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SEDIMENTOLOGICAL AND MORPHOLOGICAL EVOLUTION OF THE CRATI RIVER DELTA (CALABRIA, ITALY)

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The Crati River is the main river in Calabria. Its lower part runs through the plain of Sibari, and flows into the Ionian Sea where it builds a cusped delta. Features and evolution of the emerged delta are inferred, over the last 3000 years, from historic and archaeological data going back to the foundation of Sibari. Infilled lagoons and beach-ridges mark the delta progradation.

Medium-coarse sand forms the beaches, medium-fine one develops the dunes, while sandy mud dominates the inner areas as the product of repeated floods. Mud prevails in the palaeochannels. Sandy and gravelly bodies packed in pelitic sediments showing depositional regression make the Pleistocene-Holocene sedimentary facies sequence. Delta front and upper prodelta are not well developed. A part of sediments bypasses and feeds the deep-sea basin through canyons headed near the river mouth.

KEY WORDS: Delta, Postglacial evolution, Crati River, Italy.

GENERAL OUTLINES

The Crati River, with its length of nearly 90 km and a drainage basin covering about 2,500 km², is the major stream of Calabria. It drains mainly the Sila massif (to the East and to the South), the Catena Costiera Tirrenica (to the West) and, through the Coscile River its most important tributary, the Pollino massif (to the North). The final stretch of its course winds through the Sibari plain where the present Crati delta develops (fig. 1).

The fluvial regime of the Crati River is one of the typical streams of southern Italy and reflects the pluviometric regime of Mediterranean climates. Average monthly discharges, during January and February, exceed 50 m³/s and are below 10 m³/s during summer (July). The average monthly value of the suspended load ranges from 0.37 kg/m³ (June) to 2.10 kg/m³ (October); however this value is very changeable with peaks exceeding 30 kg/m³ (recorded during the June-October period) originating hyperpychnal flows at the mouth.

The drainage basin of the Crati River is placed in the northern end of the Calabrian Arc where the subduction of the Ionian Sea bottom takes place; its evolution is highly controlled by several phases of tectonic tectonics and by strike-slip faults developed mainly during Pliocene, but still active (Tortorici, 1980; Lanzafame & Tortorici, 1980).

Both the Sibari Plain and the facing basin are highly affected by transcurrent tectonic lines E-W and NW-SE oriented. Moreover, the plain is also subject to a general subsidence with average rates, calculated for the last 2,700 years, being close to 3.0 mm/yr, but locally touching even 4.4 mm/yr. The subsidence is partly ascribed to tectonics of this area and partly to the load of recent sediments (Guerricchio & Ronconi, 1997). Materials, products of the erosion of crystalline and partly ophiolitic rocks of the Sila massif, characterize the composition of the Crati River sediments, which only subordinately are formed by carbonate rocks coming from the Pollino massif. Sediments of the Crati River are the most important components of the Sibari Plain which developed mainly during Pleistocene; today these sediments are partly distributed by the littoral drift along the coast (Bellotti & *alii*, in press) and partly forwarded to the deep basin facing the river mouth (Ricci Lucchi & *alii*, 1984) by density currents originating when the solid river load reaches values giving rise at the mouth to hyperpychnal flows.

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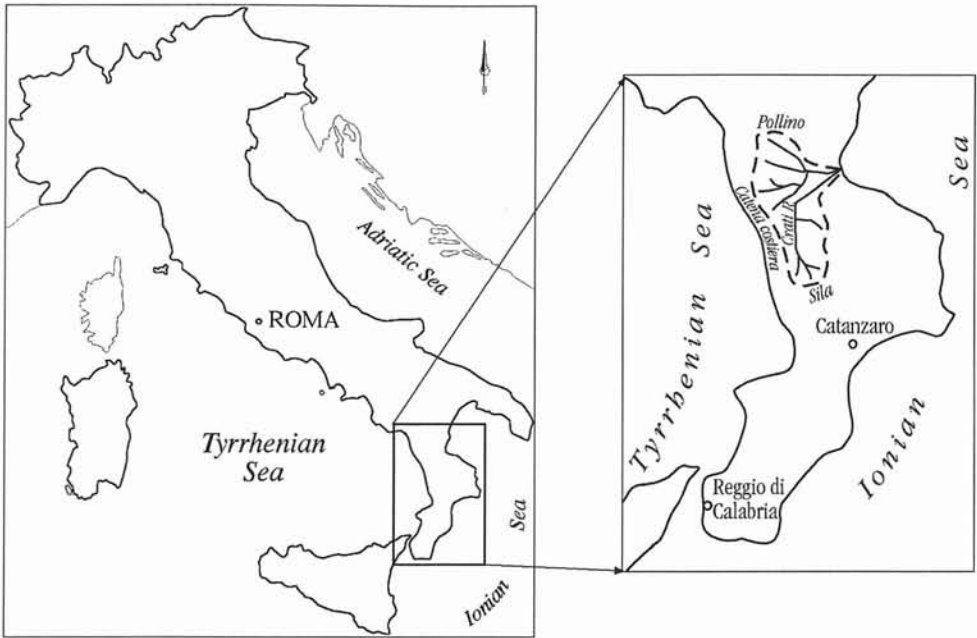


FIG. 1 - Location of the studied area.

