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FOLIATION MAP OF THE "ECLOGITIC MICASCHISTS COMPLEX" (MONTE MUCRONE – MONTE MARS – MOMBARONE, SESIA-LANZO ZONE, ITALY)

Estratto da
Memorie di Scienze Geologiche
Vol. 54

Padova 2002

Mem. Sci. Geol.	v. 54	pp. 87-100	7 figs	2 tabs	-	1 geol. map	Padova 2002	ISSN 0391-8602

Foliation map of the "Eclogitic Micaschists Complex" (monte Mucrone – monte Mars – Mombarone, Sesia-Lanzo Zone, Italy)

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ABSTRACT - This work presents a new petro-structural map in which lithostratigraphic, structural and metamorphic data are represented by means of foliation traces superimposed on lithological information. Within the inner part of the Eclogitic Micaschists Complex, along the Monte Mucrone – Monte Mars – Mombarone divide (Sesia-Lanzo Zone, Western Alps), this map allows seven phases of deformation to be identified on the basis of overprinting of kinematically incompatible tectonite fabrics. Foliations are characterized by mineralogical supports changing with respect to evolving P-T conditions. The oldest structure is a mylonitic pre-Alpine foliation (S_{pre1}) marked by amphibolite to granulite facies assemblages. D_1, D_2 and D_3 occurred in eclogite facies conditions and D_4, associated with small-scale shear zones, in epidote-blueschist facies conditions; D_5 large-scale recumbent folds and D_6 large-scale vertical folds developed in greenschist facies conditions. S_1 and S_2 foliations are marked by white mica + omphacite + glaucophane + garnet + quartz within metapelites, white mica + epidote + garnet layers ± omphacite ± glaucophane within the metaquartzdiorite of the Monte Mars-Monte Mucrone metaintrusive body, and omphacite ± amphibole within eclogite and amphibole-bearing eclogite. D_3 folds, observed only at Monte Bechit-Monte Roux, describe meter-size vertical folds, within metapelite locally associated with axial plane foliation (S_3), the latter marked by white mica + omphacite ± glaucophane + garnet layers. S_4 shear zones, marked by white mica and glaucophane, deflect the S_2 foliation. Where axial plane crenulation cleavage (S_5 and S_6) developed during D_5 and D_6 folding, it is marked by white mica and plagioclase. Oligocene andesitic dykes crosscut all the structures and represent an important time marker to constrain the end of Alpine tectono-metamorphic evolution.

Key words: Italian Western Alps, Austroalpine domain, Sesia-Lanzo Zone, subduction, foliation map.

RIASSUNTO - La nuova carta petrografico-strutturale contiene le informazioni litostratigrafiche, strutturali e metamorfiche, interpretativamente integrate per mezzo delle tracce delle foliazioni sovrapposte alle informazioni litologiche. Tale carta permette di riconoscere sette fasi deformative nel Complesso dei Micascisti Eclogitici, nella porzione interna della Zona Sesia-Lanzo (Alpi Occidentali), lungo il crinale Monte Mucrone – Monte Mars – Mombarone. La struttura più vecchia è una foliazione prealpina (S_{pre1}) definita da associazioni mineralogiche di facies anfibolitica-granulitica. Le fasi deformative D_1, D_2 e D_3 si sviluppano in condizioni di facies eclogitica, mentre D_4, associata a zone di taglio metriche, si sviluppa in condizioni di facies anfibolitica ad epidoto; le pieghe sub-orizzontali coricate (D_5) sono localmente associate ad una foliazione di piano assiale marcata da clorite e mica chiara (facies scisti verdi). Le strutture D_6 sono invece pieghe aperte a piano assiale sub-verticale e la locale foliazione di piano assiale S_6 è marcata da mica chiara e clorite. Le foliazioni S_1 e S_2 sono marcate da mica chiara + onfacite + glaucofane + granato + quarzo nelle metapeliti, da mica chiara + epidoto + granato ± onfacite ± glaucofane nelle metaquartzdioriti del complesso intrusivo del Monte Mars-Monte Mucrone e da onfacite ± anfibolo nelle eclogiti ed eclogiti ad anfibolo. Le pieghe D_3, osservate presso il Monte Bechit-Monte Roux, descivono pieghe metriche a piano assiale verticale, nelle metapeliti, associate ad una foliazione di piano assiale S_3 marcata da mica chiara + onfacite ± glaucofane e livelli a granato. Le zone di taglio S_4, marcate da mica chiara e glaucofane deflettono la foliazione S_2. Dove si sviluppa una foliazione di piano assiale (S_5 e S_6), associate alle pieghe D_5 e D_6, questa è marcata da mica chiara, clorite e plagioclasio. I dicchi andesitici Oligocenici intersecano tutte le strutture e rappresentano un importante marker temporale che vincola l'evoluzione tettono-metamorfica alpina.

Parole chiave: Alpi Occidentali Italiane, dominio Austroalpino, Zona Sesia-Lanzo, subduzione, carta delle foliazioni.

INTRODUCTION

In orogenic belts, the mineralogical composition and structures characterising present-day metamorphic outcrops result from the patchy record of successive stages of tectono-metamorphic evolution, which are heterogeneously distributed in space and time. The rate of the metamorphic transformations has been related to the amount of finite strain and/or fluid influx in a specific volumes (Passchier *et al.*, 1990; Spalla *et al.*, 1998; Spalla *et al.*, 1999; Spalla *et al.*, 2000). Innovations in geological mapping may derive from describing relationships between present-day lithologies and structural and mineralogical evolution of superposed fabrics. For this reason, structural and petrographic fieldwork exploiting the contemporaneous definition of lithostratigraphic information and relative timing of superimposed fabrics was undertaken across the Monte Mars-Monte Rosso area, with the aim of analysing all metamorphic parageneses developing during the progressive steps of the finite deformation (Spalla *et al.*, 1998). The scope of this note is to illustrate the mineralogical support of the mesostructures, which represent the main tectonic frame of the attached geological map.

GEOLOGICAL SETTING

The Sesia-Lanzo Zone (SLZ) belongs to the Austroalpine domain of the Western Italian Alps (Fig. 1). It consists of two main elements, distinguished on the basis of their lithological affinities (e.g. Compagnoni *et al.*, 1977): an upper element, consisting of metapelites and metabasites, showing a dominant metamorphic imprint in amphibolite to granulite facies conditions of pre-Alpine age, the "II Diorito-Kinzigitica" (IIDK), and a lower element, consisting of metapelite, metagranitoid and metabasite, divided into two metamorphic complexes: Gneiss Minuti Complex (GMC), showing the dominant Alpine metamorphic imprint in greenschist facies conditions, and Eclogitic Micaschists Complex (EMC) showing the dominant Alpine imprint in eclogite facies conditions.

Figure 2 shows the estimated P-T conditions for the pre-Alpine and Alpine evolution of the SLZ and the corresponding radiometric ages, methods and minerals reported in the literature. The age of the Alpine eclogitic metamorphic evolution of the SLZ has been dated as Late Cretaceous-Early Paleocene: Inger (1996, Rb-Sr on Wm) attributed an age of 63.0±1.3 Ma to eclogitic re-equilibration of the Monte Mucrone metaquartzdiorite and an age of 68.6±3.1 Ma (eclogites) and an age of 53.8±1.8 Ma (metapelites) to the surrounding rocks; they also proposed an age of 68.8±2.2 Ma for the eclogitic Monte Mars metapelite, giving an age range of 10 Ma for the Alpine high-pressure metamorphism. Ruffet (1997) obtained ages in between 64-66 Ma for the HP metamorphic event (Ar-Ar on Wm), while Duchene (1997) obtained an age of 69.2±2.7 Ma (Lu-Hf on Grt and Cpx) for the eclogites of Lillianes-Fontainemore (north-west of Monte Mars). Rubatto (1999) attributed an age of 65±5 Ma, to the Alpine eclogite facies zircons (SHRIMP method) of the Monte Mucrone metaquartzdiorite.

Our petro-structural map covers a sector of the most internal part of the EMC, located between Valle dell'Elvo (province of Biella) and Val di Gressoney (Aosta) to the north, and between lower Val d'Aosta (Turin) and Valle dell'Elvo (Biella) to the south (Fig. 1).

