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IMPLICATIONS OF CLIMATIC CHANGES FOR THE PO DELTA AND VENICE LAGOON

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SUMMARY

The north Adriatic lowlands have reached an advanced level of land use intensity, with complex inter-related agricultural, industrial and tertiary activities that are tied to national and supranational markets, with the support of a well developed communication network. Tourism, both recreational on beaches and cultural (e.g. Venice) has become a major economic resource. Resident population in the coastal zone below the +5m contour, is not high, in parts with low densities. It is stationary, if not declining, due to a zero growth rate and to migration. Population and economic growth are mainly concentrated in a belt that stretches parallel with the coast at 2-5m elevation.

There are at present serious environmental problems, due not to recent climatic oscillation, nor to the so far small rate of sea level rise, but to careless actions in the development of land use over the last 50 years. These include the urbanization of the coast, the building of deep harbours and of coastal defence structures, a decrease of the lagoons surface, enhanced land subsidence caused by water extraction, the derangement of rivers' water and solid discharges and the pollution of surface waters and the sea.

The entire coast is in a state of physical instability, and must be classified as high risk in regard to the impacts of sea level rise.

In general, climatic changes will be gradual, but with occasional exceptional events of rainfall, storms and tidal surges and water stratification, could become more frequent and dangerous.

The main threats to be foreseen are to the existence of Venice, and to other towns of artistic-historical importance; to the tourist industry; to the activities of important harbours, and to specialized agricultural products, such as the vegetable orchards on the sandy soils of the coastal barriers and relict beach ridges.

A substantial decline in the recreational use of beaches will be due to the effects of shoreline retreat on infrastructures, and perhaps to the altered climatic conditions of Europe, with drier and warmer summers in the northern countries.

As regards the extensive agriculture in the reclaimed sub-zero level lands, it might be more economical to turn them back, at least in parts to their original lagoonal state, in favour of fishing, which is at present a more efficient and remunerative activity than cereals growing.

In the Po Delta and elsewhere, lagoons and marshes could act as buffer zones between the open seas and higher land, and in parts as nature reserves. Industrial and other activities in the areas <1m would probably be moved gradually inland without excessive disruption.

Little change is expected to occur in the settlement and economic patterns of the hinterland, above +5m, during the next few decades, mainly on account of the low population growth. Main factors of regional planning, especially for urban development and agriculture, will continue to be the availability and quality of water resources and communications.

The role of the present coastal centers of heavy industry (Porto Marghera, Ravenna) and the importance of commercial ports (Venice, Chioggia, Ravenna) will be determined more by general factors of national and international demand, than by climatic changes.

Eventually, the basic resources of agriculture and fisheries should change both qualitatively and quantitatively, the former benefiting perhaps from higher temperatures and greater CO_2 in the atmosphere.

A great deal of research in advance will be needed on the impacts of higher temperatures and of sea level rise, with the systematic collection and analytical treatment of a data base ranging from climatic and oceanographic parameters to hydrology, ecosystems, and social and economic variables.

1. INTRODUCTION

The 300 km long Adriatic coast of northern Italy, from Monfalcone to Rimini, limits a lowland 15-25 km wide, generally under 2 m elevation, in which remnants of formerly more extensive lagoons, salt and fresh-water marshes alternate with reclaimed lands. Many parts actually lie below sea-level, especially in the Po Delta and between Venice and the Tagliamento river (Fig. 1).

It is a deltaic and lagoonal setting characterized by active geological subsidence and instability of natural environments, subject to river floods, storm surges and coastal shifting. Natural disasters have affected this region time and again in its history of human occupation, down to the devastating Po Delta floods of 1955 and 1966, and to the recurringly higher tidal flooding of Venice.

From most ancient times the Po river has represented the main access route from the Adriatic to the interior plains and the alpine regions. The towns of Adria and Spina were already important centers of maritime and land traffic in the early VI century BC. Commercial activities in Etruscan and Roman times were sustained also by a local coastal economy, based on cattle raising, game hunting and wood exploitation, and already important fishing, salt and brick making. The Byzantine capital of Ravenna continued these commercial activities, but devastating floods in the late VI cent AD and the fall of the city in mid- VIII Cent, led to a progressive degradation of the coastal regions. It was the protection offered by the natural lagoons and their swampy margins that favoured the initial settlement of Venice in the VI Century and later provided the basis for its development into a state and major maritime power. The well-being of Venice depended on a symbiosis with its lagoonal surroundings, in particular on their preservation in the face of siltation from rivers. The result was an increasing necessity to interfere, or at least to regulate, the natural processes for the benefit of agriculture in the lowlands and of access to the sea, which was continuously threatened by the ever changing passages between the barrier islands.

The legacy of this historical development is the existence today of cultural and artistic centers of inestimable historical significance.

The exploitation of the lowlands had remained, on the whole, on a limited scale, leaving their margins in a fairly natural condition until the first decades of this century. Transformations since the First World War have been dramatic, first by the progressive reclamation of large swampy lagoonal areas (e.g. Comacchio to Ferrara, NE of Venice), then with the development of the industrial center of Porto Marghera, and the beginning of the recreational use of beaches. Later, in the early 1950's it was decided to construct a second large harbour and industrial complex near Ravenna, following the discovery of natural gas fields there. Being located on a low coast, these new harbours required a complex of entirely artificial fixed structures.

Coastal use further exploded in the next decade, the years of Italy's economic boom, with the expansion of the industrial centers and the rapid urbanization of the shore, which became one of the largest summer recreation poles of south Europe. Tourism, both cultural (e.g. Venice) and beach-bound, is now an important resource for the regions of Romagna, Veneto and Friuli-Venezia Glulia.

Thus, the north Adriatic lowlands have presently reached a stage of advanced land-use, with complexely interrelated agricultural, industrial and tertiary activities, that are tied to national and supranational markets, and are supported by a well developed communications network. Resident population within the +5m contour, however, is not high (1.8 million), and almost stationary due to negative birth rates and to migration. Population and economic development remain limited to a belt marginal to the lowlands, at the exception of the summer seasonal tourist activities of the narrow coastal strip.

The postulated climatic changes could in time very seriously disrupt the present economy and well being of the region. A rise of sea-level would not only have a direct impact on beaches, lagoons and agricultural lands that lie below sea-level, but would also considerably aggravate a series of environmental problems that have resulted from an use of the coast and lagoons that has not taken natural processes and responses into proper account.

Most of the coast is in a state of retreat due to reduced river sediment inputs, a consequence of the water management practices upstream and of sand extraction from river beds. The Po Delta has become an area of high geological risk. Natural subsidence here and in the vicinity of industrial centers (Mestre, Ravenna), has been accelerated by the over-extraction of groundwater. Furthermore, the natural flexibility of the coastline has become constrained by the erection of numerous fixed structures, built to protect the agricultural and tourist developments and accesses to harbours.

The degradation of the Venice lagoon started with the alteration of the tidal flats for the new harbour of Marghera. The later development of base industries tied to the transformation of imported raw materials, which make a heavy use of energy and water, and produce large amounts of waste, has contributed to the extensive chemical and thermal pollution of the lagoonal waters with consequent serious ecological problems.

But problems are not purely physical. In the wake of the unprecedented concentration of population and capitals along the coast, contrasts have arisen between the different economic and political interests involved. Such are land-use conflicts between the industrial and tourist settlements, the expansion of land reclamation versus the preservation of wetlands for fishing. Lately, the increasing awareness of the degradation of the environment and the necessity to contain the pollution of coastal and inland waters, has also come in contrast with the maintenance of economic activities. Last, but not least, coastal protection nature conservation and proper coastal management are hindered by political conflicts between local authorities, backed by traditions of local autonomy, and the central government, who has the overall responsibility for coastal management.

The threat of a substantial increase of average temperature and of sea-level, is bound to complicate the situation further, but could also focus on the necessity for a controlled and balanced development programme that emphasizes more rational land-uses on the UN Adriatic coast.

2. THE SOCIO-ECONOMIC SETTING

2.1 Historical Introduction

The modern development of the north Adriatic coastal lands of Italy dates back to the first decades of this century mainly after the First World War, when the lowlands attracted the attention of the State, for the economic and partly political necessity to expand agricultural production, to increase employment and resettle population. Land reclamation affected the parts that were still swampy and lagoonal; the Po Delta, north of Ravenna, from Comacchio to Ferrara (where the drainage of wetlands had already begun in the 1880's), and northeast of Venice. These developments eliminated malaria, population expanded. Cereals were the main crop (rice paddies were used in the beginning to de-salinize the soils); later sugar beets and hemp, permitted the establishment of sugar and textile mills.

A decision was taken in the early 1920's to create a new harbour and industrial center near Mestre, to serve as a focus for industrial development (mainly basic transformation industries) at the NE coast of Italy. A port within the lagoon was sheltered from the sea and only required the excavation of tidal flats. Fishing in the Grado-Marano, Caorle, Venice and Comacchio lagoons was incremented, especially by the expansion of the traditional method of basin ('valli') aquaculture. On the coast there was a slow development of beach recreational centers (Lignano, Grado, Caorle, Lido, Porto Corsini, Cervia to Rimini), but most of the shore remained in a natural state. The urbanization and concentration of investments on the coast was yet to come.

After the end of the Second World War and the period of reconstruction, a new phase of economic expansion unfolded in the regions of Romagna, Veneto and Friuli-Venezia Giulia. As in the rest of Italy, the main feature of this development, in the 50's to early 60's, was a transformation of the economy from agrarian to industrial. In less than 10 years the traditional domination of agriculture over all other activities ceased and was replaced by a productive structure in which industry became the main activity by the number of people employed. The entire economy was transformed in the direction of specialization and exchanges. Economic growth was rapid, spurred by a large number of middle and small enterprises which, taking advantage of labour released from agriculture, were in a condition to compete in international markets, especially those of the European Economic Community.

In the lower Veneto, this phase of intense transformation involved especially the area from Padova to Venice. Mestre-Marghera became a very dynamic pole with a radial expansion. The port and industries were enlarged, with new deep access canals (allowing the passage of oil tankers) and began to serve as a terminal for trade exchanges with central Europe, as well as (together with the Venice harbour) a focus of trade for north Italy.

The southern parts of the provinces of Venezia (except for Chioggia, a historical center with a diversified economy), of Padova and the Po delta, remained, however relatively depressed. From the point of view of human occupation the Po delta was still a marginal area, outside the main roads and railways, without an urban administrative pole towards which to gravitate.

In Romagna the new industrial center and port of Ravenna was developed along the Canale Candiano, which links Ravenna to the sea, following the discoveries of natural gas fields on- and offshore in the 1950's. Oil refineries and mechanical and chemical industries were established.

A most spectacular urban development took place on many parts of the Adriatic coast, with the rapid growth of new beach resorts, especially between Lignano and Lido, between Ravenna and the Po river, and from Cervia to Rimini. This development was a response to the demand of the 'economic boom' years, for beach recreation, by the middle and working classes of Italy and northern Europe. The mass tourist industry was born, though it unfortunately accompanied by the deep alteration of the natural environments (dunes and pine woods).

Today the socio-economic situation of the NW Adriatic coastal region is complex. Activities in the lowlands (i.e. the areas under 2m elevation) are at first sight based essentially on agriculture, which has become more specialized, on summer tourism and lagoonal fishing. But there are also Venice and the major industrial centers. Venice is not only a regional and provincial capital; it lives on tourism, and is one of the busiest commercial ports of the northern Adriatic. The industrial activities at Marghera and Ravenna, though still founded on chemical and metallurgical plants, include a large number of smaller establishments producing consumer goods destined to exports.

In addition, lagoonal fishing has become more specialized and industries have appeared in several of the smaller towns, including some of the tourist centers, where the resident population has increased. The communications network includes roads parallel with the road Rimini-Ravenna-Chioggia-Mestre; the motorway Padova-Mestre-Trieste) and normal to the coast like the motorways Ravenna-Imola, Ferrara-Comecchio, and the roads Rovigo-Po delta, and Venice-Mestre). The international airport of Tessera, at the inner edge of the Venice lagoon, handles 800,000 passengers a year.

Inevitably these developments have brought with them socio-economic problems and negative environmental reactions. While inland more rational urban and territorial planning (Fig. 2.1) is now facilitated by a zero population growth and by a reduction of internal migration, in the coastal areas there are conflicts between the expansionist pressures of industries and tourism on the one hand, and environmental integrity on the other. The industrial economy and a consumer society tied to urban living and motorization, put a heavy burden on the rural and coastal landscapes, and on the artistic and cultural values of the historical centers. The touristic development of the coast has not been rational, and has been largely controlled by private investments.

The quality of the natural environment, paramount to both recreational tourism and to fishing, has deteriorated, not least in consequence of urban and industrial pollution.

The implementation of protective measures for the environment and its natural resources has, however, met with considerable bureaucratic difficulties.

2.2 Population

In 1981 the population of the lowland belt, more or less below the 3m contour, was about 1.450.000. High population densities (Fig. 2.2) and towns >10,000 inhabitants (Fig. 2.3) were located along the Portogruaro-Mestre-Padova, and Rimini-Ravenna-Alfonsine-Argenta axes. The apparent low population density of the Ravenna commune was due to the latter's large size (the city has a pop. of 150.000). Low densities occurred in the Po delta and Comacchio regions and NE of Venice, between the Piave and Isonzo rivers. In the coastal comuni, densities were much lower than inland, though in summer the population of the beach resorts usually swells to 10 times that of the resident population (ref. Table 2.1).

Table 2.1

Resident versus tourist population
Romagna Beach Resorts (1977)

		*
Lido Spina	950	1.549.000
Lido Estensi	831	1.482.000
Porto Garibaldi	3.658	238.000
Lido Scacchi	238 }	1.100.000
Lido Pomposa	318 }	
Lido Nazioni	494	604.000
Volano	165	120.000

* Presences, July-September

The settlement pattern of Veneto in general (esp >5m) is polycentric, or polynuclear, with an extreme fractionation of residential centers. Near the coast the pattern is different. There are historical centers (Comacchio, Grado, Caorle, Marano), new beach resorts, and a few old towns with a mixed economy (Venice, Chioggia). Apart from the latter, none of the lowland centers are poles of economic attraction except very locally. The tourist resorts are stretched along the shore and have a limited inland extent.

Population trends in the lowland region during the last 40 years are evidenced by comparisons between the 1961, 1971 and 1981 census data (Fig. 2.4). The mean features have been the continuing growth of the economic poles and axes, though mainly due to migration, rather than to a natural increment of population. In this part of Italy (like in France and Spain) the birth rate is low; fertility in Italy (1974-1985) has continued to fall (Fig. 2.5) reaching below the population replacement threshold.

Between 1961 and 1971 there was a strong increase in all the provincial capitals (Ravenna, Rovigo, Ferrara, Padova, Venezia) and in the surrounding comuni, and along the axes Padova-San Dona-Portogruaro-Monfacone, and Rimini-Ravenna-Comacchio. The urbanization of some parts of the coast was reflected by the increase of resident population in a number of comuni (e.g. Iesolo, Lignano, the Romagna towns, Chioggia-Sottomarina).

Negative trends occurred in rural areas, and especially in the Polesine region east of Rovigo (the population density of this province is below the average for Veneto). In the Po Delta population had increased until the 50's, but afterwards declined (by 20-25%) due to floods, farm mechanization, and the migration of labour towards the industrial centers. The only area of development was that from Rosolina to Chioggia, an area favoured by sandy soils for horticultural and by better commercial infrastructure.

Between 1971 and 1981 depopulation has continued east of Rovigo and Ferrara, economically weak areas that tend to lean towards the towns in the west, as these offer more employment in the tertiary sector. Decline has continued in the area of the Ferrara-Comacchio reclamations.

Between 1971 and 1981 population in the Romagna coastlands has remained stationary or has been moderately growing; similarly, in the lowland marginal belt of Veneto-Friuli between San Dona and Monfalcone. Growth has occurred all around the Venice lagoon but increases in this area are to be attributed entirely to a moderate expansion of Mestre, since Venice city has suffered from a population exodus, due to its poor infrastructures for some social categories, and lack of employment.

The recent general slower growth of the region is essentially a consequence of the late 70's and early 80's recession and of the end of internal migrations in Italy. Base industries are in a state of 'crisis', while the newer small industries, services, administration, and generally all the sector of tertiary activities have considerably expanded (ref. Fig. 2.6).

Blue Plan scenarios suggest there will probably be a 10 percent overall decrease in population by 2005 due to the continued depopulation of Venice, the exodus from agricultural areas, and lower birth rates.

2.3 Agriculture and Fishing

In Veneto agricultural production in the lowland areas is dominated by corn (> 50% of cropped area), especially in the reclaimed lands, rotating with fodder and soyabeans; 30-40% of the cultivated surface is dedicated to wheat, sugar beets, together with corn and soya, in order of importance; locally, there are vineyards (Fig. 2.7). Wheat, with sugar beets and in parts with corn and soyabeans, is the prevailing culture in the Po delta; and in Romagna. Rice is grown in a large area of the Ferrara reclaimed region (Fig. 2.8).

The extent of fodder and 'soft' corn cultivation reflects the economic importance of livestock (cattle raising accounts for % of the lower plains of NE Italy). Wheat and corn cultivation is said to be the most efficient in

Italy. Production of sugar beets has declined in relation to international sugar prices. The areas of recent reclamation are characterized by large agricultural enterprises, employing labourers, rather than by individually-owned farms.

Special cultures are the vegetable orchards that stretch over the sandy belt from Iesolo to Chioccia and between Chioggia, the Adige and the Po, along the relict beach ridges (Fig. 2.7). Another specialized culture, in Friuli, Romagna and the Polesine, are poplar trees, in small patches, especially along the river channels (Fig. 2.8). In Romagna there has been an increase of fruit, grapes and vegetable production in the coastal belt over the sand dunes, in relation to the development of tourism.

In more elevated areas, in Veneto, as well as in Romagna, between 2-5m contours, fruit and vineyards are the most important cultures.

Marine fishing has undergone an overall decline, due to impoverishment of stocks, competition and organizational problems (Orel, 1984). Lagoonal fishing, on the contrary, has expanded.

In the last decades basin aquaculture has increased in activity and output in respect to open fishing in the lagoons. Fish culture is based on the periodic migration of a number of fish species. The basins are lined by levees with special passages for the spring entry of the fry and the autumn capture of the grown fishes. In spring and summer the fishes remain in the <u>valli,</u> either living on natural productivity (extensive aquaculture) or in part artificially fed (intensive aquaculture). Some fishes remain in the basins more than one year (eels in particular).

At present the activity of professional fishing involves mainly fixed installations in very shallow waters, especially in the upper and central Venice lagoon, in the Caorle and Comacchio lagoons. There are now, in the Venice lagoon, 25 basins covering 8,000 ha. Fish productivity by the extensive method produces 80-150 mg/ha year. The seeding of many basins is done with imported or artificial fry.

Open lagoonal fishing involves crustacea (crabs, shrimps), mollusca (sepia, clams), bivalves and fishes (gobids, aterinids, eels, 'orate', 'pasere').

Quantitatively and economically important shell fish culture is carried out in the open parts of the Venice lagoon, especially between the Malamocco and Chioggia outlets.

2.4 Industries and harbours

At Marghera the basic industries are metallurgical, chemical, petrochemical, fertilizers and oil refining. Two hundred factories employ 40,000-50,000 workers. Industrial production in the last decades has been increasingly oriented towards exports.

At Ravenna, by size of employment the main industries are chemical and metallurgical. There are however a host of other types of industries, from mechanical to food processing and clothing. Activities in the field of construction have considerably expanded (Fig. 2.9) (Table 2.1).

Monfalcone, near the Isonzo delta, is a shipyard town. In the 1960's, 70% of employment was in mechanical industries related to the shipyard. Ship construction has much declined in Italy in the last two decades, at Monfalcone it survives only for military purposes.

The expansion of harbours before World War Two was related to exchanges between Italy, central Europe, Asia and East Africa, through the Suez Canal. This in turn stimulated the establishment of port-related industries. Since the early 50's, major changes in the function of ports have occurred, especially with the growth of oil tanker transport, with gradual technical adaptations to harbour installations due to greater tanker size, and the establishment of refining and petrochemical plants. Presently, while the original 'base industries' of Marghera, Trieste and Ravenna are in a state of 'crisis', the ports' role has changed. In general, imports and exports have much increased (raw materials versus manufactured products from/towards Third World countries). Technical adaptations in harbour have been imposed by the advent of larger oil tankers, of container and of roll-on and roll-off ships. Ravenna and Venice have become increasingly commercial ports, whereas at Marghera 75% of traffic (by tonnage) is accounted for by oil. A part of petroleum products is re-distributed along the coast of Italy by local, smaller ship traffic. Goods arrive from, or are shipped towards the interior mainly (95%) by terrestrial transport (inland navigation is limited to cereals in the region of Venice), 40% of that by rail, 60% by road.

Table 2.2

Industries and industrial employment in Ravenna
(1981 Census)

	Employees		Enterprises	
	No	%	No	%
Oil, gas extraction, refining	1029	5.45	4	0.3
Metallic/non metallic primary processing and transformation	913	4.84	46	2.9
Chemical	4650	24.66	9	0.6
Mechanical-manufacturing (metallic, incl. machines, cars, tractors, etc.)	3542	18.78	400	25.6
Food processing	1333	7.06	54	3.4
Textiles, leather (incl. clothing, shoes)	780	4.13	204	13.2
Wood, paper, rubber and finished products	1400	7.42	239	15.3
Construction	5207	27.67	604	38.7
	18.855	100.00	1560	100.0

3. THE PHYSICAL ENVIRONMENT

3.1 Climate

The climate of the northern Adriatic Italian coast is temperate (the annual temperature is below 23°). The range Alps, pre-Alps and the Adriatic Sea have a considerable influence on climate, the former on rainfall, the latter in moderating temperature (the average yearly temperature of seawater is 3° C higher than the average yearly temperature in Venice).

Relatively mild winters characterize all the coastal belt from Chioggia to Monfalcone and the NE Friuli plain, with average temperatures around 2° C. January temperatures along the Romagna coast are 2°-3° C, the lowest temperatures (2°) occur in the Po delta and the lower Veneto plain. The average summer temperature in the coastal belt is 23° C, tending to be higher (>24° C) in the Po delta and the Romagna hinterland (Fig. 3.1).

The annual yearly precipitation at the coast is about 600 mm, less in the Po Delta (< 500 mm, where it is insufficient for agriculture), higher (700-800 mm) over the Venice Lagoon and in Romagna. The rainfall maxima, NE of the Po river, are in spring (April-June) and a larger one, in the autumn (October-November), while in Romagna the peaks are in spring (May) and in autumn-winter (Fig. 3.2). In the Veneto and Friuli regions the amount of precipitation gradually increases towards the north and northeast to averages of 1000 mm/year (e.g. 1035 mm/y at Portogruaro), and of 2000 mm or more, over the Pre-Alps, especially over the eastern Julian Alps (Fig. 3.3). The precipitations are concentrated in the autumn early winter months. Snow and rain over the Romagna-Emilia Appennines amount to 1000/1500 mm a year, with maxima in autumn and spring.

Fog is a common winter feature of the coastal lowlands from Ravenna to the Po delta, with averages of 70-90 days a year in the belt from Venice to the Marano Lagoon, and a maximum of over 160/days/a year in the lower course of the Piave river (Fig. 3.5).

Air circulation patterns are paramount to the distribution of rainfall and to the directions of storms and of the wind-generated waves that attack the coast. Orographic precipitation over Friuli and the Veneto Pre-Alps is due to winds both from SW and SE; over the Apennine mountains, also to the NE winds, after they have crossed the Adriatic.

In winter and in spring low pressure systems characteristically form in the Gulf of Genova, over the Ligurian Sea and move northeastwards guided by the alpine highlands. Factors that play a role in the development of these depressions are the thermal contrast between land and sea, which affects the pattern and development of surface pressure; the interaction between the Polar Front and the sub-tropical jet streams; the enhancing effect of the Alps on the cyclogentic activity along their southern slopes, under a northerly flow; the effect of terrain features on cyclone formation; and the blocking of cold fronts along the northern rim of the Alps (Fig. 3.6).

At other times, in winter, a high pressure field over central-eastern Europe frequently causes the descent of cold air masses, attracted by the Mediterranean (or local Adriatic) depressions (Fig. 3.7). These NE winds, very cold and dry, spill over onto the Adriatic area and northern Italy, funnelled as they are through the alpine passes and valleys. The winds may reach velocities over 100 km/h and last for days. The dominant winter to spring winds are from NE (Bora).

The winds from south and southeast, which blow humid air up the Adriatic Sea, can reach high velocities, and given the long fetch, can raise substantial waves. Storms occur predominantly in winter and spring, from NE, SW and SE.

In spring the NE winds become weaker and gradually shift to SE. The summer winds are weak, from the east, southeast and southwest. Local day winds (sea breezes) reach far inland. In autumn the wind generally blows from the northwest.

For the last 100 years in the Romagna coast (Ravenna) studies of wind records, have yielded no indications of periodicity (Cencini et al, 1979). On the other hand at Lido di Venezia a change in predominant wind direction has been noted in the last decade, in comparison to the previous one, when the south and southeast winds were less frequent than the NE winds.

Regarding variability of climate during the last several decades, though records of temperature, rainfall and wind directions are available (Servizio Metereologico) no specific studies have been made, at least published, so far. A comparative analysis also needs to be carried out of catastrophic events (e.g. exceptional rainfall associated with storm surges).

3.2. Physical oceanography

The Adriatic Sea (138.595 km^2, volume 34,977 km^3, average depth 173 m) constitutes a rather individual unit of the Mediterranean (through dynamically connected with it), because of the special features of its northern part: low depths, marked temperature variations, and the low salinities due to the fresh water discharge of many rivers (one third of all freshwater supplied to the Mediterranean).

The central and southern basins of the Adriatic are deeper, are partially separated by sills, and display in general many of the characters and the circulation typical of deep seas.

3.2.1. Topography and sediments

In the northern part of the basin, the sea bottom slopes gently (0.6 m/km) to the depth of 75 m at the latitude of Ancona. Depths between Istria and Rimini are generally under 40 m (Fig. 1.1). Steeper slopes occur only off the coasts, for a distance of ± 10 km; a general slope break occurs at -20 to -25 m along the entire coast, marking the lower edge of the holocene sedimentary prism.

Irregularities occur near to the north coast, such as offshore banks with elevations of up to 5 m which have been interpreted as either ancient coastal dunes (e.g. north of the Po delta), or relict deltaic accretional or erosional features (e.g. south of the stretch from Isonzo to Marano lagoon). Further south and in deeper water, there are remnants of terraces and beaches, related to stages of the retreat of the Late Pleistocene shorelines (Colantoni et al, 1979).

The bottom sediments of the northern Adriatic are relict sands (medium to fine grained, generally 1 m thick exceptionally 5-6 m) away from the coast and related to the Pleistocene transgression, and modern sands, i.e. derived from the rivers since 6000 years BP. The Po contribution has been much greater than that of the other rivers, since its solid discharge is 10-20 larger. A coastal belt of sand to depth 6-10 m is followed by a belt of clays and silts 30-50 km wide, derived mainly from the dispersal of the Po finer load to SE and south (secondarily of the other rivers), and a mixed belt of more sandy clay-silts (Colantoni and Galignani, 1978, 1989) (Fig. 3.9).

3.2.2. Salinity and currents

The main factors in the development of the Adriatic current systems are the geographical spread of the sea, the distribution of water densities, the Earth's rotation and friction, and the fresh-water input at the northern end (Mosetti, 1984). Currents in the Adriatic are mainly gradient currents due to density contrasts, as well as tidal and wind drift currents. Water from the Mediterranean through the Otranto channel, with a constant salinity of 38°/oo, becomes progressively diluted to 32°/oo near the Po delta. The more saline Mediterranean waters dip northwards in the central Adriatic; this saline mass progressively becomes diluted and dies out in the shallower northern Adriatic.

The water of the north basin is strongly subjected to density and temperature variations, as shown below:

	Temperature	Salinity	Density
Summer :	26° C	32°/oo	20,8 (north)
	22° C	38°/oo	26,5 (south)
Winter :	6° C	36°/oo	28,4 (north)
	14° C	38°/oo	28,5 (south)

Because of the density gradient, a slope is formed in the free surface of the sea, with a difference of as much as 20 cm from NW to SE. A slope exists also between the less dense coastal waters and those offshore.

Surface waters therefore flow outwards, to SE, with a deflection to the west side of the basin, caused by the Earth's rotation (fig. 3.10). This flow is balanced by an inflow of (intermediate) waters up the eastern side of the Adriatic. Thus, at the surface a general anticlockwise circulation is developed. The flow of these gradient currents, however, is seasonal, faster in summer (velocities in the order of 25 cm/sec, increased to 50 cm/sec by tidal movements), slower to almost nil, in winter.

In the northern Adriatic basin the discharge of freshwater and the seasonal temperature changes lead to strong density differences between winter and summer (Fig. 3.11).

In winter, the water density is high and prevents the spread of the cold, diluted river waters. More saline and warmer waters occur in the rest of the basin. Loss of heat at the surface and mechanical mixing generally keep the water column in a state of complete instability. There are no areas of stagnation.

At the beginning of spring the inversion of the thermal flux causes the formation of a thermoclyne; the greater stability of the surface layer favours the progressive spread of a warm and diluted layer over a large part of the northern basin. In summer this is separated from the underlying water by a pycnocline.

Nearshore circulation in the northern Adriatic is locally complex, as it is conditioned by various factors: longshore currents, river discharge plumes, tidal currents, and the impacts of fixed structures, especially the long jetties at river and lagoonal outlets (Fig. 3.13). The freshwater plume of the Isonzo flows essentially SE, secondarily to NE and SW, those of the Tagliamento and Piave rivers to SW. The current off the Adige moves to the NE (with a velocity of as much as 80 cm sec), but turns south after a few km.

The high spring and autumn discharge of the Po river flows mainly to the east, with velocities of 18 to 100 cm/sec; after losing momentum, the main current turns south. A part of the river plume, however, diverges fan-like to NE and to SW, causing both a cyclonic vortex (in the north) and a clockwise one (in the south), with the trapping of domes of colder and denser water (Fig. ...). The Po discharge has a strong influence on the oceanographic conditions in front of the Romagna coast, by isolating a wide belt of nearshore waters. Summer stagnation is common; it is broken only by strong NE winds which cause mixing, or by SW winds (Libeccio) which may induce upwelling (Fig. 3.14).

3.2.3 Waves

The wave regime that affect the coastline of the Italian side of the northern Adriatic are related to the NE, SE and SW winds. Because of its changing orientation, the different parts of the coast are differently affected. The most important storms are from the S and SE (Scirocco), causing a high wave energy concentration on the Venice to Tagliamento coast (ref. the flooding of the Nov. 1966 storm surges). One year of measurements 15 km off Venice at 16 m depth indicated (Cavaleri et al., 1971) a 26% of Bora directions, versus 50,4% of Scirocco directions. In Romagna the frequency of SE waves is also double that of NE waves, but the latter can create wave heights to 3-6 m.

Because of gentle slopes, surf conditions in the north Adriatic develop far offshore. During major storms, waves affect the bottom 3.5-4.5 km off the shore in the north, 4-7 km in north Romagna to a depth of 10 m. In Friuli there are several wave refraction types for the different wave directions, and considerable energy concentration due to refraction of the S, SE waves (Brambati, 1967).

In addition, the narrow elongated shape of the Adriatic can induce wave reflections from the basin sides, creating confused sea conditions, not always directly related to existing meteorological conditions (Morelli, 1984).

There seems to have been some cyclicity in the frequency of storm waves from either the Bora or Scirocco directions. For instance, at Lido (Venice) the great storm surges of the 60's came from SE, but this direction had become less important in the 1970's (Gatto, 1984). A similar situation has been noted at Marina di Ravenna (Cencini et al, 1979).

It has also been stated that there has been an increase in storminess, with greater incidence of storm surges in the last two decades (Brambati, 1984).

3.2.4 Sea level variations

Tides and seiches are the predominant features of sea level fluctuations in the Adriatic basin. Because of its enclosed shape, the Adriatic Sea oscillates, the whole, or single parts, in a complex way. Resonances develop with periods close to those of diurnal and semi-diurnal tides, but there are also minor tidal oscillations (ter and quarter-diurnal), transversal oscillations, and long-period (50-70 h) tides, which are felt even in rivers and groundwater (Mosetti, 1985). The non-tidal oscillations are free (seiches) or forced (storm surges).

The semi-diurnal tidal amplitude increases not in a simple manner, from SE to NW, with a positive, counterclockwise, amphidromic point located off Ancona (Fig. 3.10). The spring tide elevations are 85 cm at Trieste, 88 at Grado, 72 at Lido, 60 cm at the Po delta.

The seiches are always present in the Adriatic Sea, but of different impact. Those that are superimposed on the rising of the sea level above the mean value, due to wind action, have greater amplitude, and are of importance in association with storm surges. In the Adriatic Sea seiches behave in close agreement with the tides, with corresponding periods. The largest amplitudes of seiches occur in coincidence with the strongest atmospheric disturbances; the seiches contribute then to cause severe damage to the coasts.

In the northern lagoons the elevation and the spread of tidal waters is strongly influenced by the depth of the access channels, by the complex network of canals that digitate from them, by depth distribution and especially the extent of tidal flats.

A considerable rise of sea-level due to the combination of tide and other effects, occurs generally between October and April, with a prevalence (60%) in November and December, at times of atmospheric depression in the northern Adriatic. Seiches, in association with Bora or Scirocco winds, elevate the high tide levels to over 1.80 m.

Lately, water surges of 130 cm (even of 200 cm) in the Marano lagoon and of 1,95 cm in the Venice lagoon, have been registered. Venice has been increasingly affected by this tidal flooding ("acque alte") (Fig. 3.15). Since 1972 the increase of the average tidal level has been at least of 40 cm (Pirazzoli, 1983). A part of this value (14 cm) has been attributed to an increase in the tidal oscillation, but 27 cm have been caused by a relative local rise of sea-level, due to land subsidence (3-7 cm for general geological reasons, 14 cm due to ground water extraction). In the last 30 years the tidal range inside the Venice lagoon has become larger by 10 cm than outside. This is related to a reduction of the surface area of the lagoon and to the deepening of its outlets. In addition to the general trend of tidal increase there are 20-30 cm high decennial oscillations attributed to the 16.6 year cycle of lunar declination (Pirazzoli, 1983).

3.2.5. Pollution and eutrophication

The quality of the waters of the Adriatic sea is considered satisfactory in broad terms. The extensive mixing that occurs in the autumn and winter still allows, generally, for good quality conditions, comparable at least to those of the Mediterranean Sea. Under particular local conditions and in areas close to the shoreline, however, eutrophic conditions arise with strong and frequent algal blooms.

The low salinity of the polluted waters coming from the Po and the other rivers, causes stratification, with a high concentrations of nutrients at the surface, thereby favouring the development of different species of algae, in particular diatoms and dinoflagellates.

The pollution sources are spread over a very wide tributary catchment area of more than 70.000 km^2 and are due mainly to municipal sewers (ref. about 25 million inhabitants), to industrial wastes (which are even larger than the urban load), and to zootechnical wastes. In summer, the sewer systems of the coastal resorts also became important pollutant sources.

A wide area close to the coast of Veneto, Romagna and the Marche is considered as eutrophicated up to 60 km from the shoreline, due to the high concentration of chlorophyll and nutrients (Fig. 3.16, 3.17).

Red tides, or more generally, algal blooms, have been well known in the Adriatic Sea since the last century but have become more common in the Emilia Romagna coastal waters since 1975. The general trend is for blooms of diatoms to develop at the end of winter in both coastal and open waters, while Dinoflagellate blooms reach maximum intensities between August and October. By the end of summer the red algal blooms jeopardize the tourist activity of the Romagna resorts, giving rise to anoxic conditions with stinking waters and mass kills of fish.

The effective management of water quality in the upper Adriatic is still an unresolved problem. At present, the contamination of inland waters is still increasing and consequently algal blooms have become more frequent and widespread.

4. GEOLOGY AND GEOMORPHOLOGY

4.1. The formation of the lowlands

At the beginning of the Pleistocene (1.200.000 years before present) the sea formed a wide marine gulf extending far into the Po valley. Active geological subsidence contributed to the accumulation of 1500-2000 m of fluvial marine sands, clays and silts. The Subsidence was influenced by the continuing deformation of the folds of the external, Padan Apennines, with a migration from SW to NE of the axis of major sediment accumulation, possibly even influencing the shift to NE of the Po system channels in the region between Ravenna and Ferrara (Veggiani, 1974).

The oscillations of sea-level in the period 600,000 to 20,000 years ago, related to the climatic shifts between the warmer optima, with their high sea levels, and the glacial minima corresponding to ice-caps expansions and low sea levels, resulted in a series of marine transgressions and regressions. At the peak of the Würmian glacial (80,000 years ago)the Adriatic sea stood about 100 below its present level, with a shoreline situated between Ancona and Zara. The northern Adriatic was a large alluvial plain crossed by a paleo-Po river system into which most of the other rivers tributed. The ensuing sea-level rise, corresponding to a gradual warming of the atmosphere, until the new climatic optimum of 6-5000 years ago, gradually shifted the shoreline northward, leaving a record of its progression in at least 17 submarine platforms, slope breaks and relict beach lines (ref. Colantoni et al, 1980).

