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THE FOGLIA RIVER ALLUVIAL SYSTEM (NORTHERN MARCHE) AND ITS RELATION TO THE LATE QUATERNARY EVOLUTION OF THE CENTRAL ADRIATIC SHELF

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ABSTRACT
The late Quaternary evolution of the mid-adriatic continental shelf and the river Foglia (Northern Marche) related sediments have been chosen as an example for a tentative correlation between marine and continental sequences.
The stratigraphic setting of the late Quaternary deposits of the Adriatic shelf has been defined by many Authors and is characterized by a low system tract, present inside the mid-adriatic depression, followed by the transgressive and highstand system tracts formed by the post-glacial sea-level rise.
Taking into account data from numerous available boreholes, a longitudinal section of the Foglia river alluvial plain has been defined that shows four depositional units. These units, supported by radiocarbon ages, correlate with the recognized marine system tracts (I – II = LST; III = TST; IV = HST).

RIASSUNTO
Il sistema alluvionale del Fiume Foglia in relazione con l'evoluzione della piattaforma continentale dell'Adriatico centrale.
L'evoluzione pleistocenico-olocenica della piattaforma continentale del medio-adriatico e gli eventi deposizionali che caratterizzano la piana alluvionale del fiume Foglia (Marche settentrionali) sono stati esaminati per tentare di correlare le successioni deposizionali marine e quelle alluvionali. La sequenza regressiva-trasgressiva pliocenico-olocenica che caratterizza la piattaforma continentale, è stata ampiamente illustrata da diversi Autori che hanno evidenziato che durante l'ultimo glaciale la linea di riva in Adriatico era localizzata circa al traverso di San Benedetto – Pescara. Di conseguenza i depositi marini di mare basso (LST) erano limitati alla depressione meso-adriatica, mentre un'ampia pianura fluvio-palustre occupava l'attuale piattaforma.
La successiva trasgressione dovuta all'innalzamento eustatico, depositò sulla piattaforma i materiali che caratterizzano la variazione del livello marino (TST e HST). Utilizzando diverse perforazioni eseguite soprattutto dalle amministrazioni pubbliche, è stata costruita una sezione longitudinale dei depositi alluvionali del fiume Foglia che ha evidenziato la presenza di almeno quattro unità deposizionali che, alla luce di alcune datazioni radiometriche, si correlano con la sequenza marina. In particolare, l'unità I e II sono riferibili al low stand system tract (LST), l'unità III con il transgressive system tract (TST) e la quarta con l'high stand system tract (HST)

Keywords: Alluvial deposits, Adriatic continental shelf evolution, correlation between marine and continental sequences, Upper Pleistocene - Holocene, Foglia river.

Parole chiave: Depositi alluvionali, evoluzione della piattaforma adriatica, correlazione tra sequenze deposizionali, Pleistocene - Olocene, fiume Foglia.

1. INTRODUCTION

The environmental differences and the depositional aspects always make it difficult to correlate the marine and continental sequences because matching environments, processes and facies that control both modern and ancient environments is never easy. Fortunately, the late Quaternary recent rise of the sea level allows us to develop models of transgressive sedimentation in shallow seas and to know how this relates to the resultant alluvial deposits and organization.

As an example of a tentative correlation we have chosen the mid-adriatic continental shelf and the river Foglia valley (Northern Marche - Italy) related sediments (Fig. 1). This is a starting point for investigating the interplay of sediments supply, tectonics and sea-level changes. Our study is based on well data, cores, high resolution seismic profiles and radiocarbon dates. Such techniques, based on extensive correlative surfaces, allow the definition of a chronostratygraphic framework according to the facies analysis and to the sequence stratigraphy principles.

We consider the influence of tectonics to be negligible (the study area is to be considered stable or slowly uplifting according to Elmi et al., 2001/2002, also if Gori, 1978, taking into account the shoreface profile for the period 1770-1968, has estimated a sinking of the coast of Pesaro ranging between 4.8 and 1.9 mm/yr).

Therefore the sea-level changes caused by eustatism are the more important factors of the evolution. This assumption facilitates correlation and dating.

