Sezioni esposte della crosta continentale

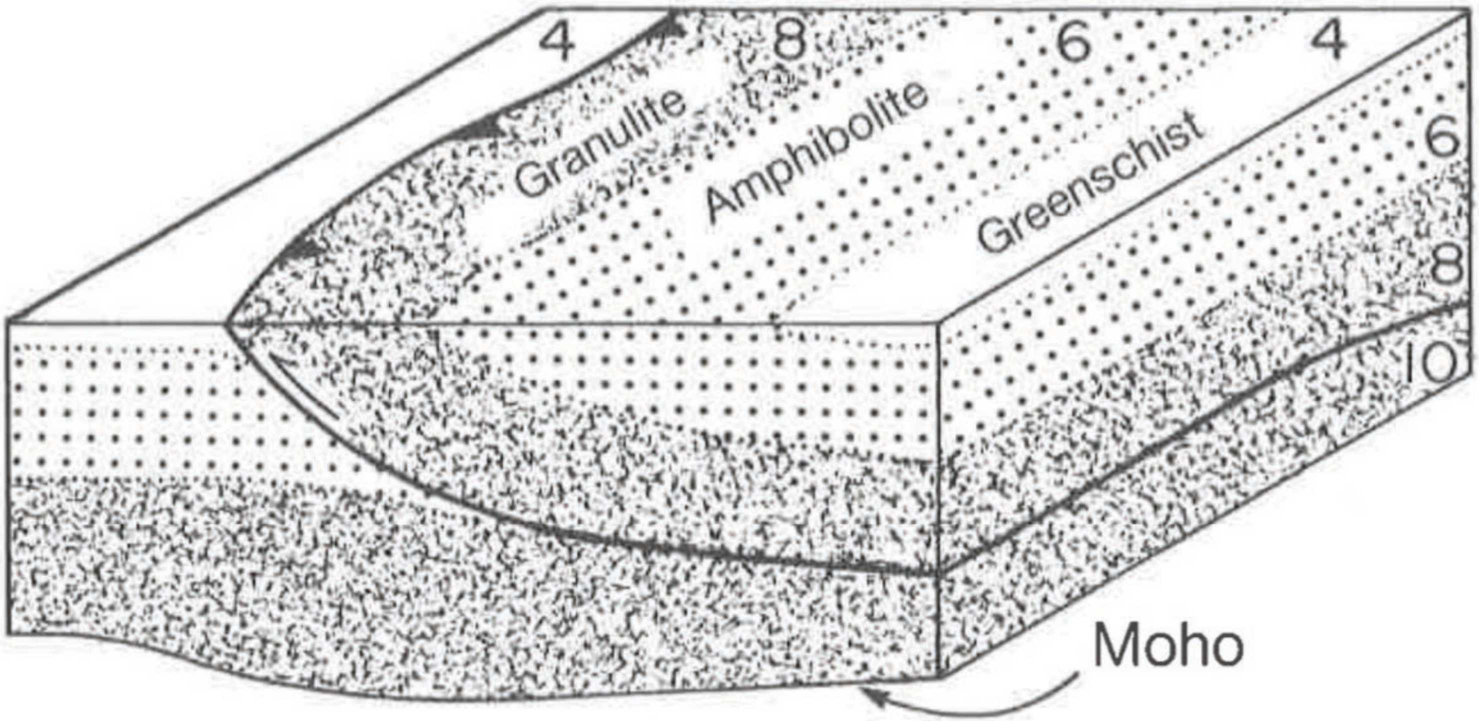


Figure 1. Characteristics of exposed crustal cross sections. Depth to Moho is about 30-50 km; lateral extent of oblique cross section is 20-150 km. Right-hand and top scales are in paleopressure (in kilobars). (from Percival, 1988).

Fountain et al (1990)

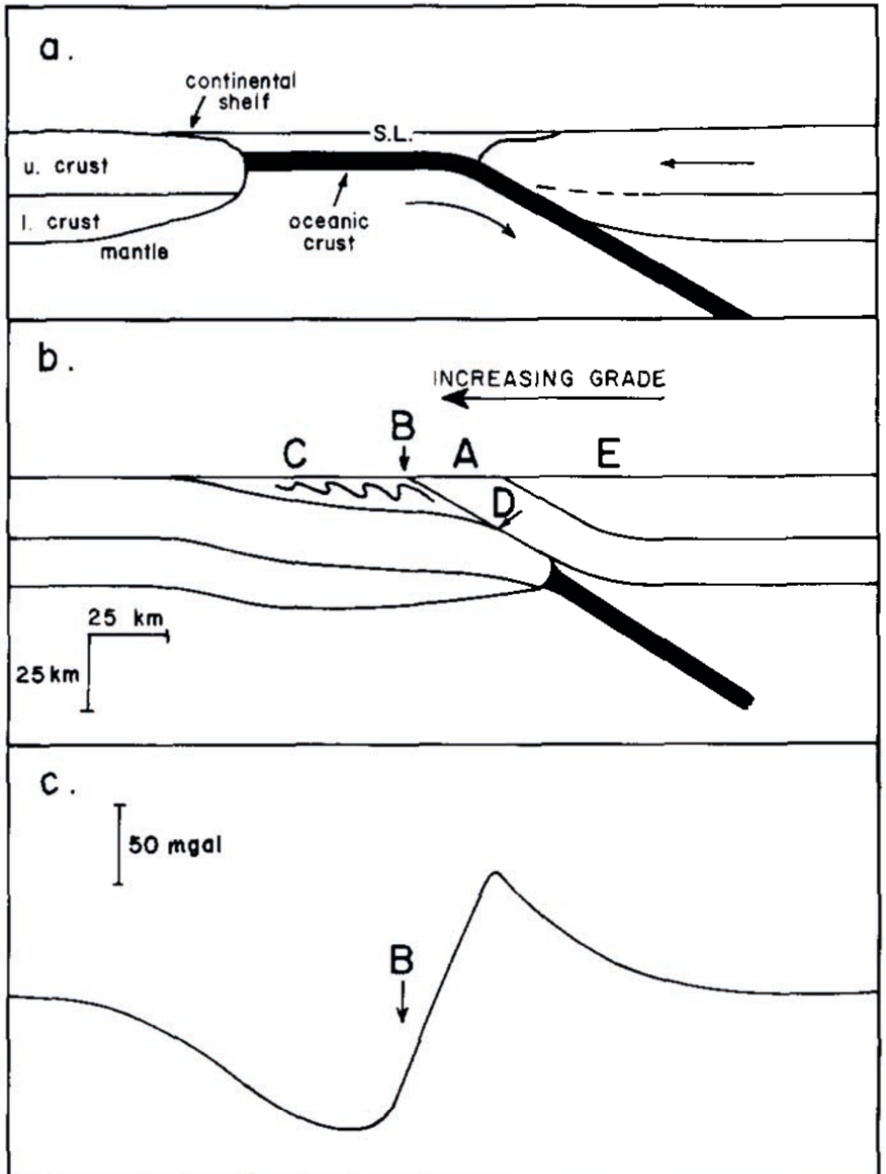


Fig. 2. (a) Impending collision between two continents; (b) postulated geometry produced by collision; and (c) theoretical Bouguer gravity anomaly calculated for crustal structure in (b) (see text).

Fountain & Salisbury (1981; EPSL)

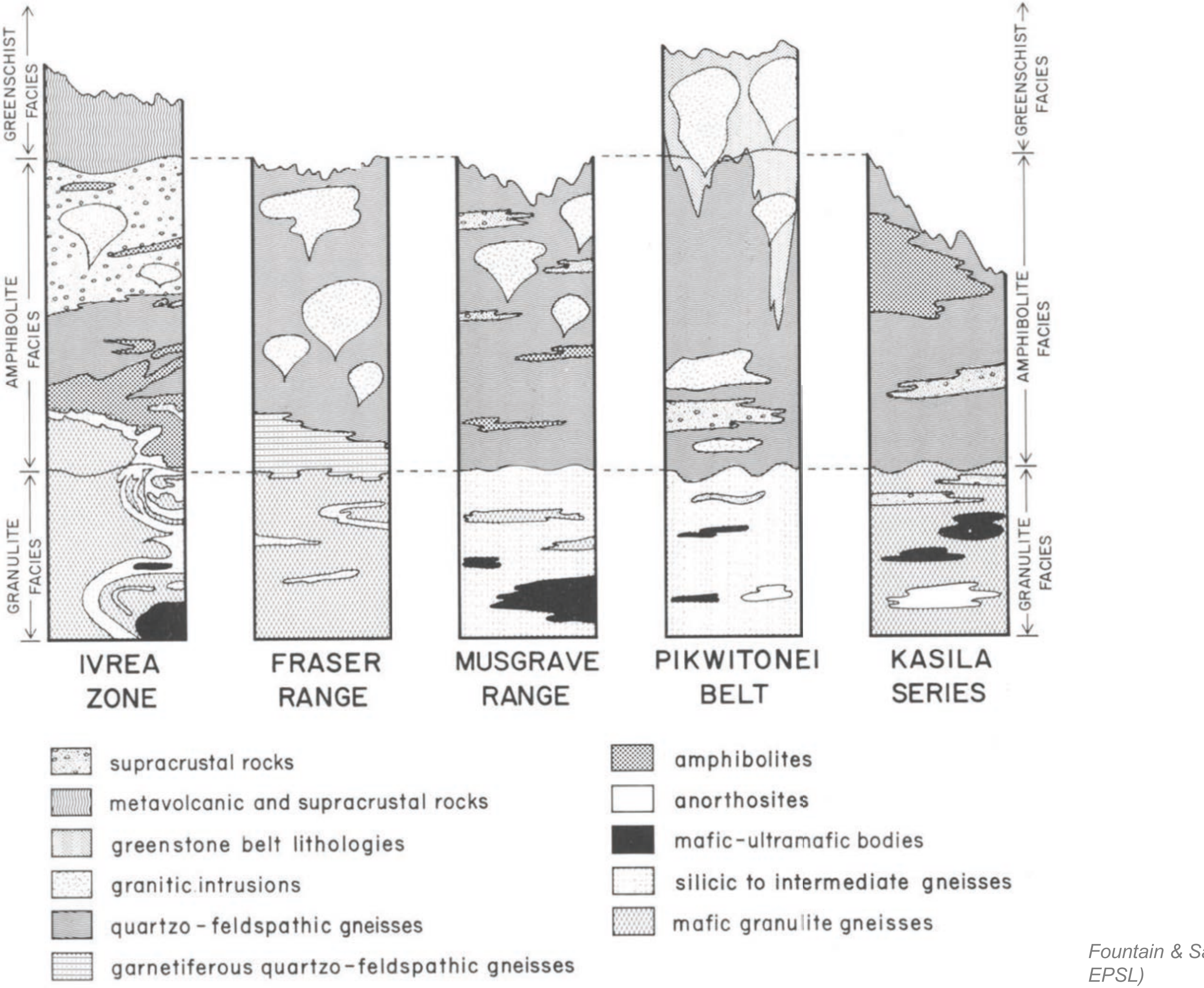
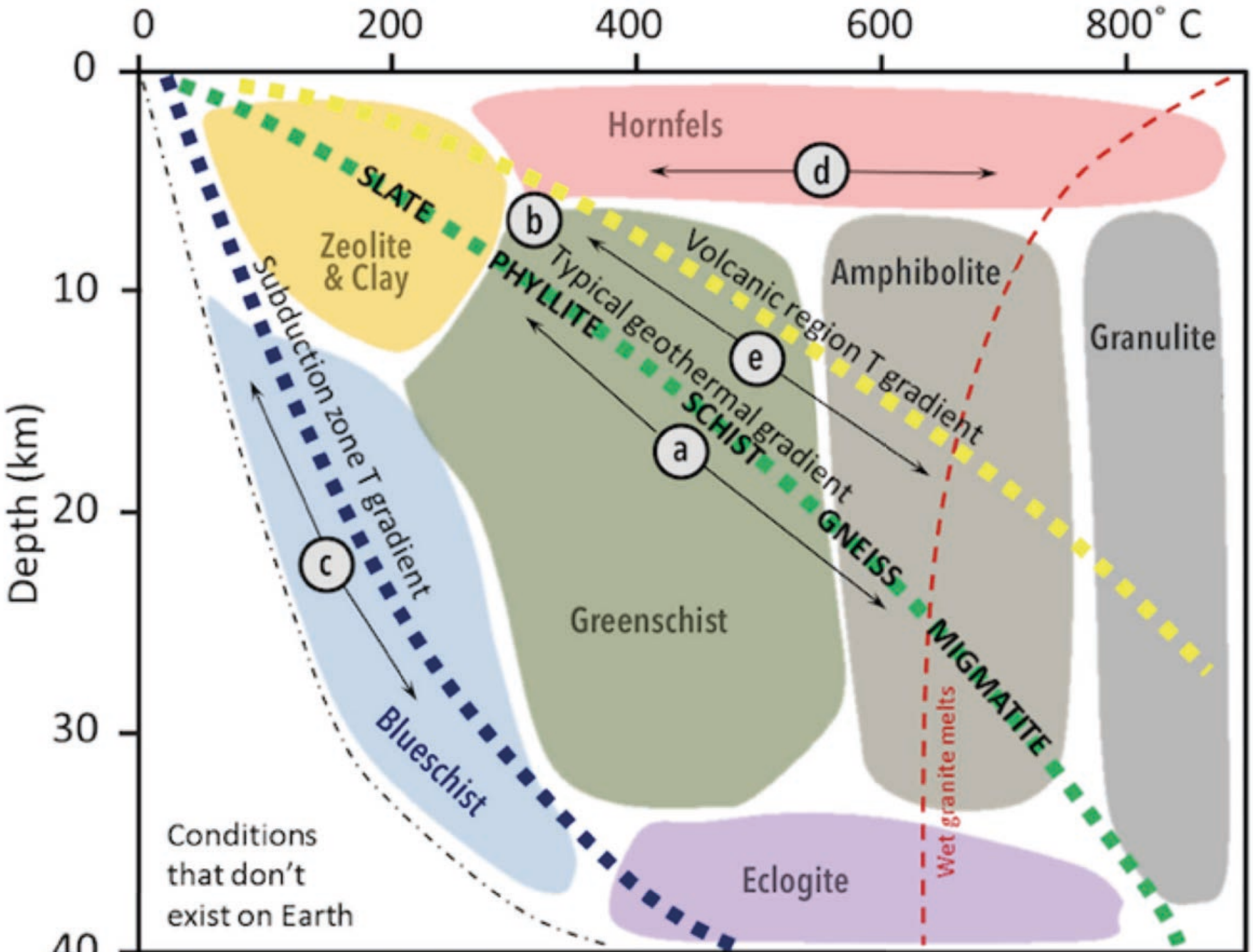


Fig. 4. Generalized cross-sections of the continental crust based on geological data for (a) Ivrea-Verbano and Strona-Ceneri Zones, (b) Fraser Range, (c) Musgrave Range, (d) Pikwitonei and Cross Lake subprovinces, (e) Kasila Group.

Fountain & Salisbury (1981; EPSL)



https://openpress.usask.ca/physicalgeology/chapter/10-4-metamorphic-facies-and-index-minerals-2/

Figure 10.35 *Metamorphic facies and types of metamorphism shown in the context of depth and temperature. The metamorphic rocks formed from a mudrock protolith under regional metamorphism with a typical geothermal gradient are listed. Letters correspond to the types of metamorphism shown in Figure 10.36. Source: Karla Panchuk (2018) CC BY 4.0, modified after Steven Earle (2016) CC BY 4.0 view source*

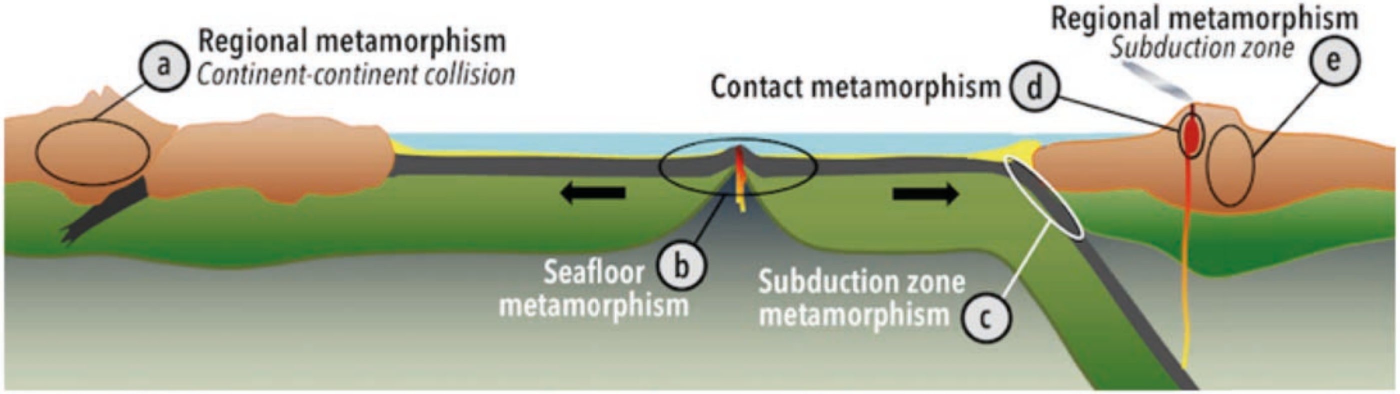
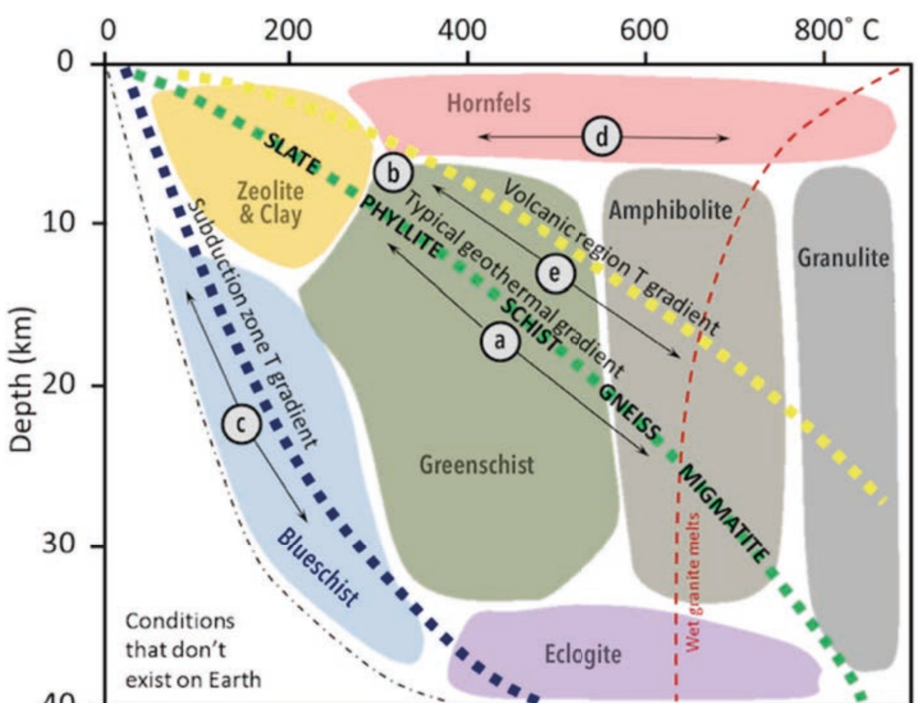


Figure 10.36 *Environments of metamorphism in the context of plate tectonics: (a) regional metamorphism related to mountain building at a continent-continent convergent boundary, (b) seafloor (hydrothermal) metamorphism of oceanic crust in the area on either side of a spreading ridge, (c) metamorphism of oceanic crustal rocks within a subduction zone, (d) contact metamorphism adjacent to a magma body at a high level in the crust, and (e) regional metamorphism related to mountain building at a convergent boundary. Source: Karla Panchuk (2018) CC BY 4.0, modified after Steven Earle (2015) CC BY 4.0 view source*

https://openpress.usask.ca/physicalgeology/chapter/10-4-metamorphic-facies-and-index-minerals-2/



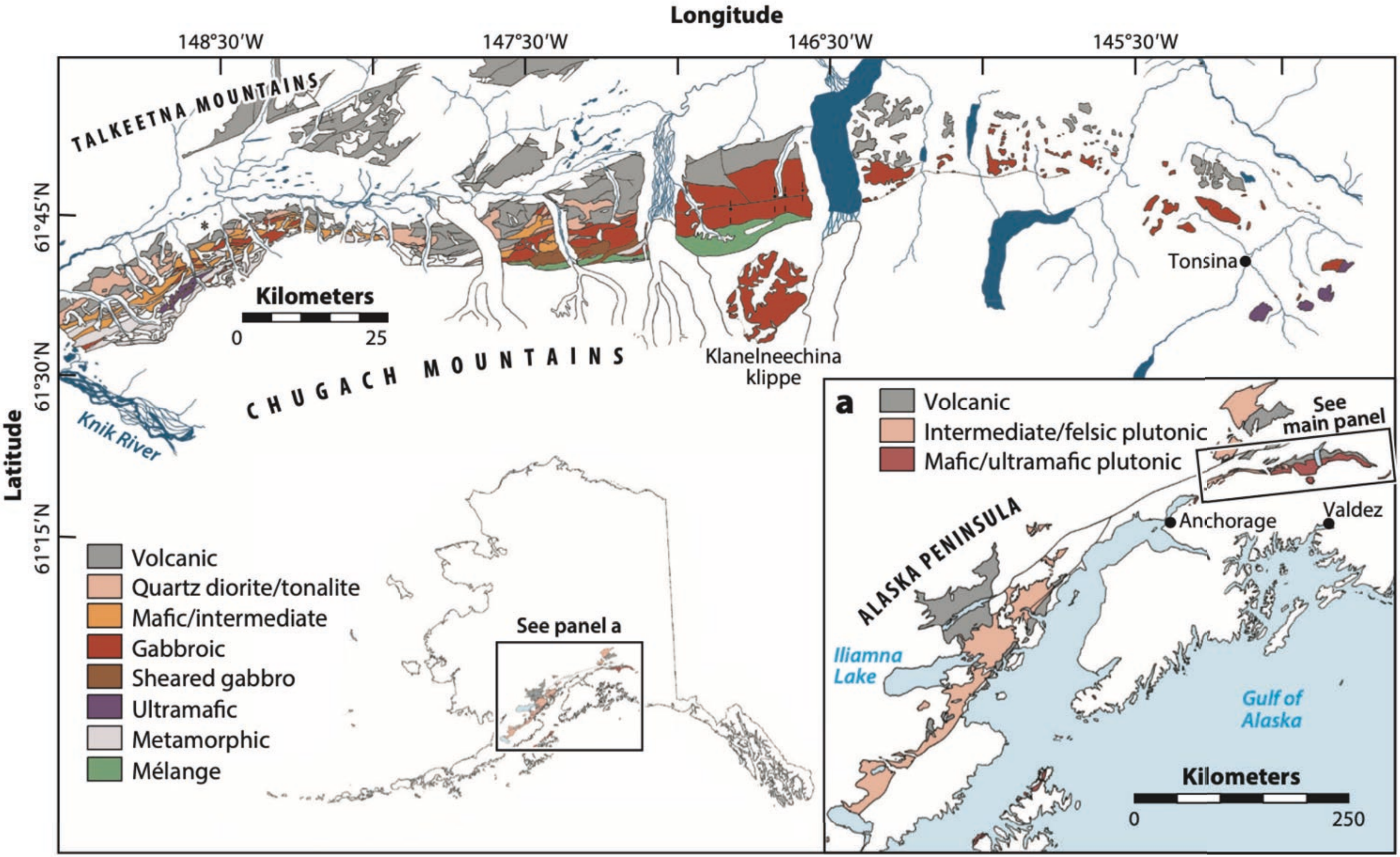


Figure 2

Simplified geological map of the Talkeetna arc. Figure modified with permission from Rioux et al. (2007, 2010).

