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LARGE SCALE REVERSE « DRAG FOLDS » IN THE LATE ALPINE BUILDING OF THE APUANE ALPS (N. APENNINES) (1)

Summary — The alpine polyphase structural evolution of the Apuane Alps in the Northern Apennines is discussed, with special emphasis to the latest deformation episodes. The earliest deformation phase began in Upper Oligocene, when the Paleozoic to Tertiary stratigraphic sequence outcropping at the bottom of the tectonic window was trapped in a mega-shear of the whole sialic crust, between the Padanian foreland and the Tuscan and Ligurian Nappes, advancing from the internal side of the arcuate belt. As a consequence, tight to isoclinal folds were produced in a greenschist facies metamorphic climate, with a pervasive axial-plane cleavage (S_1). Rotation of fold axes took place at all scales especially in the eastern outcrops, where low angles with the elongation lineation (L_1) are recorded.

Later episodes (14-11 m.y. b.p.) have refolded the early axial-plane cleavage in a complex mega-antiform whose characters are especially discussed in this paper. The mega-antiform, interesting the metamorphic core as well as the superposed Nappes, has a general apenninic trend (N 130°-170°); but cross-folds at high angle to the main structure are also present. Kilometric second-order folds with reverse asymmetry are formed on the limbs of both the apenninic and the transversal cross-folds, which were also produced in a metamorphic climate. The rules of normal asymmetry pattern still hold for the third-and higher-order folds.

The interference of the apenninic and high-angle cross-folds is discussed, together with the possible mechanisms of their formation.

Riassunto — *Pieghe di trascinamento a grande scala e a simmetria inversa nell'edificio alpino tardivo delle Alpi Apuane (Appennino Settentrionale).* Vengono illustrati e discussi i caratteri geometrici dell'antiforme di scistosità realizzata dalle Alpi Apuane negli episodi tardivi della sua evoluzione polifasata, nel corso del Terziario.

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La deformazione compressiva ha avuto inizio nell'Oligocene superiore, quando le Apuane si sono trovate in una grande fascia di taglio ensialica che ha interessato l'intero spessore della crosta, al margine interno del continente paleo-appenninico. La deformazione compressiva dei terreni del nucleo Apuano si è svolta, in tutte le sue fasi, sotto il carico delle Unità alloctone (Falda Toscana e Unità Liguri) provenienti dall'interno dell'arco appenninico. Nell'Unità più profonda dell'edificio (« Autoctono metamorfico » o « Toscanide I » della letteratura) in questa prima fase si sono formate pieghe isoclinali, con trasposizione delle preesistenti superfici in una scistosità di piano assiale molto pervasiva (S_1), che attualmente costituisce la superficie più evidente delle Apuane.

Il comportamento duttile delle rocce è stato favorito dal clima metamorfico. Lo svolgimento della deformazione lungo una fascia di taglio ensialica è dimostrato dalla rotazione passiva degli assi delle pieghe a tutte le scale: ad eccezione di una ristretta fascia (comprendente tra l'altro la sinclinale di Carrara), le pieghe di prima fase presentano per la maggior parte assi sub-perpendicolari all'andamento generale della catena, con direzioni N30°-60°. In seguito a tale rotazione gli assi si sono disposti parallelamente alla lineazione d'allungamento L_1 (indicata dagli assi maggiori dei clasti deformati, dal « longrain » del quarzo, ecc.), che materializza la direzione principale di flusso della materia (asse X dell'ellissoide finito dello *strain*) nel corso della prima fase.

Episodi più tardivi, perdurati sino a 11-14 m.a. dall'attuale (età della chiusura definitiva dei sistemi metamorfici) hanno ripiegato la scistosità pervasiva di prima fase in una antiforme complessa, la cui descrizione costituisce l'argomento principale di questa nota. L'antiforme tardiva, che interessa sia la scistosità S_1, sia i contatti con le soprastanti Unità alloctone, costituisce una struttura del primo ordine, ha una direzione appenninica (con asse orientato da N 130° a N 170°) ed occupa l'intera larghezza visibile dell'edificio apuano.

Forti inflessioni delle superfici di inviluppo delle S_1 si sono prodotte anche con assi anti-appenninici; la mega-antiforme appenninica risulta così complicata ad insenature e promontori, particolarmente vistosi sul versante orientale. Sui fianchi di queste grandi strutture, sia appenniniche che anti-appenniniche, si sono sviluppate pieghe del secondo ordine, di dimensioni chilometriche, e pieghe minori di ordini ancora superiori, con dimensioni da ettometriche a centimetriche.

