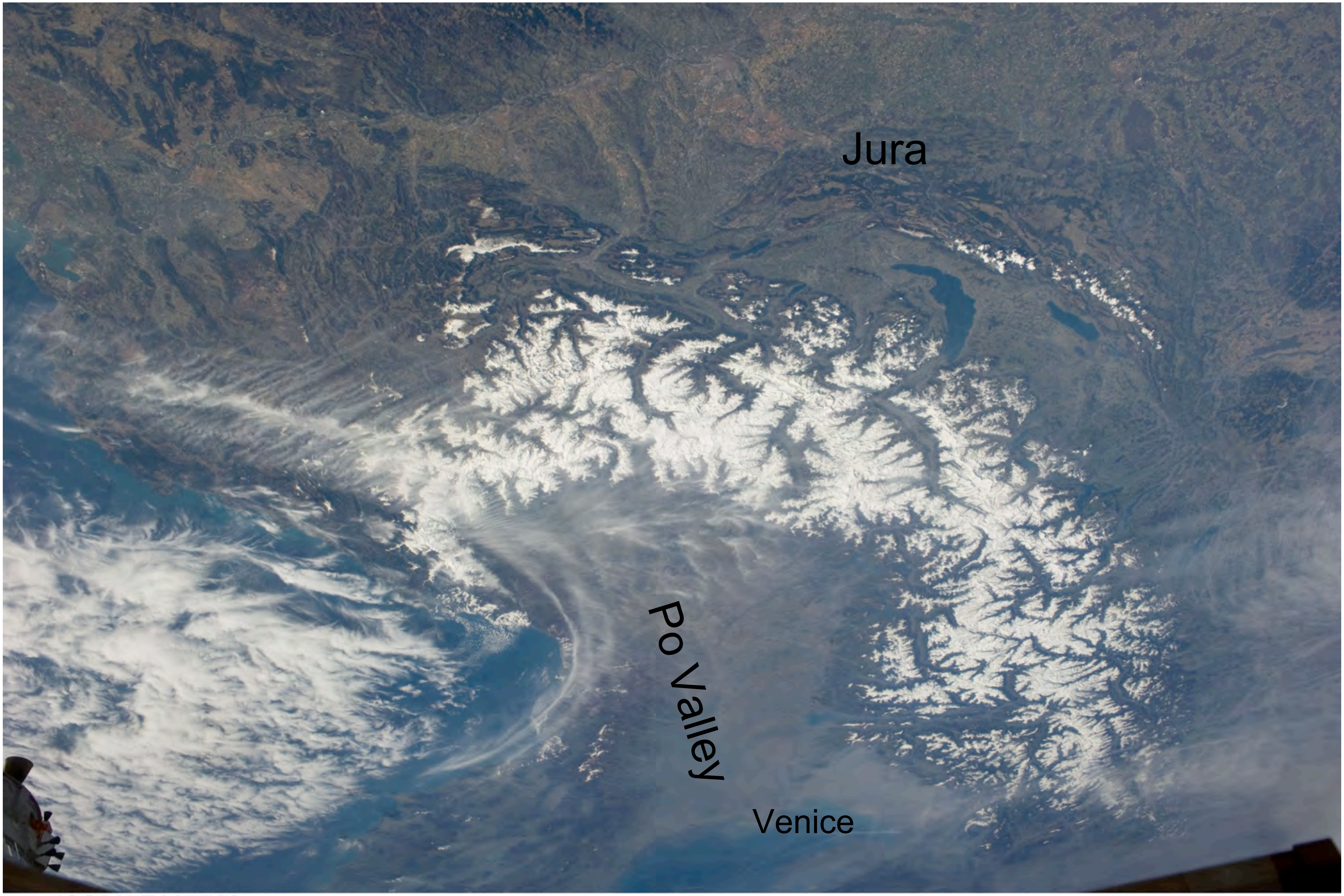
The Alps and Metamorphism



Alps, Lake Geneva, Adriatic

http://eol.jsc.nasa.gov/

The Alps
The Dolomites

http://eol.jsc.nasa.gov/

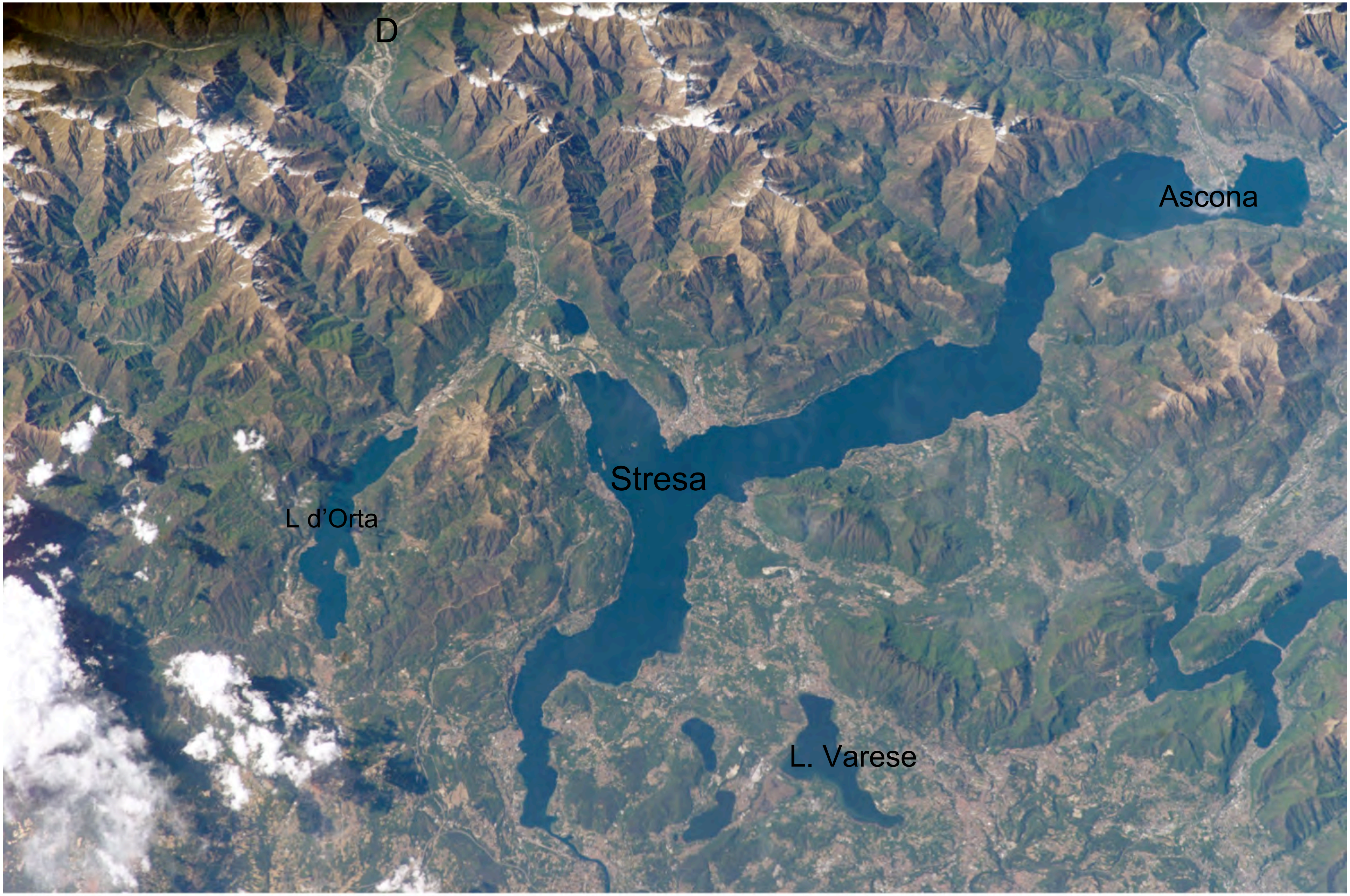
Marmalotta Massif from Pardoi Pass, Dolomites

Sella Massif and Rosengarden from Gardena Pass, Dolomites

Insubric Line along base of Vallone (hill on left)

Triassic Dolomites, Tauern Window, AustroAlpine Nappe

View North to Austria, Brenner Pass

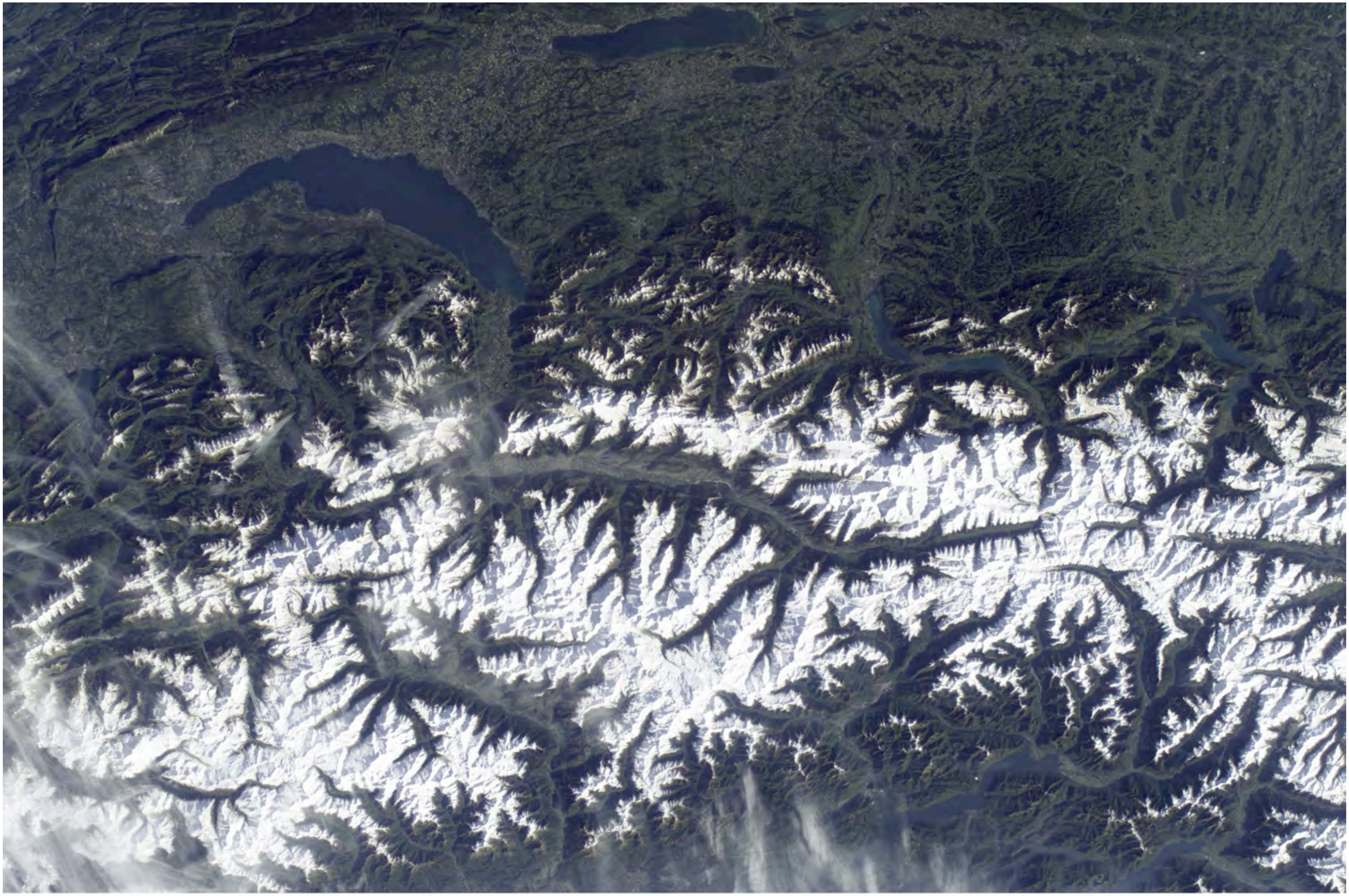


ISS004E10699

Italian Alps: Lago Maggiore

http://eol.jsc.nasa.gov/

Isola Bella, Lago Maggiore view to north



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Alps: Lake Leman, Rhone Valley, Monte Bianco http://eol.jsc.nasa.gov/

Alps: Zermatt, the Matterhorn

http://eol.jsc.nasa.gov/

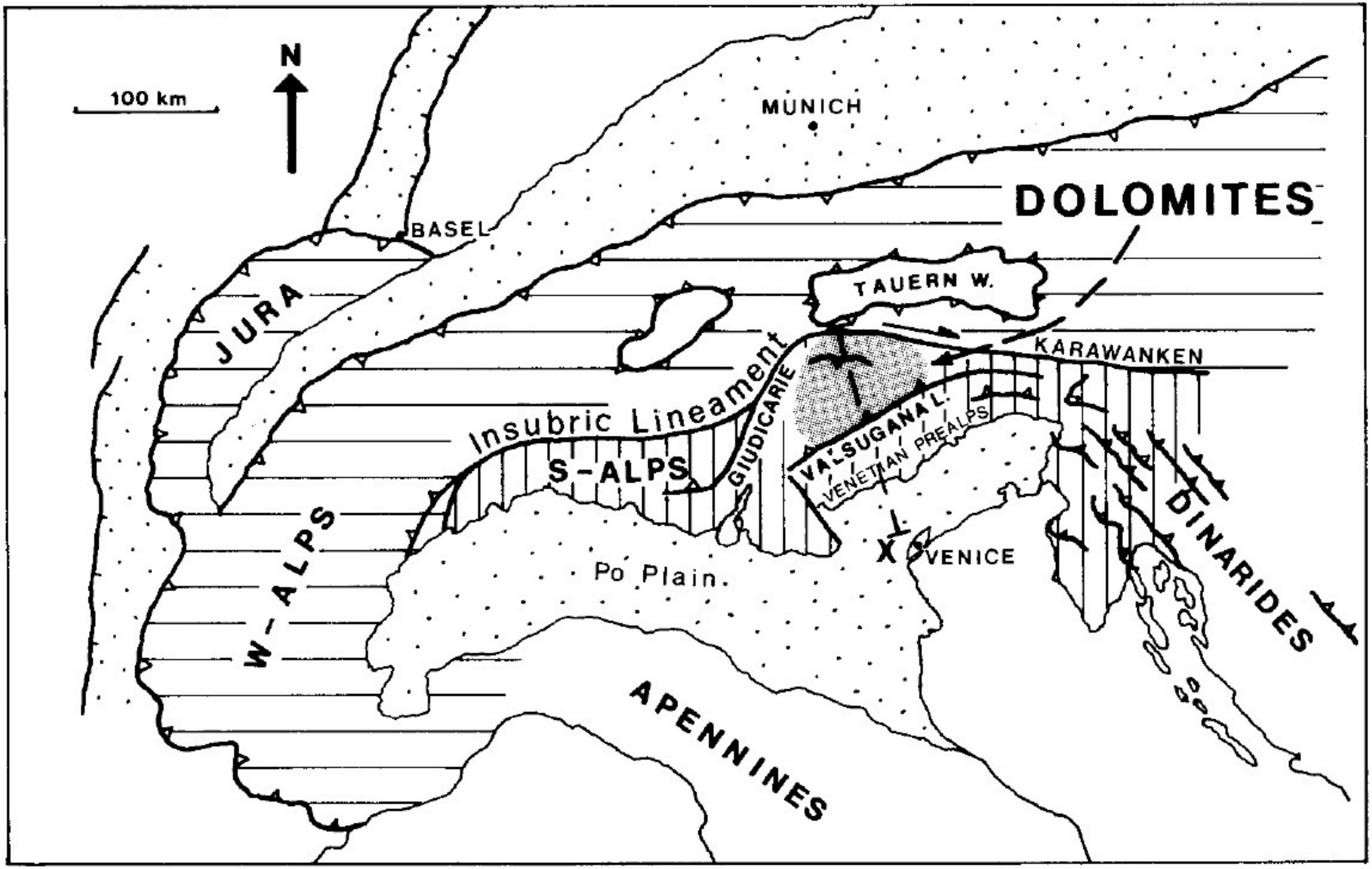


Fig. 1. Location of the Dolomites in the Alps; X shows the trace of section shown in Fig. 2.

Doglioni 1987

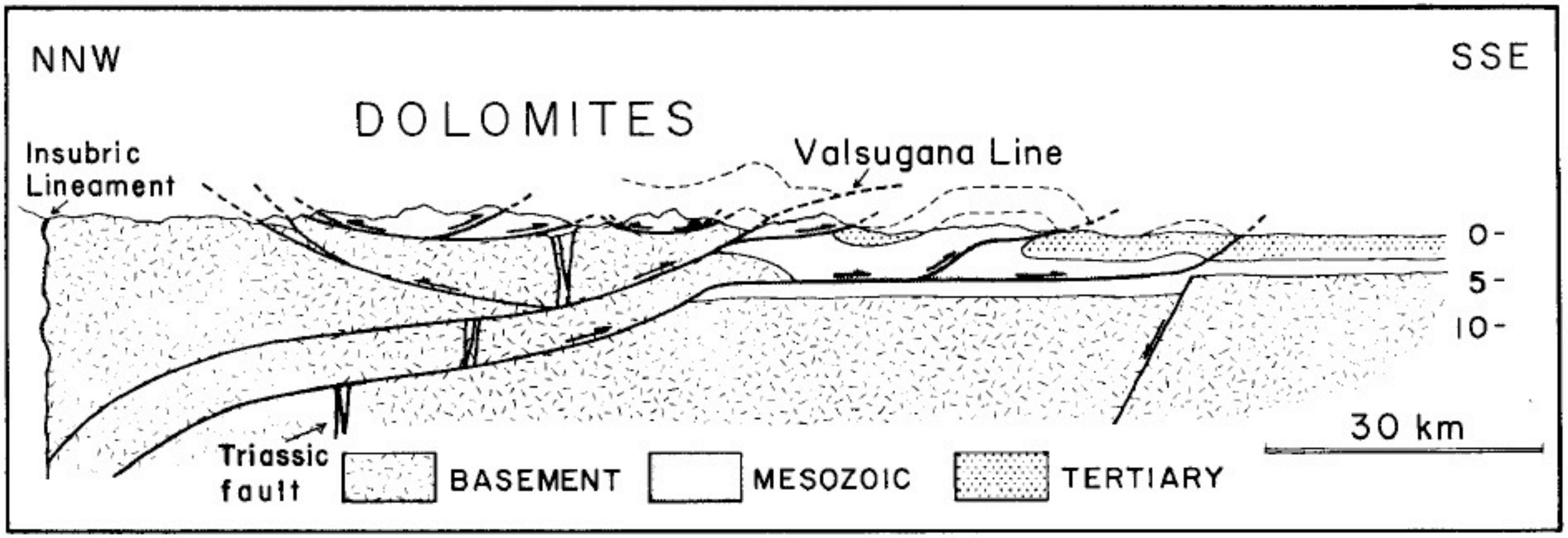


Fig. 2. Schematic cross-section of the Southern Alps across the central Dolomites, which are the innermost part of the exposed thrust belt (modified after Doglioni & Castellarin 1985). For location of the section see Fig. 1. The basement is undifferentiated; Upper Permian sediments are assumed at the base of the Mesozoic sequence and Quaternary gravels are also present on the top of the Tertiary to the south in the Veneto Plain.