2. MARINE STRATIGRAPHIC SETTING (Fig. 2)

The stratigraphic setting of the late Quaternary deposits of the adriatic shelf is well known. In particular, during the last glacial maximum (15-18 ka BP) the conti-

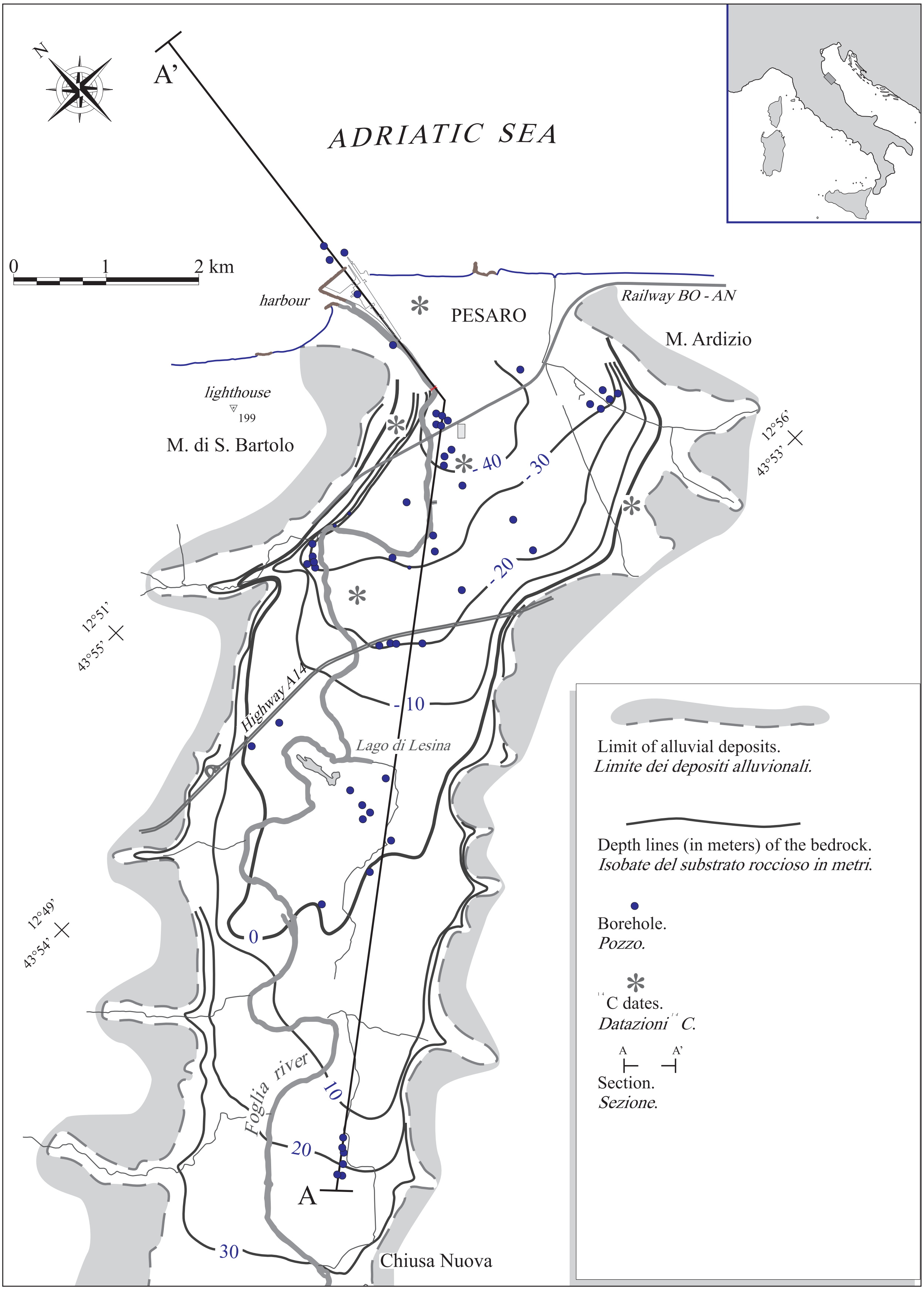

Fig. 1 - Bedrock setting (by Elmi *et al.*, 1983, mod.)
Andamento del substrato (da Elmi et al.*, 1983, mod.)*

