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PLIO-QUATERNARY CONTINENTAL DEPOSITS IN THE LATIUM-ABRUZZI APENNINES: THE CORRELATION OF GEOLOGICAL EVENTS ACROSS DIFFERENT INTERMONTANE BASINS

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ABSTRACT
A stratigraphic framework valid for the Pliocene-Middle Pleistocene continental deposits of the Latium-Abruzzi Apennines has been defined through the correlation of the depositional/erosional events (indicated by stratigraphic and morphologic units, respectively) across seven different intermontane basins. This has been made by comparing the geological evolutions of the different basins. The basic assumption for the correlation of the different events is that climatic factors have conditioned the geological evolution of the investigated sector in a substantially uniform way. Uniform climatic conditions have caused similar responses of the basins to the climatic changes. Continental deposition in the Latium-Abruzzi Apennines began during the Pliocene, prevalently with clayey-silty-sandy lacustrine deposits fed by the clayey-arenaceous flysch into which the landscape was carved at the time of the first continental deposition. The formation of an indented landscape with higher slopes bordering the basins is demonstrated by huge landslide deposits of both arenaceous and calcareous coarse material. Sediments related to the second depositional event (Early Pleistocene) are mainly characterised by a carbonate lithology in slope deposits (slope-derived breccias), in lacustrine (carbonate silts) and fluvial (carbonate gravels) sediments. This is due to the dominant carbonate lithology of the bedrock in the areas experiencing erosion during the Quaternary. The third depositional event (related to the lower Middle Pleistocene) has lithological and sedimentological characteristics comparable to those of the second event. It consists, indeed, of slope-derived carbonate breccias, carbonate silty deposits of lacustrine origin and carbonate gravels of fluvial facies. The fourth depositional event (Middle Pleistocene) is characterised by the first significant deposition of material of volcanic origin and numerous tephra levels related to the central Italy volcanic activity can be detected. Chronological constraints for the second depositional event are represented by the reverse paleomagnetic polarity of the deposits, defining ages older than 0.78 Ma and by the remains of *Arkidiscon meridionalis vestinus* Azzaroli in the L'Aquila basin. Chronological data for the third depositional event are represented by paleontological remains of *Equus altidens* Reichenau and by the association *Hippopotamus antiquus* Desmarest/*Elephas antiquus* Falc. & Cautl. and by the lack of volcanic materials which became widespread after 0.6 Ma. The age of the fourth depositional event is constrained by the presence of the tephra levels which define a deposition after about 0.6 Ma. The attribution of a Pliocene age to the deposits of the first event can only be made on a qualitative basis, since bio-chronological data or other quantitative chronological constraints are not available. In this light, the significant changes which affected the landscape between the first two depositional events seem to indicate that a very long time span passed between them.

RIASSUNTO
Viene proposto uno schema stratigrafico per i depositi continentli dell'Appenino laziale-abruzzese, fondato su una serie di correlazioni che riguardano le successioni riconosciute da precedenti lavori nelle principali conche intramontane. Le successioni sono uniformemente descritte in termini di unità stratigrafiche (del tipo "a limiti inconformi") e di unità morfologiche, definite come "unità morfo-sequenziali" e rappresentate da superfici relitte di erosione o di accumulo. Le correlazioni sono state ottenute mediante un confronto fra le successioni morfologico-stratigrafiche, effettuato sulla base di due presupposti: (i) che l'evoluzione geologica che le ha generate sia condizionata principalmente da fattori in vario modo ubiquitari (clima e sollevamento tettonico) e (ii) che l'interazione fra questi fenomeni si sia realizzata in un'area caratterizzata da una relativa costanza dei principali elementi idrografici. Questi presupposti inducono a ritenere che le alternanze di episodi deposizionali ed erosivi si siano sviluppate nelle diverse conche con modalità sostanzialmente simili.
Le correlazioni ottenute mediante questo confronto hanno portato a definire un'unica sequenza dei principali eventi deposizionali nell'area laziale-abruzzese. L'unità stratigrafica continentale più antica è costituita prevalentemente da depositi lacustri limoso-sabbiosi provenienti quasi esclusivamente da aree costituite dalle sequenze arenaceo-argillose tortoniano-messiniane. Il paesaggio nel quale si originava l'unità era quindi molto diverso da quello attuale, dominato dalla dorsali carbonatiche. I bacini di sedimentazione erano verosimilmente caratterizzati da versanti molto acclivi, localmente interessati da imponenti fenomeni franosi che andavano ad alimentare una sedimentazione molto grossolana che si rinviene localmente intercalata ai sedimenti lacustri. Gli strati di questa prima unità stratigrafica sono spesso vistosamente deformati. Anche se non esistono elementi di diretto interesse cronologico, si può riferire l'unità ad un generico Pliocene, soprattutto sulla base dei rapporti con l'unità successiva. Questo riferimento è indirettamente avvalorato sia dalla "antichità" del paesaggio circostante, molto diverso da quello attuale, sia dalla deformazione, molto più intensa di tutte le unità successive che hanno di regola un assetto sub-orizzontale. Il successivo evento sedimentario ha dato origine a successioni di varia litologia ed ambiente (sabbie e limi lacustri, ghiaie fluviali, depositi più o meno grossolani di versante) a prevalente componente calcarea; questa caratteristica è manifestamente connessa con una alimentazione proveniente da un paesaggio che, a seguito della sempre più profonda erosione delle sequenze terrigene mioceniche, era largamente costituito dalle successioni carbonatiche mesozoiche. L'attribuzione di queste successioni al Pleistocene inferiore è giustificato dal rinvenimento, nella conca dell'Aquila, di una fauna a vertebrati pre-galeriana, contenente Mammuthus meridionalis vestinus*. Congruenti con questa attribuzione sono anche alcune determinazioni di paleomagnetismo che hanno indicato una polarità inversa. Il terzo evento sedimentario ha caratteristiche abbastanza simili a quello ora descritto: se ne differenzia principalmente per la minor frequenza di episodi lacustri e per essere connesso ad una marcata tendenza all'erosione laterale che ha dato origine ad estese spianate i cui residui sono tuttora osservabili nel paesaggio. Gli unici vincoli cronologici sono rappresentati da resti di* Equus altidens, *rinvenuti nella conca del Fucino e di* Hippopothamus antiquus *e di* Elephas antiquus *in quella del Tirino. Questi ritrovamenti, unitamente alla mancanza di significativi apporti in materiale vulcanici, inducono ad attribuire l'unità al Pleistocene medio. Il quarto evento sedimentario è caratterizzato dalla prima comparsa di importanti apporti di materiale vulcanico che danno spesso origine a sequenze di strati tufitici: l'età è ancora meso-pleistocenica in quanto precedente ai grandi apparati fluvio-glaciali del Pleistocene superiore.*

Keywords: Plio-Quaternary, continental stratigraphy, paleoenvironments, Central Italy.

Parole chiave: Plio-Quaternario, stratigrafia continentale, paleoambienti, Italia Centrale.

INTRODUCTION

Plio-Quaternary stratigraphic frameworks are fundamental to chronologically constrain geological paleoevents which have deep implications in neotectonics and the reconstruction of recent paleoenvironments. The stratigraphic reconstructions are, however, reliable and based on tested methodologies if related to marine environments, while they are uncertain and often based on not consolidated methodologies if related to continental environments.

Although the above mentioned problems are sometimes unsurmountable, the object of the present paper is the definition of the continental stratigraphy of a large sector of the Latium-Abruzzi Apennines (Fig. 1), with the perspective of drawing a chronological framework for neotectonic reconstructions.

The present work represents an update of the papers by Bosi (1989) and Bosi and Messina (1991) and gathers the new knowledge supplied by investigations performed during the last ten years.

Due to the problems above mentioned, the discussion on the methodology adopted in the study of the continental stratigraphy is fundamental, particularly for the correlation of the successions through the different basins. For this reason a specific section will be entirely dedicated to this aspect. The proposed stratigraphic scheme of the Latium-Abruzzi Apennine continental stratigraphy is directly linked to the methodological aspects above mentioned. Therefore, the discussion of the general scheme and of the innovative aspects (with respect to the previous works) will follow the methodological discussion.

The general stratigraphic scheme will also represent a sort of reference framework for the following sections, dedicated to the stratigraphic description of the investigated basins. These sections are related to the basins where researchers of the former Istituto di Ricerca sulla Tettonica Recente (presently part of the Istituto di Geologia Ambientale e Geoingegneria) have worked in the last years. For each investigated basin we cited reference studies. These studies have, however, different characteristics. In some cases they are monographies about specific basins (e.g. Zarlenga, 1987; Bertini and Bosi, 1993, on the Fucino basin and the middle Aterno valley, respectively). In other cases, monographic studies are lacking and therefore stratigraphic data can be derived from works at the regional scale (e.g. Demangeot, 1965; Galadini *et al.*, 2003, on the L'Aquila basin and the Turano valley, respectively). In one case (Turano valley), due to the scarcity of published data, we mentioned a degree thesis (Melchiorri, 1987). Studies related to specific aspects of the recent geological evolution (e.g. Galadini and Messina, 1994; Barbieri *et al.*, in press, on the neotectonics of the Fucino Plain and the volcanic activity in the Piana del Cavaliere area, respectively) have also been mentioned. Papers on specific sectors of the reported basins or to outcrop-scale stratigraphies have been referred if they seems particularly significant for the purpose of our work (e.g. Bertini and Bosi, 1976; Blumetti *et al.*, 1996, for the Fucino and Salto basins and the L'Aquila basin, respectively).

Stratigraphic data on intermontane basins of the Latium-Abruzzi Apennines investigated by researchers of other institutes will be summarised in only one section.

In the concluding remarks some implications for neotectonics and paleoenvironmental investigations will be outlined [1].

[1]This paper is dedicated to the stratigraphy of the Pliocene-Middle Pleistocene. For this reason we invite to find the available information on the Late Pleistocene-Holocene stratigraphy of the investigated area in the numerous works made by the researchers of ENEA-Casaccia (e.g. Giraudi, 1994, 1995, 1996, 1998; Giraudi and Frezzotti, 1997).

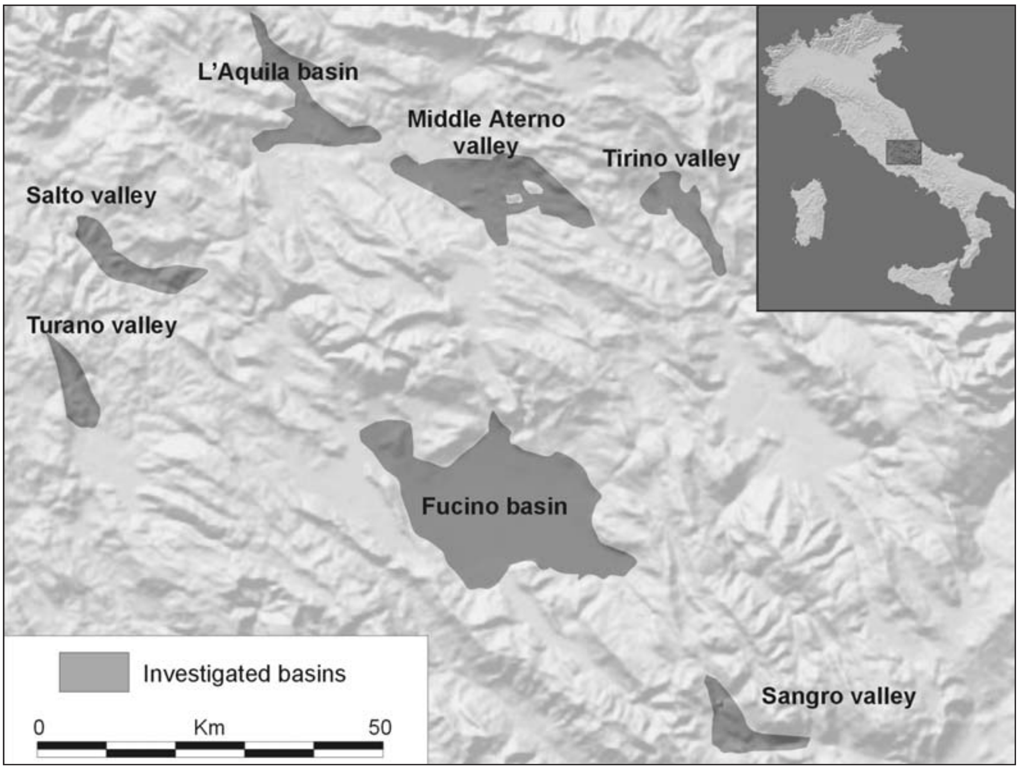

Fig. 1 - Location map of the investigated area (Latium-Abruzzi Apennines).

GEOLOGICAL FRAMEWORK OF THE CENTRAL APENNINES

The building of the central Apennines results from the superimposition of the extensional tectonics to the compressive one since the Late Cenozoic. The latter is due to the progressive NE migration of the Apennine arc related to the well-known flexural retreat of the lithosphere plate located in the Adriatic sea (Malinverno & Ryan, 1986; Royden *et al.*, 1987; Patacca *et al.*, 1990; Doglioni, 1991). Contemporaneous opening of the Tyrrhenian basin is due to rifting processes west of the Apennine chain (e.g., Faccenna *et al.*, 1996; Jolivet *et al.*, 1999). While compressive structures affected the progressively migrating Apennine front and rifting occurred in the Tyrrhenian area, extensional tectonics affected the Apennine chain (e.g. Meletti *et al.*, 1995; Cavinato and De Celles, 1999; Ghisetti and Vezzani, 1999), causing the displacement of the Pliocene-Quaternary continental sediments (e.g. CNR-PFG, 1987) and the formation/evolution of intermontane basins (Fig. 1). Pliocene deposits, mainly represented by lacustrine facies and huge landslide episodes (the so-called "megabreccias") testify to the final emersion of the Apennine chain from the sea.

