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Guide for the excursion

FLUVIAL AND LITTORAL GEOMORPHOLOGY AND ECOLOGY IN THE PO DELTA

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GEOMORPHOLOGICAL EVOLUTION OF THE PO DELTA

The River Po, the largest river in Italy, is 652 km long, has a basin of 70,091 km^2 and an average annual rate of flow of 1,515 m^3/sec.

The «Po delta» is currently considered to be the peninsula comprised between the Sacca di Goro (to the south) and Porto Caleri (to the north); however, if one refers to the area occupied by the mouths of the Po during the Holocene, the term Po delta can be extended to the whole of the coastal plain comprised between the Ravenna area and the Venice lagoon. Here various successive delta structures are clearly recognisable.

In the late Bronze Age (late Sub-Boreal), for example, two large bands of the lower beds of the Po have been identified (fig. 1):

– one to the north, with mouths between the current delta and the Venice lagoon: the main watercourses were the Po di Adria and the Po di Agna, one of its branches (VEGGIANI, 1974 & CASTIGLIONI, 1978);

– one to the south, with mouths between the current delta and Ravenna: the main watercourse was the Po di Spina, but soon the Po di Volano also became important.

The largest fossil dunes visible in the area (such as the Massenzatica dunes: fig. 1 point 1) date to the end of the Sub-Boreal.

During the following 1000 years the Po di Agna and the Po di Adria were no longer active; later the Po di Spina also became extinct (8th century AD). At the end of the 1st millennium AD the most important branches were the Po di Volano and the Po di Primaro. After the 12th century AD another branch started to assume importance (and after the 14th century AD it became the most important) which coincided with the current Po Grande almost as far as the mouth. In the Renaissance this watercourse had already formed a large delta. At the end of the 16th century the Venetian engineers, convinced that its sediments would have been able to close the mouths of the Venice Lagoon, deviated the terminal tract towards the south-east.

This intervention, known as the Taglio di Porto Viro (Porto Viro Cut) was completed in 1604 and marked the beginning of the construction of the «modern delta» which continued its development until the present century. Many branches of the delta contributed to this development apart from the Po di Goro (which had already existed for centuries). The Venetians however closed all those which flowed northwards (they partially closed the Po di Maistra, which at the beginning of the 19th century was the largest), and all the other smaller branches. In this way they favoured those branches which flowed southwards, such as the Po di Gnocca and the Po di Tolle. The latter became the major branch during the past century; subsequently the Po di Pila became the most important. These interventions resulted in the development of the two peninsulas which confer a lobate form to the southern side of the current Po delta (fig. 2): the peninsula of the Po di Go-

