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THE LATE LOWER PLIOCENE PLANATION SURFACE AND MOUNTAIN BUILDING OF THE APENNINES (ITALY)

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ABSTRACT

Investigations on the nature, age and lateral relationships of the remnants of Italian planation surfaces indicate that: 1) a single planation surface (PS) is recognisable across the Apennines along the inner part of the Italian Peninsula; 2) it was originally very flat; 3) it is better preserved on harder rocks and is not preserved on the higher relief because of major uplift and consequent dissection or glacial erosion; 4) it cuts terrain ranging in age from Palaeozoic to early Lower Pliocene; 5) it planated the tectonic structures developed in earlier times; 6) it is at places buried under continental and marine deposits younger than late Lower Pliocene; 7) the PS was eroded in a much shorter time than is usually assumed; 8) the PS was modeled during the climatic amelioration that generated the Late Lower Pliocene transgression and largely corresponds to a plain of marine erosion; 9) after the end of Lower Pliocene it was uplifted and deformed by very limited re-activation of thrusts; 10) since the Lower Pleistocene it was displaced by high angle normal faults.

The mountain building in the Italian Peninsula started during the Middle Pliocene and is still going on. Fluvial and marine terraces reveal the highest rates of uplift since the Lower-Middle Pleistocene. The oldest escarpments which displace the PS correspond to Miocene-Lower Pliocene thrust fronts and indicate their re-activation during the Middle-Upper Pliocene. Younger fault escarpments are connected with high angle normal faults that were active mostly after the Lower Pleistocene. The PS provide a key tool to determine neotectonic movements, separating pre-planation from post-planation tectonic movement. Contrary to common opinion the nappe-forming tectonics did not create the Apennine mountains.

RIASSUNTO

Lo studio circa l'origine, l'età e le relazioni laterali dei lembi di superfici di spianamento presenti nell'Appennino fornisce le seguenti indicazioni: 1) esiste una sola superficie di spianamento (PS) riconoscibile attraverso l'Appennino e lungo l'intera penisola italiana; 2) era originariamente molto piatta; 3) oggi è meglio conservata in corrispondenza delle litologie più resistenti all'erosione e può essere assente sui rilievi più elevati a causa del maggiore sollevamento e la conseguente maggiore dissezione e erosione glaciale; 4) taglia rocce di età compresa tra il Paleozoico e la prima parte del Pliocene inferiore; 5) taglia tutte le strutture tettoniche formatesi precedentemente; 6) localmente è sepolta da sedimenti continentali e marini più recenti del Pliocene inferiore finale; 7) la PS si è formata in un intervallo di tempo molto più breve di quanto normalmente assunto per il suo modellamento; 8) la PS si è modellata durante il miglioramento climatico responsabile della trasgressione del tardo Pliocene inferiore ed in larga parte corrisponde ad una piana di erosione marina; 9) dopo la fine del Pliocene inferiore è stata sollevata e deformata da modeste riattivazioni di thrust pre-esistenti; 10) dal Pleistocene inferiore è stata dislocata da faglie normali ad alto angolo.

Il *mountain building* della penisola italiana inizia con il Pliocene medio ed attualmente in corso. Terrazzi marini e fluviali indicano i più alti tassi di sollevamento sin dal Pleistocene inferiore/medio. Le scarpate più antiche che deformano la PS corrispondono a sovrascorrimenti del Miocene e del Pliocene inferiore e indicano la loro riattivazione durante il Pliocene medio-superiore. Le scarpate più recenti corrispondono a faglie normali a basso angolo attive dal Pleistocene inferiore. La PS costituisce uno strumento per determinare le deformazioni neotettoniche, separando i movimenti tettonici pre- e post-PS. Contrariamente all'opinione comune la tettonica, le pieghe ed i sovrascorrimenti non sono responsabili della creazione del rilievo appenninico.

KEY WORDS: Planation Surface, Mountain Building, Plio-Quaternary, Neotectonics, Apennines, Italy.

PAROLE CHIAVE: Superficie di spianamento; Creazione del rilievo, Plio-Quaternario, Neotettonica; Appennini.

1. INTRODUCTION

The Italian peninsula is made of an arcuate shaped mountain chain (the Apennines, Fig1), that reaches 2,912 m a.s.l. in the Gran Sasso Mt., with a mean altitude of about 1,500 m a.s.l. The Apennines forms the watershed between the Tyrrhenian and the Adriatic drainage, even though the divide often does not match the maximum altitudes (MAZZANTI & TREVISAN, 1978).

The Apennines constitute a Neogene thrust-fold belt (Fig.2) developed in a non-metamorphic regime, although low grade metamorphic and granite rocks are, in places, involved in the thrust sheets. The thrust fronts have complex imbricate geometry with a direction of transport mainly to the NE in the northern Apennine turning to the NS and

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NNE in the Calabrian area and EW in Sicily. The units involved in the tectogenesis belong to sedimentary sequences, many kilometres thick, ranging from Palaeozoic to Lower Pleistocene in age. The onset of the "compressional" events is commonly explained as the consequence of the progressive migration to the east of the thrust fronts, today located in the Adriatic and Ionic sea (ELTER *et al.*, 1975; BALLY *et al.*, 1986; BARBERI *et al.*, 1994; CARMIGNANI *et al.*, 1994; BARCHI *et al.*, 1998). This process is supposed to start during the Burdigalian with the opening of the Tyrrhenian Sea. The foreland basins, created during the eastward migration of the compression and containing different sedimentary sequences, were split by several overthrusts. In this classic model, the migration of the compressional front to the east is soon followed by the activation of extensional faults to the west. In the north-western area, low angle E-dipping normal faults led to the creation of the "Serie Ridotta" with, in places, "tectonic omission" of overthrusted structural units (BOSSIO *et al.*, 1998; DECANDIA *et al.*, 1998). The timing of the emplacement of the different thrust units is usually determined taking into account the age of the youngest formation involved. Their last activity is dated to the Middle-Upper Pliocene in the eastern areas (Gran Sasso and Maiella mountain fronts: CALAMITA *et al.*, 1991; BIGI *et al.*, 1991; 1996) and further to the south to the Lower-Middle Pleistocene (PATACCA *et al.*, 1991). In the north-western side, most authors (MARTINI & SAGRI, 1993; DECANDIA *et al.*, 1998 and reference therein) suggest that the compressional movements ended during the Upper Miocene, and were followed by the activation of extensional basins. However, BOCCALETTI *et al.* (1995; 1999 and reference therein) and COLTORTI & PIERUCCINI (1997a & b) described "compressional" basins lasting up to the Upper Pliocene-Lower Pleistocene. Recently, CALAMITA *et al.* (1999) ascribed these "compressive" features to the activity of low angle normal faults ('K Horizon' of DECANDIA *et al.*, 1998; 'Chiana fault' of BARCHI *et al.*, 1998; 'Alto Tiberina fault' of BONCIO *et al.*, 1998).

The mountain building of the Apennines was previously considered to be a direct consequence of compressional events. However, different structural units, involving rocks of different ages, are present at almost the same elevation revealing that: 1) the emplacement of the thrust sheets occurred earlier than mountain building process, 2) important erosive events preceded the creation of the relief. Therefore, the creation of the tectonic structure (orogenesis or tectogenesis), is little related to mountain building, as recently pointed out in other mountain chains by OLLIER (1999). This invalidates the model of the progressive migration of the compressional-extensional fronts to which is also connected the creation of the relief, at least after the Middle Pliocene. In fact, most of the Neogene sedimentary basins evolved under marine conditions and there is no evidence of a mountain chain existing earlier in what is now western Italy.

Remnants of planation surfaces have been described in the past across the whole Italian Peninsula, both in the northern and in the southern Apennines although the nature and the age of the planation surface, or surfaces, was assessed differently in different papers.

In this paper we suggest that the planation surface (PS) remnants in the central part of the Apennine chain were formed during a single event (the Late Lower Pliocene transgression) and at very fast rate. The PS is found on most of the interior of the peninsula, resulting in a mountain landscape with large flat parts on top (plateaus). To assess the age and extent of the erosive processes, the sedimentary records preserved in the bordering basins have been studied or reviewed both in the mountain and in coastal areas. The PS levelled all older topographic contrasts and therefore constitutes a starting point for the subsequent evolution of the landscape of the Apennines. It is a key tool to differentiate between pre-planation and post-planation tectonic activity.

