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Foliation relationships and structural facing vs. vergence determinations in refolded low-grade metamorphic rocks: an example from the Tuscan Metamorphic 'Basement' (Northern Apennines, Italy)

Andrea Brogi*

Dipartimento di Scienze della Terra, University of Siena, Via Laterina 8, 53100 Siena, Italy

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Abstract

Three tectonic foliations and their angular relation with bedding allow the determination of facing vs. vergence and fold interference pattern in polyphase low-grade metamorphic terrains, composed of Palaeozoic and Triassic turbiditic rocks cropping out in the inner part of the Northern Apennines (Mt Leoni area). The D_1 deformational event (Late Oligocene–Early Miocene) is typified by southeast-verging folds (F_1) and related tectonic foliation (S_1) with a HP–LT mineralogical assemblage, developed during the emplacement of the Northern Apennines tectonic units. The D_2 deformational event (Early–Middle Miocene) caused F_2 east-verging folds and related tectonic foliation (S_2) during greenschist facies metamorphism. The D_3 deformational event (Middle Miocene–?) formed F_3 gentle upright folds with a foliation (S_3) developed only in the fold closures, and never accompanied by blastesis. Foliation angular relationships, as well as their intersections with the bedding, allowed us to define the facing, vergence and interference pattern of map-scale folds. Where a penetrative S_2 crenulation-cleavage affected the metapelitic tops of turbiditic strata, S_1 structural facing could be misinterpreted at the outcrop scale, simulating a northwest-vergence of F_1 folds. This is due to a false dihedral angle between S_0 and S_1 occurring in the metapelites due to the rotation of S_1 in the hinges of the overprinting crenulation-cleavage domains (S_2).

Keywords: Foliations relationship; Structural facing; Fold vergence; Low-grade metamorphic rocks; Northern Apennines

1. Introduction

The angular relationship between foliation and bedding, when the younging of the strata is defined, provides a means to determine the fold facing vs. vergence in folded terrains (Shackleton, 1957; Bell, 1981). Angular relationship between bedding and two or more tectonic foliations can also provide useful information on polyphase folded and metamorphosed terrains where superimposed foliations on bedding can produce a complex geometrical pattern. The concepts of foliation (or cleavage) vergence and foliation facing, as well as fold vergence and fold facing have been discussed by Bell (1981) and summarised in Fig. 1.

During fieldwork, systematic recording of foliation vergence and foliation facing from two or more foliations, greatly simplifies the mapping in areas characterised by polyphase folding, helping to determine the position of the fold hinges where poor outcrops inhibit the mapping of fold closures. This is very helpful in clarifying the folds interference pattern, providing fundamental information for establishing the folds facing.

Turbiditic rocks of low-grade metamorphic grade are suitable for studying the relationship between fabric development and folding (Kraus and Williams, 1997 and references therein), because the deformational and metamorphic processes produce more or less penetrative tectonic foliations mainly visible in the metapelitic tops, and the stratigraphic polarity can be easily recognised. In this case, where low-grade, graded metaturbidite layers are affected by at least two folding events and the earlier foliation was overprinted by a later crenulation-cleavage, structural vergence of the earlier foliation can be potentially misinterpreted (Henderson, 1997; Johnson, 1999). False foliation relationships can develop during a later folding

* Tel.: +39 577 233 972; fax: +39 577 233 938.
E-mail address: brogiandrea@unisi.it.

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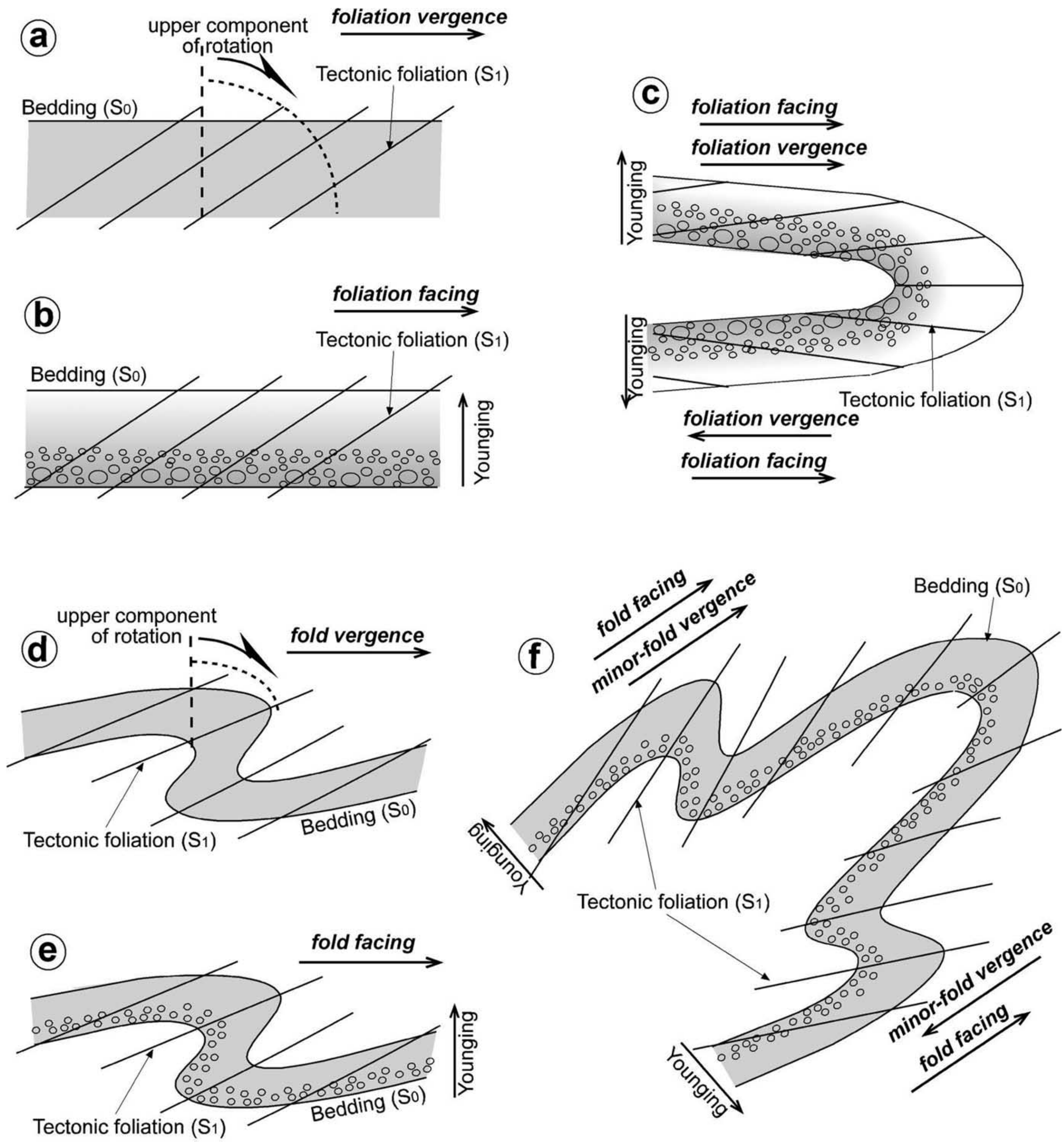

Fig. 1. Cartoon summarising facing and vergence concepts both on foliation and fold as defined by Shackleton (1957) and Bell (1981). The definition of foliation vergence (a) is independent of the stratigraphic polarity that became essential to define the foliation facing (b). Foliation vergence and foliation facing are compared in the different limbs of an overturned fold (c); there, foliation vergence contrasts with foliation facing in the overturned limb. In addition, fold vergence is independent of the stratigraphic polarity (d), but this is essential for fold facing determination. In an overturned major fold with parasitic structures (minor folds), fold facing and fold vergence are in contrast to the overturned limb (f).

event and microstructural analyses provide a useful way to determine the true vergence (Johnson, 1999).