Doglioni 1987

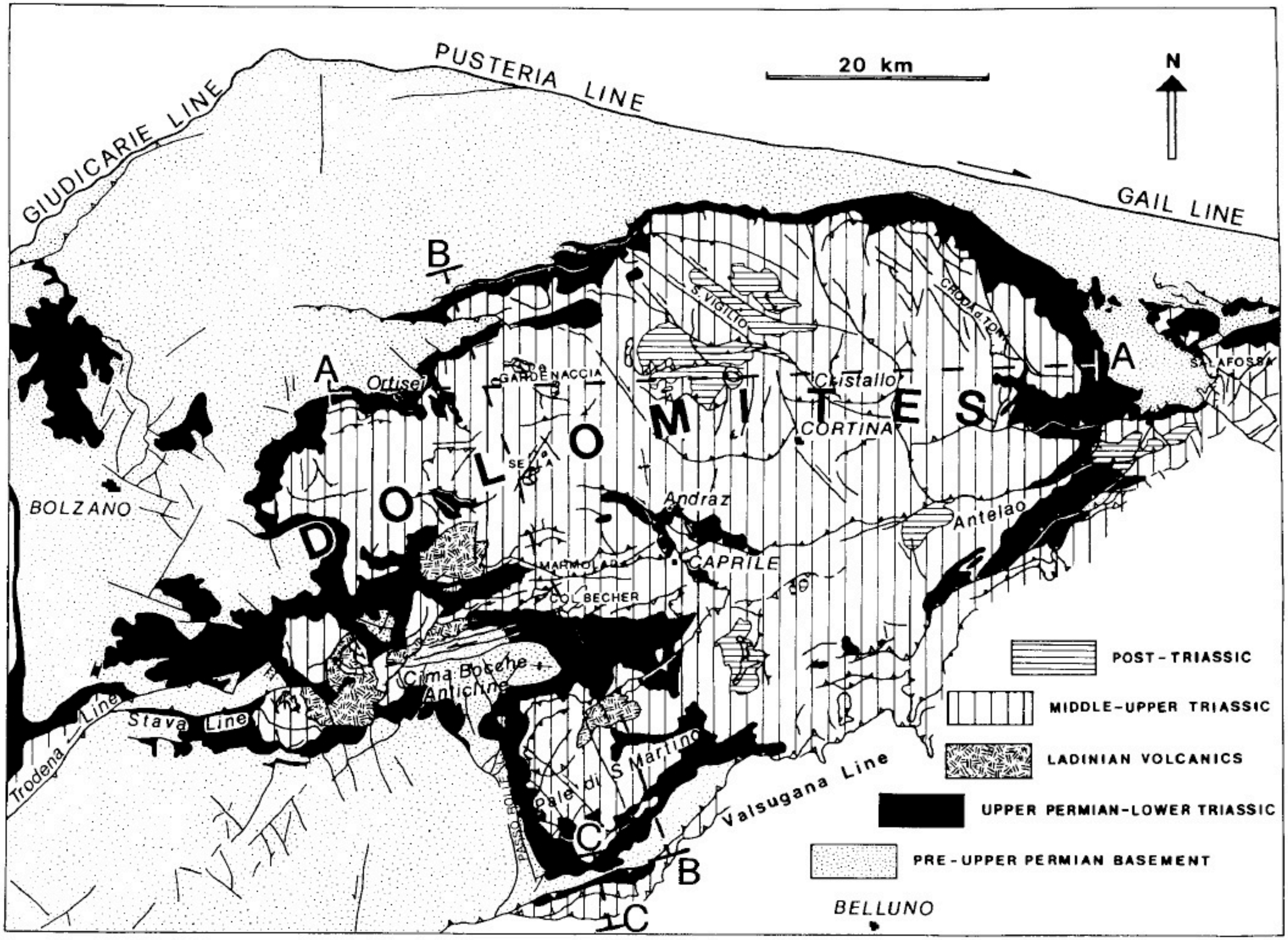


Fig. 3. General tectonic map of the Dolomites. The undifferentiated basement includes Lower Permian ignimbrites, metamorphic rocks, granitic bodies and, east of the Dolomites, the anchimetamorphic terrains of the Palaeo-Carnian Chain. A, B and C show the trace of cross-sections in Figs. 6, 8 and 9, respectively.

Doglioni 1987

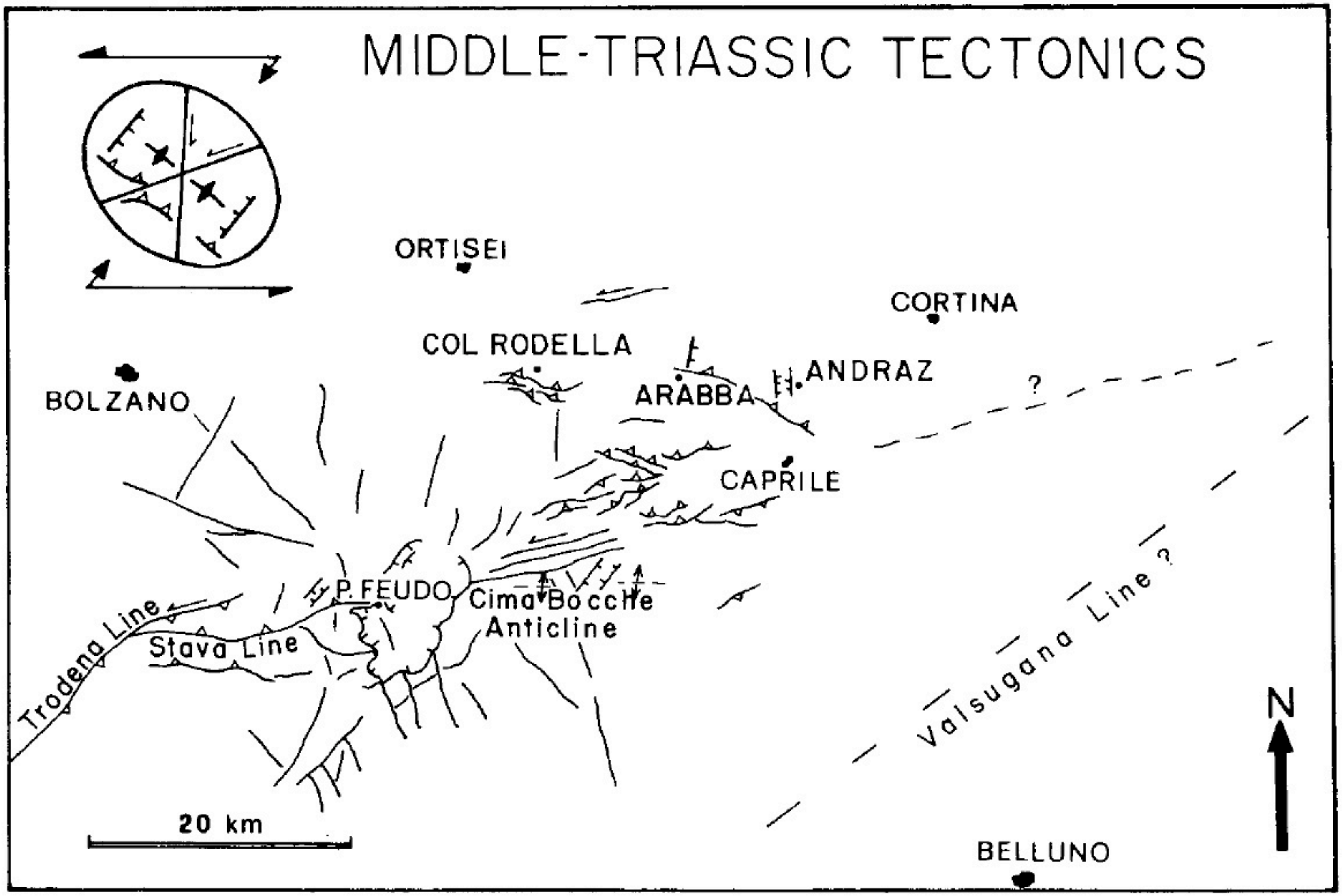
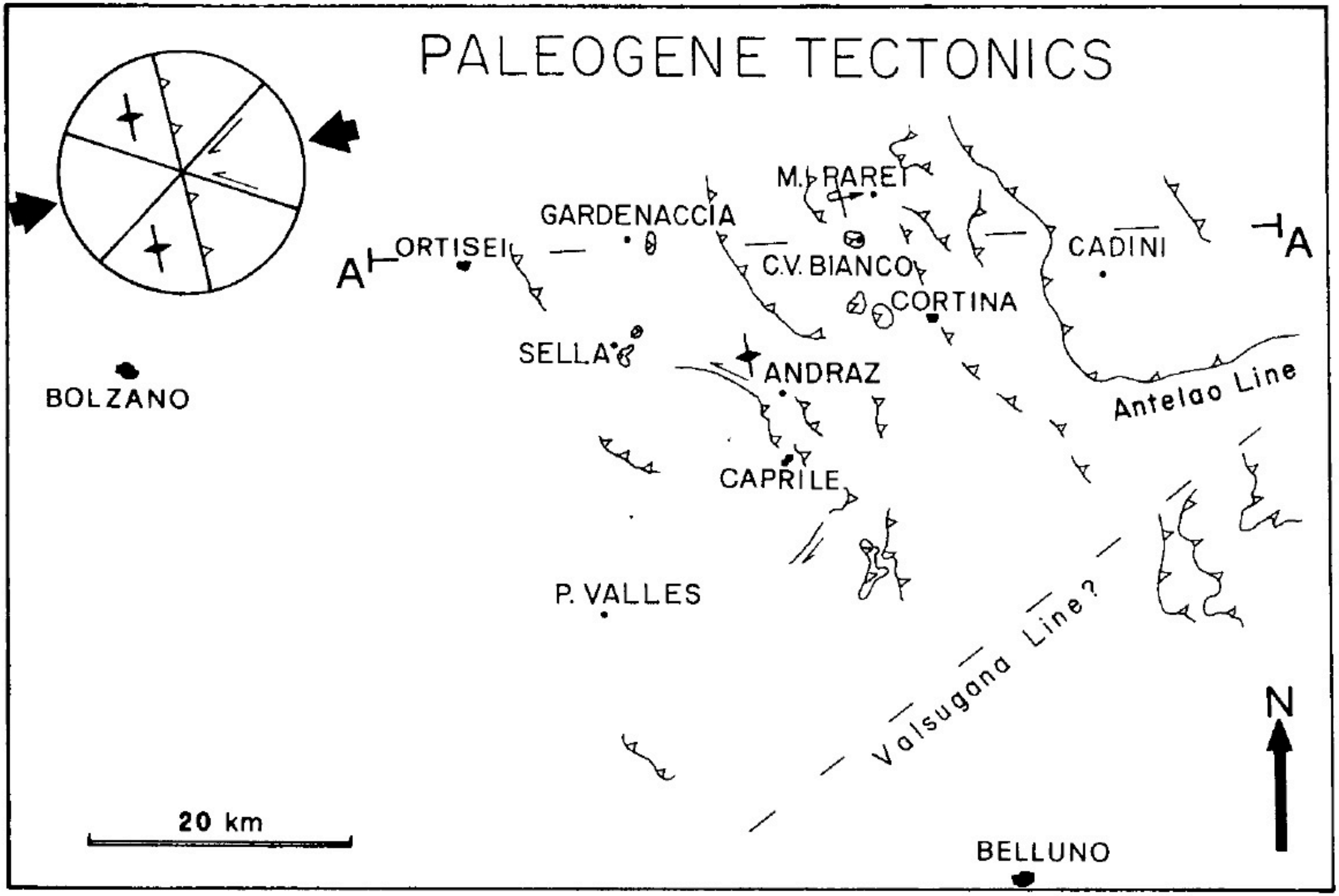


Fig. 4. Main tectonic features of Middle Triassic age in the Dolomites. Note the alignment Stava Line–northern limb of the Cima Bocche Anticline, interpreted as a sinistral transpressive zone. Volcano-tectonic features are also present in the west, related to a domal uplift and a subsequent caldera.

Doglioni 1987



5. Main tectonic features of pre-Neogene (Upper Cretaceous–Palaeogene?) age in the Dolomites. A–A is the trace of the section shown as Fig. 6.

Doglioni 1987

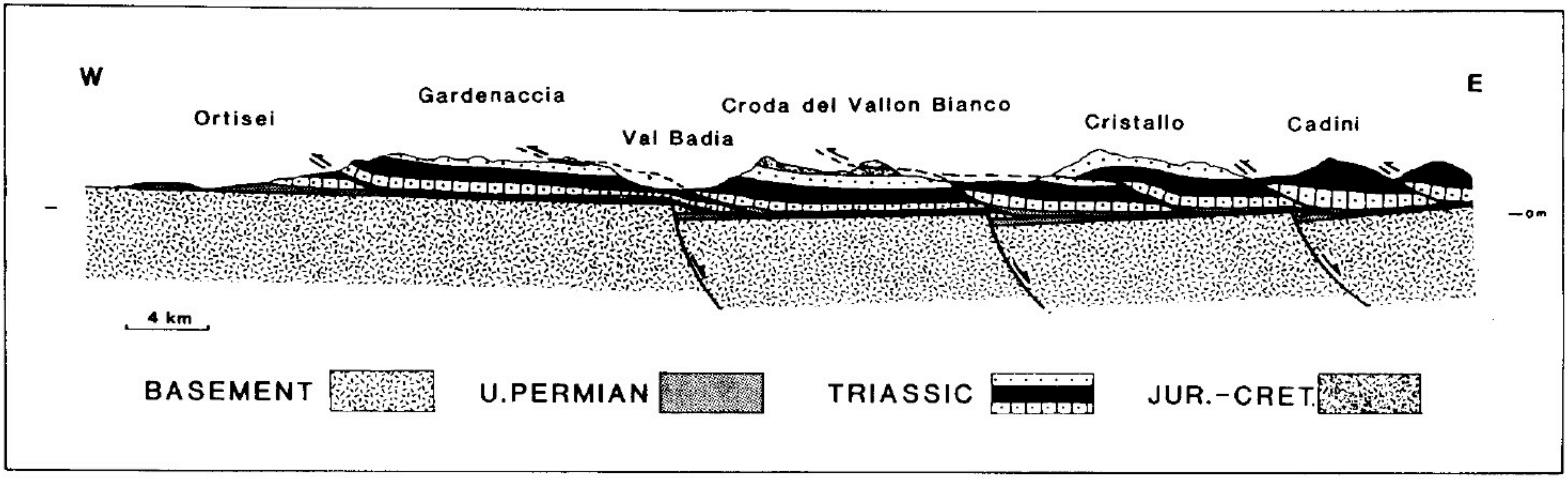


Fig. 6. Schematic E–W cross-section of the Dolomites showing the main overthrusts related to Palaeogene (?) E–W (ENE–WSW) compression. The positions of early Permo-Mesozoic normal faults in the undifferentiated basement are inferred from thickness variation of the sedimentary cover. Shortening of the sedimentary cover is at least 10 km, measured on the basis of the minimum displacement of thrusts. Structurally this section looks like a folded foreland and may be the westernmost external part of the Dinaric chain. Neogene structures are not shown in this diagram. For location of the section see Figs. 3 and 5.

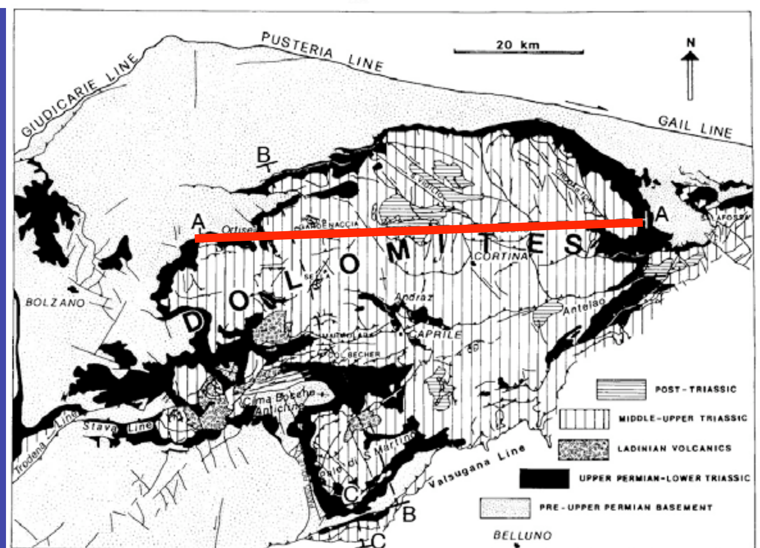


Fig. 3. General tectonic map of the Dolomites. The undifferentiated basement includes Lower Permian ignimbrites, metamorphic rocks, granitic bodies and, east of the Dolomites, the anchimetamorphic terrains of the Palaeo-Carnian Chain. A, B and C show the trace of cross-sections in Figs. 6, 8 and 9, respectively.

Doglioni 1987

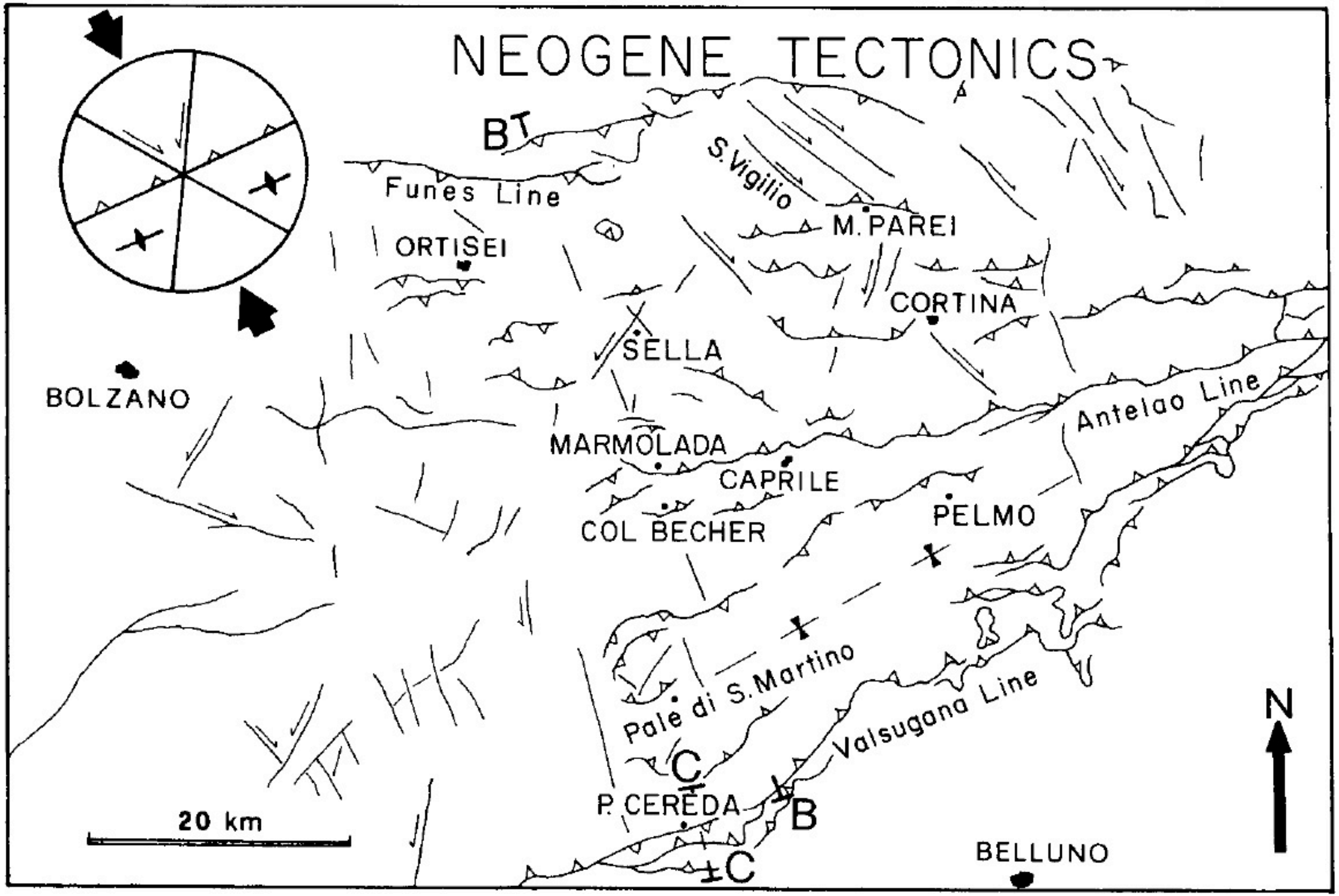


Fig. 7. Main tectonic features of Neogene age in the Dolomites. B–B and C–C are the traces of the sections shown as Figs. 8 and 9.

