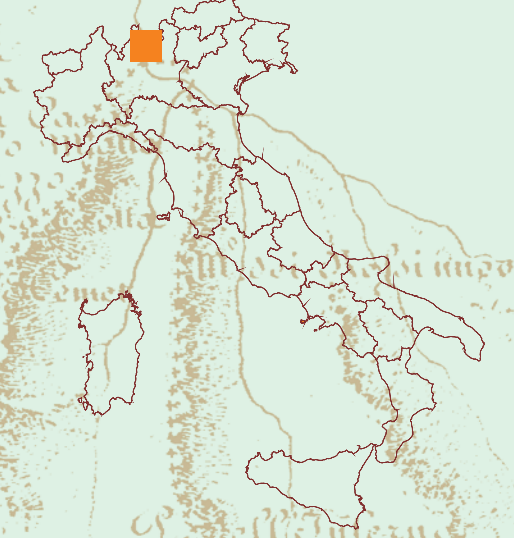

Maps of foliation trajectories and metamorphic imprints: A tool for individuating tectonometamorphic units in the Southalpine basement (Como Lake area)

Silvia DI PAOLA* & M. Iole SPALLA***

* Dipartimento di Scienze della Terra, Università di Milano, Milano, Italia
** Istituto per la Dinamica dei Processi Ambientali, Consiglio Nazionale delle Ricerche (CNR), Milano, Italia

ABSTRACT

The subdivision of polydeformed and polymetamorphic crystalline basement in tectonic units is often largely based on lithostratigraphy and dominant metamorphic imprint. This approach derives from the idea that the dominant metamorphic imprint coincides with the T_{max}-P_{Tmax} experienced by rocks and is recorded by the whole metamorphic unit, not considering the catalysing effect of deformation. Conversely, the role of fabric evolution on reaction progress must be taken into account in order to correctly define crustal units on the basis of their characteristic structural and metamorphic evolution. These concepts are illustrated here using an example from the Lake Como region (Southalpine basement).

AIMS

The definition of crustal units showing distinct structural and metamorphic imprints in polydeformed and polymetamorphic terrains is crucial in order to unravel the deep-seated tectonic processes responsible for crustal accretion or consumption. Usually, the extent, degree and timing of metamorphic re-equilibration and associated fabric changes are often inadequately known; the tectonic subdivisions in use are therefore largely inherited from a geological nomenclature established on lithostratigraphic grounds, which is strongly influenced by the metamorphic imprint dominating at the regional scale. This procedure is based on the idea that the dominant metamorphic imprint of an entire metamorphic unit is recorded when rocks experience T_{max}-P_{Tmax} conditions (ENGLAND & RICHARDSON, 1977; SPEAR *et alii*, 1984);
the catalysing effect of deformation on metamorphic reaction rate is however extensively described in Alpine terrains. The dependence of P-T evolution on the dominant metamorphic imprint, therefore, is not univocal, and the role of fabric evolution on reaction progress must be taken into account in order to avoid erroneous individuation of identifying metamorphic units. The map of the Southalpine basement (Fig. 1) illustrates the interaction of the stage of fabric evolution on the rate of metamorphic transformation, and the way in which the degree of fabric evolution discriminates the dominant metamorphic imprint at a regional scale, independently from its coincidence with T_{max}-P_{Tmax} conditions.
The structural and metamorphic evolution of the different tectono-metamorphic units constituting the Southalpine basement (Fig. 2) is summarized in a small-scale structural and metamorphic map (Fig. 3), synthesised here from recent literature (SPALLA *et alii*, 2002 and references therein). The map shows lithological associations and a regional grid of superimposed foliations and the indications of the metamorphic environments in which they developed; this is derived from an assemblage of detailed larger-scale maps, similarly to that of the Domaso-Cortafò Zone (Fig. 1). The map is an integrated report of the field and laboratory analytical work carried out in order to reconstruct the relationships between finite deformation field, metamorphic evolution and different lithological settings. The relative chronology of superimposed planar fabrics is shown on the map by the number of dots along trajectory traces. Mineral assemblages related to successive fabrics in each rock type are added in the legend, and represent the basic elements used to identify the metamorphic environment in which the successive fabric groups developed (differently coloured trajectories). In this way, information regarding the relative chronology of structural imprints and the metamorphic environment in which they developed is unified and located in space.

KEYWORDS

Foliation trajectory map, dominant metamorphic imprint, pre-Alpine metamorphism

RIASSUNTO

La distinzione di unità tettoniche nel basamento cristallino polimetamorfico e polideformato è spesso basata su criteri litostratigrafici e sull'osservazione dell'impronta metamorfica dominante. Alla base di questi criteri di distinzione vi è l'idea che l'impronta metamorfica dominante corrisponda alle condizioni di Tmax-PTmax registrate dall'intera unità: in questo modo non viene per˜ considerato l'effetto catalizzante della deformazione sulle reazioni metamorfiche. Il ruolo dell'evoluzione del fabric sulla progressione delle reazioni metamorfiche deve invece essere tenuto in considerazione per definire correttamente le unità tettoniche a scala crostale, basandosi sulla loro caratteristica evoluzione strutturale e metamorfica. Questi concetti vengono illustrati con un esempio tratto dal basamento sudalpino del Lago di Como.