Le pieghe chilometriche del secondo ordine sono, nella maggior parte dei casi, asimmetriche. Contrariamente alla regola comune, la loro vergenza non è rivolta verso la cerniera delle antiformi del primo ordine, ma verso i loro fianchi, producendo così sulla sezione trasversale di entrambi i sistemi (appenninico ed anti-appenninico) antiformi della sottoclasse IA di Ramsay (1967).

Per le pieghe minori di ordine superiore al secondo valgono invece le normali regole della vergenza: così, la asimmetria delle pieghe del terzo ordine è diretta verso la cerniera di quelle del secondo ordine.

Viene infine discusso il significato dell'edificio tardivo, prospettando la possibile contemporaneità dei due sistemi di pieghe, anche sulla base di dati sperimentali esistenti in letteratura.

Key words — Polyphase folding; cross-folds; reverse drag folds; Northern Apennines.

INTRODUCTION

Up to 1970, the more interesting feature of the Apuane Alps was represented by the large tectonic window displaying the most complete superposition of structural Units in the Nappe building of the Northern Apennines. This allowed to investigate the general timing of tectonic events and the complex relations between crustal shortening, gravity tectonics and contemporary sedimentation in the Northern section of the belt (BALDACCI & Al., 1967).

In more recent times attention was drawn towards the structural analysis of the polyphase Tertiary deformation (CARMIGNANI & GIGLIA, 1977; CARMIGNANI & GIGLIA, 1979; CARMIGNANI, GIGLIA & KLIGFIELD, 1978).

In the deepest tectonic Unit of the Apuane a low-grade synkinematic metamorphism (greenschist facies, with quartz-albite-white K mica-chlorite-chloritoïd and local upheaval to the biotite isograde) has favoured the ductile behaviour of rocks without effacing the succession of structural events. This, together with a well differentiated lithology and a rather exceptional exposition along certain cross-setions, make the Apuane Alps a suitable area for the study of a multiple Tertiary deformation whose later events are particularly investigated in this paper since they display geometrical characters and kinematic implications not very commonly described in the geological literature of low-grade metamorphic belts.

THE CHARACTERS OF EARLY DEFORMATION

The fundamentals of the early Tertiary geologic evolution of the Apuane Alps have been repeatedly described (see, for general information and previous literature in CARMIGNANI, GIGLIA & KLIGFIELD, 1978). In the following paragraphs, only some data will be recalled which are essential for the understanding of the late tectonic evolution of the massif.

Age of early deformation

The most recent data support an Upper Oligocenic age for the early compressive phase in the Apuane. A compressive stress field was set up in this area after the final closure of the oceanic crust once existing between the European and Apennino-Adriatic Plates, and subsequent continent-continent collision. Tectonic Units issued from a common oceanic basin are now resting onto both the European margin (Piemonte Ophiolite-bearing Nappes, Ubaye-Embrunnais Units) and the Apenninic one (« Ligurian Units ») following a complex polyphase deformational and metamorphic history (BOCCALETTI, ELTER & GUAZZONE, 1971; GOSSO, DAL PIAZ, PIOVANO & POLINO, 1979).

In late Oligocene the Ligurian Units were definitely and completely squeezed out of their original basins and emplaced over the Apenninic continental margin. The latter was in turn subdivided in two main tectonic Units separated by a minor wedge of penetratively deformed Triassic metasediments.

At present the tectonic Units under the Liguride complexes are, from bottom to top:

— the Apuane metamorphic core, represented by metasediments (Triassic to Oligocene in age) deposited on a continental crust (in literature: « Tuscan Autochthon » or « Tuscanid I »).

— the above mentioned metamorphic Massa Unit.

— the Tuscan Nappe (Tuscanid II) represented by a Upper Triassic to Oligocene sedimentary cover, detached along the Upper Triassic evaporites and in turn superposed to the Massa Unit or directly to the Tuscanid I.

The early superposition of these Units in the present emplacement of the Apuane Alps presumably took place in a large ensialic shear belt. A late Oligocene age for this event is supported by two kinds of data.

On one hand, the Tertiary Flysch at the top of the Tuscanid I, which is the younger lithostratigraphic Unit involved in penetrative syn-metamorphic deformation has been attributed to a time interval comprised between the P_{19} and P_{20} Blow Zones, corresponding to an absolute age of 29 m.y. b.p. (DALLAN NARDI, 1977).

The same conclusions can be drawn from radiometric ages of the early sin-kinematic metamorphic events. KLIGFIELD, HUNZIKER & SCHAMEL (1977) obtained metamorphic ages of about 27 m.y. b.p. for samples of the metasedimentary sequence in the Apuane exempt of the latest penetrative deformation phases. These results also support an Upper Oligocene age for the beginning of compressive deformation in the Apuane Alps (KLIGFIELD, 1978).