Jagoutz & Kelemen (2015)

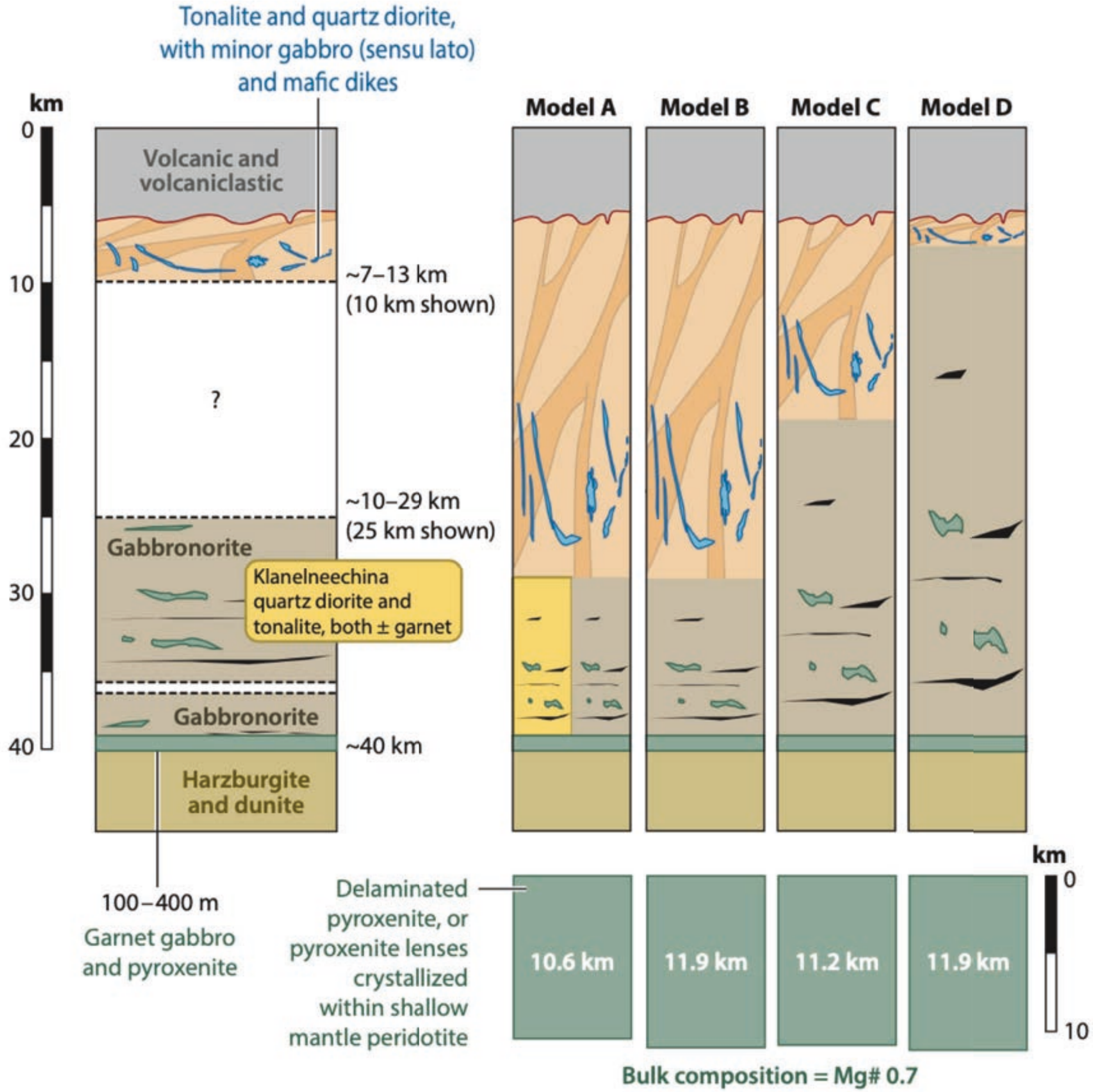


Figure 4

Simplified stratigraphic column of the Talkeetna arc section. (*Left*) The preserved rock types and their respective thicknesses. (*Right*) Four hypothetical columns where the preservation gap in the middle crust is systematically filled with more mafic compositions from A to D. Figure modified with permission from Kelemen et al. (2015).

Jagoutz & Kelemen (2015)

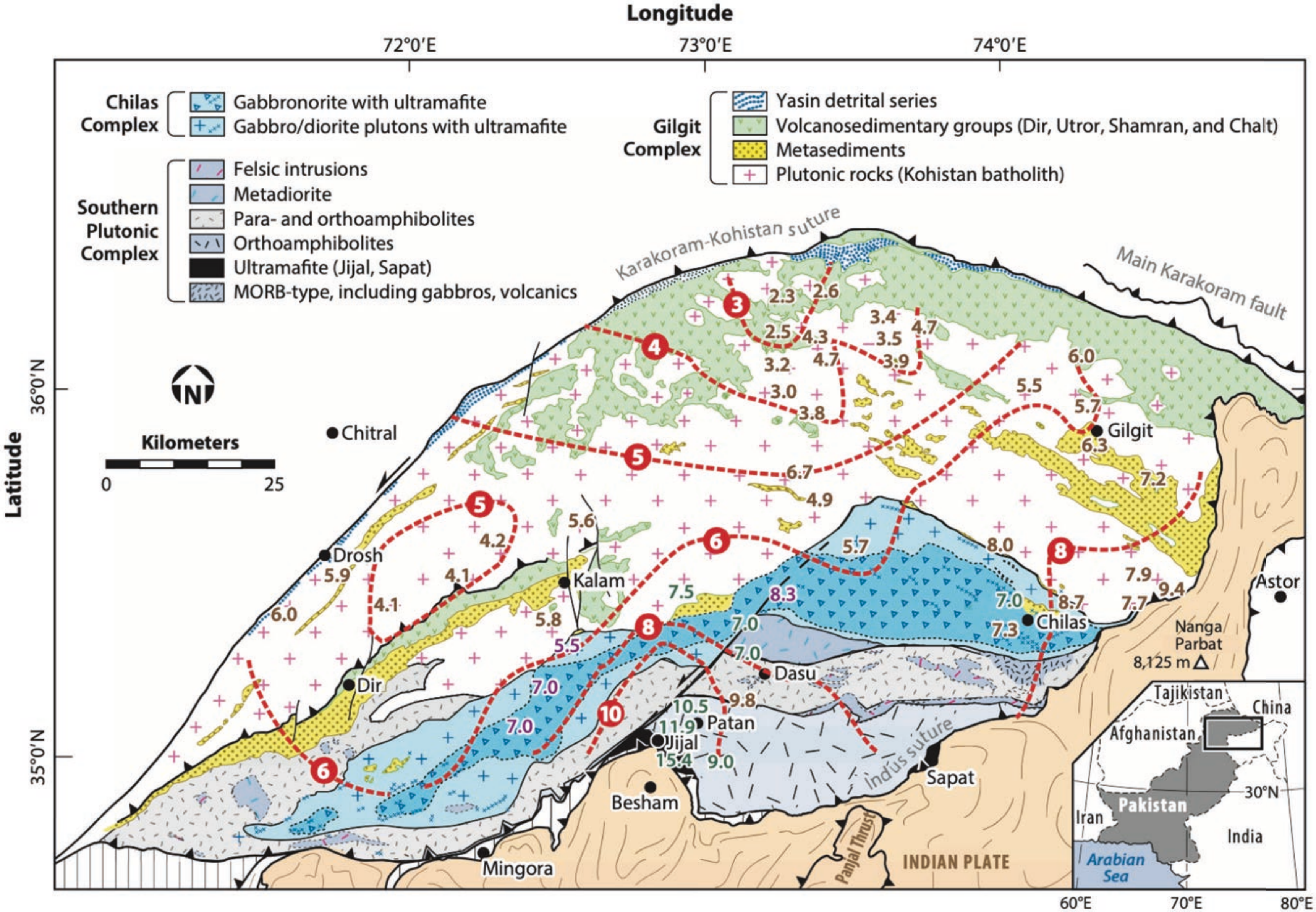


Figure 5

Simplified geological map of the Kohistan arc. Numbers indicate pressure in kilobars constrained by Al-in-hornblende barometry (*brown*) or by net transfer reactions involving garnet (*green*) or pyroxene-plagioclase-quartz (*purple*). The isobars (*dashed red lines*; associated numbers in red circles are in kilobars) illustrate the exhumation level of the Kohistan arc constrained by geostatistical modeling. Figure modified with permission from Jagoutz (2014). Abbreviation: MORB, mid-ocean ridge basalt.

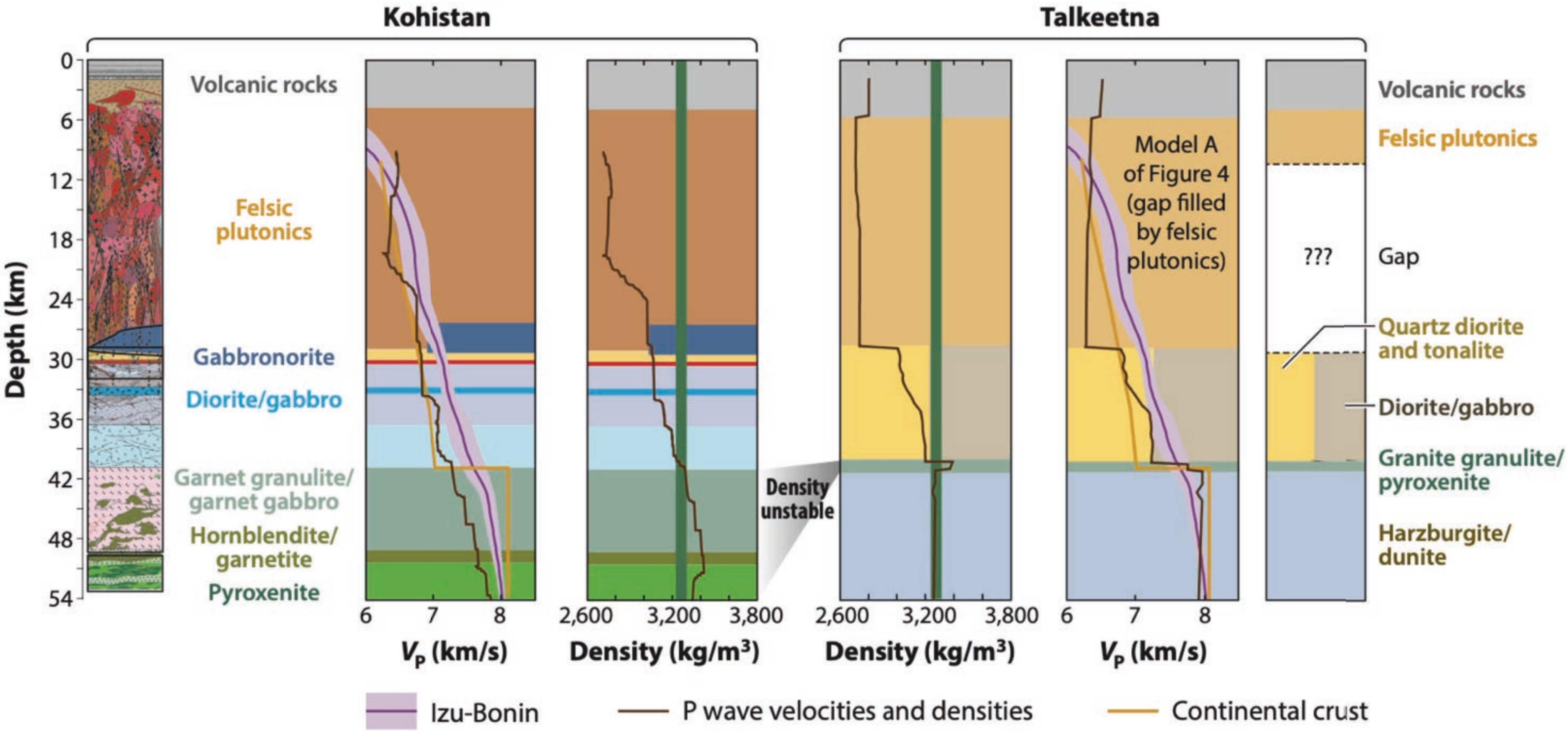


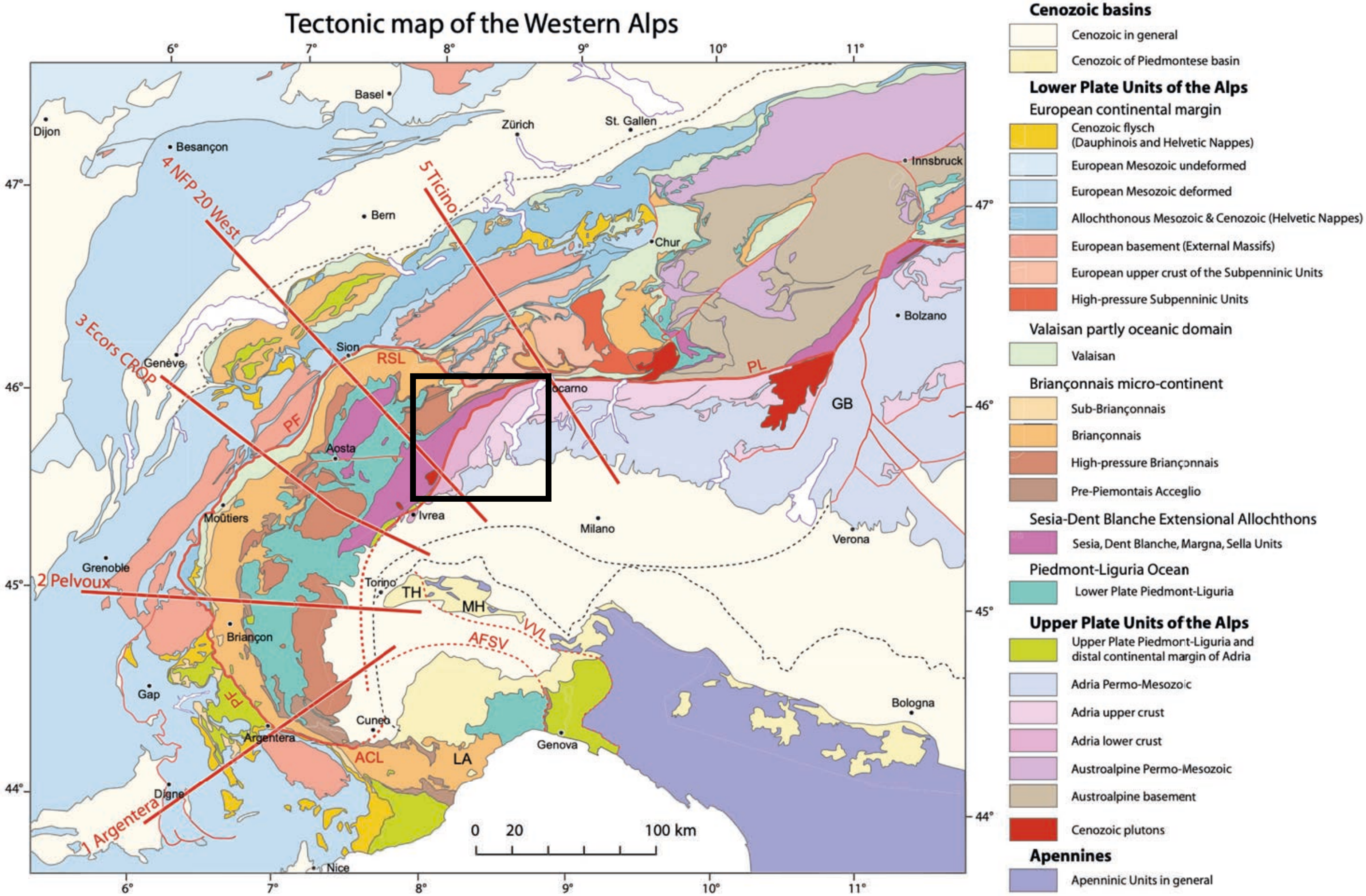
Figure 15

Schematic illustrations of the lithological, seismic, and density properties of the Kohistan and Talkeetna arc sections. Shown are simplified, schematic crustal columns and the calculated average seismic P wave velocities (V_P) and densities (*dark brown lines*) of the main crustal building blocks of the two arcs. Each dark green vertical band represents the density of peridotitic upper mantle at ~15 kbar. The reconstructed Kohistan section is seismically similar to the active Izu arc section, and the lower arc crust is denser than the underlying mantle at depths exceeding ~40 km. In contrast, the reconstructed Talkeetna section shows a jump in seismic velocities at the sharply defined crust-mantle transition, similar to that observed in continental regions. Density-unstable rocks are only preserved as relicts in Talkeetna, indicating that Talkeetna is density sorted. Figure modified with permission from Jagoutz & Behn (2013).

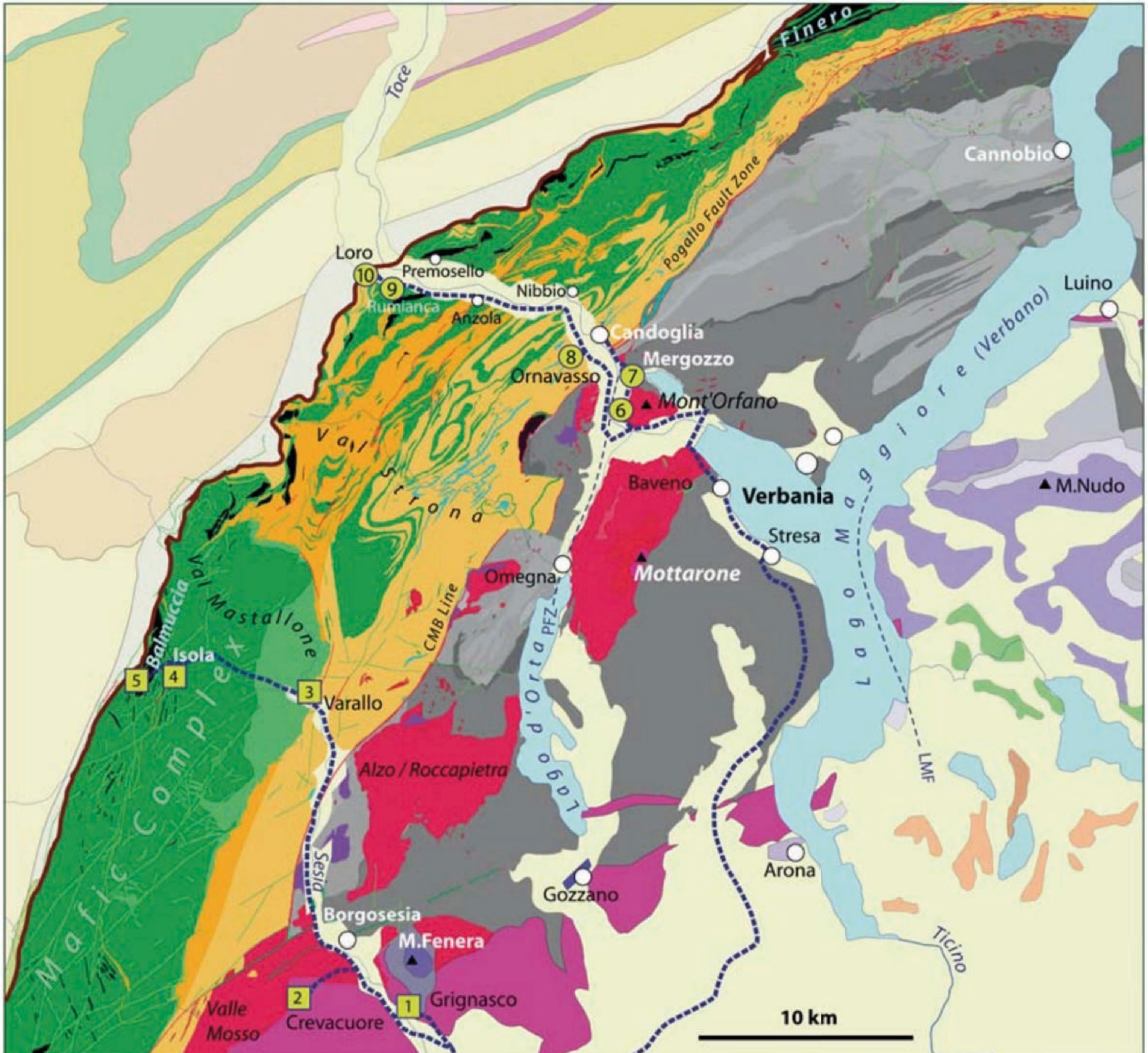
Jagoutz & Kelemen (2015)

Il corpo dell’ Ivrea-Verbano

Un po’ di inquadramento geologico



Schmid et al (2017; S.J.G.)



Brack et al. (2010; Swiss Bull.)

Brack et al.
(2010; Swiss Bull.)