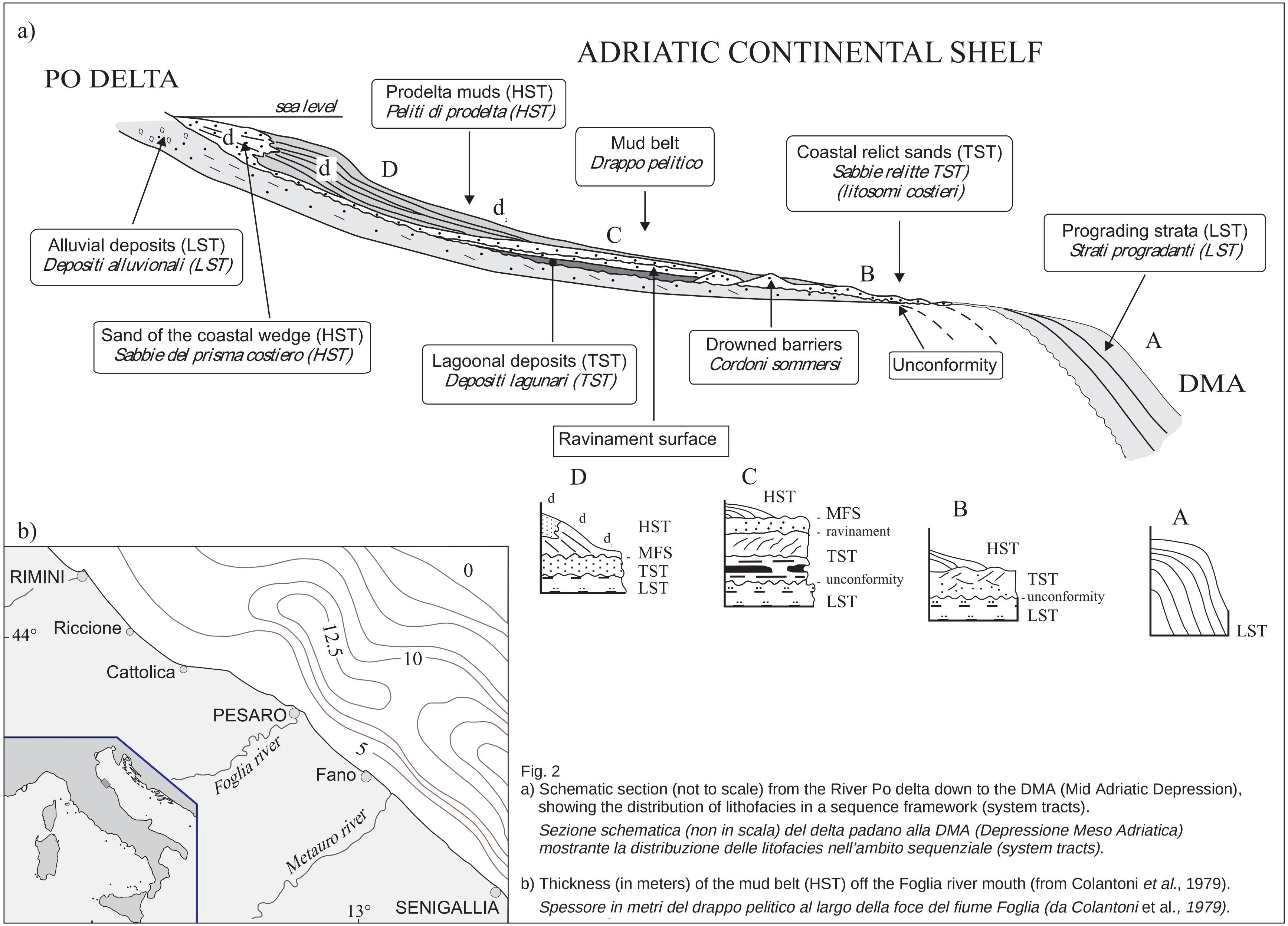

Fig. 2
a) Schematic section (not to scale) from the River Po delta down to the DMA (Mid Adriatic Depression), showing the distribution of lithofacies in a sequence framework (system tracts).

Sezione schematica (non in scala) del delta padano alla DMA (Depressione Meso Adriatica) mostrante la distribuzione delle litofacies nell'ambito sequenziale (system tracts).

b) Thickness (in meters) of the mud belt (HST) off the Foglia river mouth (from Colantoni *et al.*, 1979).