The rock association consists of Grt, Omp, Gl metapelites (micaschist and paragneisse), large bodies of Omp-Gl metaintrusive (up to 2 square km; western part of the Monte Mucrone metaintrusive body, of Upper Carboniferous-Permian age), metagranitic intercalations (metre-scale granitic bodies and meta-aplitic dykes), lenses of metabasite (hornblendite, Amp-bearing eclogite and eclogite), pure and impure marble, Ky-Ctd-Grt quartzite, meter-size lenses of serpentinite and andesitic dyke, and meter-size lenses of pre-Alpine Bt-Grt-Al silicates-Kfs metapelite ("kinzigite") are embedded within the Omp-bearing micaschists (Dal Piaz *et al.*, 1972; Compagnoni and Maffeo, 1973; Pognante *et al.*, 1980; Hy, 1984; Vuichard, 1986; Koons *et al.*, 1987; Venturini, 1995). All the lithologies show strong Alpine structural and metamorphic re-equilibration, whereas pre-Alpine assemblages are very scarce in comparison with the external part of the Sesia-Lanzo Zone (e.g. metre-scale lenses of kinzigite and decametre-scale of undeformed granodiorite, Monte Mars). Andesitic dykes (Dal Piaz *et al.*, 1979; De Capitani *et al.*, 1979; Beccaluva *et al.*, 1983) crosscut both lithological boundaries and Alpine tectonic structures.

MAPPING STRATEGY

1:5 000 mapping (redrawn at 1:10 000 scale) was carried out in an area where the coarse mineral grain size facilitates meso-scale correlations between mineral assemblages and foliations (Fig. 3a). In this area, the Monte Mucrone metaquartzdiorite and its western prosecution (Monte Mars) is involved in the polyphasic Alpine deformation. The original (intrusive) boundaries are mainly parallel with the main Alpine eclogitic foliations (*i.e.* S_1 and S_2), and only a few small volumes preserve the original igneous texture (Fig. 3b). Eclogitic foliation ($S_1 + S_2$) is widespread in all lithologies (Fig. 3) and defines the main structural feature: the meta-aplitic dykes are almost parallel with the eclogitic foliation (Fig. 3) within gneisses and micaschists; elongation of eclogite boudin is mainly parallel with the eclogite facies foliation in micaschists; glaucophane-rich layers are also aligned parallel with the eclogitic planar fabrics (e.g. S_1 and S_2) in paragneisses and basic enclaves in metaquartzdiorite are elongated parallel with the eclogite foliation in metaquartzdiorite (figs 3f and g).

In this map, structural correlation criteria widely used in various terrains (Williams, 1985; Spalla, 1990; Johnson and Duncan, 1992; Connors and Lister, 1995; Spalla *et al.*, 1998) were applied, also supported by microstructural analysis (for more detailed petro-structural analysis of the metamorphic assemblages, see Zucali *et al.*, 2002).

Each rock is described and mapped considering its mineral composition (e.g. micaschist, paragneiss, eclogite), planar and linear structural elements (e.g. foliation, lineation, etc.) and their corresponding mineral support.

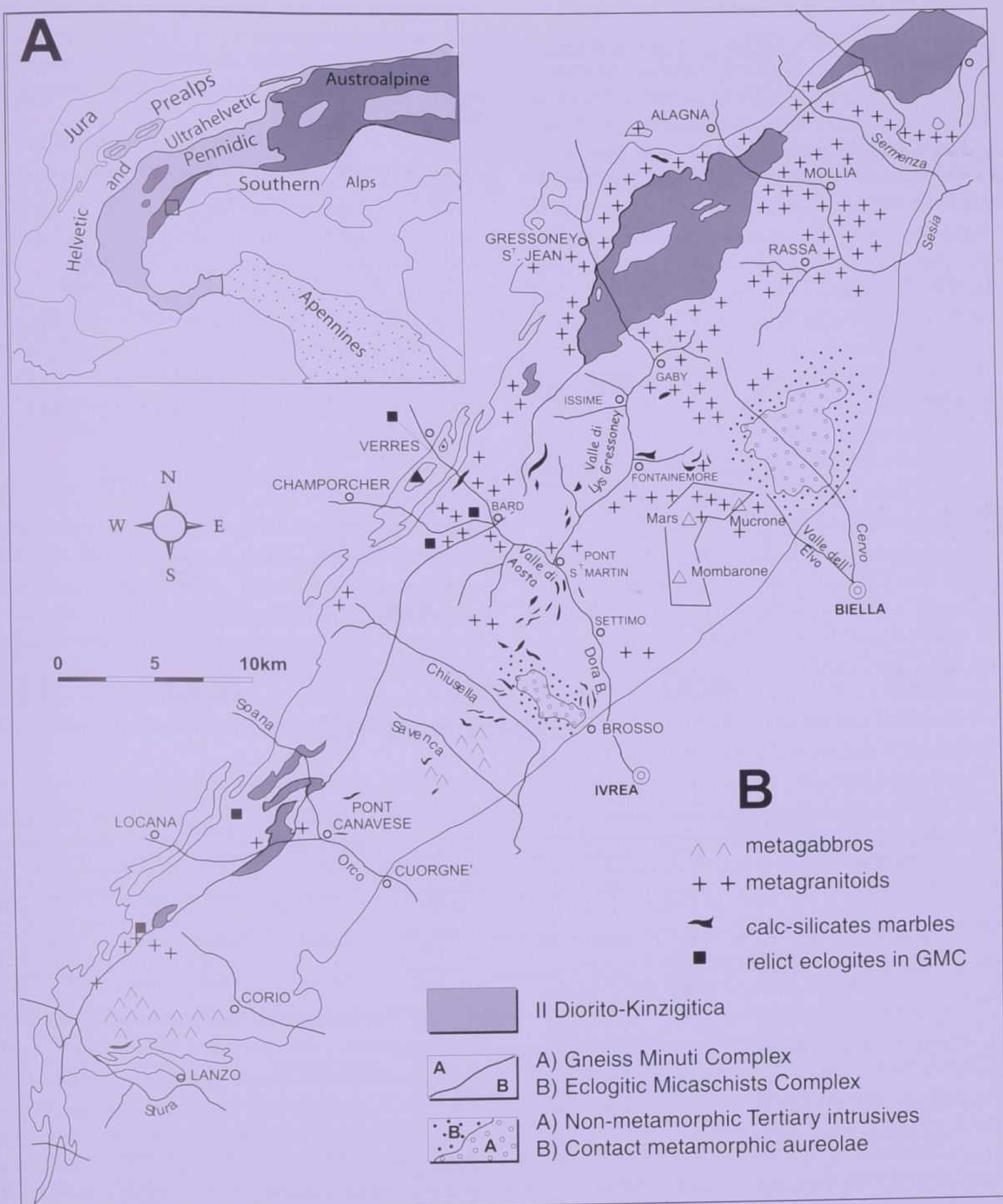
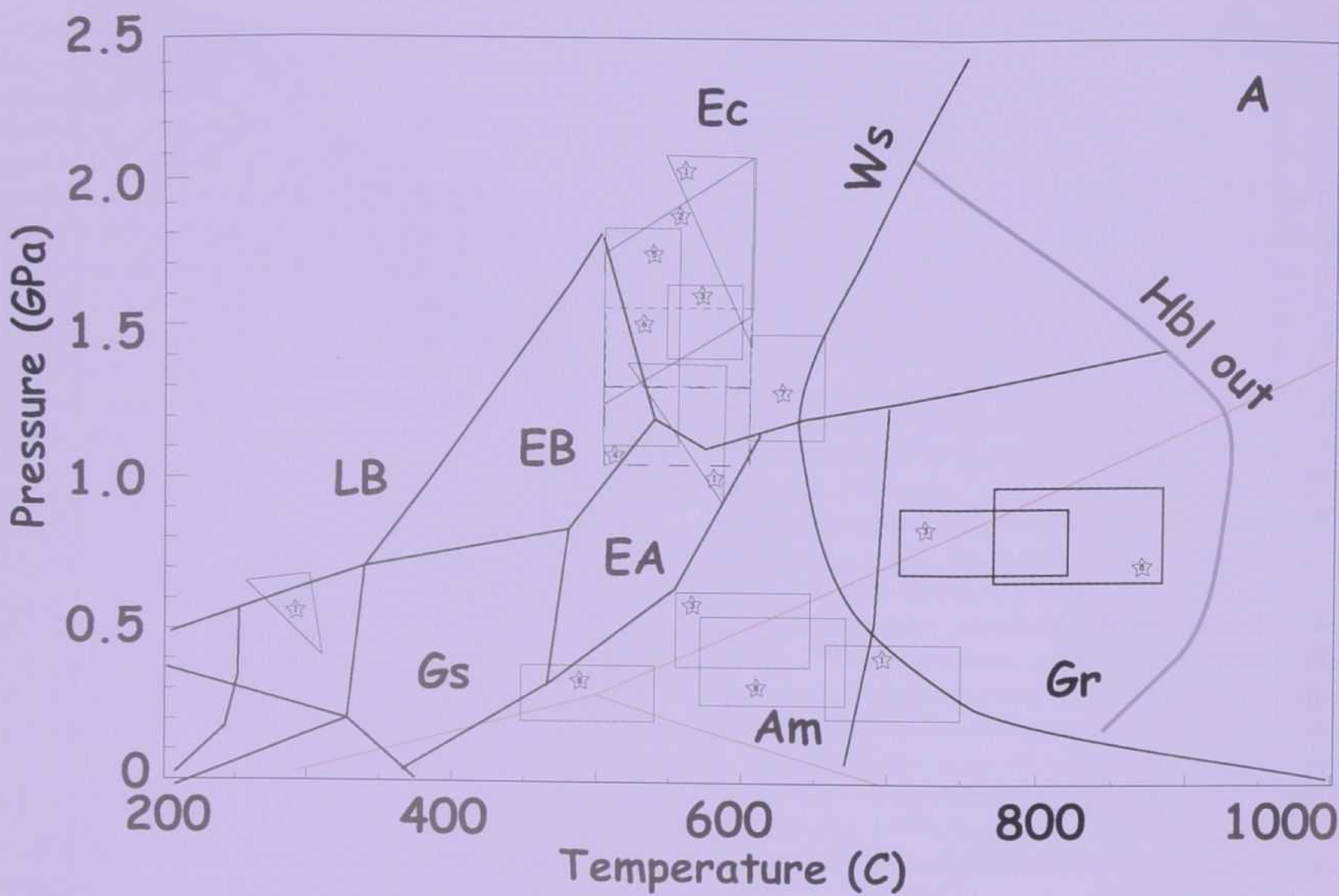


