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# GENESIS OF ISOLATED SYNCLINES: IS GRAVITATIONAL STRESS SUFFICIENT TO CREATE THEM?

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RIASSUNTO - *Genesi delle sinclinali isolate: le tensioni generate dalla gravità sono sufficienti per giustificare la loro formazione?* - Il Quaternario *Italian Journal of Quaternary Sciences* , **10**(2), 1997, 529-534 - Nell'Appennino Settentrionale si trovano alcune brachisinclinali costituite da rocce calcaree o arenacee poggianti su rocce argillose. Quasi del tutto assenti le anticlinali, talvolta sono presenti alti morfo-strutturali. La genesi di queste strutture è in genere attribuita alle principali fasi tettoniche dell'Appennino (Miocene superiore e Pliocene inferiore). Il nostro lavoro indica, come ipotesi alternativa, che la tettonica gravitativa potrebbe avere giocato un ruolo importante nella loro formazione, accentuando anche alcune caratteristiche morfologiche sinsedimentarie. Una di queste strutture, la sinclinale di Vetto-Carpineti, èun'estesa placca la cui base è costituita da *mélanges* argillosi e dalle Marne di Monte Piano su cui poggiano, nell'ordine, le formazioni arenacee di Ranzano, Antognola e Bismantova. Il substrato della placca è prevalentemente formato da unità argillose prevalentemente con assetto caotico (*mélange* di Pietra Nera, argilliti di Lupazzano, Argille Varicolori *s.l.,* "Argille Ofiolitifere" *Auctt.,* Argille a Palombini). I versanti esterni della struttura hanno una morfologia molto più acclive di quelli interni, e invariabilmente presentano strati disposti a reggipoggio. Il nucleo della sinclinale non contiene riempimento sedimentario post-tettonico, fatta eccezione per una sottile coltre di depositi eluvio-colluviali. La placca è tagliata in direzione N-S dal Torrente Enza, che attualmente scorre in meandri incassati circa 300 m più in basso rispetto al fondo del bacino formato dalla brachisinclinale. Il grado di deformazione delle rocce è ridotto in corrispondenza della sinclinale (della placca), raggiunge il massimo nei *mélanges* e nei complessi caotici argillosi soggiacenti ed adiacenti la placca e torna a diminuire a distanza maggiore da essa. Nella zona di massima deformazione le unità argillose si trovano circa alla stessa quota del fondo della sinclinale. Faglie e sovrascorrimenti alla base della placca hanno direzioni parallele ai suoi margini. Il nostro lavoro suggerisce che la sinclinale di Vetto-Carpineti potrebbe avere avuto una genesi in quattro stadi parzialmente sovrapposti: (1) emersione dal mare, (2) erosione dei litotipi meno resistenti circostanti la placca arenacea, (3) piegamento gravitativo della placca ed estrusione laterale dei complessi argillosi sottostanti, (4) sollevamento. Le ultime fasi dell'evoluzione su esposta sono probabilmente di età medio e tardo-pleistocenica.

Key words: Isolated synclines, gravitational stress, uplifting
Parole chiave: Sinclinali isolate, deformazioni gravitative, sollevamenti

## 1. INTRODUCTION

The role of gravity in orogenesis had already been stressed by several authors at the end of the 19th century (Bombicci, 1882; Reyer, 1892) and at the beginning of this century (Ampferer, 1934; de Wijkerslooth, 1934; Lugeon, 1940), as pointed out by Dal Piaz (1941). Starting from 1960 deep-seated gravitational deformations of slopes have been the subject of numerous studies (see for example Beck, 1968; Ter-Stepanian, 1977; Radbruch-Hall *et al.*, 1977; Forcella, 1984; Cancelli *et al.*, 1987; Colombetti & Tosatti, 1987; Crescenti, 1987; Varnes *et al.*, 1989; Dramis & Sorriso-Valvo, 1994) focussing to the various aspects of the role played by gravity in shallow-crustal deformations at all scales.

In this paper we analyze the geologic framework in which gravity would have played a role in the formation of isolated synclines that form when a plate of "brittle" rock rests on a "ductile" substratum. Carena *et al.* (1998) propose analytical, numerical and analogue models for this geological problem, which is complementary to that of diapirism. For our study we pointed our attention to the Northern Apennines, an area where there are several cases of isolated synclines. Up to now the genesis of these structures was referred to compression processes during the main tectonic phases of formation of the Apennines. On the contrary, we indicate that gravitational tectonics could be responsible for their formation. This result casts a new light to the structural interpretation of the late stages of formation of the Apennines and other areas with similar structures.

