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Geomorphological mapping of the Po Plain (Italy), with an example in the area of Ravenna

by

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with 5 figures

Summary. This work describes research under way in the preparation of a geomorphological map of the Po Plain, scale 1:250 000, by a large group of geomorphologists. The main criteria of the map are essentially a genetic classification and a classification of types of landforms. The work also presents some results obtained in the Ravenna area, in which the evolution of the plain and the coast may be reconstructed from the Flandrian and especially from the Bronze Age onwards. Subsidence interferes with sedimentation processes and drainage network variations, since the Apennine rivers and the Po itself have not only undergone diversions in their courses, but their sediment transport has also been considerably reduced under the influence of both natural and human factors.

Résumé. On donne information sur un travail en cours, la préparation d'une carte géomorphologique de la plaine du Pô à l'echelle de 1:250 000, par un groupe de plusieurs chercheurs. En principe, il s'agit d'une carte de classification des formes selon leur genèse et leur typologie.

On présente les résultats obtenus dans le secteur de Ravenna, où l'évolution de la plaine et de la côte peut être suivie dès le Flandrien, et surtout dès l'âge du Bronze. On souligne les interférences entre la subsidence, l'accumulation de sédiments, les variations des rivières venants de l'Apennin et même du Pô, qui ont non seulement changé leurs tracés, mais aussi leur charge pendant les siècles sous l'influence des facteurs naturels et anthropiques.

1 *Introduction*

In the 1980s increasing interest was shown in Italy in the study of plains from the viewpoints of both geomorphology and applied geology, and many study centres already operating collaborated on more complete and in-depth studies. One stimulus also came from the Working Group on Geomorphology of River and Coastal Plains of the International Geographical Union (chaired by J. ten Cate (1980–87) and M. Oya (1987–88)). The reasons for both scientific and practical interest in the geo-ecological study of plains are also related to their high degree of human occupance and utilisation, which is currently increasing.

Italian geomorphologists are grouped into several projects, one of which has already produced important results on the study of minor plains in the Italian peninsula and islands (Federici 1987). Another project, described here, aims at short-term completion of a geomorphological map of the Po Plain on a 1:250 000 scale, which – it is hoped – will be published in two large-format sheets for the entire region. About 35 researchers are working on this project, grouped into ten research units belonging to universities and other scientific

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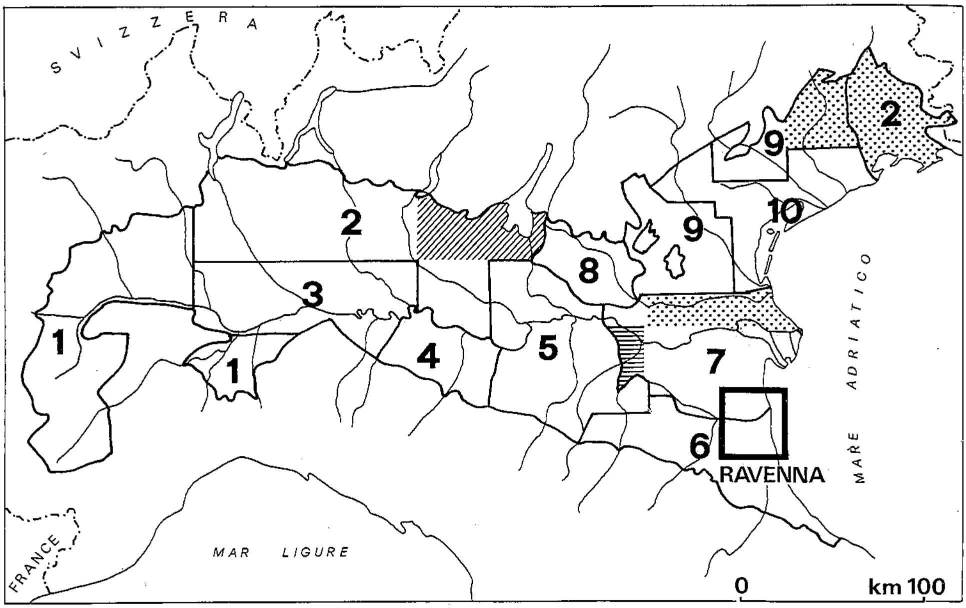

