

HISTORY OF THE SALPI LAGOON-SABHKA (MANFREDONIA GULF, ITALY)

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ABSTRACT - The Flandrian sea level rise caused the development of sand coastal ridges between Gargano Promontory and Murge Highplain. This narrow and long strip delimited a wide coastal lagoon characterized by several connections to the sea, called the "Salpi lagoon" by the Authors.

This is the first attempt to analyse the geological, geochemical, and archaeological evidence in order to reconstruct the evolution of the Neolithic lagoon-sabhka.

Several drillings and agricultural trenches have demonstrated that, during the early and middle Neolithic ages, the lagoon was characterized by typical species of the euryhaline and eurythermal biocoenoses in brackish water (*Cerastoderma glaucum*, *Abra ovata*, *Hydrobia* gr. *stagnorum*) or of the superficial muddy sands in sheltered areas (*Loripes lacteus*, *Abra ovata* and *Pirenella conica*). These brackish species are replaced towards land with species becoming more sensitive to salinity such as *Chara*, *Planorbis planorbis* and *Valvata piscinalis*. Certainly, the lagoon has existed till $5,470 \pm 40$ yr BP (AMS date on a shell of *Cerastoderma glaucum*).

Subsequently, at the beginning of the late Neolithic age the lagoon evolved into a marginal marine saline pan resembling a sabhka. Gypsum in the form of nodules, isolated crystals, clusters of crystals (rosettes and desert rose) has been found.

Mineralogical, geochemical and morphological features of gypsum and the associate evaporite deposits have given a climatological and environmental indication of this period.

Gypsum morphologies vary under distinct hydrological regimes and they are characteristic of the different subenvironments of the sabhka and therefore they can be used as a sensitive interpretative tool for evaporative palaeoenvironments. In particular the areas corresponding to saline pan, saline mud flat (blocky prisms and blocky hemipyramids morphologies) and sandy seaward side of the saline pan (discoidal hemipyramids morphology: desert roses) of the Salpi sabhka have been recognized.

The CF values during the seawater evaporation indicate that solutions were variously diluted with inflow waters poor in sodium, rich in calcium and with a Mg/K ratio higher than the value found in the present day seawater of the Gulf of Manfredonia.

The gypsum deposition suggests an arid or semi-arid climate and, therefore, the contribution of fresh water into sabhka was poor. On the other hand, in the Tavoliere plain, confined by higher land on three sides, the present climatic conditions tend to be a semi-arid continental type, maximized in the central part and coastal zone of the plain (BS according to Köppen Climatic Classification, 1923, or DdB'd, according to Thornthwaite & Mather, 1957).

The proof of this aridification and duration is also given by the analyses of the people and culture of the coastal Tavoliere sites. The late Neolithic records a technological and socioeconomic involution, as pointed out by the skilled permanent farmer who changed into a nomadic shepherd. The settlements were progressively abandoned between the end of the 4th millennium BC., through almost all the 3rd millennium BC, uncal. The abandonment of the Tavoliere settlements coincided with the beginning of the Scaloria Cave cult of the waters.

It is reasonable to place the end of the most arid phase when settlements were repopulated and, therefore, starting from the Bronze Age (Coppa Nevigata site, is dated at 3540 ± 60 BP).

RIASSUNTO - È stata studiata l'evoluzione di una laguna olocenica ubicata nel Golfo di Manfredonia, fra il promontorio del Gargano e l'altopiano delle Murge.

Numerose perforazioni per ricerche idriche e scavi per miglioramenti agricoli hanno messo in evidenza che, durante il Neolitico iniziale e medio, la laguna era caratterizzata da una fauna a *Cerastoderma glaucum* e *Pirenella conica*. A partire dall'inizio del Neolitico recente, la laguna si è evoluta in una marginal marine saline pan tipo sabhka.

Sono state trovate formazioni di gesso sotto forma di noduli, cristalli isolati, ammassi di cristalli (rosette e rose del deserto).

Studi di carattere mineralogico, geochimico e morfologico sul gesso e sui relativi depositi gessosi hanno fornito indicazioni climatiche e paleoambientali relative a quel periodo. Sono state riconosciute, nell'ambito della sabhka di Salpi, gli ambienti corrispondenti alle aree del bacino evaporante, della piana fangosa salina e del lato sabbioso verso mare. Il clima era arido o semiarido e gli apporti di acque dolci nella sabhka erano scarsi.

Il periodo arido è stato caratterizzato sia dall'abbandono degli insediamenti del Tavoliere e sia dall'involutione tecnologica e socio-economica della popolazione e della cultura.

La fine della fase arida è collocabile con l'Età del Bronzo quando gli insediamenti, precedentemente abbandonati, sono stati ripopolati.

Keywords: Lagoon-sabhka, Palaeoenvironmental Evolution, Chronology, Holocene.

Parole chiave: Laguna-sabhka, Evoluzione paleoambientale, Cronologia, Olocene.

1. INTRODUCTION

The present research is aimed at establishing a sound relationships between climatic and anthropic changes and the geomorphic processes that originated the present landscape throughout the studied area. In particular, this work focuses on the geomorphological evolution of the "Tavoliere di Puglia" in the last thousand years and it attempts to recognize and place, on the time-scale, the environmental events and socio-historical circumstances that produced it.

The sample area chosen for this project is the coastal plain of the Manfredonia Gulf which shows evidence of human settlements from the Neolithic age.

In conclusion, this is the first attempt to analyse the geological, geochemical, and archaeological evidence of the Neolithic Salpi lagoons-sabha.

2. GEOLOGICAL SETTING

The "Tavoliere di Puglia" is a broad plain, weakly tilted towards the Gulf of Manfredonia, delimited by the Promontory of the Gargano, the Highplain of the Murge and by the subapennine Chain.

From a geological point of view it corresponds to the northern part of the *Fossa Bradanica* (Bradanic Trough), a subsident trough formed from the Lower

Pliocene to the Lower Pleistocene, between the Southern Apenninic chain and the Apulian-Dinaric foreland. The sediments of the Bradanic cycle are known as "Calcarene di Gravina", "Argille subappennine", "Sabbie di Monte Marano" and "Conglomerato di Irsina" Formations. After the filling of the trough, a regional discontinuous uplift, still active, complicated by a sequence of glacioeustatic sea-level fluctuations, took place. The consequence of these contemporary phenomena are a sequence of unconforming transgressive marine sediments over the bradanic substrate or superimposed one upon the other. The former situation is better represented in the internal area of Tavoliere, near the Apenninic chain, the latter is the rule in the coastal plain (Boenzi et al., 1992).

During the Würm glaciation, when the sea level was about 120 m lower and shoreline was approximately 70 km more offshore than the present one, the Daunian rivers remarkably cut their beds and widened the valley. This regressive erosion penetrated deeply into the alluvial plain of the Gulf of Manfredonia as far as it cut the clayey substrate (Caldara & Pennetta, 1991).

