E. CENTAMORE* & S. NISIO**

QUATERNARY GEOLOGY AND MORPHOSTRUCTURAL EVOLUTION BETWEEN THE VELINO AND SALTO VALLEYS

INDEX

ABSTRACT

The present morphological configuration of the area between the Velino and Salto valleys is the result of the effects (often combined) of a general and rapid regional uplift, mainly a quaternary extensional tectonic phase and, to a lesser degree, the alternation in various climatic phases.

This gives rise to a block arrangement with differential vertical movement which produce both the *Conca di Rieti* and the smaller *Piana di S. Vittorino* depressed areas. The blocks and these depressed areas are delimited by a network of faults attributable to different systems. Such faults partly reactivate older elements, of which *the Fiamignano – Micciani Fault* has the most important role.

The progression of the regional uplift is shown by two orders of relict surface, inset in the summit surface. The tectonic effects commencing from Villafranchian, must be added to the process of the tectonic extension that promotes the normal reactivation of the *Fiamignano – Micciani Fault*, and the onset of the Rieti depressed area, giving rise to fault scarps and gravitational movement along them.

During Villafranchian there are the accentuation of the progressive sinking of the *Rieti basin* with respect to the uplifting of the oriental carbonate block, with ever more marked differences.

After the deposition of the first order terraced deposits (Middle Pleistocene), the *S. Vittorino* depressed area was formed, as a result of strike slip movement along the *Fiamignano – Micciani Fault.*

Recent tectonic activity is revealed by paleoseismic indices, such as trenches and faults that offset Olocene deposits, historical seimicity, sinkholes and ponds formation, gas anomalies and the springing up of mineral and thermal waters, presumably related to manifestation of late volcanism.

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RIASSUNTO

L'attuale assetto morfostrutturale dell'area compresa tra la valle del F. Velino e quella del F. Salto è il risultato degli effetti, talora combinati, di un generale e rapido sollevamento regionale, di un'intensa fase tettonica prevalentemente distensiva quaternaria, e, in misura minore, dell'alternarsi di diverse fasi climatiche.

Ne risulta un quadro a blocchi con movimenti verticali differenziati, in cui si aprono sia la *conca di Rieti* che quella minore della Piana di S. Vittorino. I blocchi e le conche sono limitati da un reticolo di faglie appartenenti a diversi sistemi, in parte riattivanti elementi più antichi, tra le quali assume un particolare ruolo la *Faglia Fiamignano-Micciani.*

La progressione del sollevamento regionale è evidenziata da due ordini di *superfici relitte* incassate nella *Superficie sommitale.* A questo fattore si sommano già dal Villafranchiano gli effetti della tettonica distensiva che favoriscono la riattivazione in senso normale della *Faglia Fiamignano-Micciani*, l'impostazione del *conca di Rieti*, la genesi di scarpate di faglia e di movimenti gravitativi lungo tali scarpate.

Durante il Villafranchiano si accentua il progressivo sprofondamento del *bacino di Rieti*, in contrapposizione al sollevamento del blocco carbonatico orientale, con dislivelli sempre più sensibili.

Dopo la deposizione dei depositi terrazzati del I ordine (Pleistocene medio) si forma la conca di S. Vittorino, per effetto di movimenti trascorrenti lungo la *Faglia Fiamignano-Micciani.*

L'attività tettonica recente è evidenziata da notevoli indizi di paleosismicità, quali trincee e faglie che dislocano depositi dell'Olocene, dalla sismicità storica, dalla formazione di *sinkholes* e laghetti, dalle anomalie dei fluidi gassosi e dalle risorgenze di acque minerali e di fluidi idrotermali, presumibilmente legati alle manifestazioni di un tardo vulcanismo.

KEY WORDS: North eastern Latium; S. Vittorino Plain; Morphological evolution; Quaternary

PAROLE CHIAVE: Lazio nord-orientale; Piana di S. Vittorino; Evoluzione geomorfologica; Quaternario

INTRODUCTION

The present work reports the results of a study on the geological-geomorphological evolution of the area between the Velino and Salto valleys, and more precisely between Cittaducale and Canetra (northeastern Latium). The presentday morphostructural features of this area reflect the combined effects of rapid regional uplifting, occurring between Upper Pliocene and Quaternary, extensional tectonics, and climatic variations.

1. GEOLOGICAL SETTING

This sector of the Apennines is located in the so-called *"meeting point"* (the *"zona di incontro" sensu* SCARSELLA, 1951) between the Umbro-Marchean pelagic domain, the neritic Latium-Abruzzi domain and the Sabine transition belt, between platform and basin where the effects of the synsedimentary tectonics developing from Lias to Miocene are evidenced by the presence of a sedimentary succession characterized by a great variability in time and space of the facies, and by the presence of an important structural element, whose activity has conditioned in time the paleogeographic evolution of the various above-mentioned sedimentary domains, the *Anzio-Ancona lineament* (MIGLIORINI, 1950; SCARSELLA, 1951).

The structural features of the area are tightly controlled by polyphase tectonics which developed between Upper Miocene and Lower Pliocene by means of compressional phases, which favored the building up of a thrust and fold chain, and subsequently, Upper Pliocene and Quaternary, with extensional and transtensive processes connected to the regional uplifting and the effects of the progressive opening up of the Tyrrhenian Sea.

