CARTA GEOLOGICO-STRUTTURALE DELL'APPENNINO EMILIANO-ROMAGNOLO

Scala 1:250 000

NOTE ILLUSTRATIVE

Andrea CERRINA FERONI[1] - Luca MARTELLI[2] - Patrizia MARTINELLI[1] - Giuseppe OTTRIA[1]

Rita CATANZARITI[1] *(biostratigrafia)*

a cura di **Andrea CERRINA FERONI**

1 IGG - Istituto di Geoscienze e Georisorse, CNR - Pisa 2 Regione Emilia-Romagna - Servizio Geologico, Sismico e dei Suoli

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Responsabile del Progetto: Raffaele PIGNONE
(Servizio Geologico, Sismico e dei Suoli - Regione Emilia-Romagna)

Coordinamento editoriale: Angela ANGELELLI e Sandra FORNI
(Servizio Geologico, Sismico e dei Suoli - Regione Emilia-Romagna)

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ABSTRACT

PREFACE

The Structural-Geological Map of the Emilia-Romagna Apennines (1:250.000)*, resulting from the collaboration between the Geological Survey of the Emilia-Romagna Region and the CNR, Centro di Studio per la Geologia Strutturale e Dinamica dell'Appennino, represents the coherent evolution of the Emilia-Romagna Region research programs about geological cartography; the aim of the Structural-Geological Map is to synthesize the great amount of analytical informations collected during twenty years of laboratory and field work.*

The Structural-Geological Map of the Emilia-Romagna Apennines (1:250.000) *therefore represents the natural conclusion of an extensive and very positive collaboration between the Emilia-Romagna Region and the national scientific community.*

As the product of a geological synthesis, the Structural-Geological Map could not derive from the mechanical assemblage of the structural-geological maps (scale 1:100.000) of each sector produced by the research groups taking part in the Project (fig. 1). As an effort to elaborate a sole setting for this part of Northern Apennines, the solutions of each sector have been modified, even radically; this operation has been guided starting from the original data of the geological maps of the Emilia-Romagna Region (scale 1:10.000) and of the Italian Geological Survey CARG Project (scales 1:25.000 and 1:50.000). In addition, numerous regional topics have been directly confronted by the authors through studies in many cases lacking the necessary deepening in examination of the problems taken into consideration.

Even though justifiably, the research groups involved in this cartographic synthesis have in many cases difficulty recognizing themselves in the adopted solutions and interpretations, the Structural-Geological Map of the Emilia-Romagna Apennines (1:250.000) *remains, however, the result of a collective and complex research, in which the scientific community has worked together with the Geological Survey of the Emilia-Romagna Region.*

The Structural-Geological Map is very detailed; for this reason the Map contains a tectonic sketch (scale 1:1.500.000), in which only the fundamental structural and stratigraphical units are reproduced. At foot of the tectonic sketch the Tyrrhenian-Ligurian sector (western sector) is contrasted to the Adriatic-Padan sector (eastern sector). Consequently the legend of the Map is thought out to separate the structural units and the stratigraphical successions (thrust-top basins) of the two sectors. The separation of the litostratigraphic units inside the tectonic units is made through graphic solutions of secondary order (graphics, differentiated chromatic intensity). The stratigraphical informations lacking in the Structural-Geological Map have been recovered in nineteen Stratigraphical Tables (see this volume, opposite side).

In the concluding paragraph, the relationships between the two sectors will be discussed, amongst a possible dextral transpressive tectonics that controlled the Miocene-Pliocene evolution of the Northern Apennines.

THE REPRESENTATION OF DEFORMATION

The correct mapping of deformation is a non-formal assumption in order to introduce and discuss structural topics of regional interest. In a synthetic map the difficulty lies particularly in the complicated nature of stabilizing the compatibility between "objective data" and "interpretation", this latter tending to be generally privileged in the regional syntheses.