Fig.1. The Po Plain. Index map: research units taking part in the geomorphological mapping.
1. Torino, headed by A. Biancotti (Dipartimento di Scienze della Terra, Università) and by G. C. Cortemiglia (Dipartimento di Scienze della Terra, Università di Genova).
2. Milano, headed by G. Orombelli (Dipartimento di Scienze della Terra, Università); dotted area: cooperation with Universities of Trieste (G. Vaia, P. Marocco) and Udine (P. Paronuzzi); hachure: cooperation with Museo di Scienze Naturali, Brescia (C. Baroni).
3. Pavia, headed by G. Marchetti (Dipartimento di Scienze della Terra, Università).
4. Parma, headed by C. Tellini (Istituto di Geologia, Università).
5. Modena, headed by G. Gasperi (Istituto di Geologia, Università).
6. Bologna, headed by C. Elmi (Dipartimento di Scienze della Terra, Università).
7. Ferrara, headed by M. Bondesan (Dipartimento di Scienze Geologiche e Paleontologiche, Università); dotted area: cooperation with Museo Civico, Rovigo (R. Peretto).
8. Verona, headed by L. Sorbini (Museo Civico di Storia Naturale).
9. Padova, headed by G. B. Castiglioni (Dipartimento di Geografia, Università); dotted area: cooperation with Museo di Scienze Naturali, Pordenone (M. Tonon).
10. Venezia, headed by V. Favero (Consiglio Naz. delle Ricerche, Istituto di Ricerca Dinamica delle Grandi Masse).

institutes in northern Italy (Fig. 1). This initiative, started in 1985 (Castiglioni et al. 1986) was financed by the Italian Ministry of Public Education. Two sample maps, for the areas respectively at the foot of the Apennines and in the Po Delta, have already been published by the Modena and Ferrara research units (Bondesan, Castiglioni & Gasperi 1989) in view of the 2nd International Conference on Geomorphology.

This paper presents an example of mapping from the area of Ravenna, prepared by the Bologna and Ferrara research units. The figures (in black) are simplified representations of the main original drawings, which will be in colour.

The general criteria used here classify landforms on a genetic basis, different colours indicating different processes, although not rigorously. In addition, surface sediments, predominant texture of alluvial deposits and thickness of the weathered cover occurring in the

