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NEOGENE EVOLUTION OF AN ARCUATE STRUCTURE IN THE UMBRIA-MARCHE APENNINES*

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Riassunto. L'Appennino umbro-marchigiano è una catena a pieghe e sovrascorrimenti costruitasi durante il Miocene superiore - Pliocene. Pieghe e sovrascorrimenti interessano in affioramento la copertura sedimentaria. Viene analizzata la ruga più interna nel settore compreso tra il M. Nerone a nord ed il M. Serano a sud. Questa è costituita da periclinali disposte secondo un *en-échelon* destro ed orientate NW-SE a nord e N-S (talvolta NNE-SSW) a sud. Il sistema di periclinali è inviluppato esternamente da un sovrascorrimento ad andamento arcuato.

Alla base della evoluzione neogenica delle strutture suddette, gli AA. pongono due momenti deformativi. Durante il primo si sviluppano *blind-thrusts* frontali ed obliqui, organizzati secondo una zona di trasferimento arcuata, che interessano solo il Calcare massiccio e le Anidriti di Burano e sono ricoperti plasticamente dalla successione pelagica: si generano in questo modo le macropieghe con la distribuzione planimetrica suddetta. Nel secondo si sviluppa il sovrascorrimento, che riattiva probabilmente i *blind-thrusts.* In questo momento il sistema di periclinali *en-échelon* rappresenta il tetto del sovrascorrimento stesso.

Abstract. The Umbria-Marche Apennines is an arcuate fold and thrust belt, built up during Upper Miocene-Pliocene. Folds and thrusts affect at the surface the sedimentary cover. The AA. examine the innermost ridge in the sector between M. Nerone to the north and M. Serano to the south. It is made up of a dextral *en-échelon* set of periclines, whose axial trend is NW-SE to the north and N-S (sometimes NNE-SSW) to the south. The *en-échelon* set of periclines is externally enveloped by a thrust, bent in plane view.

As the basis of the Neogene evolution of the examined structure, the AA. propose two deformation episodes. In the first the development of frontal and oblique blind thrusts (affecting only the Calcare massiccio and Anidriti di Burano formations) are responsible for macrofolds and for their planimetric distribution. The second one is due to NE thrusting along a thrust which probably reactivates the blind thrusts. In this moment of thrust the *en-échelon* set of periclines constitutes the hanging-wall of the thrust.

Introduction.

The Umbria-Marche Apennines is the most southern and external part of the Northern Apenninic Arc, which is typically convex to the northeast (Fig. 1). It is a fold and thrust belt built up during Late Miocene-Pliocene.

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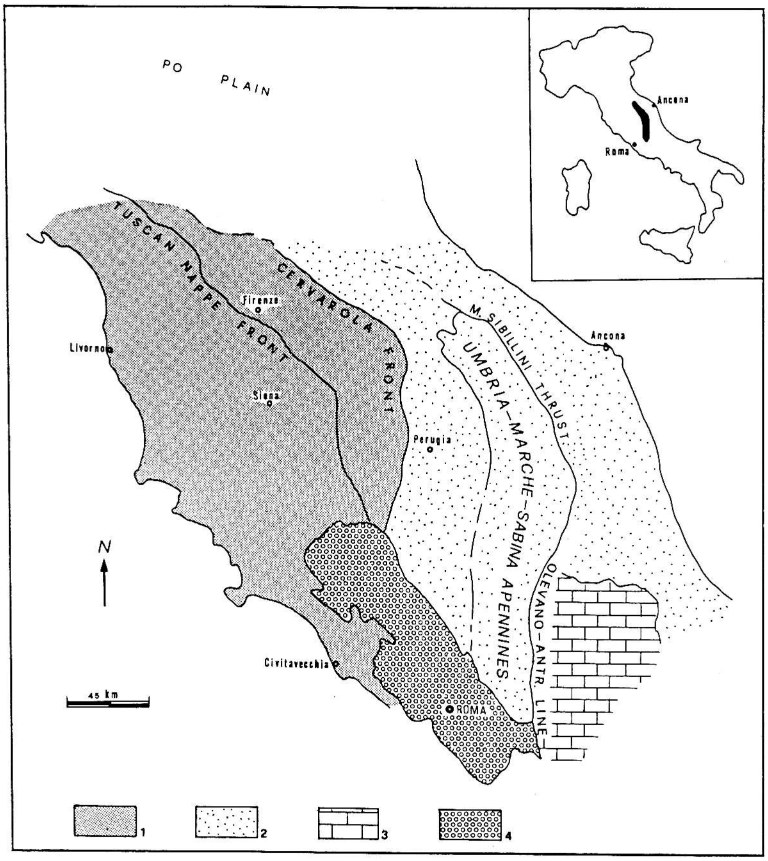