Four thrust units, piled up one on top of another and separated by regionally important thrust surfaces, and subdivided internally by a series of splays into minor structural elements, have been recognized. From the most internal and uppermost unit to the most external and lowest one, they are: the *Monti Reatini Unit*, made up by a pelagic succession of the Umbro-Marchean domain, the *Mt. Navegna Unit,* characterized by a meso-cenozoic succession of proximal scarps and ramps on the western margin of the Latium-Abruzzi platform, which are overlain by siliciclastic turbidites; the *Salto Unit,* formed by Meso-Cenozoic carbonate and ramp deposits of the Latium-Abruzzi domain and by Messinian turbidites; the *Mt. Nuria Unit,* represented at the bottom by a Mesozoic platform succession and at the top by Paleogene and Miocene ramp, and margins deposits, and Messinian siliciclastic turbidite limbs. Also recognized and distinguished in the study area were some continental depositional units made up of breccias, alluvial fans, fluvial-lacustrine and lacustrine deposits, travertine, landslide debris, and eluvial-colluvial deposits, often heteropically arranged.

The relationship between the last two structural units described above are rather complex and still not well defined; the units are separated by another structurally important element, the *Fiamignano-Micciani Fault*, which has kinetic and dynamic characteristics revealing, even in ancient times, a polyphase activity that is not easy to interpret.

Following on the compressional phase in the sector, extensional and/or transcurrent processes developed, connected to a general regional uplifting, particularly intense in Lower Pleistocene; this favored the genesis of neoformation faults and the reactivation of more ancient elements dislocating the preexistent compressional structures, as well as of Plio-Quaternary continental deposits, and controlled the morphostructural evolution of the Basin of S. Vittorino. The structures formed during these processes can be grouped into four main systems: N30°-35°W, N±10°, NE-SW, E-W.

The extensional and/or transtensive elements that have mostly affected the morphostructural evolution of the study sector are undoubtedly the *Fiamignano-Micciani Fault* and the system of faults which controlled the S. Vittorino tectonic depression.

The *Fiamignano-Micciani Fault* is a regionally important structural element difficult to interpret with regard to the age of its formation, the various phases of its reactivation, and the variations in the time of its various kinetic and dynamic characters. This lineament, trending N 30°W ± 5° and dipping SW with an average angle of 45°, but with variations from 25° to 60°, can be followed on the ground for several kilometers, even though it is dislocated various times and affected by transversal and oblique faults. It allows contact between the carbonate formations of the Mt. Nuria group and the prevalently turbiditic ones of the Valle del Salto; further north, after crossing the S. Vittorino plain along the Lago di Micciani – S. Vittorino alignment, it continues, bordering the southwestern slope of the Mt. Terminillo group between Mt. Paterno and the Montagna dei Cesoni.

The following elements belong to the same N30°-35°W system:

a) the faults dislocating the northeastern slope of the Calcariola ridge with progressive lowering to the NE;