FEATURES OF THE SUBSOIL ARCHITECTURE

Data of twenty wells have been analysed. Ten of these wells are already described in literature, while data of the others have been placed at our disposal by the Ufficio del Genio Civile (Bureau of Civil Engineers Corps) of Cosenza. Grain size characters of sediments, faunal composition

and some absolute chronological dating (^{14}C) at present allow a partial reconstruction of the stratigraphic setting.

Six depositional elements have been recognized; their vertical relations are shown in the five logs of fig. 2, which show the schematic stratigraphy of as many situations recognizable in the studied area. The recognized depositional elements are listed below.

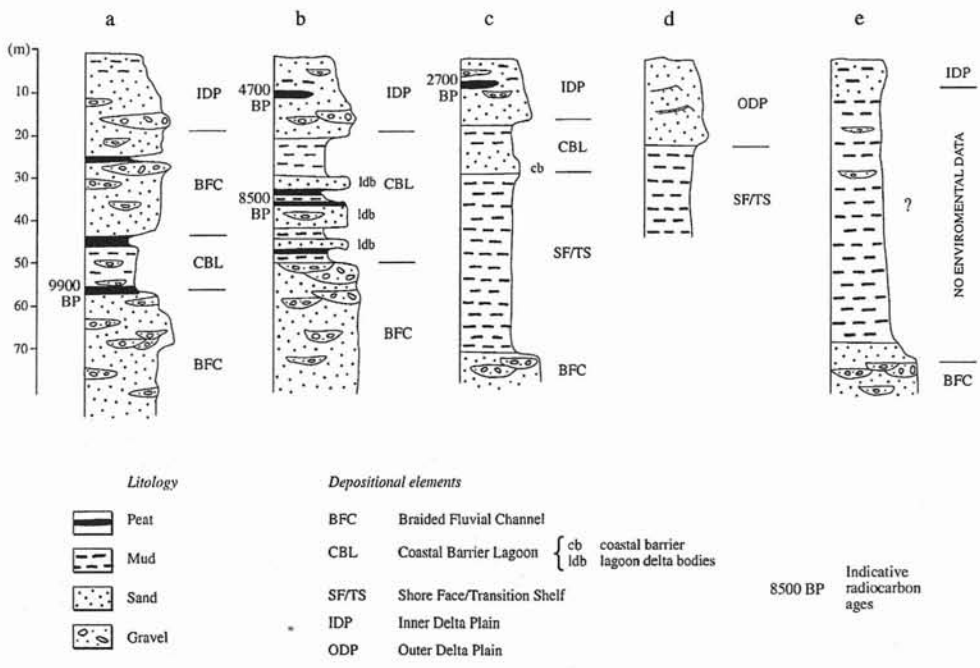


FIG. 2 - Logs schematise the stratigraphic sequence recognized in different parts of the studied area. Log a) Torre Cimino; log b) Strombi; log c) Casa Bianca; log d) Laghi di Sibari; log e) Sibari. For place names see fig. 3. The lack of subsoil sediments in the Sibari area does not allow ascribing the mud facies of log e to any depositional element.

Braided Fluvial Channels (BFC)

These are made up by sands alternating with beds and lenses of gravel changing in thickness. Polygenic pebbles exceeding even 10 cm in size form gravels, often holding water under pressure. No fauna is present in BFC. This depositional element is present everywhere at least at -70 m below the field surface and is believed to have deposited in the upper part of Pleistocene. In the southern area (Torre Cimino, log a) this element is ascribed to the lower Holocene and braided river systems are believed to have deposited these sediments.

Coastal Barrier Lagoon (CBL)

Mud deposits, with brackish fauna interbedded with large peat beds and local sand and subordinate gravel beds, characterize this depositional element. It occurs with different thickness in most part of the study area between -60 and -20 m below the field surface. Radiocarbon ages recorded for some peat beds evidence that these sediments have been deposited mainly from 10,000 to 6,000 B.P. (Guerricchio & Melidoro, 1975; Cherubini & alii, 1994). Sandy-gravelly interbeddings present in the «Stombi» area (log b) are considered to be local lagoon braided delta lobes. Sand levels with littoral fauna recognizable in the «Casa Bianca» area (log c) are ascribed to a coastal barrier body.

Shoreface/Transition Shelf (SF/TS)

This is a marine mud with infra- and circalittoral fauna. It is underlying to or heterotopical with CBL and it may also be found in the easternmost parts of the studied area (log c and d).

Inner Delta Plain (IDP)

It develops in most part of the area at the top of the succession and it is characterized by muddy sand, occasionally with vegetal remains, interbedded with beds and lenses of polygenic gravels with pebbles of some centimetres in diameter. Especially in the easternmost parts peat levels, as well as mud levels rich in brackish fauna, are present. These deposits closing the CBL at its top are ascribed mainly to alluvial facies and locally to coastal ponds. They are particularly muddy in the Sibari area (log e) and they are considered to have emplaced during the past 6,000 years starting from the innermost areas.