Doglioni 1987

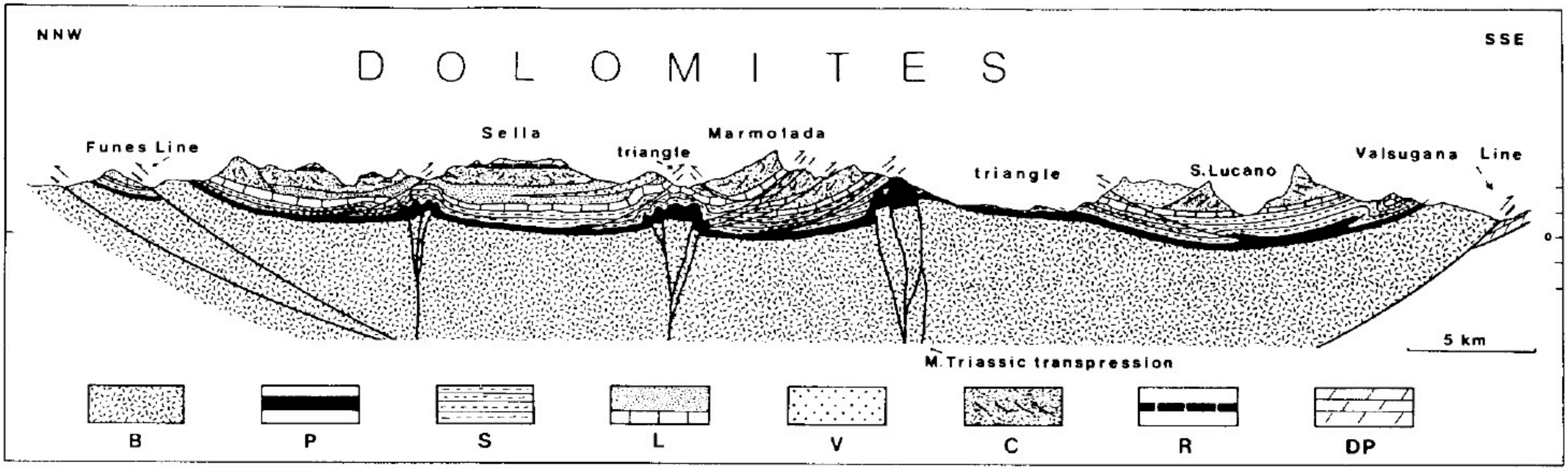


Fig. 8. N–S cross-section of the central Dolomites. The wide synclinorium or pop-up, is generated by the Valsugana Overthrust in the south, and by backthrusts on the northern side (i.e. Funes Line). Deformation in the basement is mainly inherited from Middle Triassic transpressive structures: note also Triassic diapiric squeezing above the transpression. The sedimentary cover adapted itself to the synclines of the underlying basement mainly by flexural slip. Triangle zones are present above the inherited structural highs. Pre-Neogene (Triassic and Palaeogene) overthrusts are oblique to the section and complicate the structure (e.g. Marmolada). For this reason the section is not retrodeformable in the central part. For location of the section see Figs. 3 and 7. Legend: B, undifferentiated pre-Upper Permian basement; P, Upper Permian (Val Gardena Sandstones and evaporitic Bellerophon Formation, seat of detachments); S, Scythian Werfen Formation; L, Anisian (Contrin Formation) and Ladinian-Carnian basinal sequences (Livinallongo Formation, Wengen Formation, S. Cassiano Formation); C, Ladinian and Carnian carbonate platforms; R, Upper Carnian Raibl Beds; DP, Norian Dolomia Principale.

Doglioni 1987

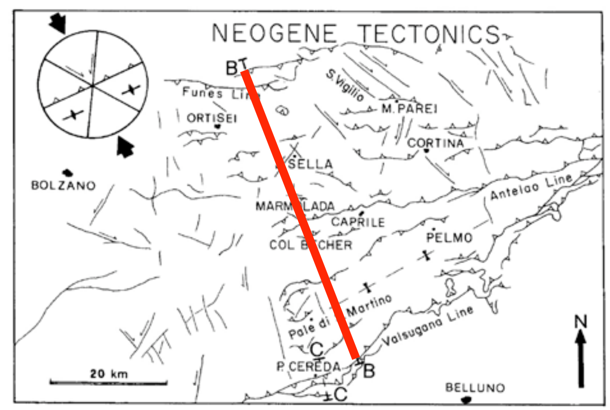


Fig. 7. Main tectonic features of Neogene age in the Dolomites. B–B and C–C are the traces of the sections shown as Figs. 8 and 9.

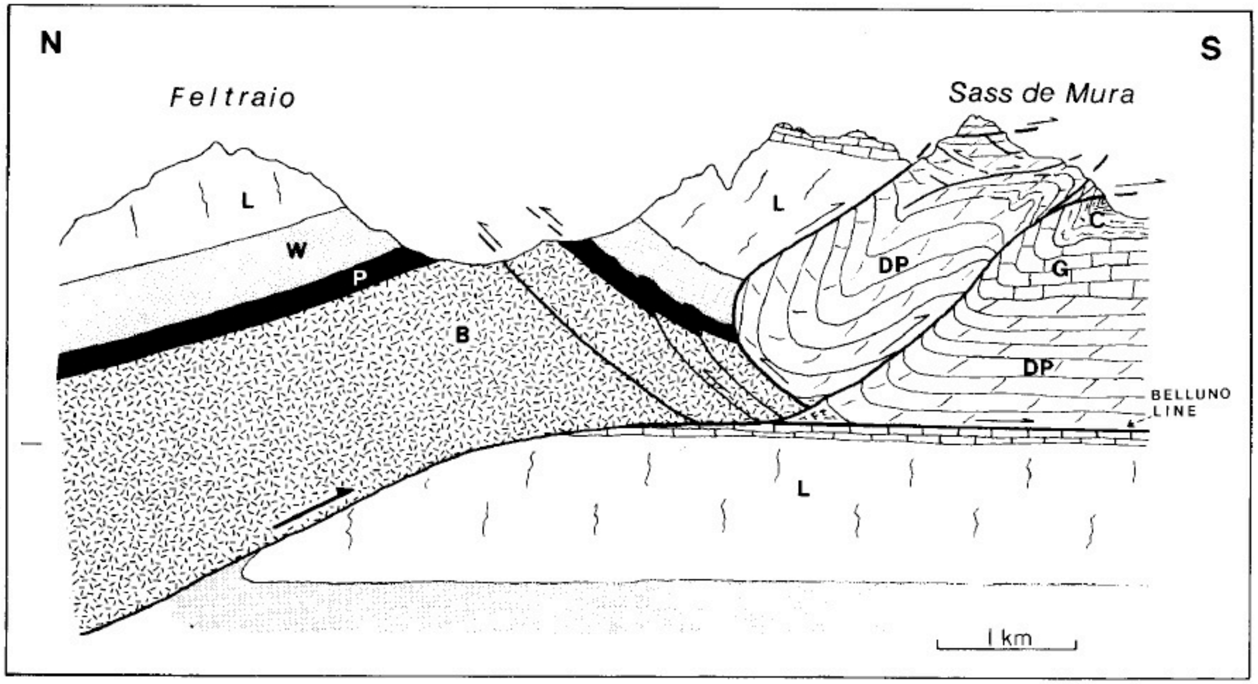


Fig. 9. Cross-section along the Valsugana Line, at the southern margin of the Dolomites in the Passo Cereda area. The basement (B) of the Dolomites overthrusts and wedges into the sedimentary cover of the Prealps in the south forming a 'fish structure'. The basement shows a ramp fold geometry. The southern limb of the fold shows the dragged Dolomia Principale (DP) wedged between basement and Ladinian carbonates (L) generating another N-vergent 'fish structure', with substitution of the cover at its base (contact basement—Dolomia Principale). This kind of structure could be present along the Valsugana Line in the whole Agordo Cereda area. Note that displacement of the main basement thrust must be absorbed by the branch line (Belluno Line) to balance the section. For location of the section see Figs. 3 and 7. Schematic stratigraphy: B, undifferentiated basement; P: Upper Permian sediments; W, Scythian and Anisian formations; L, Ladinian carbonates; DP, Dolomia Principale; G, Jurassic limestone; C, Cretaceous limestone and marls.

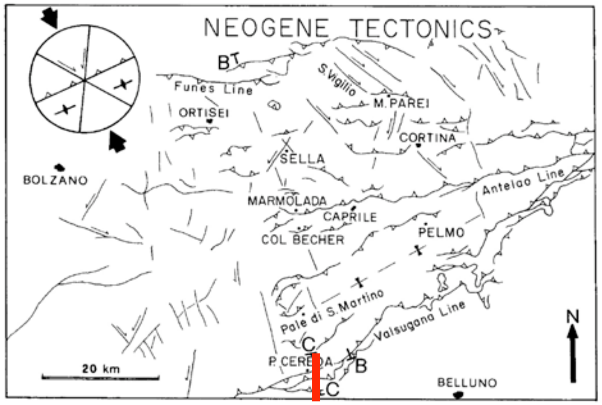


Fig. 7. Main tectonic features of Neogene age in the Dolomites. B–B and C–C are the traces of the sections shown as Figs. 8 and 9.

Doglioni 1987

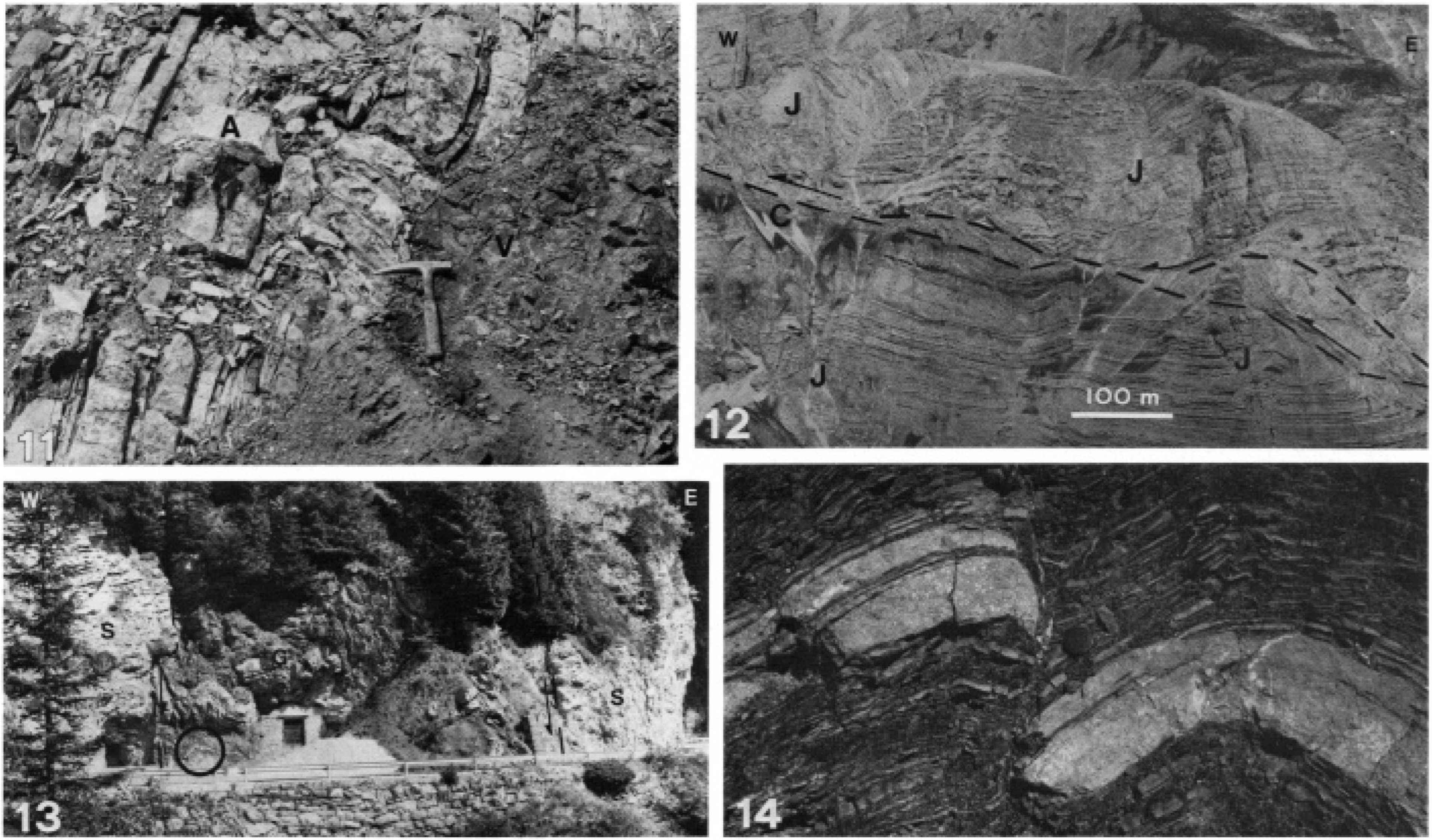


Fig. 11. Example of Ladinian pre-volcanic deformation: a Ladinian volcanic dyke (V) cross-cuts chevron folds in Upper Anisian limestone (A) at Passo Feudo. This deformation is preserved along the Middle Triassic transpressive lineament, the Stava Line-Cima Bocche Anticline.

Doglioni 1987

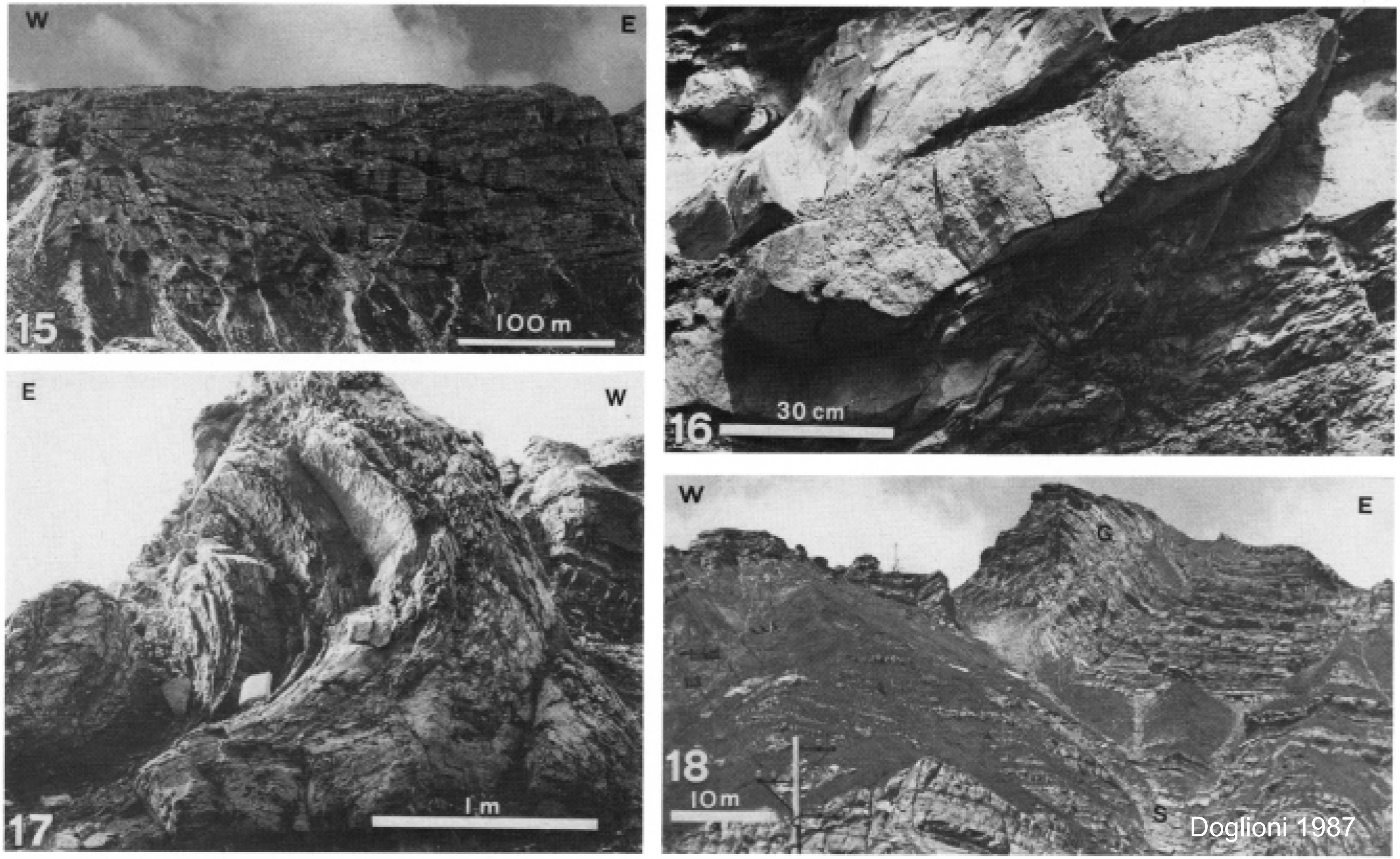


Fig. 12. Example of Palaeogene E–W compression at Croda del Vallon Bianco. The W-vergent overthrust is viewed northwards from the top of Tofana III (see Fig. 6). Note the ramp of the thrust on the right within the Jurassic limestone (J), and the flat at the base of the Lower Cretaceous marls (C). Note also the horses enclosed by two minor duplexes along the thrust plane. Drag folds are present especially in the ramp, both in the hangingwall and in the footwall. Kink-bands may also be seen in the footwall.

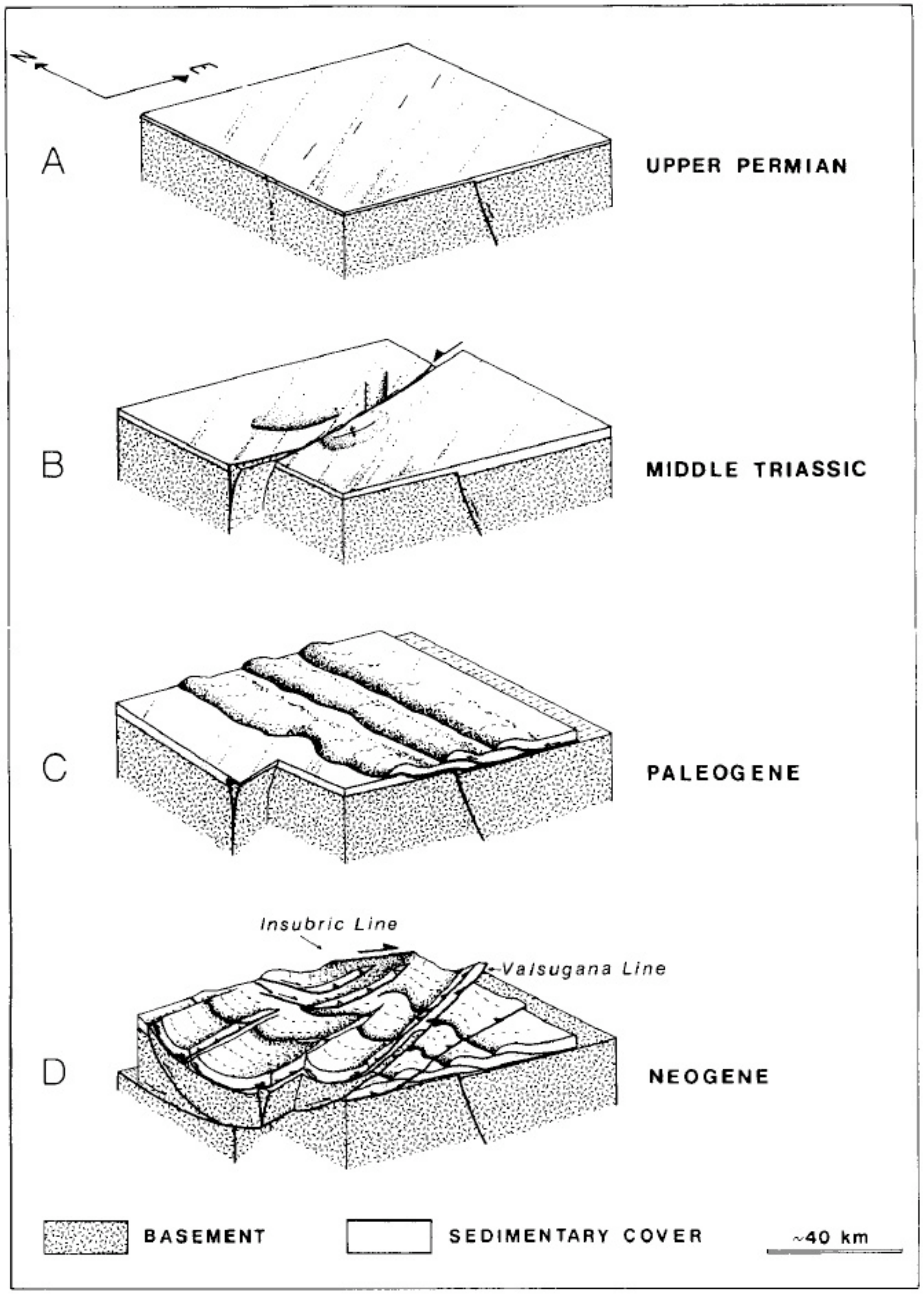


Fig. 19. Block-diagram reconstruction of the main tectonic phases in the upper crust of the Dolomites; A, start of the Permo-Mesozoic rifting; B, sinistral Middle Triassic transpression along the N70°E axis; C, Palaeogene (?) E–W compression; D, Neogene N–S compression.