At the maximum of the Holocene transgression (6-7000 BP) the sea had reached a line 5-20 km inland of the present coast (Fig. 4.1). With a decrease of the rate of sea level rise, and its stabilization (from 15 mm/y to 4 mm/y), a phase of active regression began. A prism of Holocene terrestrial, lagoonal and marginal marine sediments accumulated parallel to the present coast.

The coastal changes that followed can be traced in detail from morphological and historical evidence (Ciabatti, 1979; Fabbri, 1985; Veggiani, 1974). Between Venice and Ravenna in Etruscan and Roman times (3-2000 years BP) opened the mouths of several branches of the Po, Adige and Brenta rivers, with modest triangular deltas. In the lower Po valley region, from Chioggia to Ravenna, relict beach-dune ridges indicate the position of former shorelines and of at least ten cuspate deltas of Etruscan-Roman age (Fig. 4.2). These deltas were characterized by wide sandy beach zones, and had a low rate of advance (450 m/century).

The early phase of delta building continued until the XII century AD. The history of the modern Po delta began with a major flood break and channel switch that occurred in about 1155, west of Ferrara, the so called "Rotta di Ficarolo". Until that time the Po discharged south of the present delta through the Primaro (now the river Reno) and the Volano branches. The Ficarolo break diverted the main flow to east. In the XIV-XVII centuries there was a gradual buildup of discharge and bedload following greater upland rainfall (Ref. the "little ice age"), deforestation and increasing flood control (Zunica, 1978).

A further man-made deviation of the main Po channel, the Porto Viro cutoff of 1604, directed the river to SE, and a second one in 1770 from the northerly Po di Maestra branch, gave more importance to the southern Gnocca, Goro and Tolle branches. Finally, further regulation of the channel in 1870 emphasized the role of the present Pila Branch, as the main outlet of the Po. The post XVII century deltas were of lobate shape and characterized by rates of advance of 7 km/century (Fig. 4.2b).

Thus, the Po delta, as seen today, is a recent geomorphic development, the product of constricted river advance during the last four centuries. It could be considered to be almost an artificial body, due to the influence of growing anthropic activities in the basin (deforestation, expansion of agriculture, fixing of river beds), and to an increasingly guided and confined river discharge.

Regarding the origin of the lagoons, there is still no conclusive evidence that they (or some) were formed because of subsidence, associated with sea-level rise behind a beach barrier, or by the development of spits and barrier islands related to the advance of the various deltas of Veneto in combination with the westward littoral drift (Zunica, 1971, 1976; Favero, 1979,1986).

4.2. Coastal and lowland morphology

The coastal lowland considered in this report include the lower Po valley, Romagna and Veneto-Friuli plains and their wetlands, between the shore and the 2 m contour. The significance of this contour is that it lies quite closely to both the limit of a 100 cm sea-level rise, and the 3-5 m contours, along which are situated the main population and economic centers of the coastal region. The area of the 0-2 m surface amounts to .... km^2; of this ....% are lagoons, marshes and areas below sea level.

The coastal belt is composed of beach-dune barriers, live lagoons, salt and freshwater marshes, and of reclaimed lands (the remnants of former lagoons and interdistributary bays), separated by the more elevated channel systems of the many rivers that flow from the Alps and the North Apennines. The prominent coastal features are the cuspate deltas of the Isonzo, Tagliamento and the lobate delta of the Po.

The transversal fluvial ridges provide a convenient means of subdividing the lowlands concerned into seven sections.

1. Monfalcone to Tagliamento

On the whole, study of beach morphology and wave parameters (Brambati <u>et al.</u>, 1978) indicates a lower wave energy in the Monfalcone Lignano stretch, than from Lignano to the Brenta river. The moderate wave energy is due to the presence of offshore bars, and also by an extensive shallow seabed between the emergent and the submarine beach. The offshore banks near Grado (Banco della Mula di Muggia) are remnants of the former Natissa delta (Fig. 4.3). East of Grado beaches are intermittent and narrow (< 30 m). The Isonzo birdfoot delta is fronted by mudflats; water depths is generally <1 m, for a width from few 100's to 1 km.

The Marano-Grado lagoon is divided into four basins by areas of tidal flats. Deep channels (5-6 m, up to 10 m) connect the lagoon to streams and drains that open to its inner margin. The lagoon is transversely crossed by a navigation canal from Lignano to Grado, part of the Litoranea Veneta canal system. The lagoon is closed by a series of barrier islands and sand banks (Fig. 4.3) which are very mobile. The islands of Martignano and San Andrea, in particular are easily washed over during storms (there are no defense structures).

The Porto di Grado and Porto Buso inlets are protected by .. m long jetties. The town of Grado is defended by a sea wall (1.5 km long, 2.5 m high) built by the Austrians in 1887. There are many parallel and normal defense structures built to check beach erosion.

The entire inner margin of the lagoon is lined by a dyke not less than 2 m high. In the strip of land (from <0 to 1 m) that lies east of the Tagliamento river, canal and road embankments rise generally 2-3 m above sea level.

2. From the Tagliamento to the Piave and Sile rivers

At the margin of the Tagliamento delta there are still dunes, or sandy high ground 2-6 m high. The beaches are narrow, with gentle profiles and offshore slopes of 0,8% (low tide uncovers the coastal sand bars, the high tide reaches the foot of the beach resorts buildings). The coastal barrier is interrupted by river mouths, and by the Caorle lagoon estuary (Porto Baseleghe).

The Caorle lagoon has an area of about 1700 ha with five fish basins, fed by the Nicesolo canal. Sedimentation at the outlet of this canal is causing reduced access of marine tidal waters, with consequent decrease of salinity in the lagoon.

The large inland area that lies <1, and is mostly below sea level (Fig. 4.4), is crossed transversely by the 1-2 m fluvial ridges of the Piave and Livenza rivers (the Piave embankments are 3-5 m high). In the Ongaro Inferiore reclamation only the main road rises to 1 m above sea level, but the entire margin of the Caorle lagoon, and the Lovi and Nicesolo canals, and the coast-parallel Litoranea Veneta canal, are lined by 2 m dikes.

3. The Venice lagoon and the coast to the Adige

The Venice lagoon measures 50 x 10 km (546 km^3), it is divided into three basins (north, central and southern) by "watersheds", areas of tidal flats (barene) which represent high ground historically associated with the former alluvial ridges of the Sile and Brenta rivers.

Depth varies from 1-3 m in the open basins to 15-20 m in the outlets and canals. The tidal channels are about 4-5 m to 10 m, deep, the intertidal areas usually are <1 m (± emergent at low tide). At the inner edge of the lagoon, salt marshes with freshwater lake basins form the less active part of the lagoon ("laguna morta").

The Lido basin (northern lagoon) is the largest 270 kmq and includes the islands of Venice, Murano, Burano, Sant' Erasmo. The Malamocco basin or central lagoon (160 kmq) is the one most affected by the excavation of the deep Canale dei Petroli, between Malamocco and Porto Marghera. The Chioggia basin, or south lagoon (116 kmq) is involved mainly in fishing and shellfish farming.

The Jesolo to Cavallino shore has a narrow beach zone (60 m) made of medium-fine grained sands, the beach slope is gentle (0,8°), the sands extend to 6-7 m depth (active sand bars lie at 2,5-3 m depth). There is a discontinuous line of 2-3 m dunes and the coast is lined by a long series of groins. The land behind the Cavallino coast has elevations of 0,5-1 m (roads are 2 m high). The inner margin of the north basin of the Venice lagoon is marked by the levees of the Sile and by the embankment of the road SS14, which are 2-5 m above sea level. The airport of Tessera, as well as the islands of Venice, Murano and Burano, are in average 2 m above S.L.; most of the area of Mestre and Porto Marghera has elevations of 2-3 m.

The lagoon of Venice and its barrier islands have been much modified (Fig. 4.5). Only a part of the original tidal flats and marshland remains; the rest is reclaimed land and 'valli' for aquaculture. The barrier islands have been altered by the erection of the 1.5 to 4 km long jetties and by seawalls (central part of Lido, the 'murazzi' of Pellestrina built in 1731-1777, which are 4 m high). The island of Lido has a natural elevation of 2-3 m. At Pellestrina there is no beach, the submerged lower beach face is very steep (1.5-2.3%) with sand bars at 3.8 m depth. The medium to find grained sands extend to 4-6 m water depth. The thickness of the barrier sands in the subsurface is 10-20 m (Fig. 4.6).

The SW margin of the Venice lagoon contains areas below sea level and under one meter above, but they are interrupted by the Chioggia-Mestre road (3 m elevation) and by the road Mira-Chioggia. These, and dikes along the Brenta and Bacchiglione rivers rise no less than 5 m above sea level.

The area of the Brenta-Adige deltas (Chioggia to Porto Caleri) is similar to the Tagliamento delta, with an external complex of beach ridges and a lagoonal area behind. The narrower foreshore is relatively steep (0.9%). The plain between the Adige-Brenta rivers and Cavazere is generally under sea level, but various embankments exist, namely the "Strada Romea" (S.S. 309) road and the railway Adria-Chioggia. Relict beach ridges reach an elevation of 4 m ,exceptionally of 8 m.

4. The Po delta

East of Strada Romea, the Po delta covers an area of .... km² with a ... km long shoreline from Porto Caleri to Volano. Essentially it can be divided into two parts (Fig. 4.7, 4.8). An external belt enclosed by a line of low sandy barrier islands, with lagoons, marshes, fish basins, and thin dikes, in the north; tidal flats and marshes in the east and SE; the Sacca Scardovari bay in the south. Foreshore beach profiles are gentle (0.4-0.8%), steeper only in front of Po di Pila. The present wetlands are almost entirely isolated and hydrologically controlled.

The internal belt is constituted of agricultural reclaimed lands all below sea level (depths are quite variable, frequently 2.5-3 m below sea level). In the west they are crossed by N-S, NNE, NNW trending sandy wooded ridges, remnants of ancient shorelines that stand at 0-1 m elevations (e.g. Bosco Mesola). The ridges are discontinuous, because flattened at many places by sand removal for agricultural use. The outer margins of the agricultural lands and all river branches are lined by levees and dikes, the highest along the Pila (3.8-4 m), the Gnocca (2.5 to ± 3 m) and Goro (2-2.5 m) branches. The elevation of the smaller dikes is 0-1 m to +1.5 m. There are no defense structures at the outer edge of the Po delta, and no tourist developments. The most prominent construction is the ENEL (Electricity Board) thermo-electric plant at Polesine Camerini on the Pila branch. Because of increased subsidence in the central part, the Po delta surface has now a concave shape with the outer margins slightly emergent.

5. The lowland between the Po, Ferrara and the Reno

Much of the region west of Ferrara was lagoonal until 1870, the beginning of land reclamation. Most was lowlying basins with poor drainage, with lagoons north of Po di Volano, some freshwater. Reclamation (Grande Bonifica Ferrarese) was carried out in stages (1870-1890, 1919-1935, 1953-1967), what is left now of the wetland system lies between Argine Agosta and the littoral barrier. The Comacchio 'valli' system was brackish, but not a lagoon (there were no tidal flats), it covered an area of 293 km^2. The Comacchio lagoon of today has an area of 106 km^2.

In the Valle di Mezzano depth was 50 cm, most of the reclaimed area that has replaced it, lies now at -1.5 to -3.5 m. Most roads and towns in this reclaimed area (e.g. Comacchio, Lagosanto) are barely above sea level, up to 1 meter.

Except near the coast, the ancient beach ridges are of negligible elevation, due to subsidence. The Strada Romea is mostly <1 m. Inland, the main elevated structures are normal to the coast (the Ferrara - Porto Garibaldi motorway, the dikes along Po di Volano and the Ferrara to Porto Garibaldi navigation canal). An exception is the road Ariano Polesine to Codigoro which follows a former stream channel.

6. Reno to Cervia lowland

South of the river Reno, the main areas of low elevation (<1 m and below sea level) lie north (Colmata di Lamone), SE of Ravenna (west of the Classe beach ridge) and in the vicinity of Marina di Ravenna (Fig. 4.9).

From Po di Volano to Cervia the 3-6 km wide coastal belt of Romagna is a series of beach ridges, presently covered by pine woods alternating with freshwater lakes north and marshland areas. In three-dimension, it is a body of transgressive beach sands (Fig. ....), 20-25 m thick, that passes laterally, to west, to peats and lagoonal clays.

The Romagna beaches, 80-100 m wide, are made of fine to very fine sand, finer-grained in the north than in the south (where gravel is present). Sand dunes (2-6 m) were well developed and almost continuous until a few decades ago. Now, the only stretches where they are still preserved are between Lido degli Scacchi and Porto Garibaldi, and between Comacchio and Ravenna (Fig. 4.11).

The coast, as well as the beach-dune ridges, are interrupted by the mouths of numerous, but modest rivers of Apenninic origin (Reno, Lamone, Fiumi Uniti, Ronco, Montone, Savio) and by the outlets of several canals of natural or artificial origin: Porto Garibaldi, Logonovo (Lido Estensi), the Bellocchio canal (N of Reno), the Candiano canal (Porto Corsini, which reaches Ravenna), the Tagliata canal and those of Milano Marittima, Cervia, Rimini. All the canals and rivers of the Romagna coast communicate with lagoons (the brackish 'pialassá), wetlands or low reclaimed areas that lie at ± 0 elevation or under sea-level.

Beach protection works are numerous, especially offshore breakwaters. The Porto Corsini jetties are >2600 m long to depth of 8 m. Other jetties occur at Cervia, Casal Borsetti, Porto Garibaldi and also at the outlets of Milano Marittima and Lagonovo canals. Urban constructions near the shore, account for 65% of the coast from Volano to Rimini.

4.3 Soils

The soils of the Veneto, Friuli and Romagna coastal lowland are essentially alluvial, or alluvial-hydromorphic, with saline tendencies near the lagoons. They may be sandy or argillaceous with (A)C or A-C profiles at least 1 m thick. In the reclaimed areas soils were initially acid (peats) and organic rich, but with low permeabilities.

In the region NE of Venice (Fig. 4.2) the following pedologic units have been mapped:

(a) The sandy soils of the beach zone, with high porosity and a normal organic content;

(b) the soils of the former lagoons and swamps, which have a medium-low permeability and can be either sandy (a limited extent corresponding to former lagoonal channels and outlets), clayey-silty (with high to normal organic matter content), or humic-peaty and rich in organic matter;

(c) the alluvial soils, sandy-silty with medium permeability (organic matter: normal to good) that correspond to the distributary channels of the Piave, Livenza, Tagliamento, as well as the sandy gravelly soils of older channels of the Tagliamento:

(d) above the 3-4 m contour the soils of the plain are mainly argillaceous, with a low permeability, and correspond to the related modern and past interchannel floods of the main rivers (Fig. 4.13).

In the reclaimed areas of the Polesine and Ferrara-Comacchio region many parts that had peat and clay acid soils were improved by drainage with the Po calcareous waters and by rice paddy cultivation in the first years after reclamation. The soils of the Po delta and of the Romagna lower plain are essentially similar to those NE of Venice.

4.4. Subsidence

Subsidence at the edge of deltaic coastal plains is a common feature, due to the tectonic sinking of the depositional basin, and to the compaction of clays and peats. In the lower Padan Basin geological subsidence has been responsible for the accumulation of well over one thousand meters of Pleistocene sediments (Fig. 4.14).

In Venice geological subsidence has been estimated to be an average 1.3 mm/year. Exceptionally, at times during the Pleistocene it had reached peaks of 2.6 to 4.5 mm/year (Fontes and Bertolami, 1973). In the Po delta the greater rate of subsidence (5 mm/year between 1900 and 1950) and in the Comacchio-Goro region (3 mm/year) was compensated by sedimentation; the surface of the delta was ± at sea level. In the Ravenna region natural subsidence until the early 1950's was calculated to have been 2,5 mm/year (Bondesan et al, 1986).

Additional sinking, up to 1.3 m, had been recorded in most reclaimed lands in the years immediately following their drainage. This was attributed to a variety of causes; such as mechanical compaction after de-watering, the lowering of the water table, to chemical and volume reduction in clays (Bondesan, 1976).

Further, large areas near Venice in the Po delta and in the Ravenna regiona have experienced accelerated subsidence since the early 1950's, due to excessive extraction of ground water for industrial and urban use (Porto Marghera, Ravenna) and of methane-bearing waters (Po delta). In the Po delta, piezometric declines of 40 m were measured in aquifers 100-600 m deep, in the late 1950's. Subsidence reached in parts 30 cm/year (Fig. 4.15). Water extraction was in the order of 60 x 10^6 m^3 in 1950 increasing to 300 x 10^6 m^3 in 1959, from progressively deeper aquifers. In the region south of the delta precise levellings carried out in 1971 indicated a total sinking during the period 1950-1971 of 40 cm (Mezzogoro), 75 cm (Codigoro) and 123 cm (Ariano Polesine). Despite a halt to water extraction, in 1982 subsidence was still 2 cm/year.

The consequences of the increased subsidence were the reversal of hydraulic gradients in rivers and irrigation canals, with the need of adjustments to beds and embankments, the increased marine flooding of bays, and coastal erosion at the edges of the Po delta.

In Ravenna, land subsidence amounting to 1.2 m in the period 1955-1977, affected a gradually enlarged area (700 sq. km) inclusive not only of the city and its industrial estate, but also of the coast and the reclaimed marshlands (Carbognin et al., 1982; 1984) (Fig. 4.16). In Venice, water overpumping from aquifers 70-350 m deep, had lowered piezometric levels by 12 m between 1952 and 1969, producing a subsidence of 8 cm at Mestre, 14 cm at Porto Marghera and 10 cm in Venice (Carbognin et al., 1981; Gatto and Carbognin, 1981) (Fig. 4.17). The behaviour of the aquifers and of the groundwater surface is well known; by the end of the 70's most of the wells in Venice were ordered shut, the recovery of the flow field occurred fast, and subsidence was arrested almost instantaneously.

4.5 Present coastal processes

There have been a considerable number of detailed studies and reviews of the state of the NW Adriatic coast, starting with Zunica (1971, 1974). Later publications have dealt with the stretches NE of Venice (Brambati, 1984, 1987, Brambati et al, 1978), near Venice (Gatto, 1984), the Po delta (Bondesan and Simeoni, 1983) and the Romagna shoreline (Cencini et al, 1979, Bondesan et al, 1978, IDROSER, 1982).

At present all the Veneto and Romagna beaches are unstable, with retreat along most of the coast since the early 50's, even at the mouths of the Tagliamento, Adige-Brenta, Po and Reno (Fig. 4.18). At the Adige mouth a previous continuous growth of 6.5 m/y, stopped in 1950. Retreat has been significant especially since the stormy years of 1960-70.

In Romagna, a detailed survey of beach changes since 100 years (Bondesan et al., 1978) has shown that advance was common until about 1935, especially before 1915, at the exception of the stretch Reno mouth to Porto Corsini, in latter part of the XIX century, in correlation with the Reno sediment load deviation to the Colmata Lamone.

Afterwards the trend has been that of a general retreat, especially of the projecting deltas, a straightening of the shore and a steepening of the foreshore (Fig. 4.19). The retreat of the Fiumi Uniti beach has been 3 m year. Further north at Lido Adriano recession from 1957 to 1977 amounted to 126 m with destruction of pine woods, while at Punta Marina, retreat was 70 m. At both places, coastal erosion has coincided with land subsidence, 45 cm in the first case 35 cm in the latter (Carbognin et al., 1982, 1984).

At the edge of the Po delta most of the outer beaches and sand bars have been unstable for the last 30 years, either advancing or retreating. In the early 1980's (CNR 198.) the northern coast of the delta was mostly in a state of retreat, in the southern part advance was registered only downdrift of the (receding) mouths. Moreover, most of the marginal parts that before 1960 were marshes, tidal flats and sand bars, had returned to a lagoonal state.

Further north, the Pellestrina and Lido shores are affected by erosion, because they are cut off from the littoral sand movement by the Lido and Malamocco outlets jetties; there is a loss of beach and a deepening of the foreshore, with an irreversible retreat situation.

In the lagoon of Venice the central basin is now affected by intense bottom erosion. The islands have become unsettled and the remaining tidal flats are eroded. Occurrences of very high, but also low waters, have become more frequent.

The causes of shore instability and retreat are partly natural, partly the consequence of anthropic activities on the coast and in the hinterland. Natural erosion is the consequence of the removal of beach sand by strong littoral drift generated by the oblique SE or NE wave approach, of high (> 1.5 m) winter waves and of storm surges(± associated with high tides) and of eolian beach deflation in winter. This removal of sand however has not been balanced by sufficient inputs from rivers, or from offshore sources. A further cause of shore erosion have been the negative effects of fixed transversal structures, such as (piers, jetties, groins) that have unbalanced the longshore movement of sand.

In the northern Adriatic longshore currents move beach sands away from the river mouths, though not far (CNR, 1985). In general the sands remain close to the coast, forming a narrow band that extends to depth 10 m, beyond which the finer grained sediments are deposited (ref. Fig. 3.9). The sands of the Po, by far the largest river contribution, are dispersed both north and south, respectively as far as Porto Caleri and Porto Garibaldi. Dispersal from the Veneto-Friuli rivers is largely SW-ward, except for local divergences at the mouths of the Isonzo and Tagliamento. The Isonzo sands reach as far as Lignano (in this part there is also erosion of offshore shoals); the Tagliamento sands as far as Iesolo, the Piave sands to the Pellestrina beach. The Adige and Brenta sands on the other hand, as well as the Romagna sands, are moved northwards.

One of the principal causes of the observed shoreline retreat is the reduction of river sediment supply, principally due to lesser slope erosion (re-forestation, abandonment of farming and of plowing in hilly areas), to the retention of sediment in hydroelectric reservoirs, and lately also to the retention of the industrial dredging of sand from river beds, especially in the plains. In the period 1965-1973 the Po solid load had decreased from 16.9 mill. to 10.5 mill. tons/year. The bed load, a quarter of these figures, had become barely sufficient to satisfy the calculated sand budget of 3.1 mill. tons/year, necessary to keep the delta margin in equilibrium (Bondesan and Dal Cin, 1975, Dal Cin, 1983). Similarly, the solid discharge of the Isonzo, Tagliamento and Romagna rivers, has almost halved in the last decades, as compared to the years before 1950.

The dredging of sand from the Po river bed, officially given as 100 mill. tons for the period 1958-1981, is estimated to have been up to six times greater. In Romagna official 8 mill. tons for the period 1957-1971 is also quite short of reality. The sand yet still delivered to the sea by the Po come, in part from the erosion of the river bed itself, which has been lowered already by 5 meters. Sand input will substantially decrease, however, when engineering measures will have to be undertaken to prevent the bed from reaching below sea level. A sand deficit lasting at best 30 years, possibly even 100 years, is forecasted, even if all dredging operations were to be stopped.

To alleviate the direct impact of storm surges, and to maintain beaches, as well as to regulate the access to lagoons and harbours, seawall, offshore breakwaters, groins and jetties have been built extensively since the 1950's. The effect of these structures has been beneficial, or neutral at some places, but quite negative at others.

Quite disruptive of sediment movement have been all the fixed structures built normally to the coast (groins, jetties, piers). They do trap sediment "upstream", but generally sediment starvation and erosion take place in the "lee" (downdrift side). This is a common feature over the long stretches with groins between Iesolo and Lignano. In the Cavallino shoreline, beach retreat is accompanied by wave attack on the dunes, with a general weakening of the shore in the face of storm surges. Downdrift erosion occurs also west of natural offshore buildups, sandbars that have grown as the indirect result of groins built on the east side of river mouths (e.g. Piave, Tagliamento) to prevent their shoaling.

The construction of the jetties at the three Venice lagoon outlets, has changed the character of sediment movement with a strong accretion at the northern and southern ends (Fig. 3.13, 4.19). The jetties however deviate the littoral currents offshore, beyond the breaker zone, and there is no sediment bypass. Similar phenomena occur in correspondence of all the piers that armour the mouths of rivers and canal in Romagna. The offshore breakwaters that are common on the Romagna coast, are only initially successful, as they break the waves before reaching the beach. Beach retreat is stopped, but water tends to stagnate and sand to accumulate with the formation of tombolos. Gradually the space behind the breakwaters is filled, the beach is eliminated, and eventually the erosion process is resumed.

It must be concluded therefore, that Man's "management" of the coast and his activities in the hinterland, have generally contributed to the current loss of beaches, and at places to their degradation. The fixed structures erected during the last three decades, and the deep canals excavated in the lagoons, have considerably altered the hydrodynamic regimes of the low north Adriatic coast and of its lagoons. The lagoon of Venice, in particular is suffering from the increasing influence of the sea, e.g. higher tides and faster currents, with greater bottom erosion. The Po delta is undoubtedly in a precarious state: it is now outstretched, sediment-starved, unable to balance subsidence, and resisting wave action only by the protection of dikes along its entire perimeter.

5. WATER RESOURCES

Water in the lower plains of NE Italy is provided by rainfall, surface flow (rivers, canals, lagoons) and underground aquifers. In the past, rainfall over the Apennines and the Prealps had been sufficient to maintain a flow of surface waters, through rivers, and to recharge aquifers in the Pleistocene deposits, from the Prealps and Apennines foothills seaward. Considerable modifications have occurred in the natural flows, in consequence of flood control operations, the retention of water in reservoirs for electric power generation, and in the last decades, to a vastly increased water extraction for irrigation, industry and domestic use (the respective rates of consumption are at present of about 56%, 28% and 16%). The management of rivers, however, had been a necessity since centuries, because of the frequent floods due to the highly seasonal river discharges and to the raised river beds, and the needs of agriculture and of inland navigation.

Lately, as river regimes have been altered, dependence on groundwater has grown considerably. Pollution problems have arisen during the summer, when much of the surface flow is derived from waste waters returned to the rivers.

Water resources are on the whole satisfactory in the Veneto and Friuli regions, because of high precipitation over the eastern Alps and Prealps. In Romagna there is a scarcity of water. Rainfall is ill-distributed throughout the year, there are no natural reservoirs in the Apennines, and the streams have torrential regimes, with very little flow in summer. What rainwater is not evaporated, it runs rapidly through the river courses or percolates into the subsurface aquifers. In the Emilia-Romagna region, it has been calculated that out of a total of 9 bill. m^3 of precipitation water, 49% is surface flow, 25% is lost through evapo-transpiration, 25% percolates into the ground (10% reaching the deep aquifers) and 4% is retained by surface ponding, plants and soils (IDROSER, 1977).

5.1 River regimes

In Veneto and Friuli, surface waters are derived, besides from local rainfall and runoff, from rivers with different types of regimes.

1. Alpine rivers, like Isonzo, Tagliamento and Adige have regimes with discharge peaks conditioned by the late spring snow melting and rainfall, and by the autumn rainfall
(Fig. 5.1 Adige).

2. The rivers sourced in the Prealps, like the Piave, have a regime that is entirely rainfall-dependent with a principal discharge peak in October-November, a secondary one in April-May, and lows in winter and summer. The waters of the Piave are extensively held back by many hydroelectrics reservoirs (in the 1960's, 42% of the drainage system of Veneto was affected by reservoirs).

3. The rivers that originate in the 'risorgive' belt, at the edge of the plain (Livenza, Sile, Bacchiglione, Dese, Marzanego, Tartaro, etc.) (Fig. 5.2) flow more regularly through the year. Systematic discharge data for these, and other rivers, are lacking; furthermore all measurements stations on the major rivers are located no less than 50 km from the sea.

In the Veneto-Friuli foothill belt, upstream of the "risorgive" line, the major streams fluctuate over wide gravelly beds, losing at times a large percentage of their discharge. In this zone of high soil permeability, there is no surface drainage network related to meteoric waters, but a dense network of artificial irrigation canals.

In the plain there are many closely spaced natural streams, mostly derived from the 'risorgive'; few of them flow into the alpine-prealpine rivers, which are strongly bounded by levees. There is also a dense network of rainfall drainage ditches. In consequence of the alteration of natural river flows, and of the intense use of water, streams in this part of the plain are particularly liable to pollution.

In the coastal lowlands, water flow is attained by mechanical uplift, and near the coast, the stream regimes are influenced by the tidal oscillation; the inland extension of saltwedges prevents the use of river water for irrigation and domestic consumption. Parallel with the coast between the Tagliamento and Po di Levante, there is a network of navigation canals, which are also used as agricultural drains.

The middle and lower plain of Veneto-Friuli was considerably affected by flooding, caused by the exceptional rainfall event of 4-5 Nov. 1966 (Fig. 5.3). Flooding appears to have been only in part controlled by topography; an important factor was also the obstruction of water flow by elevated embankments of all kinds. Near the coast, river flooding was accentuated by an exceptionally high tide (1.94 m above sea level, for 11 hours above 1.5 m).

The river Po is unique. Its complex regime reflects the partial compensation of the contributions of many effluents, from areas of different precipitation types (Fig. 5.4). The river drains a basin of 70.000 km^2, in which the highest mean annual rainfall is 1120 to 2000 mm (Nelson, 1970; Mioni <u>et al)</u> (Table 4.1). The Po separates the river regimes of Alpine type (winter lows and May-July maxima) and Apenninic type (March-April maxima, summer minima). The Western and Maritime Alps have a mixed rainfall regime, with two maxima and two minima yearly.

Thus the discharge regime of the Po (Fig. 5.1) (Table 4.1) displays a smaller difference between maxima and minima than the other rivers. In the lowest reaches the river used to have discharge peaks in May-June and November, lows in January-February and in August (Table 4.1). However, both water discharge and solid load have been seriously hampered by human intervention. Summer discharge have been considerably reduced by retention of water in the mountain reservoirs; the amount missing (Pontelagoscuro) was calculated to be as much as 130 to 210 m^3/sec (Bevilacqua and Mattana, 1976). The consequences of this reduction of flow are quite serious: navigation problems in the lower course of the river; pollution from agricultural and industrial waste waters; the further upstream migration of the salt wedge, with impacts on the intakes of fresh water for irrigation, and of water for the regulation of aquaculture basins in the Po delta.

Table 4.1

Discharge variability of the River Po
at Pontelagoscuro (m^3/sec)

	1918-1979	1978	1979	1980
JANUARY	1190	1970	1150	1510
FEBRUARY	1230	1650	1690	1450
MARCH	1500	2880	1830	1790
APRIL	1590	2070	1630	1220
MAY	1840	2980	1170	1330
JUNE	1810	2660	1400	2120
JULY	1200	1580	762	1170
AUGUST	937	1370	1020	815
SEPTEMBER	1250	942	1200	958
OCTOBER	1620	1090	3160	1540
NOVEMBER	1980	815	2220	1450
DECEMBER	1470	988	1500	1160

As the Po, like the other rivers of the Adriatic coastal plain, has an elevated bed, flooding has been a common occurrence; a break at Pontelagoscuro in 1951 affected 2/3 of the Polesine region. In spite of all the river flow control works, it could be that floods have become more frequent (e.g. 22 flood breaks between 1951 and 1966, as compared to 10-22 floods per century from the XVI to the XIX centuries). This could derive from a combination of upstream mismanagements, and a greater incidence of erratic climatic events.

The regimes of the Reno and Senio, and the entity of discharge of the other Romagna rivers, are shown by Fig. 5.1 and Table 5.2. These rivers have a torrential regime, and are almost dry in summer. The extent of water extraction is such (156 mill. m^3/y for industrial and urban use alone in 1975) that in the Romagna plain they are now a) straightened, canalized, and instead of drainage flow collectors have become watersheds; b) they are mostly used as waste disposal ducts, with deleterious consequences for water quality (Table 5.2). Because of the torrential regimes, and of the elevated river beds, flooding has been a frequent event, not only in past centuries, but also in recent years. Several tracts of the rivers are under active erosion, with levees in danger of undercutting, especially through the parts of the plain that are affected by land subsidence (Fig. 5.4, 5.5).

Table 5.2.

Discharge and water quality of Romagna rivers

	Water discharge m^3/sec			Solid load	Water quality		
	yearly	min	max	kg/m^3	Mediocre	Poor	V.poor
Po di Goro	150			?	x		
Po di Volano				?		x	
Reno[1]	59	6.66	119	1.4			x
Senio[2]	3.2			2.3			x
Lamone[3]	8.8	0.90	19.3	1.8			x
Fiumi Uniti[4]	20.5	1.95	39	3			x
Savio[5]	10.8	1.04	21	5.1	x		
Rubicone	2.1	0.13	4.5	?			x
Marecchia	6.1	-	-	?	x		

[1] Years of measurements (respect. discharge - solid load) : 35-30
[2] 20-20
[3] 26-7
[4] 45-18
[5] 35-5

(From: Servizio Idrografico, Annali Idrologici, 1978; Marchetti, 1985

5.2. Underground waters

Fig. 5.6 shows schematically the distribution of aquifers under the Venetian plain. In the foothill region there is a coarse conglomeratic blanket derived from the amalgamation of fans constructed by the Tagliamento, Piave, Brenta, Astico and Adige rivers. This "Undifferentiated Freatic Aquifer" (up to 400 m thick, average permeability of 10^{-3} m/sec) is intensely exploited. The water table is situated at considerable depth near the Prealps foothills, but gradually it comes to the surface southwards, and outcrops at the Risorgive Line of springs.

In the lower-middle plain there is a surface freatic aquifer 50-80 m thick with permeabilities of 10^{-3} to 10^{-4} m^3/sec. At depth there is an alternation of fluviatile sands and silt-clays (few marine clay intercalations) that form a multi-aquifer system, 100-250 m thick, with confined water tables (Lower Confined Aquifer). Permeabilities range from 10^{-3} to 10^{-5} m^3/sec.

The basal limits of the confined Pleistocene Aquifer are the Pliocene clays aquitard, as well as the top of brackish or salt water saturation (in deep wells at the coast this discontinuity lies at depth 150-270 m; in the Po delta at 150-200 m) (Fig. 5.7).

The recharge of the Undifferentiated Aquifer is from the main rivers, from rainfall percolation, and from the infiltration of irrigation waters. The flow of the aquifer is closely related to that of the streams, with two peaks, in spring and autumn, and two lows. The natural discharge of the Undifferentiated Aquifer is through the risorgive springs (average 42 m^3/sec), and to the aquifers of the middle and lower plain.

In addition to lateral flow from the Undifferentiated Aquifer the upper freatic aquifer is fed to a limited extend from percolation of surface waters. The recharge of the Lower Confined Aquifer comes from the lateral flow of the Undifferentiated Aquifer and by leakage through the aquitards. The Undifferentiated Freatic Aquifer and the Lower Confined Aquifer are the main, and much used, groundwater resources of Veneto-Friuli. However, groundwater is suitable for drinking only from the former (i.e. not in the coastal lowlands).

In the Venice-Mestre region six deep aquifers were the most exploited until the late 70's (Fig. 5.8). The area requirement of $\pm$ 7000 1/sec (2/3 for industrial use) is now almost entirely supplied by aqueducts from the Sile and Livenza rivers. The piezometric recovery following the halt of excessive (200 1/sec) pumping has not been attributed to increased recharge, since after the 1970's the natural supply of water in the recharge areas is said to have been decreasing (Carbognin et al., 1981).

In Romagna, particularly in the Ravenna area, the aquifer system is known to the depth of 500 m with well identified silty sandy units between -90 and-430 m (Fig. 5.8). Aquifers in the upper zone are little exploited, as they contain less water and are contaminated by the polluted unconfined surface aquifer. Below 430 m the salt content is very high. The aquitards are very continuous. The aquifers consist of medium-fine sands; marine clay and silts may be present, reducing permeability. Recharge is from the foothills of the Appennines, and from the Po river basin, but the entity of the respective contribution is unknown.

5.3. Pollution of surface and lagoonal waters

The Venice lagoon is subject to a massive inflow of urban industrial and agricultural waste products as the surrounding area has a high population density and high industrial and agricultural activities. The load of pollutants far surpasses the self-cleaning capacity of the lagoonal system; their dilution and dispersal depends entirely on tidal flushing, which however has not the same degree of effectiveness over the entire lagoonal surface. The degree of pollution in the three lagoonal basins varies considerably. The flushing waters derive, anyway, from the north Adriatic, which is itself affected by various inputs of pollutants.

As regards urban pollution, from the inhabited islands and 20 freshwater inlets from surrounding lands, the amount of oxygen required to oxidize and regenerate the organic matter produced by 10 mill. people has been calculated 53.6 ton/day. In areas with oxygen depletion, or in special circumstances, ammonia and suphides produce environments favourable to the development of pathogenous bacteria; thus large areas of the lagoons have been found to be unsuitable for mollusc farming. Large quantities of nitrogen and phosphorus are also discharged (3970 tons/year and 1096 tons/year, respectively in 1975); 50% of the phosphorus comes from detergents. In certain parts, these inputs periodically cause eutrophic conditions.