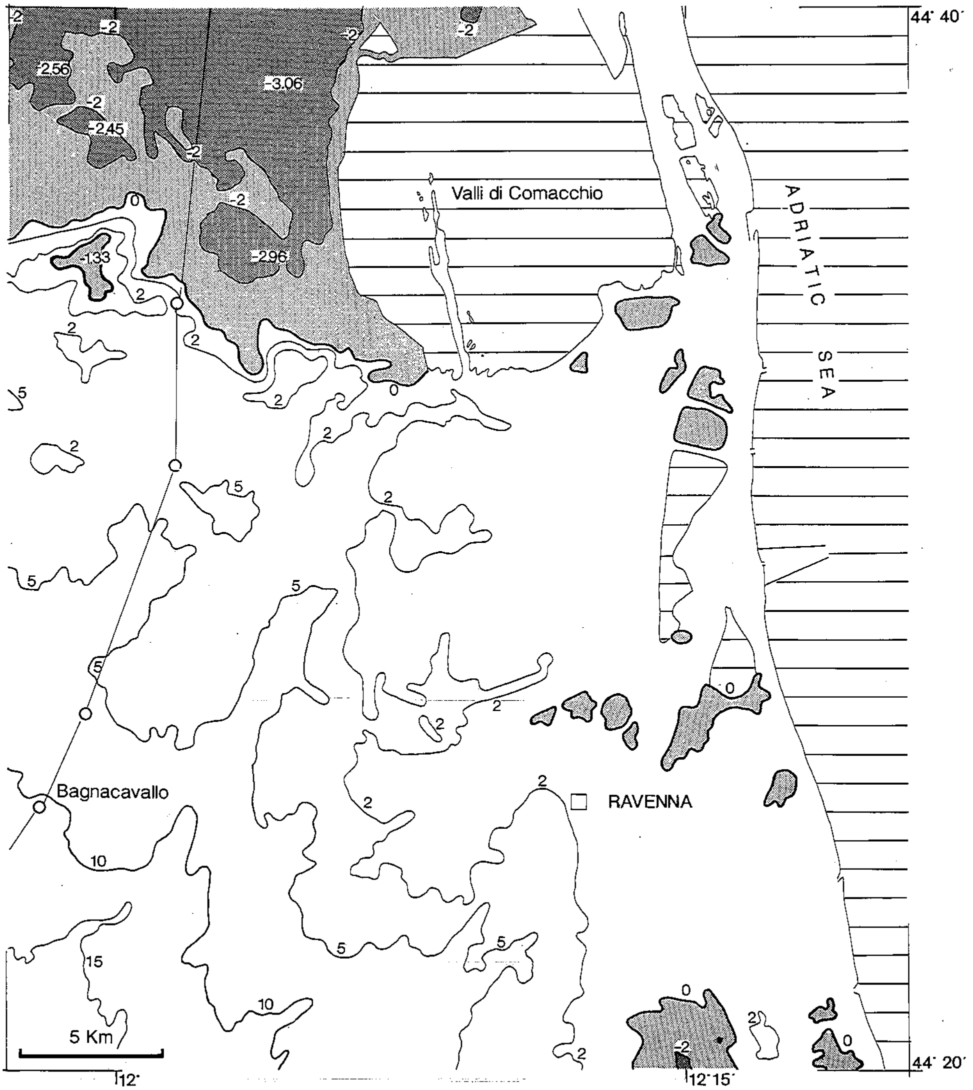

Fig. 2. Contour map of the Ravenna area. Shaded: areas below sea level; darker, areas below –2 m. On the left side, the line of the cross section of Fig. 3 is shown.

older parts of the plain will be distinguished. Important features are evidenced by the altimetric design, which shows contours at 5-metre intervals; +2 m and –2 m contours are added for better representation of the lowest parts of the plain. These altimetric data were processed from many new topographic maps made by regional authorities. Data on vertical ground movements, obtained from recent, and repeated measurements will be processed separately.

As well as this work in common, each research unit promotes more detailed research aiming at resolving either morphochronological problems, sometimes in collaboration with

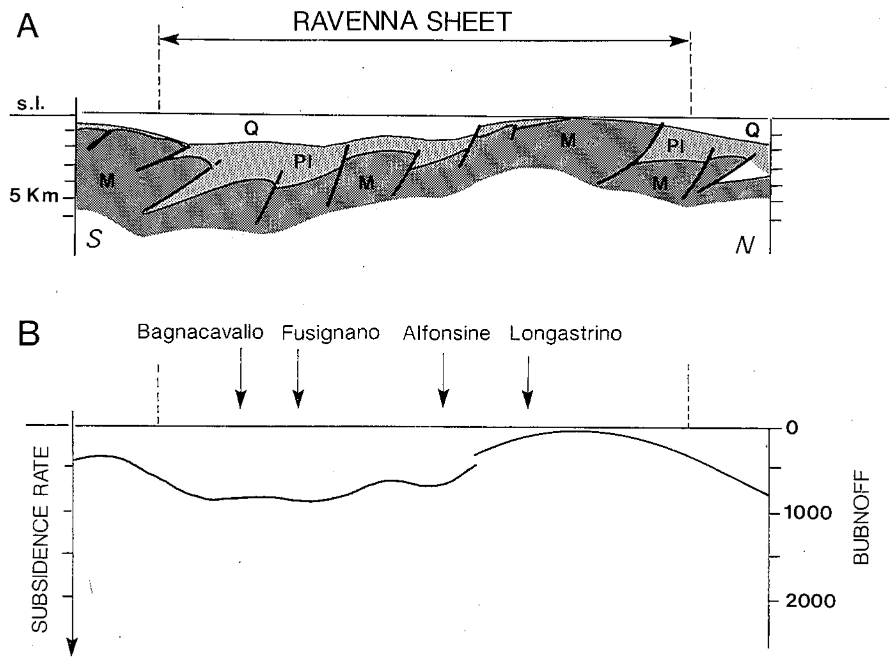

Fig. 3. A: geological cross section (the location is shown on Fig. 2). Q: Quaternary (marine and continental); Pl: Pliocene (marine); M: Miocene and pre-Miocene units (simplified after Pieri & Groppi 1981). B: Quaternary subsidence rate along the same section (Elmi 1984).

archeologists, or morphodynamic problems, and at supplying cartographic documentation for geo-ecological studies.

