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QUATERNARY EVOLUTION OF THE "CASTELLUCCIO DI NORCIA" BASIN (UMBRO-MARCHEAN APENNINES, CENTRAL ITALY)

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ABSTRACT - *Quaternary evolution of the Castelluccio di Norcia Basin (Umbro-Marchean Apennines, central Italy)* - Il Quaternario, **8**(1), 1995, 149-166 - Castelluccio di Norcia is a closed depression, 12 km in length and 8 km in width, located in the southern part of the Umbro-Marchean Apennines, westward from the highest reliefs of the chain. The Umbro-Marchean sequence outcropping in the area was folded and shifted eastward, along major overthrusts, during Late Miocene-Early Pliocene times. During the Early Pliocene, a very flat "erosion surface" was modelled on the folded and thrusted bedrock. In Upper Pliocene times, major uplifting movements began in the chain, the highest values (> 2000 m) being reached in the highest present-day summits of the southern part of the chain and to the east of the study area. A "young landscape", with many preserved smoothed parts, developed in the Apennines up to the late Lower Pleistocene; wide paleovalleys, remnants of which are today watersheds, formed during this period. Successively, in the most uplifted parts of the chain a "mature landscape" started to develop. Extensional tectonic movements, which in part originated the Castelluccio-di-Norcia Basin, affected the western part of the chain. A series of NW-SE to N-S trending faults with >1000 m vertical displacement became active. Elongated valleys developed in the western sector of the basin while only minor erosional features are present on the Costa-del-Vettore Fault scarp, probably due to the continuous activity of this major fault system. The oldest sediments outcropping in the basin are coalescent alluvial fan deposits, debris fan and stratified slope-waste deposits, sometimes interfingered with one another and containing thin beds of pyroclastic deposits, attributed to late Middle Pleistocene times. The emplacement of these old deposits is linked to a widespread glacial and periglacial morphogenesis, the former being represented on the northernmost exposures where large nivation and glacial cirques can be seen. At Piano Perduto, (1340 m a.s.l.), there are cemented remains of a frontal glacier moraine developing from the Canatra valley. Late Middle Pleistocene deposits are deeply dissected and terraced, especially along the basin eastern escarpment. During Upper Pleistocene times, no glacial sediments reached the plain, whereas large alluvial fans were being deposited at the foot of slopes. These fan deposits would subsequently be moderately dissected in the Holocene. A depositional phase followed, consequent to deforestation and intense soil erosion in historical times. The dense network of faults delimiting the plain became active before the late Middle Pleistocene, but evidence of small displacements are present along the eastern main fault scarp. Along this fault huge landslides – *e.g.* the *Colli Alti e Bassi* landslide – occurred. A very flat debris slump at the base of the main scarp suggests its close relationship to earthquakes.

RIASSUNTO - *Evoluzione quaternaria della conca di Castelluccio di Norcia (Appennino umbro-marchigiano, Italia)* - Il Quaternario, **8**(1), 1995, 149-166 - Castelluccio di Norcia è una depressione chiusa, di oltre 12 km di lunghezza e 8 di ampiezza, situata nella parte meridionale dell'Appennino umbro-marchigiano, ad ovest dei più elevati rilievi della catena. La serie umbro-marchigiana che affiora nell'area è stata piegata e traslata verso est, lungo importanti sovrascorrimenti alla fine del Miocene-inizi del Pliocene. Successivamente, durante il Pliocene Inferiore, una "superficie di erosione" estremamente appiattita venne modellata sulle rocce piegate e sovrascorse. Nel Pliocene Superiore si sono attivati movimenti di sollevamento che sono stati di maggiore entità (più di 2000 metri) in corrispondenza dei più alti rilievi attuali, ubicati nel settore meridionale della catena, ad est dell'area in esame. Un paesaggio "giovane", con ampi tratti ancora spianati, si è sviluppato in Appennino sino alla fine del Pleistocene inferiore, con la creazione di ampie paleo-valli, oggigiorno preservate in corrispondenza degli spartiacque. Dopo questo momento, sui tratti più sollevati della catena ha iniziato a modellarsi un paesaggio "maturo". Una tettonica distensiva, alla quale è legata la creazione del bacino di Castelluccio di Norcia, ha interessato la parte occidentale della catena dopo questo periodo. Essa ha condotto all'attivazione di una serie di faglie orientate circa NO-SE e N-S che presentano rigetti anche superiori ai 1.000 metri. Valli discretamente allungate si sono sviluppate nella parte occidentale del bacino mentre sulla scarpata principale, ubicata in corrispondenza della Costa del Vettore, in seguito alla continua attività di questo sistema di faglie, sono presenti solo vallecole di modesta estensione. I sedimenti più antichi affioranti nel bacino, attribuiti al Pleistocene medio finale, sono costituiti da conoidi alluvionali coalescenti, coni detritici e detriti di versante talora interstratificati e contenenti sottili livelli piroclastici. La loro deposizione è legata ad una estesa morfogenesi glaciale e periglaciale. I più estesi circhi nivali e glacio-nivali sono presenti sulle esposizioni settentrionali. All'interno del Piano Perduto, ad una altezza di 1340 m, sono inoltre presenti resti cementati di un arco morenico frontale deposto da un ghiacciaio proveniente dalla Val Canatra. I depositi del Pleistocene Medio finale sono fortemente dissecati e terrazzati specialmente ai piedi del versante orientale. Durante il Pleistocene superiore nella piana non sono giunti sedimenti di origine glaciale. Ai piedi dei versanti sono stati però deposti ampi coni alluvionali che sono stati interessati da limitati processi di incisione durante l'Olocene. Una ulteriore fase deposizionale si è successivamente sviluppata in tempi storici in seguito ai processi di erosione del suolo attivati dalla deforestazione. L'intenso reticolo di faglie che delimita la piana si è attivato prima del Pleistocene Medio finale sebbene limitate evidenze di rigetto siano state osservate lungo il versante di faglia orientale. Lungo queste scarpate si sono innescate estese frane, come quella che costituisce i Colli Alti e Bassi. Una frana rotazionale discretamente appiattita originatasi dai detriti al piede del versante principale suggerisce una stretta correlazione con l'attività sismica.

Key words: Tectonic depression, geomorphology, Quaternary, Castelluccio-di-Norcia, Umbro-Marchean Apennines, central Italy
Parole chiave: Depressione tettonica, geomorfologia, Quaternario, Castelluccio di Norcia, Appennino umbro-marchigiano, Italia centrale

1. INTRODUCTION

The Castelluccio-di-Norcia Basin is one of the largest closed tectonic depressions (Fig.1) in the northern Apennines and is bordered by impressive fault scarps, at places with a vertical displacement of more than 1000 m. The terrains to the front of the Umbro-Marchean Apennines, outcropping a few kilometers to the east and

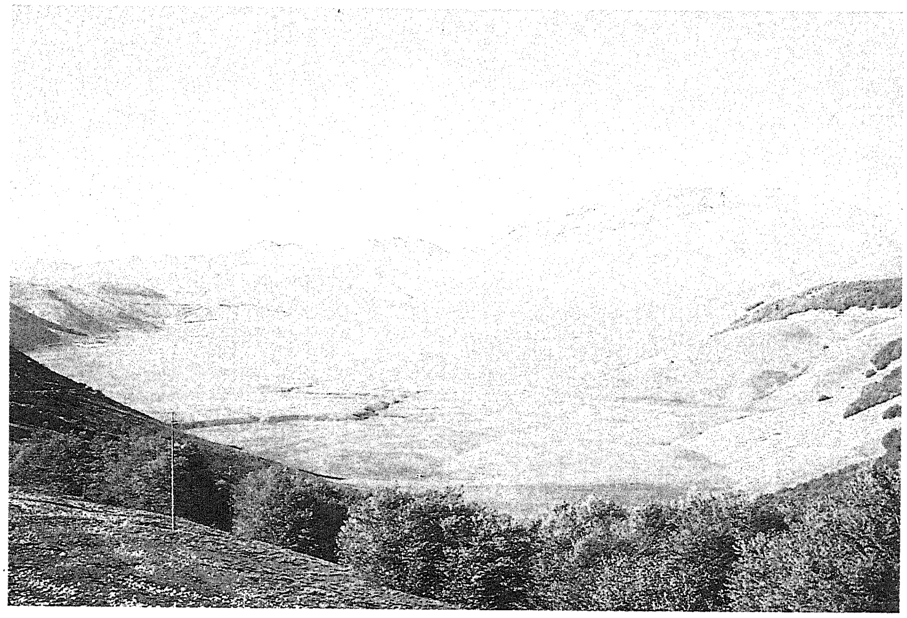


Fig.1 - General view of the plain from Mt. Cappelletta.

Veduta generale della piana dal M. Cappelletta.

south of the basin margins, overlie both those of the Periadriatic and Laga Basins and those of the Abruzzi-Latium Platform. Overthrusts, folds and extensional listric faults outcrop in a relatively small area, so that the sequence of tectonic events and their relative occurrence can be established. Because of the basin elevation and location in an area that glaciated in the coldest periods of Middle and Upper Pleistocene, deposits may also be a source of information on the relationship between tectonic and climatic changes, even though the oldest part of the sequence is not outcropping.

This study is a contribution to the understanding of the evolution of tectonic depressions in the Umbro-Marchean Apennines, and increases our understanding of the evolution of the whole Apennines chain.