P-T conditions

The presence of the whole Apenninic Nappe empilement (from top to bottom: the Ligurian Bracco, Caio and Canetolo Units, superposed to the Tuscan Nappe and the metamorphic Tuscanid I and Massa Units) is required since the early folding phases.

The stability field of metamorphic mineral assemblages, the Mg content in calcite in the presence of dolomite (CRISCI & AL., 1977), thermoluminescence curves in marbles (D'ALBISSIN, 1963), all indicate temperatures between 300°C and 400°C. Within these temperatures, the cristallinity of white K micas and phengite composition indicate pressures between 3 and 4 Kbars, corresponding to a hydrostatic pressure of a 10-15 Km rock column (KLIGFIELD, 1978).

The Apuane as a ensialic Shear belt

Even if the influence of tectonic stresses can somehow reduce the thickness of the rock column required by the mineral assemblages, it is difficult to escape the conclusion that at least the Apuane early deformation was performed at a certain depth in the crust.

This conclusion is moreover supported by the ductile character of the deformation.

In the early compressive phase the Mesozoic to Tertiary sedimentary cover, as well as the pre-Triassic basement of the Tuscanid I were involved in a series of tight to isoclinal recumbent folds. A highly pervasive axial-plane foliation was developed, transposing at various degrees the pre-existing layering. This axial-plane foliation (S_1), presumably flat-lying at the origin, has been successively refolded.

First-phase folds are generally flattened, closely approaching the similar type. An extension lineation was formed within the S_1 schistosity (L_1). It is represented by the longest axes of clasts in the sedimentary breccias of marbles, or of quartz pebbles in the Verrucano; by the dimensional grain orientation of quartz in middle Liassic Cherty Limestones; by fibrous calcite and quartz extension veins in pyrite pressure shadows.

Extension lineations consistantly maintain a WSW-ENE trend;

their plunge varies as a consequence of successive refolding (fig. 1 and Plate I). First-phase fold axes and bedding/schistosity intersections (A_1) trend N 130°-150° in the westernmost outcrops, as in the large Carrara overturned syncline (fig. 1). East of the Carrara first phase syncline, A_1 axes and intersections become progressively parallel to the L_1 extension lineation, together with an important development of stretching fabrics (evidenced by elongation of quartz aggregates in L_1) until, east of the Orto di Donna syncline and its

