenburg, 1989; Christensen, 1994). Furthermore, according to the previous DSS reconstruction (Giese, 1982; Blundel et al., 1992) the European Moho discontinuity descend regularly to the S attaining the zone below the TW. Consequently the strong deformation and rise of the TW structure may be considered intra-crustal and restricted to the orogenic wedge. Similar crustal structures are only partally confirmed by the images of the Transalp seismic Profile due to wide transparent zones in the the very deep axial sector of the profile, underneath the Tauern crest.
Completely different is the defomative Alpine history and structural setting of the zone located to the S of the IL, that is the Italian Dolomites of the eastern Southern Alps. This sector underwent, on the contrary, mostly S-verging thrusting and brittle defomation (see the previous pargraph) and only moderate uplifting as documented by the low grade metamorphic association (mostly phyllites) of the Hercynian basement and its stratigraphically superposed Permo-Triassic non metamorphic cover, located close to the IL (Plan de Corones, Bruneck). Similar conditions are well documented by the fission tracks investigations in the whole eastern Southern Alpine domain where the hanging walls of the most prominent tectonic structures (S Giudicarie transpression and Valsugana overthrust) attained uplifting up to 4-5 kms, mostly between 10 and 6 Ma B.P. (Martin et al.,1998; Dunkl et al., 1996). Moreover these vertical movements occurred in connection with the neoalpine strongest compressional events (see previous paragraph). These values in the Neogene rise are, however, strongly smaller than those recognized in the TW structure. Exept for the uplift rate not considered in these areas, stratigrafic sequences which are stongly comparable with those of the Italian Dolomites occours in the Upper Austoalpine units of the

Northern Calcareous Alps and in the "Drau Zug" belt (Lienz), where the Permo-Tertiary covers are mainly unaffected by metamorphic signature and display strong similarities in the sedimentary, mainly Triassic-Jurassic, facies associations.

The dipping in depth of the Insubric Lineament is a key to the solution of the lithospheric setting of the Alps in their axial zone. In the Central and Western Alps, the IL has been mostly considered N and NW dipping after the Argand's structural interpretation (1924) (see for istance Laubscher, 1974; Schmid et al., 1989). The modern tectonic reconstructions based on the deep seismic reflexion acquisitions in the Central and Western Alps (Roure et al., 1990a; 1996; Pfiffner et al., 1997) confirmed these deep structural settings. With regards to the Eastern Alps, the Insubric Periadriatic Lineament (IL) geometry in depth, its dipping can been assumed both to the N and to the S.

Immersions to the N of the IL in depth, in the sector crossed by the Transalp Profile, are consistent with the tectonic structures present at the surface. In fact, along the Puster Valley, the scanty places where the contacts are visible, high angle N dippings of the IL are present. These settings are always coupled by overturnig of the metamorphic Austroalpine sequence due to the backfolding of the structures close to the IL contact (see Dal Piaz, 1934, tavv. X-XIII; and the "Geological Map of Italy", sheets Bressanone , 1969 and Merano, 1970).The Transalp reflexion data may be considered consistent with this interpretation. In fact a transparent zone underneath the Tauern window southern side, produce a strong break in the reflective seismic facies which could correspond to the possible N dipping continuation in depth, for some 25 km, of the IL.

Immersion to the S of the IL in depth was proposed by few authors in the past decades (for the Western Alps see Polino et al., 1990, and Roure et al.,1996). Nevertheless, the seismic data across this Lineament in depth show high to middle angle S dipping prominent reflectors, joining the IL at the surface. Similar setting of the IL in depth could support a different general crustal interpretation of this sector of the Alps. In this frame, in fact, the S dipping IL could be seen as the upper surface of a Penninic large indentation of the TW structure protruded inside the Adriatic Plate. This view, anticipated in the past by Oxburgh (1972), is a possible innovative and interesting interpretation of the Eastrern Alps., alternative to that previously indicated. If confirmed, it could represent a drastic general change of the structural interpretation of the Alps, a true unexpected revolution!

REFERENCES

AGIP, 1977 - Temperature sotterranee. Inventario dei dati raccolti dall'Agip durante la ricerca e la produzione di idrocarburi in Italia., 1390 p., Segrate, Milano, F.lli Brugnora Publisher.

Amato A., Barnaba P.F., Finetti I., Groppi G., Martinis B. and Muzzin A., 1976 - Geodinamic outline and seismicity of Friuli Venetia Giulia Region. Boll. Geofisica teor. e appl., XIX, 72, 217-256.

Anderson H. and Jackson J., 1987 - Active tectonics of the Adriatic Region. Geophys. J. R. Astr. Soc., 91, 937-983.

Bachmann G H and Müller M, 1981: Geologie der Tiefbohrung Vorderriß 1 (Kalkalpen, Bayern).- Geologica Bavarica 81, 17-53.

Barbieri G. and Zampieri D, 1992 - Sovrascorrimento di vetta nel settore nord-occidentale dell'Altopiano di Asiago (Prealpi Venete). Atti Tic. Sc. Terra, 35 (Note brevi, 1992), 53-59.

Bertotti G., Picotti V., Bernoulli D. and Castellarin A., 1993 - From rifting to drifting: tectonic evolution of the South-Alpine upper crust from the Triassic to the Early Cretaceous. Sedimentary Geology, 86 (1993), 53-76.

Blundel D., Freeman R. and Mueller St.,1992. A continent revealed. The European Geotraverse. Pp. XII-275 - Atlas of compiled data. Pp.1-73**.** Egt- European Science Foundation. Cambridge University Press.

Brandner and Poleschinski, 1986: Stratigraphie und Tektonik am Kalkalpensüdrand zwischen Zirl und Seefeld in Tirol.- Jber. Mitt. oberrhein. geol. Ver., N.F. 68, 67-92

Caputo R., 1996 - The polyphased tectonics of Eastern Dolomites, Italy. Mem. Sc. Geol., 48, 93-106

Castellarin A., 1977 - Ipotesi paleogeografica sul bacino del Flysch sudalpino cretacico. Boll. Soc. Geol. It., 95, 501-511.

Castellarin A. and Cantelli L., 2000 - Neo-alpine evolution of the Southern Eastern Alps. Journ. of Geodyn., 30 (2000), 251-274.

Castellarin A., Lucchini F., Rossi P.L., Selli L. and Simboli G., 1988 - The Middle Triassic magmatic-tectonic arc development in the Southern Alps. Tectonophysics, 146, 79-89.

Castellarin A., Selli L., Picotti V. and Cantelli L., 1998a - Tettonismo e diapirismo medio triassico nelle Dolomiti. Mem. Soc. Geol. It., 53, 145-169.

Cesare B, Rubatto D, Hermann J and Barzi L 2002: Evidence for Late Carboniferous subduction-type magmatism in mafic-ultramafic cumulates of the SW Tauern Window (Eastern Alps).- Contrib. Mineral. Petrol 142; 449-464,

Christensen J.N., Selverstone J., Rosenfeld J.L. and De Paolo D.J., 1994 - Correlation by Rb-Sr geochronology of garnet growth histories from different structural levels within the Tauern Window, Eastern Alps. Contrib. Mineral. Petrol., 118, 1-12.

Cliff R.A., 1981 - Pre-Alpine history of the Pennine Zone in the Tauern Window, Austria: U-Pb and Rb-Sr geochronology. Contrib. Mineral. Petrol., 77, 262-266.

Coward M. and Dietrich D., 1989 - Alpine tectonics - an overview. In: Coward M. and Dietrich D.(Eds): Alpine tectonics. Geological Society Special Publication, 45, London, 1-29.

C.N.R., 1990-1992 - Structural Model of Italy. Scala 1:500.000, I-VI sheets, Selca Publisher (Firenze).

Dal Piaz G.B., 1934 - Studi geologici sull'Alto Adige orientale e regioni limitrofe. Mem Ist. Geol. Univ. Padova, 10, 1-242.

Dal Piaz G.V., 1993 - Evolution of Austro-Alpine and Upper Pennidic Basement in the Northwestern Alps from Variscan Convergence to post-Variscan extension. In: J.F. von Raumer and F. Neubauer: Pre-Mesozoic Geology in the Alps. 328-343, Springer-Verlag.

Doglioni C., 1984 - Triassic diapiric structures in the Central Dolomites (Northern Italy). Eclogae Geol. Helv., 77 (2), 261-285.

Doglioni C., 1987 - Tectonics of the Dolomites (Southern Alps, Northern Italy). J. Struct. Geol., 9, 181-193.

Doglioni C. and Bosellini A., 1988 - Eoalpine and mesoalpine tectonics in the Southern Alps. Geol. Rund., 76, 735-754.

Franz G., Mosbrugger V. and Menge R., 1991 - Carbo-Permian pteridophyll leaf fragments from an amphibolite facies basement, Tauern Window, Austria.- Terra Nova, 3, 137-141.

Frisch W., 1975 - Ein Typ-Profil durch die Schieferhülle des Tauernfensters. Das Profil am Wolfendorn (westlicher Tuxer Hauptkamm, Tirol).- Verh. Geol. B.-Anst., 1975/2-3, 201-221.

Frisch W., 1978 - A plate tectonic model of the eastern Alps. Inter Union Comm. Geodyn. Sci. Rep., 38, 167-172.

Frisch W. and Neubauer F., 1989 - Pre-Alpine terranes and tectonic zoning in the eastern Alps.- in: Dallmeyer, R.D. (Ed): Terranes in the Circum Atlantic Paleozoic orogenes.- Geol. Soc. Am. Sp. Paper 230, 91-100.

Fügenschuh B., Seward D. and Mancktelow N., 1997 - Exhumation in a convergent orogen: the western Tauern window. - Terra Nova, 9, 213-217.

Gawlick J.H., Frisch W., Vecsei A., Steiger T. and Böhm F., 1999- The change from rifting to thrusting in the Northern Calcareous Alps as recorded from Jurassic sediments.- Geol. Rdsch. 87, 644 – 657.

Martin S., Bigazzi G., Zattin M., Viola G. and Balestrieri M.L., 1998 - Neogene kinematics of the Giudicarie fault (Central-Eastern Alps, Italy): new apatite fission-track data. Terra Nova, 10, 217-221.

Massari F., 1990 - The foredeep of the Northern Adriatic margin: evidence of diachroneicity in deformation of the Southern Alps. Riv. Ital. Paleont. Strat., 96 (2-3), 351-380.

Massari F., Grandesso P., Stefani C. and Zanferrari A., 1986 - The Oligo-Miocene Molasse of the Veneto-Friuli region, Southern Alps. Giornale di Geologia (Bologna), ser. 3, 48, 235-255.

Giese P., Nicolich R. and Reutter K.J., 1982 - Explosion seismic crustal studies in the Alpine-Mediterranean Region and their impications to tectonic processes. In: Berckhemer H. and Hsű K.J. (Eds.): Alpine-Mediterranean Geodynamics. AGU, Geodyn Ser. 7, 39-74.

Kissling W., 1992: Palaeontological and facial features of the Upper Jurassic Hochstegen Marble (Tauern WIndow, Eastern Alps).- Terra Research, 1992, 184-197.

Lammerer B., 1988 - Thrust regime and transpression-regime tectonics in the Tauern Window (Eastern Alps).- Geol. Rundsch. 77/1, 143-156.

Lammerer B. and Weger M., 1998 - Footwall uplift in an orogenic wedge: the Tauern Window in the Eastern Alps of Europe. Tectonophysics, 285, 213-230.

Laubscher H.P., 1985 - Large scale, thin-skinned thrusting in the Southern Alps: kinematic model. Geol. Soc. Am. Bull., 96, 710-718.

Laubscher H.P., 1986 - The Late Alpine (Periadriatic) intrusions and the Insubric Line. Mem Soc. Geol. It., 26, 21-30.

Mandl G. W., 2000: The Alpine sector of the Tethyan shelf – examples of Triassic to Jurassic sedimentation and deformation from the Northern Calcareous Alps.- Mitt. österr. Geol. Ges. 92, 61-77.

Martin S., Bigazzi G., Zattin M., Viola G. and Balestrieri M.L., 1998 - Neogene kinematics of the Giudicarie fault (Central-Eastern Alps, Italy): new apatite fission-track data. Terra Nova, 10, 217-221.

Massari F., 1990 - The foredeep of the Northern Adriatic margin: evidence of diachroneicity in deformation of the Southern Alps. Riv. Ital. Paleont. Strat., 96 (2-3), 351-380.

Müller M. and Nieberding F.,1996 - Principles of abnormal pressure related to tectonic developments and their implication for drilling activities (Bavarian Alps, Germany). In: Wessely G. and Liebl W: Oil and Gas in Alpidic Thrustbelts and Basins of Central and Eastern Europe, OMV Vienna.

Oxburgh E. R., 1972 - Flake Tectonics and continental collision. Nature, 239, 202-204.

Pfiffner O.A., Lehner P., Heitzmann P., Mueller St. and Steck A. (Eds), 1997 - Result of NRP 20: Deep structure of the Swiss Alps. The National Research Program 20 (NRP/20), Birkhauser Verlag Basel, 1-380.