2. GEOLOGIC AND GEOMORPHOLOGIC SETTING OF THE UMBRO-MARCHEAN APENNINES

The Castelluccio di Norcia basin, located in the middle of the Sibillini Mountains (Fig. 2), is one of the easternmost tectonic basins of the southern part of the Umbro-Marchean Apennines (central Apennines). From the structural point of view, the Umbro-Marchean Apennines consist of numerous folds and overthusts with vergence varying from the northern to the southern part of the chain: NE-SW in the northern part, E-W in the central part and from NW to SE in the southern part, where it joins the Sabina folded belt (Elter *et al.*, 1975; Koopman, 1983; Boccaletti *et al.*, 1983; Bally *et al.*, 1986; Calamita & Deiana, 1988; Lavecchia *et al.*, 1988). Lithologically, the sequence consists of a sedimentary multilayer, which ranges from massive limestone (*Calcare Massiccio*) to micritic, cherty and marly limestones, Jurassic to Oligocene in age. These rocks were overlain by terrigenous sediments during the Miocene (Centamore & Deiana, 1986). The terrigenous rocks do not outcrop in the southern portion of the chain. However, their presence in the central-northern part, enhanced selective erosion processes, which are largely responsible for the creation of parallel basins elongated in the NW-SE direction, and which alternate with ridges developing in correspondence to limestone outcrops (Umbro-Marchean, Marchean and Cingoli Ridges, from W to E).

In the southern part of the chain, the various ridges join to form the Sibillini Mts., which from the structural point of view, represent the southern limit of the northern Apennines. This limit is formed by a major overthrust covering the Abruzzi carbonate platform (Centamore *et al.*, 1979) and the southern portion of the Laga Basin. This basin is composed mostly of arenaceous and pelitic sediments containing modest amounts of conglomerates and gypsum, dating from Oligocene to Miocene times. The main tectogenic phase in this part of the Apennines chain occurred in Messinian-Early Pliocene times (Calamita *et al.*, 1990; 1991), although similar structures seem to have developed earlier in the western side of Italy following the progressive eastward migration of the fold belt (Elter *et al.*, 1975; Ambrosetti *et al.*, 1978; 1987; Boccaletti *et al.*, 1986; Damiani *et al.*, 1991). In the western part of the Apennines, terrigenous sedimentation continued up to the Upper Miocene (Centamore *et al.*, 1979). However, similar sediments originating from the erosion of the substratum outcroppings to the west, fed the Inner Marchean and Periadritic Basins up to Messinian and probably even in Early Pliocene times.

In the Periadriatic Basin, Lower Pliocene transgressive sediments are found up to the front of the Marchean Ridge overthust (Calamita *et al.*, 1990; 1991). Deposition occurred while differential uplifting was affecting the chain. The chain had in part already emerged and had been eroded, as witnessed by a characteristic "erosion surface" ("*surface de sommets*" of Demangeot, 1965; "paleosurface" of Coltorti, 1981, and Dramis *et al.*, 1991). Marine sedimentation continued – with minor unconformities – up to the end of the Lower Pleistocene when a sequence of coastal and alluvial fan deposits filled the large syncline, which had been developing in the easternmost part of the Periadriatic Basin (Nanni *et al.*,

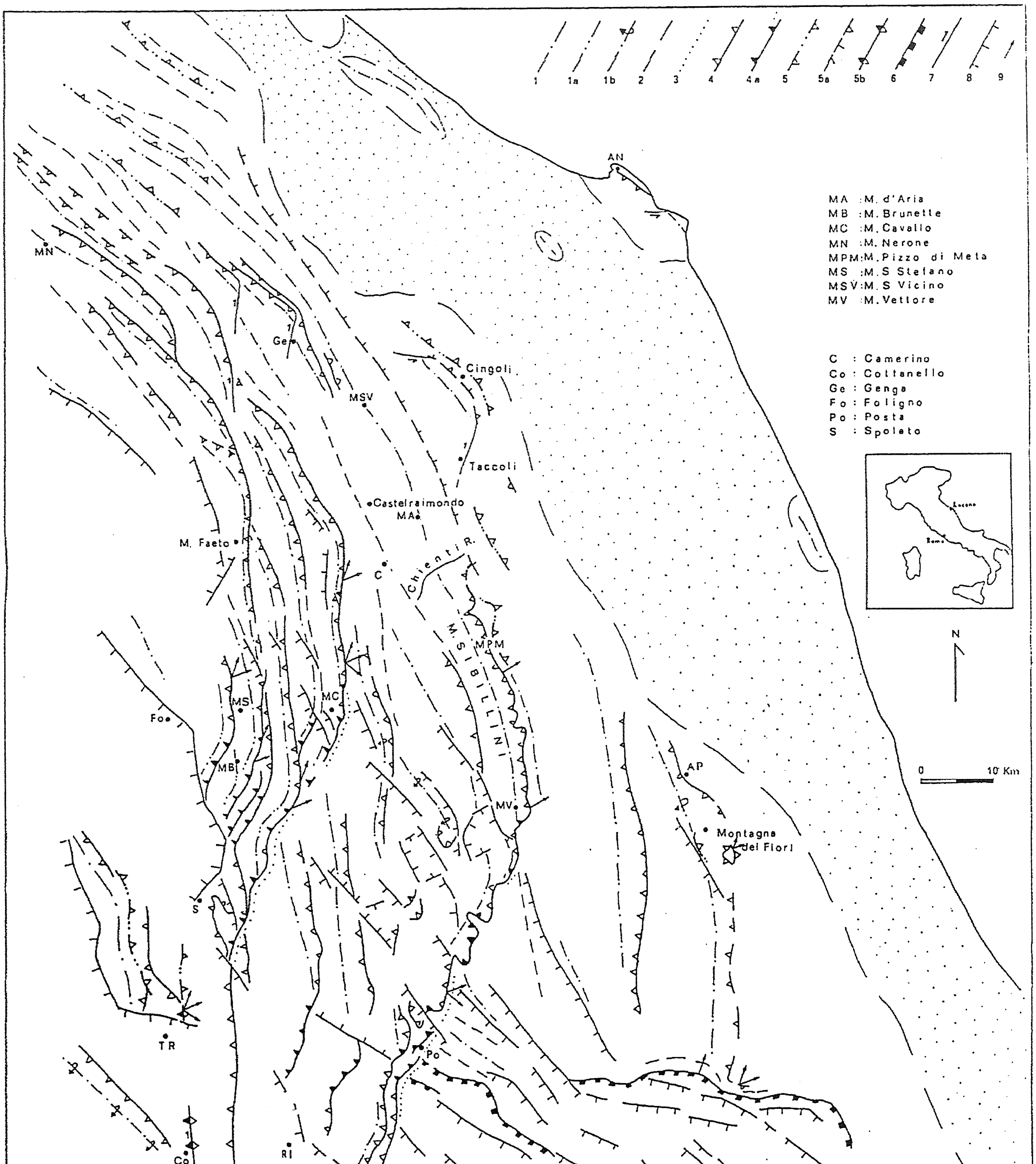


Fig. 2 - Structural map of the Umbro-Marchean mountain belt (after Calamita *et al.*, 1992). Legend: 1 - Macro-anticline (a = macro-anticline with intensely tectonized forelimb; b = macro-anticline with markedly overturned forelimb); 2 - syncline; 3 - axial trend of minor fold near the thurst fronts; 4 - thrusts; 4a - transpressive thrust and/or lateral or very oblique ramp; 5 - back-thrust; 5a - pre-existing normal fault (probably of Messinian age) reversed by back-thrust; 5b - back-thrust in a triangular zone; 6 - thrust front of the Lazio-Abruzzi Platform; 7 - transpressive tear fault; 8 - Plio-Quaternary normal faults; 9 - slip vectors of the thrusting. In the outer area the chain is buried under the sandy and clayey Middle Pliocene-Lower Pleistocene post-transgressive sequence (dotted area).

Carta strutturale della catena umbro-marchigiana (da Calamita et al.*, 1992). Legenda: 1 - Macro-anticlinale (a = macro-anticlineale con il fianco esterno molto tettonizzato; b = macro-anticlinale con il fianco esterno nettamente capovolto); 2 - sinclinale; 3 - direzione assiale delle pieghe minori in vicinanza della fronte dei sovrascorrimenti; 4 - sovrascorrimenti; 4a - sovrascorrimento transpressivo e/o rampa laterale o molto obliqua; 5 -* back-thrust*; 5a - faglia diretta pre-esistente (probabilmente del Messiniano) invertita ad opera del* back-thrust*; 6 - fronte del sovrascorrimento della piattaforma laziale-abruzzese; 7 - faglia transcorrente transpressiva; 8 - faglie dirette plio-quaternarie; 9 - vettore di scorrimento dello scorrimento; Sul lato esterno la catena è sepolta sotto la serie sabbioso-argillosa post-trasgressiva del Pliocene medio-Pleistocene inferiore (area punteggiata).*

1986; Cantalamessa *et al.*, 1986; 1990).

In the Spoleto area, on the western margin of the chain, a basin had developed at the end of the Lower Pliocene over previously folded rocks, which would eventually be filled by fluvio-lacustrine and alluvial fan deposits many hundred meters thick (GE.MI.NA, 1963; Decandia & Giannini, 1977; Coltorti & Pieruccini, in press).