Industrial pollution is due mainly to the Porto Marghera industries (where at least 60 plants produce highly polluting waste waters). There is a high concentration of aliphatic hydrocarbons, of aromatic polynucleids, cyanide, heavy metals (cobalt, copper, zinc, nickel, chrome, iron). Due to their insolubility the heavy metals end into the fine grained sediments and in animal tissues; considerable negative effects on the bottom fauna had been noted (Perin, 1975). Thermal pollution is also serious, especially in summer. Discharge of hot waters from thermo-electric plants increases water stratification and causes anoxic conditions.

Agricultural waste waters bring in large quantities of nitrates, phosphates, herbicides and pesticides. In the 70's it had been calculated that 5-20% of substances used in agriculture were washed by rainwater through drains and canals, into the lagoon, with phosphorus and nitrogen amounting to 51.7 t/y and 2642 t/y respectively.

Information available in the 70's indicated that the Venice lagoon was polluted beyond acceptable limits (Perin, 1975), but the gradient progressively decreased from the vicinity of the industrial area and the inner margins on the lagoon to the central basin east of Venice, the waters near Malamocco outlet, and the sea.

6. ECOSYSTEMS

6.1. Introduction

On the coast of NE Italy the original natural ecosystems of the littoral zone, and of the lowlands plains around the lagoons and the Po delta, have been profoundly modified by man, with land reclamation and agricultural expansion, but also by the spread of an increasingly artificial basin aquaculture, and the more recent tourist developments.

Remnants of natural environments in the zoned system from the shore to the lagoon inner margins still exist, in various more or less natural states, though much threatened by reclamation, urban and industrial developments and especially by pollution, in the lagoons of Venice, Gado-Marano and in the wetlands between Comacchio and Ravenna. Most of the external zones of the Po delta (beaches and sand bars, lagoons) have not been affected by tourism. Vegetational oases occur along the margins of canals, rivers and fish basins.

Little remains of the mesophyle woods of oak, ash and carpinus that once covered the Po valley and the Veneto plains. Tiny remnants of woodland exist in Friuli-Venezia Giulia, Veneto (eg. Cavallino, Nordio, Carpinedo) somewhat larger woods survive in the Po delta (Mesola) and in Romagna (San Vitale) (Fig. 6.1).

Nature conservation and protection is still on a limited scale. Though the major lagoons and the external parts of the Po delta (ref. fig. 2.1 and 6.2) are scheduled for protection as nature reserves or a national park, little has been achieved so far. South of the Venice lagoon, only a small percentage of the area of the proposed Po Delta National Park is actually protected (2318 ha versus 25,000 km^2 of wetlands). Nature reserves are of various type, managed by local authorities, the State (Ministry of Forests), even privately, as restricted hunting reserves. After two decades of detailed studies and discussions regarding the creation of the Po delta National Park, all that seems to have been accomplished is the construction of a large thermo-electric power station at the mouth of the Po di Pila!

The deep transformations and alterations of the lagoons and their marginal lands have considerably reduced the survival possibilities of many mammals, those that generally live in or near aquatic, in particular freshwater ecosystems. The otter for instance has entirely disappeared. There has also been a notable decrease of those woodland species that until a decade or two ago lived in the relict woods of the plain, or in limited niches amidst the agricultural areas, such as hedges, wooded river and drains margins, and in private parks. Hunting has drastically reduced the number of surviving carnivores, while the escalating use of agricultural pesticides has had a negative impact on bats.

Surviving characteristic small mammals are insectivores (Neomys anomalus and N. fodiens), the porcupine (Ericnaceous europeus), rodents (Crocidura, Sorex, Soncus, Muscardinus avellanarius) and the nutria (Myocastor coypus), a species introduced from South America.

The number of nesting birds has shrunk due to the disappearance of special environments, such as the oak woods of the plain, and the freshwater swamps and wet meadows at the margin of the lagoons; within the lagoons, many areas of tidal flats, salt marshes, and reed beds, where many wintering birds feed.

The Po delta and the other coastal wetlands are host to thousands of migrating bird species, which converge there through the central European route and the southern, Carpatho-Danubian route (Fig. 6.3). The latter is quantitatively the most important for ducks and waterfowl, plovers, ardeids etc. Many species of columbids, turdids, fringillids and passeriforms also winter there. The most important wintering species are swans (Cygnus cygnus and C. Olor) geese (Anser fabalis, A. albifrons) ducks (Anas, Aythia, Bucehala, Clangula, Mergus, etc), ardeids (Ardea cinerea, Egretta alba). More rare, wintering or nesting, are sterns, avocets, seagulls and Himanthopus himanthopus.

7. AN EVALUATION OF THE IMPACT OF CLIMATIC CHANGES

7.1 General

For the evaluation of the effects of higher temperatures and sea level on water resources, agriculture, fisheries, etc., the frequency and magnitude of climatic elements like temperature, air circulation and rainfall, should be known and a quantitative analysis made on a local or at least regional scale.

For the Mediterranean regions, there is also a need for climatic change models that could give information on how the weather there will be affected by altered larger-scale circulation patterns (e.g. North Atlantic Ocean, central and eastern Europe). Precipitation predictions need to be redefined, as they are still contradictory (Wigley, 1988).

Changed annual mean and seasonal temperatures, air circulation (e.g. greater of lesser cyclonic activity, and its directions), and precipitation would affect:

1. Surface and ground water flow and river regimes, (that is, the incidence of floods and the amount of sediment transported and delivered to the sea);

2. The movement of marine water masses , especially in terms of THE erosional impacts on the coasts and of water elevation in the lagoons.

3. The biological resources of the sea and lagoons.

4. The present patterns of man's occupation and use of the coastal lowlands, because of the altered parameters of agriculture, fishing, industry, tourism and the quality of the environment.

The impacts of climatic changes are likely to be felt gradually. Generally speaking, the first 2-3 decades would see modest environmental and geographical alterations. Nevertheless, extreme climatic events, probably occurring with greater frequency and even small increases in average temperature could have already significant impacts on ecosystems. Because of their ecological fragility, related to the land-sea transition, the wetlands would be most vulnerable.

Eventually changes will become more drastic in coastal physiography, surface waters, fauna and vegetation. Since temperature oscillations in the last 2,000 years have been within 0.5°-1°C at most, there is no doubt that increases of 3°-4° would have profound effects on agriculture and marine resources. The environment man will live in, in two to three generations from now will certainly be quite different from the one we are accustomed to today, and most likely the problems we face today will seem insignificant by comparison.

The physical impact of sea-level rise on a lowland coast are fairly predictable. They could even be modelled quantitatively on the basis of the present parameters of morphology, hydrodynamics, sediment budget, land subsidence and the effects of artificial structures. Equally, the impacts of altered rainfall distribution on surface and groundwater could be modelled quantitatively. The effects of increased air temperatures and of changed soil-water parameters on biosystems may be estimated, perhaps qualitatively, thus providing some idea of impacts on agriculture and fisheries.

What is much more difficult to estimate, however, is the impact of the physical and biological changes on the future socio-economic framework of the threatened lowlands.

The direct impact of the sea on the exposed coasts (e.g. the lagoonal coastal barriers, beach resorts) will cause shore erosion and retreat as well as damage to port, town and communication infrastructures; the transformation of lagoons into estuaries and indirectly the flooding of reclaimed lands; and salt wedges to move far inland in rivers.

Sea level increments <30cm could be considered to be moderate, because they could be coped with by progressive adjustments to existing coastal defences and by acceptance of modest losses. Larger increases (e.g. >50 cm) would certainly have catastrophic consequences, involving hard economic decisions about the cost of protection and political shore decisions about what to protect and what to abandon.

Analysis of the physical impacts is complicated, however, by the intense human occupation of the coastal zone and its enormously accrued economic value, and by the human interference with natural processes. In the lagoon of Venice a sequence of interventions through several centuries has substantially changed its evolution. If in the past the lagoon was threatened by a gradual filling by river sediments, now it has become dominated by factors of the sea with the threat of a change from a lagoonal to a marine estuary, due to the deepening of the outlets and the excavation of navigation canals, well before any augmentation of sea level.

The Po Delta is in a state of morphological instability and a high risk area in regard to natural disasters: the river branches have become too long and are all rigidly confined; the land tends to compact easily and to subside, there is no longer a compensation by flood sitting, and furthermore, there is a lack of sand in the river bed.

Present lowland uses are nevertheless enmeshed with the economy of north Italy and beyond. No return can be envisaged to the pre-development times and measures to protect the economy are inevitable. The countermeasures to be taken, however, are either a drastic and expensive, walling in of shores and lagoon margins, or the acceptance that choices must be made. These are between:

(a) irreplaceable coastal uses such as nationally important harbours, towns of historical-artistic value, lagoonal fishing or specialized agriculture;

(b) land uses that can be shifted elsewhere (e.g. industries, roads, airports);

(c) adaptations, such as different ways of beach recreation, and the replacement of extensive, uneconomical crops in sub zero lands, with lagoons destined to aquaculture.

Coastal zone management must be based on 'cost-effectiveness', an assessment of the 'value' of the threatened land uses. But, not only in terms of their present functions, in the context of the local needs and of the importance of the lowland concerned to its hinterland and farther, but especially those of decades ahead.

The local primary needs are determined by the present level of population and its trends of growth or decline; the wider economic role of the region is instead conditioned by external market forces. For instance, the future relevance of local industries, agriculture, ports, will largely be controlled by world-wide commodity prices and trade trends, such as those of mineral and energy raw materials and their effects on heavy and chemical industries; of cereals and industrial crops; and of the future demand for consumer goods in a competitive international society. The role of individual ports may change in response to altered trends of maritime trade. Local markets for consumer goods and services could change in relation to stagnating or declining urban growth. The demand for beach recreation would certainly continue, but social habits could change, in particular if the water-edge urban-type resorts of today cannot be physically maintained.

7.2 Changes of physical parameters

7.2.1 Climate and precipitation

The published General Circulation Models (GCM) envisage that the doubling of the concentration of CO_2 (or the radiative equivalent) in the atmosphere would produce over northern Italy and the Eastern Alps a warming of 3°-3.5°C (refs. Wigley, Chapter I). This would cause average winter temperatures in the plain to rise to the level of those of Naples (now 5°-6°C), while average summer temperatures might become more similar to those of Florence (26.2°C) and Palermo (27.2°C). Thus, winters would eventually be milder and summers much warmer than at present.

However, this level of warming will not be attained in the next 2-3 decades; they might be reached after 5-7 decades, considering also the lag effect, the time required by the global system to reach an equilibrium (ref. Wigley). More immediately, the impact of an increase of average temperatures of only 1.5°C, perhaps by 2,025, would principally be in emphasizing the irregularity of climatic features, with greater inter-annual variability (such as sequences of cold winters, longer and hotter summers, more irregular cyclonic events). There could also be a greater incidence of 'rare events', such as exceptional rains and marine storms.

It is not yet established how the 'greenhouse effect' warming would influence average rainfall over the Alps and the Apennines. Current GCM indicate a fair to minor increase of winter and spring precipitation over the northern Adriatic region and the Eastern Alps, a lesser increase, or possibly no change, over the central and northern Apennines. Summer precipitation would not change, while autumn rainfall might increase in a small proportion. Evapotranspiration will probably increase. Presumably precipitation patterns would remain the same, due to unchanged wind circulation, as this is dependent on the relations between the cyclogenetic depressions originated in the western Mediterranean and the colder air masses that in winter descend from NW and E Europe. The contrast between air masses in winter would remain the same (but reduced in magnitude).

In general air circulation over the northern Adriatic would remain qualitatively the same (though with more frequent and irregular storms) and rainfall patterns would still be dominated by the location of mountain ranges. The increase of winter temperatures, however, will cause a reduction of the area and time permanence of the snow cover and large areas will be frost-free in winter. For a 1.5°C warming the snowline would rise by 200-300m (Kuhn 1987).

With more rain than snow in winter, the discharge regimes of rivers from the Alps and pre-Alps will be altered significantly. More persistent higher summer temperatures will cause the disappearance of the eastern alpine glaciers, and a reduction of the western glaciers (Kuhn 1987).

An increase in precipitation would imply an increase in winter storminess (Wigley 1988). The assumption of a similar winter air circulation implies the continuation of prevalent strong easterly winds, secondarily of south and south-east winds. It is still to be seen whether their relative frequencies would change, especially that of the westerly winds, which have a lesser impact on coastal dynamics.

7.2.2 Marine parameters

The relations of the Adriatic circulation with that of the main body of the Mediterranean should remain essentially the same. Local circulation close to the coast could change on a seasonal basis due to altered river discharges. A rise of the sea level up to one meter should not have any effect on physical parameters in the open sea. Its effects would be felt more significantly near the coasts, where they would be magnified by other factors of sea level increase: low pressures related to increased cyclonic perturbations from the Western Mediterranean and higher tides in the lagoons, due to the impact of anthropic factors on lagoon hydrology. However, the effect on the tides of fresh water plumes near the coast could either be positive or negative, depending on the future entity of river discharge.

Sea water temperatures and probably salinity will increase with increased evaporation. The summer stratification effects in the shallow northern Adriatic would become more marked. Circulation near the coast, as well as wave directions could be notably influenced by possibly greater frequency of SW and SE winds. In the region south of the Po Delta, summer SW winds could produce more frequent upwelling effects.

7.3 Impacts on coastal stability

The extensive anthropic use of the beach-dune zone make a natural response of the coast to changing conditions impossible. Its natural defences have been weakened. There are no continuous belts of high dunes, beaches and lagoonal barriers are narrow and the quantity of sand in the littoral drift systems has been reduced. Artificial coastal protection and inland flood controls may have been adequate in normal circumstances until the 50's-60's, but would certainly become increasingly insufficient for a sand-starved shore, if storms become more frequent, and for rivers, if their winter-spring flood discharge increases.

Thus the shoreline will continue its process of retreat, together with the subsidence of the lowlands. Retreat, however, will be gradually enhanced by a sea level rise ten times faster than has so far occurred (10-15 cm in 10 years, exclusive of local magnification due to artificially caused subsidence and tidal increases). In the last 2,000 years, sea level rise has been balanced by sedimentation, except where delta lobes were abandoned, due to river channel switching. Such compensation is no longer possible.

What is of utmost practical interest is the manner of coastal retreat, both in the shoreline stretches that are still in a natural condition and in those that have been strongly modified by man.

As the level of the sea rises, a normal beach and barrier island are expected to migrate gradually inland (Brunn and Schwartz 1985), a 30 cm rise is supposed to cause a retreat of 30 m, though the actual amount depends on land slopes. Examples of this recession are indicated by the response of the Caorle lagoon barrier island to a storm in 1977 (Catano et al 1978); by the 126m retreat occurred at Lido Adriano (Ravenna) from 1957 to 1977 because of a 45cm subsidence (Carbognin et al. 1984); and by the recession of the Burullus beach barrier, in the Nile Delta, which has shifted southwards over lagoonal deposits (cf. Nile Delta Case Study and Sestini 1988). The rate of retreat depends on the conditions, continuous vs. discontinuous, of the dune belt, and on the thickness of the coastal sand barrier. However, the overtopping of the lagoon barrier islands, where low, and devoid of dunes, is a definite possibility with flooding behind them (ref. Fig. 5.3). The result will be increasingly marine conditions in the lagoons. The lagoonal environment will also migrate landwards, the amount depending on slopes at their inner margins.

In actual fact, all migration will be hindered by the numerous existing fixed structures: sea-walls, dykes, road embankments, etc. The sea, however, will easily overcome all those that are not hydrodynamically adjusted, such as buildings and vertical walls. A 20-30cm rise of sea level would not cause, per se, the flooding of reclaimed areas below zero level (e.g. NE of the Venice lagoon, in the Po delta, in the Comacchio and Ravenna regions), but will gradually enhance the present negative aspects of high tides, coastal retreat and sediment deficits. Venice and nearby islands will be flooded more frequently, with progressively higher water levels, unless the proposed tide regulation works are built and functioning by the end of the century.

Erosion and flooding of intertidal areas (Barene) will increase in the lagoons that have an open access to the sea, especially those parts that are affected by appreciable subsidence. The inundation will be augmented by the natural or artificial deepening of the lagoons outlets.

The edge of the Po delta will continue to be eroded, at least as far as the foot of the dykes that surround it and line the main river branches.

There will . a decrease in the effectiveness of all present parallel coastal defences that are only one meter higher than the average high storm surges. These structures (offshore breakwaters, dykes) will have to be raised periodically, perhaps re-planned more rationally, and beach nourishment scheme intensified. By the years 2,010/20 all the protection works will have needed repair and re-adjustment. The cost of beach protection and maintenance will certainly escalate contributing to the further decline of some beach resorts.

There will be increased erosion of most beaches now exploited by the summer tourist industry, considering that the deficiency of river-supplied sand will continue for no less than another 30 years (though, most likely, longer), even if all sand dredging in the lower river courses is stopped soon.

Subsequently (post 2,050) sea level increases, relative to today, of more than 50cm (to 100cm), coupled with more frequent storm surges, could have the following effects:

(a) the rapid destruction of the sea-front parts of all the coastal towns that are directly exposed (Grado, Lignano, Caorle, Lido, Rimini Cervia).

(b) on beaches all constructions (buildings, piers, groins, low sea walls) that are now no more than 1m above sea level, would be seriously damaged (if not destroyed). Some coastal resorts may no longer be viable. A 1m rise would make the maintenance, or even survival of several tourist towns impossible.

(c) Even low-lying areas of the immediate hinterland could be threatened (e.g. the important orchard belt from Iesolo to Cavallino and Chioggia; the industrial area of Ravenna).

(d) All reclaimed areas that are presently below sea level might experience increased saline water infiltration, and there would be therefore an increased need of pumping (esp. in the Po Delta), with more powerful and costly facilities. It should be noted that water levels will be higher in several rivers and canals, with consequent salt wedge penetration.

7.4 Impacts on hydrology and water resources

In the first stage (to about 2,025) slight changes may occur in the regimes of the rivers that flow from the inner Alps (Isonzo, Adige, etc.), because of changes in seasonality of runoff, which would become more similar to that of the pre-Alpine rivers (Brenta, Piave). If there is a continuation of the present patterns of catastrophic concentrated rainfall every few years, there will be greater incidence of flood-risk in the plains. The Apennine rivers will continue to carry little or no water in summer, perhaps less water overall.

In the second stage of warmer temperatures and higher sea level, increased river flow from the Alps in autumn and winter and more torrential discharge by the Apenninic rivers, together with larger sediment loads due to greater soil erosion and slope instability, would introduce serious problems for the management of: (a) hydroelectric reservoirs and irrigation; (b) flood control; (c) river banks, bridges, canals; and (d) riverine navigation.

In the plains, however, negative consequences could obtain from reduced summer surface flow due to greater use of water for irrigation. Irrigation water intakes may no longer be adjusted to the lowered river levels. River and canal pollution would become an even more serious problem than today. In the lagoons there will be problems in guaranteeing proper oxygenation in the face of activities (e.g. industries) that prevent oxygen re-charge.

Since the changes in precipitation and run-=off in the Alps and pre-Alps will probably be more qualitative (i.e. timing) than quantitative, the availability and use of surface waters should continue at present levels. The recharge of aquifers will not be altered in Veneto and Friuli, because of the porous nature of the upper Unconfined Aquifer. Negative changes may be expected, however, in Romagna, with greater problems for the shallow aquifers, especially if excessively used, like they are today.

Proper water resources management will continue to be a priority, least serious problems arise with excessive water pumping, water pollution and lack of high quality water for agriculture and drinking. The cost of maintaining a sufficient amount of good quality drinking water will increase, because of salinization and invasion by diseases. Present day tropical diseases may migrate north, and water born environmental risks could be aggravated. Water pollution could become a larger problem if polluted effluents become less diluted.

Studies of the impact of climatic change on the complex system of surface waters genesis versus utilization by different (and conflicting) users, will have to be made well in advance.

7.5. Impacts on ecosystems

The impacts of climatic changes on ecosystems could be considered in terms of their natural evolution, or more realistically in the perspective of the influence of human activities. Only small parts of the wetland system of the north Adriatic coast is protected at present and likely to be left in a natural condition, to evolve by itself. The biologic and economic importance of lagoons and marshes is based on the high primary productivity of environments that are conditioned by a delicate balance between brackish and freshwater. The existence of a rich and varied migrating and nesting bird fauna depends on the persistence of characteristic transitional environments (salt marshes and tidal flats, freshwater ponds and fish basins) with specialized vegetation (e.g. reeds beds, floating and submerged biocenosis).

The distribution of wetlands in the next 50-70 years will depend on their ability to grow vertically, relatively to rates of sea level rise, since the wetlands cannot migrate inland due to the dyked margins of the lagoons.

Any variations of salinity temperature, nutrients, of factors affecting bottom sediments (ref. anoxic conditions) that are caused by an alteration of the climate and by sea level rise, are bound in the long run to modify significantly the composition of the benthos, plankton, nekton.

Aquatic ecology is likely to be profoundly affected by a temperature rise. Shallow onshore marine areas would become warmer; the sheltered lagoonal waters could become hypersaline. In the shallow sea, conditions of fish stock and other biological parameters could be considerably altered. In particular areas even a 1°C rise might have a marked adverse effect on fish life (because of changed oxygen concentration and water chemistry). Migrating sea-lagoons, sea-rivers species would be adversely affected by alteration of coastal physiography and of inland hydrology.

In general, during the next 3-4 decades, little change is expected to be caused by a rise of 1°C and of 20-30 cm sea-level. In the shallow marine environments of the continental shelf, the proportion of some species may be altered if they are sensitive to small variation of water temperature. The main impact could be that of a continued discharge of pollutants from the Po and other rivers, enhanced by more frequent eutrophication events. More significant changes could take place in the lagoons at the lower stages of the ecosystem (plankton and bottom fauna), due to chemical modifications caused by pollutants, unless these are controlled soon.

Of greater importance could be, however, for vegetation and fauna, the effects of interannual variability of temperature (e.g. hot dry summers or very cold winters), of freshwater discharge, wind directions.

At a later stage, if the lagoons were to be transformed into bays, the location of natural marshlands and the nature of protected areas would change drastically, with serious effects on migratory birds.

. Asregards degrees of impact, a distinction should be made between those parts of the lagoons that are open and in direct communication with the sea, and the internal parts that are ± confined. Marine conditions will increase in the former with a fall in phytoplankton activity and of malacofauna (and consequent impoverishment in the adjacent marine areas). In the internal parts the main dangers are increased salinity and drainage alterations.

In the open lagoons, the migrating species that are omnivorous and quite adapted to changes (e.g. mugils, eels) , would be favoured; as well as some lagoonal fishes (Gobius). More entirely marine fishes would move in (e.g. Platychtis, Mullus barbatus, Sarpa, Atherina, etc). Perhaps the fish fauna in general would in principle be favoured by a rise of temperature.

The impacts on the bird fauna rest mainly on physical alterations to their specific nesting and feeding habitats; an increase of salinity for instance would be detrimental to freshwater aquatic plants (Phragmites, Potamogeton, etc.) that provide shelter and food to waterfowl. On the other hand, the open lagoons are increasingly used for wintering by marine birds.

Changes in fish fauna would affect fish-eating species, greater extension of brackish or saline areas (versus freshwater areas) would favour, or impede certain species. The number and types of migrating (staging and wintering) birds might also be affected by changed conditions in their traditional wintering locations, and in their nesting locations in more boreal regions.

It is generally thought that a 2° average warming would have a considerable impact on natural vegetation, with a shift of the range of species, in Europe, northwards by 300-500 km. Milder winter weather and hotter, drier summers would tend to favour the evergreen oak woods association, but generally could have a negative effect on imported tree species, that are grown in urban parks and avenues, and in private parks, as well as on all those species that require environments with relatively high moisture. The poplars and pine woods plantations of the lowlands might also suffer.

Nature conservation will require a re-assessment and new policies. The protection of rare species and the conservation of species-richness through the maintenance of local natural conditions as they are now, will no longer be possible. Only the species adapted to unpredictable, rapidly changing environments will be able to survive; rare species living in restricted ecological islands might not be able to migrate.

The principle should be that of preserving and protecting all characteristic ecosystems but, to let them evolve naturally along with climatic changes.

7.6 Impacts on the social and economic fabric

The socio-economic system of a coastal region is extremely complex, dependant on innumerable factors and elements, many of which have little to do with physical environmental conditions. In principle, an evaluation of the impacts of climatic change ought to be based on a study of the trends of at least population, economic productivity in different fields, and of social behaviour (incl. recreation). Changes that have occurred in the last three decades, however, may not at all be indicative of the possible future trends; in fact, socio-economic extrapolations may become hazardous beyond 20-30 years, due also to the effects of possible economic recessions (e.g. on demand for consumer goods, housing, travel, communications, etc).

There will be also, as there has always been, a gradual adaptation of land uses to changing physical conditions, spurred by mere economic necessity: any investment, or commercial activity that is no longer economically viable ceases to function, or is transferred elsewhere.

The level of activity of industry and agriculture is determined by market forces situated outside the coastal lowlands. For instance, the role of the present centers of heavy industry and of the commercial ports (e.g. Venice, Trieste, Chioggia, Ravenna) will be determined more by general factors of national/international demand, than by climatic changes. There could be a gradual decline of petroleum transport and refining. The trends of world trade of basic commodities may also be considerably altered by technological innovations. Likewise, agrobiological research will provide, as already now, adaptations of crops and animal husbandry, in the face of climatic changes.

Since the expected population trend in the coastal regions of NE Italy is towards an overall decrease, particularly with a decline of the lagoonal towns (incl. Venice) and in the lowlying agricultural areas, but with an unchanged situation inland (along the 2-5 m economic axes), the basic needs of the region should remain the same, with employment derived from diversified industrial, commercial and tertiary activities; and continued local food production for local use (mainly fruit, vegetable, meat and dairly farming, fishing).

The impact of temperature increases would not be direct, on the towns and their commercial-industrial activities, but indirect, because affecting fishing and specialized agriculture. Little change could be expected in the economic and settlement patterns in the (> 2m) hinterland.

There would be, however, a gradual deterioration of living conditions in the lagoonal towns (e.g. Grado, Marano, Venezia and nearby centers, Comacchio). They have in fact already experienced the effects of flooding due to winter high tides and storm surges (quite negative for power supplies, sewer systems, storage of merchandises, etc). Although the main inland centers lie above 2 m elevation, the uncontrolled rise of lagoonal and canal water levels would also lead to a gradual deterioration of infrastructures.

Since the importance of commercial and industrial harbours would continue (if not increase, under certain scenarios, ref. Blue Plan; though, changed economic premises might require re-structuration) their fixtures will necessitate maintenance, with costs of protection, after a sea-level rise of few dm, bound to become considerable.

There is no doubt that the impact of sea-level rise on beach resorts, as they have developed in the last three decades, will be generally negative, not only because of the shrinking beaches, but also of increased damages at the seafront by storms with increasing costs of protection involving technical, financial, and bureaucratic problems: A deterioration of water and of summer produce supplies also a likely. Increased mosquitoes in the marshes behind the beach zone might become a nuisance.

However, the high demand for beach recreation should remain, and temperature increases would not be detrimental. There might not be much loss of tourism due to warmer north European shores, because of environmental problems there, and of the continuing attraction of the Mediterranean scenery. Beaches, if allowed to evolve more flexibly, would continue to be available. The main problem facing decision makers would be one of policy, of what strategy to be adopted by state and local authorities on the manner of beaches utilization by the public.

Beach tourism will continue to be an important economic resource, but as a question of investments and profits, involving the need for protection works, and a high cost of maintenance and repairs, it should involve (in a situation of rapid sea-level rise) a total review of the approaches to littoral land use. The future trends of tourism must be investigated and especially the efficiency of high rise residential facilities in proximity of the shore. A philosophy of more open use of the coast, perhaps in association with green spaces and nature reserves, like in the Camargue in France, may become useful.

Regarding the impacts of temperature changes on agriculture, in principle cereals production, esp. wheat and corn, and the associated animal breeding, could benefit from higher temperatures and CO_2 concentration. Problems could arise in regard to vineyards and fruit trees, and in spite of agrotechnology adaptations, disruptions would certainly be due to salinity intrusion in soils (ref. the coastal orchard belt) and a possible increase of weeds and pests. Plants may require more nitrogen. Increased use of fertilizers and of pesticides would reflect negatively on pollution.

Irrigation would become even more necessary than now but more difficult and expensive, because more soil drainage would be required, and a greater strain would be imposed on surface and subsurface water resources.

It is not clear at this stage what effect will have a possible increase of salinity and temperature (2°-4°C) on the beach sands and on the alluvial and the clay-peat soils of the coastal lowlands. The clay soils would be quite sensitive to temperature and salinity with increased mineralization of organic matter.

A very large increase of evapo-transpiration and of soils moisture deficits will occur, particularly between late summer and early winter. Weather fluctuations (temperature, heat waves, availability of water, hail or heavy rains in the ripening stages) would affect several Mediterranean crops (wheat, soya beans, sugar beets, tomatoes, tobacco, fruit trees). Warmer winters and severe water deficits will threaten the existence of those tree cultivations (e.g. olive, nut trees) that require a dormant period at relatively low temperatures.

9. CONCLUSIONS AND RECOMMENDATIONS

Sea level is expected to rise by at least 1m by 2,050, or later in the XXI century, with rates of increase 10 times faster (10-12 mm/year) than up to now. To this must be added the effects of increasing high tidal levels in the lagoons due to man-made situations.

Although climatic changes and sea level rise will take place gradually, they will at first (next 2-3 decades) become manifest through a greater interannual variability, e.g. more frequent, very hot and dry summers, milder winters and a greater incidence of exceptional events (very heavy rainfalls, winter storms, storm tides). Consequently, the Adriatic cost of NE Italy will be exposed to much greater natural stresses than up to now: with more frequent marine washovers and a further loss of beaches, whatever the engineering measures that have, or will have been undertaken to stop it.

Temperature increments of 1-2 degrees in the next decades will have an impact more on lagoonal and marine ecology (and therefore on fishing) than on agriculture and on the social and economic fabric of the coastal region.

Changes and deterioration of environmentally and economically important parameters will derive mainly from the continuing reluctance of society to adjust land uses to natural processes (e.g. coastal dynamics, lagoon ecology, etc.).

In practical terms, it must be realized that land use planning, and in general all investments that extend over the next 2-3 decades will produce situations that, at the end of the period, will or will not be compatible with already notable climatic changes.

Technically, there is a need to:

(a) investigate the bases for, and introduce a classification of risk exposure. The high risk lowland areas will be threatened by: beach retreat and frequent washovers, substantial damage (to total destruction) to exposed fixed structures (sea walls, buildings), easier inundation of agricultural lands

(b) Investigate which beach resorts could no longer be viable, and how to apply concepts of set-back lines

(c) Control coastal developments, especially the further spread of urban-type beach resorts and of pleasure marinas, and the location of factories and power plants near the shore.

(d) Stop land reclamation, and consider instead the return of at least some lowlands below sea-level to lakes (or lagoons) for aquaculture activities, which are both economically viable and compatible with environmental protection.

(e) Investigate thoroughly ground water resources and uses, and the ways to control excessive exploitation, in order to minimize land subsidence.

In practice, the entire coast of the NW Adriatic must be classified as high risk, though not for the same reasons on all stretches. For instance, along most of the shore from Chioggia to the Isonzo, beaches are often narrow with very gentle slopes, mostly retreating, and there is no onshore protection (few stretches still have low dunes). The level of risk for the hinterland is at first sight less uniform, due to transversal dykes and embankments, but there are several river-lagoon inlets and parts are below sea level and subsident.

All the Venice lagoon and its western margins could eventually be flooded, in association with subsidence. The Po Delta is a high risk area, both on the coast and inland, for a variety of reasons (hydrology, subsidence, low sediment outputs). However, most of the Po Delta is surrounded by a dyke.

The Romagna coast is already mostly retreating and in parts subsisdent, there are too many built-up areas near the shore, many impediments to sediment movement, and numerous waterways giving access to the internal lowlands.

The prospect of a substantial rise of sea level signifies a choice between a static approach of defending the present status quo, and a flexible view of following natural changes with a planned re-development of beach uses and the restoration and management of natural wetlands, both for the sake of their biological resources, and as buffer zones against the flooding of inland agricultural areas.

Increased awareness is urgently called for, of the need of new concepts and policies of coastal use on the part of the public and of decision-making organisms.

The tendency towards an excessive anthropic exploitation of deltaic-lagoon lowlands must be inverted as it produces a constriction of the hydrological systems, and in the end results in vastly escalating costs of protection. The institution of more national parks would be a reasonable answer, though the concept should be that natural areas are left to evolve on their own, rather than be taken as fixed ecosystems that must also be defended against changes.

In Italy, one of the world's industrial powers, it is probably technically and financially feasible to protect all, or most, of the Adriatic lowlands (including Venice, Marghera and Ravenna) against higher sea-level flooding. It would be illogical, however, to envisage today, the total protection decades ahead, of all the contemporary beach resorts by means of engineering measures.

Since by law the State has the ultimate competence to decide on all activities that relate to the coast, from its physical protection to its commercial use, it ought to take a leading role in stimulating and implementing all ecologically sensitive planning, above the present local and conflicting interests, for the sake of the well-being of future generations.

A series of research activities are recommended:

(1) The coastal studies that resulted in the publication by the National Research Council, of the Atlas of Beaches, should be undertaken again, with a new approach.

(2) Dynamic model studies of sea level change for the high and medium risk stretches, including a critical investigation of which tourist towns could become undefendable.

(3) The monitoring of erosion rates, with an effort to relate them to causes, including subsidence.

(4) Studies of which coastal protection structures could be most effective, e.g. sloping dykes and beach sand nourishment, as apposed to vertical sea walls and groins.

(5) The monitoring of the variations and trends of sea level.

(6) The study of past trends of temperature and air circulation.

(7) The projection of the trends of subsidence.

(8) The mechanics of sea level rise in relation to the lagoon interiors, including the effects of closing the lagoons with sluices.

(9) Analysis of which low-lying reclaimed areas could be returned to lagoonal state.

(10) Study of the ways to restore beach and river sediment budgets, considering the needs of inland agriculture and hydropower.

(11) Research into manners of waste disposal and of pollution control, in relation to the changed hydrological parameters.

(12) The systematic study of the ecological parameters of the main components of the lagoonal and shallow marine environments (including data on nutrients and phytoplankton concentration), to permit an analysis of the impacts of salinity and temperature changes.

(13) Research into the basic elements that are needed to assess the impact of sea-level rise on the future socio-economic fabric of the regions involved.

(14) Research on the legal impacts of climatic change and on the attribution of responsibilities for the counter-measures to be taken.

Abundant basic data already exist in Italy (collected by State and Regional authorities) on topography, meteorology, waves and sea level, river discharge, subsurface waters, pollution and ecosystems. They need, however, to be elaborated into a uniform data-base that will allow the analysis of future trends and the issue of alternative scenarios.