Outer Delta Plain (ODP)

Rarely gravelly sands with littoral fauna mainly make it up and it is recognized in the area close to the sea at the top of the succession (log d). The upper levels hold vegetal remains and are partially wind reworked. These deposits overlie SF/TS and landwards the IDP sediments in part cover them. They have been deposited along a coastal belt with beach- and dune ridges and they partly were very likely developed especially during the last 3,000 years.

GRAIN SIZE ANALYSIS OF THE SURFACE SEDIMENT IN THE DELTA PLAIN

Granulometric characteristics of present sediments in the delta plain have been defined by the analysis of 43 samples, which have been taken by normal boring from a depth of about 0.8 m below the plain surface in order to avoid local and fortuitous disturbances; two more samples come from the Crati River bed. On the basis of granulometric analyses, made by using a grain size laser diffractometer, the lithological classification of each sample has been made following the ternary scheme proposed by Tortora (1999). The same granulometric data have been processed by cluster analysis programmes (Davis, 1973; Full & alii, 1982; Bezdek & alii, 1984), which allowed subdividing the 45 samples into five groups, the granulometric distribution of which is shown in fig. 3. These groups are formed by:

- group (a) - coarse-medium sand with medium sorting and symmetric distribution;
- group (b) - very coarse gravelly sand with medium sorting and symmetric distribution;
- group (c) - medium sand with medium sorting and symmetric distribution;
- group (d) - medium sandy silt with very poor sorting and symmetric distribution;
- group (e) - fine silt with poor sorting and very negative asymmetric distribution.

Histograms show the average characters of each group.

Therefore it has been possible to define four areas for each of which one of these groups follows to be clearly dominant. These areas are characterized by different sedimentary processes and show a different morphology (fig. 4).

Area 1 - coincides with the emerged beach and is made up prevalently by group (a) sediments. Processes dominating in this area are longshore drift and wave action.

Area 2 - is characterized by group (c). It includes beach ridges locally wind reworked and at present no more interested by longshore drift and wave action. Man activity has locally levelled the beach ridges thus modifying the original morphology.

Areas 3 and 4 form the inner delta plain, which at present is dominated by fluvial processes, which obliterated ancient beach ridges still showing some tops. Group (d) and some local patches of gravel characterize Area 3. This area extends on the right of the Crati River and close to its left levee; this induces to believe that these sediments must be linked up mainly with the Crati River flood. Area 4, characterized by group (e) sediments, was supplied until the 18th century by the Coscile River floods, which flowed seaward along the present «Collettore gli Stombi». After the 18th century the Coscile River became a tributary of the Crati River, and area 4 persisted as a marsh over a long time.

The three samples of group (b) are located inside the Crati River bed and along the shoreline left to the mouth and they define no peculiar area.

