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THE PLIOCENE DEPOSITS IN THE CENTRAL-EASTERN VALDELSA BASIN (FLORENCE, ITALY) REVISED THROUGH FACIES ANALYSIS AND UNCONFORMITY-BOUNDED STRATIGRAPHIC UNITS

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Riassunto. Il Bacino della Valdelsa (Toscana Centrale) è uno tra i più vasti bacini post-collisionali sviluppati ad ovest della catena nordappenninica a partire dal Miocene Superiore. Il bacino, di cui non è chiara l'origine strutturale, è colmato da oltre 2000 m di sedimenti continentali e marino-costieri, 1000 m dei quali sono riferiti al Pliocene ed affiorano estesamente. La successione pliocenica è stata suddivisa prima di questo studio in unità litostratigrafiche i cui rapporti latero-verticali sono poco chiari. La calibrazione della successione attraverso analisi biostratigrafiche, inoltre, non permette una precisa collocazione temporale a causa della mancanza di *biomarkers*. Nel presente studio la revisione stratigrafica della porzione centro-orientale del bacino, operata anche attraverso un'estensiva cartografia, è stata effettuata grazie all'integrazione tra unità stratigrafiche a limiti inconformi (UBSU) e associazioni di litofacies che esprimono il carattere stratigrafico-deposizionale della successione. Undici associazioni di litofacies sono riconosciute, infatti, nella combinazione del carattere litologico e delle facies sedimentarie e biofacies (associazioni di molluschi da marini a continentali) presenti, che nel loro insieme esprimono specifiche condizioni ambientali e deposizionali. L'analisi di terreno ha permesso di individuare vari sistemi deposizionali, da alluvionali a lacustri a fluvio-deltizi e marino-costieri, attivatisi a varie riprese in risposta a variazioni dell'apporto sedimentario e dello spazio disponibile alla sedimentazione. Nella porzione esaminata del bacino è stato riconosciuto un controllo strutturale nell'articolazione paleogeografica durante lo Zancleano finale ed il primo Piacenziano. Un alto strutturale ad andamento NO-SE divideva, infatti, una zona centrale (area di Certaldo-Castelfiorentino) dominata da condizioni marino-costiere, da una zona orientale (area di S. Casciano) dove si aveva lo sviluppo di una pianura alluvionale. Durante il Piacenziano, il bacino nel suo insieme fu caratterizzato dal progressivo avanzamento di sistemi fluvio-deltizi verso un'area marino-costiera nel settore centrale. Il riconoscimento d'importanti superfici erosive nella successione ha consentito di collocare le associazioni di litofacies entro cinque principali sintemi che registrano l'evoluzione del bacino tra lo Zancleano ed il Piacenziano.

Abstract. The Valdelsa Basin is one of the widest post-collisional basins developed in central Tuscany (Italy) since the late Miocene. More than 2,000 m of upper Miocene-Quaternary deposits fill the basin and 1,000 m of which, ascribed to the Pliocene, crop out extensively. In previous studies these deposits have been included in poorly defined lithostratigraphic schemes, and also a detailed chronologic calibration via biostratigraphic analysis has produced few results due to the paucity of biomarkers. In this study the Pliocene deposits have been subdivided into eleven lithofacies associations, in turn included in five unconformity-bounded stratigraphic units (synthems) spanning in age from the uppermost Zanclean to most part of Piacenzian. Lithofacies associations, defined as the recurring vertical alternance of several basic lithofacies, are in fact recognized based on both the lithologic features and the sedimentary/bio- (marine to continental molluscs) facies content which formed in specific environments. Several depositional systems activated in the basin, from alluvial to fluvio-deltaic to paralic and inner shelf systems, in response to change of sediment supply and accommodation space. The Pliocene paleogeography of the portion of the basin considered in this study was characterized by the occurrence of a structural high that separated two distinct depositional areas in the early stage of the basin fill. A marine (delta front to inner shelf) area developed in the central part (Certaldo-Castelfiorentino area), while an alluvial plain was forming eastward (in the S.Casciano area). During the Piacenzian the basin was characterized by the progressive filling of a shallow marine area (central part) due to the southwestward progradation of fluvio-deltaic systems.

Introduction.

Since long time the Neogene-Quaternary basins of central and southern Tuscany (central Italy, see Martini & Sagri, 1993) have attracted sedimentary and structural geologists and paleontologists. Such basins are in most cases densely populated and heavily charged with strategic infrastructures for industry and transport, involving engineering geologists into land management issues and protection from geohazards. Beside such a general interest on the geology of these basins, their stratigraphic description and interpretation in some cases date back to longer than a century ago or have been poorly updated from those early studies. A revision of the stratigraphy, involving both modern stratigraphic concepts (Bosellini et al., 1989; Mutti et al., 1994) and multidisciplinary investigations, could reveal unexpected geological implications opening new perspectives for

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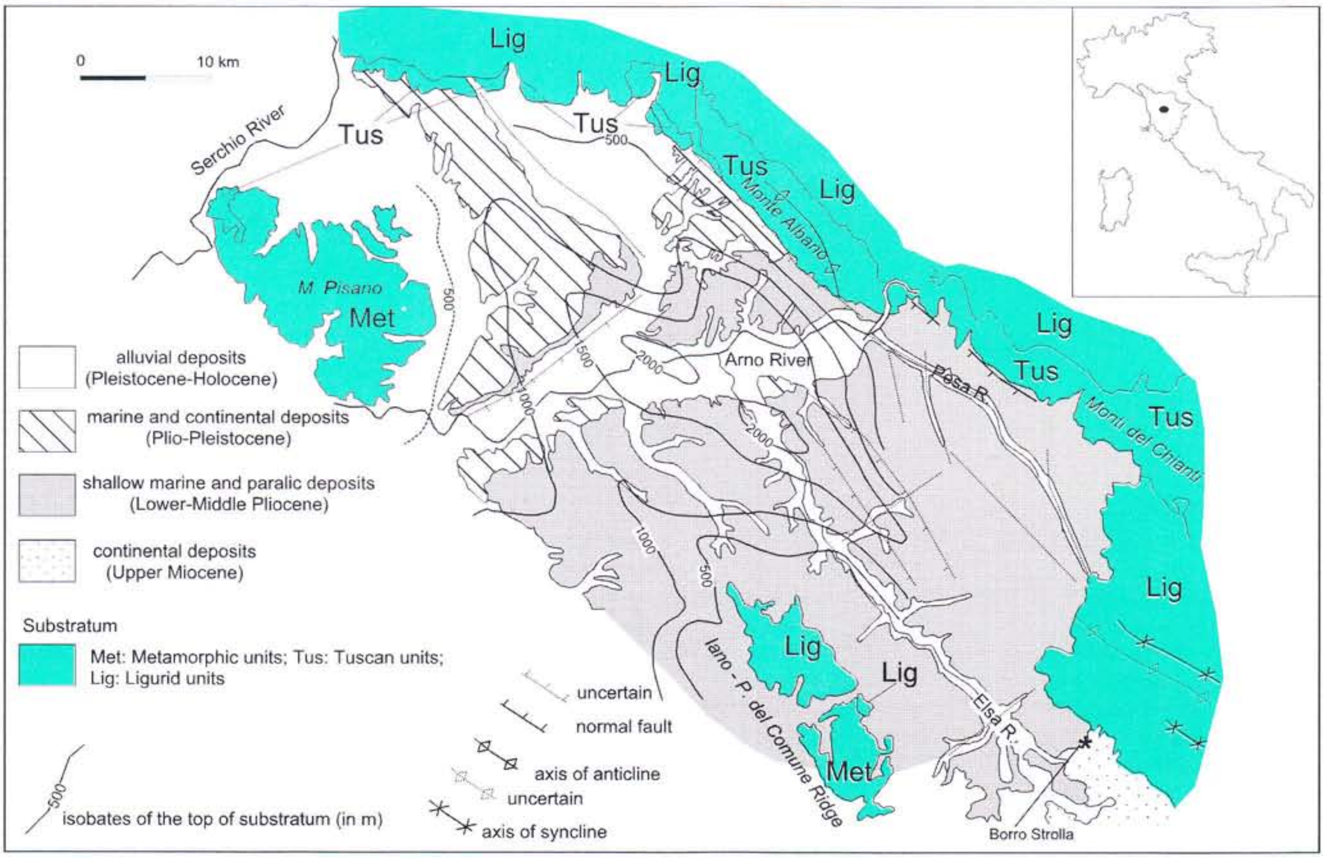

Fig. 1 - Geologic map of the Valdelsa Basin (compiled from the Carta strutturale dell'Appennino Settentrionale, 1982 - Sheet 3) with the isobates of the substratum (from Ghelardoni et al., 1968).

a better understanding of basins evolution.

This paper summarizes the results of a stratigraphic revision of the Pliocene shallow-marine and continental deposits filling the central-eastern part of the Valdelsa Basin, one of the Tuscan basins for which geological knowledge remains more fragmentary (cf. Bossio et al., 1993a).

The Valdelsa Basin (Fig. 1), which developed in central Tuscany since the Late Miocene, is a NW-SE oriented depression, about 25 km wide and 60 km long, bounded by the Monte Pisano-P. del Comune ridge (the NE end of the Mid Tuscan Ridge) to SW, and the M.Albano-M. del Chianti ridge to NE and SE (Fig. 1). The Arno River to the north delimits the portion of the basin considered in these notes, and two major Arno's tributaries drain it, the Elsa and the Pesa rivers.

Geological setting

Sediment cores and geophysical prospection show that the Valdelsa Basin is filled with more than 2,000 m thick Neogene and Quaternary sediments, about 1,000 of which m date from the Pliocene (Ghelardoni et al., 1968).

The substratum of these deposits (Fig. 1) is composed on the SW of phyllites, quartzites, evaporites and carbonates spanning in age from Late Paleozoic to Jurassic (Adria basement and Tuscan units) and by sandstones, limestones and claystones, Late Cretaceous-Paleogene in age (Ligurid units), which tectonically overlie the former rocks. Oligocene Macigno sandstones (Tuscan units) dominate on the NE side, whereas limestones and claystones of Ligurid units form the eastern and south-eastern margins of the basin.

The interpretation of the origin of the Valdelsa Basin, as well as of the several post-collisional basins west of the Northern Apennines, evades unanimous agreement. A classic picture of the Neogene-Quaternary tectonic evolution of the western side of the Northern Apennines has long been based on the "extensional" paradigm (Trevisan 1952; Sestini, 1970; Martini & Sagri, 1993). Since the Late Miocene the proto-Apennines have been considered to separate a western sector, including the Tyrrhenian Sea, dominated by crustal extension, from an eastern sector still characterized by thrust propagation. Extensional and compressional areas, linked by transitional zones (Pascucci et al., 1999), are considered to have migrated eastward during the Neogene and Quaternary. In such a picture the basins west of the chain have been structurally interpreted as grabens or half-grabens. They are filled with Upper Miocene-Pliocene fluvio-lacustrine and shallow-marine

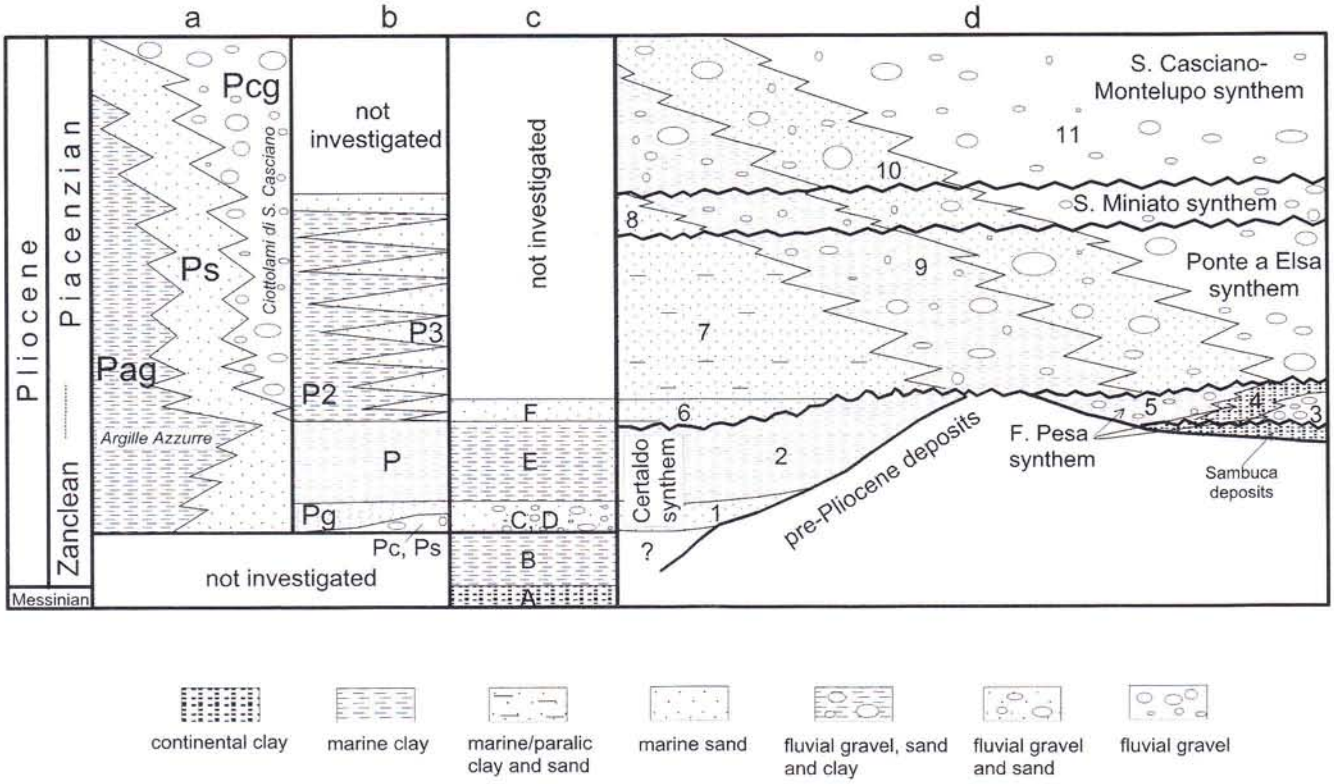

Fig. 2 - Stratigraphic frameworks defined for the Neogene deposits of the Valdelsa Basin: a) Carta Geologica d'Italia sheets 106 "Firenze", 113 "Castelfiorentino"; b) Dominici et al. (1995) for the central part of the basin (left side of the Elsa River); c) Bossio et al. (1993b) for the southeastern end of the basin (Borro Strolla); d) this study on the central-eastern part of the basin (right side of the Elsa River), numbers refer to the lithofacies associations.

deposits (central basins sensu Martini & Sagri, 1993) or exclusively with Middle Pliocene-Pleistocene fluvio-lacustrine and fluvial deposits (peripheral basins sensu Martini & Sagri, 1993) a few hundreds m up to 2,000 m thick.

