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Miocene shallow-water deposits of the northern Apennines: a stratigraphic marker across a dominantly turbidite foreland-basin succession

Alessandro Amorosi
Dipartimento di Scienze della Terra e Geo-Ambientali, Università di Bologna, Via Zamboni 67, 40127 Bologna, Italy

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Abstract

Lower-Middle Miocene shallow-water deposits commonly occur in the piggy-back-basins sequence of the northern Apennines thrust-belt. In contrast, such deposits are restricted to small bodies of reduced lateral extent in the adjacent foredeep succession. Lateral tracing of major unconformities across the two different structural domains allows reconstruction of a common sedimentary evolution for the study area, through the identification of three depositional sequences with an internal arrangement in systems tracts, generally showing lack or scarcity of lowstand deposits.

A regional unconformity, marking the erosional truncation of the underlying turbidite deposits, constitutes the base of sequence S1 (Upper Burdigalian). Above mixed carbonate-siliciclastic, shallow-water facies (transgressive systems tract, TST), sequence S1 exhibits a progradational stacking pattern of outer-shelf to inner-shelf and nearshore facies (highstand systems tract, HST). The unconformable lower boundary of sequence S2 (Lower Langhian) is the base of transgressive, glaucony-rich, tide- and storm-influenced nearshore arenites (TST). The maximum flooding surface, showing local concentration of glaucony, records the sharp change from marginal-marine arenites to highly bioturbated shelf deposits (HST). A generalized drowning of shelves during the Late Langhian-Early Serravallian is documented by rapid transition to coarse-grained siliciclastic deposits and deep-water marls (sequence S3).

Tectonics appear to have exerted a major control on sedimentation, especially at the onset of sequence S1 and during deposition of sequence S3. Conversely, a possible eustatic control may apply for sequence S2.

Introduction

The northern Apennines thrust-belt is made up of a series of stacked tectono-sedimentary units (Figure 1; De Jager 1979, Ten Haaf & Van Wamel 1979). Two major palaeogeographic domains have been distinguished within the Apenninic foreland basin system (Sestini 1970, Ricci Lucchi 1986): 1) the foredeep, developed ahead of the active thrust system parallel to the present tectonic axes (NW-SE), and migrating toward the foreland in NE direction; 2) the piggy-back (Ori & Friend 1984) or semi-allochthonous (Ricci Lucchi 1987) basins, resting on top of the main thrusts and/or on top of the advancing allochthonous Ligurian sheets that, in turn, were thrust over the chain during the Apenninic tectogenesis.

The Miocene foredeep-basin fills consist primarily of huge turbidite wedges (Ricci Lucchi 1984), a few thousands of meters thick. These turbidite bodies, that are progressively younger in NE direction according to orogenic polarity, crop out extensively in the northern Apennines and represent the filling of foredeeps that were active in closely successive times. The Cervarola and Falterona Formations (Guenther & Reutter 1985) were deposited in the outer Tuscan domain during the Early Miocene. Subsequent uplift of the former foredeep and NE-ward movement of subsidence to an outer position (Romagna-Umbria-Marche domain) resulted in deposition of the Middle-Upper Miocene Marnoso-

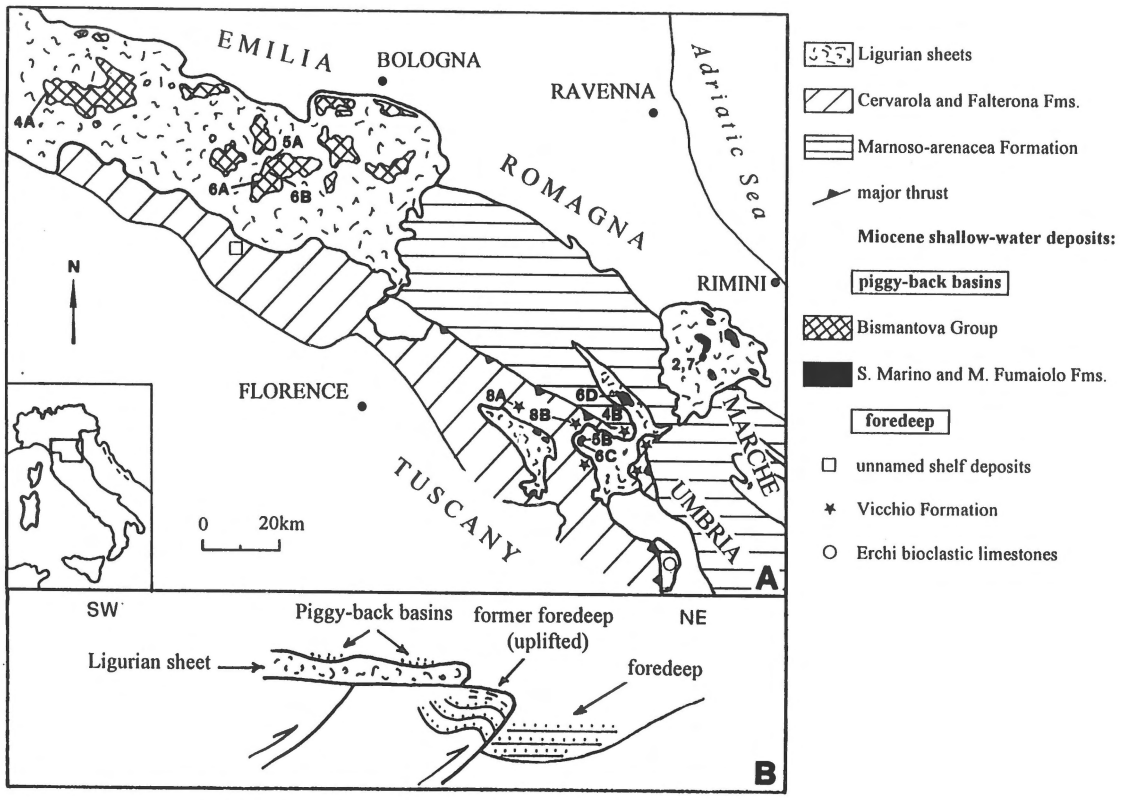

Figure 1. A: Simplified geologic sketch map of the northern Apennines, showing the major structural units, the distribution of the Lower-Middle Miocene shallow-water deposits, and the location of outcrops shown in Figures 2 and 4–8. B: schematic cross-section showing spatial relationships among the major structural domains discussed in this paper during the Early-Middle Miocene.

arenacea Formation (Ricci Lucchi 1975, 1981, 1986), subdivided in various sub-units by Dutch workers on the basis of structural features (Ten Haaf & Van Wamel 1979, De Feyter et al. 1986, 1990, Van Wamel & Zwart 1990). The Miocene units of the piggy-back basins are generally less than 1000 m thick and include nearshore to turbidite deposits. The foredeep and piggy-back-basin sequences have been correlated on the basis of major unconformities and facies changes (Ricci Lucchi 1986, Amorosi et al. 1995, 1996a), but a detailed stratigraphic framework is still lacking, due to absence of 'physical' correlation between marginal and basinal domains.