Picotti V., Prosser G. and Castellarin A., 1995 - Structures and kinematics of the Giudicarie - Val Trompia fold and thrust belt (Central Southern Alps, Northern Italy). Mem. Sc. Geol., 47, 95-109.

Polino R., Dal Piaz G.V. and Gosso G., 1990 - Tectonic erosion at the Adria margin and accretionary processes for the Cretaceous orogeny of the Alps. Mém. Soc. Géol. France,156, 345-367.

Prosser G., 1998 - Strike-slip movements and thrusting along a transpressive fault zone: the Northern Giudicarie line (Insubric line, Northern Italy), Tectonics, 17, 6, 921-937.

Prosser G., 2000 - The development of the North Giudicarie fault zone (Insubric Line, Northern Italy). Journal of Geodynamics, 30, 229-250, Pergamon Press.

Roure F., Bergerat F., Damotte B., Mugnier J.L. and Polino R., (Eds.) 1996 - The ECORS-CROP Alpine seismic traverse. Mem. Soc. Geol. France, 170, 1-113.

Roure F., Heitzmann P. and Polino R., (Eds.), 1990a - Deep structure of the Alps. Soc. Geol. Ital., Vol. spec. 1, 1-367.

Roure F., Polino R. and Nicolich R., 1990b - Early Neogene deformations beneath the Po Plain: constraints on the post-collisional Alpine evolution. In: Roure F., Heitzmann P. and Polino R., (Eds.): Deep structure of the Alps. Soc. Geol. Italiana, Vol. Spec. 1, 309-322.

Scarascia S. and Cassinis R., 1997 - Crustal structures in the central-eastern Alpine sector: a revision of a available DSS data. Tectonophysics, 271, 157-188.

Selli L.,1998 - Il lineamento della Valsugana fra Trento e Cima D'Asta: cinematica neogenica ed eredità strutturali permo mesozoiche nel quadro evolutivo del Sudalpino Orientale(NE-Italia). Mem. Soc. Geol. It., 53, 503-541.

Selverstone J., 1983 - Evidence for east-west crustal extension in the Eastern Alps: implications for the unroofing history of the Tauern window. Tectonics, 7, 87-105.

Schmid S.M., Aebli H.R. Heller F. and Zingg A., 1989 - The role of the Periadriatic line in the tectonic evolution of the Alps. Geol. Soc. London Spec. Publ., 45, 153-171.

Schwerd K., Doppler G. and Unger H.J. 1996 - Gesteinsfolge des Molassebeckens und der inneralpinen Tertiärbecken. In: Bayer. Geol. L. Amt. (Eds) Geol Kt. Bayern 1:500 000, Erl. 141-187, München 1996

Söllner F., Höll R. and Miller H., 1991 - U-Pb-Systematik der Zirkone in Meta-Vulkaniten (Porphyroiden) aus der Nördlichen Grauwackenzone und dem Tauernfenster (Ostalpen, Österreich). Z.dt. geol. Ges. 142, 283-299.

Trümpy R., 1973 - The timing of orogenic events in the Central Alps. In: K.A. De Jong and R. Scholten: Gravity and Tectonics, 229-251, J. Wiley and Sons.

Von Blankenbourg F., Villa I.M., Baur H., Morteani G. and Steiger R.H., 1989 - Time calibration of a PT-path from the Western Tauern Window, Eastern Alps: the problem of closure temperatures. Contrib. Mineral. Petrol., 101, 1-11.

Von Quadt A.H.F.C., 1992 - U-Pb zircon and Sm-Nd geochronology of mafic and ultramafic rocks from the central part of the Tauern Window (Eastern Alps). Contr. Mineral. Petrol., 110, 57-67.

Wagreich M., 1995 - Subduction tectonic erosion and Late Cretaceous subsidence along the Northern Austroalpine margin (Eastern Alps, Austria).- Tectonophysics 242, 63-78.

Winterer E.L. and Bosellini A., 1981 - Subsidence and sedimentation on a Jurassic passive continental margin (Southern Alps, Italy). Amer. Assoc. Petrol. Geol. Bull., 65, 394-421.

Zampieri D., 1995 – Tertiary extention in the southern Trento Platform, Southern Alps, Italy. Tectonics,14/3, 645-657.

Itinerary

Fri. 11. 7. By car: München - Frasdorf – Rohrdorf concrete quarry
Nappe of the Helvetic zone: Paleocene to Early Eocene l*ithothamnia* limestones, and *nummulite* marls in the Rohrdorf concrete quarry; folded and faulted and with impressive slump structures within marls, sandstones and fine conglomerates. Facies shallow marine or litoral. Large foraminiferas as *nummulites, assilina and discocyclina* as well as debris of lithothamnia fragments (algae crusts) are frequent. These rocks are the youngest pre-Molasse sediments and they show a lot of indications of beginning tectonic activity.

Stop 1. Slump folds in Eocene sandstones of Rohrdorf.

Stop 2. Millstone quarry Hinterhör:
From 1572 – 1860 this quarry was used to mine millstones from Helvetic quartzitic sandstones by use of only hammer and cisel.

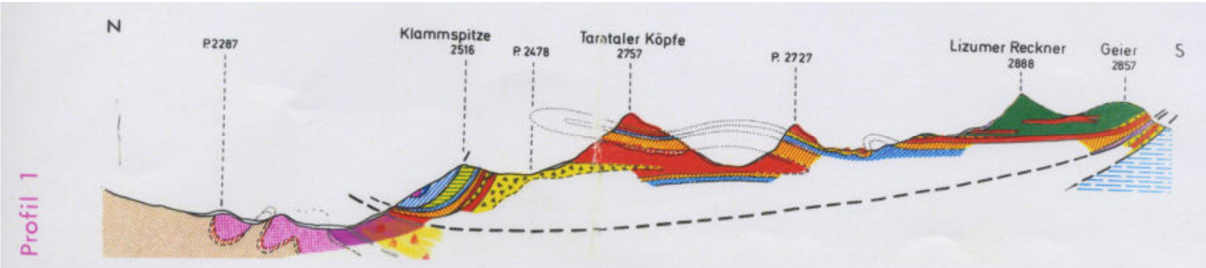
We continue by car to the **Spitzingsee. Ascent by cable car to the Taubensteinhaus – walk to the Rotwand and Rotwandhaus 1737 m**
Synclinorium of the Northern Calcareous Alps (seismic section Nr. 1): tightly folded Late Triassic - Jurassic reef and basin sediments, impressive patch reefs with the coral *thecosmilia clathrata,* Jurassic deep water cherts. Guide: Dr. U. Haas (Landesamt f. Umwelt).

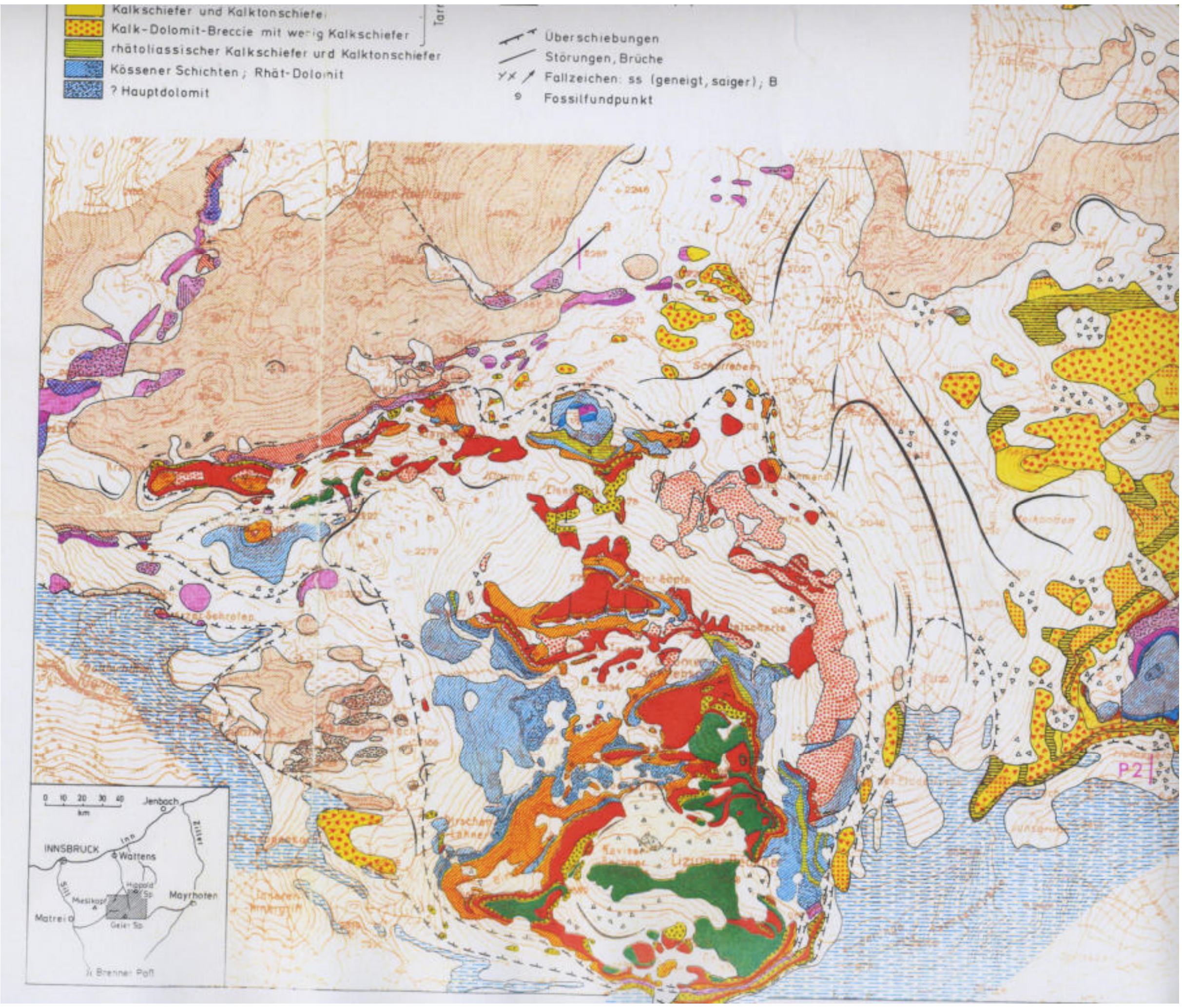
Sat. 12. 7. Descent and walk through the Valepp valley to Kaiserhaus (~20 km): Cross section through the Northern Calcareous Alps; the Wamberg Anticline, late Triassic neptunian dikes, submarine slumps in the Lower Jurassic coloured limestones and cherts, Aptychus marls, Guffert thrust over Cretaceous sediments, Late Cretaceous Gosau basin with red terrigene clastics, fluvial conglomerates, and marine limestones, Cretaceous folds in the Wetterstein limestone. Strike-slip tectonics and deep erosion during Cretaceous times.

The Gosau group comprises synorogene sediments of Late Cretaceous age. The deep Gosau group starts with terrigene fluviatile and shallow marine sediments, the upper Gosau group is deep marine with turbidites and, locally, large olistholite bodies. Typical are the actaeonella limestones (see photo below) and rudist reefs along steep coasts. The Gosau transgredes over Hauptdolomit and, in the section of the Valepp, over Wetterstein - limestone. This indicates a pre-Gosau folding event and a ca. 2000 m of erosion of the anticlines.
We cross the Wetterstein anticline of the scenic Kaiserklamm with thick bedded Ladinian limestones.

Sun. 13. 7. Kaiserhaus – Brandenberg – Kramsach - Wattens – Lizumer Hütte 2019 m (Ü):
by car: Brandenberg Gosau sediments, of the southern Gosau basin with rudist reefs und Actaeonella limestones, (photo left side) Inntal-Tertiary. **Afternoon**: ascent through the Quarzphyllite zone (2 h) to the Lizumer Hütte (**Accomodation)**

Mon. 14. 7. walk in the surrounding of the Lizumer Hütte (Ü) and Reckner (2886 m)**:** Tarntal Mesozoic, high pressure metamorphism, Reckner serpentinite – Hippold – Breccianappe, coloured Mélange zone. Guide: P. Veselá, B. Lammerer;





Tue. 15. 7. walk Lizumer Hütte – Junssee – Geier, 2.857m to Tuxer Joch Haus 2.313m, (06:[30] h), Geyer serpentinite, Mylonites, contact Austroalpine nappes to Penninic nappes, Triassis slices as thrust horizon markers. Guide: P. Veselá, B. Lammerer.

Accomodation Tuxer Joch Haus telefone: 05287 87216 (Info & Fax: 05285 64555).