Structural evidence in these deposits, credited to compressive stress, has successively suggested quite an articulated tectonic control on basin evolution, with possible compressive pulses interrupting the overall extension (Bernini et al., 1990; Boccaletti et al., 1991). On the other hand the extensional model has been strengthened (Carmignani et al., 1994; Elter & Sandrelli, 1994) to explain the post-collisional dynamics of the chain. Accordingly, the Northern Apennines region is considered to have undergone a mega-extensional regime from the Oligocene, due to gravitational collapse of the loaded orogenic belt along low-angle, deeply-rooted listric faults. The Tuscan basins, bounded by high-angle normal faults, are considered a late, small-scale, expression of such a tectonic regime. At the same time, supporters of the compressive model pushed even farther the idea of a dominant compressional regime W of the chain during the Neogene and Pleistocene (Boccaletti et al., 1995; Boccaletti & Sani 1998). Reactivation of thrusts controlled the opening and the geometry of the Tuscan basins in most cases, thus considered to be thrust-top basins (sensu Butler & Grasso, 1993).

Geological and paleontological investigations in Valdelsa have been carried out since long ago. Leonardo da Vinci provided the first modern scientific explanation for the abundant marine molluscs in the Valdelsa deposits, hinting at sea-level fluctuations. Successive stratigraphic studies allowed to distinguish several lithostratigraphic units in the basin fill (Dainelli & Videssot, 1930). The exposed deposits have been generally referred to the Pliocene, although their precise calibration has been made difficult by paucity of biostratigraphic markers (see below). The western-central portion of the basin is better known and a transgressive-regressive succession has been since long described (Dainelli & Videssot, 1930; Bossio et al., 1993a; Dominici et al., 1995) (Fig. 2a and 2b). This consists of basal "transgressive" fluvio-deltaic sands, inner-shelf silty clays ("Argille Azzurre") and a "regressive" alternation of paralic and shallow marine muds and sands on top. The geologic knowledge of the eastern portion is scantier (Fig. 2a). Gravelly and sandy deposits ("Ciottolami di S. Casciano") of inferred fluvial-marine origin have been only grossly described (Canuti et al., 1966). Such coarse-grained deposits are held to be accumulated in two main deltas, which graded basinwards into a shallow-marine area where the "regressive" sandy-pelitic portion was depositing above the "Argille Azzurre".

Field mapping carried out during this study allowed to recognize a quite articulated structural arrangement of these deposits. The bedding of the Pliocene deposits outlines the presence of gentle folds with axes oriented along a NW-SE direction well expressed in the Certaldo-S.Casciano area (see Fig. 12). Just north of Certaldo, on the east side of the Pesciola Creek, the folds show bending of their axes toward W. On the west side of the creek and in the Montespertoli-S. Pancrazio area the folds don't seem to be influenced by such a disturbance. In the study area there are some normal faults which appear to have not controlled the deposition during the Pliocene.

Quaternary deposits are present in the NE portion of the basin (Caredio et al., 1995) and along the major rivers valleys and consist mainly of fluvio-lacustrine and alluvial deposits, the latter distributed in different terraces (Dominici et al., 1995).

Open problems and aim of the study

The major deficency or lack of information on the Valdelsa Pliocene deposits concerns: a) biostratigraphic calibration of their age; b) lithostratigraphic and paleoenvironmental differentiation of constituting muds, sands and gravels; c) a stratigraphic synthesis at the basin scale.

a) Despite the abundance of marine fossils in the Valdelsa deposits, the lack of biostratigraphic markers represents a major problem to calibrate their age (e.g. Bossio et al., 1993a). Attempts to bypass this problem led to the development of a local biostratigraphy, making possible to refer the inner shelf muddy deposits ("Argille Azzurre") and the overlying regressive deposits respectively to the uppermost "Early" and "Middle" Pliocene, for the occurrence of foraminifer associations considered to be indicative of the *Globorotalia puncticulata* and the *G. aemiliana biozones* (Bossio et al., 1993a). Micropaleontological analysis of fossil nannoplancton, based on widely accepted biostratigraphic subdivision of the Pliocene in the Mediterranean region (Rio et al., 1994), allowed a significant chronological calibration only for the "Argille Azzurre" cropping out in the central part of the Valdelsa Basin (Conti, 1993). Based on the occurrence of the marker *Discoaster tamalis*, their age can be referred to an interval ranging from the upper part of Zanclean to most part of the Piacenzian. Villafranchian mammal faunas in the regressive portion of the succession allow more precise chronological considerations. Early-middle Villafranchian vertebrates (Triversa and Montopoli faunal units) suggest to refer this part of the succession to the Piacenzian, i.e., to a time span ranging from about 3,3 to about 2,6 Ma (Benvenuti et al., 1995a).

b) In the official geological maps of the study area (Carta Geologica d'Italia - CGI -, sheets 113 "Castefiorentino" and 106 "Firenze") little stratigraphic and paleoenvironmental differentiation of the lithotypes in the succession has been performed. Such a flaw was discussed in terms of mapping and stratigraphic interpretation by Dominici et al., (1995). The muddy deposits mapped in CGI (unit Pa, Fig. 2a) contain pelites differing for stratigraphic position and paleoenvironment (from inner shelf to paralic to continental settings; Dominici et al., 1995; Degli Innocenti, 1997). The same can be said for the sandy bodies that are common in the upper part of the succession. High-resolution integrated sedimentologic and paleoecologic analyses suggest that the sands deposited in alternating fluvial, deltaic and shallow marine depositional systems (Benvenuti & Dominici, 1992; Dominici, 1994; Benvenuti et al., 1995b).

c) The Pliocene succession of the Valdelsa Basin lacks a stratigraphic synthesis possibly due to the difficulty of tracing lateral transitions among gravels, sands and clays. These rock units have been classically considered to be eteropic into a general lithostratigraphic scheme (Fig. 2a). Detailed stratigraphic and facies analysis of these deposits carried out in limited areas of the basin (Benvenuti & Dominici, 1992; Benvenuti et al., 1995a) suggest that the relations among the various rock types are quite complex and better explainable in a framework of different scale sedimentary units bounded by unconformities rather than characterized by lateral and vertical transition.

The present study attempts to bring some contributions to fill the gap of knowledge discussed in the points b) and c). The field study has been based on detailed mapping of different lithofacies associations which have been included into major unconformity-bounded stratigraphic units (UBSU, International Subcommission on Stratigraphic Classification, 1994). The main purpose of this paper is to provide a picture of the stratigraphic architecture of the basin. Firstly the lithofacies associations will be described and interpreted in terms of paleoenvironmental dynamics. Secondly, a subdivision of the Pliocene succession by means of UBSU will be presented and discussed.

The map of the lithofacies associations

The lowest-rank unit adopted in this study is the lithofacies, that is a sedimentary body made of beds and bedsets, characterized by lithology, sedimentary structures and fossil content well distinguishable from others in the succession (Fig. 3) (see discussion in Mutti et al., 1994). In this respect the lithofacies are lithologic units

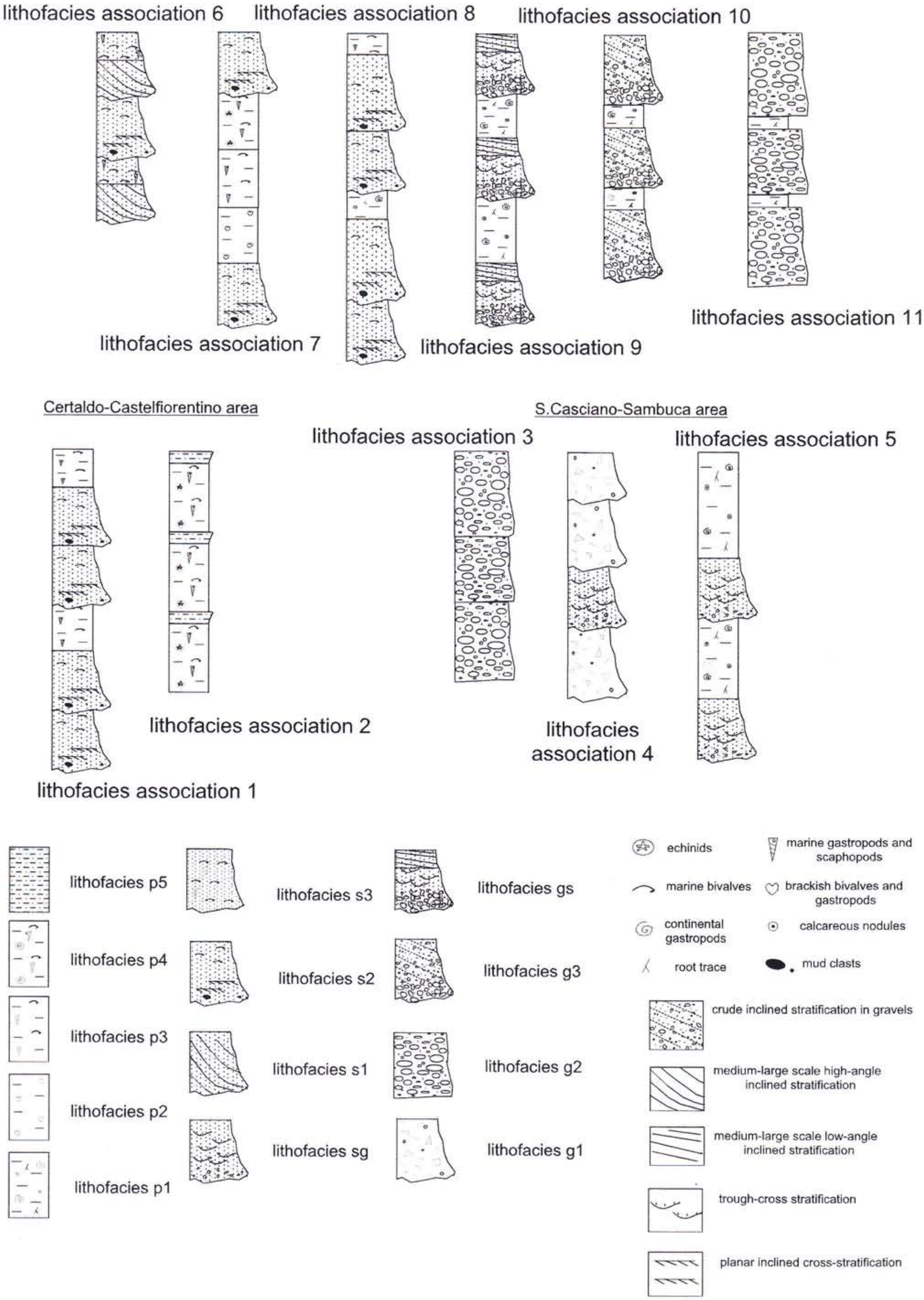

Fig. 3 - The lithofacies (each is dm to few m thick) and the lithofacies associations (each is 5-20 m thick) of the Valdelsa Basin.

bearing information about the depositional environment. Lithofacies are grouped into lithofacies associations (Fig. 3, 4), which in this study therefore can be seen both as 1) classic lithostratigraphic units and 2) the lithological expression of depositional systems which activated in the basin. Lithofacies associations in turn are part of higher-rank units characterized by bounding unconformities traceable all over the basin, regarded here as synthems (Fig. 2d and see below).

The lower part of the succession is composed of five lithofacies associations (1 to 5), which are not distributed homogeneously in the study area. Lithofacies associations 1 and 2 crop out in the central-southern reaches. On the contrary, lithofacies associations 3, 4 and 5 are present along the northern and eastern margins of the basin. The middle and upper parts of the succession are composed of six lithofacies associations (6 to 11) exposed on most of the study area.

Lithofacies association 1

This association is composed of yellowish coarse-medium sands (lithofacies sg, s2 and s3, Fig. 3), thickening toward SE, in dm to m thick tabular beds, grouped in three main sandy bodies up to 20 m thick alternating with greyish silty clays (lithofacies p3, Fig. 3). Around Certaldo sandy beds are coarse-grained with small pebbles and mud clasts dispersed and/or concentrated at their base (lithofacies sg, s2). Sedimentary structures are represented by normal grading and horizontal planar lamination. Rare high-angle cross-lamination, indicating provenance from SSE, also occurs. To the north (Pesciola Creek valleys) sands are massive (lithofacies s3) due to intense bioturbation and characterized by a rather abundant molluscan fauna. Characterising species include *Glans intermedia, Glycimeris insubricus, Panopea glycimeris, Pitar subgigantea, Pteria phaelanacea, Ostrea edulis, Turritella vermicularis,* either scattered throughout the sediment or concentrated in thin horizons. The silty clays interbedded within the sandy bodies are massive and bear a similar fossil fauna.