Spessore in metri del drappo pelitico al largo della foce del fiume Foglia (da Colantoni et al., *1979).*

nental shelf edge was located down to the Mid-Adriatic Depression (Jabuka trough - DMA) margin (Van Straaten, 1965 and 1970; Rizzini, 1974; Colantoni *et al.*, 1979; Colantoni, 1981; Ciabatti *et al.*, 1986; Colantoni *et al.*, 1992; etc.). Therefore, marine deposits of the low-stand system tract (LST) can only have developed inside the depression and at present water depths greater than 110 -130 meters. An alluvial plain, characterized by stiff clays and sands, covered the present shelf.

Subsequently, the post-glacial rise brought the sea to cover the alluvial plain with transgressive deposits (TST), first represented by beach sands and later by lagoonal sandy and pelitic sediments approximately north off Ravenna, where a short stillstand of the sea level and an increase of sediment supply favoured the formation of barrier/lagoon systems (Colantoni *et al.*, 1990). These deposits were cut by the ravinament surface and covered by a thin veneer of sand and numerous shell remains. Finally, when the sea reached its maximum level (Flandrian transgression 7-8 Kyr BP), the present highstand sedimentation (HST) took place: sand and pebbles formed the coastal wedges and a long mud belt extended offshore overlying the transgressive deposits that remain largely exposed on the shelf (relict sediments). Amorosi et al. (1999) have published the more recent contribution on the glacial eustatic control of continental – shallow marine cyclicity of the facies distribution in the lower Po Plain. In spite of a different context of subsidence the results achieved can be fairly correlated on the continental shelf.

Between Ravenna and Cattolica, in an area affected by rapid subsidence, at least three coastlines have been detected (Elmi *et al.*, 2001/2002) referred to the Boreal, Atlantic and Sub-Boreal/Sub-Atlantic according to the chronozones of the northern Europe (Orombelli & Ravazzi, 1996) within the last phases of the Holocene transgression. Conversely, between Cattolica and Fano a retreating sea cliff up to 200 m high is cut into the Miocene bedrock. Here, in a gently uplifting context, the three shorelines are external to the present coastline (Elmi *et al.*, 2001/2002) and can only be interpreted according to the morphology of the seafloor and by means of historical data (Fig. 3).

The last coast evolution was then characterized by active northwestward long-shore drift of coarse sediments and thick bars at the river mouths were formed, thus limiting the marine ingression and favouring the deposition of fine alluvial materials in lagoons and coastal ponds.

3. ALLUVIAL SEDIMENTS (Fig. 4)

The longitudinal section of the alluvial plain, which has been reconstructed taking into account data from boreholes available from the public administration, shows the substratum setting and the depositional events notwithstanding the difficulties to pick the sequence boundaries.

The bedrock beneath the alluvial deposits of the Foglia River valley shows a flexion (Elmi *et al.*, 1983) similar to those observed in the valleys of Conca (Elmi *et al.*,1991) and Metauro rivers (Elmi *et al.*, 1981). In fact, at about 5 km from the river mouth, its slope increases from about 5 ‰ to 12 ‰ reaching a depth of about 50 - 60 m below the present sea level near the coastline. It is not clear if this flexion is of erosional or tectonic nature. On the most sloping sector of the bedrock we can observe a first conglomeratic unit of non defined facies (Unit I): according to the hypothesis on the flexion origin it should be either of a marine or alluvial nature. This first deposit is truncated by an erosional surface that joins up landwards the less inclined substratum. On this surface lies the most continuous and wide conglomeratic unit of the valley (Unit II) that, from about 3 km far from the present shore, shows sandy and muddy bodies. In addition, due probably to a great marine ingression that reached at least 2.5 km from the present shoreline, this unit is truncated by an erosional surface. From this point a marine sedimentation took place seawards, while the river mouth was progressively closed by a retreating conglomeratic bar that caused the landward deposition of widespread alluvial sandy muds of low-level energy (Unit III).