***Bad* weather alternative:** by car to Hintertux, by cable car to Tuxer Joch, geology close to hut.

Interferierende Kleinfaltensysteme des Tuxer-Joch-Gebietes

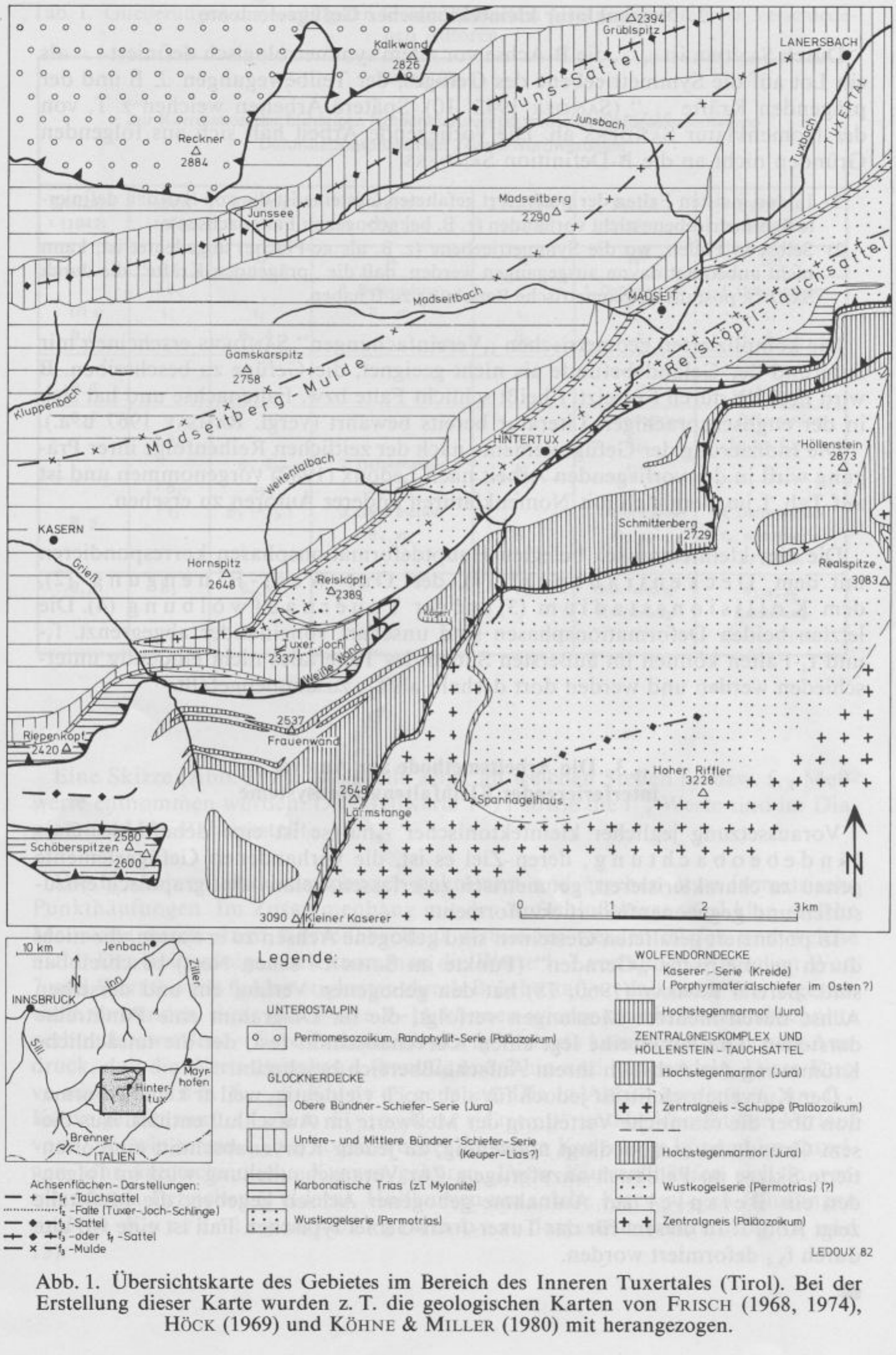


Abb. 1. Übersichtskarte des Gebietes im Bereich des Inneren Tuxertales (Tirol). Bei der Erstellung dieser Karte wurden z. T. die geologischen Karten von FRISCH (1968, 1974), HÖCK (1969) und KÖHNE & MILLER (1980) mit herangezogen.

Ledoux 1984

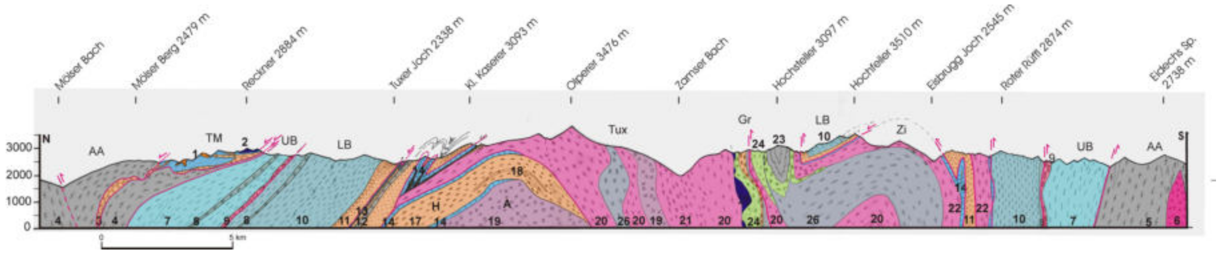


Fig. 15/7/1: *Geologic section through the western Tauern Window:* **Legend: Austroalpine nappes:** 1 = Rensen granite and dykes, Oligocene; 2 = Jurassic shales and cherts; 3 = Serpentinite; 4 = Triassic carbonates and cargneuls; 5 = Quartzphyllite (mainly ?Ordovician); 6 = gneisses south of the Tauern Window. **Penninic nappes:** 7 = phyllites and calcphyllites of the higher Bündnerschiefer nappe; 8 = Amphibolites and Prasinites; 9 = thrust horizon with lenses of serpentinites and Triassic quartzites, Dolomites, gypsum and breccias; 10 = Phyllites of the lower Bündnerschiefer nappe; 11 = ?Permo – Triassic clastic metasediments and cargneuls (Wustkogl and Kaserer Series); 12 = dolomite marbles (Middle Triassic); 13 = tectonic horizon with lenses of Cambrian microgabbro, **Inner Tauern Window duplex system:** *A: Post Variscan metasediments:* 14 = Hochstegen marble (Upper Jurassic; 15 = blackshists (± cyanite) and quartzites (?Liassic) and brown sandy limestones (?Dogger); 16 = Triassic Limestone or dolomite marbles, white hematite or magnetite bearing quartzites; 17 = clastic sediments, metaconglomerates, metarkoses (Pre Upper Jurassic); 18 = dazitic porphyry; *B: Late Variscan Plutonites;* 19 = Ahorn porphyric biotitegranite, 20 = Tux granodiorite; 21 = migmatic rocks and injection gneisses; 22 = Zillertal granites, granodiorites tonalites and gabbros; *C: Pre Variscan and early Variscan rocks:* 23 = black graphite schists; 24 = amphibolites and garbenschiefer; 25 = serpentinites and meta-ophicalcites; 26 = injected gneisses and amphibolites. AA = Austroalpine nappen; TM = Tarntal Mesozoic; LB = Lower Bündnerschiefer nappes; UB = Upper Bündnerschiefer nappes, Tux = Tux gneiss; Gr = Greiner Series; Zi = Zillertal gneiss; A = Ahorn gneiss; H = Höllenstein nappe with clastic metasediments of the Riffler – Schönach Basin.

Wed. 16. 7. Tuxer Joch - Tuxerferner – Spannaglhaus 2531 m, (Ü): walk through Penninc nappes, ductile folding and backfolding, Zentralgneiss thrust over Hochstegen limestone, deformed conglomerates. Guide: P. Veselá, B. Lammerer, **Accomodation Spannaglhaus** fone +43/5287/87707; Fax +43/5287/86162

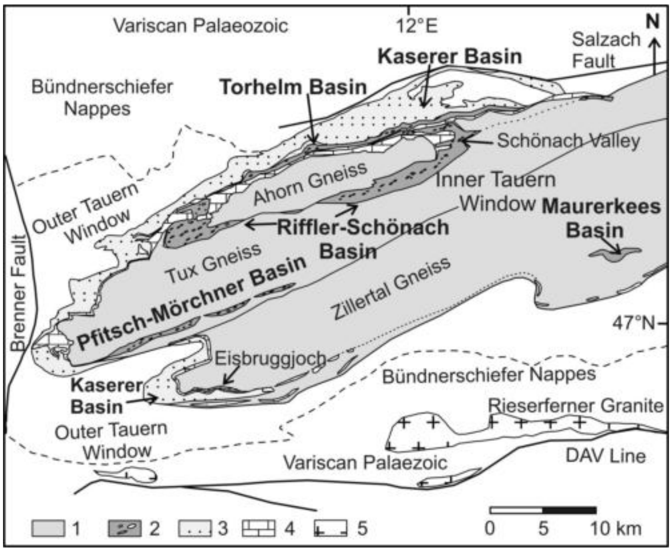


Fig. 16/7/1. Geological sketch map of the Tauern Window and the position of the post-Variscan basins (modified after Veselá et al. 2008). Legend: 1 – Palaeozoic rocks and Variscan granites, 2 – post-Variscan clastic sediments (Upper Carboniferous-Lower Jurassic), 3 – Triassic clastic sediments and carbonates at the base of the Bündnerschiefer, 4 –Hochstegen Formation (Jurassic), 5 – Alpine granites (Oligocene), DAV Line – Defereggen-Antholz-Vals Fault.

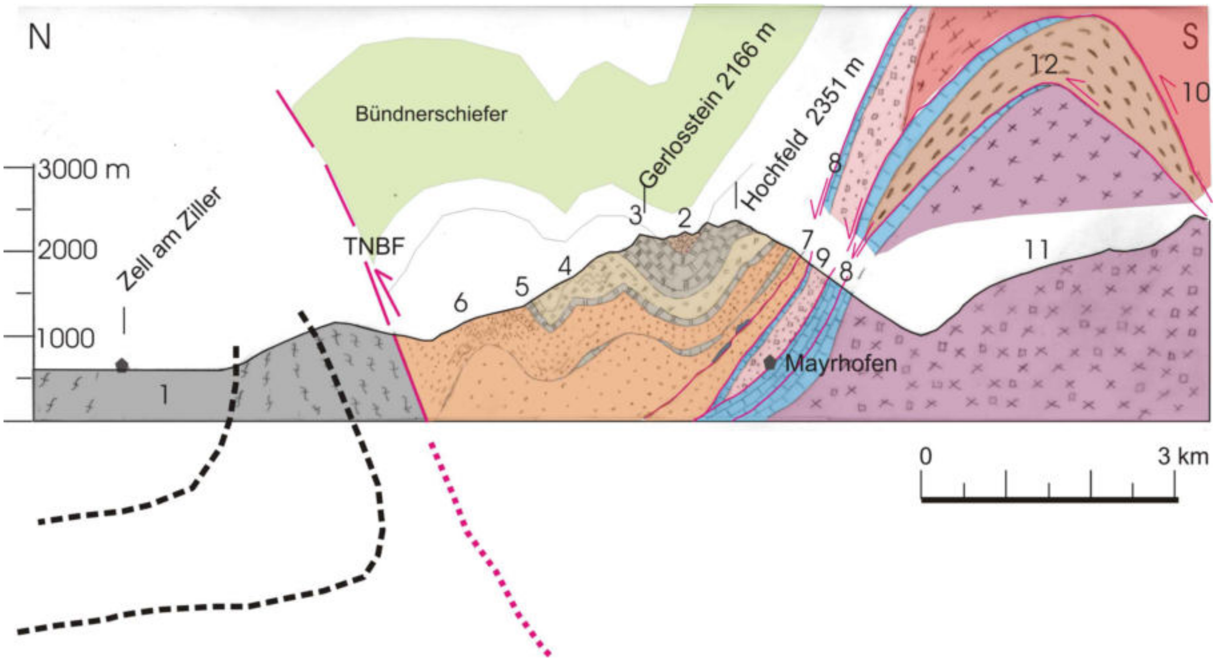
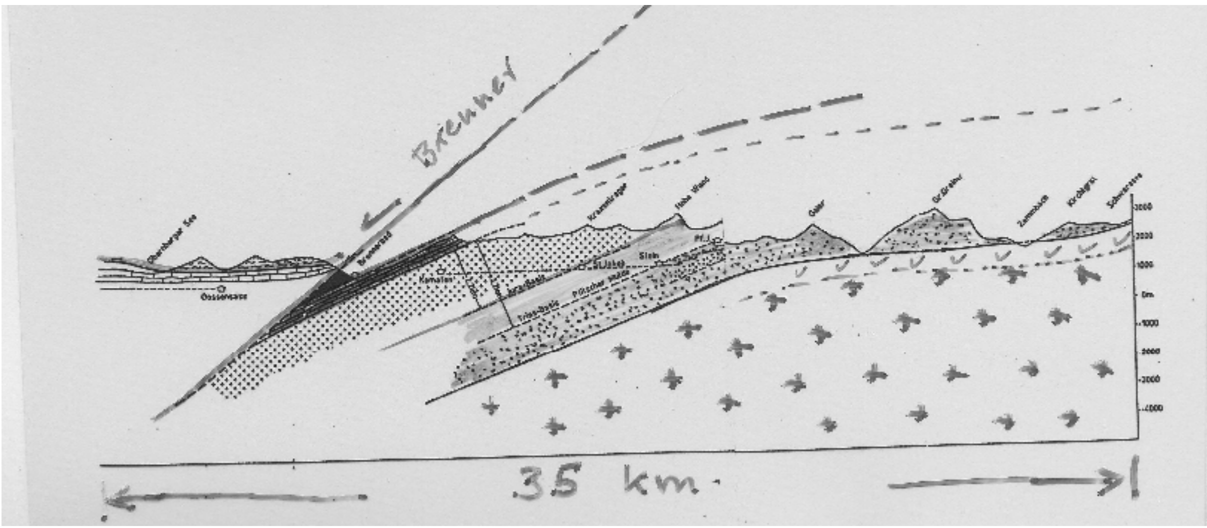