Fig. 1 - **A**: Tectonic outline of Alpine chain. Rectangle locates Sesia-Lanzo Zone; **B**: Simplified geological map of the Sesia-Lanzo Zone.

These data are represented on the petro-structural map as coloured foliation traces superimposed on standard lithological information. Each family of foliation and structure is attributed to a chronological class (S_1, S_2, S_3, etc.), graphically represented by dots and characterised by the metamorphic condition in which it developed (trace colours), testified by compatible metamorphic assemblages. The extensive and systematic application of this integrated field and laboratory method allows representation of petro-structural data in the form of the foliation trace map.

The resulting map, structurally and petrologically constrained, is a mosaic of foliation traces, which includes graphic representation of: i) rotation, dislocation, and overprinting of structures, ii) incompatibilities of metamorphic assemblages related to planar and linear fabrics, enhanced by the overprinting of several colour traces; iii) map-scale finite strain gradients (e.g. undeformed rocks



PRE-ALPINE						ALPINE					
Locality	Lithology/metamorphic conditions	Method	Mineral	Age (Ma)	Reference	Locality	Lithology/metamorphic conditions	Method	Mineral	Age (Ma)	Reference
SLZ Nord	metaporphyrites	U-Pb	Monazite	448±5	Romer et al. 1996	Monte Mucrone (EMC)	Eclogite	SHRIMP	Zircon	65±5	Rubatto et al. 1999
Ivozio Complex (EMC)	metagabbros	SHRIMP (sensitive high-resolution ion microprobe)	Zircon	355±9	Rubatto 1998	Aosta Valley (EMC)	Micaschist	SHRIMP	Zircon	65±3	"
Cima di Bonze (EMC)	metagabbros	SHRIMP	Zircon	350±4	Rubatto 1998	Cima di Bonze (EMC)	Mafic rocks	SHRIMP	Zircon	68±7	"
Monte Mucrone (EMC)	metaintrusive	U-Pb	Zircon	293+1/-2)	Bussy et al. 1998	Monte Mucrone (EMC)	Metaquartz-diorite	Rb-Sr	White Mica	63±1.3	Inger et al. 1996
Corio-Monastero SLZ	metagabbros granulite facies metamorphism	structural relationships	-	~270	Rebay and Spalla 2001	Monte Mucrone (EMC)	Micaschists Eclogite	Rb-Sr	White Mica	63±1.4	"
SLZ	amphibolite facies metamorphism	structural relationships	-	≤ 240	Lardeaux & Spalla 1991 - Rebay & Spalla 2001	Monte Mars (EMC)	Metapelite	Rb-Sr	White Mica	63±1.5	"
SLZ	greenschist facies metamorphism	structural relationships	-	≤ 170	Rebay & Spalla 2001	Settimo Vittone (EMC)	Metapelite	Ar-Ar	White Mica	64-66	Ruffet et al. 1997
SLZ	metasomatic stage/ veins	SHRIMP	Zircon	221±14	Rubatto 1998	Lilliones-Fontainemore (EMC)	Metaintrusive/eclogite	Lu-Hf	Garnet and Pyroxene	69.2±2.7	Duchene et al. 1997

B

			Eclogitic Micaschists Complex		
References	Pre-Alpine	Blueschist	Eclogite	Blueschist	Greenschist
(1)			D1	D2	D3
(2)		D0	D1	D2	D3
(3)	D0		D1	D2	D3+D4
(4)	D1	D2	D3	D4	D5
(5)	D0		D1 + D2 ---------> D2		
(6)			D1	D2	D3
(7)			D1 + D2 ---------> D2		D3
(8)	D0	D1	D2+D3		D4
(9)	D0		D1+D2	D3	static
This work & (10)	pre-D1	D1 + D2 + D3		D4	D5+D6

with coronitic structures, normal S/L tectonites, mylonites) achieved during a given metamorphic stage, iv) distinction of areas preserving contrasted stages of structural and metamorphic re-equilibrations.

MESOSTRUCTURAL ANALYSIS

The relative timing of structures inferred by superimposed features (Turner and Weiss, 1963; Ramsay, 1967; Ramsay and Huber, 1987) and analysis of the mineral assemblages marking each fabric element allowed definition of the relative timing of structures within each lithology (i.e. phases of deformation e.g. D_{pre1}, D_1, D_2) with respect to the metamorphic conditions in which they developed. The orientations of the fabric elements are plotted on Schmidt diagrams in Figure 4. Tables 1 and 2 report geological sections.

Pre-Alpine structures

S_{pre1} foliation is preserved within metre-sized lenses of Bt-Grt *micaschists*; S_{pre1} is marked by SPO (Shape Preferred Orientation) of Bt, Fds, ± Sil in layers alternating with Qtz-rich ribbons, containing large Grt porphyroclasts. The pre-Alpine assemblage (Bt, GrtI, ±WmI, Pl ± Kfs and Qtz) defines discontinuous layering within the metapelites and in places fine grained aggregates of Wm grow on foliation planes and rims of Bt grains.

In the less deformed domains of *metaquartzdiorites*, heterogranular igneous texture is preserved (Fig. 3b): igneous minerals are completely replaced by Alpine HP minerals, with the only exception of Qtz. In places, *aplitic dykes* still preserve angles with respect to the Alpine planar and linear structures.

Alpine structures

D1 deformation event The only preserved D_1 structure is S_1 foliation (table 1 and 2), well preserved only in metapelite at the boundary between Monte Rosso - Colle Carisey and Monte Mucrone - Monte Mars. S_1 is a well-differentiated millimetric foliation (Passchier and Trouw, 1996), within micaschists and gneisses. Films are marked by SPO of Wm, elongated Omp and Gl, and by Grt-rich bands. Within micaschists and gneisses, S_1 has been recognized where overprinting relationships between D_2 folds and S_1 foliation occur (e.g. Figs 5a, b). In metaquartzdiorite and metabasite S_1 can be distinguished only where it was developed with an angle higher than 10° with respect to the S_2 surface.