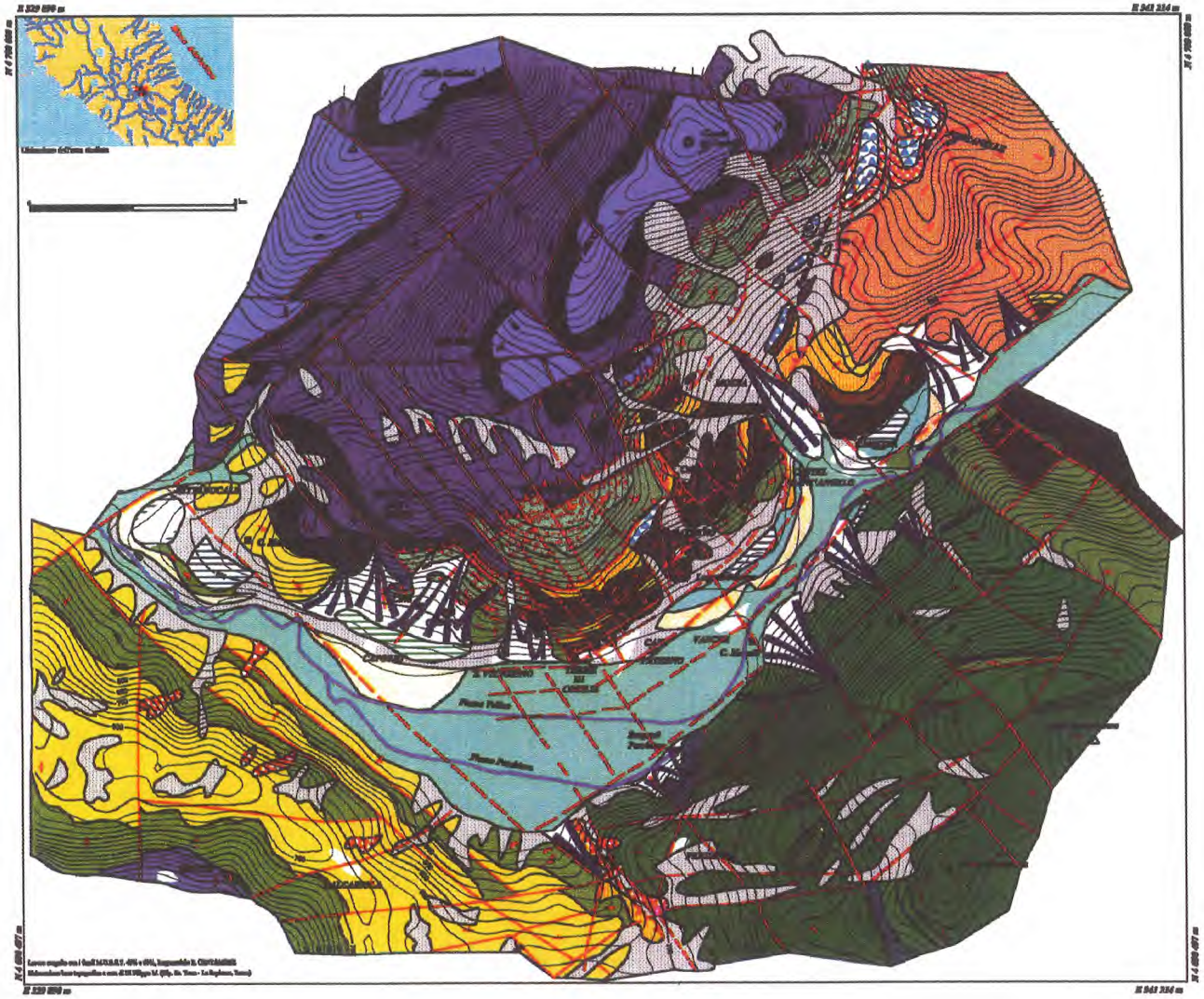
b) the dense network of fractures present in the Reatini Mts sector between Cittaducale and Cimata del Castello. In this area, first of all a SW-ward lowering from Fontanelle to Pagliara can be observed and then a clear uplift of the Cimata del Castello – Canetra block, on the southwestern edge of which the *Piedimozza – Cerquara Fault* is located; this presents a marked SW displacement. Between Colle della Croce and Cittaducale there is a new motif of blocks lowered SW-ward, in which the dislocation located between Terme di Cotilia and the Montagna dei Cesoni presents a considerable displacement of more than 400 m.

The N35°-40°E system is well represented in the Colle Impicciavera sector, with a general lowering of the blocks towards the NW; the carbonate slope is bordered along the Velino by faults with considerable displacement of more than 500 m. Also belonging to this system are the faults dislocating Mt. Paterno, with a SE-ward lowering, the fault at the border between Case di Paterno and Vasche, the one affecting the southwestern edge of the Fontanelle slope, and, as well, the one dislocating the northeweastern sector of the Calcariola ridge which then continues in the Fosso Valle Ottara – Fosso delle Valli with a marked NW-ward lowering.

The E-W system is well represented on the Calcariola ridge, in the Reatini Mts sector, between Mt. Paterno and the Fosso delle Valli, and between Cimata di Castello and Fontanelle. Also in the neighborhood of Pendenza, E-W trending faults are present, with a progressive southward lowering. The dislocations bordering the southeastern slope of the Montagna dei Cesoni, between S. Vittorino and Terme di Cotilia, also belong to this system. Faults trending N ± 10° are present on the Calcariola ridge, near Paterno, and in the Fosso di Valle Santa depression. All the faults described testify to a Quaternary activity since they dislocate paleosurfaces and even recent continental deposits and are pointed to by clear morphological evidence such as tri-

GEOLOGICAL MAP OF THE S. VITTORINO AREA

CENTAMORE E., NISIO S., SABATINELLI A. & FIORENZA D. (for the southeastern area)



LEGEND

CONTINENTAL DEPOSITS

- Present and recent alluvional deposits (OLOCENE)
- Fluvial - colluvial deposits; talus (OLOCENE)
- II order travertines (upper PLEISTOCENE)
- II order fluvial deposits (upper PLEISTOCENE)
- I order travertines (middle PLEISTOCENE)
- I order fluvial deposits (middle PLEISTOCENE)
- Fontenelle breccias (upper PLIOCENE ? - lower PLEISTOCENE)
- Fontenelle paleolandslide deposits (upper PLIOCENE ?)
- Rieti Basin Succession:
  - Upper depositional unit (lower PLEISTOCENE)
  - Lower depositional unit (upper PLIOCENE? - lower PLEISTOCENE)

MARIN DEPOSITS

M^{si} Rentini Unit

- Scaglia cinerea Fm. (EOCENE p.p. - OLIGOCENE)
- Scaglia rossa Fm. (CENOMANIAN p.p. - EOCENE p.p.)
- Marne a fucoidi Fm. (APTIAN p.p. - CENOMANIAN p.p.)
- Maiolica Fm. (TITONIAN - lower CRETACEOUS)
- Calcari di Cittaria del Castello Fm. (BAJOCIAN - TITONIAN p.p.)
- Calcari e marne del Sentino Fm. (TOARCIAN p.p. - AALENIAN p.p.)
- Corniola Fm.(SINEMURIAN p.p. - lower TOARCIAN)
- Calcare massiccio Fm. (lower LIAS)

M^{te} Nevegna Unit

- Calcareous-marly unit : marly member (TORTONIAN p.p.)