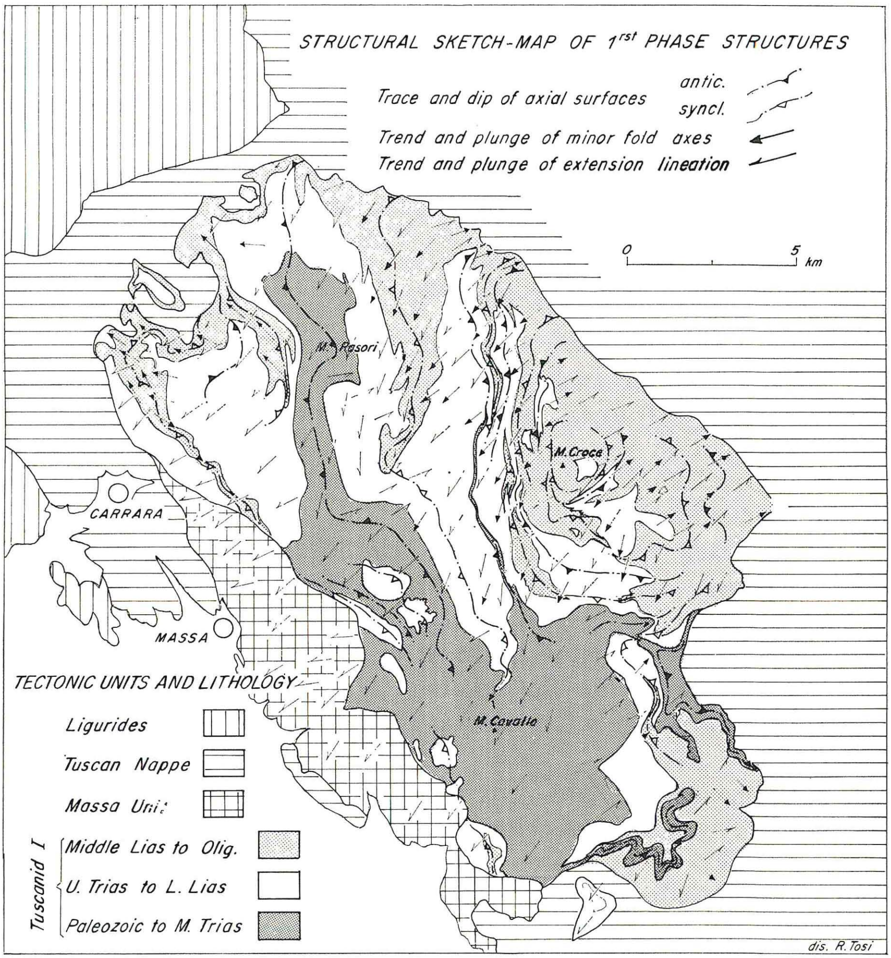

Fig. 1 - STRUCTURAL MAP OF I^{rst}-PHASE STRUCTURES IN APUANE ALPS. The transversal trend of A_1 axes, parallel to the extension lineations (L_1) is clearly visible in the Eastern outcrops.

southern prosecution, only fold axes at high angle to the regional apenninic trend are found (CARMIGNANI & GIGLIA, 1979; CARMIGNANI, GIGLIA & KLIGFIELD, 1978). An example of this structural style is represented in the Structural Map of Plate I, where first-phase anticlinal structures with axes trending N 30°-60° indifferently close both towards NW or SE.

The disposition of fold axes into parallelism to the extension lineation, at high angle to the regional trend of the belt, is currently interpreted as a result of passive rotation of pre-formed axes with originally normal trend in the axial-plane schistosity, within a band of high simple shear component, adjacent to large thrusts (SANDERSON, 1974; ESCHER & WATTERSON, 1974).

Besides the rotation of fold axes, other features are present which can be considered as characteristic of shear belts (RAMSAY & GRAHAM, 1970; ESCHER & WATTERSON, 1974). The most important one is the formation of typical angular discordances between contemporaneously formed axial-plane cleavage and shear boundaries. As an example, in the western slope of the massif the tectonic contacts between the Tuscanid I, the Massa Unit and the Tuscan Nappe (Tuscanid II) always dip WSW at a lower angle than the S_1 first-phase axial-plane schistosity. This arrangement is moreover consistant with a overall WSW to ENE sense of movement, confirming an internal origin of the tectonic Units and a original westwards dip of the Apuane shear zone.

LATE DEFORMATIONS PHASES

Timing of late deformation

With the end of Oligocene or the beginning of Miocene, a first Nappe building was already set up in a ensialic shear belt at the emplacement of the Apuane; sedimentation was still going on in the external basins (Cervarola, Umbria-Marche Domain, Padanian sub-soil).

Deformation continued in the Nappe empilement, refolding the early S_1 axial-plane cleavage as well as the shear surfaces represented by the contacts between the different Tectonic Units.

New penetrative structures were formed, still accompanied by metamorphic recristallization. GIGLIA & RADICATI DI BROZOLO (1970) have found radiometric ages of 14 and 11 m.y. b.p. for the final closure of metamorphic systems; similar ages were obtained by KLIGFIELD, HUNZIKER & SCHAMEL (1977) in rocks of the Apuane overprinted by the last deformational events which, on the base of metamorphic record, seem to have lasted up to the Serravallian.

The general structure

The general structure realized by the Apuane Alps in the late deformation phases is represented in the Map of Fig. 2 showing