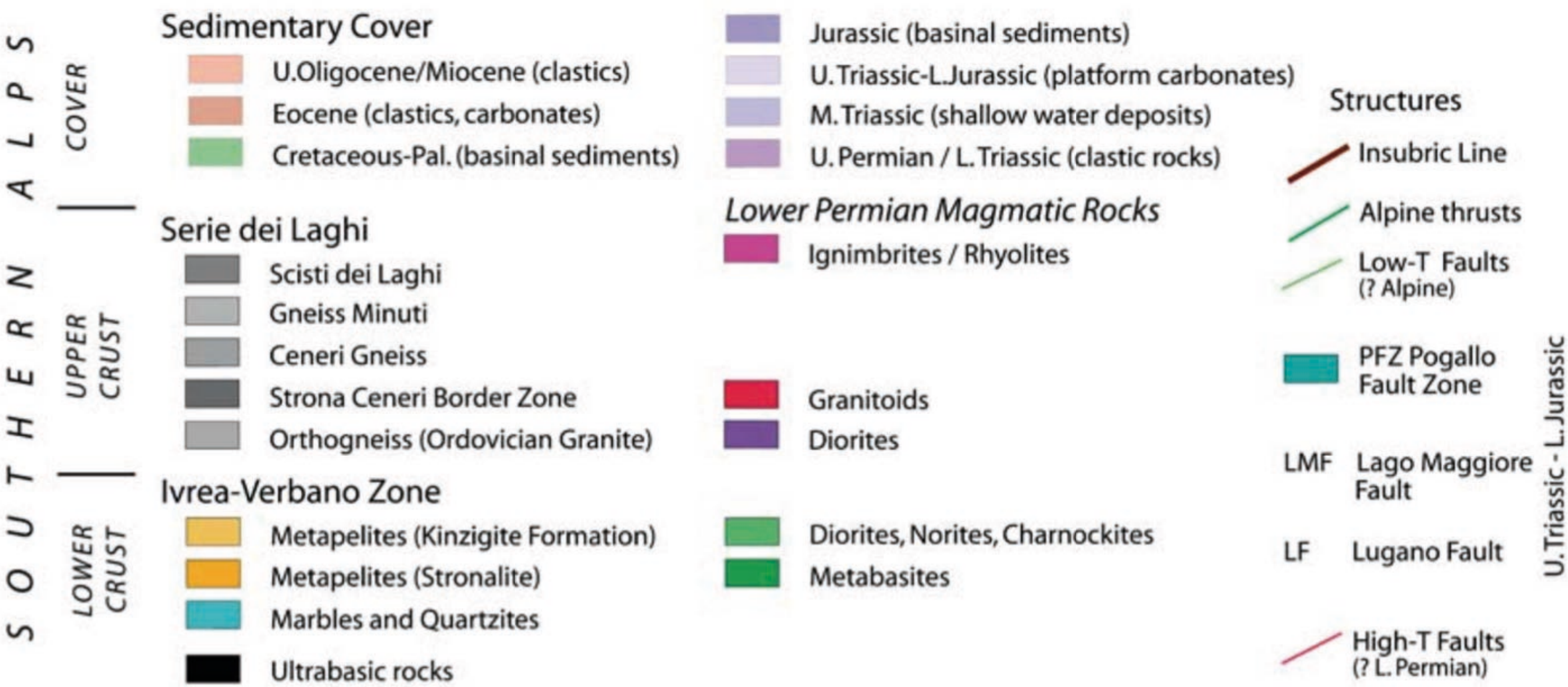
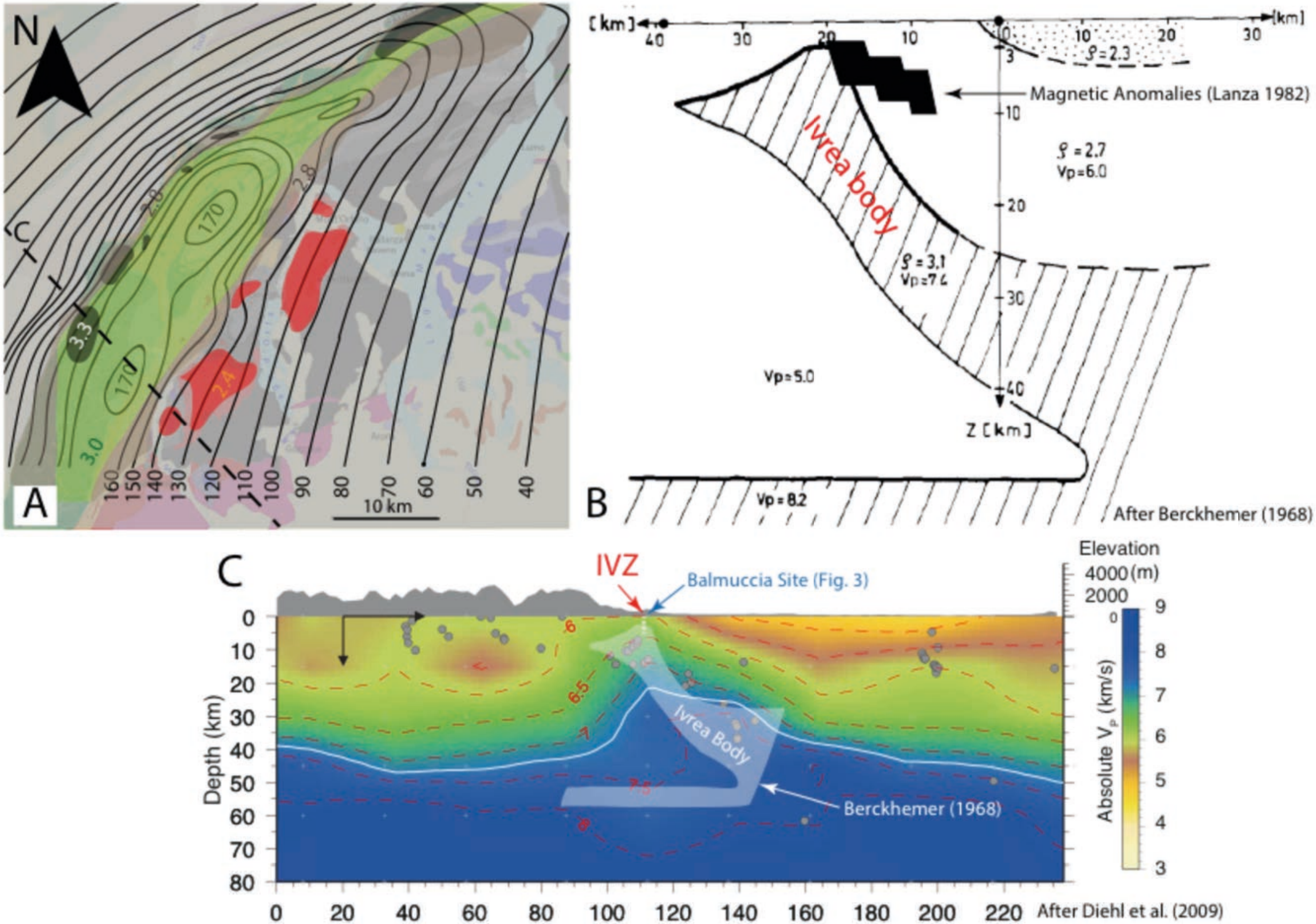
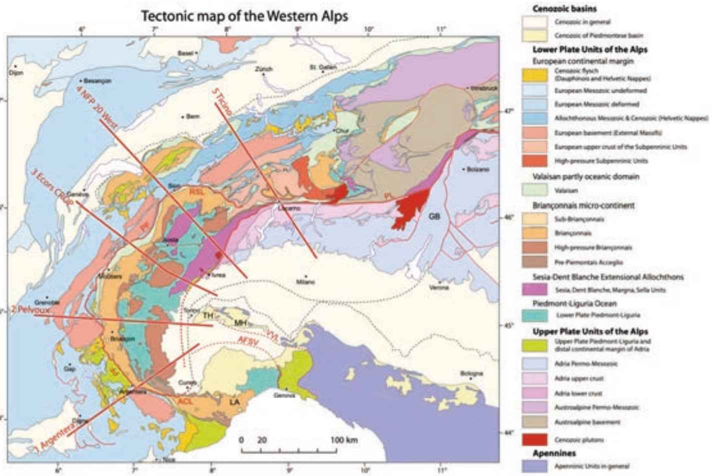
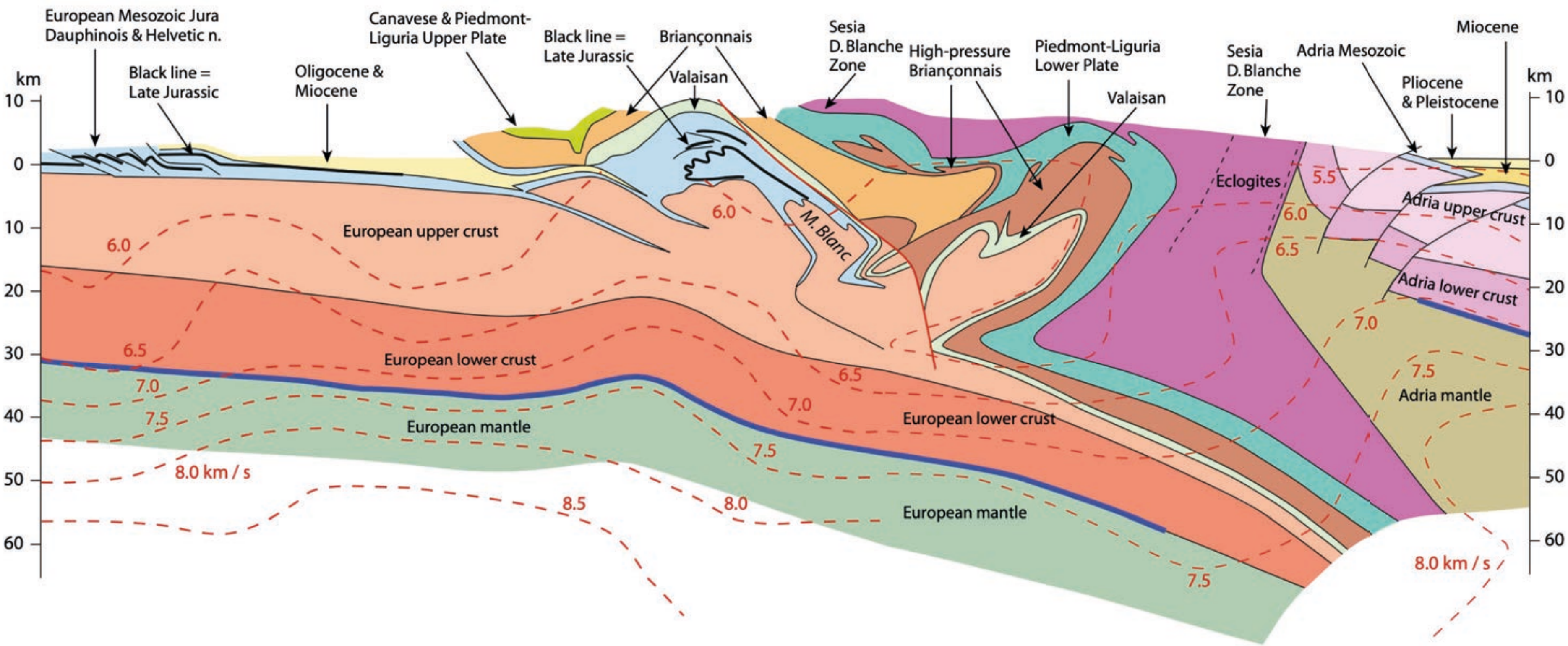


Fig. 3: Geological map of the Massiccio dei Laghi west of Lago Maggiore (Ivrea-Verbano Zone and Serie dei Laghi; simplified after a compilation by T. James 2001). The proposed field trip itineraries and stops are indicated: crustal section and mantle rocks in Valsesia (squares), upper and lower crustal rocks in Val d'Ossola (circles).



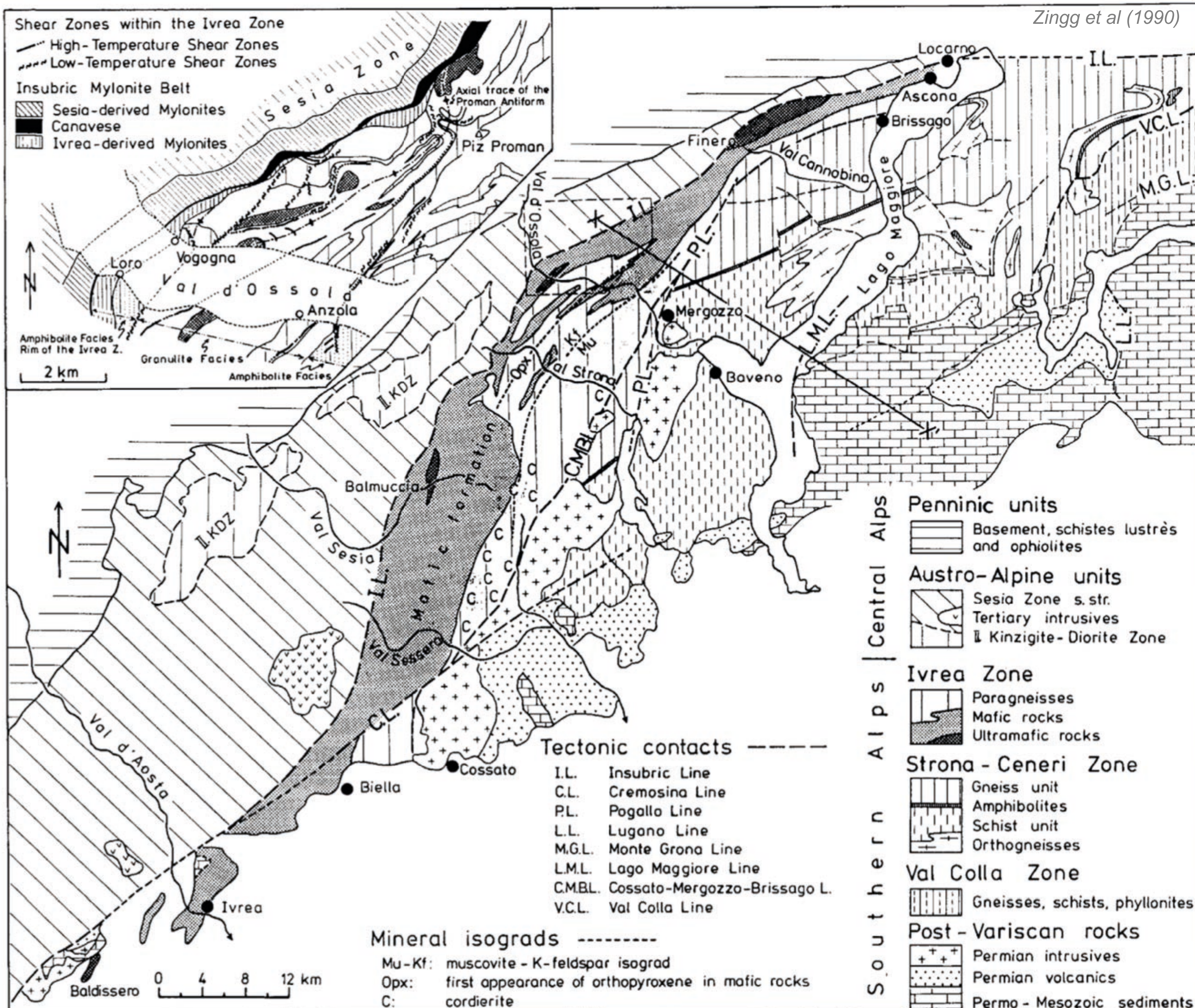
A) Densità (g/cm3) di alcune rocce affioranti in superficie (aree colorate) e contorni delle anomalie di gravità (mgal) (Kissling 1984, ridisegnato da Mattia Pistone, p.c.). B) Modello di velocità e densità secondo Berckhemer (1968). C) Profilo sismico secondo Diehl et al (2009)





Schmid et al (2017; S.J.G.)

Zingg et al (1990)



Zingg et al (1990)

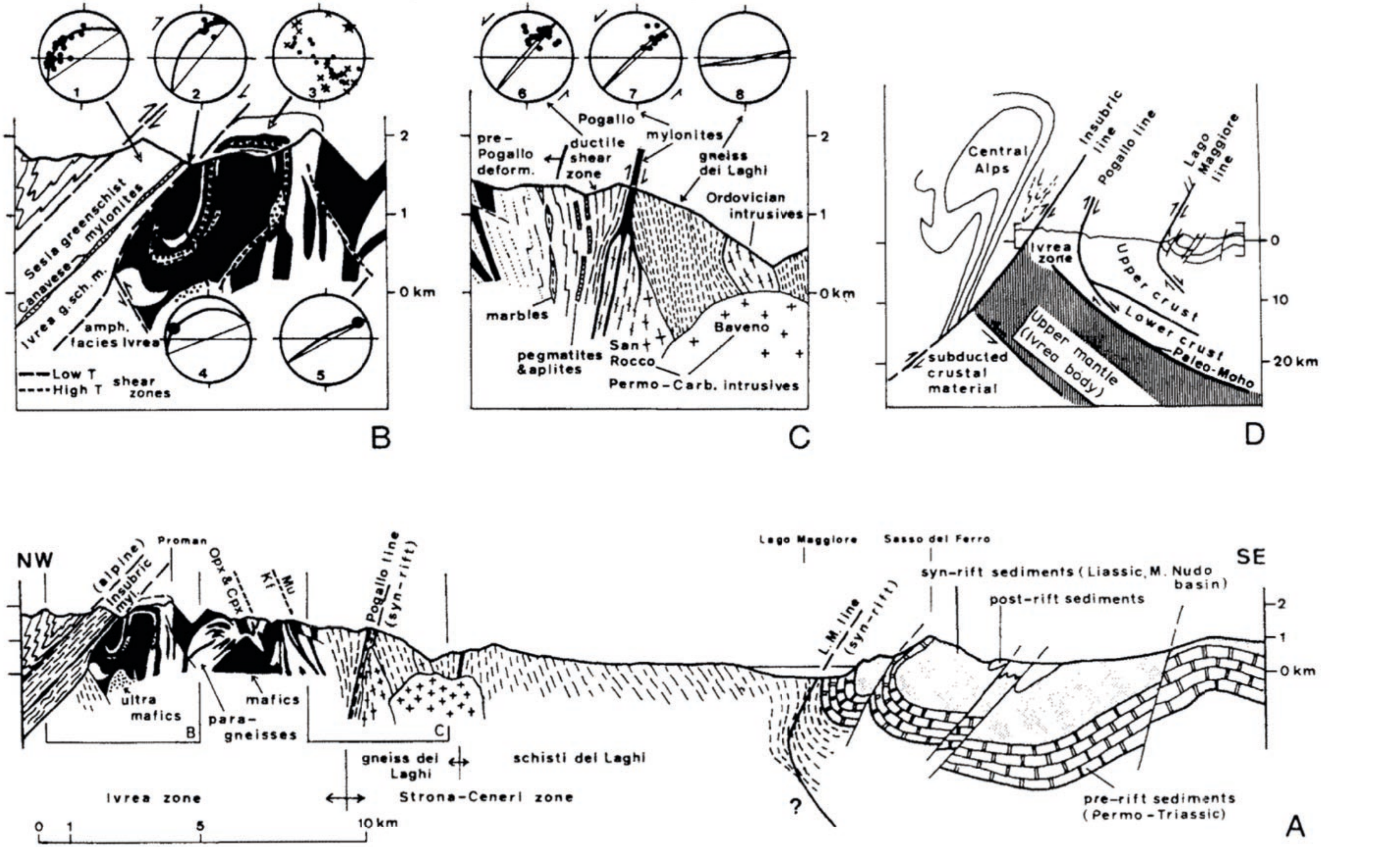
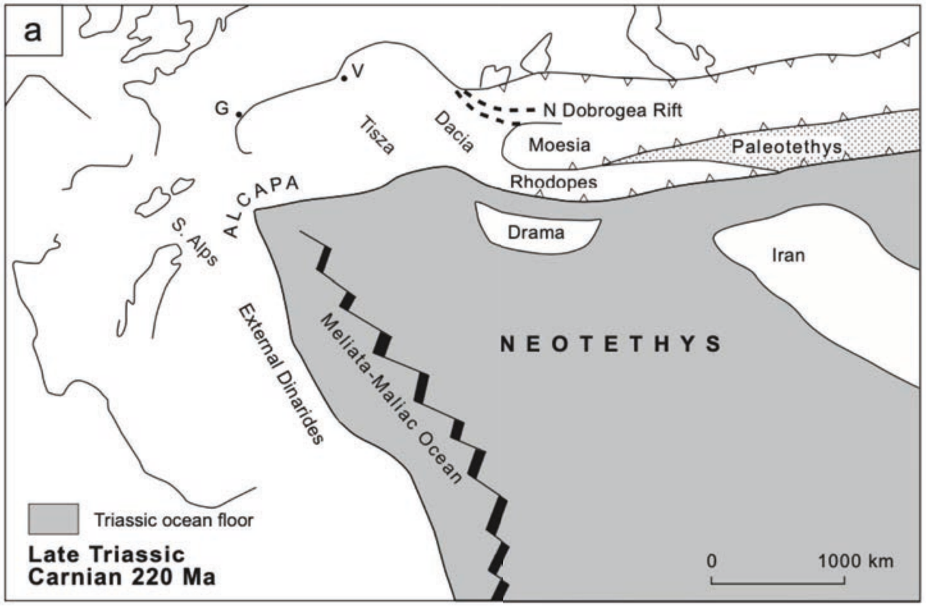


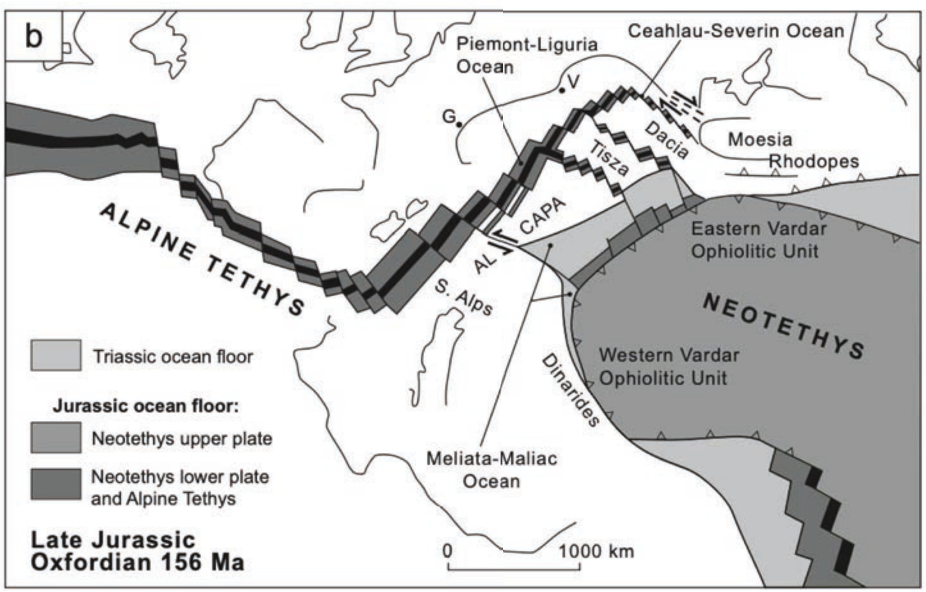
Fig. 3. (A) Geological section from the Insubric Line to the cover of the Southern Alpine basement. Location of profile indicated in Fig. 2. (b) Details of the Proman antiform and adjacent areas. The stereographic projections are lower hemisphere and indicate the average foliation and stretching lineations (dots) of the Insubric mylonites (projections 1 and 2 from S.M. Schmid et al., 1987); measurements from the Proman antiform (projection 3: dots = foliation poles; crosses = slickenside lineations; star = fold axis orientation); average orientation of foliation and stretching lineation within the high-temperature shear zones (projections 4 and 5, from Brodie and Rutter, 1987). (c) Details of the area around the Pogallo ductile fault zone. The stereographic projections are lower hemisphere and indicate the average foliation and lineation orientations (dots) within the Pogallo ductile fault zone (projection 6), the mylonites of the Pogallo Line (projection 7) and the gneiss dei Laghi (projection 8). (d) Sketch illustrating the position of the profile depicted in Fig. 3A within a larger context.

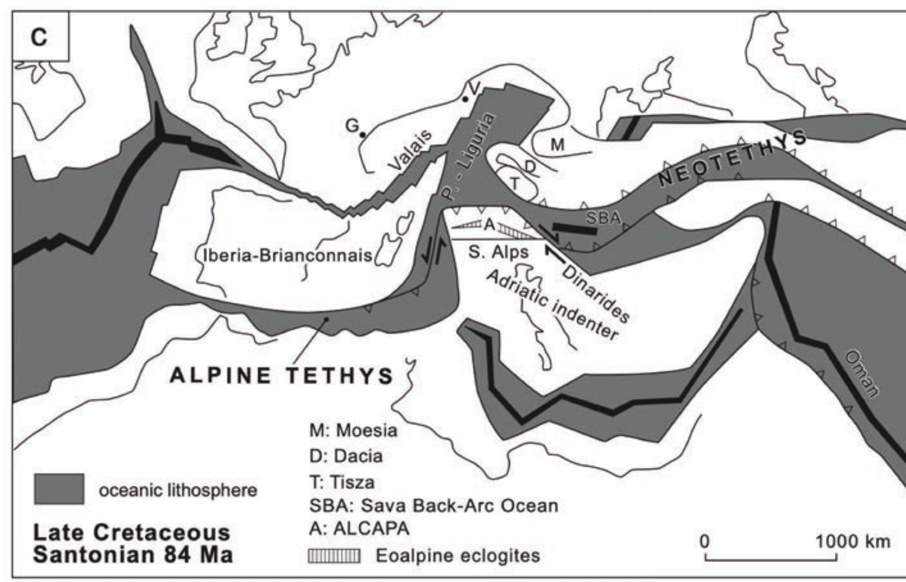
Il corpo dell’ Ivrea-Verbano

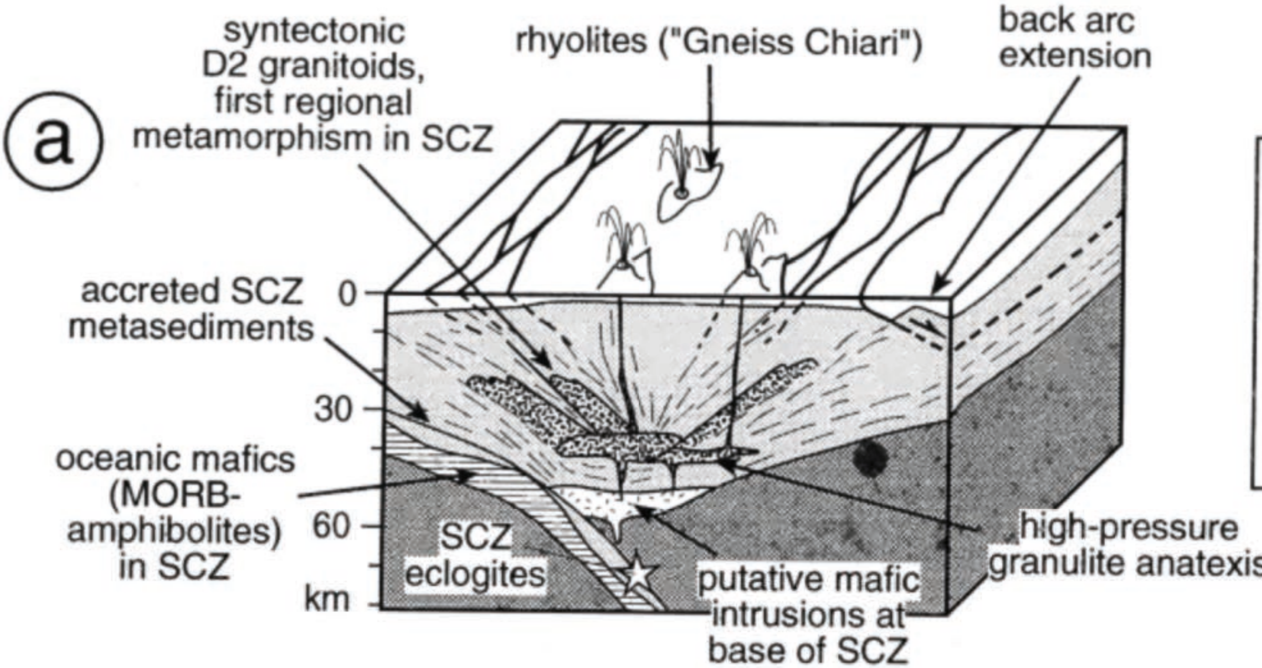
Un po’ sull’evoluzione geologica



Schmid et al (2008; S.J.G.)