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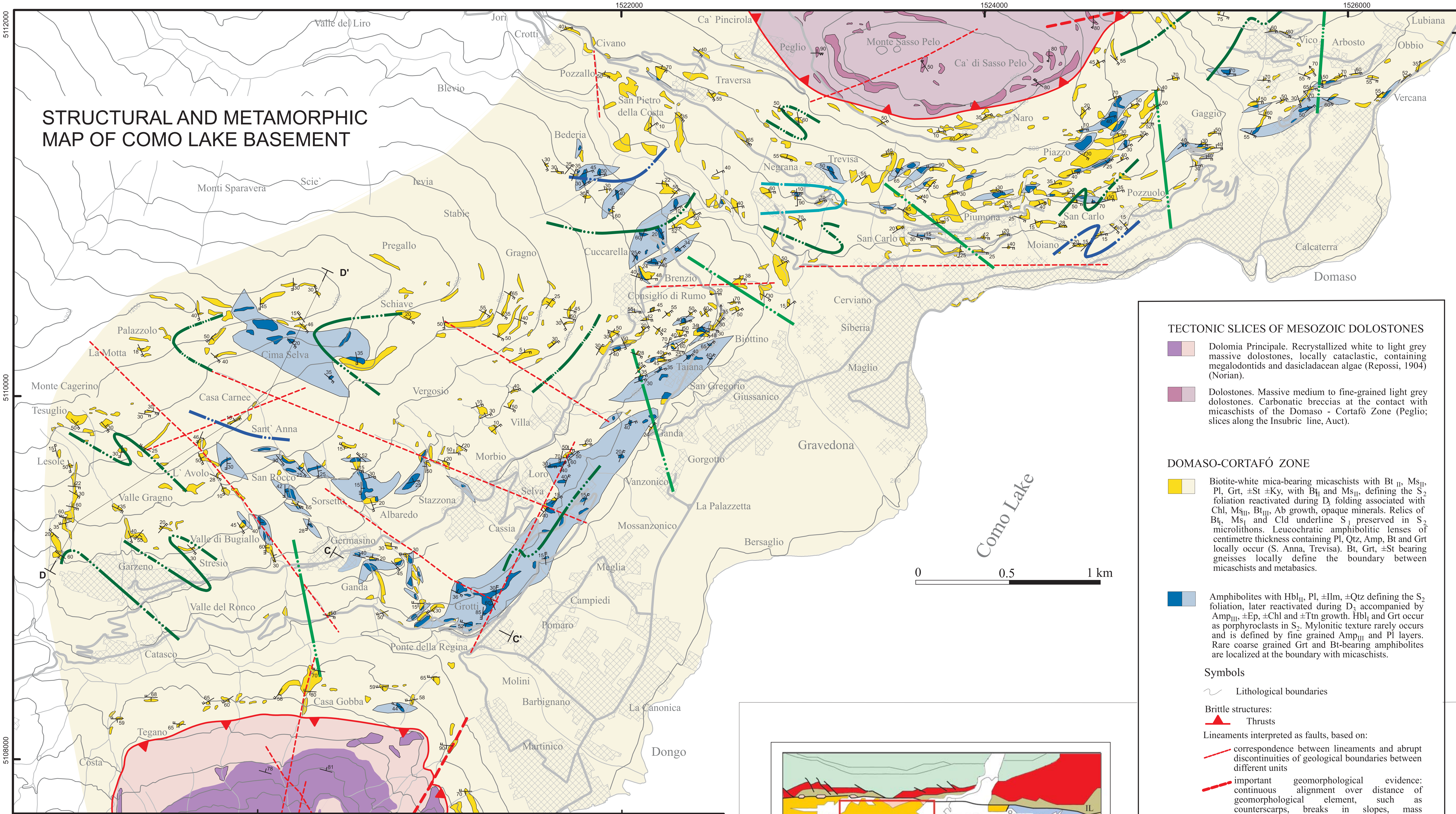
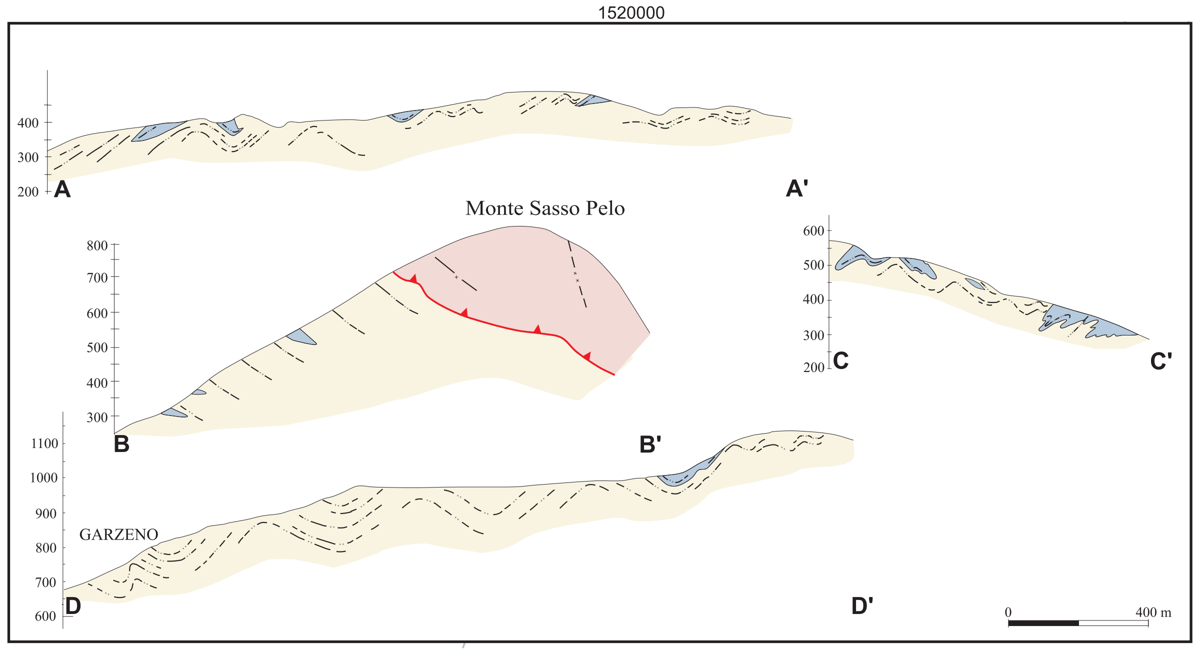


Fig. 1 - *Structural and metamorphic map of the Domaso-Cortafò tectono-metamorphic unit (DCZ), with geological cross-sections. The original geological survey was performed at a 1:5,000 scale.*