The NE migration of this structural system is well recognised for the compressive structures, based on the fact that progressively younger thrusts affect the Italian peninsula towards NE (Patacca *et al.*, 1990). Presently, the active compressive front is located in the Adriatic sea along the peninsula and in the Po Plain in the northern Apennine sector, according to the view by Patacca *et al.* (1990). In contrast, more recent works suggest that thrusting and related folding is no more active along the Apennines (e.g. Di Bucci *et al.*, in press and related bibliography).

Progressively NE shifted intra-Apennine extensional domains have also been hypothesised (e.g. Lavecchia *et al.*, 1994). The lack of a detailed stratigraphic framework related to the continental facies, however, has prevented the proposal of reliable chronological constraints for the Plio-Quaternary structural evolution of the intra-Apennine extension.

The persistence of the extensional activity in the Apennines is documented by the numerous works on active tectonics and paleoseismology (e.g. Pantosti *et al.*, 1996; Galadini and Galli, 1999 and reference therein) and by the occurrence of earthquakes with M>6 (e.g. Working Group CPTI, 1999).

METHOD OF ANALYSIS OF THE PLIO-QUATERNARY CONTINENTAL SUCCESSIONS

The reconstruction of the continental stratigraphy at the regional scale results from fragmented information, due to the scarce lateral continuity of the depositional environments and to the intense erosion which usually affects continental areas. Moreover, the chronological definition of continental successions is often hindered by 1) the scarcity of the fossil remains which is evident if a comparison with the amount of dating fossils of the marine environment is made and 2) the limit of applicability of methods for obtaining numerical datings (both in terms of material suitable for dating and in terms of chronological intervals covered by the different methods). Due to these problems, since the 80s a method for correlating the continental geological history of different basins has been elaborated and applied to the Latium-Abruzzi Apennines (see Fig. 1 for location). Procedures and results have already been published in the works by Bosi (1989) and Bosi and Messina (1991).

This approach is based on 1) the reconstruction of the depositional/erosional history of single intermontane basins and 2) the comparison of the successions of events which characterised the different basins of the investigated region. Both points are based on the assumption that the traces of the depositional/erosional activity are roughly representative of the real geological evolution of a certain basin, if the geological history is defined through chronological steps of hundreds thousand years. The reliability of this assumption is corroborated by the evident comparability of the geological events which affected the different investigated basins (see below). As for point 1, we define the succession of the erosional and depositional events which conditioned the deposition of lithosoma over erosional surfaces, usually embedded one into the other (e.g. Fig. 2). This kind of morphologic and stratigraphic relationship has been observed in all the investigated basins. The resulting landscape is made of a succession of terraced landforms, related to the top depositional surfaces of the lithosoma and/or to erosional surfaces carved into other lithosoma or the marine substratum.

The comparison mentioned at point 2 is aimed at defining chronological relationships between depositional/erosional events across the different basins. The reliability of the correlation of events throughout a region is fostered by the persistence through time of the main basins and of the main portions of the hydrographic network. This persistence indicates that the terraced succession of the single depressions has to be primarily related to the climatic history of the region. This history has to be considered common to the investigated area, considering its limited extension (Fig. 1).

The correlation of the depositional units and the related erosional/depositional landforms across basins (the oldest with the oldest, the youngest with the youngest, etc..) is consistent with the sparse available chronological data (paleontological findings, paleomagnetic data, the presence of sedimentary materials related to the post-Early Pleistocene volcanic activity, see below). The correlations are also supported by other qualitative similarities regarding: 1) the number of depositional events alternating with erosional phases in adjacent basins, 2) the sedimentological and paleoenvironmental characteristics of depositional units belonging to different basins, 3) the intensity of the deformation affecting the depositional units; 4) the relationship between certain deposits and the landscape (e.g. the attitude of slope-derived breccias in comparison with the morphology of the present slopes).

The procedure above described (with the evident limits due to the fragmentation of the geological information) permits to define geological events which are ubiquitous across the different basins of a region. As a result of this approach, the morpho-stratigraphic schemes we obtained for each basin (Fig. 2) define the geological evolutions in terms of depositional and erosional events. These schemes are much more informative than

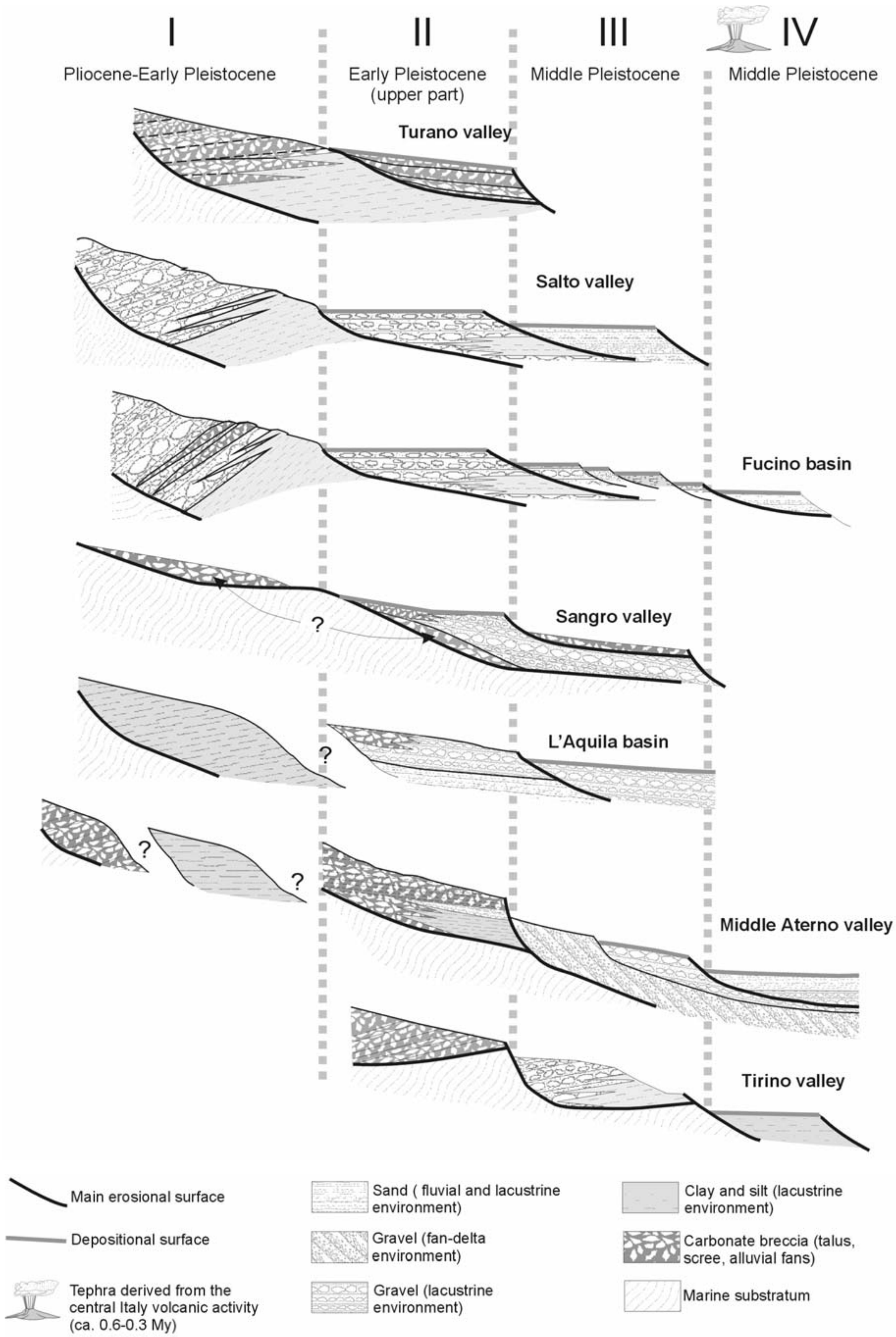

Fig. 2 - Morpho-stratigraphic schemes of the investigated basins in the Latium-Abruzzi Apennines. Numbered columns define the different depositional events.

simple stratigraphic columns. The latter, indeed, do not define the "geomorphic role" of the continental evolution, since they do not indicate the fundamental processes of terracing, or the most significant areal erosional surfaces, or the depositional top surfaces, thus limiting the vision of the areal geological-geomorphological evolution.

An example of correlation among depositional/erosional events of different basins contributes to cast light on the adopted procedure. This case is represented by the first continental sedimentary event which affected a number of intermontane basins of the Latium-Abruzzi Apennines. Aspects common to the different basins are: 1) this event marks everywhere the earliest deposition following the orogenic phase in the chain axis area (the continental deposits unconformably cover the marine substratum, see for example Bertini and Bosi, 1976 for the Salto Valley); 2) the lower portion of the succession (directly overlaying the marine substratum) is characterised in all the basins by clayey-sandy deposits (lacustrine environment) fed by the Miocene clayey-arenaceous flysch; 3) the carbonate clastic deposition becomes predominant towards the upper part of the succession in all the investigated basins; 4) a strong tectonic deformation affects the deposits (which are tilted up to 40° and intensely faulted) in all the basins before the deposition of younger units which unconformably cover the older ones; 5) an erosional phase is in all the basins indicated by an erosional surface representing the base of the subsequent units. The five points suggest that the first depositional episodes in the different intermontane basins, with the similar characteristics above mentioned, can be related to a synchronous depositional event. Obviously, sinchroneity has to be intended as chronological comparability of events within a time span of several 0.1 Ma (which is the adopted "chronological scale").

The definition of common aspects in the depositional/erosional histories of basins implies that most of the field research has to be addressed to the reconstruction of geological evolution of basins (Fig. 2).

The chronological aspect, as indicated at the beginning of this section, is a further problem of continental stratigraphy. In the investigated region, key biochronological data are represented by *Arkidiscon meridionalis vestinus* Azzaroli (Early Pleistocene[2]; Azzaroli, 1983) of the L'Aquila basin, *Elephas antiquus italicus* Osborn (Middle Pleistocene; Maini, 1956) of the middle Aterno valley, *Equus altidens* Reichenau (Middle Pleistocene; Blumetti *et al.*, 1997) of the Fucino basin, *Elephas antiquus Falc.* & Cautl. and *Hippopotamus antiquus* Desmarest (Middle Pleistocene; Gazzetti, pers. com.; Petronio pers. com.) of the Tirino valley.

A further chronological element is represented by the presence, in the continental deposits, of abundant sedimentary material related to volcanic activity. These sediments indicate an age subsequent to the beginning (about 0.6 Ma) of the most recent volcanic phase in central Italy (both in the Tyrrhenian sector and in the Apennine area; see Fornaseri, 1985; Narcisi and Sposato, 1989; Barbieri *et al.*, 1996 on the chronological aspects).

Chronological constraints can also be derived from paleomagnetic data which indicate reverse polarity for some deposits of the Abruzzi Apennines (D'Agostino *et al.*, 1997; Messina *et al.*, 2001), suggesting an age older than the limit Bruhnes-Matuyama (0.78 Ma). These data are available for slope-derived breccias distributed throughout the entire Latium-Abruzzi Apennines, for alluvial deposits of the upper Aterno valley and for lacustrine sediments of the middle Aterno valley.

The available chronological dataset permits to constrain the age of most of the Pleistocene deposits detected in the investigated area. The age of the oldest deposits, generically attributed to the Pliocene in the works on the Fucino Plain, the Salto Valley and the Turano Valley (e.g. Bertini and Bosi, 1976; Bosi, 1989; Bosi *et al.*, 1995), cannot be defined in detail, due to the lack of bio-stratigraphic constraints. The reasons for attributing these deposits to the Pliocene are:

1) they are younger than continental sediments related to the Messinian (Bosi and Messina, 1990; Cipollari *et al.*, 1999) which experienced the compressive deformations of the central Apennines;
2) these deposits unconformably cover the Miocene marine substratum (e.g. Bertini and Bosi, 1976);
3) sedimentary material from the lower part of the successions defines a provenance from areas not related to a physiography comparable to the present one; in particular, the abundance of clayey-sandy sediments indicates that the deposition was fed by areas entirely made of Miocene flysch (Bertini and Bosi, 1976); in contrast, the Quaternary deposition is conditioned by erosion of the carbonate bedrock in which most of the present slopes are carved;
4) the changes which affected the landscape (e.g. in terms of amount of erosion) between the first depositional event and the second one are much more significant than the changes of the landscape during the last 1 Ma;
5) an erosional surface separates, in the different basins, the sediments of the first event from those related to the second (Early Pleistocene) depositional event (Fig. 2);
6) an evident unconformity separates the sediments of the first depositional event (strongly deformed, tilted and displaced along normal faults, e.g. Fig. 2) from those of the second depositional event, indicating the occurrence of significant tectonic deformations preceding the erosional surface of point 5;
7) the sediments of the first depositional event are characterised by a large thickness (more than 300 m in the Salto valley and in the Fucino basin) indicating the persistence of the related depositional environment for a long time interval.

