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Geomorphological Map of the Po Plain: Progress Report of the Working Group

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RIASSUNTO. La Carta Geomorfologica della Pianura Padana. Stato di avanzamento della ricerca di gruppo.

Un gruppo di una trentina di ricercatori sta lavorando nella preparazione della Carta Geomorfologica della Pianura Padana alla scala di 1:250.000. Essi sono coordinati in dieci unità di ricerca e appartengono alle Università dell'Italia settentrionale, ad un Istituto del Consiglio Nazionale delle Ricerche e a quattro Musei di Scienze naturali. La conclusione del lavoro è prevista per la fine del 1989.

I disegni originali degli autori vengono preparati alla scala di 1:100.000 e, come criterio generale, rappresentano il rilievo secondo una classificazione genetica; inoltre forniscono dati sull'altimetria, per mezzo di isoipse tracciate sulla base di dati recenti, sui sedimenti di superficie, sulla coltre di alterazione e, in minor misura, sull'evoluzione del rilievo ai giorni nostri. Tuttavia gli aspetti evolutivi si deducono in maggior misura dalle informazioni riguardanti le modificazioni della rete idrografica e della linea di costa, nonché dalle indicazioni su forme artificiali e su forme condizionate indirettamente da opere artificiali.

Questo rapporto preliminare contiene anche due saggi della nuova carta al 250.000, a scopo d'esempio; l'uno preparato dall'unità di ricerca di Modena, l'altro dall'unità di ricerca di Ferrara. La prima concerne una fascia di pianura pedemontana lungo il margine appenninico, presso Modena, la seconda invece un ampio settore del delta del Po.

Il gruppo è inoltre impegnato in ricerche, meno sistematiche ma più particolareggiate, relative a problemi geomorfologici specifici delle aree in corso di studio, che riguardano sia temi di ricerca fondamentale, sia aspetti applicativi.

Termini chiave: *Carta geomorfologica, rete idrografica, delta, Pianura Padana.*

SUMMARY

Since 1985 a group of about 30 researchers has been working on the preparation of the Geomorphological Map of

the Po Plain, scale 1:250,000. They are organized into ten research units and belong to Universities in Northern Italy, to one Institute of the Italian National Council for Research, and to four natural Science Museums. Final results are planned for the end of 1989.

The original work of the authors is on the scale of 1:100,000 and deals with the genetic classification of landforms, the representation of altitudes by means of contour lines (traced according to new data), surface sediments and weathering covers and, to a lesser extent, the present day evolution of relief. However, the latter is also being explored from much information on modifications in the river network and the coastline and by the representation of many elements belonging to artificial forms or indirectly caused as by anthropic works.

This report presents and discusses two small examples of the new map, prepared by the research units of the Universities of Modena and Ferrara respectively. The first one shows a strip of the pedemontane plain along the boundary of the Apennine chain (southern border of the Po plain, near Modena), the second one a large sector of the Po River delta.

The group is also carrying out research in a less systematic but more detailed way, going deeper into specific geomorphological problems of areas on which they are working, on topics regarding both basic research and applied aspects.

Key words: *Geomorphological map, river network, delta, Po Plain.*

1. *General aspects (G.B. Castiglioni)*

1.1. *Introduction*

A geomorphological map of the Po Plain is being prepared within the framework of the national project "Geomorphology and Recent Evolution of the Po Plain", partly financed by the Italian Ministry of Public Education, and headed by Prof. Vincenzo Francani. The first part of this report (1) has been prepared by the coordinator of the subproject for the Geomorphological Map, on behalf of all the researchers in question, who number about thirty, all belonging to many universities in the north of Italy, to the Italian National Council for Research, and to other scientific organizations. The working program was agreed upon in 1985 and published in a note a year later. This note contains the working criteria, timings, and legend (CASTIGLIONI & alii, 1986). The Map will be published in colour, on a scale of 1:250,000, in two sheets. The original drawings of the authors are being prepared on a scale of 1:100,000. It is believed that the Map will be sufficiently clear to represent not only general phenomena but also many, albeit simplified, details. As work gradually proceeds, many previously unknown geomorphological details are coming to light and, above all, the authors are aware that the choice of homogeneous criteria, necessary for coordination of the research over the entire region, reveals many possibilities for comparison and methodological improvement.