Fig. 16/7/1. *Geologic section along the northern boundary of the Tauern Window along the Ziller Valley and up-structure projection of the Ahorn gneiss structure.* **Legend:** A: *Lower Austroalpine nappes*: 1 = Quartzphyllite; B: *Penninic nappes*: 2 = clastic metasediments (?late Triassic or ??early Triassic); 3 = carbonates of the Gerlosstein (middle Triassic); 4 = dolomites and cargneuls (middle Triassic); 5 = dolomites (middle Triassic); 6 = Kaserer Series (?early Triassic; ??Cretaceous); 7 = thrust horizon with lenses of serpentinite; C: *Inner Tauern window duplex:* 8 = Hochstegen marble (late Jurassic); 9 = Porphyry (early Permian); 10 = Tux orthogneiss; 11 = Ahorn porphyric granite; 12 = metaconglomerates of the Höllenstein nappe (Permian to Middle Jurassic?). TNBF = Tauern North Boundary Fault; M = Mayrhofen

The cover rocks of the inner Tauern Window show a clear affinity to the Germanic facies realm and are thus very similar to those of the Helvetic and some of the Penninic crystalline massifs of the Swiss Alps. Post Hercynian sedimentation started shortly after the emplacement of the plutons. (?)Upper Carboniferous or Lower Permian plant fossils in graphite schists are reported from the southern Tauern Window (Franz et al. 1991, Pestal *et al.* 1999). Clastic sediments filled topographic depressions or tectonic grabens until Lower Jurassic times, interrupted by a short marine ingression during the Anisian, which is documented by carbonate horizons (see Veselá et al.; this volume). A graben-horst or a basin-and-range topography is presumed. The Upper Jurassic Hochstegen marble is the youngest exposed sediment of the inner Tauern Window. It was deposited as a deeper marine platform carbonate that covered the entire region (Kiessling 1992). Proven Cretaceous rocks are unknown until now.

Do. 17. 7. Descent to Hintertux, by car to Jenbach – Innsbruck – Brenner – Pfitsch Valley: Brenner fault, Pfitsch landslide, Aigerbach formation. Guide: P. Veselá, B. Lammerer
Accomodation Pfitscher Joch Haus (Sepp Volgger) fone 0039 0472 630119



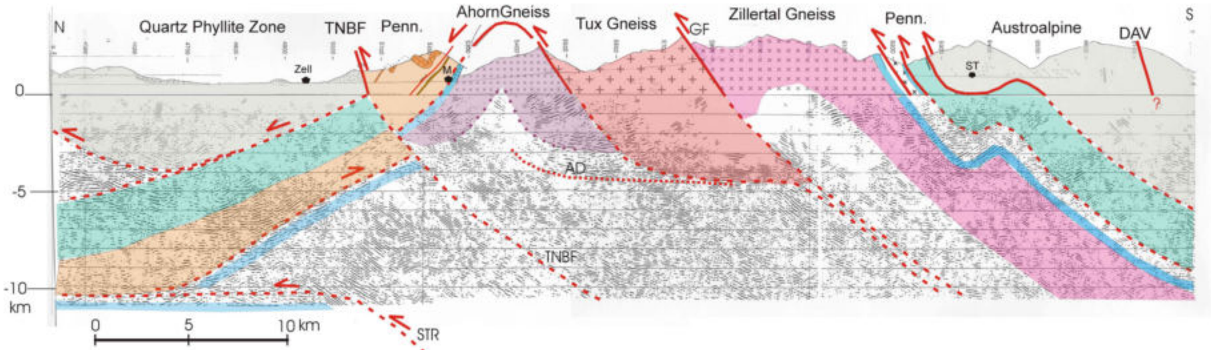


Fig 7: *Upper 12 kilometres of the TRANSALP line between CDP 4400 and 6800 (depth migrated).* Depth scale in kilometres, surface geology extrapolated to depth. Explanation: M = Mayrhofen; ST = Sand in Taufers; STR = Sub Tauern Ramp; TNBF = Tauern North Boundary Fault; GF = Greiner Fault; AD = Ahorngneiss detachment.

age (method)	**rocks**	**reference**
534 ± 9.4 Ma (U/Pb Zrn)	meta-gabbro within the Kaserer Basin, Tux Alps	Veselá et al. 2008
309,8 ± 1.5 Ma (U/Pb Zrn)	meta-rhyodacite, Riffler-Schönach Basin, Tux Alps	Söllner et al. pers. comm.
309 ± 5 Ma (U/Pb Zrn)	ultramafic cumulates, Zillertal Gneiss core, Italy	Cesare et al. 2001
295 ± 3 Ma (U/Pb Zrn)	metagranodiorite, Zillertal Gneiss core, Italy	Cesare et al. 2001
293 ± 1.9 Ma (U/Pb Zrn)	meta-rhyolite, Pfitsch-Mörchner Basin, Zillertal	Veselá et al. 2008
284 +2/-3 Ma (U/Pb Zrn)	rhyolitic to andesitic metavolcanic rocks, Tux Alps	Söllner et al. 1991
280.5 ± 2.6 Ma (U/Pb Zrn)	meta-rhyolite, Pfitsch-Mörchner Basin, Zillertal	F. Söllner pers. comm.
fossils		
Late Carboniferous	plant fossils in graphitic schists in the Maurer Kees Basin, southern Venediger Alps	Franz et al. 1991 Pestal et al. 1999
Middle Triassic	crinoids in marbles, Pfitsch Valley	Frisch 1974
Late Jurassic	ammonite (Perisphinctes sp.) radiolarians in the Hochstegen Marble	Klebelsberg 1940 Kiessling 1992

Table 1. Chronometric and palaeontologic markers in the western Tauern Window

Fr. 18. 7. around Pfitscher Joch Haus (Ü): Zentralgneis – old roof rocks, Greiner shear zone, Granite porphyry dike, prolate amphibolites, conglomerates (prolate and oblate), Metarhyolite, metamorphic playa sediments, Aigerbach syncline. Guide: P. Veselá, B. Lammerer, **Accomodation Pfitscher Joch Haus**

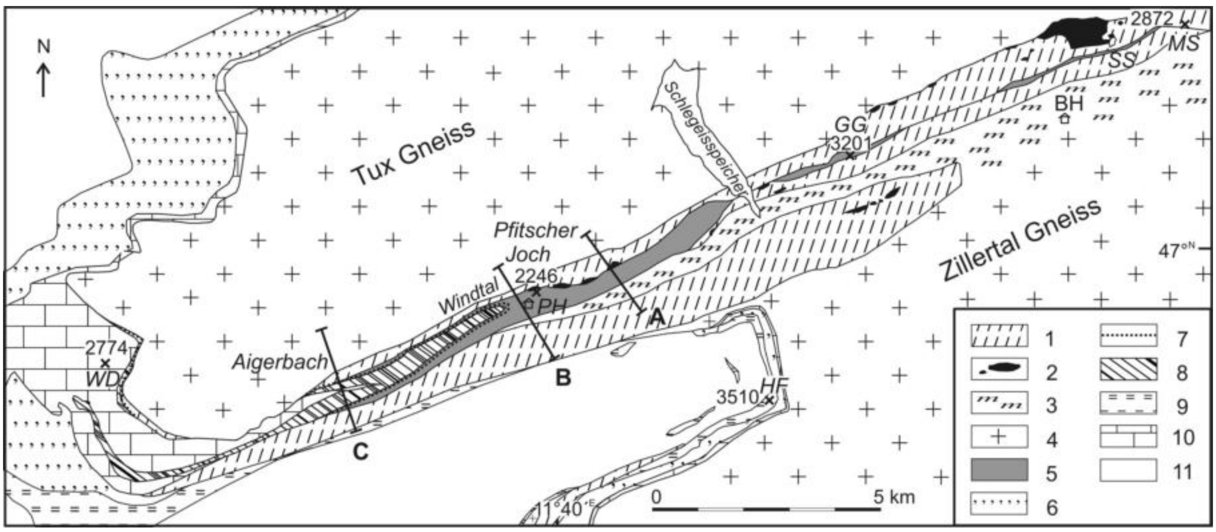
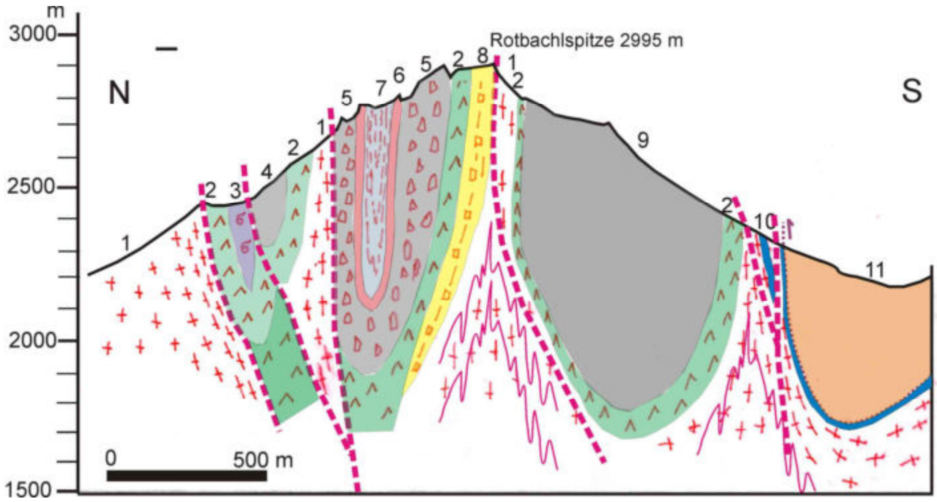


Fig. 3. Geological map of the SW Tauern Window: Legend: 1 – pre-Variscan basement rocks (Greiner Schists: amphibolites, hornblende-garben schists, graphite-bearing schists), 2 – serpentinites, 3 – migmatites and sheared gneisses, 4 – Variscan granitoids ("Zentralgneise"), 5 – Pfitsch Formation (clastic metasediments) 6 – Kaserer Basin metasediments, 7 – Windtal Formation (clastic metasediments), 8 – Aigerbach Formation (carbonates and evaporites), 9 – Middle Triassic carbonates on the base and within the Bündnerschiefer nappes, 10 – Hochstegen Formation (predominantly marine carbonates), 10 – Bündnerschiefer metasediments. Lines A,B,C show positions of sections shown in Fig. 4.



Sa. 19. 7. by car to Kematen, ascent Burgum - Sterzinger Hütte – Sandjoch 2642 – Brixener Hütte 2307 m (Ü): 6 h walk throug Bündnerschiefer, prasinites and serpentinites (with large zirkon cryistals), **Accomodation Brixener Hütte** Fam. Oberhofer Tel. 047254 71 71 , Telefon Hütte: 0472 54 71 31. ***Bad* weather alternative:** by car to *Vals – Ochsensprung, 2 h ascent to Brixener Hütte).*

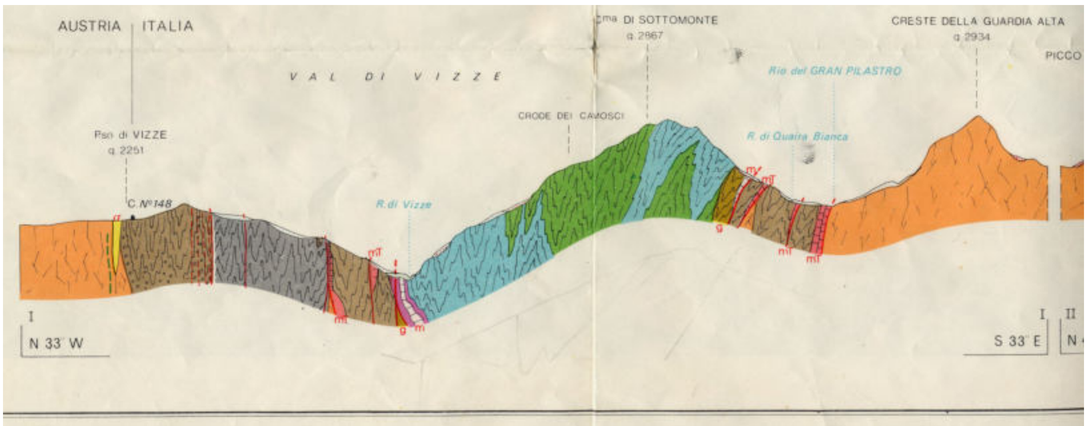


Fig: 19/7/1: Cross section through the area of the Pfitsch Valley and the Büncnerschiefer to the south

So. 20. 7. Ochsensprung – Vals – Jugendherberge Brixen, (Ü): Contact Tauern window - old crystalline gneisses with alpidic dikes – Rensengranite – Pustertal line, Brixen granite.
Accomodation Jugendherberge Brixen Brunogasse 2, I-39042 Brixen Tel. +39 0472 279 999, Fax +39 0472 279 998, E-Mail: brixen@jugendherberge.it

Fig. 20/7/1: Pustertal line at Mauls: to the right: Brixen granite (290 Ma), at the fault: tonalite (30 Ma), foreground left hand: Mauls Triassic rocks. Background to the left: Bündnerschiefer.