This lithofacies association is sharply overlain by association 2

Interpretation

Basing on the paleocurrent directions and the change of bedset thickness from SE to NW the sandy beds are observed from proximal (SE) to distal (NW) depositional areas. Along such a direction the sandy lithofacies shows sedimentary and paleontological features pointing to a shallow marine paleoenvironment affected by coarse-grained sediment supply from high-density flows. Normal grading indicates rapid settling from fall-out, horizontal lamination can be the effect of a) upper-flow regime or b) development of traction carpet, i.e., the basal portion of dense flows where dispersive pressure dominated on other sustaining mechanisms. The occurrence of dispersed floating pebbles and mud clasts at the base of the beds suggests that they were sustained in the dense dispersion by uplifting forces, such as dispersive pressure or buoyancy. Occasional high-angle cross lamination can be related to the migration of low-flow regime bedforms. On the whole, such evidence points to hyperpycnal flows on a marine delta front (see Mutti et al., 1996) fed by a NNW-flowing, flood-dominated, river system. Major floods deposited cm to m thick beds, which in the distal portion underwent pervasive bioturbation. The molluscan fauna points to a lower shoreface environment, a biotope characterized by a sandy substratum under normal marine water. This does not imply that the environment was a shoreface in terms of wave diffusion processes. No clear evidence of wave action has been in fact observed either in these lithofacies or in similar sandy lithofacies elsewhere in the basin, (Benvenuti et al., 1995a, b) suggesting a Pliocene shoreface environment characterized by very low-energy conditions. The sandy bodies are referred to major episodes of activation of the river-dominated delta while interfingered inner shelf pelites point to episodes of inactivation (see below).

Lithofacies association 2

This association consists of greyish silty clays (lithofacies p4) with abundant marine molluscs and subordinately massive silts (lithofacies p5) in tabular beds up to 2 m thick. Beds are generally massive due to the high degree of bioturbation. Fossils are both dispersed in the sediment or concentrated in thin shell-rich beds. The fossil benthic fauna is represented by a diversified association of molluscs e.g., *Anadara diluvii, Amusium cristatum, Pelecyora islandicoides, Petaloconchus intortus,* echinids, bryozoans, anthozoans *(Dendrophyllia* sp., *Cladocora coespitosa)*. The occurrence of *Discoaster tamalis* allows to refer this lithofacies association to the uppermost Zanclean-Piacenzian (Conti, 1993).

This association is unconformably overlain by associations 6 and 7 through a basin-wide high-relief erosional surface whose meaning will be discussed in a following section.

Interpretation

The paleontological evidence clearly points to significantly deep and quiet a marine environment equated to an inner shelf (Dominici et al., 1995). The continuous settlement of fines from suspension, giving rise to lithofacies p4, was episodically interrupted by the arrival of the dilute tail of density flows, whose evidence is the lithofacies p5, introduced in the basin by river floods. A rich invertebrate infauna thrived in the bottom causing

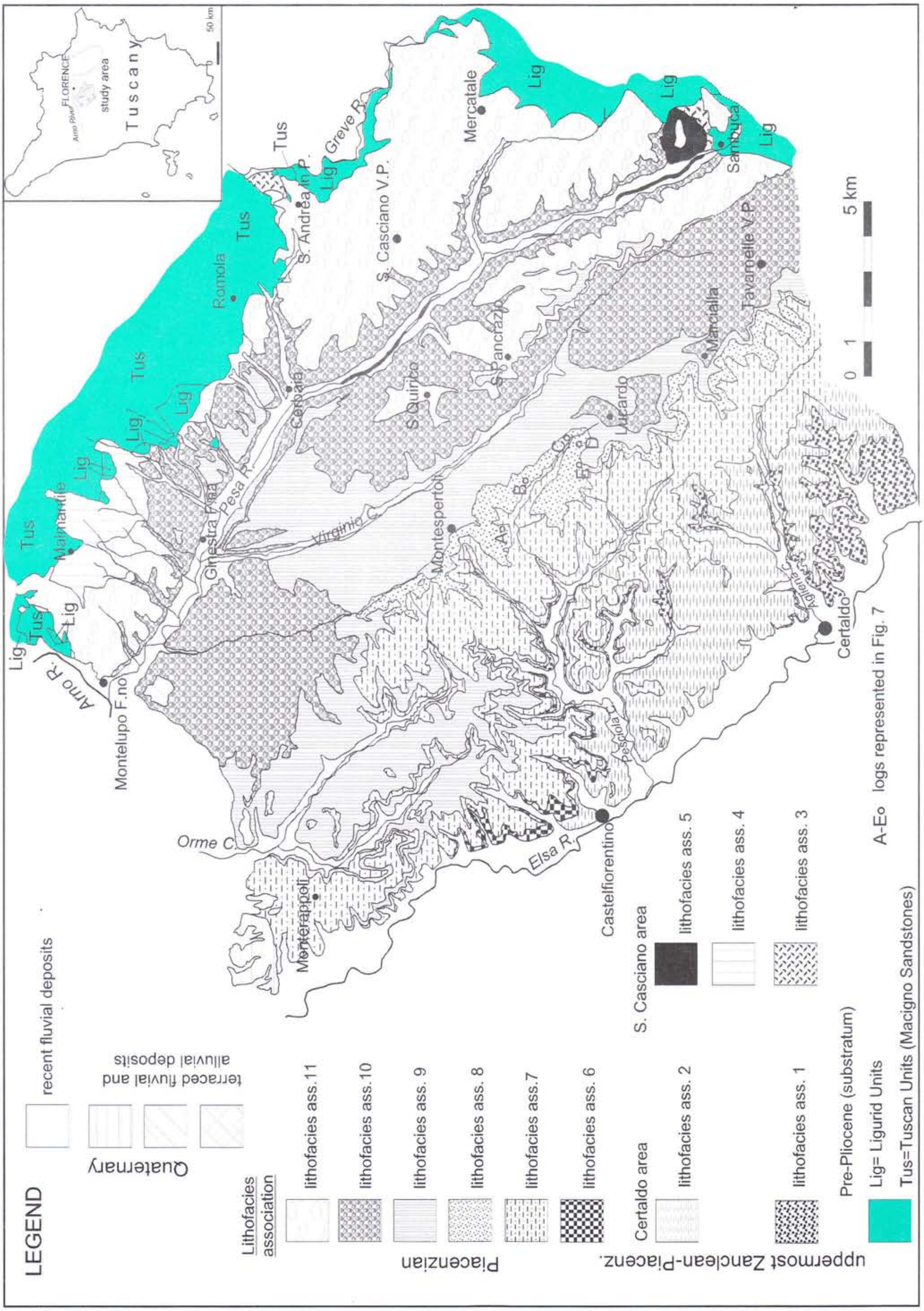

Fig. 4 - The map of the lithofacies associations.

its pervasive bioturbation. Shell-rich levels in the muddy lithofacies possibly testify to periods of sediment starvation.

Lithofacies association 3

This association, exposed exclusively in two small areas (north of S. Casciano and Sambuca, Fig. 4) along the north-eastern margin of the basin, consists of the gravelly lithofacies g2 in amalgamated beds, resting directly on the local substratum. Gravels are polymodal with common cobbles and boulders, with a clast-supported framework and abundant poorly sorted sandy-silty interstitial matrix (Fig. 5a). No sedimentary structures have been observed, with the exception of a poorly developed imbrication. The lithologic composition of gravels suggests that they have been supplied from the underlying substratum corresponding to the Macigno Formation (Tuscan units) for the S.Andrea outcrop, and to the M. Morello Formation (Ligurid units) for the Sambuca outcrop.

This association is sharply overlain by associations 4.

Interpretation

Textural features and coarseness of the gravels suggest deposition in an alluvial environment (alluvial fans?-incised valleys?) characterized by sediment supply from hyperconcentrated flows, in which mixed sustaining mechanisms co-operated. Massive texture points in fact to rapid deposition in a sediment-laden flow where clast collisions should have played a major role. The abundant sandy-silty matrix could have sustained the clasts either with a buoyancy effect or due to the cohesion of the small amount of clay. The crude imbrication finally records a possible role of the turbulence in orienting the clasts.

Lithofacies association 4

This association is composed of yellow-reddish clayey silts with dispersed angular to sub-rounded clasts (lithofacies g1) and scattered sandy-gravelly beds (lithofacies sg) and overlies the lithofacies association 3 prevalently on the northern margin of the basin. The clayey silts are massive and locally mottled. The dispersed clasts are mainly derived from the Macigno Fm. In few places gravels and sands have been observed arranged in lenticular beds with erosional base.

Field evidence suggests a vertical transition from association 4 to association 5. This association is unconformably overlain by associations 10 and 11 in

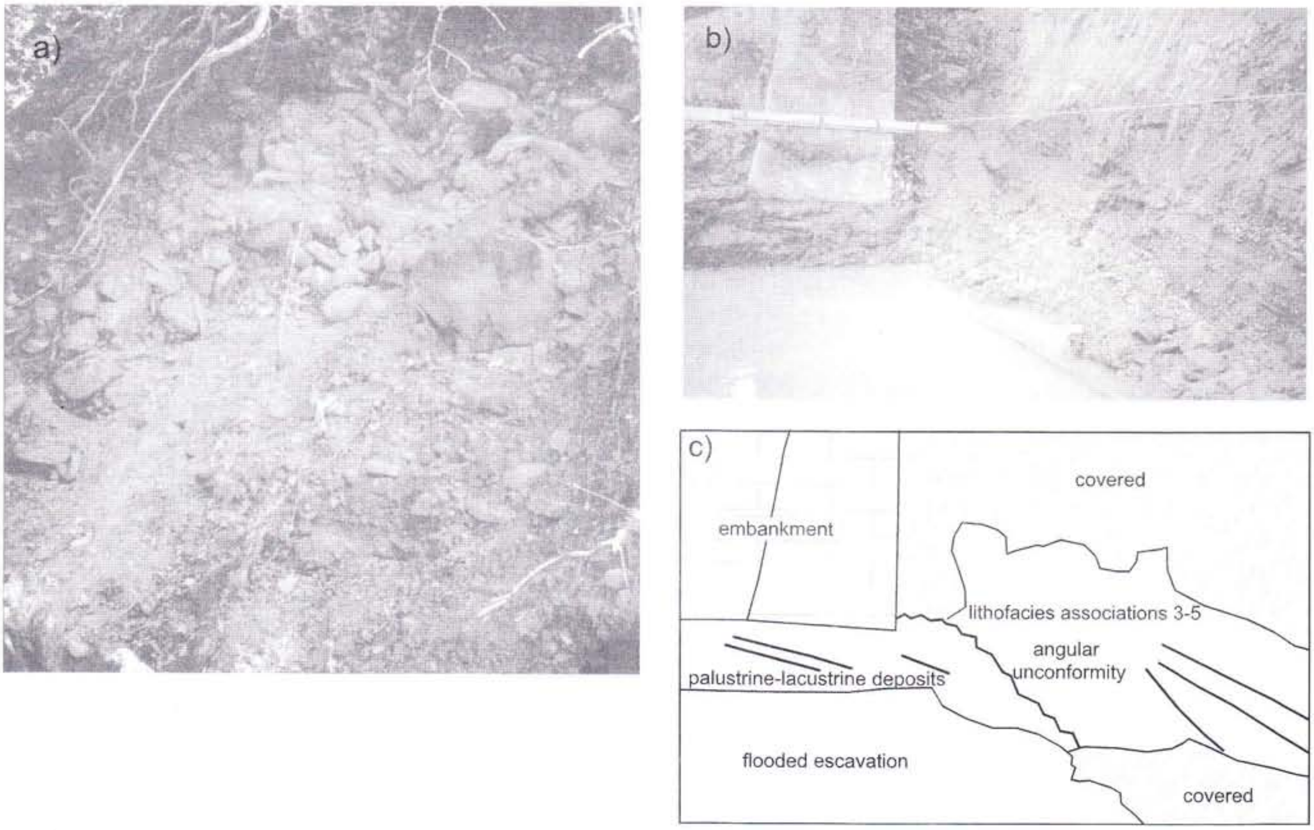

Fig. 5 - a) Coarse-grained, clast-supported gravels (to notice large boulders) of lithofacies association 3, the rod is about 1.50 m long; b) and c) The Sambuca outcrop with interpretative sketch: lignite- and lacustrine mollusc-bearing clays (on the left) are unconformably overlain by fluvial gravel and sands (on the right) of lithofacies associations 3 and 5. The thick lines in c) evidence the apparent bedding, the palustrine-lacustrine clays dipping to SE, while the fluvial gravel and sand dip to NNW, indicating therefore an angular unconformity between these deposits. The embankement wall is about 2 m high.

the Montelupo and S. Casciano areas.

Interpretation

The lithofacies g1 could have been accumulated in a mass-flow-dominated piedmont area locally characterized by the presence of small alluvial systems, responsible for the deposition of the lithofacies sg. The poorly reworked and oligomyctic nature of the coarse-grained fraction points to a local sediment supply. The dominance of structureless fine-grained deposits suggests that depositional mechanisms such as mud flows, operated on slopes.