2 *Example of an area near Ravenna*

One area of interest for its evolutionary features, mainly the result of human activity, is located in the south-eastern sector of the Po Plain on the "Ravenna" sheet of the Topographic Map of Italy of the "Istituto Geografico Militare". This area may be divided into three parts: 1) a northern sector, north of the river Reno (near the ancient Po di Primaro), in the sedimentary domain of the Po, now occupied by a vast salt-marsh (Valli di Comacchio); 2) a south-western sector, composed of alluvial material of the Romagna rivers; 3) an eastern sector, formed of a series of beach ridges and deltaic structures of various ages.

2.1 *Geological and altimetric framework*

From the geological viewpoint, a Pliocene-Quaternary sequence may be reconstructed, with an upper part composed of a Pleistocene-Holocene cover of continental, alluvial, lagoonal and littoral origin, with thicknesses ranging between 300 and 600 m (Selli & Ciabatti 1976), and a lower part composed of a sequence of marine Plio-Pleistocene sediments, with thicknesses exceeding 7 km immediately south-west of Ravenna (Pieri & Groppi 1981). The whole area is thus confined in a structural context characterized by substantial tectonic deformations (Adriatic folds of the so-called "buried Apennine"), with strong subsidence in the Pliocene and even more in the Quaternary. Subsidence is particularly marked in the south-western sector of the Ravenna sheet (subsidence rate exceeding 1.1 m per 1000 years), but is greatly reduced in the northern belt at the border with the Comacchio salt-marsh (see Fig. 3, Longastrino structural high, Pieri & Groppi, 1981; Elmi, 1984). A preliminary examination indicates that the morphological elements are influenced mainly by depositional processes and by human activity, while tectonic control appears to be limited to general trends.

Fig. 2 shows the ground surface, with contours at 5 m (and partly at 2 m), obtained from maps on a 1:10 000 scale compiled in 1986–87.

In the south-western sector, the plain descends at gradients of 1–2‰ towards the north-east. This direction is common to all the water-courses of the Romagna plain and is presumably due to the above-mentioned tectonic depression, which was active in the Quaternary. The contours define three large ridges corresponding to the three main rivers – Senio, Lamone and Montone – crossing the plain at this point. The ridges also show irregular branches produced by fluvial diversions, often man-made, which define large closed or semi-closed depressions (Fabbri 1973).

Altitudes in the remaining portion of the territory are under 2 m. The northern part has an enormous surface area under 0 m (descending to –3 m) in the Valli di Comacchio, partly reclaimed between 1921 and 1964. Smaller isolated depressions descending to depths below sea level also occur in the belt behind the present and recent coastal ridges. The latter show some small relief, rarely being higher than 2 m, while the older ridges are either buried or are less than 1 m high.

2.2 *Holocene evolution*

The main morphological features of the Ravenna area are due to fluvial (ridges, interfluvial basins, crevasse splays, traces of extinct river beds) and littoral processes (Fig. 4). Their pattern and relationships, and geological knowledge of superficial deposits allow the Holocene evolution of this territory to be reconstructed. The evolution was controlled by three concomitant factors: progradation of alluvial and deltaic structures, eustatic variations in sea level, and subsidence, to which the effects of recent human activity must be added.

The coastline corresponding to the maximum sea level in the Holocene crossed this area from north-west to south-east, 9–25 km from the present-day coastline; today it is completely buried under new sediments. Traces of the later eastward growth of the coastal plain up to the late Bronze Age remain in the half-buried ridges found in the reclaimed part of the Valli di Comacchio (Bondesan & Bucci 1972) and immediately west of Ravenna (Veggiani 1976) (Fig. 5). The Iron Age belts (9th–4th century B.C.) are mainly buried and show discontinuous relief; they partly emerge from the Comacchio salt-marsh. The most ancient part of the city of Ravenna, which goes back to the 5th century B.C., is set on one of these outcrops.

As the coast gradually moved eastwards, subsidence inland – due to tectonic deformation and even more to sediment compaction – gave rise to the formation of enormous marshes and lagoons, some of which still exist.

In Roman times, the great delta of the Po Eridano (in the northern part of the area examined) grew and the whole Po Plain was subject to intense human activity. In the area examined here, this is shown by the agri centuriati (Roman grids), still evident in the south-western sector and by other remnants in Ravenna and the surrounding area.