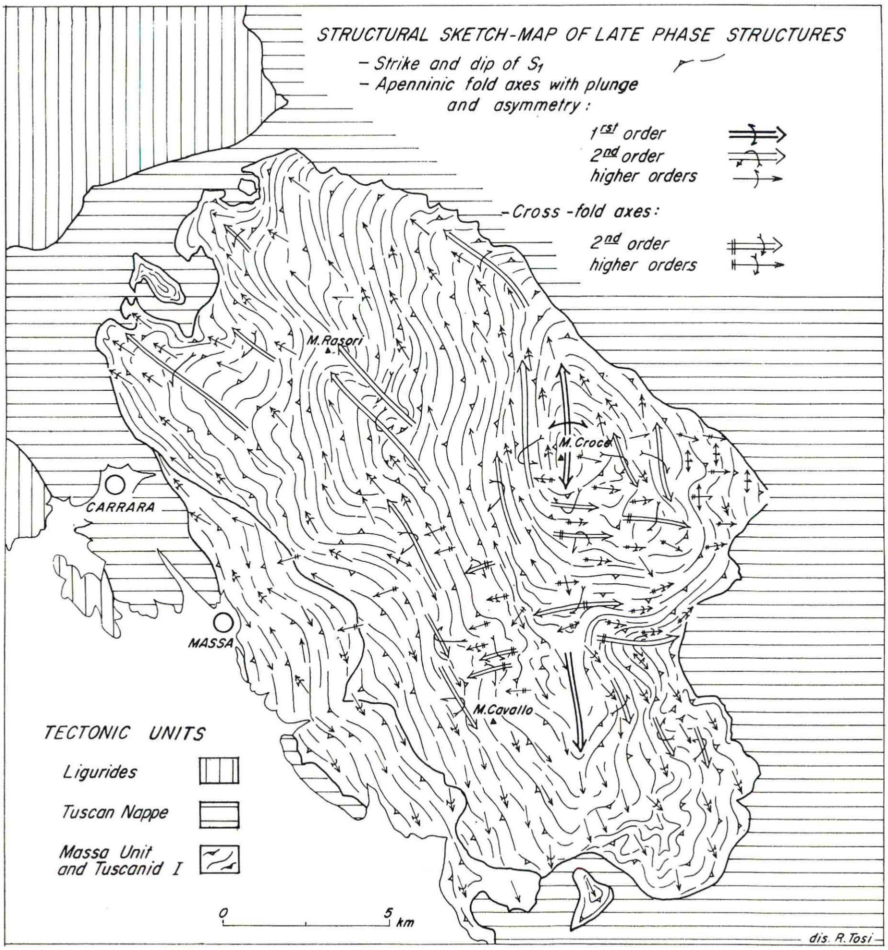

Fig. 2 - LATE-PHASE STRUCTURES IN THE APUANE ALPS. The trend and dip of Irst first-phase axial-plane schistosity (S_1) is indicated.

the strike and dip of first phase axial-plane schistosity in the metamorphic outcrops of the whole massif, together with the axes of the late-phase folds.

The most prominent and persistant character is a complex symmetrical mega-antiform, with a N-S trend from Ruosina to M. Croce, which seems to turn to N-NW in the north-eastern outcrops, with a crest line highly eccentrical in relation to the axis of the metamorphic window.

On both limbs of the mega-antiform, occupying the whole width of the Apuane Alps (and which is to be considered as a first-order structure), second-order folds of kilometric size are developed, with asimmetry directed away from the hinge, towards the limbs of the first-order mega-antiform.

The longitudinal continuity of the apenninic mega-antiform is interrupted, particularly in the central area of the metamorphic outcrops, by a set of E-W trending crossfolds.

Both the Apenninic and the E-W fold systems have developed their own axial-planes cleavages. Kilometric folds of the transversal system also display an asymmetry away from the culminations. The main features of the two systems will be analyzed separately in the following paragraphs.

GEOMETRICAL PATTERNS OF THE LATE PHASE STRUCTURES

The apenninic mega-antiform

The general characters of the late-phase apenninic mega-antiform are represented in the composite cross-sections of fig. 3, using the plunge of the axis to show its evolution in depth.

The geometrical features of the major first-order antiform and the size and asymmetry of the second order folds on both limbs of it are clearly visible.

The S_1 surfaces are deformed in a series of folds at many scales with variable shapes mainly depending on rock competency and structural position. Conjugate kinks of apenninic direction are also present but subordinate, always at a mesoscopic scale, presumably formed at the very end of the deformation process.

In second-order folds, S_1 surfaces in more competent layers can realize slightly asymmetric open folds, with a high angle fan-shaped cleavage. More ductile rocks such as slates and phyllites, or even thin competent layers in a more ductile matrix of consistant