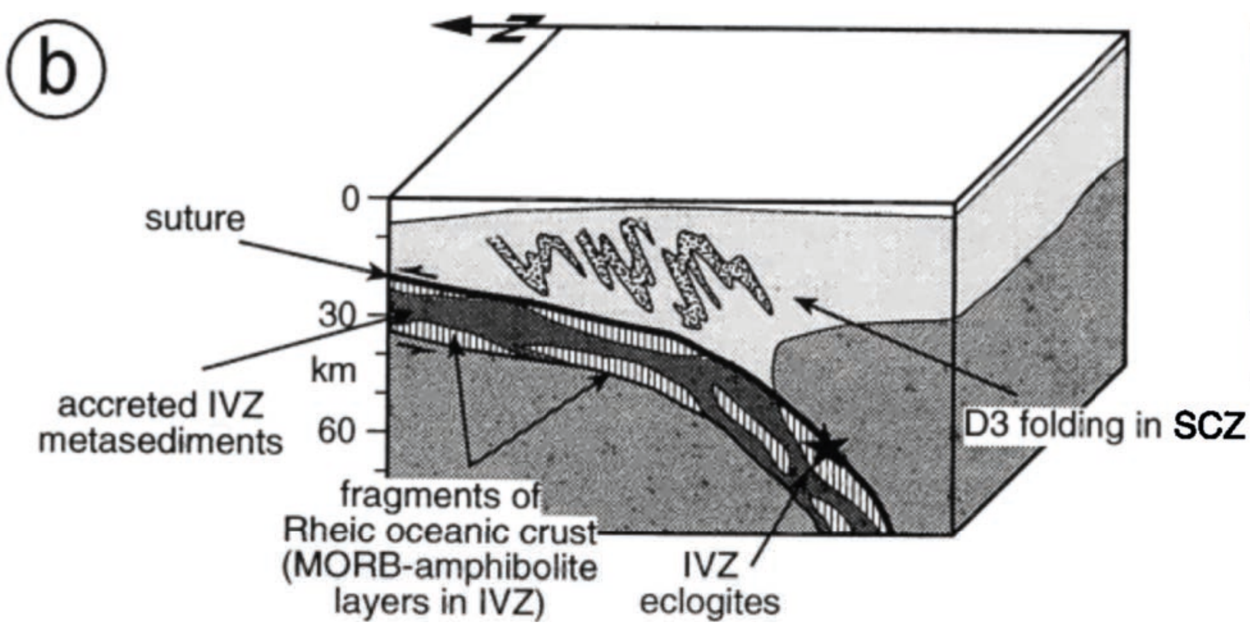




440-480 Ma

Sardic Event

- accretion and subduction of SCZ metasediments and MORB-mafics
- D2 magmatism in all crustal levels, regional metamorphism in the SCZ and VCZ

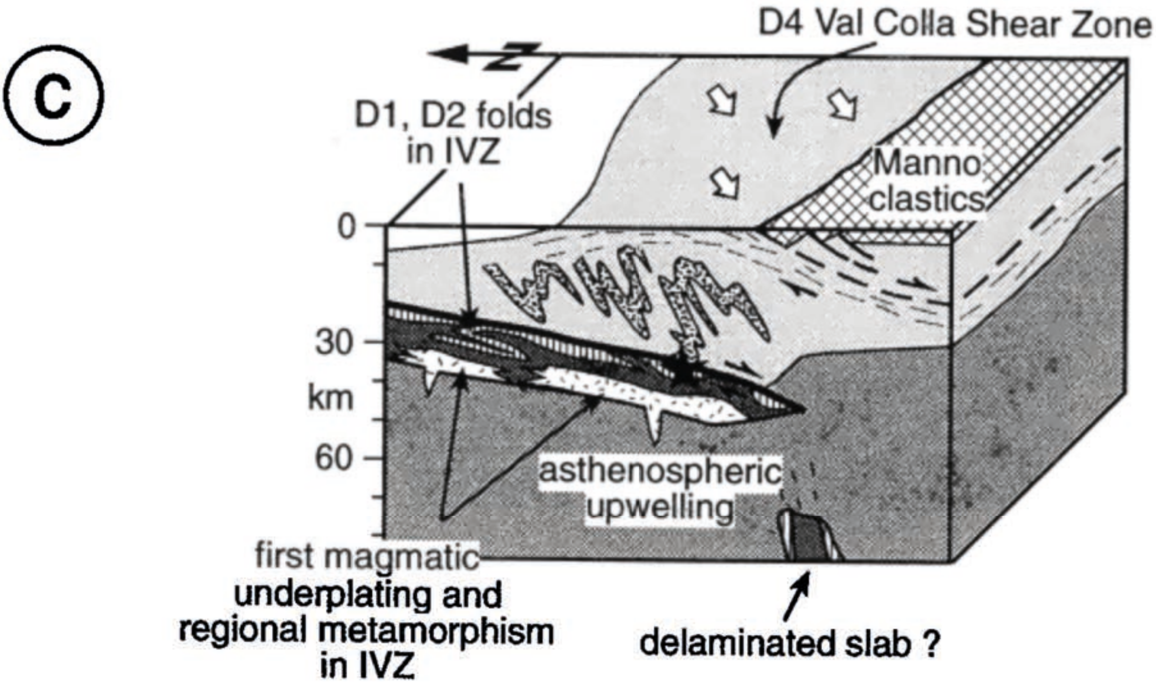


320-350 Ma

Variscan Subduction

- accretion and subduction of IVZ metasediments, high P metamorphism in IVZ

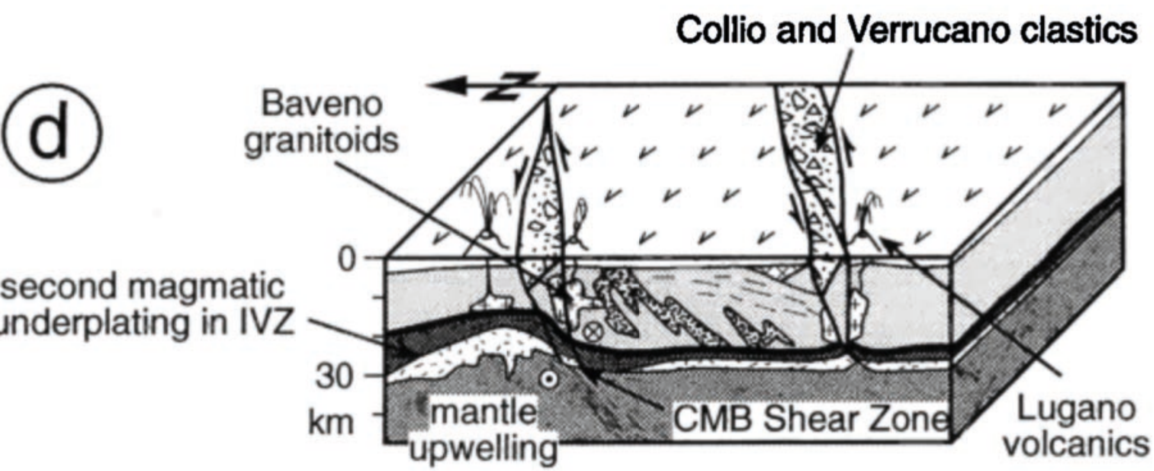
Handy et al (1999; Tectonics)



290-320 Ma

Late Variscan Delamination

- mafic underplating, regional metamorphism in IVZ and SCZ
- extensional exhumation and erosion of SCZ

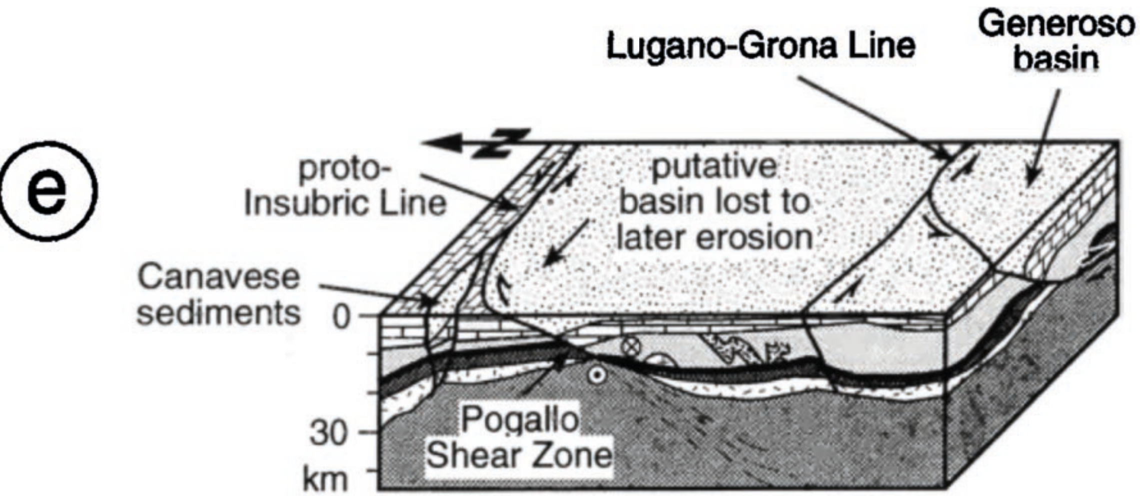


270-290 Ma

Permian Transtension

- CMB mylonitic shearing and local transtensional exhumation of the lower crust (IVZ)
- mafic underplating in IVZ, calc-alkaline magmatism along fault systems in all crustal levels

Handy et al (1999; Tectonics)

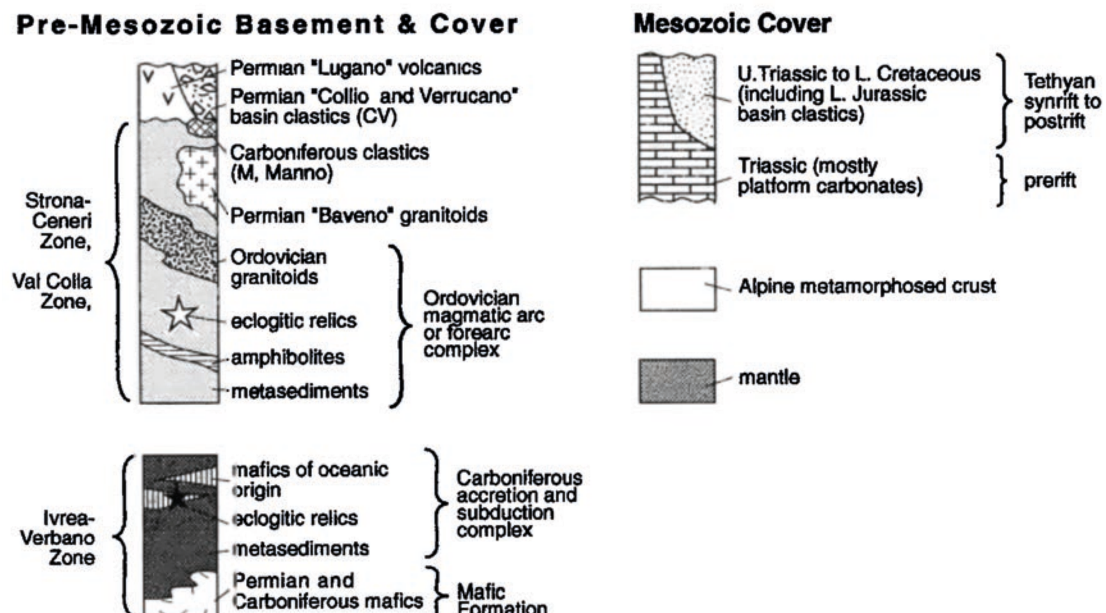


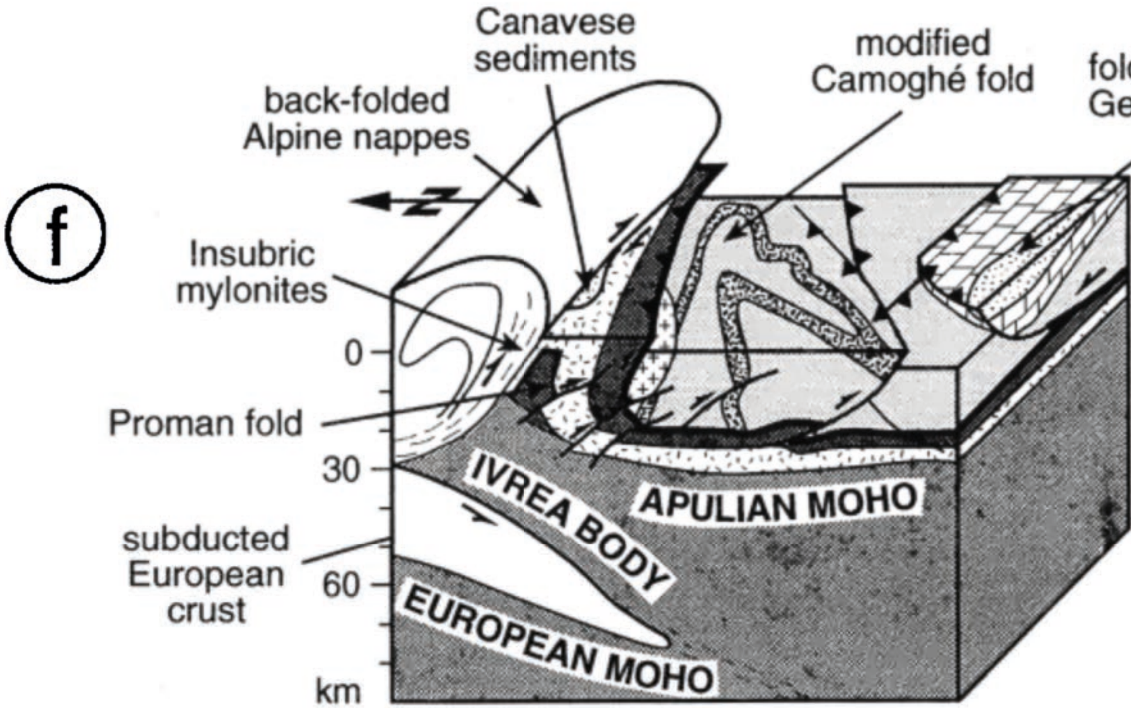
180-230 Ma

Tethyan Rifting

- Pogallo mylonitic shearing associated with strong attenuation and extensional exhumation of the intermediate and lower crust (IVZ)
- asymmetrical rift basins in the upper crust

Handy et al (1999; Tectonics)



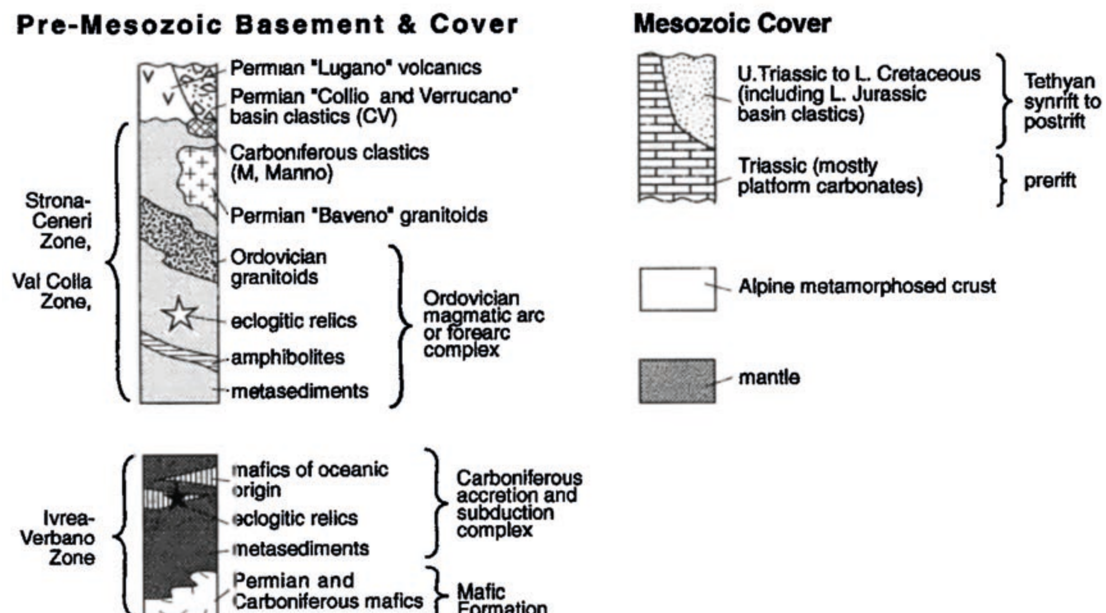


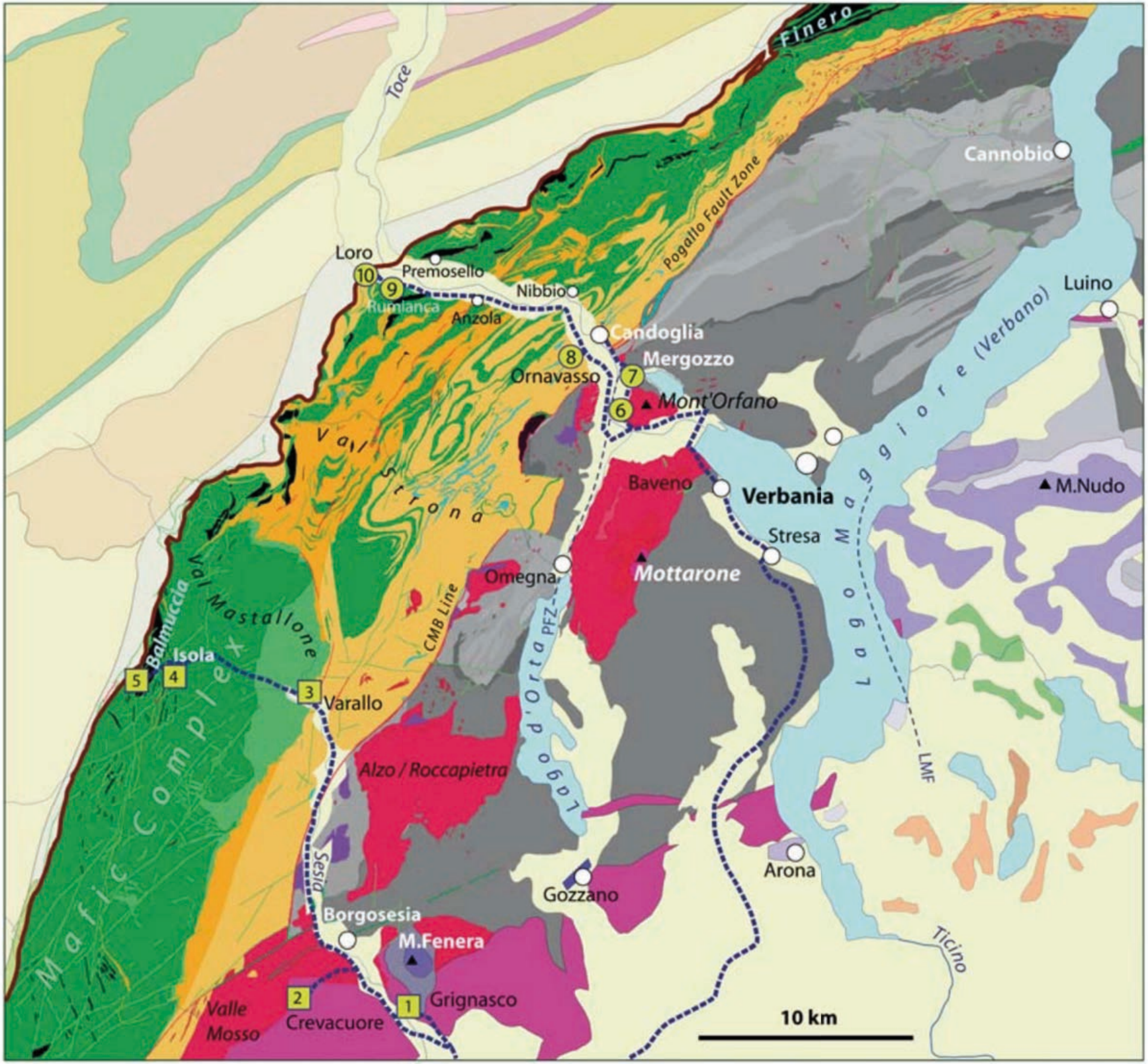
20-50 Ma

Alpine Emplacement

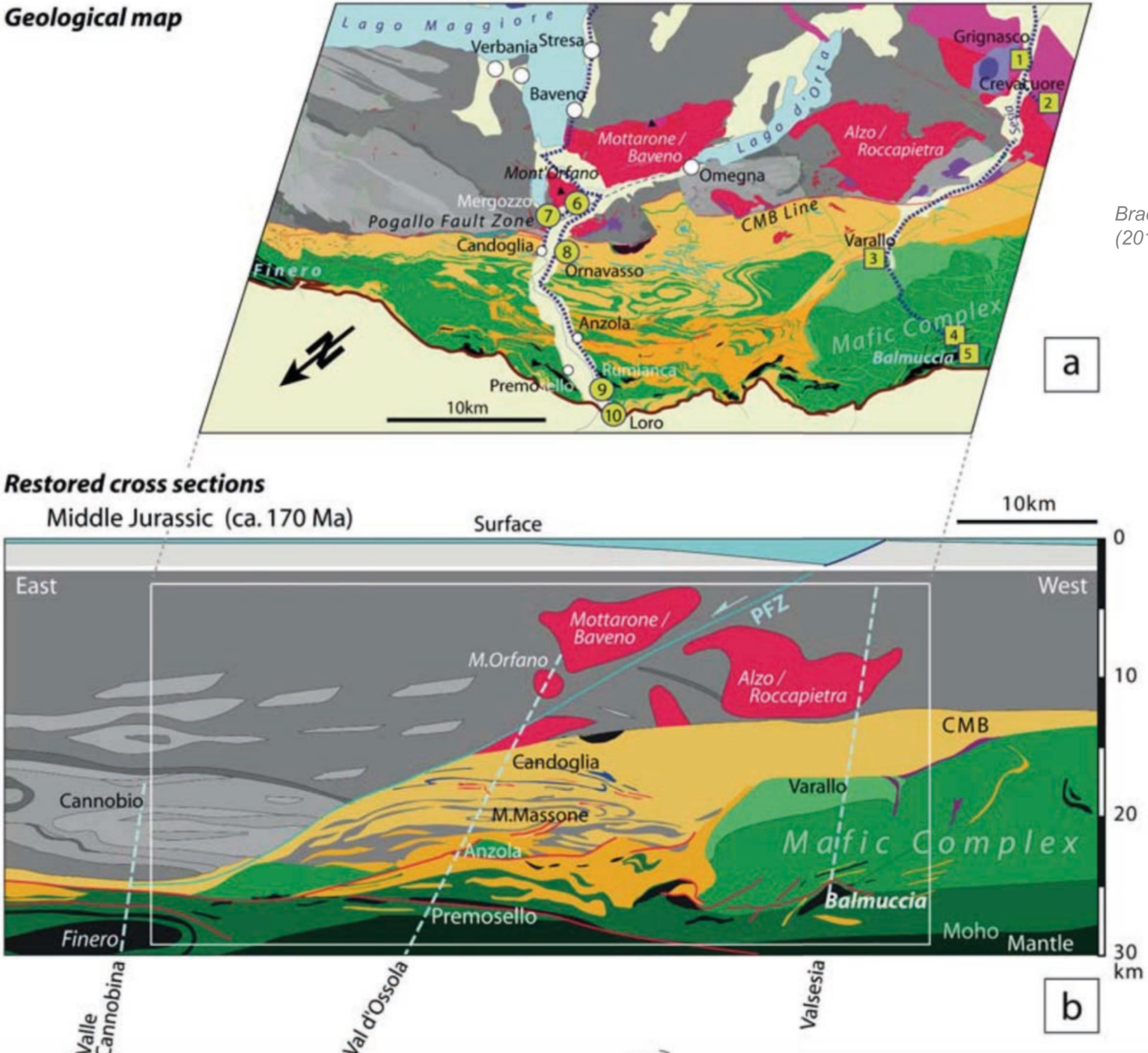
- brittle folding and thrust faulting
- final emplacement of IVZ to surface, fragmentation of crustal section

Handy et al (1999; Tectonics)





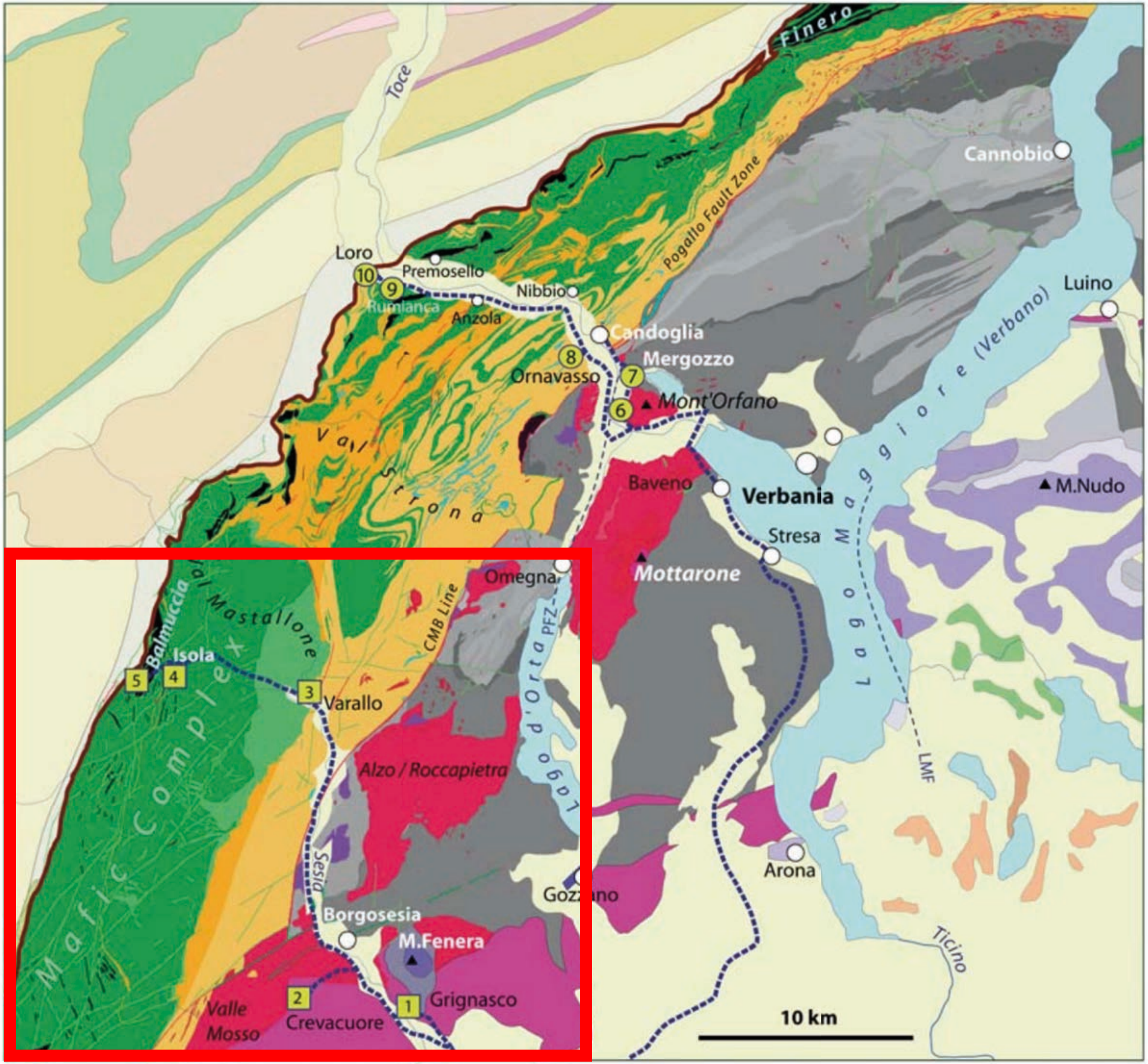
Brack et al.
(2010; Swiss Bull.)