Salto Unit

- Velino-Salto sandstones (lower MESSINIAN)

M^{te} Nuria Unit

- Velino-Salto sandstone (lower MESSINIAN)
- Marne ad Orbulina Fm. (lower TORTONIAN p.p. - early MESSINIAN)
- Calcareous-marly unit (SERRAVALLIANO p.p. - TORTONIAN p.p.):
  - marly member
  - calcareous-marly member
- Calcareniti a punti rossi Fm. (LANGHIAN p.p. - SERRAVALLIAN p.p.)
- Calcareniti arenacee Fm. (AQUITANIAN p.p. - LANGHIAN p.p.)
- Calcari a macroforaminiferi Fm. (PALEOCENE)
- Calcari a radiolitidi Fm.(upper TURONIAN - SANTONIAN)
- Calcari intraclastici Fm. (CENOMANIAN p.p.)
- Calcari cicloteniici a requienie Fm.(APTIAN p.p. - ALBIAN p.p.)
- Calcari a marne a chaetetidi(pigopora)fm. (lower APTIAN p.p.)
- Calcari cicloteniici a gasteropodi e oolitii Fm. (BARREMIAN p.p. - APTIAN p.p.)
- Calcari a clasti neri e gasteropodi Fm. (upper MALM)
- Calcari a oncoliti e dasycladali Fm. (upper MALM p.p.)
- Calcari a echinodermi e oncoliti Fm. (BAJOCIAN p.p. - KIMMERIDGIAN p.p.)

STRIKE AND DIP STRATA

- 0°- 25°
- 25°- 45°
- 45°- 90°
- Overturned
- Fault
- Thrust
- Alluvional fan
- Landslide deposits

Fig. 1 - Geological map of the S. Vittorino area

angular or trapezoidal facets, recent scarps or steps, hanging valleys, alignments of sinkholes and dolines with anomalous concentrations of gassy fluids along the discontinuities.

2. GEOMORPHOLOGICAL SETTING

From the geomorphologic standpoint, some sectors having their own morphological features have been distinguished in the study area:

a) a northern mountain-foothill sector, located to the N of the River Velino, representing the southern portion of the Reatini Mts;

b) a central flat zone, represented by the S. Vittorino plain, characteristically triangular in shape with the apex facing south;

c) a mountain-foothill sector located in the southeastern zone of the area and corresponding to the Colle Impicciavera – Pendenza block;

d) a southwestern foothill sector represented by the Calcariola ridge.

In the highest parts of the mountainous sectors, remains of ancient flat surfaces can be identified, inside the *Auct. Summit Surface* and arranged in two levels of altitude, probably corresponding to ancient bedrock levels of the paleonetwork; these are the *Cimata del Castello Surface*, located between 1500 m and 1310 m a.s.l. in the ridges of Cimata del Castello - Prato Miccio – Colle Riofagio, Colle Cesarini – Colle Falzola, and Colle Impicciavera - Mt. Serrasecca, which represent the higher element, and the *Fontanelle Surface,* from 1200 m to 1050 m a.s.l., which is evident between Fontanelle and Ara del Popolo, at Mt. Paterno and at Pratello, to the NW of Colle Impicciavera.

The Reatini Mts sector presents a somewhat articulated morphology. The summit part of the sector examined is characterized by the presence of the relict surfaces described above, markedly dissected by the Quaternary tectonics and in which are opened the deep downcuttings of Valle Ottara-Fosso delle Valli and of Valle Santa, whose slopes are cut by a dense network of rectangular-type small valleys. Both the main trenches and their affluents are almost all in the previously described fault systems. Due to selective erosion, on the southern slopes of Mt. Paterno there are other flattened surfaces, all localized at the emergence of the thrust surfaces that afford contact between lithologic units with different resistance to erosion. The most evident and extensive of these is the one located halfway up the southern slope of Mt. Paterno, between Colle Croce and the flat area at 675 m a.s.l., which corresponds with the main thrust of the *Reatini Mts Unit* and offers a contact between the *Scaglia cinerea* and the lowest member of the *Marly-limestone unit.*

Karst landforms are considerably widespread: these are represented by numerous dolines, even of large size, many of which especially on the southern slopes of the sector have undergone collapse. Particularly interesting are the ones present on the southeastern slope of Mt. Paterno between Terme di Cotilia and Castel S. Angelo; the bottom of these caves, almost all collapsed on the southern side, is located where a splay emerges from the *Mt. Nuria Unit*, on the footwall of which the upper part of the *Marly-limestone unit* crops out.