2. THE PLANATION SURFACE PROBLEM

The term 'planation surface' is a descriptive term for a geographically plain surface resulting from erosion which includes many terms like peneplain, panplane, pediment, pediplain, wave-cut platform, etchplains etc. (BROWN, 1969). The 'planation surface' term is recommended because it has no genetic implication (SMALL, 1978). Earlier in the century there was great debate about the models of landscape evolution and planation surfaces were named accordingly to the model adopted by the different authors. At first the major debate was about the subaerial or submarine origin of planation surfaces. Although many researcher emphasised the importance of marine erosion (JOHNSON, 1930) this model was progressively abandoned after the formulation of the Peneplain concept by DAVIS (1899). The idea of a polyciclic modelling of the landscape, in which the erosional processes followed the creation of the relief due to tectonic movements, was widely applied to different mountain chains. Later discussion focussed on the processes and mechanisms of subaerial erosion (PENCK, 1953; BUDEL, 1957; KING, 1962) but it was commonly accepted that planation surfaces were modelled close to the base level and that it takes a long time span to develop (10^6-10^7 years). Despite continuing debate on mechanisms, remnants of planation surfaces of various ages have been described on different continents and in different geodynamic contexts (PECSI, 1970; ADAMS, 1975; KING, 1976; OLLIER, 1991; SUMMERFIELD, 1995; OLLIER & PAIN, 1997; WIDDOWSON, 1997).

3. THE PLANATION SURFACE IN THE APENNINES

3.1 Geomorphological evidence

In the highest parts of the landscape, from Liguria to Sicily and on both sides of the Peninsula, more or less extensive remnants of planation surfaces have been recognised. These remnants are located at different elevations but frequently the maximum height is recorded in correspondence with the mountain axis. In places, where the landscape is more dissected and no flat remnants are preserved, summits of accordant heights suggest former flat surfaces. Horizontal flat surfaces are also preserved for many kilometres on the watersheds and at very high elevations although their mapping cannot be recorded on a small scale map. This occurs in: 1) Western Emilian Apennine, (BERNINI *et al.*, 1977; 1980); 2) Tuscany Apennines, (BARTOLINI, 1980; SESTINI, 1981); 3) in the Middle Tuscany Ridge (BOSSIO *et al.*, 1998); 4) in the Umbria- Marche Apennines (Fig.3) (COLTORTI, 1981; MORETTI, 1982; DRAMIS, 1992); 5) in western Umbro-Marchean Apennines (DESPLANQUES, 1969; COLTORTI, 1991; COLTORTI & PIERUCCINI, 1997a); 6) in the Abruzzi Apennines where remarkable continuity has been observed at over 2500 m a.s.l. (DEMANGEOT, 1965; CINQUE *et al.*, 1993; GIULIANI & SPOSATO, 1993; BOSI *et al.*, 1996; BASILI & MESSINA, 1997; CHIARINI *et al.*, 1997); 7) in the Molise Apennines (COLTORTI & CREMASCHI, 1982); 8) in the Campano-Lucano Apennines (AMATO *et al.*, 1992; CINQUE, 1992;

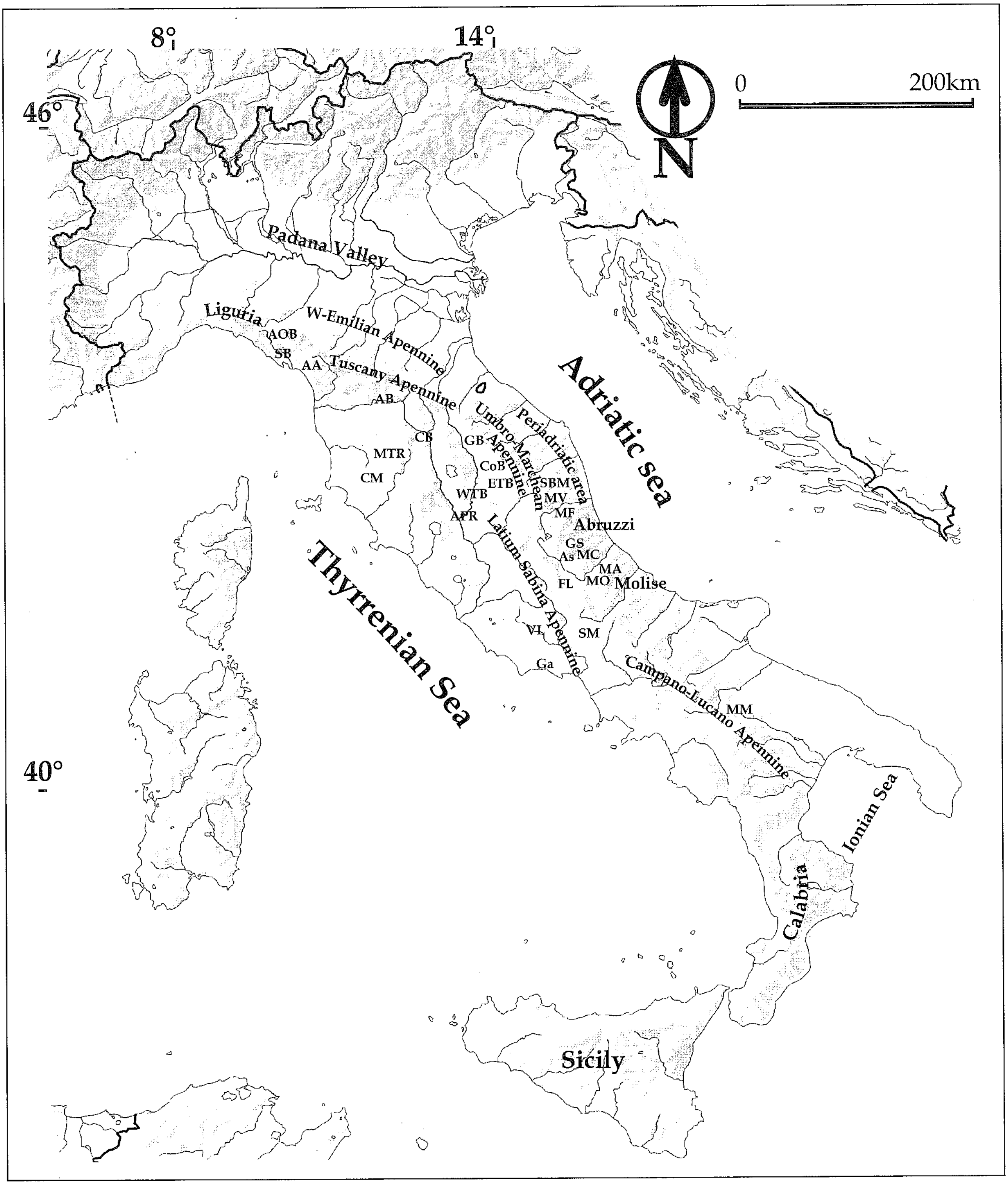


Fig. 1 - Italian Peninsula and location of the cited localities:
AA – Apuane Alps; AB – Arno Basin; AOB – Aulla-Olivola Basin; APR – Amelia-Peglia Ridge; As – Assergi; CB – Chiani Basin; CM – Colline Metallifere; CoB – Colfiorito Basin; ETB – East Tiber Basin; FL – Fucino lake; Ga – Gaeta; GB – Gubbio Basin; GS – Gran Sasso; MA – Maiella Mt; MC – Camicia Mt; MF – Montagna dei Fiori; MM – Matese Massif; MO – Morrone Mt; MTR – Middle Tuscany Ridge; MV – Vettore Mt; SB – Sarzana Basin; SBM – Sibillini Mts; SM – Simbruini Mts; VL – Valle Latina; VM – Val Marecchia; WTB – West Tiber Basin.

CINQUE *et al.*, 1993); 9) in the Calabrian Apennine (GUEREMY, 1972; ITALIAN NATIONAL GROUP FOR PHYSICAL GEOGRAPHY AND GEOMORPHOLOGY, 1989). Some of these authors attributed the planated remnants located at different elevations to different erosional phases but most of them agree on the proximity of the palaeolandscape to the sea-level.