Fig. 1 - Main structural zones of Central-Northern Apennines, partially masked by recent volcanic rocks (4). 1) Tuscan zone; 2) Umbria-Marche zone; 3) Lazio-Abruzzi zone.

At the surface, folds and thrusts affect the sedimentary cover, which is formed by: a) Upper Triassic evaporites (Anidriti di Burano formation, about 1500 m thick) cropping out only in western Umbria and identified at depth during AGIP borings (Burano 1 and Fossombrone 1 Wells in Martinis & Pieri, 1964); b) the Calcare massiccio formation, an 800 m thick massive, carbonate neritic sequence (Upper Triassic-Lower Lias); c) a well-bedded calcareous-marly-cherty pelagic and hemipelagic sequence (Middle Lias-Lower and Middle Miocene), which thickness varying from 1400 m, where the Jurassic sequence is complete (Corniola, Rosso Ammonitico/Calcari e Marne del Sentino, Calcari a Posidonia, Calcari diasprini umbro-marchigiani), to 900 m where it is represented by a condensed sequence (Calcari nodulari) (Centamore et al., 1971); d) siliciclastic-turbiditic deposits of a migrating foreland basin (Burdigalian p.p.- Lower Pliocene), sometimes 1000 or 3000 m thick (Fig. 2).

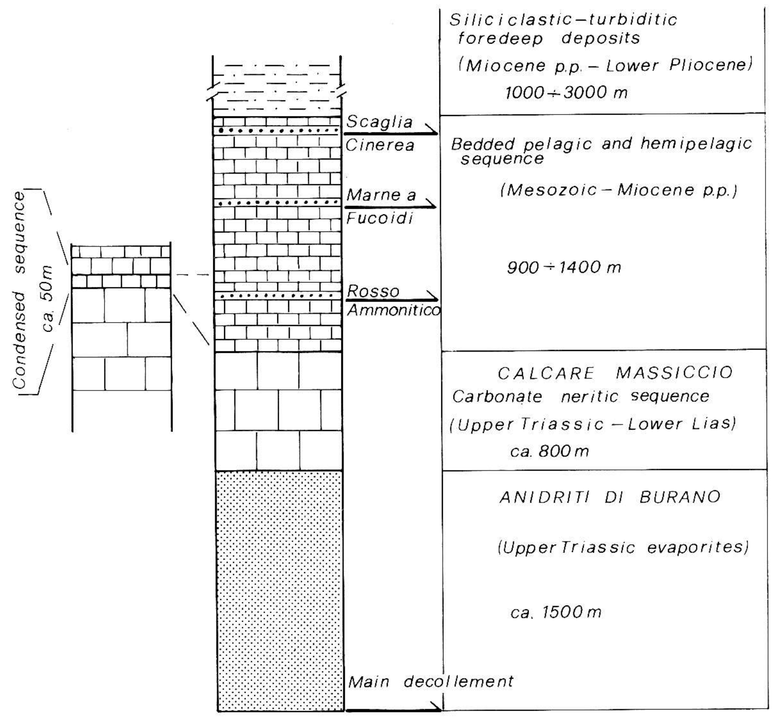

Fig. 2 - Schematic stratigraphy of the Umbria-Marche area.

The last of these crop out extensively in western Umbria (Marnoso- arenacea Formation: Burdigalian p.p.- Lower Tortonian) and in the eastern Marche (Laga Formation: Messinian-Lower Pliocene) where towards the east they are buried under sandy and clayey Middle Pliocene-Lower Pleistocene transgressive deposits.