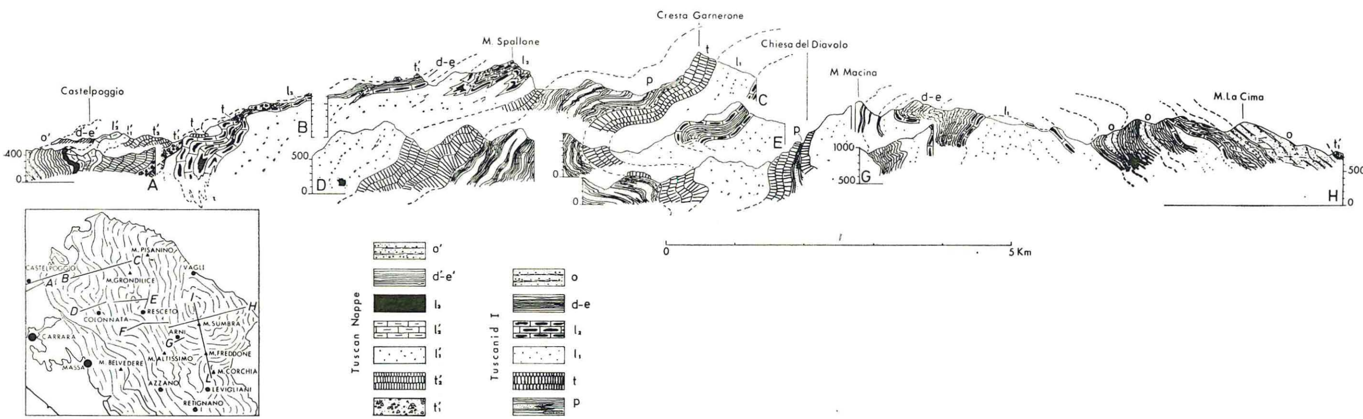

Fig. 3 - Composite Geological Sections across the Apuane Alps. Symbols in Tuscanid I: *p*, Paleozoic and Triassic mainly detrital complex; *t*, *dolomite* (Upper Trias); l_1, marble (Lower Lias); l_2, metamorphic cherty limestones (Middle Lias); *d-c*, calcschists, meta-radiolarites, phyllites, chloritic marbles (Dogger-Eocene); *o*, turbiditic meta-sandstones (Oligocene).
Symbols in Tuscan Nappe: t'_1, cellular limestone (Upper Trias); t'_2, black limestones (Rhaetian); l'_1, massive limestone (Lower Lias); l'_2, grey-black limestone (Lower Lias); l_3', red nodular limestone (Sinemurian); *d'-e'*, marls, radiolarites, shales (Dogger-Eocene); *o'* turbiditic sandstones (Oligocene).

thickness can instead realize markedly asymmetric folds, often with a short overturned limb indicating a vergence away from the hinge zone of the major first-order antiform. In these cases a highly pervasive axial-plane cleavage of variable character can develop at a low angle with the S_1 refolded surface.

In the most common cases asymmetric minor folds normally display a vergence towards the hinge of the major folded structure, and this provides a largely used method for the recognition of individual limbs of major folds by recording the symmetry pattern of minor scale folds.

The second-order folds in the Apuane display a reverse pattern since their asymmetry is away from the hinge zone of the first-order apenninic mega-antiform.

At the scale of the whole massif, the enveloping surfaces of these second-order folds generally display a simple geometry. As a rule, they have steeper dips in the inner core of the main antiform, and gentler dips away from it. This can account for a overall mega-antiformal structure with a thinned hinge zone, approaching RAMSAY-*s* sub-class IA (with curvature of the inner arc exceeding that of the outer arc) and is consistant with the vergence of the second-order kilometric folds indicating asymmetry away from the hinge and towards the limbs of the first-order mega-antiform.

Notwithstanding the reverse asymmetry of second-order folds in relation to the main antiform, the rules of normal asymmetry pattern still hold for the third- and higher-order folds, which often closely approach the similar type, since the refolded A_1 and L_1 lineations are dispersed within a plane.

The characters and symmetry relations between the folds of different orders in the Apuane are schematically represented in fig. 5. Plate I is a detailed geological and structural map of a second-order fold (located on the western limb of the main apenninic antiform), in which the geometrical relations of the structural elements, together with a calculated profile perpendicular to the fold axis, showing the real attitude of S_1 surfaces, are also represented.

The transversal cross-folds

A system of E-W trending fold structures, strongly developed in a transversal band across the massif is also formed by the enveloping surfaces of S_1.

Transversal second-order folds of kilometric size are again found, step-like in form or strongly asymmetrical, depending on various factors (rock competency, structural position), which will be discussed later.

The apenninic and anti-apenninic systems share many common features. Apart from the identical characters of axial-plane foliation, the most important analogy is that even the E-W trending asymmetric structures display reverse asymmetry in the second-order kilometric folds, and normal asymmetry pattern in the higher-order folds. The enveloping surfaces of second-order transversal folds again show attenuation of the crests of the structures. Fig. 4 is a section across the southern limb of a E-W trending antiform showing the geometrical pattern of this fold system.

