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MORPHOLOGICAL EVOLUTION OF LÈSINA LAGOON (SOUTHERN ADRIATIC, ITALY)

ABSTRACT: DE PIPPO T., DONADIO C. & PENNETTA M., *Morphological evolution of Lèsina Lagoon (Southern Adriatic, Italy).* (IT ISSN 0391-9838, 2001).

Geomorphological features of the lagoonal system of Lèsina (Apulia Province, south-eastern Italy) are highlighted in this research; it has been possible to point out the late Quaternary evolution of this coastal transitional environment through morphological surveys, both of the emerged and underwater landscape of the basin.

The lagoonal system is the result of a constant evolution due to mutual equilibrium between eustatism, coastal paleomorphology, sediment supply, tidal effects and modification of the hydrographic network pattern. The Quaternary geologic history and the morphological characteristics of this coastal zone suggest that the lagoon development and evolution are linked to interactions between tectono-sedimentary, climatic and hydrodynamic factors during the late Pleistocene-Holocene.

These physical factors acted on a landscape of inherited morphostructures bordered by high morphological relief, generating a different positioned littoral compared to the present-day one. The genesis of Lèsina Lagoon is linked to littoral dynamics that led to progressive development of composite littoral spits inside a shallow-water marine bay. During the post-glacial age, the bay was gradually filled with clasts drifted out from the Fortore River mouth, few kilometres westward of the lagoon. Probably, the lagoonal system has developed after the Holocene climatic *optimum,* when the neotectonic phases had already faded and the landscape was rough enough but quite comparable to the present-day one.

The growth of a steady littoral sandy ridge, first NW-SE then W-E oriented, on which dune ridges developed, led to the genesis of a lagoon behind the dunes. Subsequently, the lagoon shape has undergone a change because of constant sediment filling, reducing the area of an originally trapezoidal basin. The same process caused the decrease of lagoon depth and number of channels. Thin peat levels alternating with marine sandy-silty sediments, suggest that marine and marshy stages alternated during the lagoonal system evolution.

KEY WORDS: Coastal geomorphology, Lagoons, Holocene, Southern Adriatic, Apulia, Italy.

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Vengono presentati i risultati delle indagini geomorfologiche condotte lungo le aree emerse e sommerse della laguna di Lèsina, in Puglia. Le analisi morfologiche e stratigrafiche hanno consentito di mettere in luce l'evoluzione dell'area lagunare in relazione alla paleomorfologia costiera, agli apporti terrigeni, alle maree, alle modificazioni del reticolo idrografico dell'immediato entroterra nonché ai fenomeni eustatici.

L'evoluzione geologica ed i caratteri geomorfologici della fascia costiera indicano che la genesi e lo sviluppo del bacino lagunare sono legate alle mutue interazioni tra fattori tettono-sedimentari, climatici ed idrodinamici manifestatesi a partire dal tardo-Pleistocene fino ai nostri giorni. Questi fattori hanno agito su un paesaggio caratterizzato da morfostrutture ereditate, confinate da alti morfologici, lungo una fascia litoranea orientata in maniera differente rispetto all'attuale.

La genesi della Laguna di Lèsina è riconducibile soprattutto a processi di deriva litoranea che hanno consentito la costruzione ed il progressivo accrescimento di frecce litorali composite all'interno di una baia marina caratterizzata da bassi fondali. Tale baia è stata gradualmente colmata durante il postglaciale dagli apporti clastici provenienti dalla foce del F. Fortore, ubicata alcuni chilometri a W della laguna.

Il sistema lagunare probabilmente si è individuato successivamente all'*optimum* climatico olocenico, quando ormai si erano smorzate le fasi neotettoniche ed il paesaggio aveva assunto una fisiografia articolata, ma a grandi linee simile a quella odierna.

Lo sviluppo di un cordone sabbioso stabile, dapprima orientato in direzione NW-SE, poi circa W-E, su cui successivamente si sono impostati i cordoni dunari, ha determinato la genesi di una laguna nell'area retrodunare. In seguito la geometria della laguna avrebbe subito variazioni connesse al suo progressivo colmamento, causando la graduale contrazione del bacino, in origine trapezoidale. Lo stesso processo avrebbe inoltre causato la diminuzione della profondità e la riduzione del numero delle bocche lagunari. Le successioni stratigrafiche mostrano inoltre sottili livelli torbosi, alternati a depositi sabbioso-siltosi di ambiente marino; ciò indicherebbe, durante l'evoluzione del sistema lagunare, l'alternarsi di fasi marine e palustri.

TERMINI CHIAVE: Geomorfologia costiera, Laguna, Olocene, Adriatico meridionale, Puglia.

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INTRODUCTION

The Lèsina Lagoon (fig. 1), located on the coastal plain at the north-western part of Gargano carbonatic promontory, on the right of Fortore River, extends between Pietre Nere Point on the W and Mount d'Elio on the E. The lagoon covers about 53 square km, has a regular elongated shape and is subparallel to the coastline with a W-E orientation. It is about 22 km long; its width ranges between 3.5 and 1.5 km and its mean depth is around 1 m. The lagoon is separated from the sea by a recent dune ridge of about 15 km length. It is fed by many streams with regulated, moderate flow, mainly debouching along the south-eastern shore after cutting through the carbonatic reliefs of Sannicandro Garganico. Two outfalls, one at the central-eastern (Schiapparo) and the other at the western part (P. Pietre Nere), enable the exchange of lagoonal waters with the sea. A third outfall (S. Andrea), situated between the other two, is not active anymore, since it has been completely filled with sediments.

The study of the lagoonal system of Lèsina involved interpreting geomorphological data and analysing historical and recent maps. This research led to a better understanding of the morphological dynamics during the late Quaternary of this paralic environment consisting of coastal plain – lagoon – beach, which enabled the reconstruction of possible evolution mechanisms of the Holocene.

The lagoon environments, elements of physical discontinuity and conservative environments too, are wet lands of regional importance and of great scientific interest, especially for the reconstruction of the morphological dynamics of the coastal plains. From the morphological point of view, a lagoon is a shallow coastal sheet of water (<10m deep), varying from fresh water (<5‰) to hypersaline (>35‰) depending on the existence and number of tributary steams flowing into it. Its basin is separated from the sea by one or more littoral spits bearing dune ridges at intervals and is connected with it through one or more active outfalls or channels. Other outfall systems might also be present in the adjacent areas. Sometimes, low, sandy-silty islets (shoals and velmes) within the lagoon might be observed (Cooper, 1995).

The lagoons differ from coastal ponds, because the latter are completely isolated from the sea by a continuous clast barrier, they are smaller in size and shallower than lagoons, they also have low salinity and the sediments consist of fine materials like silt and clay due to poor water circulation. The morphological differences between lagoons and coastal swamps are major. The latter develop in low coastal plains, often without the presence of dunes or streams, due to extensive subsidence or filling of earlier lagoons or marshy environments. They are characterised by alternating levels of clayey sediments and peat horizons.

The present-day conformation of a plain and a lagoon, the hydrographic characteristics of the territory, the outlines and orientation of the coast in which they are situated depend on the interaction of many different geomorphic, and especially climatic processes, which took place during the Quaternary (Seibold & Berger, 1996).