Around the 8th century A.D. the Po Eridano became extinct, while a new southern branch of the river, the Po di Primaro, came into being. Its activity is shown by the marked

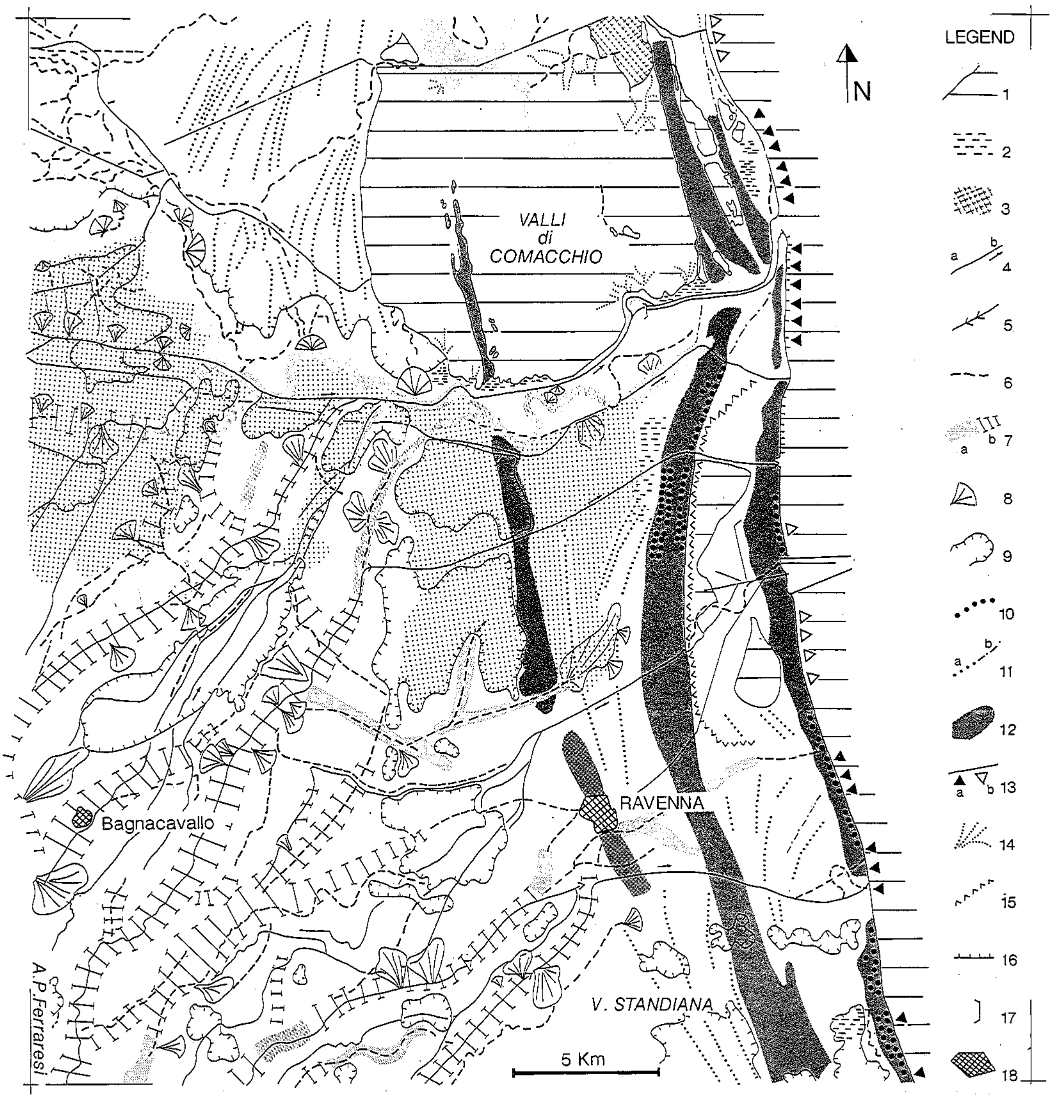

Fig. 4. Landforms. 1: sea and other sheets of water; 2: swamps; 3: salina; 4: river (a), canal (b); 5: recent downcutting of river bed; 6: traces of paleobed; 7: fluvial ridge well defined (a), wide, gently convex (b); 8: crevasse splay; 9: border of depression; 10: dunes; 11: simple beach ridge, buried or levelled (a), elevated (b); 12: complex beach ridge; 13: retreating (a) or prograding (b) beach; 14: inactive lagoon delta; 15: inner boundary of recent lagoon basin; 16: seaward dam; 17: fluvial barrage; 18: historical city centre. Dotted: land reclaimed by silting (*colmata*).

cuspate form of the old delta which may be seen in the beach ridge which developed between the 10th and 16th centuries. It enclosed a series of basins inland, from the Valli di Comacchio to Valle Standiana.