## 2. GEOLOGICAL SETTING

The Northern Apennines, in Italy, are part of the collision margin between the African and the European plates, and during their formation the tectonic transport was toward the NE (Papani *et al.*, 1987). Within the Apennines chain there are numerous piggy-back sedimentary basins (from Middle Eocene to Serravillian in age); one of these basins is the Epiligurian Vetto-Carpineti-Canossa basin (VCC), which is located on the Ligurian thrust sheets.

The studied area is formed by three sub-basins within the principal VCC basin, 30 km South of Parma (the Scurano-Vetto-Carpineti basin, the Ranzano-Sasso basin, and the Groppo-Tassobbio basin).

The stratigraphy of the area consists of highly tectonized Ligurian Units, which formed during the

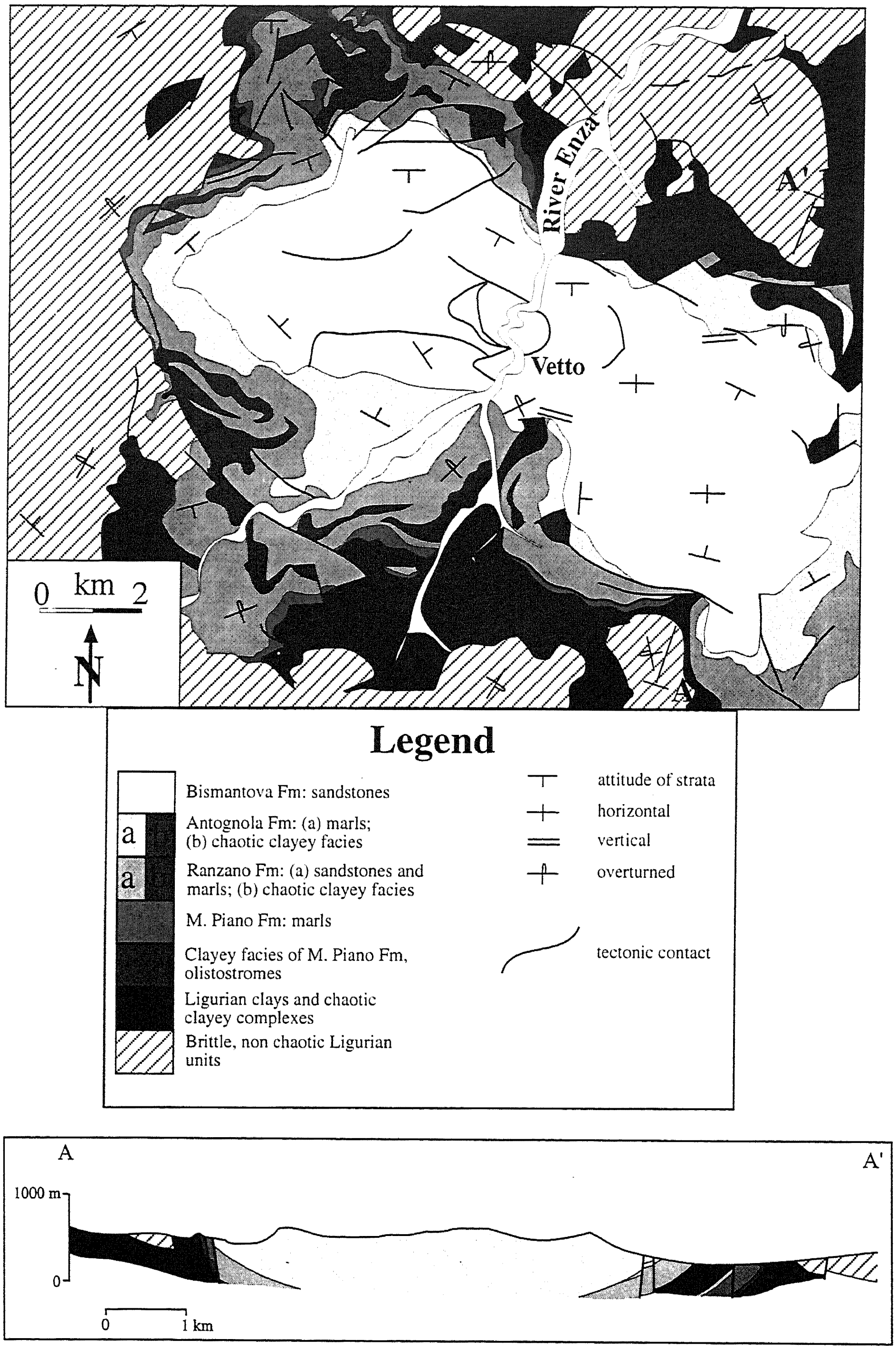



Fig. 1 - (Above) Schematic geo-rheological map. Dashed areas show the brittle substratum; gray-colored ramp indicates the rheology of rock units from "brittle" (light) to "ductile" (dark). Data are from the 1:10,000 Geologic Map of Emilia-Romagna and this work. (Below) Cross-section showing a clay diapir at the southen end of the plate (same legend as above)..