The planated remnants cut rocks belonging to formations of different structural domains but are better preserved on more resistant lithologies (Figg. 4,5,6,7,8). They are well preserved on sandstones (e.g. "Macigno Fm" in the Tusco-Emilian Apennines, "Cervarola Fm" in the Tuscany Apennine and Western Umbro-Marchean Apennines, "Marnoso-Arenacea Fm" and "Laga-Cellino Fms" from Tuscany to Marche and Abruzzi Apennines), fillads, schists and metarenites (Tuscany Apennines), limestones (i.e. Tuscany and Umbro-Marchean-Abruzzi Apennines, etc.), granites (Calabrian Apennine) and mixed terrains

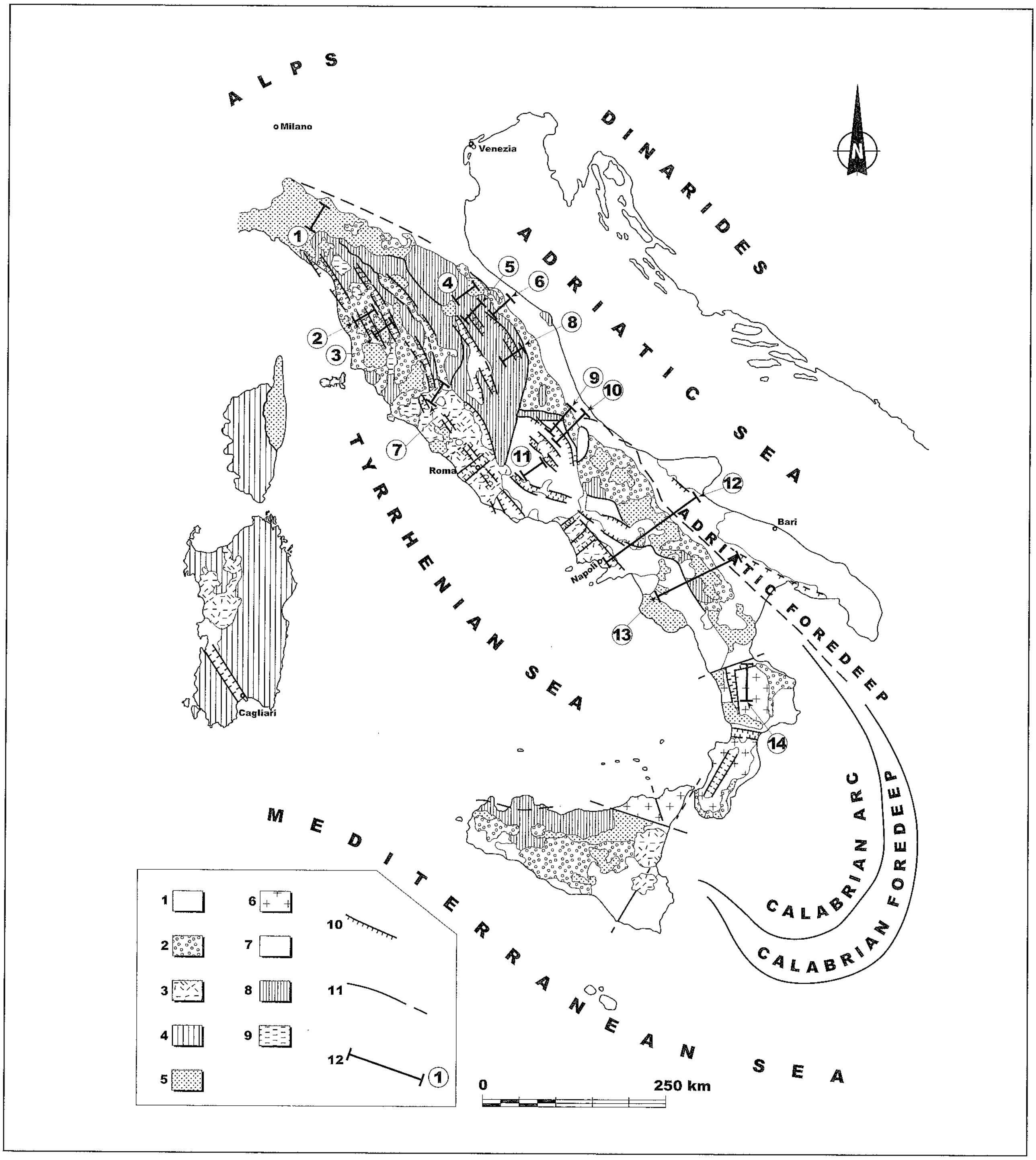


Fig. 2 – Structural scheme of the Italian Peninsula and cross-sections locations:
1-Quaternary continental and marine deposits; 2-Pliocene continental and marine deposits; 3-Quaternary volcanic deposits; 4-Sardo-Corsican Massif; 5-Ligurian, Molisan and Sicilian Units; 6-Calabrian Units; 7-Latium-Abruzzi, Apulian, Iblean and Campanian-Lucanian Units; 8-Tuscan, Umbro-Marchean, Molisan, Lagonegrese, Imerese and Sicano Units; 9-Tuscan Autochton and Parautochton; 10-Normal faults; 11-Main thrust fronts; 12- Cross sections location (Figg.4-8).

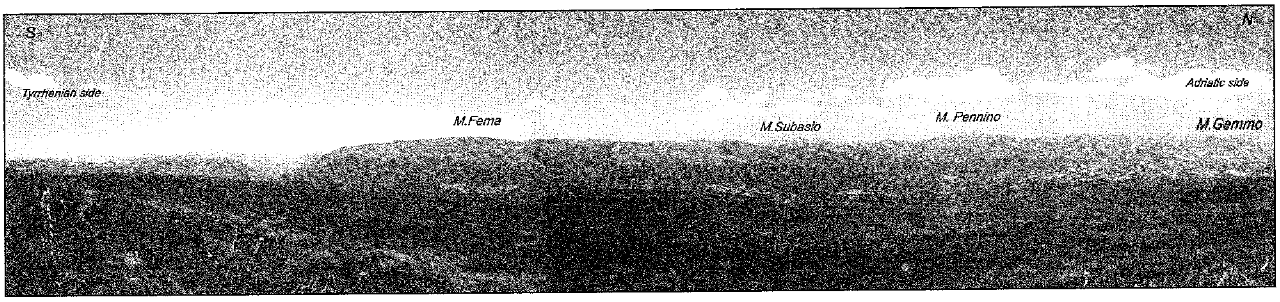
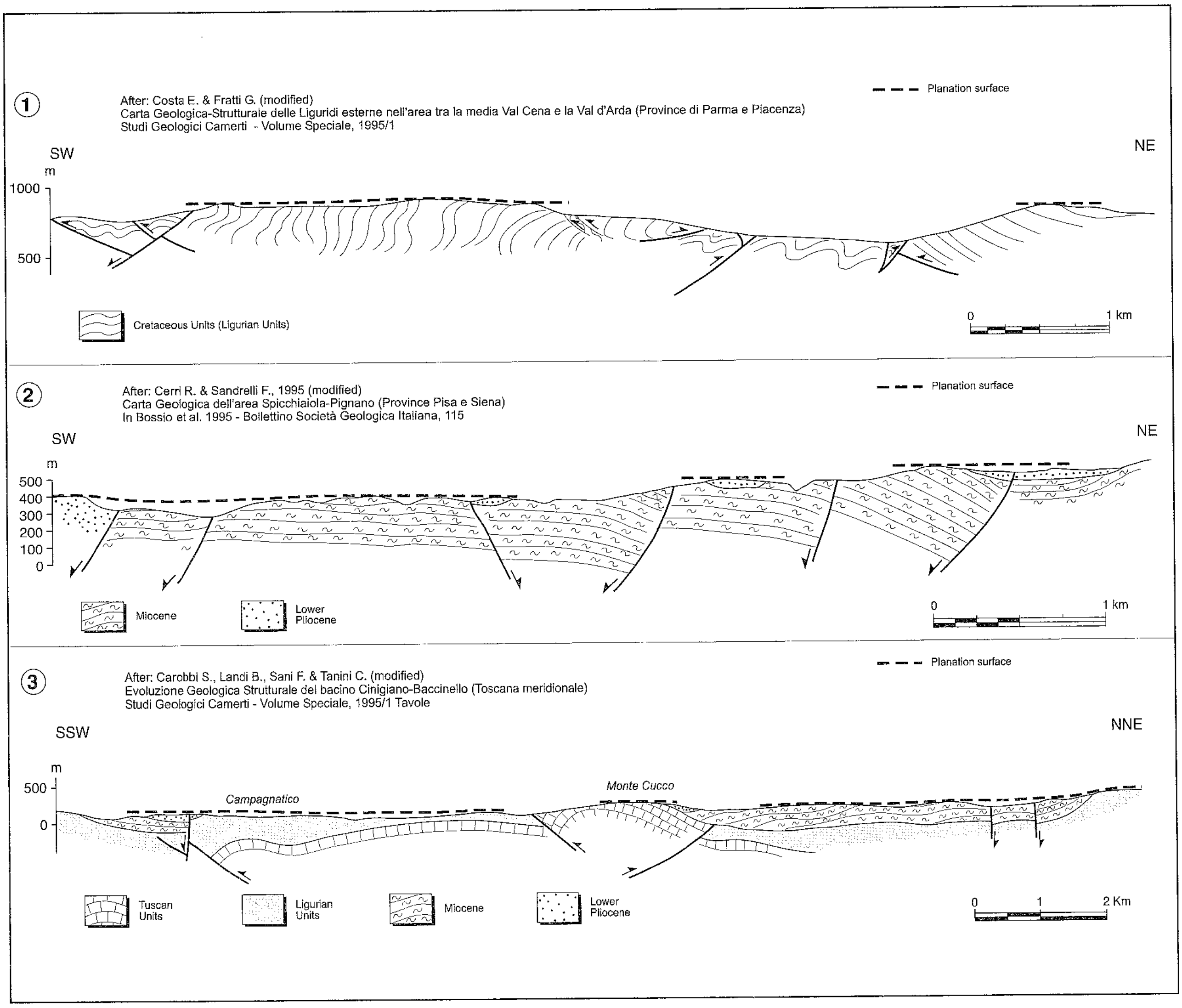