Doglioni 1987

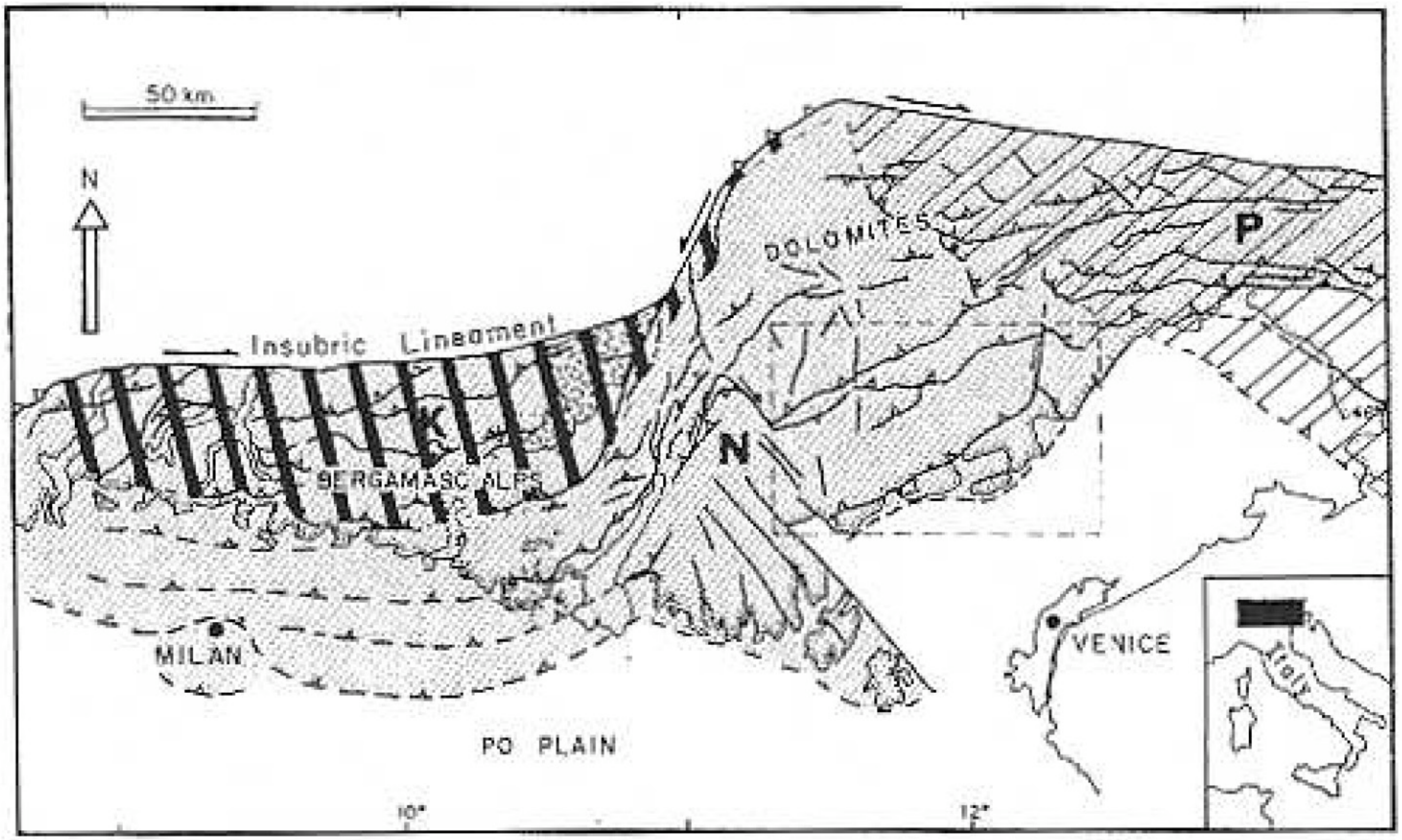


Figure 1. The Southern Alps underwent compressions at different times and in different areas. K: area of Late Cretaceous—Palaeogene compression; P: Palaeogene—Early Neogene compression (Dinarides); N: Palaeogene—Neogene compression (Southern Alps). The rectangle indicates the study area which has been deformed only by the SSE-vergent Neogene South Alpine thrust belt and was located in the foreland of the Palaeogene WSW-vergent Dinaric thrust belt. Note in the eastern side the overlapping between Southern Alps and Dinarides.

Doglioni 1992

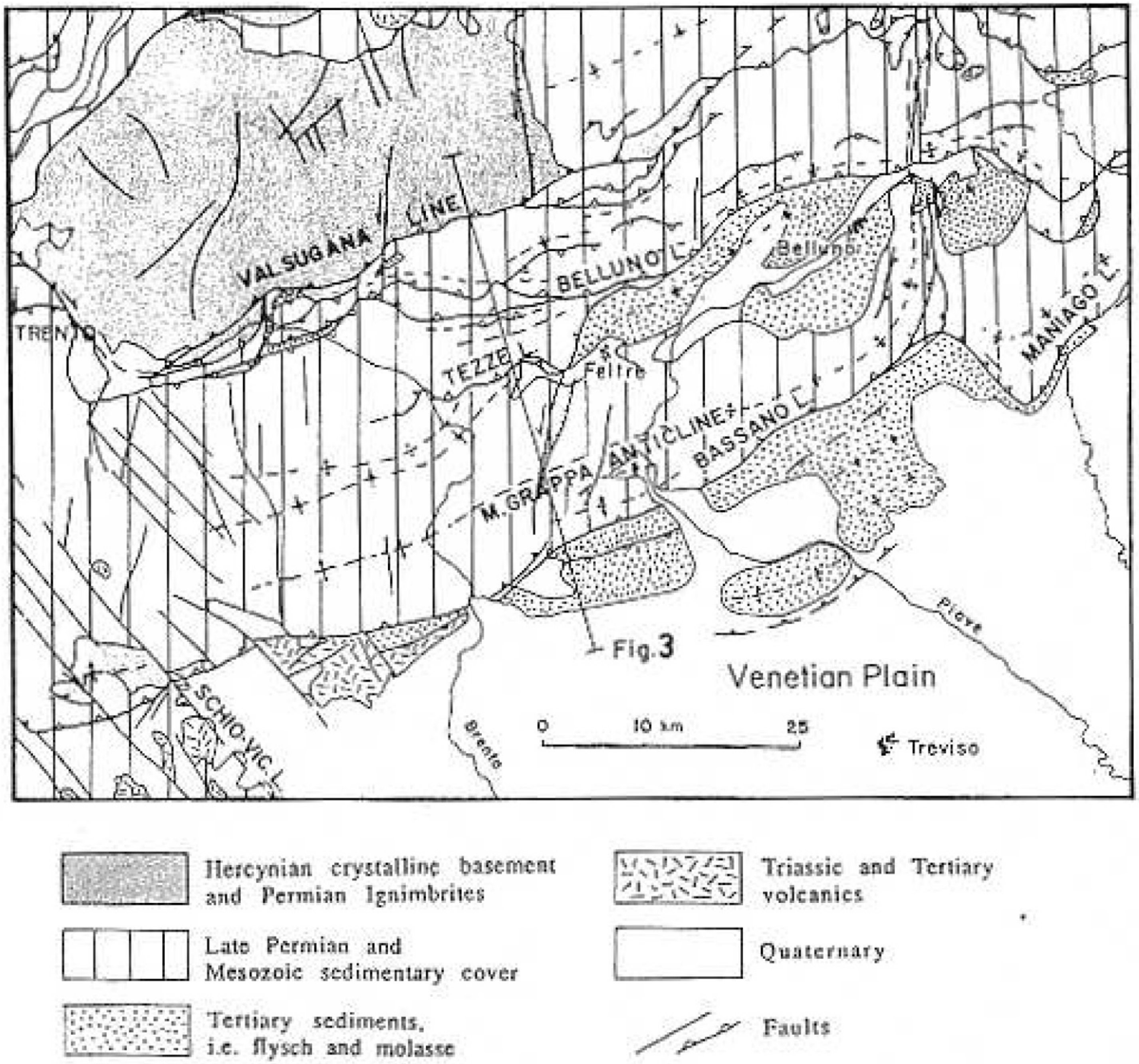


Figure 2. Simplified tectonic map of the Venetian Alps.

Doglioni 1992

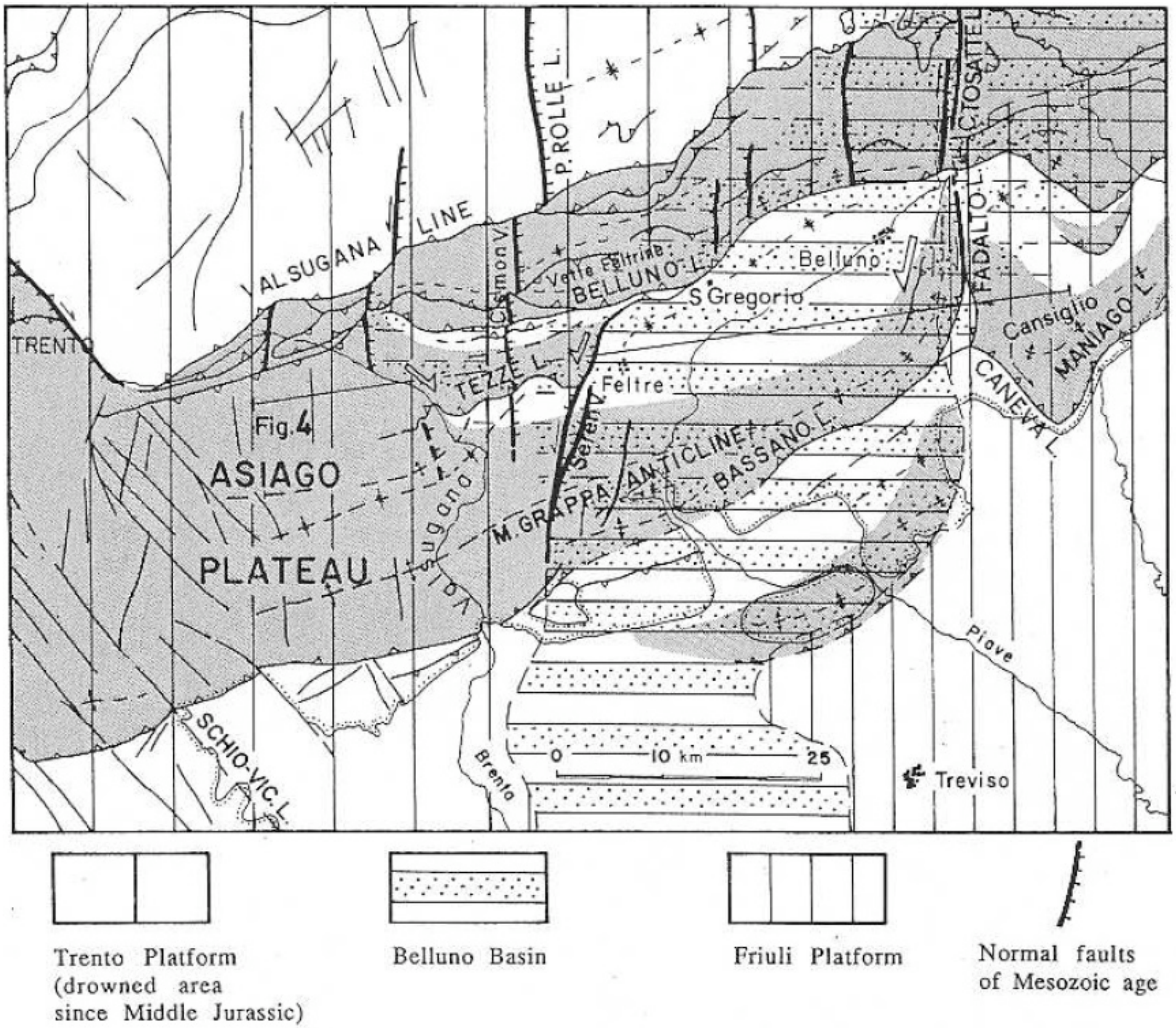


Figure 5. The Mesozoic basins and swells clearly controlled the geometry of the Venetian Alps thrust belt, resulting in axial undulations of the structures. Shadow, structural reliefs to the south of the Valsugana Line. Transpressive or transfer zones are located at inherited faults, thickness changes and facies transitions of the sedimentary cover. The relief of the Asiago Plateau—M. Grappa Anticline suddenly decreases in size when the deformation enters the Belluno Basin and eastward becomes a sinistral transpressive zone at the intersection with the Friuli Platform. Note how the structural reliefs are more diffuse within the inherited Belluno Basin. Compare Figure 4.

Doglioni 1992

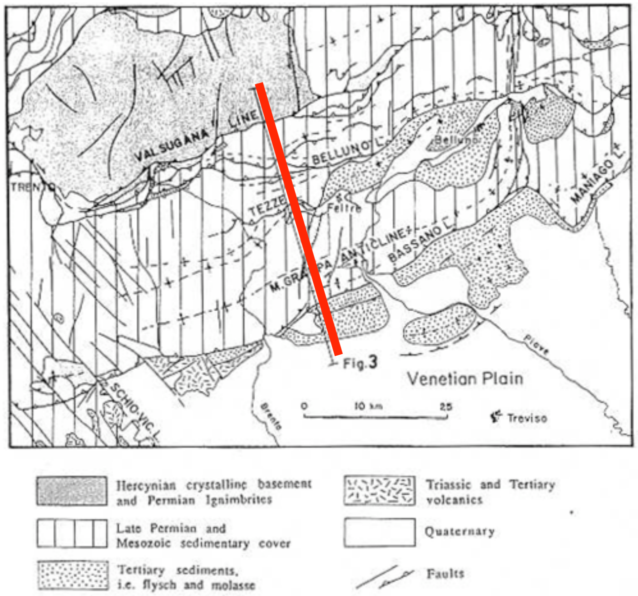
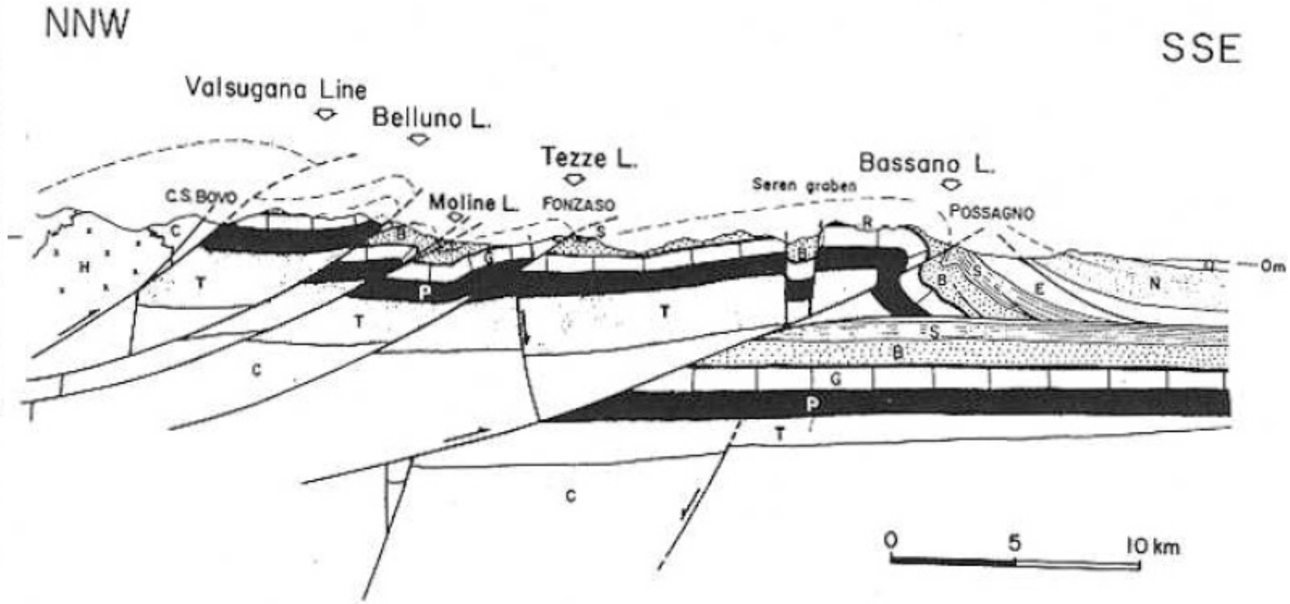


Figure 2. Simplified tectonic map of the Venetian Alps.



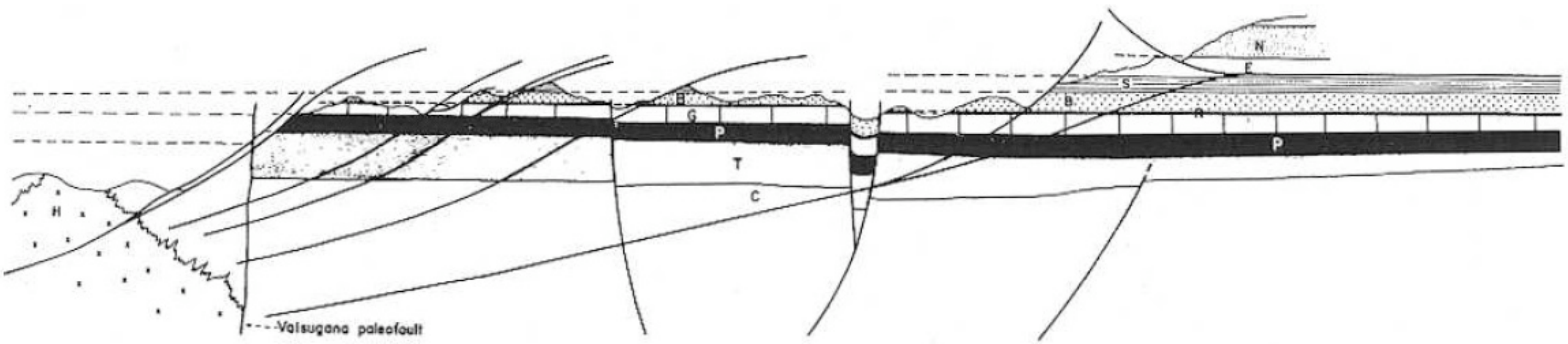


Figure 3. Balanced cross section across the Venetian Alps. See Figure 2 for location. Horizontal scale = vertical scale. Legend: C, crystalline basement; H, Late Hercynian granite; T, Late Permian-Lower and Middle Triassic formations; P, Late Triassic (Dolomia Principale); G, Liassic platform facies (Calcari Grigi) gradually southward passing to Liassic-Dogger basinal facies in the Venetian Plain (Soverzene Formation, Igne Formation, Vajont Limestone); R, Dogger-Malm basinal facies (Lower and Upper Rosso Ammonitico, Fonzaso Formation); B, Early Cretaceous (Biancone); S, Late Cretaceous (Scaglia Rossa); E, Palaeogene (Possagno Marls, etc.); N, Late Oligocene—Neogene Molasse; Q, Quaternary.