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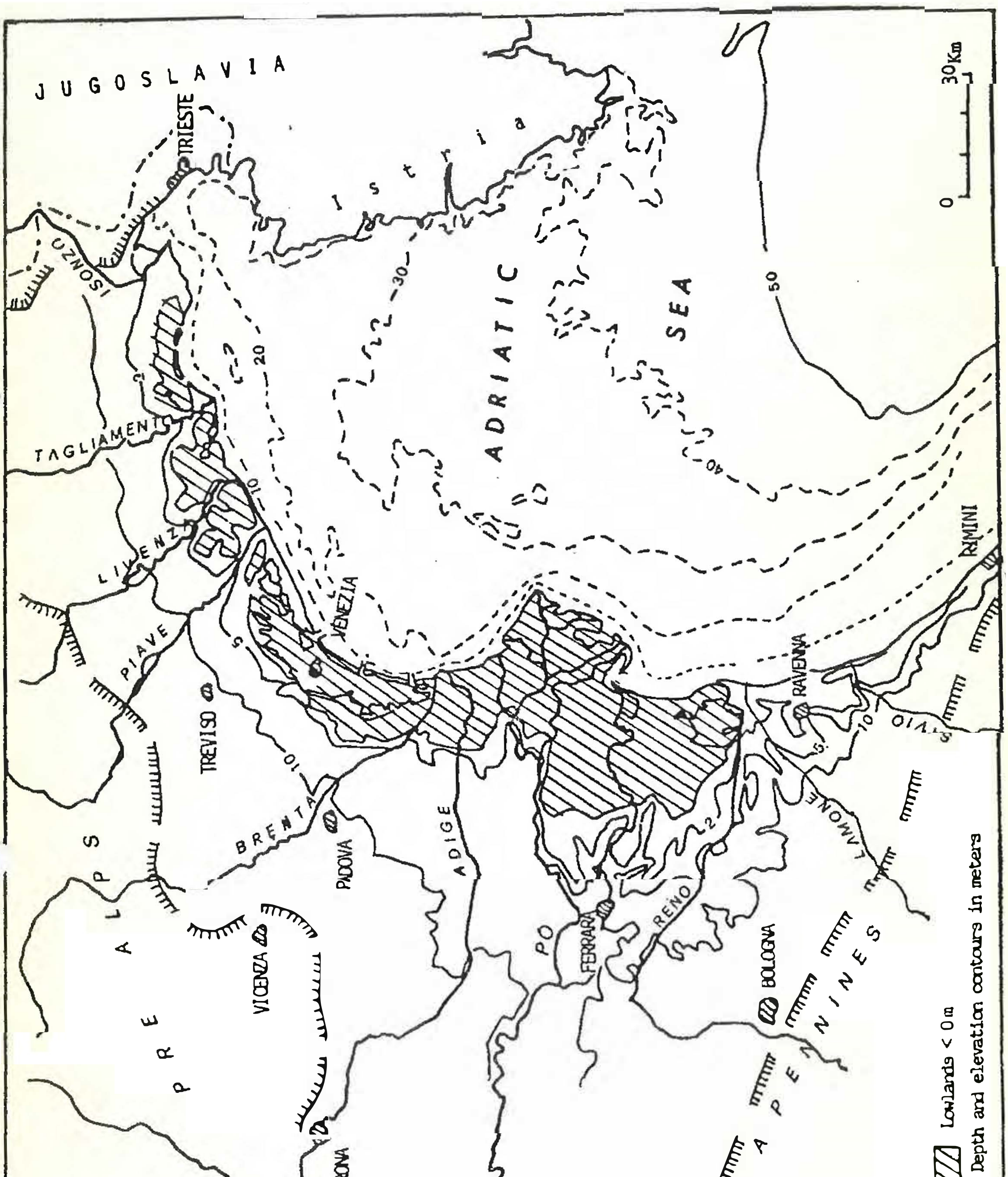

JUGOSLAVIA
TRIESTE
Istria
ADRIATIC
SEA
ISONZO
TAGLIAMENTO
LIVENZA
PIAVE
TREVISO
VENEZIA
BRENTA
PADOVA
ADIGE
PO
FERRARA
RENO
BOLOGNA
RAVENNA
RIMINI
SAVIO
LAMONE
VICENZA
VERONA
PRE ALPS
APENNINES
0 30 Km
Lowlands < 0 m
Depth and elevation contours in meters

FIG.1

VENETO : SCHEMA DI SVILUPPO TERRITORIALE

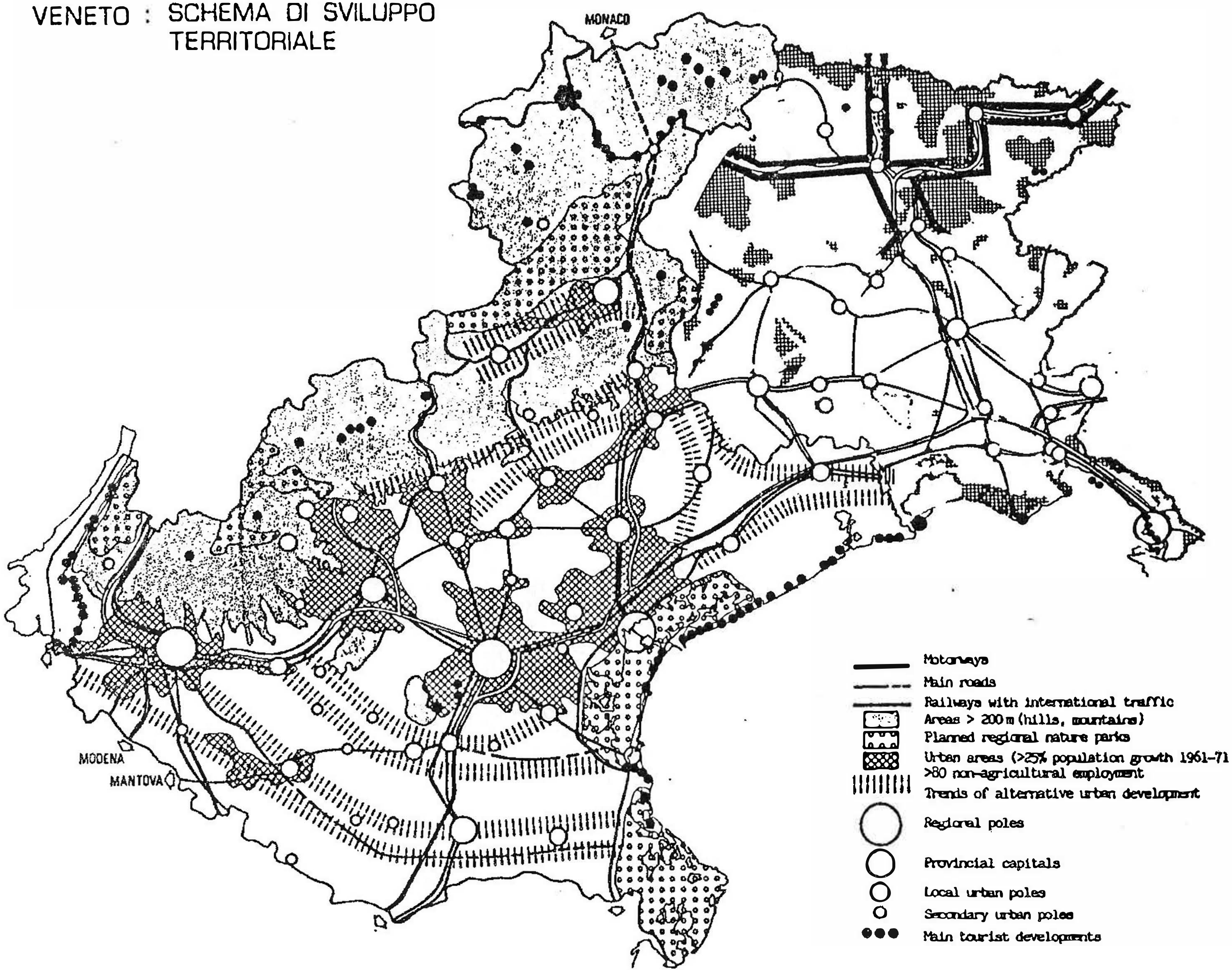


FIG. 2-1

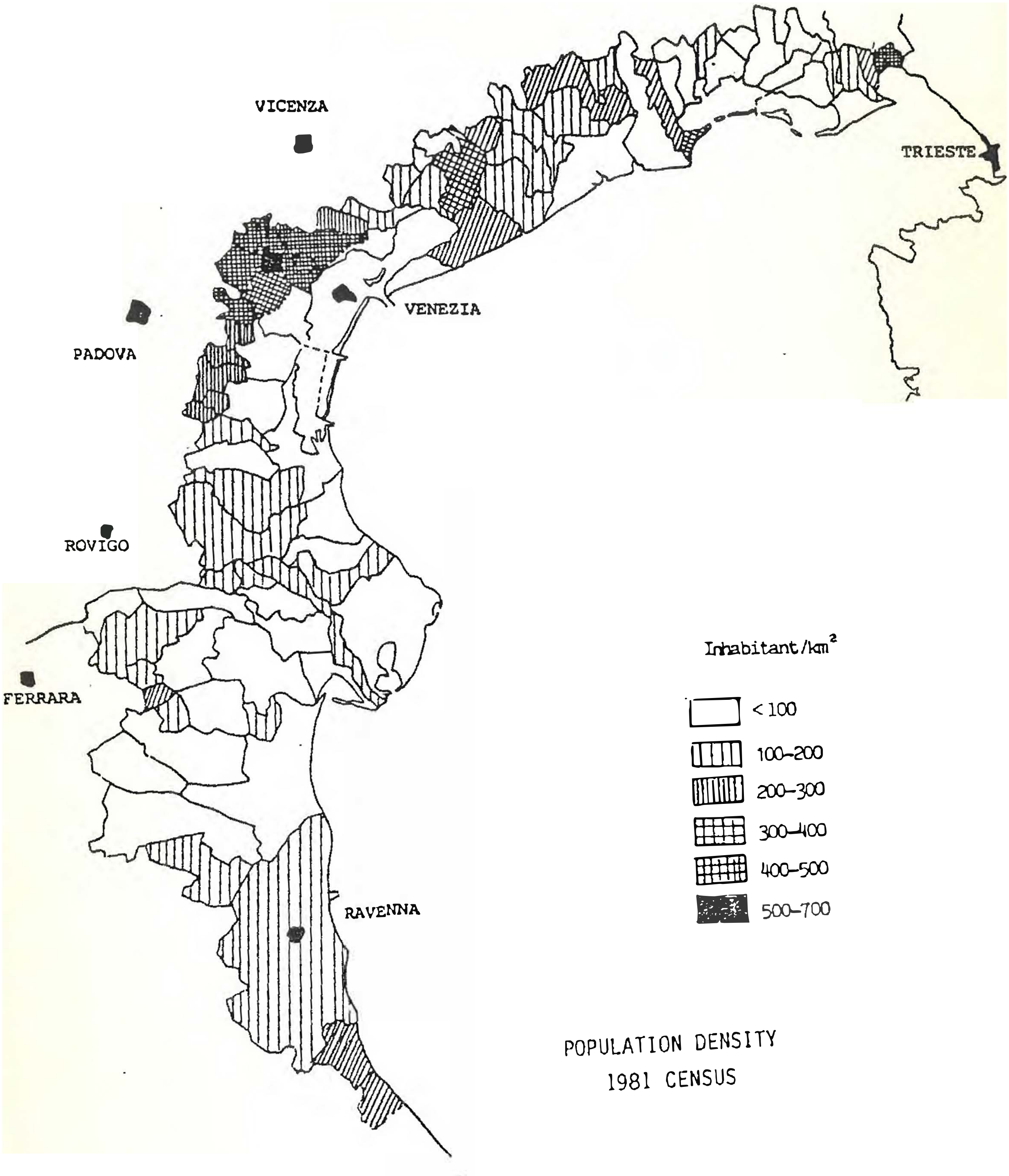

VICENZA
TRIESTE
VENEZIA
PADOVA
ROVIGO
FERRARA
RAVENNA
Inhabitant/km²
< 100
100-200
200-300
300-400
400-500
500-700
POPULATION DENSITY
1981 CENSUS

FIG. 2.2

PROVISIONAL

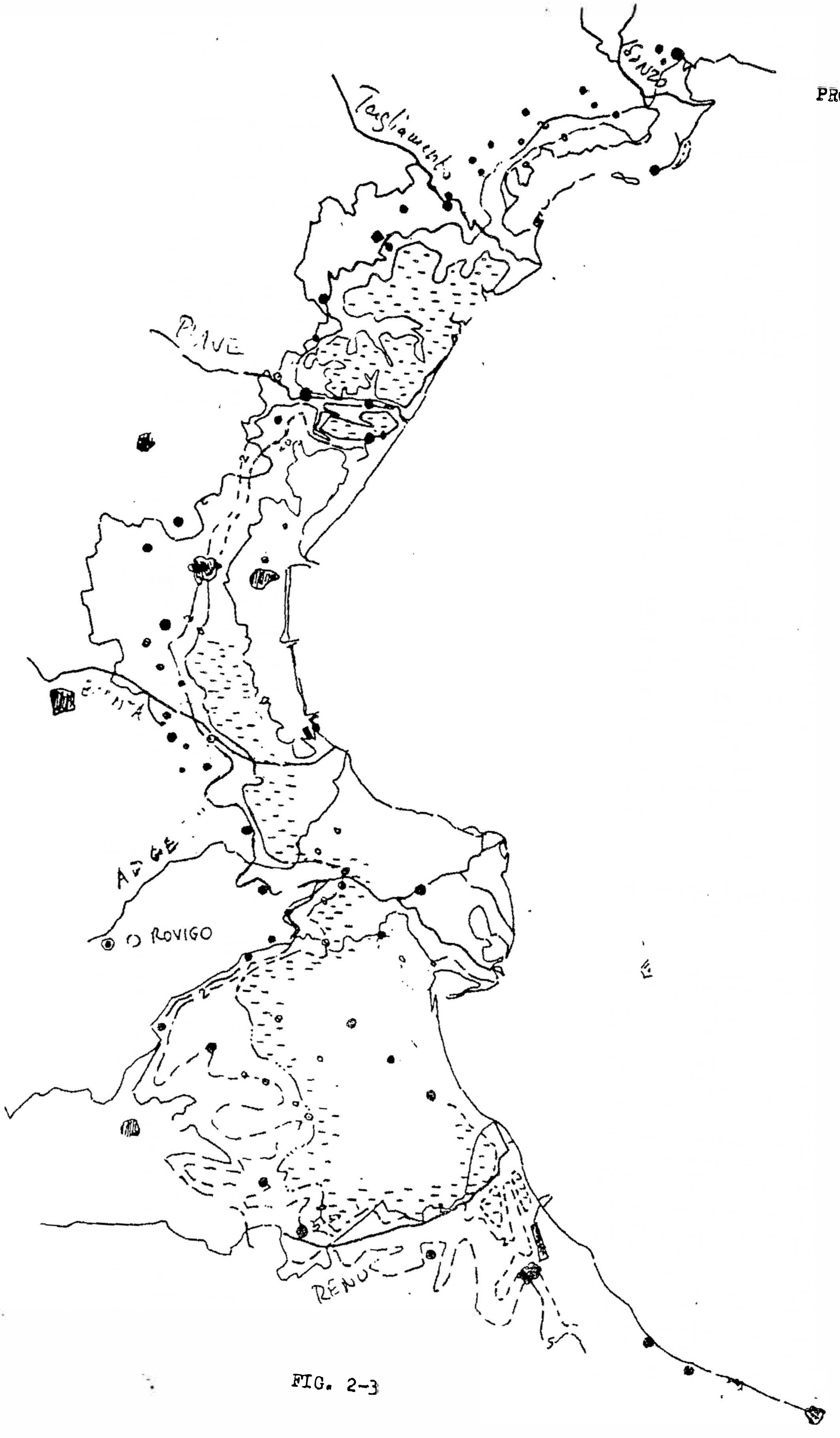


FIG. 2-3

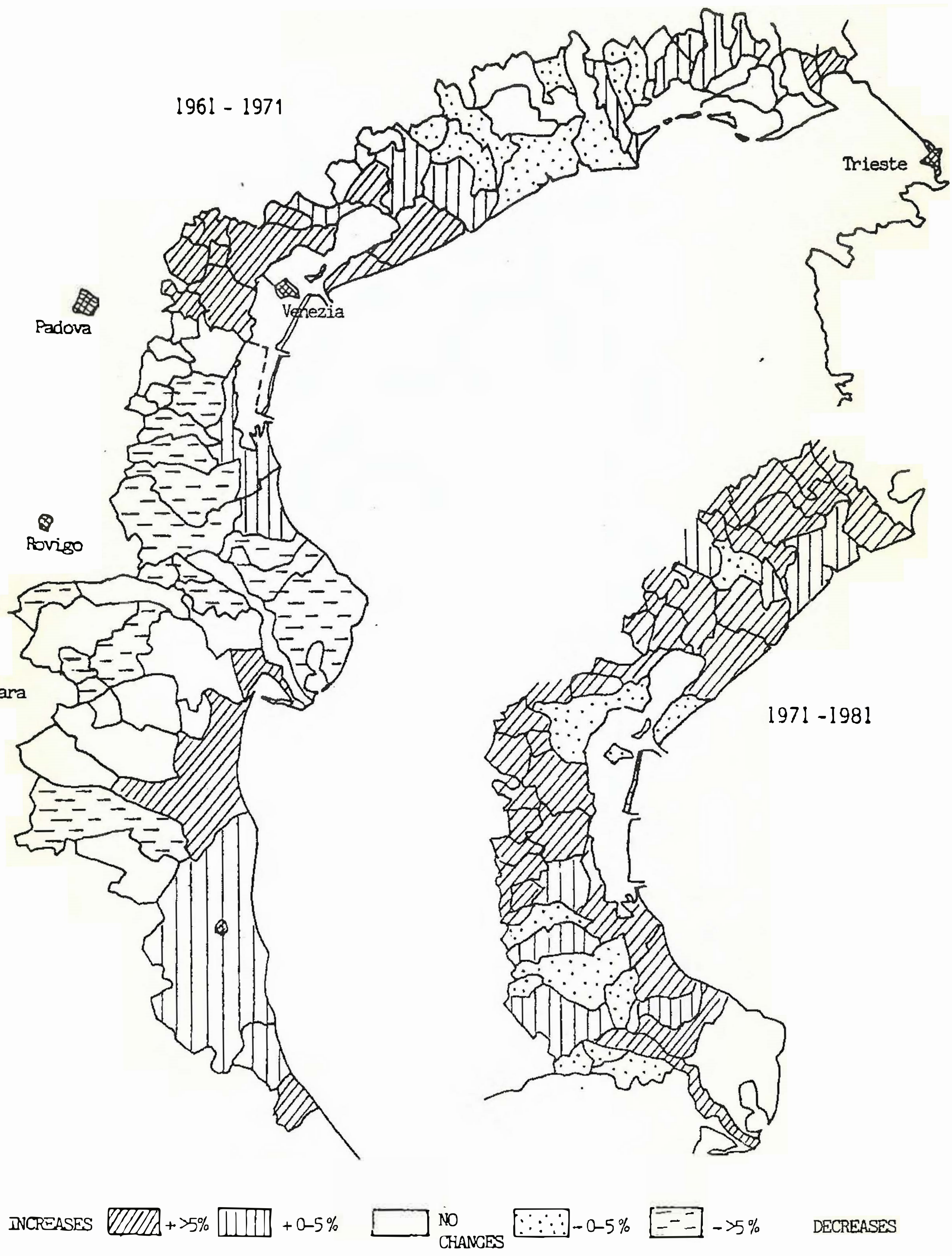
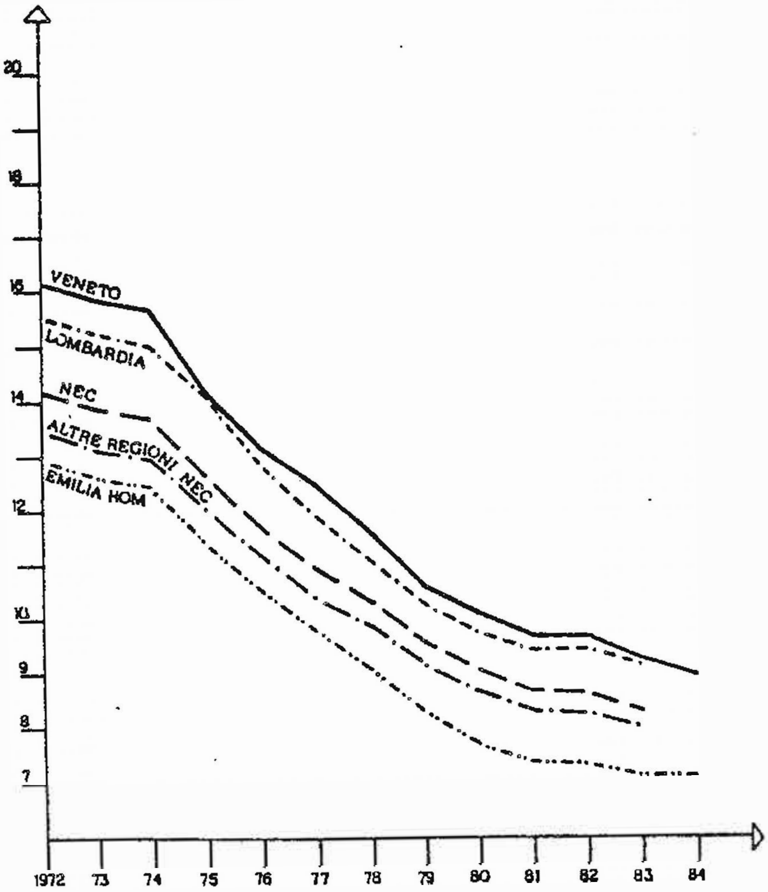


Fig. 2.4 Population changes between the 1961 and 1981 Census



Birth rate decline

FIG. 2.5

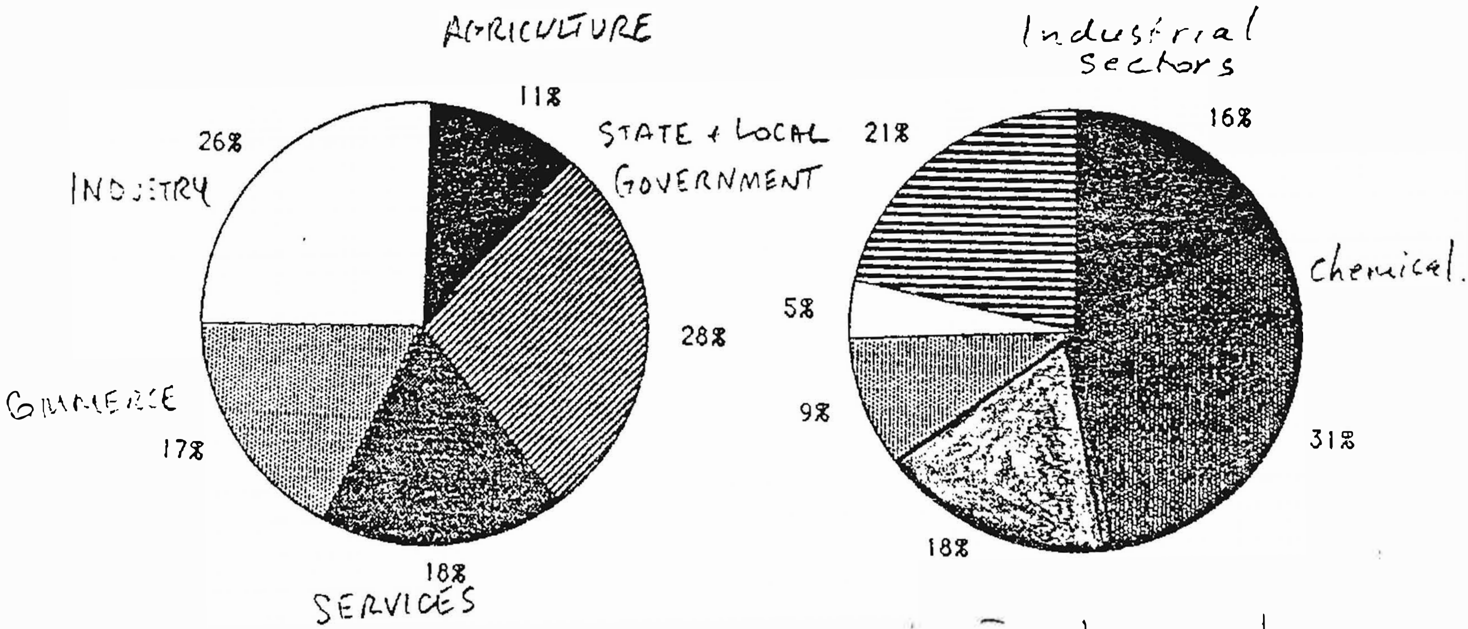


FIG. 2.6

Employment
RAVENNA, 1981 census

PROVISIONAL

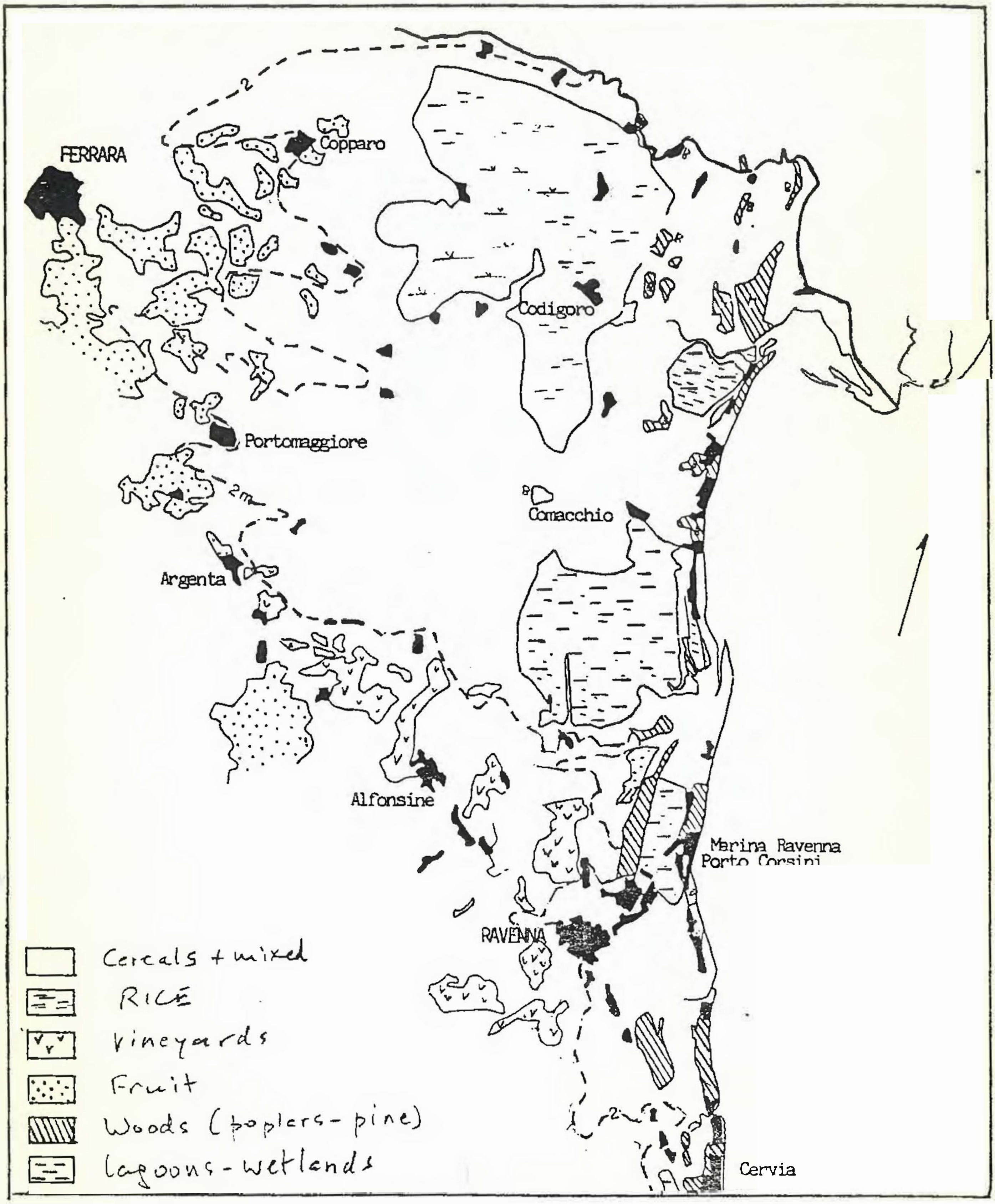
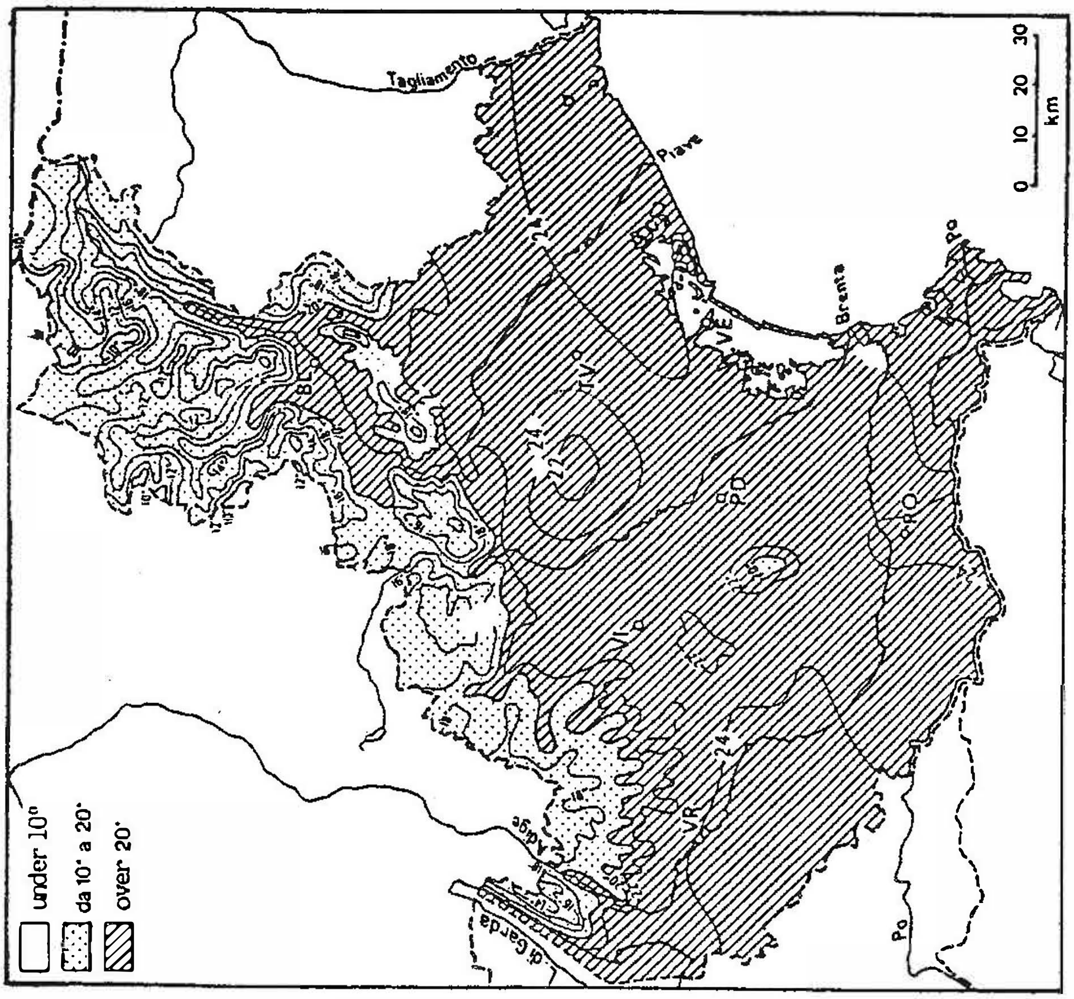
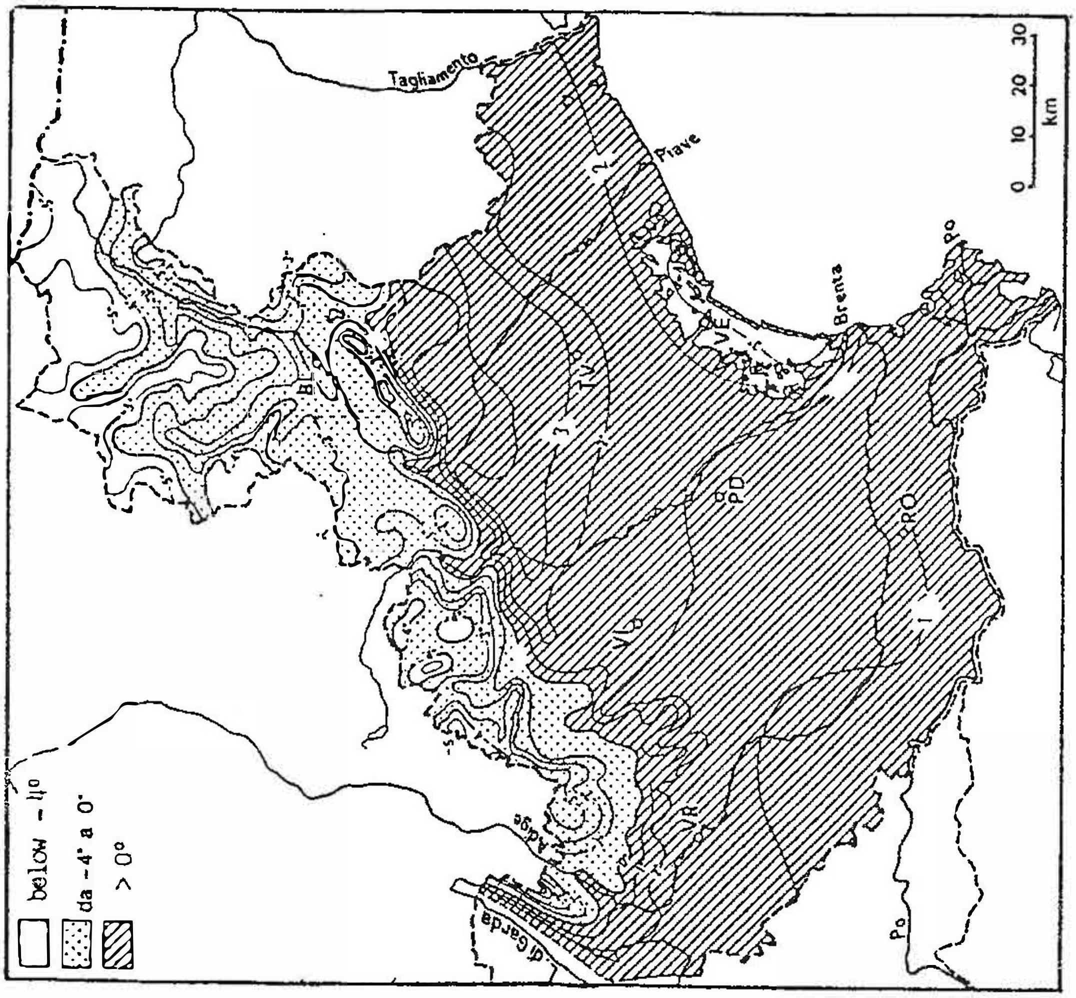


FIG. 2.8

AGRICULTURE, ROMAGNA

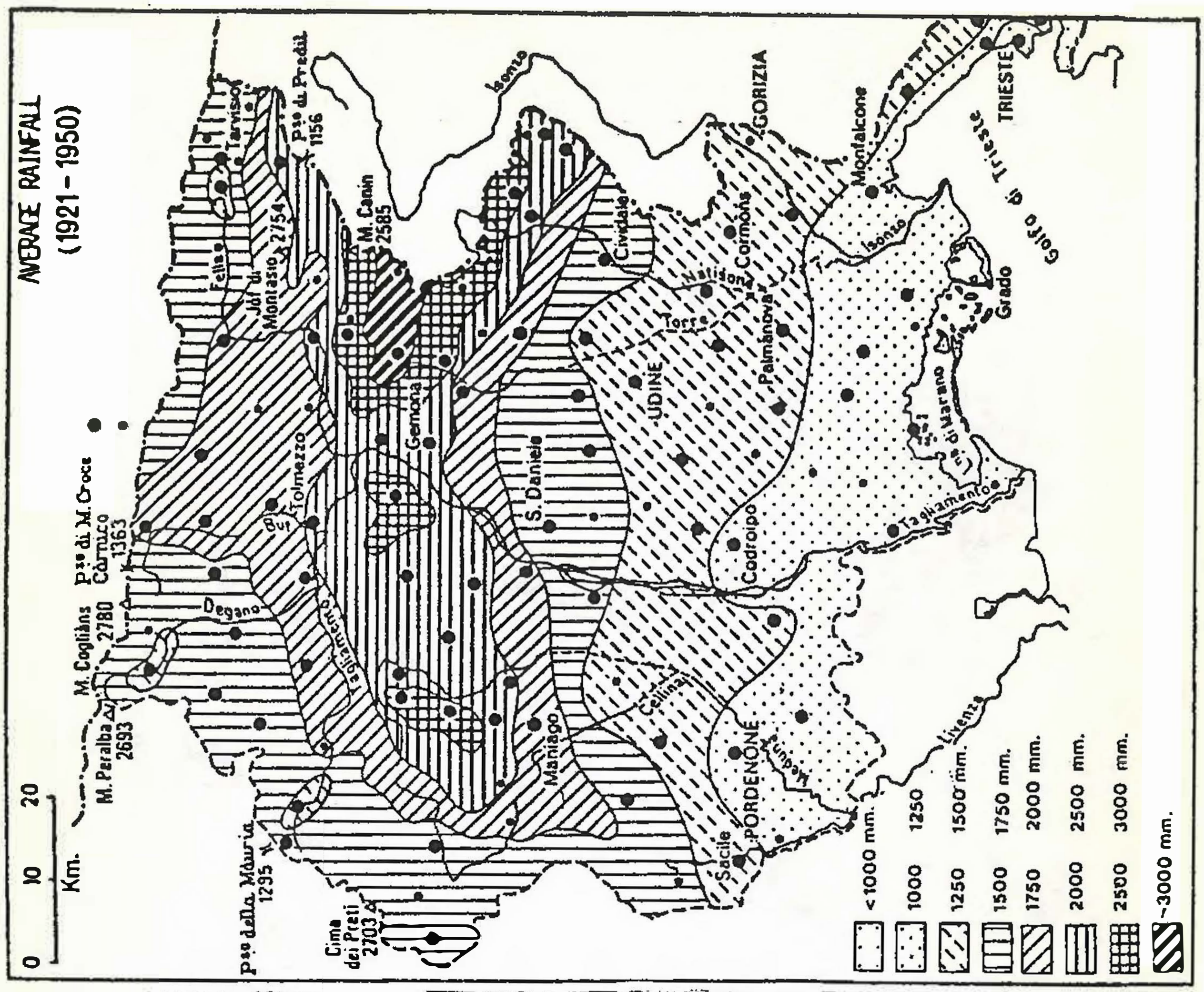


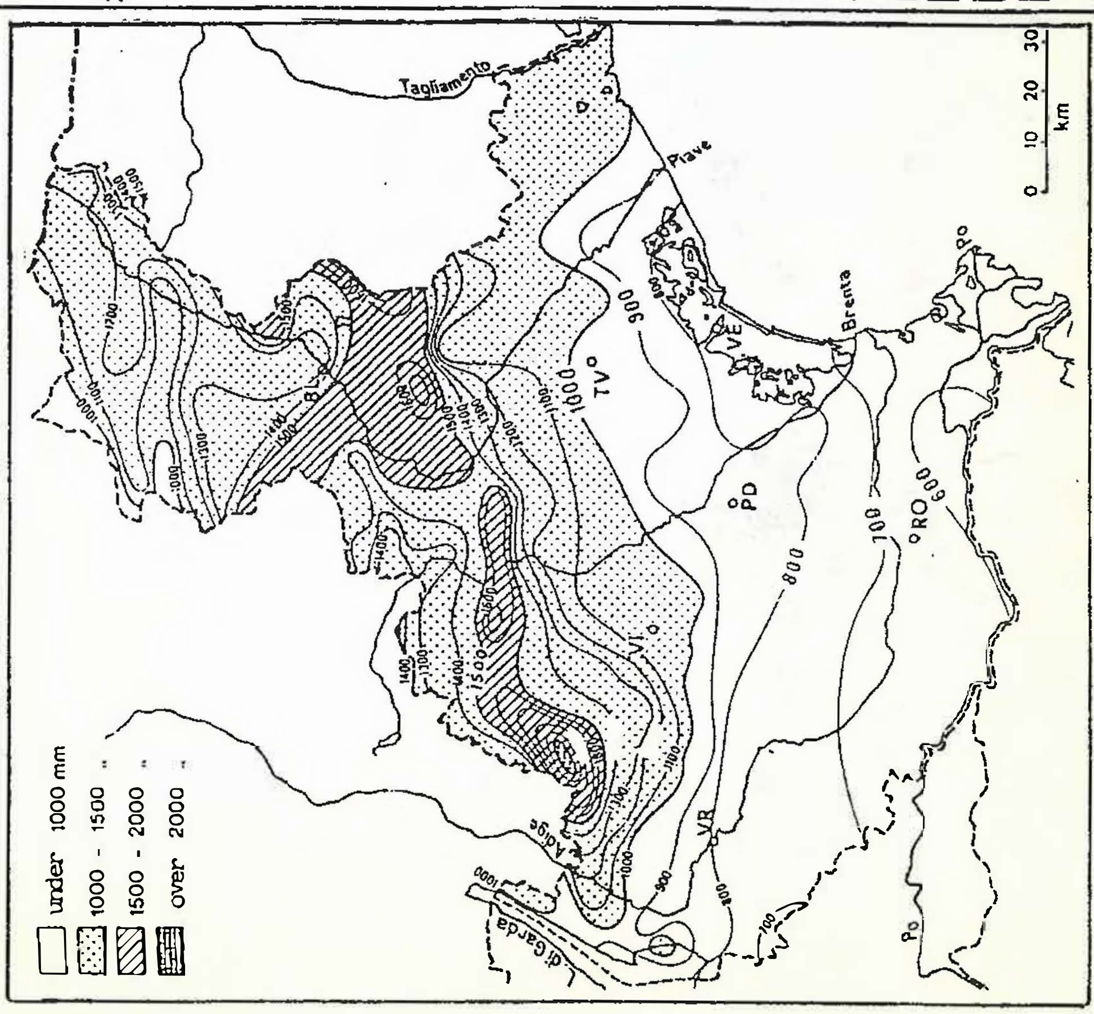
July isotherms (1925-1959 averages)