During the post-Würmian climatic improvement, the sea-level progressively arose even if with small fluctuations reaching and perhaps exceeding the present level by a few meters, after the *Climatic Optimum*, in the 3rd millennium BC (Caldara & Pennetta,

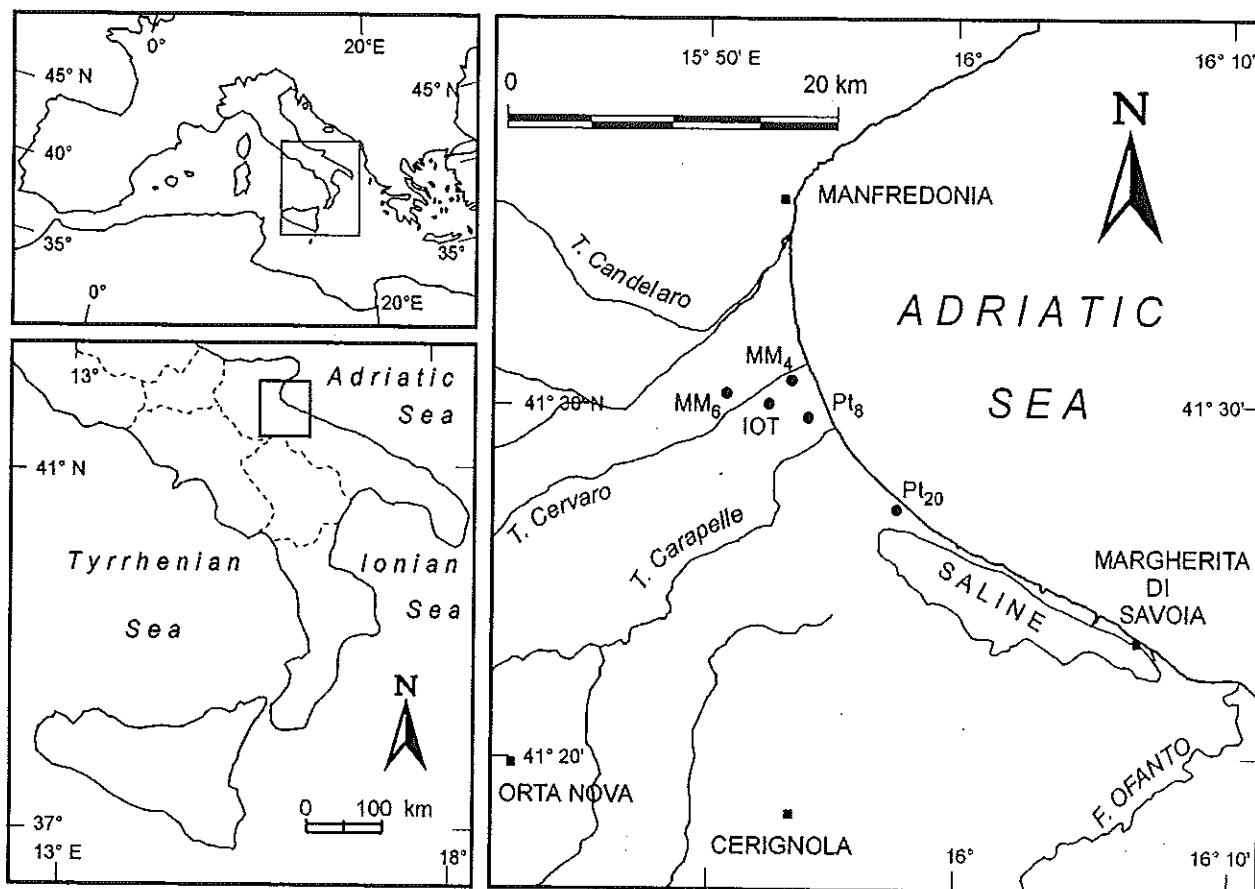


Fig. 1 - Location of the studied areas. MM_n = core positions, IOT = agricultural trench position.
 Ubicazione dell'area studiata. MM_n = posizione sondaggi, IOT = posizione trincea agricola.

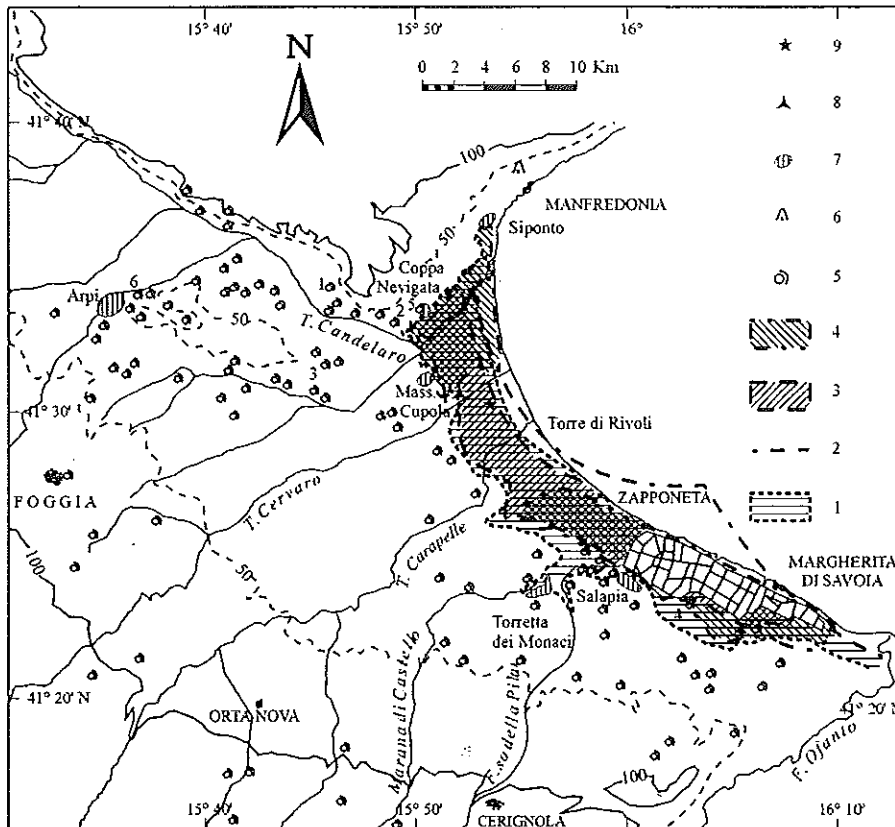


Fig. 2 - Coastal plain of the Gulf of Manfredonia showing the distribution of the most significant Neolithic ditched villages; the evolution of the coastal lagoon from the Neolithic Age to Present and the sites where gypsum was found. Key to symbols. 1 - Neolithic lagoon; 2 - Probable Neolithic shoreline; 3 - Lagoon of the 3rd century BC (Schmiedt, 1973); 4 - Lagoon of the 1st century BC (Delano Smith, 1978); 5) Ditched Neolithic villages (1 = Mass. Candelaro, 2 = Fontanarosa Uliveto, 3 = Santa Tecchia, 4 = Scaramella di S. Vito, 5 = Coppa Nevigata, 6 = Passo di Corvo); 6) Scaloria Cave; 7 - Principal Daunian settlements (Torretta dei Monaci, Mass. Cupola, Coppa Nevigata were inner lagoon harbours, while Arpi was a river port) and then Roman (Salapia was an inner lagoonal harbour, while Siponto was a sea port); 8 - Location of the drilling MM₆ at "Beccarini"; 9 - Occurrences of the desert roses at "Isola degli Olivi di Torelli".