Owing to the continuous uplifting affecting the whole region after the end of the Lower Pleistocene (Ambrosetti *et al.*, 1982; Coltorti *et al.*, 1991), the Sicilian-Crotonian beach sediments, close to the Adriatic coast, outcrop at altitudes around 300 m a.s.l. Uplifting rates were higher along the chain axis where remnants of the "erosion surface" lie generally at elevations higher than 1000 m a.s.l. Major uplift values are recorded at the Sibillini Mts., the higher tops of which are over 2400 m and where erosion surface has been totally cancelled by later processes (Damiani, 1975; Coltorti & Dramis, 1990).

Many NE-SW faults with small displacement, have become active since Middle Pleistocene times (Coltorti *et al.*, in press-b) as well as several NW-SE-trending normal faults displaying the westward listric geometry typical of master faults (Decandia & Giannini, 1977; Raffy, 1981; Calamita *et al.*, 1982; Lavecchia *et al.*, 1984; Bally *et al.*, 1986; Calamita & Pizzi, 1992). These subdivided the southern Umbro-Marchean chain into three NW-SE trending blocks, forming a step-like morphology progressively lowering to the west. Along the foot of the main fault escarpments, which are up to 1000 meters in height, at the junction with antithetic NW-SE secondary faults and, locally, with NE-SW faults, tectonic depressions formed.

A Middle Pleistocene age is hypothesized (Biella et al., 1981; Calamita *et al.*, 1982; Coltorti *et al.*, 1989; Blumetti *et al.*, 1990; Brozzetti *et al.*, 1991) for sediments outcropping in the Norcia and Cascia depressions. However, an uncertain K/Ar age of 1 MY (Lower Pleistocene) was obtained (Blumetti & Dramis, 1992) for sediments at Norcia, which had previously been attributed to final Middle Pleistocene times on the basis of radiometric age determinations and morphostratigraphic correlations.

Other basins in the Umbro-Marchean Apennines have been interpreted as being of tectonic origin (Centamore *et al.*, 1978; Borselli *et al.*, 1988; Gregori, 1990). One of these is the Colfiorito basin, which recent studies (Coltorti *et al.*, in press-a) have however shown to be the remains of a paleodrainage system modelled after the "erosion surface" rather than a tectonic depression. The central part of the basin, which is up to 100 m thick, was filled during the Jaramillo Event.

3. GEOMORPHOLOGY OF THE CASTELLUCCIO DI NORCIA BASIN

The "Castelluccio di Norcia" basin is a closed depression more than 12 km long and 8 km large, stretching NNW-SSE in the Apennine direction. To the east, it is bordered by some of the main reliefs of the chain (Mt. Porche, 2233 m; Quarto San Lorenzo, 2247 m; Mt. Vettoretto, 2052 m). These mountains form the highest easternmost block of the three into which the area was divided by extensional tectonics (Calamita *et al.*, 1982; 1992; in press). To the west, the crests delimiting the basin (Mt. Delle Rose, 1861 m; Mt. Vetica, 1714 m; Mt. Ventosola, 1718 m) have lower elevations owing to the activity of a master fault bordering the above-mentioned block. Antithetic faults are located at the foot of the eastern slopes of these mounts. Another main fault is located a few kilometres to the west delimiting the third block and bordering the Norcia-Preci tectonic depressions.

3.1 Poligenic landforms

Remnants of the "erosion surface" characterize some of the tops in the area (Coltorti, 1981; Coltorti & Dramis, 1990; Dramis *et al.*, 1991; Dramis, 1992). This surface cuts all the formations regardless of their resistance, creating very flat surfaces at places. The elevation of these remnants varies along the chain from 600 m (Cingoli Ridge) to more than 1900 m at Pintura-del-Ragnolo in the northern Sibillini Mts., where this morphology is still preserved. The altitude increase may be either gradual or sharp when in presence of steep fault scarps, indicating a single modelling event for the erosional surface.

Moreover, an "undulated landscape", consisting of large valleys and rounded low-energy reliefs, has been identified in some parts of the Umbro-Marchean Apennines (Calamita *et al.*, 1982; Ciccacci *et al.*, 1985; Dramis *et al.*, 1991; Dramis, 1992). This morphological feature was firstly mentioned by Demangeot (1965) who observed remnants of what he called "the Villafranchian surface" widespread on the mountains of a large part of Marches and Abruzzi. Modelling of this surface was attributed to a reduced tectonic activity under tropical climatic conditions (Demangeot, 1965) or, according to Dramis *et al.* (1991), under arid climatic conditions. The remnants of this surface observed in the Colfiorito area (Coltorti *et al.*, in press-a) confirm that, in agreement with Demangeot (1965), the drainage system was already developed in late Lower Pleistocene times. Its formation ended when more generalized uplifting movements became active (Ambrosetti *et al.*, 1982), soon followed by an extensional tectonic activity along the western side of the Apennines. The late Lower Pleistocene - Middle Pleistocene age of the Colfiorito deposits, outcropping within wide hanging valleys, can be taken as a reference to date the "undulated landscape".

In conclusion, two surfaces are present in the Umbro-Marchean Apennines area, namely: the "erosional surface", characterized by very flat parts, and the "Villafranchian" surface, which modelled wide valleys, and which dissected the other surface for many hundred metres at places. The "undulated landscape" described by Ciccacci *et al.* (1985), Dramis *et al.*, (1991) and Dramis (1992) seems

Fig. 3 - Mt. Prata and Mt. Rotondo, northern part of the basin: a view of the "erosional surface" from Castelluccio di Norcia.

M. Prata e M. Rotondo nella parte settentrionale del bacino: veduta della "superficie d'erosione" da Castelluccio di Norcia.

to include both these morphological units.

Well-preserved flat remnants of the older erosional surface are present in the study area, on Mt. Prata (1800 m) and Mt. Rotondo (1707 m) (Fig.3). It is to be noted that the highest hills of the "Castelluccio di Norcia" basin, to the west of the master fault, have similar altitude, giving rise to a morphology characterized by "peaks of equal heights" (Pecsi, 1970). To the east of the master fault, the remnants of this old surface have been eroded, but their presence is reported a few kilometers northward (Coltorti, 1981; Coltorti & Dramis, 1990; Dramis *et al.*, 1991) showing that the surface reached altitudes higher than those of the present-day crests (over 2400 m) on the highest easternmost block elongated in the NW-SE direction, where the maximum uplifting rates are also recorded (Calamita *et al.*, 1982, 1992; Calamita & Pizzi, 1992).

At lower elevations, with respect to the older surface remnants, wide saddles are present on watersheds, showing that large valleys crossed the area. The northernmost paleovalley, with a NW-SE orientation, is prensered at Forca di Gualdo (1496 m) (Fig. 4), and in its southern part at Forca Canapine (1521 m) and Colle Le Cese (1480 m). Another wide paleovalley is preserved on the ridge between Mt. Cappelletta (1650 m) and Mt. Guaidone (1647 m), and part of a similar feature is found on the top of Mt. Veletta (1614 m) and in the Canatra valley (Coste Valloni, 1695 m; Colle Bernardo, 1663 m).

All these features suggest that there was an open drainage system formerly extending to the Abruzzi to the south, to the Norcia Basin to the west, and to the Marches region to the north and east. However, there were also secondary valleys, as their remains on the flanks of the Caprelli valley (1517 m) show.

A similar morphology is present at Forca Viola (1736 m) on the "Costa del Vettore" slope. Morphology in the "Forca di Presta" area (el. 1535 m) is more problematic and may be the result of successive headward erosive episodes. The elevation of the Forca Viola saddle is the lowest of this part of the chain and the saddle may be explained as the remnant of a paleovalley feeding the huge fan deltas of Mt. Ascensione in the Periadriatic Basin during the Upper Pliocene (Cantalamessa *et al.*, 1986). The prevalent limestone composition of Mt. Ascensione conglomerates seems to support this hypothesis.

Wide paleovalleys indicate the presence of a "young

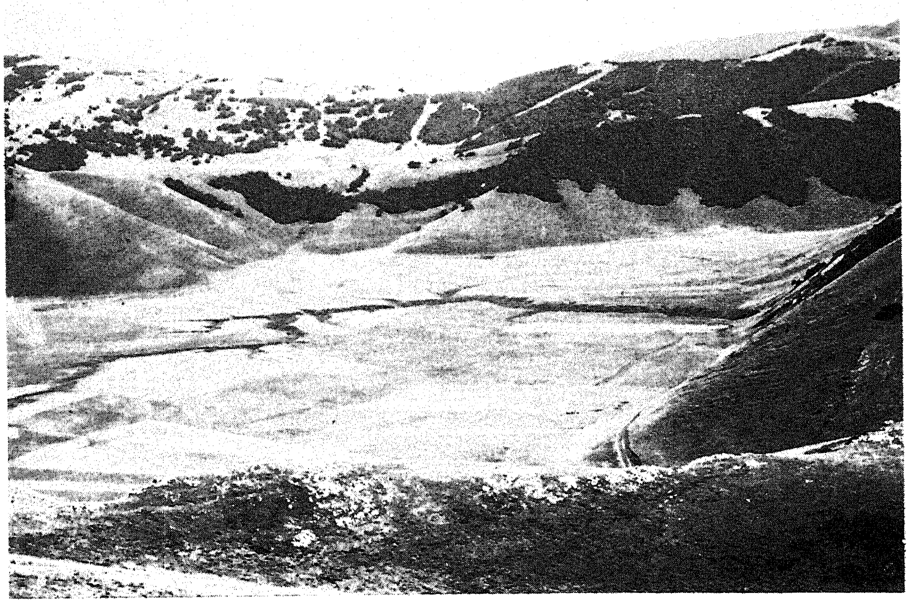


Fig. 4 - The "Forca di Gualdo" paleovalley cut when the area was a "young landscape" in the Lower Pleistocene.