The Tuscan Metamorphic 'Basement', in terms of low-grade metamorphism, tectonic history and lithological assemblage, is very suitable for structural facing and vergence determination as a tool for understanding macroscale structural geometries. In particular, in the Mt Leoni area (Fig. 2), the geometrical features of folds affecting the Tuscan Metamorphic 'Basement' were refined using this tool, and microstructural studies combined with

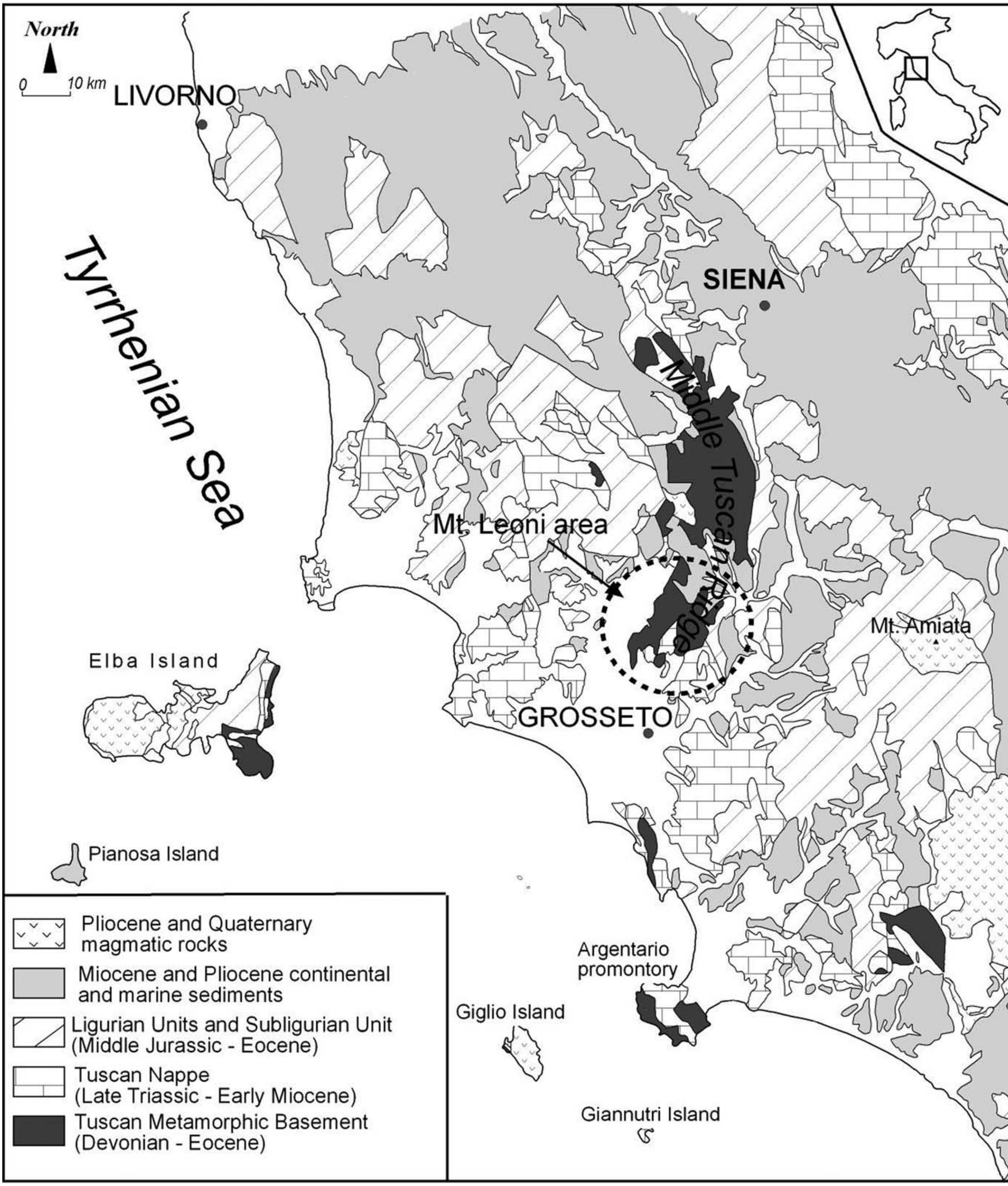

Fig. 2. Geological sketch-map of southern Tuscany and the location of the Mt Leoni area.

outcrop-scale analyses highlighted that, in some cases, foliation/bedding angles are rotated, supporting Johnson's (1999) concept. This can be misleading for folds vergence and facing determination.

2. Geological setting of Mt Leoni

The Mt Leoni area (Fig. 3) represents the southern prolongation of the Middle Tuscan Ridge (Fig. 2), an

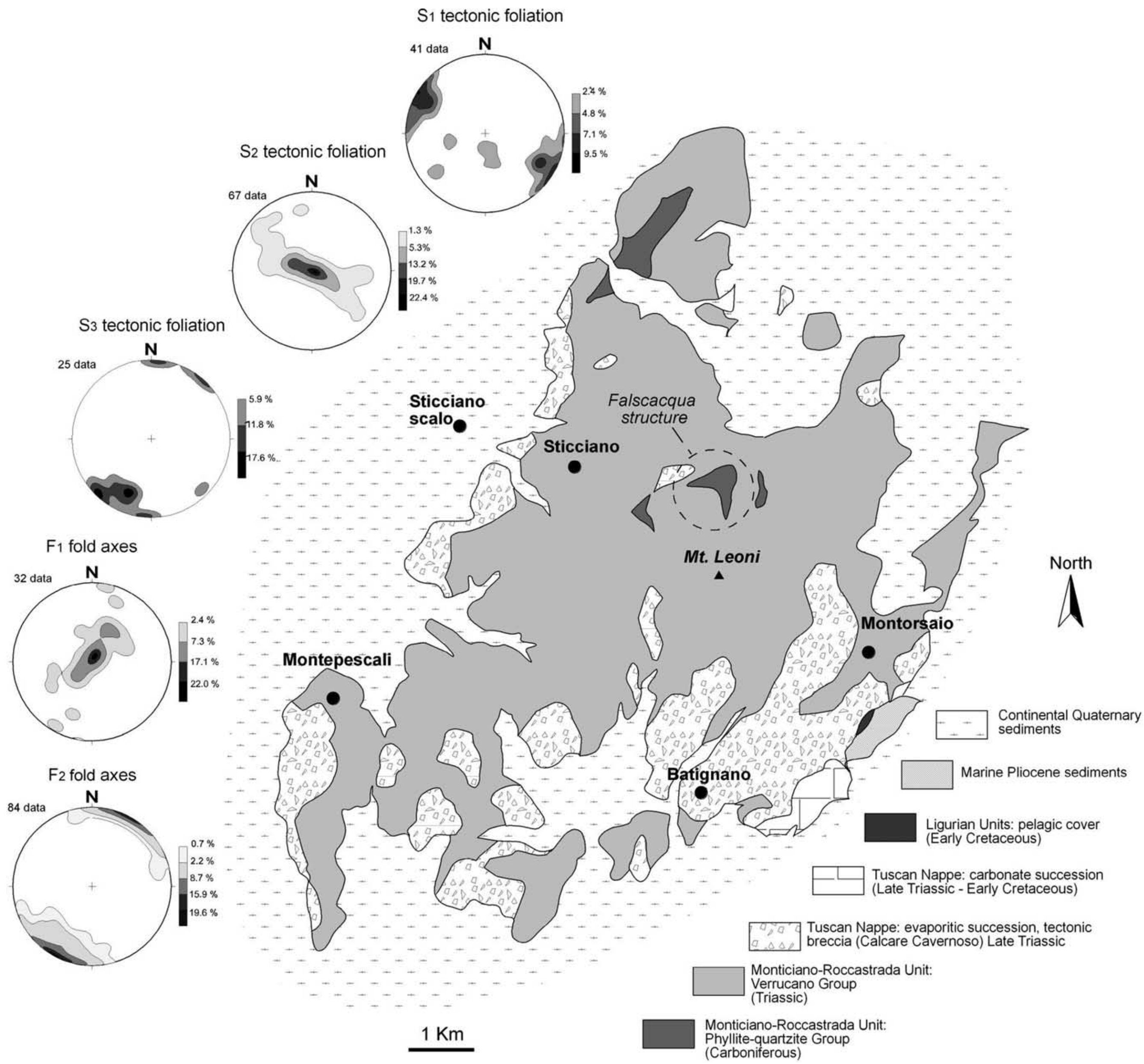

Fig. 3. Simplified geological map of the Mt Leoni area. Stereonets (lower hemisphere, Schmidt diagram) indicate the main structural elements detected in the study area.

arcuate geomorphologic feature extending from the Alpi Apuane to the Argentario Promontorio, in which the deepest outcropping metamorphic rocks of the Northern Apennines are exposed (Monticiano–Roccastrada Unit, Devonian–Eocene). These rocks were affected by HP/LT (Giorgetti et al., 1998; Brunet et al., 2000) to greenschist (Franceschelli et al., 1986) metamorphism during the Northern Apennines collisional event and later extension during orogenic collapse (27–11 Ma; Giglia and Radicati di Brozolo, 1970; Kligfield et al., 1986; Deino et al., 1992). The Monticiano–Roccastrada Unit is overlain by non-metamorphic tectonic units composed of the crustal oceanic remains and their pelagic cover (Ligurian Units, Middle Jurassic–Eocene) and the sedimentary cover of the Adria continental crust (Subligurian Unit, Palaeocene–Eocene and Tuscan Nappe, Triassic–Early Miocene) (Carmignani et al., 2001 and references therein).