Distribuzione dei più importanti villaggi trincerati neolitici nella piana costiera antistante il Golfo di Manfredonia; evoluzione della laguna costiera dal Neolitico ad oggi e ubicazione delle aree di ritrovamento dei gessi.
 Legenda dei simboli: 1 - Laguna neolitica; 2 - Probabile linea di costa neolitica; 3 - Laguna del III secolo a.C. (Schmiedt, 1973); 4 - Laguna del I secolo a.C. (Delano Smith, 1978); 5) Villaggi trincerati neolitici (1 = Mass. Candelaro, 2 = Fontanarosa Uliveto, 3 = Santa Tecchia, 4 = Scaramella di S. Vito, 5 = Coppa Nevigata, 6 = Passo di Corvo); 6) Grotta Scaloria; 7 - Principali insediamenti dauni (Torretta dei Monaci, Mass. Cupola, Coppa Nevigata erano porti lagunari interni, mentre Arpi era un porto fluviale) e romani (Salapia era un porto lagunare interno, mentre Siponto era un porto sul mare); 8 - Localizzazione della perforazione MM₆ a "Beccarini"; 9 - Ritrovamenti di rose del deserto a "Isola degli Olivi di Torelli".

1992). The sea level rise caused the development of sand coastal ridges between Manfredonia and Barletta. This narrow (about 0.5 km) and long (about 40 km) strip delimited a wide coastal lagoon, which has been called "Salpi lagoon" by the Authors, and had several connections to the sea (Fig. 1). The sand dune ridges, which are parallel to the shore during the formation, indicate a Neolithic shoreline. More inland in correspondence with the mouth of the present Candelaro stream in the northern part of the Manfredonia Gulf, and more seawards beginning from Torre di Rivoli (Schmiedt, 1973), in the central part (Fig. 2).

The lagoon was usually only five km wide, but it might reach several tens of km in correspondence with the river valleys, especially the Candelaro one.

In the second century BC the alluviations of the Cervaro stream divided the coastal lagoon into two parts. The subsequent sanding of the lagoon inlets and stream deposits favoured the wide-spread formation of coastal lakes (Versentino, Contessa, Salso e Salpi). The natural evolution of the last two lakes has been obstructed for a long time by human activity either with the formation of salina (former Salpi lake) or with land reclamation during the last two centuries.

3. COASTAL PLAIN STRATIGRAPHY

The only geological knowledge of the coastal plain deposits derive from drillings undertaken for water research and from some agricultural trenches.

The bore-holes have enabled the recognition of the deposits of four sedimentary superposed cycles, referable to the Middle - Upper Pleistocene - Holocene (Caldara & Pennetta, 1993), transgressive on the "Argille subappennine" Formation lying at 120 m b.s.l. near the coastline (drilling Pt₃). The sediments of the most recent cycle are transgressive on the gravelly, clayey and sandy continental deposits referable to Würmian. Further on only the stratigraphy of one core will be described and an agricultural trench located the former in the internal areas of the lagoon and the latter near the dune ridges. This choice has been made among a hundred cores at our disposal because this is the richest in product of the evaporite sedimentation. The chosen core MM₆ is located near Beccarini site (Fig. 2). The pre-Holocenic deposits are represented by three units: gravel and sandy gravel (as far as -23 m a.s.l.); grey clay (-23 ÷ -16 m a.s.l.); olive-brown silty sand rich in land gastropods such as *Helix*

cidae and *Limax* sp. (-16 ÷ -8 m a.s.l.). The top of this unit shows the effect of pedogenesis, characterised by numerous rhizoliths (Fig. 3).

The Holocene deposits are represented by two units. The former is a light olive brown or dark and very dark grayish brown clay (-8 ÷ 6.5 m a.s.l.) with gypsum that contain fossils: *Helicidae* (MM_{6/4}), *Characea* (MM_{6/3}), *Planorbis planorbis* and *Valvata piscinalis* (MM_{6/2}). The uppermost core-sample of this unit, MM_{6/1} is sterile. The latter is a clayey filled deposit (6.5 ÷ 8 m a.s.l.) due to the reclaiming of the last two centuries.

The studied agricultural trench is located at *Isola degli Olivi di Torelli* site (hereafter IOT), between Cervaro and Carapelle streams (Fig. 2) and only 1.5 km

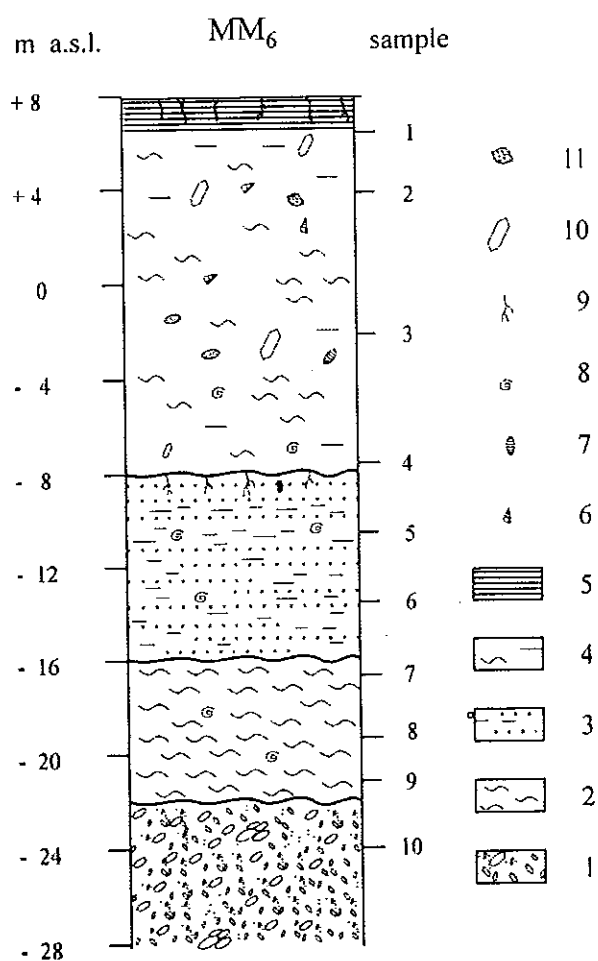


Fig. 3 - Schematic stratigraphic column for the uppermost portion of core MM6.

Key to symbols. 1 - gravel; 2 - clay; 3 - silty sand; 4 - silty clay; 5 - filled deposit; 6 - brackish molluscs; 7 - *Chara cogonia*; 8 - land gastropods; 9 - rhizoliths; 10 - gypsum crystals; 11 - gypsum microcrystalline nodules.