A coastal plain is always located a few meters above the present-day sea level and its morphological evolution is influenced by coastal zone dynamics (Capobianco & *alii*, 1995). These processes depend on atmospheric agents and on sediment transport to the coasts by longshore currents carrying sediments from the river mouths (Cooper, 1998). The action of the sea is increased or decreased depending on the vertical fluctuation of the ground, the subsidence phenomena and the tectonic events to which correspond the submersion or emersion periods of wide coastal zones (Garner, 1974).

FIG. 1 - Location of Lèsina Lagoon and simplified geological scheme of eastern part of Apulia coast (from Bonardi & *alii*, 1988, modified): 1 - Apulo-garganic carbonatic platform unit; 2 - Bradanic unit; 3 - sediment deposits; 4 - other stratigrafic-structural units of Apennines chain; 5 - fault; 6 presumed or buried fault.

The genesis and development of lagoons, both in wave and in tide-dominated coasts (Donadio, 1999), seem to be connected to regional tectonic events that structure the coastal depressions in the long run. Whereas, in the mid run, they are clearly controlled by climatic variations and, to a lesser extent, by local subsidence phenomena which also determine the accumulation of sediments within wide, shallow-water marine bays (Lòpez-Buendìa & *alii*, 1998). Not only the interactions between littoral dynamic (Brambati, 1988) and coastal morphology (De Pippo & *alii*, 1995), but also short, climatic crises (Ortolani & Pagliuca, 1994; Carbognin & Marabini, 1996), and storms (Liu & Fearn, 1993; Sanchez-Arcilla & *alii*, 1995; Cleary, 1998), as well as the man modifications of the landscape, like drainage, dams, quarries, land reclamation (Dias & Peneda, 1986; Palanques & Guillen, 1995), are considered the main factors which control the evolution of lagoons in the course of their history.

GEOLOGICAL FRAMEWORK

Within the framework of alpine orogeny, the Adriatic area forms the foreland of the Apennines and Dinaro-Hellenic chains with opposite vergence, which is the limit between the African and the European plates; whereas, the southern Adriatic basin represent the foredeep of the Albanian chain (Ricchetti & *alii*, 1992; Argnani & *alii*, 1996). The evolution of this sector of the earth's crust is attributed to the final phases of collision between plates and to tectono-sedimentary and morphogenetic processes linked to orogeny.

From the Neogene to the Plio-Pleistocene, the Apennine foreland has shown a quite uniform geo-dynamic behaviour, with intense subsidence rates (>1 mm/year) connected to the subduction of the Adriatic Plate immersing towards W and to its consequent flexural retrogradation towards the E (Doglioni & *alii*, 1994). The neogenic succession is characterised by a transgressive phase, followed by a period of sub-aerial weathering and karstification of mesozoic limestone (Abbazzi & *alii,* 1996).

During the Pliocene, extending tectonics have controlled the sedimentation, configurating high and low structures and forming a succession of deposits of environments getting gradually less deep, from turbiditic to littoral and to deltaic (Capuano & *alii*, 1996). Between the low Pliocene and the Pleistocene, the western margin and the depo-center of the foredeep have migrated towards the E, parallel to the transfer of the allochthonous front, with a mean speed of 5 cm/year (Pagliarulo, 1996).

Starting from the middle Pleistocene, while the central-adriatic sector continued being subsident, the Apulia foreland and the Bradanic foredeep have begun to rise (0.2÷0.5 mm/year: Ricchetti & *alii*, 1994; Doglioni & *alii*, 1996), as evidenced in Le Murge by the presence of numerous terraces located at various altitudes up to around 450 m above sea level, dating back to a period between the middle Pleistocene and the Tyrrhenian. In particular, along the carbonatic paleocliffs, traces of sixteen raised coastlines have been observed, represented by abrasion platforms and discordant marine terraces on mesozoic limestone and on units dating to the late-Pliocene and mid-Pleistocene in Le Murge.

The coastal area under study is attributed to the units of Apulo-Garganic foreland and foredeep (Boni & *alii*, 1969; Bonardi & *alii*, 1988). To the E and S of the lagoon appear the limestone of Gargano platform, the flinty limestone and cretaceous carbonatic resediments of Mount d'Elio and some strips of bioclastic and organogenes calcarenites (Calcarenites of Apricena). The reliefs are positioned mainly NW-SE and E-W, although, faults with a N-S and a NE-SW orientation (Aucelli & *alii,* 1997) and with a slight inclination towards the NW (Cinque, 1992) are also quite frequent. At the edge of the carbonatic reliefs appear the extremities of the Bradanic Unit, which are also present to the S and E of the lagoon (Calcarenites of Gravina) and to the SW, near the right bank of Fortore River, where they appear as sand and clay (Calvello Unit). To the NW of the lagoon, only at the Pietre Nere Point, melagabbric-melasyenitic rocks and triassic evaporites are observed (Bigazzi & *alii*, 1996). Whereas, the plain deposits to the S and W of the lagoon are formed by terraced fluvio-marine sediments, dune and beach sands dating to the Quaternary. At last, within the perimeter of the lagoon, alluvial deposits, together with limnic, marsh, lagoon, beach and dune sediments of the Holocene are present (Ambrosano & *alii*, 1986; Viel & *alii*, 1986).

DATA ANALYSIS

On the basis of many morphological and geological elements, the coastal plain (fig. 2) located between the Gargano Promontory on the E and Fortore River valley on the W, presents different features proceeding inland from the coast. The emerged and submerged beach forms a physiographic unit delimited by Pietre Nere Point to the W and by the offshoots of Mount d'Elio to the E (Sannicandro Garganico) and it consists of marine abrasion platforms of the eastern coast and dune ridges.

The lagoon basin and part of the plain situated behind it, extending to the base of the first terraces (about +5 m), are probably correlated to Würm II - Würm III interstadial (Cotecchia & *alii*, 1969), and they represent a joining point of a typical coastal zone and a piedmont. The ridge of hills on the S, composed of both erosional and sedimentary terraces, present morphological differences between eastern and western zones, caused by a different response both to erosion and to tectono-sedimentary events. In particular, terraces modelled in limestone up to +200 m and above (Mount d'Elio, Sannicandro Garganico) are observed to the E; whereas to the W, the terraces consist of rudithic-arenaceous sediments up to around +70 m (Torretta, Ripalta).

Slightly convex relief formed by the outcropping of conglomerate limestone of the substrate, are found to the W, between the lagoon and the littoral dunes (C. Zurrone); they are NW-SE oriented, 6-8 m tall and remod-