The Monticiano–Roccastrada Unit cropping out in the Mt Leoni area (Fig. 3) consists of two groups, which are, from top to bottom, the Verrucano Group (Triassic) and the Phyllite Quartzite Group (Carboniferous–Permian) (Gelmini, 1969; Meccheri et al., 1987; Moretti, 1991; Aldinucci et al., 2005). The Verrucano Group is composed of, from bottom to top (Aldinucci et al., 2005) (Fig. 4): the Civitella M.ma Fm. composed of continental and transitional metaconglomerates, quartzose metasandstones and

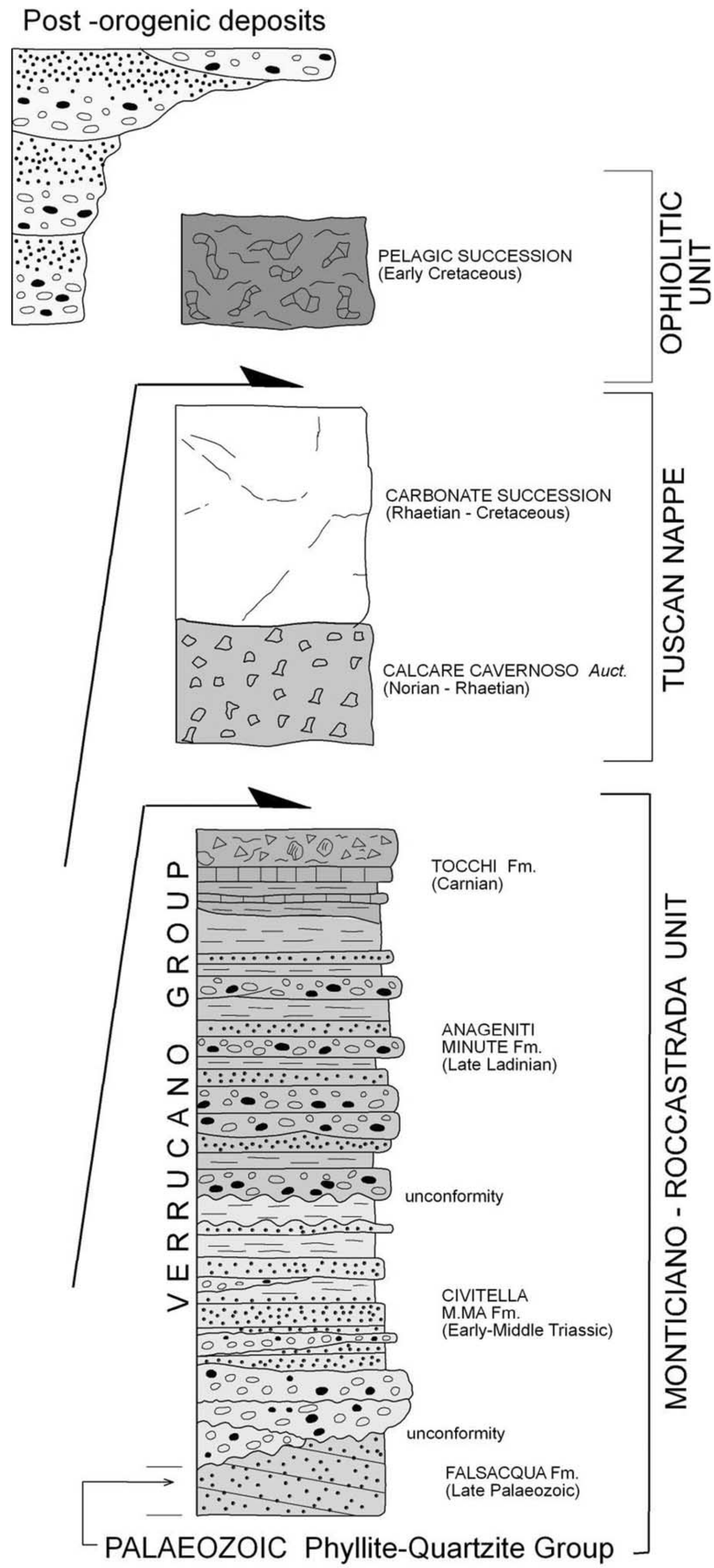

Fig. 4. Tectono-stratigraphical relationships between the tectonic units occurring in the Mt Leoni area (from Aldinucci et al., 2005, modified).

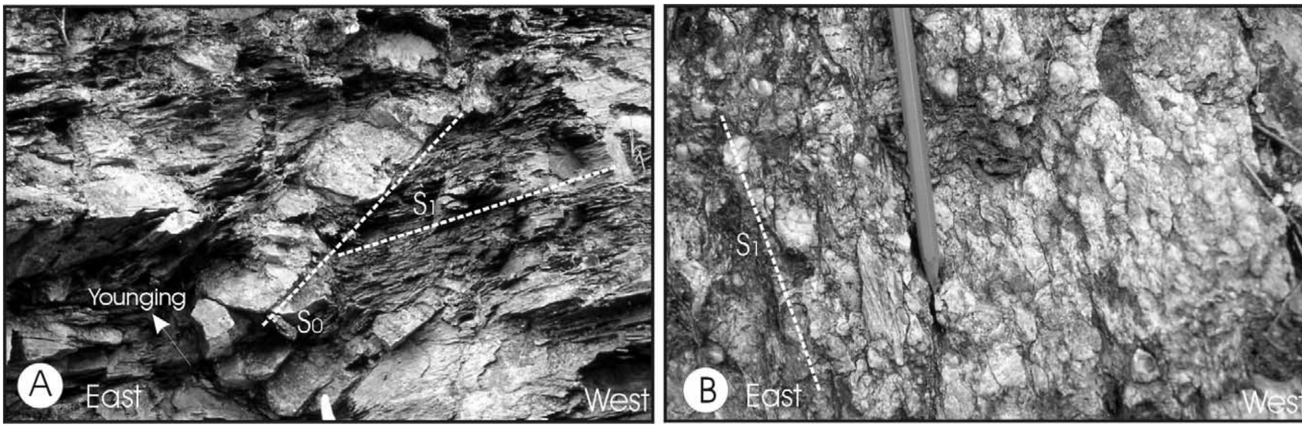

Fig. 5. Bedding/foliation (S_1) relationship as observed in different lithotypes: (A) in the Palaeozoic metasandstones and metapelites (Falsacqua Fm.); S_1 is very penetrative in the metapelites and poorly evident in the metasandstone beds (finger in the lower side of the photo for the scale); (B) in the Triassic quartzose metaconglomerate (Civitella M.ma Fm.) typified by a widespread quartz-clasts flattening.