La paleovalle di "Forca di Gualdo" che si è formata quanto la zona era in uno stadio di "sviluppo morfologico giovane" durante il Pleistocene inferiore.

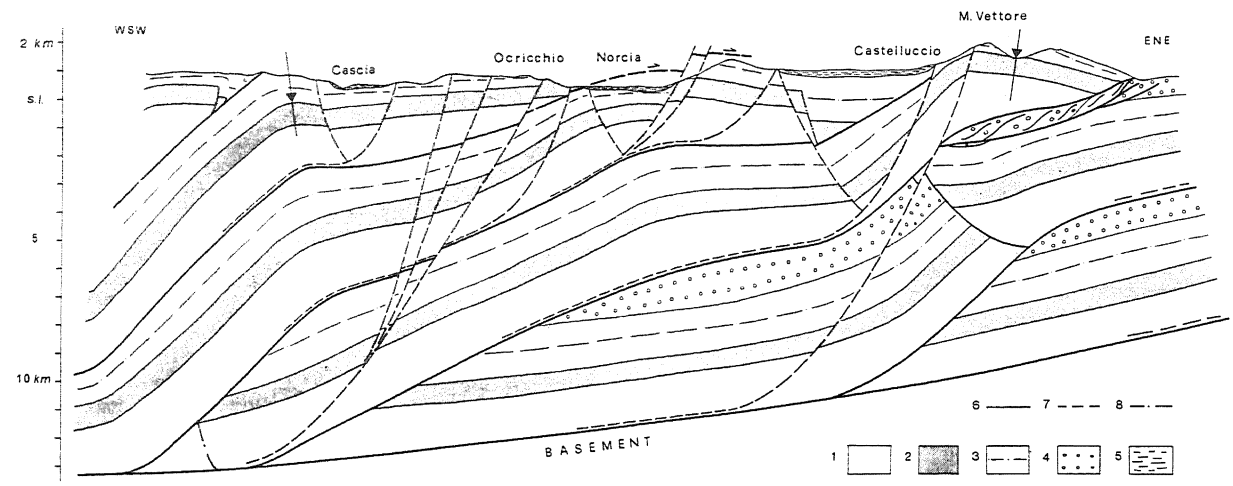


Fig. 5 - Geological cross section (after Calamita *et al.*, 1992). 1: Triassic evaporites (*"Anidriti di Burano"*); 2: *"Calcare Massiccio"*; 3: pelagic and hemipelagic sequence; 4: silicoclastic turbiditic deposits; 5: Quaternary continental deposits; 6: thrusts; 7: Quaternary normal faults; 8: Jurassic normal faults. Vertical and horizontal scales are the same.

Sezione geologica (da Calamita et al., *1992). 1: evaporiti del Trias ("Anidriti di Burano"); 2: "Calcare Massiccio"; 3: sequenza pelagica e emipelagica; 4: depositi turbiditici silico-clastici; 5: depositi continentali del Quaternario; 6: sovrascorrimenti; 7: fagli dirette quaternarie; 8: faglie dirette giurassiche. Le scale verticale e orizzontale sono eguali.*

landscape" (*sensu* Davis, 1899) in central Italy, originating from the slow dissection of the older flat erosion surface during the first uplifting stages. In a later time, in those parts of the chain where uplifting movements were stronger, a "mature landscape" set in.

3.2 Structural setting and neotectonics

Many authors have described the geological setting of the Castelluccio di Norcia Basin (Scarsella, 1941; Castellarin *et al.*, 1978; Calamita *et al.*, 1992; 1994). The outcropping sequence starts with the massive limestone of the *"Calcare Massiccio"* formation of Triassic-Jurassic age. Extensional tectonics affected this formation so severely during the Hettangian as to alter both paleotopography and the sedimentary sequence. Many hundreds of metres of micritic, marly and cherty limestone were deposited in newly formed depressions ("Complete Sequence": Centamore *et al.*, 1973), whereas elevated structures were covered by a few dozen metres of nodular limestones ("Condensed sequence"). The sea bottom was regularized by the deposition of micritic limestone (*"Maiolica"*) during the Titonian, followed by a marly carbonate sedimentation (*"Marne a Fucoidi"*, *"Scaglia Bianca"*, *"Scaglia Rosata"*, *"Scaglia Variegata"* and *"Scaglia Cinerea"*) which continued up to Oligocene times, *"Scaglia Cinerea"*(a grey marl) being the youngest deposit in the area.

The plane of the overthrust of the Sibillini Mts., which pushed the limestone terrains onto the arenaceous and pelitic sediments of the Laga Basin, does not outcrop in the Castelluccio di Norcia Basin. This plane can be seen a few kilometers to the east, in the northern part of the basin almost entering it to the NE of Forca-di-Presta (Fig. 5).

During the erosional processes which affected the slopes in the area, many escarpments were formed along the contact between formations with different lithological char-acteristics. For instance, a major escarpment is that of Costa-del-Vettore between a huge olistolith of massive limestone (*"Calcare Massiccio"*) and the cherty limestone (*"Corniola"*) including it (Castellarin *et al.*, 1978). Minor escarpments formed at the contact between *"Maiolica"* (micritic limestone) and *"Marne a fucoidi"* (marl) and between the layers of micritic limestones themselves; this can be seen on the eastern slope of Mt. Lieto and Mt. Castello and on the western slope of Mt. Palazzo Borghese. It must be noted however, that alignments of saddles and valleys on opposite slopes of reliefs may indicate that erosional processes took place along faults and fractures.

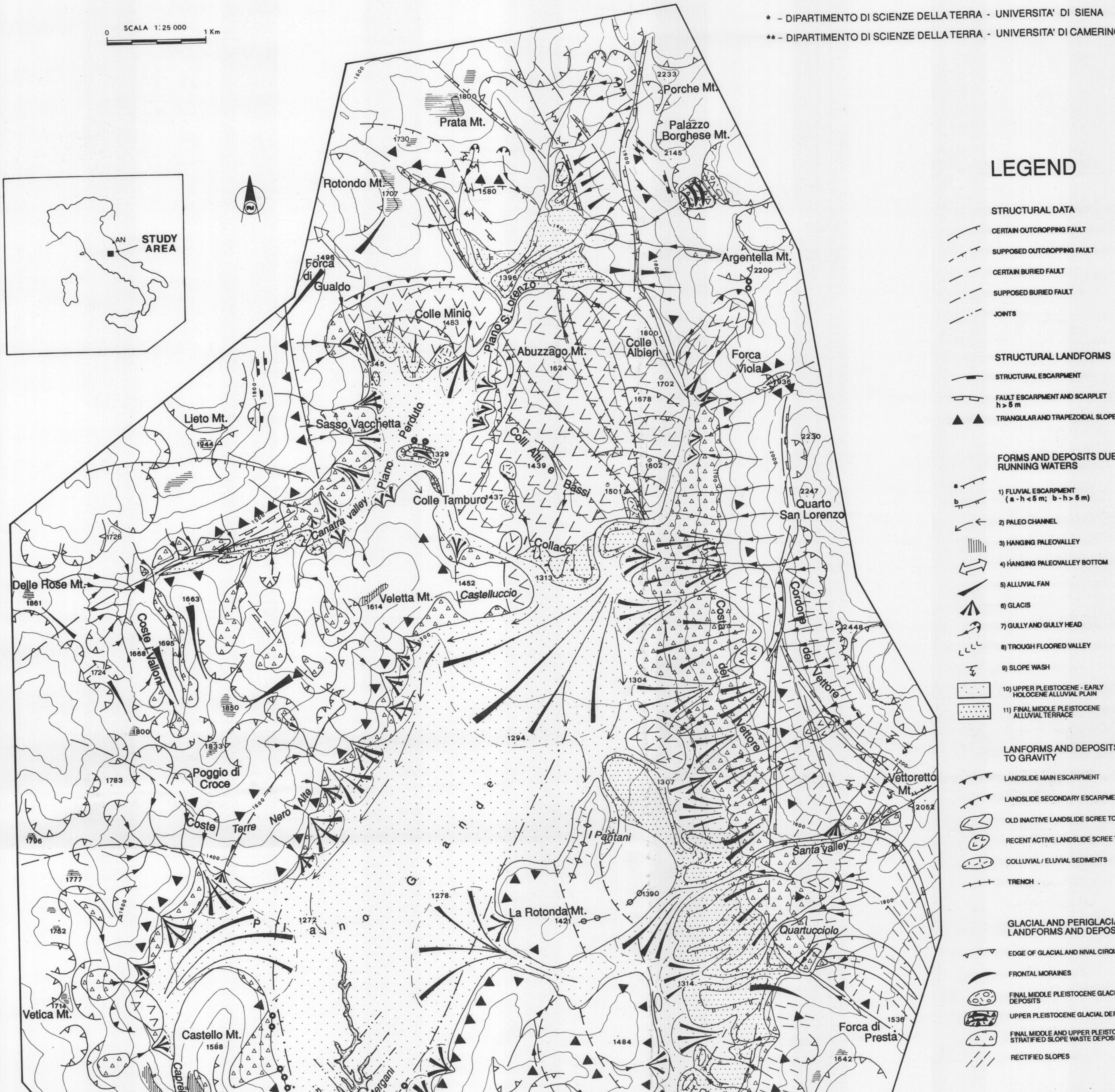
The easternmost fault zone, the offset of which is locally more than 1000 m, is delimited by minor faults (Fig. 6) which in the northern part of the basin have given rise to a stepped slope to the west of Mt. Porche, where active faults having a few metre displacement affect the bedrock and alluvial fan deposits. In the "Colli Alti e Bassi" area, the slope is subdivided into many elongated blocks which had been considered of tectonic origin by Calamita *et al.* (1992). In our opinion, such blocks could be related to a huge gravitational slide, most probably activated by tectonic movements. The characteristics of the slide will be described in the following pages. Southwards, the main fault outcrops at the foot of the Piano Grande slope splitting into two branches: one, passing to the east of the Mt. La Rotonda-Mt. Guaidone alignment, delimits Piano Piccolo and crosses the watershed to the west of Colle Saliere; the second passes to the west of such reliefs, borders Piano Grande, where it