Finally, the last phases of the Holocene transgression (Unit IV) brought the coastline to the present level with minor variations. This is due to first prograding and

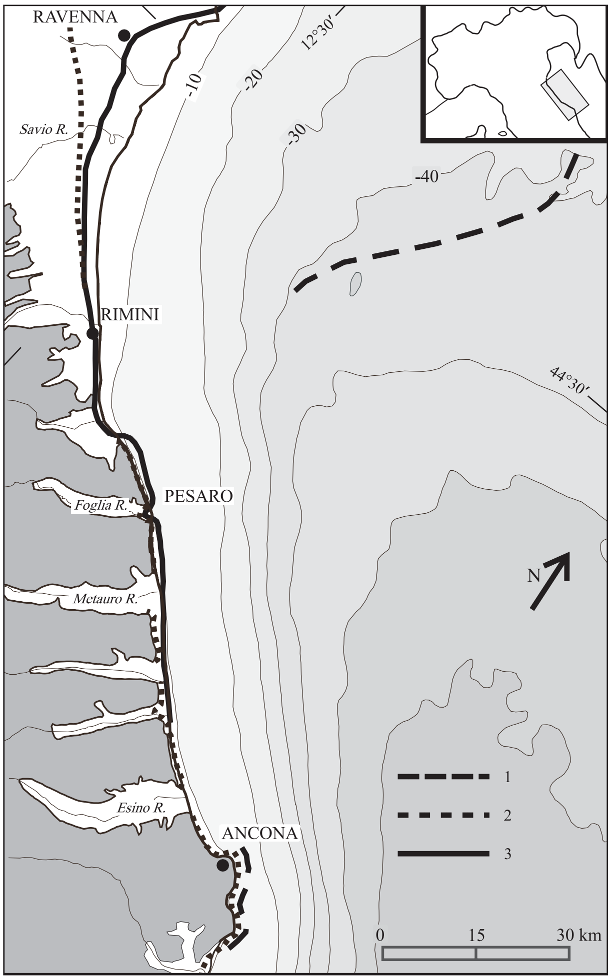

Fig. 3 - Holocene shorelines detected in the northern Adriatic Sea. 1 = Boreal; 2 = Atlantic; 3 = Sub-Boreal/Sub-Atlantic (from Elmi *et al.*, 2001/2002, mod.).

Linee di riva oloceniche individuate nell'Adriatico centro-settentrionale. 1 = Boreale; 2 = Atlantico; 3 = Sub-Boreale/Sub-Atlantico (da Elmi et al.*, 2001/2002, mod.).*