In the Structural-Geological Map of the Emilia-Romagna Apennines (1:250.000), *where tectono-stratigraphical units and deformations of the upper crust levels are represented, the folding deformation is expressed by the trace of the axial surfaces; if available, the fold axes are placed on the axial surfaces, utilizing a punctual symbol (arrow) also used for the representation of axes of minor folds which are not associated with traces of axial surfaces.*

The traces of the axial surfaces are organized in four categories (anticlines, synclines, antiforms and synforms), further subdivided in relation to the two orogenic cycles recognized in the Northern Apennines: Alpine cycle (pre-sin Mesoalpine Phase) and Apenninic cycle (post Mesoalpine Phase). The utilization of the axial surface traces is an indispensable resource in particular for the representation of the recumbent folds with overturned limbs of kilometric size (normal to the fold axis) which characterize the Helminthoid Flysch Lower Unit (Mesoalpine Phase). These folds were refolded during the Oligocene-Miocene and Pliocene-Pleistocene phases of the Apenninic orogenic cycle.

In order to highlight the main overturned limbs and more generally the regional structural setting, the geometry and polarities of selected bedding surfaces belonging to tectono-stratigraphical units have been mapped.

Regarding brittle deformation, kinematic indicators associated with ever overthrusts and faults are extremely lacking in the standard geological cartography; this evident gap of precise informations has not been bridged by the studies performed for the Structural-Geological Map of the Emilia-Romagna Apennines (1:250.000)*. Therefore faults have not been separated in the traditional categories (normal, reverse and strike-slip faults) inverting a very common trend which prefers the interpretation of faults even without kinematic constraints.*

The overthrusts have been separated in two groups relative to the Eo-mesoalpine tectonic phase and to the tectonic phases of the Apenninic cycle. In the context of the second group the main out-of-sequence thrusts are distinguished particularly in order to call attention to the system of longitudinal thrusts which control the exhumation of the Cervarola and Falterona foredeep successions, thus determining the overthrusting on the external Miocene foredeep (Romagna Marnoso-Arenacea Formation) corresponding to the eroded/buried Romagna-Emilia duplex.

STRUCTURAL EVOLUTION

The Emilia-Romagna Apennines, and more generally the whole Northern Apennines is the result of a polyphase evolution which develops within two successive, but geodynamically independent, orogenic cycles (Alpine cycle and Apenninic cycle).

In the Structural-geological Map we attribute the complex structure of the Ligurian Units (Ligurides) and the embryonic structure of the tectono-stratigraphical units pertaining to more distal domains with respect to the European margin (Subligurian Units, Sporno-Sarpegna Unit, Samoggia-Sillaro Unit) to the Alpine orogenic cycle.

The structures of the Oligocene-Miocene foredeep units and those of the thrust-top basin successions developed above the Ligurides, are referable to the Apenninic orogenic cycle. Below the Ligurides and above the foredeep successions, also the structural evolution of the Subligurian Units, Sporno-Carpegna Unit and Samoggia-Sillaro Unit completed during the Apenninic cycle.

THE ALPINE STRUCTURE (Eo-mesoalpine Phases)

The structure of the Ligurides (eo-mesoalpine stacking) is due to the Alpine orogenic cycle with limited modifications in the course of the Apenninic phases. In both sectors (western and eastern sectors) the Helminthoid Flysch (Upper Campanian-Maastrichtian) are attributed to two tectonic units (Helminthoid Flysch Upper Unit and Helminthoid Flysch Lower Unit). The Upper Unit is represented by the Mt. Antola Flysch (western sector) and by the Mt. Cassio Flysch (eastern sector), both structurally expressed by large normal limbs and scarcely developed overturned limbs, associated with Adria-verging thrusts belonging to both late Alpine and Apenninic phases.