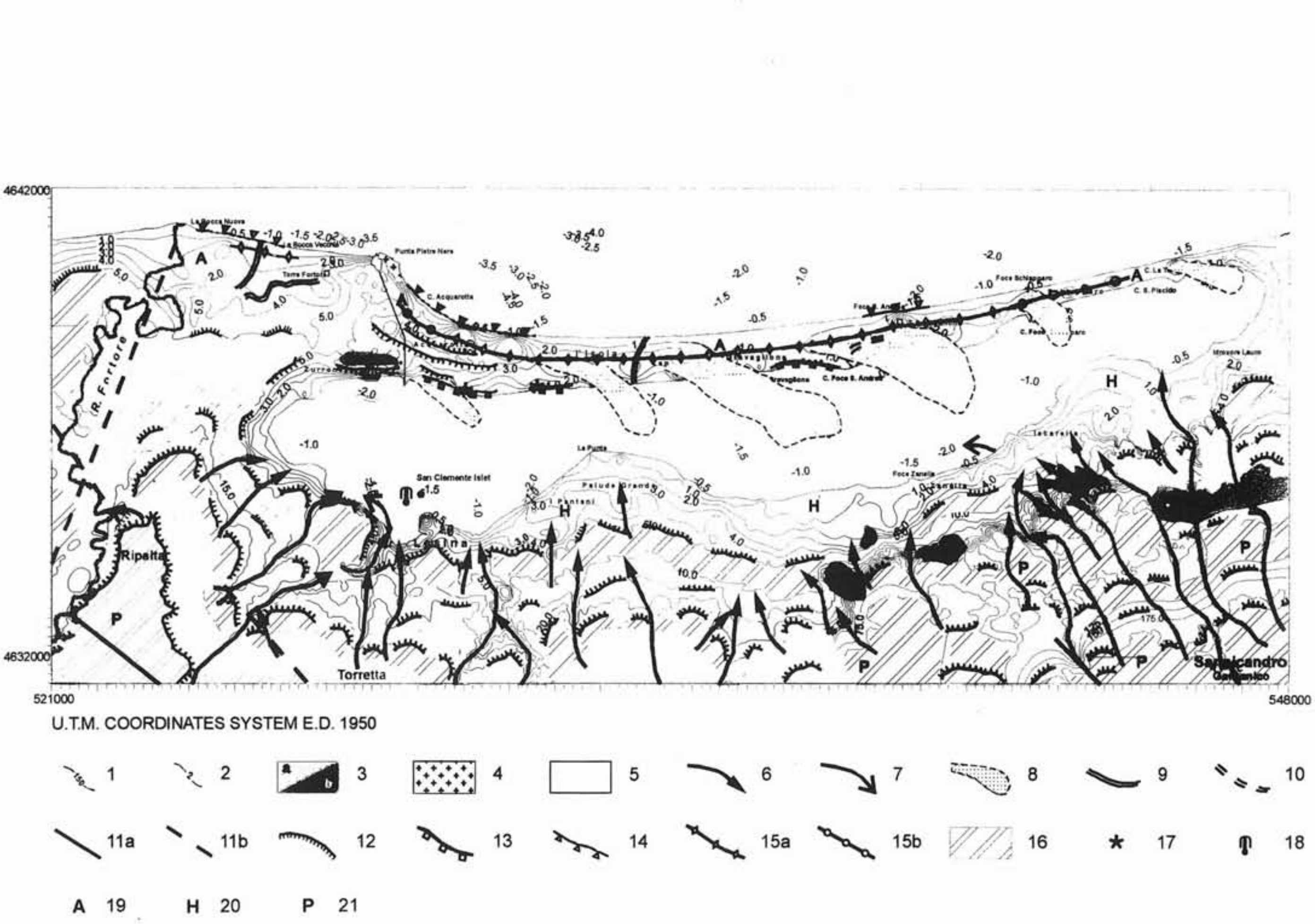

FIG. 2 - Geomorphological map of perilagoonal area and basin of Lèsina: 1 - contour lines; 2 - isobathic lines; 3 - limestone rocks: a - jurassic-cretaceous substrate; b - miocenic rudithic cover; 4 - intrusive rocks; 5 - arenite and pelitic rocks; 6 - small valley; 7 - underwater gully; 8 - trace of ancient littoral spit; 9 - trace of ancient abandoned segment of fluvial riverbed; 10 - trace of ancient abandoned segment of lagoon channel; 11 - fault: a - certain; b - presumed or buried; 12 - terrace edge; 13 - erosional bank with <5 m of height; 14 - coastline in regression; 15 - dune ridge: a - natural; b - man-modified; 16 - flat surfaces; 17 - ^{14}C radiometric datation sample; 18 - archaeological remains; 19 - A: present-day forms; 20 - H: Holocenic forms; 21 - P: Pleistocenic forms.

elled at the top. Within the area of the coastal plain, to the right of Fortore River, there are relics of alluvial belts (Ripalta); the N-S orientation of which (Aucelli & *alii,* 1997) makes believe that during the mid-late Pleistocene the coastline was differently positioned. To the NW of the lagoon, abandoned meanders are found located to the E of the present-day Fortore River delta, most probably belonging to the previous river mouth complex. Furthermore, at the northern areas, parts of ancient lagoon channels are observed, about SW-NE (Acquarotta) and S-N (Zappino) oriented.

The present-day dune ridge extends for about 15 km from the W to the E and is interrupted by the transversal channels of Pietre Nere Point, Sant'Andrea and Schiapparo river mouths; the second one, which holds the central position, is inactive due to obstruction by sediments. The dune ridge extends inland for about 200 m and is composed of 4-5 irregular rows of sinuous dunes, which are distributed almost parallel to the coastline and they show a gradual, anti-clockwise rotation from the W to the E (fig. 2). In fact, the orientation of the crests is NW-SE near Acquarotta (W), whereas it is about W-E at Foce Schiapparo (E). The dune located on the middle tract is not modified by man and is colonised by a highly natural, thick, mediterranean vegetation; whereas, proceeding from Foce Schiapparo towards the Gargano Promontory, the dune ridge appears to be modified by the presence of numerous manufacts.

Within the plain, ancient dune ridges neither have been found nor reported; nevertheless, the hump-shaped morphology observed behind the present-day dune (fig. 2), together with the presence of modest ephemeral ponds and limited marshy zones on the northern shore, might represent the relic of a more ancient, NW-SE oriented, partly demolished dune field. At the bottom of the lagoon, forms that appear to be the continuation of sandy ridges existing on the beach are observed. They might represent the relics of the extension of ancient littoral spits, actually submerged and partly demolished.

Behind the lagoon, there are flat surfaces and parts of marine terraces connected to tectonic uplift of the Pleistocene, observed at heights ranging between 5 and over 200 m above sea level. These are sometimes deeply cut by U-shaped valleys, well-preserved in limestone substrates to the W of Gargano and found especially over 100 m above the sea level. The lowest marine abrasion terrace (+4 m) is observed in the area in front of Torre Mileto, slightly to the E of the lagoon. This surface, about twenty meters wide, is characterised by erosional subcircular forms of marine origin (potholes). At its base, discontinuous parts of a terrace, a couple of meters wide, characterised by a present-day sea notch, are noticed. Other flat surfaces, cut in limestone, observed at higher altitudes to the E of the studied area, have slopes with a mean degree of steepness, which become steeper towards the top and which bear dip breaking only at some parts (Sannicandro Garganico). On the terraces, small, subcircular depressions of about 1 m in diameter, with slightly rounded rims, filled by residuals (clay), are widely observed. Although they are reminiscent of the coastal potholes and the erosional forms observed at Torre Mileto (De Pippo & Donadio, 1999) for their aspect and dimensions, the genesis of such forms is mainly linked to karstic phenomena (Abbazzi & *alii*, 1996); even if the effects of mixed marine and biochemical erosion processes should not be excluded. At last, about 4 km to the W of the lagoon, there is the terminal part of the Fortore River, sinuous and meandering, which debouches to the W of Pietre Nere Point, after running along the western side of the terraced, conglomerate surfaces of Ripalta (about +60 m).