Doglioni 1992

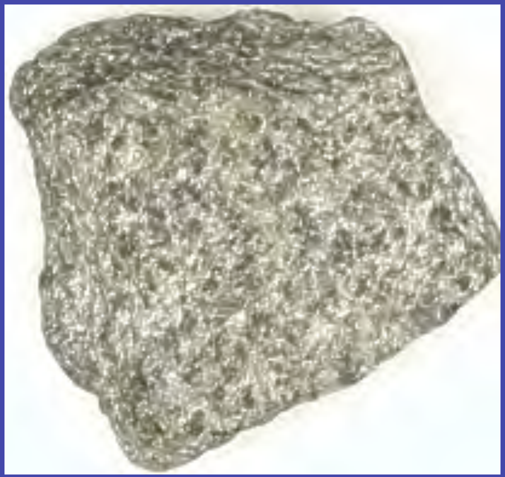
Short digession into metamorphism . . .

Metamorphic Rock Textures

Claystone
(Unmetamorphosed)

Slate Low Grade

Phyllite Low Grade



SchistMedium Grade

Gneiss: High Grade

ERSC 3P21 - Mineral Assemblages, Metamorphic Zones, Metamorphic Facies and Metamorphic Grade

Mineral assemblages for different facies of metamorphism, i.e. each facies represents the same T and P conditions, of three common rocks.

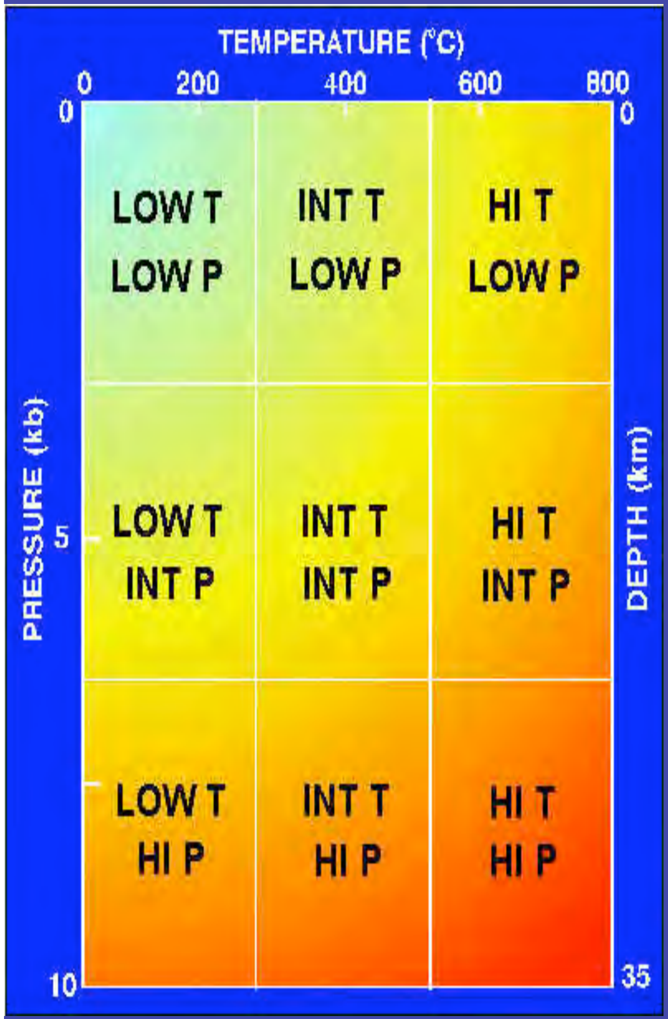
Unmetamorphosed Rock	Facies A	Facies B	Facies C	Facies D	Facies E
Shale - Mudstone	*chlorite* muscovite *albite* quartz	*biotite* chlorite muscovite albite quartz	*garnet* biotite muscovite albite* quartz	*staurolite* garnet biotite *plagioclase** quartz	*sillimanite* garnet biotite plagioclase quartz
	Slate or phyllite	**Phyllite**	**or Schist**	**Schist or**	**Gneiss**
Andesitic Volcanic Tuff	*actinolite* albite epidote chlorite quartz	actinolite albite epidote chlorite quartz	*hornblende* albite epidote quartz	hornblende *plagioclase* quartz	hornblende plagioclase quartz
	Chlorite or	**Actinolite Schist**		**Amphibolite**	
Sandy Limestone or Siliceous Dolomite	*dolomite* calcite quartz	*tremolite* calcite quartz	tremolite calcite quartz	*diopside* calcite quartz	diopside calcite quartz
	Marble	**Tremolite**	**Marble**	**Diopside**	**Marble**

* - plagioclase compositions change from albite (< An_{10}) to oligoclase-andesine (An_{20} to An_{30}).

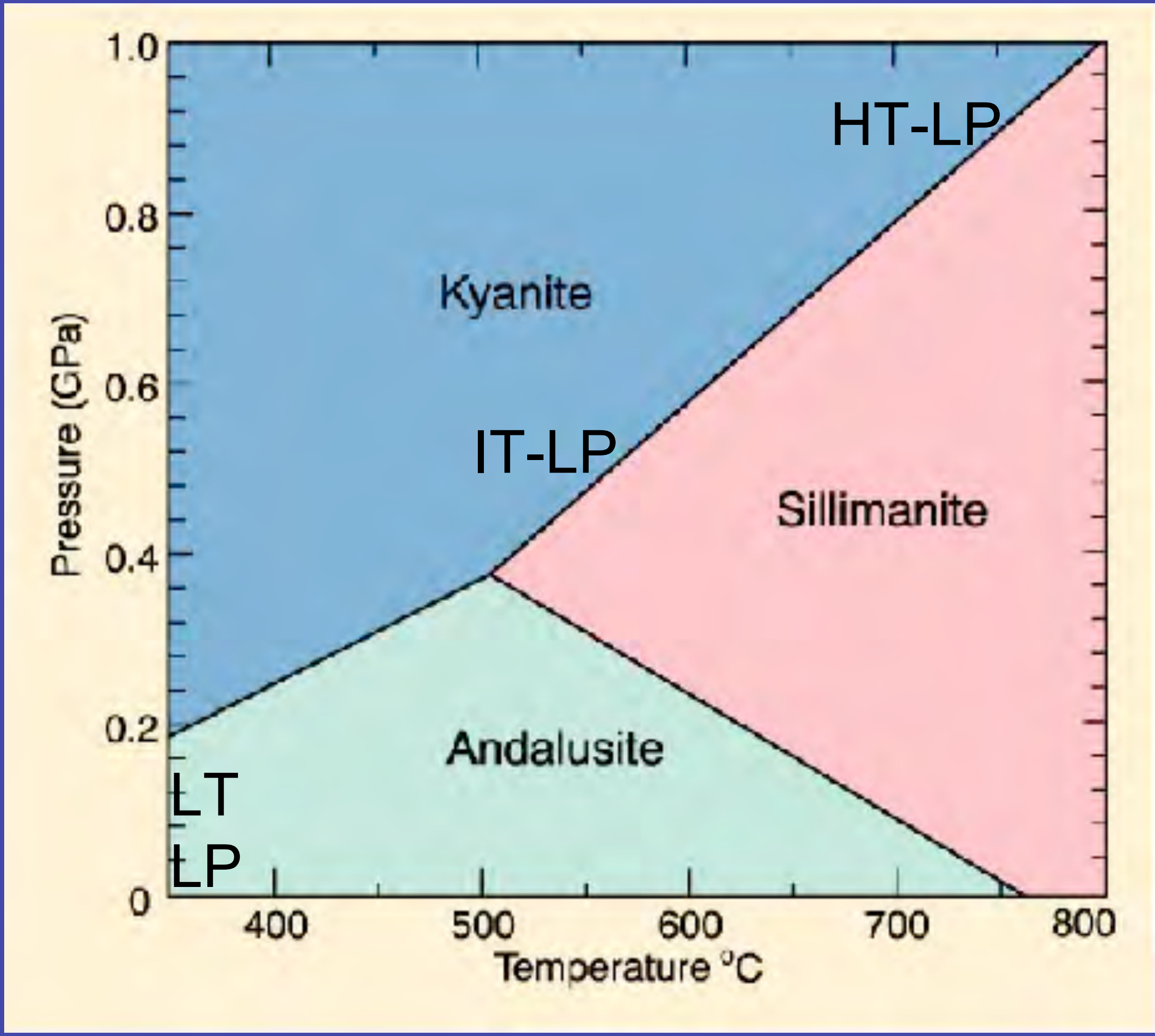
(From Hyndman, 1972)

http://www.brocku.ca/earthsciences/people/gfinn/petrology/barrow2.gif

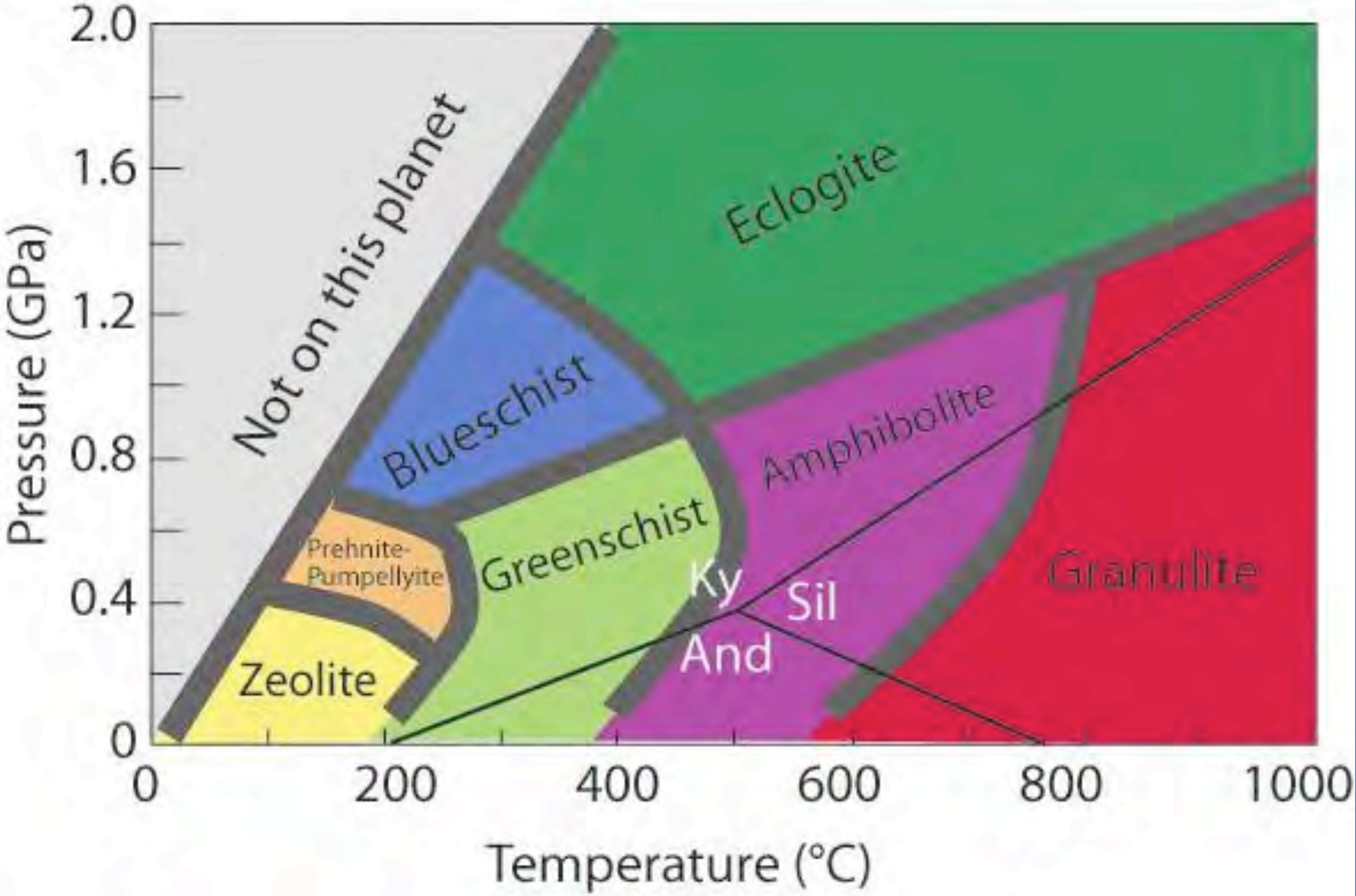
Temperature-Pressure-Grade



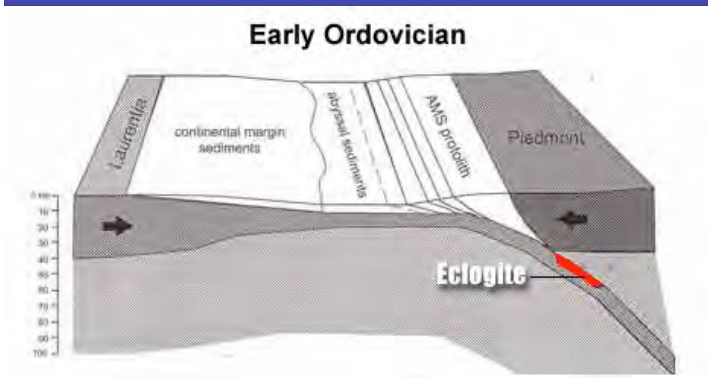
Grade Indicator Minerals Al2SiO5

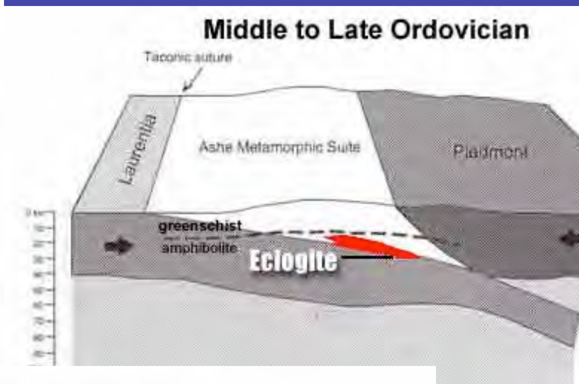


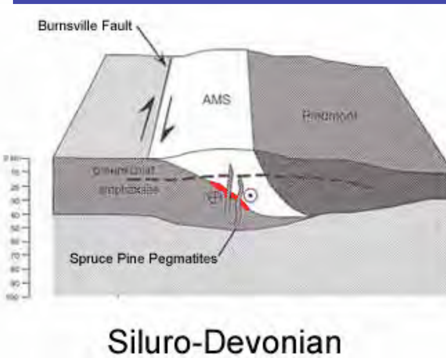
Metamorphic Facies

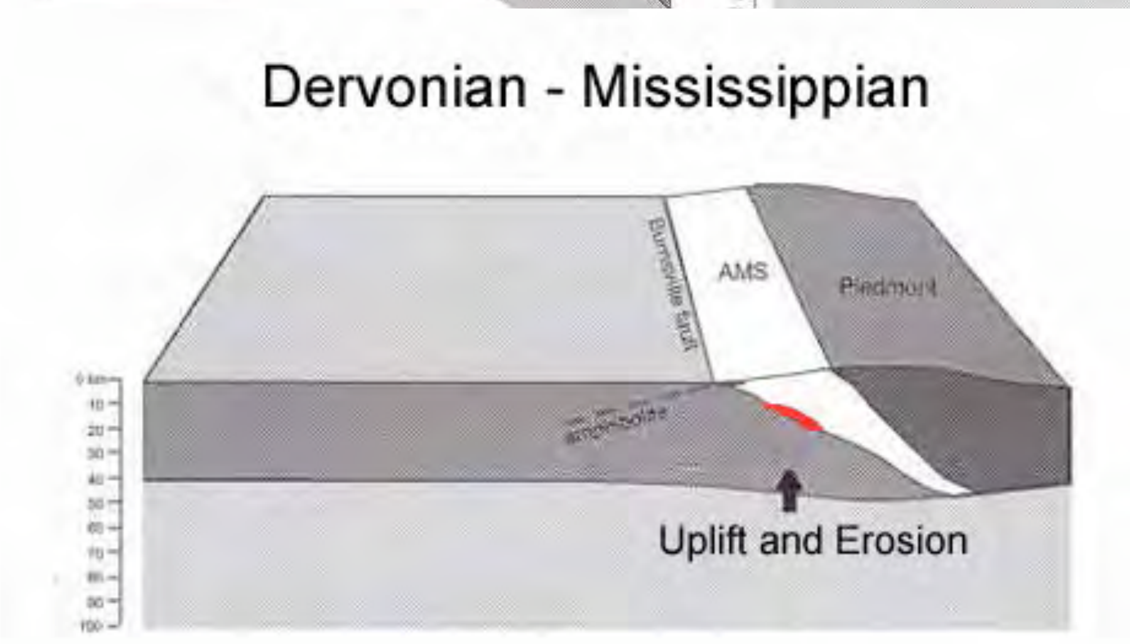


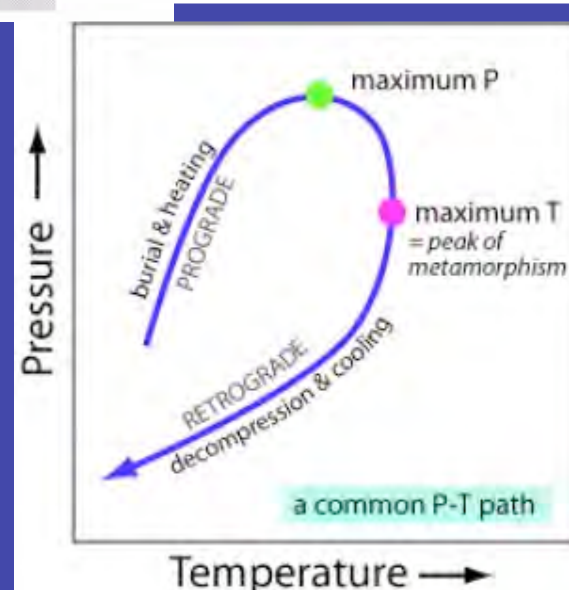
How do we make these rocks?