Shallow-water deposits, occurring on top of the allochthonous Ligurian units as gravitationally displaced remnants of destroyed shelves (Figure 2), have been widely reported from the Miocene piggy-back-basins succession of the northern Apenninic thrust belt, and included within a single depositional sequence of Langhian-Serravallian age (Ricchi Lucchi 1986). Unfortunately, previous work has not studied these units so much in detail as their deep-water (mostly turbidite) counterparts, most studies being of local interest only, with rare attempts at establishing interbasinal correlations (Sestini 1970, Ricci Lucchi 1975, 1981, Amorosi 1992b).

Recently, shelf deposits of Early-Middle Miocene age, occurring as closure facies of thick turbidite bodies, have also been reported from the foredeep basin fills of the outer Tuscan domain (Pizziolo & Ricci Lucchi 1991, De Donatis 1993, Delle Rose et al. 1994).

The aim of this paper, representing a compilation of previous work and summarizing a few years of field work conducted by the author (Amorosi 1992a), is 1) to emphasize the stratigraphic and sedimentologic significance of shallow-water deposits within a predominantly turbidite succession; 2) to show how recognition of a common stratal architecture, and its discussion in the

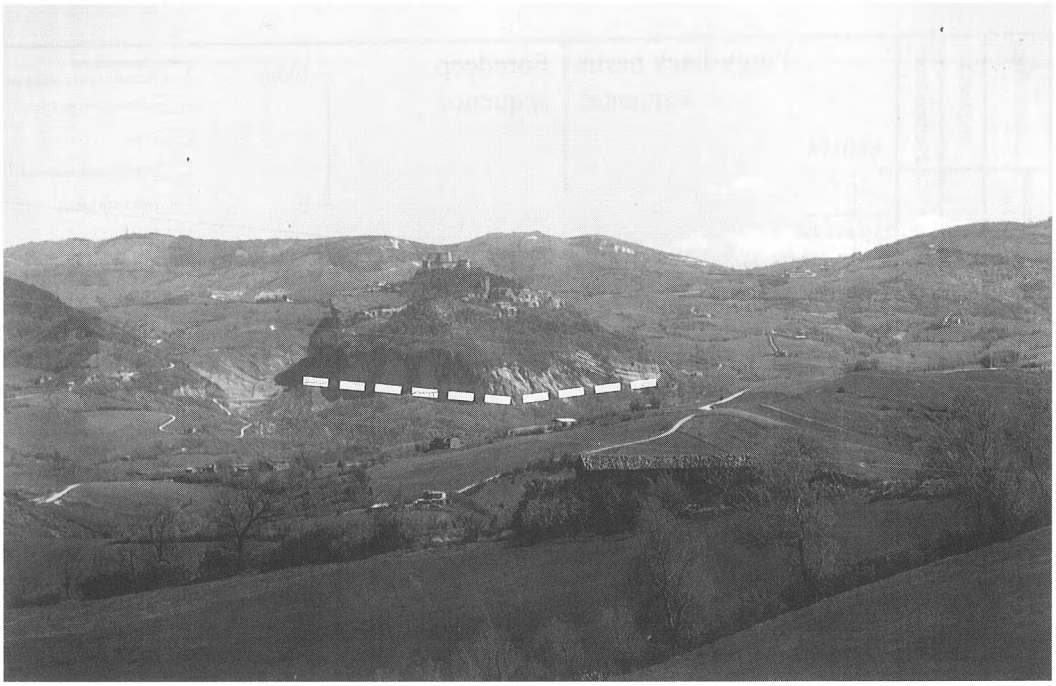

Figure 2. Isolated block of shallow-water deposits of the piggy-back basins sequence (S. Marino and M. Fumaiolo Fms), 'floating' on a predominantly argillaceous substratum (Ligurian sheet). The boundary between the two units is marked by a dashed line. A possible parental relationship among the Miocene shelf units of the northern Apennines was first envisaged by Dante Alighieri (Divina Commedia, Purgatorio, canto IV), based upon geomorphic evidence alone. See Figure 1 for location.

context of sequence-stratigraphic concepts, may constitute an important tool for correlation of sedimentary sequences across an entire foreland basin system.

Piggy-back basins

The Miocene shelf deposits of the piggy-back basins include the lower Bismantova Group in the Emilia area and the S. Marino and M. Fumaiolo Formations in the Romagna-Marche area (Figures 1, 3).

Emilia area

The Bismantova Group shows a varied facies architecture, including coastal to deep-water deposits, with an overall deepening-upward tendency. Nearshore and inner-shelf facies, vertically stacked in two distinct transgressive-regressive cycles (depositional sequences S1 and S2 in Amorosi 1992a, b), characterize the lower part of the unit (Pantano Fm, Late Burdigalian-Langhian). The lower boundary of the Bismantova Group is an unconformity separating glaucony-bearing, shallow-water deposits from the silica-rich, deep-water marls of the underlying Antognola Formation (Figure 4A). Above the transgressive unit, the Upper Burdigalian deposits display a peculiar 'regressive' trend, marked by a progradational parasequences set (Figure 5A), showing the vertical transition from burrowed and structureless very fine arenites to more proximal, wavy-bedded inner-shelf deposits.