Between these two areas there is the Apenninic Ridge (the Umbria-Marche-Sabina calcareous Apennines), where the Mesozoic-Paleogenic sequence crops out extensively (Fig. 3). North of Visso this Ridge divides into two minor ridges (western and eastern ridges) separated by the complex Fabriano-Visso intrapenninic depression, where siliciclastic turbiditic Tortonian-Messinian deposits crop out. The Apenninic Ridge develops from north (near allochthonous sediments of the Marecchia valley), to south (as far as the Sabina Mountains) with a typical arcuate shape, due to the main structural elements trend.

On the basis of structural considerations and/or of paleomagnetic data, the arcuate shape of the Umbria-Marche-Sabina Apennines has been interpreted as the result of orocline bending (resulting from a primarily rectilinear or arcuate belt), or as a primary feature (Ogniben, 1969; Castellarin et al., 1978; Channel et al., 1978; Koopman, 1983; Boccaletti et al., 1983; Eldredge et al., 1985; Lowrie & Hirt, 1986; Lavecchia et al., 1988; Calamita & Deiana, 1988; Hirt & Lowrie, 1988).

In this context we have analyzed the arcuate structure of M. Nerone-M. Serano ("internal ridge" of Scarsella, 1951), for which we propose a kinematic evolution (Fig. 3).

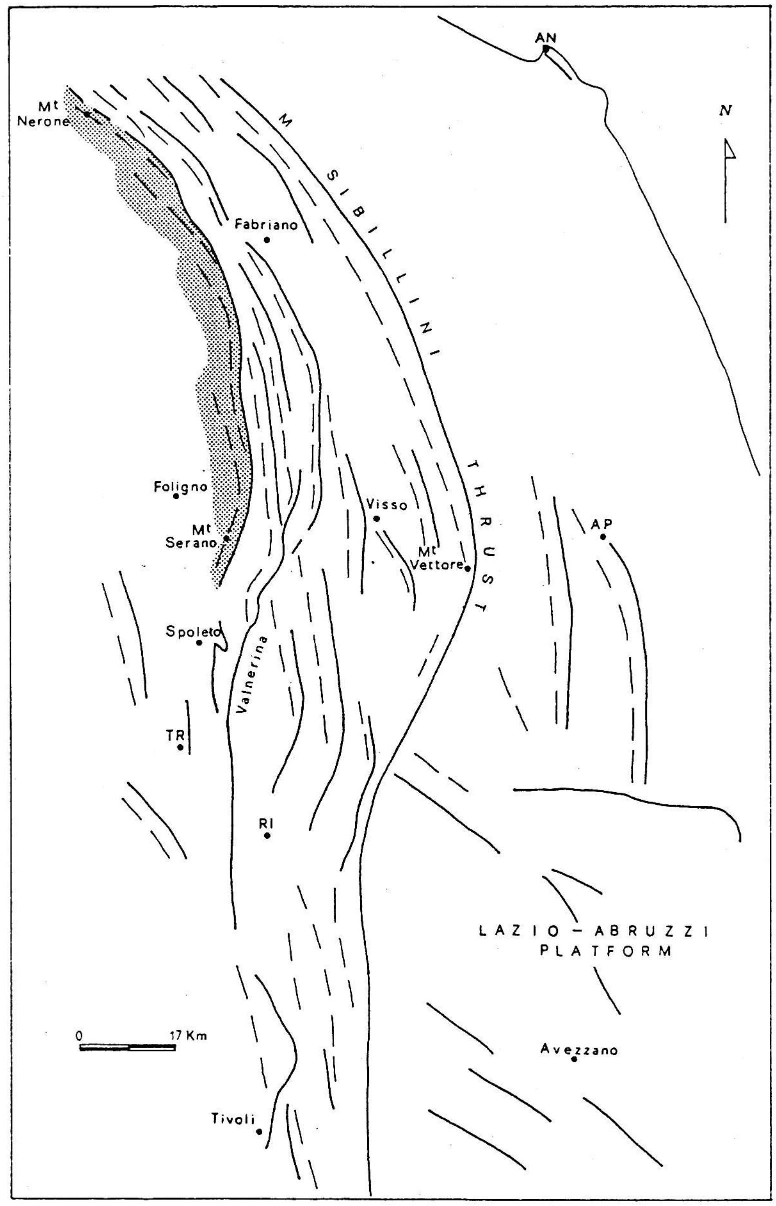

Fig. 3 - Trend of main folds (dashed line) and thrusts (heavy line) in the Umbria-Marche Apennines. The dotted area shows the M. Nerone-M. Serano arcuate structure.