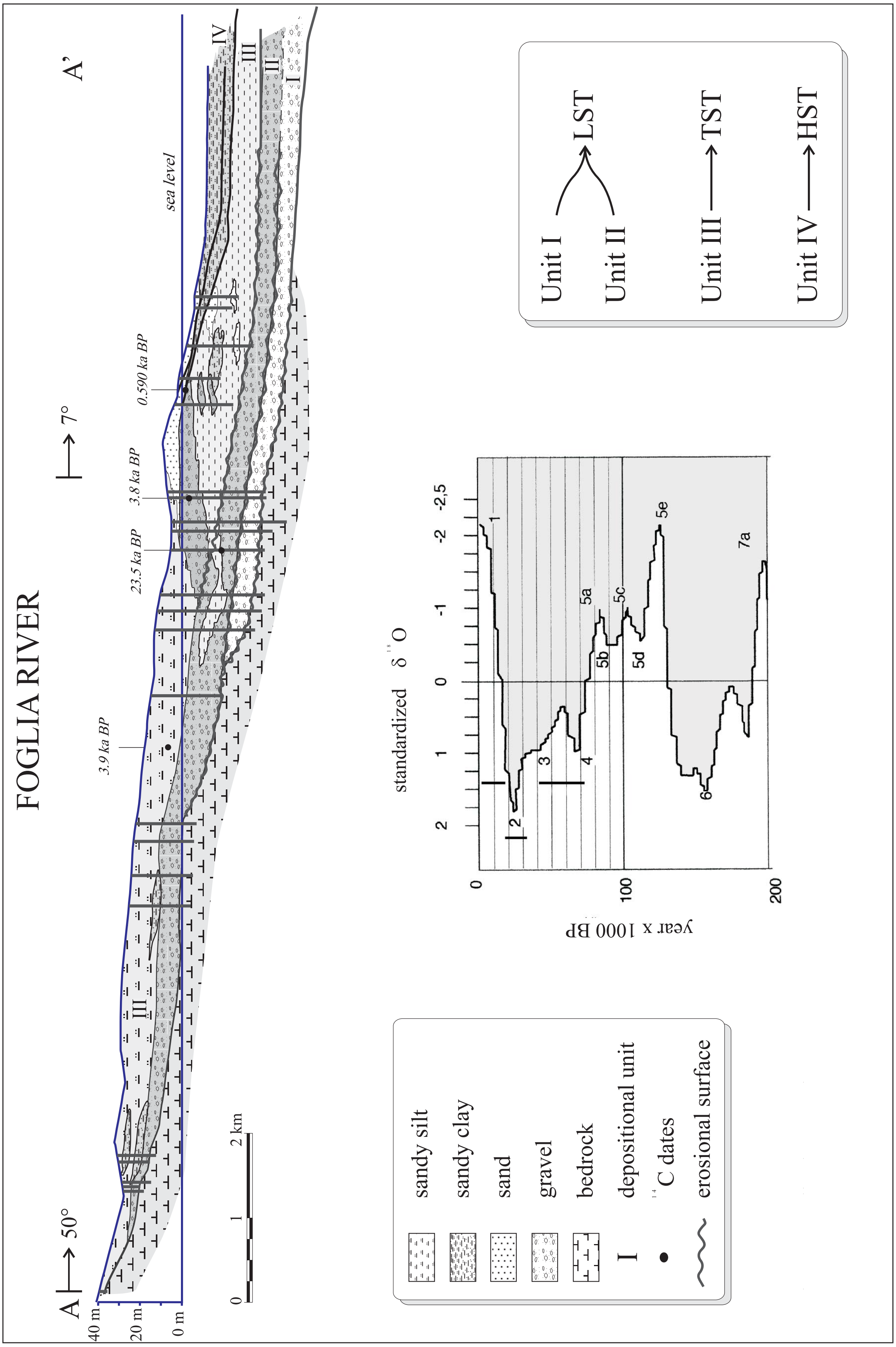

Fig. 4 - Foglia river section.
Sezione lungo la valle del fiume Foglia.

later retreating beach deposits. In particular, two surfaces seen in the seismic profiles despite the difficulties of interpretation due to the presence of coarse deposits and organic matter, mark the deposition event (transgressive/regressive?).

4. DISCUSSION

Waiting for paleontological evidence and confirmation, which are still in progress, fluvial facies are currently described in geometrical and lithological terms and we can try to define a tentative stratigraphic framework of the late Quaternary sedimentation based only on the available depositional data on land and off-shore.

The low topographic gradient of the adriatic continental shelf together with the low sedimentary input to the sea, caused an important shift of the shoreline and transgression-regression, especially near river mouths. Such observation is supported by the presence of marine deposits interfingered with alluvial and paralic sediments. However, interfingered layers are rarely continuous in space and time, making the interpretation in terms of sea-level changes sometimes equivocal (Pirazzoli, 1996). Moreover, we could not relate floodplain deposits with those of the river channels (Ori & Cremona, 1988).

Our reconstruction is therefore very preliminary and tentative. It is based on climatic changes, which we regard as the main cause of eustatic variations, and is calibrated on some radiocarbon ages. As reference, a time scale of the isotope stages ($\delta^{18}O$) defined by Woillard & Mook, 1982 and reviewed by Dansgaard *et al.*, 1993 has been considered (Fig. 4). Going from land seawards, the first evolutionary phase that can be observed within the Foglia River valley is the deep incision into the pre-Quaternary substratum. This incision, which probably began with the demolition of previous sediments, must have occurred during a low-stand sea-level and was followed by the deposition of the units I and II. A sample of wood (*Ulmus laevis*) that was collected within the depositional Unit II at a depth of 20 m below sea level (point A of Fig. 5), shows an uncorrected ^{14}C age of 23,5 ± 1.2 ka BP (Calderoni *et al.*, 1997). Therefore, the Unit II has been deposited during the phase of climatic deterioration recorded between about 29 and 11 ka BP (isotopic stage 2 = Würm pleniglacial). As a consequence, we deduce that the Unit I and the incision of the substratum took place during the isotopic stages 3 and 4 (about 73-61-29 ka BP) or during an older one.