COLTORTI MAURO* - FARABOLLINI PIERO**

GEOMORPHOLOGICAL MAP OF THE CASTELLUCCIO DI NORCIA BASIN

(UMBRIA - MARCHE APENNINES, ITALY)

* - DIPARTIMENTO DI SCIENZE DELLA TERRA - UNIVERSITA' DI SIENA
** - DIPARTIMENTO DI SCIENZE DELLA TERRA - UNIVERSITA' DI CAMERIN



is marked by an alignment of dolines up to the Forca Canapine area. To the W of Scoglio-del-Lago, the "Cordone del Vettore" fault (Fig. 7) enters the basin where it splits into many branches. The lower branch runs N10°E and crosses the watershed west of Mt. Macchialta; the middle one cuts the Mt.Vettoretto ridge and the Sibillini Mts. overthrust with a displacement of more than 300 m (Calamita *et al.*, 1992; Calamita & Pizzi, 1992); a further branch reaches Mt. Vettoretto. Triangular and trapezoidal facets are associated with these fault zones, where the alluvial fans of Piano Piccolo and Costa del Vettore are cut by very fresh scarplets. In the Costa del Vettore area, huge landslides occurred, as shown by very fresh swelling features, trenches and the counterslope arrangement of bedrock. To the south of Mt. Vettoretto, these faults displaced the ridge with an *en-échelon* sinistral component; similar characteristics have been observed in the southern part of the fault zone, on the right side of Piano Piccolo. Triangular facets associated with antithetic faults have been observed on the eastern flank of Mt. Guaidone and Mt. La Rotonda. Minor E-W faults, listric to the main fault scarp, border the watershed between Mt. Delle Prata (1800 m) and Mt. Rotondo (1707 m). The erosion surface, preserved on the top of such hills, is lower by approximately 100 m. A fault with similar orientation cuts the top of Mt. Lieto.

To the west, the basin is bordered by other important faults stretching in the NW-SE direction. In the northern sector two faults cut the eastern slope of Mt. Lieto (1944 m): the lower one crosses Forca di Gualdo and delimits Piano Perduto; the higher one displaces the slope only. Triangular and trapezoidal facets are the structural elements formed by these faults. To the south of the Canatra valley, the Mt. Veletta - Poggio di Croce ridge was affected by a NW-SE fault system. Along the contact with any fault, the ridge has been displaced suggesting a sinistral component associated with prevalent vertical movements. The connection of this fault system with the one present on its southern continuation – to the east of Mt. La Rotonda-Mt. Guaidone alignment – is masked by the Piano Grande deposits.

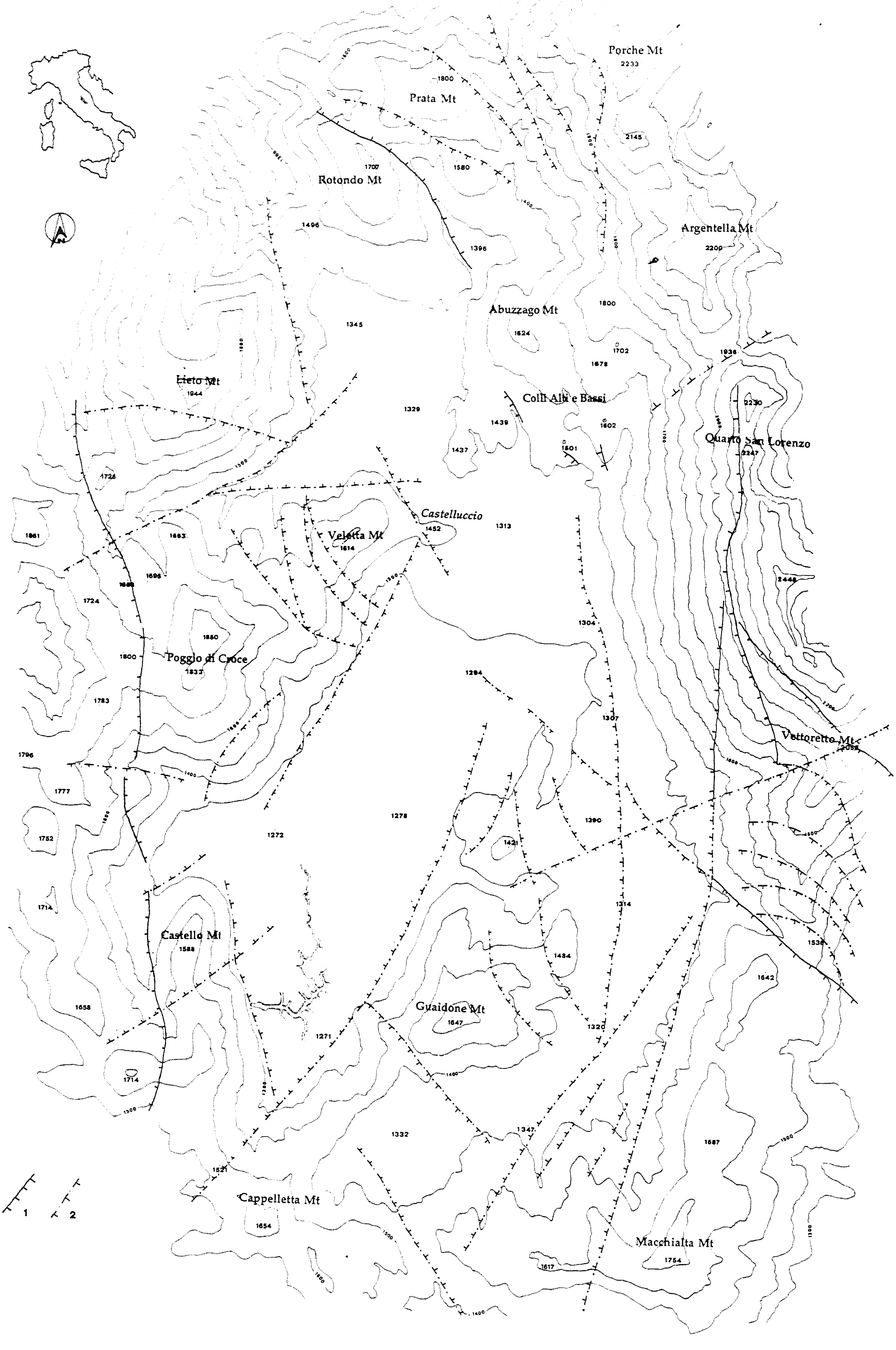
The southern margin of Piano Grande is formed by the NNW-SSE trending fault-slope of Mt. Castello-Mt. Cappelletta, and by its continuation toward Colle-Le-Cese. Mt. Castello, to the southwest, is bordered by a fault parallel to the fault-slope, the continuation of which outcrops in the Caprelli valley. No fault evidence have been observed at the foot of the Mt.Veletta-Poggio di Croce eastern slope, although a main step-like structure, most probably associated with a NNE-SSW fault, is present at Coste Terre Nero Alte. In the southern part of Piano Grande, a network of NE-SW and NW-SE faults is shown by the Mergani river course pattern.

An evaluation of fault activity may be given by the age of the deposits covering or being cut by all the above mentioned faults. Most faults are older than the late Middle Pleistocene; the "Cordone" and "Costa del Vettore" faults have scarps displaying continuity between their rectified slope and Upper Pleistocene debris deposits. A further proof of the recent age of these faults are the very few karstic microstructures observed on fault scarps modelled on limestone rocks.