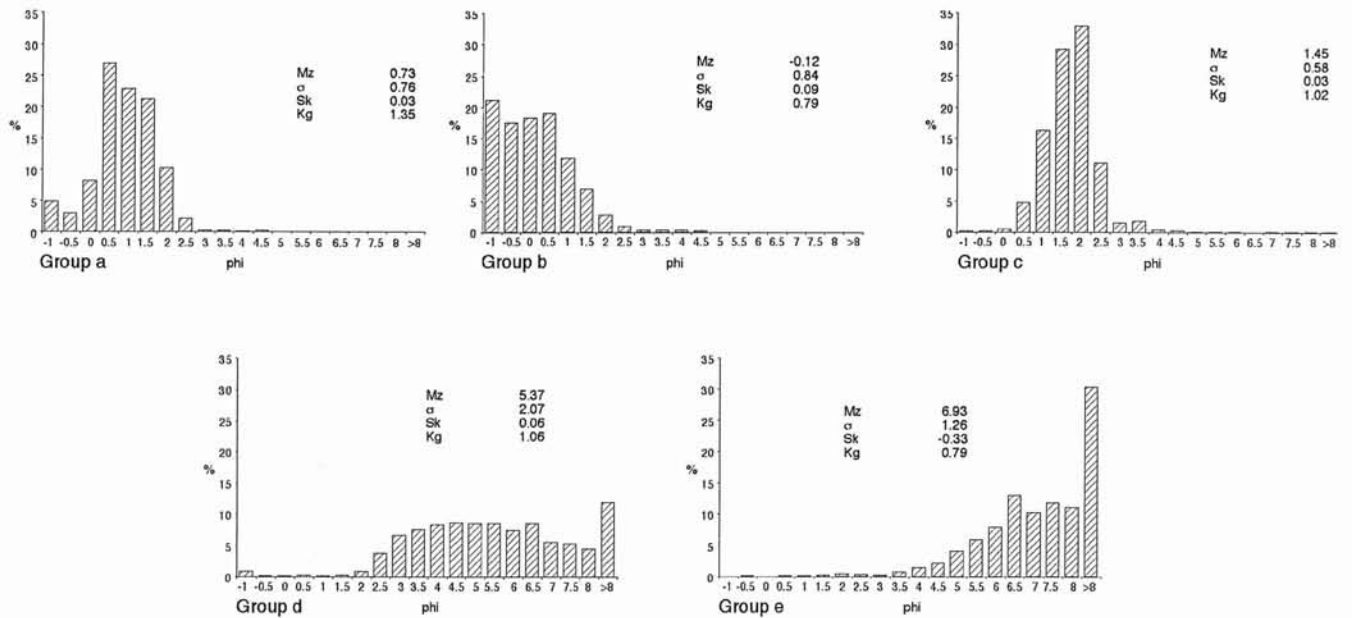


FIG. 3 - Distinctive grain size distribution of the five-grain size groups defined by cluster analysis.

FEATURES OF THE EMERGED DELTA

The Crati River plain shows features of a cusped delta, built by the filling up of coastal lagoons (bordered by ridges) and by the supply of the Coscile River as well. This plain underwent important changes not only following the

deposition of remarkable amounts of alluvium causing a progradation, but also by repeated migrations of the Crati and Coscile riverbeds inside the plain itself. So the two wings show different characteristics. Generally the right wing is higher (about 3 m) than the left one; it shows traces of paleobeds of the Crati River, which about 2,500 years

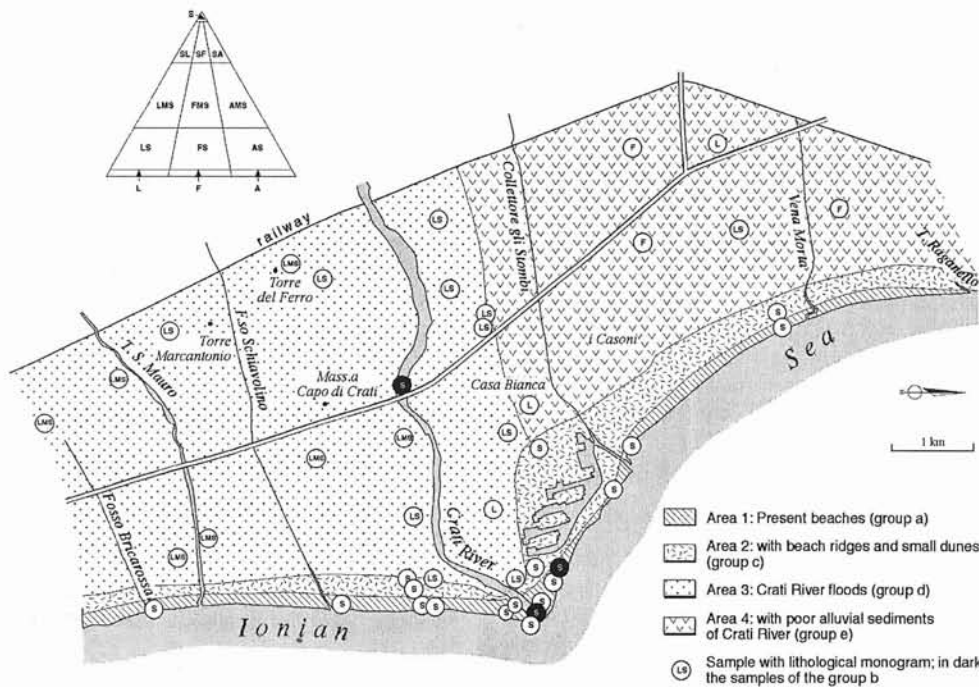


FIG. 4 - Map of areas showing good granulometric uniformity. Monograms of each sample mark lithological characteristics according to the triangular diagram of Tortora (1999).

ago flowed roughly 1.5 km more southwards than today (D'Arrigo, 1959).

Still on the right wing but more inland, owing partly to frequent migrations of the Crati River and partly to man's activity, the ridges (especially older ones) show a higher splitting up; it is possible to recognize them from topographical evidences (altitudes of about 2-3 m a.s.l.) and because they have been preserved from agriculture levelling as old farmhouse ruins, still persisting on their tops, demonstrate (C. Amantea, C. Ogliastro; fig. 5).

Only along the coastal belt these ridges are developed longitudinally and not much spaced. Their altitudes, like the oldest ones, attain 2-3 m a.s.l. and at present they still show their integrity and are well preserved, also because of the thick man-planted vegetation.

On the left wing ancient and present ridges show a better longitudinal development than those on the right wing, and they are higher and more spaced one from the other. The oldest ones (1,500 B.C. - 700 B.C; according to Guerichio & Ronconi, 1997) still show good topographic evidence allowing to follow how they develop, especially the one closing the Sibari paleolagoon (I Casoni). This lagoon was active in Roman imperial times (3rd century A.D.). More evident are the recent most beach ridges, which heights range from 3 to 2 m and show wet areas in the back-ridge zone. Moreover several more inland placed morphological evidence bears witness to the ancient riverbed and the flood plain of the Coscile River.