Brack et al. (2010; Swiss Bull.)

Il corpo dell' Ivrea-Verbano

Zona meridionale – *Sesia Magmatic System*



Brack et al. (2010; Swiss Bull.)

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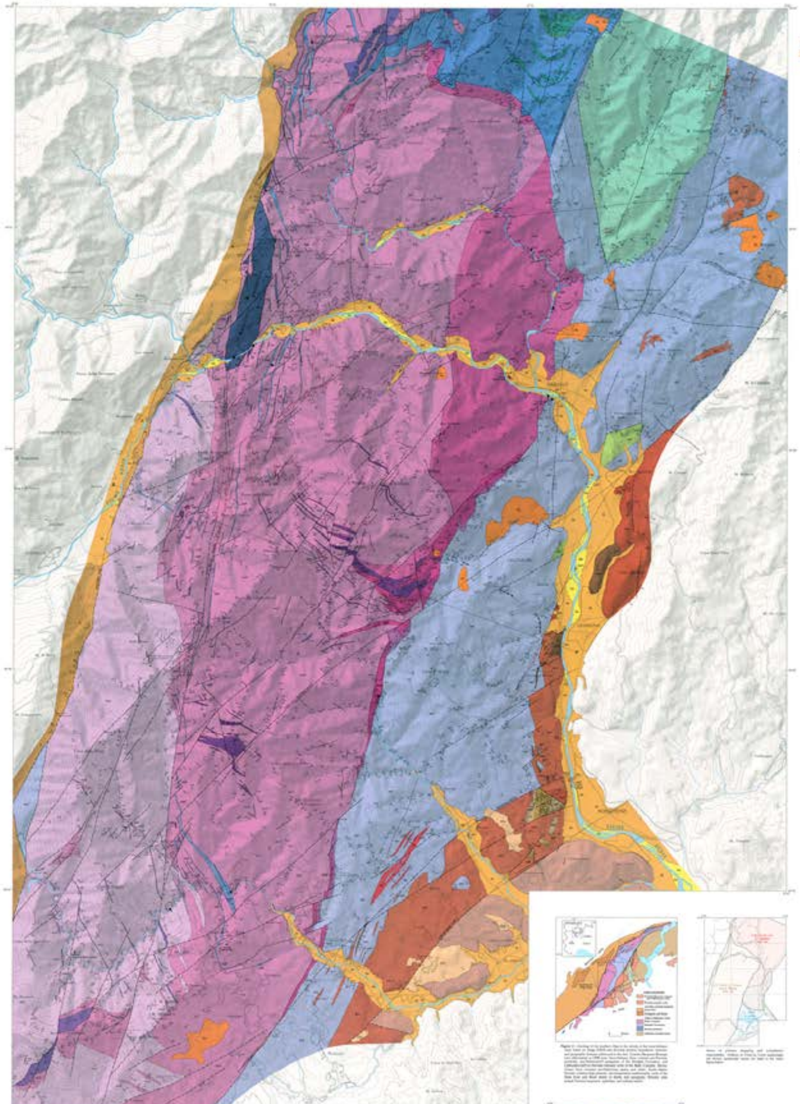
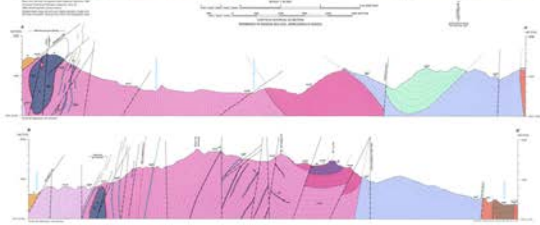




CORRELATION OF MAP UNITS

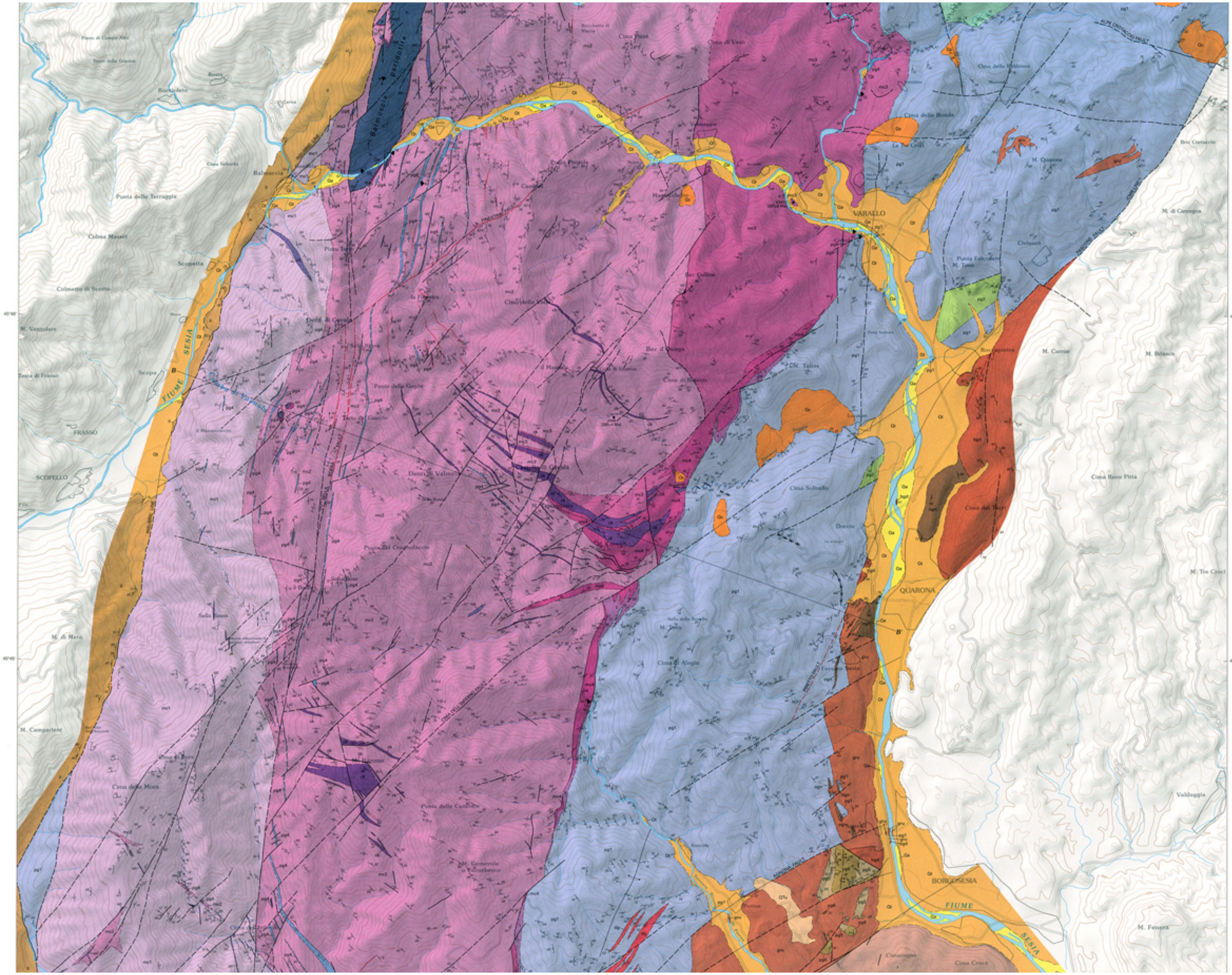
DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

EXPLANATION OF MAP SYMBOLS

GEOLOGIC MAP OF THE SOUTHERN IVREA-VERBANO ZONE, NORTHWESTERN ITALY

By
James E. Quick,[1] Silvano Sinigoi,[2] Arthur W. Snoke,[3] Thomas J. Kalakay,[3] Adriano Mayer,[2] and Gabriella Peressini[2,4]



QTu **Sedimentary deposits, undivided (Quaternary? to Tertiary?)**—Conglomerate, poorly sorted sandstone, shale, and minor carbonate. Distinguished from Quaternary deposits by greater consolidation and moderate dips (10°–20°) of bedding. Beds range from 0.5 centimeter (cm) thick (interbedded sandstone and shale) to massive (sandstone and conglomerate)

ROCKS OF THE INSUBRIC LINE

il **Mylonitic rocks of the Insubric Line (Tertiary)**—Synkinematically recrystallized rocks imbricated within the west-dipping, up to 1 kilometer (km) thick, north-northeast-striking, greenschist-facies mylonite belt that constitutes the Insubric Line (Zingg and Hunziker, 1990). Includes mylonite, phyllonite, and schist derived from the Mafic Complex of the Ivrea-Verbano Zone and terranes west of the Insubric Line

s **Serpentinite (Tertiary? or older)**—Dark, fine-grained, schistose to massive serpentinite containing quartz and carbonate lenses cropping out within the mylonitic rocks of the Insubric Line

IGNEOUS ROCKS OF PERMIAN AGE

r **Rhyolitic rocks (Permian)**—Orange- to red-weathering volcanic and hypabyssal(?) rhyolite porphyry that contains small (0.5–3 millimeter (mm)) crystals of quartz and feldspar dispersed in a pink aphanitic matrix. Includes ignimbrite with abundant fiamme, volcanic breccia, and massive porphyry

grv **Granitic rocks, undivided (Permian)**—Light-gray to white granitic rocks, ranging in grain size from medium grained (1–3 mm) to pegmatitic, and consisting chiefly of quartz and feldspar, with variable amounts of biotite, muscovite, and garnet. Characterized by a low color index (<5), these rocks are predominantly leucotonalite, although minor amounts of leucogranodiorite and leucogranite are included. Locally contain inclusions of biotite schist and orthogneiss, and form dikes that cut the foliation in these rocks. The unit is poorly exposed in most places as a result of deep weathering but can be recognized by a grus of quartz and white feldspar

bgd **Biotite granodiorite (Permian)**—Fine- to medium-grained (<1–3 mm), medium-gray biotite granodiorite that contains biotite, quartz, feldspar, and minor muscovite. Color index ranges from 10 to 20. Inclusions of fine-grained, subangular, mafic rock (up to 1 m in size) are locally abundant. Biotite schist and quartzofeldspathic paragneiss inclusions are less abundant. In places, rocks display a strong magmatic flow foliation defined by orientation of biotite grains and by biotite-rich schlieren that drape inclusions. Development of foliation is nonuniform with rocks showing strong flow foliation grading into nonfoliated rocks

INTRUSIVE ROCKS OF THE MAFIC COMPLEX, IVREA-VERBANO ZONE

dg **Dioritic and gabbroic dikes (Permian to Carboniferous?)**—Medium- to dark-gray, fine-grained dioritic to gabbroic dikes and minor coarse-grained pyroxenitic dikes. These rocks are mutually intrusive with white to light-gray tonalitic leucosomes from the Kinzigite Formation

t **Leucotonalite of Val Strona di Postua (Permian to Carboniferous?)**—Medium- to coarse-grained (1–5 mm), white to light-gray leucotonalite exposed in Val Strona di Postua that forms a laterally extensive, thin sheet between the eastern contact of the Mafic Complex and the paragneiss (pg1) of the Kinzigite Formation. Extremely low color index (<3) and heterogeneous mineralogy consisting mainly of plagioclase, quartz, and minor biotite, with variable amounts of potassium feldspar, muscovite, garnet, and orthopyroxene. Biotite locally defines a weak foliation. Contains abundant inclusions of paragneiss. Leucotonalite grades into agmatitic paragneiss in the wall rocks as the ratio of paragneiss inclusions to leucotonalite increases

mc4 **Biotite granodiorite of Val Strona di Postua (Permian to Carboniferous?)**—Light-gray, medium-grained (1–3 mm) biotite granodiorite that crops out near the eastern edge of the Mafic Complex and contains abundant subangular to subrounded, very fine grained (0.1–0.3 mm) mafic inclusions up to 2 m long and less abundant subrounded inclusions of quartzofeldspathic paragneiss. Rock consists of feldspar, quartz, biotite ± garnet and is locally porphyritic with blocky plagioclase phenocrysts up to 2 cm across. Color index ranges from about 10 to 20. Biotite-rich schlieren up to 2 m long and 10 cm wide define a magmatic flow foliation

mc3 **Diorite of Val Sesia (Permian to Carboniferous?)**—Medium-gray, medium-grained (1–4 mm) biotite-rich rocks composed mainly of plagioclase and biotite. Lithologies include diorite, quartz diorite, and monzogabbro. Amphibole, orthopyroxene, and clinopyroxene locally present but subordinate to biotite in abundance. Quartz and potassium feldspar locally present. Garnet is abundant near the contact with the Kinzigite Formation. Color index ranges from 30 to 40. Nonfoliated to weakly foliated with foliation best developed near the contact with paragneiss of the Kinzigite Formation (pg1). Fine-grained (≤0.2 mm), porphyritic mafic enclaves with plagioclase phenocrysts (≤1 cm) are common

ch **Charnockitic rocks (Permian to Carboniferous?)**—White to light-gray, medium- to coarse-grained (1 to >5 mm) granitic rocks that crop out within the Mafic Complex and consist of quartz and plagioclase, variable amounts of alkali feldspar, and minor red-brown-weathering, iron-rich orthopyroxene. Garnet is locally abundant, and biotite is present in rocks that crop out in the eastern 2 km of the Mafic Complex. Color index is typically ≤3. Igneous foliation is common, especially deep in the complex. Outcrops weather white to orange and have a nubby surface due to resistant weathering of quartz

uc **Cumulus ultramafic rocks (Permian to Carboniferous?)**—Dark-gray ultramafic rocks including dunite, harzburgite, and websterite. Dunite and harzburgite weather orange to red, and websterite weathers dark gray to black. Resistant-weathering, poikilitic orthopyroxene in harzburgite results in distinctive hobnail surface. Bodies near and within the Kinzigite Formation are locally rich in amphibole and phlogopite, and contain accessory apatite, iron-titanium oxides, and carbonate. Form sheet-like bodies and isolated pods in the gabbroic and noritic rocks (mc2). Form discordant intrusions and dikes (dashed where approximately located) that cut the amphibole gabbro (mc1) and paragneiss of the Kinzigite Formation (pg1). Locally contain copper- and nickel-rich sulfides

pc **Pegmatitic clinopyroxenite (Permian to Carboniferous?)**—Pegmatitic, locally feldspathic clinopyroxenite with green clinopyroxene crystals up to 20 cm long. Located at the contact between peridotite (p) and gabbroic and noritic rocks (mc2). Grades into gabbro with increasing feldspar

mc2 **Gabbro and norite (Permian to Carboniferous?)**—Light- to dark-gray, medium-grained (1–3 mm) gabbroic and noritic rocks composed primarily of plagioclase, pyroxene, and amphibole and distinguished from amphibole gabbro (mc1) by the presence of abundant pyroxene and from diorite (mc3) and biotite granodiorite (mc4) by minor or absence of biotite. Garnet crystals up to 10 mm across are present in proximity to or along strike with septa of paragneiss (pg4); these rocks are shown by pattern south of the Fiume Sesia and are present, although not depicted, north of the Fiume Sesia. In the central to eastern exposures of the Mafic Complex, minor biotite (<5 percent) is present near charnockitic rocks (ch), septa of paragneiss (pg4), diorite (mc3), and biotite granodiorite (mc4). Foliation is defined by the preferred orientation of mafic mineral grains. Lineation is defined by the elongation of mafic mineral grains within the plane of foliation. Locally, centimeter-thick to meter-thick banding is defined by variation in color index. In general, foliation, lineation, and banding are weak in the valley of the Fiume Sesia and near the eastern contact of the Mafic Complex but are increasingly more clearly defined westward. Synmagmatic boudinage and small stretching faults deform banding. In the valleys of the Fiume Sesia and the Torrente Mastallone, the dominant lithology is gabbro with a color index between 40 and 50 and composed primarily of plagioclase, brown-weathering orthopyroxene, green clinopyroxene, and black amphibole. South of Monte Luvot and Castello di Gavala, norite and leuconorite are abundant, consisting of plagioclase, brown orthopyroxene, black amphibole ± quartz. The color index is typically lower than 40. Black amphibole oikocrysts locally form distinctive large (1–3 cm) grains that grow across the foliation in the easternmost outcrops but are flattened in the plane of foliation elsewhere. Less abundant rock types are anorthosite, which forms layers up to 3 m thick, amphibole gabbro, and scarce olivine-bearing gabbro, which crops out in the Val Sesia, Val Mastallone, and Val Strona di Postua

mc1 **Amphibole gabbro (Permian to Carboniferous?)**—Medium- to dark-gray, medium-grained (2–4 mm) gabbro with distinctive granoblastic texture composed mainly of white plagioclase and black amphibole, minor pyroxene ± spinel. The color index is close to 50. Locally, noritic rocks are interfingered. Garnet is present locally in Valmala. A weak foliation is defined by the trails of amphibole grains. Centimeter-thick to meter-thick banding defined by variation in color index and deformed by synmagmatic boudinage and small stretching faults

PRE-PERMIAN MANTLE ROCKS

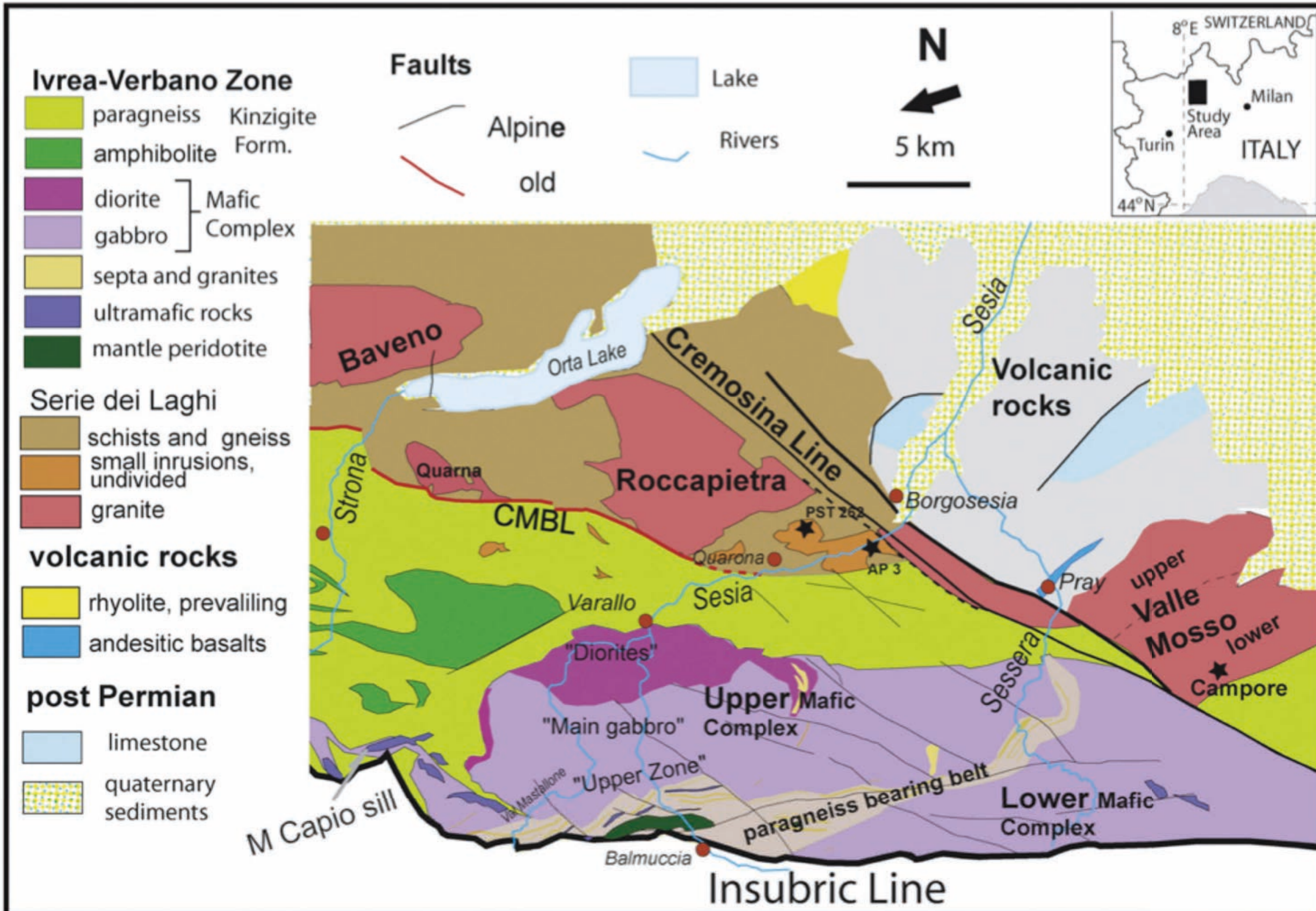
p **Peridotite (pre-Permian)**—Dark-gray-green, medium-grained (1–3 mm) spinel lherzolite and associated ultramafic rocks that crop out near the Insubric Line. Lherzolite, the dominant lithology, consists of orange-weathering olivine, greenish-brown-weathering orthopyroxene, green-weathering clinopyroxene, and black-weathering spinel. Includes minor amounts of dunite and harzburgite. High-temperature foliation defined in outcrop by trails of flattened spinel grains. Dikes and bands of bright-green-weathering clinopyroxenite are abundant and invariably cut by younger aluminum-augite dikes composed of lavender-weathering augite and black spinel. The peridotite is distinguished from the cumulus ultramafic rocks by lighter orange weathering and the presence of pyroxenite dikes and a spinel foliation