Point 3 indicates a physiography of the first event basins very different from that of the second depositional event; points 4, 5 and 6 qualitatively indicate that a long time span separates the first two depositional events; point 7 indicates that the first depositional event may have lasted for a long period. On this basis, we hypothesise a Pliocene age for the first depositional event (although it may have partly occurred during the Early Pleistocene). The occurrence of Pliocene continental deposition in the intermontane basins of the

[2] In the present paper, as currently proposed in Quaternary geology, we consider the limit Early Pleistocene-Middle Pleistocene coinciding with the limit Bruhnes-Matuyama of the paleomagnetic stratigraphy (i.e. 0.78 Ma).

Latium-Abruzzi Apennines has also been hypothesised by other authors (e.g. Cavinato, 1993; Carrara *et al.*, 1995; Barberi *et al.*, 1995; Cavinato *et al.*, 2002). The chronological attribution is generally based on considerations similar to those summarised in the previous points.

THE LATIUM-ABRUZZI APENNINE CONTINENTAL STRATIGRAPHIC SCHEME

The procedure above discussed brought to a first stratigraphic scheme at the end of the 80s (Bosi, 1989) which was revised by Bosi and Messina (1991). In these schemes, depositional and morphological units were correlated among five different basins. The same schemes were redrawn by Galadini (1999) who included information on the Liri valley derived from Carrara *et al.* (1995).

Other attempts to correlate continental successions in central Italy have been published during the 90s (Cavinato *et al.*, 1994; Cavinato and De Celles, 1999). The former work tried to correlate the tectonic-sedimentary evolution of intra-Appennine basins with the volcano-tectonic activity of the Tyrrhenian margin. The correlation of intermontane basins (Leonessa, Rieti, Fucino, Sulmona) is made on the basis of the comparison of continental successions (for which chronological constraints are not abundant), without defining depositional/erosional histories for each of the reported basins. Only the Fucino basin is common to the schemes of Cavinato *et al.* (1994) and Bosi and Messina (1991). Cavinato and De Celles (1999) is, instead, aimed at correlating geological events along a transect across central Italy, thus considering the events of the Tyrrhenian sector, those of the Apennine chain and those of the Adriatic margin during the Pliocene and the Quaternary. Due to the non-stratigraphic aim of the paper, the authors attribute chronology to the continental successions without justifying the choices made. It is not possible, therefore, to define the reliability of the stratigraphic background. This work, however, has only the Fucino and L'Aquila basins in common with the Bosi and Messina's scheme. In the case of these basins the two stratigraphic proposals seems comparable.

We updated the scheme by Bosi and Messina (1991), summarising the knowledge related to seven different basins (Figs. 2 and 3). As indicated in the introduction, in the new scheme we defined stratigraphic and morphologic features of the basins for which the writers have had direct field experience. For this reason, the stratigraphy of the Liri valley (Carrara *et al.*, 1995) is not reported in Figure 3. Moreover, although the stratigraphic knowledge for the Rieti and Sulmona basins (similar to the other investigated depressions as for the continental physiographic evolution) is very detailed (e.g. Cavinato, 1993; Miccadei *et al.*, 1998a), data are not expressed through schemes similar to those of Figure 2. Therefore, these data cannot be used for our purposes.

Chronological attributions in Figure 3 have to be taken with caution particularly for the age of the first depositional event above discussed. Some remarks on the continental succession of this area are proposed, however, in the section dedicated to the stratigraphic data from other basins. Symbols for defining lithological/sedimentological characteristics of the different units have been adopted in Figure 3, together with specific symbols which permit to identify extended erosional paleosurfaces carved into the deposits and depositional top surfaces of stratigraphic units.

The main differences between the old scheme and the new one are: 1) the Salto and the Turano valleys have been reported as two different basins, due to new fieldwork (unpublished data) made during 2001 by the authors of the present paper; 2) the Tirino valley has been reported in Figure 3 as the result of the work made by Giuliani and Sposato (1995) and further fieldwork made during 2002; 3) a third unit has been defined in the Salto Valley after new geological surveys made during 1999 (Messina, unpublished data); 4) the stratigraphic setting of the Fucino Plain has been slightly changed after the fieldwork made since the beginning of the 90s (Bosi *et al.*, 1995 and further unpublished data); 5) a first depositional event has been defined in the L'Aquila basin, resulting from fieldwork of the middle 90s (unpublished data); 6) a first depositional event has been tentatively defined for the middle Aterno valley on the basis of geological surveys made during 2000-2001 (unpublished data); 7) new bio-chronological data have been reported (*Hippopotamus antiquus* Desmarest, *Elephas antiquus* Falc. & Cautl. in the Tirino Valley, Gazzetti, pers. com.; Petronio pers. com.; *Equus altidens* Reichenau in the Fucino basin, Blumetti *et al.*, 1997); 8) paleomagnetic data indicating reverse polarity of deposits, i.e. ages older than 0.78 Ma have been reported (data derived from D'Agostino *et al.*, 1997 and Messina *et al.*, 2001).

The most important change is, however, represented by the different location of the erosional events represented by the Aquilente, Mt. Marine and Anzano top paleolandscapes. These are extended flat and subhorizontal erosional landscapes, carved into the marine substratum. The Aquilente top paleolandscape (TPL) followed, in the scheme by Bosi and Messina (1991), the first depositional event in the Salto Valley. The other two above mentioned TPLs were put in the same stratigraphic position in the old scheme, although evidence for the first depositional event was lacking in the L'Aquila and middle Aterno basins. Recent surveys in the Salto valley permitted to make a different hypothesis about the relationship between the Aquilente TPL and the deposits of the first depositional event (Galadini *et al.*, 2003). According to the mentioned authors, indeed, the modelling of the top paleolandscape occurred before the deposition of the first unit. This hypothesis is based 1) on the observation of coarse deposits related to the first depositional unit along the slopes roughly corresponding to the present ones and 2) on the inferred necessity of a stable base level over a large area for the formation of the Aquilente TPL. Point 1 defines a persistence of the Salto basin slopes during time since the deposition of the first unit, i.e. a persistence of the Salto depression during time. The consequence is that since the first depositional event, this area was characterised by an indented landscape. This evidence renders the hypothesis of a TPL formation subsequent to the first depositional event problematic, since the condition for a base level stable during a long time span in the TPL area (characterised, on the contrary, by unstable slopes and basin areas with lacustrine deposition), cannot be easily satisfied.

Similar conclusions may be drawn for the other two above mentioned TPLs (Mt. Marine and Anzano) and for this reason, following the hypothesis by Galadini et al. (2003) we put the TPL remnants before the first depositional event in Fig. 3.

CONTINENTAL STRATIGRAPHY OF SOME INTERMONTANE BASINS

In the sections below, a short summary of the continental stratigraphy related to the basins we investigated is proposed.

Turano Valley
Reference studies: Melchiorri (1987); Bosi (1989); Galadini et al. (2003).

The middle-upper Turano valley was a closed basin during the first continental depositional event, as indicated by the presence of lacustrine deposits. During most of the Quaternary, however, this area was drained and the old lacustrine deposits eroded. These deposits represent the lower portion of the first unit ("Santa Croce" in Fig. 3; see also Fig. 2) and are mainly made of sandy-silty deposits (Fig. 4A) with sparse arenaceous and carbonate pebbles (Melchiorri, 1987; Bosi, 1989). The lithology of fine sediments indicates a deposition fed by the Miocene clayey-arenaceous flysch extensively outcropping in the investigated area.

The upper stratigraphic horizons are, instead, made of conglomerates with mainly arenaceous and secondarily carbonate pebbles (Fig. 4B), alternating with sands and silts. Close to the valley flanks, the presence of large boulders and blocks both arenaceous and cal-

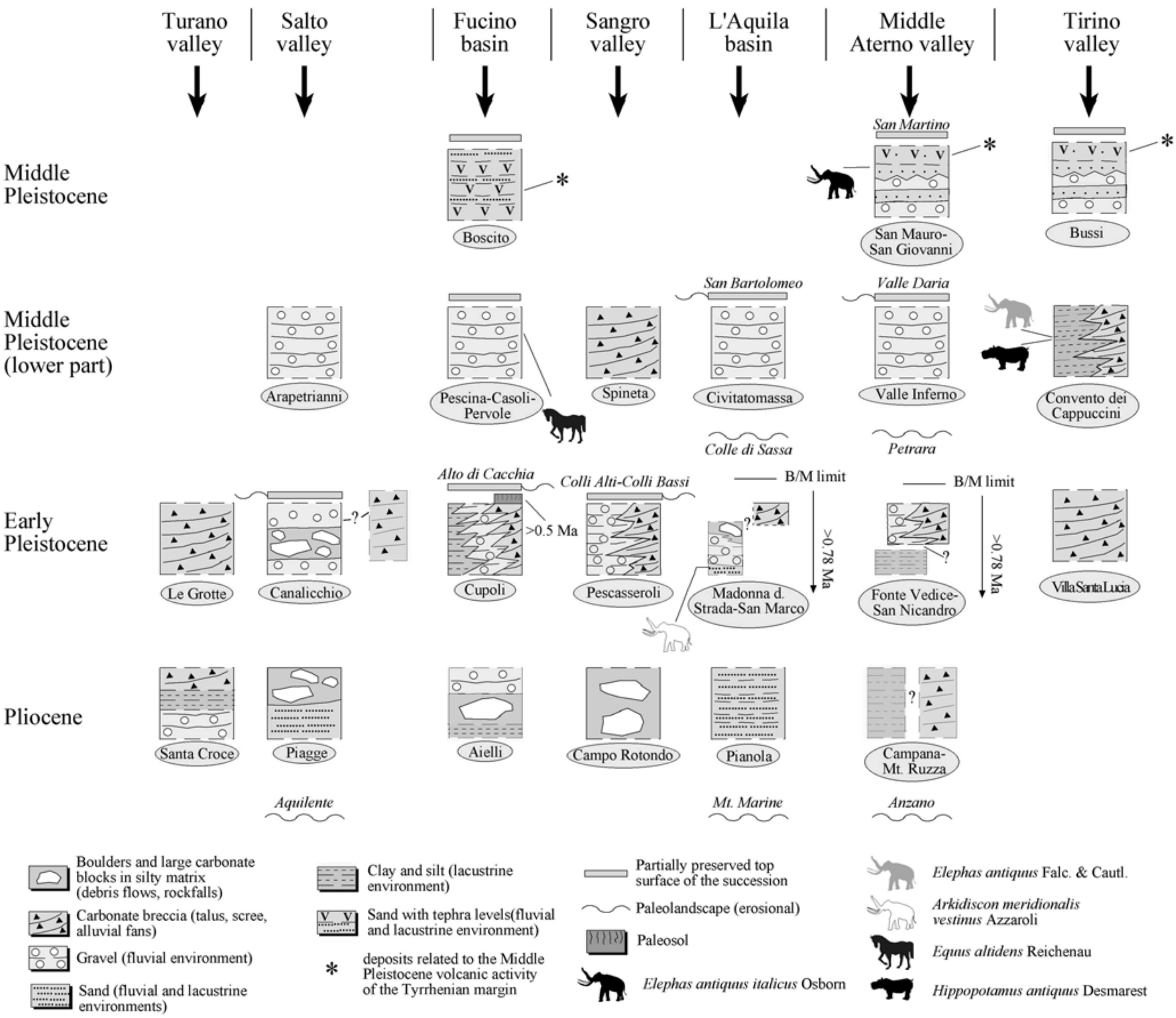

Fig. 3 - Stratigraphic scheme (and morphological features related to the main erosional landscapes and top depositional surfaces) of the Latium-Abruzzi Apennines. The available chronological constraints (bio-chronological data, volcanic deposits, paleomagnetic data) have been summarised.

careous indicate instability phenomena along the basin borders during the deposition of the Santa Croce unit.

The uppermost deposits of this unit are represented by carbonate slope-derived breccias conformably covering the mainly clayey-arenaceous deposits. These breccias define a modification of the landscape in the investigated area, since it was initially characterised by slopes mainly carved into the clayey-arenaceous flysch and subsequently (until the Present) characterised by more indented slopes carved into the carbonate bedrock. The entire Santa Croce unit generally displays layers dipping towards N or NE (Fig. 4A), i.e. the deposits are evidently tilted as a result of the activity of the NW-SE normal fault bordering the depression to the NE (Melchiorri, 1987; Galadini *et al.*, 2003). The thickness of the preserved deposits related to this unit can be estimated in about 200 m.

The second unit ("Le Grotte" in Fig. 3; see also Fig. 2) is entirely made of carbonate slope-derived breccias, with layers dipping towards the valley, unconformably covering the older unit. The breccias are made of angular-to-sub-rounded carbonate pebbles usually in pink-orange matrix, sometimes characterised by an open-work texture. This unit is made of the typical slope-derived breccias outcropping along many slopes of the central Apennines. The thickness does not exceed several tens of metres (Melchiorri, 1987; Galadini *et al.*, 2003).

Salto Valley
Reference studies: Bertini and Bosi (1976); Bertini et al. (1986); Mariotti and Capotorti (1988); Bosi et al. (1989); Galadini and Messina (2001); Galadini et al. (2003).