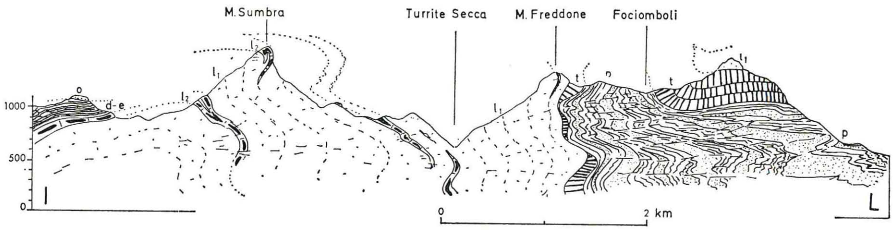

Fig. 4 - MERIDIAN GEOLOGICAL SECTION ACROSS THE TRANSVERSAL LATE-PHASE STRUCTURE OF THE TURRITE SECCA VALLEY. Symbols and trace of section in Fig. 3.

Even in the cross-folds an axial-plane foliation is developed which can be either a spaced crenulation- or strain-slip cleavage or a more pervasive one, dipping in the same sense as the enveloping surface of S_1 first-phase schistosity, and leading to asymmetric intrafolial folds.

Like in the apenninic system, second- and higher-order minor folds closely approximate the similar geometry (CARMIGNANI & GIGLIA, 1977).

GEOMETRICAL RELATIONSHIPS BETWEEN THE LATE PHASE FOLDS AND CROSS-FOLDS

The interference between the apenninic and anti-apenninic late-phase structures has been studied in the Apuane Alps by CARMIGNANI & GIGLIA (1977) and CARMIGNANI & GIGLIA (1979). In the above mentioned literature, the two sets of structures were respectively considered as a second (the anti-apenninic cross-folds) and a third (the apenninic) folding phases in the multiply deformed Apuane Alps. As a consequence of two years of new field observations, the Authors do not share any more this reconstruction of structural events, since no conclusive evidence has been found on the precedence of one system relative to the other.

The interference of the two systems produces domes and basins of different sizes and shapes, more or less elongated and pointed in relation to the order (and hence the wavelenght and amplitude) of the interfering structures.

Two major irregular domes are by this way formed (fig. 2). They are separated by a very pronounced E-W structural depression eastwards; in the western limb of the apenninic mega-antiform the subdivision in two separated domes is less clear-cut, consisting in several transversal structures of lesser wavelength and amplitude than the eastern ones, with steeply plunging axes.

Second-order folds of the combined apenninic and transversal systems display a centrifugal asymmetry away from the culminations. When the structural elements of the two systems mutually interfere in the same outcrop, they are generally well recognizable since their structural elements (axial-plane cleavages and axes and intersection lineations) can form at high angles.

Only in the south-western side of the M. Croce dome, the apenninic second-order folds show a tendency to rotate eastwards, soon smoothing to be substituted by the E-W trending system.

At the mesoscopic scale the assignement of a precedence in time between the two systems in very difficult. In the Turrite Secca Valley, the apenninic system seems to slightly refold the transversal one; in Arnetola the situation is the opposite.

However, as soon as larger Domains are considered, the picture emerging is invariably that of two sets of plane-non cylindrical folds, since the loci of dispersion of apenninic and transversal late-phase axes and intersections are in their own axial-plane schistosity surfaces. This situation is particularly evident in the upper Frigido Valley, where the two fold systems interfere with particular intensity (CARMIGNANI & GIGLIA, 1979).

CONSIDERATIONS ON THE MECHANICS OF FORMATION OF LATE-PHASE STRUCTURES

The inheritance of early deformation

The first-phase deformation has produced an anomalous superposition of rocks leading to a complex multilayered vertical alternance (and also abrupt lateral variations) of mechanical properties.

When individually considered the Upper Triassic dolomite behaves as a competent layer, together with the Upper Jurassic radiolarian cherts and pure marbles of Lower Lias. But these latter, when they are multiply tectonically interlayered with slates and chlorite marbles of Cretaceous age or Upper Jurassic radiolarites can instead have a ductile behaviour, together with Paleozoic phyllites when they are exempt of thick arenaceous intercalations. These short references to the mechanical behaviour of single lithotypes can easily account for the multiple kind of rheologic properties acquired by the rock pile as a conseguence of the different combinations realized in the early deformation phases.

This inheritance has certainly conditioned the emplacement of late-phase structures. Late asymmetric structures of all orders are generally found in layers of more ductile behaviour, and have a tendency to die out in the more competent layers, leading to asymmetric intrafolial folds at all scales.

Slip along discrete surfaces, marking boundaries along layers with different mechanical properties, seems to be confirmed by striae along some deformed S_1 foliations.

These characters, together with the asymmetry of minor folds, suggest a general flowage of materials away from the crests where actually stretching of pre-existing surfaces seems to be the rule.