Fault pattern and an approximate evaluation of displacements using geomorphological evidence (Fig. 6) support the assumption of Quaternary dynamics in the area. The progressive southward rise of the axis of the eastern block and the conforming lowering of the axis of the western one, are a further feature. Most faults in the southern part of the basin tend to meet the master fault with an *en-échelon* array. Visible displacement of the master fault is 400 m in the northern part of the basin, where this latter is a few hundred metres wide, and 800 m in the southern part where the basin reaches its greatest width. Minor synthetic and antithetic faults are present elsewhere but they do not change the overall pattern. The correlation between maximum extension-maximum displacement, and the fact that the latter is produced by listric faults joining the overthrust planes (Calamita *et al.*, 1994), may support the hypothesis of large-scale gravitational tectonics (Ollier, 1981) involving a large part of the Umbro-Marchean Apennines chain. Friction breccias, protocataclasites, fault breccias and gouges (Calamita & Pizzi, 1992; Calamita *et al.*, 1992; 1994) which, according to Sibson (1977) are generated in an elasto-frictional usually seismic regime, may be evidence of this hypothesis. These might have been the product of the displacement of deep fault planes by a fault creep movement, as stylolitic cleavage elements superimposed onto cataclastic elements and tectonites S/C (*sensu* Lister & Snocke, 1984) would suggest. The E-W direction of the extension would be linked to the progressive opening of the Tyrrhenian Sea (Patacca *et al.*, 1991), while the greater opening of the southern part of the basin seems to be related to the reversal reactivation of the uppermost overthrust plane acting as a sliding plane. The high energy of the relief of the area with consequent uplifting movements, can be considered as one of the major factors of such activation.

3.3 Landforms, deposits and processes due to glacial and periglacial morphogenesis

The Mts. Sibillini suffered important glacial and periglacial morphogenic processes (Klebesgerb, 1933; Sestini, 1934; Suter, 1940; Sacco, 1941; Scarsella, 1945; Lippi-Boncampi, 1948; Nangeroni, 1952; Demangeot, 1965; Mongini, 1970; Losacco, 1973; Giovagnotti, 1975; Damiani, 1975; Dramis *et al.*, 1980; Coltorti & Dramis, 1990). Glacial valleys, cirques and moraines, are present on the highest crests of the eastern block, outside the study area. The glaciers of the nearby Ambro and Aso valleys, located on the northern and northeastern slopes


Porche Mt
2233
Prata Mt
Rotondo Mt
Argentella Mt
2200
Abuzzago Mt
Lieto Mt
1944
Colli Alti e Bassi
Quarto San Lorenzo
Castelluccio
Veletta Mt
Poggio di Croce
Vettoretto Mt
Castello Mt
Guaidone Mt
Cappelletta Mt
Macchialta Mt
1
2

of the eastern block, such as many glaciers of the Apennines (Demangeot, 1965), were more than 10 km long, a few 100 m wide and more than 500 m thick. Small glacial cirques are preserved on the eastern side of the "Castelluccio di Norcia" basin. The valley head of the largest cirque, located between Mt. Argentella and Palazzo Borghese, has an elevation of about 2000 m while the bottom is at 1979 m. The cirque, having well defined "depression" and "threshold", is filled with nivation-eolian morainic ridges, the arcuate arrangment of which shows a strong eastward wind direction. The local provenance is responsible for the coarse grain size and for the sharp edges of the clasts. The freshness of forms, the absence of cementation and of an evolved soil profile are all elements in favour of an Upper Pleistocene age for the clastic deposits of the present cirque floor. However, this cirque was affected by a relief inversion. In fact, the actual valley head coincides with an eastward convex moraine ridge, which had a cirque edge to the west. This ridge is composed by cemented moraine debris floating in a reddish matrix giving the appearance of a *"breccia mortadella"* (Demangeot, 1965) to the sediments. The cementation is due to the Cca horizon of a leached paleosol, the upper horizon of which having been eroded; the reddish matrix shows a migration of clay from the paleosol upper horizons. Sols with these characters have been attributed at least to late Middle Pleistocene times (Demangeot, 1965; Dramis *et al.*, 1980; Coltorti & Dramis, 1990). After their deposition, the original valley head was regressively eroded and the older moraine ridge became the present watershed.

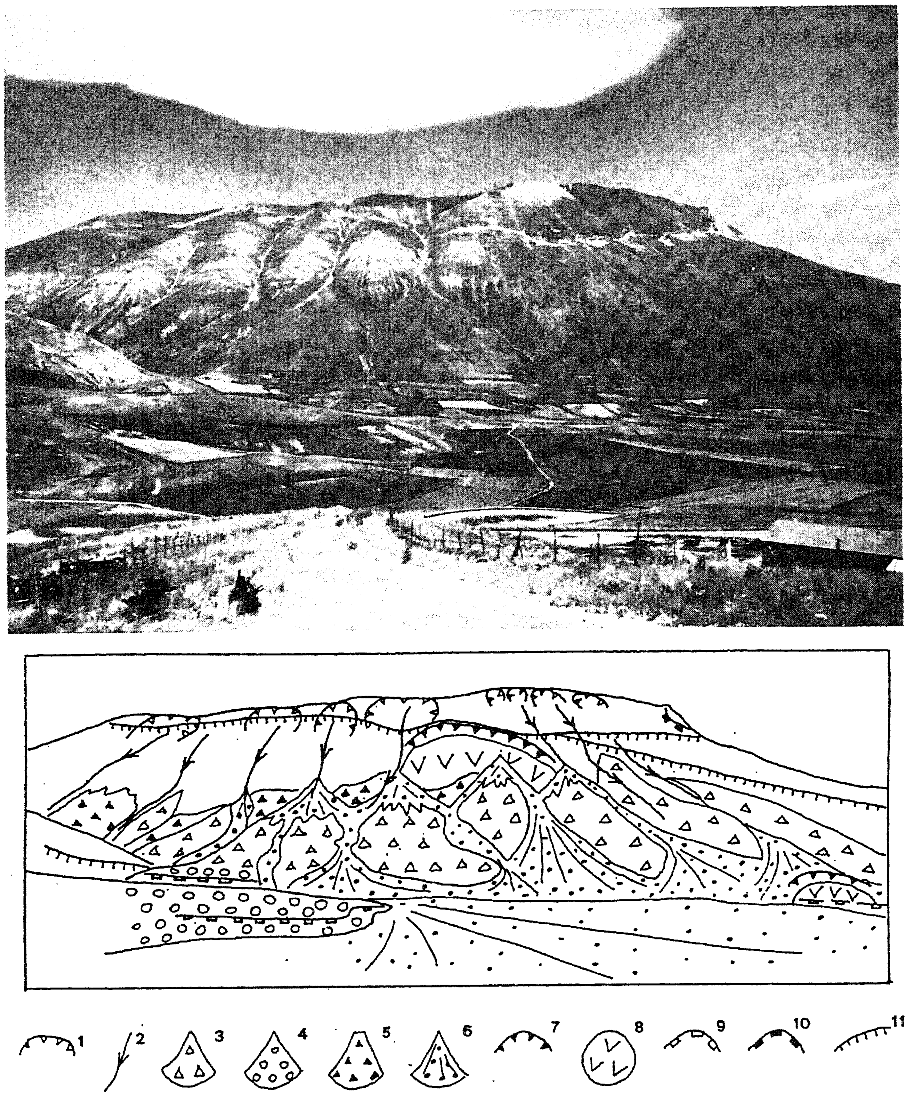


Fig. 7 - Principal geomorphological characters of the Mt. Vettore eastern fault scarp. 1: nivation cirque; 2: gullies and avalanche traces; 3: debris cone of late Middle Pleistocene; 4: alluvial fan of late Middle Pleistocene; 5: Upper Pleistocene debris deposits; 6: Upper Pleistocene and Holocene alluvial fans; 7: landslide scarp; 8: landslide scree-tongue; 9: fluvial scarp; 10: structural escarpment; 11: low scarp.

Caratteri geomorfologici principali della scarpata della faglia orientale del M. Vettore. 1: nicchia nivale; 2: calanchi e tracce di valanga; 3: cono di detriti del Pleistocene medio finale; 4: conoide alluvionale del Pleistocene medio finale; 5: depositi detritici del Pleistocene medio finale; 6: conoidi alluvionali del Pleistocene superiore e Olocene; 7: scarpata di frana; 8: piede della frana; 9: scarpata fluviale; 10: scarpata strutturale; 11: piccola scarpata, probabilmente di origine sismica.

Other important glacial cirques are present to the west of Mt. Vettoretto, and to the north of Mt. Macchialta and Mt. Cardisciana at the head of Valle Santa, Fosso dell'Inferno and Fosso di Macchialta, respectively. Glacial cirques can also be seen on the western side of the basin, to the east of Mt. Cappelletta and Mt. Ventosola (Caprelli

Fig. 6 - Structural scheme of the basin faults. 1: outcropping fault (certain); 2: outcropping uncertain fault.

Schema strutturale delle faglie del bacino. 1: faglia affiorante certa; 2: faglia affiorante non certa.

Fig. 8 - Moraine at the mouth of the Canatra valley.
Morena all'uscita della valle Canetra.

valley) and to the north of Poggio di Croce (Canatra valley). On the basin eastern side cirques are suspended on the basin floor, whereas on the western side they gave rise to valley glaciers. Their evolution is probably one of the main factors for the asymmetry of the basin which has the longest valleys on the western slope. No Upper Pleistocene moraines have been identified elsewhere in the basin.