In the mesoalpine stacking the Helminthoid Flysch Lower Unit occupies the opposite geometric position, at the base of the nappe pile; in contrast with the Upper Unit, the Helminthoid Flysch of the Lower Unit are affected by recumbent folds with overturned limbs which are developed more than ten kilometres orthogonal to the fold axes. This folding structure, together with the geometric position, has been utilised to correlate on structural basis some Helminthoid Flysch usually separated in the regional geological cartography (Ottone-S. Stefano, Orocco, Bettola, Caio, M.Venere). In both sectors between the Upper and the Lower Helminthoid Flysch Units, siliciclastic units (Gottero Unit, Media Val Taro Unit) and ophiolitic units (Bracco-Colli Tavarone Unit, Upper Ophiolitic Unit) are interposed. The Paleocene as younger age of the structural units overlying in both sectors the Lower Helminthoid Flysch Unit suggests the subdivision of the Mesoalpine Phase in two deformative events (ELTER, 1993):

-The initial event (Upper Paleocene) was responsible for the emplacement of the Helminthoid Flysch as a sole nappe on the underlying stacked units (Gottero Unit on the Bracco Unit in the western sector; Media Val Taro Unit on the Upper Ophiolitic Unit in the eastern sector) with a transport direction towards the European margin (subduction towards east).

- During the progressive subduction towards east, a second tectonic phase (Mesoalpine Phase s.s.; Middle Eocene) produced in the upper crust levels the retroflexion towards the Adria plate of eoalpine and Paleocene protomesoalpine stacking. During the retroflexion the Paleocene Helminthoid Flysch nappe was broken down into two units by the overthrusting towards the Adria plate margin of both the Antola-Gottero-Bracco Units (western sector) and Cassio-Media Val Taro-Upper Ophiolitic Units (eastern sector) onto the Helminthoid Flysch deposited farther from the European margin; at the footwall of the mesoalpine stacking these Helminthoid Flysch were deformed in Adria-verging kilometric-scale recumbent folds. The units derived from the western margin of the Paleocene-Eocene calcareous Flysch domain (Vico-Penice Unit, Groppo Sovrano Unit) were also involved in the orogenic mesoalpine prism below the folds of the Helminthoid Flysch Lower Unit.

Therefore in the Middle Eocene, at the end of the Alpine orogenic cycle, a belt was generated showing a vergence contrasting with the Europe-verging Alpine belt. The relationships between the pre-Oligocene units of the Subligurian domain and the Sporno-Carpegna Unit and Samoggia-Sillaro Unit, more external (eastern) than Vico-Penice and Groppo Sovrano Units, are problematic in the context of the mesoalpine Appenninic belt.

In the evolution of the Ligurian Units the informations relative to the Eoalpine Phase are scarce and indirect. We may correlate to this phase the massive ophiolitic detritus (Lower Campanian) and clastic deposits of Alpine provenance (Salti del Diavolo Conglomerate at the base of Mt. Cassio Flysch).

THE APENNINIC STRUCTURE (Oligocene-Miocene and Pliocene-Pleistocene phases)

In the Emilia-Romagna sector of the Northern Apennines, the Apenninic evolution is characterized by the migration of the foredeep-belt system, which begins in the Oligocene successively to the exumation of the eo-mesoalpine stacking. The prolonged deformative process of the Appeninic cycle is developed with higher continuity in comparison to the traditional resolution in distinct tectonic phases. The main unconformities of the episutural successions, together with the time progression of the tectono-stratigraphical units involved in the overthrusts and more particularly the diachronous age of the foredeep succession top overthrust by the nappe system, suggest the following event steps.

Oligocene phases

- *Thrusting and folding of the internal and intermediate sectors of the Subligurian Domain (emplacement of the Aveto-Petrignacola Unit on the Bratica-Salsominore Unit) which is overthrust by the Ligurides of the eo-mesoalpine stacking.*
- *Thrusting accompanied by synsedimentary tectonics (debris flows, megaslumping) of the lower Epiligurian Succession (Monte Piano Marl and Ranzano Sandstone) deposed between the Middle-Upper Eocene and the Lower Oligocene (CATANZARITI* et al.*, 1999).*
- *Overthrusting of the Ligurian Units, already joined to a part of the Subligurian Domain, on the more internal sector of the western foredeep (Macigno Formation of La Spezia area, and its extension towards the SE).*
- *In the eastern sector, emplacement of structural units, only partially constructed (eo-mesoalpine Ligurides, Subligurian Units, Sporno-Carpegna and Samoggia-Sillaro Units) on the Chattian foredeep sandstones perhaps corresponding to the Macigno Formation of the Pratomagno and towards the NW to its extension in more internal zone of the Mt. Modino Sandstone.*