Mo. 21. 7. Brixen – Waidbruck – Kastelruth – Pordoi Joch: transgressive contact quartzphyllite – Waidbruck conglomerate, Bozen Quarzporphyry, Geologic trail to Seiser Alm, Werfener and Buchensteiner formations, Reef – basin relations, Triassic volcanism From Pordoi Pass ascent with cable car to Cima Pordoi, walk to Boe Hütte 2873m (1 hour) **Accomodation Boe Hütte fone 0039 0462 847303**

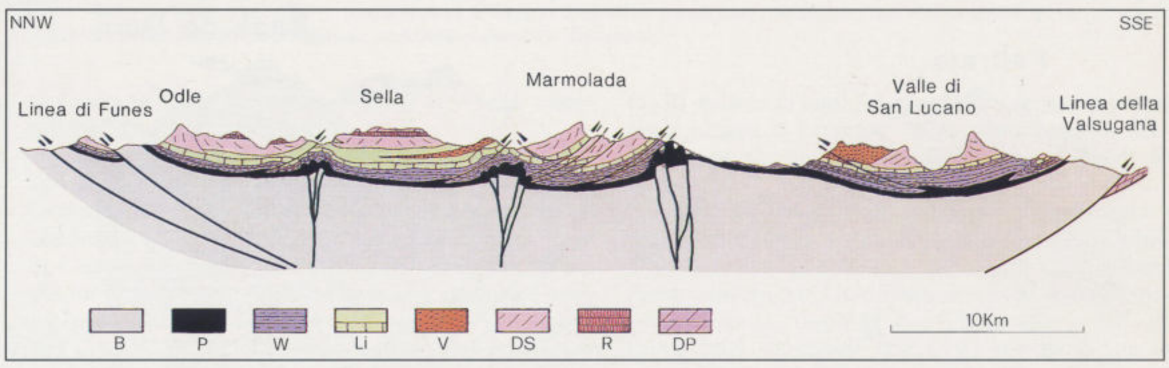


Fig. 18.6 - Sezione geologica nord-sud, semplificata, attraverso la Regione Dolomitica; B - basamento e porfidi quarziferi; P - terreni permiani; W - Formazione di Werfen; Li - Formazione di Contrin e successioni bacinali ladino-carniche (Formazione di Livinallongo, «Strati di La Valle», Formazione di S. Cassiano); v - rocce vulcaniche; DS - piattaforme carbonatiche ladiniche e carniche; R - Formazione di Raibl; DP - Dolomia Principale.

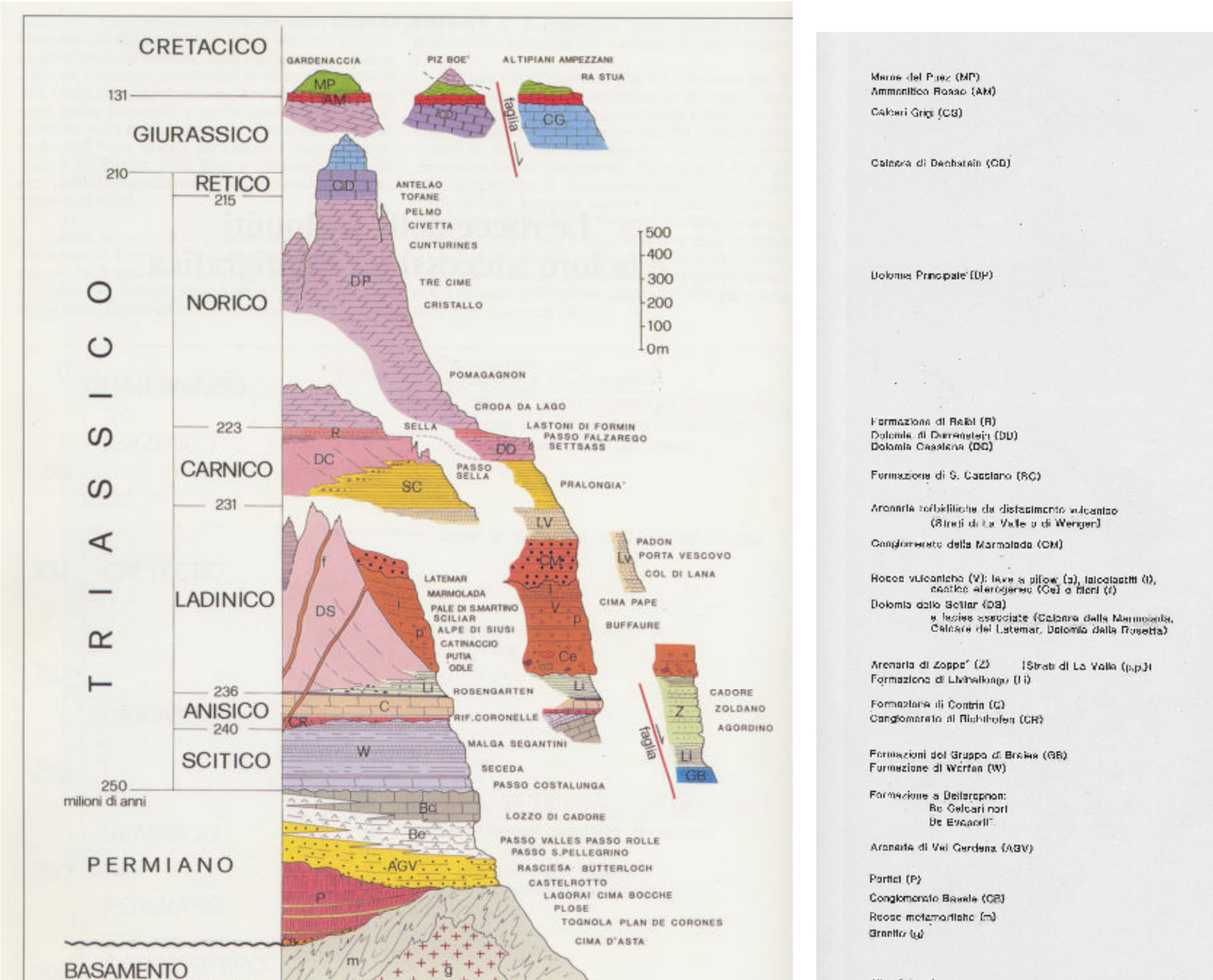


Fig. 5.1 - La successione stratigrafica che compare nelle vallate della Regione Dolomitica.

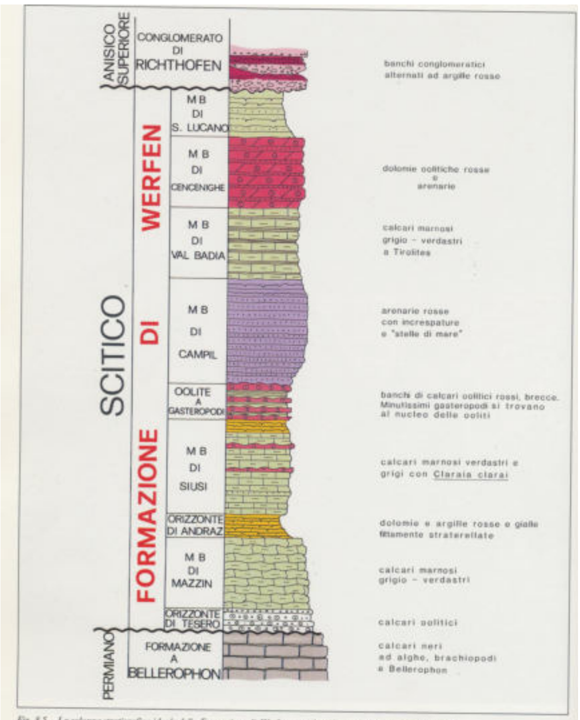


Fig. 8.5 - La colonna stratigrafica ideale della Formazione di Werfen, completa di tutti i suoi membri e orizzonti.

Di. 22. 7. Ascent to Piz Boe 3152m - Rifugio Passo San Nicolo 2340 m
“Gipfelfaltung” peak-folds and thrusts of the Sella, descent to Pordoi, by car to Valle San Nicolo, ascent to Passo San Nicolo.

Fig. 22/7/1 The altiplano of the Sella

Fig. 22/7/2: “Gipfelfaltung” at the Boe Peak

Afternoon: ascent to the Passo San Nicolo: Spectacular folded Bellerophon formation (Permian), Triassic volcanism, Marmolada overthrust. **Accomodation Rifugio Passo San Nicolo** Tel: 0462/763269

Mi. 23. 7. by car to Moena, Passo Pellegrino, Cencenighe, to Agordo Triassic volcanism monzonite type locality, contact-metamorphism of Predazzo (famous because of the dispute between plutonists and neptunists), Val Sugana thrusts and copper ore deposits; Cambrian phyllites
Accomodation Youth hostel Le Miniere - 32020 Rivamonte Agordino (BL); Cell. 329/2105989; E-mail: ostelloimperina@dolomitipark.it

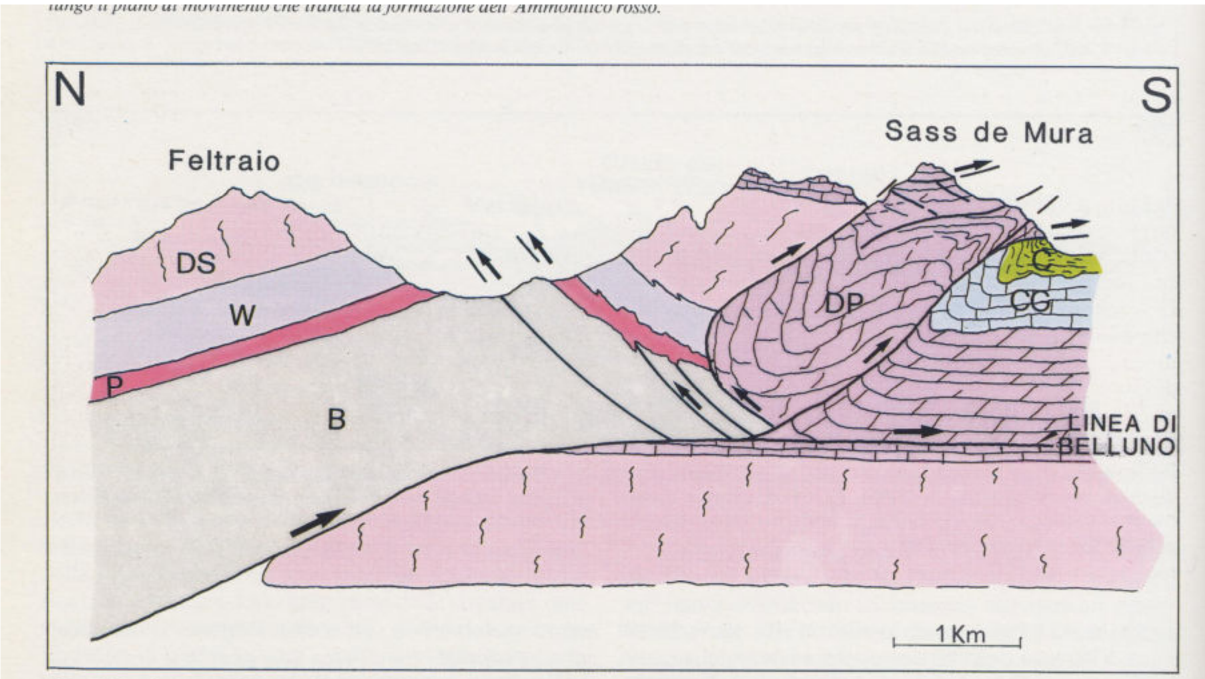


Fig. 18.8 - Sezione geologica nella zona del Passo Cereda mostrante il grande raccorciamento verificatosi lungo il piano di accavallamento della linea della Valsugana. B - basamento; P - sedimenti permiani; W - formazioni scitiche e anisiche; Cg - calcari grigi e Ammonitico rosso; C - terreni cretacei (Biancone).