The authors have previous experience of studies of plain geomorphology and also of particular problems regarding basic or applied research. They work in ten groups (see attached list: fig.1). During their work together they have recognized the fact that such a large plain region - extending as it does over an area about the size of Holland and among the most densely populated in Europe - must be studied systematically by means of the already well-known method of geomorphological mapping. About three-quarters of the work is now complete (spring 1989) and the rest is proceeding.

The group of geomorphologists working in the Po Plain on the completion of this Map have been stimulated by fre-

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(1) Presented by G.B. Castiglioni at the "Joint Meeting on Geomorphological Hazards", Firenze, Modena and Padova (Italy), May 28-June 4, 1988.

quent contacts with two groups of the International Geographical Union: the Working Group on Geomorphological Survey and Mapping, and the Working Group on the Geomorphology of River and Coastal Plains. They hope in a few years' time to present their final results, which will be a useful contribution to international scientific aims. Moreover, that Map in its entirety should bring together much knowledge already acquired through local studies and national research on single themes.

1.2. *Legend*

The basic criterion of the Map is the genetic classification of landforms. The key is divided into eight parts which, although not rigorously, correspond to the colours chosen for the phenomena shown, grouped as follows: 1 - hydrography; 2 - fluvial, fluvioglacial and fluviolacustrine forms and deposits; 3 - eolian forms and deposits; 4 - glacial accumulation forms; 5 - littoral and lagoonal forms and deposits; 6 - tectonic forms; 7 - anthropic forms; 8 - various forms of complex origin.

As only a plain region will be represented, without the complexity of mountainous and hilly reliefs, colours can be used for clear map reading. Moreover, in order to highlight some groups of landforms, clear coloured lines will contrast other colours used for mainly areal distribution.

1.3. *Processing of altimetric data*

Between 1978 and 1988 much progress was made in Italy on completing a new topographic large-scale (1:5,000, 1:10,000) map on the part of specially created offices of the regional administrations, legally delegated to undertake coordinated work with the "Istituto Geografico Militare" of Florence. As regards the areas of the Po Plain, at the beginning of 1989 the only unfinished parts of this new map (called "Regional Technical Map") were some parts of Piedmont, although the prospects of further substantial progress are good.

The geomorphological study of the plain is thus based on a topographic map of modern conception, containing essential and detailed information on altimetry too, particularly "micro-reliefs". This information is now being processed and coordinated in order to obtain:

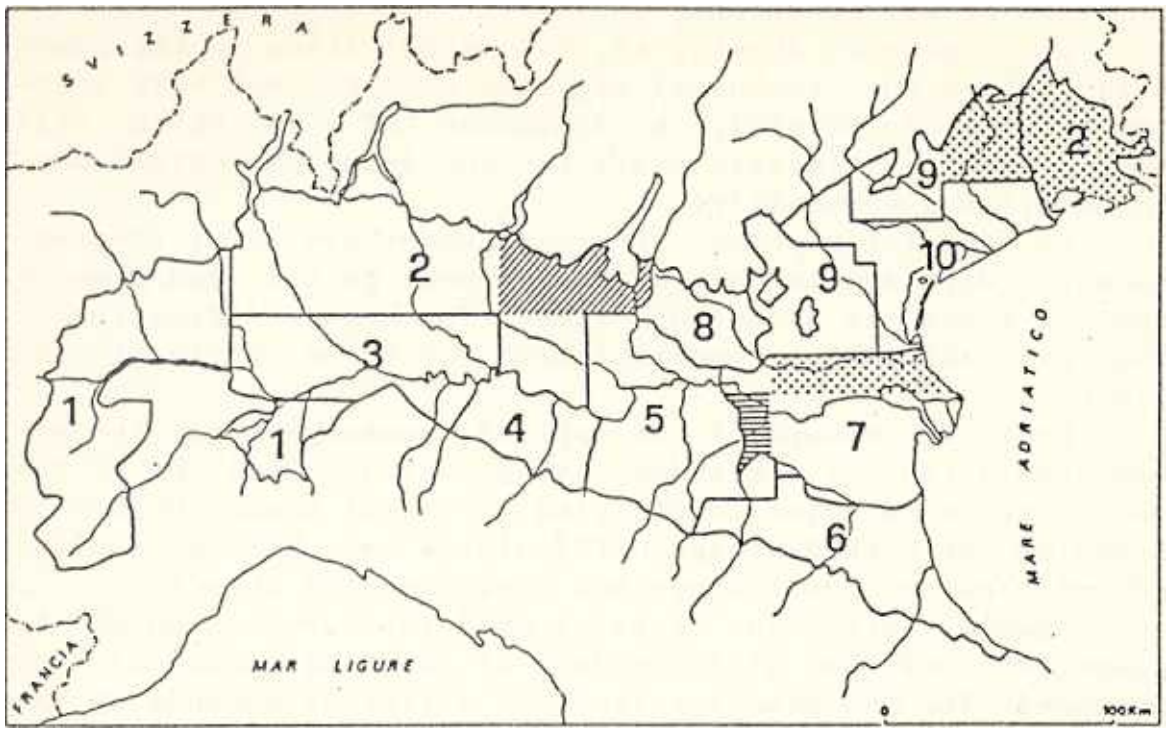

Fig. 1 - Research units taking part in the geomorphological mapping of the Po Plain.

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.

Parma, headed by C. Tellini (Istituto di Geologia, Università)

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).

a) morphometric definitions, essential for the classification of all landforms;

b) a general drawing of the contour lines in the plain area (where the technical map does not show but only indicates altitude points), at distances of 5 m, which will serve as an altimetric basis for the geomorphological map, to be printed separately;

c) special mapping of areas under sea level (depressions), with annotation of the lowest points and also of the -2 m and +2 m contour lines, for better definition of the plano-altimetric configuration of these parts of the plain.

From the viewpoint of applied geomorphology, the new representation of altitudes using contours will be of direct use in studies identifying critical areas subject to flooding or with drainage difficulties and, more generally, for studies on hydrogeology and environmental impact.

Special attention is being paid to sources used and to comparison of the altitude data of existing technical maps prepared for the same territory at different moments in the past. Differences mainly derive from the methodologies used and errors, except in cases of real territorial transformations, e.g., drainage by pumping and reclamation works, and their effects as regards different degrees of compaction of sediments.

1.4. *Data on lithology: surface sediments and weathered layer*

Until now the availability of lithological data on the Po Plain has been irregular. Using simple criteria, it seemed best to re-process existing data and to complete them in the most incomplete sectors by means of direct observations. The "prevalent" textures in the superficial alluvial sediments are grouped as gravel, sand, silts and clays, no separation being made between the last two. Reference is made to the last significant sedimentation episode, in order to describe the materials underlying the layer of agricultural soil at a depth of about 1 m.

As well as special marks indicating peat and eolian, beach or lagoonal sediments, the layer of superficial weathering, where it exists, will be indicated, both for thicknesses of less than 1 m and for greater thicknesses. These data are related to the various ages of the different parts of the plain.

Morphochronology and evolutionary trends

As regards the explicit representation of chronological and evolutionary data, the Map is not ambitious. It shows the exact spatial relationships between the various landforms and their interfingering and overlapping, so that some evolutionary sequences - such as the progressive advance of the coastline and delta (sometimes subject to interruptions or inversions), changes in hydrographic patterns or the alternative phases of accumulation and erosion of terrace systems - may all be shown. Appropriate symbols are planned for some very important morphodynamic aspects, e.g., coastline modifications (on the basis of data already published in researches promoted by the CONSIGLIO NAZIONALE DELLE RICERCHE, 1986) and the deepening of river beds in the last 30-50 years. Data on the most important fluvial deviations, if known, are also shown.

Territorial evolution in time, studied by geomorphological methods, is of great interest in the fields of ancient and historical topography. During their work, the geomorphologists working on the Map have often been able to establish excellent working relations with specialists in the field of archeology.

It is known that the dynamic aspect of altimetry, as revealed by soil movements and specially by subsidence, may only be shown by means of precision levelling along alignments. This problem is being studied by a special research group within the national program. Their work is of great interest, but it will be shown in a different map. The Geomorphological Map does show the apparently static general pattern of elevations and gradients, but also reveals some macroscopic effects of soil movements which occurred over the centuries and, in certain cases, also due to more recent transformations.