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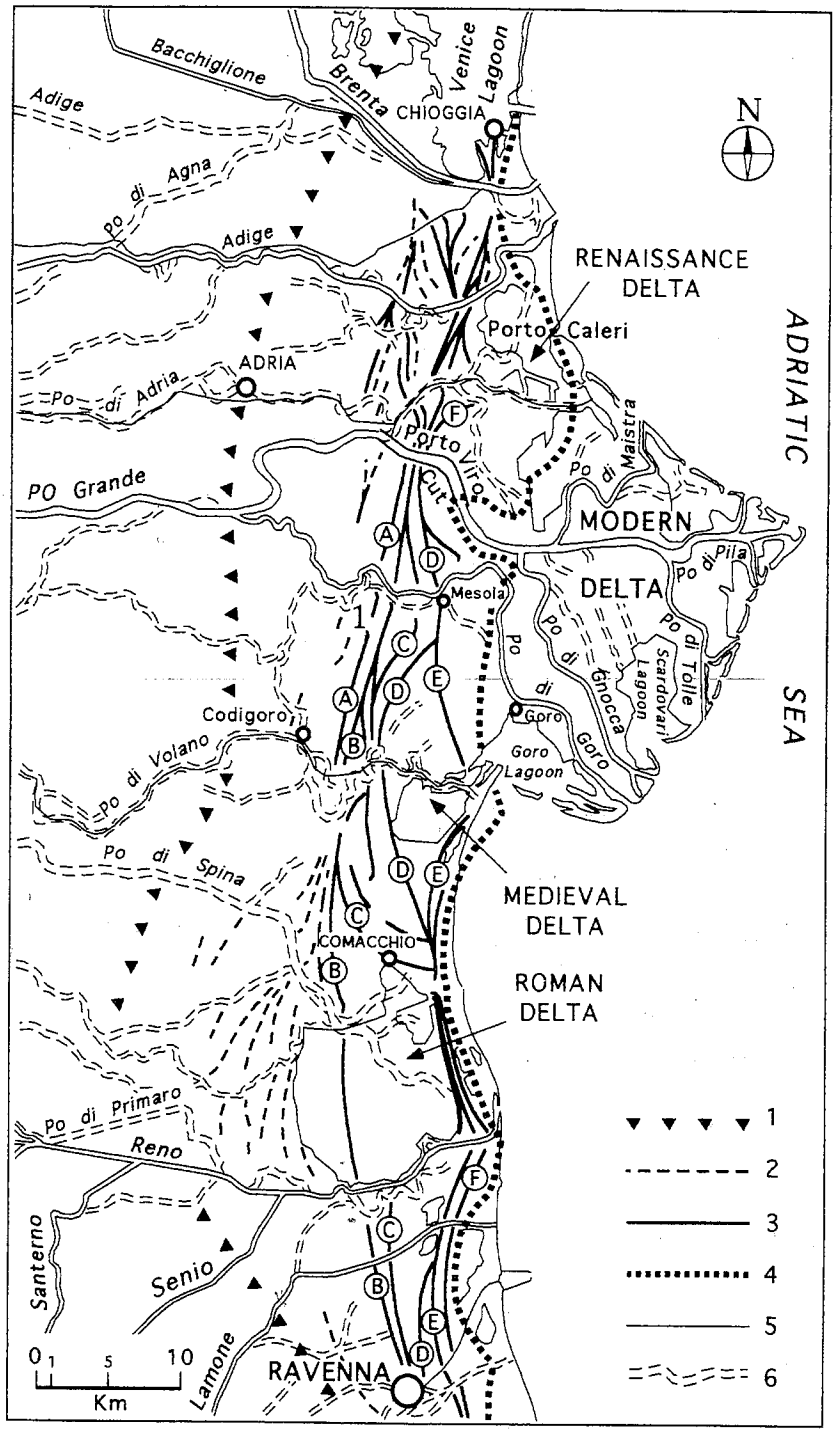

FIG. 1 - Geomorphological map of present-day and ancient mouths of the Po. 1) possible location of the coastline of the post-glacial transgression; 2) buried beach ridges; 3) outcropping beach ridges, with ages: A = Sub-Boreal Sub-Atlantic transition, B = 6th-4th century BC, C = 1st-2nd century AD, D = about 5th century AD, E = about 10th century AD; F = about 14th century AD; 4) coastline at the end of the 16th century; 5) present-day coastline; 6) main paleobeds.
After: BONDESAN & *alii*, 1989; 1990.

ro and the Po di Gnocca, which formed from 1750 onwards, and the peninsula of the Po di Tolle which started to form in 1810. These two peninsulas have enclosed two lagoons, the Sacca di Goro (Goro lagoon) and the Sacca di Scardovari (Scardovari lagoon), which in the last 100 years have become even more isolated from the sea as a result of the formation of islands and spits at their mouths.

The whole of the evolution of the eastern Po Plain has been characterised by sea and river floods. These phenomena have been the main causes of the creation of vast marshes, brackish ponds and sometimes small lagoons (the formation of lagoons is favoured by the tide, which reaches 120 cm). The majority of these wetlands were reclaimed between 1870 and 1970 by means of mechanical drainage. The remaining wetlands are today used intensively for fish farming.