The Coscile River had a mouth separated from that of the Crati River and entered directly into the Sibari lagoon, gradually filling it up. During the past 2,000 years, the Coscile River course underwent continual deviations, still be-

ing separate from the Crati River and entering directly into the sea. Only during the 19th century (D'Arrigo, 1959) it was forced to inflow the Crati River with the trial of reclamation of the left wing, which is more depressed and wetter than the right one up to now. The old Coscile riverbed has been used for draining backwaters of the wet areas and at present it coincides with the «Collettore gli Stombi». The lagoon, placed just close to the sea and to the present mouth of the Crati River, has been modified into a marina in recent times.

RECENT SHORELINE CHANGES

During the roughly hundred years past, the delta cusp records an active dynamics with migration of the river mouth for about 1 km southeastwards and a clockwise rotation (about 30°) of the delta apex. This implied an erosion, occurred between 1872 and 1990, averaging 350,000 m² for an 11 km long shore (about 32,000 m²/km; fig. 6).

More in detail, during the 1872-1954 period, the most important shoreline retreat has been recorded especially along the right wing between Torrente S. Mauro and the Crati River delta: to a maximum linear retreat evaluated in 350 m corresponds an areal loss of about 1 km². On the contrary, during the 1954-1978 period, a widespread progradation took place (about 400,000 m²), which at least in part brought to an areal reconstruction of beaches as ante-1872. The shoreline of the left wing may be considered in equilibrium throughout the 1872-1978 period. During the

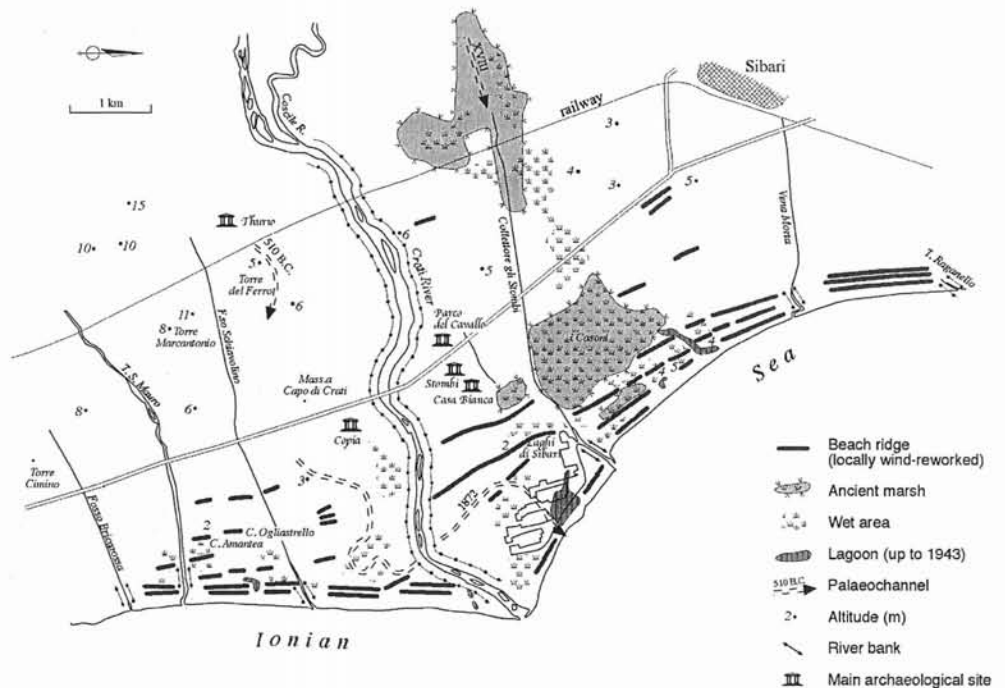


FIG. 5 - Geomorphological outline of the Crati River emerged delta.