Role of anthropization

About 20 signatures indicate forms of anthropic origin, representing difinitely artificial intervention on reliefs or the river network. However, as well as these, the Map will give an overall view of the complex works which, over many centuries, have transformed the hydrographic network, delta structures and lagoons. Urbanization is also an important factor in the physical remodelling of the territory: the main areas involved in urban expansion are no-

ted, data sources being the regional technical maps and updated aerial photographs. Extensive areas are foreseen to be covered by symbols representing urbanization, e.g., particulary apparent in the Milanese area. Although mainly aimed at natural aspects, part of the interest of the Map lies in its references to anthropization and some significant historical elements. The ancient cities, originally surrounded by fortifications and moats, will be indicated by special signatures clearly identifying urban sites, very often connected with waterways, terraces or small reliefs.

1.7. *Results obtained until now*

Results are composed of: a) drawings, on a scale of 1:100,000, destined for later reduction to 1:250,000 and assembly; b) special studies.

a) The preparation, in April 1989, of drawings on a scale of 1:100,000 (research units of Turin, Modena, Ferrara, Bologna and Milano-Trieste), covers about one-half of the entire Po Plain, and in particular the high Piedmont plain and the stretch along the lower course of the river as far as its delta. The whole of eastern Friuli (where some drawings have already been published with no reduction of scale) and many other sectors covered by almost complete drawings must be added.

b) Special studies have been carried out on specific themes or on areas of various sizes, on the initiative of single authors or groups of authors. In these researches, for which homogeneity was not necessary, results appear to be less well-coordinated, but they are more detailed and deal with problems regarding particular parts of the plain (see References). The capacity of the various authors to apply their own methodologies is more manifest in these studies than in the Map.

Another indirect result of all these studies is their effect on various scientific environments and territorial organizations: we have noted lively interest in the methodologies proposed by our working group, together with recognition of their potential in the development of applied research.

1.8. *Some open problems*

In studies on regional geomorphology, the capacity of the mapping method to reveal some problems and propose in-

terpretation has often been recognized. We mention briefly here some stimulating study topics which have arisen several times during the mappers' meetings. It is impossible to speak of others in this short report.

Within the Po Plain, it is becoming increasingly possible to recognize subdivisions into regional morphological types, thus enriching and inproving the well-known subdivision into the "high" and "low" belts of the plain itself, so manifest in the differences in its drainage density. In one extensive part of the low plain, the area characterized by the association of fluvial ridges and basins is very typical; but other fluvial ridges of different types may also be shown in the high parts of the plain. The forms of contact between the plain and the reliefs are also becoming more definite.

The central problem still remains interference between the tectonic processes which modelled the overall setting of the region and its substrate and which are still active, and the fluvial and coastal processes which create and remodel the most common groups of landforms. The orographic and geological characteristics of the two mountain chains (Alps and Appennines) may explain many differences in the two piedmont belts in terms of sediments and of the geomorphic action of the actual and Pleistocene rivers which, on the Alpine side, also include fluvio-glacial processes.

The Pleistocene-Holocene transition and related changes in river regime are reflected in the morphological traces left by the watercourses, often with phenomena of "fluvial metamorphosis". These are shown on the Map and require appropriate interpretation case by case. As regards the watercourses flowing into the Adriatic, another open problem deals with the importance to be attributed to cutting and sedimentation processes caused by eustatic variations in sea level. For this and many other problems only briefly mentioned here, it is abundantly clear that studies on the Upper Pleistocene and Holocene up to the Present are still necessary.

2. *Examples of Geomorphological Mapping in the Po Plain*

An example of the Geomorphological Map of the Po Plain is presented here, scale 1:250,000. It comprises two parts, prepared by the Research Units of the Universities of Mo-

dena (2) and Ferrara respectively.

The two maps highlight the great geomorphological variety of the Po Plain. The first (Pedemontane Area) shows a strip of the high plain at the boundary with the Apennine chain, the second (Po Delta) a sector of the lower part of the plain.

Although referring only to the landforms and processes of these two areas, the legend uses most of the symbols foreseen in the general legend.

2.1 *Pedemontane Area (G. Gasperi)*

The Emilian Area lies at the foot of the Apennine chain, an orogene still in full evolution. The Emilian plain exemplified here is representative of the conditions of most of the southern margin of the Po Plain.

The plain/chain boundary is influenced by the substrate structures of the plain. It is purely morphological, considered as the boundary between the emerging Apennine chain and its buried part whose front lies about 30 km north of the area shown on the map, covered in some places only by the Quaternary alluvial deposits. Fault or fold deformations may also involve the Holocene deposits in this area.