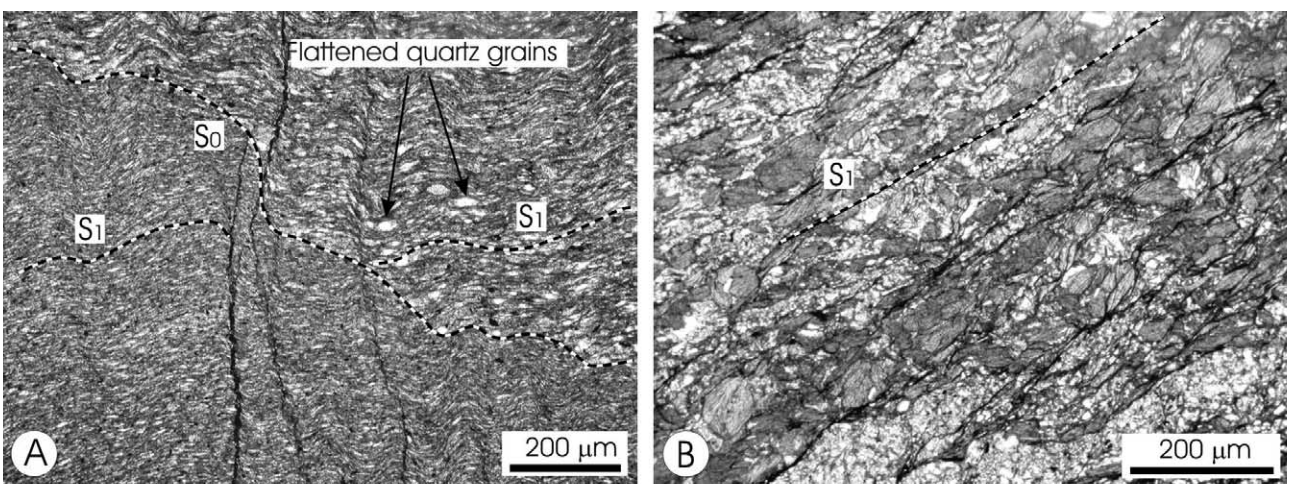

Fig. 6. Microphotographs of samples affected by S_1 tectonic foliation, definable as continuous foliation (*sensu* Passchier and Trouw, 1996). Microphotograph (A) (plane-polarised light; Civitella M.ma Fm. metapelites and very fine metasandstone) shows strongly flattened quartz grains aligned on the S_1 foliation. Microphotograph (B) (plane-polarised light; Civitella M.ma Fm. very fine metasandstone) shows detrital phyllosilicates, such as white mica and chlorite, rotated and reoriented along S_1 foliation.

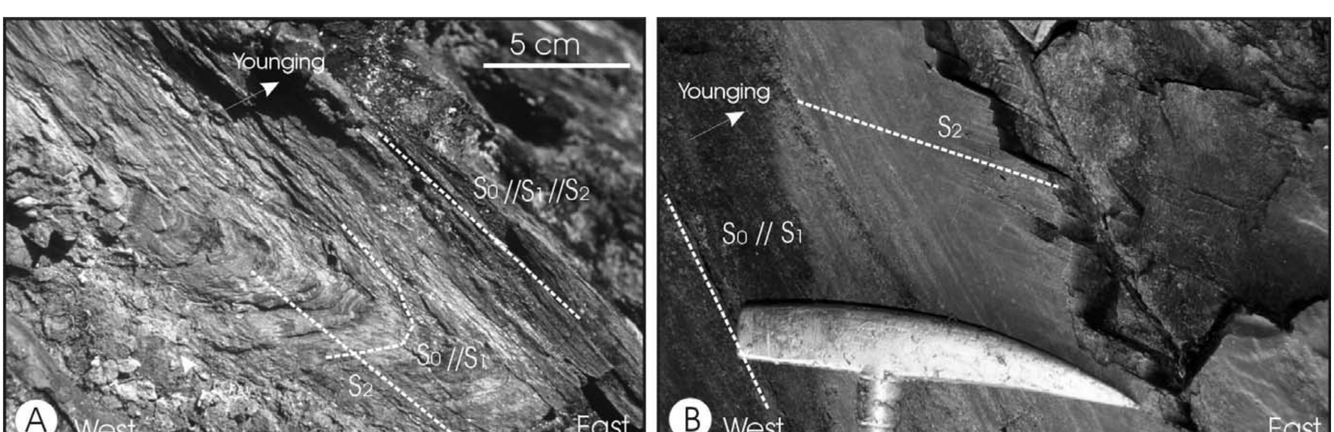

Fig. 7. S_2 at the outcrop scale. Such a foliation is very pervasive in the metapelites, mainly at the hinge of F_2 folds (A) or at the pelitic tops of the metaturbiditic strata (B). In both cases, S_2 shows the spaced cleavage features.

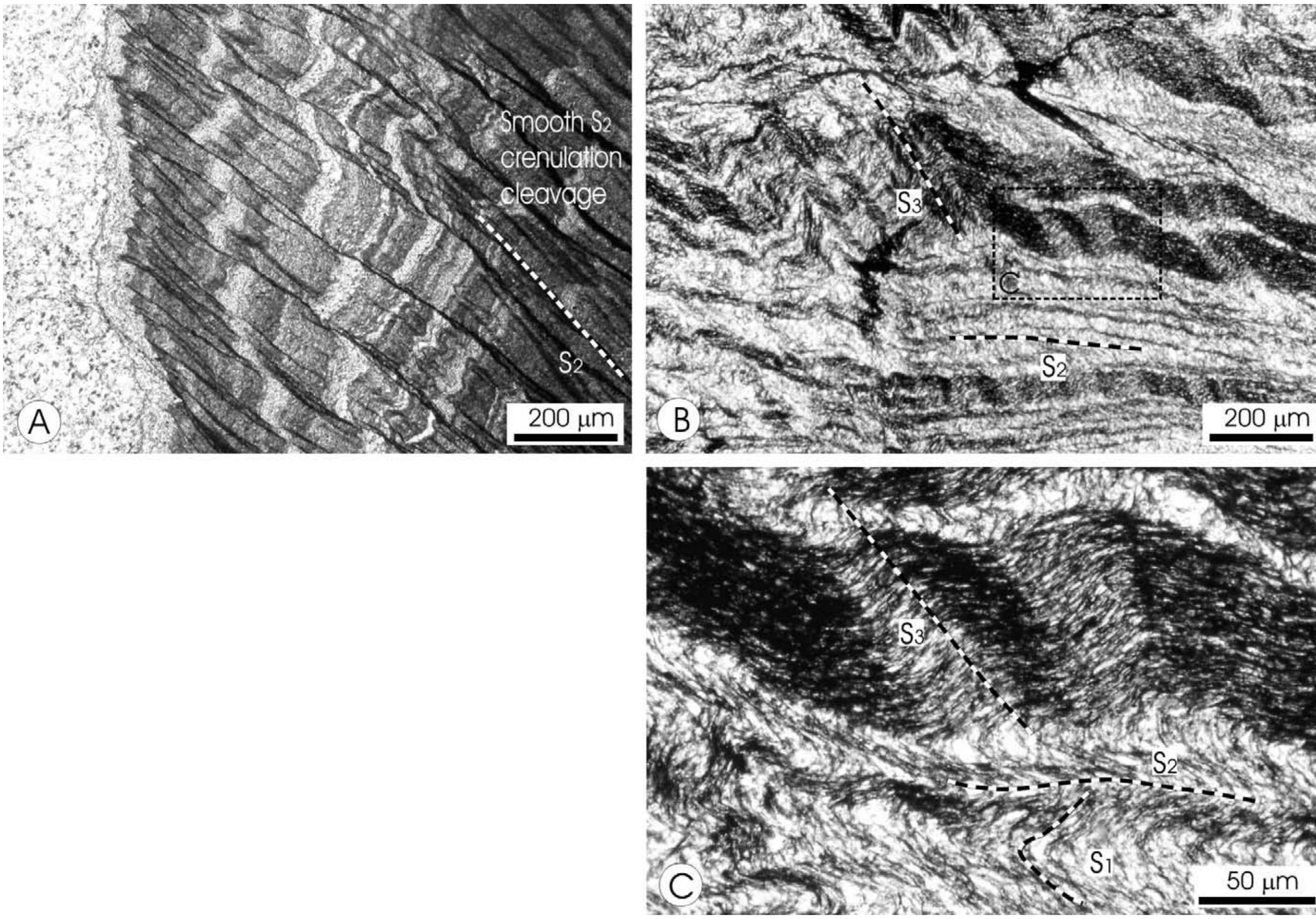

Fig. 8. (A) Microphotograph (plane-polarised light) of metapelite and very fine metasandstone belonging to the Civitella M.ma Fm. affected by S_2 tectonic foliation, definable as rough and smooth crenulation-cleavage (*sensu* Passchier and Trouw, 1996). (B) Microphotographs (plane-polarised light) of metapelite belonging to the Civitella M.ma Fm. affected by S_3 tectonic foliation superimposed on S_1/S_2 foliations. S_3 is only developed in the phyllosilicate films; such a foliation is definable as smooth crenulation-cleavage (*sensu* Passchier and Trouw, 1996). (C) Detail of B.

metapelites (Early–Middle Triassic); the Anageniti Minute Fm. composed of continental to transitional metaconglomerates and quartzose metasandstones (Late Ladinian); and the Tocchi Fm. composed of marine metacarbonates and metapelites (Carnian). The Palaeozoic Phyllite Quartzite Group is only represented by a Carboniferous succession (Falsacqua Fm. in Aldinucci et al. (2005) and references therein) composed of alternating graphitic metapelites and metarenites with metacarbonate beds at the top. These metamorphic formations are discontinuously covered by klippens consisting of the basal succession of the Tuscan Nappe, composed of Triassic evaporites (Burano Fm.), and their alteration products, a carbonatic breccia named as the Calcare Cavernoso Fm. (Gelmini, 1969; Moretti, 1991; Aldinucci et al., 2005).