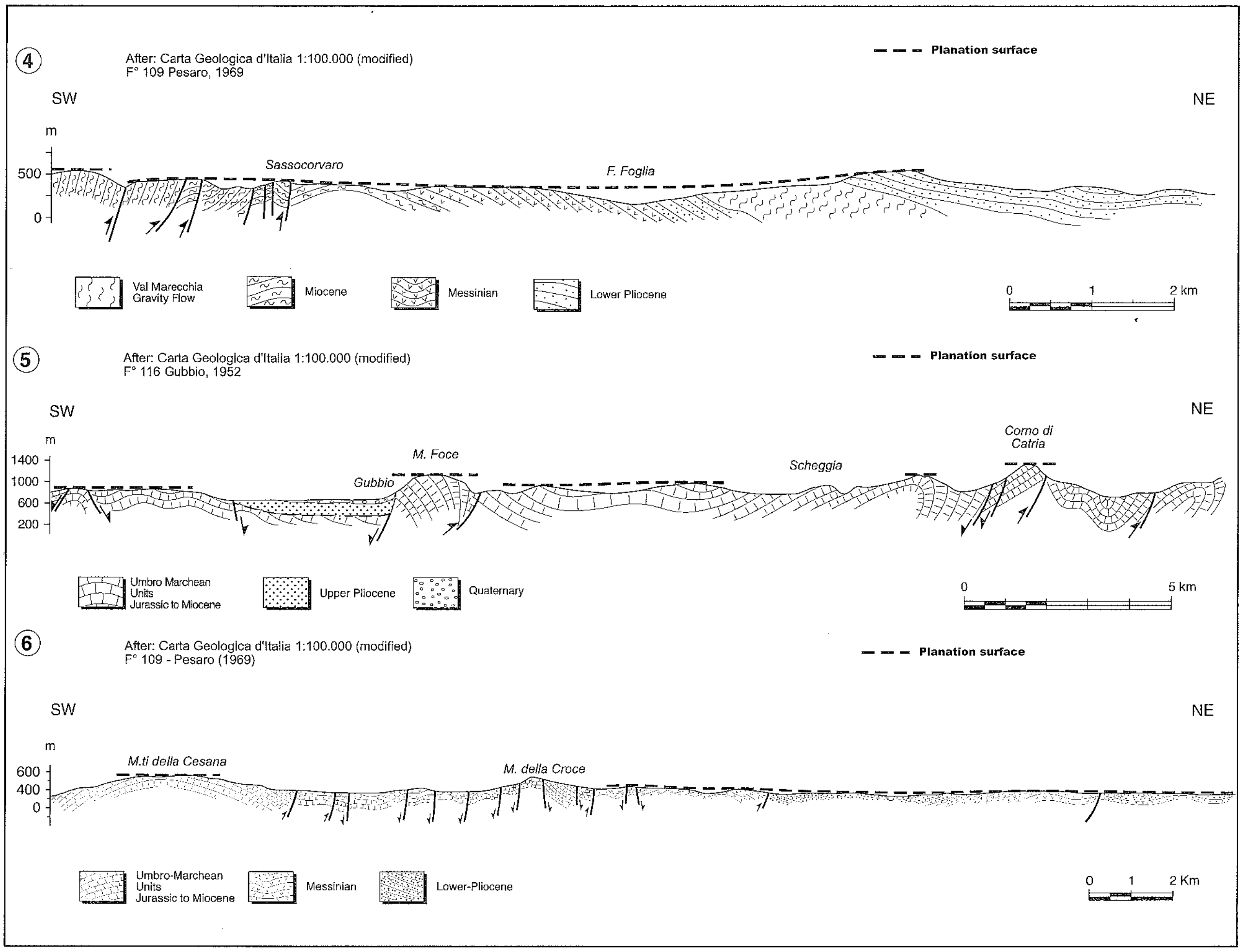
Fig. 3 –The planation surface across the Umbro-Marchean Ridge, from the Adriatic side (right) to the Tyrrhenian side (left).

(Ligurides complex).

Progressive changes in elevation from around 2,000 to 700 m a.s.l. and even less, were observed going away from the Apennine axis (Western Emilian Apennines, from the watershed to the Padana Valley margin) as well as along the length of the Apennine chain (Eastern Umbro-Marchean Apennines to the north of Sibillini Mts). Some authors (e.g. DRAMIS, 1992) interpret these features as the result of pediplanation. It is difficult to establish if the remants represent an original sloping pediment or deformations of an initially flat surface. We prefer the second hypothesis because post-Lower Pliocene tectonic deformations are reported in many parts of the chain (BIGI *et al.*, 1991; 1996; COLTORTI & PIERUCCINI, 1997a and b; BOCCALETTI *et al.*, 1999 and ref.) and expecially documented inside the sedimentary basins, where a major unconformity is present in between severely deformed Lower Pliocene terrain and less deformed Late Lower and Middle-Upper Pliocene terrain. During the modelling of the PS, as evidenced in the following chapter, warm and wet climatic



Figg. 4, 5, 6, 7, 8 - Schematic geological sections across the Italian Peninsula with evidence of planation on the different structural units.



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conditions prevailed, making difficult the onset of long-lasting pediplanation processes. It must be outlined that frequently a progressive transition exists from the PS sculptured on the mountain ridges and the unconformity buried in the basins as i.e. in the whole Periadriatic area, in the Tiber Basin, in large part of Tuscany as well as in the Calabrian Apennine (ITALIAN NATIONAL GROUP FOR PHYSICAL GEOGRAPHY AND GEOMORPHOLOGY, 1989; BOCCALETTI *et al.*, 1999; CALAMITA *et al.*, 1999a). As regards to pedimentation hyphotesis, usually very low rates of scarp retreats, between 0,1 and 6 mm/yr-1, have been reported for pediments and, furthermore, this process seems to be very limited to arid and semiarid climates (OBERLANDER, 1997).

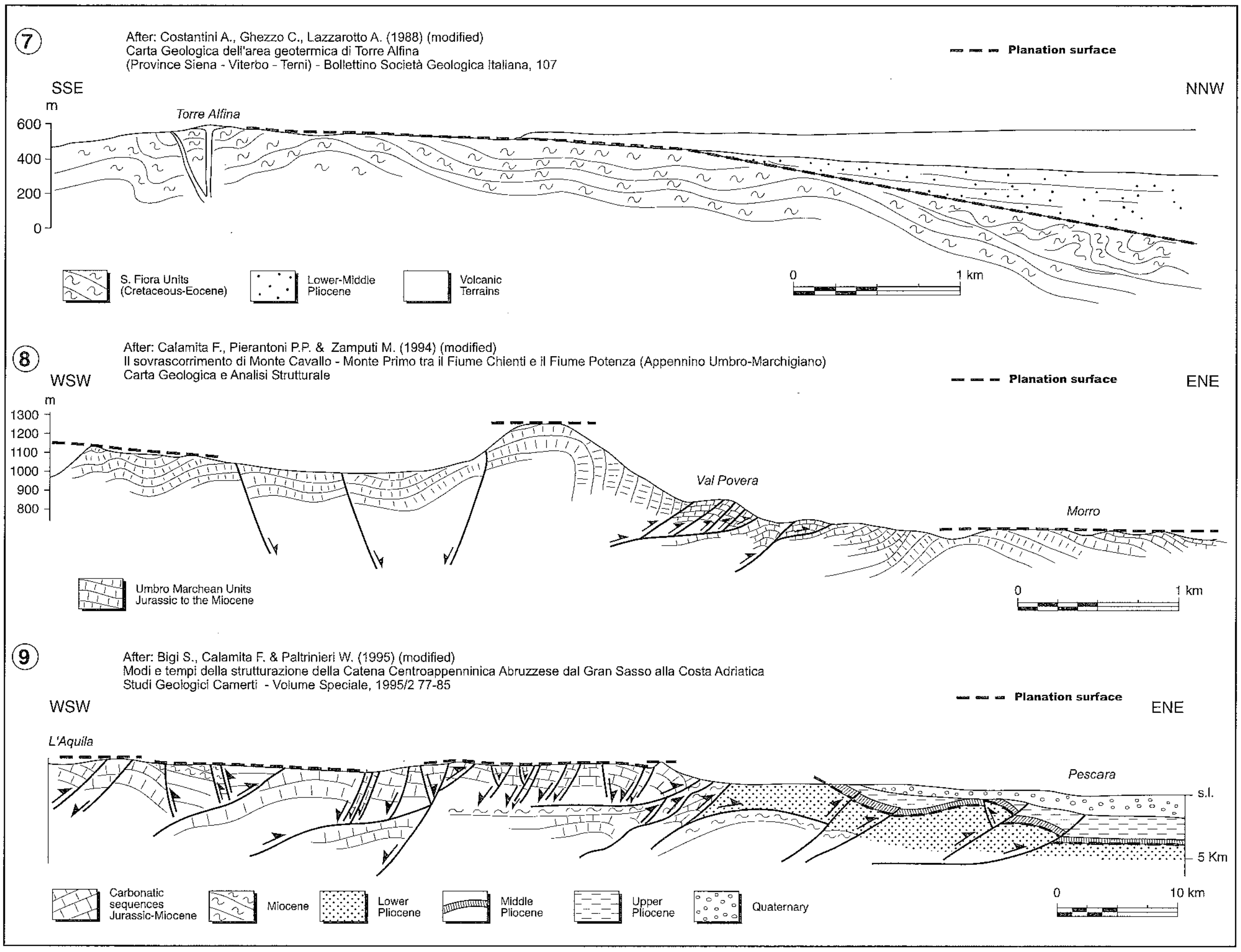
The changes in elevation of the PS remnants can also occur as a series of steps, which frequently prevents the identification of a single planation surface over long distance. In the large number of areas investigated by ourselves, we always found active faults at the base of the escarpments, and many active faults have been mentioned in the literature. These mainly trend NW-SE and dip toward the Tyrrhenian Sea but displacements are also associated with normal faults oriented in different directions (N-S, E-W or NE-SW) (CALAMITA *et al.*, 1999b). The fault planes are sometime masked by colluvial and/or alluvial sediments. Moreover, old fault escarpments are degraded to a gentle gradient; but we observed steep gradients on all the escarpments, suggesting for them an almost common age. In the Apennine there are also gentle escarpments, frequently preserved as saddle on the valley sides or delimiting large hanging palaeovalleys cut inside the PS. They are also locally filled with Lower Pleistocene deposits suggesting a younger age for the fault escarpments, which have a steeper gradient.