D2 deformation event D_2 structures mainly consist of isoclinal folds, from centimetric to metric in size, transposing the S_1 foliation into a new pervasive S_2. D_2 large-scale structures are well preserved in the southernmost part of the area (Mombarone-Druer) where marbles, silicate-rich marbles and Cld-Grt-Ky bearing quartzites (Pognante *et al.*, 1980) describe huge vertical D_2 folds, from close to isoclinal in shape (Figs 5e, f; table 2). S_2 foliation occurs in micaschists and quartzites S_2 corresponds to an axial plane crenulation cleavage. Decametre-scale refolded D_2 folds are also well represented within metapelites at Monte Rosso, Alpe Carisey and at the margins of the Monte Mars metaquartzdiorite; D_2 folds are mainly evidenced by metagranitic/meta-aplitic lenses from metre to decametre in size. The eastern boundary between the Monte Mars metaquartzdiorite and gneisses also describes large-scale D_2 folds; here the S_2 foliation occurs within fold hinges as an axial plane foliation.

S_2 is the most pervasive planar structure at the scale of the studied area, whatever the lithology micaschists, gneisses or metaquartzdiorites. It is a well differentiated crenulation cleavage marked by SPO of Wm, Ky and Ctd in quartzites. S_2 shows a spaced to continuous character: it is marked by SPO in Wm, Qtz, Omp, Amp, Rt and Zo, and by Grt-rich bands in micaschists and gneisses (Fig. 6); rootless D_2 fold hinges can be also transposed within S_2 planes (Fig. 6). In metaquartzdiorite, S_2 is marked by SPO in Wm, Qtz, Omp, ± Ep, ± Amp and Grt bands; in places it is localized within metre-scale shear zones (Fig. 6). The D_2 deformation event generated both L_2 intersection lineation between S_1 and S_2 and L_2 stretching lineation. The latter is marked by Wm SPO, in micaschists, gneisses, quartzites and metaquartzdiorites. Meter-size metabasic enclaves are widespread within the metaquartzdiorites of Monte Mars (Lago Goudin, Figs 6f and 4h); they are constituted of Omp, Zo, cm-sized Grt, ± Gl and minor Qtz. When folded, enclaves show pervasive S_2 foliation and L_2 lineation marked by SPO in Omp, Amp, Zo and Wm; the X/Y ratio of the basic enclaves increases up to 10:1, where the surrounding metaquartzdiorite shows a well-developed S_2 foliation.

In metabasites, L-S tectonite mainly developed during D_2, in volumes where L_2/S_2 is marked by SPO in Omp, ± Amp, Rt and Wm, in eclogites and Amp-bearing eclogites, or by SPO in Gl and ± Rt, in glaucophanite. S_1 and S_2, marked by the same mineralogical assemblages, are also similar in geometry and size; they can only be distinguished where D_2 folds occur. In micaschists, the mapped

Fig. 2 - **A**: Summarized P-T-t evolution of Sesia-Lanzo Zone: A) graphic comparison between estimated P-T conditions available from literature for pre-Alpine and Alpine evolutions (1= Zucali *et al.*, 2002; 2=Tropper *et al.*, 1999; 3= Lardeaux and Spalla, 1991; 4= Oberhansli *et al.*, 1985; 5= Pognante, 1989; 6=Compagnoni *et al.*, 1977; 7=Hy 1984; 8=Rebay and Spalla, 2001); metamorphic facies fields are after Peacock (1993): Gs= greenschists facies, Am= amphibolite facies, Gr= granulite facies, Ws= wet solidus, Ec= eclogite facies, EA= epidote amphibolite facies, EB= epidote blueschists facies, LB= lawsonite blueschists facies. **B**: schematic geochronological references for pre-Alpine and Alpine evolutions of Sesia-Lanzo Zone and the relationships between deformation and metamorphism in Eclogitic Micaschists Complex of Sesia-Lanzo Zone, according to literature and present work: (1) Gosso, 1977; (2) Pognante *et al.*, 1980; (3) Passchier *et al.*, 1981; (4) Williams and Compagnoni, 1983; (5) Hy, 1984; (6) Ridley, 1989; (7) Ildefonse *et al.*, 1990; (8) Venturini *et al.*, 1991; (9) Inger and Ramsbotham, 1997; (10) Zucali *et al.*, 2002.

Fig. 3 - Mesoscopic features of some lithologies: a) large (up to 1cm) Omp grains within micaschists at Monte Rosso. Omp porphyroblasts are wrapped and aligned parallel to S_2 eclogitic foliation; b) metaquartzdiorite of Monte Mars still preserves igneous textures; darker sites are aggregates of Wm+Omp+Grt±Ep; c) alternate dm- to m-thick layers of micaschists (dark) and meta-aplite (light layers). Boundaries between micaschists (mainly Omp and Gln bearing micaschists) are parallel to eclogitic foliation S_2; d) eclogite boudins within Omp-Gln bearing micaschists at Lago Carisey: eclogite boudins are wrapped by S_2 foliation, which also collapses into boudin necks. e) Omp-Gln-rich enclaves within deformed metaquartzdiorite at Monte Mars, elongated parallel to eclogitic foliation. f) Cm-thick Gln-rich layers alternate with cm-thick eclogite layers and Omp-bearing gneisses. Eclogitic foliation is marked by SPO in Omp, Wm and Gln within gneisses, by Gln within glaucophanites and by Omp SPO within eclogites. **Mineral symbols used in the text**: **Ab** , albite; **Amp**, amphibole; **Bt**, biotite; **Chl**, chlorite; **Ctd**, chloritoid; **Ep**, epidote; **Fds**, feldspar; **Gl**, glaucophane; **Grt**, garnet; **Kfs**, K-feldspar; **Ky**, kyanite; **Omp**, omphacite; **Rt**, rutile; **Sil**, sillimanite; **Wm**, white mica; **Zo**, zoisite.

S_2 foliations are also distinguished on the basis of modal amounts of Omp and Amp. At the regional-scale, strain partitioning, during D_2 produced up to 100 metre-size volumes, with static mineral coronitic transformation of metaquartzdiorites. These volumes completely escaped Alpine deformation but recorded the mineralogical re-equilibration marked by the assemblage Qtz, Zo, Wm, Grt, Omp, ± Gl (e.g. Monte Mars and Monte Mucrone).