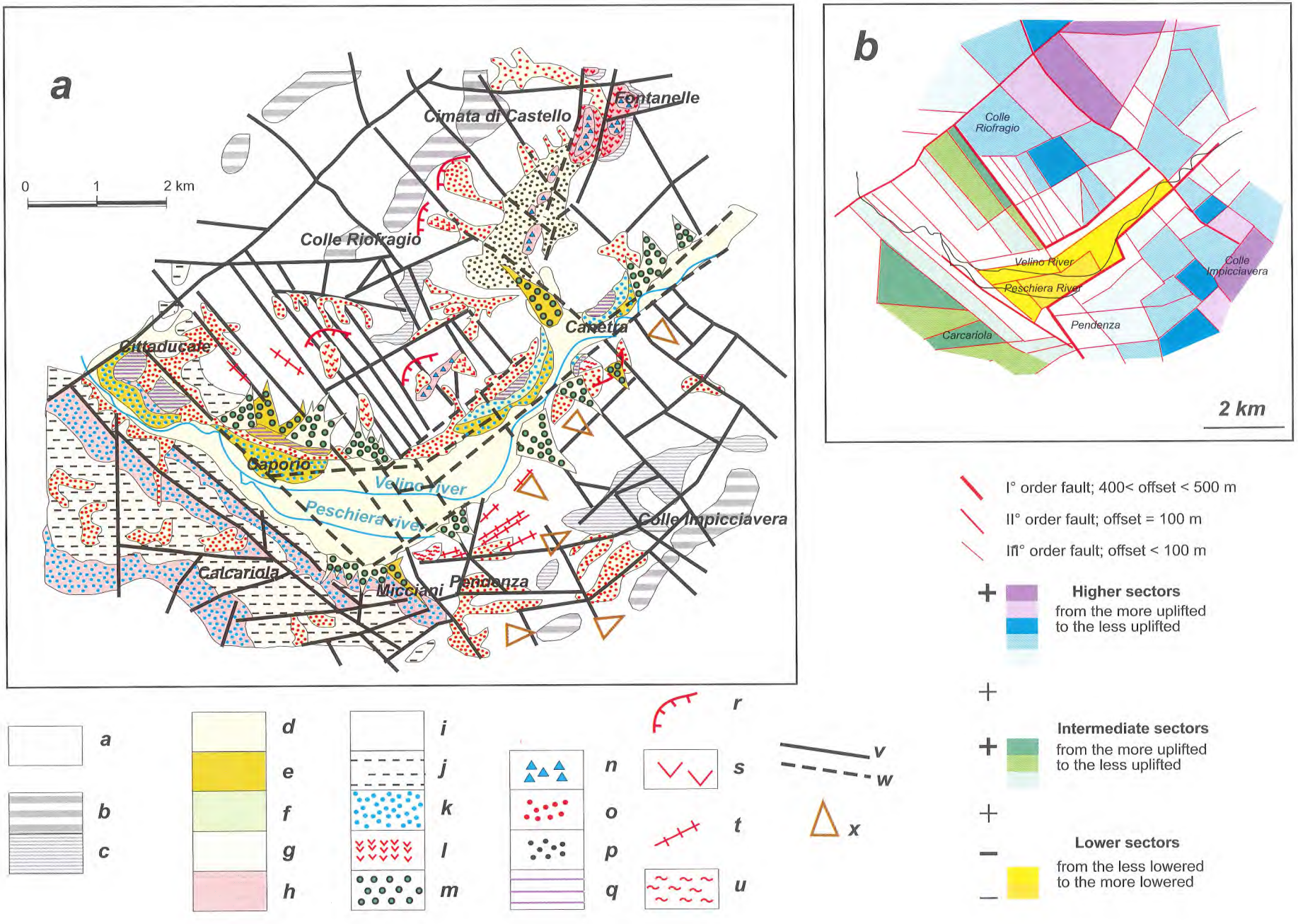
The southern edge of the Montagna dei Cesoni is characterized by the presence of some trenches located on the tectonic lineaments, which in certain points (Cava dei Cesoni) dislocate the Upper Pleistocene and Holocene terms with clear evidence of paleoseismicity (Michetti *et al.*, 1994). On the steeper slopes, landslide niches can also be observed, mainly lying on tectonic lineaments. At the foot of the Montagna dei Cesoni, Upper Pleistocene and Holocene alluvial fans are present.

Since the end of the last century, the central sector, coinciding with the characteristically triangular shaped S. Vittorino plain, has undergone a series of drastic antrophic working which have markedly modified the original landscape; e.g., the course of the River Velino has been straightened at several points. Along the right-hand border of the plain, some flattened areas are present, between 500 m and 450 m a.s.l. (Canetra, S. Rocco, Cittaducale) and between 440 m and 420 m a.s.l. (Terme di Vespasiano - Caporio), where continental deposits crop out arranged over two orders of terraces. The plain in question displays some interesting and peculiar phenomena such as numerous karst caves (collapsed chimneys or sinkholes) often full of water, even of mineral type, mineral springs, gassy fluid anomalies, collapses, and important springs (Ciotoli *et al.*, 1998, 2000).

The sinkholes and small lakes are concentrated on the northern border of the plain and in a belt with Apennine trend between S. Vittorino – Cotilia and the Peschiera springs. The sulfuric and ferric springs, and as well the gassy fluid anomalies, are located along the northern border of the plain itself, and to a lesser extent in the belt between S. Vittorino and the Peschiera springs and along the *Mozza-Cerquara alignment*. At the margins of the carbonate structures, freshwater springs emerge; of these the Peschiera ones are particularly important, whereas those sited on the northern border give less high volumes, (Ciotoli *et al.*, 1998, in press).