Similarly to the previously described basin, also the middle Salto valley was characterised by the presence of a lacustrine environment during the deposition of the local first unit ("Piagge" in Fig. 3; see also Fig. 2). After the deposition of this unit, however, the basin was drained and a large part of the lacustrine deposits was eroded. Presently, the Salto river incides the marine substratum made of Miocene flysch.

The oldest geomorphic feature detected in the Salto valley area is represented by the remnants of a top paleolandscape ("Aquilente" in Fig. 3) at 1,350÷1,450 m a.s.l. It is a flat and sub-horizontal erosional landscape which formed during a phase of stability of the base level, in a geomorphic framework completely different from the present one (Galadini *et al.*, 2003).

The oldest unit outcropping in this area ("Piagge" in Fig. 3) defines a geological evolution similar to that of the Turano valley. This unit is mainly made of fine sands and silty sands whose lithological characteristics indicates a lacustrine deposition. The pebbles of the gravel horizons are mainly arenaceous in the lower part of the succession and become more and more rich of carbonate pebbles towards the upper part. In the middle part of the succession, a several-m-thick horizon containing arenaceous boulders of tens of cubic metres (Fig. 5A) was detected by Bosi *et al.* (1989). This portion defines instability phenomena along the borders of the sedimentary basin. It is clear, indeed, that the presence of big boulders is anomalous within the lacustrine depositional environment. The thickness of the preserved deposits related to the Piagge unit is larger than 300 m. Outcrops of this unit have been observed between about 700 and 1000 m a.s.l. in the Fiamignano area.

The second unit ("Canalicchio" in Fig. 3; see also Fig. 2) is made of a thick succession of carbonate gravels and conglomerates. Sometimes, 10-m-thick layers consisting of rounded arenaceous boulders (diameter 30÷40 m) are present. The matrix in these cases has a sandy (fed from arenaceous rocks) and pebbly (carbonate pebbles) grain size. The thickness of the outcropping deposits is about 400 m (Bosi *et al.*, 1989). Other horizons containing boulders have been observed in the lower part of the succession ("Strati di Concerviano" in Bosi *et al.*, 1989). The boulders (several cubic metres) are both arenaceous and calcareous. Slope-derived breccias in the Fiamignano area (Fig. 5B) can also be related to the second depositional event. Remnants of a flat and horizontal surface overlaying the Canalicchio unit have been observed at places in the northern sector of the depression. They have been interpreted as faintly re-modelled remnants of the original depositional top surface.

The third unit ("Arapetrianni" in Fig. 3; see also Fig. 2) is entirely made of well layered gravels with

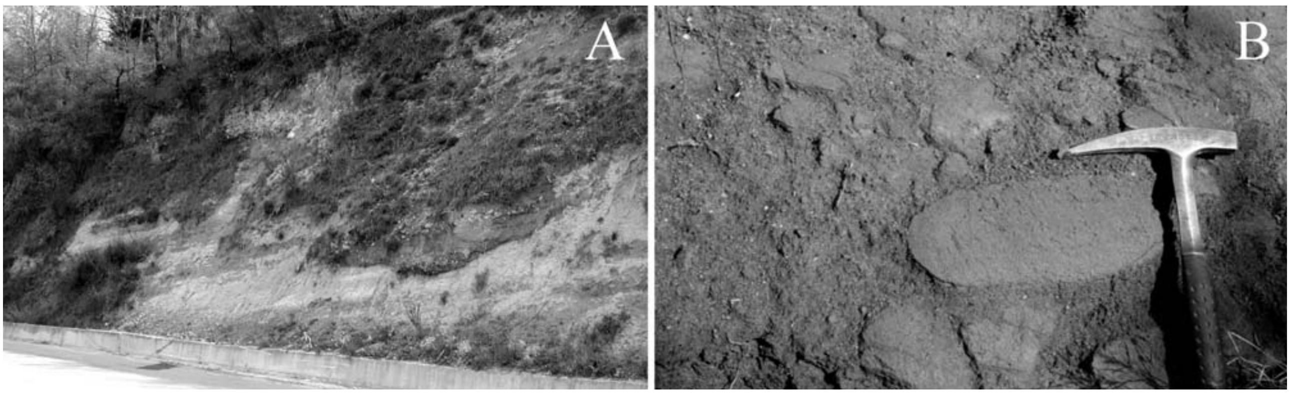

Fig. 4 - A) Layered sands and silts of the first depositional units in the Turano valley ("Santa Croce" in Fig. 3); the deposits have been tilted (towards NE) as a result of the tectonic activity of the fault bordering the basin; B) Sedimentological characteristics of the pebbly portion of the first depositional event (Turano valley); pebbles and matrix derived from the erosion of the Miocene clayey-arenaceous flysch.

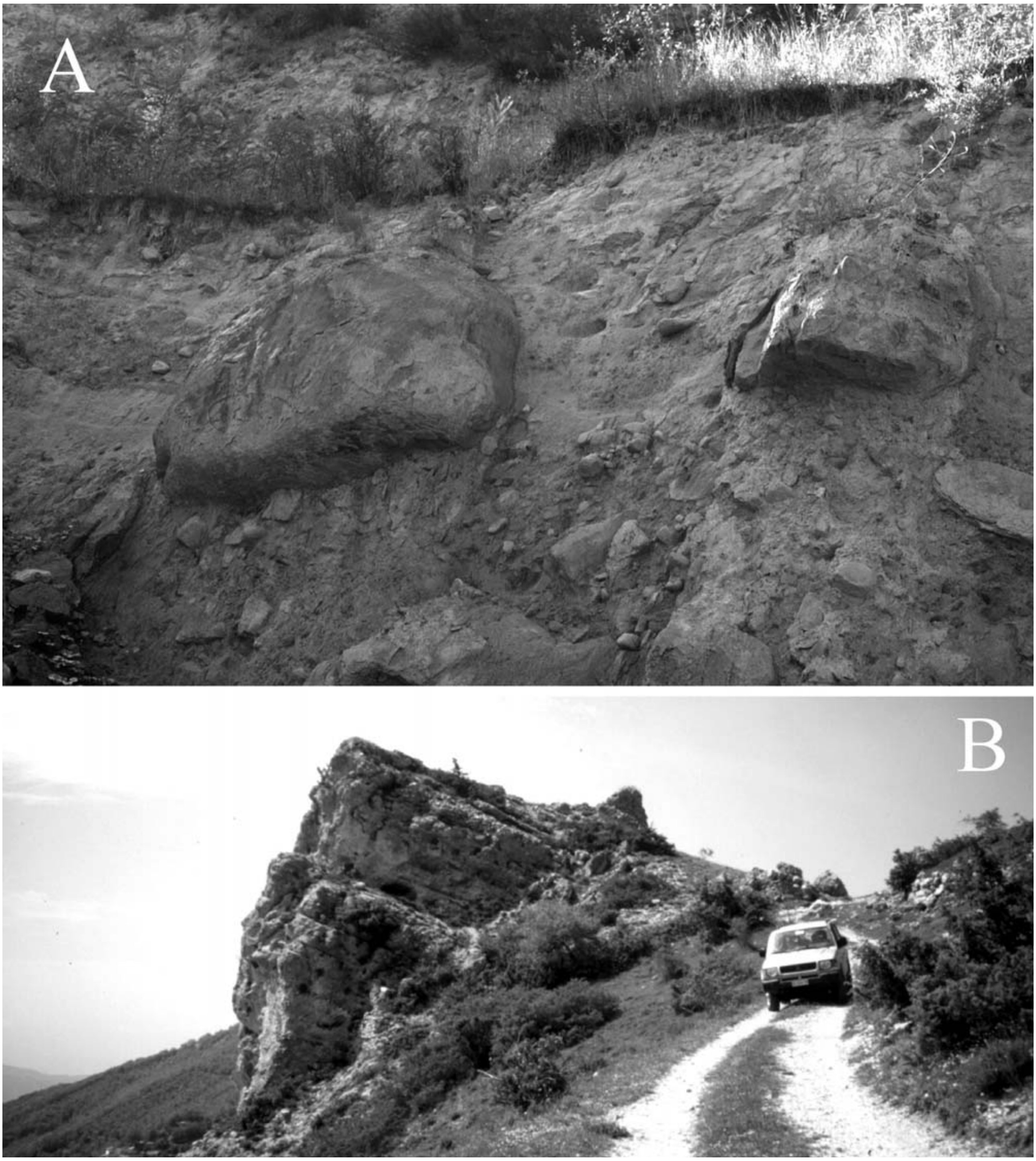

Fig. 5 - A) Arenaceous blocks in sandy matrix related to the first depositonal unit of the Salto valley ("Piagge" in Fig. 3); B) Layered slope-derived breccias of the second depositional unit in the Salto Valley; the breccias are presently dipping into the slope as a result of tilting due to gravitational phenomena.

mainly carbonate pebbles. These deposits, outcropping in the area of the Arapetrianni village, are characterised by a thickness of several tens of metres. Ongoing investigations will provide more detailed stratigraphic and sedimentological information on this unit.

Fucino Plain

Reference studies: Beneo (1939); Demangeot (1965); Raffy (1970 and 1983); Nijman (1971); Accordi (1975); Bertini and Bosi (1976); Zarlenga (1987); Bosi and Messina (1990); Blumetti et al. (1993 and 1997); Galadini and Messina (1994); Bosi et al. (1995 and 1999); Messina (1996); Cavinato et al. (2002).

The Fucino Plain has been investigated by researchers of different institutions during time (Fig. 6). Most of the works have been made in the neotectonic perspective, to evaluate the history of the vertical movements in sectors separated by Plio-Quaternary faults or to define the recent structural evolution. The large number of available studies (whose conclusions in stratigraphic terms are summarised in Fig. 6) is due to the fact that the continental deposits in the Fucino area outcrops much more extensively than in other central Apennine intermontane basins. This is a paradox if one considers that the Fucino basin is the only presently closed depression among the basins investigated in the present paper, that is the erosion of a river has not entrenched the continental deposits. Indeed, the structural framework of this area, with parallel normal faults which isolate "slices" of continental deposits and suspend them over the present plain bottom, is the main cause for the "visibility" of the Plio-Quaternary deposits.

We took stratigraphic information on the Fucino basin from the works by Bosi *et al.* (1995 and 1999), although a more recent work is available (Cavinato *et al.*, 2002). The authors of the latter work, indeed, do not

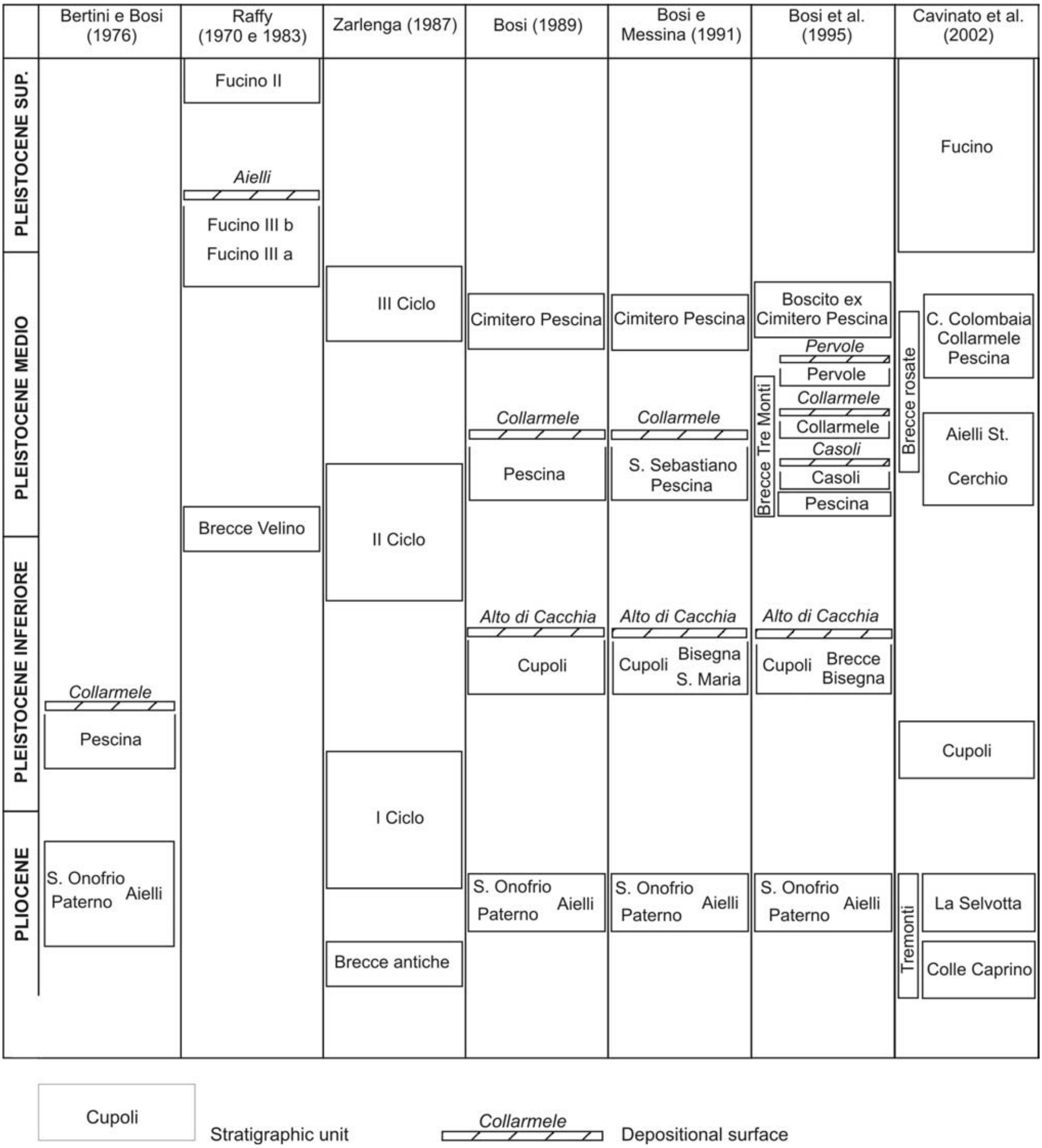

Fig. 6 - Schematic representation of the available knowledge on the Fucino stratigraphy according to the different works.

take into account the evidence of erosional phases which are clearly recorded in the Fucino landscape as remnants of extended erosional paleosurfaces carved into the continental deposits (see section dedicated to the general stratigraphic scheme for a discussion). This limits the use of the stratigraphic data in the perspective of the continental geological evolution and, in practical terms for our paper, does not permit to give a picture of the Fucino stratigraphy comparable to that of the other basins.