A synthesis of all the evidence suggests a major single planation surface (PS) along the central part of the Italian Peninsula (COLTORTI & PIERUCCINI, 1999).

The most suitable method to assess the time interval for the modelling of the PS is the observation of the age of the rocks truncated by the unconformity or overlying it. Normally, on the higher parts of the Apennines, the sediments that once covered the PS have been mostly eroded.

However, all along the Apennine chain and especially in the Abruzzi area, there are some well-studied areas where dated coarse-grained deposits are associated with the PS. Since these deposits are located on the higher part of the Apennines, we believe their significance can be extrapolated to the rest of the chain.

The conglomeratic Formation of Monte Coppe (GHISETTI & VEZZANI, 1990; CASNEDI & MOSNA, 1992) crops out on the ridges of the Gran Sasso massif. They are deltaic conglomerates, Early Pliocene in age (*Gt margaritae* and *Sphaeroidinellopsis spp.* zone), made up of rocks coming from the erosion of structural units today located in

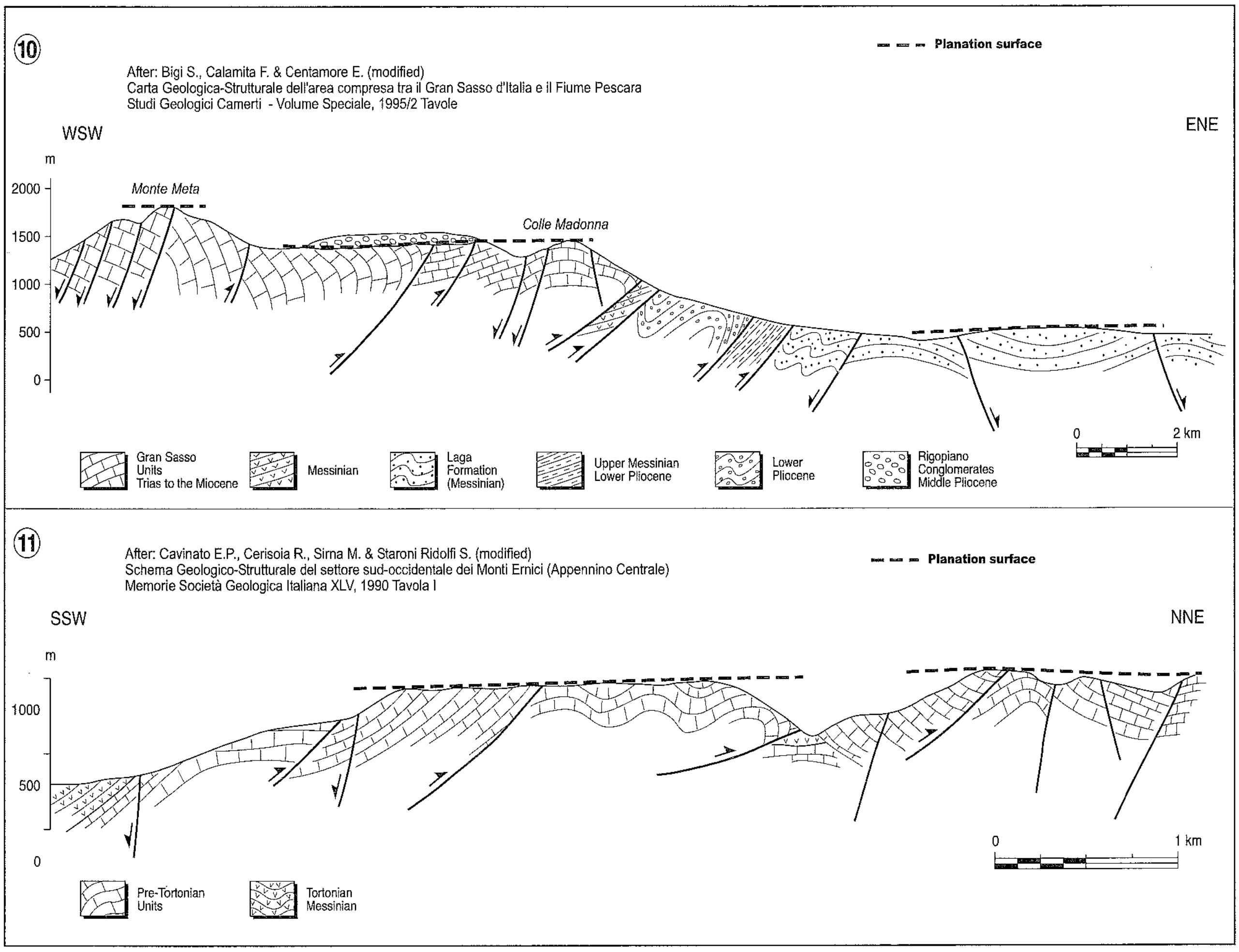


Figg. 4, 5, 6, 7, 8 - Schematic geological sections across the Italian Peninsula with evidence of planation on the different structural units.

the north-western side of the peninsula (i.e. Tuscany and Ligurian Nappe, as well as granites and metamorphic rocks). Similar conglomerates have been described in the surroundings of the Fucino Lake, on the Simbruini Mountains, in the Valle Latina and, southward, up to Gaeta (Le Vicenne Fm of BOSI & MESSINA, 1990; 'poligenic conglomerates' of DAMIANI, 1991). After their deposition, these sediments have been thrusted over previously faulted and folded units (DAMIANI, 1991; GHISETTI & VEZZANI, 1998). In places, it has been possible to recognise, at the base of these sediment an unconformity, corresponding to the Zanclean Trasgression. Therefore, the erosion of a large part of the pre-Pliocene sedimentary cover occurred during the Messinian and the Earliest Pliocene as suggested by ABBATE *et al.* (1994) with fission track datings for the Northern Apennines. After the Zanclean Trasgression, tectonic movements deformed both the unconformity and the overlying sediments (CALAMITA *et al.*, 1991; 1999a). Traces of this transgression have been recognised all over Italy (SIGNORINI, 1948; CRESCENTI, 1971; BIGI *et al.*, 1996) and was followed by the deposition of Lower Pliocene continental, littoral, and coastal sediments in many parts of the Peninsula (RICCI-LUCCHI, 1987; ORI *et al*, 1986; CINQUE *et al.*, 1993; BOSSIO *et al.*, 1998 and ref.). Most authors agree that the mountain chain did not exist yet or was quite embryonic. In fact Lower Pliocene marine sediments are today preserved in peninsular Italy up to 100 km from the present day coastlines, revealing that the emerged lands were, at most, 150 km wide. These marine sediments are also preserved up to 2,000 m. In fact, on the Morrone Ridge, at over 2.000 m a.s.l., the PS cut also thin conglomeratic deltaic sediments of local provenance (Fig.7) (Rigopiano Formation: *Gt. puncticulata-Gt. margaritae* zone) (GHISETTI & VEZZANI, 1998).