Along the perimeter of the lagoon, at a short distance from the present-day northern shore, a small terrace (~0.7 m) extending for about fifty meters is observed. Two trenches, about 1 m high, dug at the foot of the terrace, enabled the study of its stratigraphical features. At the base of the first (fig. 3 - trench T1), a brown-coloured, clayey deposit of unknown thickness is found; it is followed upwards by a fine, sandy deposit with abundant fragments of mollusc shell, then a level of peat, then well-sorted sandy sediments with whole mollusc shells, another thin level of peat, and finally, a layer of recent soil, which closes the succession. Slightly to the E, there is a strip of a terrace extending for about twenty meters, at an altitude comparable to the previous one. The trench dug at the foot of this terrace (fig. 3 - trench T2) brings into deposits finer and different than the previous ones, due to the presence of paleochannels filled with recent muddy sediments. At its base, there is a light-coloured sand with abundant bioclasts, of unknown thickness; it is followed upwards by a brown-coloured, clayey deposit with vegetal remains, then a thin level of peat, then a greyish, sandy-silty sediment, and finally, a

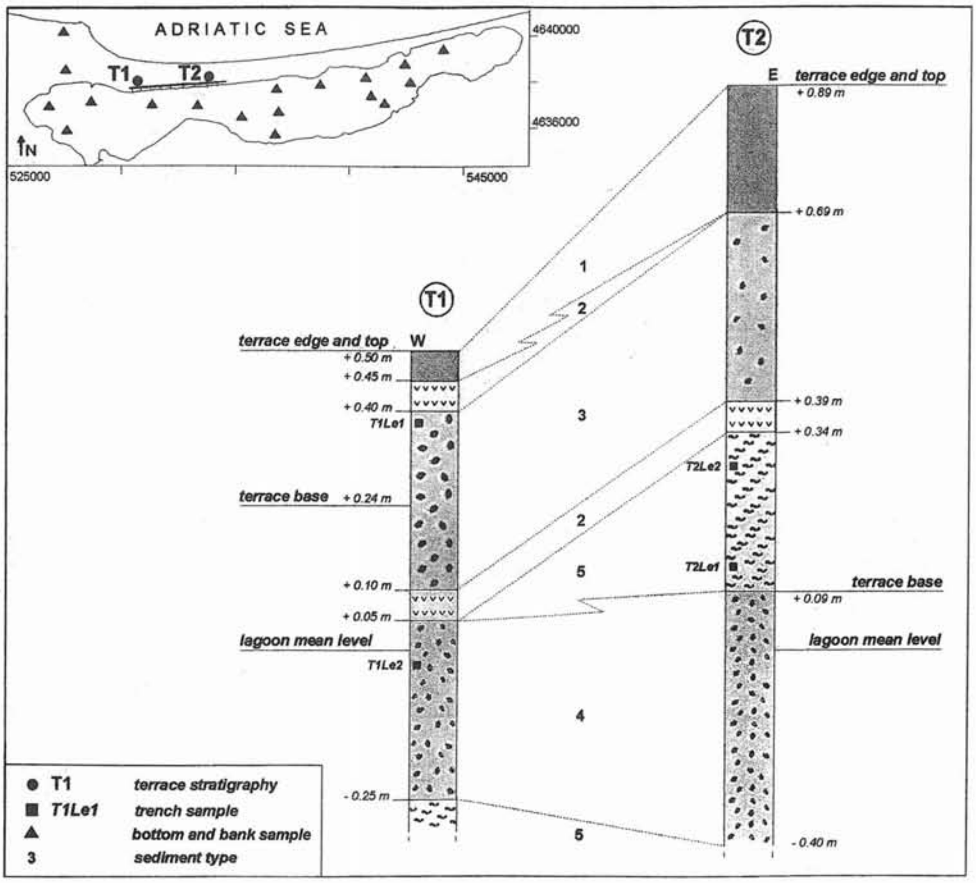

FIG. 3 - Location of sediment samples, terrace and stratigraphy of trenches T1 and T2 near northern shore of Lèsina: 1 - soil; 2 - peat; 3 - sand with whole mollusc shells; 4 - sand with mollusc bioclasts; 5 - clay. Abbreviations refer to analysed samples; ^{14}C radiometric age of peat layers results very recent (next to 1950).

rubefacted sandy deposit covered by a recent soil, which closes the succession.

Traces of pseudocylindric bioturbation are observed at various points in these deposits. They are also found in a similar strip of terrace located more to the E, modelled in grey clay, of a little more than a meter of height and extending about fifty meters (S. Andrea). This more or less continuous terrace, which probably represents a tract of a more ancient lagoon bottom and shore, has laminated fine deposits and bioturbates. The study of the wide excavations already existing in the zone, has enabled to verify the presence of well-sorted and slightly rubefacted medium sand, forming a layer of 4-6 m, lying on clayey deposits to the W of the lagoon (fig. 4). Whereas towards the E, these deposits diminish progressively until they disappear completely to the E of the basin where only the clayey soil is seen. Therefore, the surface of the clay bed is slightly inclined towards the NW.

The lagoon complex is about WSW-ENE oriented, almost parallel to the present-day coastline, and shows a progressive narrowing of the water surface at central and eastern parts. The major development of the western part of this salt-water basin seems to depend on the lithology behind it, less conservative compared to the others. The narrowing of the central part, at la Punta, is linked to the presence of both a fan stretching out towards the N with a weak gradient to NNW, and an underwater sandy ridge, partially eroded, found within the lagoon, which forms a high morphological relief. They divide the sheet of water in two, therefore, control the flow of water in the lagoon (Ficca & *alii*, 1996). Other fans are observed near the town of Lèsina and at the eastern part of the lagoon, between Iscarella and Idrovore Lauro, at a short distance from the talus of limestone reliefs. The lagoon bottom is undulated, has a depth varying between 0.5 and 2 m and follows the outline of the ancient morphology, characterised by sandy ridges forming NW-SE oriented littoral spits.

Even the textural characteristics, obtained through the analysis of the sediments done on bottom samples (fig. 3), taken with boxcorer of 2 dmc, confirm that great amounts of coarse sand (about up to 74%) present in these elongated lithosomes is to attribute to the sediments composing the sandy ridges which gradually closed the lagoon from the sea. Therefore, the muddy portion, together with these sandy deposits, is interpreted as the product of recent and present-day sediments. The mud is clearly minor in quantity where the forms attributed to the relic spits exist, whereas it results prevalent within the area between them. Its presence indicates low sorting of sediment distribution and enables to group unhomogeneously the sediments within the classes varying from silt to coarse sand.

The eastern and western areas of the lagoon form wide shallows, which deepen to the S of Capo Foce Schiapparo, also because of the presence of the active channel bearing the same name. The weak inflection towards the N of the isobathic lines near Capo Foce Sant'Andrea represents the relic form of the continuation of the channel bearing the same name, now completely obstructed by sediments. Whereas, the western zone is deeper on the average, especially near where the P. Pietre Nere channel debouches into the lagoon. In the same zone, there are some artificial underwater channels with a depth of up to −4 m, sometimes intersecting with each other, used for the navigation of light fishing boats.