If this assumption is correct, Unit III should be deposited during the isotopic stage 1 (about 11 ka BP to present = Holocene). In fact, a ^{14}C date of 3.9 ka BP has been obtained from a trunk of *Ulmus laevis* collected in a quarry at the depth of about -7 m together with

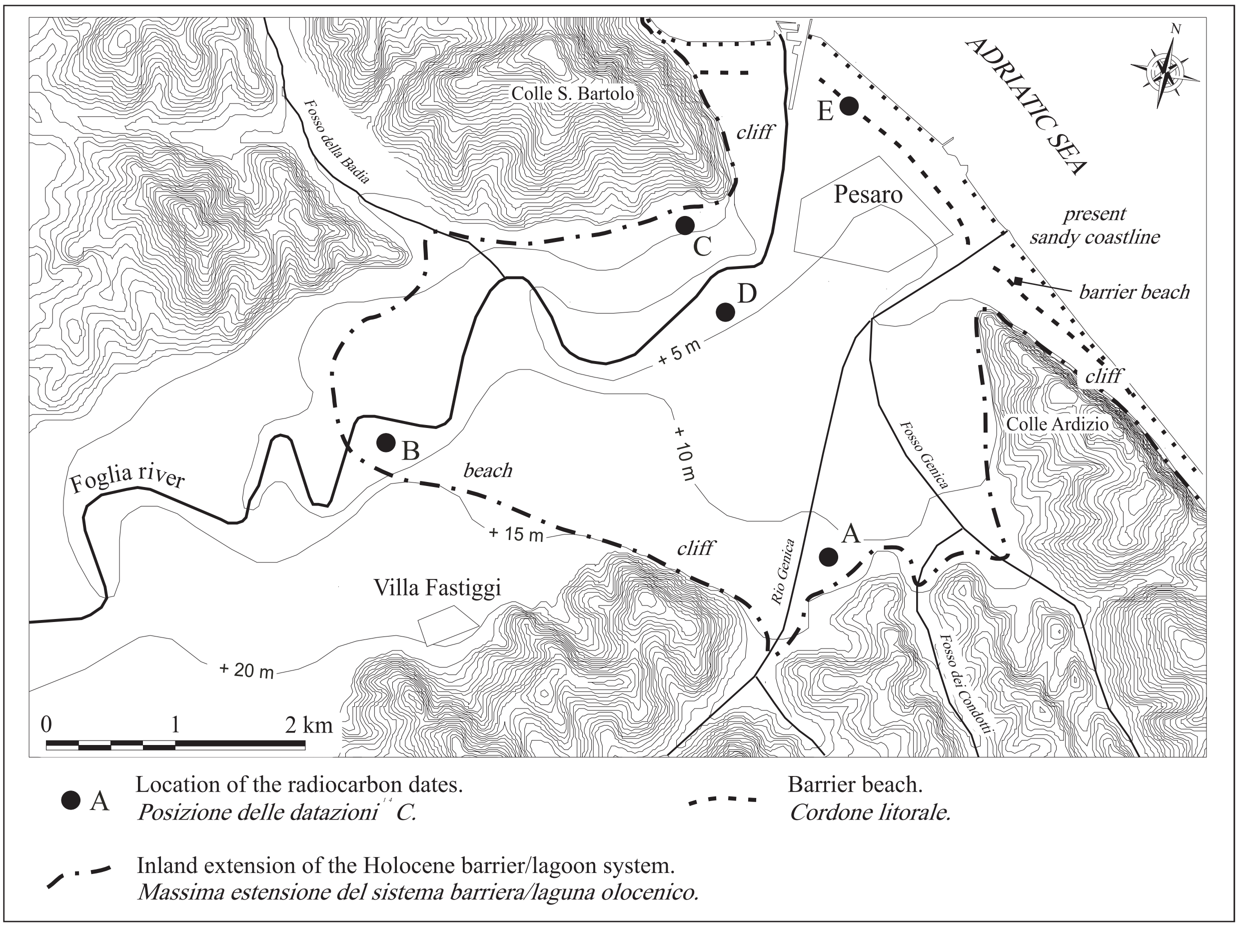

Fig. 5 - Topography of the study area. Contour lines in meters.
Topografia dell'area di studio. Isoipse in metri