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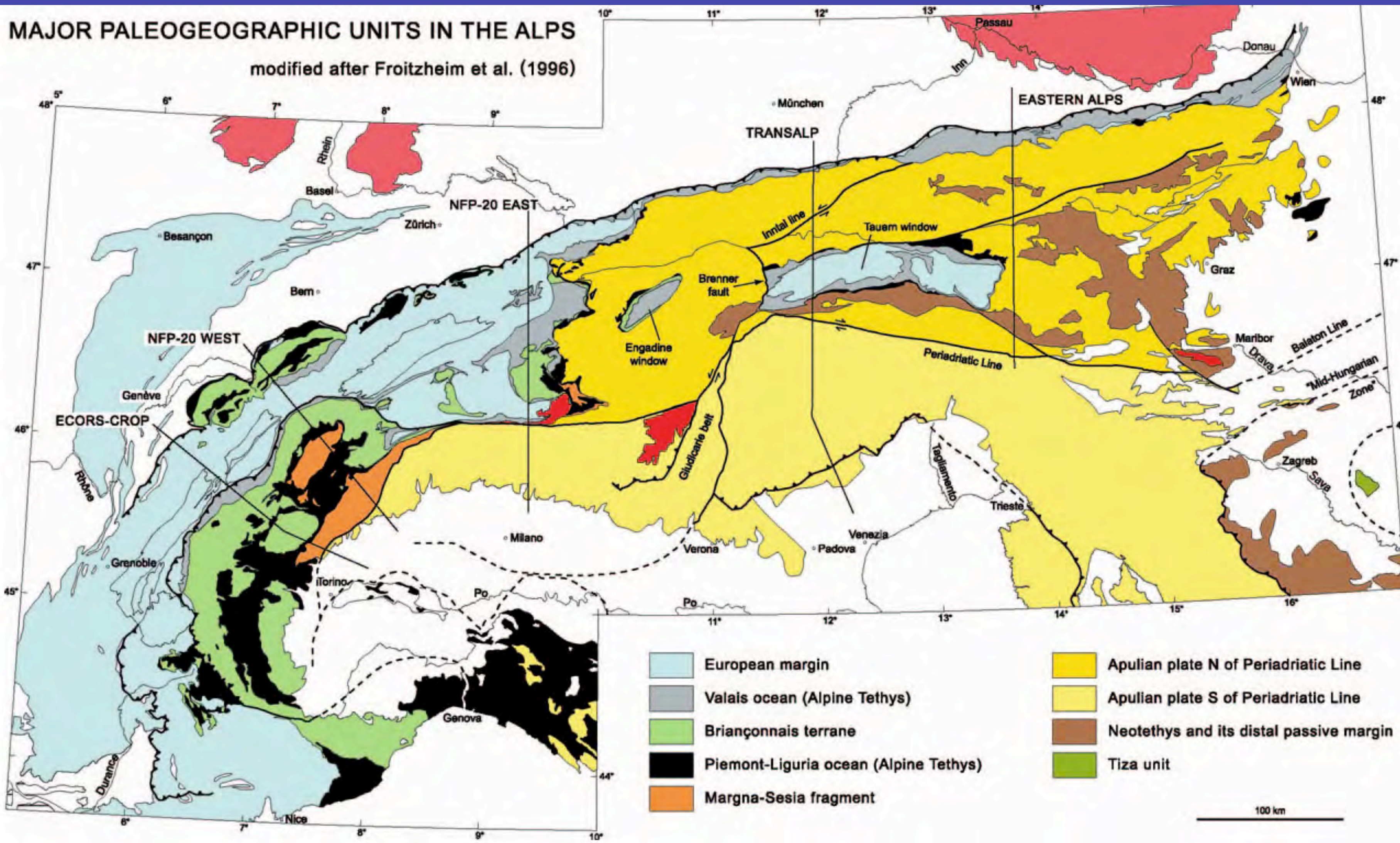
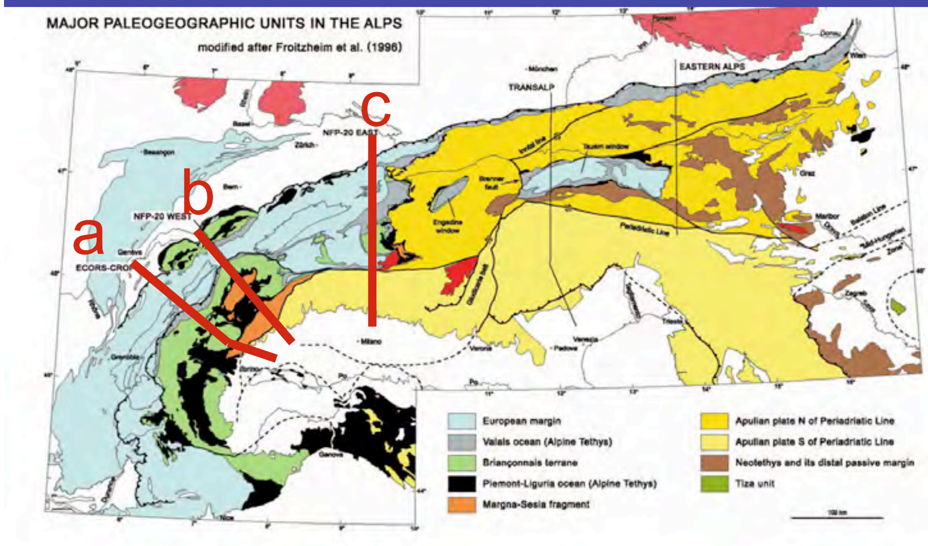


Fig. 1. Map of the major paleogeographic and tectonic units in the Alps.

Schmidt et al 2004

Alpine Crustal Profiles



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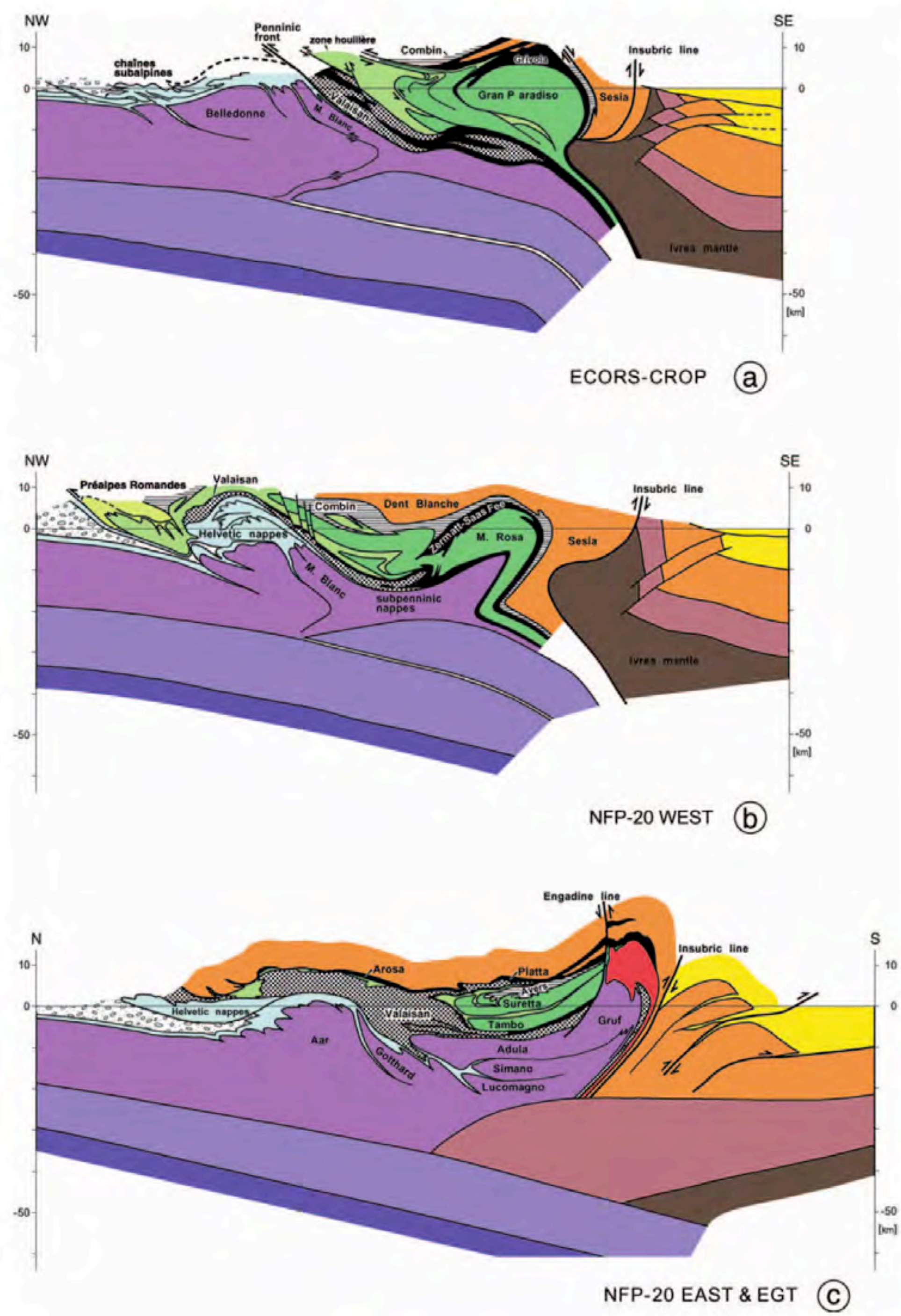
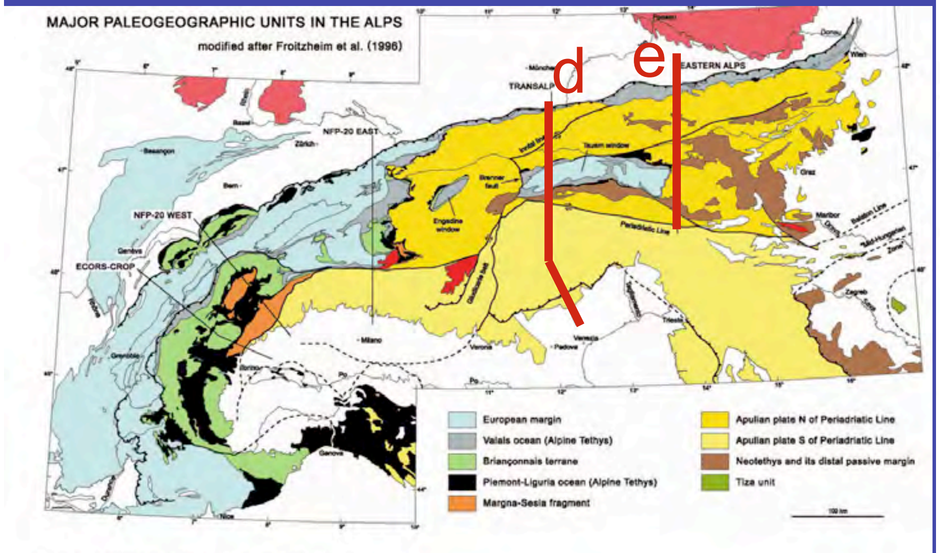


Schmidt et al 2004

Alpine Crustal Profiles



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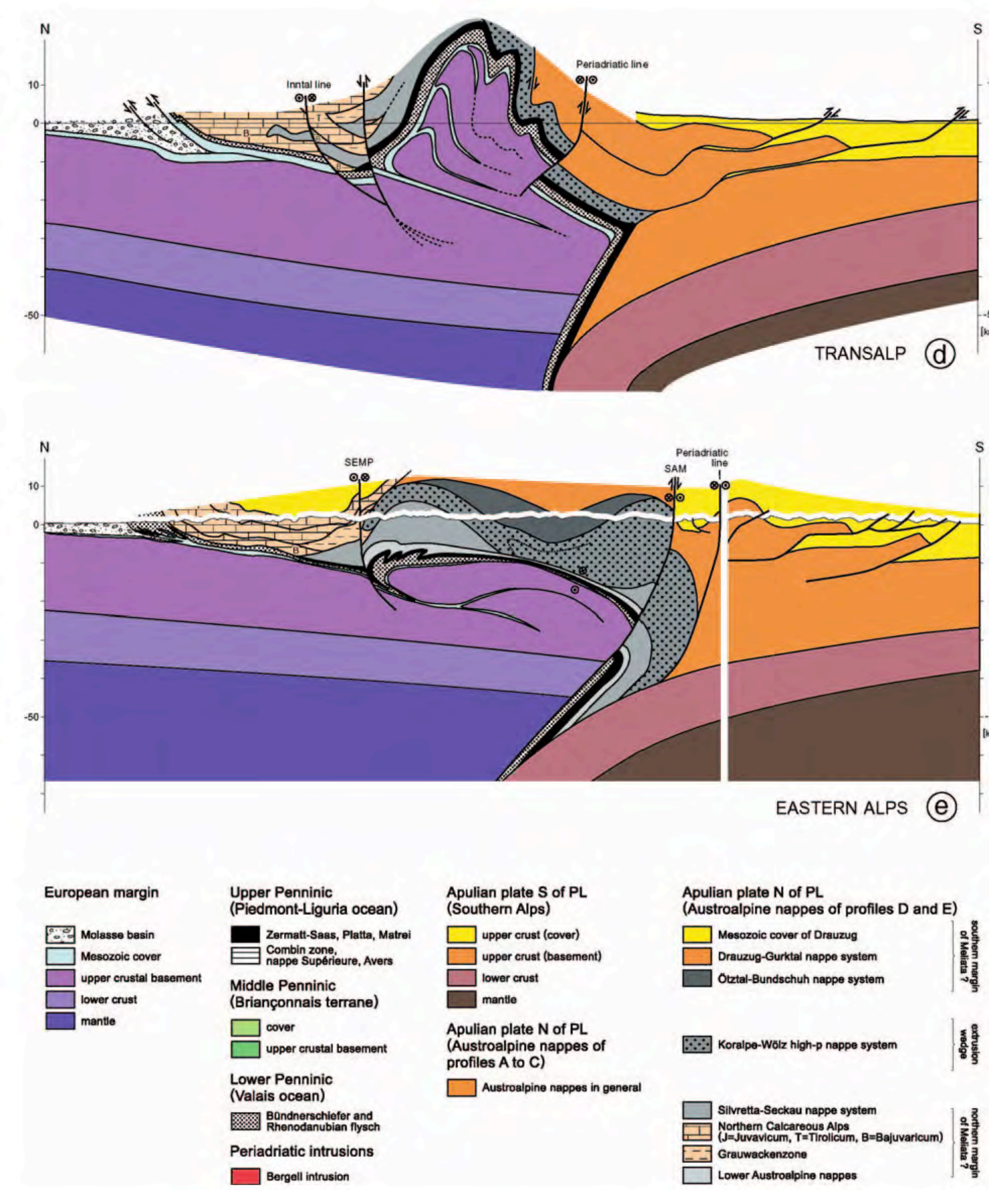


Schmidt et al 2004

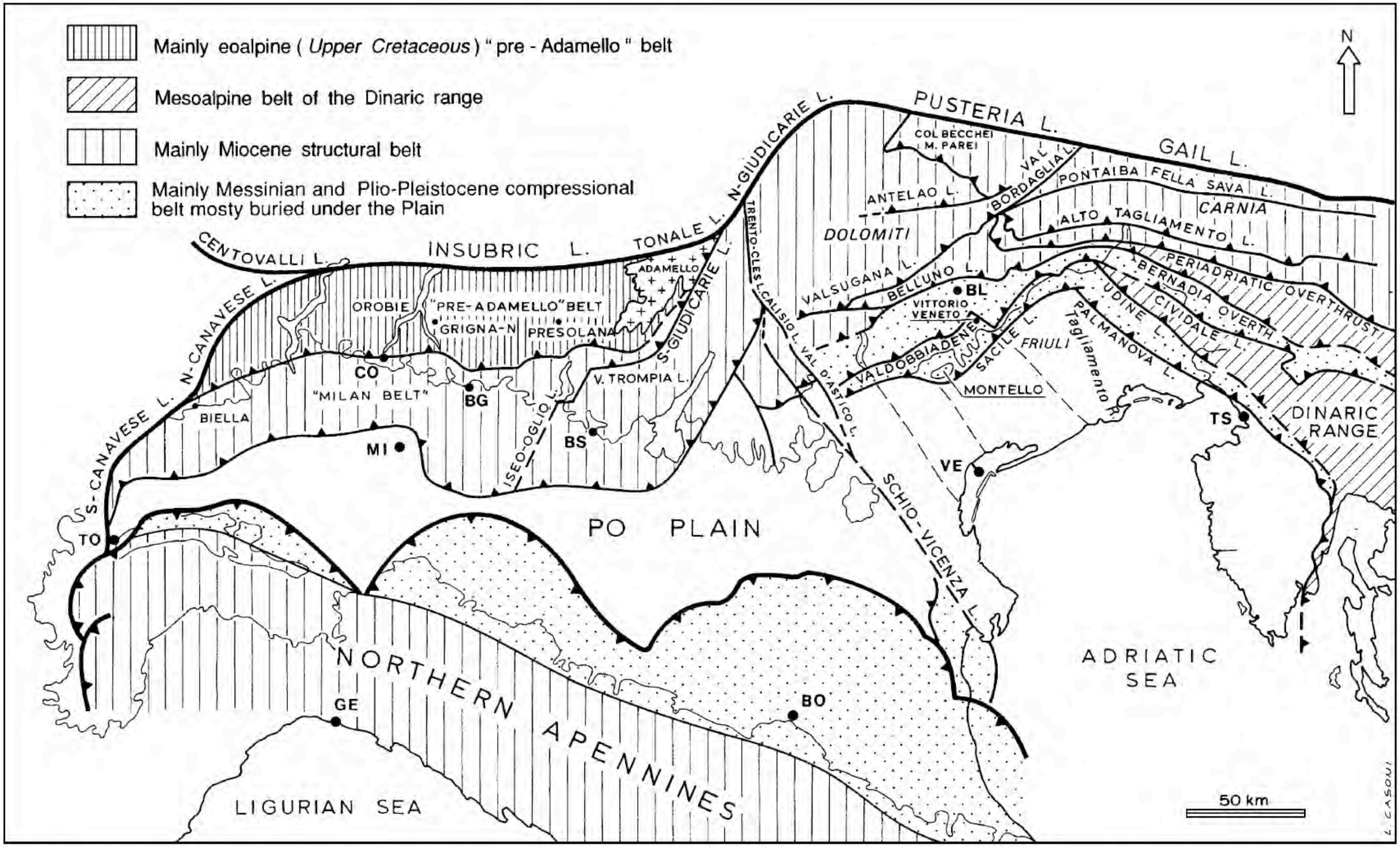


Fig. 1. Simplified structure of the Southern Alps. Geometrical relationships with the southern foreland zones (Po Plain and N Apennines). (From Castellarin et al., 1992).

Castellarin et al 2006

SEDIMENTARY COVER (UPPER PERMIAN - NEOGENE)

PALEOGENE ADAMELLO GRANITOIDS

PALEOGENE BASALTIC AND SUBVOLCANIC DIFFERENTIATES (EUGANEI HILLS)

MAINLY MIDDLE TRIASSIC EFFUSIVES AND INTRUSIVE (+)

LOWER PERMIAN VOLCANIC PLATEAU (MAINLY RYOLITIC EFFUSIVES)