Lithofacies association 5

This association is made of greyish clayey silts (lithofacies p1) and coarse-grained sands (lithofacies sg) cropping out in the valley of the Pesa River. Clayey silts are generally massive at places, with calcareous nodules and abundant vegetal remains, carbonized roots in physiologic position, and locally rich in continental molluscs. The molluscan fauna, still under study, is particularly interesting for its biostratigraphic and paleoecological meaning. A preliminary analysis allowed to recognize the following taxa (D. Esu, pers. comm., 2000): *Carychium (Carychiella) puisseguri, Carychium* sp., *Negulus villafranchianus, Vitrea* sp., *Limax* sp., *Discus* sp., *Cecilioides acicula, Vertigo antivertigo, Vertigo moulinsiana, Pisidium* sp., *Galactochilus senensis*. Vertebrate remains (*Anancus arvernensis*, hosted at the Museo di Paleontologia, University of Florence, IGF 12784) have been collected in this lithofacies.

The sands, arranged in lenticular bodies resting erosively on the previous lithofacies, are coarse-grained and locally rich in granules and small pebbles. Large carbonized tree trunks and smaller vegetal remains are also present. The bodies, up to 5 m wide up and to 3 m thick, are internally characterized by planar- and through-cross stratification indicating a lateral accretion in respect with a paleocurrent direction from ENE. The pebbles composition is characterized by sandstones and subordinately limestones deriving from the Macigno Fm and the Ligurid units present on the northern and eastern margins, respectively.

A small, but very favourable temporary exposure in the Pesa River (Sambuca, Fig. 5b, c) showed this lithofacies association to rest unconformably on lignite-bearing greyish silty clays characterized by abundant freshwater molluscs. The latter deposits have not been observed anywhere in the study area and therefore are not included in the classification of the exposed lithofacies (Fig. 3). The lignite, at least 1 m thick, is thinly stratified with plant (reeds) remains. It is abruptly overlain by greyish, thinly laminated silty clays in which mollusc remains are either dispersed or concentrated in the laminae. A preliminary analysis of the molluscan fauna revealed the following association (D. Esu pers. comm., 2000; Esu et al., in press): *Theoxodus* sp., *Valvata* sp., *Bithynia* sp.,*Emmericia cauponia, Melanopsis* sp., *Prososthenia cf. dalmatina, Pyrgula* sp., *Lymnaea (Adelinella)* sp., *Pisidium* sp.

Lithofacies association 5 is unconformably overlain by association 10 (see Fig. 13).

Interpretation

The two lithofacies record the development of an alluvial plain. The fine-grained deposits accumulated in areas of flood expansions characterized by poorly drained condition and settlement of silts and clays. Palustrine vegetation locally developed in wet areas, although the occurrence of calcareous nodules indicates pedogenic modification, hence temporary changes in water-logging of soils. In this setting, continental molluscs were compatible with a subaerial, locally humid environment such as a floodplain. The terrestrial species *C. puisseguri, N. villafranchianus, V. antivertigo and V. moulinsiana* are highly hygrophilous and colonize very damp habitats, such as soils covered with ferns, marshes and stream and river banks. The extinct large helicid *G. senensis*, very common in this mollusc assemblage, ought to prefer the same type of environment. This mollusc association preliminarly suggests a chronological attribution to the Middle Pliocene (Piacenzian); *N. villafranchianus* is known in Italy from the Middle Pliocene (Ciangherotti et al., 1998) and did not survive the Middle Pliocene (D. Esu pers. comm., 2000).

This low-energy depositional environment was affected by incision by river channels in which the pebbly sandy lithofacies accumulated. Sedimentary structures such as cross-bedding, due to frontal and lateral accretion, suggest that channels were locally characterized by a low-sinuosity pattern and by the development of small point or side bars.

The fragmentary lithological and paleontological evidence of the deposits unconformably overlain by this lithofacies association at the Sambuca site, points to a palustrine-lacustrine depositional setting developed in the basin probably in the (early?) Pliocene. The first occurrence of the sub-genus *Lymnaea (Adelinella)* is in fact recorded in the Pliocene of Eastern Europe and the whole character of the fauna suggests an early Pliocene age (D. Esu pers. comm., 2000).

Lithofacies association 6

This association consists of yellowish medium-fine sands in horizontal (lithofacies s2) or inclined (lithofacies s1) beds, from few dm to 5 m thick, exposed in isolate outcrop north of Castelfiorentino. Planar inclined beds, indicating a provenance from NNW, are

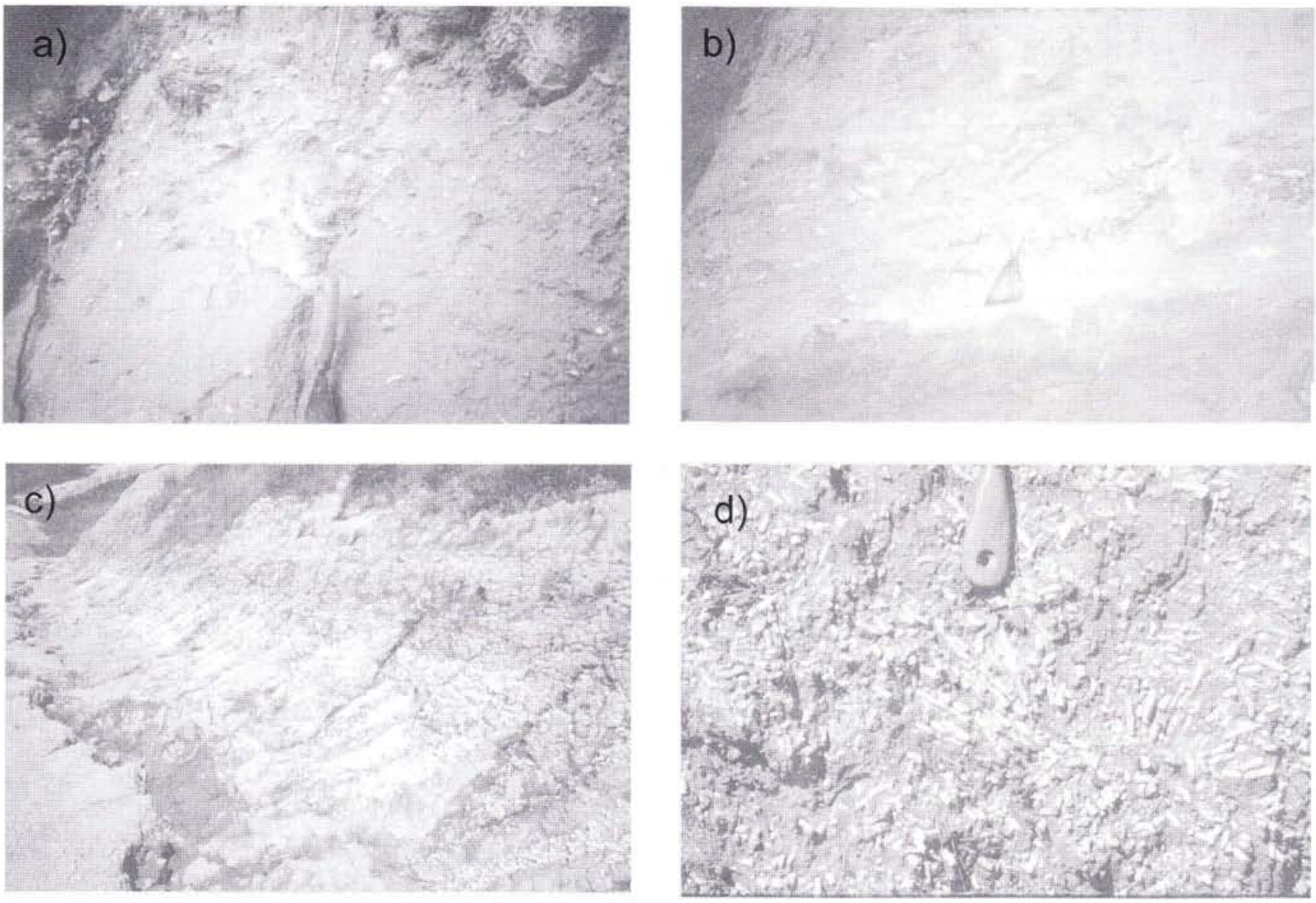

Fig. 6 - Lithofacies in association 7: a) Shell debris and articulated bivalves in the sandy litofacies s3 . Trowel for scale; b) The sandy lithofacies s2 . The abundant mud clasts and the poorly-sorted sand point to massive deposition from sediment-laden flow within a fluvio-deltaic channel incised in the marine lithofacies p3. Trowel is 20 cm long; c) Oblique view of shell-rich pelites (lithofacies p2) characterized by a monospecific association of *Potamides* cf. *tricinctus* pointing to a brackish environment. The outcrop is 2 m thick; d) Detailed view of a fossiliferous key-bed made of lithofacies p3 bearing large amount of *Cladocora coespitosa*. Trowel for scale.

up to 4 m thick, internally massive or normally graded. Horizontal beds are massive and strongly bioturbated with a rich molluscan fauna composed of large bivalves *(Panopea glycimeris, Pitar subgigantea, Pteria phaelanacea)* in life position or shell fragments dispersed in the sediment. The inclined-bedded sands pass downflow to horizontal silty sands and are in turn sharply overlain by the horizontal bedded, mollusc-bearing sands.

This association is erosively overlain by association 7.

Interpretation

This association is interpreted to record the development a marine delta front fed by a SSE-flowing river system. Such a river system is related to the development of a paleovalley located in correspondence of a major alluvial entry-point (see below). The delta front was characterized by large-scale frontal accretion, depositing the inclined beds by the rapid suspension fall-out of density flows moving down the depositional slope. Horizontal beds were probably deposited by hyperpycnal flows (see lithofacies ass. 1), and after deposition underwent pervasive bioturbation. The molluscan fauna points to a lower shoreface environment, as previously discussed.

Lithofacies association 7

This lithofacies association consists of alternating yellowish medium-fine sands and greyish silty clays and silts in beds few dm to a few m thick.

Sands are represented by two lithofacies: generally massive due to bioturbation with scattered molluscs or shell debris the first (lithofacies s3, Fig. 6a), normal graded, with lags bearing mud clasts, pebbles and bioclasts, and cross-laminated the second (lithofacies s2, Fig. 6b). In general the sandy beds, dm to m thick, with massive structure and bioclasts have an apparently non-erosional base, while those with sedimentary structures and grading show basal erosional surfaces.

The fine-grained lithofacies range from massive silty clays to sandy silts, with a rich molluscan fauna that can be subdivided in three main specific assemblages. A few silty clayey beds or bedsets are characterized by an oligotypic fauna represented by *Cerastoderma edule,* *Potamides tricinctus, Cerithium* sp.,*Ovatella myotis, Corbicula fluminalis* (lithofacies p2, Fig. 6c).

A second assemblage is characterized by *Chamelea gallina, C. amidei, Solen marginatus, Spisula subtruncata, Corbula gibba, Ostrea edulis, Turritella vermicularis* dispersed or concentrated in shell-rich beds of clayey to sandy silts (lithofacies p3). A specific fossil-rich level, among others, is a key-bed in the study area, as well as in the central-western part of the basin (S. Miniato area, Benvenuti et al., 1995b). It is dominated by the anthozoan *Cladocora coespitosa*, associated with the bivalves *Chlamys varia* and *Venus verrucosa* and several gastropod species (Fig. 6d).

A further mollusc association is characterized by *Venus multilamella, Striarca lactea, Amyclina semistriata, Aporrhais uttingeriana* among the bivalves and gastropods, the scaphopod *Dentalium fossile*, and the echinid *Schizaster* sp.dispersed in a silty clayey sediment (lithofacies p4).

This lithofacies association is interfingered with association 9 and is erosively overlain by lithofacies association 8.

Interpretation

Features of the sandy lithofacies point to several processes and depositional environments. The erosively based sandy beds and bedsets can be referred to deposition in river or deltaic distributary channels from sediment flows ranging from high-density fluidal suspension to low-concentration bedload and suspended load. The non-erosional base sandy beds can be referred to deltaic lobes, deposited by hyperpicnal flows and completely bioturbated by the benthic fauna.

The fine-grained lithofacies point to different depositional environments, well expressed by the three mollusc assemblages.

The composition of the mollusc assemblage in lithofacies p2 indicates a depositional setting with pronounced variability in water salinity, comparable to the ecological condition of the present-day Mediterranean lagoons. Physical processes were dominantly settlement of fines introduced in the basin by river floods. The mollusc assemblage in lithofacies p3 suggests frankly marine conditions equated to those of a low-energy environment very close to the coast (offshore-transition) and to the nutrient and terrigenous supply from rivers.

Deeper marine conditions are indicated by the mollusc assemblage in lithofacies p4, that is referred to the inner shelf where settling of fines and dominantly biogenic reworking were the most important processes.

The vertical stacking pattern of the lithofacies composing such association points to a cyclic succession of environmental conditions. An ideally complete succession, 5-20 m thick, shows fluvio-deltaic channel sands that are overlain by fine-grained deposits, showing a vertical transition from lithofacies p2 to lithofacies p3 and p4. These can be capped by deltaic lobe sands that are in turn overlain through an erosional surface by fluvio-deltaic channel sands. On the whole, such succession records small-scale relative fluctuations of sea level (see below).