Multiple deformation events affected the metamorphic rocks cropping out in the Middle Tuscan Ridge during the Northern Apennines structural evolution (Costantini et al., 1988; Conti et al., 1991; Corsi et al., 2001; Liotta, 2002; Lazzarotto et al., 2003). During the first deformation event (D_1), reverse faults and isoclinal east- and southeast-verging folds (F_1) developed. F_1 folds are typified, at present, by mainly N–S and/or NE–SW striking meso- to map-scale structures. An axial planar tectonic foliation (S_1), consisting of a pervasive slaty-cleavage mainly developed in the fine-grained lithotypes, is associated with the folds. The successive deformation event (D_2) was typified by micro- to map-scale asymmetric folds (F_2) and an associated locally pervasive crenulation-cleavage (S_2). F_2 fold axes are mainly NNE–SSW-oriented, east-verging and frequently exhibit recumbent attitude and overturned shorter limbs. S_2 is very pervasive in the metapelites and discontinuous in the metasandstones. A later deformation event (D_3) produced map-scale gentle folds (F_3) with axial directions mainly NE–SW-oriented. They are characterised by a spaced tectonic foliation (S_3) only developed close to fold closures. Extensional structures consisting of normal faults developed during the Miocene–Quaternary times and displace the earlier structures (Carmignani et al., 1994).

3. Description of the tectonic foliations

In the Mt Leoni area, all three deformational events (D_1, D_2 and D_3) affected the metamorphic rocks and caused the

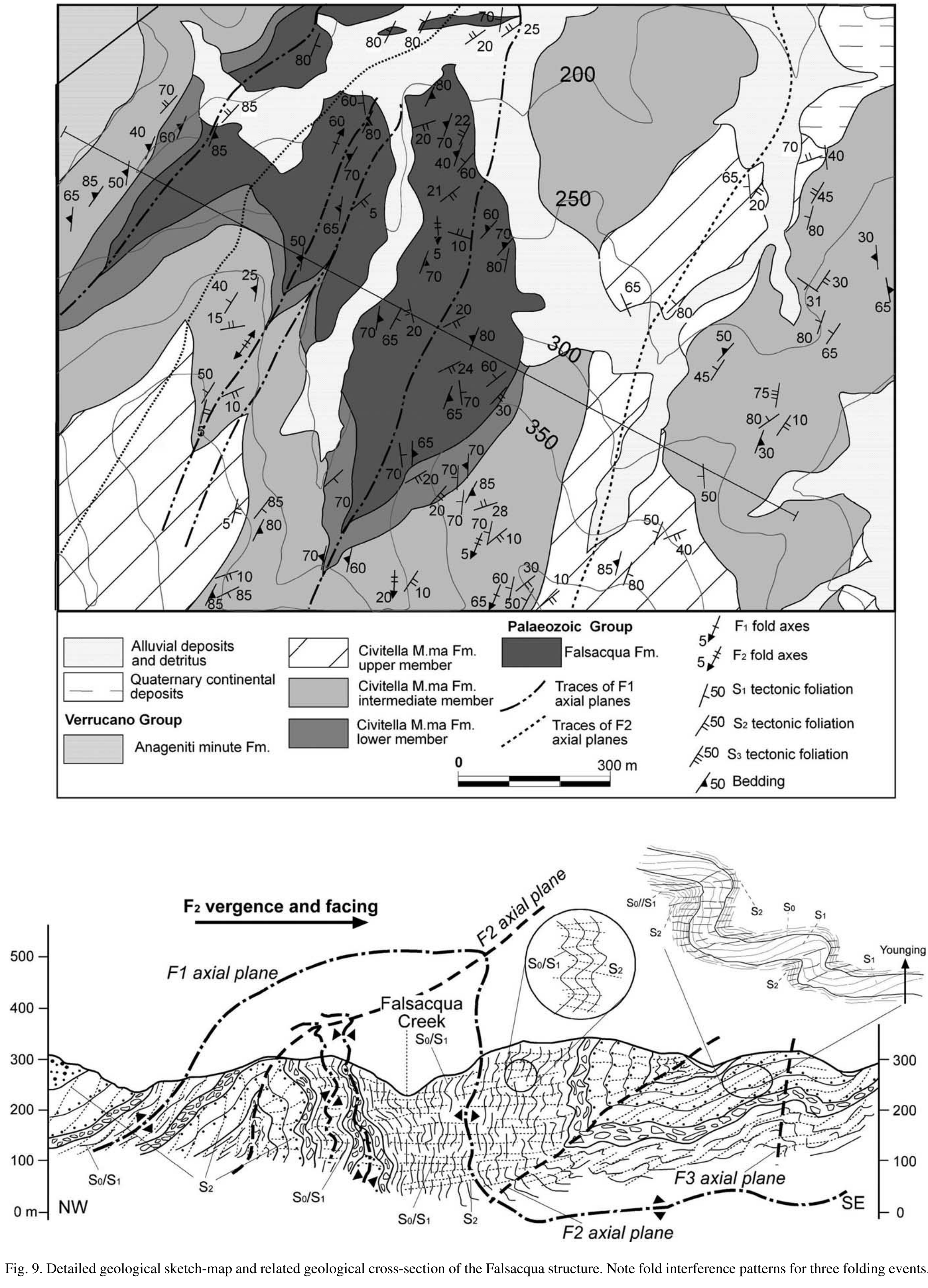

Fig. 9. Detailed geological sketch-map and related geological cross-section of the Falsacqua structure. Note fold interference patterns for three folding events.

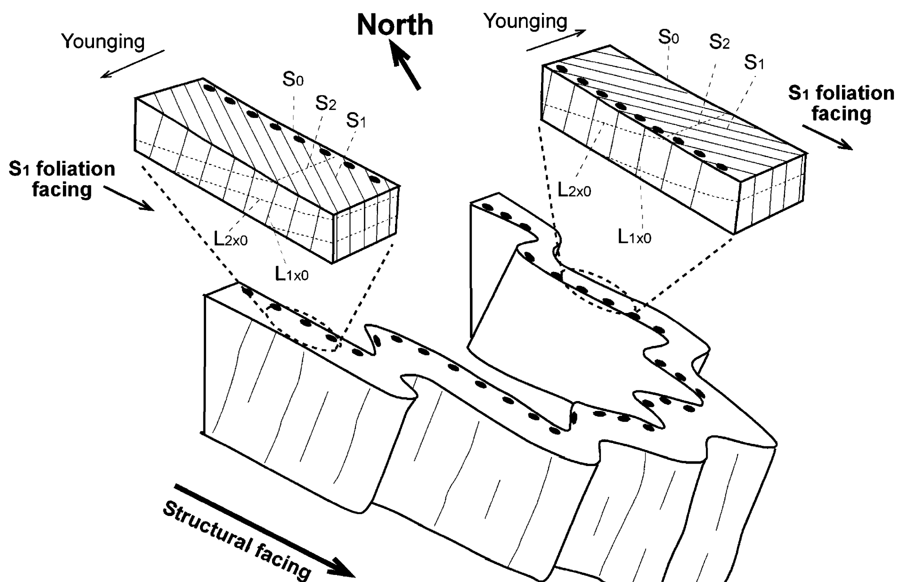

Fig. 10. Cartoon showing the geometric attitude and foliation/bedding relationship of the F_1 anticline as recognised in the Falsacqua structure.

development of both mesoscopic and macroscopic scale folds. Tectonic foliations (S_1, S_2 and S_3) developed during folding and are more or less penetrative, depending on the affected lithotypes.