Structural setting.

The arcuate shape of the Umbria-Marche-Sabina fold and thrust belt is described fundamentally by thrusts, striking nearly N 135° to the north and nearly N-S to the south (west of the Lazio-Abruzzi carbonate Platform). An average strike of N 20°, due to the envelope of segments trending N 30°-60° and N-S, characterizes the segment connecting the NW-SE with the N-S thrusts (Calamita & Deiana, 1986) (Fig. 3).

The tectonic transport is mainly towards the NE (Koopman, 1983; Lavecchia, 1985; Calamita & Deiana, 1986); it follows that the northern segments of the thrusts have an inverse character, whereas the southern segments have a transpressive one (Coli, 1981; Koopman, 1983; Calamita et al., 1987). In particular the N 30°-60° trending segments can be interpreted as initial lateral ramps (Calamita et al., 1987). A further, though subordinate, NNE-verging motion is observable mainly in the innermost thrusts (Calamita, in press).

As far as the macrofolds are concerned, they trend axially N 135° in the northern sector; in the central-southern one they trend N 160°-170°, sometimes N-S, and terminate near the thrusts. Minor folds parallel to the latter ones can often be observed.

The Umbria-Marche-Sabina Apennines are thrust towards the NE, along the M. Sibillini thrust, on the more external units, represented by the Lazio-Abruzzi carbonate Platform to the south and the Marche-Abruzzi domain to the north (Scarsella, 1951; Dallan Nardi et al., 1971).

More to west of the M. Sibillini thrust, other thrusts characterize the structural setting of the internal ridge and continue to the south, parallel to the M. Sibillini one. Between these thrusts the most eastern ones join with the N 20°-30° trending Valnerina thrusts, whereas the most internal one (M. Nerone-M. Serano thrust) probably joins with the Spoleto thrust (Fig. 3).

The hanging-wall of the M. Nerone-M. Serano thrust, is an arcuate dextral *en-échelon* set of periclines (from north to south: M. Nerone-M. Catria, M. Cucco, M. Maggio-Annifo e M. S. Stefano-M. Serano). In particular these periclines have an axial trend N 135° to the north, N 160°-180° in the central sector, until a probable trend N 30°-45° for the M. S. Stefano-M. Serano structure. The forelimbs of the periclines are affected by thrusts which root near the northern pericline termination and the displacement is transferred to the forelimb of the pericline more to the east (Fig. 4). Scarsella (1951) described the periclines pattern as "virgazione scalare".

Kinematic evolution of the M. Nerone-M. Serano arcuate structure.

To understand the kinematic evolution of an arcuate element the relationship between folds and thrusts must be analyzed.

In the arcuate dextral *en-échelon* set of M. Nerone-M. Serano, the folds have a box-fold profile with vertical or gently overturned forelimb. Where the macrofold core crops out, the Calcare massiccio does not follow the complete fold geometry. It has no outer hinge and no vertical or overturned forelimb and its subhorizontal or gently NE