Lithofacies association 8

This association is composed of alternating coarse-medium yellowish sands (lithofacies s2, s3) and greyish clayey silts (p1, p3). Sands are dominant and can be subdivided into three main bodies 15-20 m thick (Fig. 7). Each body is composed of tabular, dm to m thick beds with a massive or normally graded structure, evidenced by the vertical transition from coarse-grained sands with mud clasts, pebbles and bioclasts into medium-fine sands (lithofacies s2). Horizontal or cross-lamination characterizes some beds. Other beds are massive with dispersed molluscs (lithofacies s3), including large bivalves and gastropods often in life position and locally showing large *Ophiomorpha*-like burrows.

The clayey silts are massive and are characterized by either marine molluscs (lithofacies p3) or absence of fossils. In the latter case the deposits are characterized by calcareous nodules and mottling (lithofacies p1).

Association 9 unconformably overlies this association all over the study area.

Interpretation

The sandy beds show features suggesting both processes due to primary deposition and to biogenic post-depositional modification. Normal grading can be referred to deposition from high-density suspensions, while current structures point to plane bed formation, bedform migration and filling of erosional scours in supercritical or subcritical low-concentration flows, respectively. Massive structure in the shell-rich sands is generally due to pervasive bioturbation operated by the benthic fauna. On the whole, the sands are referred to a distributary channel/delta front environment with sediment delivered by flood-derived hyperpicnal flows.

The intervening fine-grained lithofacies is referred to contrasting low-energy depositional environments. A paralic or marine environment (offshore transition-inner shelf) for the shell-rich type, and a non-marine environment (coastal plain) for the barren type, where nodules and mottling suggest pedogenic modification.

This lithofacies association on the whole represents alternating depositional environments possibly recording relative sea-level fluctuations. The major difference with association 7, showing similar environmental changes, is the dominance of sands on fine-grained sediments suggesting a period, in the basin fill evolution,

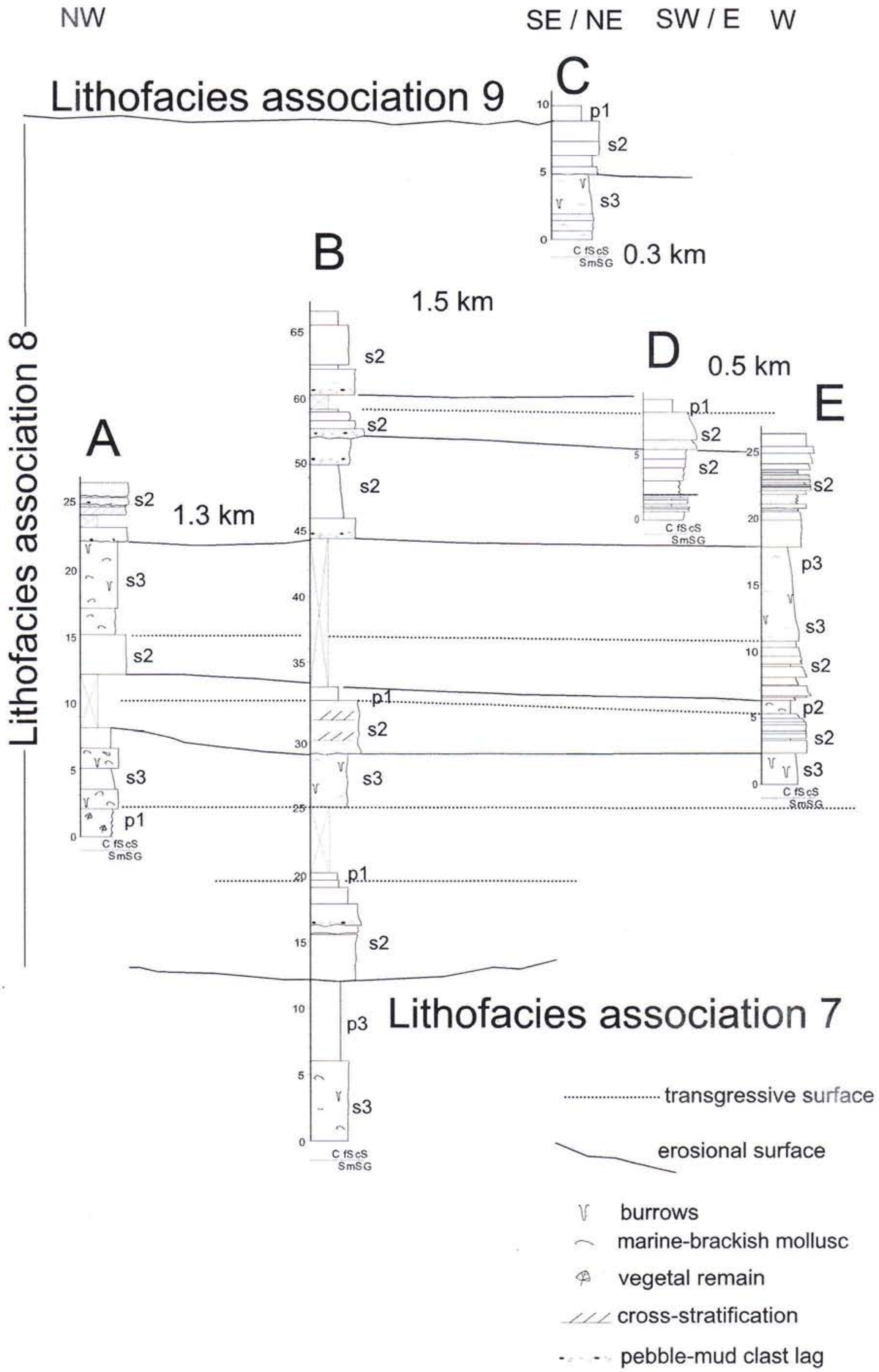

Fig 7 - Stratigraphic correlation within lithofacies association 8 along a land (logs A-B-C) - sea (logs D-E) transect. (See Fig. 4 for location of logs A-B).

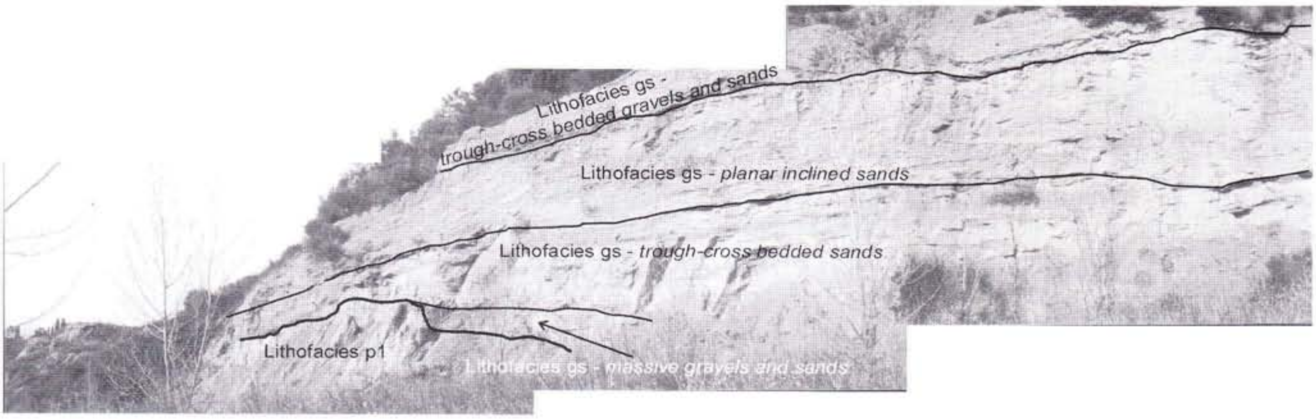

Fig. 8 - Oblique view of lithofacies stacking in association 9. Lithofacies gs rests through an erosional surface on lithofacies p1, outlining an incised valley fill. This shows an internal architecture that is interpreted to record the rising of base-level within the fluvial valley. The outcrop is 8 m thick.

of stronger sediment supply from the northern basin catchments (see below).

Lithofacies association 9

This association is made of an alternation of gravels and sands (lithofacies g2, gs) and greyish silty clays (lithofacies p1) in beds up to 5 m thick (Fig. 8). Gravels are polymodal with abundant cobble-sized clasts and sandy-silty matrix in the clast-supported framework. Lithological composition of the clasts shows dominance of whitish micritic limestones and marlstones, grey-greenish limestones and subordinately sandstones, ophiolites and cherts, derived on the whole from the Ligurid units. Sedimentary structures range from moderately to well developed imbrication with paleocurrent direction from ENE in the S. Casciano-Montespertoli area and from NNE in the Montelupo-Orme River area, normal grading, medium to large-scale cross bedding. Sands are generally coarse- to medium grained with horizontal, planar- or trough-cross lamination, and often rest erosively on top of gravels. The gravelly-sandy bedsets overlie the silty-clayey lithofacies through erosive, in some cases high-relief, surfaces. Silty clays are massive to thinly laminated, locally with small lenses of massive silty sands. Calcareous nodules, root traces, grey dark banding and dispersed carbonized vegetal remains are common features of this lithofacies. Fossil content is characterized by scattered continental molluscs (*Galactochilus senensis, Melanopsis* sp., D. Esu pers. comm., 2000) and vertebrate remains (teeth of *Stephanorhinus* sp., Degli Innocenti, 1997).

To the north of Castefiorentino, up to the Orme River valley, this association is interfingered with association 7, while in most part of the basin it is interfingered with association 10.

Interpretation

The gravelly-sandy lithofacies shows features pointing to depositional processes operating in the distal portion of flood-dominated river systems. The high-relief erosive bases of the gravelly bodies suggest filling of incised fluvial valleys. The massive gravelly type, found both as the unique costituent and as the lowermost portion of beds in the bodies, points to deposition from highly concentrated flows, in which mechanisms other than turbulence alone cooperated in sustaining clasts. Collisions among clasts, buoyancy and cohesion of the silty-clayey fraction in the interstitial matrix may have operated in the suspension. On the whole, this type can be referred to hyperconcentrated flows possibly generated by floodwater progressively bulked with sediment. The gravelly and sandy type characterized by cross bedding is generally found above the former deposits in the channel fills. Good exposures on the right side of the Orme River (lower reach) show that the cross-bedded gravelly-sandy units indicate both lateral and frontal accretion of macroforms with respect to a palaeoflow directed toward SSW. The internal massive structure of the large scale cross beds suggests also in this case rapid deposition from hyperconcentrated suspensions. In other cases the occurrence of either trough- or planar-cross beds in the intermediate part of the bodies testify the development of dunes in a bedload-dominated river.

The fine-grained lithofacies is interpreted to record a floodplain environment characterized by waterlogging, settlement of fines and episodically of coarser material from overbank of major floods, bioturbation from vegetal and animal organisms.

The rhythmic alternation of the two lithofacies reflects activation/deactivation of two depositional elements of a floodbasin, channels and floodplain respectively. Similarly to the lithofacies successions observed in associations 7 and 8, these alternance can be viewed as small-scale depositional cycles starting with incision of a thalweg into a floodplain, followed by filling with gravels and sands with change of the fluvial regime. The complete sequence shows (fig. 8) hyperconcentrated flow-dominated river massive gravels overlain by mobile, multichannel river gravels and sands, in turn capped by low-sinuosity, single channel river gravels and sands. An abrupt transition to floodplain fines is often marked by sandy channels resting on top of the coarse-grained deposits. Such a cycle records the evolution of a river system as a change of sediment supply with time, possibly related to uplift/denudation cycles and base-level variation (see below).

Lithofacies association 10

This association includes alternances of gravels and sands (lithofacies g2, g3, gs) with subordinated grey-yellowish silty clays (lithofacies p1). Gravels and sands are coarser-grained with respect to the lithofacies association 9 and dominate over the sandy and silty fraction. They show textural features and lithological composition very similar to those described above. In some cases cross bedding is characterized by rhythmic grading of openwork and framework gravelly beds (Fig. 9). Sandy beds are frequently massive with scattered, floating pebbles. The silty clays are thin levels separating the gravelly-sandy bedsets. The fine-grained stacks contain the scattered continental molluscan fauna described above.

This association is erosively overlain by association 11.

Interpretation

This association is believed to record deposition in more proximal portions of the same river systems forming association 9. Massive gravels are attributed to sediment-water flows characterized by hyperconcentrated bedload and suspended load due to sediment bulking. Cross-bedded gravels and sands testify to dune and bar migration in shallow channels. The frequently observed alternance of openwork and matrix-rich, clast-supported, inclined gravelly units (Fig. 9) suggests that such bedforms prograded through a rhythmic change of grain sorting. This is a condition frequently described in ancient coarse-grained river deposits, where similar rhythmically graded inclined units are common (Steel & Thompson, 1983; Rust, 1984; Anketell & Rust, 1990). Its interpretation is not univocal and can be variedly influenced by: 1) temporal and longitudinal sorting of different grain-size populations arriving as pulses of bedload at the edge of the bedform and deposited on the lee side as rhythmically-sorted foreset units, 2) gravity flows over the lee side of the macroform, responsible for the polymodal massive inclined units and 3) secondary sand infiltration, possibly responsible for bimodal foresetted units. Massive sands are related to rapid deposition from hyperconcentrated flows. Sands frequently rest on a lag of gravels, suggesting vertical segregation of the various grain populations carried in the flow. This phenomenon has been described in ancient alluvial deposits accumulated from flows with hyperconcentrated bedload (Todd, 1989).

The fine grained deposits formed in low-energy settings similar to those of association 9, namely a floodplain dominated by sediment settlement, biogenic and pedogenic modification.

Alternances of gravelly-sandy and muddy deposits constituting the architecture of this association point to a depositional dynamic similar to that of association 9.