Colonna stratigrafica schematica relativa alla parte alta della perforazione MM6.

Legenda dei simboli: 1 - ghiaie; 2 - argilla; 3 - sabbie siltose; 4 - argille siltose; 5 - depositi di colmata; 6 - molluschi salmastri; 7 - oogoni di *Chara*; 8 - gasteropodi continentali; 9 - rizoliti; 10 - cristalli di gesso; 11 - noduli microcristallini di gesso.

from the present shoreline. It corresponds to one of the most outer basins of the reclaimed historical lands and it is less than 2 m a.s.l. The deposits, about 2 m thick, are practically impermeable as they are made of clay or silt materials carried by bypass channels of the nearby streams. Under them there are sands with a thickness which can reach 12 m.

The sandy deposits are normally almost barren in fossils, however they are only located in the upper part of the unit where the specimens are generally autochthonous or showing displaced shells belonging to neighbouring palaeocommunities. The malacofauna is very rich in species, among them there are: *Arca noae*, *A. tetragona*, *Glycymeris glycymeris*, *Chlamys glabra*, *C. multistriata*, *Ostrea edulis*, *Pinna* sp., *Cerithium vulgatum* and *Phyllonotus trunculus*.

Recently, in order to improve the agricultural characteristics of the local soil, due to the bad drainage of the surface clays, some 4 m of topsoil has been turned over by backhoes. The result has been a mostly sandy soil with a good cohesion and without stagnations, fit for any valuable cultivation. This technique is drawing the underlying sands, which, swept by the wind, have uncovered gypsum aggregates of a desert rose type.

4. SAMPLING AND ANALYTICAL PROCEDURES

To define some among the environmental conditions that controlled precipitation and distribution of gypsum, mineralogical and chemical analyses have been carried out on specimens of "desert roses" and sediments from drilling MM₆. The analysed samples are whole specimens of the sediment containing gypsum (MM_{6/1} to MM_{6/4}), their fractions, single crystals and nodules of gypsum selected by hand. The sandy fractions (from very coarse to very fine) have been separated by sieving.

The mineralogical composition, determined by X-ray fluorescence, is given in table I. The gypsum from the MM_{6/3-4} samples has not been analyzed due to its occurrence only in the pelitic fraction being seriously contaminated and the ions were released from poorly crystallized clay minerals and oxi-hydroxides.

The chemical analyses of sediment samples (Table II) have been separately performed on water-soluble (sulphates), acid-soluble (carbonates) and insoluble (silicates plus oxides-hydroxides) components. Gypsum has been dissolved in distilled water by agitation of the sample suspension for many days. SO₄⁻ has been determined as BaSO₄ precipitated, after the addition of BaCl₂. Mg⁺⁺ and Ca⁺⁺ of carbonates have been analyzed by flame atomic absorption starting from solutions obtained after a fast treatment with HCl 2% of sulphates free samples. All oxides of insoluble residue have been analyzed by means of X-ray fluorescence. LOI refers to the loss on the ignition at 900°C.

The ion/Ca (mol/mol) ratios of gypsum samples have been measured by flame atomic absorption (table III). The solutions have been prepared after the removal of the carbonates previously dissolved and the filtering of the insoluble components.

5. RESULTS

5.1 Gypsum morphology

The product of the evaporite sedimentation, found in different sedimentary cycles, has been discovered in some drillings which took place along the coastal plain (Fig. 2), formerly occupied by the lagoon. Gypsum is the predominant evaporite mineral laid down in the recentmost cycle. Different morphologies have been found and they clearly vary both with lithology of the host sediment and with depositional conditions.

"Discoidal hemipyramids" (Castens-Seidell, 1984) occurred in the sand unit of the IOT. This morphology is referred to clusters of large crystals both single rosettes and "desert roses". The gypsum crystals are grey in colour because of the abundance of the included sand.

Rosettes (maximum size ca. 5 cm in diameter) are made up of numerous discoidal hemipyramids intergrown in radial arrangements. Desert roses, here considered as large aggregates of rosettes, include many marine and brackish shells. The sedimentary bedding is still marked by thin sand layers or colour changes. As a rule the crystal aggregates are horizontally grown with the planes of the larger vertical crystals. Many specimens closely resemble the accretionary structure like bioturbations. The largest desert rose found was 27 cm in size.

"Blocky prisms" in small agglomerations, "blocky hemipyramids" (Castens-Seidell, 1984) and "microcrystalline nodules" (Ali & Wests, 1982) have been found in clayey lithotypes of the bore-hole MM₆.

Various hyaline crystals of "blocky prisms" morphology are found in MM_{6/1} sample. They are barrel-like in shape with swallowtail twin terminations. The largest crystal is 2 cm long.

Numerous hyaline crystals of "blocky hemipyramids" morphology, not exceeding 1 cm in size, are found in MM_{6/1-3} samples, in particular in the upper part of the clayey unit.

Agglomerates of "microcrystalline nodules" are spread in MM_{6/2} sample, their size ranges from a few mm up to 1 cm across. These nodules are composed of fine-grained lenticular or tabular crystals. The single crystal is hyaline, while the whole nodule is opaque.

5.2 Geochemical and mineralogical data

The relative abundance of the main mineralogical components (carbonates, quartz+feldspars, phyllosilicates) indicates that the composition of sediment samples (Table I) varies from marly silt (MM_{6/1}), marl (MM_{6/4}) and clay (MM_{6/2-3}). Moreover, in the group of marly and clayey samples, the ratios of quartz+feldspars to phyllosilicates (as well as the SiO₂/Al₂O₃ ratios) indicate that the MM_{6/2} sample has a grain-size coarser than MM_{6/3} and MM_{6/4} samples.

The gypsum content is nearly constant in the whole sediment samples, although crystals change in morphology and decrease in grain-size with depth (Table I-II, Fig. 4). Discoidal hemipyramids of gypsum are concentrated in the coarse-medium sand of the MM_{6/1} sample. Nodules of microcrystalline gypsum are abundant in each sandy fraction of the MM_{6/2} sample, and MM_{6/3-4} samples only contain gypsum in the pelitic fraction.

These changes are likely to be related to the grain-size of the sediment as the previous observations suggest.