Do. 24. 7. Mas – Bolago – Tisoi - Agordo (Ü): southern Molasse, condensed strata with sharc teeth, frontal monocline, Val Medon: Triassic – Jurassic formations of the Southern Alps, southalpine flysch **Accomodation Youth hostel Le Miniere**

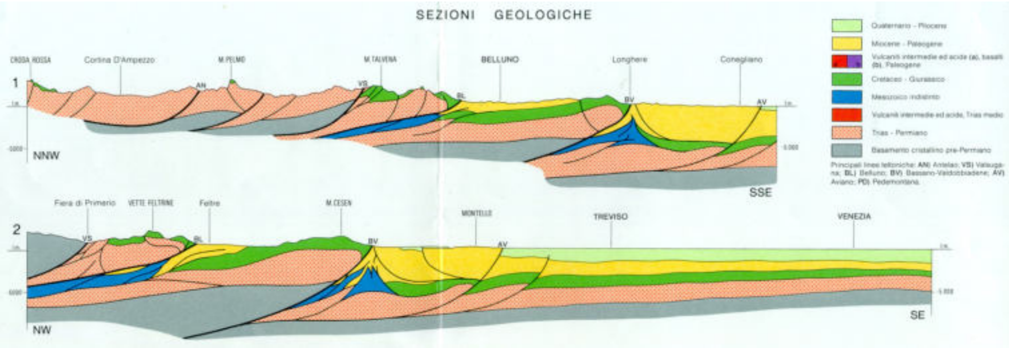


Fig: 24/7/1: backthrusting along the southern margin of the Alps

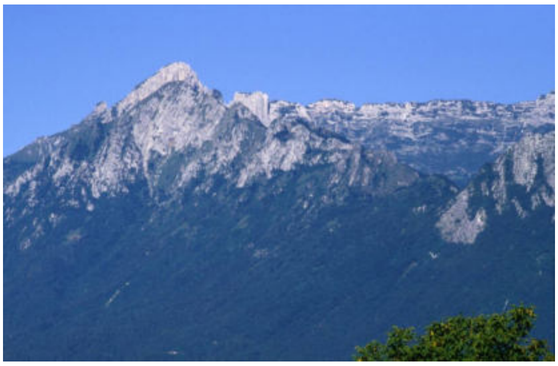


Fig: 24/7/2: frontal flexur near Mas

Fr. 25. 7. Passo San Boldo - Belluno – Longarone (Vajont reservoir) – Cortina – Felbertauern – Kitzbühel – München: Montello frontal thrust and flexure, folded Tertiary, Vaiont landslide – **back to Munich.**

Fig. 25/7/1: Vajont – reservoir and landslide, which filled the reservoir on

The Vajont Dam, completed in 1961, was one of the highest dams in the world with the height of 262 meters (860 ft). On October 9, 1963 at around 10:35 p.m., the combination of the drawing-down of the reservoir and heavy rains triggered an enormous landslide of about 260 million cubic meters of forest, earth, and rock, which fell into the reservoir at up to 110 km per hour (68 mph). The resulting displacement of water came up to 50 million cubic meters and overtopped the dam in a 250 meter high wave. The wave of water was pushed up the opposite bank and destroyed the village of Casso, 260 meters above lake level. The water then fell more than 500 meters onto the villages of Longarone, Pirago, Villanova, Rivalta and Fae, totally devastating them. About 2,500 lives were lost. However, the dam was not destroyed and is still standing today.

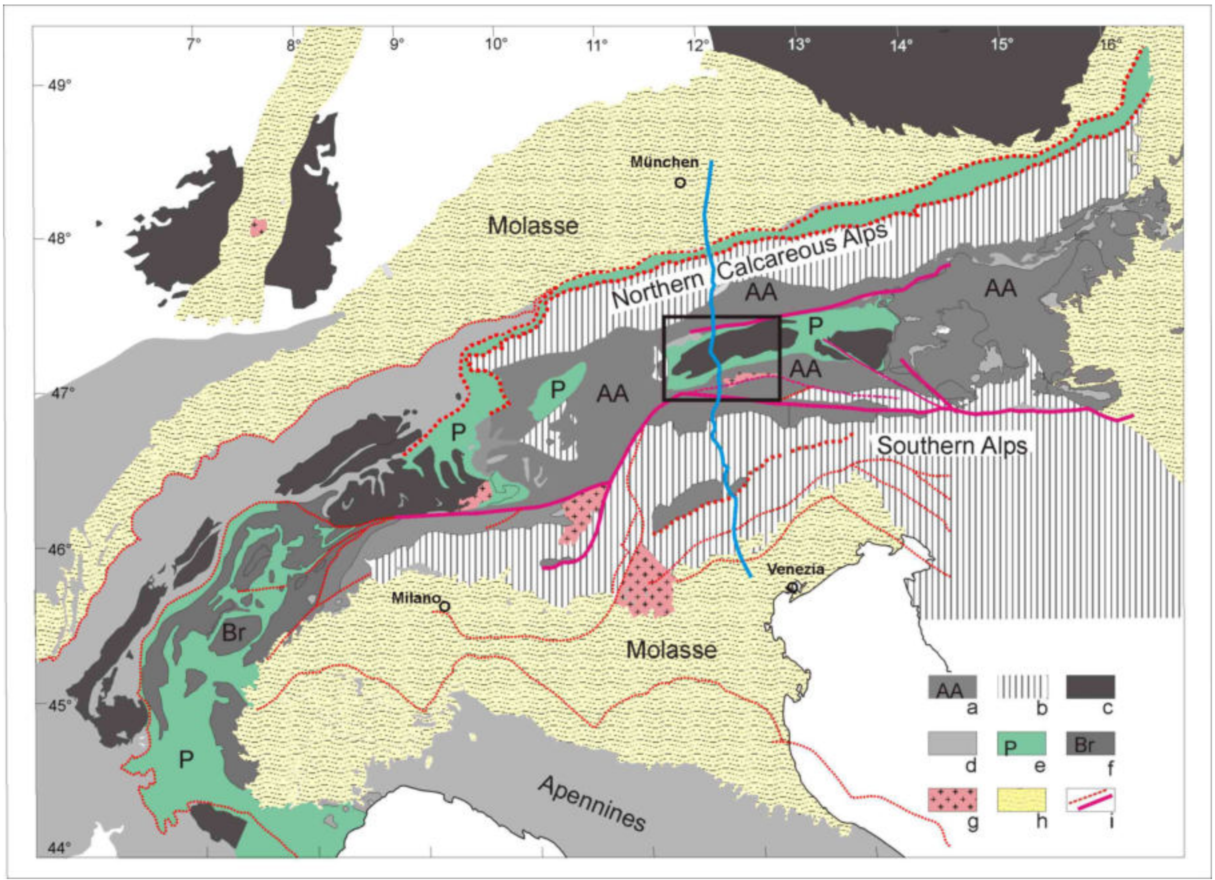


Fig. 1. *Tectonic sketch map of the Alps*: Explanation: a = Austroalpine and Southalpine basement; b = Austroalpine and Southalpine Mesozoic cover; c = European basement; d = European cover; e = Valais- and Ligurian oceanic sediments and ophiolites; f = Briançonnais terrane; g = Tertiary magmatites; h = Tertiary sediments of the Molasse and Rhinegraben; i = dotted line: thrusts, bold line: faults with mainly strike slip movements. Bold line between München and Venezia = TRANSALP seismic section; Apennine = undifferentiated. The inset frame marks the position of fig. 2 in the western Tauern window. After Schmid et al. 2004.