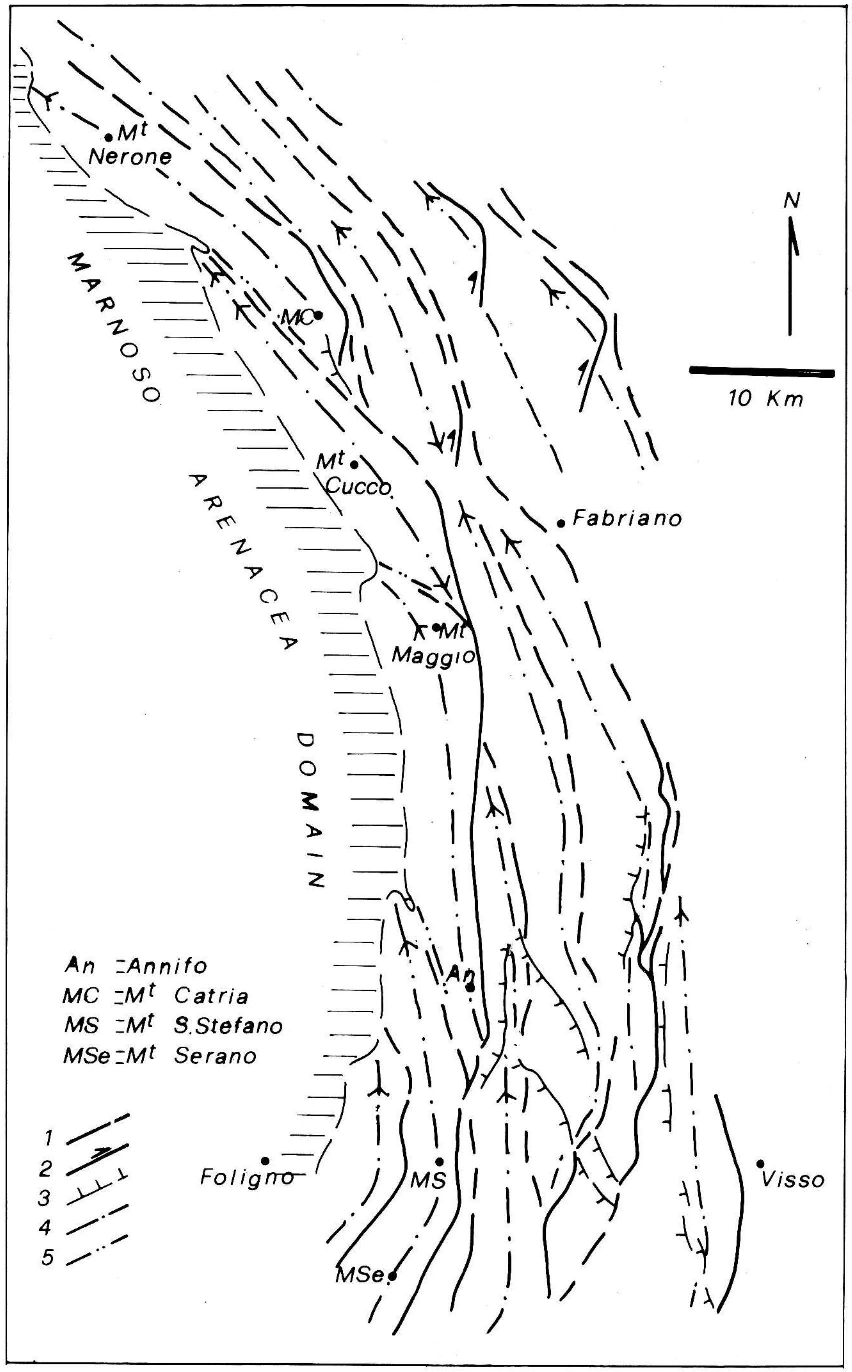

Fig. 4 - Structural scheme of the western ridge. 1) thrust; 2) transpressive fault; 3) normal fault; 4) anticline and its axial plunge; 5) syncline.

dipping layers, are in tectonic contact, along an up-thrust, with the overlying Maiolica and Corniola Formations, in a condensed series and in a complete one, respectively. Therefore, the above mentioned up-thrust may be considered a blind-thrust dislocating the Calcare massiccio alone.