The ion/Ca ratios measured in the gypsum samples and those calculated for the inferred brines are summarized in table III. The ion/Ca ratios for the inferred brines have been calculated on the basis of the partition coefficients $D_x = (X/Ca)_{solid} / (X/Ca)_{brine}$ according to Kushnir (1980) for saturation conditions next to the equilibrium (slow crystal growth). This choice has been adopted because the absence of halite and/or K-salts in all sediments indicates that the parent solutions were not supersaturated. The lower values are observed in the gypsum nodules of the

		sample code	gy	ca	do	ar	qz	fd	il	ch	ka	sm
whole samples		MM _{6/1}	8	21	5	n.d.	26	7	13	5	7	8
		MM _{6/2}	7	13	n.d.	n.d.	17	3	17	10	13	20
		MM _{6/3}	7	9	n.d.	5	12	2	19	8	15	23
		MM _{6/4}	5	16	5	n.d.	12	8	15	9	12	18
sandy fractions	coarse medium	MM _{6/1}	86	8	n.d.	n.d.	4	n.d.	2	n.d.	n.d.	n.d.
		MM _{6/1}	8	35	5	n.d.	33	7	8	4	n.d.	n.d.
	fine	MM _{6/1}	n.d.	30	7	n.d.	33	14	11	5	n.d.	n.d.
		MM _{6/2}	56	29	n.d.	n.d.	7	n.d.	5	3	n.d.	n.d.
	very fine	MM _{6/2}	35	25	n.d.	10	15	3	7	5	n.d.	n.d.
		MM _{6/2}	28	14	5	9	21	8	9	6	n.d.	n.d.
	very coarse	MM _{6/2}	24	23	5	n.d.	20	10	11	7	n.d.	n.d.
		MM _{6/2}										

Note. Analyses obtained by means of X rays diffraction; gy = gypsum, ca = calcite, do = dolomite, ar = aragonite, qz = quartz, fd = feldspars, il = illite, ch = chlorite, ka = kaolinite, sm = smectite, n.d. = not detected

TABLE I: Mineralogical composition (vol. %) of the sediments.

Composizione mineralogica dei campioni della carota MM₆ e della relativa frazione sabbiosa per MM_{6/1-2} (% in volume).

	100% insoluble residue											soluble components		
	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	MgCO ₃	CaCO ₃	CaSO ₄
MM ₆₁	57.75	0.89	17.49	9.14	0.07	3.71	0.65	0.98	2.81	0.09	6.42	2.41	23.24	5.61
MM ₆₂	54.86	1.01	20.49	7.88	0.08	3.15	0.51	0.56	2.25	0.10	9.11	0.34	13.81	5.82
MM ₆₃	52.27	1.06	22.40	7.68	0.09	3.38	0.82	0.45	2.37	0.10	9.38	0.18	14.77	5.39
MM ₆₄	52.11	1.07	21.08	8.85	0.06	3.42	0.57	1.02	2.91	0.09	8.82	2.13	17.44	4.05

TABLE II: Chemical composition (weight %) of the whole samples.
Composizione chimica dei campioni della carota MM₆ (% in peso).

		gypsum				brines						
		Mg/Ca (x 10 ⁻³)	Na/Ca (x 10 ⁻³)	K/Ca (x 10 ⁻³)	Sr/Ca (x 10 ⁻³)	Mg/Ca	Na/Ca	K/Ca	Sr/Ca (x 10 ⁻³)	Na/Mg	Na/K	Mg/K
MM ₆₁	light crystals	0.080	1.15	0.094	0.63	6.15	63.89	1.57	0.126	10.39	40.69	3.92
	dark crystals	0.094	1.23	0.086	0.57	7.23	68.33	1.43	0.114	9.45	47.78	5.06
MM ₆₂	very coarse sand	0.040	0.16	0.019	0.47	3.08	8.89	0.32	0.094	2.89	27.78	9.63
	light nodules	0.042	0.16	0.020	0.41	3.23	8.89	0.33	0.082	2.75	26.94	9.79
	dark nodules	0.032	0.14	0.025	0.49	2.46	7.78	0.42	0.098	3.16	18.58	5.86
	coarse sand	0.050	0.23	0.017	0.39	3.85	12.78	0.28	0.078	3.32	45.64	13.75
	fine sand	0.038	0.12	0.035	0.53	2.92	6.67	0.58	0.106	2.28	11.50	5.03
desert rose	coarse crystals	0.158	1.49	0.129	0.65	11.38	82.78	1.98	0.130	7.27	41.81	5.75
	small crystals	0.131	1.58	0.122	0.78	10.08	87.78	2.03	0.156	8.71	43.24	4.97

TABLE III: ion/Ca (mol/mol) ratios determined in gypsum and calculated for inferred brines.
Rapporto ione/Ca (mol/mol) determinato per i gessi e le brine.

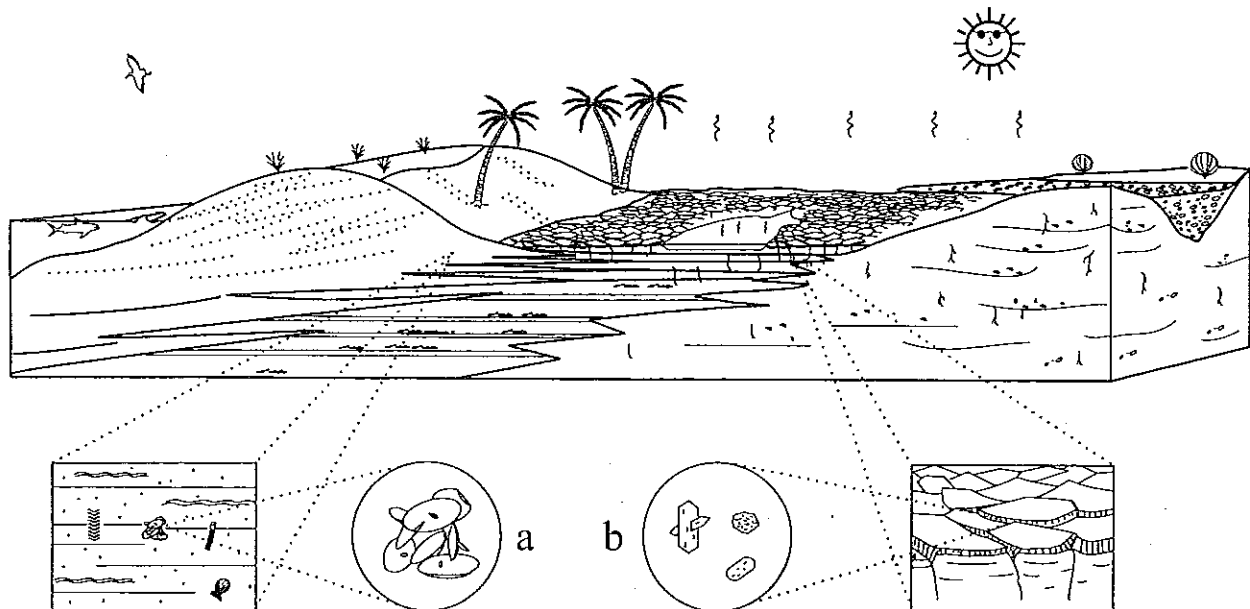


Fig. 4 – Evolution from lagoon to sabhka environments. Different gypsum morphologies, which correspond seawards (a) and towards land (b) of the lagoon-sabhka, are represented in the enlargements.

Ricostruzione paleoambientale con evoluzione da laguna a sabhka; negli ingrandimenti sono riportate le diverse morfologie di gesso corrispondenti al lato verso mare (a) e al lato più interno della laguna-sabhka (b).