The upper depositional cycle within the Pantano Formation, locally marked at the base by a transgressive pebble layer, records the vertical change from glaucony-rich, tide-influenced (Figure 6A) and wave-influenced (Figure 6B) arenites to Lower Langhian bioturbated inner-shelf siltstones.

The Cigarello Formation is made up of resedimented sandstone bodies (storm layers and turbidites), resting erosively on sequence S2, and overlain by outer-shelf to slope hemipelagic marls. A regional unconformity, Late Serravallian in age, marks the upper boundary of the Bismantova Group with the Termina Formation (Amorosi et al. 1996b).

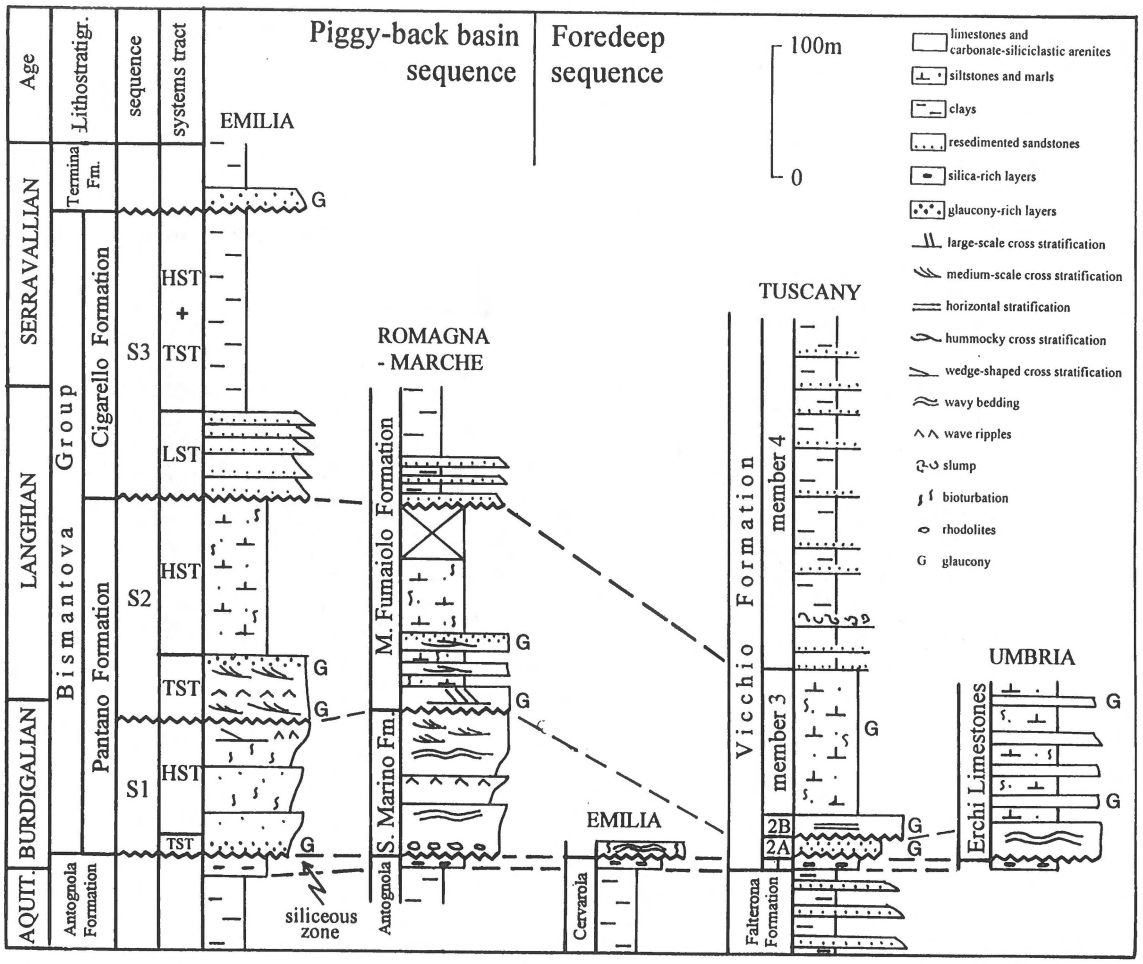

Figure 3. Detailed correlation scheme of Miocene shallow-water deposits of the northern Apennines, with sequence-stratigraphic interpretation. Indicated ages are taken from the literature.

Romagna-Marche area

The two transgressive-regressive cycles observed within the Pantano Formation are also recognizable in the Lower-Middle Miocene succession of the piggy-back basins in the Romagna-Marche area. In this case, the boundary between the two cycles (Figure 4B) corresponds to the lithostratigraphic boundary between the S. Marino and M. Fumaiolo Formations (Amorosi 1992a, b).

The S. Marino Formation (Ricci Lucchi 1967) consists of a basal transgressive, massive and brecciated facies, made up predominantly of skeletal limestones, characterized by the typical bryorhodalgal lithofacies reported from other Miocene formations (Nelson 1978, Carannante et al. 1988, Flecker et al. 1995). This lower unit, commonly intercalated in its lower part with thick debris-flow deposits including material of extraformational origin, is overlain by a shallowing upward sequence, defined by a progradational parasequence set (Figure 5B) and capped by high-energy, mixed carbonate-siliciclastic, inner-shelf facies.

A sharp unconformity, associated with an abrupt increase in the amount of siliciclastic components (M. Fumaiolo area), separates the S. Marino Formation from the overlying M. Fumaiolo Formation (Figure 4B). Glaucony-rich and phosphate-bearing, wave- and tide-influenced arenites, with well-developed wedge-shaped and large-scale trough stratification, form the lower part of the M. Fumaiolo Formation. These