January isotherms (1925-1959 averages)

FIG. 3.1





AVERAGE ANNUAL RAINFALL

FIG. 3.2

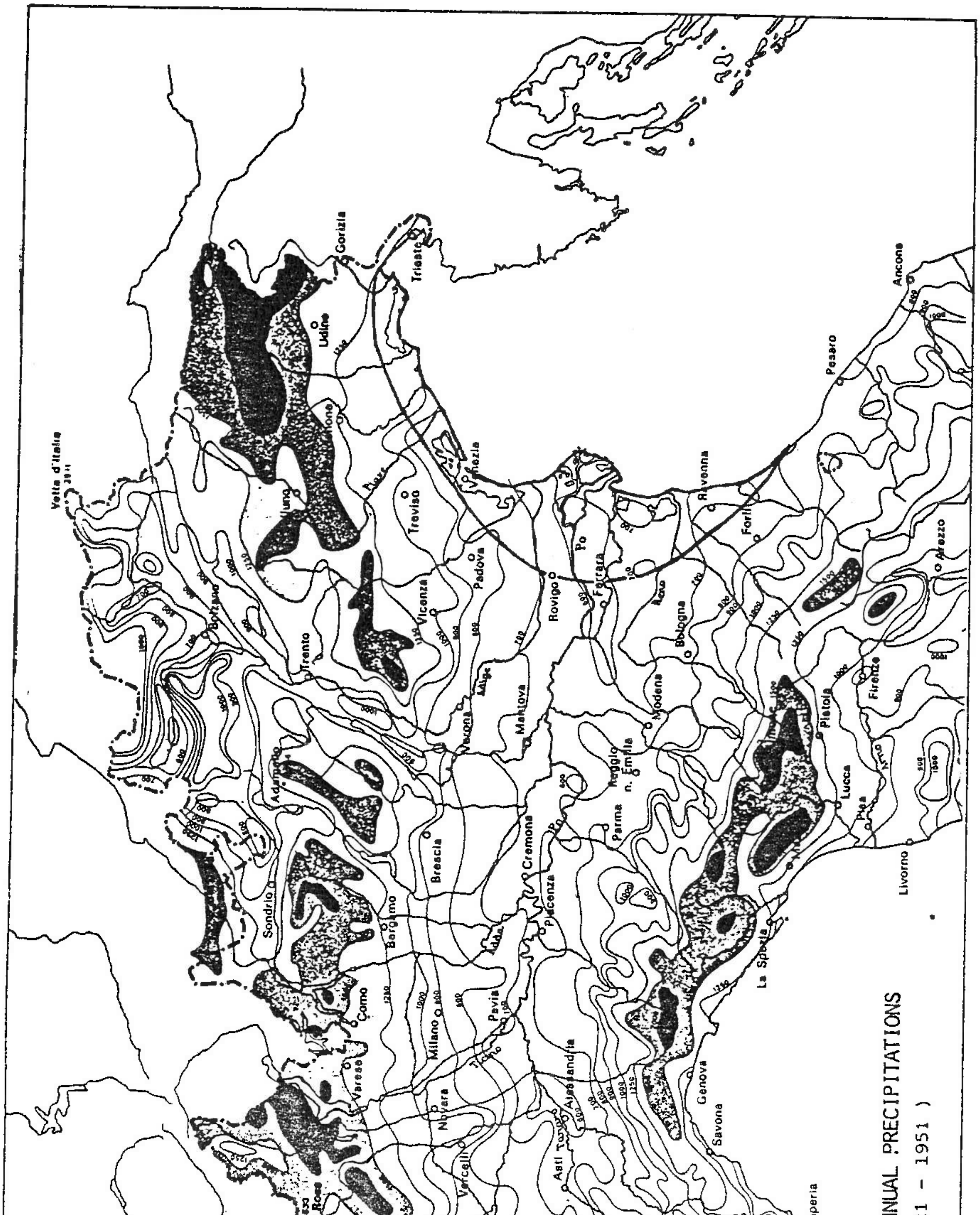
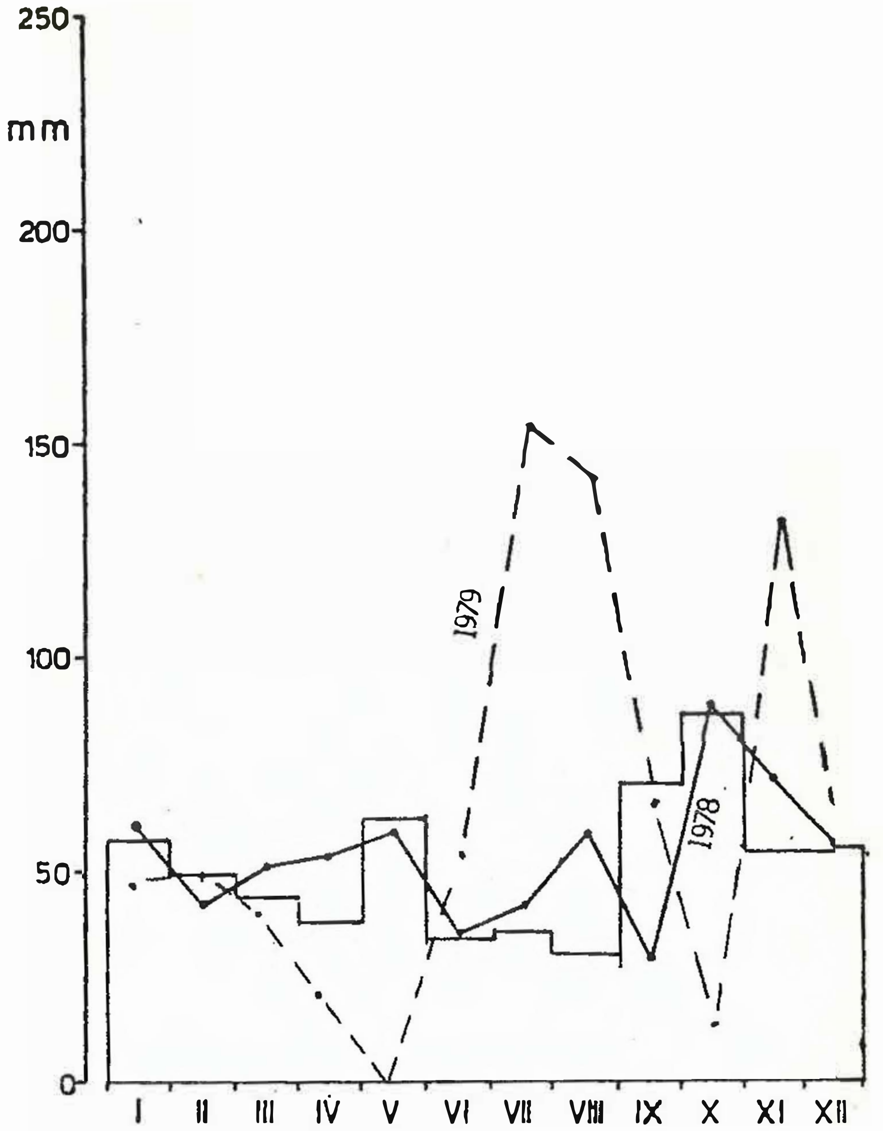

AVERAGE ANNUAL PRECIPITATIONS
(1921 - 1951)
Vetta d'Italia
Gorizia
Trieste
Udine
Ancona
Pesaro
Ravenna
Forlì
Arezzo
Treviso
Padova
Vicenza
Rovigo
Po
Ferrara
Bologna
Modena
Trento
Bolzano
Mantova
Verona
Brescia
Cremona
Reggio n. Emilia
Parma
Piacenza
Pistoia
Firenze
Lucca
Pisa
Livorno
La Spezia
Sondrio
Bergamo
Como
Varese
Milano
Pavia
Novara
Alessandria
Genova
Savona
Vercelli
Asti
Imperia
Aosta
Torino
Cuneo
M. Bianco
4810

Fig. 3.3



Average values of monthly precipitation over a 20-year period (histogram, 1951-1973) and inter-year variability. Marina di Ravenna.

FIG. 3.4

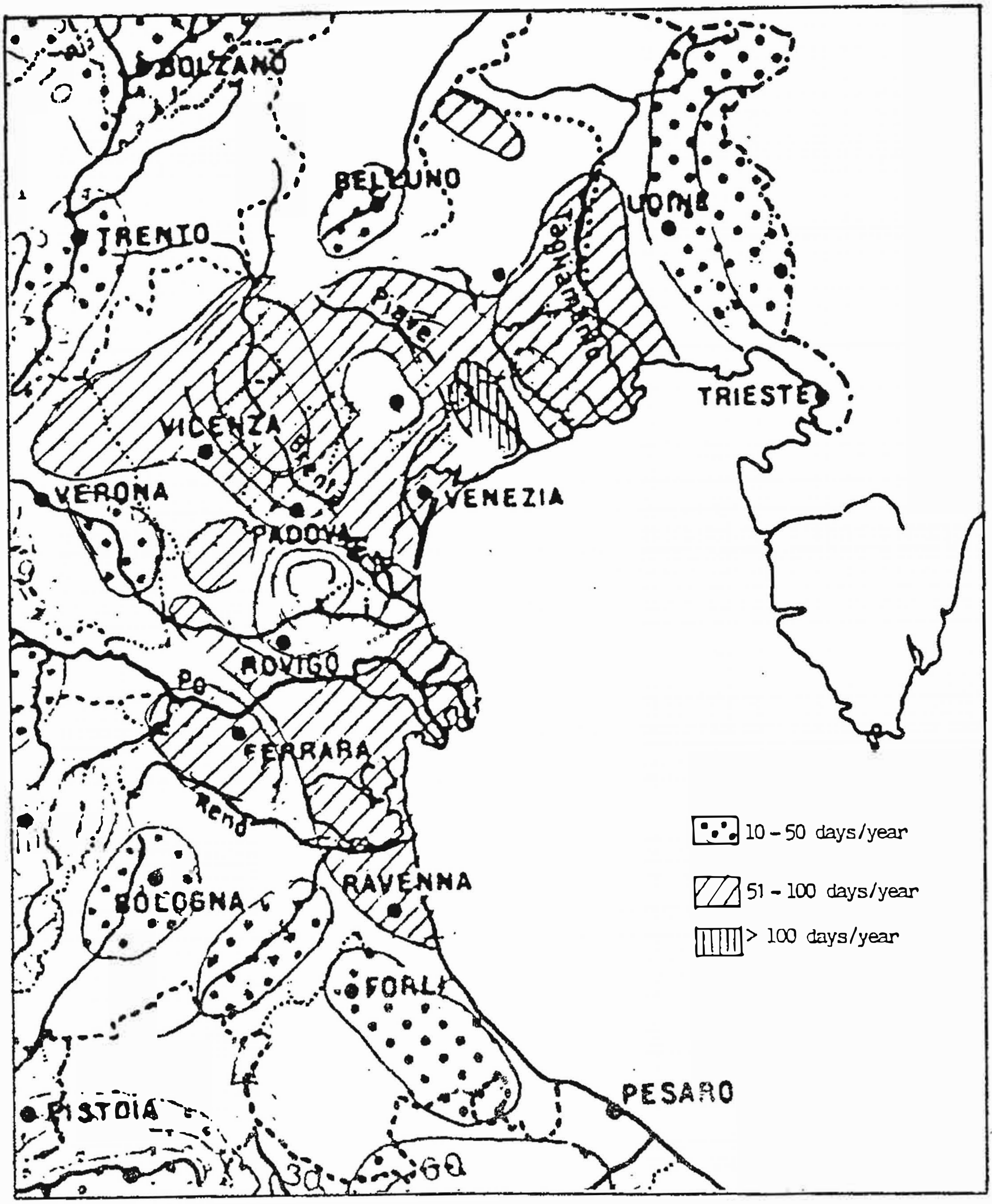
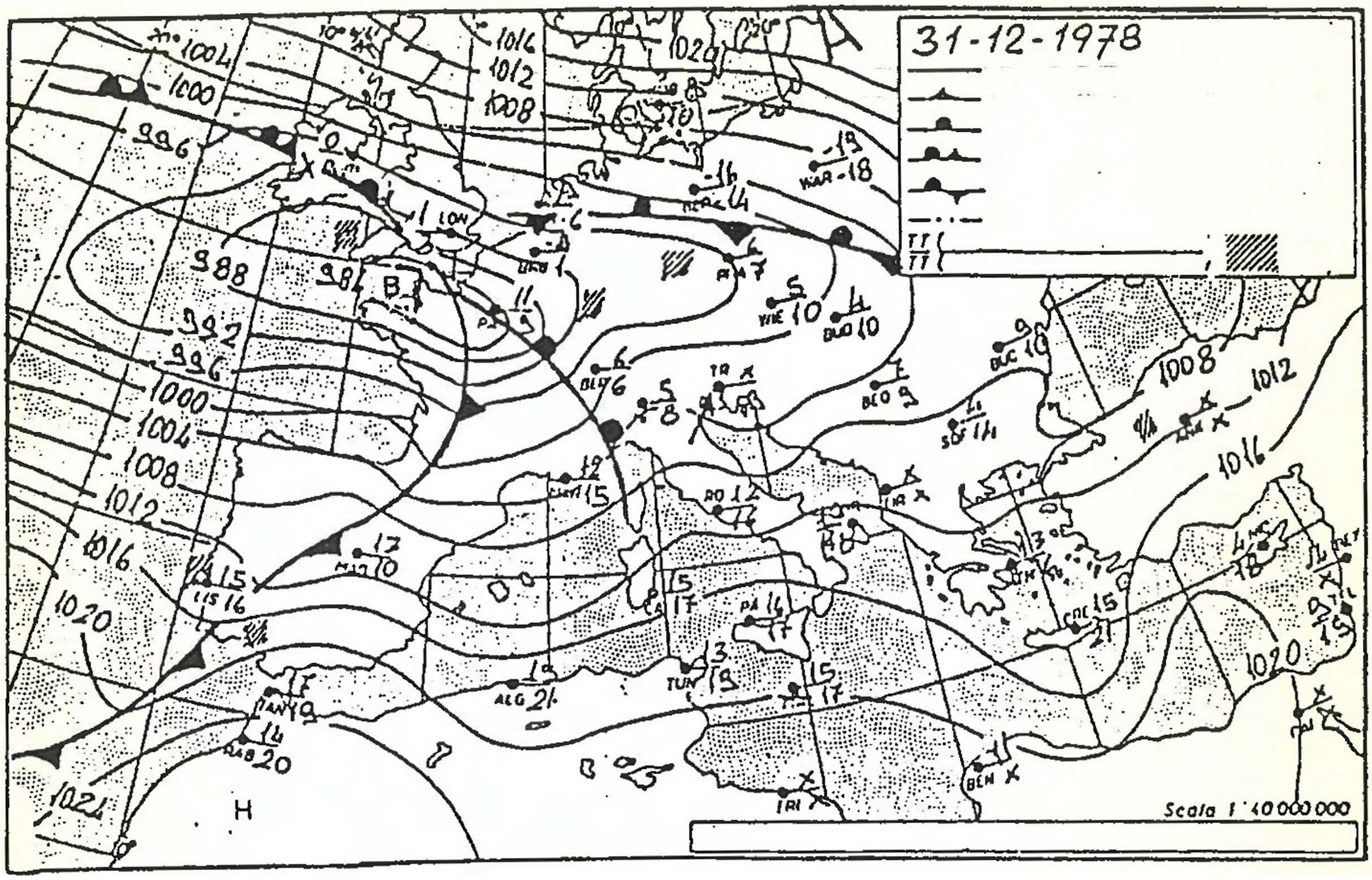
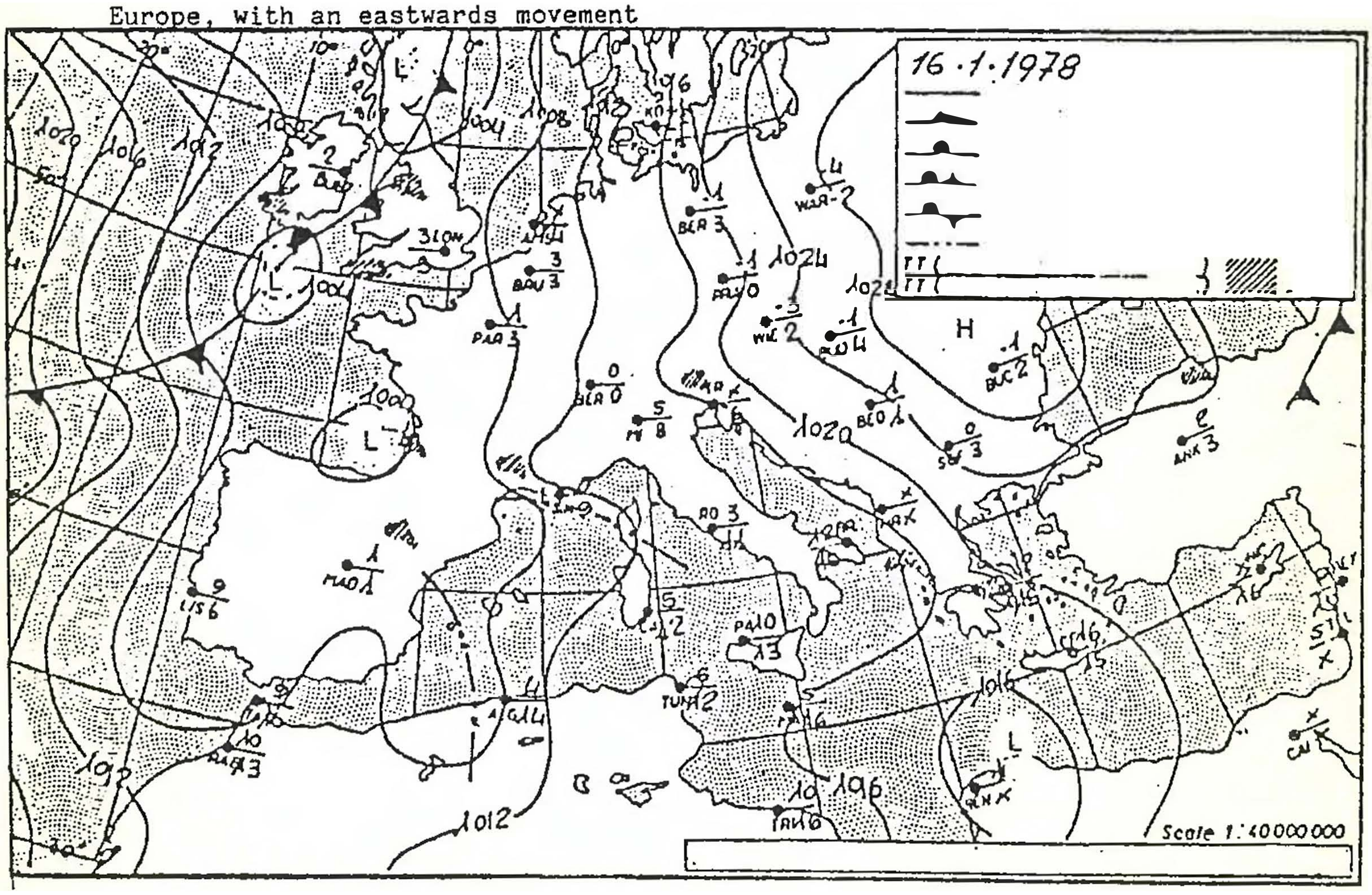


FIG. 3.5

Occurrence of fog in NE Italy

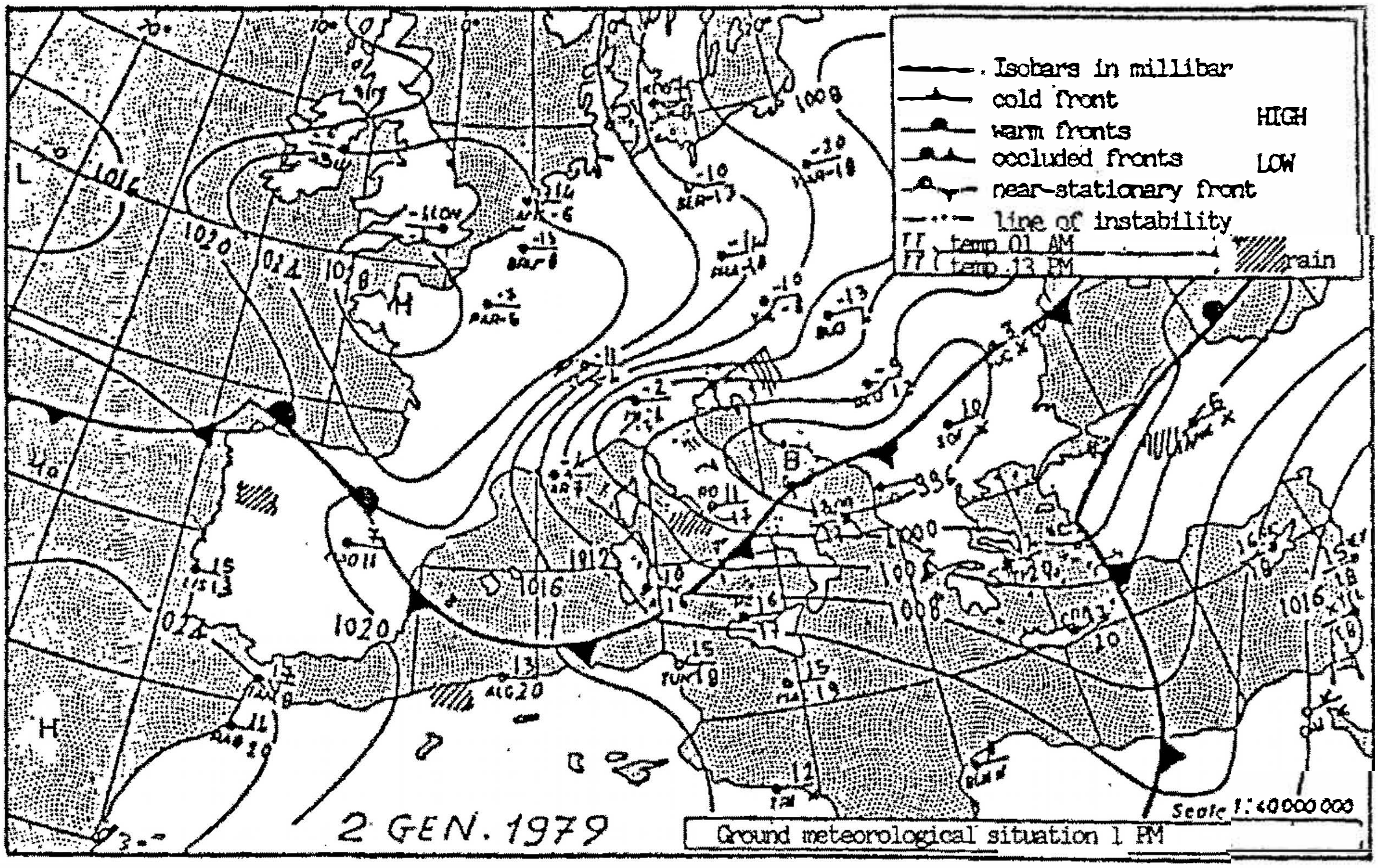


Other typical weather situations in the northern Adriatic are characterized by SW winds ('Libeccio'), related to a deep and wide depression over central Europe, with an eastwards movement

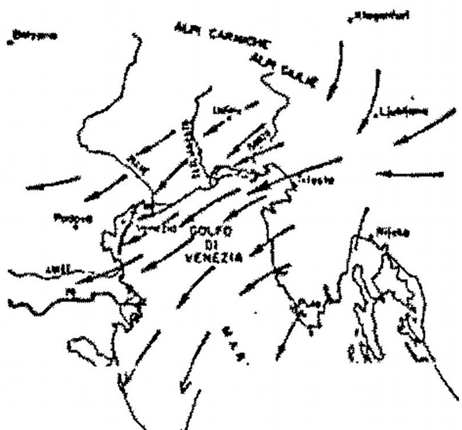


A depression field over western Europe attracts southern air (Scirocco winds along the Adriatic. The stable anti-cyclonic area over eastern Europe blocks the tendency of the discontinuous fronts to shift eastwards

2 1



The formation of 'Bora' winds is related to the occurrence of an anti-cyclonic field over western Europe, in contrast with a depression over the central-southern Adriatic.



Direction of the 'Bora' winds over the northern Adriatic

3, 7

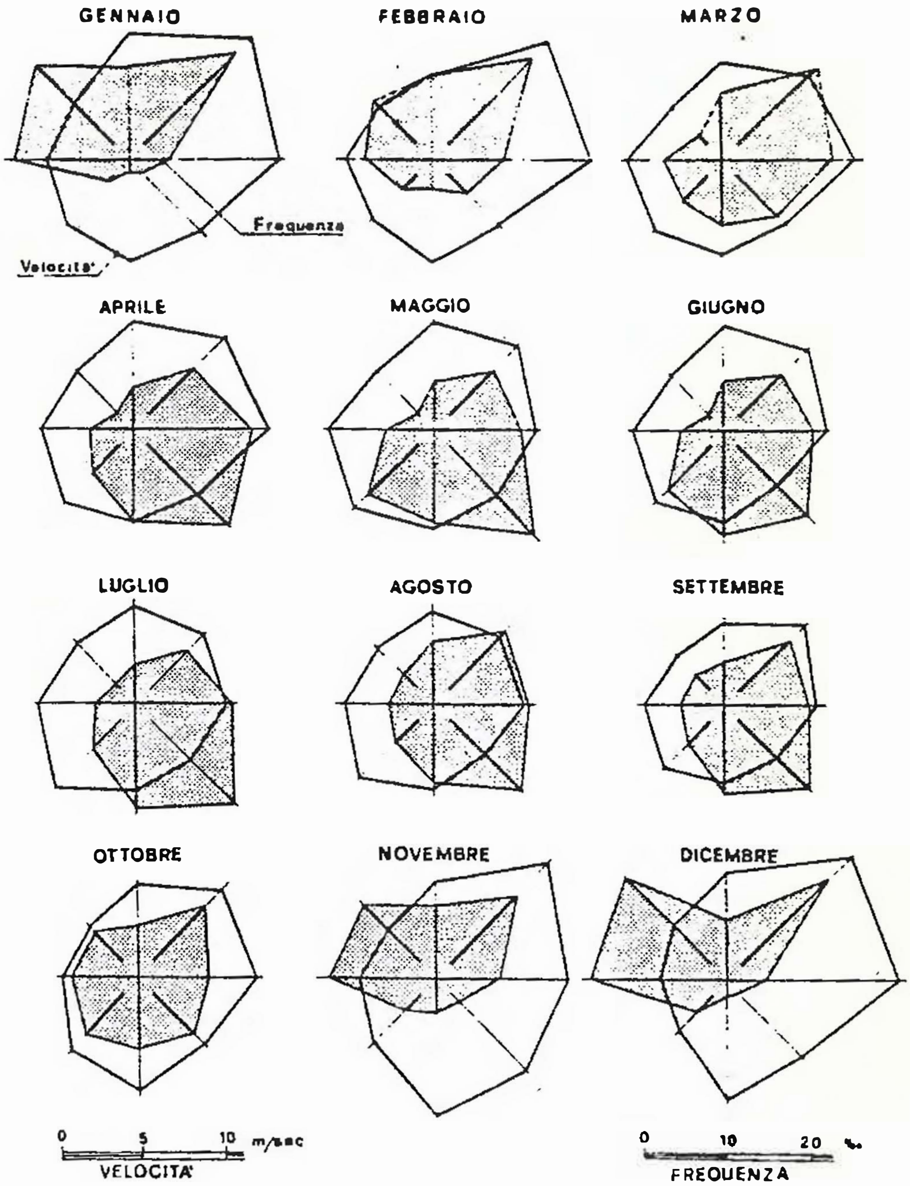
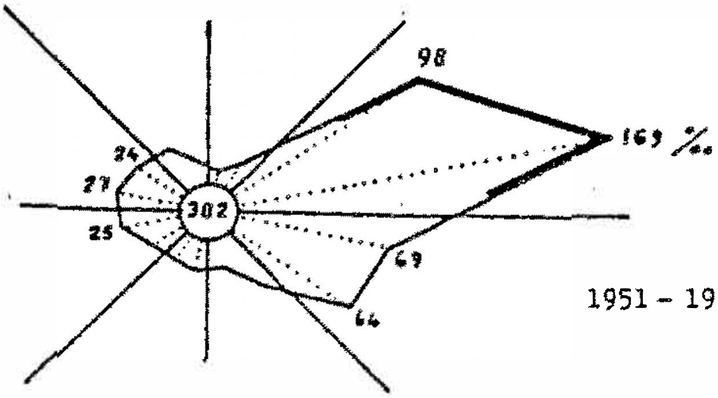


FIG. 3.8

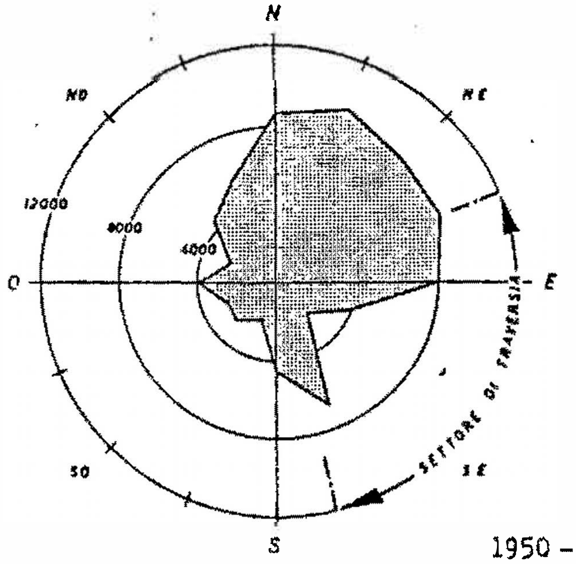
Monthly average frequency and velocity of wind
Po Delta (Rossetti 1978)