Aquitanian Phase

- *Completion of the structure of the Subligurian Units by emplacement of the internal and intermediate units already stacked (Aveto-Petrignacola and Bratica-Salsominore) on the external Subligurian Domain (Marra Marl and its equivalents of Aquitanian age).*
- *Emplacement of the whole Subligurian-Ligurian Units, by now almost completely structured, on the Macigno Domain (western foredeep) which in the Alpi Apuane area shows an Aquitanian stratigraphic top (Ponteccio Marl). In the eastern sector the overthrusting on the Oligocene-Aquitanian foredeep (Mt. Modino Sandstone) complete; in the Emilia sector the Ligurian (and Subligurian ?) Units complete their overthrusting on external calcareous flysch domain. Therefore it is once again affirmed that the Sporno-Carpegna Unit is extraneous to the Ligurides which represent the tectonic units of the eo-mesoalpine stacking. In this context, the presence at the top of the Mt. Sporno Flysch (Parma Appennine) of Oligocene marly-calcareous deposits (flysch facies) with abundant siliciclastic content (Val Sporzana Formation) is very important.*

In the epimesoalpine successions (Tertiary Piedmont Basin and Epiligurian Basin), the Aquitanian Phase is expressed by an unconformity accompanied by massive amounts of debris flows (Canossa Mélange) which are inserted in the Antognola Formation (eastern sector).

Burdigalian Phase

In the eastern sector it is particularly well expressed by the unconformity at the base of the platform deposits of the Bismantova Unit. Nonetheless, in the Structural-geological Map, the importance of this unconformity is reduced as the regional angular discordance which determines the direct superposition of the Bismantova Unit on the lower episutural succession (Monte Piano-Ranzano) and also on the Ligurian Units and locally (Modena Apennine) on the Subligurian Units has been interpreted as a Miocene-Pliocene low angle subtractive

tectonic contact.

At deeper structural levels, the Burdigalian Phase is also clearly expressed, in the eastern sector, by the overthrusting of the Ligurian-Subligurian Units on the San Salvatore Sandstone (Trebbia Valley, Piacenza Apennine) which represents the northernmost outcrop of the Burdigalian foredeep. The foredeep closure and the footwall syncline affecting the San Salvatore Sandstone occurred contemporaneously (LABAUME, 1992).

Post Burdigalian Phase evolution

After the Burdigalian Phase, between Serravallian and Lower Pliocene, the complete overlapping of Miocene foredeep of the eastern sector (Romagna Marnoso-Arenacea Formation) occurred. The Romagna Marnoso-Arenacea is structured according to a thrust system, recently interpreted as an eroded synorogenic duplex (CERRINA FERONI et al*., 2001). In the context of a time-transgressive deformative process migrating towards the Apulian foreland, two distinct tectonic phases may be recognized: the intra-Messinian Phase and the Lower Pliocene Phase. Both phases are expressed by an uncorformity as much as in the successions of the Romagna margin with the Po Plain (post foredeep "autochthonous" Succession) as in the "allochthonous" thrust top basin successions of the Emilia margin. Within the time-space evolution of the foredeep-belt system, the unconformities seem to be correlated to the uplift (expressed by the evolution from turbidite deposits to shallower up to continental deposits) which anticipates the emplacement of the belt front.*

*The Lower Pliocene Phase (*G. puncticulata *Phase), understood as the last notable emplacement event of the belt-front, precedes the deposition of the Pliocene-Pleistocene succession which represents therefore a "post nappe" succession along the whole Emilia-Romagna margin. This succession is disassembled into two segments by a regional unconformity recording the Middle Pliocene Phase. The NE-verging thrust and fold tectonics is still active up to the Lower Pleistocene (f.e. the overturned footwall syncline outside the Viano structure; Reggio Emilia Appenine). Antiforms and synforms, in the southeastern Romagna sector, deform the stratigraphic succession together with the thrusts of the Pliocene imbricate fan, external to the duplex.*

The post Burdigalian foredeep structure of the eastern sector (eroded Romagna duplex) longitudinally extends in the Emilia sector as a duplex buried beneath the allochthonous nappe, while, outside the Pliocene belt-front, evolves in a imbricate fan. This interpretation suggests the possibility that even the older and more internal foredeep deposits of the eastern sector were affected by a duplex successively destructured by the out-of-sequence thrust system which controlled the exhumation of the Cervarola Unit (Bobbio, Castiglione dei Pepoli) and its overthrusting upon the external duplex; the duplex plunges toward the NW under the Ligurides in correspondence of the "Sillaro Line" (Bologna Apennine) which assumes the significance of duplex roof thrust.