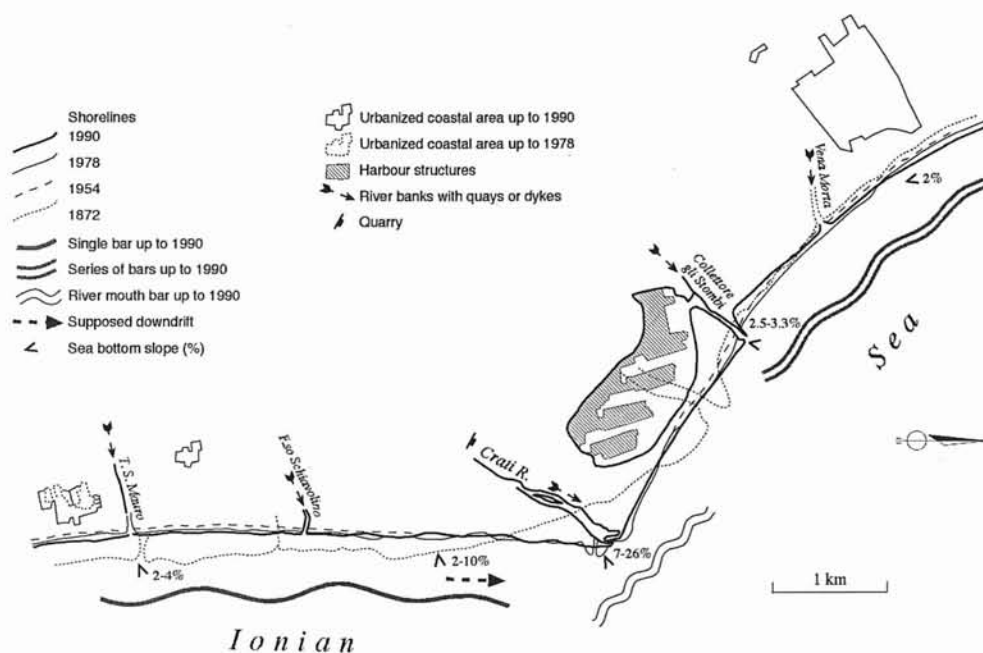


FIG. 6 - Recent evolution of the Crati River delta shoreline and morphological features of the floor as far as the -30 m depth contour.

last ten-years span, the more widespread urbanization for tourism on the left wing and the building of the Sibari marina, without any doubt helped the erosion to start. Up to now the erosion occurred only along the left wing, while on the right one the coastal belt is still in its natural state and so less vulnerable.

FEATURES OF THE SEA-FLOOR

Bathimetric surveys made in September 2001 by echometric profiles perpendicular and parallel to the shoreline and by direct observation made by divers, allowed to single out the main morphologic features of sea floors between 0 and -30 m in depth. It is clear that the bottoms are sloping differently in the northern and southern parts of the Crati River mouth area. In the northern area, close to the mouth of the «Collettole gli Stombi», the slope is of about 2.5% up to a depth of -20 m and of 3.3% between -20 and -30 m. More to the north the slope is steadily about 2.0%. For the southern area the slope is close to 2.2% as deep as -12/-14 m, while at higher depths it ranges from 10.0% (close to the apical area of the delta) to 4.0% (close to the Torrente S. Mauro mouth). The area adjacent the Crati River mouth records the highest slope gradient close to 7.0% between 0 and -6 m and to 26.0% between -6 and -30 m. In this area, between -8 and -10 m, heads of canyons feeding the Crati River submarine fan start (Ricci Lucchi & alii, 1984).

Along both wings, at a distance ranging from 30 to 100 m off the shoreline, discontinuous submerged longshore sandy bars originate periodically; on the contrary no submerged mouth river bars have been recognized.

HISTORICAL BACKGROUND

Sibari (the ancient *Sybaris*) was founded by the Achaei about the half of the 8th century B.C. It started as a small agricultural and trade centre, quite soon becoming after Taranto the richest and most important colony of the Magna Graecia. Like nearly all Greek colonies, Sybaris was placed not far away from the sea between the two rivers *Crathis* and *Sybaris* (the present Crati and Coscile rivers respectively), and where, according to Scillace (6th-5th century B.C.), an existing lagoon was used as a harbour. The famous historian Strabo (63? B.C. - 21? A.D.) described it as a town spreading out over 510 hectares and populated by 100,000 inhabitants. It had a rich agricultural activity and a widespread trade system extending through the Crati River towards the interior and reaching through its harbour the peoples of the eastern Mediterranean area, as far as Miletus in Asia Minor.

The wealth and might of Sybaris, which reached their height especially during the 6th century B.C., excited envy of *Kroton* (Crotona, at present) above all on the ground of merchant competition. So, when on 510 B.C. an insurrection was overthrowing the aristocratic government of Sybaris for setting up the tyranny, Krotonians availing themselves of the political instability current in the enemy town and following an epochal war upon it razed it to the ground. According to traditional accounts, especially supported by the historian Herodotus (484? - 425? B.C.) in his Histories (V, 45), Krotonians should have diverted the Crati River and flooded the ruins of Sybaris to bury once and for all the memory of that town.

After several attempts Sybaris was rebuilt about 444 B.C. by Athenians and named *Thurio*. Because of its stra-

tegic position and great wealth, this town continued to suffer the hostility of Lucanians and Brutii. Starting from 194 B.C. Thurio went under the rule of Rome and was renamed *Copia Thurii* (fig. 7). From the 1st century B.C. to the 3rd century A.D. the progressive filling up of the harbour, its conversion into a necropolis and the progradation of the shoreline caused the decline of *Copia*.

The whole Crati plain has been subject to anthropogenic activities from the foundation of Sybaris (about 2,700 years ago) up to the 6th century A.D., when the history of *Copia* took its end. The following filling up of lagoons caused this area to become marshy and malarial and thus an uninhabitable region. That is why the descendants of Sybarites settled down on the neighbouring hills, places which, besides being more wholesome, could surely guarantee higher defence against invaders (barbarians and Saracens).

After the reclamation of the 19th century the Crati plain has been and still is used mainly for agriculture (especially citrus plantations), while its coastal belt is the scene of a more and more increasing tourism.