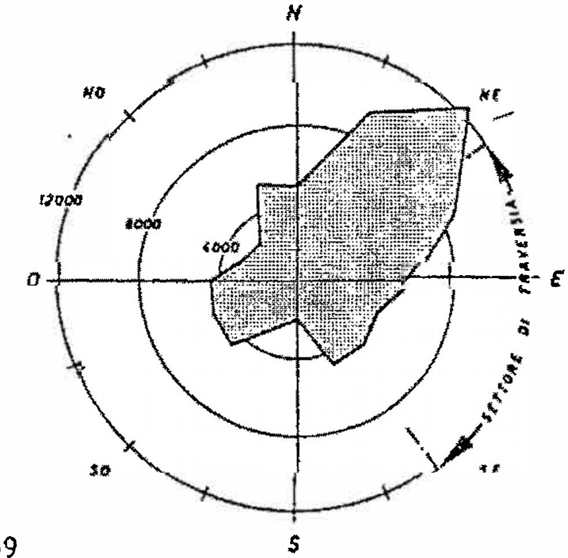
PROVISIONAL



TRIESTE

1951 - 1977

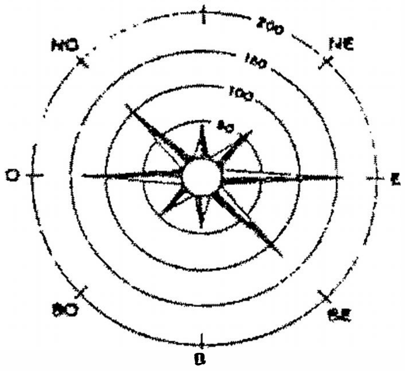


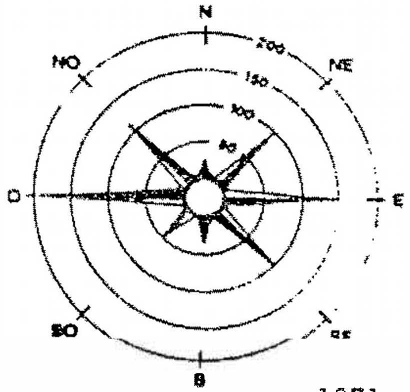


VENEZIA

1950 - 1959

CHIOGGIA



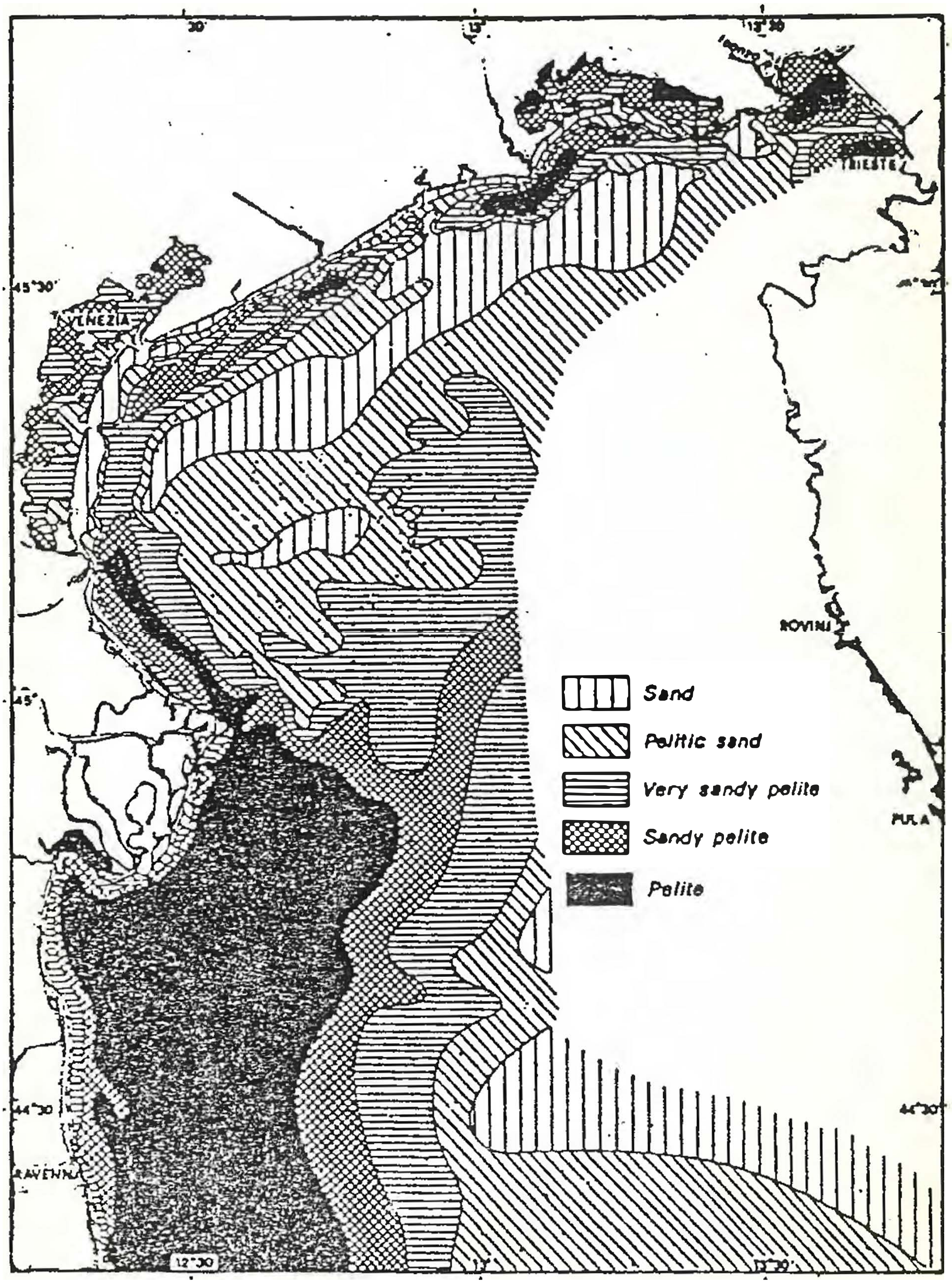


1960 - 69

1971 - 1977

RAVENNA

WINDS - 3.8



Offshore sediments in the northern Adriatic Sea

FIG. 3.9

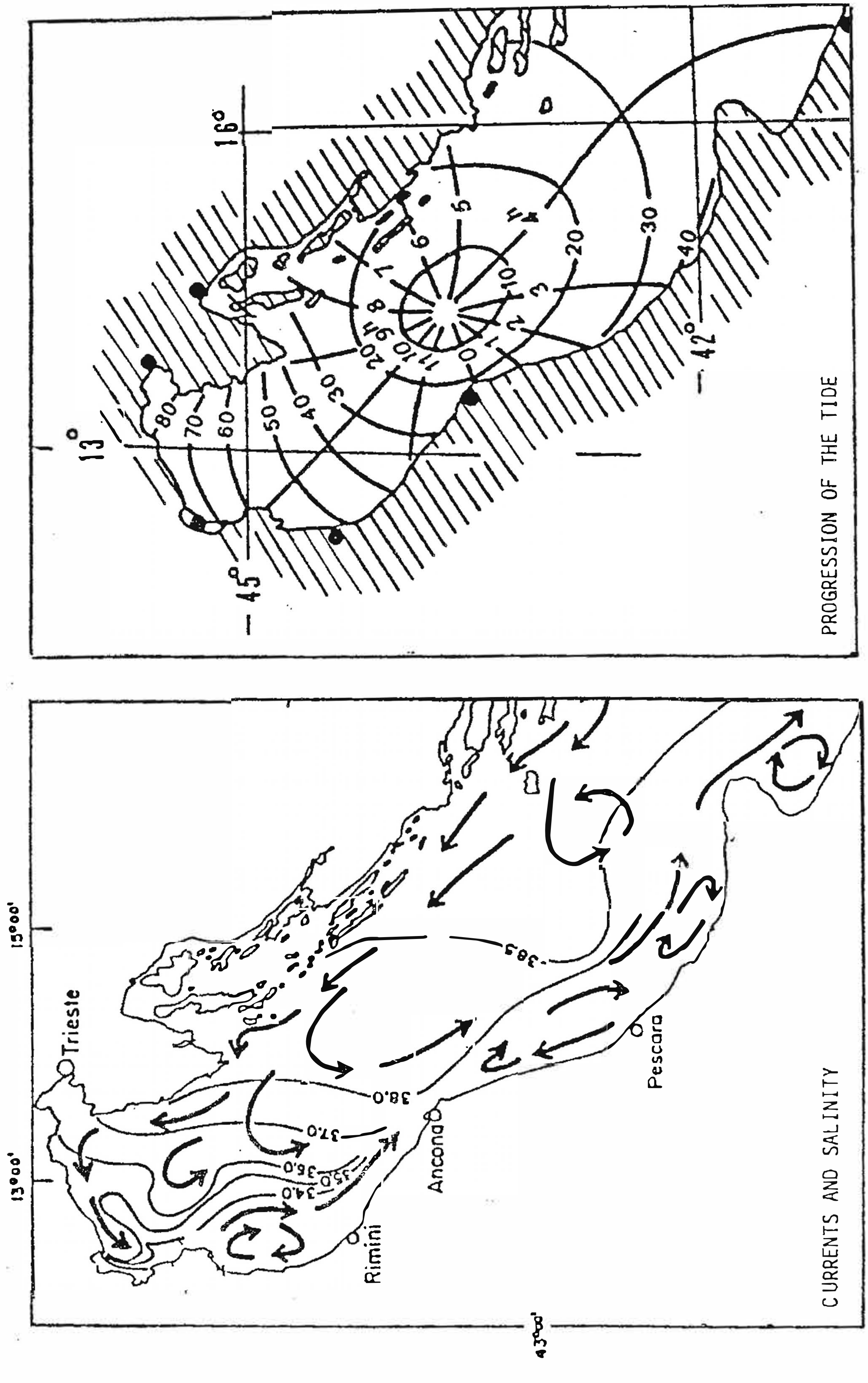

PROGRESSION OF THE TIDE
45°
13°
16°
42°
80
70
60
50
40
30
20
10
CURRENTS AND SALINITY
Trieste
Rimini
Ancona
Pescara
13°00'
15°00'
43°00'
34.0
35.0
36.0
37.0
38.0
38.5

FIG. 3.10

PROVISIONAL

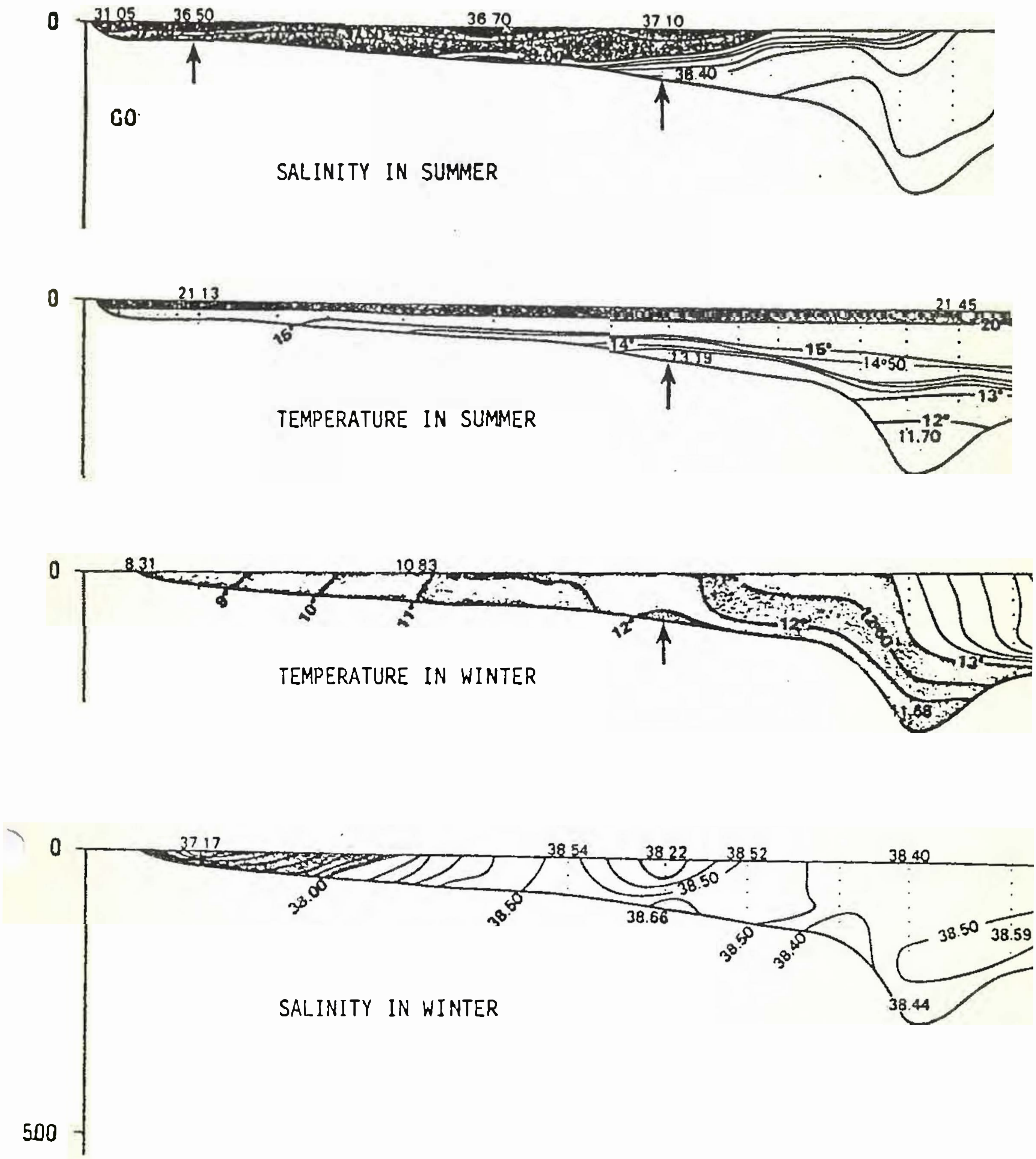
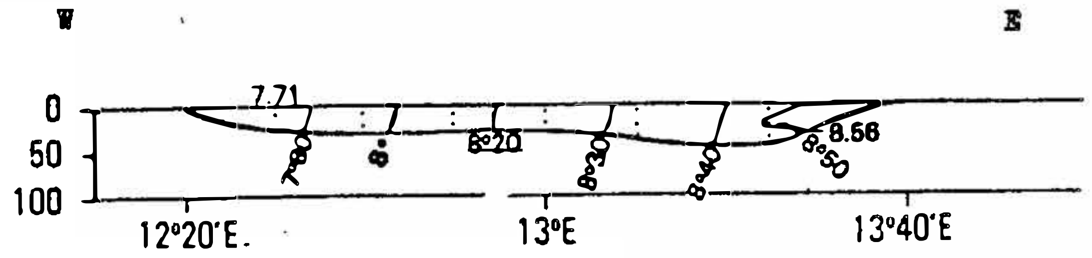
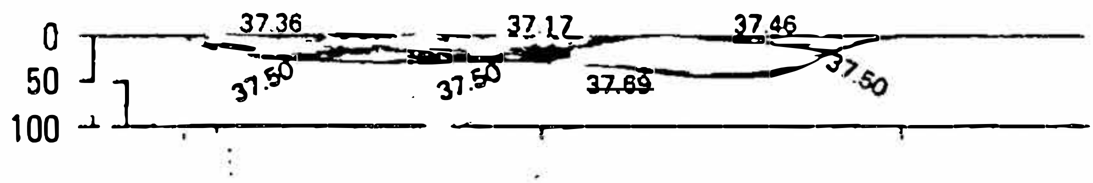


FIG. 3.11

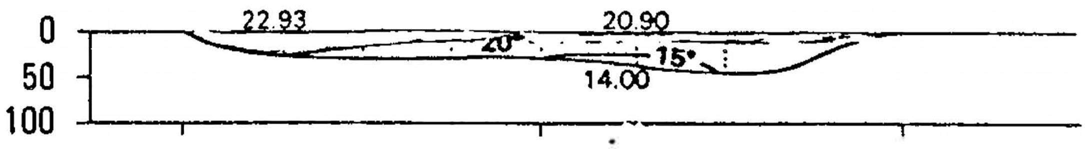
PROVISIONAL



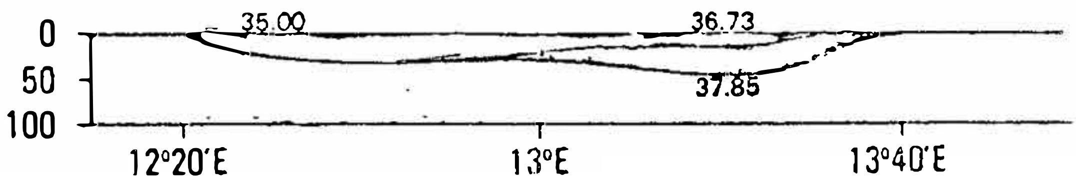
WINTER TEMPERATURES



WINTER SALINITY



SUMMER TEMPERATURE



SUMMER SALINITY

FIG. 3.12

PROVISIONAL

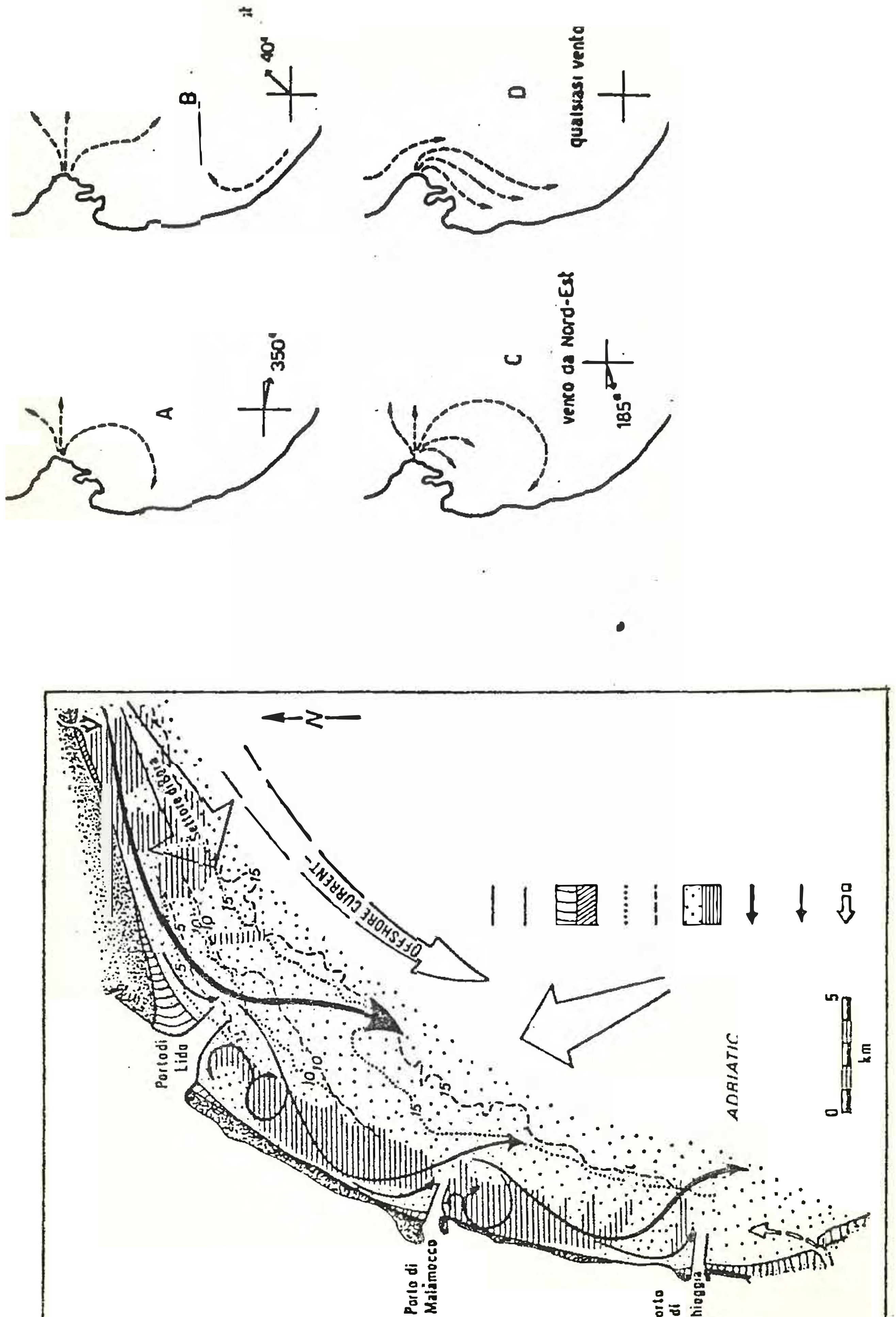
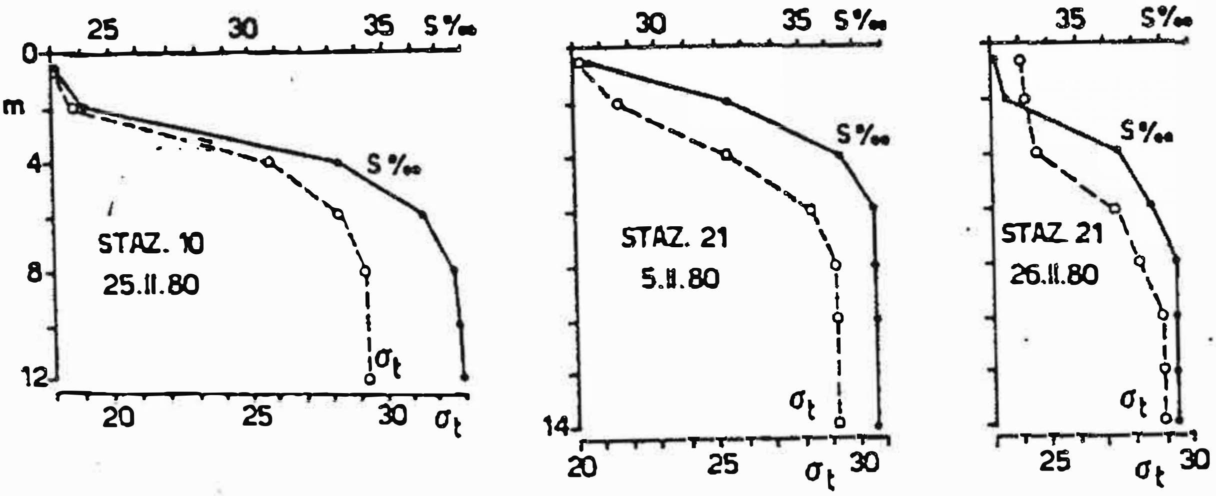


FIG. 3.13

PROVISIONAL



(Salinity and Density stratification)

(upwelling)

3.14

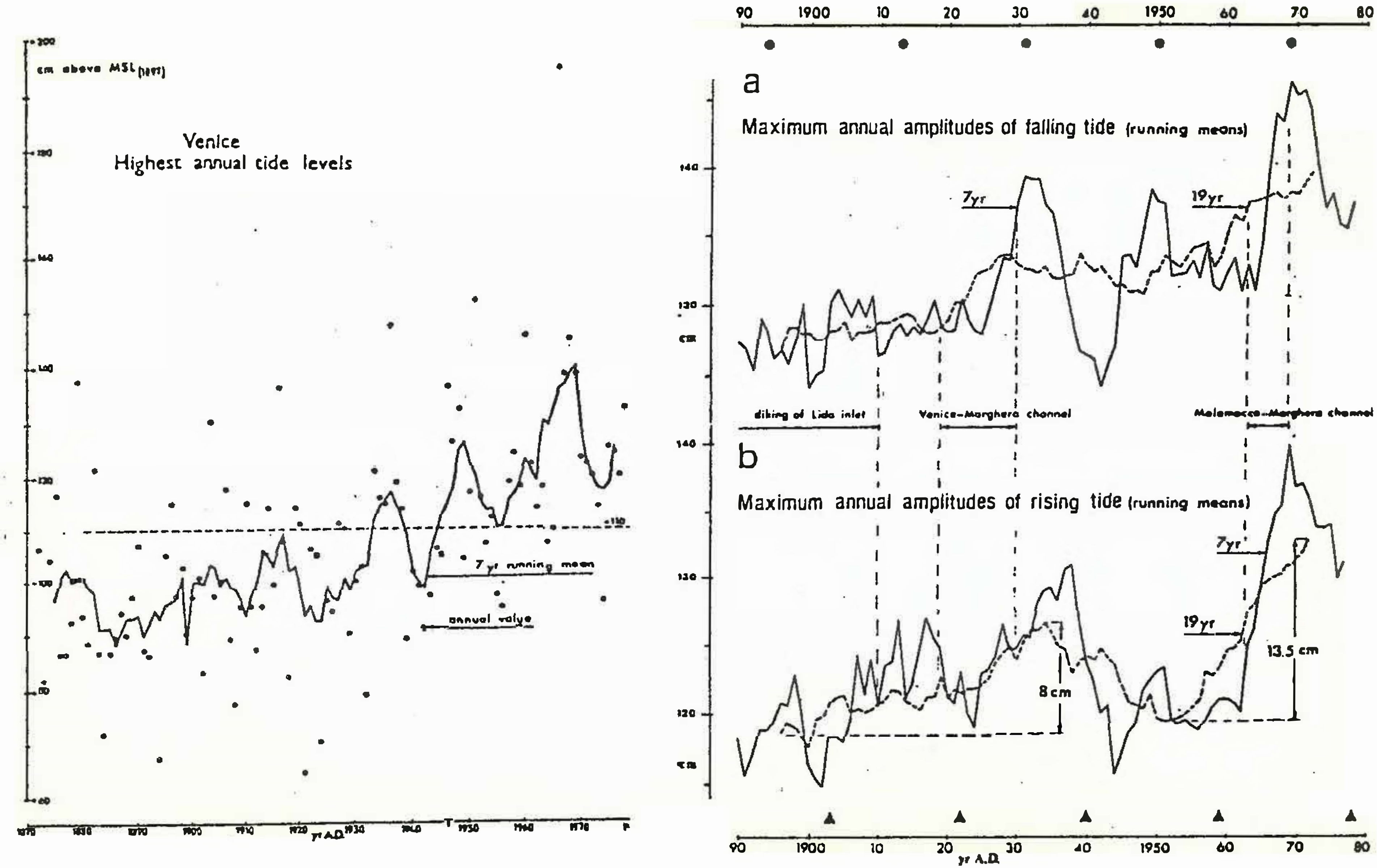
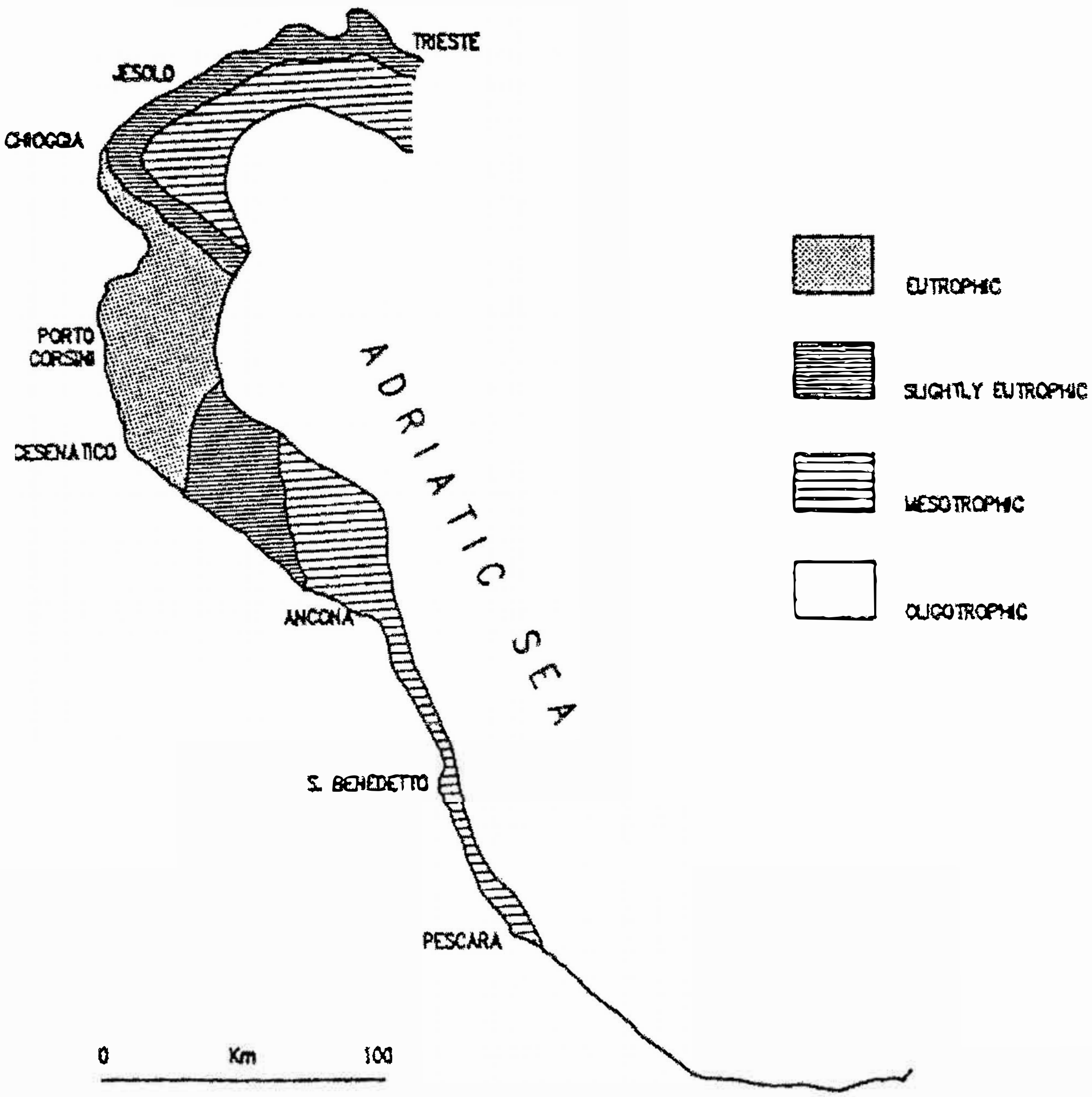


FIG. 3.15

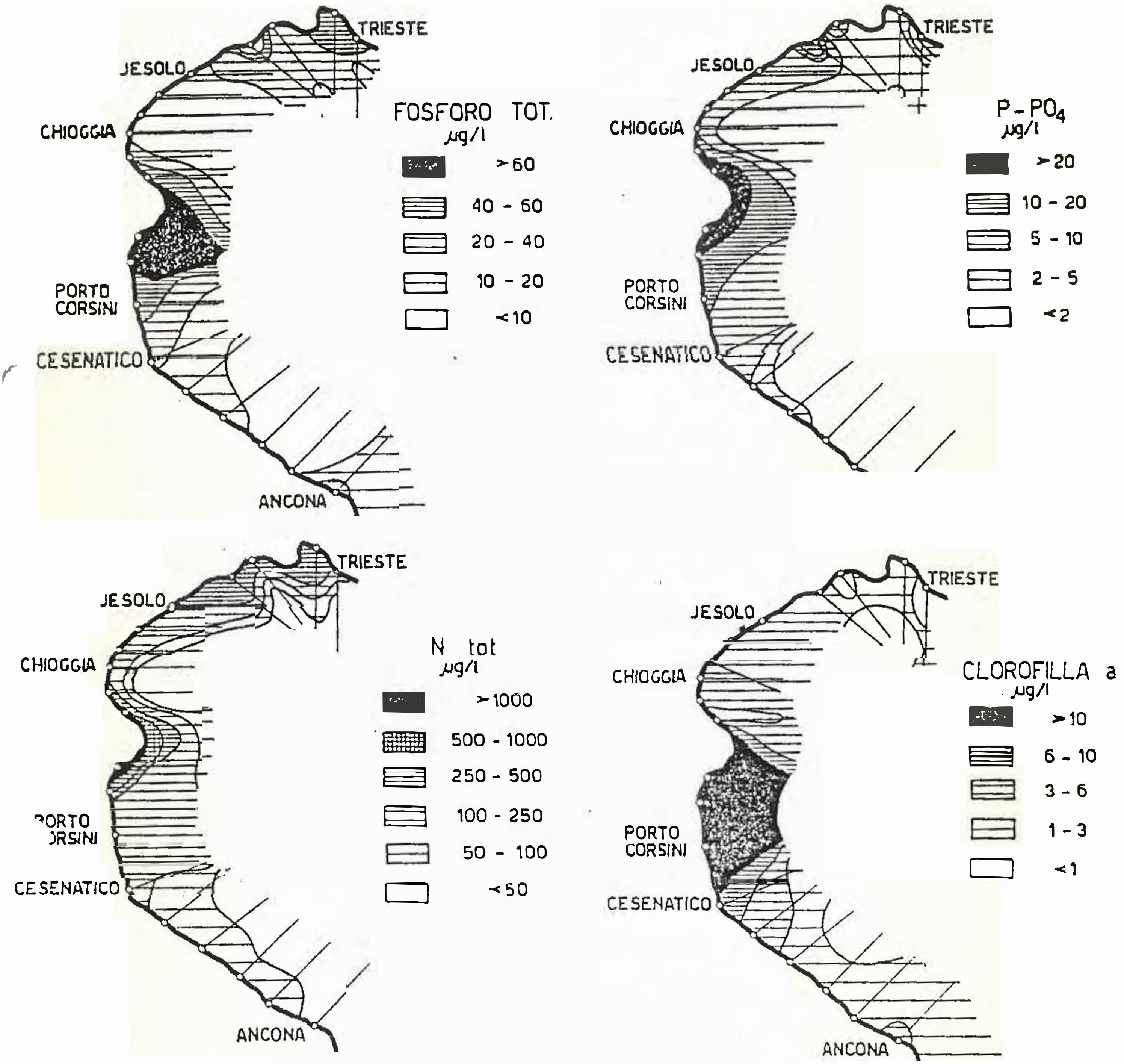
Highest annual tide levels in Venice from 1872 to 1981. Solid circles : annual values; continuous line: 7-yr running means. Data are related to the MSL of the year 1897.



Scheme of trophic conditions in the coastal zone of the Adriatic sea, according to IRSA

(From: Marchetti *et al.*1985)

FIG. 3.16



TRIESTE
JESOLO
CHIOGGIA
PORTO CORSINI
CESENATICO
ANCONA
FOSFORO TOT.
µg/l
>60
40 - 60
20 - 40
10 - 20
<10
P - PO4
µg/l
>20
10 - 20
5 - 10
2 - 5
<2
N tot
µg/l
>1000
500 - 1000
250 - 500
100 - 250
50 - 100
<50
CLOROFILLA a
µg/l
>10
6 - 10
3 - 6
1 - 3
<1

FIG. 3.17

PROVISIONAL

FIG. 4-1

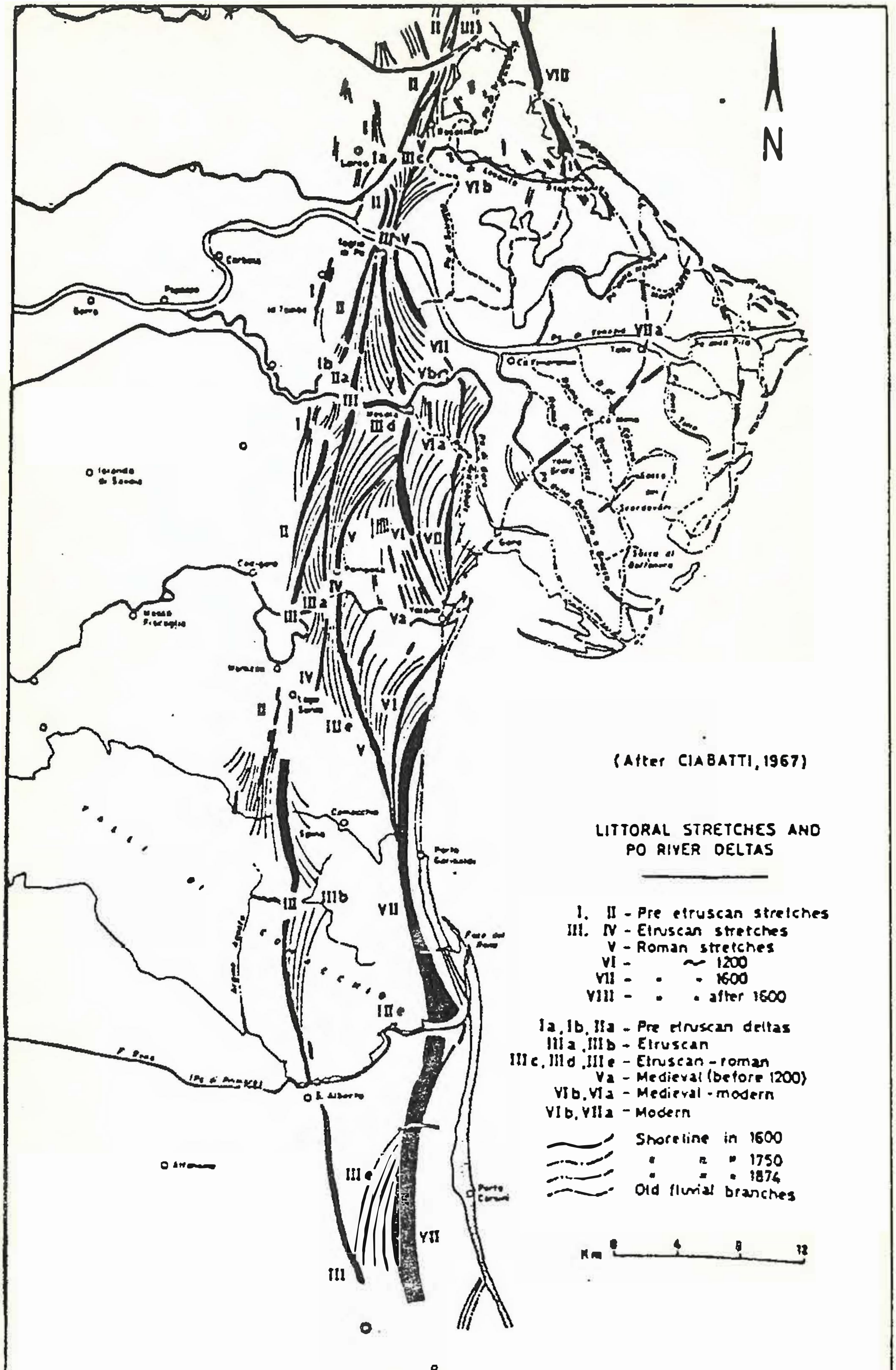
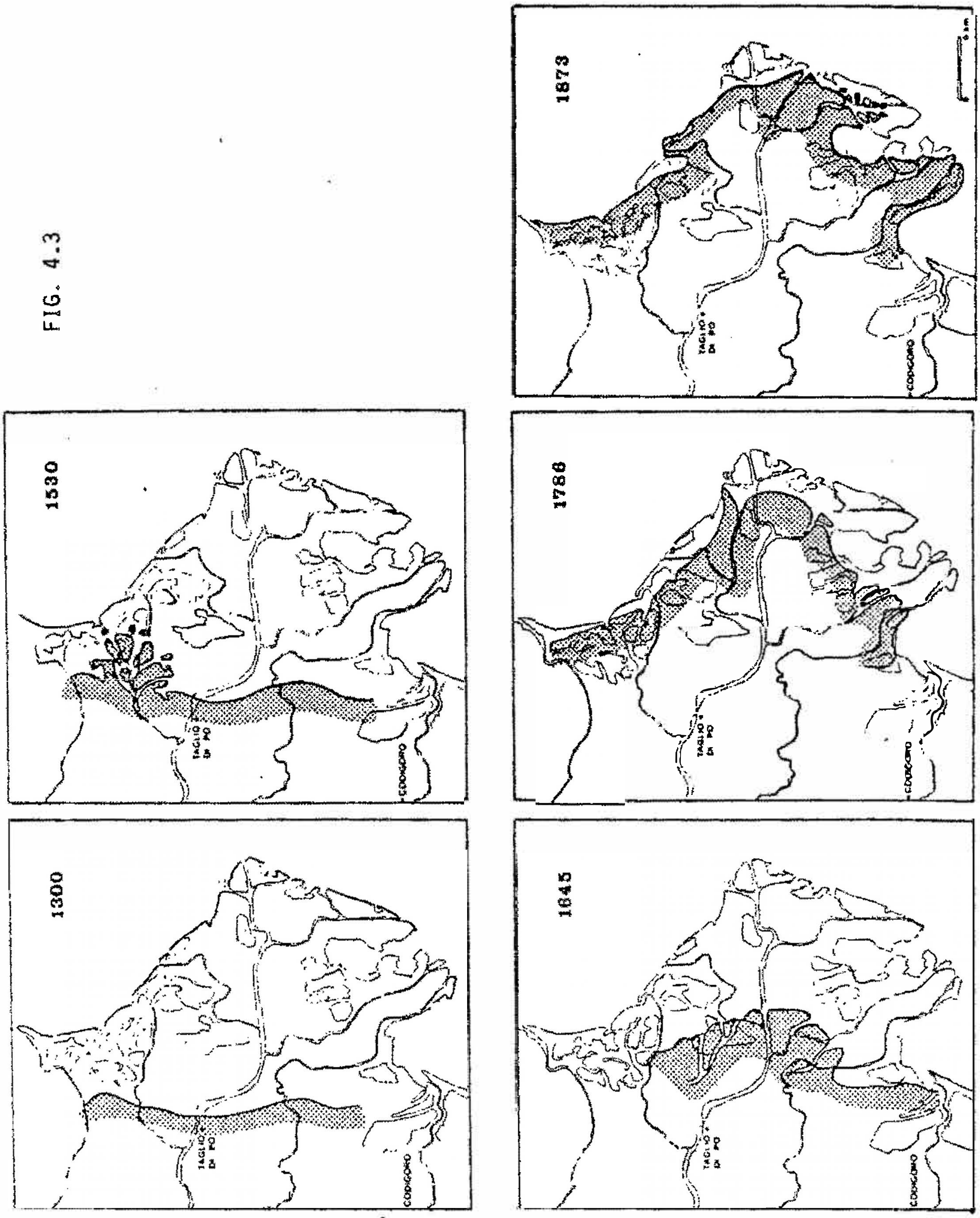