*(Sopra) Carta geo-reologica schematica. Il retinato diagonale è il basamento "fragile"; la scala di colori grigi indica la reologia delle unità da "fragile" (chiaro) a "duttile" (scuro). Dati derivati dalla Carta Geologica dell'Emilia-Romagna alla scala 1:10.000 e da questo lavoro. (Sotto) Sezione geologica. Un diapiro di argilla è visibile all'estremità meridionale della placca (stessa legenda della parte alta della figura).*

emplacement of the Ligurian thrust (Late Cretaceous-Middle Eocene tectonic phase), and which are unconformably overlain by olistostromes and younger and less deformed pelitic and arenaceous turbiditic units of the Epiligurian sequence (De Nardo *et al.*, 1990). Between these two sequences there are other units formed by chaotic clayey materials, characterized by a pervasive deformation, which may enclose tectonized blocks — up to a few hundred meters in size — of ophiolite, limestone and sandstone. Vai & Castellarin (1992) interpreted them as complexes originated during the Eo-alpine phase, whereas Papani *et al.* (1987) consider them (at least some of them) as Tertiary *mélanges* of reworked Ligurian material, which would have formed in the interval Early Eocene-Aquitanian.

## 3. GEOLOGY AND GEOMORPHOLOGY

### 3.1 Geomorphological data

The Epiligurian turbiditic sandstone forms a brachysyncline (the Vetto-Carpineti syncline; Papani *et al.*, 1987) overlying a clayey substratum (Fig. 1). The syncline forms a bowl-shaped mesa-like relief (plate) that stands out on the surrounding morphology, where clay-rich more erodible rocks are present (Fig. 2). The "bowl's" bottom is at about the same elevation as the top of the "clayey" hills surrounding the plate. The maximum elevation corresponds to the western end of the plate. The "bowl" is deeply dissected into two parts by the Enza River in a NNE direction. The western half of the plate is well preserved, with little erosion and a rather continuous perimetrical cliff, whereas the eastern part is much more eroded and presents deep valleys interrupting the cliff.

There are many paleosurfaces that cut one another in a time sequence (Fig. 2). An erosional paleosurface (internal paleosurface) occupies nearly half of the western part of the plate and is conform to strata. In the plate eastern half there are only a few small remnants of a similar surface. All these surfaces may be remnants of an old marine abrasion platform. Other paleosurfaces (external paleosurfaces) cut the strata and are found all around the plate; some of these terraces are buried by younger deposits that landslided off the cliff.

Paleomeanders and terraces can be recognized inside the "bowl". Terraces dipping toward the center of the "bowl" are found at various elevations on the internal paleosurface; their position and distribution indicate, for some of them, a lacustrine origin. In the center of the "bowl", paleomeanders are entrenched into the Bismantova Formation (like the present meanders of the Enza River) for a minimum of 300 meters.

Along the river banks a number of recent terraces are present: some are cut into the Bismantova Formation, others into ephemeral alluvial and lacustrine deposits of the Enza River itself. There are also several terraces due to block slumping and tilting along concave normal faults that face the Enza River.

## 3.2 Lithologies and stratigraphic relationships

The oldest lithotypes in the area (Fig. 1) belong to the Ligurian Units and form the plate substratum, which consists of a variety of chaotic units whose origin and age are seldom defined. These units are predominantly made of clays; therefore, they have similar "ductile" rheological properties. They have variable thickness (from about 100 m to 1000 m): the maximum thickness being reached in the area to the east of Enza River, whereas the thickness is minimal at the western end of the plate. The principal of these units is the *'Argille Varicolori'* Formation, composed of multicoloured banded clayey shales showing a characteristic isoclinal and complex folding. The Ligurian Units contain also a number of "brittle" flysch formations, particularly present in the western zone.