At 1330 m along the mouth of the Canatra Valley, on Piano Perduto, there are outcrops of frontal arc cemented moraine deposits (Fig. 8). These are made up of subangular and subrounded gravels and blocks in a whitish silty matrix with a cement locally reddish in colour. Some of the clasts show evident striae from glacial transport, which was in the order of 3-4 km considering the distance from the cirque head. Colluvial materials cover the slopes of the moraine ridge. These contain a great amount of brown-reddish clay with flint debris, such the ones usually produced under the pedogenic regime characteristic of the Last Interglacial (Coltorti, 1981; Chiesa *et al.*, 1990). This confirms a late Middle Pleistocene age for these moraines. Terraced cemented gravel with no striae are present in front of the remnants of the moraine ridge suggesting a fluviatile reworking toward Piano Grande. These evidence support the assumption that even the largest cirques can be related to a glacial episode in these valleys during late Middle Pleistocene times. The episode of severe climatic conditions lasted for a very long time, because the mean chain altitude at that time had to be lower if the continuous uplifting of the Apennines is taken into account.

Smaller nivation cirques are present on all slopes. Many are of Upper Pleistocene age because they dissect the larger glacial forms previously described, as proven by many examples in the Sibillini Mts. (Dramis *et al.*, 1980; Coltorti & Dramis, 1990).

At the foot of nivation cirques and rectified slopes – one of the main characteristics of the area – two generations of stratified slope-waste deposits are present. The older deposits –the best outcrops of which are at Sasso Vacchetta in the western part of Piano Perduto and along Costa del Vettore – are as well cemented as the moraine deposits. At Costa del Vettore they are related to the emplacement of a huge coalescent debris fan, the apex of which was at about 1900 m a.s.l.

On the S. Lorenzo plain, on the top of a cemented alluvial fan of late Middle Pleistocene age, there is a pyroclastic layer. Although its actual stratigraphic position is uncertain, it could be correlative of one of the three pyroclastic layers, some 15 cm thick, which have been described in the late Middle Pleistocene deposits of Poggio Valaccone in the nearby Norcia basin (Blumetti *et al.*, 1991). These layers that are older than the Last Interglacial soil, may indicate the Vico volcano activity in late Middle Pleistocene times (Barberi *et al.*, in press).

The second generation of debris deposits is found on the interfluves between older cones and at the foot of main slopes (Fig. 7). The thickness of these deposits – generally less than 10 m – is less than that of the older deposits and of that of the ones of the Umbro-Marchean Apennines (Coltorti *et al.*, 1983; Dramis, 1983; Coltorti & Dramis, 1987; 1988). In the Quartucciolo area, a quarry face shows that debris deposits are interfingered with reworked silt sediments containing pyroclastic components. These sediments may be interpreted as loess materials reworked by slope-washing due to snow water. It is worth noting, however, that a 20÷40 cm thick layer of pyroclastic products has been identified along the road E of Mt. Castello, in the same stratigraphic position as the "loess" deposit.

Debris deposits are in places covered by colluvial deposits containing pyroclastic sediments which, like many others observed in the central Apennines, have been attributed (Frezzotti & Narcisi, 1989) to the Neapolitan yellow tuff (*"Tufo Giallo Napoletano"*) volcanic episode (about 10,000 ÷12,000 years B.P.).

Avalanche traces, hundreds of metres long and carved in the bedrock for a few metres, are present on the upper part of the "Costa del Vettore" slope; these evolve as gullies during storms.

3.4 Landforms, deposits and processes due to superficial running waters

Running water is rare in the area, although forms controlled by this morphogenic agent are common in other parts of the Apennines formed by rocks similar to the ones of the study area. Scarcity of running water is probably due to the nature of bedrock, the permeability of which has highly been increased by the thick network of faults and fractures.

Running water is responsible for slope-wash processes and concentrated erosion in gullies, which are widespread on bare slopes. Erosion is active in the Mergani riverbed, which stretches across the southern part of Piano Grande; the Mergani river valley is about 10 m deep and as much wide and it is more than 2 km long. The most depressed area of this plain seems to have been occupied by a lake until 1600 A.D. (Secchi, 1860), although depth and extension of the Mergani river suggest swampy conditions not very different from the present-day ones.

Slopes are often cut by through-floored valleys, locally filled by debris, which in turn are generally cut by V-shaped valleys accounting for a younger phase of downcutting.

Alluvial fans are common at the mouth of the valleys coming out at the plain and a *"bajada"* (Bull, 1977) characterizes the foot of the eastern slope of the basin. Three generations of alluvial fan deposits have been identified. The oldest alluvial fan unit, composed of rounded and subrounded gravel in a sandy matrix, is highly cemented. In the inner part of the basin – for example, at "Piano Perduto", "Piano Piccolo", "Piano di S. Lorenzo" and in the northern part of "Piano Grande" (locality "I Collacci") – the alluvial fans of this unit are dissected and terraced, while in the central and southern parts of "Piano Grande" they are generally buried under younger deposits. The largest alluvial fan deposits of the oldest generation are found at the foot of the main fault scarp (Fig. 7). The best example is at the mouth of Valle Santa, to the west of Mt. Vettoretto, where alluvial fan deposits have a lateral extent of about 700 m. The fluvial escarpment separating the upper depositional surface of these alluvial fan deposits from that of the next ones, is about 5 m high in the average. At places, such as at the mouth of Valle Santa, they are more than 10 m thick. Locally, the flat depositional surfaces may show a gradual transition to an erosion glacis uphill.

The gravel terraces located in the valley to the east of Colle Tamburo, which show a lateral transition to the mentioned Canatra valley moraines of late Middle Pleistocene age, have been included in the oldest alluvial fan unit. They are interpreted as outwash braidplain sediments. As noted above, truncated horizons of reddish clay and flint debris are found at the top and on the escarpments bordering most alluvial fans of this unit, supporting the hypothesis that an intense leaching under proctacted Mediterranean conditions during the last Interglacial is responsible for the cementation of alluvial fan deposits.

The second younger generation of alluvial fan deposits is well recognizable along the basin margins and shows lateral transition to alluvial plain sediments. The fan size is smaller than that of the oldest fans, except for the huge alluvial fan covering Piano Grande. On the basis of field observations it can be said that the buried portion of these deposits was deposited in the earlier phases of alluvial fan deposition. Progressive transitions to erosion glacis of limited extent and to rectified slopes have been observed. As in other parts of the region (Coltorti *et al.*, 1983; 1987), a transition to stratified slope-waste deposits, has locally been inferred. Very elongated paleochannels, cutting the surface of the Piano Grande fan and filled by finer sediments, are clearly visible on aerial photographs. Some fans on the eastern side of Piano Grande, as well as in Piano Piccolo, blocked the valleys and small swamps formed upstream (*e.g.* "I Pantani"). The valley of the Mergani river has terraced this unit. Soil with a well-developed blackish A1/C profile but with no B horizon are widespread on this unit, suggesting that alluvial fan deposits were in place before the Holocene *optimum*. They may be slope materials reworked during the last Glaciation and at the beginning of the Holocene.

On a large part of the area, and on the "Costa del Vettore" slope in particular, deforestation, which probably started in the Bronze Age and has been increased from the Middle Age up to the present (Vita-Finzi, 1969; Sereni, 1979; Gentili & Pambianchi, 1989), caused the rejuvenation of part of the fans. Where this occurred, no soil profile is present. Locally, the deposits of rejuvenated fans are found in gullies dissecting the 2nd generation alluvial fan unit described above.

Boreholes drilled by GE.MI.NA (1963) at Piano Grande, crossed a thickness of more than 90 m of loose sediments overlying the bedrock, formed of (from bottom to top): 1) clays with gravel lenses; 2) alternating clays and sands with gravel lenses; 3) polygenic gravels. On the basis of geomorphological considerations, the upper units would correspond – at least in part – to Upper and late Middle Pleistocene deposits, indicating that Middle Pleistocene deposits may be found at a greater depth.

3.5 Landforms, deposits and processes due to gravity

The dense network of faults, probably associated with seismic activity both in past and present times (Biella *et al.*, 1981; Menichetti, 1991; Blumetti *et al.*, 1993), and the high energy of the relief, are the main factors governing the activation of large-scale landslides.

In the northern part of the basin, a rock-slump (Varnes, 1978; Carrara *et al.*, 1985) 1500 m wide and 750 m long has been recognized at Colle Minio (1483 m), to the

Fig. 9 - *"Colli Alti e Bassi"* deep-seated landslide.
Frana profonda dei Colli Alti e Bassi.

south of Mt. Rotondo. Although its thickness has not been measured, it seems to be more than 50 m. The slump involved the *"Marne a Fucoidi"* and *"Scaglia Rosata"* Formations – both downslope dipping – and extends downslope to the Piano Perduto plain. The right side of the slump covers the northeastern slope of M. Lieto up to el. 1400 m, and its left side extends up to the S. Lorenzo plain. The main evidence for this slump is a large E-W trending trench at an altitude of about 1470 m. Colle Minio is the highest part of the landslide scree-tongue. The slump deposits were subsequently moved by minor slides, giving rise to secondary escarpments. An important dissection was caused by stream erosion with newly-formed large V- and through-shaped valleys. Alluvial fans of the 1st and 2nd generations at the mouth of the valleys suggest a Middle Pleistocene age of the process.

Minor rock-slumps are present to the north of Colle Cardisciana (1617 m) and east of Mt. Ventosola, where there are disconnected bedrock blocks of great size along the paved road. At Mt. Ventosola the rock-slump has affected late Middle Pleistocene stratified slope-waste deposits and pyroclastic sediments, indicating an age younger than the late Middle Pleistocene.