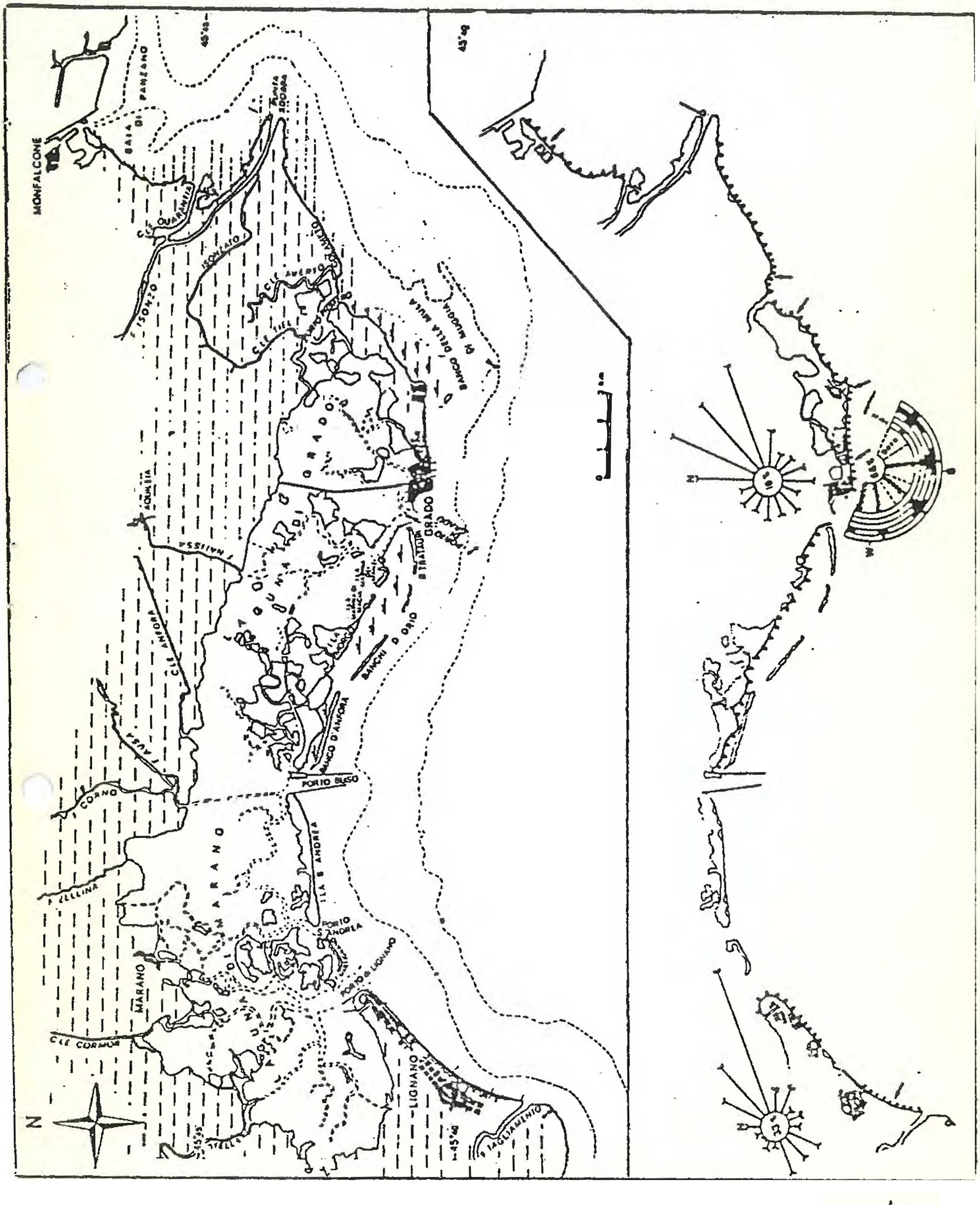
FIG. 4.2

The ancient deltas of the River Po

FIG. 4.3


1300
TAGLIO DI PO
CODIGORO
1530
TAGLIO DI PO
CODIGORO
1645
TAGLIO DI PO
CODIGORO
1786
TAGLIO DI PO
CODIGORO
1873
TAGLIO DI PO
CODIGORO

PROVISIONAL



4.3 (P.)

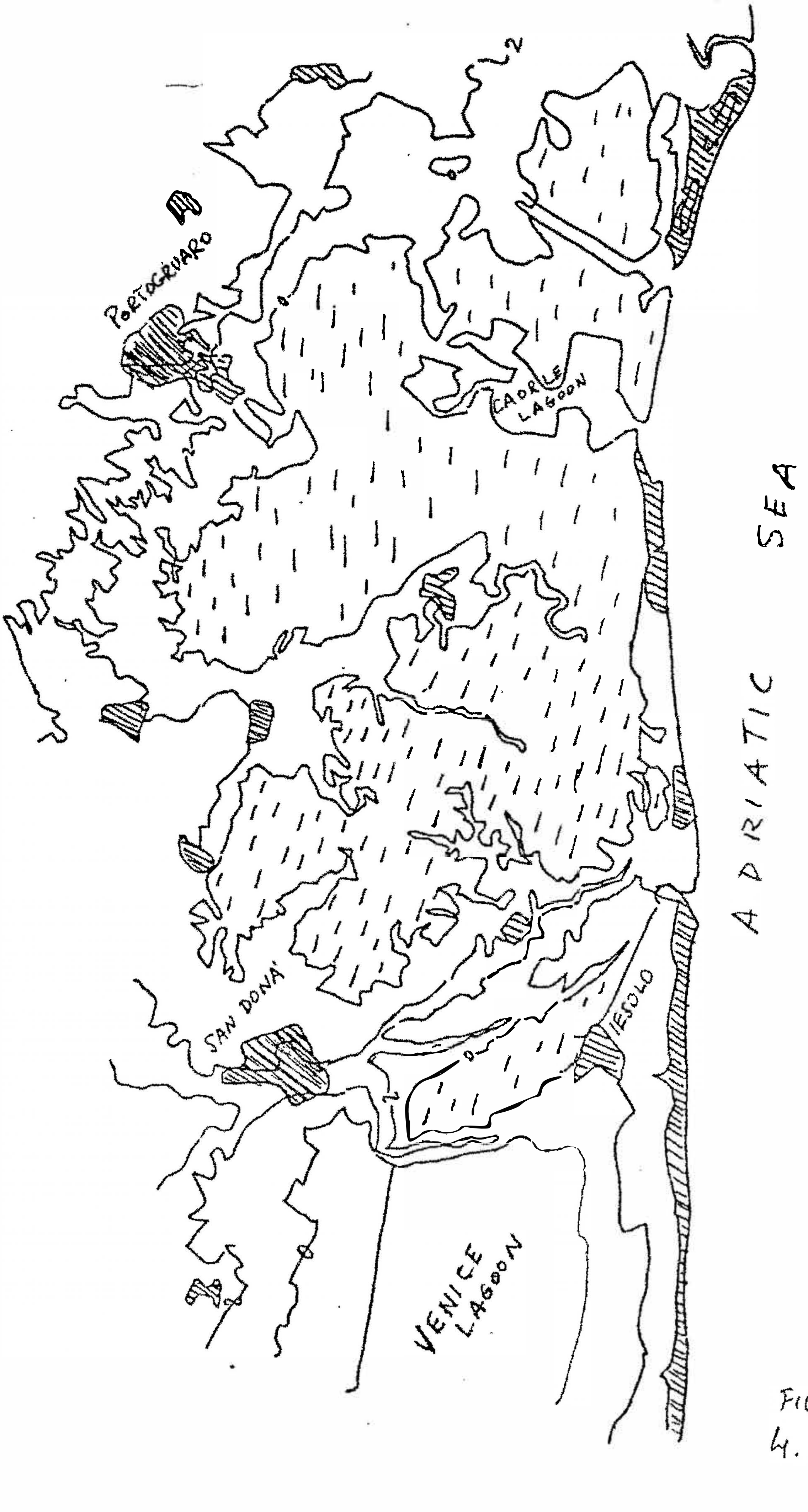
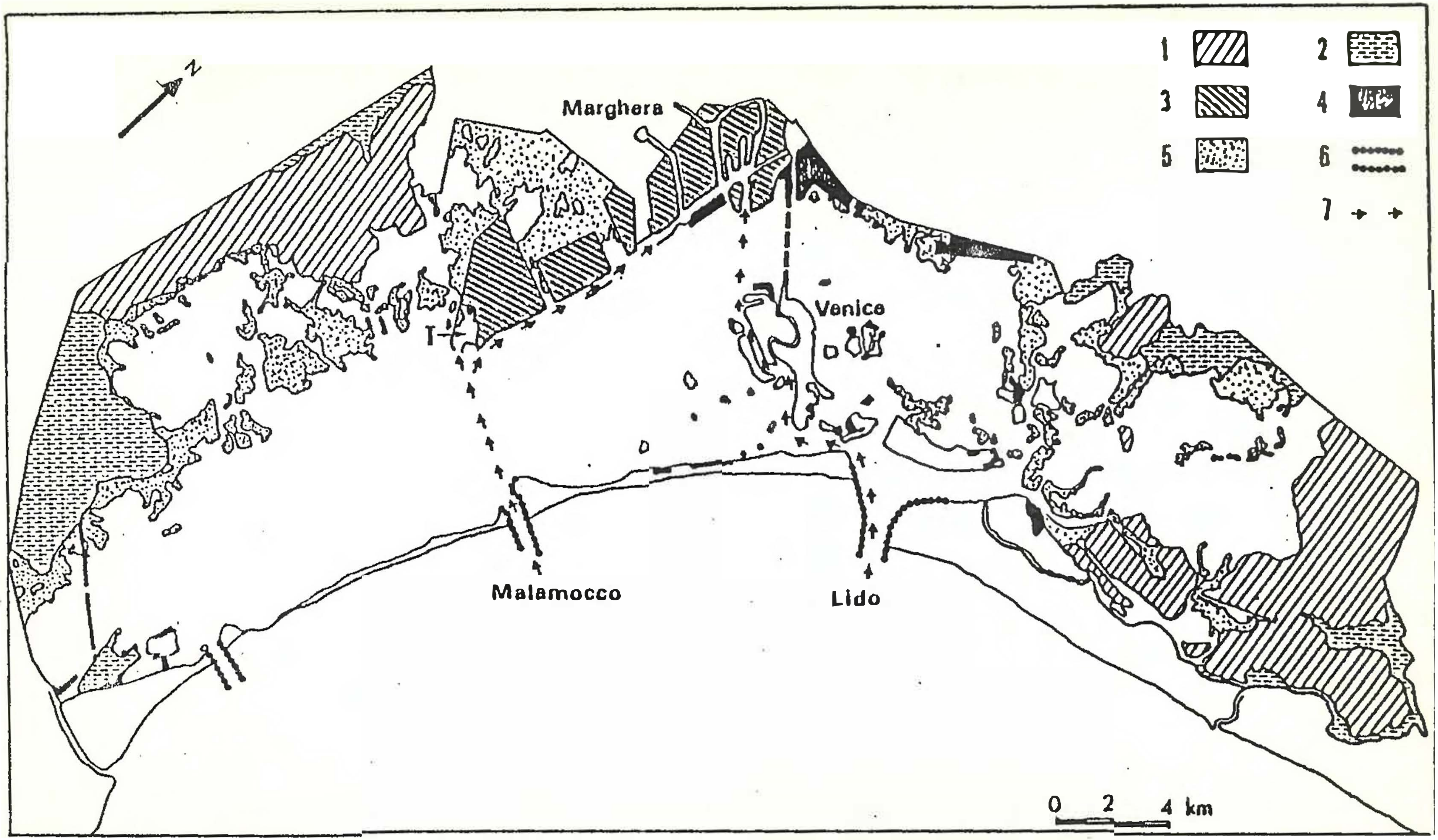
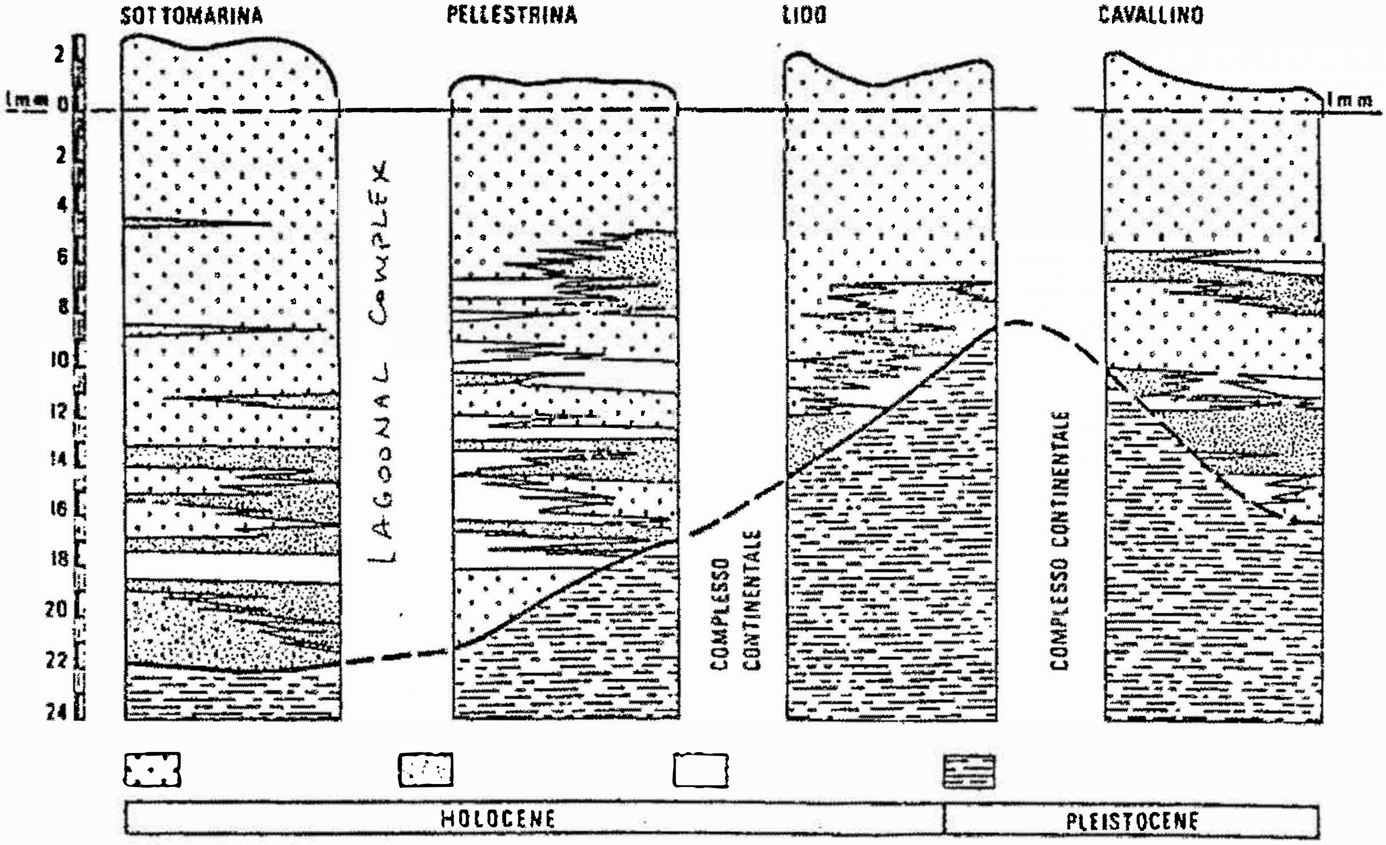

PORTOGRUARO
CAORLE LAGOON
ADRIATIC SEA
SAN DONA'
JESOLO
VENICE LAGOON

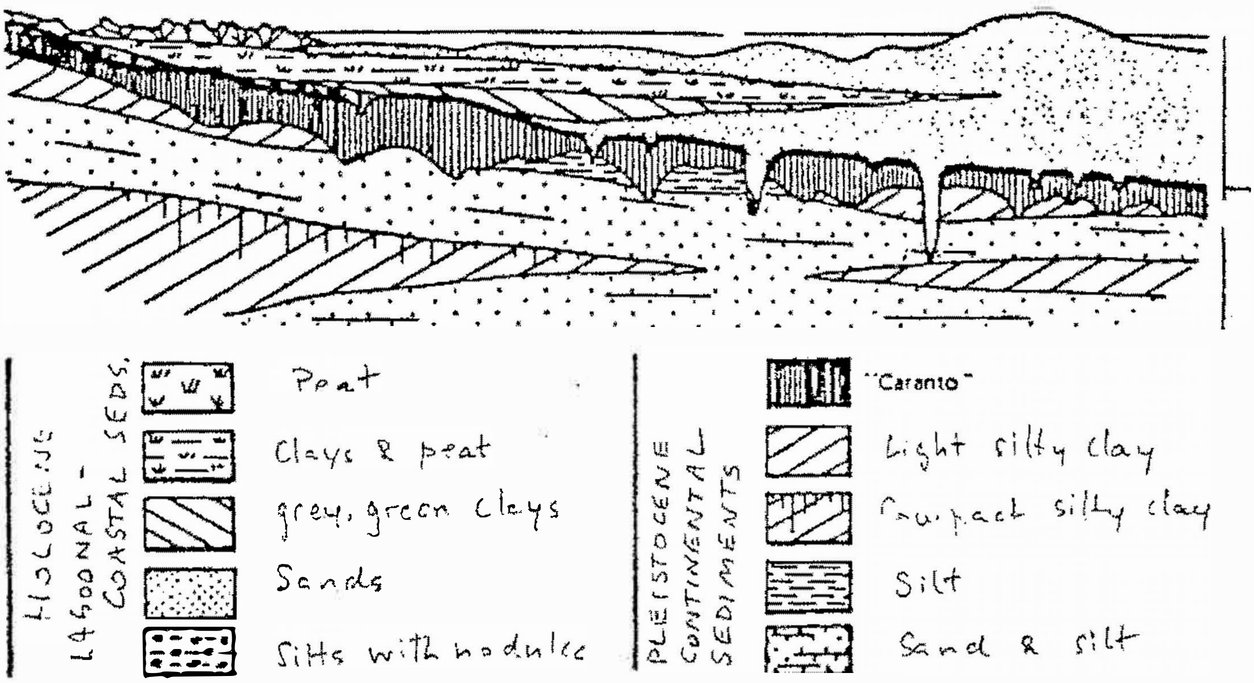
FIG. 4.4.



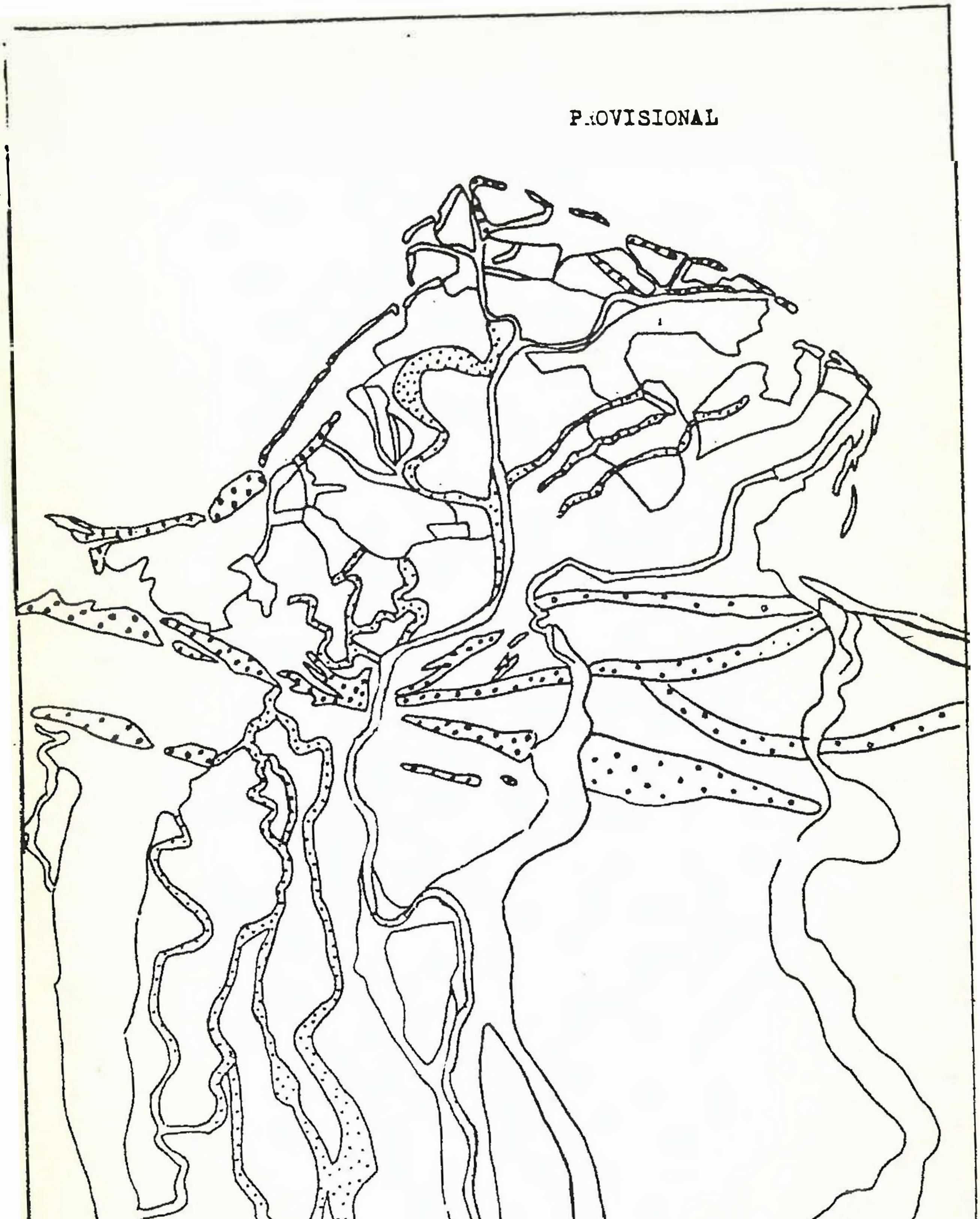
Man's recents interventions in the lagoon of Venice. 1:diked valli (fisheries); 2:diked reclamation areas for agricultural use; 3:diked barene for industrial use; 4:urbanized areas, dumping grounds (since AD 1900); 5:barene currently open to tide; 6:dikes of the inlets; 7:artificial channels; T:oil Terminal.

6.5


SOTTOMARINA
PELLESTRINA
LIDO
CAVALLINO
l.m.m.
LAGOONAL COMPLEX
COMPLESSO CONTINENTALE
COMPLESSO CONTINENTALE
HOLOCENE
PLEISTOCENE


HOLOCENE LAGOONAL - COASTAL SEDS.
Peat
Clays & peat
grey, green clays
Sands
Silts with nodules
PLEISTOCENE CONTINENTAL SEDIMENTS
"Caranto"
Light silty clay
Compact silty clay
Silt
Sand & silt

4.6



4.7 Morphological units of B Delta

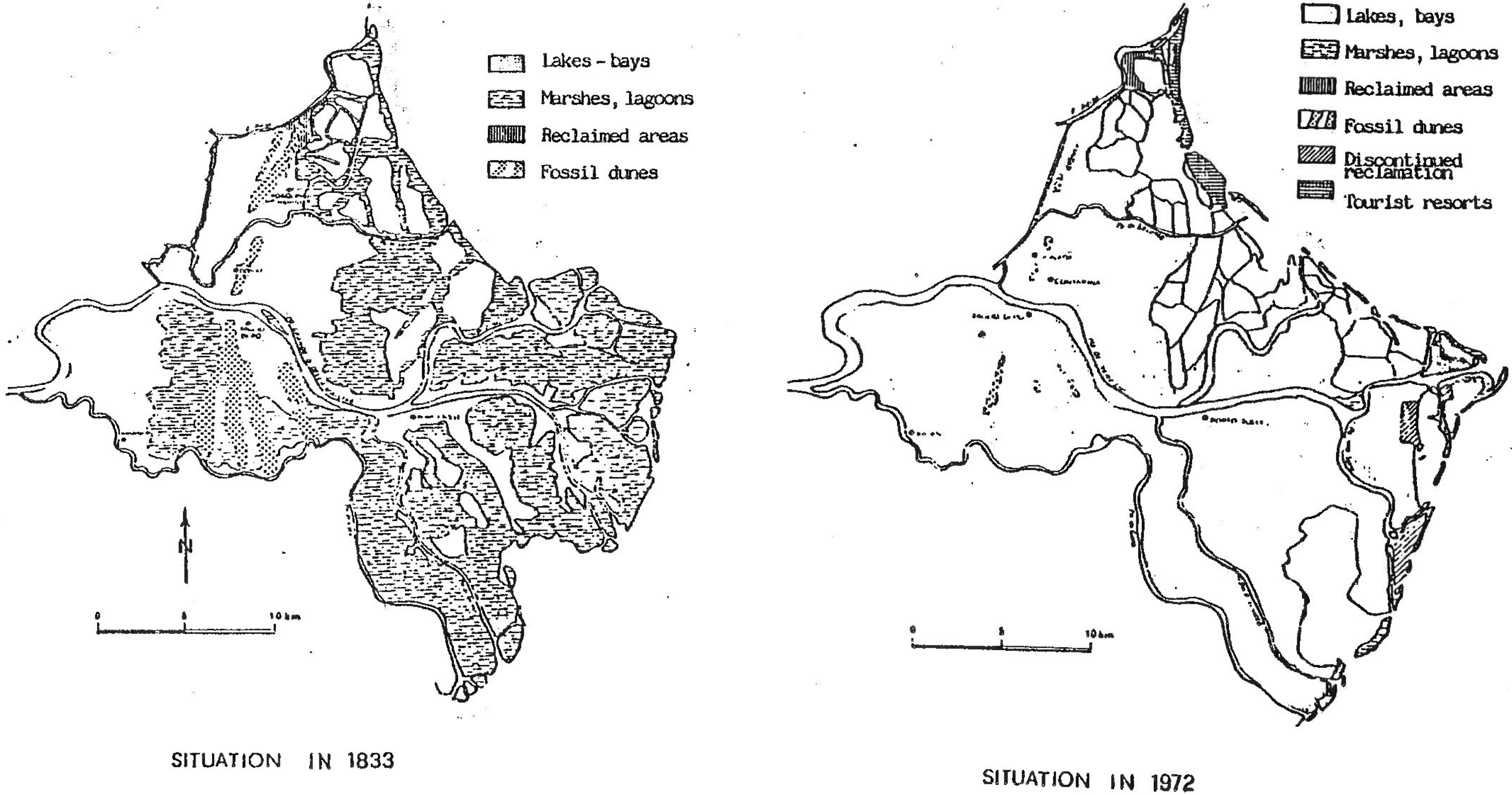

Lakes - bays
Marshes, lagoons
Reclaimed areas
Fossil dunes
N
0
5
10 km
SITUATION IN 1833
Lakes, bays
Marshes, lagoons
Reclaimed areas
Fossil dunes
Discontinued reclamation
Tourist resorts
0
5
10 km
SITUATION IN 1972

FIG. 4.8

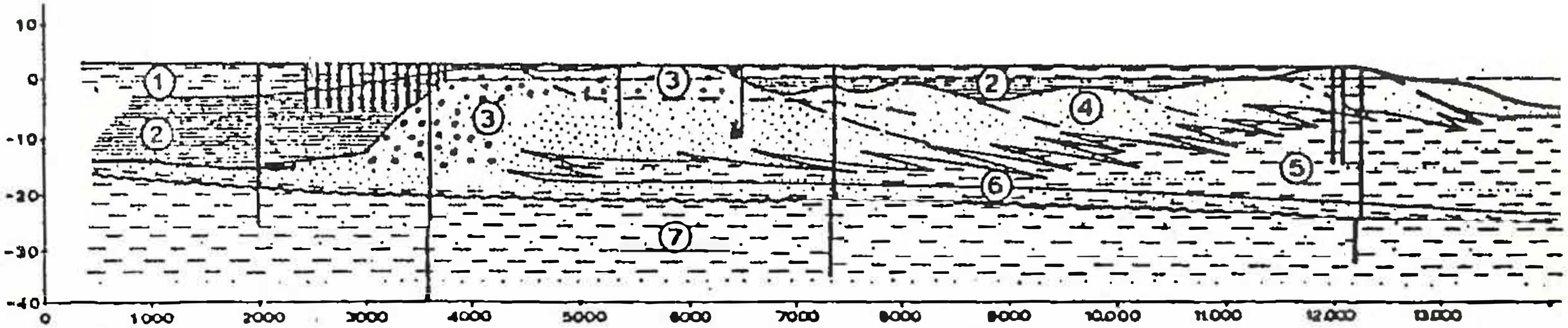
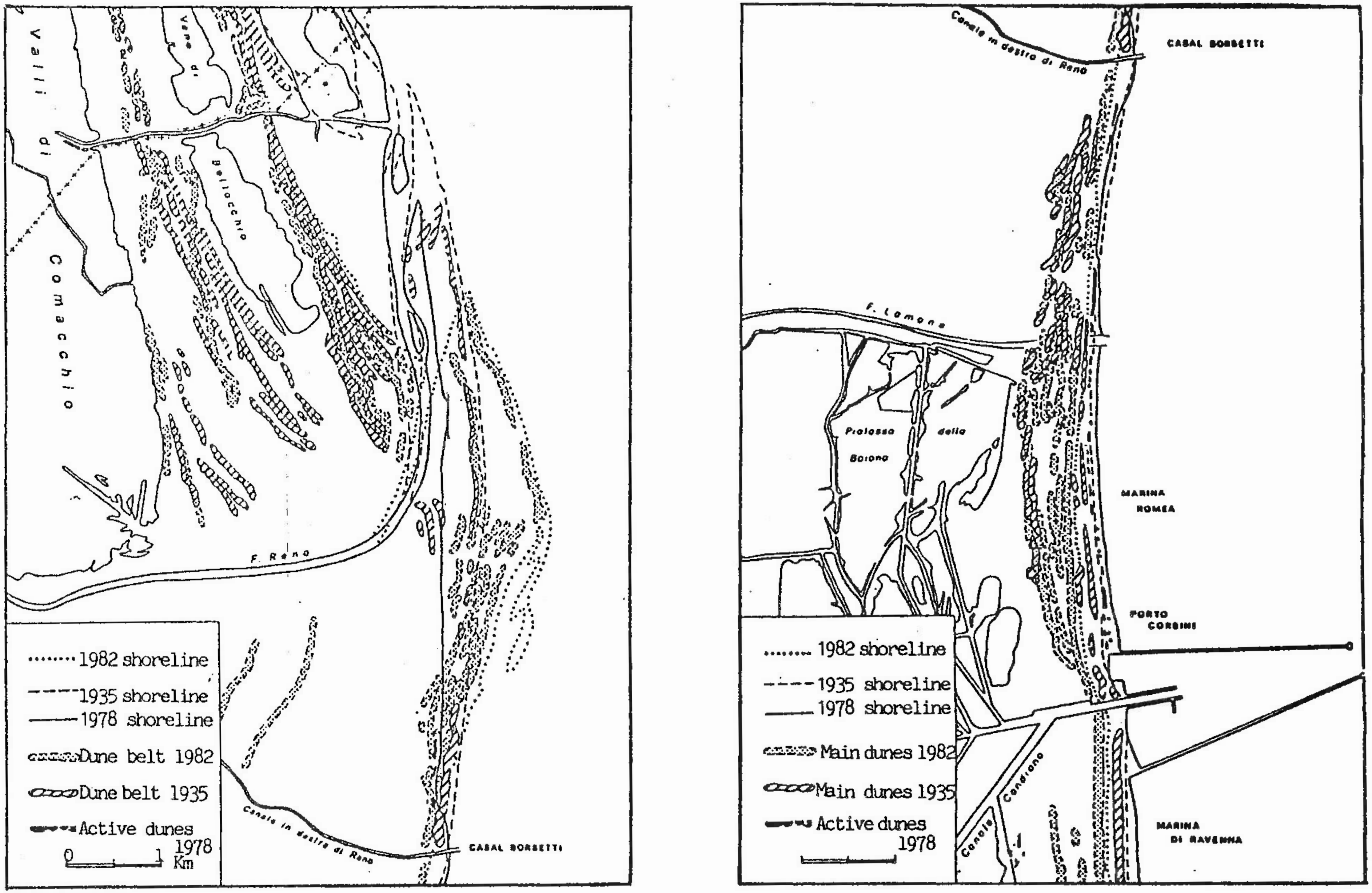


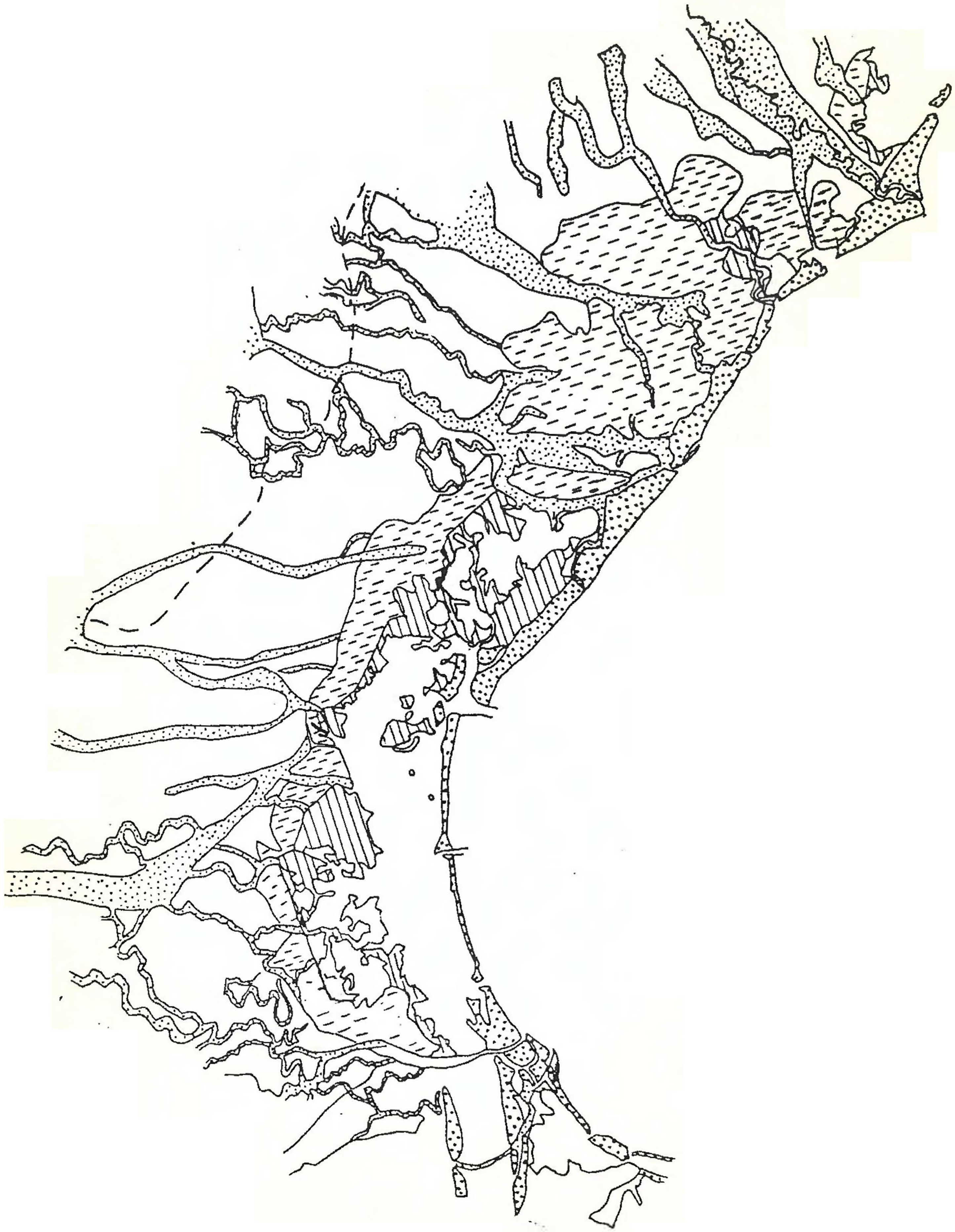
FIG. 410

Schematic section of the subsurface stratigraphy of the Ravenna area. 1. Clays of recent reclamations. 2.Clays, with peat and sandy -clayey silts of lagoonal environment. 3. Beach sand and gravels 4. Beach and nearshore littoral sands. 5. Marine nearshore silts with thin sands. 6. Sands and silts of the Holocene transgression. 7.Clays, silts and sands of continental environment. [From: Rizzini 197).