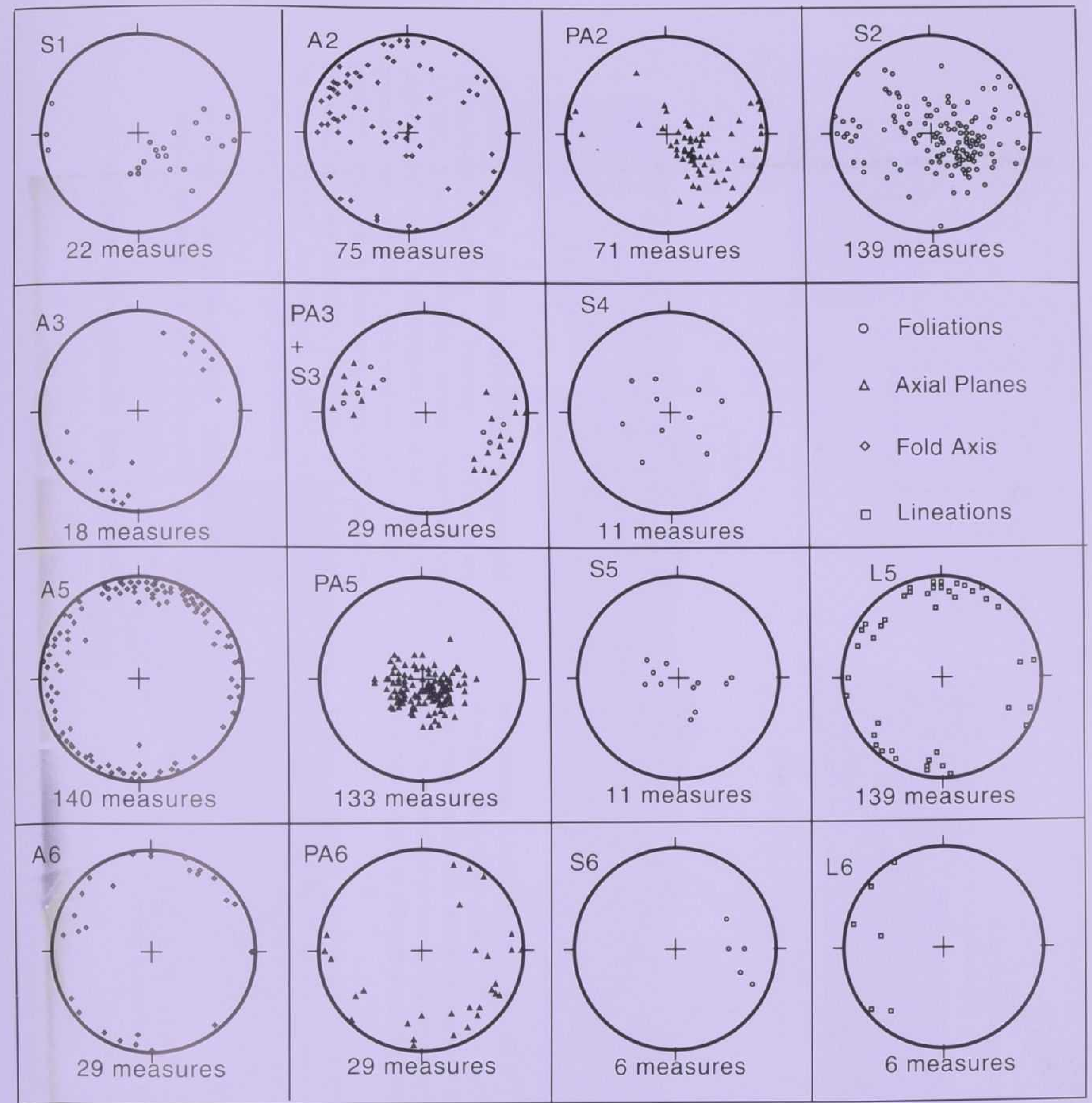
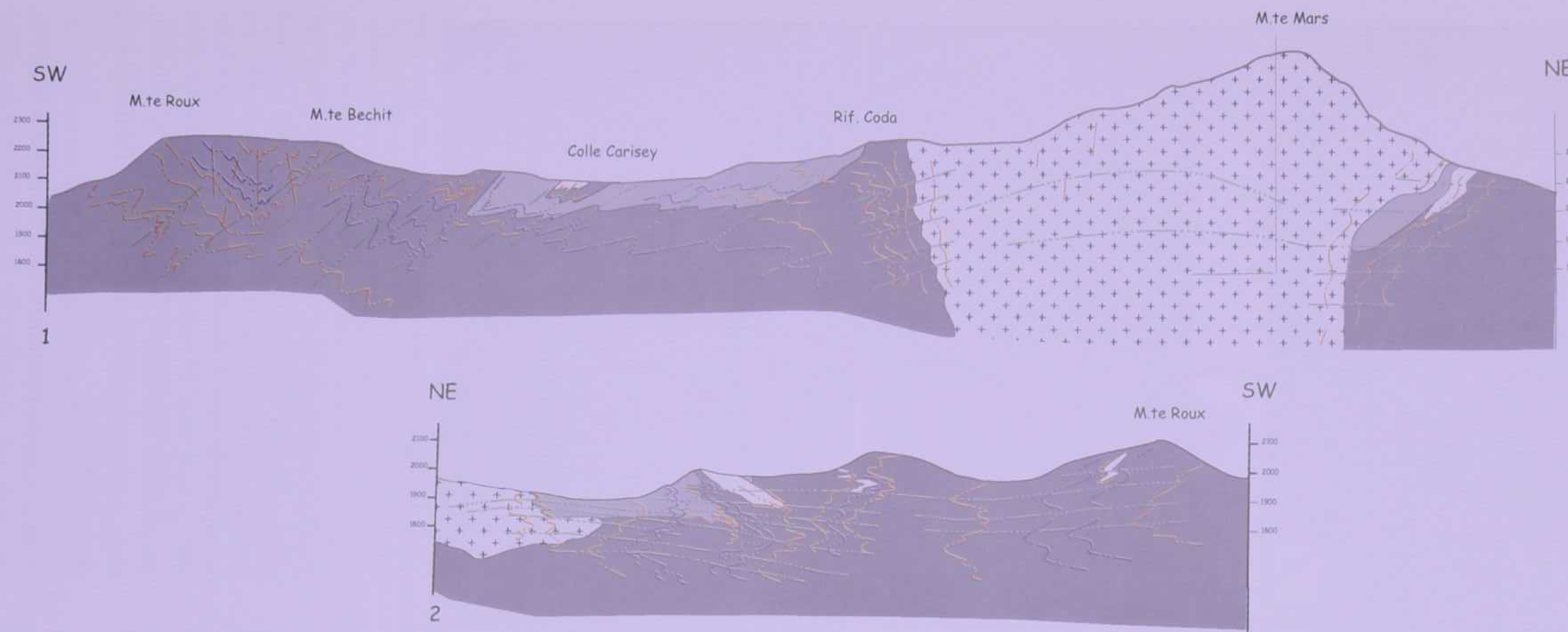


Fig. 4 - Schmidt projections (lower hemisphere) of fabric element orientations within metapelite, metaquartzdiorite, metabasite and quartzite. Synoptic diagrams.

D3 structures were only detected in the quartz-rich micaschists between Monte Bechit and Monte Roux (Table 1); they consist of an open to isoclinal fold system with nearly vertical axial planes and horizontal fold axes (Figs 4 and 7), marked by Omp and Amp SPO. In some places, S_3 crenulation cleavage, marked by SPO of Wm, Omp and Amp developed. D_3 folds are well marked by metre-sized gneisses and metagranitic lenses, where S_2 foliation, parallel with lithological boundaries, is folded by D_3.

D4 structures consist of thin (up to 10 cm) shear zones both within the metaquartzdiorite of Monte Mars-Monte Mucrone and metapelites. Within micaschists, they are marked by SPO in blue Amp, Wm and ribbon Qtz, and form an angle with S_2, ranging from 5° to 25°. In metaquartzdiorites, S_4 shear zones are marked mainly by SPO in blue Amp. In tectonitic volumes, S_4 shear zones are cm-thick and deflect the pre-existing S_2 foliation. Omp, marking S_2 foliation, is replaced by Amp (Gl) in S_4 shear zones.

D5 structures produce the most recurrent fold system (Figs 2, 3 and 7 and tabs 1-2). D_5 folds show tight to isoclinal geometry and range from centimetric to hectomet-



Micaschists: White mica (phengite, paragonite), omphacite, glaucophane, garnet, quartz, albite, chlorite, green amphibole, epidote (zoisite, clinozoisite, Fe-epidote), rutile, titanite. Dominant fabric is defined by S2 foliation marked by shape preferred orientation of Wm, Omp, Gln and Qtz; Grt- rich layers also mark the S2 eclogitc foliation.

Gneisses: White mica (phengite, paragonite), garnet, quartz, omphacite, glaucophane, albite, chlorite, green amphibole, epidote (zoisite, clinozoisitze, Fe-epidote), rutile, titanite. S2 foliation is dominant fabric; it is defined by Shape Preferred Orientation of Wm, Omp, Gln. Qtz and Grt- rich layers.

Ky-Ctd-Grt Quartzites: White mica (phengite and paragonite), garnet, chloritoid and kyanite quartzites.