MM_{6/2} sample; no systematic variation of the ratio exists in respect to the grain-size of the nodules. Much higher ratios characterize the crystals of the MM_{6/1} sample and the highest ratios are found in the desert roses.

6 PALAEOENVIRONMENTAL RECONSTRUCTION

The Holocene deposits are represented prevalently by sand and clayey-sand rich in species characteristic of upper infralittoral biocoenoses¹ such as fine well-sorted sands "SFBC" (*Spisula subtruncata*, *Macra corallina* and *Donax* sp.), Pt₈, or the fine sands in very shallow waters "SFHN" (*Lentidium mediterraneum*), drilling Pt₂₀ (Fig.1). These marine facies are replaced upperwards by beach or dunar sands with *Helicidae* in the bore-holes located near the shoreline, IOT; while, in the bore-hole located further the shoreline, they are replaced by grey or dark clay, alternated with thin sandy levels that are absent from the inner area (MM₆). The fauna is dominated by typical species of the euryhaline and eurythermal biocoenoses in brackish water "LEE" (*Cerastoderma glaucum*, *Abra ovata*, *Hydrobia* gr. *stagnorum*), Pt₂₀, or of the superficial muddy sands in sheltered areas "SVMC" (*Loripes lacteus*, *Abra ovata* and *Pirenella conica*), MM₄. These brackish species are replaced both upperwards and towards land (MM₆) with species becoming more sensitive to salinity such as *Chara*, *Planorbis planorbis* and *Valvata piscinalis*.

In conclusion, this situation is the natural evolution of a barrier island-lagoon system.

The presence of the gastropod *Pirenella conica* is very interesting, because of its abundance in many coastal lagoons and/or sheltered bottoms washed by waters of normal salinity in the southern Mediterranean warmer areas (Pérès, 1967). Therefore, the climate during the development of the lagoon must have been warmer than the present one.

Evaporite deposits can accumulate in three basic depositional settings (Lowenstein & Hardie, 1985): deep perennial basins (such as Dead Sea), shallow perennial lakes or lagoons (such as Great Salt Lake, Utah, and the Gulf of Karabogaz, Turkmenistan), and ephemeral saline pans, both continental (such as Death Valley, California) and marginal-marine (sabkha) setting (such as Baja California, Mexico and Tunisian sabkhas).

In our case the occurrence of gypsum in marine, lagoonal and continental sediments suggests a marginal marine setting.

The marginal saline pans are shallow depressions flooded both by meteoric waters and by seawater washed on the pans by storm surges and unusually high spring tides (Lowenstein & Hardie, 1985). An important role is carried out by sandy dunes, in fact their high permeability allows abundant seepage of marine derived phreatic waters from dune into salina in the summer-autumn period, when the water level in the marginal depression has been lowered by evaporation (*model of coastal salina*, Warren, 1982).

The saline pans are characterised by an annual cycle in which three stages are recognized: flooding, resulting in a *brackish lake*, evaporite concentration, when the lake becomes saline, and the desiccation stage with consequent *dry saline pan* (Lowenstein & Hardie, 1985).

The development of evaporites occur only in areas where the capillary fringe intersects the ground surface, usually where the surface is within 1.5 m of the water table. This fringe can be up to 2.5 - 3 m when the sediments are fine and the climatic conditions are very arid (Ali & West, 1983).

Gypsum morphologies vary under distinct hydrological regimes (Warren, 1982) and they are characteristic of the different subenvironments of the sabkha (Castens-Seidell & Hardie, 1984) and therefore they can be used as a sensitive interpretative tool for evaporative palaeoenvironments (Fig. 4).

The "blocky prisms" and "blocky hemipyramids" crystallize in *dry saline pan* during the desiccation stage. It is a vadose diagenetic growth of gypsum along polygonal cracks of the mud layers due to the desiccation (blocky hemipyramids) or in intergranular voids and dissolution vugs (blocky prisms).

The "discoidal hemipyramids" crystallize in the mud flat surrounding the pan within the silicoclastic sediments (Masson, 1955) during the evaporative concentration and desiccation stages of the saline pan. This intrasediment growth of gypsum is driven by evaporative pumping of brine from shallow subsurface brine body, or precipitation from phreatic water.

The development of the lenticular crystals, such as desert roses, is stimulated by sodium (Watson, 1985), thus accounting for their presence and their abundance in the sandy seaward side of the saline pan (IOT), where the sea-water seepage is very important.

The "microcrystalline nodules" occur a few decimeters beneath the surface (zona IV di Ali & West, 1982) in the supratidal sabkhas, partially vegetated with nebkhas.

The mineralogical analysis might also suggest that gypsum crystallized under different environmental conditions. The ion/Ca ratios calculated for the inferred present brines may be used to evaluate the CF values (concentration factor measured as the ratio of Cl in brine to Cl in normal seawater) during the seawater evaporation (Braitsch, 1962; Eugster *et al.*, 1980; Kushnir, 1982). The CF values were almost 5-6 and almost 3-4.5 in the brines from which respectively the desert roses and the gypsum of the MM_{6/1} sample crystallized. On the other hand, the values measured in gypsum of the MM_{6/2} sample give a brine composition with a CF parameter lower than that required for gypsum precipitation (CF = 3.5) from pure seawater.

These results indicate that solutions were variously diluted with inflow waters poor in sodium, rich in calcium and with a Mg/K ratio (brine average = 8.35) higher than the value found in the present day seawater of the Gulf of Manfredonia (average = 5.32). The stratigraphical change of gypsum composition suggests a progressive decreasing of the freshwater contribution, and this trend could reflect a condition of persistent aridity.

The gypsum deposition is evidence of an arid or semi-arid climate (Watson, 1988). Moreover, the sus-

¹ The terminology of biocoenoses and zone adopted is that proposed by Pérès and Picard (1964), Picard (1965), Pérès (1967).

ceptibility to dissolution when the climate becomes wetter, limits gypsum preservation to the regions where aridity has lasted quite long (Watson, 1989) or where the deposit has been quickly sealed by impermeable sediments.

The evaporite structures are forming in North Africa and in the Middle East, where the annual rainfall is less than 250 mm (Watson, 1985). The only exception is known in Rajasthan (mean annual rainfall up to 300 mm). This can be explained by the hot temperatures which maintain potential evaporation levels above precipitation levels throughout the year (Watson, 1985²).

In the Tavoliere plain, confined by higher land on three sides, the present climatic conditions tend to be a semiarid continental type, maximized in the central part and coastal zone of the plain (Battista et al., 1993). Yet there have been periods, even recently, for instance between 1935 and 1942, with an average of annual rainfall of only 383 mm (Bissanti, 1967), that is a value approximating those of arid zones. This value has been registered at the pluviometric station of Zappone, only operating between 1935 and 1942. In general, this area includes with BS, a dry climate of a semiarid type (according to Köppen Climatic Classification, 1923), or DdB'd (Thorthwaite & Mather, 1957) a semiarid climate type steppe with a rainfall deficient in all seasons, belonging to the third mesothermal, characterised by a summer concentration of thermal efficiency and potential evapotranspiration between 855 and 997 mm (Caldara & Pennetta, 1993); mean annual evaporation reaches levels of about 2300 mm in Margherita di Savoia (Caldara et al., 1993).