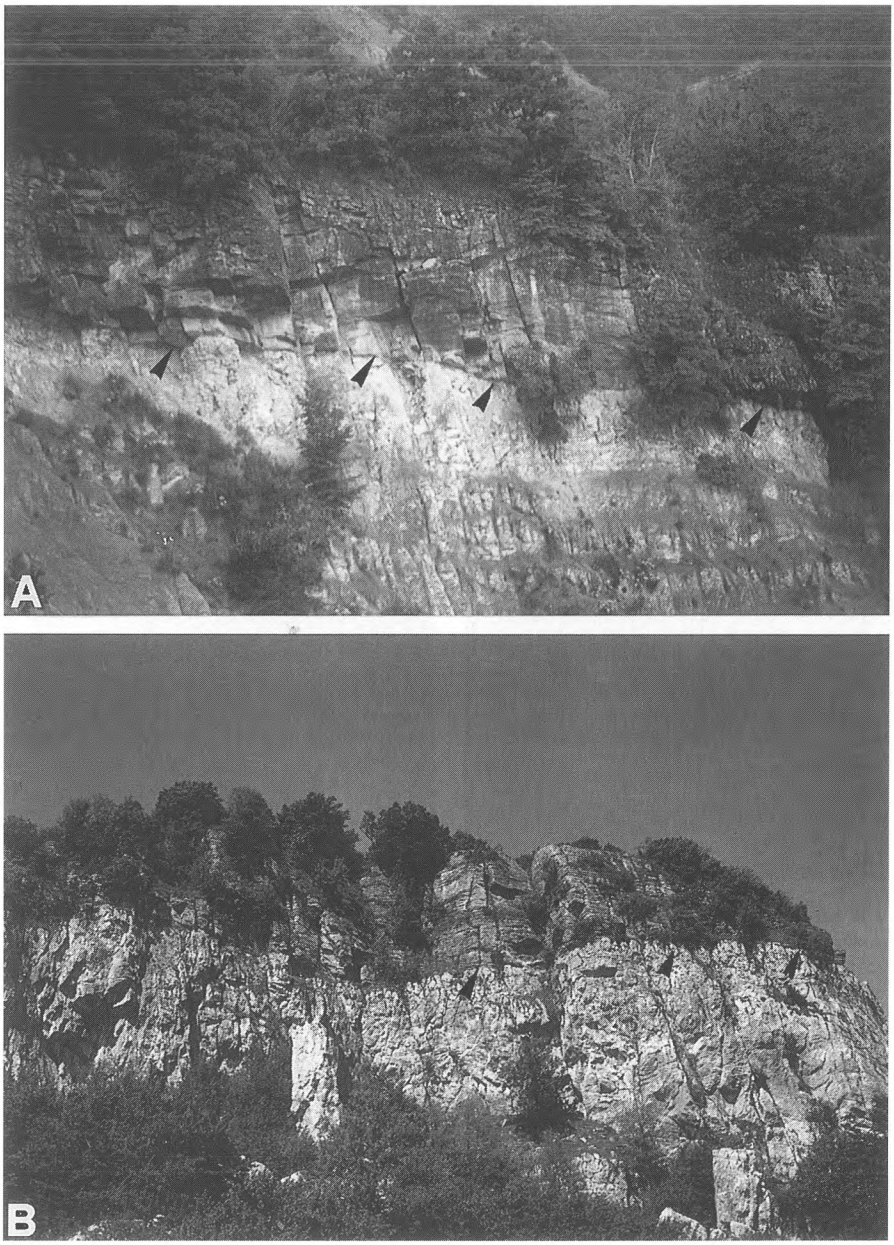

Figure 4. The shallow-water deposits of the piggy-back basins sequence. A: unconformable lower boundary (arrows) of the Bismantova Group on the underlying Antognola Fm in the Emilia area. Stratigraphic thickness shown is approximately 35 m. B: sharp boundary (arrows) between the S. Marino Fm (below) and the M. Fumaiolo Fm (above) in the Romagna-Marche area. Stratigraphic thickness shown is approximately 90 m. See Figure 1 for locations.

deposits grade upward into highly bioturbated Langhian inner-shelf siltstones, intercalated with storm-dominated arenitic bodies, showing hummocky-cross stratification (Figure 6C). The upper part of the M. Fumaiolo Formation (Upper Langhian-Serravallian) is characterized in the type area by glaucony-bearing, storm-dominated arenites interbedded with outer-shelf marls (Figure 6D). In contrast, inner-shelf, tide-dominated arenites (Figure 7), alternated with structureless, bioturbated beds, constitute the upper M. Fumaiolo Formation in the S. Leo area.