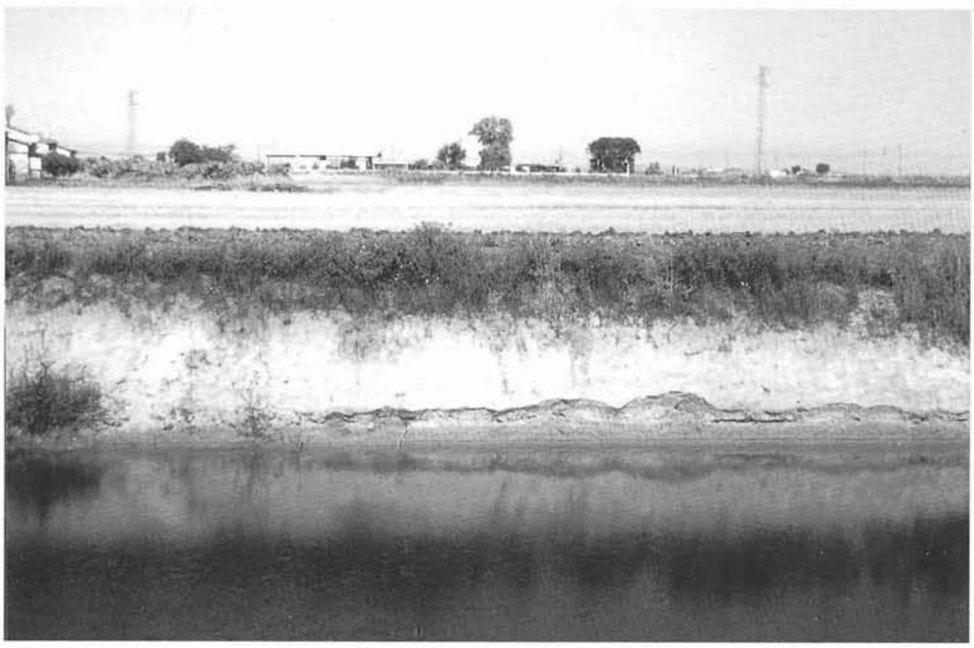

FIG. 4 - Slightly rubefacted sand deposits, of about 6 m of height, found to the NW of lagoon in an excavation; at its base there are clayey sediments of unknown thickness.

FIG. 5 - Terrace of about 1 m of height, extending for fifty metres, near northern shore of Lèsina; the surface is modelled in sandy-silty deposits and characterised by weak undulations which follow the morphology of littoral spits.

In Pontone, near the shore, the track of a SW-NE oriented, short channel is found, which forms the continuation into the lagoon, of a gully present in the emerged area. In the zone in front of the Vecchia Foce Càldoli and the Foce Zanella, there is a deeper area delimited to the E and the W by shallow zones which correspond to the accumulation of sediments deposited by streams coming from the S. At last, there is the San Clemente Islet, located within the lagoon, to the NW of the town of Lèsina. It is a very small, flat surface which almost outcrops from the bottom, on which, at about half-a-meter of depth, exist the traces of a fishing boat dating back to the Roman period.

The sediments of the lagoon bottom are composed of sand and silt with frequent whole mollusc shells and bioclasts. The discovery of *Abra segmentum* sin. *ovata* and *Cerastoderma glaucum* in these deposits probably indicates a mesosaline lagoon environment (Caldara & Pennetta, 1989a and 1989b), more suitable to the development of the former which tolerates a lower salinity (14-27‰) compared to the latter (18-37‰).

VARIATIONS OF THE PERILAGOONAL AREA IN THE HISTORICAL PERIOD

The study of historical maps of the coastal plain enables the definition of the transformation of the Lèsina lagoonal system over the last 500 years. Among the historical maps studied, the most ancient one is «*Carta d'Italia del 500*» (Map of Italy of the 16th Century), dating back to mid-16th century (fig. 6), conserved in Sala degli Arazzi of the Palazzo Ducale of Venice, attributed to G.B. Ramusio. In this map there is no trace of the lagoon (Colozzi, 1932), probably because of the lack of details due to its scale. The map shows a narrow bay, where the lagoon lies currently, elongated towards the S; whereas, the mouth of the Fortore River (*Torr.te Fortore*) is located more to the W than its present-day position.

The «*Pianta del Lago e Bosco dell'Isola*» map (The Plan of the Lake and the Woods of the Isle - fig. 7) taken from the Grande Real Archivio of Naples, considered by Colozzi of a later date than the one of Ramusio, probably dates back to the end of the 16th - beginning of the 17th centuries. This perspective map, full of place names, geographical references, morphological elements and indications on vegetation, indicates also, proceeding from the W to the E, the three coastal towers (*Torre di Fortore, Torre Mozza, Torre Miletta*) erected with the same distance between each other (nine miles). It shows that the eastern part of the lagoon is larger than the western part (Ripalta), where the low hills of Zurrone are also represented. Moreover, in this map, the mouth of the Fortore River, the wide, marshy areas (*padule*) of the northern shore, the meandering channels (*Acqua Morta, Foce Pescaria, Foce Vecchia*) and the coastal dunes are all represented. It should be specified that both the dimensions of the sheet of water and the extension of marshlands appear greater than the current ones.

The «*Pianta dell'Intero Territorio di Lèsina (il Feudo* Ave Gratia Plenae *con le Difese della Città e di Azzia)*» map (The Plan of the Entire Territory of Lèsina), dating

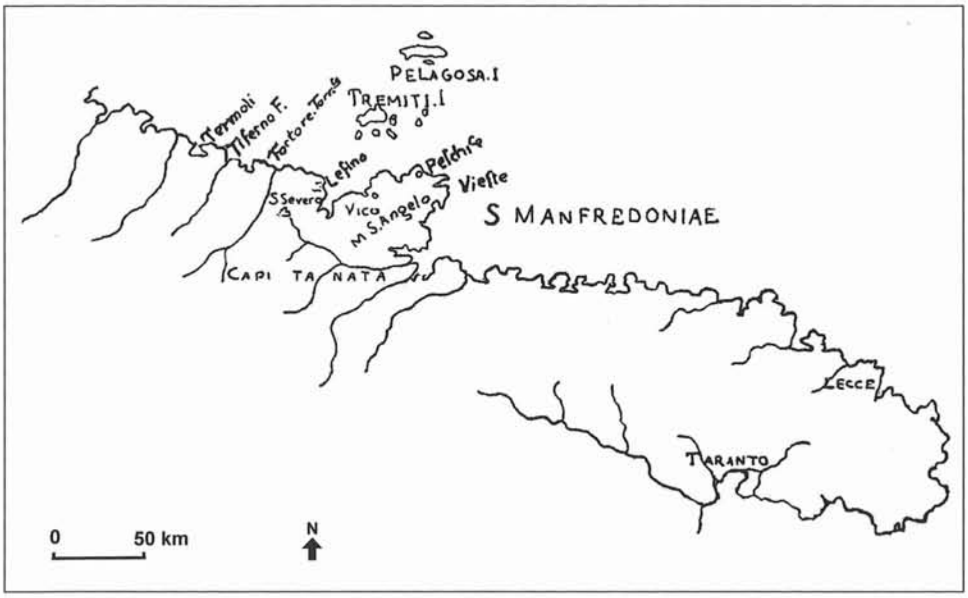

FIG. 6 - Reproduction of «*Carta d'Italia del 500*» map (Map of Italy of the 16[th] century), conserved in Sala degli Arazzi of the Palazzo Ducale of Venice, mid-16[th] cent., attributed to G.B. Ramusio.