Above the substratum there are the Epiligurian Units, which begin with a "ductile" level made of olistostromes, *mélanges,* and clayey units of the *'M.Piano'* Formation, having a thickness of about 100 m and a rheology comparable to the deformable units of the substratum. For this reason, when using the term "substratum", we will refer to all the "ductile" deformable units below the plate, including the Epiligurian olistostromes and clays. On top there is the "brittle" level corresponding to the plate, formed by the sequence *'M. Piano-Ranzano-Antognola-Bismantova'* Formations, a mainly turbiditic sequence where sandstones predominate in the upper part and marls predominate in the lower one. The *Bismantova* Formation, Langhian to Serravallian in age, is the youngest one; the nucleus of the syncline does not contain any sediments apart from a veneer of alluvial and colluvial deposits. Some deformable chaotic lenses are embedded in the *'Ranzano'* and *'Antognola'* Formations, like the "Canossa Olistostrome" in the *'Antognola'* Formation (Papani, 1971). The thickness of the plate sequence varies from several hundred meters in the west to more than a thousand meters in the east.

## 3.3 Structural data

### 3.3.1 Deformations in the arenaceous plate

The plate is bent into a brachisyncline elongated in a E-W direction, mimicking the original shape of the sedimentary basin (Fig. 1). On the outer cliffs of the "mesa" strata dip inward, being parallel to the topographic surface of the "bowl".

Along the plate margin there are large normal faults with concave fault traces (Fig. **?**), which cause the blocks along the margin to slid down and away from the center of the plate. These faults are very clear in aerial photographs, but have poor evidence in the field because of the relatively small erosion. An active collapse structure, characterized by block slumping and tilting surrounds the Enza River gorge. Its activity is documented by the well-defined fault scarps and open fractures that move periodically. The *Antognola* Formation presents several large asymmetric folds, which involve the underlying *Ranzano* Formation; they show both apenninic (NE-SW) and alpine (E-W) trends, and seem to have formed in the sedimentary basin.

### 3.3.2 Deformations in the surrounding chaotic units

The most relevant structures are: 1) an isoclinal folding which is evident in several types of banded clayey shales; and 2) a chaotic structure (disarrangement) of some clays and clayey formations. In the substratum there are several small thrusts and strike-slip faults parallel the plate margins. Thrusts vergence is almost invariably away from or towards the plate.

Three clay diapiric structures (Fig. 1) occur, one at the easternmost plate edge, the other two along the southern margin of the "mesa" (one is visible in the cross section of Fig. 1). The contact between plate and clay diapirs is delaminated and sandstone strata around them are vertical to overturned. These diapirs form elongated "tongues" of substratum into the plate. Pieces of the *'M. Piano-Ranzano'* sequence, stretched and overturned, are surrounded by clays along the north-eastern margin of the plate. Deformation and density of structures in the clays are high in proximity of the contact with the plate, and diminish toward and away from it.

# 4. DISCUSSION AND CONCLUSIONS

The fact that the "bowl" bottom (the nucleus of the arenaceous syncline) is at the same elevation as the top of the hills of the clayey chaotic substratum surrounding the plate demonstrates the sinking of the plate into the clayey units. This sinking produced the lateral squeezing and bulging of the underlying clays. In this context clays are also squeezed upward through faults and fractures to form elongated diapirs.

The thickness of clays is a fundamental parameter conditioning the velocity and extent of plate sinking: at the western end, a minimum thickness of clays corresponds to a maximum elevation of plate (minimum sinking)