The southeastern sector, represented by the Colle Impicciavera-Pendenza carbonatic block, is made up of a block structure lowered towards the River Velino; in this structure, a series of ridges can be observed, extending NE-SW, separated by narrow depressions, and often filled with eluvial-colluvial materials. On the slope towards the Velino, which has marked acclivity, a series of small trenches is

Fig. 2 - ***a) Morphological scheme of the S. Vittorino area;*** a) **Lithoid substratum; Erosional units (relict surfaces):** b) *Cimata del Castello upper surface*; c) *Fontanelle lower surface;* **Depositional units:** d) *S. Vittorino syntheme* (Olocene); e) *Caporio syntheme* (Upper Pleistocene); f) *Canetra – Cittaducale syntheme* (Middle Pleistocene); g) *Fontanelle syntheme* (Upper Villafranchian); h) *Calcariola syntheme* (Lower Villafranchian); **Continental deposits (Overprint on the syntheme colour):** i) *recent alluvial deposits*; j) *sandy-clayey lacustrine deposits*; k) *conglomeratic alluvial deposits*; l) *paleolandslides; m) alluvial fan deposits; n) breccias; o) alluvial-colluvial and detrital deposits; p)debris slope; q) travertines;* **Slope landforms and deposits due to gravity:** r) *landslide scarps; s) landslide deposits; t)slope involved in slope deep gravitational deformations (S.D.G.D.); u) trench;* **Structural elements:** v) *fault with quaternary activity*; w) *buried faults*; x) *tectonic facet slope.* ***b) Morphotectonic scheme of the S. Vittorino area.***


a
0
1
2 km
Cimata di Castello
Fontanelle
Colle Riofragio
Cerbara
Cittaducale
Caporio
Velino River
Peschiera River
Colle Impicciavera
Calcariola
Micciani
Pendenza
b
Colle Riofragio
Velino River
Peschiera River
Colle Impicciavera
Carcariola
Pendenza
2 km
I° order fault; 400< offset < 500 m
II° order fault; offset = 100 m
III° order fault; offset < 100 m
Higher sectors
from the more uplifted
to the less uplifted
Intermediate sectors
from the more uplifted
to the less uplifted
Lower sectors
from the less lowered
to the more lowered
a
b
c
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located parallel to the slope and with triangular facets.

The structure in question is further complicated between Colle Impicciavera and Pendenza by a series of blocks progressively lowered SW-wards in which scarps and triangular facets can be observed. In the sector mentioned, karst caves can be noted, sometimes (Casali S. Marco) of considerable size. On the slope to the NW of Pendenza, and on that of Cerquara, deep-seated gravitational deformation phenomena are testified to by collapse of some portions of the slope as well as by the trenches. All the ridges, deformations, karst caves, and deep-seated gravitational deformation phenomena are located on the tectonic lineaments present in the sector.

The fourth sector, that of the Calcariola ridge, stretching out in Apennine direction, displays at its summit limited flattened areas and gentle undulation with depressions filled with eluvial-colluvial deposits; these are located on the main dislocations. The ridge is separated from the Colle Impicciavera sector by a narrow and deep valley cut into the carbonate deposits of the *Mt. Navegna Unit*. The markedly steep northeastern slope is cut by numerous transverse trenches and characterized by a series of blocks lowered NE-wards, trenches cut into Apennine faults, and triangular facets.

3. EVOLUTION OF THE LANDSCAPE FROM PLIOCENE TO QUATERNARY

The first evidence of evolution in this sector of the central Apennines is given by the deposition of the *Sabbie di Piagge,* which crop out in the Salto depression slightly to the south of the study area, and are made up of sands intercalated with sandstone clast conglomerates laid down in lacustrine environments and deriving exclusively from Lower Messinian turbidites. Their age is not easy to define, although they are known to be involved in some tectonic phases which, according to some Authors (BERTINI *et al.*, 1986), took place with compressional features in Lower Pliocene. Probably they were deposited in a continental environment during the first structural phases of the chain, when the underlying carbonate deposits had still not been laid bare by erosion and the tectonics. They could be coeval with the Upper Messinian Oligoaline deposits to the south of the Fucino (Le Vicenne, COLACICCHI *et al.*, 1967) unconformably overlain on the already folded and eroded carbonatic bedrock, and have been involved in the definitive Lower Pliocene structuring of the chain. Immediately after, the area emerged definitively and underwent a first modeling by the areal erosional processes, with the formation of a landscape with soft and only slightly accentuate shape; today only few and limited traces remain, representing the so-called *Summit Surfaces* (DEMANGEOT, 1965).

From Middle Pliocene to Quaternary, due to the continuous regional uplift connected with the extensional tectonics and the climatic and eustatic variations, an alternation of erosional and depositional phases is observed. Two main erosional units can be distinguished in the area and four depositional ones made up of continental deposits characterized by a marked facies heteropy.

3.1 Erosional surface

Inside the *Summit surface* are traces of some *relict surfaces* arranged in two different orders of altitude and connected with areal erosional processes: *the Cimata di Castello Surface* of the I order and the more lowered *Fontanelle surface* of the II order. Both these surfaces are considerably dislocated by the various systems of faults identified in the area.