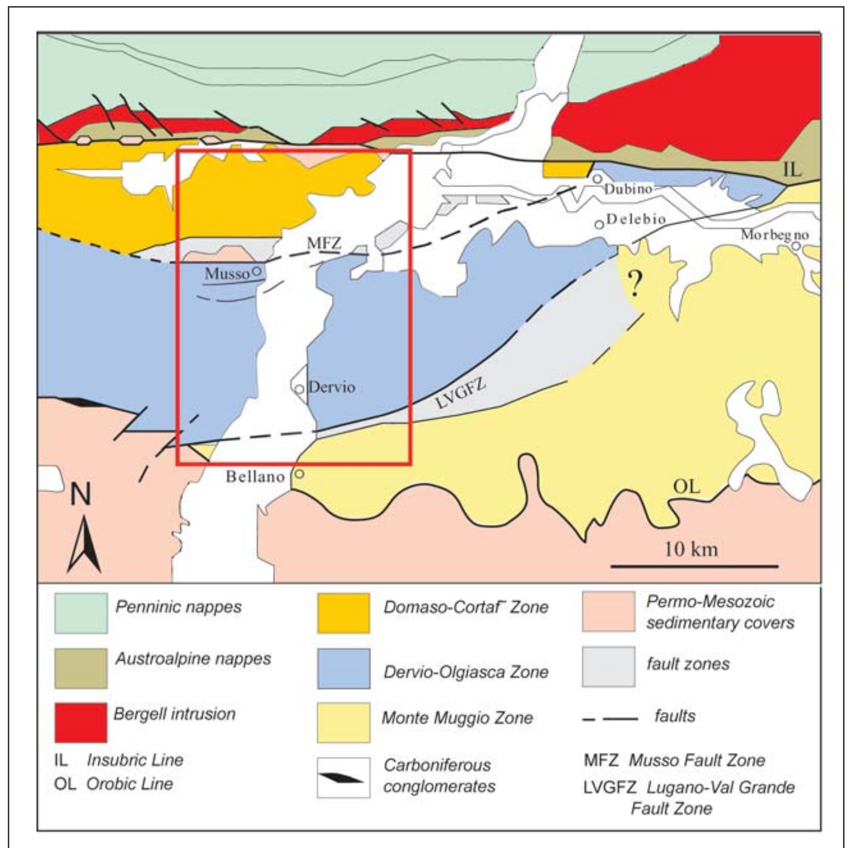
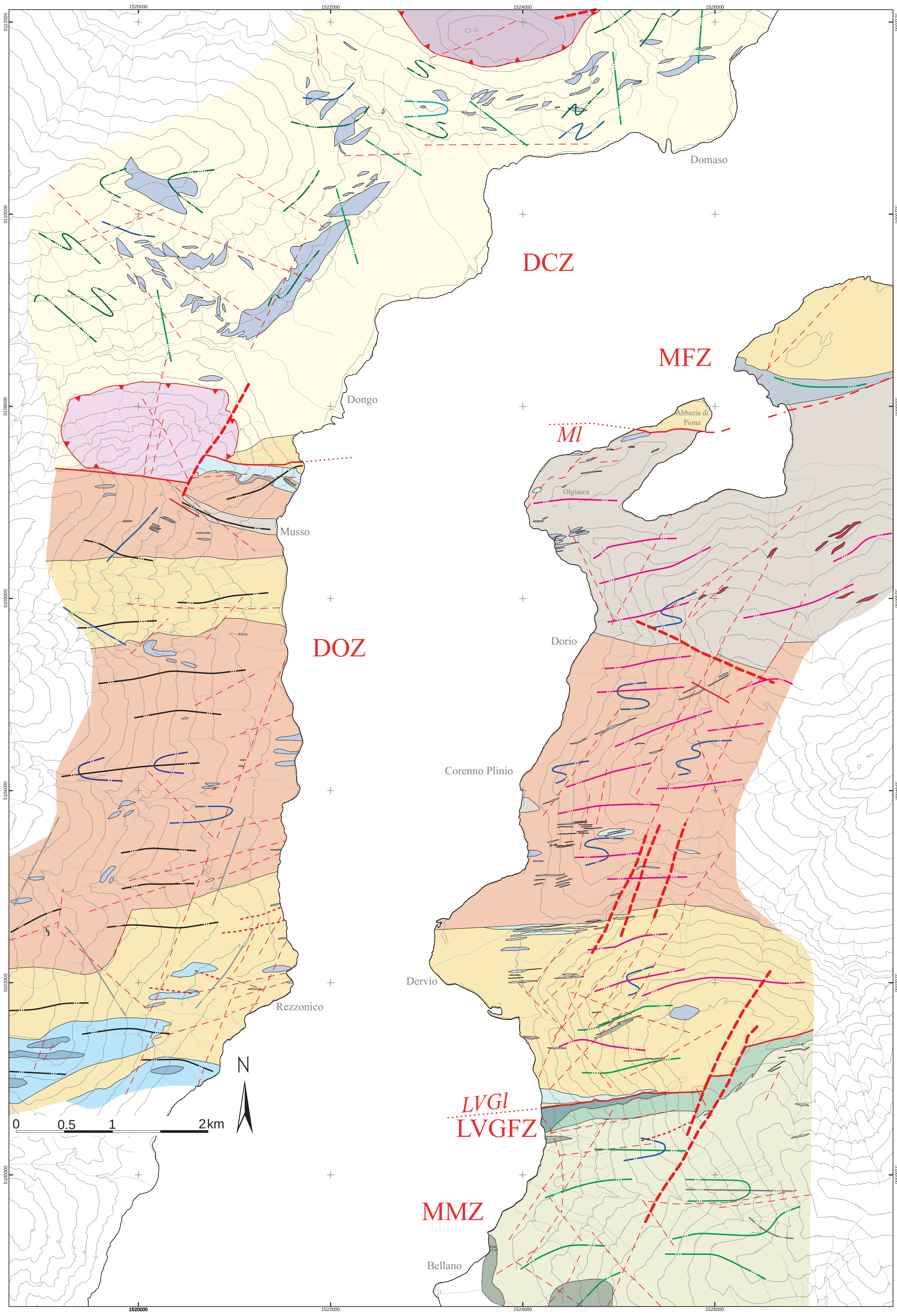


Fig. 2 - *Tectono-metamorphic outline of the Como Lake pre-Alpine basement, redrawn according to* S*PALLA et alii (2000). The red rectangle locates Fig. 3.*



TECTONIC SLICES OF MESOZOIC DOLOSTONES

Dolomia Principale. Recrystallized white to light grey massive dolostone, locally cataclastic, containing megalodontides and dasicladacean algae (Repossi, 1904) (Norian).

Dolostone. Massive medium to fine-grained light grey dolostone. Carbonatic breccia at the contact with the micaschists of the Domaso - Cortafò Zone (Peglio; slices along the Insubric line, Auct).

DOMASO-CORTAFO' ZONE (DCZ)

Biotite-white mica-bearing micaschists. Micaschists with Bt_{II}, Ms_{II}, Pl, Grt, ±St ±Ky, with Bt_{II} and Ms_{II}, defining the S_2 foliation reactivated during D_3 folding associated with Chl, opaque minerals, Ms_{III}, Bt_{III} and Ab growth. In places, relics of Bt_I, Ms_I and Cld are preserved in S_2 microlithons.

Amphibolites with Hbl_{II}, Pl, ±Ilm, ±Qtz defining the S_2 foliation, later reactivated during D_3, accompanied by Amp_{III}, ±Ep, ±Chl and ±Ttn growth. Hbl_I and Grt occur as porphyroclasts in S_2. Mylonitic texture rarely occurs and is defined by fine grained Amp_{III} and Pl layers. Rare coarse grained Grt and Bt-bearing amphibolites are localized at the boundary with micaschists.

MUSSO FAULT ZONE (MFZ)

Chl-bearing micaschists and Ab- Chl bearing gneisses. Micaschists with Chl and Ms defining the mylonitic foliation (S_3) associated with s - c structures. Fine-grained gneisses with Ab and Chl underlining the mylonitic foliation.

Mylonites. Fine-grained phyllonites with Chl, Ms, Ab and ribbon Qtz, locally with ultramylonitic texture. Shear planes and extensional crenulation cleavages are widespread.

DERVIO-OLGIASCA ZONE (DOZ)

Pegmatites. Qtz, Kfs, Ms, Tour, ±Grt-bearing pegmatites. Generally with undeformed cores and foliated margins (S_2) (Middle - Late Triassic).

Porphyrites. Dark coloured, very fine grained dykelets, containing Pl, Bt, Amp, Qtz, Ilm, Ep, Ap. Ttn occurs at Ilm rims or as coarse pink grains. Ms and Ep overgrow Pl.

Metatonalites with Pl, Qtz, Bt, Hbl and Chl, locally preserving igneous texture.

Amphibolites with Pl, Hbl_{II}, ±Qtz, ±Grt, ±Bt, ±Ep and relics of Hbl_I, in places leucocratic (Piona Peninsula). Amphibolites with Hbl, Di, Pl, ±Ttn (Piona Peninsula). S_2 is defined by the Hbl_{II} and Pl compositional layering or by the shape preferred orientation of Hbl and Di. Rare hornblendites with Chl, Ttn, Ilm show coronitic texture.