S_1 consists of a pervasive and penetrative 'slaty-type' (*sensu* Durnay and Kisch, 1994) tectonic foliation (penetrative slaty-cleavage in Williams (1972, 1977) and Hobbs et al. (1976)), near-parallel or at a low angle to bedding (S_0)

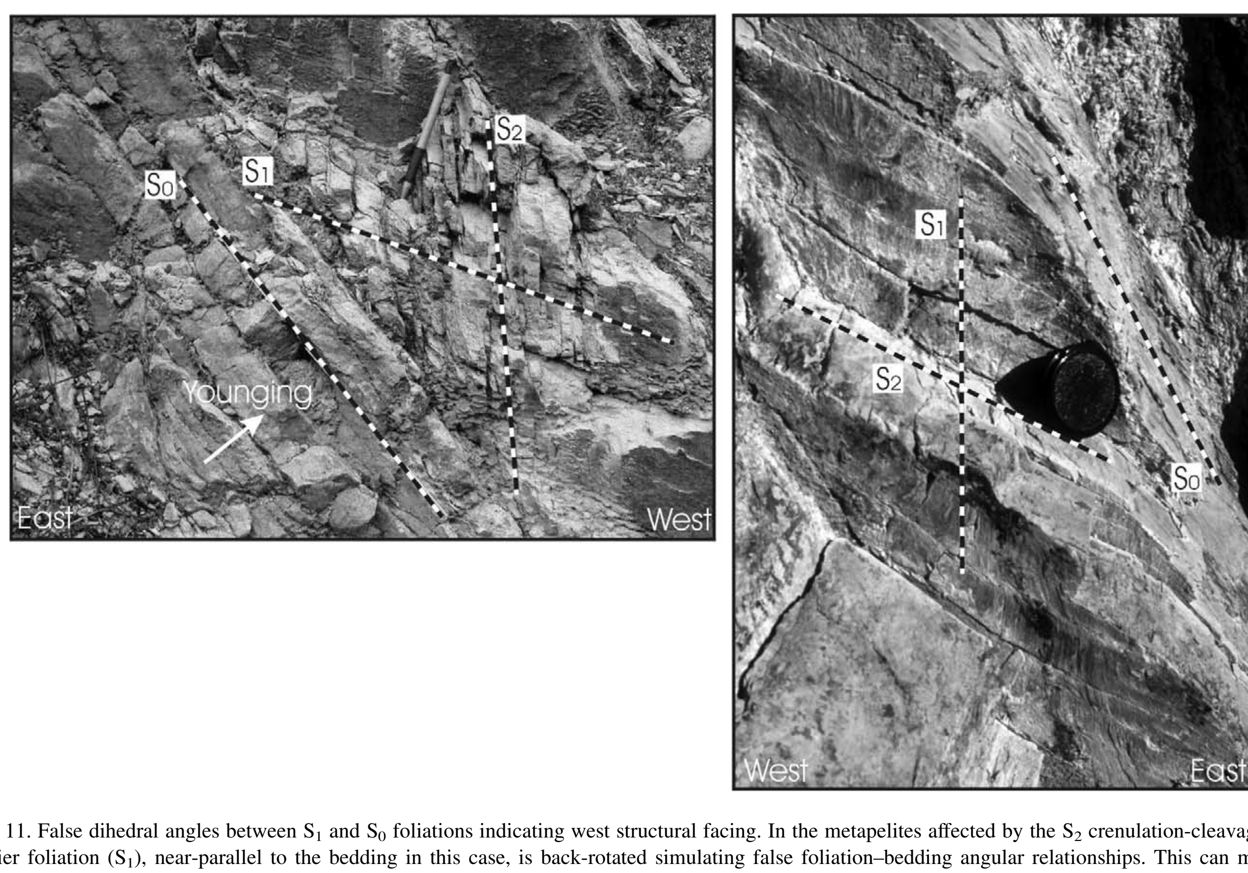

Fig. 11. False dihedral angles between S_1 and S_0 foliations indicating west structural facing. In the metapelites affected by the S_2 crenulation-cleavage, the earlier foliation (S_1), near-parallel to the bedding in this case, is back-rotated simulating false foliation–bedding angular relationships. This can mislead analysis of the structural vergence and facing and, consequently, the F_1 folds geometry.

and well developed in the fine-grained lithotypes such as the metapelitic tops of turbiditic strata where a smooth-fissility (Powell, 1979; Dennis, 1987) occurs (Fig. 5A). Mineralogically differentiated domains are typically recognisable at the macroscopic scale in the quartzose metasandstones and rarely in the metaconglomerates where alternating quartzose and micaceous layers are present (Fig. 5B); rough-fissility (Durnay and Kisch, 1994 with references therein) typifies these rocks.

Synkinematic metamorphism gave rise to a mineralogical assemblage (M_1) associated with the S_1 foliation, consisting of albite, carbonates, chlorite, chloritoid, fine-grained muscovite, oxides, paragonite, pyrophyllite and quartz (Franceschelli et al., 1986; Giorgetti et al., 1998). In thin section, the S_1 fabric can be described as continuous foliation (*sensu* Passchier and Trouw, 1996) mainly defined by flattened and elongate quartz grains and non-domainal homogeneous distribution of platy mineral grains with a preferred orientation (Fig. 6A), likely developed via rotation/reorientation of the greatest grains mainly composed of detrital phyllosilicates such as white mica and chlorite (Fig. 6B). Rotation of detrital phyllosilicates was the effect of a coaxial shortening involving pure shear. This was mainly related to pressure solution and solution transfer (Rutter, 1976; Swager, 1985; Spiers et al., 1990), as well as recrystallisation and neocrystallisation processes (Knipe, 1981; Williams, 1990). These were the mechanisms that produced flattening of quartz and enhanced preferential grain growth within the tectonic foliation. This implies that there is likely new growth of quartz and phyllosilicates associated with grains rotation, to help to define the planar fabric.

S_2 consists of a spaced and non-penetrative foliation (*sensu* Durnay and Kisch, 1994) defined as crenulation-cleavage (Rickard, 1961; Gray, 1977) and spaced schistosity. This foliation is well developed in fine-grained metapelites (spaced schistosity) and in the metapelites (crenulation-cleavage) (Fig. 7A) but is poorly evident, discontinuous, or absent in the metasandstones and metaconglomerates (spaced cleavage) (Fig. 7B). Synkinematic mineralogical association (M_2) only developed in the very fine-grained metapelites. The M_2 mineralogical assemblage consists of carbonates, fine-grained muscovite, oxides and quartz (Franceschelli et al., 1986). At the microscopic scale, S_2 can be described as spaced schistosity (*sensu* Passchier and Trouw, 1996). Cleavage domains have rough outlines in the metasandstones and smooth outlines in the metapelites (Fig. 8A). In metapelites, the microlithons (cleavage-lamellae in Weber, 1976) are tabular and contain earlier fabric elements (S_1 foliation) oblique to the S_2 cleavage domains. These latter are defined by shorter limbs of asymmetrical microfolds in which concentration of micaceous minerals produces mica-rich layers (Weber, 1981). The zones of progressive shearing become differentiated crenulation-cleavage seams through shear strain, which controlled dissolution process (Bell et al., 2003).