7 ARCHAEOLOGICAL AND CHRONOLOGICAL DATA

During the Neolithic Age, the Tavoliere was the site of villages (Fig. 2) having concentric ditches³. More than 1200 ditched settlements have been identified in the Tavoliere (Odetti, 1975). Some of them had been inhabited since the 6th millennium BC uncal., particularly those on the coastal plain.

From the early Neolithic there is evidence of the presence of a wide lagoon there (Caldara & Pennetta, 1996). In fact, in the sites near the lagoon an economy based largely on brackish molluscs gathering, i.e. *Cerastoderma glaucum*, was practised (Deith, 1988), and a specialised flint industry developed especially for dealing with these shellfish (i.e. *Coppa Navigata* site, Puglisi, 1955, Ronchitelli 1988; *Mass. Candelaro*

site, Cassano, 1988). These shells were also used to decorate the local peculiar pottery, particularly widespread in the Tavoliere area, known as Cardial Impressed Ware⁴ (Manfredini and Cassano, 1988). During the middle Neolithic the Impressed Ware were at first in association with painted pottery and then replaced by them (Tinè & Simone, 1984). While the presence of Cardial Impressed Ware is consistent with the existence of a lagoon, their disappearance might not be due to the extinction of the lagoon but to the introduction of new pottery techniques. Levels with Impressed Ware are dated between 7600 ± 100 BP uncal (*Santa Tecchia* site, Belluomini & Delitala, 1983; the calibrated date range is of 1σ 6555 (6441) 6262 cal BC, Skeates, 1994) and 6490 ± 150 BP uncal (*Masseria Fontanarosa Uliveto* site, Whitehouse, 1988; the calibrated date range is of 1σ 5550 (5472,5440,5423) 5245 cal BC, Skeates, 1994). However, there are two other older dates for levels with Impressed Ware at *Coppa Navigata*, respectively: 8150 ± ? BP, made on shell of *Cerastoderma* (Tongiorgi et al., 1959); and 7780 ± 320 BP (Ambers et al., 1989), 1σ 7038 (6550) 6233 cal BC, although both are considered unreliable by some Authors (i.e. Whitehouse, 1994).

Between the 5th and the first half of the 4th millennium BC uncal., the Neolithic culture reached its greatest development, above all along the coastal plain. In fact, during the early and middle Neolithic the agricultural methods had improved and reached advanced techniques with the cultivation of selected species, among them: *Triticum aestivum*, *T. compactum* and *T. spelta* (Tinè & Simone, 1984). Furthermore, stock-breeding was widespread, represented by both goat-sheep and numerous cattle (Castelletti et al., 1987).

However, during the late Neolithic, stock-breeding and especially sheep-breeding, predominated over agriculture. From the last half of the 4th millennium BC uncal. numerous settlements were abandoned (Gravina 1988) and the ditches were progressively filled (i.e. *Scaramella di S. Vito*, Geniola, 1980). From this period on, the relationship between the Neolithic populations and the lagoonal area was not clear any longer.

Rare archaeological finds have been found in the agricultural trench at IOT; the stratigraphic position is unclear, perhaps they come from the superficial sands. Such remnants are fragments, partially abraded, of rough paste pottery referring to a generic Metal Age, probably Eneolithic or Bronze Age.

The absence of Neolithic industry over the studied area could indicate the existence of the lagoon at those times and, in contrast, the Metal Age materials could suggest that the lagoon was dry and transformed into a coastal plain.

The considerations so far have certainly allowed for the historical reconstruction of the neolithic coastal plain with its lagoon-sabhka. Although the presence of the lagoon is chronologically well documented, a reli-

² An annotated, regional bibliography is available from this Author, this is integrated with factors controlling gypsum deposition

³ At present the significance of the ditches is not well known. The hypothesis advanced on the meaning of the external ditches are numerous: they are used as defensive works, as enclosures for the livestock, as hydraulic functions such as reclamation, drainage and for intercepting ground-water (Simone, 1980), and so on. Probably the most truthful hypothesis is that they were used for more than one of these purposes. Certainly the principal function of the coastal plain ditches must be the flowing of meteoric waters and draining of the phreatic water.

⁴ The species of *Cerastoderma glaucum* Poirer for a long time was retained at subspecies rank of *Cardium edule* Linneo, hence "Cardial" ware which is otherwise not explained.

able chronology of its evolution to the sabhka is lacking, owing to the difficulties involved in determining the age of gypsum.

The only possibility is given by the dating of carbonate remains included in the gypsum crystals from the agricultural trench of the IOT. The choice fell on a shell of *Cerastoderma glaucum* (sample IOT 1) to be sure that, once the additional surficial material which may have been altered had been removed, the remaining carbonate material used for dating was of sufficient quantity and fresh. Nevertheless, the cleaned shell yielded very little carbon and analysis by accelerator mass spectrometry (AMS) was required. The sample, submitted to Geochron Laboratories, Cambridge Massachusetts (Lab. no. GX-24885-AMS), yielded a conventional radiocarbon age of $5,470 \pm 40$ yr BP (^{13}C corrected)⁵.

In order to convert conventional radiocarbon age into calibrated years the version 4.0 of the CALIB computer programme of Stuiver & Reimer (1993) was used, and it was run using MARINE98.14C calibration file (Stuiver *et al.*, 1998). The results obtained respectively are: 1σ 3946 (3920) 3881 and 2σ 3969 (3920) 3786 yr cal BC.

The age of included artefacts and radiometrically datable substances may not be representative of the gypsum age. Nevertheless, the desert roses cannot be older than this date and, therefore, they must be of late Neolithic age or more recent.

This date is congruent with the so-called "cult of the waters" in the Scaloria Cave (Tinè, 1991), a big complex of caves at the foot of the calcareous relief of the Gargano Promontory near Manfredonia, occupied from beginning of the Paleolithic age. The caves contain many vases placed under the stalactites to select the water from karst spring seepage. This is to say that the symbolic/ritual explanations of the "cult of the water" (Whitehouse, 1992), confirmed also by traces of hearth observed near some vases (the calcareous-carbonaceous earthy material from hearth dated at 5480 ± 70 BP, Alessio *et al.*, 1969; the calibrated date range is of 1σ 4450 (4348) 4248 BC, Skeates, 1994),

might have been related to a water shortage (Tinè, 1991).

8 DISCUSSION

The evolution of the Salpi lagoon during prehistory is similar to that of various marginal-marine settings in arid zones of north Africa.

Particularly, in Tunisia, the sabhka of El Melah near Zarzis has been studied (Perthuisot *et al.*, 1972), which shows many similarities with ours. They are both coastal sabhka developed by "paléolagune comblées" (Perthuisot, 1974) due to the Flandrian sea-level rise.