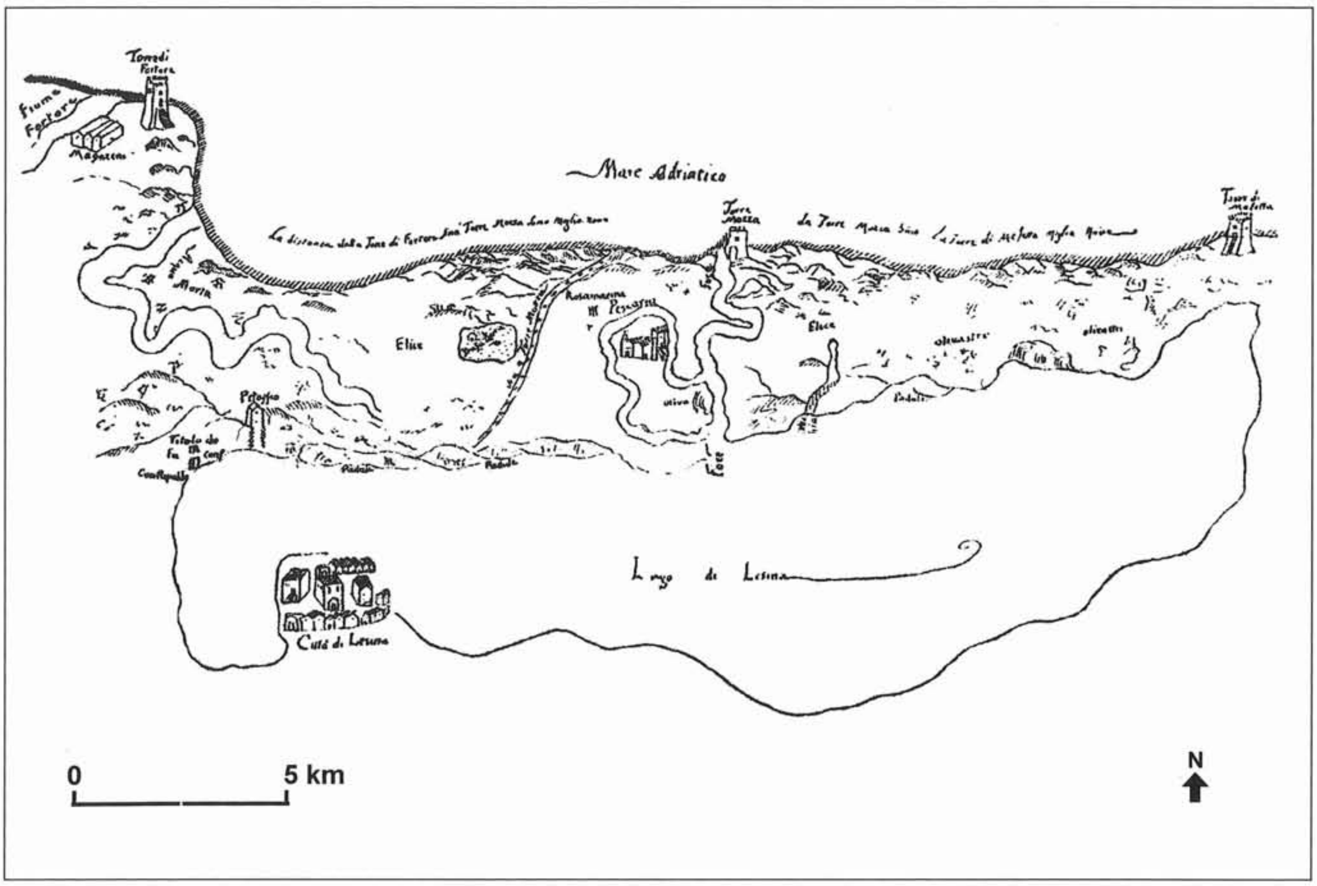

FIG. 7 - Reproduction of «*Pianta del Lago e Bosco dell'Isola*» map (The Plan of the Lake and the Woods of the Isle), 16[th] - 17[th] cent., taken from the Grande Real Archivio of Naples.

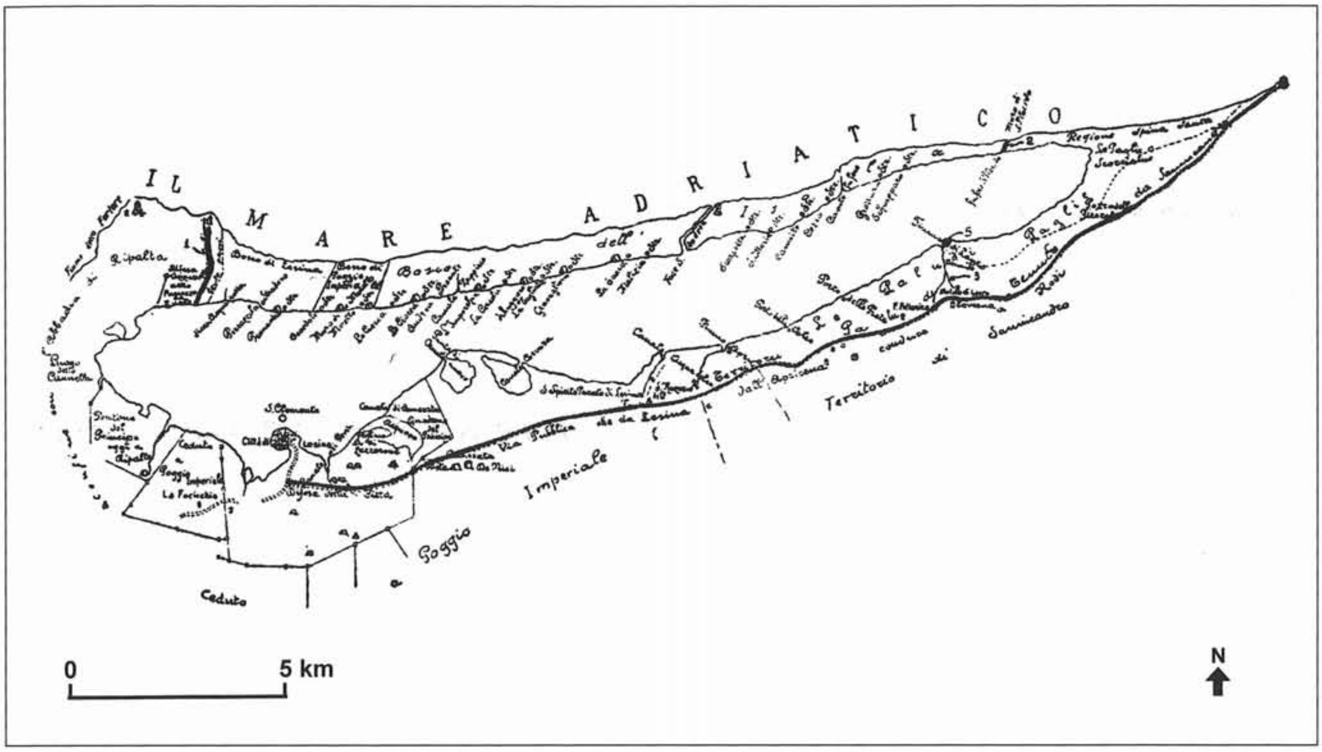

FIG. 8 - Reproduction of «*Pianta dell'Intero Territorio di Lèsina (il Feudo* Ave Gratia Plenae *con le Difese della Città e di Azzia)*» map (The Plan of the Entire Territory of Lèsina), 19[th] cent. (from Colozzi, 1932 modified). Compared to previous historical maps, the salt-water basin shows a decrease in width and length.

back to the 19[th] century (fig. 8), shows the lagoon with a similar morphology to the current one. However, there are some differences compared to previous maps and to the present-day configuration. Particularly, numerous channels (*Canale dei Ponti, di Camerata, Nuovo, Corvara, Acquadolce*) and some steams (*Fiume Apri, di Lauro*), which cross the small marshy zone (*Le Paludi*), are present along the southern shore. The Fortore River mouth is much closer to the lagoon and on the northern shore there are some channels (*Acquarotta, Zappino*), two inactive mouths (*Cavuto fu foce, fu foce S. Placido*) and a central mouth (*Foce S. Andrea*) which is now filled with sediments.