Even after the northward displacement of the main course of the Po (12th–14th centuries), the growth of the Po di Primaro delta was considerable, since various Apennine torrents were often made to debouch into it.

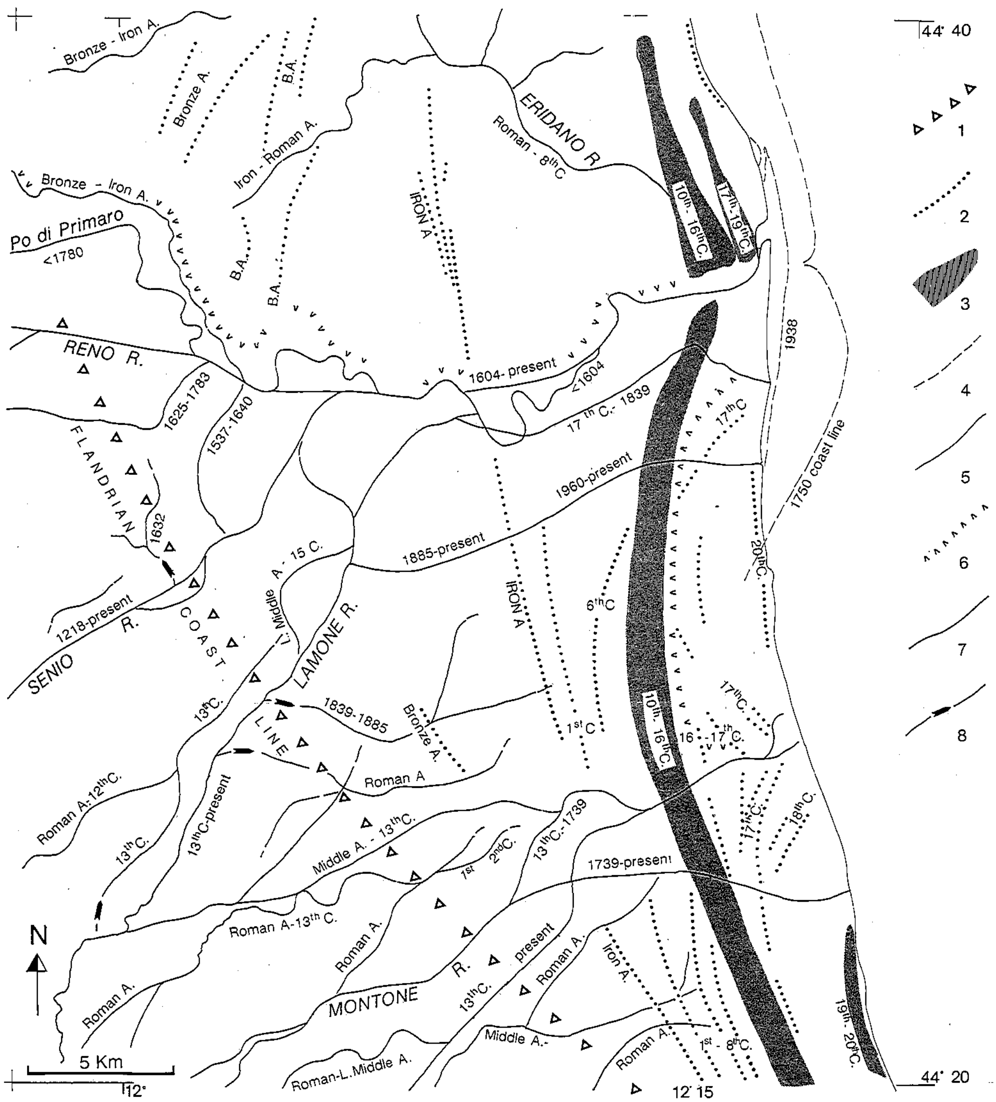

Fig. 5. Age of main coastal and fluvial features, from historical and archaeological data. 1: Flandrian coast line; 2: main beach ridge; 3: main complex beach ridge; 4: ancient coast lines (1750 and 1938); 5: present coast line (1987); 6: inner boundary of recent lagoon basins and salt-marshes; 7: river or trace of paleobed; 8: crevasse channel

Large cuspate deltas also developed at the mouth of the rivers Montone (16th–18th centuries) and Lamone (17th–18th centuries). These forms indicate a period of strong erosion of the Apennine slopes and of high sediment transport by the Romagna rivers; farther north, similar rapid advance also occurred in the Po delta.