Lithofacies association 11

This association is dominantly composed of gravels (lithofacies g2), in generally amalgamated tabular bedsets up to 15 m thick, which in the S. Casciano-S.Pancrazio area give rise to a characteristic "stepped" morphology. Thin (one to few m thick) yellowish clayey silty beds (lithofacies p1) occur within the gravelly bedsets. The gravels, having the same composition and

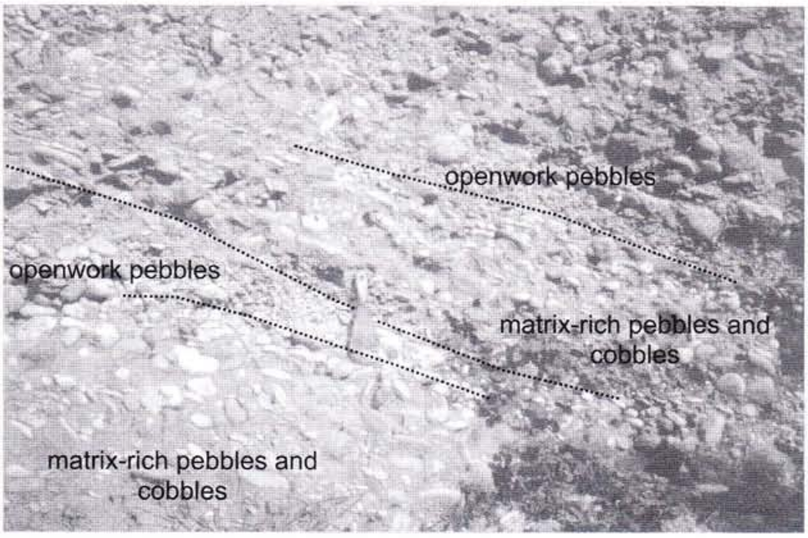

Fig 9 - Internal, rhytmic, inclined layering of lithofacies g3 in the association 10, trowel for scale.

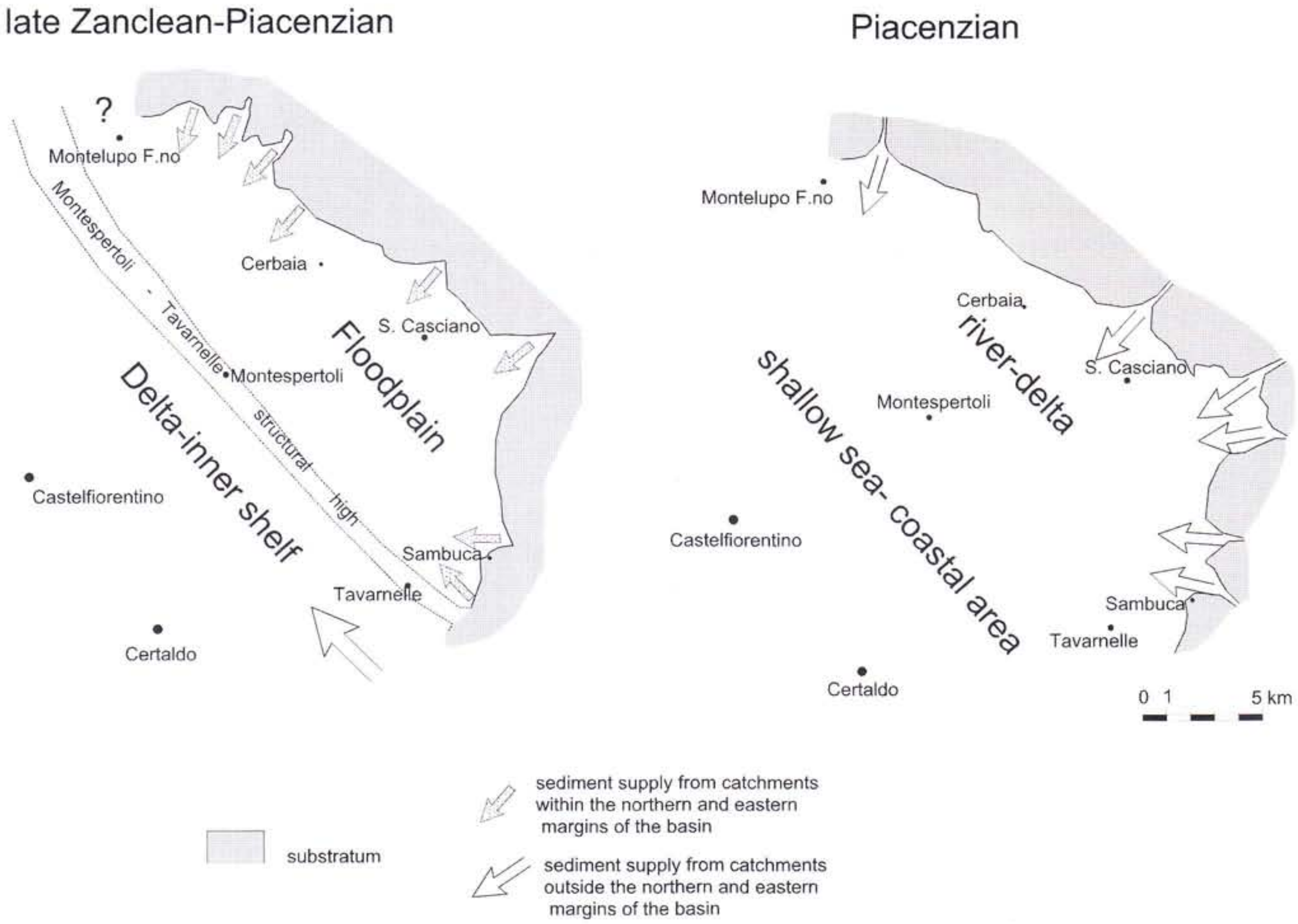

Fig. 10 - Paleogeography of the central-eastern Valdelsa Basin during the late Zanclean-Piacenzian.

provenance described above, are coarser-grained, with common boulder-sized clasts. With the exception of moderately to well developed imbrication, gravels are in most cases massive. The clayey-silty lithofacies is massive with calcareous nodules and reddish horizons possibly due to pedogenic modification.

Interpretation

This association records deposition in a more proximal part of the alluvial systems developed on the northern catchments of the basin. The coarseness and massiveness of gravels and amalgamation of beds and bedsets point to deposition of broad gravelly lobes from hyperconcentrated flows. The radial pattern of grain size variation in the gravels, here mapped as lithofacies association 11, found by Canuti et al. (1966), suggests that these deposits possibly formed in alluvial fans. Similarly to associations 9 and 10 the fine-grained stacks are referred to a low-energy floodplain.

Each gravelly bedset testifies major activation of alluvial fans followed by their deactivation marked by floodplain fines.

From lithofacies associations and their bounding surfaces to the depositional evolution

Two recurrent features characterize the vertical stacking of lithofacies and lithofacies associations as a whole: 1) different scale sedimentary cycles, reflecting both rhythmic and tendential depositional changes, and 2) occurrence of unconformities of different rank.

At the scale of the whole succession, the depositional conditions in the central part of the basin (Certaldo-Castelfiorentino area) changed, during the late Zanclean-Piacenzian, from a delta fed by a NNW-flowing river system (association 1) to an inner shelf environment (association 2). On the eastern and northern margins, a possibly time-equivalent continental setting was developing, with depositional transition from alluvial and slope systems (associations 3 and 4) to low-energy floodbasin (association 5). Localized short rivers draining the northern and eastern margins supplied sediments to this part of the basin (Fig. 10, 11).

Altogether, the assemblages of lithofacies associations in the two zones point to a depositional evolution characterized by an increase in accommodation within the basin. Nevertheless, the spatial relationships between assemblages 1-2 and 3-4-5 are not easily explainable in terms of laterally related environments. It is in fact difficult to link directly through a gradual transition over such a short distance (about 5 km) the inner shelf conditions recorded by association 2 to the alluvial plain environment of association 5, since intermediate environments are not recognized. Not discarding possible diachroneity between both assemblages, it is here suggested that a structural threshold could have separated these two depositional areas. On the basis of outcrop locations of associations 2 and 5, the possible boundary between the two areas can be identified along the Tavarnelle-Montespertoli alignment, this corresponding also to the axis of a gentle anticline (Fig. 12). A possible evidence of such a threshold is provided by the isobates of the top substratum (Ghelardoni et al., 1968; Fig. 1). Although not traced in the southeastern side of the basin, the isobates indicate a rise of the substratum approximately along the NW prosecution of this alignment.

A major erosional surface marks an important depositional and palaeogeographical change related to a sudden decrease in accommodation within the basin. Geological mapping revealed an articulated morphology of the surface separating associations 6 and 7 from the underlying deposits. A major palaeovalley has been identified north of Castelfiorentino, where delta deposits of association 6 rest on association 2. A few km just north of Malmantile this palaeovalley is cut in the substratum, outlining a major river system (Canuti et al., 1966; Bartolini & Pranzini, 1981) that supplied the basin in the Piacenzian. Other similar systems are recognized north of S.Andrea in Percussina (this was already active during deposition of association 3) and north of Mercatale. The unconformable boundary between associations 5 and 9 in the Pesa River thalweg south-east of S.Casciano and north-west of Sambuca, marks the base of these eastern palaeovalleys (Fig. 13). The following evolution is the overall filling of such palaeovalleys occurring at the scale of the whole succession, through a latero-vertical transition from a delta system (association 6) to coastal-shallow marine conditions (association 7). These were interrupted, north of Castelfiorentino, by the episodic basinward shift of a fluvial environment (association 9). Association 8 marks the onset of a basin-wide progradation of the fluvio-deltaic systems, well typified by the coarsening-upward succession of associations 9, 10 and 11. The gravelly portion of these deposits reflects a significant change of sediment source with respect to the coarse-grained supply during deposition of association 3. The dominance of clasts from the Ligurid Units, even where the local substratum is made up of Tuscan Units, reflects denudation of the structurally higher units in the nearby Middle Pliocene Northern Apennine divide (see Bartolini & Pranzini, 1981). This implies a significantly different tectono-sedimentary role of these gravelly deposits compared with the coarse-grained supply recorded by association 3. The latter, in fact, testifies local, intrabasinal sources of sediment, while the former implies wider fluvial catchments located outside the basin in an area undergoing relief rejuvenation and denudation.

The large-scale paleoenvironmental evolution depicted in this paper apparently agrees quite well with the conclusions of a previous study (Canuti et al., 1966) in referring the Pliocene deposits to deltaic environments, relying on 1) the basinward interfingering of subaerial gravels and sands with shallow marine sands and clays and 2) the distribution of the gravel size and paleocurrent data for the "Ciottolami di S. Casciano". Nevertheless, the data collected in this study point to a more complex depositional evolution, characterized by activation of depositional systems on different time scales, reflecting change in base-level and sediment supply (see below) (Fig. 14).

When viewed at the scale of single lithofacies associations, the depositional evolution can be interpreted in terms of cyclic changes. With the exclusion of the lithologically homogeneous association 2 and the poorly exposed associations 3, 4, and 5, the remaining associations show alternating depositional conditions, which indicate activation / deactivation of depositional systems. In particular associations 9, 10 and 11 show a quite simple depositional alternation between alluvial channels and floodplain. A possible explanation of such cyclicity can be searched in the "uplift/denudation cycle" concept (Mutti et al., 1996). Uplift pulses in the northeastern margins of the basin caused relief rejuvenation, with production of sediments that filled up the upper catchment valleys. Subsequent high-magnitude floods distributed the sediment to the fluvial and deltaic systems. During the tectonic stages responsible for each uplift the basin was starved with coarse-grained sediment, allowing the development of low-energy marine and continental depositional systems.

Associations 7 and 8 are characterized by a more articulated pattern of high-frequency change of depositional conditions. Each small-scale cycle seems to reflect a partial or complete relative sea-level fluctuation from low-stand fluvial and deltaic deposits to transgressive paralic and shallow marine deposits, finally to highstand shallow marine deposits.