The study of I.G.M.I. (Italian Military Geographic Institute) maps of 1869, 1909 and 1957, puts in evidence a certain stability of the shape of the basin over the time, although some of the mouths are closed and the emerged beach is eroded. Analysing historical maps enable to observe a progressive narrowing of the basin, a reduction of its extension and a decrease in number of its channels over the last five centuries. On the other hand, between 1869 and 1957, important variations of the morphology of the lagoon are not observed, while the facing coastline has undergone a widespread retreat.

RECONSTRUCTION OF THE MORPHOLOGICAL EVOLUTION

The surveys conducted suggest that genesis and morphological evolution of the Lèsina Lagoon have been mainly controlled by coastal paleomorphology together with the effects of glacio-eustatic oscillations, sediment supply of Fortore River and littoral dynamic processes. In the area under study, the effects of vertical fluctuations of the ground are seen both on the morphology of the area and on the stratigraphical succession. In fact, within the perilagoonal area, successions composed of alternating marine and continental sediments, and strips of terrace dating back to the Pleistocene are both observed (Westaway, 1993). Moreover, there are submerged artefacts of the Roman period inside the lagoon, while to the NE of it, ruins buried under the sediments of the beach have been reported (Colozzi, 1932).

In the region, the presence of marine terraces at different altitudes, linked to the variations of the base level during the Quaternary (Pirazzoli, 1981 and 1993), witnesses how vertical movements of the ground have certainly interacted with the glacio-eustatic oscillations of the sea level. The NW-SE orientation of the coastline during the late-Pleistocene (Aucelli & *alii*, 1997), different from the current W-E development of the shore, outlined a wide bay called the paleogulf of Candelaro. This paleomorphology is probably the result of tectono-sedimentary events of the mid-late Pleistocene that affected the Gargano Promontory. These events, together with the climatic oscillations, would have changed the entire drainage network, diverting it towards the N, which initially had a parallel pattern. This process had also an effect of reducing the sediment supply to the paleogulf of Candelaro, located to the E of the Gargano.

Based on data obtained from field surveys, it is considered that the lagoon might have been formed within a bay which had begun to assume a structural configuration similar to the current one since the end of the Pleistocene, most likely during the Würm I - Würm II interstadial (Cotecchia & *alii*, 1969).

At the beginning of the Holocene, when the vertical movements of the late-Pleistocene have already brought the bordering terraces to their present-day altitudes (Ricchetti & *alii*, 1992; Aucelli & *alii*, 1997), the sea level was lower than the current one and the coastline was situated more to the N than the present line. Subsequently, while the sea was reaching an altitude close to the present-day level, the presence of a high structure composed of limestone and gravelly-conglomerate reliefs of Ripalta and C. Zurrone, leaning against the outcropping intrusive rocks of Pietre Nere Point, might have represented a topographic obstacle on the coast. The latter, intercepting the fluvio-marine sediments deriving from the W and from Fortore River mouth, contributed to establish favourable conditions for the development of the lagoon (fig. 9). In fact, the combined action of coastal currents and wave motion allowed the sediments, deriving from the W, to accumulate on the shallows, composed of an abrasion platform modelled by previous glacio-eustatic oscillations. As a consequence, sandy ridges (littoral spits) have been formed and emerged, isolating a partially closed basin.

The development of sandy ridges has continued in time following the same mechanism, but with a different orientation. In fact, first, they were NW-SE oriented, then they have gradually rotated towards W-E, as new ridges welded to the pre-existing ones near the terminal 'hook' of the littoral spit. So, the coast connected up to the limestone offshoots of Gargano, assuming a concave physiography, on which a series of dune ridges have formed. At this point, a fairly stable littoral was formed, interrupted by wide mouths created by overwash during storms.

The bay to the E of Gargano has been barred the same way by littoral spits with dunes developing on them, originating another salt-water basin (Varano Lagoon). In the meanwhile, the Fortore River mouth has progressively migrated towards the W, as evidenced by the ancient riverbed relics, until it assumed the present-day position. During this process, which has taken place while the sea level was oscillating around the current altitude, wide marshlands were forming behind the strand. On the other hand, the beach was stabilising thanks to

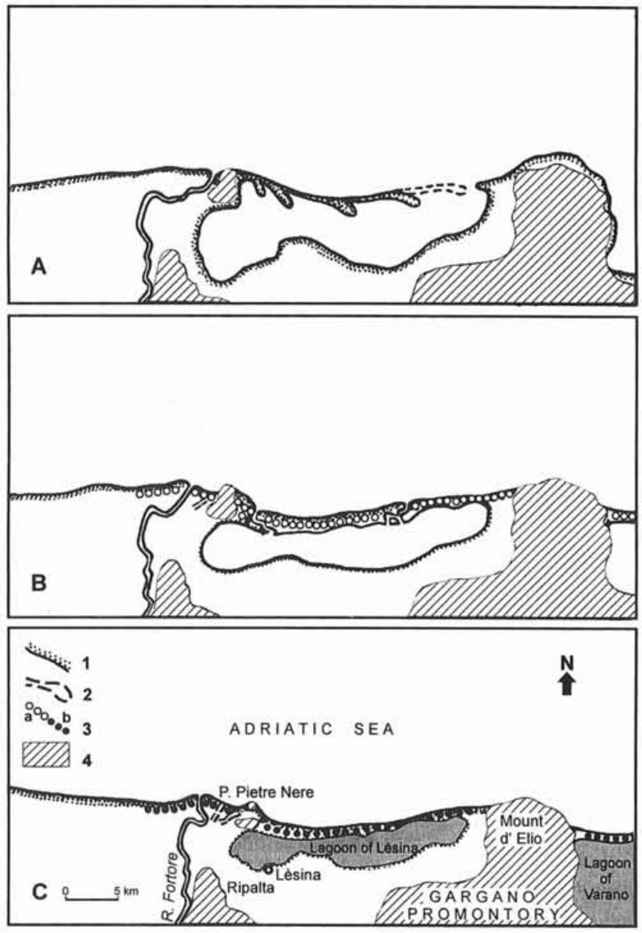

FIG. 9 - Possible reconstruction of morphological evolution of Lèsina Lagoon: 1 - sandy deposits; 2 - trace of littoral spit; 3 - dune ridge; 4 - rocky relief; A - Low-middle Holocene: presence of obstacles to littoral dynamic processes (Pietre Nere Point and Zurrone Hill), to the E of Fortore River mouth, determines development of composite littoral spits which isolate a partially closed salt-water basin; B - mid-Holocene - historical period: paleolagoon is delimited by a littoral spit interrupted by wide channels and stabilised by a series of dunes; the dunes, first NW-SE oriented, gradually rotate to a W-E direction, proceeding towards Gargano Promontory; the bay to the E of Gargano is barred by a littoral spit on which develops a dune, originating another salt-water basin (Varano Lagoon); Fortore River mouth progressively migrates towards the W; C - historical period - present-day: the lagoon is partially filled with sediments which reduce its depth, modify geometry of its shores and close its channels; Fortore River mouth slowly migrates towards the W, abandoning segments of riverbed until it assumed present-day position.

the presence of the dune ridge composed of numerous ridges subparallel to the coastline. For some short periods in the Holocene, probably around climatic hot peak (around 5500 and 3400 years b.p.; Antonioli & Ferranti, 1996), the increase of the frequency of the waves (Bondesan & *alii*, 1995) and the progressive transformation of the coast into marshland around 3000 years b.p. (Cotecchia & *alii*, 1969; Schiattarella, 1989-90) might have accelerated the physiographic modifications of the coastal landscape, contributing to the creation and evolution of the lagoonal system.