A complex landslide, from 2050 to 1600 m a.s.l., can be seen to the west of the "Cordone del Vettore" slope. The upper part of the landslide is a rock-slump dismembering the *"Corniola"* Formation at the junction between the Cordone and Costa del Vettore low scarp (Fig. 7). At the foot of the scarp a small depression due to recent secondary movements, is locally present filled with fresh debris. Undulations and small trenches in the bedrock and debris fan deposits have been observed downslope. The lower part of the landslide body is covered by late Middle Pleistocene and younger deposits suggesting that, apart from limited reactivation episodes, movements are older than that time.

At the lower left side of this landslide a debris-slump is present. The lowermost portion is very flat and cut by a trench elongated parallel to the slope, which suggests the *"tapis roulant"* effect proposed by Demangeot (1973) for earthquake-controlled landslides.

An interesting indication of deep-seated gravitational movements is given at "Colli Alti e Bassi", an area of some 4 km^2 at the foot of the main fault scarp (Fig. 9), where, in the hanging-wall, the *"Corniola"* overlies the *"Calcare Massiccio"* Formation (Calamita *et al.*, 1992). In the footwall, below "Cordone del Vettore" and the main fault scarp, the *"Bugarone"* Formation covers the *"Calcare Massiccio"* Formation and underlies the *"Calcari Diasprini"* and *"Maiolica"* Formations. Calamita *et al.* (1992) think that this contact is due to the presence of a Jurassic fault delimiting a "structural low" from a "structural high" sunk during the *"Calcari Diasprini"* deposition. However, acc. to Calamita *et al.* (*op.cit.*) the *"Calcari Diasprini"* and *"Maiolica"* Formations are affected by minor folds and are locally deeply deformed while the lower ones are gently dipping. The name itself of *"Colli Alti e Bassi"*, meaning "high and low hills", highlights the irregular morphology of the area. As a matter of fact a series of hills, oriented in the Apennine direction and progressively lowering westward, have crests and saddles delimited by "faults" which create a "horst and graben" morphology. Minor E-W sliding planes have been observed to the south of Colle Albieri, southward displacing the continuity of the ridge; other NNE-SSW oriented sliding planes lower the western part of the area at the border with Piano Perduto. Very well bedded limestones alternated with brecciated limestones and debris deposits have been observed. In a quarry, on the eastern slope of the town of Castelluccio di Norcia, a cut shows strips of a soil in the debris deposits, which are mixed with highly fractured limestones. This suggests the occurrence of a very huge landslide involving the whole area and having a thickness of more than 200 meters, the sliding surface of which being probably at the base of the *"Calcari Diasprini"* Formation. The landslide front might be made up by the eastern part of the Castelluccio slope, although it cannot be excluded that the town itself of Castelluccio is located on the westernmost part of the landslide body.

[The nearby Norcia area has similar morphology (Dramis *et al.*, in press)]. The landslide flanks, as well as part of the front, have been dissected by fluvial erosion. The origin of this landslide is to be seen in the structural setting, the high energy of the relief brought about by faults activity and the high seismicity of the area (Biella *et al.*, 1981; Calamita *et al.*, 1982; Calamita & Pizzi, 1992; Blumetti *et al.*, 1993).

3.6 Karstic landforms

The "Castelluccio di Norcia" area has always been considered as a *polje* or a tecto-karstic depression (Rovereto, 1923; Scarsella, 1947; Lippi-Boncampi, 1950; Giovagnotti, 1975), although Villa (1939) hypothesizes only a tectonic origin.

It is difficult to precisely evaluate the amount of karstic erosion, because of fault activity and the lack of information on the thickness of deposits preserved in depth. However, we can say that the volume of materials lost after the erosion of slopes and valleys in the basin must have been washed away mostly by solution. The Mergani river is drained by a major sinkhole located at the base of the eastern slope of Mt. Castello and represents the major feature of N-S trending dolines (Fig. 9). Aligned NNE-SSE oriented dolines are located also on the opposite side of Piano Grande and in Piano Perduto where they are aligned in an E-W direction. Most of water comes out in the Patino valley (Norcia Basin) feeding the Sordo River. Dolines are found on *"Calcare Massiccio"* on the basin eastern slopes at Mt. Palazzo Borghese and Mt. Argentella. Everywhere limestone of the *"Calcare Massiccio"* formation crops out, minor karstic forms such as *"karren"*, solution holes, and *"kamenitze"* are common.

3.7 Anthropic landforms

Although human activities have been common in the area since prehistory, as in most Mediterranean regions (Vita Finzi, 1969; Delano-Smith, 1979; Coltorti, 1991), their impact in early times is difficult to evaluate. Most slopes have a stepped morphology due to agricultural activities, although in more recent times agriculture has been limited to flat areas.

The area, such as most areas in the Apennines (Sereni, 1979; Pinna, 1985), was already severely deforested by the Middle Age, as reported also for the nearby Nera Basin by Buccolini *et al.* (1989). The rejuvenation of some Late Pleistocene alluvial fans and of some debris flows, mostly at the foot of the main fault scarp, is attributed to such deforestation practices.

4. GEOMORPHOLOGICAL EVOLUTION OF THE BASIN

In Pliocene times, the area suffered a widespread deep erosion responsible for modelling the very flat surface that is nowadays preserved mostly as "summits of equal heights" feature and in a very few instances on part of the watersheds. An open drainage system, with paleovalleys close to the then base level, was active in Upper Pliocene and Lower Pleistocene creating a "young" landscape, which connected the area with the sorrounding regions. The paleovalley cutting the eastern hills at Forca Viola probably fed the Mt. Ascensione fan-delta in the Periadritic Basin. No data on the age of the Castelluccio paleovalleys are avalaible; however, similar paleovalleys at Colfiorito, further to the north in the chain, were active more than 1 MY B.P. and lasted until the beginning of Middle Pleistocene. Probably, this datum may also be a valid hypothesis for the Castelluccio paleovalleys.

The activation of fault systems in this part of the chain was the main factor of the dismembering of drainage systems and of the origin of a closed tectonic depression. An impressive fault scarp still delimits the basin, although karst erosion contributed to successive landscape modelling processes in the basin.

To the east, a stepped morphology characterizes the Mts. Sibillini area where the "erosional surface" was progressively uplifted to altitudes of more than 2000 m and of 1700÷1800 m in the remaining part of the study area. To the west, in the Norcia area, remnants of the "erosional surface" are located at elevations 1000÷1100 m. The main fault scarp has locally more than 1000 m of vertical displacement. However, in the Forca di Presta area, on the continuation of the main fault line, the overthrust plane is displaced by 300 m only, while displacement, as evaluated on the basis of geomorphological evidence, would be in the order of 800 m. Most displacement seems therefore to have occurred in the uppermost overthrust plane along a listric fault. Because of the very limited thickness of the sequence above the overthrust, the bearing of large-scale gravitational tectonics would have been great in governing movements. On the other hand, distribution and characteristics of the "Castelluccio di Norcia" fault system point to greater extensional movements toward the southern part of the basin, where displacements are the effect of a series of minor synthetic and antithetic faults (for instance, the ones in the Mt. Guaidone area), probably related to the reverse reactivation of the overthrust plane as sliding surface.

Extension was mainly directed westward and can be associated to the extensional field caused by the opening of the Tyrrhenian sea; this stress field was probably active in the study area after 0.7 MY B.P., contemporary to the first diffuse episodes of volcanic activity along the Tyrrhenian side of Italy.

Fault systems would have been active before the deposition of the late Middle Pleistocene deposits, which cover fault scarps. A few scarplets, displacing the continuity of rectified slopes as well as debris deposits, seem to have been active in Holocene times.

Two phases of extensive debris and alluvial fans deposition are recorded at Castelluccio di Norcia: the oldest one corresponds to the late Middle Pleistocene cold phase and to the emplacement of moraine deposits at the mouth of the Canatra valley. These deposits are one of the examples of moraine deposits preserved at very low altitudes in the Apennines. Alluvial fans have been dissected and terraced during the last Interglacials, although base level was conditioned by underground drainage. Only minor downcutting occurred after the deposition of the last debris and alluvial fan deposits in the Upper Pleistocene.

Surprisingly no moraines were deposited in the plain in Upper Pleistocene times, although average elevation was increasing owing to the continuous uplifting. Only limited amounts of Upper Pleistocene debris deposits are preserved on the slopes of the basin. On the contrary, these form thick deposits outcropping at lower altitudes on the whole area or at similar heights on the eastern side of the chain. This may be explained by taking into account that the eastern side of the Apennines toward the Adriatic sea was much more snowy than the western and southern regions which were characterised by progressively milder climatic conditions. In any case, the late Middle Pleistocene glaciation was more severe than the following one and it may be assumed that, in the colder phase of last Glaciation, the western slopes at the highest altitudes had a dry climate.

After the creation of fault scarps, large landslides occurred, probably controlled by seismic activity. The "Colli Alti e Bassi" area, characterized by a "horst and graben" morphology delimited by minor fault-like scarplets, has been interpreted as being the result of a huge gravitational movement. The landslide scree-tongue split the basin into two parts and blocked drainage of the northermost portion of it until regressive erosion opened it once again.

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