3.2 The continental succession

In addition to the already mentioned *Sabbie di Piagge,* cropping out more to the south in the study sector, four depositional units have been identified, characterized by numerous facies heterotopy. From the most ancient to the most recent they are: *the Rieti Basin Unit,* subdivided into *lower and upper depositional units (*BARBERI & CAVINATO, 1993*); the Canetra-Cittaducale Unit; the Caporio Unit;* and the *Piana di S. Vittorino Unit.*

3.2.1 The *Rieti Basin Unit*:
Two units can be distinguished:

the lower depositional unit:

this represents the most ancient fill-in deposit of the Rieti basin. It is mostly made up of alluvial fan heterometric conglomerates in which, towards the bottom, chaotic deposits and carbonatic breccia horizons are intercalated (BARBERI & CAVINATO, 1993). Apparently both the paleolandslide deposits and the overlying breccias deposited above the II order *Fontanelle Surface* can be correlated to these deposits. This suface probably constituted a relatively gentle connection between the slopes and the basin. Also in the adjacent localities of the central Apennines (the surroundings of Micigliano, in the Velino valley; of Terracino, on the southeastern slopes of the Sibillini Mts; of Scoppito and Conca Aquilana; of Pietracamela and Prati di Tivo, etc.) analogous deposits are present with the same depositional characteristics, above a II order *relict surface*. During the depositional phase of the the unit in question, a sharp reactivation of the extensional tectonics can be observed, which was particularly intense on the margins of the basin: the bedrock deposits are dislocated and tilted by a series of faults with displacements greater than 100 m (Fosso Canalicchio). The age of this unit is not easily definable in the absence of remains. However, since at the base of the overlying *upper depositional unit* faunas of Upper Villafranchian have been found, the deposits of the lower unit are more ancient and an age of Lower Villafranchian can probably be ascribed to them.

the upper depositional unit:

made up mainly of conglomerates intercalated with fluvial-lacustrine environment sandy-clayey deposits, this unit assumes clear onlap over both the *lower depositional units* and the pre-Pliocene bedrock, until the innermost areas of the ridges over the Salto and Turano valleys, where it sutures the previous dislocations. In Upper Villafranchian, a period of relative tectonic stasis is recorded, as was already hypothesized by BARBERI & CAVINATO (1993).

After the Villafranchian, notable variations of climate can be observed in the studied area, with greater or lesser humidity together with a sharp reactivation of vertical movement and extensional tectonics. These factors favored

the activation of linear erosion processes, with the formation of narrow and deep valleys which were then filled by alluvial deposits and travertine, while alluvial fans and detritic belts were formed at the foot of the slopes.

3.2.2 *The Canetra - Cittaducale Unit:*

This is made up of Middle Pleistocene terraced alluvial deposits (I order terraces) and travertine (CARRARA *et al.*, 1993). In the vicinity of San Rocco and Cittaducale, cascade travertine can be found probably as a result of the formation of small tectonic scarps.

3.2.3 *The Caporio Unit:*

II order alluvial terraces, travertine and alluvial fans (Upper Pleistocene) belong to this unit.

3.2.4 *The San Vittorino Unit:*

This is formed of presentday and recent flooding, travertine, alluvial fan and slope deposits, bodies from recent landslides, and eluvial-colluvial (Holocene) deposits. Of particular interest is the Holocene alluvial fan at the Terme di Vespasiano, of historic age, which has covered the ancient constructions with considerable thicknesses.

4. DISCUSSION AND CONCLUSIVE REMARKS

An analysis of the data reported above allows us to advance some hypotheses on the morphostructural evolution of the area studied, on the timing and dynamics of the formation of the S. Vittorino basin, and also on the way in which the various factors (Plio-Quaternary tectonics, regional uplifting, climatic and eustatic variations, etc.) controlled the evolution and genesis of the various phenomena characterizing the area.

The deposition of the *Sabbie di Piagge* in the continental environment (Upper Messinian? - Lower Pliocene?) is evidence of the incipient emersion of the area during the first phases when the chain was being structured, and the carbonate deposits underlying the Messinian turbidites had still not been laid bare by erosion and tectonics.

The *Summit surface,* instead, was certainly formed after the complete structuring of the chain, which occurred in Early Pliocene. During Late Pliocene, the phases of the slow but progressive uplifting of the area are evidenced by the presence of paleosurfaces entrenched in the *Summit one* at various altitudes which testify the occurrence of periods of relative tectonic stasis during the transition from the tectogenetic compressional phase to the extensional one. However, the paleolandslides present in the II order *Fontanelle surfaces* suggest a sharp increase in the rate of uplifting, connected with a more pronounced extensional phase leading to the formation of tectonic scarps, and probably with the triggering effect of regional seismic events which favored the triggering of gravitational movements. The subsequent deposition of breccias is to be correlated with the rapid erosion of the carbonatic members on the slopes with high relief energy. In the same period, probably Late Pliocene, the formation of the Rieti basin commenced and the *lower depositional unit* alluvial fan sediments began to be deposited. The chaotic deposits and carbonatic breccias intercalated in the base portion of this unit, in the areas closest to the basin, suggest the hypothesis of a relative connection between the II order paleosurfaces and the basin itself, on which both the paleolandslides and the breccias were deposited.