The oldest unit ("Aielli" in Fig. 3; see also Fig. 2) outcropping in the Fucino area (mainly along the northern basin border) is made of clays, silts and sands of greyish and yellowish colour (Fig. 7A), mainly related to a lacustrine environment. Outcrops of the basal horizons have been observed at 750 m a.s.l. in the Aielli area. As in the previous cases, the lithology reveals that deposition was fed by the Miocene flysch. In the middle part of the succession (900 m a.s.l.), the percentage of gravel layers increases. The gravels are mainly made of carbonate pebbles (subordinately arenaceous pebbles) in sandy matrix. The upper part of the succession is made of breccias laterally transient to gravels, sands and layered silts dipping towards NNE. The breccias contain carbonate blocks with volume up to hundreds of cubic metres. The presence of million-cubic-metres blocks defines significant instability of the slopes close to the basin at the time of the first unit deposition. The uppermost portion of the succession is exposed at about 1,050 m a.s.l., north of the Aielli village. The thickness of the outcropping deposits is about 400 m.

The second unit ("Cupoli" in Fig. 3), embedded in the older one (Fig. 2) is exposed between Celano and Aielli and along the eastern basin border. It consists of gravels intercalated with sands and, more rarely, with silty-clayey horizons. Whitish silts outcropping between Collarmele and Pescina, unconformably covering the Pliocene deposits and underlaying the Pescina unit, have been attributed to the Cupoli unit by Bosi *et al.* (1995). The depositional environment is lacustrine and fluvial. The maximum thickness of the outcropping deposits is about 120 m. In the area of Cupoli, a flat and sub-horizontal surface ("Alto di Cacchia" in Fig. 3) is carved into the uppermost portion of this unit (Fig. 7B). This surface probably represents a faintly modified remnant of the original depositional top surface. Faults affecting the deposits related to the Cupoli unit and the tilted geometry of the whitish silts along the eastern basin border define the significant tectonic activity experienced by the sediments of the second unit.

When the deposition related to the second unit occurred within the basin, the "Bisegna breccias" (Bosi and Messina, 1990) deposited along the slopes (Fig. 7C). The breccias are the typical product of the slope deposition related to the second unit in all the basins discussed in the present paper. They are made of carbonate angular pebbles in pink-orange sandy-silty matrix, are well layered and usually dipping towards the basin or characterised by a sub-horizontal attitude. The main outcrops of breccias have been detected along the southern slope of the Tre Monti relief, the southern slope of the Magnola Mts. and the left flank of the

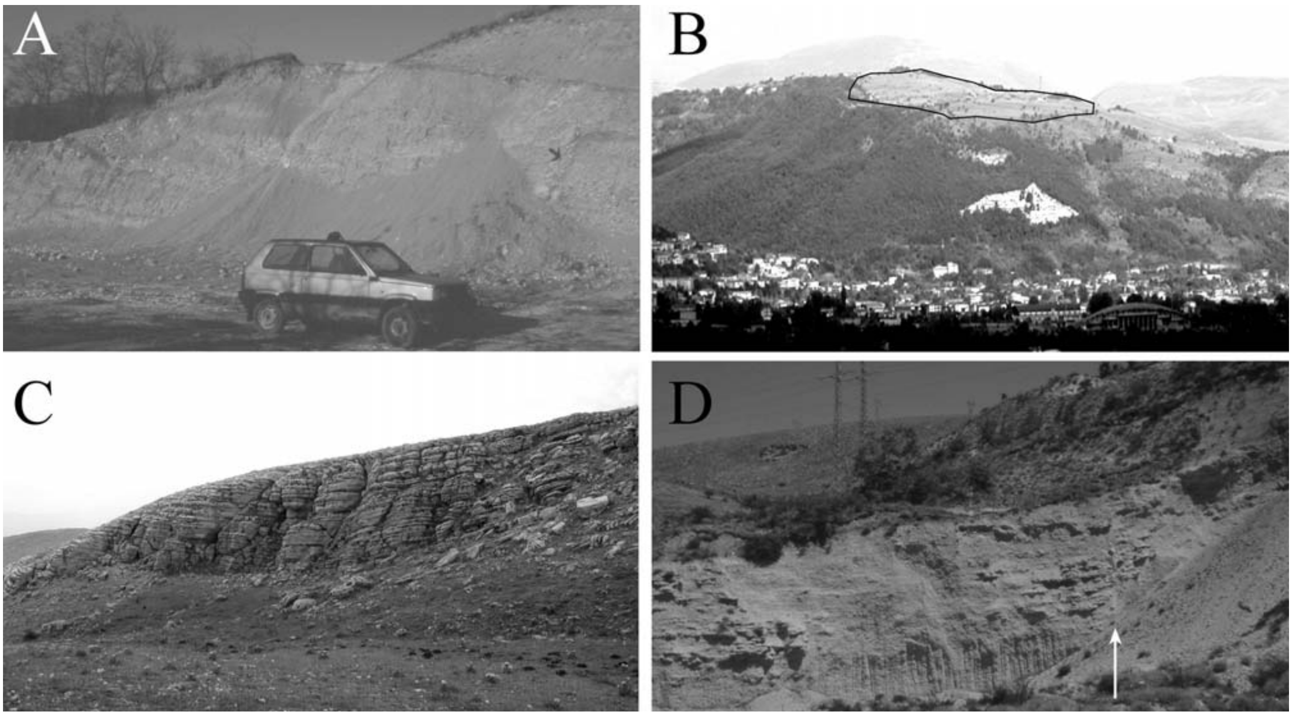

Fig. 7 - A) Alternating sands and gravels of the upper portion of the first depositional unit ("Aielli" in Fig. 3) in the Fucino basin (photograph taken at the beginning of the 90s at the southern entry of Aielli); B) Panoramic view (from WNW) of the Cupoli hill, entirely carved into the gravels and silts of the second depositional unit; the top of the hill (encircled by the black line) roughly correspond to the depositional top surface of the deposits; C) Slope-derived breccias of the Fucino second depositional unit, along the southern slope of the Magnola Mts. (northern border of the Fucino basin); D) Layered gravels of the Fucino third depositional unit ("Pescina-Casoli-Pervole" in Fig. 3) along the Giovenco valley (eastern border of the Fucino basin); the white arrow indicates a fault affecting the gravels.

Celano gorge. A mature red paleosol developed over the "Bisegna breccias" along the southern slope of the Tre Monti relief. The maturity of the paleosol and the comparison with similar soils in other parts of the Apennines suggest an age of several hundreds thousand years (Magaldi, pers. com.).

The third unit ("Pescina" in Fig. 3), embedded in the second one (Fig. 2), is prevalently made of carbonate gravels outcropping along the eastern basin border (Fig. 7D). The sedimentological characteristics define a fluvial environment ("braided stream"). The maximum thickness of the outcropping deposits is about 50 m. A fragment of *Equus altidens* Reichenau has been found within this unit by Blumetti *et al.* (1997) in a pedogenized reddish soil sediment. This remains permits to relate the deposits to the early-middle Middle Pleistocene. Stratification is generally sub-horizontal or slightly dipping into the slope as a result of the tectonic tilting. The tectonic suffered by this unit (Fig. 7D) is also indicated by the fault planes detected in the gravels by Bosi *et al.* (1995). The depositional top of the Pescina unit is not preserved and the layers are truncated by erosional surfaces at about 870 m a.s.l. At lower elevations, in the same area where the Pescina deposits have been identified, slightly younger deposits have also been detected by Bosi *et al.* (1995) and Messina (1996), included in the Pescina unit in the scheme of Figure 3. These deposits have been reported as "Casoli", "Collarmele" and "Pervole Formations" in the mentioned papers. They consist of gravels and sands of fluvial origin; their depositional top surfaces are, in these cases, well preserved.

The fourth unit ("Boscito" in Fig. 3; see also Fig. 2) marks the beginning of the volcanic deposition in the Fucino basin. It consists of sands rich of volcanic minerals and subordinately carbonate gravels of fluvial origin. It can be related to the Middle Pleistocene on the basis of the chronological data on the beginning of the most recent volcanic phase in central Italy (Fornaseri, 1985; Narcisi and Sposato, 1989; Barbieri *et al.*, in press).

Sangro Valley

Reference studies: Colacicchi (1967); AA.VV. (1986); Galadini and Messina (1990, 1993a, 1993b); Galadini et al. (1998); Pace et al. (2002).

The oldest unit of the Sangro Valley outcrops along the southern margin of the Pescasseroli basin ("Campo Rotondo" in Fig. 3; see also Fig. 2) between 1,200 and 1,450 m a.s.l. It is made of carbonate cobbles and boulders (Fig. 8A) with dimensions up to some cubic metres and directly overlays the marine substratum. Fieldwork permitted to identify few blocks with dimensions up to 40÷50 cubic metres. The thickness of the preserved deposits related to this unit is about 60÷70 m. The deposition is due to large landslide episodes related to landscapes which are no more preserved (Galadini and Messina, 1990). The mentioned authors also mapped some NW-SE faults responsible for the displacement of the Campo Rotondo unit.

The second unit ("Pescasseroli" in Fig. 3; see also Fig. 2), embedded in the older one, is made of gravels and conglomerates laterally transient (towards the valley flanks) to slope-derived breccias (Figs. 8B, C and D). Few layers of sands and silts have been detected within the carbonate gravels. The attitude is generally sub-horizontal (Fig. 8D); grading is both normal and reverse (Galadini and Messina, 1993a).

The breccias are made of carbonate angular pebbles and cobbles and are characterised by a varied degree of cementation. The calcareous sandy matrix has often a pinkish colour. Layers are generally dipping towards the valley and present a sub-horizontal attitude in the area of transition to the gravels (Galadini and Messina, 1993a). The lithological characteristics and the stratigraphic position within the continental succession of the Sangro basin permits to correlate these breccias with the second unit breccias extensively outcropping in other basins of the central Apennines.

The Pescasseroli unit is characterised by a maximum thickness of 140÷150 m. Remnants of the depositional top surface are sporadically preserved at elevations between 1,460 and 1,470 m a.s.l. The described unit is clearly affected by tectonic displacements. The most evident effect of the recent tectonic activity is represented by the 60÷120 m high fault scarp separating the Colli Alti and the Colli Bassi areas, close to Pescasseroli (Fig. 8B). The fault scarp is entirely carved into the gravels and conglomerates of the described unit.

The third unit ("Spineta" in Fig. 3; see also Fig. 2) is entirely made of slope-derived carbonate breccias, with angular pebbles of dimension up to 20 cm, in carbonate sandy matrix of generally whitish colour. The thickness does not exceed 10 m.

Since direct chronological constraints for the described units are lacking, their position in the chronological framework of Figure 3 has been defined by correlating the Sangro Valley deposits with those of the Fucino area (Galadini and Messina, 1993a). Correlation has been based on the comparison of the Quaternary geological history of the two adjacent basins. As usual, the slope-derived breccias of the Early Pleistocene, due to their deposition along most of the central Apennine slopes, represent a fundamental unit for the definition of chronological constraints.

Continental deposits have also been detected in the southern part of the upper Sangro valley. They mainly consists of slope-derived breccias outcropping along the southern slope of Mt. Greco (AA.VV., 1986; Pace *et al.*, 2002). Most of the breccias mapped in AA.VV. (1986) in this area can be attributed to the second unit. On the basis of the work by Pace *et al.* (2002) it is clear, however, that also more recent slope deposits outcrop. Ongoing investigations by the authors of the present paper will define a detailed stratigraphy for this sector.

L'Aquila basin

Reference studies: Demangeot (1965), Bosi (1989); Blumetti et al. (1996); Messina et al. (2001).