remains of *Cardium sp*. and *Mytilus sp*. (Bedosti, 1985). This finding (point B of Fig. 5) confirms the presence of lagoons and coastal ponds in the area that extended as far as about 5 km from the present coastal line in which rivers entered protected by littoral barrier beach (Coltorti, 1997). The presence of the barrier is testified by another radio-carbon date obtained from wooden fragments of a fossil trunck (cfr. *Tilia*) collected by drilling at a depth of 10 m (- 5 m below the present sea-level) in the area of Miralfiore-Pesaro (point D of Fig. 5). The plant, if compared with the present day woodlands of the Mediterranean zone, greew along a flood-susciptibile plain (Coltorti, 1997) about 3,6-3,8 ka B.P.

The erosional surface that lies at the base of the Unit could be considered as due to the Younger Dryas climatic change. The suggestion is enhanced by another ^{14}C date. Accordingly, Gori (1988) reports another finding of *Ulmus* in a fan deposit at a controversial depth that we assume of 11,5 m from the present ground level (point C of Fig. 5), dated 10.09 ± 0.8 ka BP (= Younger Dryas). This event "probably is the most significant potential producer of global sea-level fluctuation which occurred since the last glacial maximum" (Pirazzoli, 1996). It consisted of acceleration and deceleration during a period of rapid sea-level rise and is expected to have caused sea-level oscillation especially at the river mouth. The effects of such a climate change can hardly be detected on the continental shelf.

In the north Adriatic Sea the cold event of the Younger Dryas (13-11.7 calendar ka BP; 11-10 ^{14}C ka BP) is highlighted by peat layers that mark the base of the post-glacial transgression (Correggiari *et al*., 1996).

Therefore, the preservation of the barrier/lagoon system (about 8 ka BP) that favoured the paralic deposits and the last phase of the Flandrian transgression (Colantoni *et al*., 1990), is to be related to the rapid drowning, which in turn is due to the subsequent increased rate of sealevel rise, connected to the climatic amelioration occurred between 11 and 6 calendar ka BP.

The maximum marine ingression is recorded at 6ka BP (Climatic Optimum) by beach deposits, cliffs and barrier beaches (Fig. 5). In the central Adriatic Sea, off the Foglia mouth, the event can be tentatively identified by the marker shown in the high resolution seismic profiles at the base of the depositional Unit IV. It is only 2-3 ka BP (Sub-Atlantic) that the marine ingression leaves signs on the Foglia alluvial plain and evidence of ~1.5 m high shorelines. From this phase (Roman) a regressive and prograding beach caused the retreat of the coastline approximately to the present position (except for minor recent variations).

According to Coltorti (1997), the coastal aggradation in the Marche region started in the Middle Ages and increased after the Renaissance maintaining a barrier-lagoon depositional setting. The presence of lagoons and swamps is documentated by peats sampled 5 m below the present beach in the Pesaro area (point E of Fig. 5). The obtained date is 590 ± 50 yr BP(with a $\delta^{13}C$ of 26%) (courtesy of G. Calderoni, 1994).

5. CONCLUSION

Notwithstanding the many interpretative difficulties, the study of the river mouth sediments provides an unique opportunity of correlation between continental and marine deposits.

The most recent depositional bodies can be interpreted as the result of a complex evolution of alluvial plain, wave dominated shorefaces and barrier/lagoon systems that interfinger their products with the transgressive and regressive marine deposits.

The numerous surfaces that mark the details of the depositional pulses are not easily correlated on the continental shelf. In fact, many surfaces form downlapping features that end laterally.

Nevertheless, the limit of sequence that denotes the last phases of the Flandrian transgression is very clear. In addition, it is easy to recognize and divide both the lowstand transgressive and the highstand system tracts (LST, TST and HST), while the ravinament surface (RS) and the maximum flooding surface (MFS) are coincident (cfr. Correggiari *et al*., 1996, Figg. 3 e 4).

From a general point of view, the alluvial Units I and II, that formed the greatest conglomeratic alluvial plain, correspond and laterally blend in stiff clays and sands of the LST of the shelf. Unit III comes into the TST and the Unit IV into the HST.

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