The most important translational deformations developed from the Oligocene onwards and resulted in a northward and northeastward piling of structures. Their activity, which may be identified up to the Middle Pleistocene, created the "Pede-Apennine Thrust Front", whose present-day Apennine border is the morphological expression of the outcropping part. This margin represents a line along which vertical movements are inverted: uplift of 1-2 mm/year continues in the emerging Apennines, while the adjacent plain is sinking. This trend may be verified from the city of Parma to the Adriatic sea, and therefore includes the area considered here.

Marine deposition was gradually replaced by continental (fan and alluvial-plain) deposition proceeding from the Apennine boundary towards the centre of the plain, from the end of the Early Pleistocene (approx. 1 million years B.P.) onwards. The marine deposits are covered by alluvial deposits ranging from a thickness of about 100 m at the border of the plain to more than 300 m at the northern boundary of the map.

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(2) Geomorphological study by G. Gasperi, in collaboration with D. Castaldini.

At the Apennine margin the water-courses reaching the plain have built up alluvial fans which extend to the north. Since they are laterally connected with each-other, they can be regarded as part of continuous belt of coarse alluvial deposits spreading all along the Apennine fringe.

The alluvial fan on which the city of Modena stands and the other two fans to the south-west occupy special positions, being further advanced than all the other fans and superimposed on the alluvial plain. The three structures, morphologically similar to fan lobes, represent depositional episodes of the Fossa torrent which, in the 15th century, was artificially diverted westwards into the Secchia river in order to avoid damage to Modena.

Remains of old fans appear at the foot of the Apennine chain, and are characterized by paleosols and Pleistocene eolian covers (loess), terraced upstream and buried downstream by the Holocene alluvia (GASPERI, 1987).

The fan/alluvial plain transition is shown by the changing gradient of the topographic surface.

Many ridges caused by the local evolution of meanders or meander bars of ancient water courses depart from the foot of the fans, their patterns revealing the recent migration of these rivers. For examples, the Panaro and Samoggia watercourses gradually moved away from each other, the Panaro to the west and the Samoggia to the east, so that these two rivers now occupy extreme positions.

The surface distribution of lithological types of sediments reflects their differing depositional environments: the larger fans are characterized by gravels and sandy gravels, while their feet have given rise to elongated sandy bodies, which in some places have formed ridges and in others are partly covered by more recent silty-clayey deposits.

In the last 30 years the riverbeds in the fan areas have been subject to considerable deepening, which has reached up to 10 m in the larger watercourses. Downstream from fans, the drainage network has been strongly influenced by artificial embankment which confine the rivers in narrow beds within which they tend to become of the hanging type. The lesser watercourses are completely canalized: the canal network downstream Castelfranco Emilia was created by the Romans in the 2nd century B.C. (Ager centuriatus).

The territory has also undergone increasingly heavy urbanization during the last 30-40 years, as a consequence of industrialization.

2.2. *Po Delta (M. Bondesan)*

The second area, mapped by the Ferrara Research Unit (3), is part of the low plain which contains most of the present-day Po Delta and the adjacent coastal belt to the south.

The present geomorphological setting of this area has been substantially influenced by man's activities.

The substrate of its south-west sector is made up partly of some structures of the front of the Apennine orogeny and partly of the Adriatic homocline (Po Plain). The substrate is covered by Middle-Upper Pliocene and Quaternary sediments, in layers rapidly increasing in thickness before the Apennine front. The thickness of the Quaternary sediments alone may exceed 2000 m (PIERI & GROPPI, 1981). Traces of the post-Würmian transgression have been recognized as far as Codigoro. The surface sediments are dated to the recent Holocene.

The growth of the plain during the last few thousands of years is clearly shown by the old beach ridges, simple or complex (central-eastern part of map).

The oldest beach ridges (to the west) and some along the present-day Po Delta are totally or partially buried by lagoonal and fluvio-marshy materials. Mapping of many of the minor ridges was not possible, due to scale.

The two most important deep structural factors influencing the recent evolution of the low Po plain are:

- the orientation of some important paleobeds;
- the northward migration of the main courses of the Po (which may be identified, with some exceptions, even in historical times).