POST HERCYNIAN GRANITOID

METAMORPHIC BASEMENT ROCKS

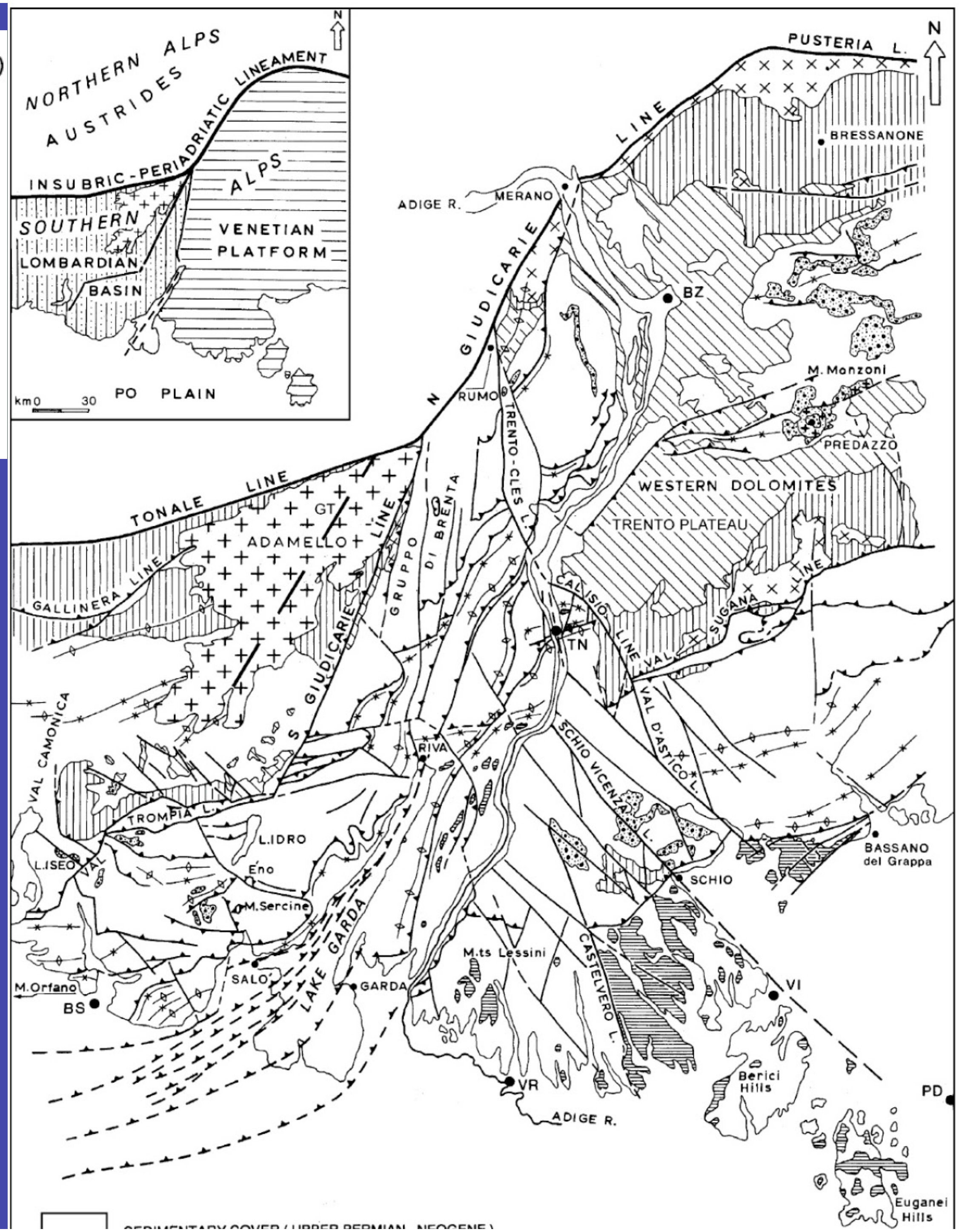
KLIPPE AND SUMMIT OVERTHRUST

TECTONIC WINDOW

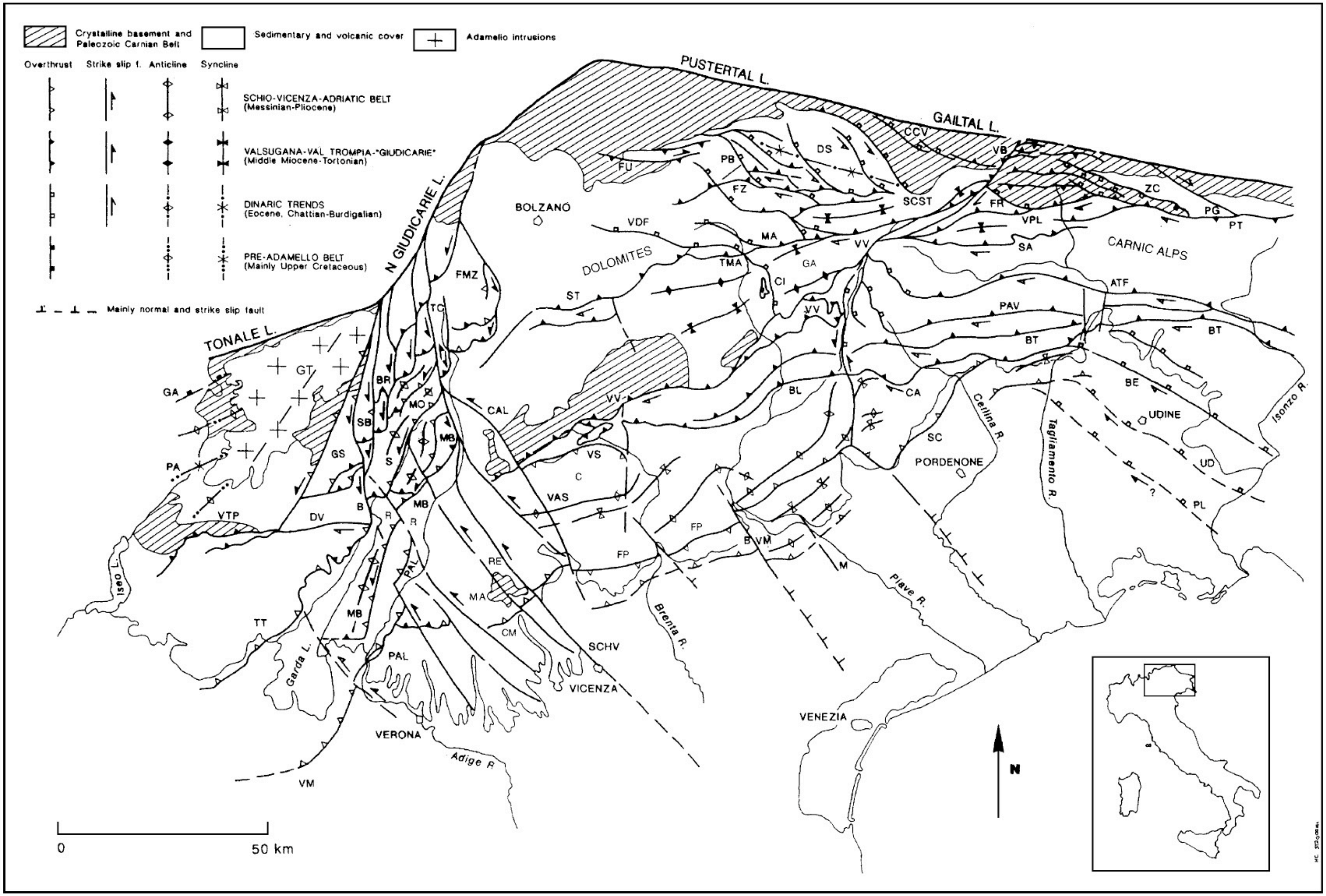
ANTICLINE

SYNCLINE

THRUST



Castellarin et al 2006



Castellarin et al 2006

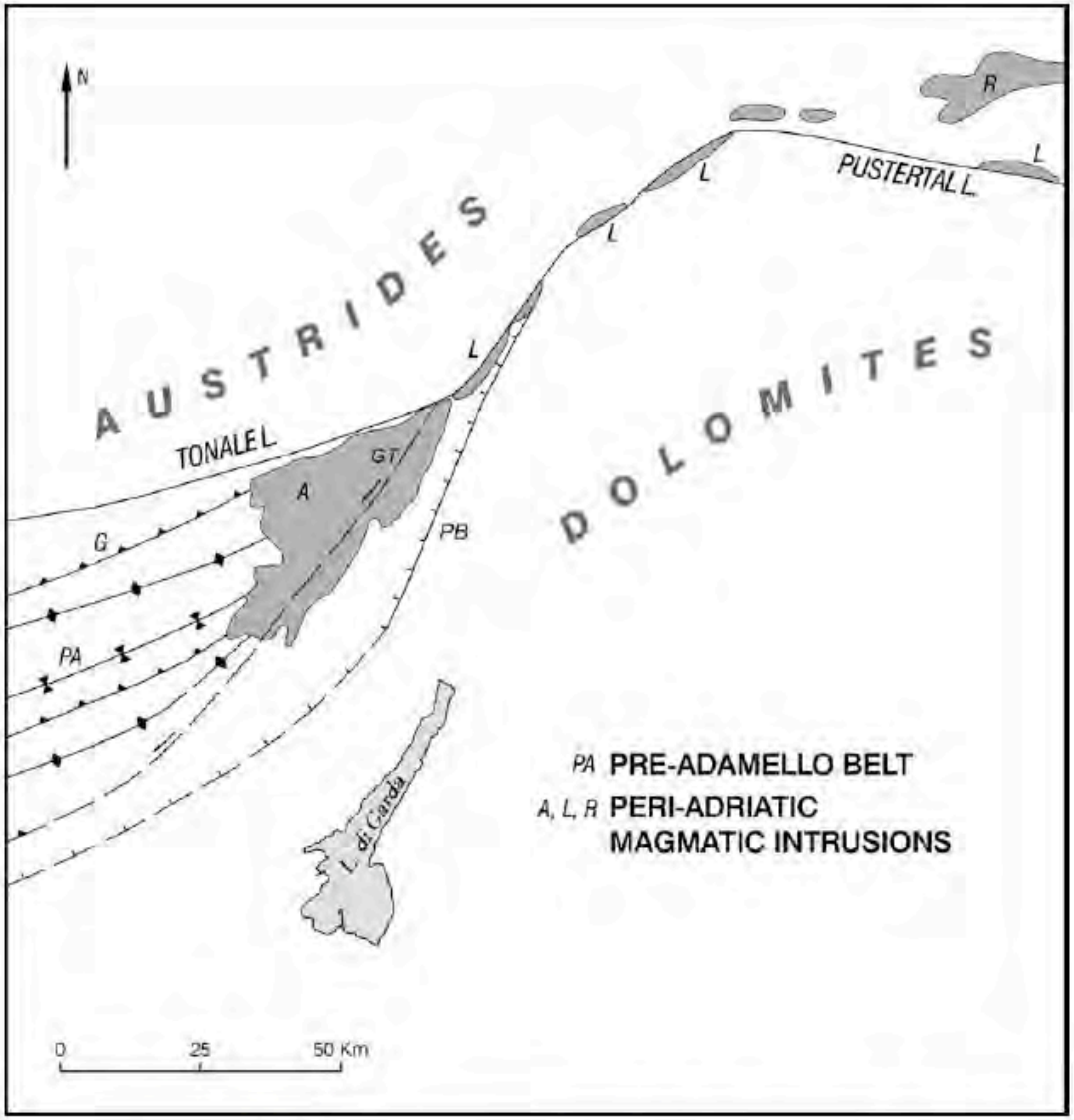


Fig. 4. Tectonic scheme of the Late Cretaceous–Early Eocene pre-Adamello structural belt and location of the Paleogene, intrusive magmatic bodies along the central and eastern sector (C.N.R., 1990) of the Periadriatic belt (*PA*) incorporating the Gallinera thrust (*G*). Letters: *A*, Adamello batholith sealing the southern part of the presumed Giudicarie transfer zone (*GT*) (see Fig. 7); *L*, tonalite *lamella*; *R*, Riesenferner intrusion; *PB*, outer rise (see Fig. 7). Note that "Pusteria Line" in Figs. 1, 2 corresponds to Pustertal L. of Figs. 3, 4.

Castellarin et al 2006

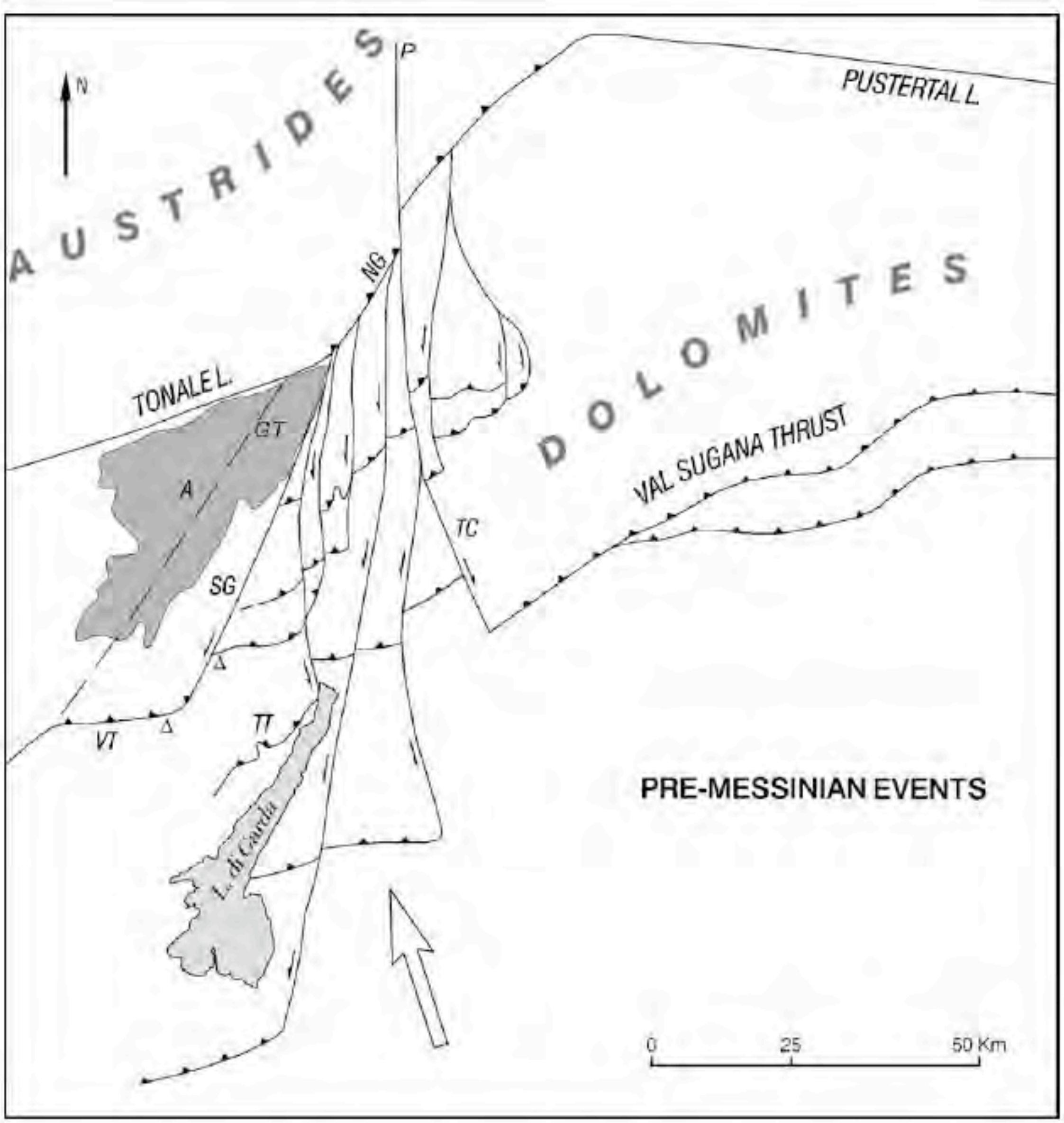


Fig. 5. Tectonic scheme of the main structures of the Giudicarie belt produced by the Valsugana compression event (Serravallian–Tortonian): note the sinistral transfer motion (open triangles) affecting the S-Giudicarie fault during this event (more explanation in the text). Symbols and letters: *GT*, pre-Adamello Giudicarie tranfer zone; *A*, Adamello intrusion; *NG*, *SG*, North and South Giudicarie faults; *P*, Passeirtal fault; *VT*, Val Trompia thrust zone; *TT*, Tremosine Tignale thrust; *TC*, Trento-Cles transfer fault; wide open arrow: compressional axis.

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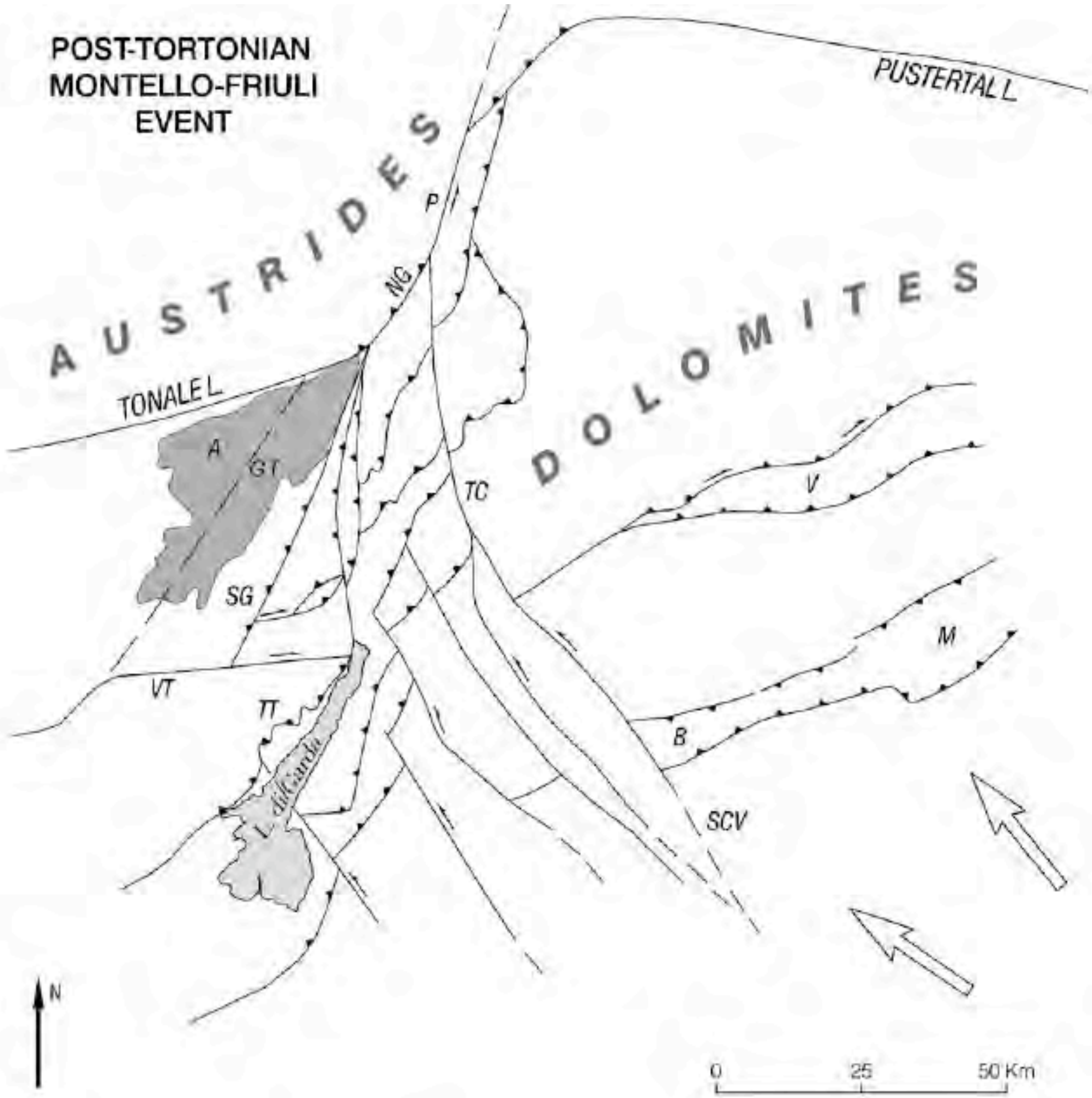

Fig. 6. Tectonic scheme of the main structures of the Giudicarie, Valsugana (*V*) and Montello (*M*) belts produced by the Adriatic compressional event affecting mostly the eastern zone (Montello–Friuli) from the Messinian onward. Symbols and letters: *SCV*, Schio–Vicenza transfer system; *B*, Bassano zone; *P*, Passeirtal fault; wide open arrow: compressional axe. Other letters as in Figs. 4, 5.

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ıbr 7. Synthetic reconstruction of the southern side of the Alps during the Late Cretaceous–Early Eocene times. In the scheme the Lombardy and
noıbric Flysch domains are connected with N Dolomites and Slovenian basinal area along the Giudicarie corridor: I, Lombardian Flysch
runomanian/Turonian–Early Eocene); II, Giudicarie, Insubric Flysch (Turonian–Early Eocene); III, Flysch in the northern Dolomites (Ra Stua,
e (ıruilles) (Aptian–Albian and, for the minor interval of Antruiles, Turonian–Campanian); IV, Carnic and Slovenian Flysch (Late Cretaceous); GT:
; pe Cretaceous–Early Eocene presumed location of the Giudicarie transfer zone, to the S, buried underneath the Paleogene Adamello intrusions
ıdi; PB: fault scarp of the outer rise, separating the basinal Flysch deposits from the pelagic structural high sediments of the Scaglia Rossa (for the
ıdicarie belt, see Figs. 4, 8–10). IL: east and western setting of the present Insubric (or Periadriatic) lineament.