Metagranitoids with Ms and Chl, containing relics of Bt and Grt. S_2 is a compositional layering.

Mylonitic metagranitoids. Fine-grained mylonitic metagranitoids with Ms and Chl, with millimetre-sized Kfs porphyroclasts.

Sillimanite- biotite-bearing micaschists. Micaschists and minor gneisses with Bt_{II}, Grt_{II}, Sil, Pl, ±Ms, ±Kfs grown during D_2 development; Bt_{II} and Sil underline shear and foliation planes in the extensional crenulation cleavage (S_2). Relics of Grt_I, Ky and St are locally preserved. Centimetre-sized And poikiloblasts grew during late D_2 (Corenno Plinio and Musso). Locally Chl replace Grt_I and Grt_{II}.

Garnet-staurolite-bearing micaschist. Micaschists and minor gneisses containing Ms_I, Bt_I, Grt_I and St contemporaneous with S_1. S_2 crenulation cleavage is defined by Bt_{II}, Ms_{II}, Grt_{II}, ±Sil. Chl and Ms_{II} grow during D_3 reactivation of S_2.

Chlorite-bearing micaschists and chlorite- albite-bearing gneisses. Micaschists with Chl and Ms underlining S_3, in places with mylonitic textures or s - c structures. Locally Grt and Bt relics are preserved. Gneisses with Ab and Chl underlining S_3. In S_2 microlithons Bt_{II} and Grt_{II} rarely occur and are partly replaced by Chl and Ms. The modal amount of Chl increases towards the Lugano – Val Grande fault zone.

Marbles. Fine to medium grained, white to light grey marbles locally containing Amp and Px. Silicate-rich layers consist of Zo, Tr, Tlc, Chl. S_2 is a compositional layering. In places boudinaged amphibolites are interlayered (Castello di Musso).

Carbonatic schists with Ms, Qtz, ±Bt (Castello di Musso). Ms and rare Bt underline S_2 foliation.

Quartzite layers of centimetre to metre thickness, containing Chl, Bt and Ms.

LUGANO-VAL GRANDE FAULT ZONE (LVGFZ)

Mylonites. Mylonitic micaschists and gneisses with Qtz, Ab, Ms and Chl underlining S_3, with Grt and Bt porphyroclasts; shear zones with s - c structures, extensional crenulation cleavages and dark coloured ultramylonites are widespread.

Cataclastic gneisses. Feldspar, sericite-bearing gneisses with granular texture. S_3 is well developed at the boundaries with the mylonites.

MONTE MUGGIO ZONE (MMZ)

Chlorite- albite- white mica-bearing gneisses and micaschists. Gneisses and micaschists with Qtz, Chl, Ab, Ms_{II} and ±Mrg underlining S_2 foliation. Relics of Grt, Bt, St and Ky, developed during D_1. Locally Ms and Chl are associated to D_3 structures. Grt-amphibolites rarely occur as metre-sized lenses elongated within S_2.

Quartzite layers of centimetre to metre thickness, containing Chl, Bt and Ms. S_2 is a mineral layering.

Metagranitoids with Qtz, Ab, Kfs, Ms, Chl and ±Bt. S_2 is a mineralogical layering defined by alternating quartz-feldspar and sheet silicates layers ("Gneiss Chiari" Auct.).

Lithological boundaries

Brittle structures:

Thrusts

Faults (*Ml*: Musso line; *LVGl* Lugano Val Grande line)

Lineaments interpreted as faults, based on:

correspondence between lineaments and abrupt discontinuities of geological boundaries between different units.

brittle fault rocks outcropping along lineaments.

important geomorphological evidence: continuous alignment over distance of geomorphological elements such as counterscarp, break in slopes, mass movements.

Traces of foliations and axial planes:

Relative age

D_1 — D_2

D_3 — D_2 reactivated by

D_3 — D_4

Metamorphic facies inferred from the mineralogical support of foliations:

epidote amphibolite facies

intermediate pressure amphibolite facies

low pressure amphibolite facies - granulite facies

intermediate pressure amphibolite facies re-equilibrated under greenschists facies

greenschists facies

non metamorphic

undetermined

Fig. 3 - *Structural and metamorphic map of the Southalpine basement in the Como Lake area, modified according to* Spalla et alii *(2002).*