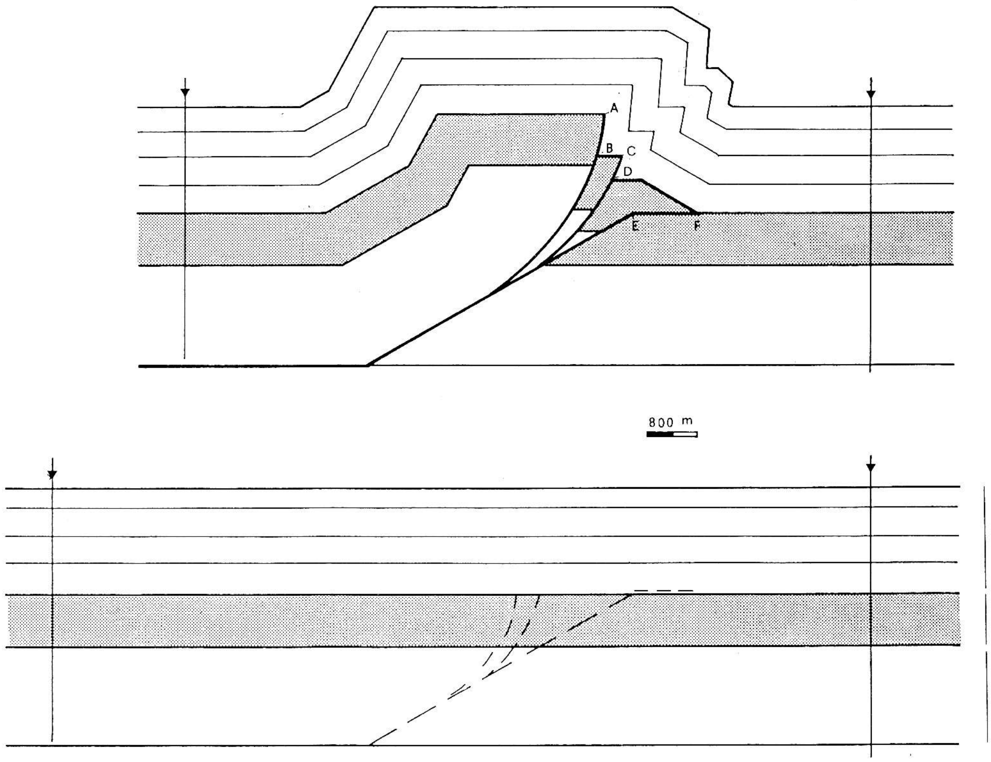

Fig. 5 - Folding model. 1) Anidriti di Burano; 2) Calcare massiccio; 3) Pelagic sequence (by Calamita, in press). The pelagic sequence (between points A and F) is detached and back-thrusted with regard to the underlying competent unit.

On the basis of the relationships of the Calcare massiccio and overlying pelagic sequence, Calamita (in press) proposed, for the Umbria-Marche Apennines, the folding model of Fig. 5. The Triassic evaporites and the Calcare massiccio are affected by a low-angle blind-thrust having the point F as its tip, located at the top of the Calcare massiccio where there is a flat.

As soon as the displacement on the blind-thrust begins, the sequence above the Calcare massiccio (between points A-F) is back-thrusted, thus assuming an independent behavior with regard to the underlying stiffer unit. In the latter (referring to the sector delimited by the points A-F) up-thrusts develop contemporaneously with low-angle blind-thrust. These branch out from the latter and are then covered continuously by the overlying sequence.