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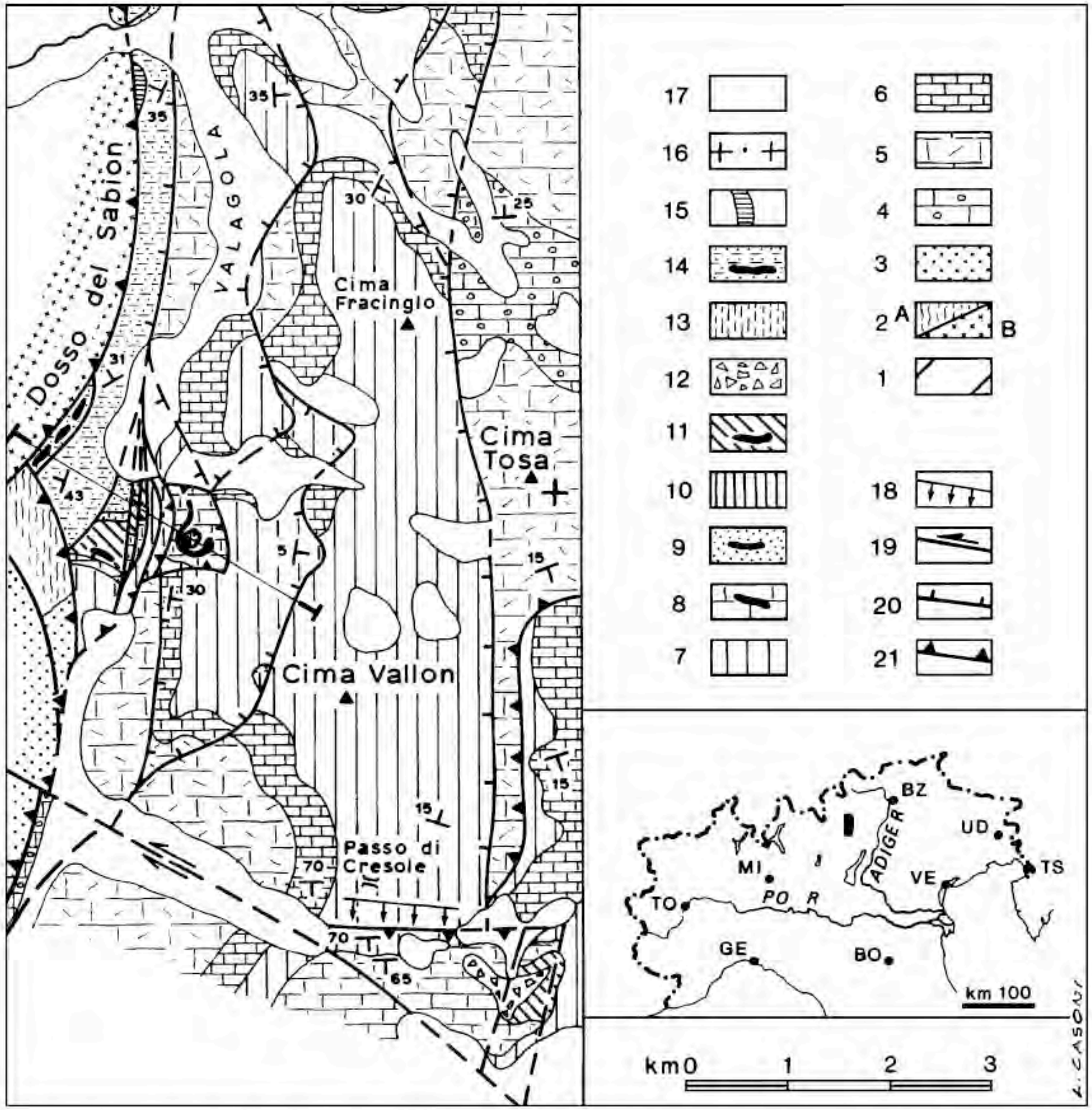

Fig. 8. Geological map of the Doss del Sabion–Pala di Mughi area (Brenta Mountain Group, Trento Province) Numbers: 2, Mt. Sabion granitoids (Lower Permian) (A) and phillites (pre-Permian) (B); 3, Val Gardena sandstones Fm (Upper Permian); 4, Ladinian dolomite; 5, Dolomia Principale Fm (Norian); 6, Calcare di Zu Fm (Rhaetian); 7, Calcari Grigi Fm (Lias); 8, Tofino Fm (Lias); 9, Tenno Fm (Lias); 10, Oolite di S. Vigilio Fm (Upper Lias); 11, Rosso Ammonitico, Biancone, Selcifero and Maiolica Fms (Dogger–Lower Cretaceous); 12, Marugini Breccias (Cretaceous); 13, Scaglia Rossa Fm (Upper Cretaceous); 14, Val D'agola Fm, Upper Cretaceous Flysch; 15, marly clay and micrite limestones (Eocene); 17, Quaternary cover: black spots indicate presence of enclosed breccias. Units related to 1 (Austroalpine metamorphics) and 16 (Adamello tonalites) are not cropping out in this area.

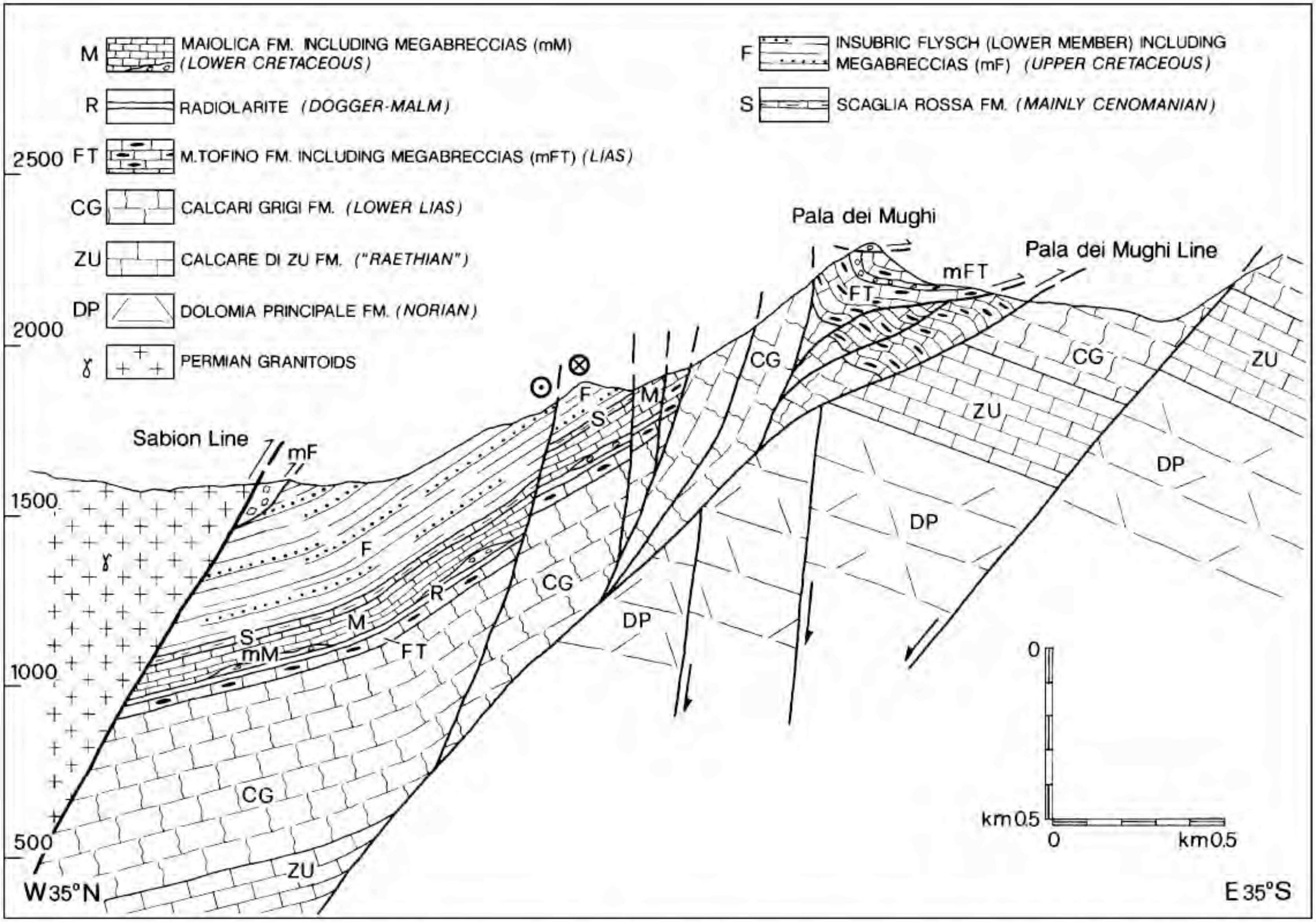

Fig. 9. Cross-section of the Mt. Sabion and Pala dei Mughi peak (Brenta Mountain Group, Trento Province) showing the Neogene structural inversion of the Liassic and Late Cretaceous tectonic setting (compare with Fig. 10, A,B). (From Castellarin et al., 1993).

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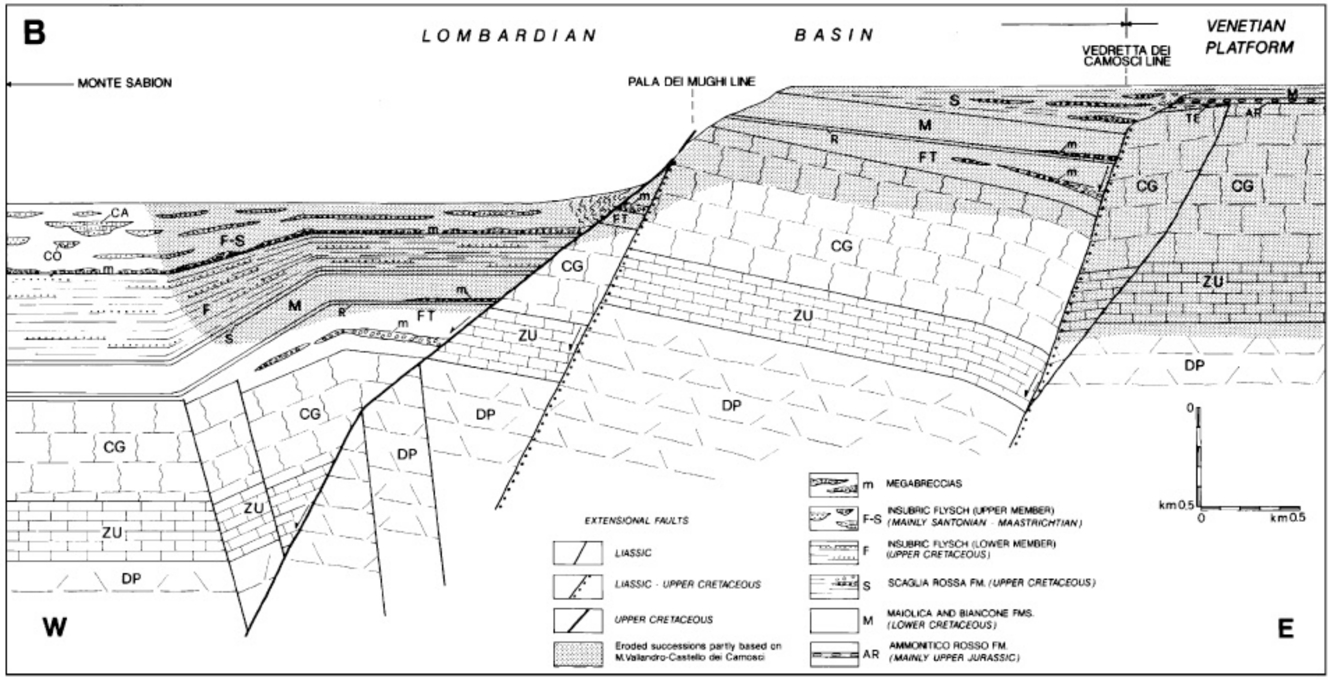
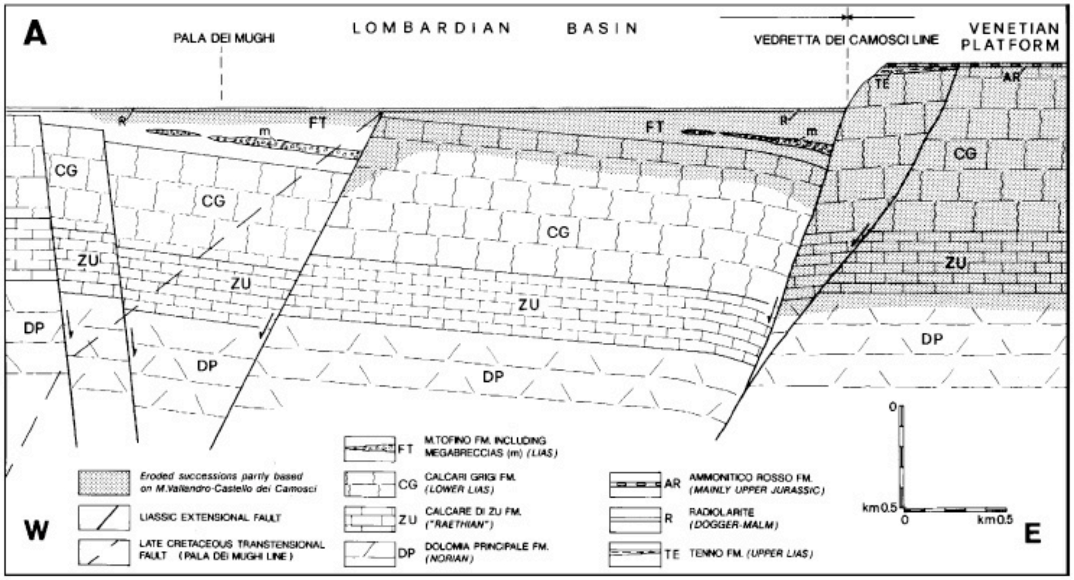
Upper Cretaceous Balanced Section



Jurassic Restored Section



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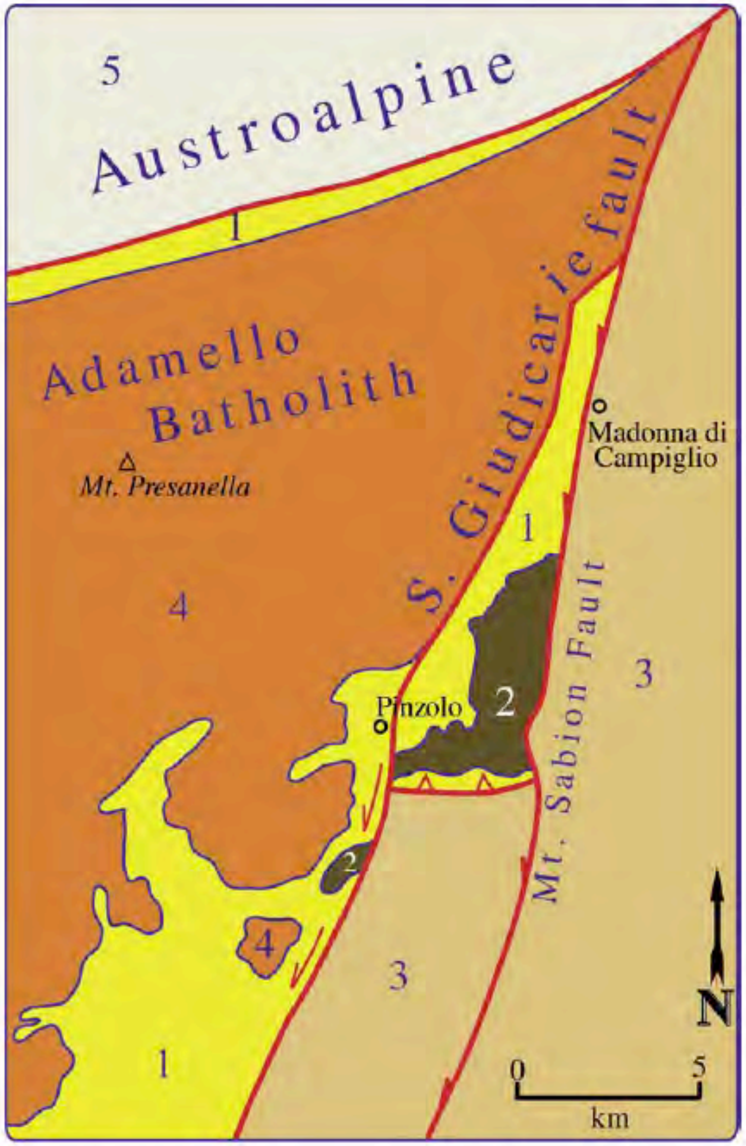

Fig. 11. The sinistral displacement of the Mt. Sabion Permian intrusion along the S-Giudicarie fault, near Caderzone. (Courtesy of the Trento Province, Geological Service). Southern Alps: 1, pre-Permian crystalline metamorphic basement; 2, Lower Permian intrusion (Mt. Sabion); 3, PermianCenozoic mainly sedimentary cover; 4, Adamello Paleogene intrusion. Northern Alps: 5, Austroalpine crystalline metamorphic rock.

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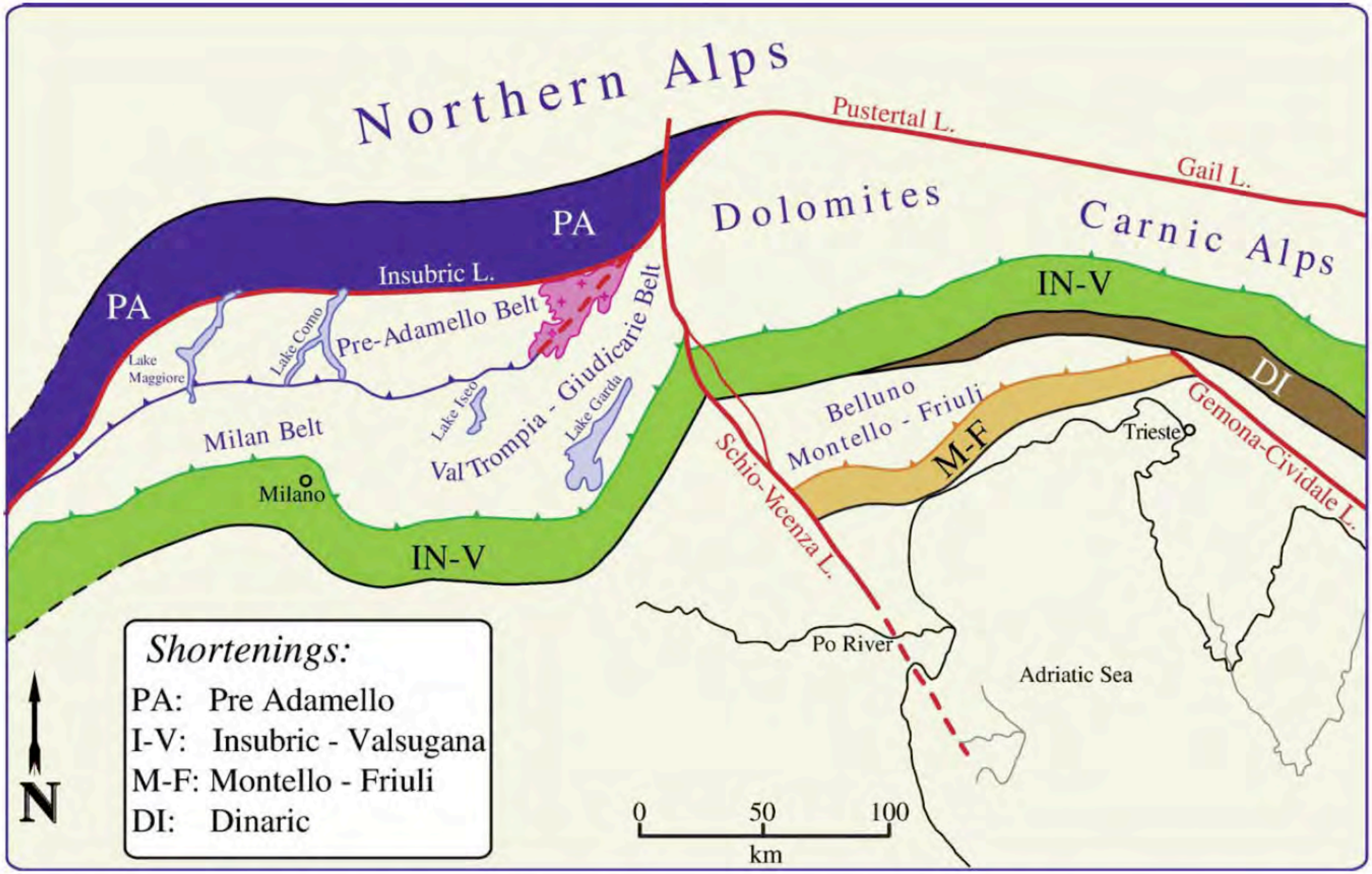

Fig. 12. Synthetic restoration of the shortening produced by Alpine compression in the Southern Alps during the convergence evolution (Late Cretaceous–Pleistocene) (more explanation in the text). Letters: PA, shortening of the Cretaceous–Early Eocene pre-Adamello phase; D, shortening of the Eocene phase affecting the external Dinarides; I–V, shortening of the Oligocene to Tortonian, Insubric–Helvetic and Valsugana phases; M–F, shortening of the Messinian to Pleistocene Adriatic phases mostly of the Montello–Friuli zone.

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