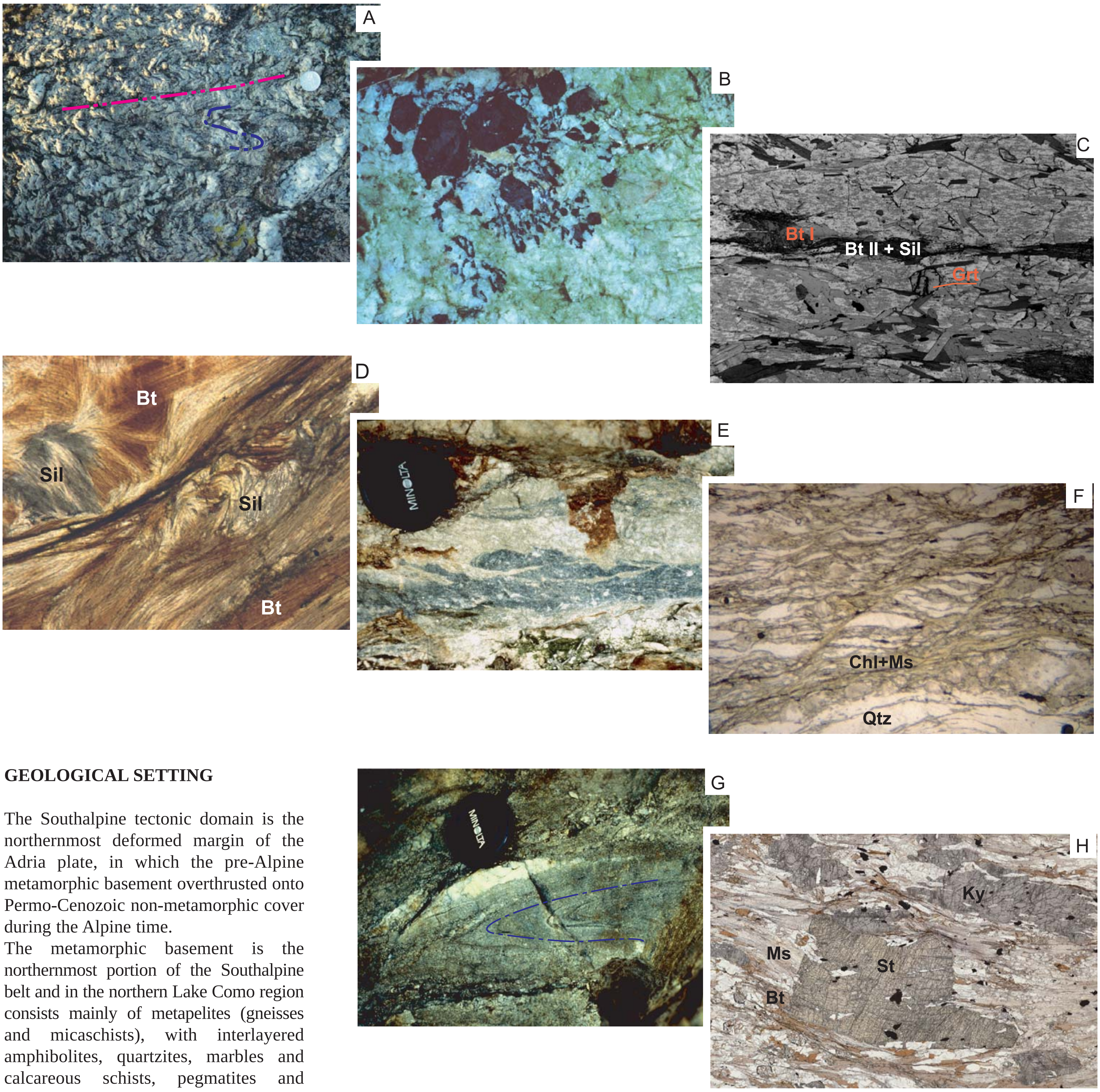


Fig. 4 - DOZ*:* A - *S1 relict foliation finely crenulated during D2 in the sillimanite and biotite gneiss near Vestreno; garnets locally show feldspar coronas and are replaced by a sillimanite-rich micro-aggregate;*
B - *Decimetre-size tourmaline crystals in the undeformed core of a pegmatite dyke (abandoned muscovite quarry of Piona);*
C - *Sillimanite partly overgrowing garnet and biotite along S2 - plane polarised light, long side of the photomicrograph = 1 mm;*
D - *Biotite and sillimanite schist with a S2 mylonitic foliation - plane polarised light, long side of the photomicrograph = 5 mm.*
LVGFZ*:* E - *Fine-grained cataclastic band within Gneiss Chiari.*
F - *Extensional crenulation cleavage underlined by chlorite and fine-grained white mica, developed in the green schist mylonites of LVGFZ-plane polarised light, long side of the photomicrograph = 8 mm.*
MMZ*:* G - *D2 isoclinal folding of the S1 foliation in a gneissic layer.*
H - *Staurolite and kyanite porphyroblasts underline S1 together with biotite and white mica; in the left-lower corner, small garnets occupy S2 microlithons - plane polarised light, long side of the photomicrograph = 25 mm.*

GEOLOGICAL SETTING

The Southalpine tectonic domain is the northernmost deformed margin of the Adria plate, in which the pre-Alpine metamorphic basement overthrusted onto Permo-Cenozoic non-metamorphic cover during the Alpine time.

The metamorphic basement is the northernmost portion of the Southalpine belt and in the northern Lake Como region consists mainly of metapelites (gneisses and micaschists), with interlayered amphibolites, quartzites, marbles and calcareous schists, pegmatites and metagranitoids. Alpine tectonics is responsible for the thick-skinned thrust belt, verging to the South and involving basement and cover units in the central sector of the Southern Alps (CADEL *et alii*, 1996). This developed at shallow crustal levels, as testified by the brittle deformation and the local very low-grade metamorphism, associated with Alpine lineaments (CRESPI *et alii*, 1981).

In the Southalpine domain of northern Lake Como the Lugano Val Grande fault zone (LVGFZ) and the Musso fault zone (MFZ) - two greenschist mylonitic bands reactivated by cataclastic deformation - separate three main portions of the pre-Alpine metamorphic basement: the Monte Muggio (MMZ), the Dervio - Olgiasca (DOZ) and the Domaso - Cortafò (DCZ) Zones, from South to North (Fig. 2). The P-T-t-d evolutions in MMZ, DOZ and DCZ are diachronous and thermally contrasted (DIELLA *et alii*, 1992; BERTOTTI *et alii*, 1993; DI PAOLA & SPALLA, 2000; SPALLA *et alii*, 2000), and the three zones correspond to three different pre-Alpine tectono-metamorphic units (e.g. SPALLA *et alii*, 2002).

In the metapelites of the Monte Muggio tectono-metamorphic unit (MMZ) the pre-Alpine D1 deformation was contemporaneous with the Grt + Bt + Qtz + Pl + Ms + Rt + Tour ± St ± Ky assemblage (abbreviation from KRETZ, 1973); K-Ar age determinations on minerals yielded values of 330 Ma that are interpreted as the minimal age of the intermediate-pressure amphibolite facies imprint (BOCCHIO *et alii*, 1981; MOTTANA *et alii*, 1985). D2 deformation took place during greenschist retrogression, as testified by the development of Qtz + Ab + MsII + Chl ± Mrg; the D2 stage predated deposition of Permian sediments and is thus older than 260 Ma (Figs. 3 and 4).