Middle-Upper Pliocene coastal conglomerates lie unconformably on the limestone rocks of Amelia and Peglia Mountains, belonging to the Umbro-Marchean and Latium-Sabina Apennines, on the Alburni Mountains (AMATO *et al.*, 1992) and on the crystalline rocks of the Calabrian Apennine (TORTORICI, 1980). It is no coincidence that in the Apuane Alps and in the Colline Metallifere the last exposure of the metamorphic complex at the surface has been dated, with Apatite Fission Tracks and 40Ar/39Ar methods, in the interval between 5.0- 2.0 and 3.68- 2.81 Ma respectively (CARMIGNANI & KLIGFIELD, 1990; DALLMEYER & LIOTTA, 1998).

In the intramontane tectonic basins, developed inside the Apennine chain, a thick sequence of Middle Pliocene marine and continental sediments overlie unconformably the Lower Pliocene sediments. They record the beginning of the final emersion of the western side of Italy (BARBERI *et al.*, 1994; BOSSIO *et al.*, 1998; BOCCALETTI *et al.*, 1999 and ref.). Coeval continental sediments are known in the Aulla-Olivola basin (BERTOLDI, 1988), Sarzana basin



Figg. 4, 5, 6, 7, 8 - Schematic geological sections across the Italian Peninsula with evidence of planation on the different structural units.

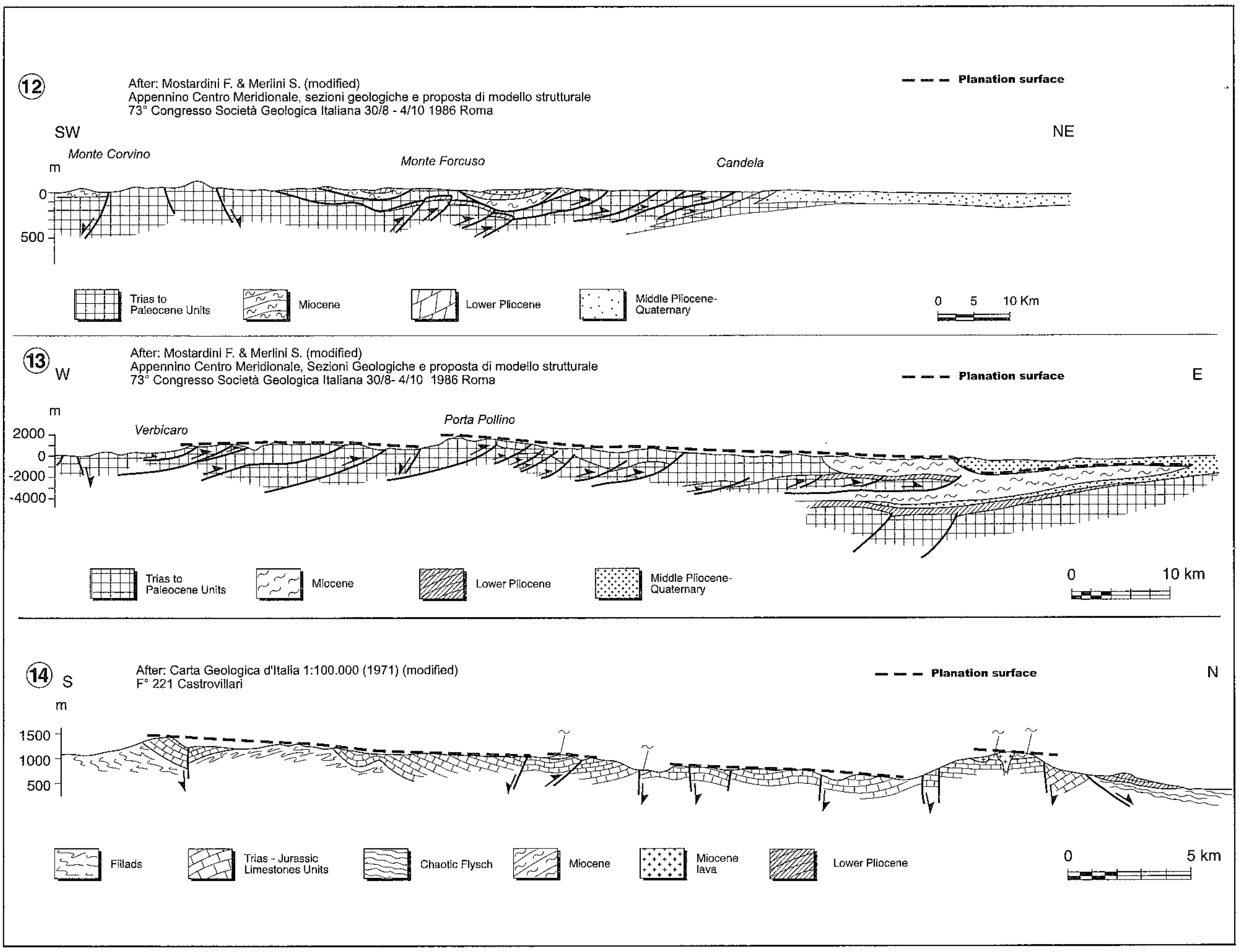
(RAGGI, 1985), the Arno-Chiana-Tiber basins and, probably, in the Gubbio basin (MARTINI & SAGRI, 1993; ALBIANELLI *et al.*, 1995; COLTORTI & PIERUCCINI, 1997a and b). The original extent of the basins are usually assumed to be located in correspondence with the present-day boundary of the outcropping sedimentary filling, frequently bounded by normal faults. Detailed structural studies recognized 'compressional' features in many of these basins. Sedimentological investigation and recent mappings suggest that the original basins were much more extended and that their extent changed according to the type and importance of following tectonic deformations (BOCCALETTI *et al.*, 1995; 1999 and ref.; COLTORTI & PIERUCCINI, 1997b).

To the east, in the Periadriadric basin, the Miocene-Early Pliocene marine sediments were deformed and cut by an unconformity which corresponds to the Late Lower Pliocene marine transgression surface (CALAMITA *et al.*, 1991). On the margins of this basin, and in the Adriatic sea an unconformity, easily recognisable both in field and in seismic profiles, affected a series of buried thrusts that are covered in places with thin layers of Middle Pliocene sediments (ORI *et al.*, 1986; ARGNANI & GAMBERI, 1996). However, in these areas, shallow marine conditions persisted through the Middle Pliocene-Lower Pleistocene interval, being subjected to downwarping and only after the Lower Pleistocene the area finally emerged. The same unconformity also cuts across tectonic units thrusted over lower Pliocene terrains both in the north, as i.e. the "Val Marecchia" Ligurian units in the Romagna-Marchean area (Fig.5), and in large part of the Southern Apennines (RICCI LUCCHI, 1986; MOSTARDINI & MERLINI, 1986).

The Intra-Apennine (intramontane) tectonic basins, delimited by high angle normal faults, seems to be younger than Late Lower Pleistocene, although relatively few chronological constraints are available (FOLLIERI *et al.*, 1992; ASCIONE *et al.*, 1992; BARBERI *et al.*, 1994; AMBROSETTI *et al.*, 1995; COLTORTI & PIERUCCINI 1997a and b). Abandoned valleys, up to 1-2 km wide and many kilometres long, sometimes preserved as saddles on the watershed, are locally recognisable on the upper part of the chain, especially on the more resistant lithologies (DRAMIS *et al.*, 1991; DRAMIS, 1992; CALAMITA *et al.*, 1999a). Most of these palaeovalleys were dammed by high angle extensional faults. In the Colfiorito basin, which is a well-dated example, the sediments were deposited at the end of Lower Pleistocene (COLTORTI *et al.*, 1998). The difference in elevation between the mountains and the valley bottom, which has been increased by the still-active fault activity (CALAMITA *et al*, 1999b), suggests that up to the Lower-Middle Pleistocene the relief of this sector was very low.

3.3. Later planation surface

On the Tyrrhenian side of the Italian Peninsula, there are Middle-Upper Pliocene sediments located at elevations



Figg. 4, 5, 6, 7, 8 - Schematic geological sections across the Italian Peninsula with evidence of planation on the different structural units.

up to about 700-750 m a.s.l. They overlie an unconformity which cut the bedrock and/or Middle Pliocene terrains and are, in turn, planated (i.e. "Calcari ad *Amphistegina*" in Tuscany, AMBROSETTI *et al.*, 1978; Middle Pliocene marine conglomerates in Southern Appennines, AMATO *et al.*, 1992; CINQUE *et al.*, 1993). The same occur in the Campanian-Lucanian Apennine, where Lower Pliocene marine sediments preserved on large part of the Apennine watershed are planated and unconformably buried under Middle Pliocene sediments at their turn planated (DI NOCERA *et al.*, 1988; BONARDI *et al.*, 1988). To this phase of planation, younger than Middle Pliocene and frequently overimposed on the PS, can be associated large flat remnants in the Peri-Tyrrhenian and Peri-Adriatic areas and probably most of the planation surfaces of southern Italy (to the south of the Matese Massif).