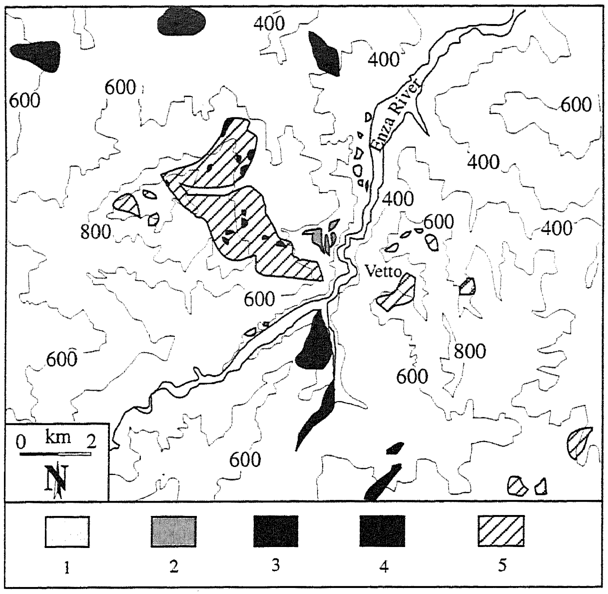
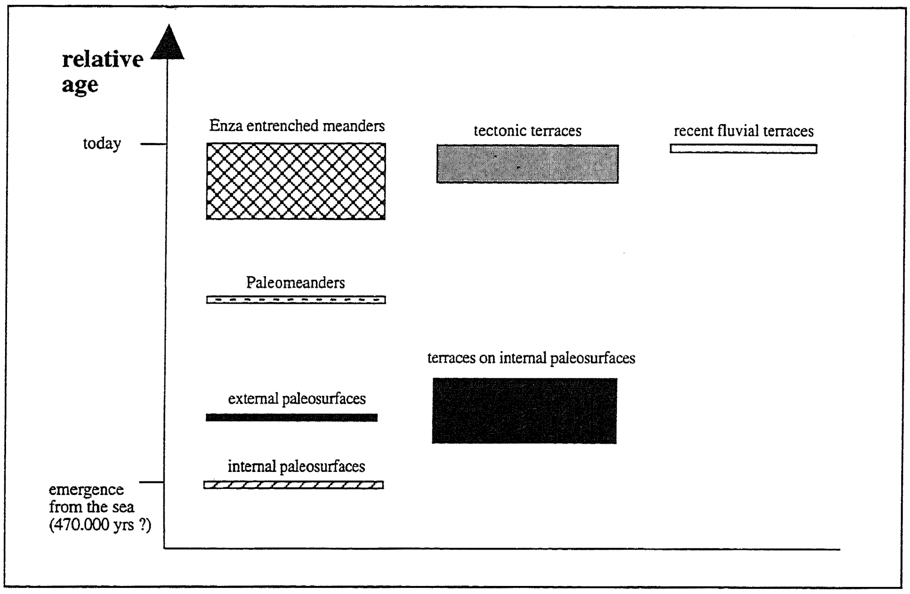



Fig. 2 - (Above) Morphological map indicating the major paleosurfaces (from youngest to oldest): 1) recent alluvial deposits; 2) slump-related terraces; 3) terraces on internal paleosurface; 4) external paleosurface; 5) internal paleosurface. Map based on 1:5,000 scale maps (Carta Tecnica Regionale, Regione Emilia-Romagna), 1:15,000 stereo-aerial photographs and our field work; elevations are in meters a.s.l. (Below) Relative age distribution of morphological features; see text for discussion on the estimated age of emergence from the sea.

*(Sopra) Carta morfologica delle principali paleosuperfici (dalla più giovane alla più vecchia): 1) depositi alluvionali recenti; 2) terrazze legate a "slumps"; 3) terrazze sulle paleo superfici interne; 4) paleosuperfici esterne; 5) paleosuperfici interne. Carta basata sul rilievo 1:5.000 (Carta Tecnica Regionale, Regione Emilia-Romagna), le foto aeree stereoscopiche 1:15.000 ed il nostro rilievo di campagna; quote in metri s.l.m. (Sotto) Età relative degli elementi geomorfologici; vedere il testo riguardo all'età stimata per l'emersione.*




and least deformation, whereas at the eastern end, the maximum thickness of clays is associated with lesser elevations and maximum structural complexity.

According to our hypothesis, the geological evolution of the area could have been:

– Formation of the first erosional surface at the sea level.

– Emergence from the sea and onset of deformation, because sinking of the plate into the clays could occur only if the plate had been at least partially isolated by erosion. During deformation, a "lake" formed inside the growing syncline; marine erosional surfaces formed outside the plate.

– As regional uplift and deformation proceeded, the northern barrier of the lake was eroded, the lake disappeared, and meanders formed inside the syncline; meanwhile, the external paleosurfaces were bent toward the syncline.

– While the uplift continued, the Enza River formed the present entrenched meanders causing the formation of several block-slump terraces along its banks.

– Finally, the present alluvial terraces formed.

The well preserved western paleosurface suggests a Quaternary age (Amorosi *et al.*, 1996). Quaternary continental deposits, immediately to the north of this area of the Apennines, are <800,000 years old, with a stratigraphic and angular unconformity at 470,000 years. This last event probably dates the regional uplift (Di Dio *et al.*, 1996) that is related to the bending of the plate.

A Quaternary gravitational bending of the plate, well after the end of the great regional tectonic phases, also explains why faults and thrusts do not follow the regional trend, but are on the contrary parallel to the plate margins.

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