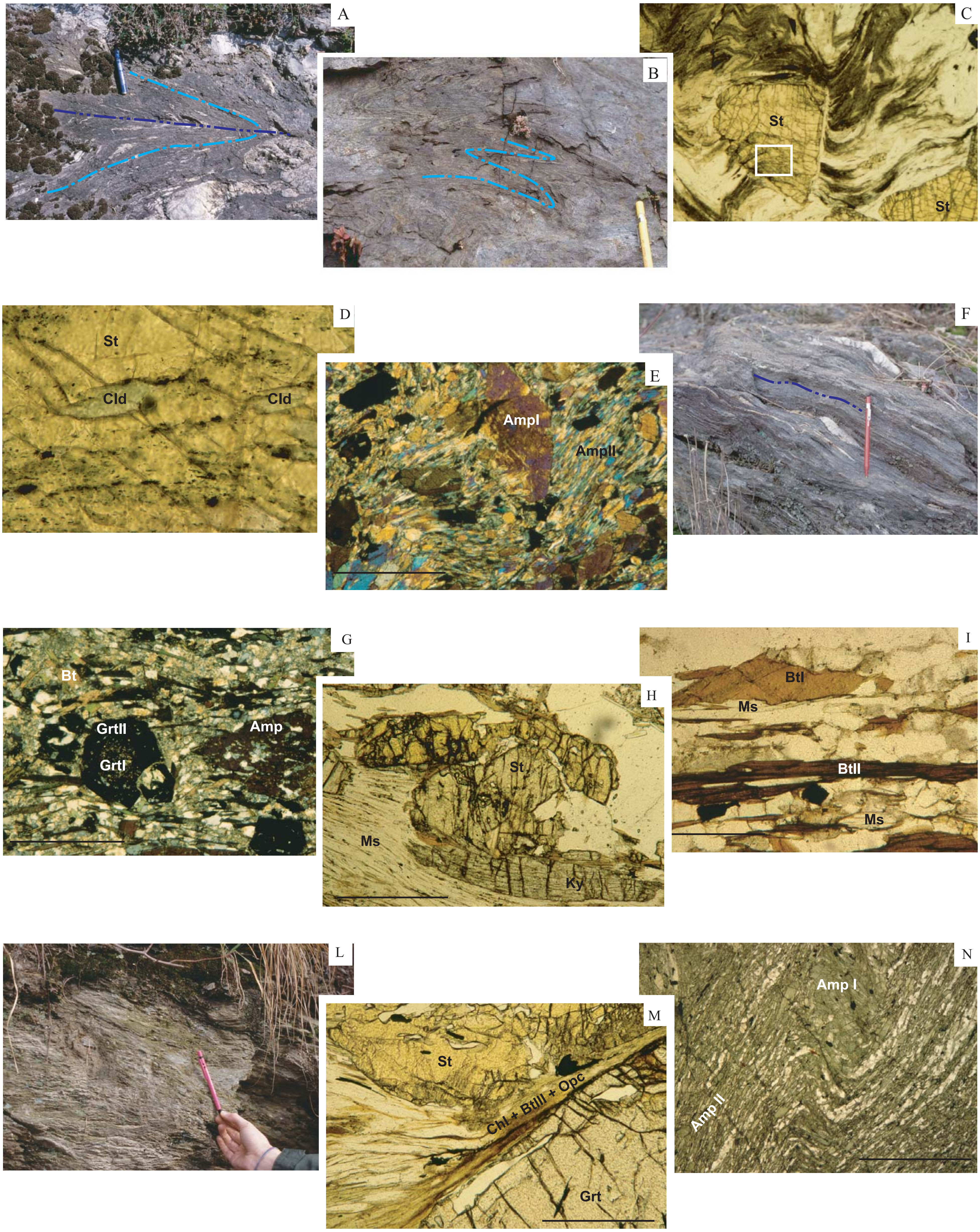


Fig. 5 - DCZ*: A - Folded S1 foliation preserved in micaschists, in volumes where D2 deformation is poorly pervasive.* B - *S1 mineralogical layering in amphibolites, folded during D2.* C - *Cld elongated in S1 foliation is preserved as inclusion in St; S1 foliation has been folded during D2 - plane polarized light, scale bar 2mm.* D - *Close-up of syn-D1 Cld enclosed in St of fig. C - plane polarized light.* E - *AmpI porphyroclasts are preserved in S2 mylonitic foliation, marked by fine-grained AmpII - cross-polarized light, scale bar 1 mm.* F - *Mylonitic S2 foliation in micaschists of the DCZ.* G - *Bt- Grt- bearing amphibolites; S2 foliation marked by shape - preferred orientation of Amp and Bt. Garnet shows a core rich in colourless inclusions (GrtI) and an inclusion-free rim (GrtII) - cross-polarized light, scale bar 1 mm.* H - *Syn-D2 Ky and St in micaschists. Ky shows an internal foliation parallel and continuous with the external S2 foliation - plane polarized light, scale bar 0.5 mm.* I - *BtII and Ms underline foliation S2 in metapelites; relics of BtI show shape preferred orientation oblique to S2. Plane polarized light, scale bar 2 mm.* L - *S3 foliation crosscutting S2 in micaschists.* M - *S3 foliation, with growth of BtIII, Chl and opaque minerals (Opc), crosscutting syn-S2 minerals in metapelites - plane polarized light, scale bar 0.2 mm.* **N**- *In amphibolites, S2 mylonitic foliation wrapping porphyroclasts of AmpI, is folded by D3.*

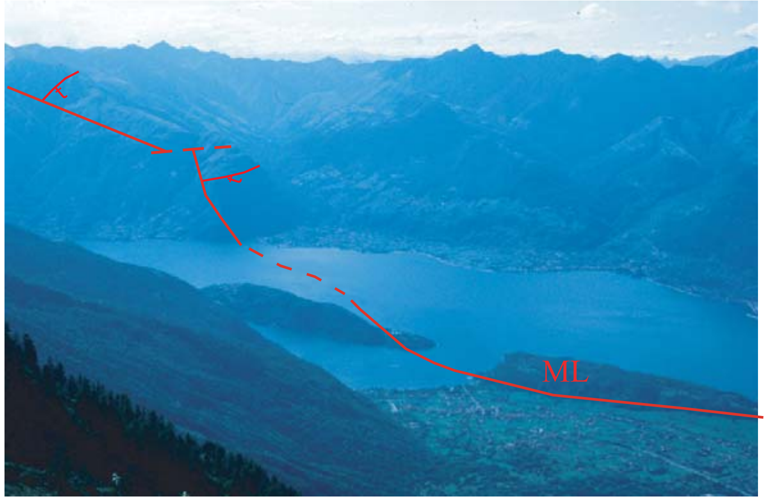


Fig. 6 - *Panoramic view of the Domaso-Cortafò Zone from the opposite side of the lake. The red line locates the Musso fault.*

Fig. 7 - *Massive, medium-to-fine-grained dolostone at Monte Sasso Pelo. The contact with the micaschists of DCZ is underlined by carbonatic breccias.*

In the metapelites of the Dervio Olgiasca tectono-metamorphic unit (DOZ), D1 was contemporaneous with the growth of Grt + Bt + Qtz + St + Ms + Pl + Ilm + Tour ± Ky ± Rt. During D2, Sill + BtII + GrtII + PlII ± Kfs developed. Greenschist facies minerals define D3 fabrics. D2 deformation is synchronous with pegmatite emplacement (226±2 Ma; SANDERS *et alii*, 1996) (Figs. 3 and 4).
In the metapelites and amphibolites of the Domaso Cortafò tectono-metamorphic unit (DCZ), the pre-Alpine D1 and D2 fabrics are defined by epidote-amphibolite and amphibolite facies mineral assemblages, whereas, during development of the D3 foliation, greenschist facies mineral assemblages were formed. The deformation - metamorphism relationships of DCZ rocks are described in detail below. A K-Ar age of ~385 Ma was obtained in amphibolites from hornblende (FUMASOLI, 1974), a mineral associated with D1 and D2 fabrics, whose age therefore predates syn-D3 greenschist retrogression.
The mylonitic bands bounding the basement blocks (MFZ and LVGFZ in Figs. 2 and 3) are 100-200 m wide and developed under greenschist facies conditions (Chl + sericite + Ab-rich Pl); they have been later reactivated by brittle shearing and minor pseudotachylite seams (SILETTO *et alii*, 1990). The age of the most recent movements along the MFZ is inferred to be post-Triassic, actually, the tectonic contact with the basement at the bottom of the Triassic dolostone (Dolomia Principale, REPOSSI, 1904), near the village of Musso, appears to be crosscut by the Musso fault (SCHUMACHER, 1990).