Whatever the forcing mechanism, the depositional dynamics expressed by the small-scale sedimentary cycles show quite a complex picture of the depositional systems (Fig. 14) if compared with the simple and generalized attribution of the Pliocene succession to delta and shallow marine systems (Canuti et al., 1966). Delta fronts as well as fluvial and shallow marine systems characterized specific, though recurring, stages (i.e. T1-T3 in Fig. 14) in the development of the basin fill, thus neither a "delta" nor a "river" nor an "inner shelf" should repre-

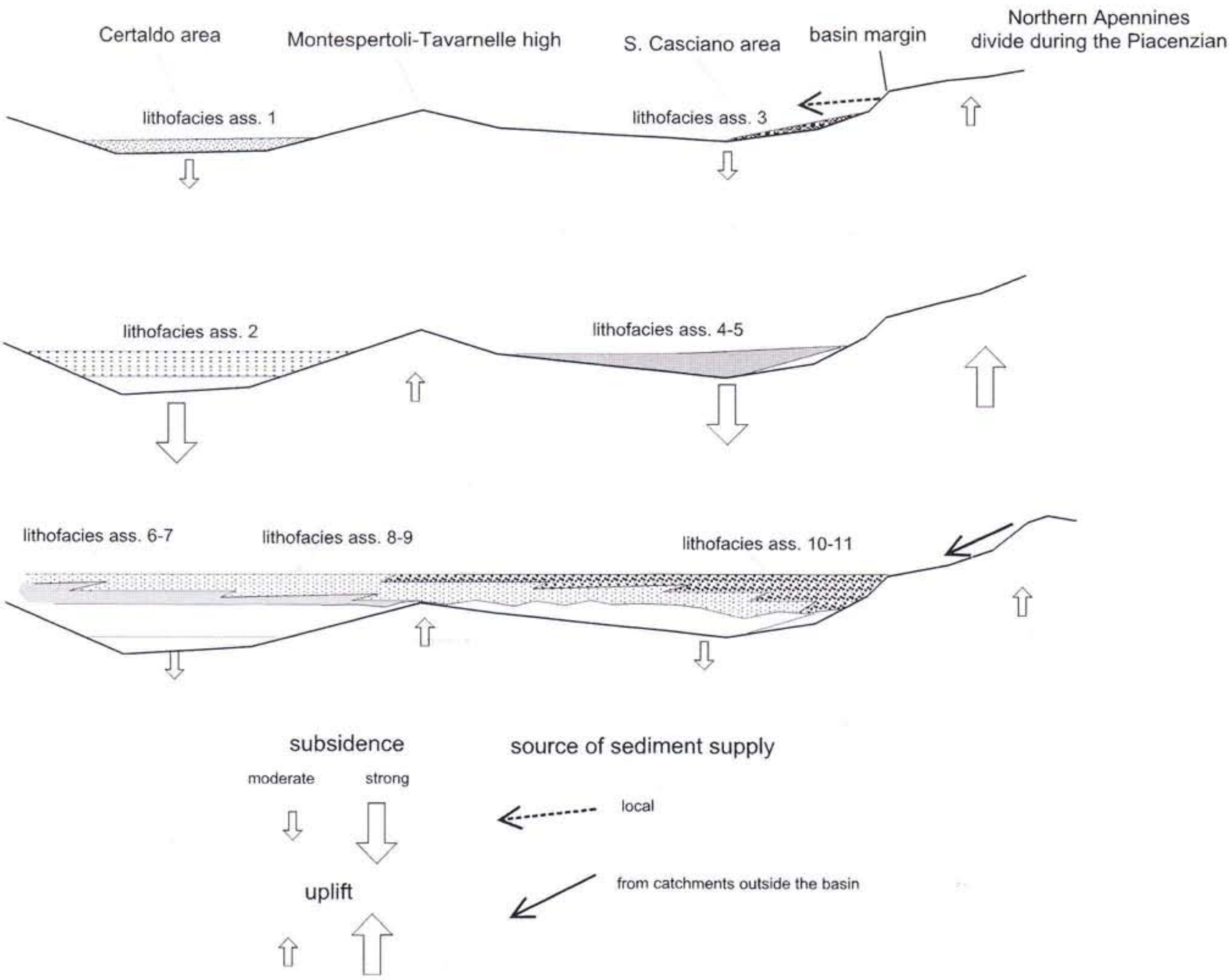

Fig. 11 - Schematic sections showing the change of sediment supply and basin subsidence/margin uplift during the late Zanclean-Piacenzian evolution of the Valdelsa Basin.

sent the general depositional setting developed in the Valdelsa during the Pliocene.

The map of the unconformity-bounded stratigraphic units

On the base of the stacking pattern of lithofacies associations and of the occurrence of major erosional surfaces, a subdivision of the Pliocene deposits by means of UBSU (ISSC, 1994) is here proposed (Fig. 2d; 12). The deposits described above are therefore grouped into five synthems. From the older these are (Fig. 2d):

a) Certaldo synthem (uppermost Zanclean-Piacenzian). Compared with previous stratigraphic subdivisions this synthem includes the Ps and Pa p.p ("Argille Azzurre") (Carta Geologica d'Italia, 1965, sheet 113 and Carta Geologica d'Italia, 1967, sheet 106). Although in the study area the basal unconformity of this synthem has been not observed, stratigraphic data from a nearby area (i.e. Borro Strolla, see below) suggest that the Certaldo synthem overlies, through a disconformity, Zanclean marine deposits. This erosional contact points to a major relative sea-level fall occurred in the late Zanclean in the central part of the basin (i.e. between Poggibonsi and Castelfiorentino) with widespread subaerial erosion in the basin followed by relative sea-level rise controlling the deposition of lithofacies associations 1 and 2;

b) Pesa River synthem (uppermost Zanclean?-Piacenzian?). The deposits included in this synthem have been previously considered (Canuti et al., 1966) to be conformably overlain by the gravelly succession of the S.Casciano-Montelupo area (Pcg, Ciottolami di S. Casciano). At the Sambuca site this synthem rests over palustrine-lacustrine deposits through an angular unconformity suggesting that uplift and tilting of the eastern margin of the basin occurred prior the deposition of lithofacies associations 3-5. The Pesa River synthem is tentatively considered to be time-equivalent to the Certaldo synthem;

c) Ponte a Elsa synthem (Piacenzian). This synthem, including Pa and Ps units of earlier subdivision, erosively overlies the Certaldo and Pesa River synthems pointing to a major reorganization of the basin and of

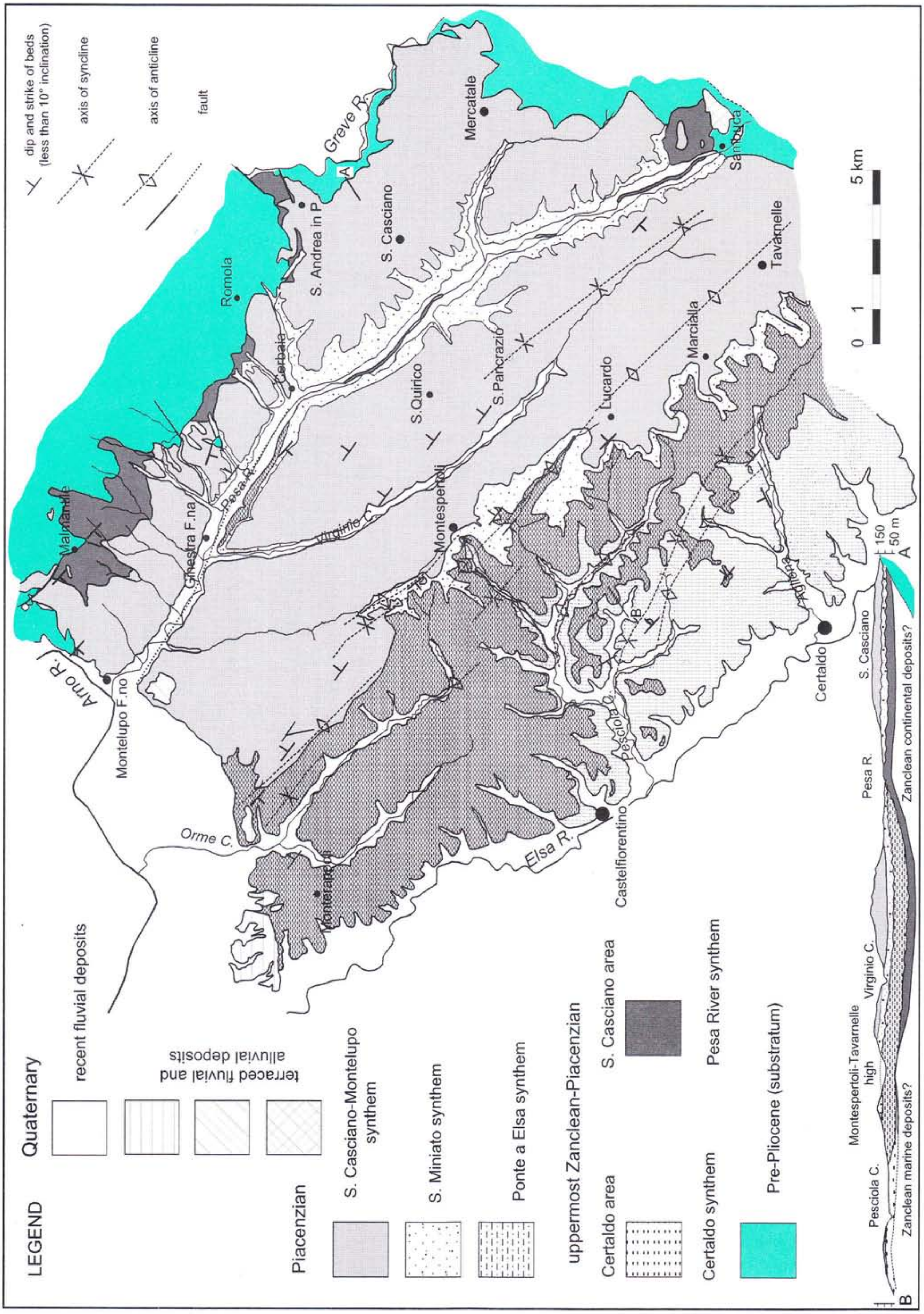

Fig. 12 - Map of the synthems definined within the Pliocene basin fill of the central-eastern Valdelsa Basin.

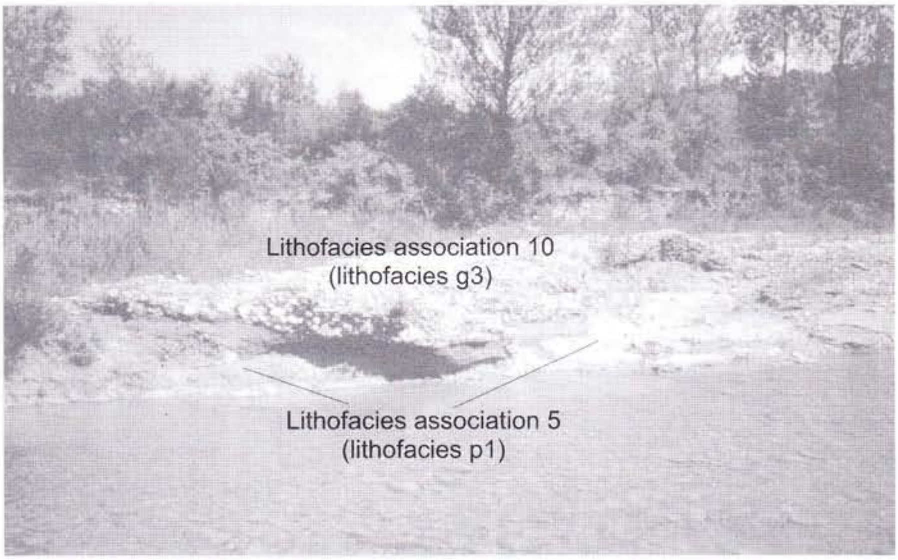

Fig. 13 - Unconformable contact between lithofacies association 5 (i.e. the Pesa River synthem) and 10 (i.e. the S. Miniato synthem) in the valley of the Pesa River. Notice the high-relief erosional surface between lithofacies p1 and g3. The outcrop is about 1 m high.

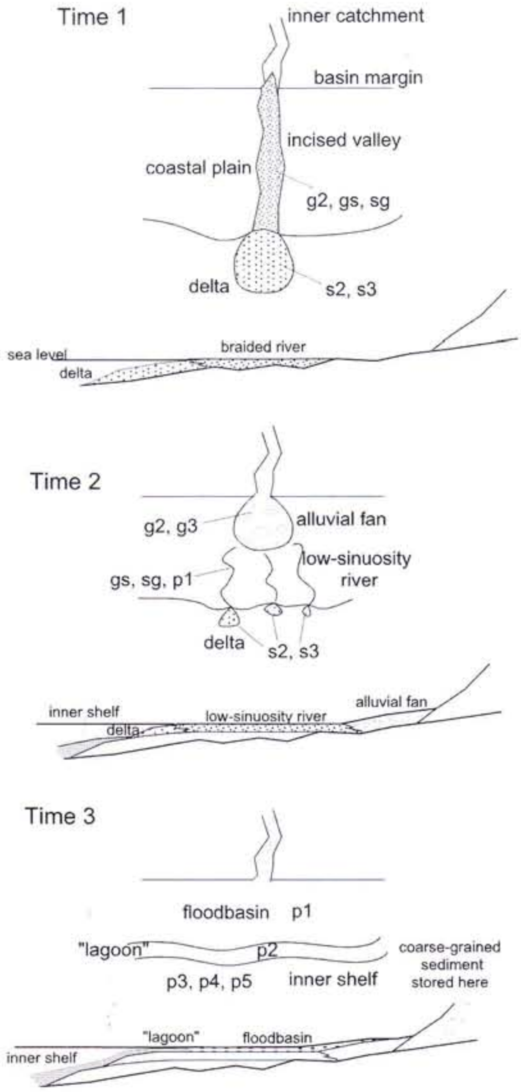

Fig. 14 - Conceptual scheme of the response of the depositional systems of the Valdelsa Basin to base-level and sediment supply change at the scale of lithofacies associations included in the Ponte a Elsa, S. Miniato and S. Casciano-Montelupo synthems.

the drainage network. Uplift of the north-eastern shoulders caused a massive denudation of the mid Pliocene Apennine divide and huge supply of coarse-grained material to the basin via three major fluvial systems. The entry points in the basin were respectively north of Montelupo F.no, north of S. Casciano (S. Andrea in Percussina area) and northeast of Mercatale. Other small fluvial systems drained the eastern margin of the basin. Sediment was supplied to a coastal-shallow marine area in the central basin;

d) S. Miniato synthem (Piacenzian) including deposits formerly classified as Ps. The contact with the underlying Ponte a Elsa synthem is an erosive surface possibly fluvial in origin and associated to a phase of progradation of the fluvio-deltaic systems fed from the north-eastern margins of the basin. Along these margin the S. Miniato synthem is in angular contact with the deposits of the Pesa River synthem pointing therefore to a deformation of the latter deposits due to uplift and tilting of the basin's margins;

e) S.Casciano-Montelupo synthem (Piacenzian). The deposits of this synthem have been previously either mapped as Pcg, Ps and Pa. The synthem erosively overlies the S. Miniato synthem testifying the final progradation of the fluvial systems in the basin. Similarly to the S. Miniato synthem the S.Casciano-Montelupo synthem is in angular contact with deposits of the Pesa River synthem along the north-eastern margins.