In the Periadriatic basin as well as in the Adriatic sea an unconformity cuts the Middle Pliocene as well as the Lower Pleistocene deposits and is covered by Early - Middle Pleistocene sediments ("Sicilian" CANTALAMESSA *et al.*, 1986). The overlying littoral sediments ("Sabbie e Conglomerati di tetto", CANTALAMESSA *et al.*, 1986) are now found up to 500 m, revealing a very rapid Middle Pleistocene uplift of this part of the chain.

In the pedemont sector this younger surface was mostly modelled across clays and sands making difficult its preservation, but on many watersheds sculptured on more resistant rocks (sandstone and conglomerates), large flat remnants of a planation surface are also preserved. In many cases these remnants are directly connected to unconformities of marine origin. In the inner part of the chain, this younger sedimentary cycle is chronologically connected with the filling of the wide valleys that cut the PS and, therefore, the two planation phases and related unconformity cannot be confused. The same occurs in the western side of the Western Umbro-Marchean Apennines, where the Lower Pleistocene coastline, indicated by marine landforms and mussel borings (GIROTTI & PICCARDI, 1994), is located some hundreds meters below well preserved PS remnants. It is difficult to assess the extent of these more recent transgressive events on the emerged land. Moreover, it must not be forgotten that all along the Peninsula there are numerous marine Pleistocene terraces revealing a continuous enlargement of the emerged land as it was uplifted.

4 . MODEL OF PS MODELLING AND CLIMATIC IMPLICATIONS

The limited remnants of marine sediments overlying the PS suggest that it is the result of a series of processes that occurred at sea level, and that during the Lower Pliocene the Italian peninsula was mostly below sea level. Although the whole area emerged during the Messinian it was again largely covered by the sea at least twice: firstly during the Zanclean Transgression and secondly during Late Lower Pliocene. The PS corresponds to the second phase because it affected deformed and thrusted deposits of Messinian to Early Pliocene age. It is difficult to assess the origin of the PS partly because the original inland extension of the plain of marine erosion is unknown as well as the importance of the subaereal processes that could have played an important role.

The erosional rates calculated for pedimentation processes seems too low to be applied for the PS extent although other processes, i.e. river erosion, can localy increase these rates, as suggested in many young mountain chains of the world (ADAMS, 1985; BRUNSDEN & LINN, 1991; BURBANK *et al.*, 1996; ABBOTT *et al.*, 1997; SMALL & ANDERSON, 1998; SUGAI, 1990).

The modelling of the PS is simpler explained in terms of marine erosion. In fact, marine sediments are present below and in places above the unconformity. Exceptional rates of coastal erosion are known on soft rocks ranging from 0,4 to 3 m/yr (TWIDALE, 1976; BEST & GRIGGS, 1991). SUNAMURA (1983) and TRENHAILE (1987) report maximum erosional rates of 35 mm/yr for granite and limestones rocks. However, these rates were associated uniquely to weathering and wave processes and also these authors agree that, taking into account the other erosional processes at work on the shorelines, greater rates might be expected.

We realise that the development of a planation surface, which might have flattened large part of the whole Peninsula, in a very short time span, creates problems when compared with present-day rates of formation of erosional surfaces, but the evidence is difficult to refute. A further problem is the necessary occurrence of a period of tectonic quiescence, because it is even harder to explain the PS modelling in a context of active mountain building. Marine erosion seems the most rapid process capable of producing the observed planation surface over a large area in a relatively short time.

Therefore, to model an extensive marine erosional surface is necessary a long lasting trasgression. As matter of fact, major global climatic changes are recorded throughout the Pliocene and in many works Early Pliocene warming events related to eustatic sea-level rises are reported. HAQ *et al.* (1987), based on sequence stratigraphy, refer two main Early Pliocene eustatic highstands: ≈5.2-4.0 and ≈3.7-3.1 Ma intervals. In the Mediterranean area, the Late Lower Pliocene transgression is recorded also by faunal assemblages indicating warm to warm-temperate conditions during the *Gt. Margaritae extinction-Gt. puncticulata* last occurrence interval (3,7-3,3 Ma). Cool to cold conditions followed up to the beginning of the glacial-interglacial regime (ca.2,8 Ma) when transgression occurred again (CHANNEL *et al.*, 1992) but the climatic signal of Late Middle-Upper Pliocene transgression is less important than the previous one. Similar trends of climatic changes are reported in the Northern Atlantic and in the eastern equatorial Pacific Oceanic drills, where the benthic oxygen isotopic records show warm conditions in the 3,5-3,0 Ma interval (DOWSETT & CRONIN, 1990; CRONIN & DOWSETT, 1991; KRANTZ *et al.*, 1991). A comparable climatic framework is showed for the Gulf of Alaska and adjacent regions by LAGOE & ZELLERS (1996) where the comparison of benthic O^{18} with the lito-stratigraphic data reports the Beringian transgression in the 4,0-3,5 Ma interval. Moreover, the pollen records obtained from ODP holes in Japan clearly show a marked increase of warm species and decline of cool species in the 4,0-3,5 Ma interval (HEUSSER & MORLEY, 1996), whereas paleoceanographic records from the Sea of Japan refer of warm conditions in the 3.4-2.3 Ma interval (CRONIN *et al.*, 1994). As regards the Anctartic continent, an interglacial interval between 4.2 and 3.6 Ma is reported by PICKARD *et al.* (1988) for marine sediments on the eastern coastline. Almost the same results are showed by BARRON *et al.* (1991) and MCMINN & HARWOOD (1995) based on diatomaceous sediments, by QUILTY (1993) on vertebrate remains. In the Southern Ocean the same results are obtained by BOHATY & HARWOOD (1998) from silicoflagellate biostratigraphy.

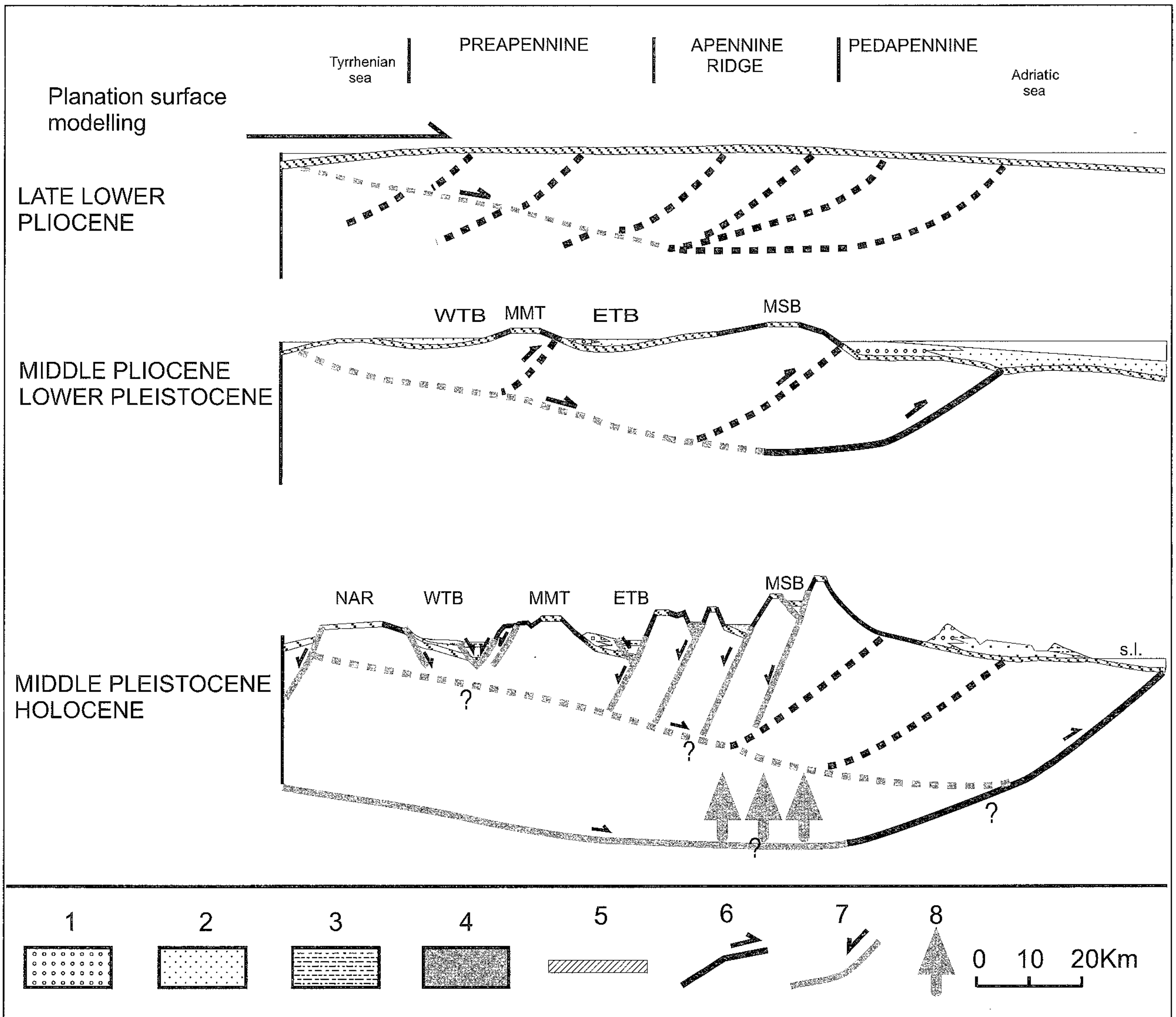
In conclusion, the palaeoclimatic data show a global warming event, lasted about 300-500 ka, responsible for a major transgression in the Late Lower Pliocene.