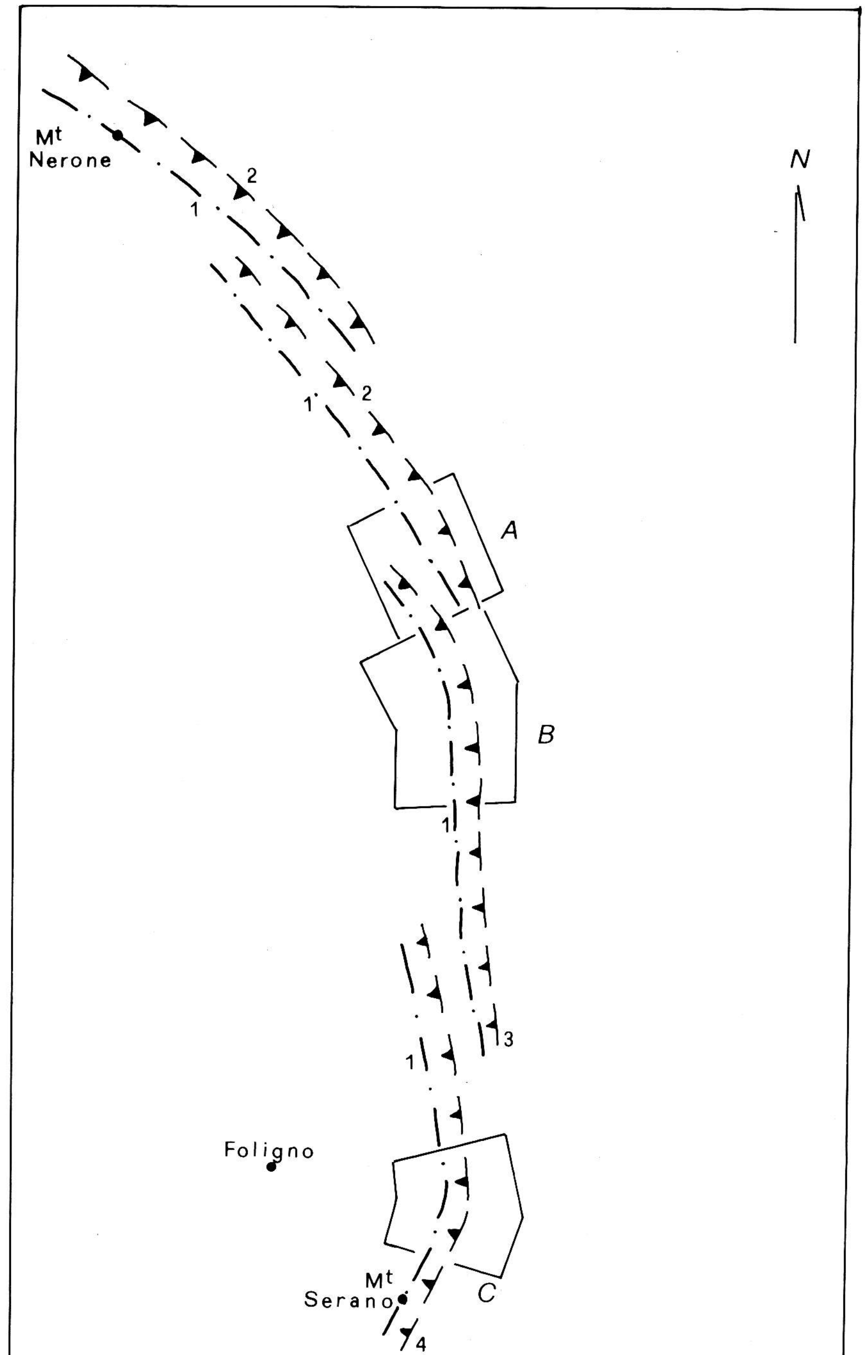

Fig. 6

The overall picture is that of a macrofold with a backlimb parallel to the blind-thrust ramp and with a forelimb, parallel to the up-thrust, affecting the pelagic sequence only. Therefore, the axial trend of the macrofolds and their planimetric pattern are probably controlled by the geometry and pattern of the blind-thrusts; the direction of tectonic transport and the pre-existent discontinuities may guide the development of the blind-thrusts themselves.

It is in this context that we interprete the M. Nerone-M. Serano arcuate structure (Fig. 6), where the periclinal system, arranged *en-échelon*, can be related to blind-thrusts arranged according to a transfer zone (Fig. 6A).

The change of the axial trend of the M. Maggio-Annifo pericline, from NW-SE to N-S, and that of the M. S. Stefano-M. Serano structure, from NNW-SSE to NNE-SSW,