River migration is also revealed in the area examined: both extinct and present-day rivers are all branches of the Po.

The area as far as the actual coastline and the main beach ridges to the north, which continue in the same direction, formed as a consequence of the activity of the many paleo-riverbeds mapped here and of the growth of their deltas. Instead, the course of the Po (north-west part of map), called as far back as the 12th century the "Ficarolo Breach", became particularly active in late Medieval times.

At this point, the importance of man's activities in this area becomes abundantly clear. The course of the Po further downstream (northern part of map) was created by

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(3) Geomorphological study by M. Bondesan; altimetric analysis by M.C. Turrini. P. Talassi collaborated on mapping and lithologic investigations.

the diversion carried out by the venetians in 1604. The growth of the present-day delta is to be attributed to the latter riverbed and its branches, many of which are now extinct. In the last two centuries the large branches of Goro, Gnocca and Tolle have created peninsulas which enclose the lagoonal inlets of Sacca di Goro and Sacca di Scardovari.

All the mouths of the river are characterized by small marshes and minor lagoons, small islands, lagoonal deltas and lagoonal channels, both active and extinct. Many splay crevàsses and crevasse channels are linked to both paleo- and actual riverbeds.

Man is also responsible to a considerable extent for the raising of the most recent and present riverbeds above the level of the surrounding land. Embankments built as protection against flooding have favoured sedimentation within the riverbeds and reduced sediment deposition in the intervening areas, thus favouring the expansion of marshland in parts where subsidence is no longer compensated. Marshland has long been dominant, particularly in the western part of the map, where the outflow from precipitation and floodwaters has been greatly hindered by very high beach ridges (BONDESAN, 1985).

Most of this territory has also been subjected in historical times to the gradual entry of salt-water from the sea. The inland boundaries of the lagoonal basins thus formed are indicated on the map.

Surface lithology clearly reflects this evolution. Sandy materials prevail in the largest beach ridges (mainly in the central part of the area) and along the main riverbeds and paleo-riverbeds. Instead, in the depressions between one bed and another, silts and clays prevail, together with large peat deposits in the west.

Until the second half of the last century, the area in question was practically entirely submerged under fresh or brackish waters. It has now been almost completely drained by means of a dense network of drainage canals and by pumping. This type of reclamation has brought about further lowering of the soil, accompanied by other phenomena of "artificial subsidence" (caused, for example, by the extraction of methane-bearing waters) during the last 50 years (BONDESAN & SIMEONI, 1983). Quarrying and agricultural operations have now destroyed most of the dunes and levelled many of the ancient beach ridges.

This explains the present-day altimetric situation. Almost all the mapped area is under sea level (darker grey areas), with the exception of a few coastal strips, some

large beach ridges, and the largest paleo- and actual riverbeds. The map also shows the -2 m contour line and the points of maximum depression. An absolute minimum of -5 m is recorded in the centre of the modern Po Delta.

In order to avoid further submergence of the area, sea- and lagoon-facing dykes and dams have been built, connecting embankments near river mouths and also further inland.

Man's activities have also strongly influenced coastal dynamics. At Porto Garibaldi, jetty construction and later extension has hindered longshore drift of sediments, causing erosion of beaches further north, where large-scale tourist facilities and tourist towns have been operating since 1950. Various types of defences have therefore had to be built to protect the beaches. A continual series of offshore breakwaters, extending to beyond the Lido delle Nazioni, has thus transferred sea erosion towards the Lido di Volano.

Lastly, man's activities have created other serious situations. One of these is reduced solid transport by rivers, mainly due to gravel and sand quarrying from riverbeds. The total solid transport of the Po near Ferrara has fallen by about 30% in the last 30 years (DAL CIN, 1983). This trend has deepened the riverbeds (see the north-west stretch of the Po on the map) and, together with subsidence, has also caused:

- the almost complete arrest of growth of the Po Delta;
- further accentuation of marine erosion;
- still more generalized degradation of the coastal belt, aggravated in some stretches by the practice of levelling even the dunes along the present-day beaches;
- a trend towards even more accentuated invasion by the sea.

Further coastal defences have become necessary as a result, and the already extensive lagoon- and sea-facing dykes have been completed and reinforced.

The ensemble of anthropic landforms is completed by navigable canals, artificial lagoonal channels, irrigation works, abandoned canals, quarries and landfills.

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