Metaquartzdiorite: White mica (phengite, paragonite), garnet, quartz, omphacite, glaucophane, albite, chlorite, green amphibole, epidote (zoisite, clinozoisitze, Fe-epidote), rutile, titanite. In metre-size undeformed volumes igneous textures are well preserved. Within tectonitic to mylonitc volumes main foliation is marked by Shape Preferred Orientation of omphacite, glaucophane, white mica and epidote

Meta-alpitic dykes:white mica, epidote (zoisite, clinozoisite and Fe-epidote), albite, clorite

Marbles and silicate-rich marbles

Table 1 - Geological cross-sections 1 and 2 of petro-structural map and corresponding legend

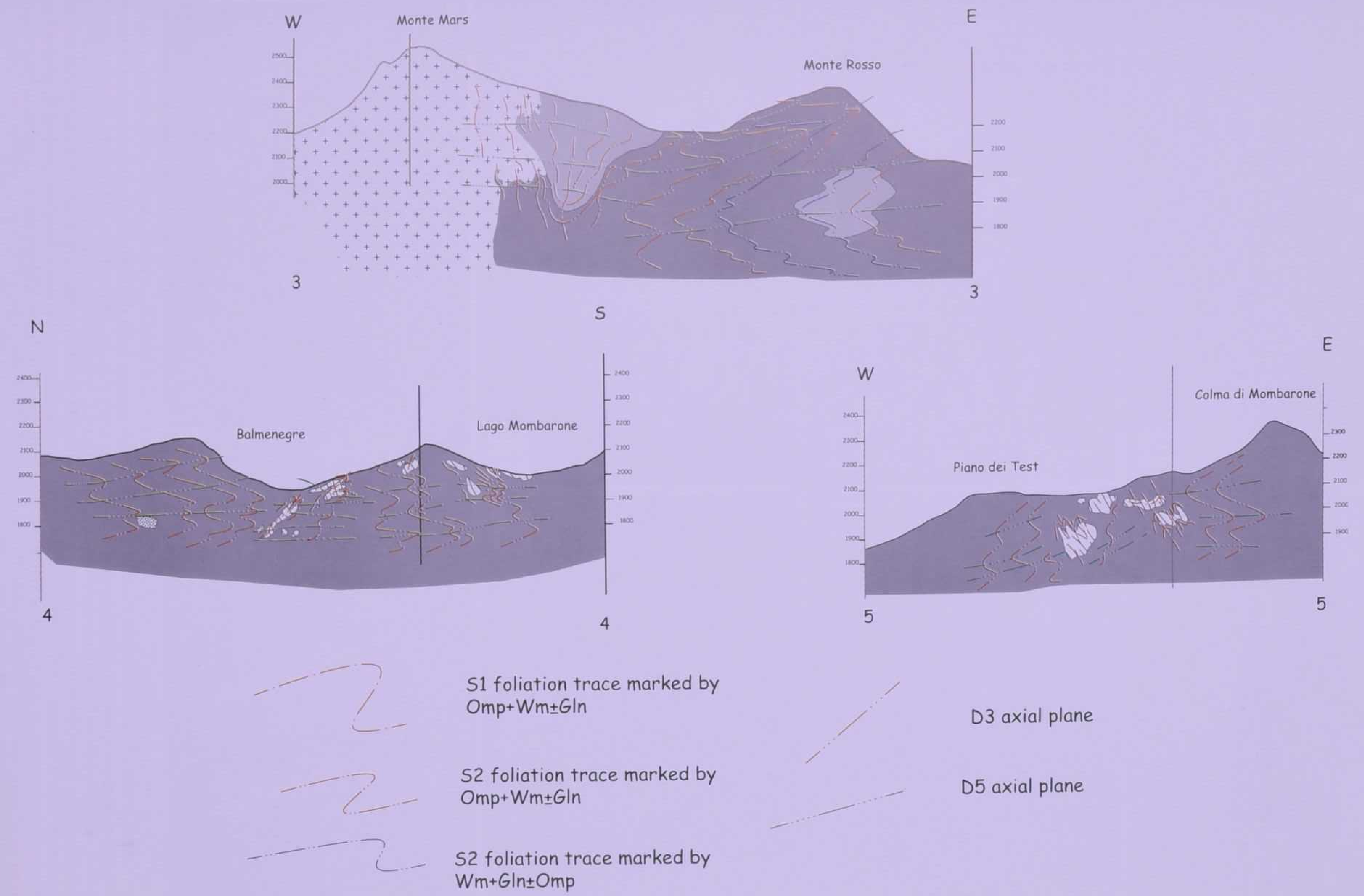


Table 2 - Geological cross-sections 3, 4 and 5 of petro-structural map and symbols of the foliation traces

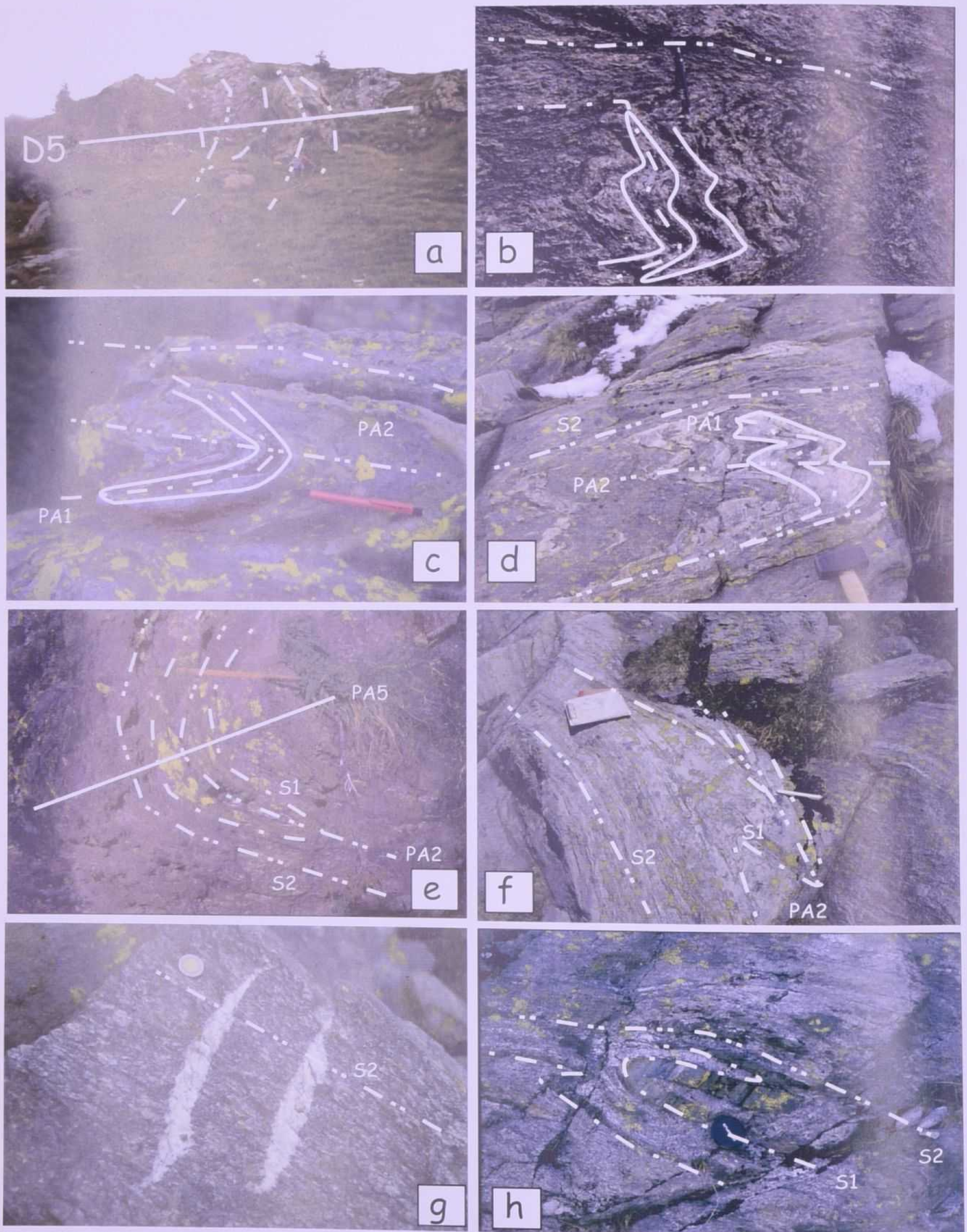


Fig. 5 - D_1 and D_2 mesostructures within various lithologies: a) S_1 foliation within micaschists and impure marbles at Balmenegre is refolded by D_2 folds, marked by a vertical axial plane foliation; D_5 gently dipping folds slightly bent this structure. b) Centimetre scale D_1 folds with axial plane S_1 foliation folded during D_2. S_2 foliation, marked by Ky, Ctd and Wm SPO, wraps relict domains. c) Superimposed D_1+D_2 folds defined by quartz multi-layer within Omp-Grt-bearing gneisses at Monte Rosso-Colle Chardon. d) Transposed S_2 foliation within Omp-Gln bearing micaschists at Colle Chardon. D_1 and D_2 rootless hinges still preserved within decimetre thick domains. e) Type 3 (Ramsay, 1967) refolded folds (D_2+D_5) at Colle Carisey; S_1 eclogitic foliation, marked by SPO of Gln, Omp and Wm within micaschists, is only preserved in rootless centimetre scale fold hinges. f) Metre size meta-aplitic dykes well preserve D_2 folds embedded within S_2 foliation underlined by SPO of Wm+Omp+Qtz. g) Eclogitic foliation underlined by Wm+Ep±Omp±Gln within metaquartzdiorite of Monte Mars. h) S_1 and S_2 foliation marked by elongated eclogite layers within micaschists. S_1 foliation is preserved only within micaschists and is parallel with lithological boundaries.