The possibility that the out-of-sequence thrust which displaces the allochthonous antiform of Castiglione dei Pepoli coincides with the eastern limit of the Mugello intramontane basin is particularly interesting also from a seismotectonic point of view.

THE NORTHERN APENNINES AS A POSSIBLE TRANSPRESSIVE BELT

In the Structural-geological Map and in the tectonic sketch, the boundary between the Tyrrhenian-Ligurian western sector and the Adriatic-Padan eastern sector, corresponds in its northern part (NW the Mt. Molinatico transversal overthrusting) to the late overthrusting of the Internal Ligurian Units on the External Ligurian Units. Therefore, we may describe this boundary as an out-of-sequence tectonic contact, which ties together two pre-existent structural stacking. From this point of view, we may begin to discuss the hypothesis that the Northern Apennines structure derive from a dextral transpressive tectonics.

Presuming the "Internal Ligurides"-"External Ligurides" boundary as the expression of a late shear surface, the composition of the poliphase structural stackings of the two sectors cannot be analysed through the boundary itself (i.e. transversally to the belt) but rather, referring to the NE axial immersion, longitudinally to the direction of the Apenninic belt.

Within this setting, moving from the lowermost to the uppermost units, we are able to reconstruct the western and eastern structural stackings, whose compositions are schematised in fig. 2. In the western sector the structural stacking is completed below, beneath the Tuscan Nappe, with the Tuscan Metamorphic Units (Apuane Pisani Mountains, Punta Bianca) (see the tectonic sketch).

Each stacking presents from the bottom to the top, an integrity and regional continuity which does not require integration with the structural units of the adjacent nappe pile. According to a transversal trajectory, the retrodeformation of the Internal Ligurides overthrusting on the External Ligurides does not bring to a restoration of a more complete eo-mesoalpine structural stacking, and leaves unresolved some regional problems. Among these, the most evident problem is the occurrence of coarse clastic deposits, locally with proximal characteristics, at various levels in the Epiligurian Succession of the central sector of the Emilia Apennine; these deposits derive from the erosion of Alpine lithostratigraphic units which are lacking in the substratum of the Epiligurian Succession. The arkosic sandstones of the Loiano Formation (Middle Eocene), the conglomerates of the Ranzano Formation (Lower Oligocene), and the metaophiolite-bearing conglomerates of the platform arenitic facies of the Bismantova Unit (Langhian) represent the main examples of these problematic deposits occurring in the Northern Apennines.

The problem is the same for the Aveto-Petrignacola Formation (internal Subligurian Domain), showing conglomerates (Lower Oligocene) with crystalline rock and andesitic clasts, these also being of difficult explanation in the context of the Apennine units of the eastern sector.

The supply of these coarse clastic deposits would be possible repositioning the units of the eastern sector close to the zones with Alpine supply by a retrodeformation, not pertaining to overthrusting, but to a dextral strike-slip faulting along the junction between western and eastern sectors. The dextral strike slip movement was necessarily active even after the Langhian and determined the duplication of the eo-mesoalpine (Ligurides) and the Oligocene-Aquitanian stacking (Subligurian Units). This movement would have, furthermore, produced the duplication of the Oligocene-Aquitanian foredeep (Macigno Formation of the Tuscan Nappe in the western sector; Mt. Modino Sandstone in the eastern sector) already partially overthrust by the stacking composed of Ligurian-Subligurian Units and Sporno-Carpegna and Samoggia-Sillaro external units.