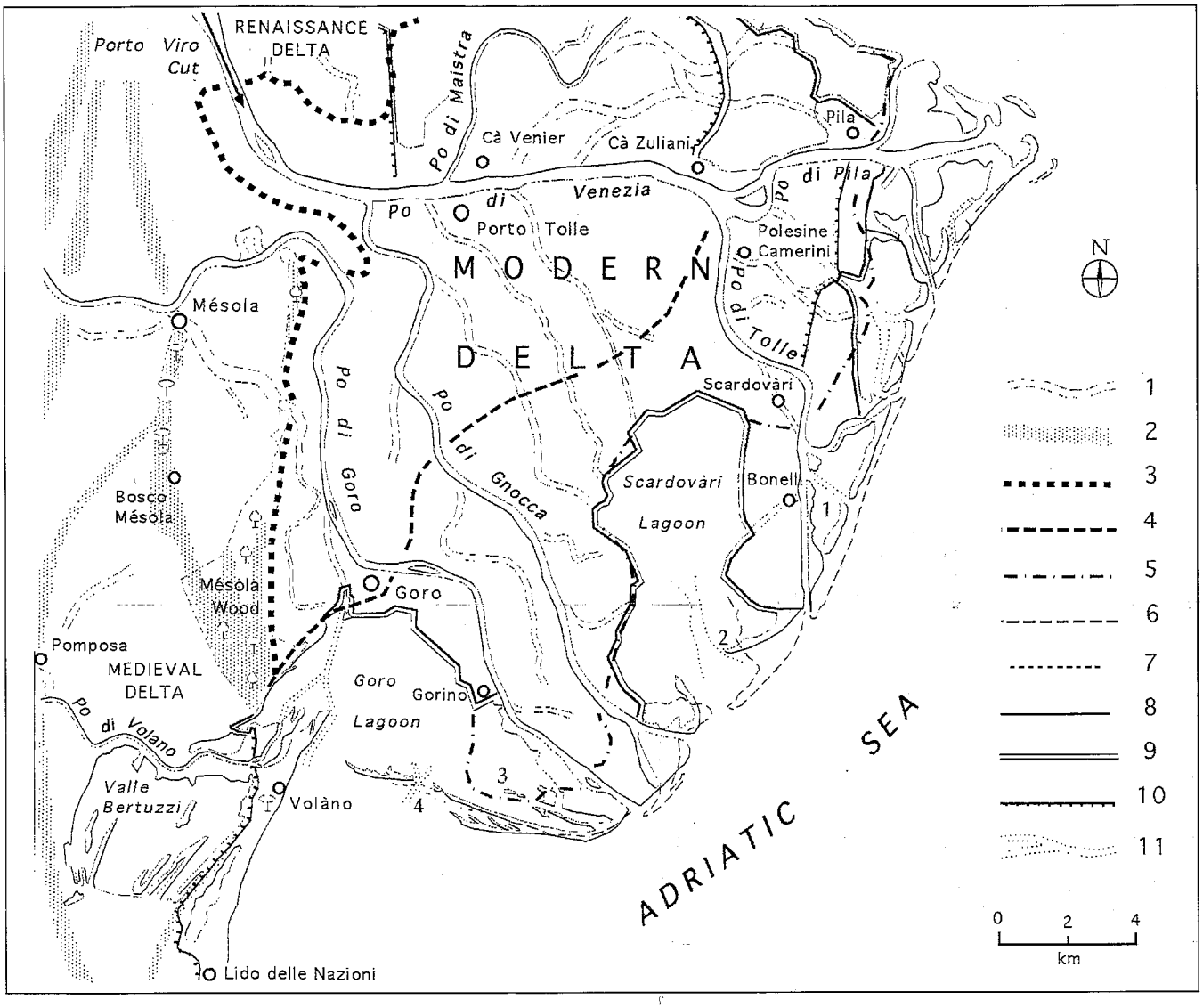

FIG. 2 - Modern Po delta: central and southern areas. 1) main paleobed; 2) paleodunes; 3) coastline at the end of the 16th cent.; 4) coastline in 1735; 5) coastline in 1835; 6) coastline in 1954; 7) coastline of the Goro spit in 1977; 8) present-day coastline; 9) sea and lagoon dams; 10) secondary embankments to protect against invasion by the sea water; 11) lagoon channels.