During the deposition of the basal unit of the Rieti basin, the extensional tectonics activity was relatively intense: in the marginal areas the conglomeratic deposits were dislocated in blocks lowered towards the basin by a series of faults, with considerable displacements, at times, of more than 100 m.

The deposition of the second lacustrine unit during Late Villafranchian occurred in a period of relative tectonic stasis, as is shown by the onlap bedding of these deposits which, in addition to suturing the previous dislocations also fills the most uplifted and internal parts of the basin itself, up to the flattened areas of Mt. S. Vittorino and Longone Sabino.

After the closing of the Rieti basin cycle, a sharp and intense reactivation of the rate of regional uplifting and extensional tectonics occurred, as well as a change to a colder climate, which caused significant modifications to the morphostructural features. In this setting, the linear erosion processes developed which led to the formation of the present hydrographic network, characterized by narrow and deep V-shaped valleys inside the *Fontanelle surface,* with rapid lowering phenomena of the order several hundreds of meters (400-500 m) along the main dislocations, both of neoformation and reactivating more ancient elements. Of these dislocations, those that seem to assume particular importance because they controlled and conditioned the evolution and drainage of the paleo-Velino are: the one bordering all the northwestern slope of the Colle Impicciavera-Pendenza block, which lowers the whole of the southern sector NW-wards, and the one located at the foot of the Montagna dei Cesoni slope, that in the neighborhood of Cittaducale dislocates and tilts the upper deposits of the Rieti basin lacustrine succession.

In Middle Pleistocene, in a period of relative tectonic calm and of stasis in the regional uplifting, the Canetra - S. Rocco - Cittaducale I order complex of terraced alluvial material and travertine was deposited. The waterfall deposits identified in the S. Rocco and Cittaducale travertine (CARRARA *et al.*, 1993) may be correlated with small scarps overlain on the synsedimentary faults which characterized the first phases of evolution of the S. Vittorino basin.

After the deposition of the I order alluvial terraces, a sharp change can be noted in the morphostructural setting, which evolved towards its presentday features, mainly due to the effects of tectonics with a considerable strike-slip component favoring different vertical and horizontal movements.

In this interval, the most important structural elements controlling the morphostructural setting proved to be the *Fiamignano-Micciani Fault*, which was reactivated with transtensive characteristics, the *Piedimozza-Cerquara Fault,* and the *Fontanelle Fault.* The different amounts of horizontal and vertical movement between the Reatini Mts block and that of Mt. Nuria - Colle Impicciavera - Pendenza, along the tracks built by the above-mentioned faults, favored the formation of the almost pull-apart Valle Santa depression, (where the paleolandslide deposits and

the overlying *Fontanelle breccias* are involved), as well as those of the S. Vittorino basin.

The tectonic origin of the basin, due to collapse phenomena, is evidenced by the considerable thickness of the fluvio-lacustrine deposits (ca 180-200 m) that accumulated in the central part of the basin between Case Paterno and the Peschiera springs, while it is minimal in the extreme northwestern area between Caporio and Cittaducale, which in fact represents the northeastern border of the basin itself (CIOTOLI *et al.*, 1998, 2000) The formation of the basin, delimited to the NE by the *Piedimozza-Cerquara Fault* and to the SW by the *Fiamignano-Micciani Fault,* is characterized by the activity of other faults belonging both to the same system as the first two and to systems trending E-W and N35°-40°E.

The combination of these systems and of the transcurrent processes along the N30°-35°W system, evidenced by mesostructural observations (FACCENNA *et al.*, 1993, in the surroundings of Micciani; BOSI *et al.*, 1994, in more southerly areas; COSTA PISANI, unreported data, in the neighborhood of Cotilia and Lago del Salto) is the factor responsible for the peculiar triangular shape of the basin itself, characterized by a progressive lowering of sectors of the Reatini Mts block towards the southern quadrants, and of the Calcariola block NE-wards.

Thus, attributable to this tectonic phase are: the dislocations of the paleosurfaces, and the *paleolandslide deposits* and *Fontanelle breccias*, the I order terraced alluvial material and travertine, with displacements greater than 100 m; the structuring of a system of small horsts and grabens with Apennine trend in the Reatini Mts. block; the progressive lowering towards NW and SW of the Colle Impicciavera - Pendenza sector; the formation of the karst caves, almost all following tectonic alignments or lying at their crossing points; the genesis of deep-seated gravitational movements on the fault slopes (eg. the trenches and collapse features on the slopes NW of Pendenza and Cerquara).

Even if the recent tectonic activity has left the above-described morphostructural setting almost unaltered, it has been and still is relatively intense, as can be seen by: 1) the presentday formation and areal distribution of the sinkholes and small lakes, 2) the alignments of gassy fluid anomalies and mineral water springs (CIOTOLI *et al.*, 1998, 2000), and 3) the historic and recent seismicity, the latter being evidenced by trenches and faults dislocating Upper Pleistocene and Holocene deposits (MICHETTI *et al.*, 1994).

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