IGNEOUS ROCKS OF ORDOVICIAN(?) AGE

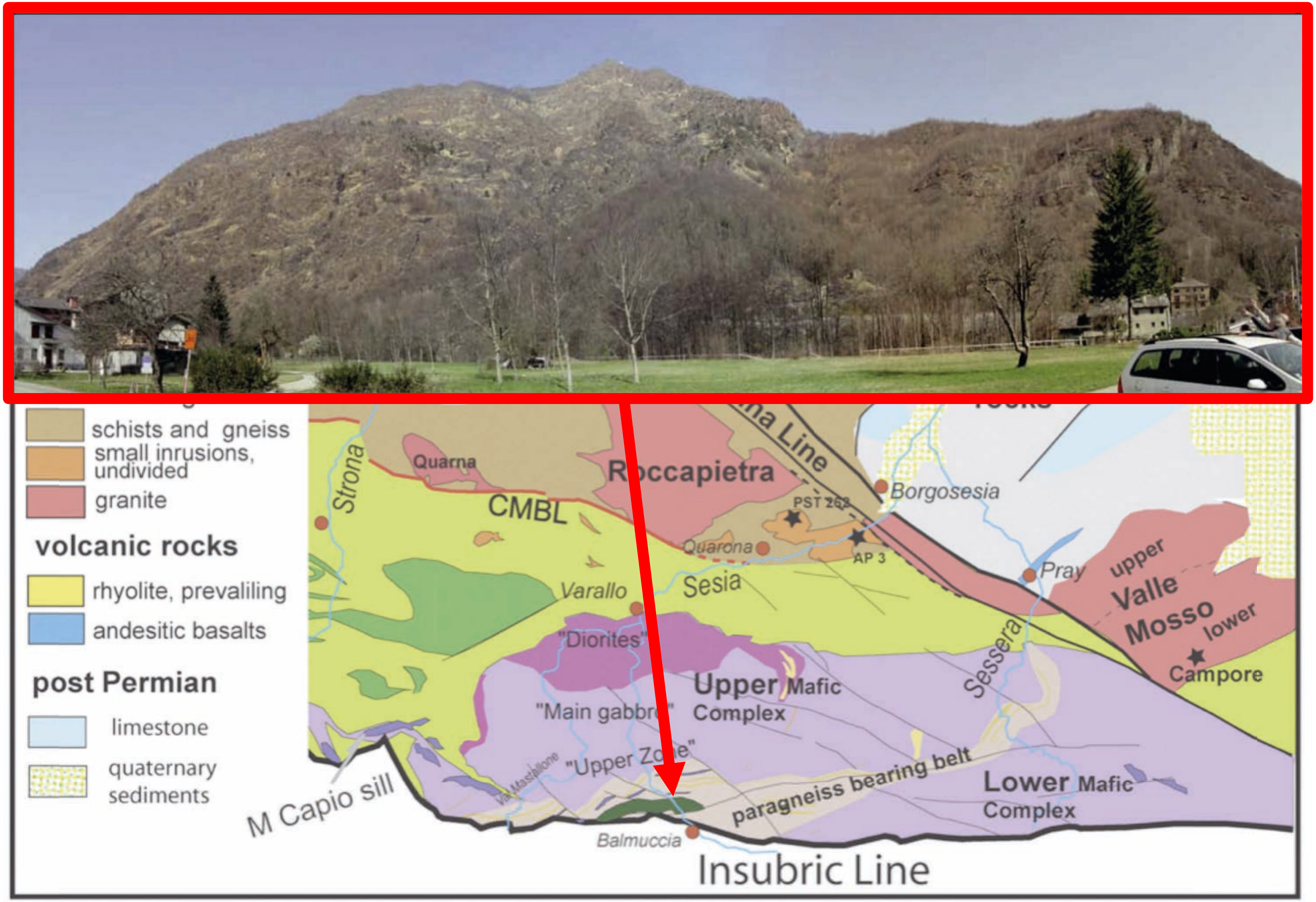
ogn **Orthogneiss (Ordovician?)**—Light-gray, medium- to coarse-grained (1–6 mm) granodioritic orthogneiss composed of quartz, feldspar, biotite, and minor muscovite. The color index is ≤20. Gneissic banding well defined and ranges from 0.1 to 2 cm in thickness. Augen structures locally present. Cut by abundant intrusions of leucogranite and fine-grained mafic dikes

METAMORPHIC ROCKS OF THE STRONA-CENERI ZONE

pg6 **Schist and quartzofeldspathic paragneiss (pre-Ordovician?)**—Rusty-brown-weathering, interlayered two-mica schist, chlorite schist, and quartzofeldspathic paragneiss. Distinguished from paragneiss of the Kinzigite Formation (pg1) within the mapped area by the presence of abundant muscovite. Sparse andalusite porphyroblasts are replaced by



Sinigoi et al (2016; Lithos)



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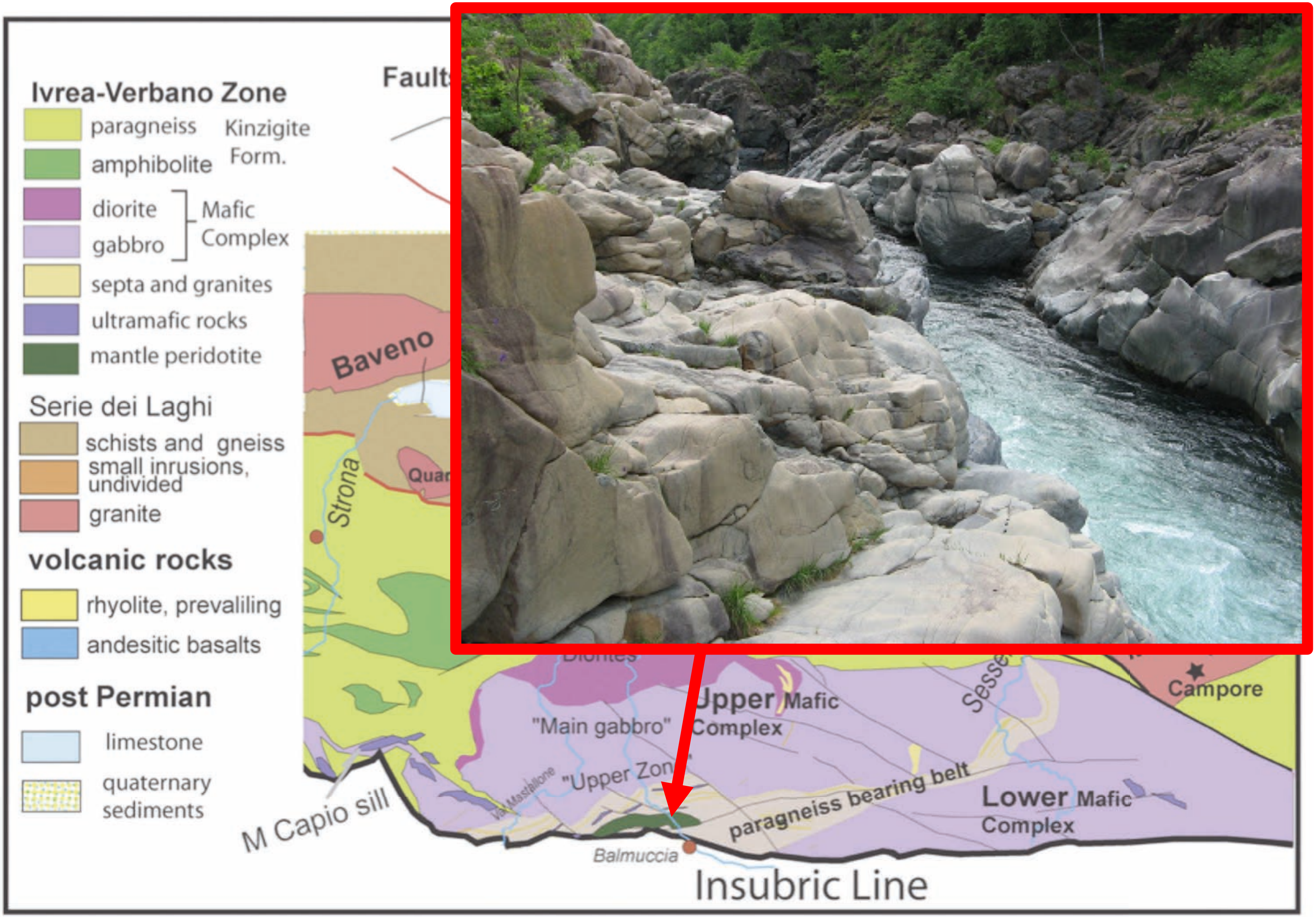

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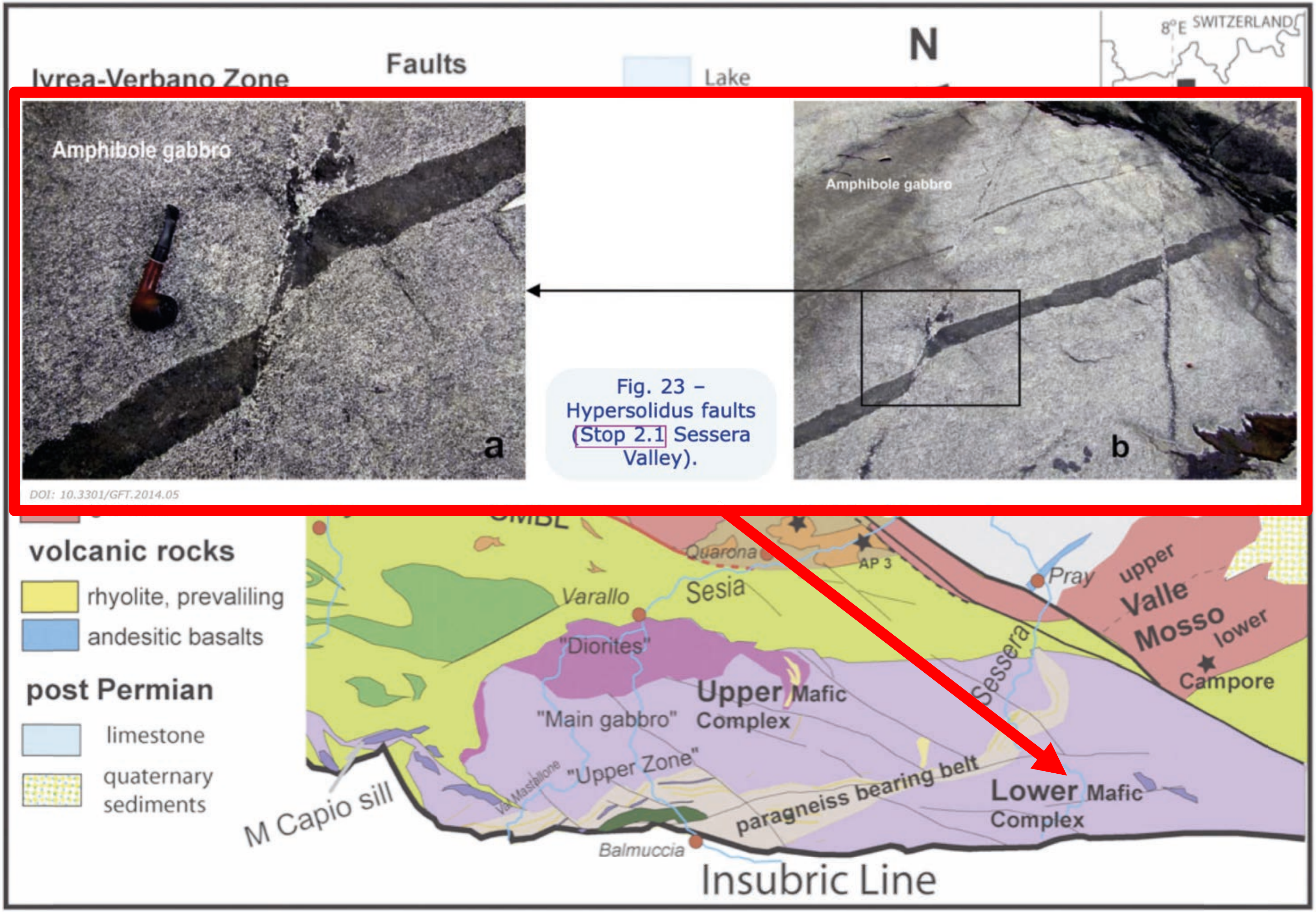

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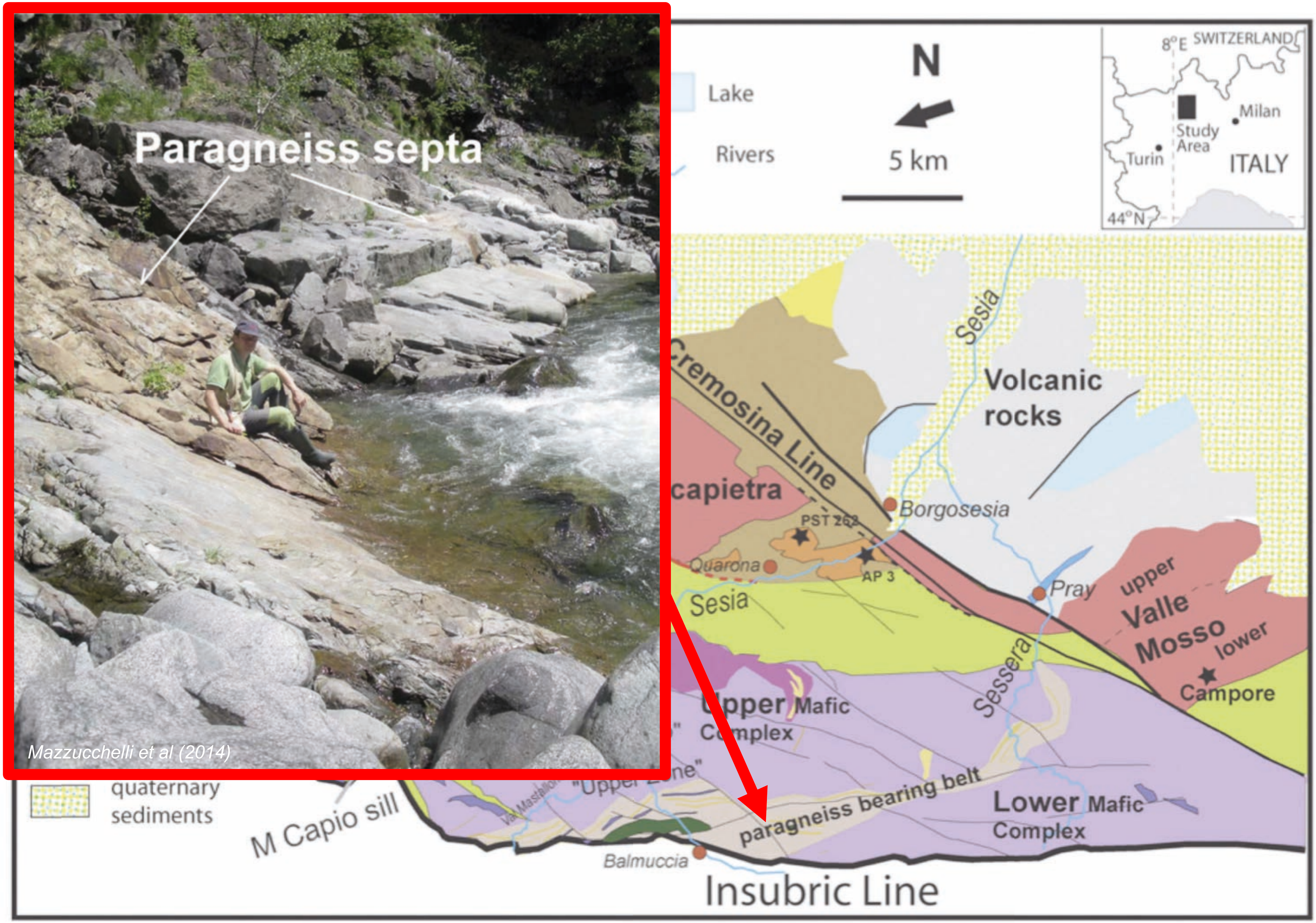

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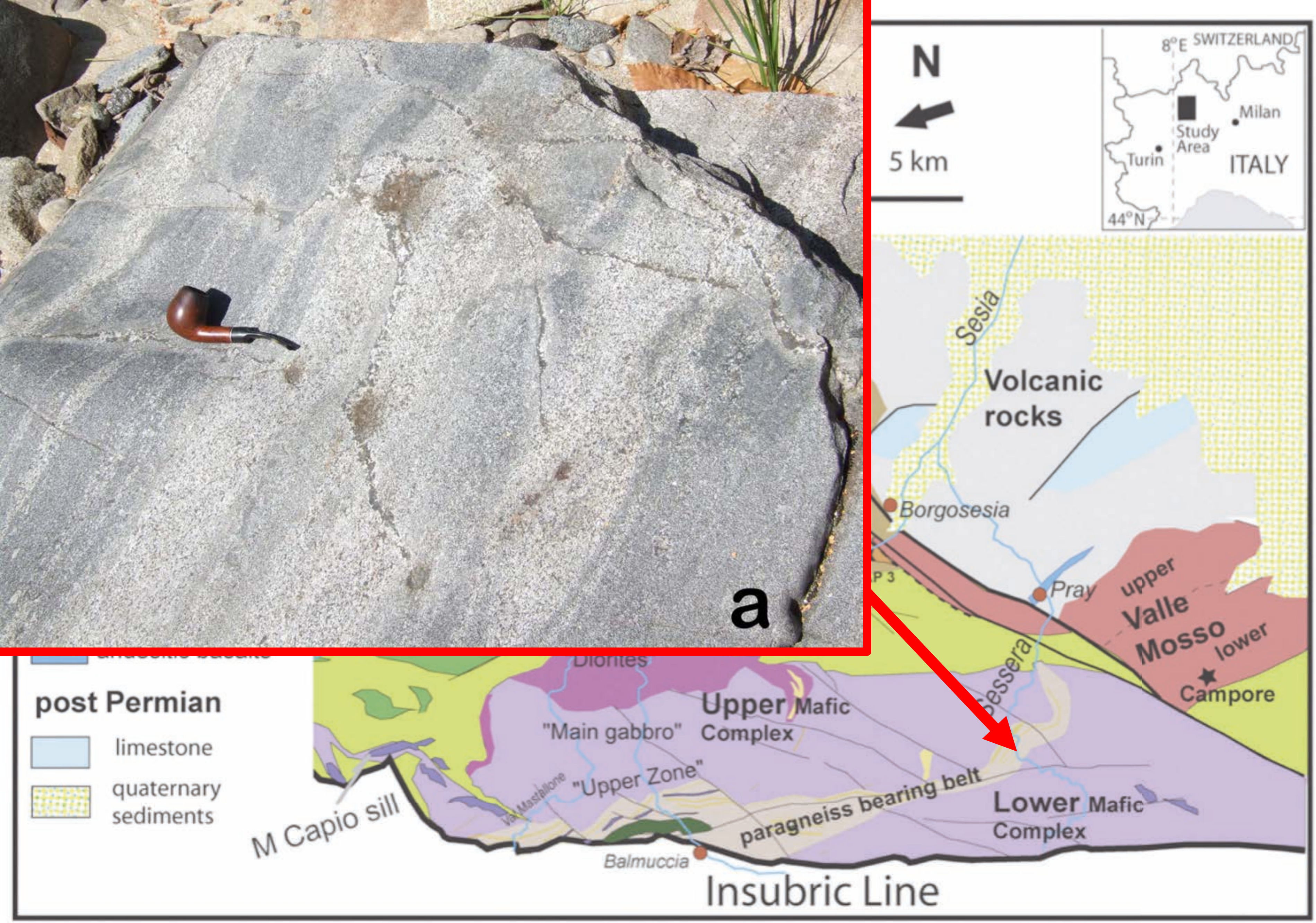

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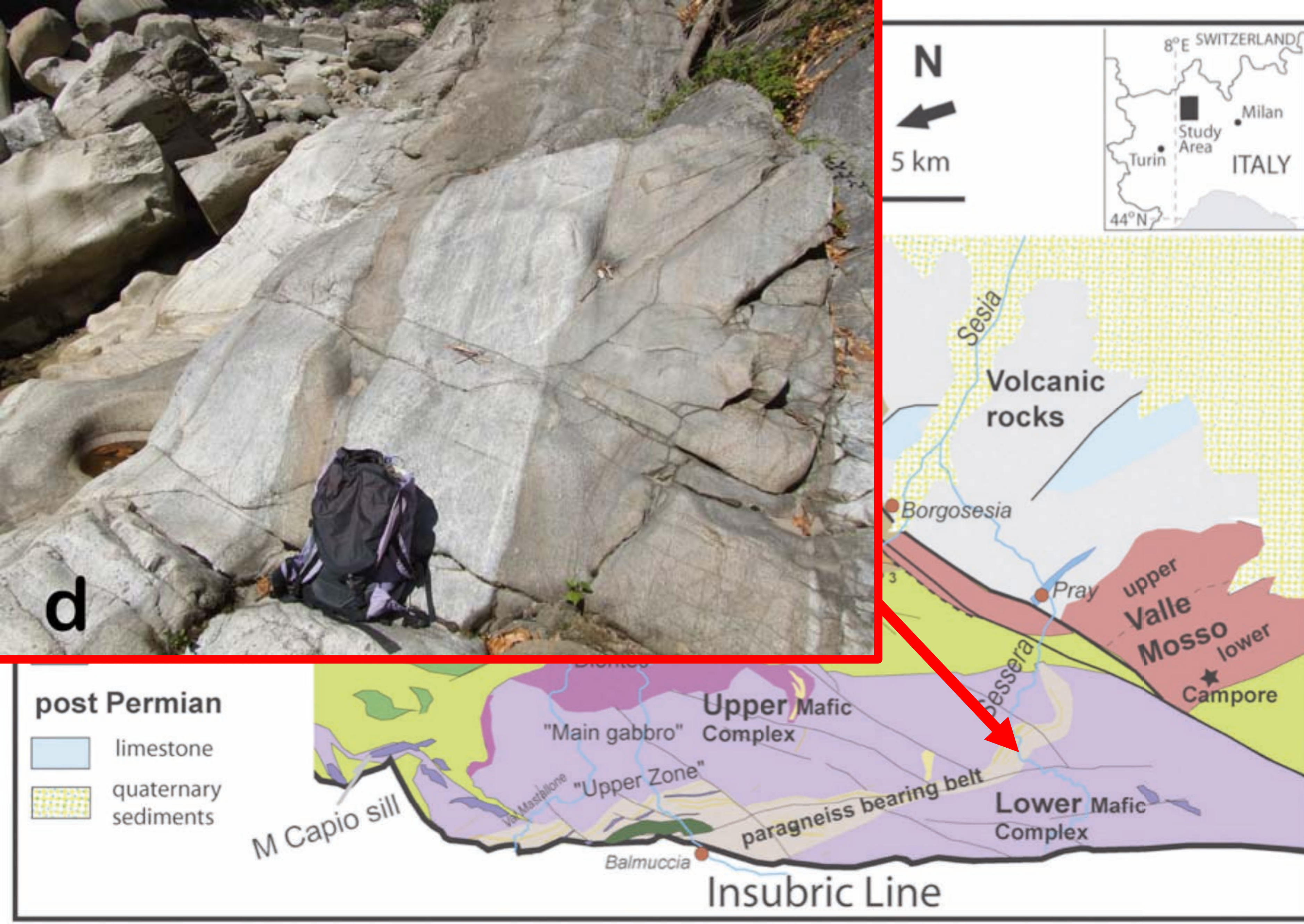