ENVIRONMENTAL PROBLEMS OF THE AREA

Since the Po delta and the whole of the adjacent coastal strip have been intensely exploited (agriculture, gas and water extraction, urbanisation, tourism), major environmental problems have surfaced. Some of these are of a natural origin, while others have been caused or accelerated by anthropic activity (BONDESAN, 1989). The most important of these are:

- natural subsidence (1-2 mm per year)
- rigidity of the local hydrographic network (due above all to the construction of artificial embankments along the rivers)
- artificial subsidence
- reduction in the sediment transport by the rivers
- rise in sea-level.

Artificial subsidence was provoked by the drainage carried out for reclamation (and in particular the oxidation of the peat), by the forced drainage of the watertable and, most of all, by the exploitation of methane-bearing water from the Quaternary deposits between 1938 and 1964; the latter type of subsidence can now be considered completed (fig. 3), but in recent decades in various areas subsidence has been caused by the excessive drainage of underground water for agricultural and industrial use.

The sediment transport of the river Po has decreased by 28%, which is analogous to the decrease recorded in the majority of the Italian rivers such as the Adige and the Reno. This phenomenon can only partly be attributed to works for controlling the flow of the rivers and the construction of artificial lakes; in the majority of cases it has in fact been caused by the excessive extraction of gravels and

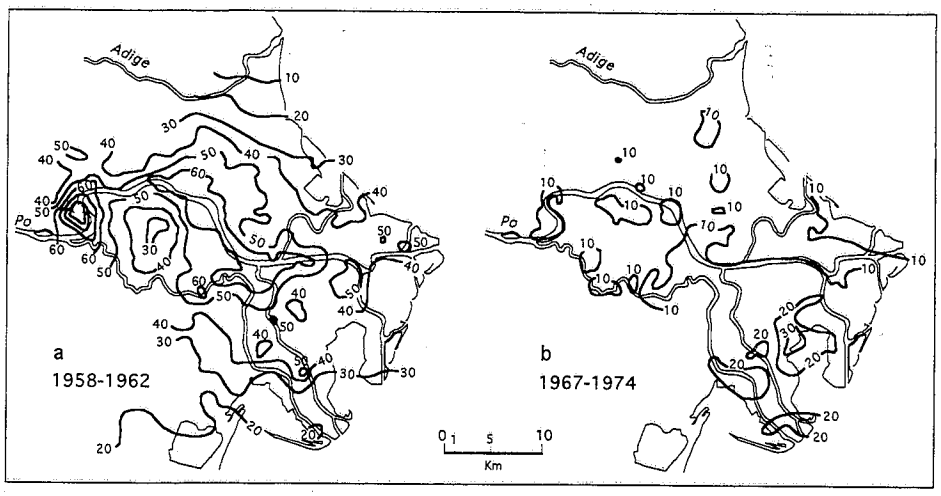

FIG. 3 - Contour lines showing land subsidence in the Po delta area (in cm) during and after methaniferous-water exploitation. After: a) CAPUTO & *alii*, 1970; b) BONDESAN & SIMEONI, 1983.

sands from the river beds which has been carried out since the Second World War (SIMEONI & BONDESAN, 1997).

The lack of new sediment supply to the plain (due to the embankments built along the rivers), the subsidence phenomena (both natural and artificial) and the drying up of deep stretches of water has resulted in the current altimetry: the majority of the area lies below sea-level and is subdivided into «polders» to prevent flooding. It has in fact been necessary to construct sea and lagoon dams and high embankments on the delta branches which flow above ground level. Along the drainage canals it has been necessary to set up various pumping stations in order to transport the water to the sea. In the area between Chioggia and Ravenna there are more than 100 pumping stations which have to be kept working almost continuously to ensure the discharge of the water, and other pumping stations have to be put into action during the months when it doesn't rain in order to irrigate. The functioning of the canals and the pumps is however compromised by the continuous subsidence of the soil.