THE DOMASO-CORTAFÒ TECTONO-METAMORPHIC UNIT

The DCZ forms the northernmost sector of the Southern Alps basement of Como Lake (Fig. 6). It is mainly constituted by micaschists and quartz-rich micaschists, with minor amphibolites. This zone was mapped in detail, in order to unravel its deformation and metamorphic history, through the integration of lithostratigraphic, structural and petrologic observations (Fig. 1). During field mapping, attention was particularly focused on the superposition of foliation, fold systems and mylonitic zones, and a grid of foliation traces was superimposed on lithostratigraphic information. This synthesises the succession of tectonic events that imprinted granular scale fabrics, which were subsequently correlated to the development of mineral assemblages. Rock volumes displaying equivalent successions of structural and metamorphic imprints are regarded as tectono-metamorphic units. The same detailed work performed in DCZ to unravel its structural and metamorphic evolution was also carried out in DOZ and MMZ, enabling the synthetic map shown in Fig. 3 to be drawn up.
The DCZ is mainly formed of micaschists and quartz-rich micaschists containing white mica, chlorite, biotite and garnet. Staurolite porphyroblasts up to millimetre-size may occur, rarely with kyanite (DI PAOLA *et alii*, 2001). Different types of metabasites are interlayered in the metapelites. These consist mainly of amphibolites with minor volumes of biotite and garnet-bearing amphibolites and more leucocratic garnet and amphibole-bearing gneisses. The Mesozoic sedimentary cover is a slice of slightly coloured, fine-grained, massive dolostone, about 300 m thick (Fig. 7).
In the basement, three syn-metamorphic groups of structures have been recognized (D1, D2 and D3). They are considered to be pre-Alpine in age since none of these structures have correlatable counterparts within the Mesozoic sedimentary cover (Figs. 1 and 5). Rare relics of S1 folded foliation are preserved in centimetre to metre-sized domains, which escaped any successive reconstruction of the fabric. In micaschists, S1 is a continuous foliation underlined by biotite and white mica, in which centimetre-scale quartz-rich lozenges are aligned. In amphibolites, S1 consists of a millimetre-thick compositional layering with alternating plagioclase-rich and amphibole-rich layers. At the micro-scale, S1 structural relics in metapelites are marked by shape and lattice-preferred orientations (SPO and LPO) of MsI, and BtI and are preserved in rootless folds with axial surfaces parallel to S2 foliation. Rarely, S1 is a discontinuous foliation in which opaque minerals-rich domains alternate with mica-rich and quartz/plagioclase-rich

Table 1 - *Deformation vs. mineral growth relationships in DCZ amphibolites.*

MINERALS	D1	D2	D3
amphibole	I ——	II ——	Act ——
plagioclase	——	——	Ab-rich ——
garnet*	— I —	— II ——	
biotite*		——	
quartz	——	——	——
chlorite			——
epidote			——
white mica			——
rutile	——	— —	
ilmenite	— —	——	
titanite			——
undistinguished opaque minerals	——	——	——

Table 2 - *Deformation vs. mineral growth relationships in DCZ metapelites.*

MINERALS	D1	D2	D3
quartz	——	——	——
plagioclase	——	——	Ab-rich ——
white mica	——	——	——
biotite	red-brown ——	red-brown ——	green ——
chloritoid	——		
garnet	I ——	II ——	
staurolite		——	
kyanite		——	
rutile	——		
tourmaline	——	——	
chlorite			——
epidote			——
undistinguished opaque minerals	——	——	——

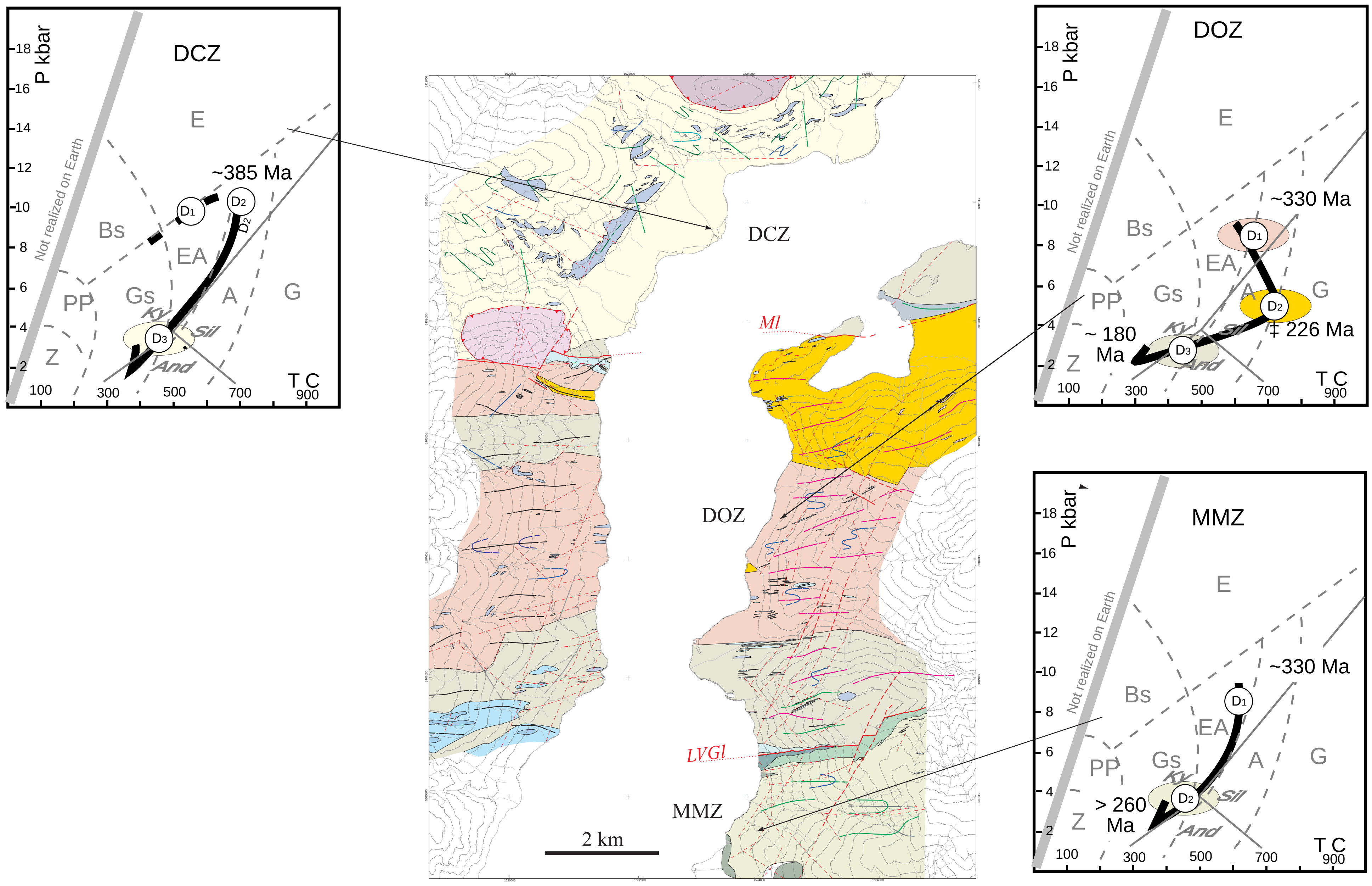


Fig. 8 - *Boundaries of the DCZ, DOZ and MMZ tectono-metamorphic units on the interpretative structural map. The dominant metamorphic imprints recorded in the three units are evidenced in the P-T-d-t loops. The petrogenetic grid showing the metamorphic facies fields as reference is redrawn according to* Spear *(1993). Legend: Z= zeolite facies; PP= prehnite pumpellyite facies; Gs= greenschist facies; Bs= blueschist facies; E= eclogite facies; EA= epidote amphibolite facies; A= amphibolite facies; G= granulite facies; Al_2SiO_5 triple point from* Holdaway *(1971). Circled D_1, D_2 and D_3 correspond to PT conditions for assemblages formed during the development of the first, second and third generation of structures, respectively. Colours attributed in the PT diagrams to different tectono-metamorphic imprints correspond in the map to volumes in which each P-T re-equilibration stage is dominant. See the discussion in the text for the location of ages with respect to the tectono-metamorphic stages.*