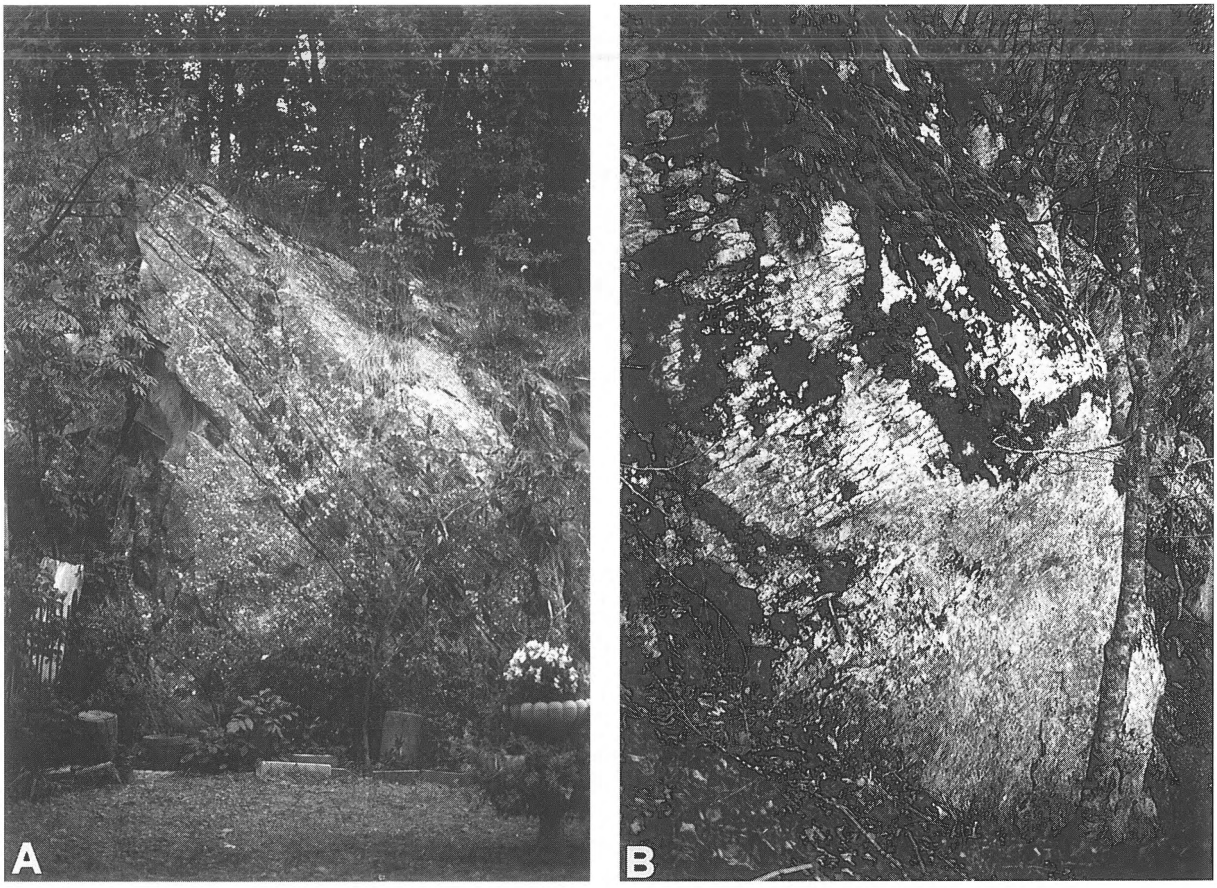

Figure 5. Close-ups of parasequences in the Pantano Fm (A) and S. Marino Fm (B), respectively. See Figure 1 for locations. A shallowing upward tendency is indicated in both cases by a slight increase in grain size combined with the upward transition from burrowed, structureless carbonate-siliciclastic arenites to less bioturbated carbonate-siliciclastic arenites showing wedge-shaped cross stratification (A) and wavy bedding (B).

Foredeep

The turbidite Cervarola and Falterona Formations represent the bulk of the Lower Miocene Apenninic foredeep basin fill (Figure 1). Aquitanian and Lower Burdigalian thick turbidites grade upward into thin turbidites and marls associated with silica-rich beds and volcano-sedimentary layers (Figure 3). These silica-rich deposits, that are laterally correlative with the upper Antognola Formation of the piggy-back basins, have been inferred to be part of a synchronous marker horizon, extending across the entire northern Apennines (siliceous zone of Amorosi et al. 1995), and possibly correlative across the entire Mediterranean area (Bellon 1981, Lorenz 1984).

An unconformity, recently reported by Pizziolo & Ricci Lucchi (1991) across most of the outer Tuscan domain, separates the turbidite deposits from the overlying shelf facies. Three areas can be distinguished from NW to SE: the Emilia, Tuscan, and Umbria Apennines.

Emilia Apennines

Few scattered slabs of Lower Miocene shelf deposits have been observed in the Bologna Apennines on top of the siliceous zone, sealing the turbidite Cervarola Formation (Pizziolo & Ricci Lucchi 1991). Shelf calcarenites showing no obvious stratification and lacking primary structures, due to intensive bioturbation, rest on top of either the siliceous member of the Cervarola Formation or equivalent units. This facies strongly resembles the Burdigalian deposits of the piggy-back basins and is locally overlain by thick Middle Miocene turbidites.