In addition to a considerable risk from flooding, subsidence causes today, together with relative sea-level rise, other effects, such as sea-water intrusion into aquifers, particularly in the coastal strip, and movement upstream of the salt wedge in rivers (BONDESAN & *alii*, 1995).

The subsidence and the reduced sediment transport of the rivers have also caused a general retreat of the beaches; it has been necessary to protect long tracts of these with breakwaters and other structures in order to retain the sediments. At the end of the 1940s the delta had stopped growing, with the only exception of the beaches dominated by the mouths of the Po di Pila (DAL CIN, 1983). In subsequent years many marginal areas also flooded: in 1956, for example, a lagoon formed on top of cultivated land in the south-eastern part of the Po di Tolle peninsula (fig. 2 point 1). A large part of the islands and spits around the preexisting lagoons retreated. Those in front of the Scardovari lagoon were destroyed: here the current spit started to reestablish itself in 1965 (fig. 2 point 2), and its development has been encouraged by means of deliberate interventions.

The situation in the Sacca di Goro has also changed. Here, in front of the first system of spits-islands, which developed in a north-western direction between 1880 and 1930 (fig. 2 point 3) a new spit had formed, and in 1977 it was 7.8 km long. Between 1977 and 1980 the erosion crisis of the Po delta also affected this spit; it shortened for about 1 km and was protected by defensive structures (mainly Longard tubes). Between 1986 and 1991 it grew about 450 m. At the beginning of the 1990s, in order to improve the circulation of water within the lagoon and to prevent the more and more frequent phenomena of eutrophication and anoxia of the water, two openings in the spit were made illegally (fig. 2 point 4). This caused a marked change in the dynamics of the spit and, in a few years, the southern opening had transformed itself into a real lagoon mouth about 800 metres wide.

REFERENCES

BONDESAN M. (1989) - *Geomorphological hazards in the Po delta and adjacent areas.* Geogr. Fis. Dinam. Quat., Suppl. 2, 25-33.

BONDESAN M., CASTIGLIONI G.B. & ELMI C. (1990) - *Geomorphological mapping in the Po Plain (Italy), with an example in the area of Ravenna.* Zeit. Geom., Suppl. bd. 80, 35-44.

BONDESAN M., CASTIGLIONI G.B. & GASPERI G. (1989) - *Geomorphological Map of the Po Plain; progress report of the Working Group.* Mat. Dip. Geogr. Univ. Padova, 8, 1-23.

BONDESAN M. & SIMEONI U. (1983) - *Dinamica e analisi morfologica statistica dei litorali del delta del Po e alle foci dell'Adige e del Brenta.* Mem. Sc. Geol., 36, 1-48.

CAPUTO M., PIERI L. & UNGUENDOLI M. (1970) - *Geometric investigation of the subsidence in the Po Delta.* Boll. Geofis. Teor. Appl., 13 (47), 187-207.

CASTIGLIONI G.B. (1978) - *Il ramo più settentrionale del Po nell'antichità.* Atti Mem. Acc. Patav. Sc. Lett. Arti, *90*, 157-164.

DAL CIN R. (1983) - *I litorali del delta del Po e alle foci dell'Adige e del Brenta: caratteri tessiturali e dispersione dei sedimenti, cause dell'arretramento e previsioni sull'evoluzione futura.* Boll. Soc. Geol. It., 102, 9-56.

SIMEONI U. & BONDESAN M. (1997) - *The role and responsability of man in the evolution of the Italian Adriatic coast.* In: F. Briand & A. Maldonado (eds.), *Evolution des côtes méditerranéennes, 3,* Sc. Ser., Commission Internationale pour l'Exploration Scientifique de la mer Méditerranée, Bull. de l'Institut Océanographique, Monaco, 20-43.

VEGGIANI A. (1974) - *Le variazioni idrografiche del basso corso del Po negli ultimi 3000 anni.* Padusa, 1-2, 39-60.