Similar conditions are not recorded during the Upper Pliocene-Quaternary, and it is therefore impossible to find an 'actualistic' example of planation surface modelled under similar conditions. Moreover, the tectonic regime in the Italian Peninsula also changed afterward, creating even more difficulties in finding an actualistic example. On the other hand, flat unconformity several hundred kilometres wide, are described in cratonic and in peri-cratonic areas affecting Palaeozoic or even older mountain chain and they are usually covered by marine deposits (SMALL, 1978). Most of the unconformities known in geological literature delimit important sedimentary basins, whereas in the Apennine there was short time for deposition because the PS was soon deformed and uplifted.

5. THE PLANATION SURFACE AND NEOTECTONICS.

The PS levelled the previous tectonic structures (faults and folds) as well as the pre-existing relief. This surface constitutes a morpho- and chrono-stratigraphic unit that could be used where no dated sediments are present. Comparing the geological with the geomorphic displacement it is possible to evaluate the neotectonic movements (RESEARCH GROUP FOR QUATERNARY TECTONIC MAP OF JAPAN, 1969; 1973; BURBANK & PINTER, 1999; COLTORTI & OLLIER, 1999 and 2000; SUGAI & OHMORI, 1999).

Along a cross-section through Central Italy it has been pointed out that initially, during the Middle-Upper Pliocene, deformation occurred mostly as downwarping and upwarping (Fig. 9) (COLTORTI & PIERUCCINI 1997b). Based on further observations and evidence gathered from BOCCALETTI *et al.* (1994; 1999) it seems that this can be extrapolated in the rest of the chain. Downwarping generated "sinform basins" which were filled with continental and marine sediments all along the Peninsula. "Sinform basins" is used as a descriptive term that does not imply a tectonically genetic significance, either compressional or extensional, such as piggyback basins (ORI & FRIEND, 1984; BUTLER & GRASSO, 1993), satellite basins (RICCI-LUCCHI, 1986), or perched/ thrust top basins (BOCCALETTI *et al.*, 1995). Upwarping played an important role in the creation



Major steps in Plio-Quaternary development of Apennine relief in central Italy.
1-Pliocene coarse-grained deposits; 2-Pliocene fine-grained deposits; 3-Marine and continental deposits (Lower Pleistocene); 4-Intramontane basin deposits; 5-Planation surface; 6-Thrusts (dotted lines=inactive; dotted lines with arrows=re-activations; 7-Normal faults; 8-Generalized uplifting NAR=Narni-Amelia Ridge; WTB=Western Tiber Basin; MMT=Martani Mts; ETB=Eastern Tiber Basin; MSB=Sibillini Mts; MAS=Ascensione Mt

Fig. 9 - Plio-Quaternary tectonic regimes and morphogenesis along a cross section of the Umbria-Marche Apennines from Amelia-Peglia Ridge to the Adriatic coast.

of the main Apennine ridges, leading locally to over 900 m of displacement of the PS (i.e. Marchean-Abruzzi-Molise Apennines fronts). The displacements mostly occur in narrow belts located in correspondence of older thrust fronts, suggesting their limited re-activation at least as reverse falts. In our opinion, the contemporaneous activity of "west dipping thrust fronts" to the east and "east-dipping low angle normal faults" to the west might represent detachment planes affecting the Upper Crust of the whole Peninsula. This setting is consistent with a gravitational tectonic regime as suggested already long time ago by MERLA (1952). Being the activity of reverse faults and thrusts associated to basal detachment, it seems possible that these movements record their last activity. Therefore thrust fronts become inactive before the end of the PS modelling and only a few of them show limited re-activations afterwards, mostly separating up-warped from down-warped areas. The east dipping low-angle normal faults are mostly planated (CALAMITA *et al.*, 1999a). Regional uplift followed during the Lower Pleistocene and it is difficult to differentiate the amount of uplift during the local warping from the subsequent general uplift.

Other examples of pre-planation normal faults, high or low angle west dipping, are the Battiferro-Sabina (Latium-Umbria), M.Camicia-M.Prena (Abruzzi) and the Montagna dei Fiori western (Marche-Abruzzi) faults, (CALAMITA *et al.*, 1994; 1998; CALAMITA *et al.*, 1999a; PIZZI & SCISCIANI, 1999). Some faults, i.e the Assergi and the M.Vettore Fault System, were activated or re-activated after the Lower Pleistocene and local tectonic inversion has been pointed out (CALAMITA *et al.*, 1994; CALAMITA *et al.*, 1999a). Despite some uncertainty of the timing, high angle extensional faults, were mostly generated during the final part of the Lower Pleistocene (AMBROSETTI *et al.*, 1995; CALAMITA *et al.*, 1999b).

Since we suppose there is a single planation surface across the whole peninsula, the maximum uplift of the chain is about 2500 m (higher preserved PS in the Gran Sasso area) in about 3.2 Ma with rates of 0.78 mm/yr. Mean value of 0,42 are obtained for most of the lower-lying mountain belt located at the mean elevation of 1500 m. However, in some basins (i.e. East Tiber), where the PS is today located at m 80 below the sea level, there is a negative value of -0,02 mm/yr. Moreover, the presence of fluvial terraces hanging at progressive elevation and even at hundred meters on the valley floor all across these areas suggests continuous uplifting since Lower Pleistocene.

The high angle normal faults show higher slip-rates after the Late Lower Pleistocene. Faults with about 1,000m of vertical displacement, common in many Apennine tectonic basins, record slip-rates of about 1 mm/yr. Their activity can be concentrated in periods of tectonic crisis because in many parts of the northern Apennines Late Middle and Upper Pleistocene sediments record little evidence of faulting. All these faults are connected to the general uplifting and to the following gravitational collapse of the chain that marks the Late Lower Pleistocene-ongoing stages of the mountain building (CALAMITA *et al.*, 1999a).

The origin of the uplift is still unclear. However, if the pre-PS tectogenesys of the Apennine took place in a context of gravitational tectonics, then the following uplift of the chain may be explained with the progressive deepening of the detachment planes which would compensate the opening of the Tyrrhenian sea (Fig.9). It would suggest an extensional and not a compressional regime.

6. CONCLUSIONS

A single very flat Planation Surface was cut across the Italian Peninsula during the Late Lower Pliocene marine transgression. Evidence of a marine transgression of this age has been reported from all over the world. On both sides of the Italian Peninsula, minor phases of marine transgression occurred in more recent times. Related planated remnants are located at high elevations but they are less extensive and do not reach the inner part of the mountain ranges. The most important erosional phase is associated with the Late Lower Pliocene event, which planated older tectonic structures and the pre-existing relief., providing a starting point to the evolution of Peninsular Italy.

The Italian Peninsula was planated in a very short time, at most 300-500 Ka, which is the estimated duration of the Late Lower Pliocene transgression. The planation surface formed close to sea level, as indicated by associated coastal and shallow marine deposits.

Tectonic deformation affected the PS after the Late Lower Pliocene and fluvial and marine terraces reveal that, since the Late Lower Pleistocene, the whole Peninsula was affected by a regional uplift. Following these vertical movements, normal faults were activated mainly on the eastern side of the Peninsula.

The detailed study of the PS provides unique information about the recent evolution of the Peninsula and about the rates of uplift and faulting which show differences from place to place. The evolutionary history of the Italian peninsula is much more dynamic and rapid than previously supposed. Locally it is possible to distinguish for a single fault the amount of activity pre- and post- PS and, coupled with the study of displacements which affected more recent sediments, the occurrence of periods of accelerated tectonic activity.

Contrary to common belief the creation of the Apennine relief is not a direct consequence of the nappe-forming tectonic activity that preceded formation of the planation surface. At least since the Middle Pliocene there are no evidence of progressive migration of the compression-extension from the east to the west of the Peninsula. The major mountain forming process was vertical uplift.

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