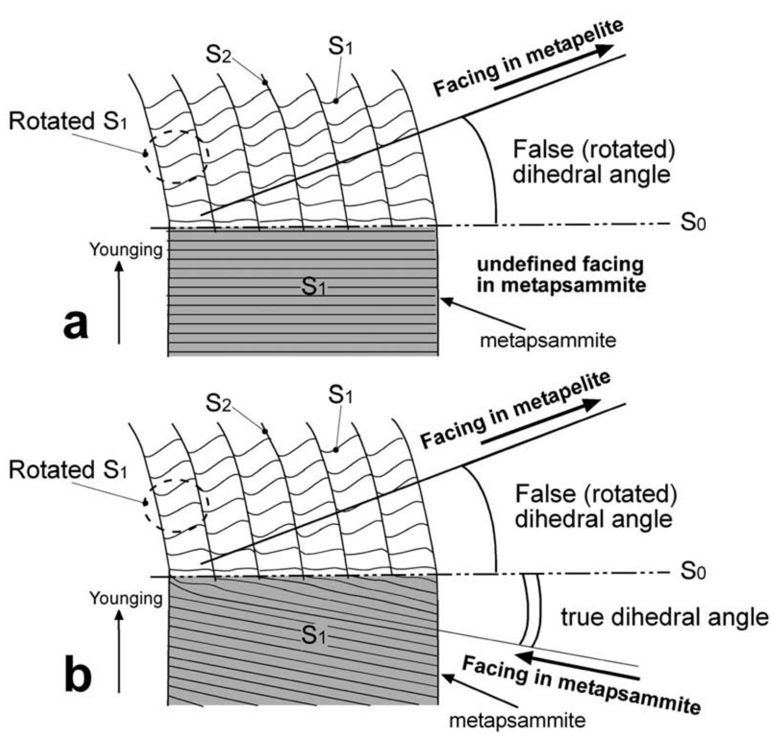

Fig. 12. Cartoon showing the S_0/S_1 foliation relationships as observable in the Mt Leoni area adopting Johnson's (1999) concept. (a) S_0 and S_1 are near-parallel, but in the metapelites strongly affected by a S_2 crenulation-cleavage, the foliation angular relation displays a false dihedral angle, which indicates an opposite vergence and facing. (b) This is most evident if S_1 is at a low angle with respect to the bedding; if this is the case, the dihedral angles are opposite in different lithotypes (from Johnson, 1999, modified).

Solution transfer, recrystallisation and neocrystallisation are the main operative metamorphic processes during S_2 foliation development in metapelites.

The S_3 foliation consists of a locally developed and widely spaced cleavage. It is only present in very fine-grained rocks and in F_3 fold closures. In thin section, S_3 foliation is developed only in mica-rich layers and is discontinuous (Fig. 8B and C). S_3 foliation development was not accompanied by blastesis; it is a smooth crenulation-cleavage, parallel and gradational with a 10–30 vol% of cleavage domains (*sensu* Passchier and Trouw, 1996).

4. Foliation and fold relationships

Although the Monte Leoni area has a thick vegetative cover, there are sufficient outcrops for analysing the structures. Many outcrops exhibit intersecting foliations and bedding, essential for determining the geometry of the map-scale folds; e.g. scattered outcrops of the Phyllite–Quartzite and Verrucano Groups show S_1, S_2 and locally S_3 superimposed foliations. Such foliation relationships, together with structural facing determinations, have been very useful for mapping the macroscopic fold hinges. A particularly clear example of superimposed folds and foliations (Falsacqua structure; Fig. 9) was studied along the north-western side of the Monte Leoni. There, a F_1 fold system, refolded by F_2 and later F_3 folds, has been reconstructed on the basis of bedding (S_0) and foliation angular relationships.

Subvertical bedding with opposite younging of the turbiditic strata and the S_1 tectonic foliation facing, as well as the subvertical attitude (70°) of the $L_{1\times0}$ lineation (intersection within bedding and S_1 foliation) suggest the occurrence of a subvertical upright F_1 anticline with

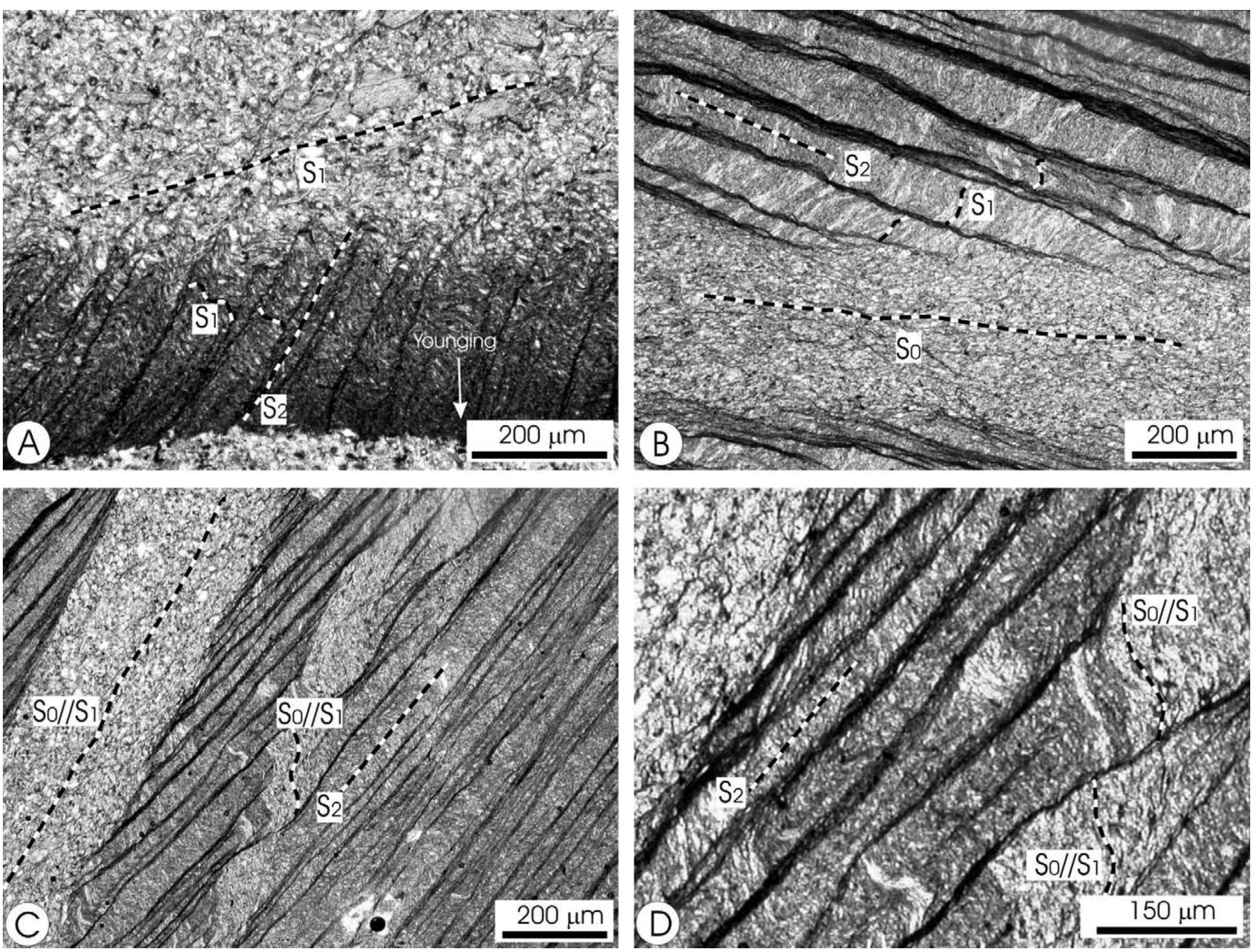

Fig. 13. Microphotographs (plane polarised light) illustrating the transition from metaspammitic base to metapelitic top in graded metaturbidite couplet. (A) (Civitella M.ma Fm.) shows different angular relationships between S_0 and S_1 as schematically shown in Fig. 11B. (B) (Civitella M.ma Fm.) illustrates an illusive dihedral angle occurring in the metapelitic top with respect to the bedding. (C) (Anageniti Minute Fm.) shows dihedral angles between S_0/S_1 near-parallel in the metapsammitic level and S_0/S_1 near-parallel in the metapelites; this confirms the rotation of the S_0/S_1 system in the hinge of the overprinting S_2 crenulation-cleavage. (D) Detail of C.

the Palaeozoic Falsacqua Fm. at its hinge (Fig. 10). The subvertical F_1 macro-fold attitude has also been supported by the asymmetry of some parasitic F_1 meso-folds on the macro-fold limbs, observed at the outcrop and map-scale, which have subvertical axes and opposite shear sense on the F_1 macro-fold limbs. The S_2 foliation is subhorizontal or gently west- and east-dipping and intersects the S_0 and S_1 near-orthogonally (Fig. 10). The $L_{2\times0}$ lineation is subhorizontal, suggesting a westward gently dipping or subhorizontal attitude for F_2 fold axial planes. This is also supported from the presence of numerous symmetric and asymmetric parasitic meso-folds, presumably F_2 folds, with subhorizontal axes. $S_0/S_1/S_2$ relationships allow the determination of the S_2 structural facing and, consequently, the F_2 vergence and facing (Fig. 9). The direction of younging along the S_2 fabric, measured in the direction perpendicular to the foliation/bedding intersection lineation ($L_{2\times0}$), also taking into account the trend of F_2 axes (Fig. 3), allows us to infer the east-facing of D_2 structures. This is also strongly supported by the asymmetry of F_2 meso-folds (Fig. 9). On the eastern side of the Falsacqua structure, $S_0/S_1/S_2$ foliations are cut by a S_3 foliation, which is sub-vertical and related to upright F_3 folds (Fig. 9). Summarising, the F_1 originally recumbent anticline was deformed by a F_2 subhorizontal, asymmetrical, east-facing folds system. The F_1 anticline is exposed in correspondence to the F_2 subvertical shorter limb and in the gently west-dipping limb (Fig. 9). The lack of significant outcrops, due to the impervious cover vegetation occurring in the neighbouring areas, inhibits the determination of the complete geometrical setting of the F_1 fold system; in fact, the syncline associated with the above-described anticline has not been geometrically defined. Nevertheless, S_0/S_1 relationships as detected in numerous outcrops, as well as the F_1 folds geometry, confirm the southeast structural facing of the F_1 folds even if, in some cases, as discussed below, S_0/S_1 angular relationships are false, causing the misinterpretation of both the S_1 and, consequently, the F_1 structural facing.