FINAL REMARKS

Stratigraphic, morphological, sedimentological and historic-archaeological surveys carried out on the Crati River plain, make it possible to outline the Holocene evolution of this area. It has been driven, in a tectonically active context, mainly by the postglacial sea-level rise and by the sediment supply of the Crati River and other minor streams draining the Sila and Pollino slopes.

During the first time of the postglacial sea-level rise (Late Pleistocene) many river channels wandering through the coastal plain characterized the studied area. At this time the shoreline was 0.7-2.2 km more seaward as today (fig. 8a). Later on the area was drowned and a large lagoon originated (fig. 8b). On the ground of the considerable thickness of fluvial facies recognized in the southern part of the investigated area (fig. 2), we believe that during the sea-level rise stage the Crati River probably flowed into the sea more southward as today, while other streams debouched directly into the lagoon. At the end of the postglacial sea-level rise (5,000/6,000 years ago) the Crati River very likely started its migration toward the present position. This probably took place because of a tectonic phase having produced a slow lowering of the area more to the north. Between 3,500 and 2,700 BP the Crati River flowed about 1.5 km more to the south as today and at its left side a lagoon existed into which the Coscile River was debouching (fig. 8c). This large lagoon was well linked with the sea and has been used until the 3rd century A.D. for harbour activities of the Greek-Roman centres of *Sybaris*, *Thurio* and *Copia*. The following northward shift of the Crati River course caused the infilling of the southern part of the lagoon. On the contrary the northern part was filling up very slowly because of the poor and mainly clayey sediment supply of the Coscile River.

Latter area lasted as a very marshy and unhealthy territory until the 18th century in spite of several attempts of diverting the Coscile River course into the Crati River, but the final reclamation of this area started only during the 19th century. From the end of the 18th century the Coscile River flows into the Crati River and its ancient course

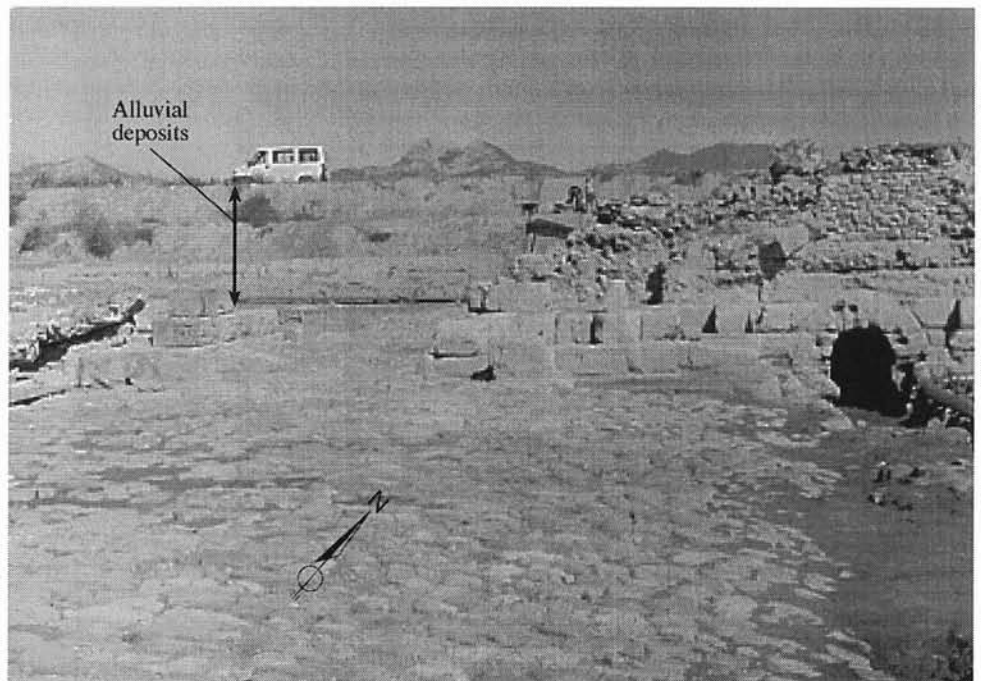


FIG. 7 - Archaeological remains of *Copia*. The alluvial deposits of the Crati River may be recognized on the background.