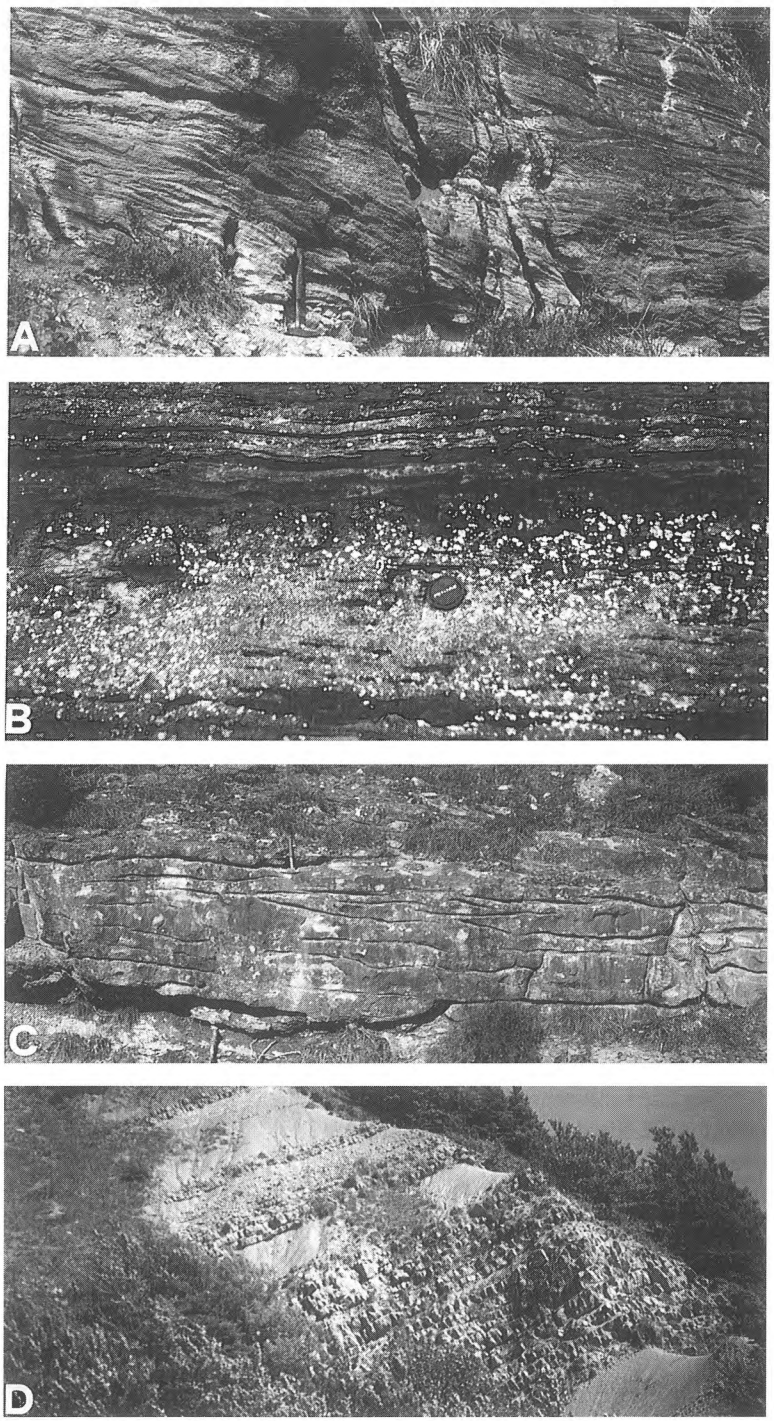

Figure 6. Sedimentologic features of shallow-water deposits in the piggy-back basin sequence. See Figure 1 for locations. A: cross-bedding in tide-influenced arenites; B: heterolithic, wave-dominated carbonate-siliciclastic arenites; C: hummocky cross-stratification in storm-dominated carbonate-siliciclastic arenites; D: storm sandstone layers intercalated with open-marine marls. Stratigraphic thickness shown is approximately 15 m.

Figure 7. Sigmoidal stratification, of supposed tidal origin, within a carbonate-siliciclastic arenitic body (approximately 8 m thick) of the M. Fumaiolo Fm in the Romagna-Marche area. See Figure 1 for location.

Tuscan Apennines

Shelf deposits in the Tuscan Apennines are included within the Vicchio Formation which overlies the silica-rich beds. The lower Vicchio Formation (Figure 8A; member 2 of Pizziolo & Ricci Lucchi 1991) consists primarily of glaucony-bearing, storm-dominated arenites. A very thin unit (labelled 2A in this paper) consisting of glaucony-rich, outer-shelf bioturbated sandstones, is present at the very base of the unit and is separated from the overlying arenites (unit 2B) by an obvious angular unconformity. The inner-shelf arenites of member 2 show a transitional upper boundary to fully bioturbated shelf siltstones and sandstones (member 3), of Langhian age (Pizziolo & Ricci Lucchi 1991). Coeval, glaucony-bearing marls have also been reported from the discontinuous successions of the High Marecchia and Tiber valleys, where more or less pronounced stratigraphic breaks have been recorded (De Donatis 1993, Delle Rose et al. 1994). Barite nodules constitute local lithostratigraphic markers. Member 4 of the Vicchio Formation (Figure 8B), Late Langhian to Serravallian in age (Delle Rose et al. 1994), crops out extensively in the High Tiber and Marecchia valleys: it is several hundreds of meters thick and consists of outer-shelf to basinal clayey marls, intercalated with slump deposits and resedimented sandstones with local concentration of glaucony (De Donatis 1993).

Umbria Apennines

Lower-Middle Miocene deposits of the Umbria Apennines on top of the siliceous zone generally consist of hemipelagic marls (Schlier Formation) overlain by thick turbidite bodies. Shelf deposits (Erchi bioclastic limestones of De Feyter 1982) have been reported in the M.S. Maria Tiberina area; at this location, mixed carbonate-siliciclastic arenites, with fossiliferous assemblages very similar to those of the S. Marino Formation, occur on top of the silica-rich marker horizon. These inner shelf deposits are overlain by outer-shelf marls intercalated with resedimented glaucony-bearing arenites.

Sequence-stratigraphic interpretation

The large-scale architecture of Lower-Middle Miocene shelf deposits of the northern Apennines shows an overall upward-deepening tendency at all study locations, with similar facies distribution (Figure 3). In a sequence-stratigraphic framework, the vertical subdivision in depositional sequences defined by Amorosi (1992a, b) in the piggy-back basins of the Emilia area can be used as a reference for the other, more discontinuous, successions. Systems tracts are considered in