The oldest geomorphic feature preserved in the L'Aquila basin (corresponding to the area of the upper Aterno valley) is represented by the remnants of a flat and sub-horizontal TPL, at elevations between 1,400 and 1,500 m a.s.l. It is carved into the Meso-Cenozoic carbonate succession and the clayey-arenaceous flysch of Miocene age. The major remnants of the paleolandscape are preserved in the footwall of the Mt. Marine fault. Considering the large extension of the Mt. Marine TPL and therefore the evidence for its formation during a phase of stability of the regional base level (i.e. when

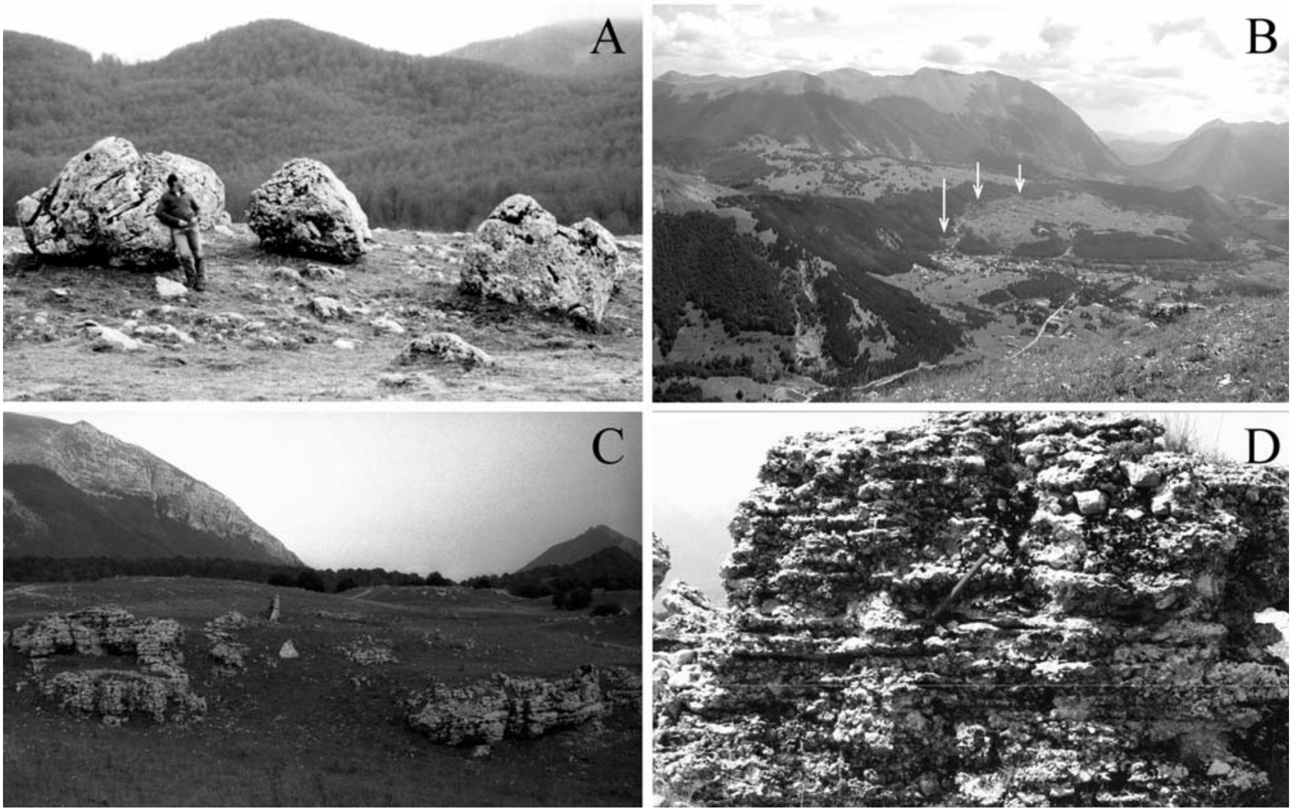

Fig. 8 - A) Blocks of the first depositional unit of the upper Sangro valley (Campo Rotondo area, Pescasseroli basin); B) Panoramic view (from north) of the Pescasseroli basin (upper Sangro valley); most of the depression is filled by gravels and conglomerates of the local second depositional unit ("Pescasseroli in Fig. 3); the white arrows mark the base of the scarp affecting the Colli Alti-Colli Bassi area, resulted from the activity of a fault which displaced the top depositional surface of the sediments; C) View of the conglomerates of the second depositional unit and of the landscape roughly corresponding to the top depositional surface in the Colli Alti area (eastern Pescasseroli basin, upper Sangro valley); D) Detail of the sub-horizontal conglomerates of the second depositional unit in the upper Sangro valley; carbonate pebbles are angular, indicating a proximity to the slope.

a local basin was not present), we believe that the L'Aquila basin formed as the result of the Mt. Marine TPL displacement, according to models already published in Basili *et al.* (1999) and Galadini *et al.* (2003).

The oldest unit ("Pianola" in Fig. 3; see also Fig. 2) outcrops south of the L'Aquila basin and is made of layered sands and silts of prevalently lacustrine origin. The mineralogical composition is represented by abundant quartzose, plagioclase and muscovite granules which indicate that the deposition of this unit was fed by the Miocene flysch. The investigated outcrops showed that the deposits are intensely deformed, as indicated by the number of outcrop-scale faults and by the attitude of the layers, suggesting a tilting of 15÷20° towards north. Sandy-silty deposits (intercalated with gravels) have been paleomagnetically analysed in the northernmost sector of the L'Aquila basin (area of Barete). The analysis defined a normal polarity (Messina *et al.*, 2001). Since these sediments represent the oldest unit of the area, the mentioned authors hypothesised an age older than 1,770 Ma, thus providing evidence for the presence of Pliocene deposits in the upper Aterno valley.

The second unit ("Madonna della Strada-San Marco" in Fig. 3; see also Fig. 2) can be detected between 680 and 1,010 m a.s.l. and is made of alternating silts and sands in the lower part and gravels (coarsening upward) in the upper part. The *Arkidiscon meridionalis vestinus* Azzaroli was found in the lower part of this unit (Azzaroli, 1977).

This unit is probably ("question mark" in Fig. 3) laterally transient to slope-derived breccias which extensively outcrop along the northern portion of the Mt. Pettino fault ("San Marco breccias", Fig. 9A). This hypothesis is not based on direct field observation but on the similarity of the L'Aquila basin stratigraphy with that of the other basins where the lateral transition from basinal to slope-derived breccias was observed in the field.

Paleomagnetic analyses sho-wed a reverse magnetic polarity for the breccias, thus indicating an age older than the Bruhnes-Matuyama li-mit (0.78 Ma) (Messina *et al.*, 2001). Similar results have been obtained from paleomagnetic analyses on the alluvial succession of the Cona della Croce excavation (Fig. 9B), south of Arischia (Messina *et al.*, 2001). These deposits have been related to the second depositional event by the mentioned authors.

Two different erosional surfaces (preserved as remnants in the landscape of the L'Aquila basin) are carved into the deposits of the second unit. The remnants of the highest and oldest surface ("Colle di Sassa" in Fig. 3) can be detected at 800÷900 m a.s.l., while the lowest surface ("San Bartolomeo" in Fig. 3) is preserved at 775÷800 m a.s.l. (Fig. 9C).

The third unit ("Civitatomassa" in Fig. 3; see also Fig. 2) is made of gravels related to a fluvial depositional environment. The top depositional surface of this unit is preserved at places (at 730÷740 m a.s.l.) and it may be correlated (on the basis of the altitude and of the relationship with the other, older and younger, paleosurfaces exposed in the area) with the above mentioned erosional surface of "San Bartolomeo" (Fig. 9C).

Part of the successions described by Blumetti *et al.* (1996) for this area are related to the Madonna della Strada unit. They are mainly made of sands and gravels, while the Colle Macchione succession (about 25 m thick), mainly consists of "megabreccias" with carbonate blocks of several cubic metres overlaying sandy silts of lacustrine origin. The authors defined a debris flow origin for the "megabreccias". Younger sediments have also been found in the 15-m-thick Case Buccella succession, made of gravels (with cut-and-fill structures) alternating with sands. The presence of abundant volcanic minerals may indicate a Middle Pleistocene age (on the basis of the chronology of the central Italy volcanic activity). These sediments may represent a local fourth unit. The lack of conclusive data on this point, i.e. the impossibility to exclude that these deposits are significantly more recent than the beginning of the volcanic activity, presently prevent the representation in Figure 3.

Middle Aterno Valley
Reference studies: Demangeot (1965); Bosi and Bertini (1970); Bagnaia et al. (1989); Bertini et al., (1989); Galadini and Giuliani (1991); Bertini and Bosi (1993); D'Agostino et al. (1994 and 1997).

As in the case of the previously described basin, also in the Middle Aterno area remnants of an old TPL ("Anzano" in Fig. 3) have been detected at about 1,400÷1,500 m a.s.l. The TPL is carved into the marine carbonate substratum and is suspended of about 1,000 m over the Aterno depression. Since all the outcropping deposits and the related geomorphic features (both erosional and depositional top surfaces) are embedded into the TPL, the latter is the oldest geomorphic feature detectable in the investigated area (Galadini *et al.*, 2003).

The oldest deposits detectable in the area of the middle Aterno valley ("Campana" unit in Fig. 3) have been observed in the lowest sector of the tectonic depression which formed in the area between San

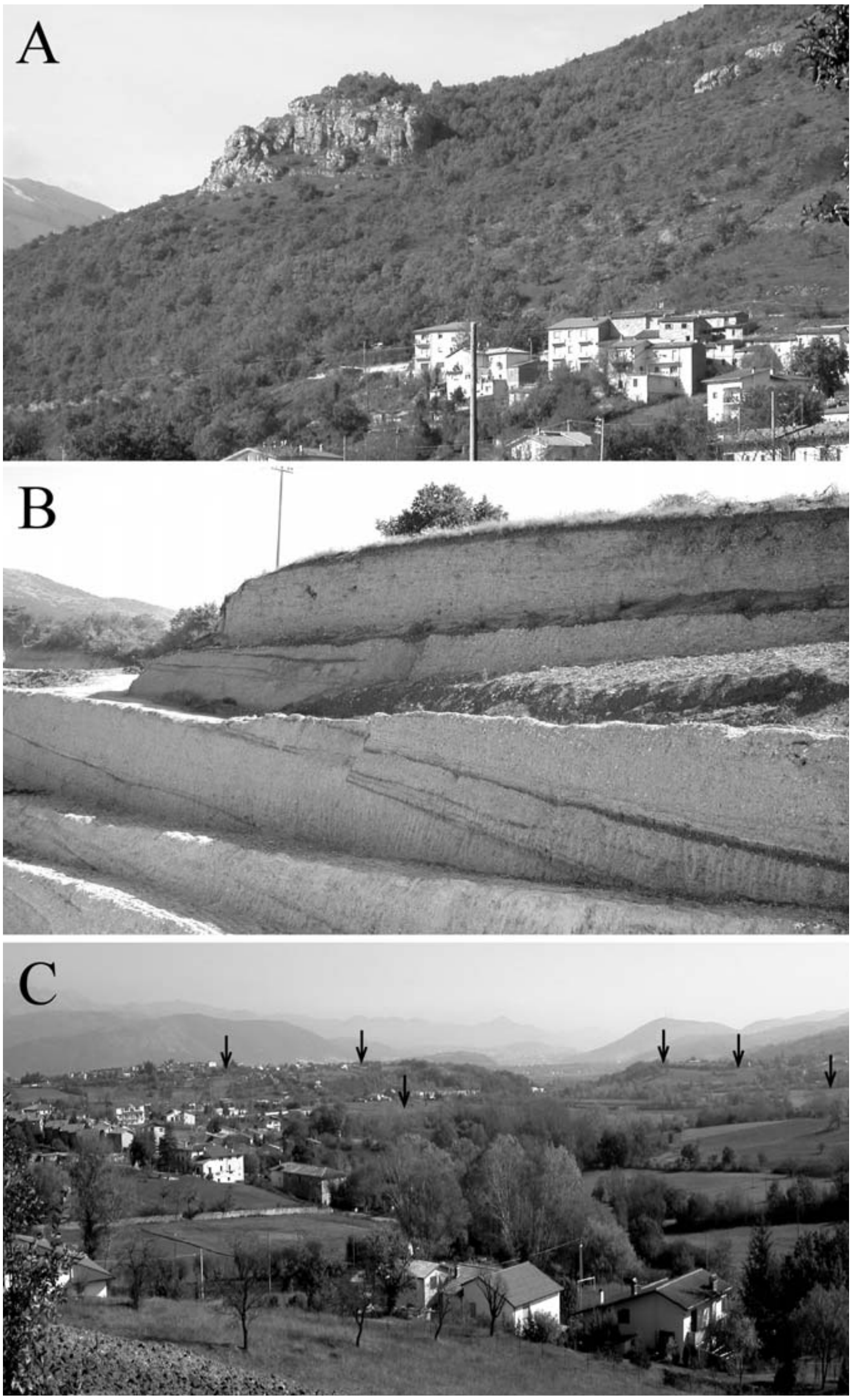

Fig. 9 - A) Panoramic view of the San Marco area (L'Aquila basin, upper Aterno valley); outcropping rocks are made of cemented slope-derived breccias of the second depositional unit; paleomagnetic analyses indicate an age older than the limit Bruhnes-Matuyama (0.78 Ma); B) Gravels, sands and silts of alluvial origin, related to the second depositional unit, in the Arischia area (excavation of Cona della Croce; upper Aterno valley); also in this case the paleomagnetic analysis gave an age older than the limit Bruhnes-Matuyama (0.78 Ma); C) Panoramic view from Scoppito towards south (L'Aquila basin, upper Aterno valley); the arrows indicate the remnants of the San Bartolomeo surface, roughly corresponding to the depositional top of the third depositional unit.