domains. The inferred mineral assemblage stable along S1 foliation in metapelites is MsI + BtI + Qtz + PlI + GrtI + Rt + Tour + opaque minerals ± Cld. In amphibolites, rare S1 structural relics are underlined by SPO and LPO of AmpI, defining a continuous foliation together with polygonal Pl and Ilm grains. More frequently, AmpI, strongly-deformed porphyroclasts are enclosed in S2, showing undulose extinction, microboudinage and subgrains. Deformation D2 generated centimetre- to decimetre-sized, tight-to-isoclinal folds and a pervasive S2 foliation, in places of crenulation cleavage type or, more rarely, mylonitic.

Foliation S2 is marked by white mica and biotite in garnet- and staurolite-bearing metapelites, in which kyanite may occur. In quartz-rich micaschists, the foliation is a millimetre-thick mineralogical layering with quartz-rich and mica-rich alternating layers. In places foliation, S2 is a crenulation cleavage; rarely S2 becomes a mylonitic foliation, with ribbons and grain size reduction of quartz. In amphibolites, S2 is defined by amphibole, plagioclase and minor quartz, in places associated with biotite and garnet. Rarely, S2 is mylonitic and marked by fine-grained oriented amphiboles, associated with fine-grained plagioclase. At the micro-scale, S2 in metapelites is a discontinuous foliation with alternating Q- and M-domains. Rarely, it corresponds to a simple crenulation or to a crenulation cleavage (stages 3 and 4 of Bell & Rubenach, 1983). S2 foliation in metapelites is underlined by MsII + BtII + Qtz + PlII + GrtII + Tour + opaque minerals ± St ± Ky. In amphibolites, S2 is generally a continuous foliation defined by Hbl + Pl + Qtz + Ilm/Rt ± Grt ± Bt; locally, S2 is a spaced foliation coinciding with a compositional layering, with Pl and Qtz occurring as polygonal small-sized grains within leucocratic layers. In places, S2 is a continuous mylonitic foliation defined by fine-grained AmpII, showing SPO and LPO and wrapping AmpI and minor PlI porphyroclasts. Due to the reactivation of S2, with growth of new minerals and to the occurrence of a poorly pervasive S3 foliation that crosscuts S2 at a low angle, D3 caused the development of a composite S2/S3 fabric. D3 folds also occur at the meso-scale and constitute the regionally dominant fold system. At the micro-scale, D3 deformation is not always associated with new foliation development. Scarcely penetrative S3 planes may crosscut S2 at a low angle. Where S3 planes are not developed, the syn-D3 assemblage grows on reactivated S2 surfaces, or a coronitic texture develops on syn-D2 minerals. The inferred assemblage Chl + MsIII + BtIII + PlIII + Ep + opaque minerals is stable during D3. In amphibolites, a locally developed S3 is contemporaneous with the growth of Act + Ab + Chl + Qtz + Ttn + Ep + opaque minerals ± Ms ± Cal. In D3 fold hinges, AmpI and II recrystallised or new amphibole needles grew parallel to the D3 axial surface.

Pre-Alpine deformation-metamorphism relationships in DCZ are illustrated in Fig. 5 and synthesised in Tables 1 and 2, referring respectively amphibolites and metapelites.

Alpine deformation is responsible for the thrusting of the Mesozoic dolostone outcropping in the Monte Sasso Pelo area (cross-section in Fig. 1). The tectonic contact separating dolostone and basement is marked by a thick breccia horizon (up to 10 metres thick); the breccia contains randomly-oriented, centimetre-sized dolomitic clasts, enclosed in a calcite-bearing matrix. Two perpendicular Alpine systems of subvertical fracture cleavages affect the dolostone, the earlier N-S-trending system being overprinted by a successive E-W-trending system.

CONCLUSIONS

The investigation method illustrated for the DCZ example was used throughout the Lake Como basement, and results are represented in the map, shown in Fig. 3, and simplified and integrated with P-T-d-t paths in Fig. 8. The contours of the different tectono-metamorphic units (DCZ, DOZ, MMZ) traced according to their P-T-d-t histories based on walk-correlated foliations do not coincide with the lithostratigraphic outline proposed in literature, where the three units are described as belonging to the same lithostratigraphic unit of the Morbegno or Stabiello Gneisses.

Considering the metamorphic history together with the planar fabric evolution, as reconstructed using the method illustrated here, the dominant metamorphic imprint of DCZ does not coincide with the T_{max}-P_{max} of the P-T-d-t loop (Fig. 8). In fact, the dominant metamorphic imprint is that of the most pervasive fabric at the regional scale, which in this tectono-metamorphic unit coincides with D3 and D2 reactivated during D3 fabric (Fig. 1). This mismatch between dominant metamorphic imprint and T_{max}-P_{max} of the P-T-d-t loop characterizes all three tectono-metamorphic units (SPALLA *et alii*, 2000). In DOZ, as an example (Fig. 8), if the planar fabric S2 evolved less, the syn-D1, intermediate-pressure amphibolite-facies is the dominant metamorphic imprint (pink field on the map and pink spot on the DOZ P-T-t-d path). If S2 planar fabric evolved more, up to a mylonitic foliation, the HT-LP metamorphic imprint is dominant (yellow field on the map and yellow spot on the DOZ P-T-t-d path): this is the only case of coincidence of T_{max}-P_{max} and the dominant metamorphic imprint in the Lake Como basement. Where S3 is the most penetrative fabric, the syn-D3 greenschist facies is the dominant metamorphic imprint (grey-green field on the map and grey - green spot on the DOZ P-T-t-d path), as it is the case in DCZ.

The regional distribution of dominant metamorphic imprints does not necessarily correspond to the "metamorphic field gradient" of ENGLAND & RICHARDSON (1977) and SPEAR *et alii* (1984), and therefore cannot be used to distinguish tectono-metamorphic units in terrains that underwent polyphase deformation and metamorphism without considering the area distribution of superposed syn-metamorphic fabrics. Indeed, within a single tectono-metamorphic unit, different metamorphic imprints may dominate in adjacent areas, as in the case of DOZ, or the dominant metamorphic imprint occurring in different tectono-metamorphic units may be recorded under similar P-T conditions, as in the case of MMZ and DCZ. In this case, in spite of dominant metamorphic imprint similarities, the sequence of superposed structures and timing of equivalent metamorphic conditions are different (Figs. 3 and 8).

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