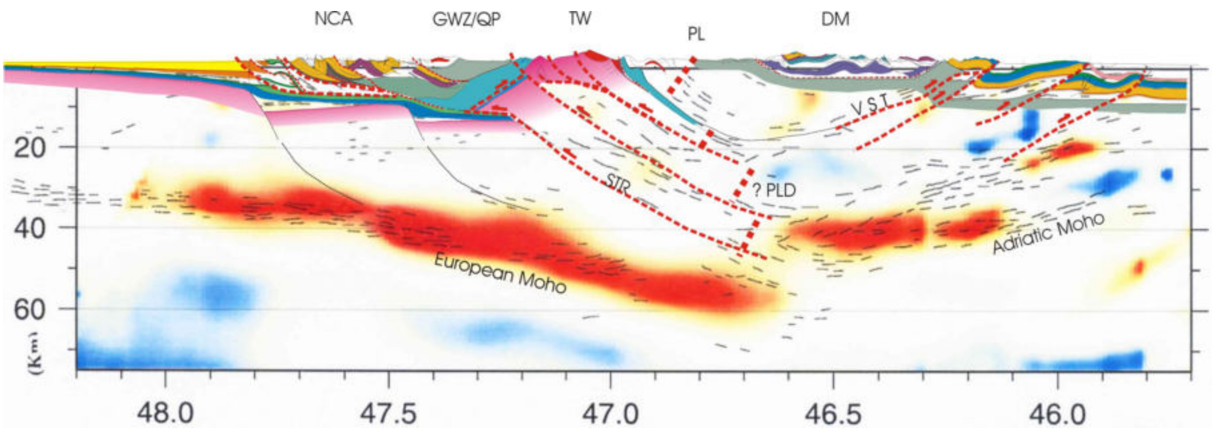
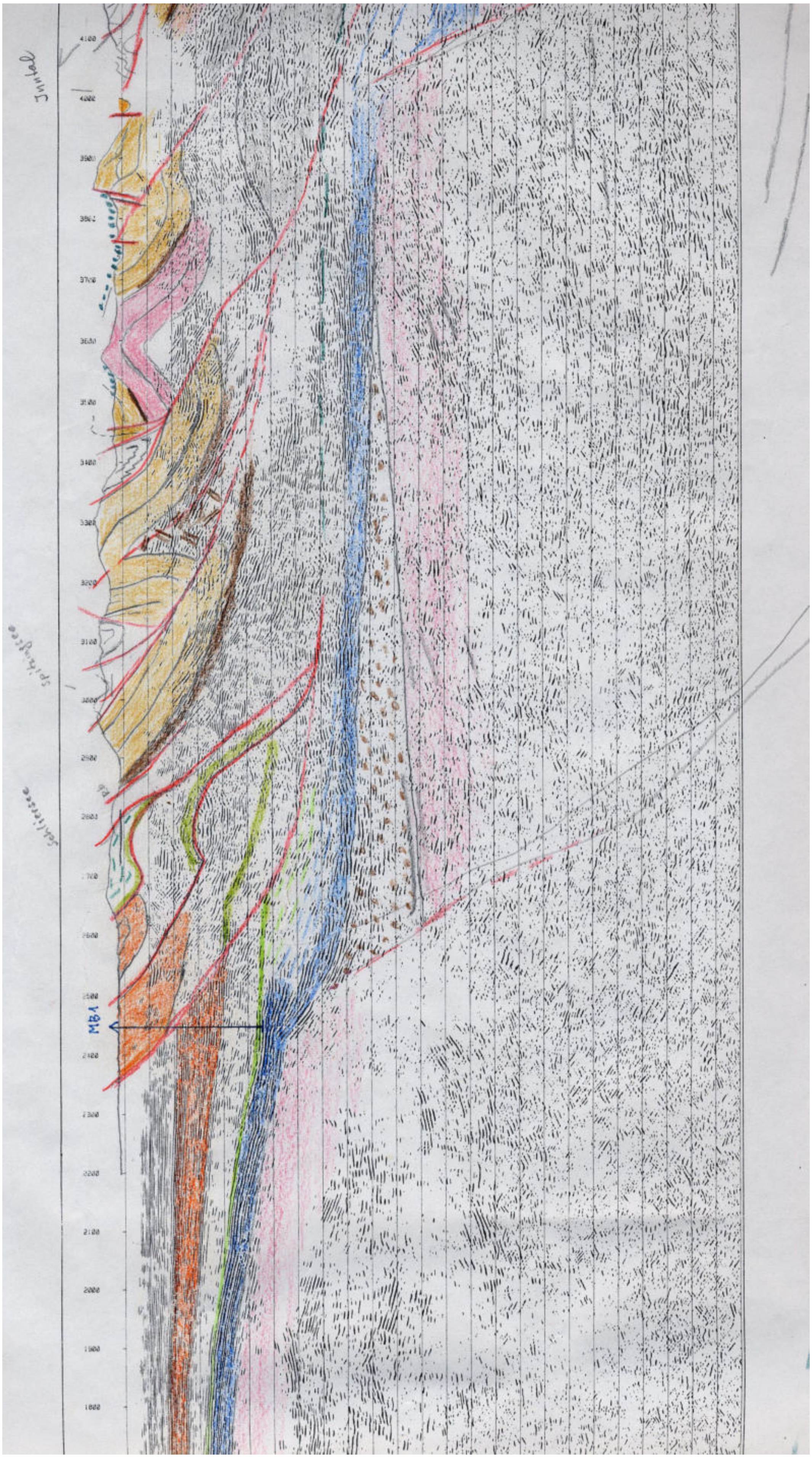
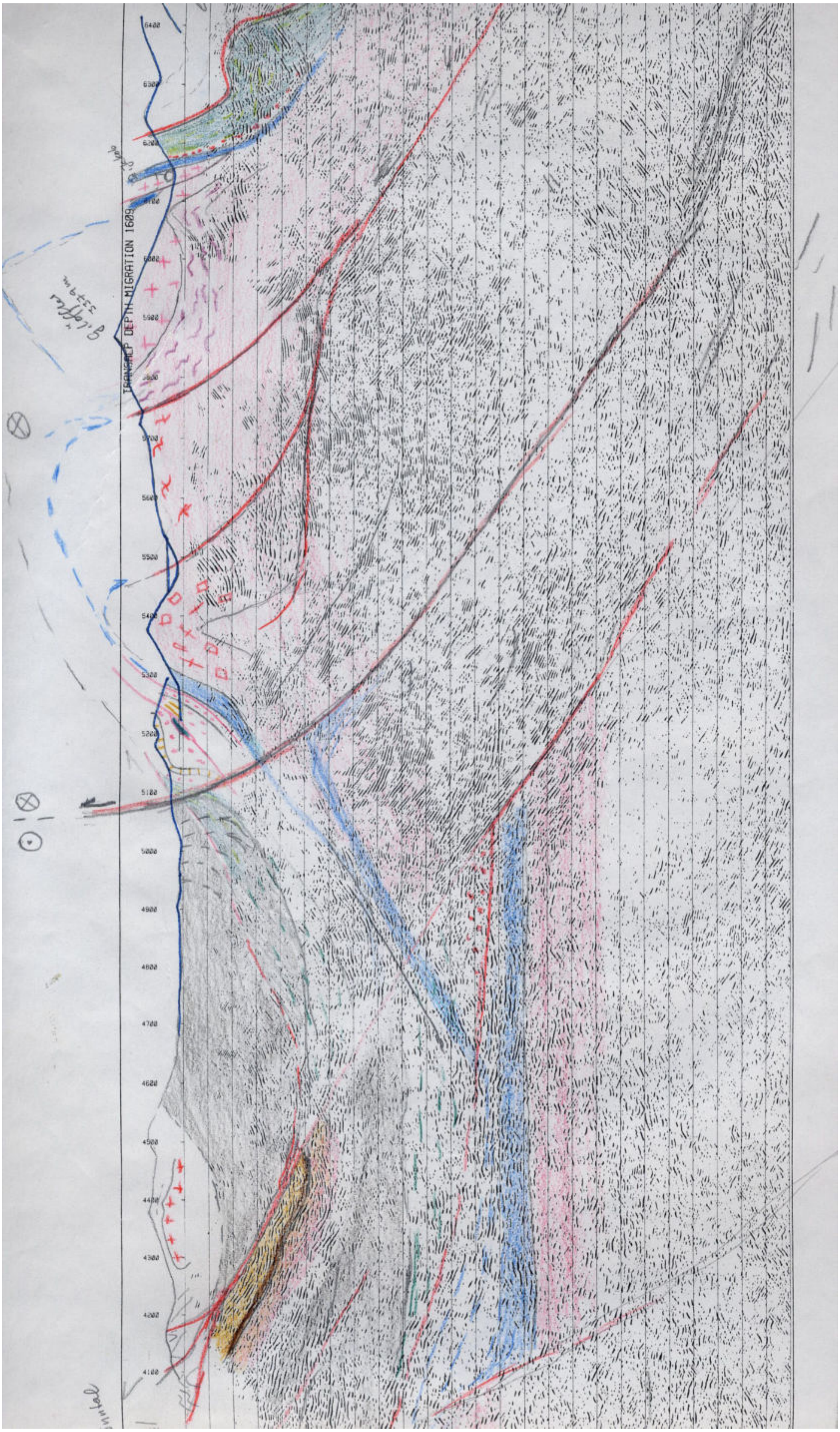
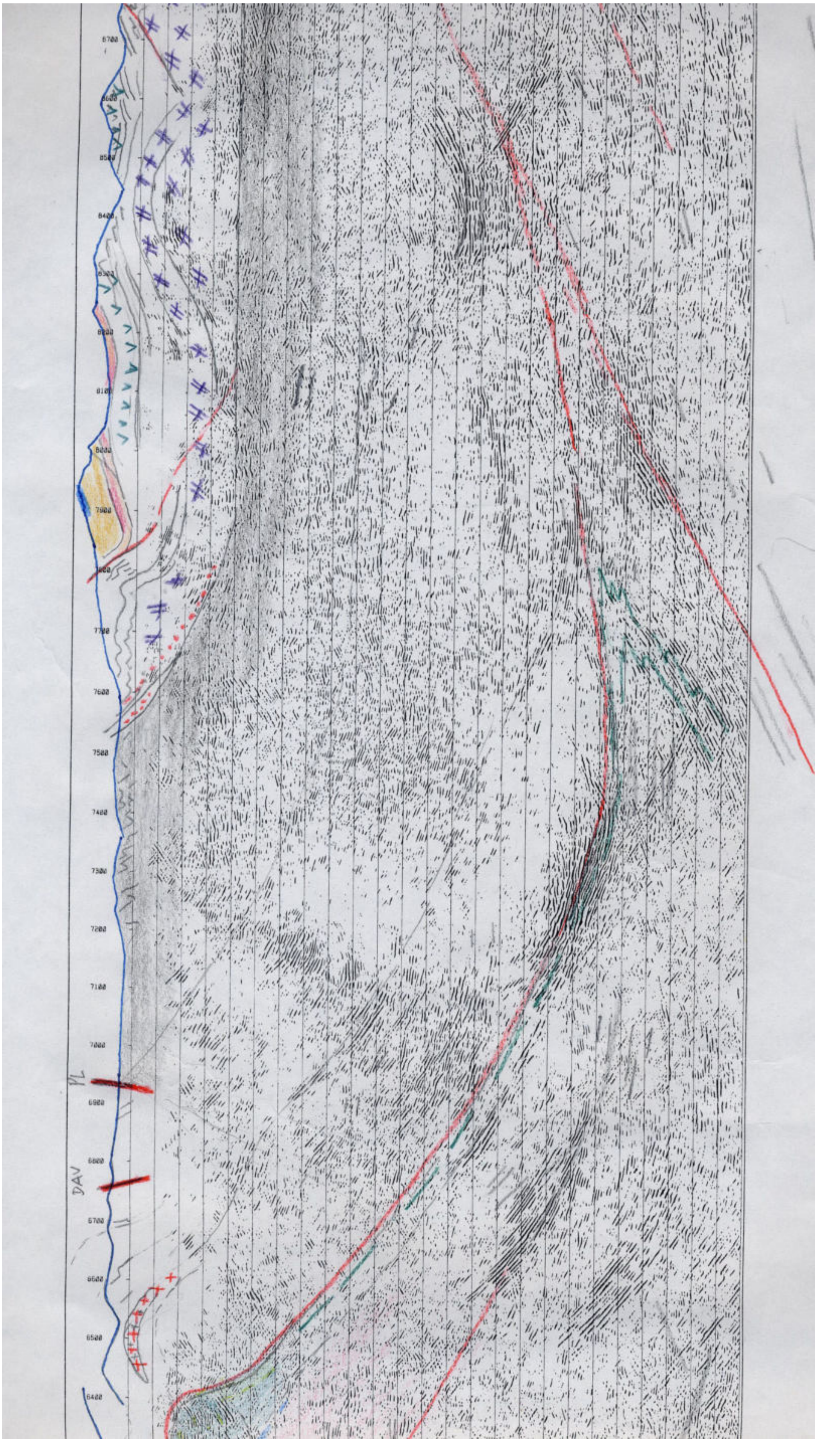


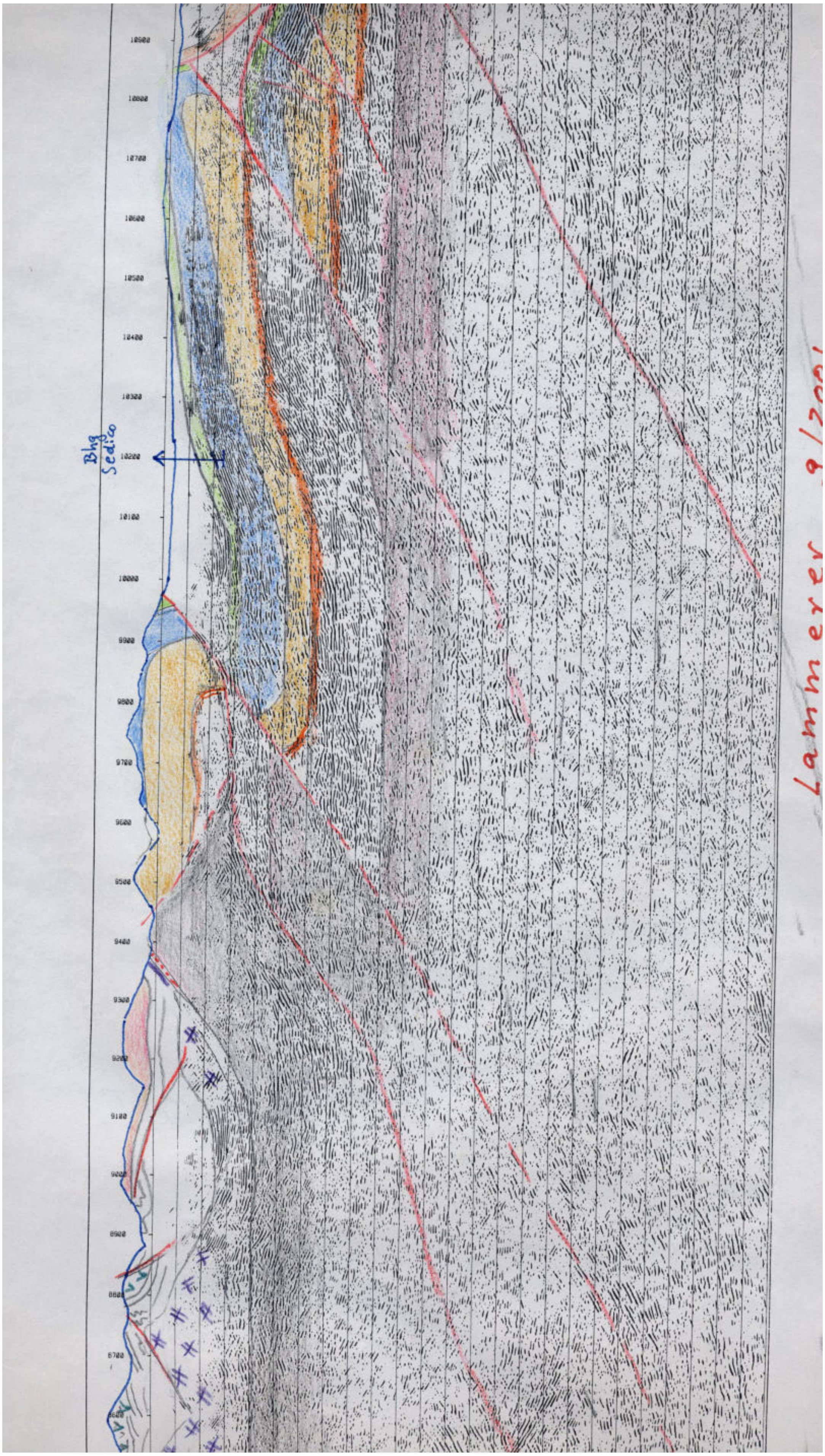
Fig 2. *Deep structure of the Alps from receiver function studies and line drawing from vibroseis and explosion seismic studies.* NCA = Northern Calcareous Alps; GWZ/QP = Greywackezone and Quartzphyllite zone; TW = Tauern Window; DM = Dolomite mountains; PL = Pustertal line; PLD = Pustertal line, disrupted?; VST = Val Sugana thrust.