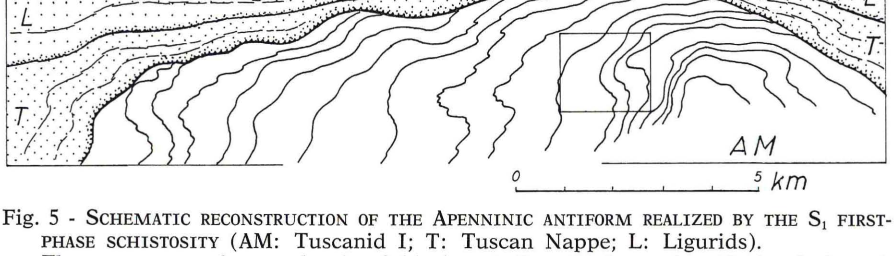

Fig. 5 - SCHEMATIC RECONSTRUCTION OF THE APENNINIC ANTIFORM REALIZED BY THE S_1 FIRST-PHASE SCHISTOSITY (AM: Tuscanid I; T: Tuscan Nappe; L: Ligurids).
The symmetry of second-order folds in relation to the major (first-order) antiformal structure is reverse.
Tuscan and Ligurian Nappes are thinned towards the crest of the main antiformal structure.

Even the contacts between the major tectonic Units have been reactivated in the later phases, and the Units themselves are therefore attenuated in correspondence with the axis of the metamorphic window and accumulated towards both limbs of the broad antiformal structure. A kilometric cascade fold with western asymmetry is realized by the Tuscan Nappe North of Carrara (DECANDIA & Al., 1967; see also cross-sections in fig. 3, this paper).

The late-phase cross-folds seem to be controled too by the inheritance of first-phase structures which have caused large-scale lateral strain discontinuities in successive refolding. The more pronounced transversal cross-folds are in fact located in correspondence with a WSW-ENE major contact between the Paleozoic and Mesozoic rocks. This contact is at the original emplacement of a first-phase hinge zone, where the Paleozoic core of a large rotated recumbent anticline with N 60° trending axis was brought side to side with its Mesozoic envelope situated to the NNW.

GENETICAL RELATIONSHIPS BETWEEN APENNINIC AND TRANSVERSAL CROSS-FOLDS

The impossibility to decide wether the apenninic or the anti-apenninic systems of folds were formed earlier is, in the Authors' opinion, in relation to the fact that the two systems were formed contemporaneously during progressive deformation with elongation along the axis of the major apenninic antiformal structure. By this, anti-apenninic folds were superposed to apenninic folds and vice-versa, the latest system generally displaying a less ductile character.

Even the « *a* » kinematic axes calculated for minor similar folds of both systems seetm to consistantly maintain a SW-NE trend throughout the entire region (KLIGFIELD, 1978), and this is another datum in favour of a genetical relationship between the two systems.

As can be seen from figg. 3 and 4 the overall geometry of the main apenninic and anti-apenninic antiforms is that of RAMSAY's sub-class IA (RAMSAY, 1967). Antiformal structures with an attenuated crestal zone had been previously termed « flowage folds » by BAIN (1931). BHATTACHARJI (1958) proposed the synonimy between « flowage folds » and « supratenous folds », a term which was referred to folds connected with differential compaction of sediments on a structural high of the basement. We have preferred

RAMSAY's classification for its purely geometrical character, without implications on the mechanism of formation for such type of folds.

But the problem exists and cannot be avoided. Vertical uplift is the first mechanism which comes to mind in the formation of antiforms with attenuated hinges, or better more or less pointed domes, with attenuation of the culminations and thickening of the intervening troughs. This kinematic interpretation is also suggested by the existence of mantled gneiss domes with a granitic core.

This is not however the only possible mechanism. BHATTACHARJI (1958) has experimentally produced synchronous folds and high-angle cross-folds with an overall geometry surprisingly similar to those of the Apuane through one-directional non-uniform compression in the incompetent members of a multilayered association with differing mechanical properties. In incompetent layers at a sufficient depth, as soon as an arching of the main fold is produced, plastic flow is set up along the axis of the main fold and the contemporaneously producing secondary cross-folds.

Both explanations are possible within the general geological picture of the Apuane.

Compressive stresses could have continued up to 11 m.y. b.p. at the emplacement of the belt; besides all they were certainly present in the external zones of the Northern Apennines.

But vertical uplift is also a possible explanation. Ensialic shear in first-phase deformation has certainly produced an important crustal thickening. Isostatic re-equilibration as a response to crustal thickening could have ensued, irregularly uplifting the whole Nappe building and thus forming the complex antiformal structure which presently characterizes the Apuane Alps. Minor fold asymmetry pattern is also consistant with this alternative model.

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