Demetrio ne' Vestini and Barisciano. Similarly to other investigated basins, the lithology of this unit, mainly made of sands, indicates a deposition fed by the Miocene flysch.

About 6 km north of Barisciano, in the area of Mt. Ruzza, slope derived breccias outcrop extensively. The cemented breccias are displaced and affected by fault scarps. The deposition occurred over the Anzano TPL and the sub-horizontal attitude indicates that it affected an area with scarce relief energy. This means that the breccias deposited before the formation of the Middle Aterno Valley depression, whose bottom is located about 1,000 m below the Anzano TPL. Although these breccias represent the oldest depositional episode in the area where the Anzano TPL is preserved, the relationship with the sands of Campana cannot be defined. Similarly to other basins, the Mt. Ruzza breccias may represent the typical product of deposition in slope areas in a period during which the innermost portion of the basin was characterised by the deposition of the sands of Campana.

In the second unit ("Fonte Vedice-San Nicandro" in Fig. 3; see also Fig. 2) we put different sub-units. The oldest sub-unit is represented by the San Nicandro whitish silts (Bosi and Bertini, 1970; Bertini and Bosi, 1993), related to a lacustrine environment. The silts are well layered, sometimes laminated and affected by significant tectonic deformation indicated by the numerous outcrop-scale faults which can be detected in the investigated area and by the tilted geometry of the layers (Fig. 10A). Paleomagnetic analyses made on the San Nicandro silts defined a reverse magnetic polarity (Speranza pers. com.) which indicates an age older than the Bruhnes-Matuyama limit (0.78 Ma). These silts are laterally transient to slope derived breccias made of angular to sub-angular carbonate pebbles and cobbles (Fig. 10B) in carbonate sandy matrix ("Valle Valiano Formation" in Bertini and Bosi, 1993). The breccias are well layered and usually (when not affected by tectonics) dip towards the Aterno basin.

The "Fonte Vedice Breccias" represent a younger sub-unit made of the typical cemented carbonate breccias with orange-pink matrix widely outcropping in the entire Abruzzi region (Bertini *et al*., 1989). D'Agostino *et al*. (1997) defined a reverse paleomagnetic polarity which suggests an age older than 0.78 Ma. The breccias can be detected along the slopes bordering minor depressions between the Barisciano sector of the middle Aterno valley and the Gran Sasso chain (Bertini *et al*., 1989). According to Bertini and Bosi (1993), these breccias are laterally transient to conglomerates of fluvial origin ("Valle Colle Formation" in Bertini and Bosi, 1993) in the area WNW of Barisciano.

Extended remnants of an erosional paleosurface ("Petrara" in Fig. 3) is carved into the deposits of the second unit (San Nicandro silts, Valle Valiano breccias) and into the carbonate units of the marine substratum (Bertini and Bosi, 1993).

The third unit ("Valle dell'Inferno" in Fig. 3; see also Fig. 2), embedded in the second one, is made of well-layered gravels and conglomerates intercalated with silty-sandy levels (Fig. 10C). This unit sometimes covers lens-shaped levels of a reddish soil sediment, similar to that previously mentioned in the Fucino basin, which gave the remains of *Equus altidens* Reichenau. Its top depositional surface is preserved in many places ("Valle Daria" in Fig. 3; Fig. 10D) and is laterally transient to an erosional paleosurface carved into the marine substratum.

The fourth unit of the middle Aterno valley ("San Mauro-San Giovanni" in Fig. 3; Bertini and Bosi, 1993), is made of carbonate gravels and sands in the lower part ("San Giovanni Formation" in Bertini and Bosi, 1993). The upper part ("San Mauro Formation" in Bertini and Bosi, 1993) is made of gravels and sands passing upward to sands intercalated with tuffite levels and layers rich of mammal bones. A peculiar aspect is represented by the abundance of tephra levels which, instead, are completely absent in all the preceding units. The youngest phase of volcanic activity in central Italy began during the Middle Pleistocene (Fornaseri, 1985; Narcisi and Sposato, 1989; Barbieri *et al*., in press) and this age is usually attributed to the oldest continental deposits showing abundant tephra levels in the central Apennines (see Bertini and Bosi, 1993 for the specific case of the Middle Aterno valley). This age is also consistent with the *Elephas antiquus italicus* Osborn reported in Maini (1956) and found in the upper portion of the fourth unit.

The depositional top surface of the fourth unit (San Martino in Fig. 3) is sparsely preserved throughout the investigated area.

Tirino Valley

Reference studies: Bosi and Locardi (1991); Giuliani and Sposato (1995).

Differently from the previously mentioned basins, no evidence of deposits which may be related to the first depositional event has been found in the depressions of the Tirino valley (Fig. 11A). The oldest deposits of the local succession, indeed, are represented by the slope-derived breccias ("Villa Santa Lucia" in Fig. 3; see also Fig. 2) lithologically comparable to the second event breccias extensively outcropping in the central Apennines and directly overlaying the marine substratum (Fig. 11B). These breccias are made of carbonate angular pebbles in sandy matrix characterised by the typical pink-orange colour. They are layered and usually dip towards the basin (Fig. 11B). Outcrops of breccias have been found between 600 and 1,100 m a.s.l., sometimes with evidence of tectonic displacements (Giuliani and Sposato, 1995; Fig. 11B).

A younger unit ("Convento dei Cappuccini" in Fig. 3), embedded in the older one (Fig. 2), is made of whitish silts of lacustrine origin laterally transient (towards the basin borders) to slope-derived carbonate breccias. The silts are layered, sometimes laminated. Sparse layers of sands and gravels have also been detected (Giuliani and Sposato, 1995). In the area of Bussi Officine, remains of *Elephas antiquus* Falc. & Cautl. and *Hippopotamus antiquus* Desmarest have recently been found. This paleontological association define an age related to the lower part of the Middle Pleistocene (Petronio, pers. com.). The area of these findings is very important since it represents the zone of transition from the Tirino basin to the Sulmona basin.

According to Giuliani and Sposato (1995), the whitish silts observed in a borehole (made in the Tirino plain) up to 150 m below the ground surface may be related to the Convento dei Cappuccini unit. Outcrops

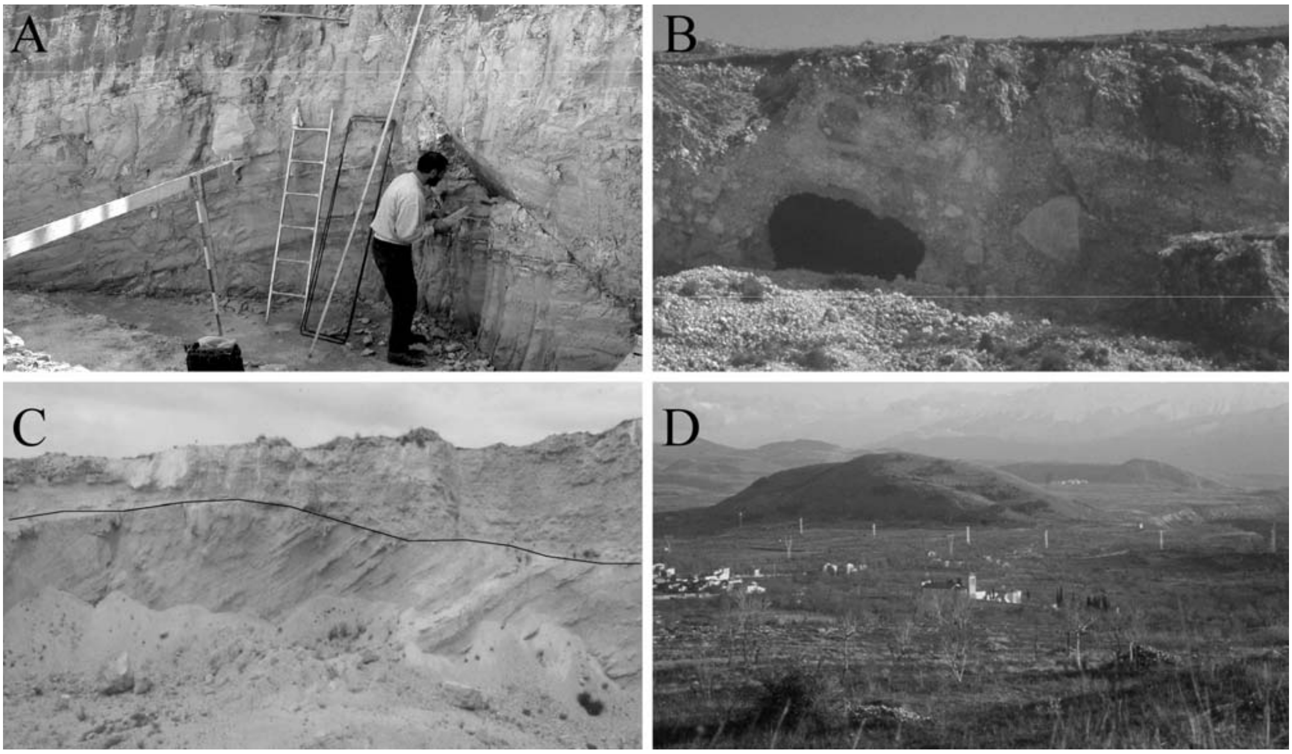

Fig. 10 - A) Carbonate silts of lacustrine origin related to the second depositional unit of the middle Aterno valley; the silts have been tectonically tilted and are affected by a fault passing close to the head of the geologist (photograph taken at San Pio delle Camere, in a temporary excavation); B) View of the "Valle Valiano Breccias", second depositional unit, along the road between Barisciano and Santo Stefano di Sessanio (middle Aterno valley); note the huge block exposed in the central part of the photograph; C) Gravels of the third depositional unit of the middle Aterno valley, underlaying the surface of Valle Daria; note the unconformity marking the separation between two different sub-units; D) Panoramic view of the Valle Daria surface, representing the depositional top of the third unit of the middle Aterno valley.

related to these lacustrine deposits have been detected between 430 and 500 m a.s.l. Slope-derived breccias have been observed at elevations usually lower than 600 m a.s.l. and are clearly embedded in those related to the Villa Santa Lucia unit. As in the case of the older unit, also the Convento dei Cappuccini breccias dip towards the basin. The entire unit (breccias plus silts) has been affected by tectonic deformation (Giuliani and Sposato, 1995).

A younger unit ("Bussi" in Fig. 3; see also Fig. 2), embedded in the second one, is made of sands, gravels and silts of fluvial and lacustrine origin, containing a high percentage of volcanic minerals which give a greyish-brownish colour to the fine lacustrine sediments. The deposits related to this unit outcrops between 340 and 420 m a.s.l. The depositional top surface is usually well preserved and easily detectable.

The Bussi unit represents the first local depositional episode affected by abundant tuffite levels. For this reason it has been correlated with the tuffite succession of Carapelle Calvisio (Giuliani and Sposato, 1995), found in a closed depression near the main Tirino basin by Bosi and Locardi (1991),

STRATIGRAPHIC DATA FROM OTHER BASINS

Further works have been published at the end of the 80s or during the 90s which reported stratigraphic information on intermontane basins not discussed in the previous sections.

Data on the Rieti basin can be derived from the works by Bosi *et al.* (1989), Cavinato *et al.* (1989), Cavinato (1993), Barberi *et al.* (1995) and Cavinato *et al.* (2000). Continental deposits mapped in Cavinato (1993) and Barberi *et al.* (1995), mainly consisting of conglomerates and breccias, have been attributed to two main units. The oldest one has been related to the Upper Pliocene-Early Pleistocene and the youngest to the Early Pleistocene. The age of the second unit has been defined on the basis of remains of *Equus Stenonis* Cocchi (Cavinato *et al.*, 1989).

In the Piana del Cavaliere area, deposits characterised by predominant material of volcanic origin with thickness of several metres have been detected (Barbieri *et al.*, 1996 and in press). Radiometric analyses (40Ar/39Ar) made by the mentioned authors gave an age of 0.531 Ma. Although this age is consistent with the chronology of the volcanic activity in the Tyrrhenian area, the Sr isotope ratios suggest that the deposit originated from local volcanic activity. The nature of the deposits indicates that this activity is related to a surge volcanism. These data increase the importance of the intra-Apennine volcanic activity, already documented in the work by Bosi and Locardi (1991) for the Tirino basin.

Information on the continental deposits in the Liri valley can be found in Devoto (1965 and 1967) and Carrara *et al.* (1995). The latter authors divided the succession in different units and defined chronological constraints. Therefore, in the mentioned work, Pliocene, Plio-Pleistocene, Early Pleistocene, Middle Pleistocene and Late Pleistocene-Holocene deposits are described. The Pliocene deposits are represented by the "Breccias of the 1st depositional phase", mainly made of carbonate angular pebbles and related to depositional environments completely different from the Quaternary ones. The authors included the "Santopadre Formation" in the deposits of Plio-Pleistocene age. The lower part of this "formation" is made of sandy-silty horizons alternating with clayey-silty levels rich of organic matter of fluvial, lacustrine and marshy environments. An erosion surface separates this portion from the upper part of the succession made of conglomerates with mainly carbonate pebbles, without sedimentary material of volcanic origin. The thickness of the outcropping deposits is several hundreds metres.