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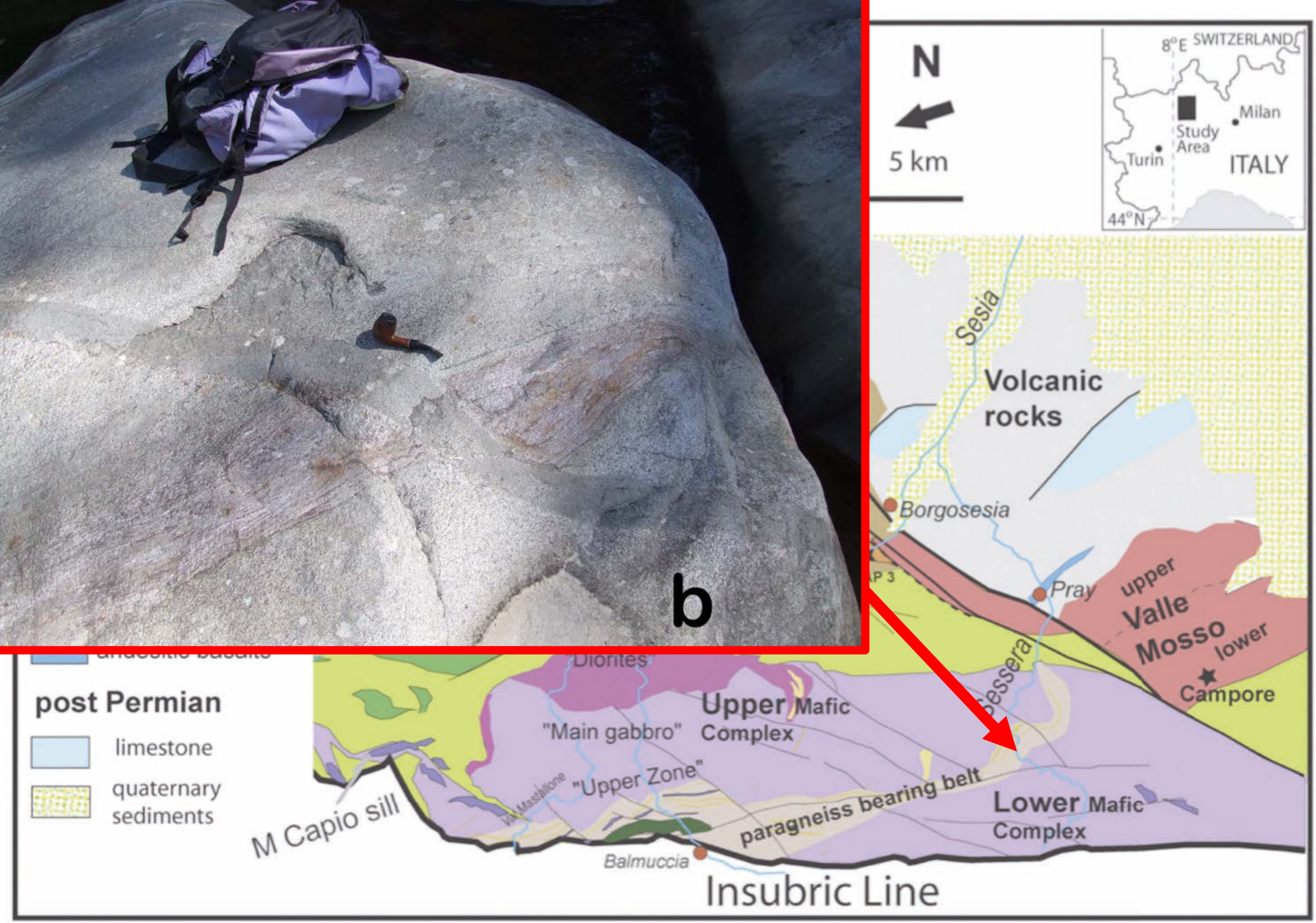
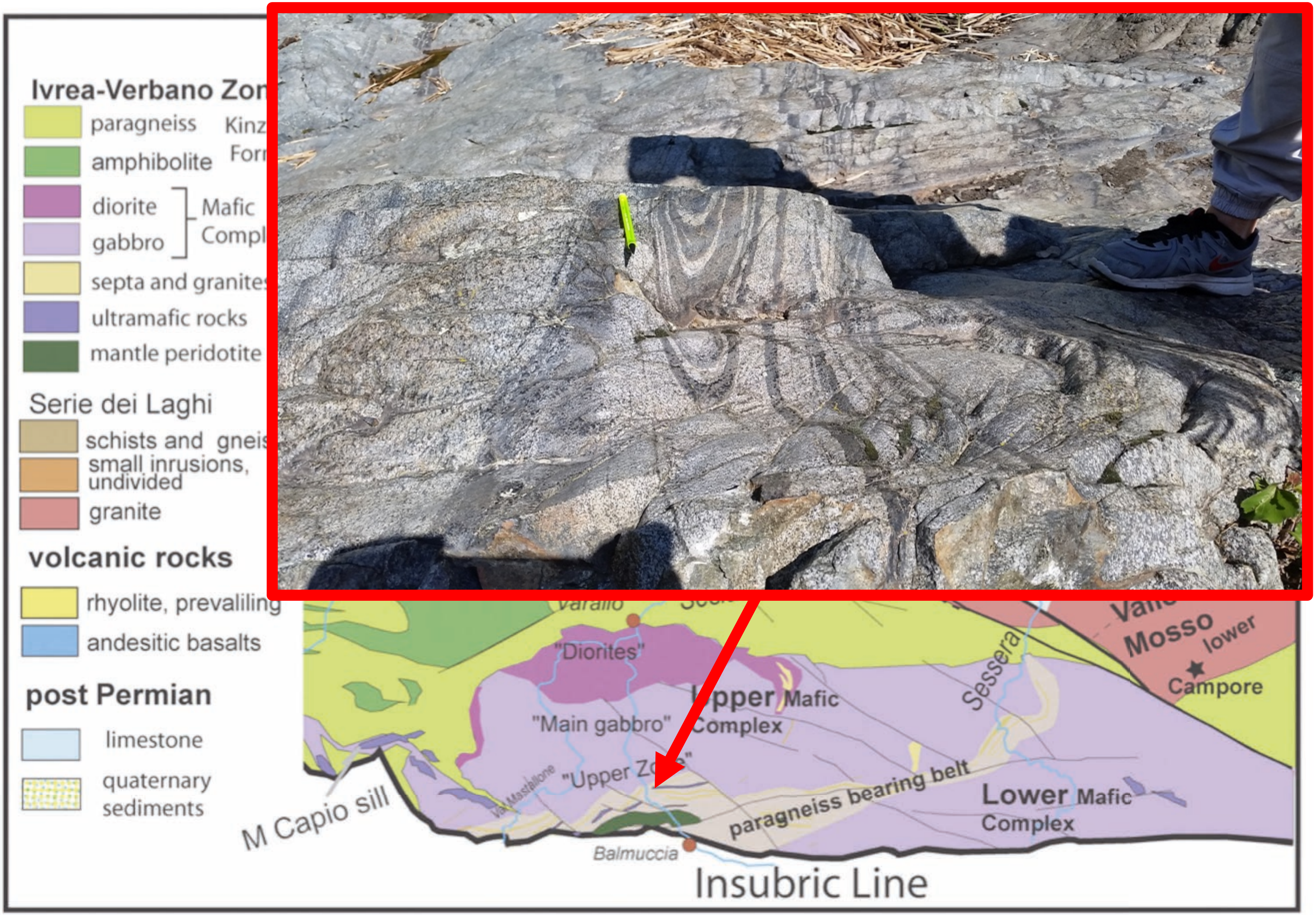


Sinigoi et al (2016; Lithos)


Sinigoi et al (2010; J.V.E.)
b


Sinigoi et al (2010; J.V.E.)
Mazzucchelli et al (2014)



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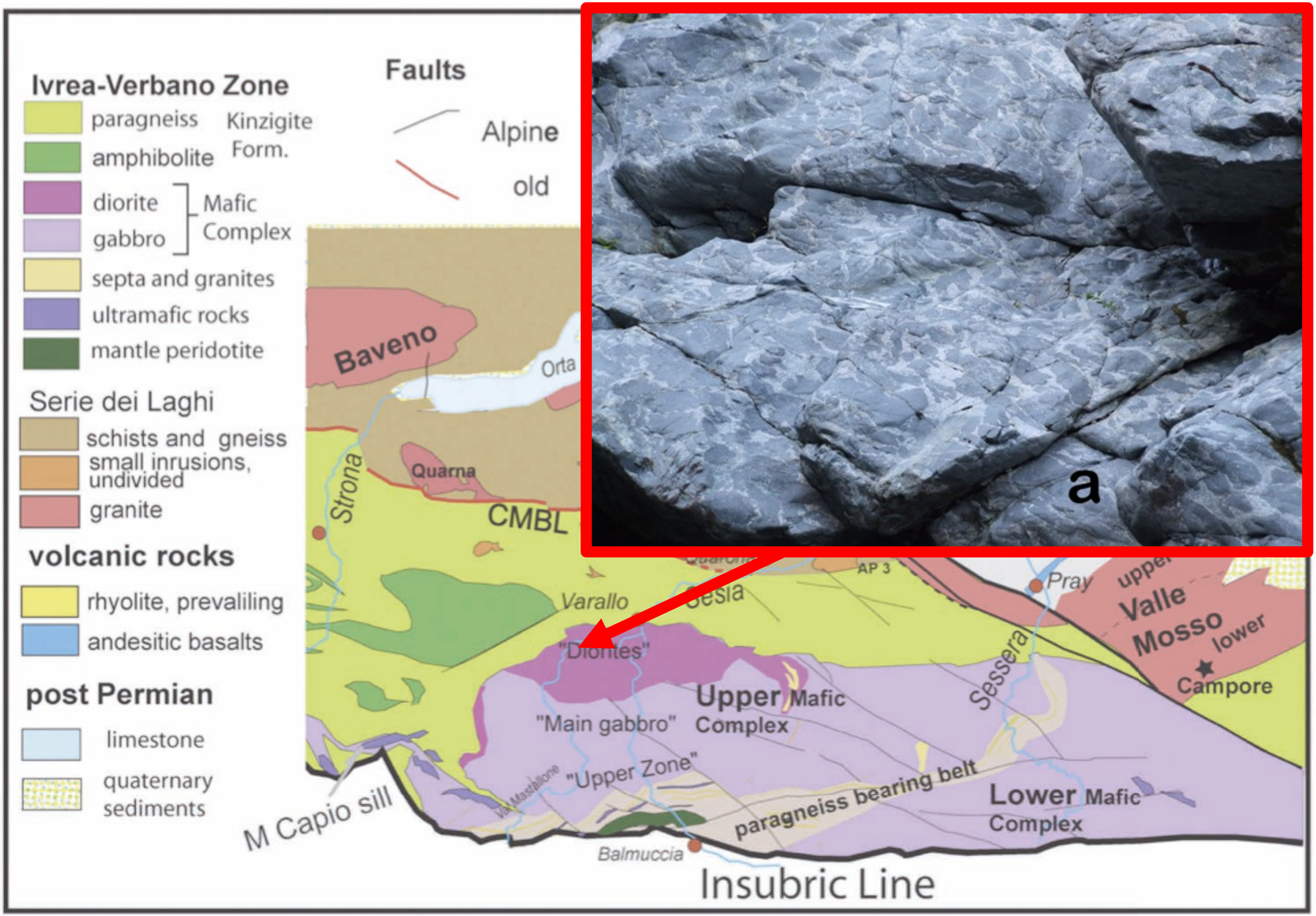

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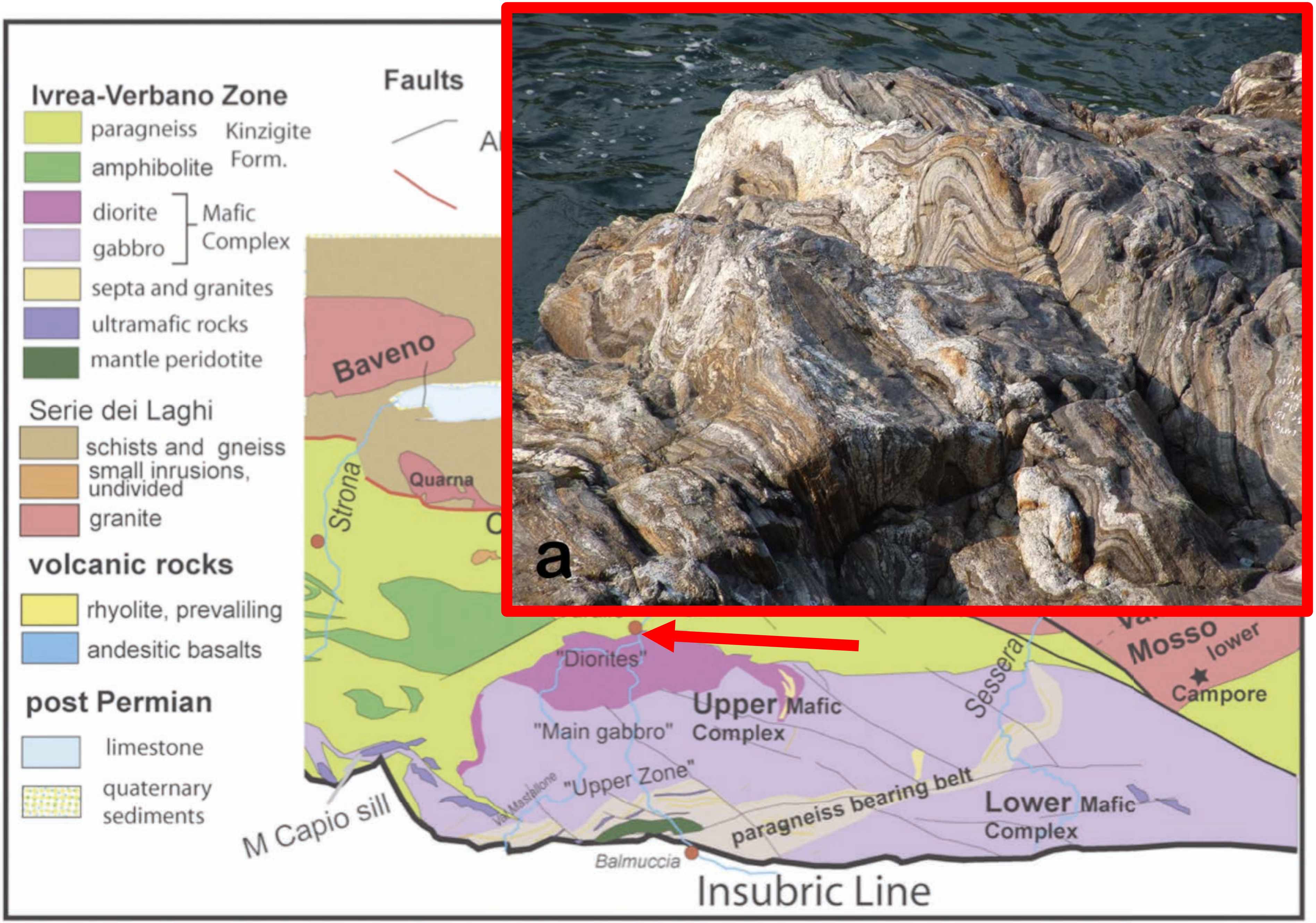

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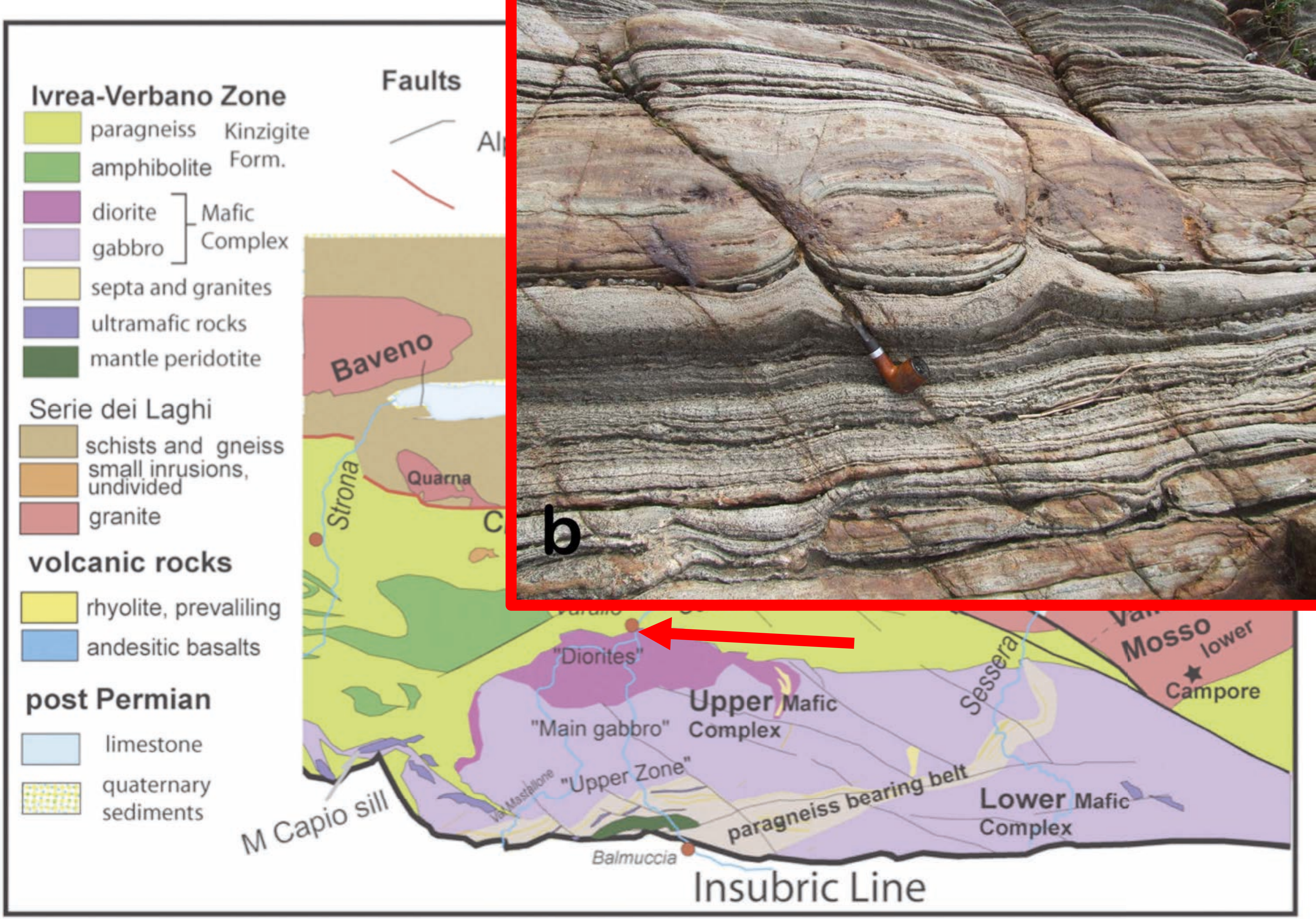

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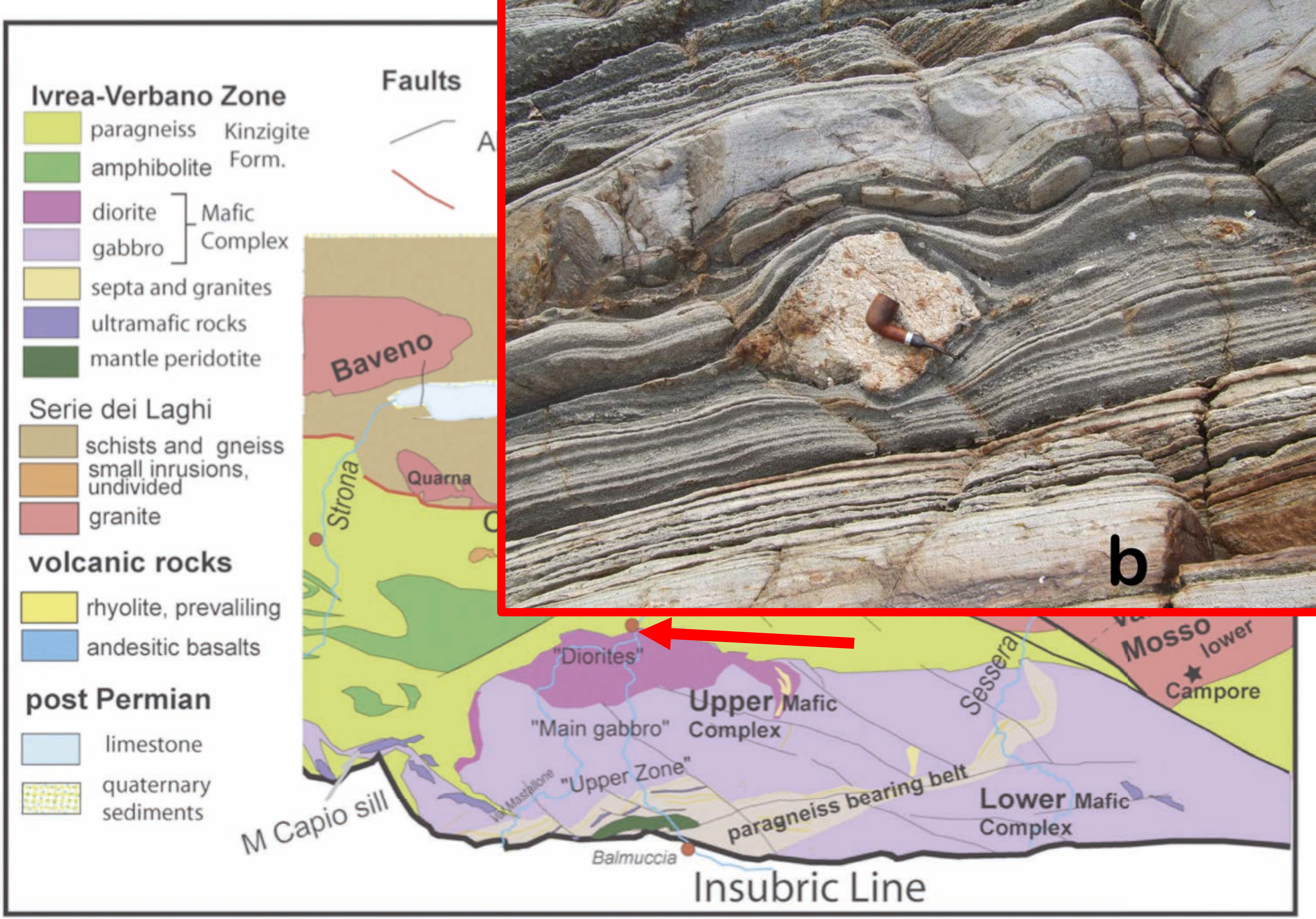

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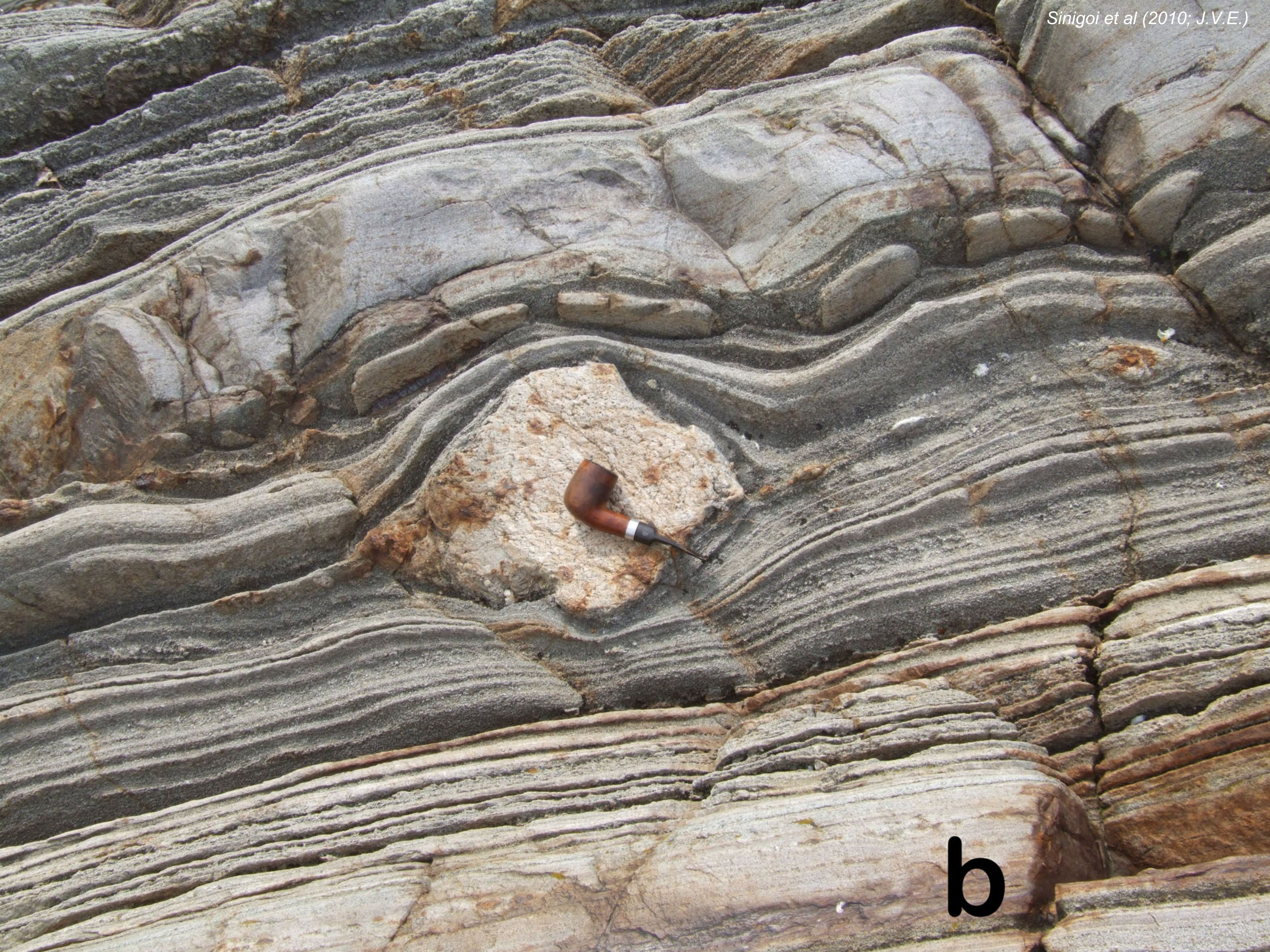
Sinigoi et al (2010; J.V.E.)
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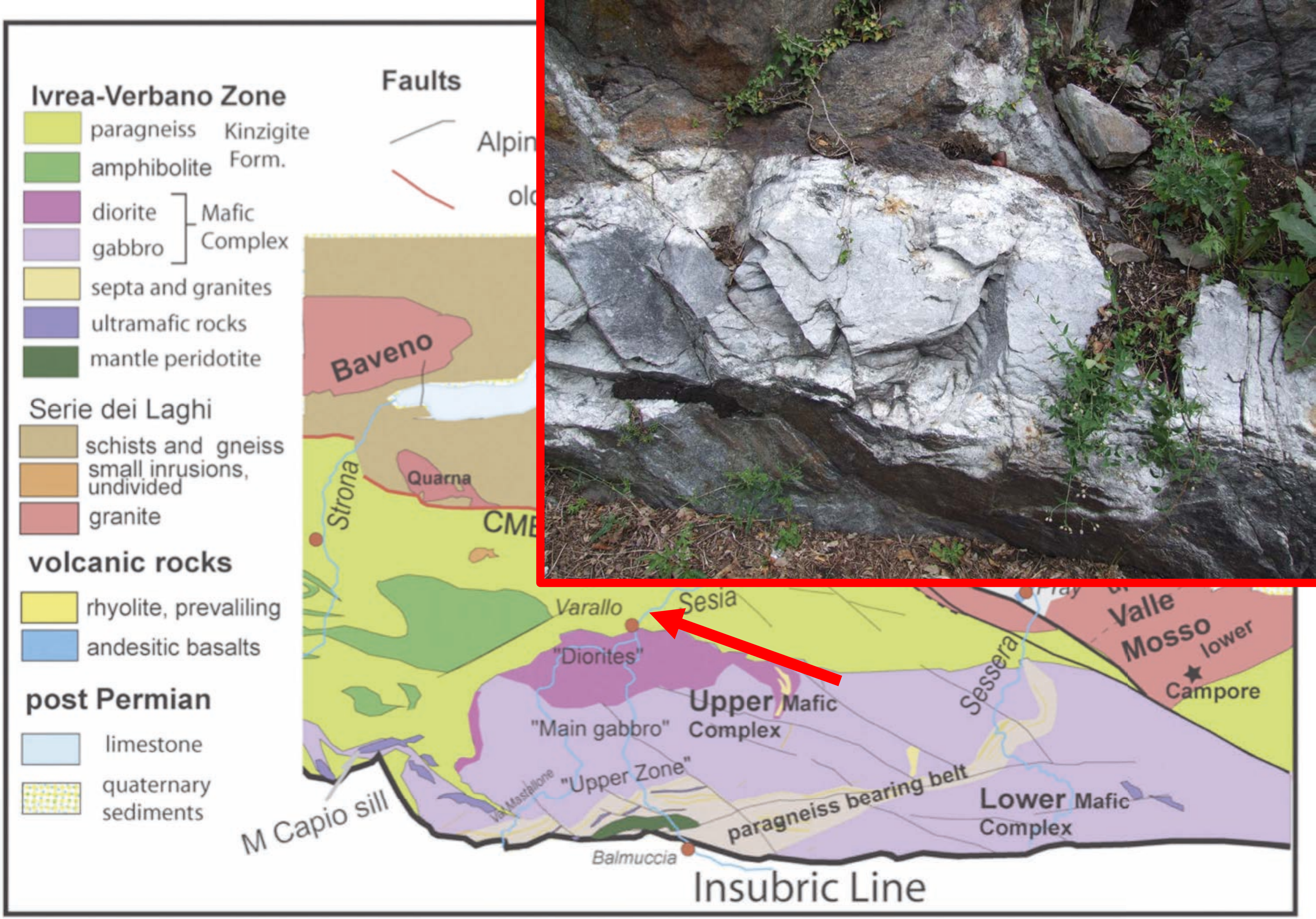