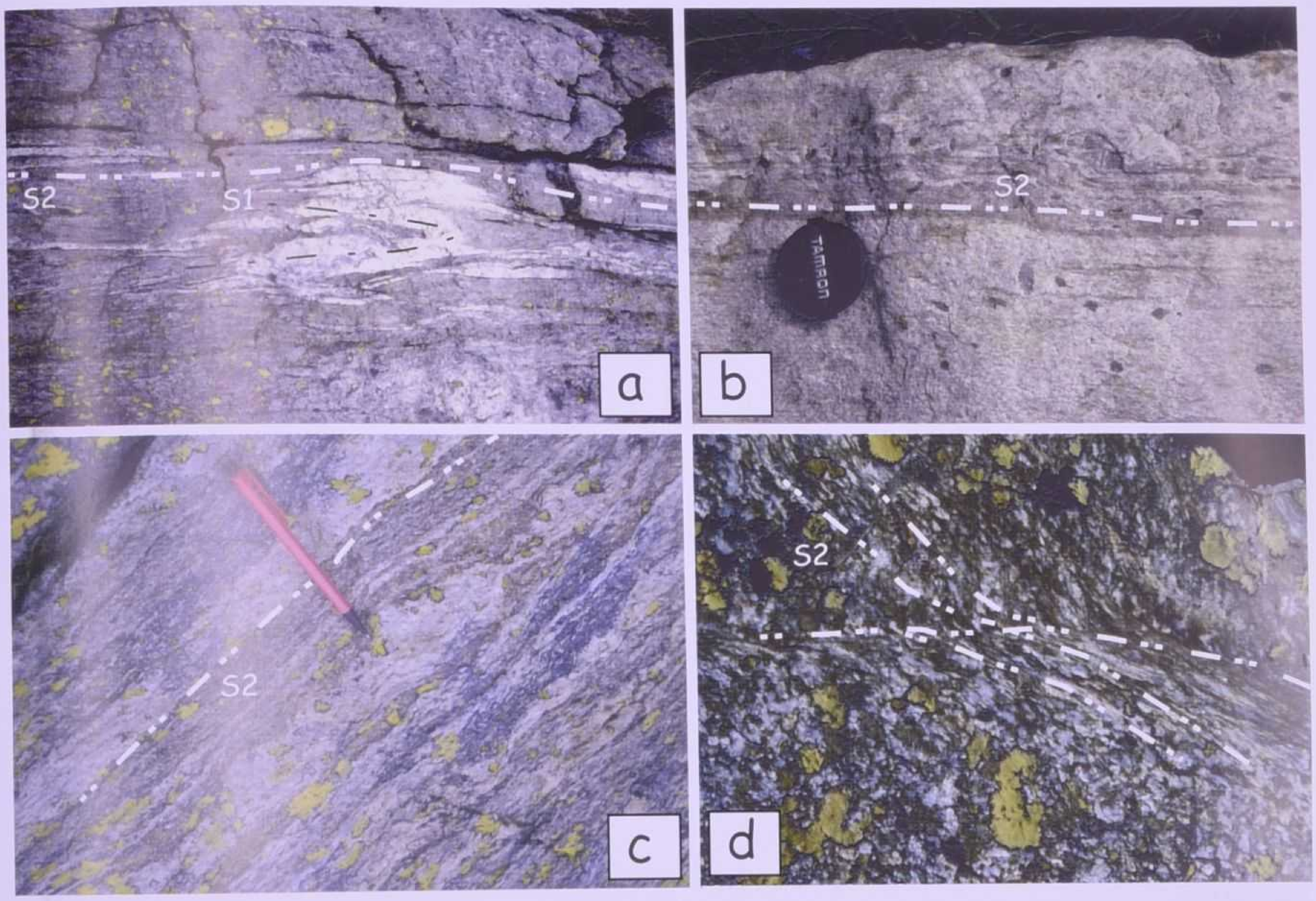


Fig. 6 - a) S_2 foliation within Omp-bearing micaschists. Thin metaaplitic levels also define S_2 eclogitic foliation; D_2 folds are rootless fold hinges with axial surface plane parallel with S_2. b) S_2 foliation within Gln-bearing micaschists; S_2 is underlined by SPO in Wm and Gln. Large Gln porphyroblasts are wrapped by Wm within S_2 foliation. c) S_2 foliation within gneisses; marked by SPO of Wm within mica-rich layers and by Ep+Qtz and Gln SPO within Qtz-rich layers.

ric in size, with a sub-horizontal dipping axial plane. In micaschists and gneisses, D_5 produces overprinting patterns of type 2 (Ramsay, 1967), generated by the overprinting of D_5 on to D_2 folds (figs 4f and 4g); locally, differentiated axial plane foliation occurs (S_5), marked by SPO in Chl, Ab, green Amp and Wm. S_5 mainly develops in the fold hinges of micaschists and quartzites. At Monte Rosso, D_5 deformation is associated with a L_5 lineation, due to the intersection of S_5 with S_2, marked by SPO in Wm. In marbles, in the southern part of the area (Mombarone-Druer), large-scale D_5 folds, with a horizontal axial surface, are rounded to cuspate in shape, with no axial plane foliation. In metaquartzdiorites, D_5 are open folds with no axial plane foliation. At the boundary between metaquartzdiorites and surrounding micaschists, S_5 foliation develops in metaquartzdiorites, and D_5 folds are tighter. Where D_5 bends lenses of metabasites, no axial plane foliation develops and folds are open in shape. D_5 bends boundaries between main lithotypes, which are generally parallel with S_2, describing a large recumbent fold system with a gently dipping axial plane. Metagranitic lenses at Colle Carisey, marbles at Balmenegre and metagranitoids between Montagnit and Colle Chardon describe large-scale D_5 folds and superimposed folds (D_2 + D_5). D_5 structures are re-oriented by the successive deformation phase D_6. Omp, Gl and Grt grains are often rimmed by corona reaction rims, formed of greenschist facies minerals, such as Ab, green Amp and Chl.

D6 in micaschists and gneisses is characterised by local cm-sized ductile shear zones in which Wm and Chl define S_6 planes. Large-scale D_6 deformation results in gentle undulation of the S_2 foliation and kilometre-scale D_5 fold system. Within small volumes of metapelites, D_6 is associated with an intersection lineation (L_6), mainly marked by SPO of Wm and Chl. D_6 structures also consist of brittle-ductile small faults and Chl joint systems.

Post-D_6 structures The *andesitic dykes* are m-thick and mainly 10-m long; they are preserved at Monte Rosso (Fig. 7) and Colle Carisey – Monte Bechit, where they crosscut at a high angle the S_2 foliation and D_5 folds and D_6 shear planes in metapelites and metagranitic lenses.