The "Breccias of the 2nd depositional phase" have been included in the Early Pleistocene deposits. They are made of carbonate angular pebbles and at places are laterally transient to conglomerates. The breccias experienced Quaternary tectonic activity, as indicated by the numerous fault planes detected in the investigated outcrops. The same chronology has been attributed to the "Veroli alluvial fan" and to the "Breccias of the 3rd depositional phase" which can be observed among the deposits of old alluvial fans displaced by the local fault bordering the Val Roveto depression.

Products of the volcanic activity have never been observed in the "Breccias of the 3rd phase" to which a pre-Middle Pleistocene age has been attributed by Carrara *et al.* (1995).

The "Breccias of the 4th depositional phase" represent the youngest deposits without minerals of volcanic origin and have been related to the Middle Pleistocene. The first deposits characterised by the presence of tephra levels have been reported as "Fluvio-lacustrine complex of the Sora basin and Lirino lake" by Carrara *et al.* (1995). These deposits consist of gravels and sands of fluvial origin and clayey silts and sands of lacustrine environment. Volcanic levels have been dated at 0.58÷0.35 Ma by the mentioned authors. Further Middle Pleistocene deposits (embedded in those previously reported) have been described for this area by Carrara *et al.* (1995). However, since their age is younger than that of the 4th unit deposits described in the previous sections, the description is beyond the scope

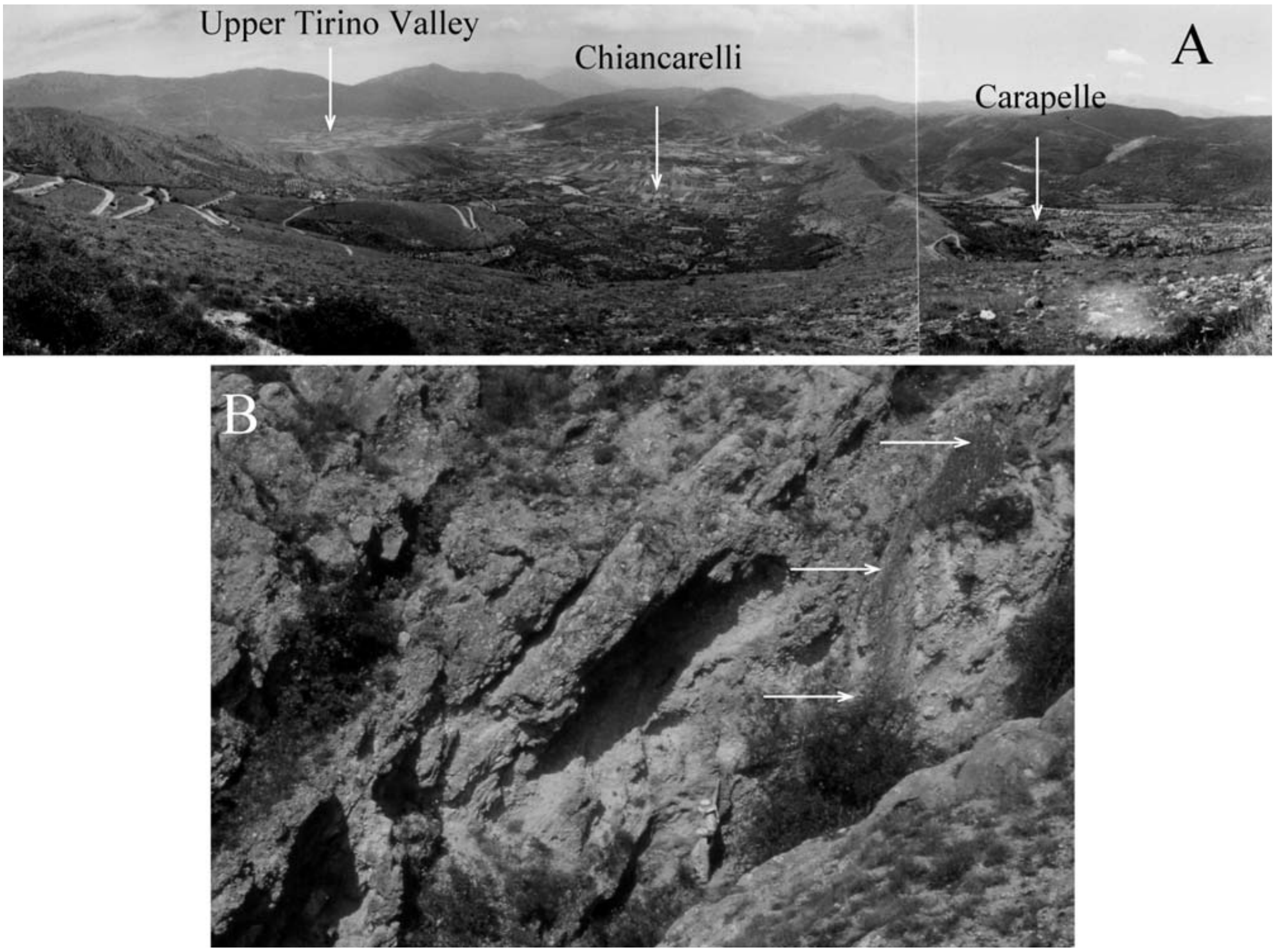

Fig. 11 - A) Panoramic view of the depressions in the Tirino Valley area; the Carapelle, Chiancarelli and Upper Tirino valley basins are separated by low carbonate hills elongated in a N-S direction; B) slope-derived breccias (more than 20 m thick) related to the second depositional event, outcropping along the northern border of the Carapelle depression; the white arrows indicate a fault affecting the breccias.

of the present paper.

Data on the stratigraphy of the Subequana basin have been published by Miccadei *et al.* (1997). The authors identified the typical breccias we related to the upper Early Pleistocene and more recent deposits both of lacustrine and fluvial origin. These younger deposits are characterised by the presence of centimetric volcanic levels and therefore they have been attributed to the Middle Pleistocene. Other alluvial fan deposits and paleosols have been related to the Late Pleistocene or to the upper Middle Pleistocene.

A number of papers have been dedicated to the Sulmona basin (Miccadei *et al.,* 1992 and 1998a; Sylos Labini *et al.*, 1993; Vittori *et al.*, 1995; Cavinato and Miccadei, 1995 and 2000; Ciccacci *et al.*, 1999). These works define a continental succession which begins with breccias related to the Early Pleistocene. The deposits may be correlated with the slope-derived breccias of the second unit reported in the previous sections, based on their facies and stratigraphic position. Middle Pleistocene deposits are related to fluvial and lacustrine environments, the latter being indicated by typical whitish silts. As in the other areas, sediments containing abundant volcanic minerals or tephra levels have been observed in the Sulmona Plain. These sediments have been related to post-0.6 Ma deposition.

Preliminary works are available for the continental stratigraphy of the Sagittario valley and the Cinquemiglia Plain area. As for the former, deposition began during the Early Pleistocene with slope-derived breccias (Barberi *et al.*, 2001). Our recent surveys in this area permitted to identify slope-derived breccias laterally (towards lower elevation) transient to conglomerates. These deposits may be related to the Early Pleistocene. Moreover, our data indicate that an older unit is present in the area and made of breccias which deposited in an environment completely different from the present one (and not related to the mentioned conglomerates), in the Serra di Ziomas area.

In the case of the Cinquemiglia Plain area, Miccadei *et al.* (2001) defined a continental succession whose deposition occurred since the lower Middle Pleistocene. The oldest deposits are represented by the slope-derived breccias which deposited along the SW slope of Mt. Pizzalto (already mapped by Miccadei *et al.*, 1998b and attributed to the Middle-Late Pleistocene). However, our preliminary surveys permit to relate these breccias to the typical slope deposits of the second depositional event (e.g. the Fonte Vedice breccias of the Middle Aterno Valley), based on the facies and the stratigraphic position. If this hypothesis is confirmed, the age of the breccias would be slightly older than that proposed by Miccadei *et al.* (2001).

The continental deposits of the Amatrice basin have been entirely related to the Quaternary (Cacciuni *et al.*, 1995). The mentioned authors identified alluvial fan deposits, landslides and pediments and defined eight units. The oldest unit (Sommati-Amatrice) detected outcrops between 960 and 1,100 m and mainly consists of alluvial fan laterally transient to fluvial deposits and accumulations of paleolandslides. Although the authors does not report explicitly the age of the unit, they relate the beginning of the deposition in the Amatrice area to the Early-Middle Pleistocene. This age can be, therefore, attributed to the Sommati-Amatrice unit.

CONCLUDING REMARKS

In the previous sections we summarised the available data on the Pliocene-Middle Pleistocene continental stratigraphy. The general scheme we propose has been drawn on the basis of the "correlation procedure" above described.

The general view of the continental stratigraphy of the Latium-Abruzzi Apennines, although the knowledge is far from being complete, permits to point out some aspects which have significant implications in the paleoenvironmental and neotectonic perspective. These aspects will be briefly summarised in the points below.

1) In almost all the basins, where the first depositional event has been identified, the lower part of the successions is characterised by sediments fed from the clayey-arenaceous flysch (Turano, Salto, Fucino, L'Aquila). This means that, at least in these basins, when the continental evolution began, the landscape was extensively carved into these marine units, differently from the Quaternary landscape which was carved into the carbonate substratum.
2) In most of the basins where the first depositional event has been defined, very coarse deposits have been detected. These deposits are generally related to huge landslide phenomena within the lacustrine basins and define instability of the slopes bordering them. These sedimentary episodes i) mark the progressive indentation of the landscape as a result of the regional uplift and ii) indicate that slopes bordering basins with significant amplitude of relief where already present in the central Apennines during the first depositional event.
3) All the investigated basins present on their borders the typical slope-derived breccias of the second depositional event which can be related to a period preceding 0.78 Ma (based on paleomagnetic data). The ubiquitous presence of these breccias is probably related to climatic factors which conditioned the widespread deposition. Since chronological data continuously corroborates the previous chronological hypotheses, the breccias may be considered as a stratigraphic marker of regional importance for the definition of paleoevent chronologies or the evaluation of tectonic rates.
4) The correlation between deposits and landforms related to the third event of the proposed stratigraphic scheme seems convincing due to the peculiar geomorphologic features which characterize this event. Indeed, the deposits are bounded upward by an important flat landform partly representing the depositional top of the units, in the L'Aquila, middle Aterno valley and Fucino basins. The surface overlays a typical reddish soil sediment in the latter two mentioned basins.
5) A further important stratigraphic marker is represented by the units recording the beginning of the volcanic activity. The investigations of the last ten years corroborate the previous hypotheses of Middle Pleistocene age for the first sediments containing volcanic minerals or tephra levels.

Generally speaking, the proposed correlations give the impression of the comparability of the depositional events in the different basins. This comparability may be interpreted as the effect of diachronous basin evolutions, each evolution passing through characteristic steps which are the same for the different basins. This hypothesis would strongly contradict the possibility to correlate the depositional events across different basins on a chronological basis. It is evident, however, that an evolution of this kind cannot justify the evident comparability (across the different basins) of the succession of events (depositional, erosional) discussed in the previous pages. The comparability of successions of events (their number, the paleoenvironmental aspects, etc..) necessarily defines their sinchroneity, since it implies that the events are due to ubiquitous geomorphic agents. On this basis, we consider the proposed stratigraphic scheme as a reliable starting point for chronologically constrained neotectonic evaluations.

The data summarised in the scheme proposed above and the available knowledge from the other basins not investigated by the authors of the present note indicate the lack of deposits related to the first depositional event in the easternmost depressions (e.g. Tirino valley, Sulmona plain, Amatrice basin). This may suggest a more recent nucleation of the extensional basins towards east. Although the lack of outcropping deposits related to the first event cannot exclude that the deposits are buried within the basins, the significant extension of the area where these deposits cannot be detected corroborates the younger age of formation of the eastern basins. This evidence fosters the already published hypotheses on the eastward migration of the extensional tectonics during the Quaternary which were not based, however, on a detailed view of the continental stratigraphy (e.g. Lavecchia *et al.*, 1994; Cavinato and De Celles, 1999; Galadini *et al.*, 2001).

Uncertainties can affect the proposed stratigraphic scheme as for the correlation of parts of the succession related to the transition from the second to the third unit. We cannot exclude, in this case, the existence of minor depositional events different from those represented in our stratigraphic scheme. Similar uncertainties may affect the upper part of the fourth unit.

The main unsolved issue is the age of the first depositional event, since available chronological constraints are vague. Our conjecturing indicates a long time interval between this event and the second one, but cannot quantify the length of the time span. On this basis, although a deposition mainly related to the Pliocene is probable, we cannot exclude that part of the sediments are related to the Early Pleistocene. The individuation of the method which may cast light on this fundamental issue is presently not easy. Indeed, the future discovery of paleontological findings is improbable, since nothing has been found until now, although the thickness of the outcropping deposits is several hundred metres and a large number of outcrops have been investigated in the last thirty years. We believe, therefore, that only the investigations on the relationship between dated marine deposits on the Tyrrhenian margin and intra-Apennine continental deposits (in the few places where a lateral transition can be detected) will produce reliable data to precisely define the age of the first depositional event.

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