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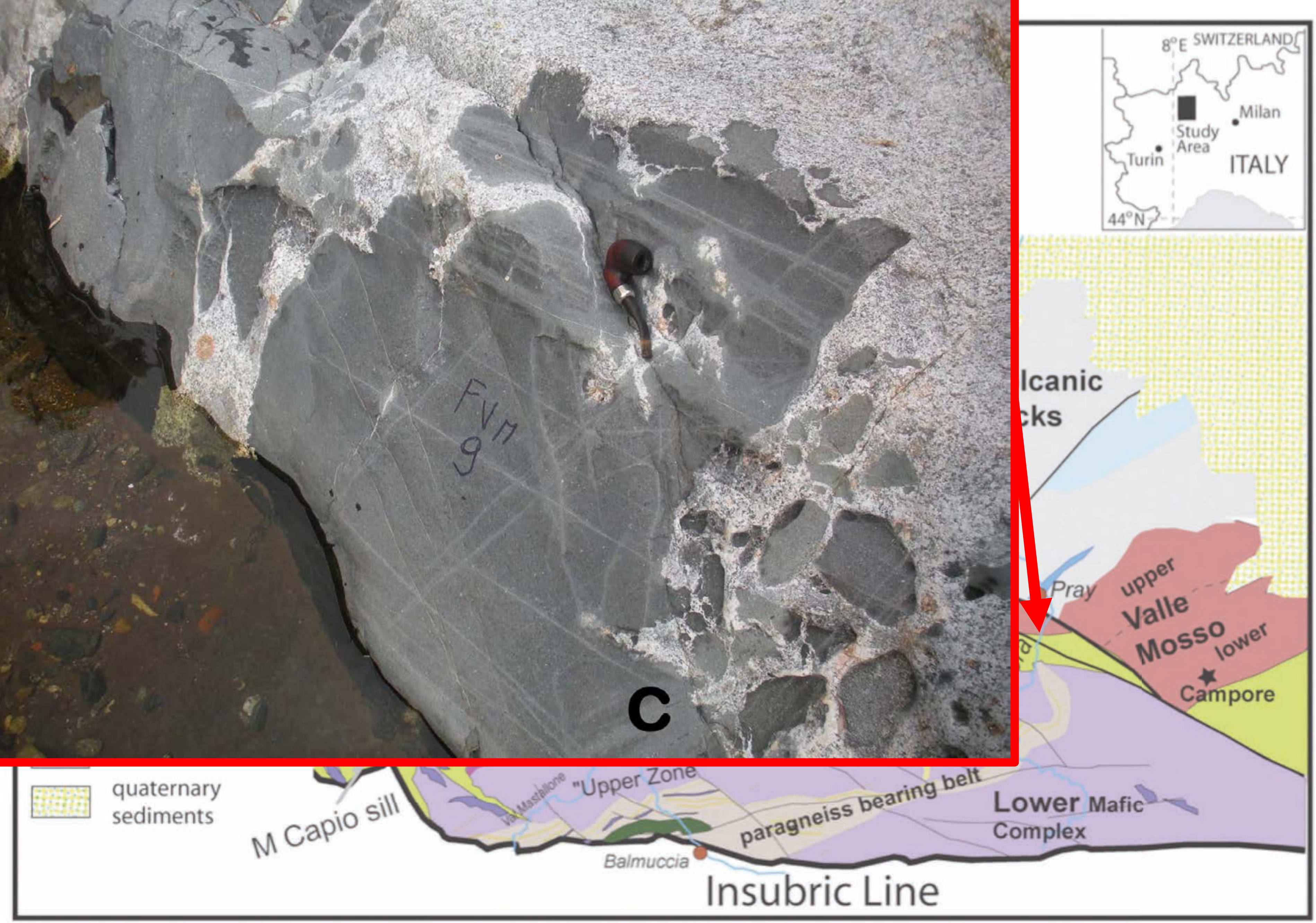

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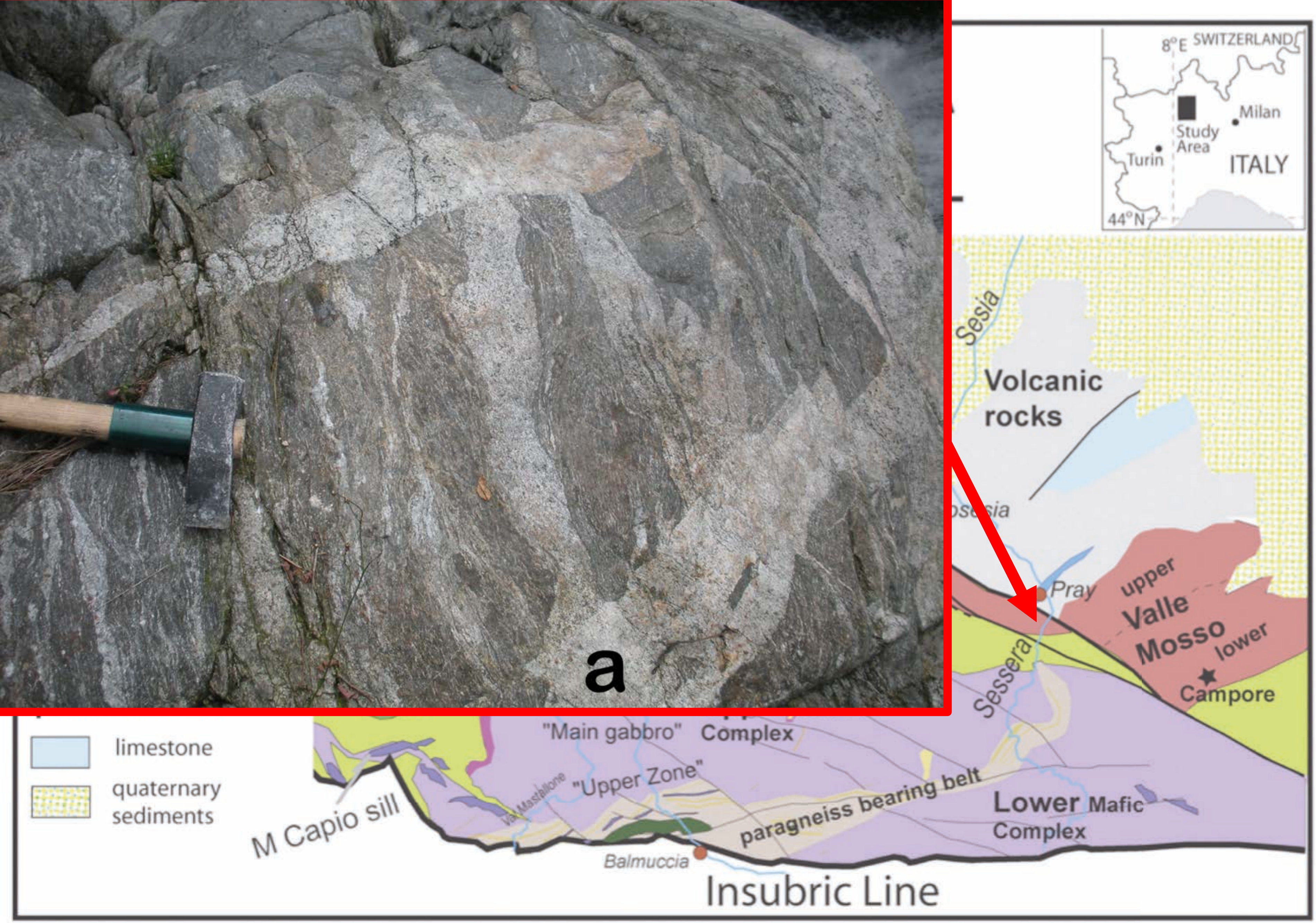

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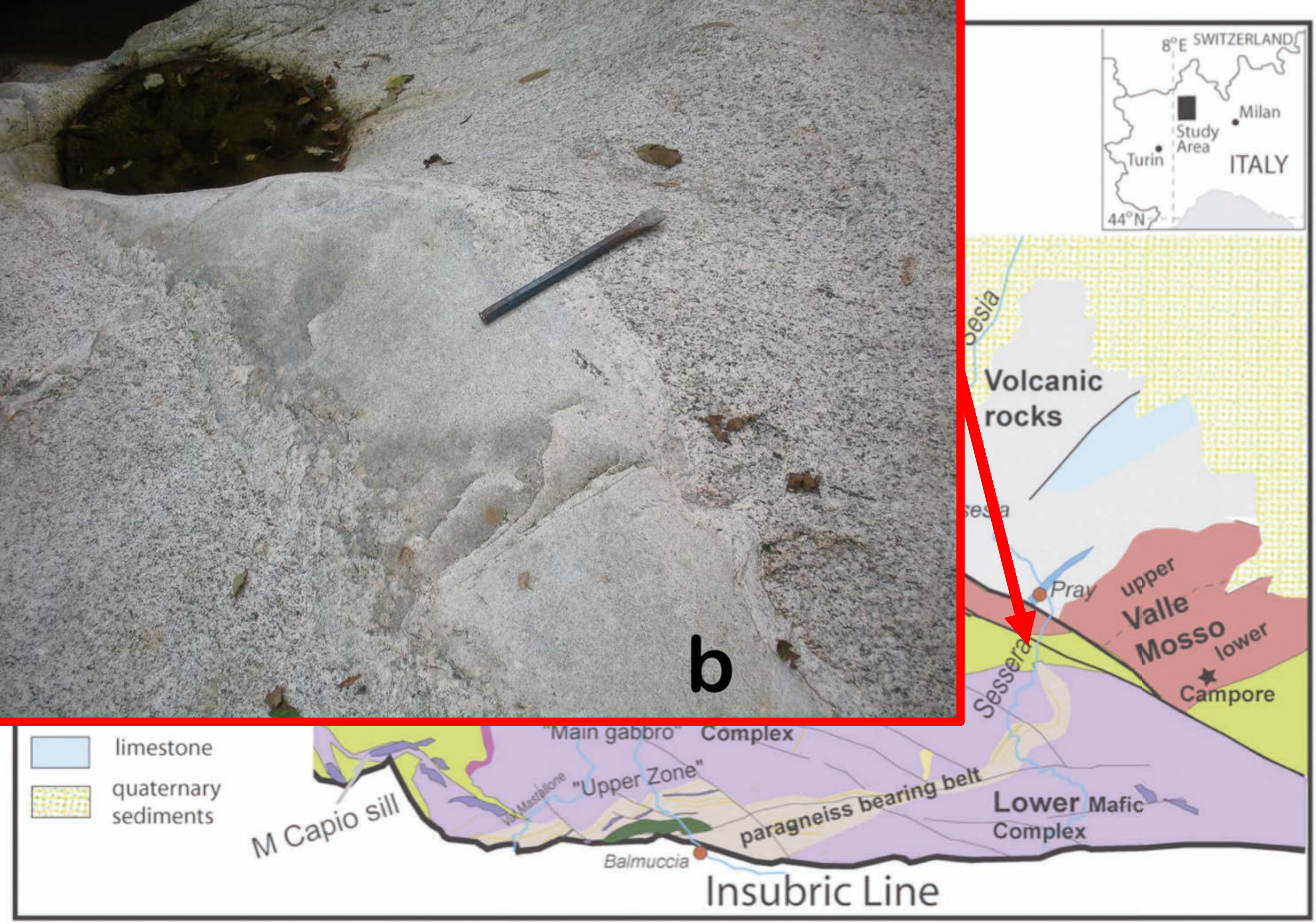

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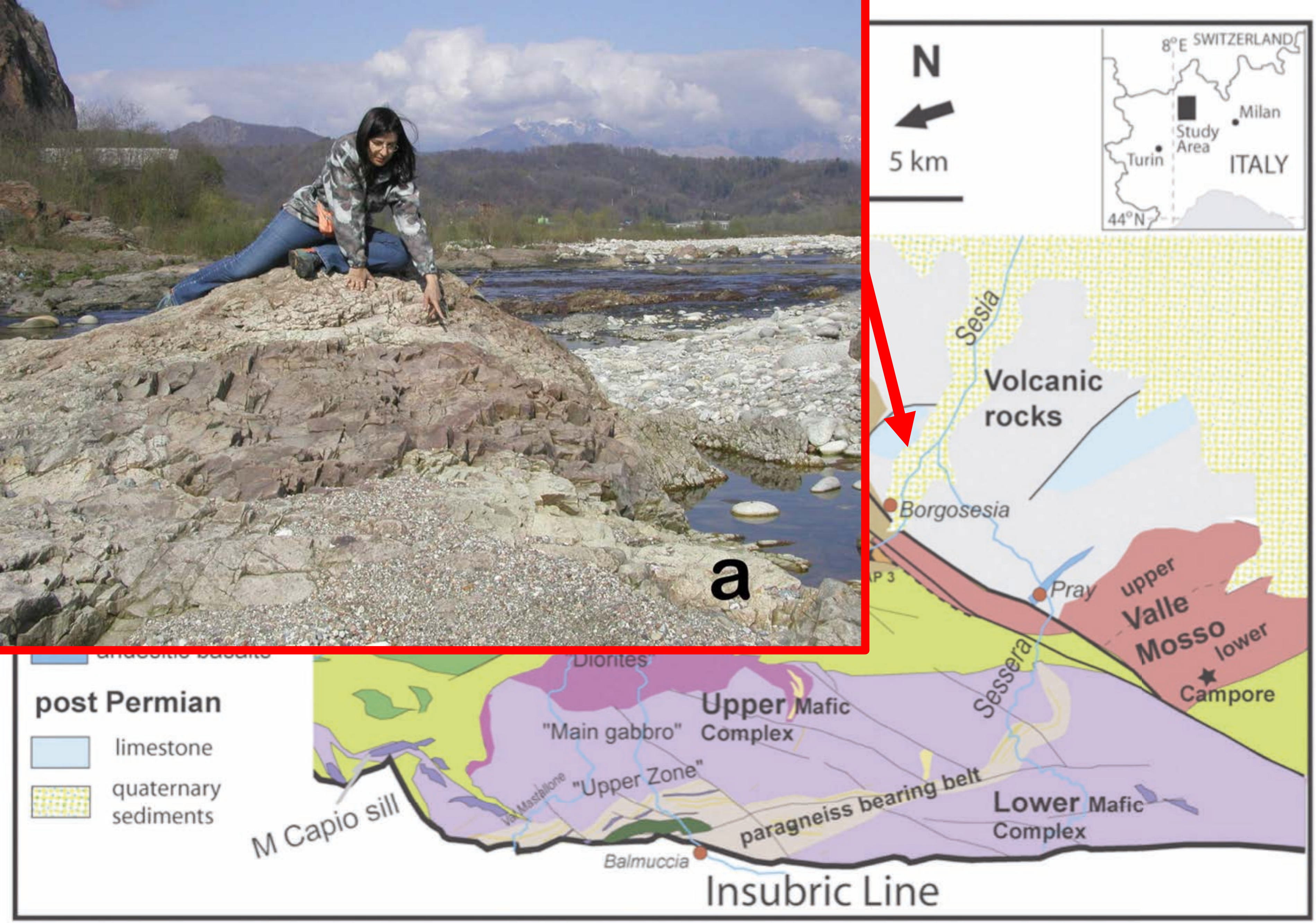

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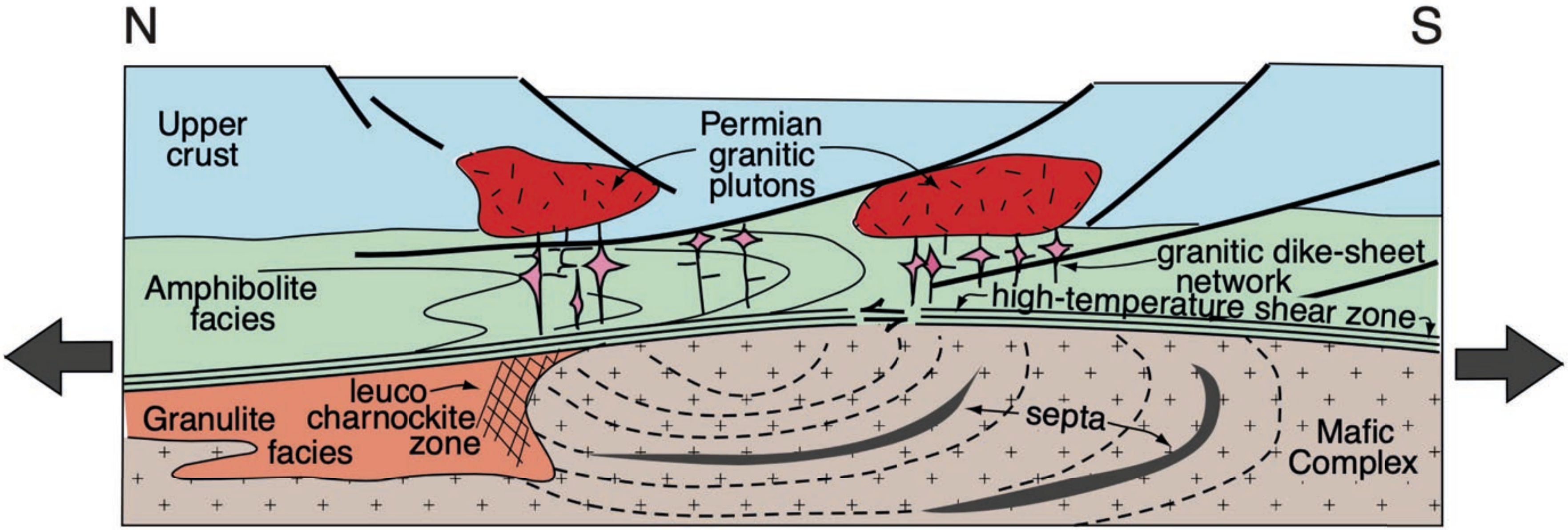
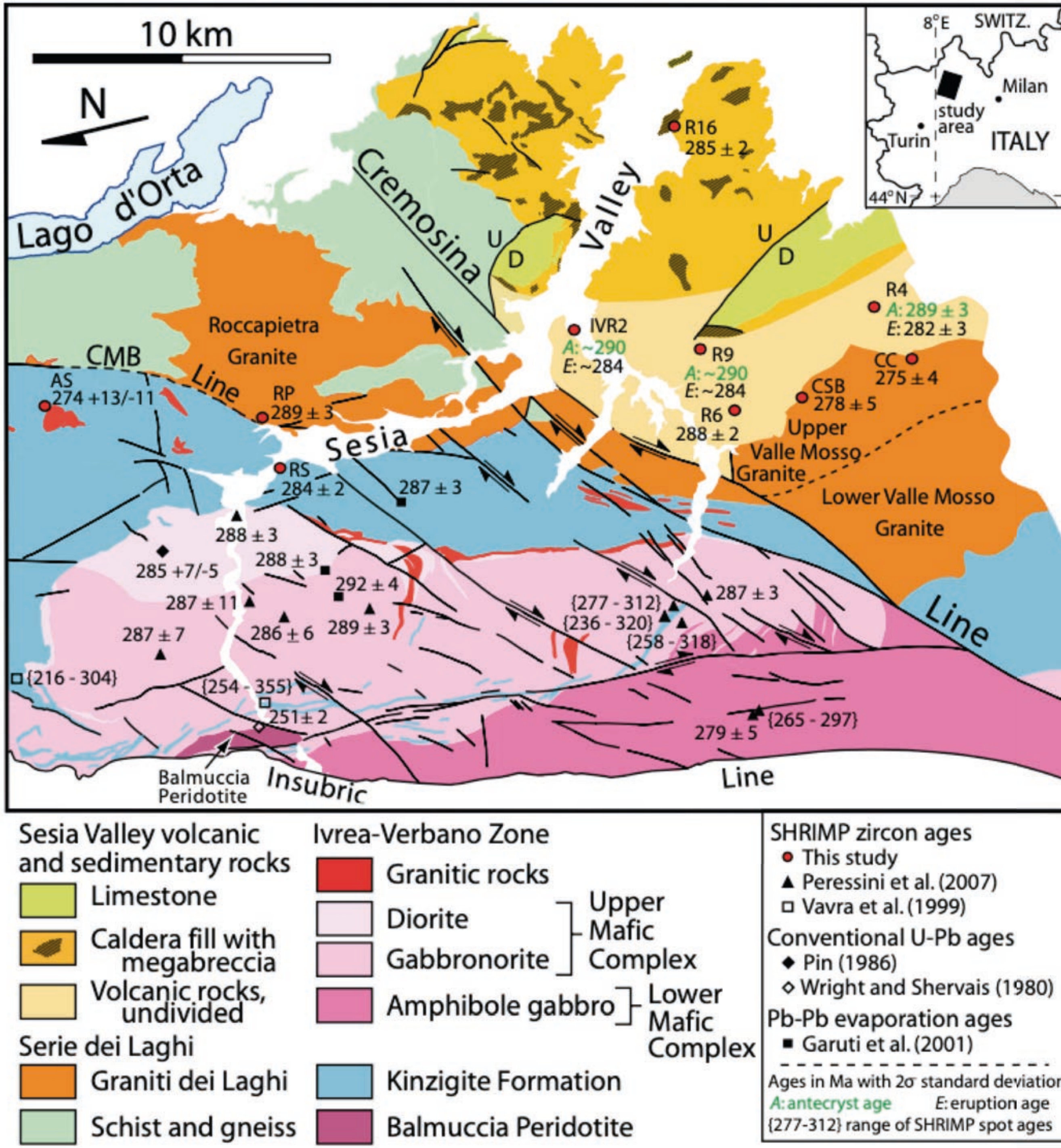


Fig. 6. Integrated model of the development of the Mafic Complex (multiple intrusion of mantle-derived magma into the lower crust and downward and outward flow of dense cumulates and entrained roof-rock septa), partial melting in roof rocks, and non-coaxial ductile deformation in a high-temperature shear zone (stretching fault). Migration of melt/magma along channelways within the shear zone and concentration in low-strain regions. Migration of magmas out of the shear zone and concentration in networks of dikes and small plutons in the eastern IVZ. This scenario occurred during a tectonic regime of crustal extension. Structurally higher, late Paleozoic plutons exposed in the Serie dei Laghi (Strona–Ceneri zone) are inferred to have been fed by magmas generated in the IVZ. Modified from Sinigoi et al. ([6], their fig. 11c).

Snoke et al (1999)



Quick et al (2009; Geology)