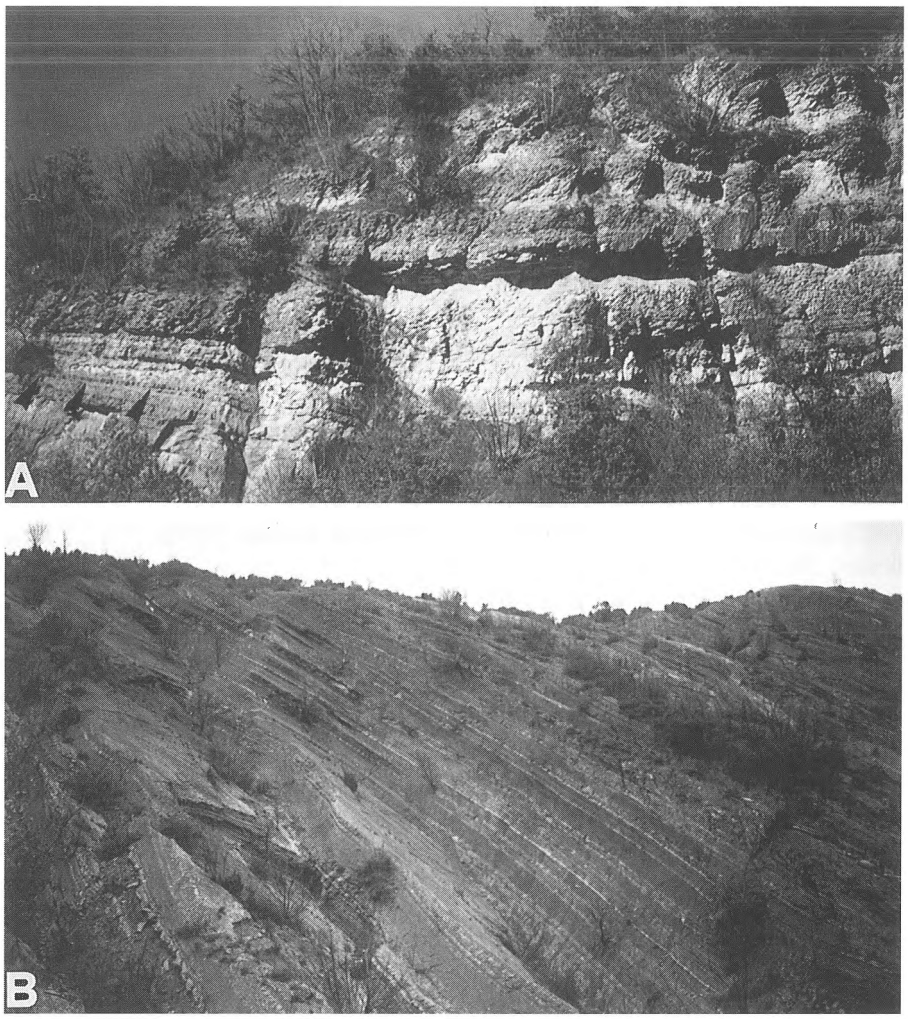

Figure 8. Shallow-water deposits of the foredeep sequence. See Figure 1 for locations. A: glaucony-bearing arenites of the lower Vicchio Fm (member 2); note the angular unconformity (arrows) which separates unit 2A from unit 2B in lower left corner. Stratigraphic thickness shown is approximately 20 m. B: thick succession of marls with intercalated slumped deposits and storm layers (member 4 of the Vicchio Fm). Stratigraphic thickness shown is approximately 100 m.

this paper as descriptive entities and not necessarily interpreted in terms of eustatic fluctuations.

Sequence S1 (Late Burdigalian)

This sequence consists predominantly of nearshore and shelf facies, unconformably overlying the deep-water, silica-rich deposits included within the siliceous zone (Amorosi et al. 1995). In the piggy-back-basins sequence, the thin open-marine, glaucony-bearing deposits at the base of the Bismantova Group and the lower S. Marino Formation represent the transgressive systems tract (TST). Lowstand deposits (LST) are lacking and the TST directly overlies the sequence boundary. The shallowing-upward tendency recorded in the overlying deposits has been interpreted to reflect the highstand systems tract (HST).

Sequence S1 in the foredeep succession is represented by scattered outcrops of glaucony-rich, outer-shelf deposits in the Tuscan Apennines (member 2A of the Vicchio Fm). These units are correlative in the Emilia and Umbria areas with inner-shelf, mixed carbonate-siliciclastic arenites, which closely resemble those reported from the piggy-back units. All these sequences are markedly incomplete; poor exposure of

these units does not enable their attribution to a specific systems tract.

Sequence S2 (Langhian)

The facies architecture of sequence S2 is very similar to that of the underlying (LST-missing) sequence S1. In the piggy-back basins, the lower sequence boundary is an unconformity traceable at the base of transgressive, glaucony-bearing wave- and tide-influenced arenites, locally marking a sharp increase in the amount of siliciclastic components (boundary between the S. Marino and M. Fumaiolo Fms). The basal marginal-marine arenites form the TST. These units, that are correlative with similar tide-influenced deposits in the piggy-back-basins succession of South and central Tuscany (Martini et al. 1995), are sharply overlain by bioturbated, storm-dominated outer-shelf deposits interpreted as the HST. The maximum flooding surface is locally characterized by remarkable concentrations of glaucony and phosphate grains (Amorosi 1995).

A similar sequence architecture can be observed in the foredeep succession, recording the vertical change from glaucony-bearing, marginal-marine arenites of member 2B of the Vicchio Formation (TST) to the deeper-water deposits of member 3 (HST). Further evidence for correlation between the piggy-back basins and the foredeep may be provided by the barite nodules within member 3, which are tentatively correlated with the local enrichments in Ba recorded in the type area of the Vicchio Formation (F. Ricci Lucchi, pers. comm. 1990), and reported by Zuffa (1969) from the upper Pantano Formation in the Emilia Apennines.

Sequence S3 (Late Langhian-Serravallian)

Sequence S3, spanning a time interval of several millions of years (and, for this reason, likely to include parts of distinct third-order depositional sequences), displays a remarkable internal variability across the different tectonic domains of the northern Apennines. As a consequence, the assignment of some of the facies to distinct systems tracts is equivocal or doubtful.

In the piggy-back basins, the lower sequence boundary is locally marked by the base of coarse-grained siliciclastic sediments, interpreted as the LST; these deposits are overlain by an undifferentiated marly unit, presumably belonging to different sequences. In the Emilia area the sequence boundary is marked by a sharp compositional change from mixed carbonate-siliciclastic, to predominantly siliciclastic arenites (Basoli 1991, Fontana & Spadafora 1994, Amorosi & Spadafora 1995, Spadafora 1995), corresponding to the boundary between the Pantano and Cigarello Formations. In the adjacent Romagna-Marche area, the sequence boundary marks the base of storm-dominated sandstones in the upper M. Fumaiolo Formation.

A stratal architecture similar to that of the piggy-back basins can be observed in the outer Tuscan domain of the foredeep (Vicchio basin), where the boundary between the sequences S2 and S3 corresponds to the base of turbidite deposits (boundary between members 3 and 4 of the Vicchio Fm, cf. Montesilvestre Unit of Delle Rose et al. 1994). Local variations to this overall 'transgressive' trend are reported from the High Marecchia Valley, where Serravallian inner-shelf deposits have been observed (Pizziolo & Ricci Lucchi 1991, De Donatis 1993).

Sedimentary evolution

The deep-to-shallow-water vertical succession is a characteristic motif of foreland-basin-fill sequences and reflects the natural evolution of foredeep sedimentation during late orogenic stages, when proximal parts of the foreland basin are progressively incorporated into the thrust system (Ricci Lucchi 1986, Caron et al. 1989, Cant & Stockmal 1993). Shelf deposits, however, are not necessarily developed on top of turbidite clastic wedges, as documented by a detailed study of Middle-Late Miocene foredeep deposits of the northern Apennines (F. Ricci Lucchi, pers. comm. 1996).

The onset of nearshore and shelf sedimentation in the Burdigalian was approximately time-equivalent in the different domains of the northern Apennines, as suggested by the biostratigraphic framework and relative stratigraphic position of marginal-marine deposits on top of the siliceous zone (Figure 3). This suggests a unique external control on Lower Miocene shallow-water sedimentation in the northern Apennines.