The Macigno-Modino-Cervarola relationships have been always discussed in a bipolar context, which opposes the "stratigraphic solution" (lateral-vertical continuity of sedimentation between the sandstone units interrupted by olistostromes; NARDI, 1965) to the "tectonic solution" according to transversal trajectories to the belt (REUTTER, 1969; PLESI, 1975; BETTELLI et al*., 1987; PLESI* et al*., 2000). Now we may propose a third possibility, restoring the Macigno and Modino-Cervarola foredeep domains by retrodeformation of a longitudinal dextral strike-slip fault.*

In this context, excluding the "stratigraphic solution", the geometric (tectonic) position of the Modino-Ventasso Unit has a key role. In fact the Modino-Ventasso Unit backthrusts the Macigno of the Tuscan Nappe front in the internal sector, while outside occurs above the foredeep succession (Cervarola Unit) by a low-angle overthrust (fig. 3).

The Modino-Cervarola low-angle overthrusting relationships imply primary relations of contiguity between the two domains; the two stacked units (and their "cover" of Ligurian and Subligurian Units) can, vice versa be connected to the Macigno, at the Tuscan Nappe front, through a longitudinal back thrust with significance of west-verging splay of a flower structure belonging to the transcurrent zone. The Mt.

Modino succession, whose original base is represented by the Cerreto-Secchia Triassic gypsum, associated with slivers of Hercynian basement (Passo del Cerreto micashists, gneiss and anphibolites) would be placed by retrodeformation, not inside, but rather along the N-NW longitudinal extension of the Macigno front.

The Epiligurian Succession, and more in general the episutural thrust-top basins, should be repositioned northward adjoining the coeval successions of the Tertiary Piedmont Basin of which the Epiligurian Succession would represent the less proximal facies. In this case their supply from Alpine units would occur across the Tertiary Piedmont Basin. The recomposition of the original paleogeographic setting implies a dextral strike slip faulting with a displacement greater than 100 km.

The eastward splays of the flower structure, symmetrical to the Mt. Modino westward back thrust, seems identifiable with the out-of-sequence thrusts which segments the Cervarola Unit, converging in the junction between western and eastern sectors.

The northern part of the dextral transpressional system ("Internal Ligurides"-"External Ligurides" boundary and its extension towards the Villalvernia-Varzi Line) would have been deactivated by the kinematic system limited by the Mt. Molinatico frontal ramp and by the sinistral lateral ramp of the La Spezia fault (see the tectonic sketch), thus maintaining active the dextral strike slip fault system only along the central-southern segment of the junction; a very recent activity of this kinematic system would be in accordance both with the allochthonous nature of the Mugello intramontane basin (Castiglione dei Pepoli-Falterona out-of-sequence thrust) and with the mesoscale strike slip faults affecting the Late Neogene and Pleistocene successions of the Southern Tuscany ($\sigma 1$ direction about N10; BOCCALETTI et al.*, 1988).*

The few kinematic data, collected along the junction line (west of Pracchiola and Lima Valley) show dextral strike slip faulting (see the Structural-geological Map for location of data).

The geometry of the dextral transpressional system between the two sectors, along the Cerreto-Secchia traverse, would imply a flat connecting two high angle faults, the internal of which corresponds to the eastern limit of the "Serchio graben". Along the flat, we may verify the longitudinal (from NW to SE) overthrusting of the Tuscan Nappe on the Triassic gypsum of the Modino-Ventasso Unit and on the Passo del Cerreto slices (Ligurides s.l.) (fig. 4).

The dextral transpressional system along the junction between western and eastern sectors is contemporary with the development of the duplex-imbricate fan system in the eastern sector of the Emilia-Romagna Apennines.

In this way, the complessive structure of the Northern Apennines would be the result of a transpressive tectonics, according to a model which seems to imply paleostress directions, differently oriented in the two sided crust blocks (around NS in the western block, around SW-NE in the eastern block). In fact, for incompatibility in the dimensional ratio with the strike slip faulting, the link thrusts of the Miocene foredeep duplex and expecially the Miocene-Pliocene overthrust coinciding with the duplex roof thrust seem hardly interpretable how as many splays of the flower structure.