Lastly, a new system of beach ridges evolved in the 19th century, starting with the mouth of the Reno, which was made to flow into the ancient bed of the Po di Primaro in

1775. Lagoonal basins again formed inland from these recent ridges (especially north-west of Ravenna). They have now been partly reclaimed.

Although the advance of the coastline may have been influenced by sea-level oscillations in a few cases (e.g., early Iron Age, Hallstatt Age; Veggiani 1975), it was mainly depositional in type: systems of deltaic and interdeltaic beach ridges developed and followed each other, subject to rapid changes caused by diversions and silting-up of the mouths.

As already mentioned, human activity played an important role in this evolution – many river diversions and long stretches of rivers are artificial. The results of man's actions are also clearly shown by the altimetric situation. The construction of embankments meant that river beds were raised above the level of the surrounding land, and many rivers have become suspended (e.g., the Reno). Considerable traces in the relief have also been left by reclamation, which was carried out according to two different techniques:

- already many centuries ago, using the *colmata* system, the Apennine rivers were diverted into depressed areas, to be reclaimed by silting; this practice was mainly used in the areas south of the Reno (dotted in Fig. 4);
- in the 20th century, reclamation became mechanical, i.e. by pumping; many sectors of the Comacchio salt-marsh were drained in this way.

The most marked phenomena of artificial subsidence caused by mechanical as opposed to *colmata* reclamation methods explain why the depressions lying below sea level are mainly located north of the Reno (Fig. 2).

In the last 30 years, other phenomena of artificial subsidence have also occurred, especially around Ravenna, due to exploitation of Quaternary aquifers for industrial, agricultural and urban use and, to a lesser extent, to extraction of methane from deep pre-Quaternary levels. The resulting lowering exceeds 1 m (Selli & Ciabatti 1977), with peak subsidence rates exceeding 10 cm/year.

The marked reduction in sediment transport by rivers, mainly in the last 50 years, is due to human activity – works on mountain basins, abandonment of agriculture in hilly and mountainous areas, construction of dams, and gravel and sand quarrying from river beds (Bondesan & Dal Cin 1975). Apart from riverbed deepening, considerable coastal erosion is taking place for all rivers, at the expense of their mouth structures. In the period 1945–72, the amount of sediment yield reaching the sea and contributing to the beach nourishment is calculated to have fallen by about 70% (Idroser 1981). In the last ten years, marine erosion has given the Reno a new mouth, more than 2 km inland from the previous mouth (Fig. 4).

In addition, the whole coastal belt is now subject to serious degradation, due to urban expansion, flattening of most of the coastal dunes, artificial subsidence (Carbognin et al. 1982), rises in sea level, and beach erosion (Bondesan et al. 1978, C.N.R. 1979). These problems are now being faced by the construction of seaward and lagoon-ward protective works and other coastal defences (breakwaters, etc.).

3 *Preliminary conclusions*

This preliminary work uses an example to illustrate the main aim of the project: the unification in a single map of current knowledge on the territory of the entire Po Plain from the morphographic, morphogenetic and evolutionary viewpoints. Detailed knowledge already available for parts of the plain has been processed so that it can be integrated with knowledge obtained from new research. The aim is a synthetic but sufficiently expressive representation of many, sometimes local, data. The usefulness of this work covers various fields, and aims at:

1) presenting much information which has already been published but in a fragmentary or sporadic manner, in sometimes poorly accessible publications, and facilitating comparison of opinions;
2) promoting knowledge on the overall effects of various morphogenetic processes overlapping in time;
3) laying the bases for geomorphological regionalisation;
4) highlighting those parts of the Po Plain which are most vulnerable, owing to morphological and altimetric conditions caused by problems of coastal dynamics, river dynamics and subsidence, all strongly influenced by human activities;
5) stimulating further studies on regional and subregional scales, on interpretative aspects that, until now, have been poorly defined; understanding the geomorphological evolution, and distinguishing the part due to tectonic movements from that due to sedimentary and erosional history.

These questions should be posed in terms of interacting processes. The map currently being prepared may contribute towards solving these problems by presenting an objective regional picture.

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