Inntal
MB1


TRANSALP DEPTH MIGRATION 1609


PL
DAV



10900
10800
10700
10600
10500
10400
10300
Bhg
Sedico
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10100
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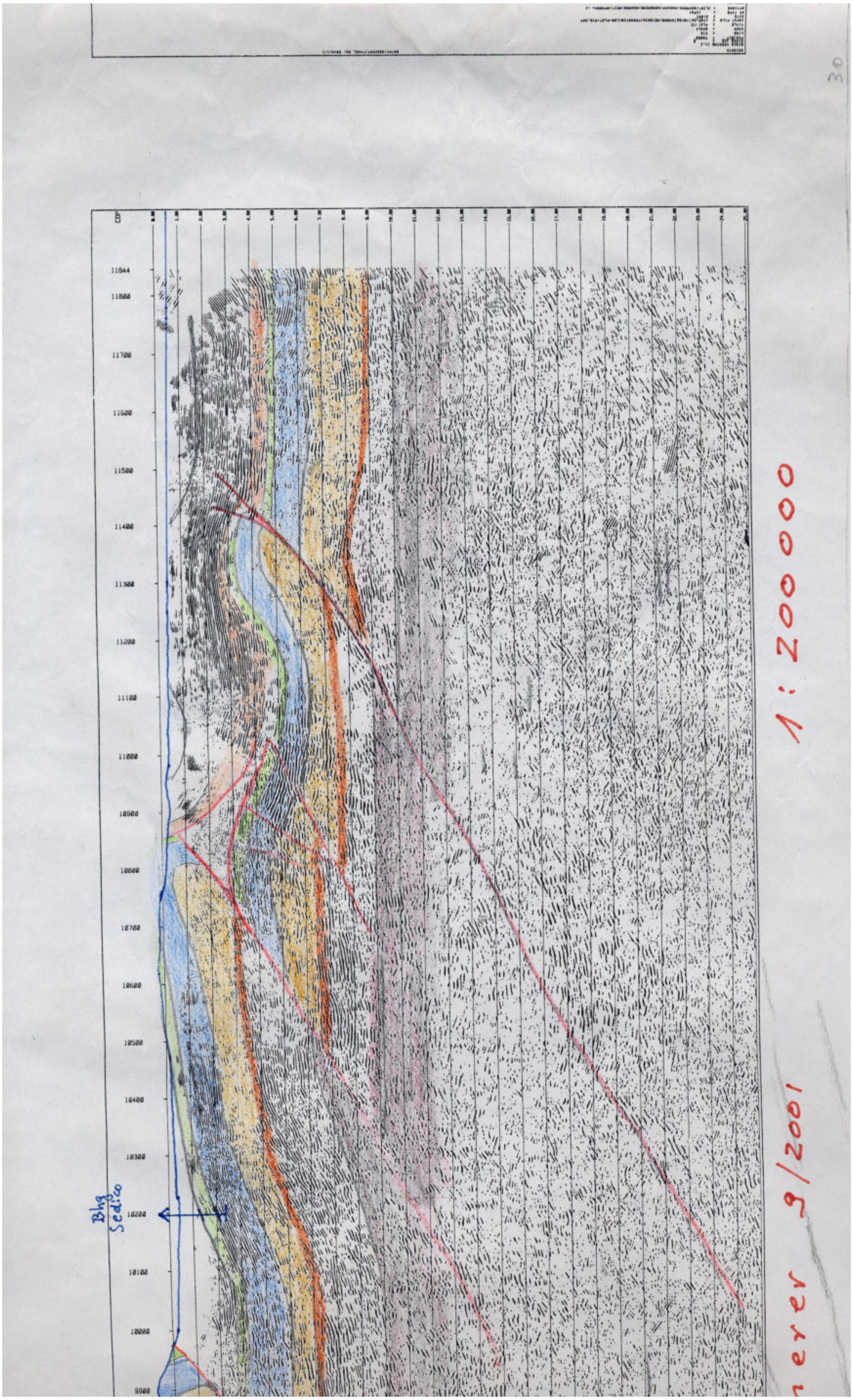
Lammerer 9/2001



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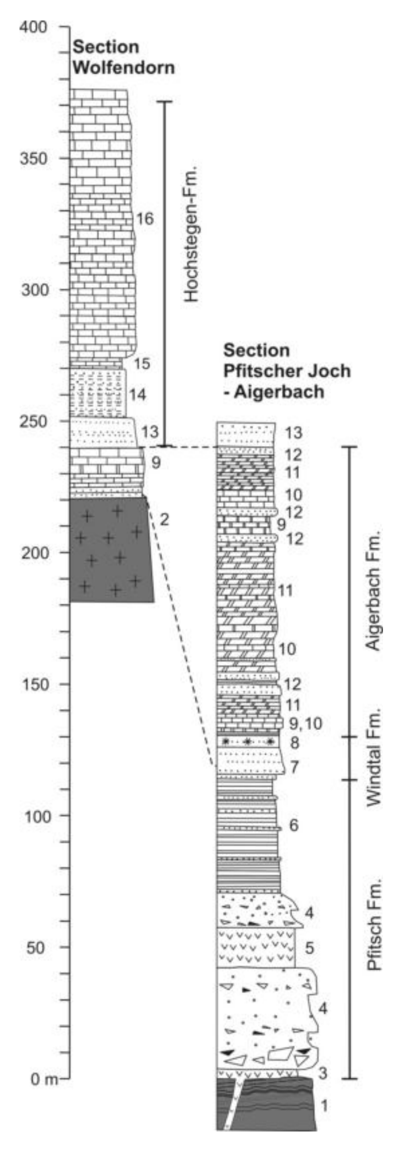


age	lithostratigraphical unit	facies /protolith	interpreted deposi environment
Hochstegen Formation			
Late Jurassic	greyish, bluish marbles (16) sandy marbles	carbonates	deeper marine envi
? Middle Jurassic	brownish sandy marbles (15), mica- graphite- bearing horizons	sandy impure carbonates	neritic environment
? Lower Jurassic	kyanite-graphite- phyllite and quarzite-schists (14) graphite-quartzite, pure quartzite (13)	sands, Fe- and Al- rich pelites mud	floodplain deposits fluvial sands
Aigerbach Formation			
? Late Triassic	chloritoid-, mica-quartzite (12)	sands, impure sands and pelites	supratidal area, coa
	dolomite and cargneuls (11) yellowish sandy marbles (10) dolomitic marbles (9)	carbonates, anhydrite, gypsum	shallow marine to s environment
	chloritoid-, kyanite-quartzite, mica-, chlorite-schists (12)	fine sands high Fe content, pelites	fluvial sands, mudc channels
	white dolomitic marbles, cargneuls (11), thin marble beds (10)	carbonates, anhydrite, gypsum	sabhka environmen evaporation
	calcareous/dolomitic quartzite, kyanite-, chloritoide-, mica-schists, and -quartzite (12)	impure sands and pelites	supratidal area, coa channels
	dolomite and cargneuls (11)	anhydrite, gypsum	sabhka environmen evaporation
? Middle Triassic	greyish, yellowish sandy marbles (10), yellowish,violet dolomitic marbles (9)	carbonates partly dolomitizied	shallow marine env
Windtal Formation			
? Early Triassic	locally lazulite-kyanite quartzite (8), mica-, hematite-quartzite (7)	Fe-rich sand deposits, locally P-, Al-rich sediments	channel sands, brai deposits? palaeosol area apart from cha
Pfitsch Formation			
? Late Permian	epidote-ankerite schists and quartzite (6)	pelites, mud with sand laminae	distal part of (semi fan muddy floodpla
280,5 ± 2,6 Ma	meta-rhyolite (5)	volcanic deposits	subaerial lava flow
? Early Permian	meta-conglomerate (4)	crude gravel, matrix/clast supported, sand	proximal, middle p arid alluvial fan, si
293 ± 1.9 Ma	meta-rhyolite (3) Mörchnerscharte	volcanic deposits	subaerial lava flow

Table

COL DELLA CHIAVE
2212
Caminata
1440
Fosse
1396
Fontana
Saletto
R. di Vizze
VALLE DI VIZZE
CRODA DELLA PORTA
2640
Miniera di talco
Bargone
di Vizze
1174
M.ga di Montegrande
Novale
Lago di Novale
alla Diga
M.ga Leitner
CRODA DELLE CESTE
MONTE GRANDE
2701
M. DI BARGONE
ex Rif.° Picco della Croce
M.ga di Bargone
Avenes
1253
CIMA DEL CAVO
2458
2656
2517
CIMA DEL LAGO

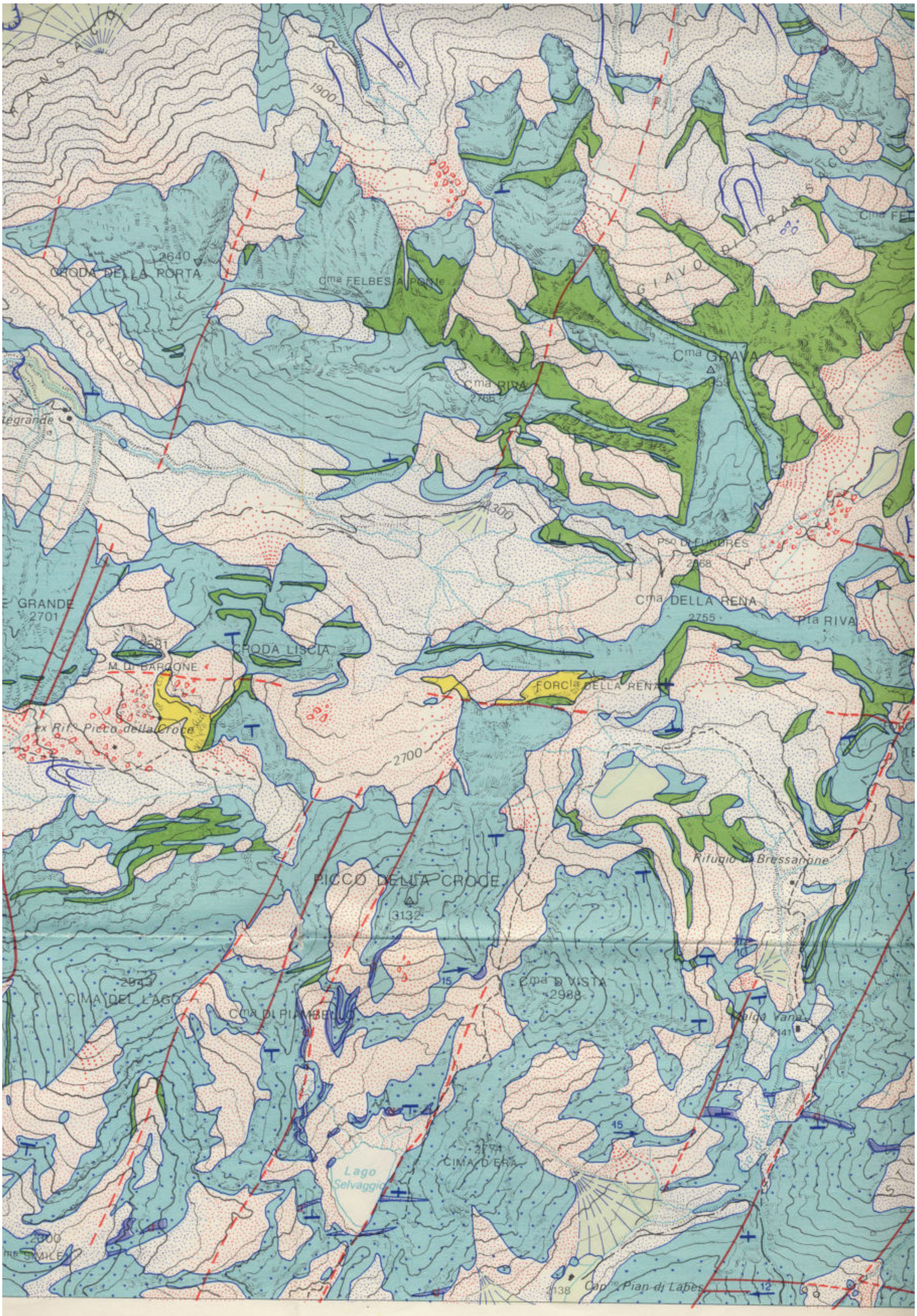
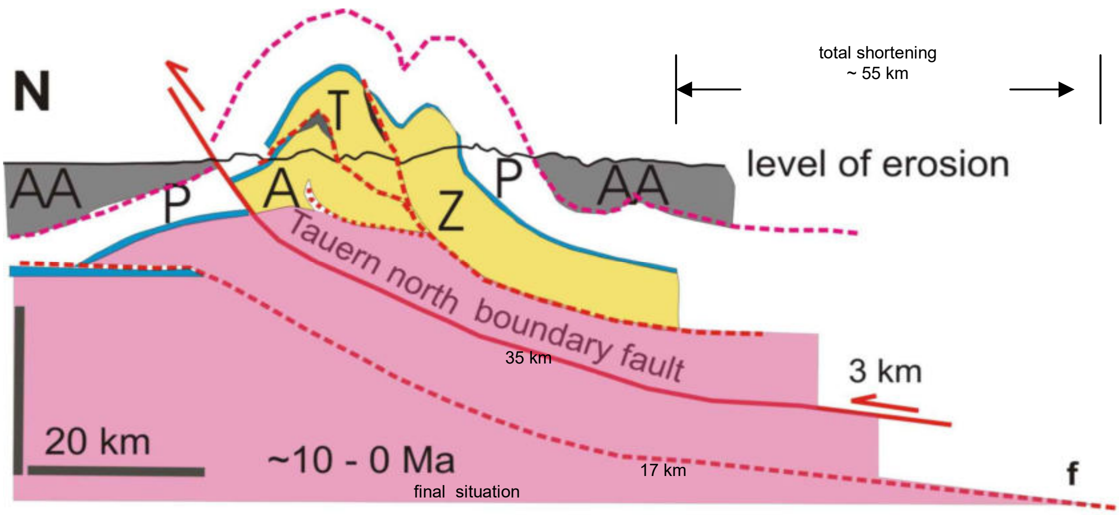


Fig 19/7/2: The gross structures of the Tauern Window.



The Tauern Window

Folded Bellerophon Beds near Passo San Nicolo


At the Rotwand/Schliersee

At Piz Boe

Coffee break


Vajont Reservoir – disaster 1963


The Southern front of the Alps!