5. Discussion

Since F_1 folds are very poorly exposed in the Mt Leoni area, the only way to determine their vergence and facing is based on the S_0/S_1 angular relationships together with the F_2 geometry. As a rule, in the fold limbs S_1 foliation, in the metapelites, is near-parallel to the bedding (S_0), but in the metapsammitic levels, S_1 is refracted and may be at a low angle to S_0. Furthermore, S_2 tectonic foliation is superimposed on the S_0/S_1 system and mainly developed in the metapelites. It is observed that S_0/S_1 angular relationships can indicate contradictory structural facing in some metaturbiditic outcrops if these were also affected by S_2 tectonic foliation. In particular, east and west (Fig. 11) S_1 structural facing can occur in the same F_1 limb making it hard to reconstruct the F_1 fold vergence and facing. With regards to this problem, Johnson (1999) underlined that in graded metaturbidites, where bedding and near-parallel foliation are overprinted by a later crenulation-cleavage, the earlier foliation (S_1 in our case) in the metapelitic layers can be back-rotated in the hinges of the overprinting crenulation-cleavage (S_2), simulating an opposite structural facing (Fig. 12). Some additional examples of this scenario were described from polyphase low-grade metamorphic rocks in

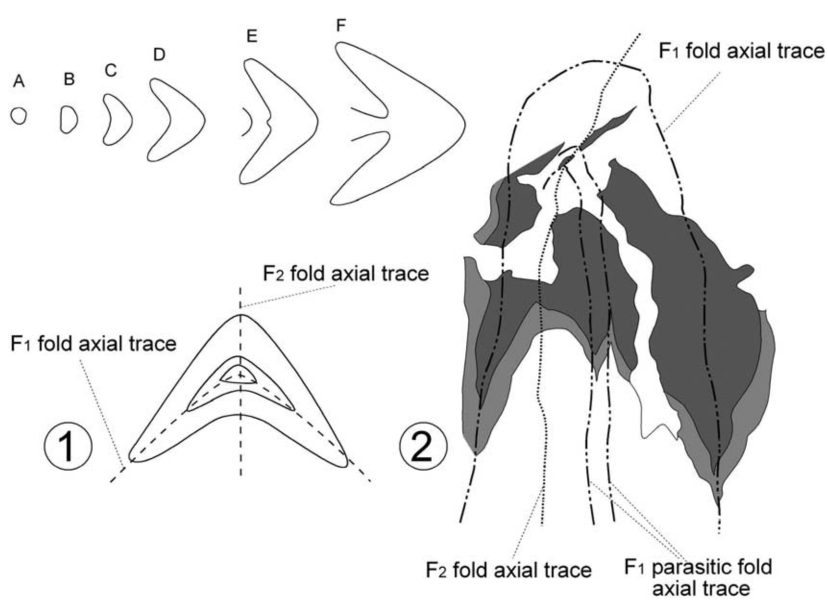

Fig. 14. Cartoon showing the fold interference pattern resulting from the superimposition of the F_1 and F_2 folding in the Falsacqua structure. A–F are the 2D interference forms of Type 2 interference patterns, as a single surface is eroded to greater depth (from Ramsay and Huber, 1987). 1 and 2 show, respectively, the theoretical interference Type-2 pattern as proposed by Ramsay and Huber (1987) and the interference pattern of the Falsacqua structure.

various metamorphic cores in the world (Henderson, 1997; Kraus and Williams, 1997, 2001; Johnson, 1999). Consequently, to avoid such a misinterpretation, structural facing on the earlier foliation (S_1) should be determined in the metapsammitic layers. However, because foliations that intersect bedding at a low-angle are commonly hard to identify in metapsammitic rocks, microstructural analyses must be carried out in these lithotypes. Oriented samples have been collected from outcrops where $S_0/S_1/S_2$ foliations are recognisable in outcrop scale and were then analysed in thin section. The microstructural analyses confirmed Johnson's (1999) concept. In fact, S_0/S_1 angular relationships can indicate opposite structural facing and vergence in the metapsammitic and metapelitic layers. In particular, it is observed that in the metapelites, S_1 foliation in the S_2 microlithons was rotated during S_2 crenulation-cleavage development, and consequently S_1 in metapsammites is oblique to S_0, but in the adjacent metapelites, it dips in the opposite direction relative to S_0 (Fig. 13A). This is not observed in the metapsammitic layer because they are not strongly affected by S_2 crenulation-cleavage. Many examples show that rotated dihedral angles occur even if S_0 and S_1 were originally near-parallel (Fig. 13B–D) and also in this case, rotated dihedral angles between S_0 and S_1 in the metapelites indicate a false westward S_1 facing.

From fieldwork and foliation relationships, it was interpreted that southeast-facing F_1 folds were deformed by east-facing F_2 folds. F_1 and F_2 folds were then deformed by later upright F_3 folds. This scenario fits well with the tectonic setting as documented in southern Tuscany (Carmignani et al., 2001) and, in particular, in some tracts of the Monticiano–Roccastrada Ridge (Corsi et al., 2001; Costantini et al., 2002).

The geometry of the folds permits highlighting two different fold interference patterns. The superposition of F_2 folds on the earlier F_1 folds generated a Type-2 fold interference pattern (dome–crescent–mushroom pattern; *sensu* Ramsay and Huber, 1987). The angle between F_1 and F_2 axial planes is high, the F_1 fold axial surfaces were strongly folded, and the F_1 fold hinges were strongly bowed. The two-dimensional fold interference pattern of the Falsacqua structure, as emerged from the morphology cutting this structure, gave rise to a *crescent rounded triangular form*, which fits well with the D example proposed by Ramsay and Huber (1987) (Fig. 14). This is indicative of the occurrence of an overturned F_1 fold limb, as also attested by opposite younging of the turbiditic strata at the hinge of the F_1 fold.

The F_3 gentle folds do not deform the Falsacqua structure but they occur in the neighbouring areas. There, they superimposed on F_2 folds and gave rise to a Type-3 fold interference pattern (convergent–divergent pattern; *sensu* Ramsay and Huber, 1987), even though the axial directions of F_2 and F_3 folds are not parallel.

6. Concluding remarks

The fold development gave rise to a complex interference pattern and three superimposed tectonic foliations, which are locally recognisable at the outcrop and microscopic scales. The fold geometry and closures have been determined through foliation relationships and bedding angular relation analyses, which, because of the very thick cover vegetation, have been the only way to realise the geometrical analyses of the different folds in the Mt Leoni area. The S_1 vergence and facing, and consequently the F_1 fold facing and geometry, can be misinterpreted at the outcrop scale because the S_2 crenulation-cleavage development caused the back-rotation of the S_0/S_1 system in metapelites, causing rotated dihedral angles between S_0 and S_1 (Fig. 11). This geometrical feature is recurrent in the Mt Leoni area and, consequently, can mislead the F_1 folds vergence and facing determination. Consequently, S_1 structural facing must be determined with considerable care and it must be supported by microstructural analyses. Foliations and bedding relationships as observed in the Mt Leoni low-grade metamorphic rocks are in agreement with the geometrical pattern described by Johnson (1999) and strongly support the validity and importance of his concept, which must be considered in clarifying the geometry of map-scale structures during fieldworks.

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