In the case of El Melah, the last lagoonal faunas give the ^{14}C reading of 5.160 ± 110 BP uncal., while the first evaporitic deposits, showing the change from lagoon to sabhka, are dated at 5.330 ± 170 BP uncal. (Fontes & Perthuisot, 1971). In the Tavoliere di Puglia the presence of a lagoon is testified by brackish molluscs such as *Cerastoderma glaucum* beginning perhaps from $8150 \pm ?$ BP, but certainly at least from 7600 ± 100 BP and until $5,470 \pm 40$ yr BP. The change from lagoon into sabhka, with the first gypsum deposits, should be contemporary or subsequent to the earliest date.

Other analogies are evident with the Holocene deposits from Wadi el Akarit (southern Tunisia). In this area the stagnation episode (between 8700 ± 200 and 5995 ± 500 BP, Fontes *et al.*, 1983), with rich malacofauna dominated by *Cerastoderma*, then *Melania* and at least *Hydrobia* (Rognon *et al.*, 1983), indicates a humid Holocene phase. This is followed by an aeolian gypsum crust underlying aeolian sands with terrestrial gastropods (*Helix* dates at 3600 ± 40 BP Fontes *et al.*, 1983), that indicate a re-established arid condition. Thus, the beginning of this climatic worsening is registered between about 6000 BP and 3600 ± 40 BP.

Moreover, the presence of the "microcrystalline nodules" in the Salpi sabhka matches a comparable feature of partly vegetated sabhkhas, nebkhas, situated

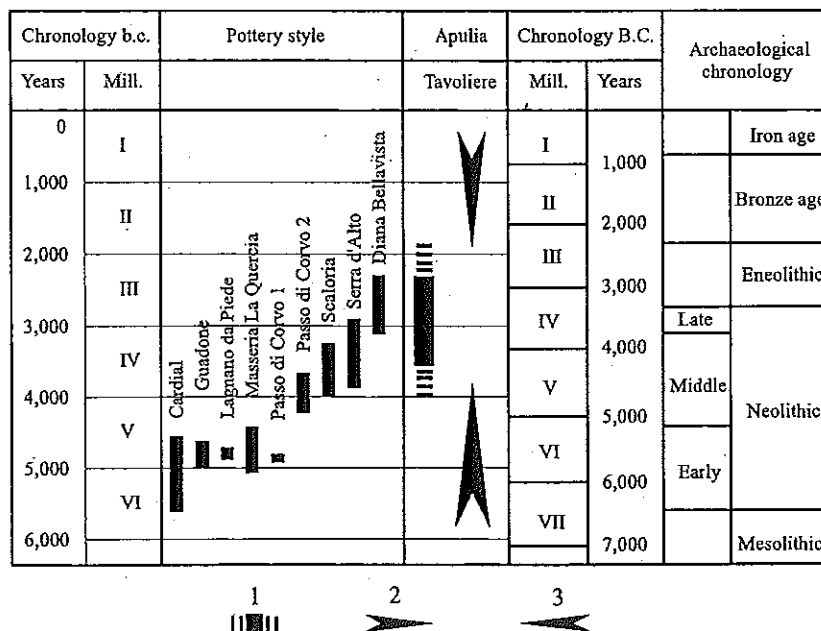


Fig. 5 - Correlation among conventional (bc) and calibrated (BC) ^{14}C chronologies, pottery typology, archaeological chronology and pattern of change of the population in the Tavoliere. Key to symbols: 1 - arid phase; 2 - repopulation; 3 - decrease of the population.

Correlazioni fra cronologia convenzionale (bc) e calibrata (BC), tipologia delle ceramiche, cronologia archeologica e cambiamenti nelle popolazioni nel Tavoliere di Puglia. Legenda dei simboli: 1 - fase arida; 2 - ripopolamento; 3 - diminuzione della popolazione

in the west of Alexandria on the semiarid Mediterranean coast of Egypt (Ali & West, 1983), where nodules of this type are crystallizing.

The gypsum deposition in the Tavoliere di Puglia suggests an arid or semi-arid climate. The proof of this aridification and duration is given by the analyses of the people and culture of the coastal Tavoliere sites. The late Neolithic records a technological and socio-economic involution, as pointed out by the skilled permanent farmer who changed into a nomadic shepherd. Some Authors (i.e. Tinè, 1975; Delano Smith, 1978) have already suggested that this involution may be due to the establishment of arid climatic conditions.

On the other hand, the Tavoliere archeological sites are rich in pottery association between the Guadone Ware and *Passo di Corvo 2* Ware, while pottery from late Serra d'Alto Ware and late Scaloria Ware to that of a Diana one is extremely rare or completely absent. This fact indicates that the settlements were progressively abandoned between the end of the 4th millennium BC., through almost all the 3rd millennium BC, uncal. It is possible that the populations migrated progressively towards the hilly areas, which offered better climatic conditions. Therefore, the abandonment of the Tavoliere settlements coincided with the beginning of the Scaloria Cave cult of the waters (5480 ± 70 BP) found on the Gargano mountain (Fig. 5).

The end of the most arid phase is marked by the gradual repopulation of the settlements, starting from the Bronze Age. The earliest known Bronze Age occupation of the Tavoliere plain is that of the *Coppa Navigata* site, dated at 3540 ± 60 BP and 3520 ± 70 BP uncal., measured on charred annual vegetation (Calderoni et al., 1994).

9 CONCLUSIONS

During the Versilian sea-level rise in the Manfredonia Gulf a lagoon, characterised by a *Cerastoderma glaucum* and *Pirenella conica* fauna, developed.

In the early and middle Neolithic Age the lagoon reached its highest level in coincidence with the development of numerous village settlements, whose subsistence economy was, also, based on brackish molluscs gathering with a relatively specialised flint industry, and on mixed farming, both agriculture and stock breeding.

During the late Neolithic Age both a technological and socio-economic involution with the change of the permanent farmer into nomadic shepherd, and an abandonment of the settlements of the coastal plain with relative migration towards the hilly areas take place. In this period the lagoon becomes a marginal marine saline pan type sabkha with distinct subenvironments, among these two principal palaeoenvironments are recognized. The former is the dry saline pan with "blocky prisms" and "blocky hemipyramids", grown in polygonal cracks or in intergranular voids due to vadose diagenetic growth of gypsum. The latter is the sandy dune-beach ridge of IOT with "discoidal hemipyramids", referred to clusters of large crystals both single rosettes and "desert roses" due to phreatic water rich in sodium because of the nearness of the sea. Moreover, the presence of "microcrystalline nodules" (MM₆), typical of sabkhas partially vegetated with

nebkhas, indicates an area where the capillary fringe intersects the ground surface, where the surface is usually within 1.5 m of the water table.

All this data indicates an arid phase between the late Neolithic (last half of the 4th mill. BC uncal.) and the Bronze Age (end of early half of 2nd mill. BC uncal., Caldara et al. 1999) when some previously abandoned settlements (i.e. Coppà Navigata site) are repopulated (Fig. 5); in any case Bronze Age occupation of the Tavoliere was nothing like as dense as the Neolithic.

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