In the 16th century, as reported in «*Carta d'Italia del 500*», the lagoon was not apparent. This leads to the assumption that, as Colozzi (1932) sustains, the narrow and elongated bay seen on the map originated after the break of some sandy ridges, which separated the lagoon from the sea, caused by a violent sea storm registered in ancient chronicles. It is supposed that even the lagoonal environments of the Mediterranean might have been influenced by storms. In addition, the opening of a 800 m long passage in the *flèche* of Trabucador (Ebro River delta), caused by a storm in the October of 1990, sets up a well-documented example (Sanchez-Archilla & *alii*, 1995) of an event possibly not episodic.

The successive filling of the lagoonal area with sediments transported from the beach and by the streams, has created wide marshy environments, described in the map of the 19th century, still existing at places. The geometrical variations of the shores have determined the present-day shape of the lagoon and its position parallel to the coastline. Such kind of recent evolution is probably linked to the availability of clasts produced during the floods of the cold-damp periods (6th - 4th cent. BC; 5th - 8th cent. and 16th - 19th cent. AD) and transported many times during the short environmental crises of dry-desertic periods (2nd - 4th and 11th - 14th cent. AD).

During these climatic fluctuations, the shortest Brückner cycles (10-35 years) may have contributed to the remodelling of the coastal physiognomy of this part of the Adriatic (Carbognin & Marabini, 1996). At last, between 1869 and 1957, the shape of the basin remained quite stable, whereas some channels of the lagoon were filled with sediments and the emerged beach has shown a general retrogradation.

CONCLUSIONS

The Lèsina Lagoon is part of the Fortore River delta-lagoon system. It most probably originated after the post-glacial eustatic rise and was remodelled into the present-day configuration due to littoral dynamics, responsible for the development of littoral spits, which acted on an inherited morphology, bordered by high morphological reliefs.

In the lower-Adriatic coastal belt, the conditions suitable for the creation of lagoonal systems, represented by wide coastal tectonic depressions, are established as from the mid-late Pleistocene (Würm I - Würm II interstadial), when the neotectonic phases had already faded and the landscape was quite comparable to the present-day one. Within these ancient depressions, late-glacial sediments have accumulated, generating wide areas characterised by low sea.

In the studied area, the littoral morphological conditions suitable for the future creation of the Lèsina lagoonal system were established in a paleobay, originated from the previous tectono-sedimentary evolution of the paleovalley of Fortore and the Gargano Promontory, limited towards inland by a curved paleocliff. Clastic materials accumulated along the coasts by streams, especially during the post-glacial age, were redistributed within the inherited paleomorphology. On this paleomorphology, around the climatic *optimum* (about 6000 years b.p.), during which the rising sea level has reached an altitude similar or maybe superior to the present-day one, the conditions for the successive development of the lagoon were created.

The position of the Fortore River mouth and the presence of topographic obstacles to littoral dynamics, composed of high morphological reliefs of Ripalta, C. Zurrone and mainly of P. Pietre Nere, facing a sea characterised by shallow waters, have consented the gradual shaping of littoral spits. The latter were first NW-SE oriented and then, they have gradually rotated about 40° anticlockwise, until they assumed a W-E orientation. These composite forms progressively barred a tract of the sea, isolating a salt-water basin; successively, they became stabilised by the forming of the dunes.

Following the barring, the progressive filling of the lagoon has begun, leading to the genesis of marshy environments in the back areas. As from the Graeco-Roman period (about 2500 years b.p.), the lagoonal system has begun to stabilise, even if the plain was exposed to slight subsidence phenomena. In fact, the presence of Roman manufacts found underwater at about 0.6 m of depth within the lagoon, near the almost emerging San Clemente Islet, considering also the lower sea level during the Roman period compared to the current one (Pirazzoli, 1981 and 1993), suggests a mean rate of subsidence of about 0.3 mm/year. As from mid-17th century, the geometry of the lagoon has undergone alterations, which have caused the reduction of both its extension and its width, as evinced by the study of historical maps.

These transformations are most probably connected to the major fluvial clastic supplies accumulated as from 1500 till 1850 (Little Ice Age). After all, over the last five centuries, a progressive tapering of the lagoon, together with a reduction of its extent and a decrease in number of its channels have been registered; whereas between 1869 and 1957, important variations of the geometry of the lagoon are not observed, although the coast shows a general retreat.

In the historical period, from the Graeco-Roman age up to the present, the transformations of the landscape, directed or induced by man, like drainage, fluvial diversions and land reclamation, have influenced on the evolution of the lagoonal environment, combining with the previous events and phenomena and controlling its development. Some forms found both in the emerged, western zone and within the lagoon, all with a NW-SE orientation, are probably relics of the first sandy ridges, which developed along that direction.

The decrease of the thickness of recent beach sand deposits, proceeding from the W towards the E, to the point of emersion of underlying clay, which has an inclined surface, suggests that the paleomorphology of the bay had its depo-centre more towards the NW compared to the present-day salt-water basin.

The physical limit to the development of the lagoon towards inland is represented by the belt of conglomerate reliefs (Ripalta, Torretta) to the W and of limestone reliefs (Sannicandro Garganico, Mount d'Elio) to the E. The different lithologies of these, which result in diverse resistance to erosion, have conditioned the shape of the lagoon, as the pre-existing bay was larger at its western part. The genesis of small depositional terraces found near the northern shore of Lèsina Lagoon is instead, attributable to very recent sediment deposition, for the presence of almost actual peat layer.

Within the adjacent dune area, in contrast to the Lagoon of Venice (Bondesan & *alii*, 1995; Carbognin & Marabini, 1996), morpho-stratigraphic elements like storm depositional fans or breaks proving the recurrence of protohistoric or historic storms, are not observed: this fact might be because of the coastal orientation; although, it is possible to hypothise, based on historical maps, that such an event happened before the 16th century.

The current subcircular forms of the lagoon shores are due to the modelling of the wind, especially those blowing from the W, and of superficial currents caused by it (Ficca & *alii*, 1996), given the mean low depth, in accordance with what Dias (1998, dir. com.) observed for some lagoons in Portugal. This phenomenon, together with sediment transport by tidal currents through the only two open lagoon channels, not only have influenced the distribution of fine sediments on the lagoon bottom within the area affected by narrowing due to the presence of alluvial fan, where also the relic forms of an ancient littoral spit exist, but also have started the segmentation of this basin, that was originally subtrapezoidal.

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