The major Burdigalian tectonic event has been suggested as the principal factor controlling the remarkable change in sedimentation from predominantly turbidite-hemipelagite to shallow-water deposits in the northern Apennines (Ricci Lucchi 1986). This tectonic phase caused a general uplift of the thrust belt and a significant rearrangement of the structural domains of the northern Apennines, leading to the closure of the outer Tuscan foredeep and to the opening of the Romagna-Umbria foredeep in an outer, less deformed, position. As a result, Lower Miocene turbidites of

the outer Tuscan domain were incorporated into the thrust system; the former foredeep was converted into a series of piggy-back basins, shallow-water sedimentation taking place unconformably on the older deep-water deposits. Mixed siliciclastic-carbonate facies were deposited in the Emilia and Tuscan areas, whereas a predominantly carbonate-shelf sedimentation occurred more to the east, in the Romagna-Umbria area.

Lower-Middle Miocene shelf deposits have been reported from many parts of Italy. These units, showing striking lithologic and sedimentologic similarities to the coeval deposits of the northern Apennines, originated in different structural settings with independent geodynamical evolution, such as the Tertiary Piedmont Basin (Gelati & Gnaccolini 1988, Clari et al. 1995), the Venetian Basin (Massari et al. 1986), and various basins in the Southern Apennines (Carannante & Simone 1986, Carannante et al. 1988), Sicily and the Iblean plateau (Pedley & Bennett 1985, Carbone et al. 1987, 1993, Lentini et al. 1995). General biostratigraphic similarities of most of these units, documented by Amorosi (1992a) on the basis of the literature, suggest a regional significance of the above shelf deposits, and indicate that factors other than tectonics probably played a fundamental role in shelf facies development in the Mediterranean area. Palaeoceanographic factors as well as an increase in organic productivity could account for the widespread development of carbonate and mixed siliciclastic-carbonate shelf systems in the Early-Middle Miocene (cf. Clari et al. 1995). This hypothesis, however, deserves further research.

The general upward-deepening tendency recognized within the Lower Langhian deposits (sequence S2) in the study area matches the Langhian 'transgressive' event, recognized by Boccaletti et al. (1990) all over Italy. At that time, almost identical facies developed in different structural domains, as documented by the lithologic similarity between the Langhian bioturbated, shallow-marine deposits of the northern Apennines described in this paper, and time-equivalent units, such as the Cessole Marls of the Piedmont Basin (Ghibaudo et al. 1985), the Monfumo Marls of the Venetian Basin (Massari et al. 1986), and the Tellaro Marls/Blue Clay Formation of the Iblean-Malta plateau (Pedley 1981, Romeo & Sciuto 1987). Sediment starvation during the Langhian is suggested by the occurrence of evolved glaucony (locally associated with phosphate nodules and fish teeth) recorded within the Bismantova Group and M. Fumaiolo Formation (Amorosi 1992a), the Vicchio Formation (De Donatis 1993, Delle Rose et al. 1994), the Venetian Basin succession (Massari et al. 1986), the subsurface of the Venetian Plain (Dondi & D'Andrea 1986) and, more to the south, the Ragusa Formation (Pedley & Bennett 1985). The maximum flooding surface of sequence S2, assigned to Zone N8 of Blow (1969) in Amorosi (1990), is correlative with one of the four major condensed sections of the Neogene (cf. Haq et al. 1987, 1988), suggesting a possible eustatic control on sequence development.

The Late Langhian was characterized by the drowning of the majority of shelves in the northern Apennines, as documented by the generalized upward transition in arenite composition from mixed carbonate-siliciclastic to siliciclastic, combined with the sharp change from outer-shelf to turbidite-hemipelagic facies. A contrasting sedimentary evolution, however, affected different sectors of the foreland basin area, as documented by the local deposition of inner shelf arenites in the Romagna-Marche area. This varied facies architecture is likely to reflect a partially independent sedimentary evolution in the various sectors of the chain, although it is probably also due to difficulties in correlation of markedly incomplete successions. The deepening-upward tendency recorded by sequence S3 deposits contrasts with the eustatic curves reconstructed for the Serravallian (Haq et al. 1987), and suggests that eustacy did not exert an important control on sedimentation patterns of this sequence.

The occurrence of shallow-water deposits in scattered outcrops of limited lateral extent across the study area suggests that only a negligible part of the original volume of shelf sediments survived destruction during uplifting of the Apennines. This hypothesis is consistent with the huge volume of shelf clastic material delivered to the basin plains during deposition of Middle to Upper Miocene Apenninic-derived megaturbidites (Ricci Lucchi, 1975, 1981, Gandolfi et al. 1983).

Conclusions

The stratigraphic and palaeogeographic significance of Lower-Middle Miocene shallow-water deposits of the northern Apennines, cropping out as scattered slabs within a predominantly turbidite succession, has been highly underestimated in previous work. These nearshore deposits, interpreted as remnants of destroyed Miocene shelves, are relatively abundant in the piggy-back basins, whereas they are preserved at

very few locations as closure facies of major turbidite wedges in the foredeep area.

Correlation of shallow-water deposits across different tectonic domains provides the basis for reconstructing a common depositional history for the entire Apenninic thrust belt. Deposition in shallow-water environments started in the Late Burdigalian (base of sequence S1) and halted in the Early Serravallian (sequence S3), under a predominantly tectonic control. Eustatic fluctuations probably exerted a major control on the internal architecture of sequence S2. Sequences S1 and S2, that can be regarded as third-order depositional cycles, display an internal arrangement in systems tracts and are correlative across the entire study area. Sequence S3, spanning a longer geologic time and lacking a clear internal subdivision in systems tracts, is likely to include parts of distinct third-order depositional sequences.

Although time equivalence of all the studied units has not been firmly established, the synchroneity of vertical facies changes in different parts of the Apennines foreland basin system suggests a genetical relationship among these units. The establishment of a sequence-stratigraphic framework provides a valuable tool for reconstructing the tectono-sedimentary evolution of the northern Apennines in the Early-Middle Miocene, through the recognition of basinwide, synchronous events.

A special emphasis has been laid in this paper on the need for accurate sedimentological investigation of siliciclastic foreland basin fills, where marginal-marine deposits can be intercalated at various stratigraphic levels within dominantly turbidite successions. Recognition and interpretation of these shallow-water deposits, even if volumetrically unimportant, can be critical to a correct palaeogeographic reconstruction of the entire thrust belt.

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