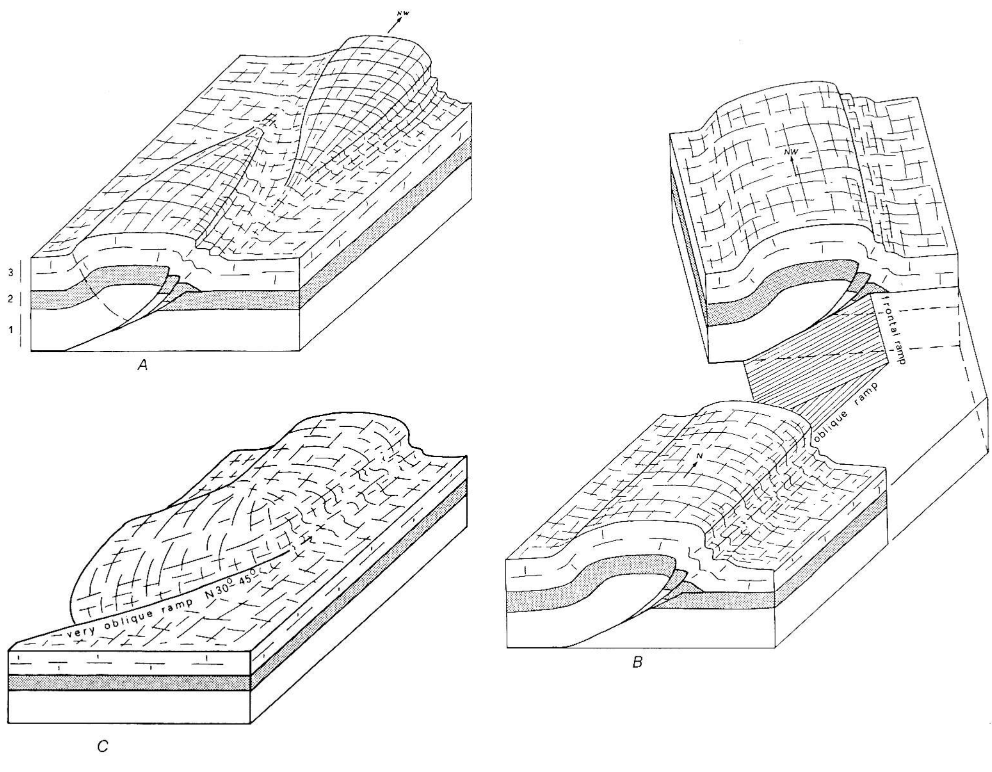

Fig. 6 - Scheme showing as the planimetric distribution of the macrofolds (1) can be related to blind-thrusts (2, 3, 4).
The periclines, arranged *en-échelon*, can be related to blind-thrusts arranged according to a transfer zone (Fig. 6A; by Calamita, in press): 1) Anidriti di Burano; 2) Calcare massiccio; 3) Pelagic sequence.
Preexisting discontinuities trending N-S, N 20° and N 30°-45° control the oblique (3) and very oblique (4) blind-thrusts. These latter develop the M. Maggio-Annifo and M. S. Stefano-M. Serano arcuate macrofolds, respectively (Fig. 6B and 6C; by Calamita, in press).

can be due to the control of pre-existing discontinuities on the blind-thrusts geometry. In particular, pre-existing discontinuities trending N-S, N 20° could have conditioned the oblique blind-thrust (Fig. 6B) while pre-existing discontinuities trending N 30°-45°, could have controlled the very oblique blind-thrust (1) (Fig. 6C).

A NE thrusting follows this folding moment: its thrust reactivates the blind-thrusts and envelopes the whole *en-échelon* set of periclines, which are preserved in the hanging-wall.

On the basis of the proposed kinematic evolution, the arcuate shape of the M. Nerone-M. Serano element can be considered a primary feature.

Finally, the paleomagnetic data concerning the arcuate Umbria-Marche chaine have not yet led to a univocal interpretation. In fact, while Channel et al. (1978) and Eldredge et al. (1985) suggest oroclinal bending on the basis of the Scaglia rossa paleomagnetic data, Lowrie & Hirt (1986, 1988) conclude that the Maiolica paleomagnetic data do not support oroclinal bending.

Conclusion.

In the arcuate Umbria-Marche fold and thrust belt, a dextral *en-échelon* set of periclines characterizes the innermost ridge in the sector between M. Nerone to the north and M. Serano to the south. The axial trend of the periclines is NW-SE to the north and N-S (sometimes NNE-SSW) to the south. A thrust, bent in plane view, envelopes externally the set of periclines.

Starting from a folding model based on blind-thrusts, affecting the Calcare massiccio and covered continuously by the overlying pelagic sequence, and from the relationships between folds and thrusts (Calamita, in press), a kinematic evolution of the M. Nerone-M. Serano arcuate structure is proposed. This evolution is characterized by two deformation events.

In the first, frontal and oblique blind-thrusts develop (the latter controlled by preexisting discontinuities in the southern sector). These blind-thrusts are arranged according to an arcuate transfer zone and affect the Calcare massiccio and Anidriti di Burano. They are covered continuously by the overlying pelagic sequence: in this way an *en-échelon* set of periclines is formed.

In the second event, a NE thrusting develops. The thrust reactivates the blind-thrusts and envelopes the whole *en-échelon* set of periclines, which are preserved in the hanging-wall.

On the basis of the proposed kinematic model, we also predict that the arcuate shape of the M. Nerone-M. Serano structure cannot be considered as an orocline, but as a primary feature.

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(1) Previous Authors ascribe the dextral *en-échelon* set of periclines to wrenching tectonics (Lavecchia & Pialli, 1980; Lavecchia et al., 1981; Boccaletti et al., 1983; Lavecchia et al., 1984).

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