CONCLUSIONS

This petro-structural map interpretatively reproduces tectonics of the structural imprints, attributed to the pre-

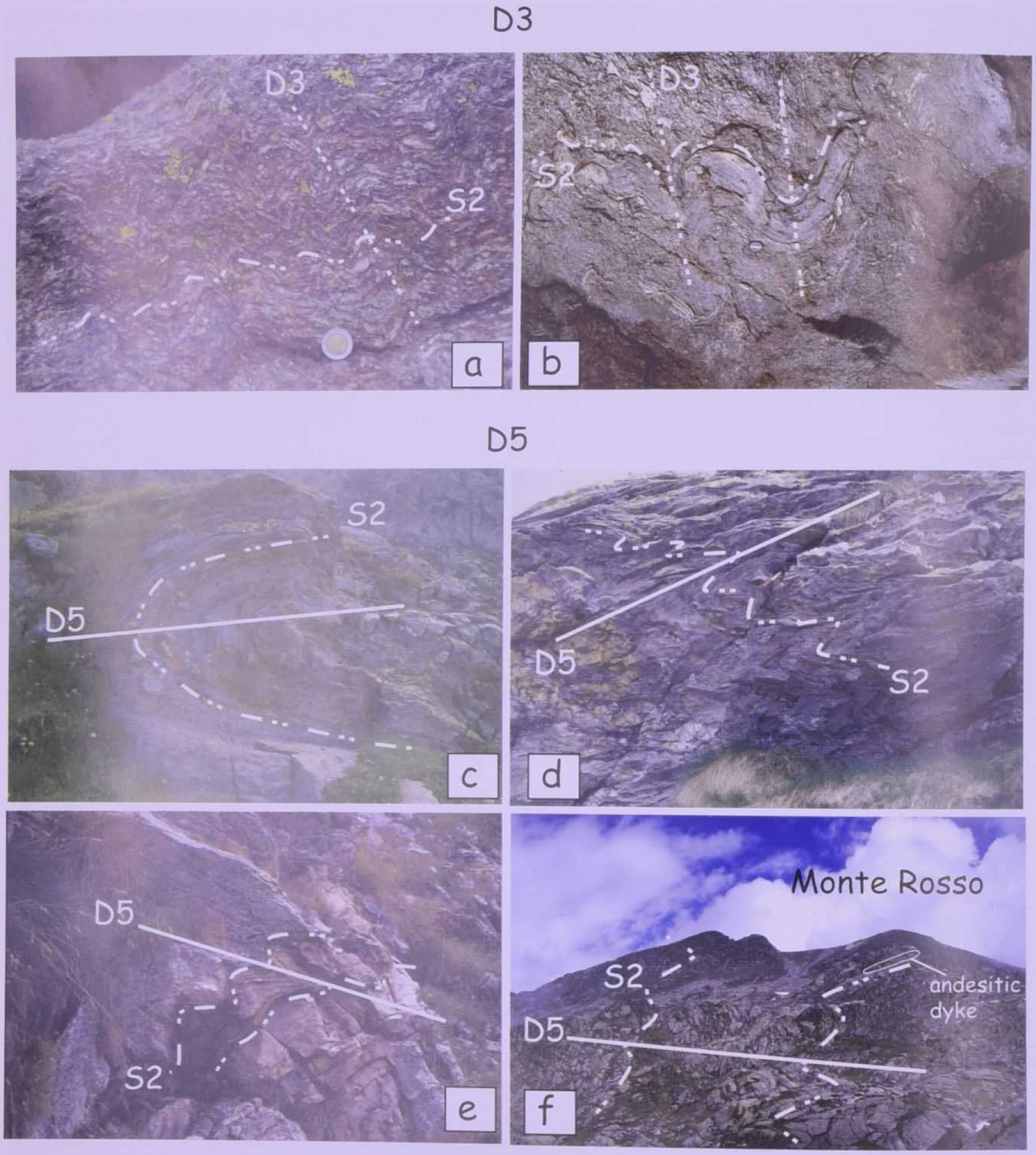


Fig. 7 - a) D_3 sub-vertical centimetre-scale folds within quartz-rich micaschists at Monte Bechit; S_2 foliation is crenulated at centimetre scale and Omp grains marking foliation are gently bent during D_3. b) Eclogite boudins embedded within Omp-bearing micaschists refolded during D_3. c) Gently dipping metre-scale D_5 folds within micaschists and glaucophanite. D_5 axial plane surface is locally associated with a S_5 foliation within micaschists. d) D_5 folds in micaschists at Monte Rosso; associated with D_5 folds locally developed axial plane crenulation cleavage marked by SPO of Chl and Wm. e) D_5 gently dipping folds at Druer-Balmenegre within Ctd-Ky-Grt bearing quartzites and pure-impure marbles. f) Large-scale D_5 folds at Monte Rosso: the S_2 foliation marked by SPO Omp, Gln and Wm describe open D_5 folds. In places, axial plane is marked by centimetre-scale S_5 crenulation cleavage. Decametre-size andesitic dyke crosscuts S_2 foliations and D_5 axial planes.

Alpine crustal thinning (Lardeaux and Spalla, 1991) and to the Alpine subduction cycle of the Eclogitic Micaschists Complex, between Monte Mucrone-Monte Mars and Mombarone (lower Aosta Valley, Val di Gressoney and Biellese, Italian Western Alps). There are various pre-Alpine structures: e.g. S_{pre1} foliation, marked by HT/LP mineralogical assemblages, within metre-thick metapelitic lenses; preserved igneous textures within the Monte Mars

– Monte Mucrone low-strain metaintrusive body of Permian age (Bussy *et al.*, 1998). The Alpine evolution is characterised by the development of penetrative S_1 foliation marked by eclogite facies mineralogical assemblages, well preserved within micaschists, gneisses and silicate-rich marbles at Mombarone. However, the most penetrative foliation in the whole area is an S_2 plane, marked by eclogite facies minerals, and well recorded in all lithologies. The D_3 deformation phase, recorded only at Monte Bechit - Monte Roux, produces from tight to isoclinal metre-sized folds associated, in places, with S_3 crenulation cleavage; where S_3 occurs, it is marked by Wm + Omp ± Amp ± Grt, suggesting that it develops in eclogite facies conditions. The D_4 deformation phase develops from mm- to cm-sized shear zones marked by Wm + Amp (Gl) + Ttn + Czo + Grt in metapelites and metaquartzdiorites, suggesting that it develops in epidote-blueschist facies conditions. D_5 structures mainly consist of isoclinal recumbent folds, only locally associated with a crenulation cleave. S_5 crenulation cleavage mainly develops in metapelite, where it is marked by Wm, Pl, Czo and Chl (greenschist facies conditions).

Structures which developed in eclogite facies conditions (S_1, S_2, D_3), control structural and metamorphic re-equilibration in the area. Large-scale lithological boundaries are mainly parallel with S_1 and S_2. S_1 foliation and interference patterns between D_2 and D_5 folds mainly control the geometry of the Monte Mars – Monte Mucrone metaquartzdiorite. The main contacts between metaintrusive rocks and surrounding metapelites are parallel with S_1 foliation; D_2 structures, in the eastern part of the metaintrusive body, fold this contact, developing in places a new penetrative foliation (S_2), which crosscuts lithological boundaries. D_5 folds post-date these structures, producing a large-scale "type 3" interference pattern (Ramsay, 1967). Similar large-scale interference patterns occur in the southernmost part of the map where marbles and Ctd – Ky – Grt-bearing quartzites describe plurimetric D_2 + D_5 folds.

This structurally and petrologically oriented map highlights the complex network of foliations, in which older structures are wrapped by the most penetrative one (S_2), later folded and crosscut by earlier structures and foliations (e.g. D_3, S_5). The overprinting of structures also corresponds to the juxtaposition of volumes dominated by different mineralogical assemblages, which developed in different metamorphic conditions (e.g. kinzigites, marked by Bt, Pl and ex-Sill or Chl, Ab, Czo-bearing metapelites close to Omp, Gl, Grt-bearing metapelites at Monte Rosso). The analytical method used to prepare this map is a primary tool to correlate superimposed structures with respect to their tectono-metamorphic evolution and to show the heterogeneity of deformation and related metamorphic imprints on map scale: the meso- and micro-scale heterogeneous structural and metamorphic imprints within the Sesia-Lanzo Zone, as shown in the literature (see table b in figure 2) may easily be explained by strain-controlled metamorphic imprinting, partitioned on the mega-scale. Conversely, meso to mega-scale field correlations, only based on structural orientation and style of superposed structures, may lead to large scale misunderstandings if attention is not paid to correlating volumes characterized by the same structural and metamorphic evolution.

ACKNOWLEDGEMENTS

M.I. Spalla and G. Gosso are greatly thanked. Rifugio Coda and Funivie Mucrone supported fieldwork with their hospitality. Careful reviews of G.V. Dal Piaz and J.-M. Lardeaux greatly improved the manuscript. This work was financially supported by MURST "Cofin" and CNR Agenzia2000 fundings, with contributions for printing from the former "CNR-Gruppo di Ricerca per la Geodinamica del Sistema Alpi-Appennino".

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Issued, November 2002