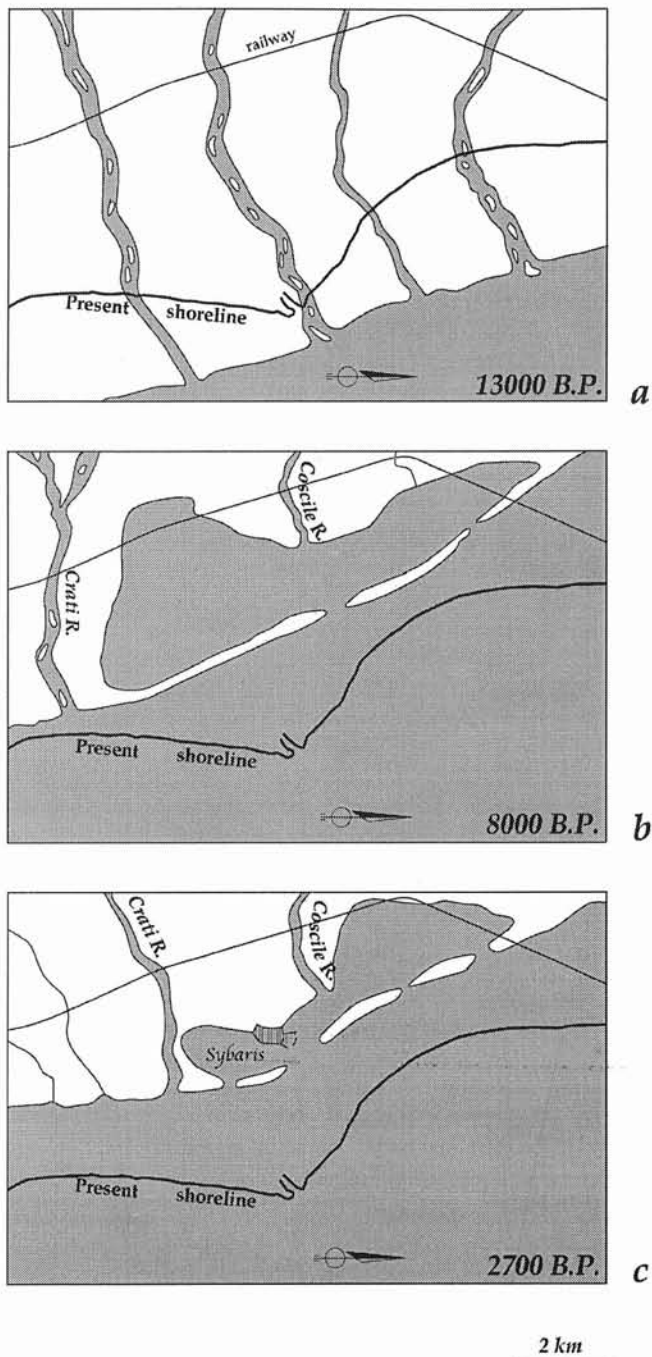


FIG. 8 - Sceneries referring to a period ranging from 13,000 yr B.P. and the beginning of historical times. Reconstructions are based on stratigraphic, morphological and archaeological data.

should correspond at present to the «Collettore gli Stombi», canal draining waters that still would last in the remnants of the ancient lagoon (fig. 7).

As from the stabilization of the sea level, the Crati River built up a cusped delta; it is practically symmetrical with its southern wing showing higher altitudes and coarser sediments as to the northern one. The latter does not appear to be directly fed by the Crati River except for the coastal belt reached by the Crati River sediments through the littoral drift.

REFERENCES

- BELLOTTI P., CAPUTO C., DAVOLI L., EVANGELISTA S. & PUGLIESE F. (2003) - *Preliminary results of researches on sedimentology and littoral dynamics of the Crati River Delta*. Geol. Romana, 37 (in press).
- BEZDEK J.C., EHRLICH R. & FULL W.E. (1984) - *The Fuzzy C-means clustering algorithm*. Comp. & Geosc., 10, 191-203.
- CHERUBINI C., COTECCHIA V. & PAGLIARULO R. (1994) - *Geological and geotechnical problems connected with the disappearance of the ancient city of Sybaris*. Science and Technology for Cultural Heritage, 3, 95-112.
- DAVIS J.C. (1973) - *Statistics and data analysis in Geology*. Wiley & Sons, New York, 646 pp.
- D'ARRIGO A. (1959) - *Premessa geofisica alla ricerca di Sibari*. L'Arte Tipografica, Napoli, 192 pp.
- FULL W.E., EHRLICH R. & BEZDEK J.C. (1982) - *Fuzzy Q-Model - A new approach for Linear Unmixing*. Journ. Math. Geol., 13, 331-344.
- GUERRICCHIO A. & MELIDORO G. (1975) - *Ricerche di geologia applicata all'archeologia della città di Sibari sepolta*. Geol. Appl. Idrogeol., 10, 107-112.
- GUERRICCHIO A. & RONCONI M.L. (1997) - *Osservazioni geomorfologiche nella Piana di Sibari e variazioni delle linee di costa storiche nella zona degli scavi archeologici*. I Quaderni dell'I.R.F.E.A., 1, 1-31.
- LANZAFAME G. & TORTORICI L. (1980) - *La tettonica recente della valle del Fiume Crati (Calabria)*. Geogr. Fis. Dinam. Quat., 1, 11-21.
- RICCI LUCCHI F., COLELLA A., GABBIANELLI G., ROSSI S. & NORMARK W.R. (1984) - *The Crati submarine fan, Ionian Sea*. Geo-Marine Letters, 3, 71-77.
- TORTORA P. (1999) - *Una classificazione ternaria per la descrizione del sedimento sui fondali marini*. Boll. Soc. Geol. It., 118, 65-73.
- TORTORICI L. (1980) - *Osservazioni su una sintesi neotettonica preliminare della Calabria settentrionale*. P.F. Geodinam. Pubbl., n. 356, 811-820.