Basing on data from literature the proposed subdivison adopting UBSU can be extended to a wider scale including other portions of the Valdelsa Basin.

On the left side of the Elsa River (Fig. 2b) fluvio-deltaic sands (unit Pg) and inner-shelf clays (unit P) are equated to the lithofacies associations included into the Certaldo synthem. Units P2-P3, resting above unit P, have been included in the S. Miniato area within the Ponte a Elsa and S. Miniato synthems (Benvenuti et al., in progress).

Lowermost Pliocene marine deposits (Fig. 2c, unit B of Bossio et al., 1993) are known in the south-eastern end (Borro Strolla valley) of the Valdelsa Basin. They rest apparently through a conformity, more probably through a paraconformity (study in progress), on continental deposits (unit A in Fig. 2c) ascribed to the Messinian and are unconformably capped by Middle Pliocene paralic and shallow marine gravels (unit C), sands (unit D) and clays (unit E), in turn erosively overlain by shallow marine sands (unit F). A tentative identification of the Middle Pliocene deposits of the Borro Strolla with the Certaldo (i.e units C-E) and Ponte a Elsa (i.e. unit F) synthems is proposed. As a consequence, the lowermost marine deposits of Borro Strolla (i.e. unit B) should represent, for the Valdelsa Basin, the basal Pliocene synthem. The latter could have a time-equivalent synthem in the study area partly represented by the palustrine-lacustrine deposits of the Sambuca Site. Such a virtual correlation will be eventually confirmed by a more detailed biochronologic study of the freshwater mollusc assemblage collected in the Sambuca deposits (Esu, in progress).

Conclusion

The main results of the stratigraphic revision of the Pliocene Valdelsa Basin deposits are:

1) the subdivision of previously undifferentiated shallow marine to continental deposits by means of lithofacies analysis. Lithofacies associations are defined combining lithology with depositional features, interpreted through integrated litho- and bio-facies analysis. Field recognition of distinctive marine-paralic (Benvenuti et al., 1995b) and continental molluscan assemblages revealed to be a fundamental tool to infer the depositional environment of the generally massive fine-grained lithofacies. Analysis of continental molluscan assemblages (D. Esu, study in progress), only partially described before (De Stefani 1876-1880; Pantanelli 1879), will provide further data to reconstruct the depositional settings of the previously unreported continental deposits;

2) the recognition of different scale sedimentary cycles and unconformities revealing important aspects of the depositional evolution either at long and short time scales;

3) the first recognition of a quite complex structural arrangement of the Pliocene deposits providing suggestions for future integrated tectono-stratigraphic analysis devoted to model the basin origin and its deformation;

4) a stratigraphic synthesis, by the subdivision of the Pliocene succession adopting the unconformity-bounded stratigraphic units. Five synthems, spanning in age from the latest Zanclean to the Piacenzian, are established grouping the lithofacies associations among major unconformities. A comparison with stratigraphic data available for other portions of the Valdelsa Basin suggests that such a framework could be extended to the whole basin.

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REFERENCES

Anketell J.M. & Rust B.R. (1990)- Origin of cross-stratal layering in fluvial conglomerates, Devonian Malbaie Formation, Gaspé, Quebec. *Can . J . Earth . Sci .*, 27: 1773-1782, Toronto.

Bartolini C. & Pranzini G. (1981)- Plio-Quaternary evolution of the Arno basin drainage. *Zeitschr. Geomorph., N.F.*, 40: 77- 91, Berlin-Stuttgart.

Benvenuti M., Dominici S. & Rook L. (1995a)- Inquadramento stratigrafico-deposizionale delle faune a mammiferi villafranchiane (unità faunistiche Triversa e Montopoli) del Valdarno Inferiore nella zona a sud dell'Arno (Toscana). *Il Quaternario*, 8: 457-464, Roma.

Benvenuti, M., Bertini, A., Conti, C., Dominici, S. & Falcone D. (1995b)- Analisi stratigrafica e paleoambientale integrata del Pliocene dei dintorni di S. Miniato. *Quad. Mus. St. Nat. Livorno*, 14: 29-49, Livorno.

Benvenuti M. & Dominici, S. (1992)- Facies analysis, paleoecology and sequence stratigraphy in a Pliocene siliciclastic succession, San Miniato (Pisa, Italy). *Boll. Soc. Paleont. It.*, 31: 241-259, Modena.

Bernini M., Boccaletti M., Moratti G., Papani G., Sani F. & Torelli L. (1990)- Episodi compressivi neogenico-quaternari nell'area estensionale tirrenica nord-orientale. Dati in mare e a terra. *Mem. Soc. Geol. It.*, 45: 577-589. Roma.

Boccaletti M. & Sani F. (1998)- Cover thrust reactivations related to internal basement involvement during Neogene-Quaternary evolution of the Northern Apennines. *Tectonics*, 17: 112-130, Washington D.C.

Boccaletti M., Cerrina Feroni A., Martinelli P., Moratti G., Plesi G. & Sani F. (1991)- L'alternanza distensionecompressione nel quadro evolutivo dei bacini neogenici dell'Appennino Settentrionale. *Studi Geol. Camerti*, Spec. 91/1: 187-192, Camerino.

Boccaletti M., Bonini M., Moratti G. & Sani F. (1995)- Nuove ipotesi sulla genesi e l'evoluzione dei bacini post-nappe in relazione alle fasi compressive neogenico-quaternarie dell'Appennino Settentrionale, In Atti del convegno rapporti Alpi-Apennino e guide alle escursioni (eds R. Polino and R. Sacchi), *Accademia Nazionale delle Scienze. Scritti e Documenti*, 14: pp. 229-262, Roma.

Bosellini A., Mutti E. & Ricci Lucchi F. (1989)- Rocce e successioni sedimentarie., V. of 395 pp, UTET, Torino.

Bossio A., Costantini A., Lazzarotto A., Liotta D., Mazzanti R., Mazzei R., Salvatorini G. & Sandrelli F. (1993a)- Rassegna delle conoscenze sulla stratigrafia del Neoautoctono toscano. *Mem. Soc. Geol. It.*, 49: 17-98, Roma.

Bossio A., Mazzei R., Salvatorini G. & Sandrelli F. (1993b)- Nuovi dati sui depositi mio-pliocenici del settore meridionale del bacino del Fiume Elsa. *Palaeopelagos*, 3: 97-108, Roma.

Butler R.W.H. & Grasso M. (1993)- Tectonic controls on base-level variations and depositional sequences within thrust-top and foredeep basins: examples from the Neogene thrust belt of central Sicily. *Basin Research*, 5: 137-151, Oxford.

Canuti P., Pranzini G. & Sestini G. (1966)- Provenienza ed ambiente di sedimentazione dei ciottolami del Pliocene di S. Casciano (Firenze). *Mem. Soc. Geol. It.*, 5: 340-364, Roma.

Caredio F., Esu D. & Testa G. (1995)- Il margine orientale del bacino plio-pleistocenico di Lucca-Montecarlo-Vinci: evoluzione stratigrafica e tettonica. *Studi Geol. Camerti, Spec.* 95/1: 235-253, Camerino.

Carmignani L., Decandia F.A., Fantozzi P.L., Lazzarotto A., Liotta D. & Meccheri M. (1994)- Tertiary extensional tectonics in Tuscany (Northern Apennines, Italy). *Tectonophysics*, 238: 295-315, Amsterdam.

Carta Geologica d'Italia (1965)- Foglio 106 - Firenze. Serv. Geol. d'It., Roma.

Carta Geologica d'Italia (1967)- Foglio 113 - Castelfiorentino. Serv. Geol. d'It., Roma.

Carta strutturale dell'Appennino Settentrionale (1982) - Sheet 3. C.N.R., Prog. Fin. Geodin., pubbl. 429, Tipografia Senese 1987.

Ciangherotti A.D., Esu D. & Girotti O. (1998)- Review of the history of the Late Neogene-Early Quaternary non-marine molluscs of Italy. *Meded. Ned. Inst. Toegepaste Geowetenschappen TNO*, 60: 491-498, Amsterdam.

Conti C. (1993)- Studio biostratigrafico e sedimentologico dei sedimenti pliocenici dell'area nord-orientale del Bacino dell'Elsa (Certaldo). Unpublished Laurea Thesis, Dipartimento di Scienze della Terra, Università di Firenze, 193 pp.

Dainelli G. & Videssot P. (1930)- Il mare pliocenico della Toscana Settentrionale. *Mem. Geol. Geogr. di G. Dainelli*, 1: Firenze.

De Stefani C. (1876-1880) - Molluschi continentali finora notati in Italia nei terreni pliocenici ed ordinamento di questi ultimi. *Atti Soc. Tosc. Sci. Nat.*, 2, 3, 5: Pisa.

Degli Innocenti D. (1997)- I sedimenti pliocenici nella zona di Montelupo Fiorentino (Fi). Unpublished Laurea Thesis, Dipartimento di Scienze della Terra, Università di Firenze, 87 pp.

Dominici S. (1994) - Regressive-transgressive cycles from the Pliocene of the San Miniato area (Tuscany, Italy): paleoecology and sequence stratigraphy. *Boll. Soc. Paleont. It.*, 2: 117-126, Modena.

Dominici S., Mazzanti R. & Nencini C. (1995) - Geologia dei dintorni di S. Miniato tra l'Arno, *l'Elsa e l'Era. Suppl. Quad. Mus. St. Nat. Livorno*, 14: 1-35, Livorno.

Elter F.M. & Sandrelli F. (1994)- La fase post-nappe nella Toscana Meridionale: nuova interpretazione sull'evoluzione dell'Appennino Settentrionale. *Atti Tic. Sci. Terra*, 37: 173-193, Pavia.

Esu D., Girotti O. & Truc G. (in press) - New data on fossil Emmericiinae from Italy and France. (Gastropoda, Prosobranchia, Emmericiinae). *Arch. Moll.*, Frankfurt.

Ghelardoni R., Giannini E. & Nardi R. (1968)- Ricostruzione paleogeografica dei bacini neogenici e quaternari della bassa valle dell'Arno sulla base dei sondaggi e dei rilievi sismici. *Mem. Soc. Geol. It.*, 7: 91-106, Roma.

International Subcommission on Stratigraphic Classification (1994) - A guide to stratigraphic classification, terminology, and procedure. V. of 214 pp. 2nd ed.: IUGS, Boulder

Martini I.P. & Sagri M. (1993)- Tectono-sedimentary characteristics of Late Miocene-Quaternary extensional basins of the Northern Apennines, Italy. *Earth Sci. Rev.*, 34: 197-233, Amsterdam.

Martini I.P., Sagri M., & Colella A. (in press)- Neogene-Quaternary basins in the inner Apennines and Calabrian arc, Italy. In Vai, G.B. & Martini, I.P. (eds)- Anatomy of a mountain: the Apennines and adjacent mediterranean basins: Chapman & Hall, London.

Mutti E., Davoli G., Mora S. e Sgavetti M. (1994, eds)- The eastern sector of the south-central folded pyrenean foreland: criteria for stratigraphic analysis and excursion notes. II International Conference on High-resolution Sequence Stratigraphy, Guidebook, Istituto di Geologia, Univ. Parma, V. of 83 pp: Parma.

Mutti E., Davoli G., Tinterri R. & Zavala C. (1996)- The importance of ancient fluvio-deltaic systems dominated by catastrophic flooding in tectonically active basins. *Mem. Sci. Geol. Padova*, 48: 233-291, Padova.

Pantanelli D. (1879)- Sugli strati miocenici del Casino e considerazioni sul Miocene italiano. Atti R. Acc. Lincei, 276: Roma.

Pascucci V., Merlini S. & Martini I.P. (1999)- Seismic stratigraphy of the Miocene-Pleistocene sedimentary basins of the northern Tyrrhenian Sea and western Tuscany

(Italy). *Basin Research*, 11: 337-356, Oxford.

Rio D., Sprovieri R. & Di Stefano E. (1994)- The Gelasian stage: a proposal of a new chronostratigraphic unit of the Pliocene series. *Riv. It. Paleont. Strat.*, 100: 103-124, Milano.

Rust B.R. (1984)- Proximal braidplain deposits in the Middle Devonian Malbaie Formation of Eastern Gaspé, Quebec, Canada. *Sedimentology*, 31: 675-695, Oxford.

Sestini G. (1970)- Postgeosynclinal deposition, In Sestini G. (ed.)- Development of the Northern Apennines Geosyncline. *Sedimentary Geology*, 4: 481-520, Amsterdam.

Steel R.J. & Thompson D.B. (1983)- Structures and textures in Triassic braided stream conglomerates ('Bunter' Pebble Beds) in the Sherwood Sandstone Group, North Staffordshire, England. *Sedimentology*, 30: 341-367, Oxford.

Trevisan L., (1952)- Sul complesso sedimentario del Miocene Superiore e del Pliocene della Val di Cecina e sui movimenti tettonici tardivi in rapporto ai giacimenti di lignite e di salgemma. *Boll. Soc. Geol. It.*, 70: 66-78, Roma.

Todd S.P. (1989)- Stream-driven, high-density gravelly traction carpets: possible deposits in the Trabeg Conglomerate Formation, SW Ireland and some theoretical considerations of their origin. *Sedimentology*, 36: 513-530, Oxford.