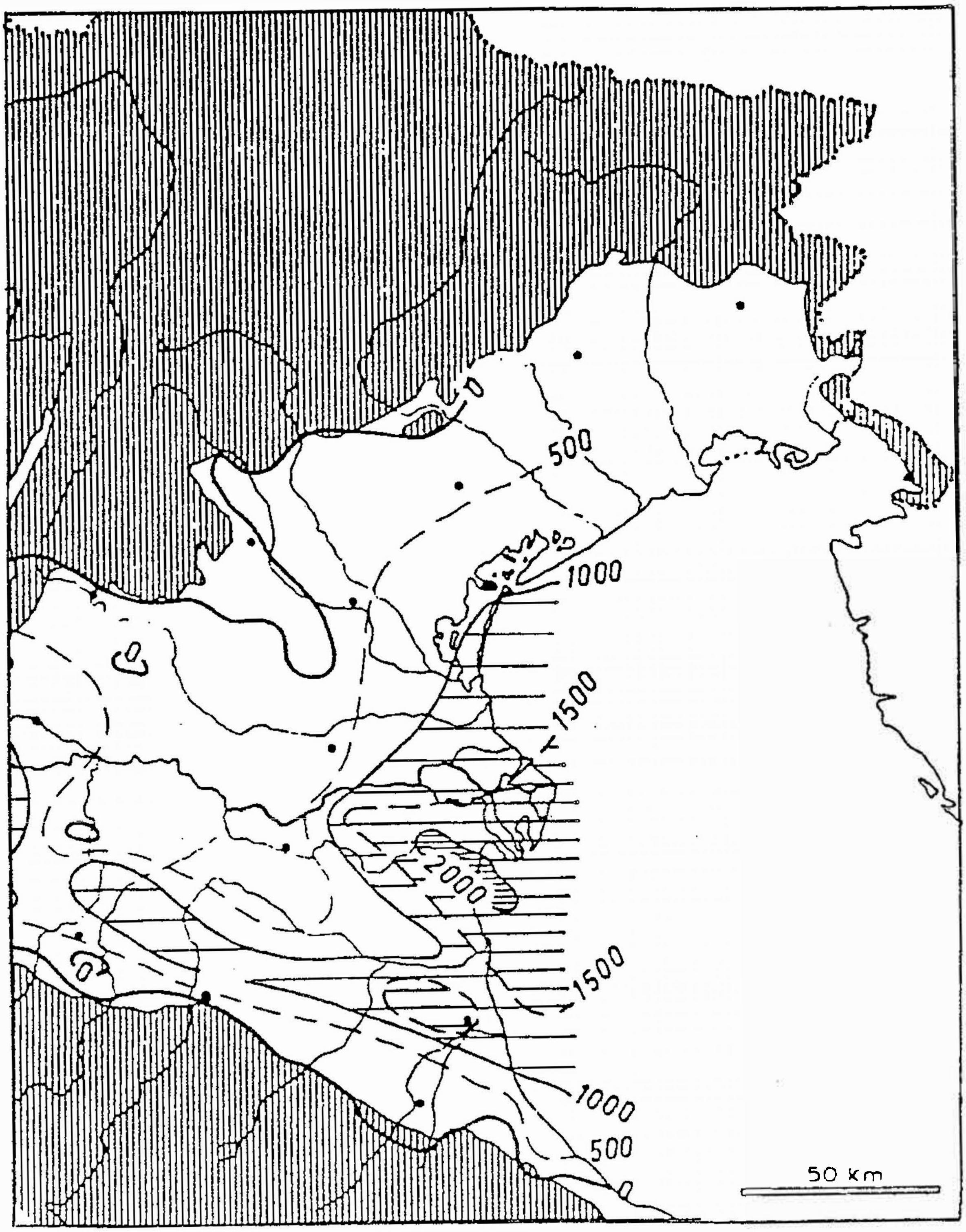


The dune situation in two stretches of the Romagna coast

4.11

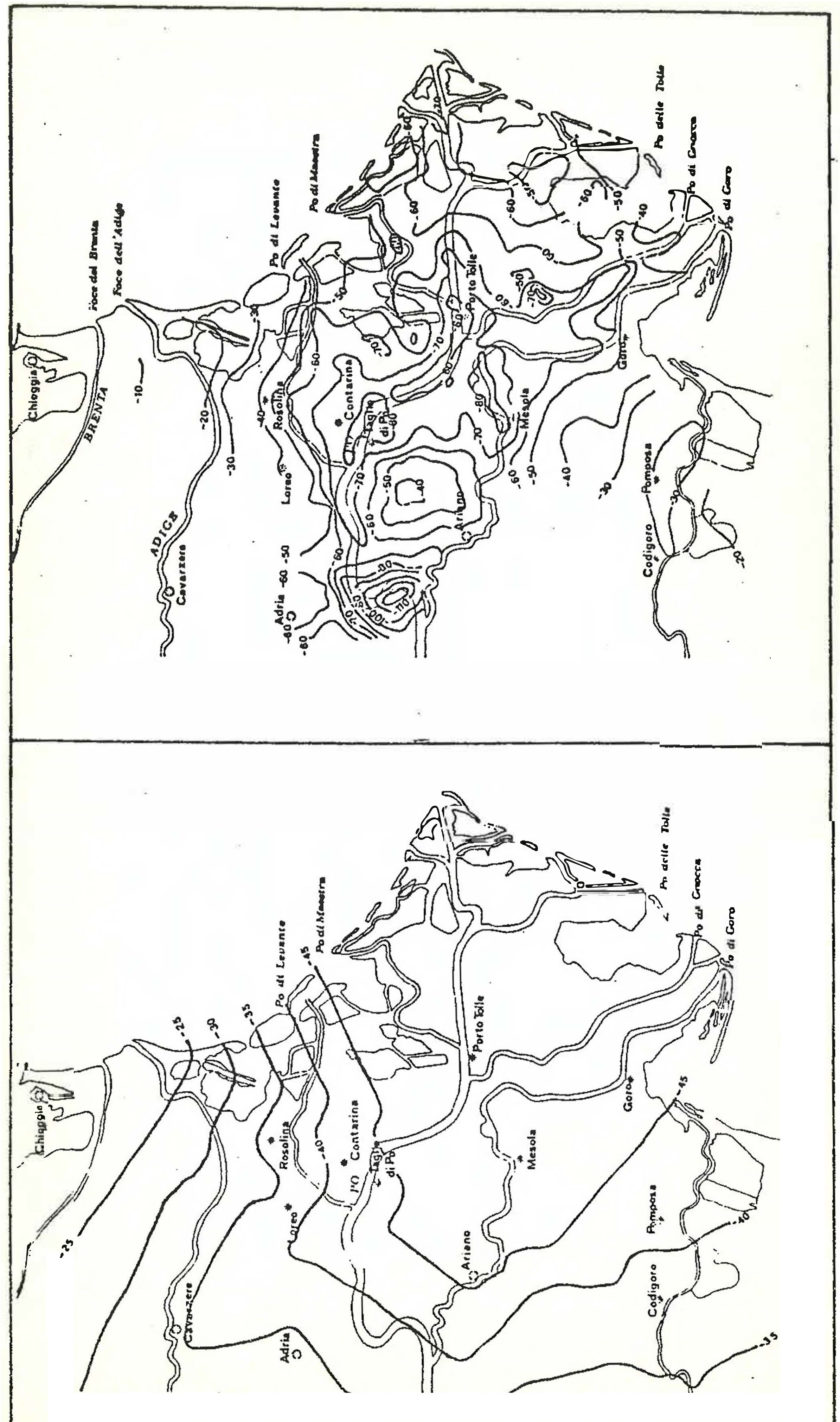


4.13



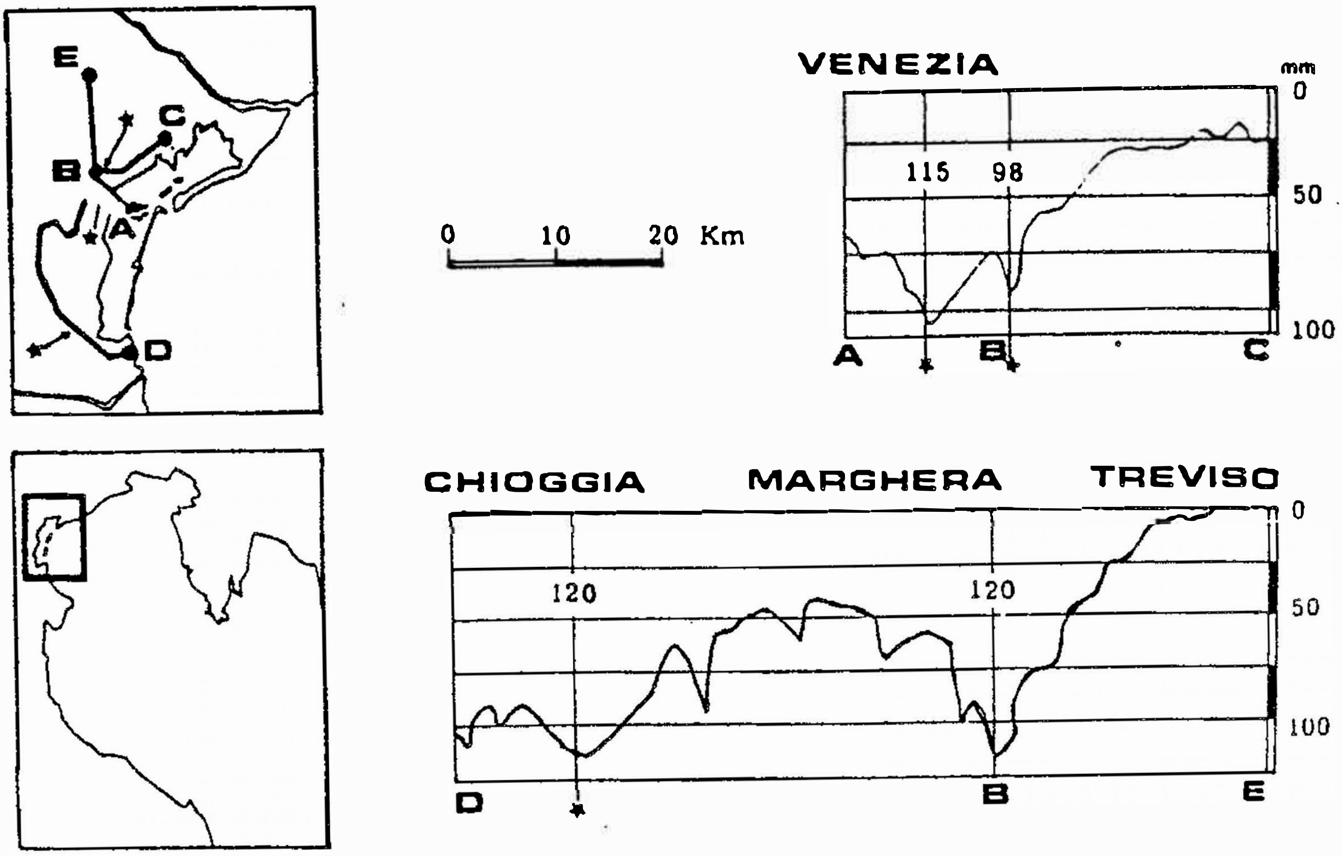
Thickness of Pleistocene sediments

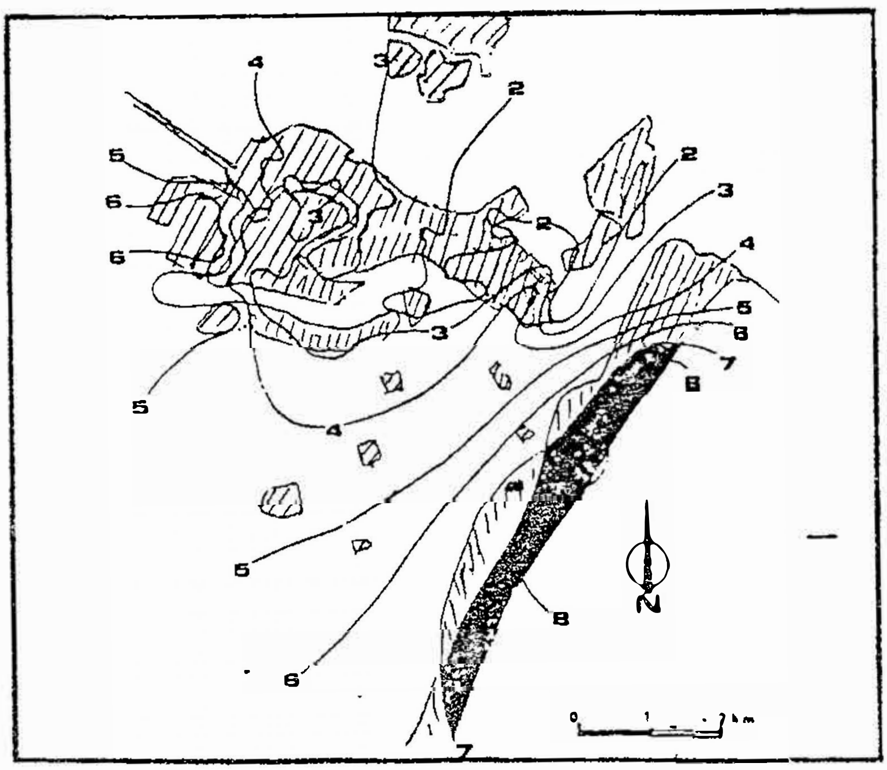
4. 14



4.15 Po Delta Subsidence

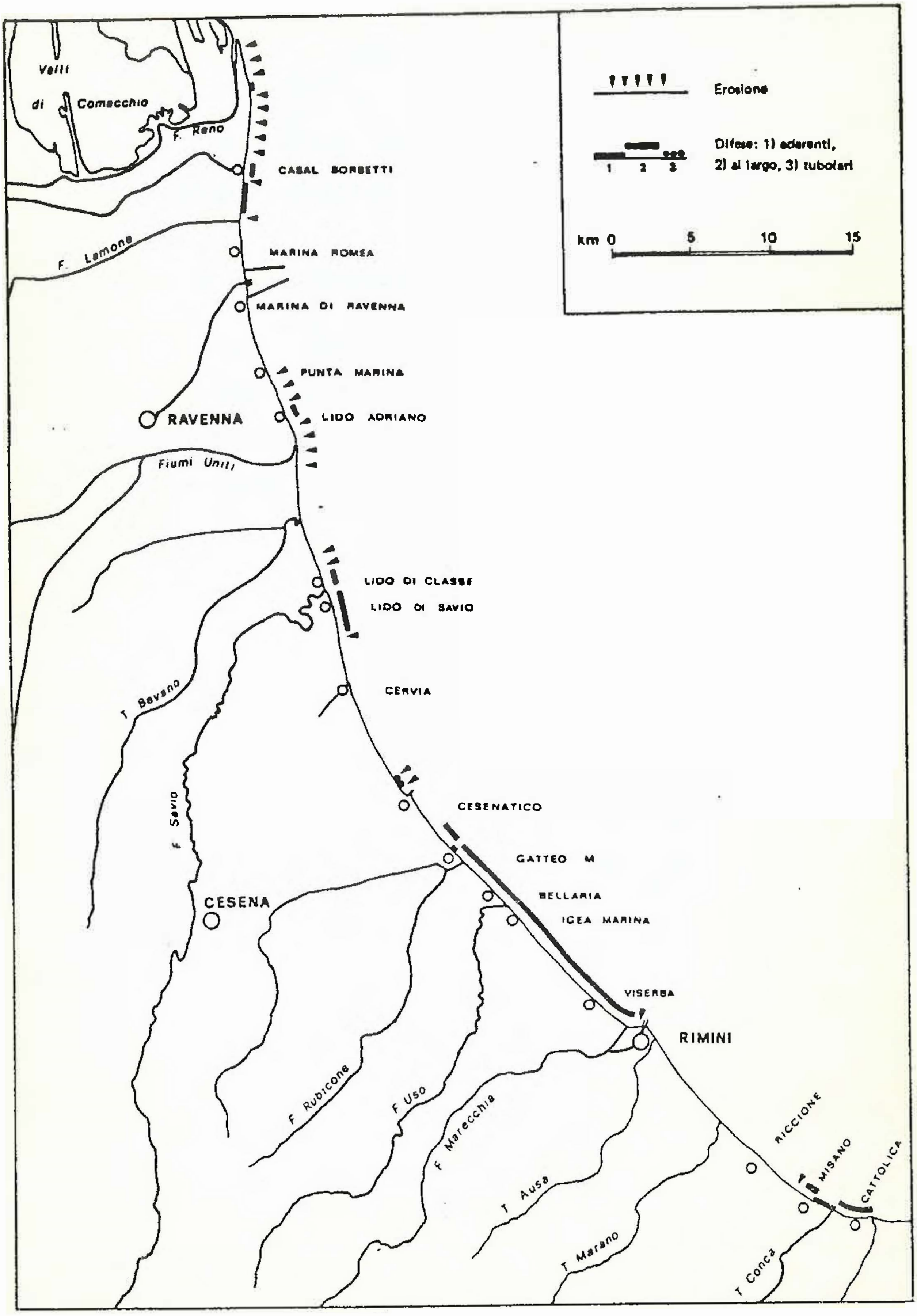
PROVISIONAL





4. 17

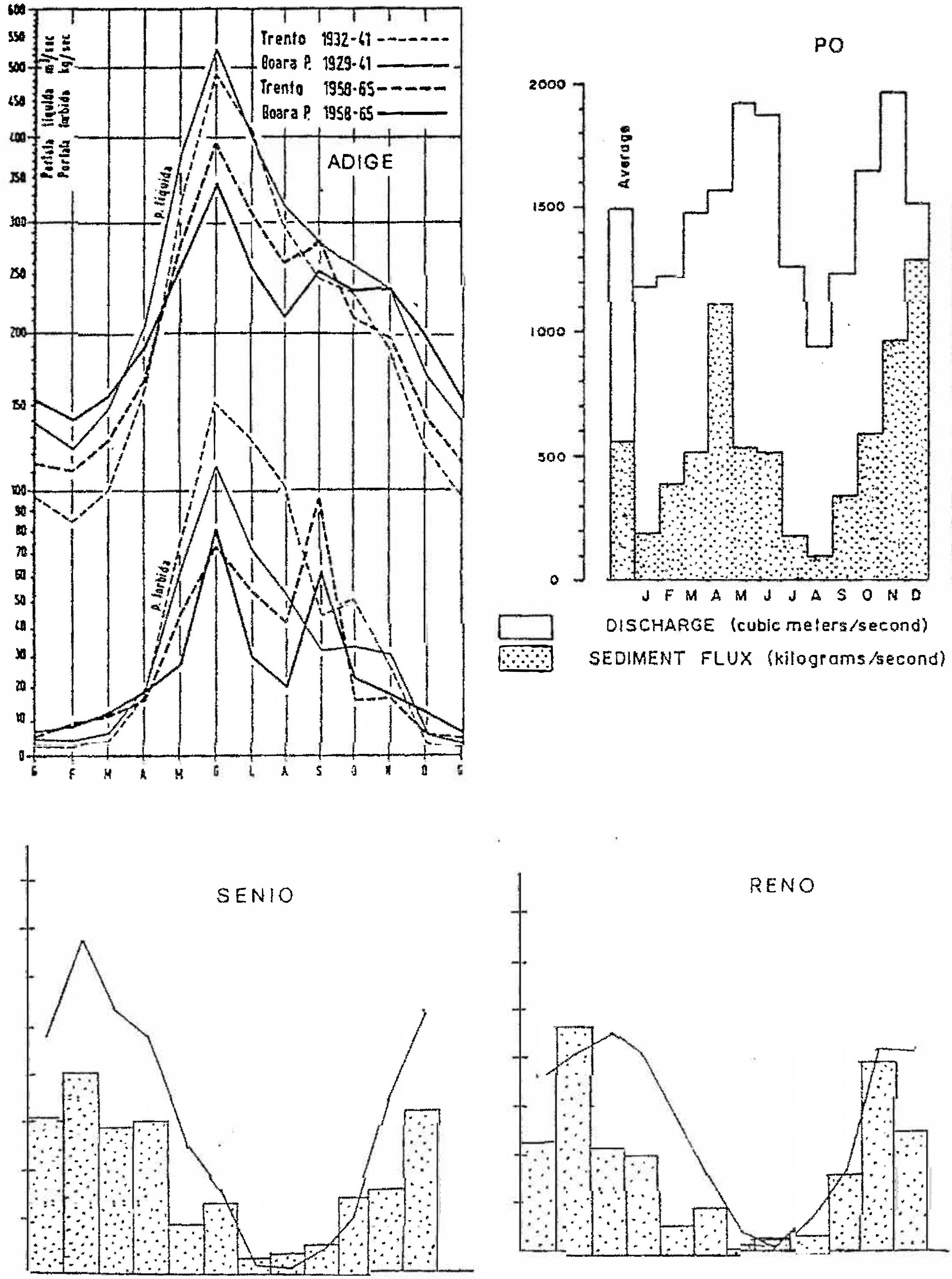
PROVISIONAL



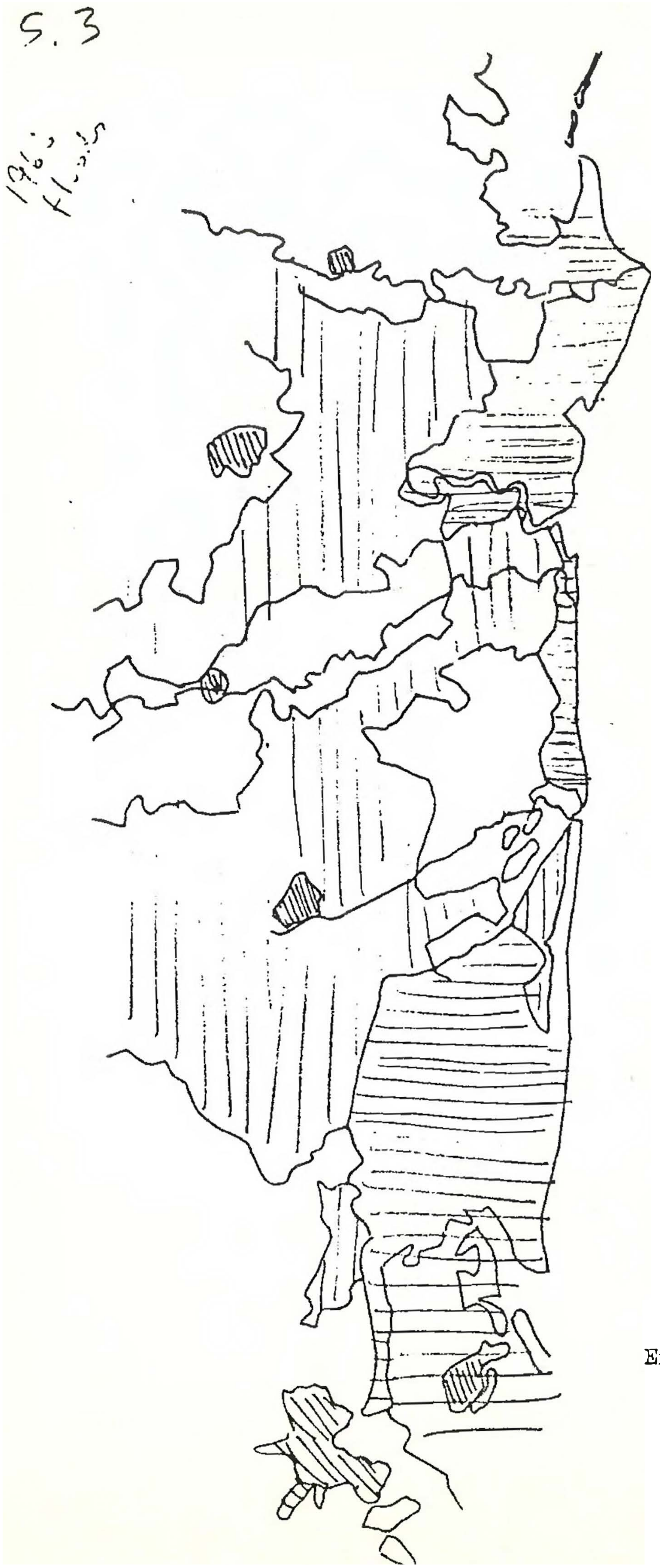
– Spiagge difese e spiagge in erosione.

4. 18

PROVISIONAL

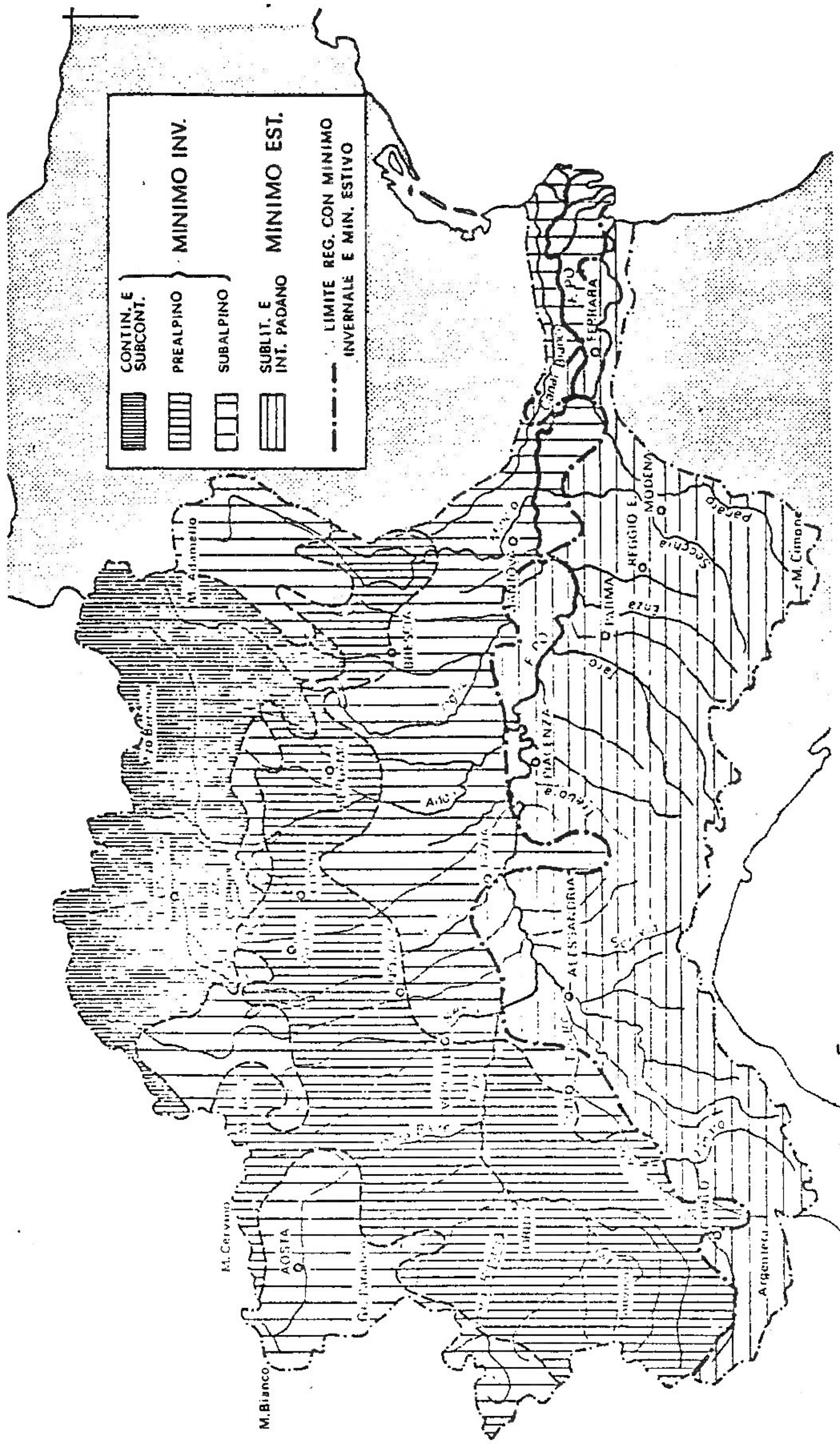


5.I



5. 3

Extent of 1966 floods



5.
FIG.4-REGIME DELLE PRECIPITAZIONI NEL BACINO DEL PO

(da A.Mori modificato)

PROVISIONAL

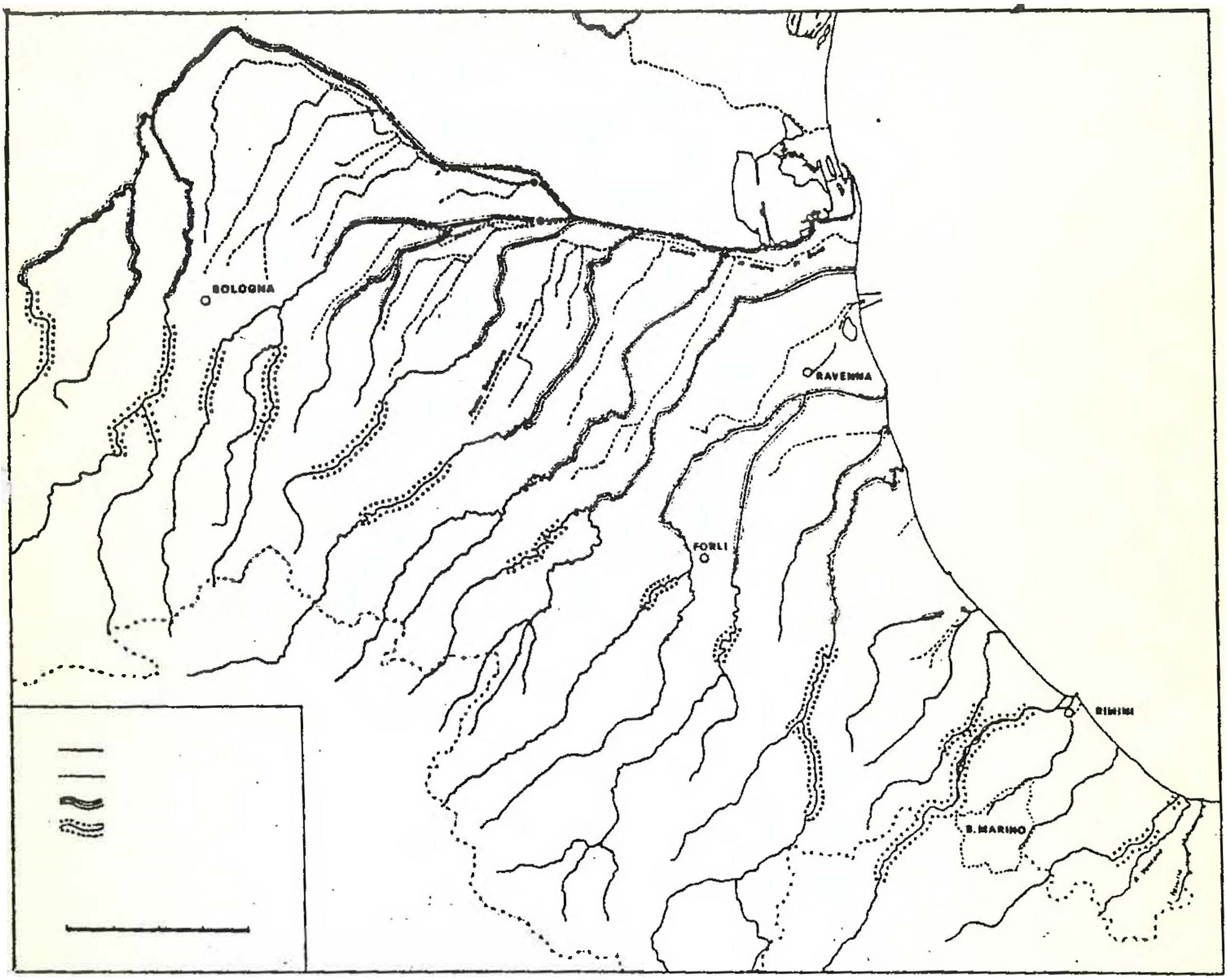
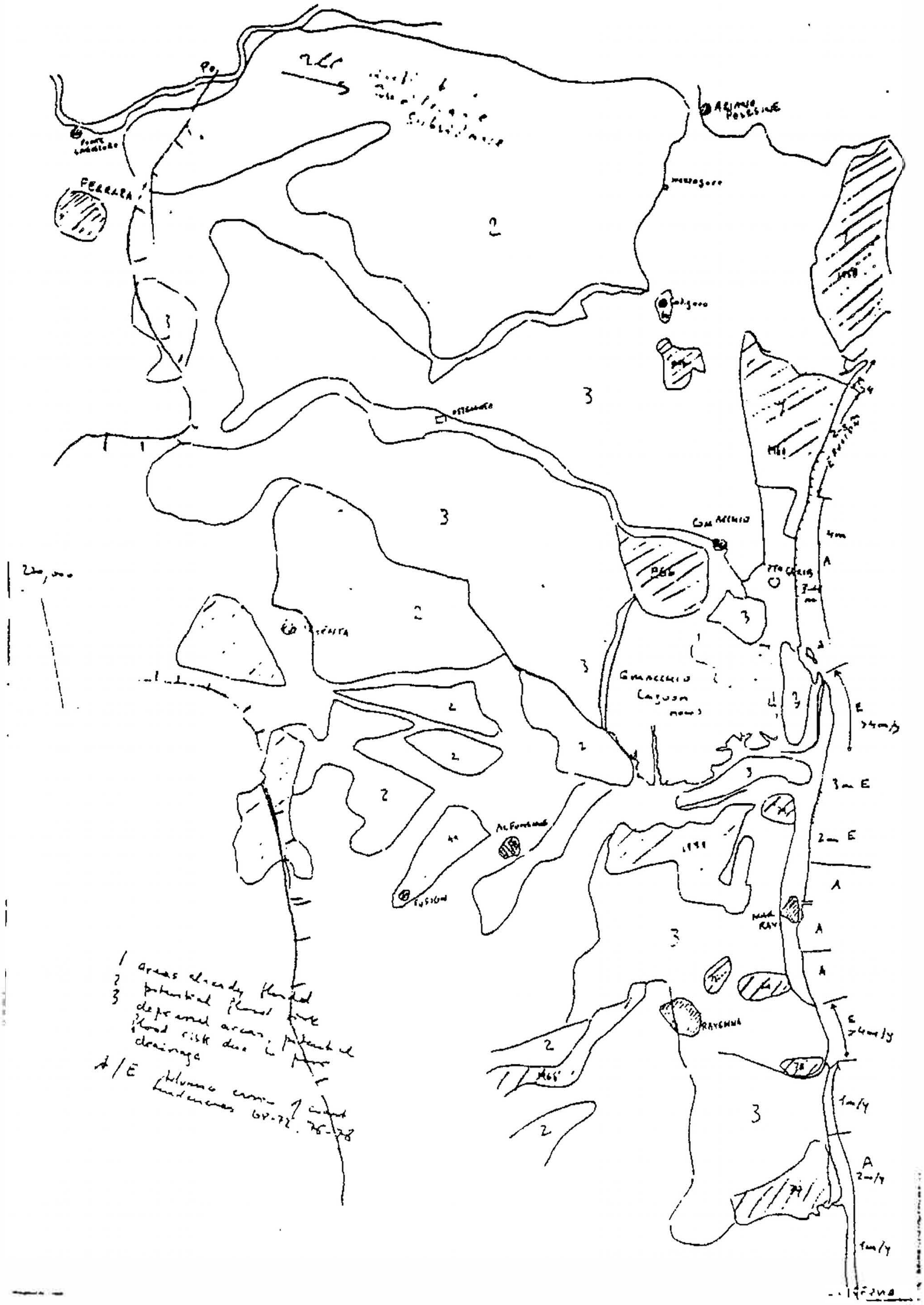


FIG. 5.4

PROVISIONAL



Areas affected by floods in Romagna

5.5

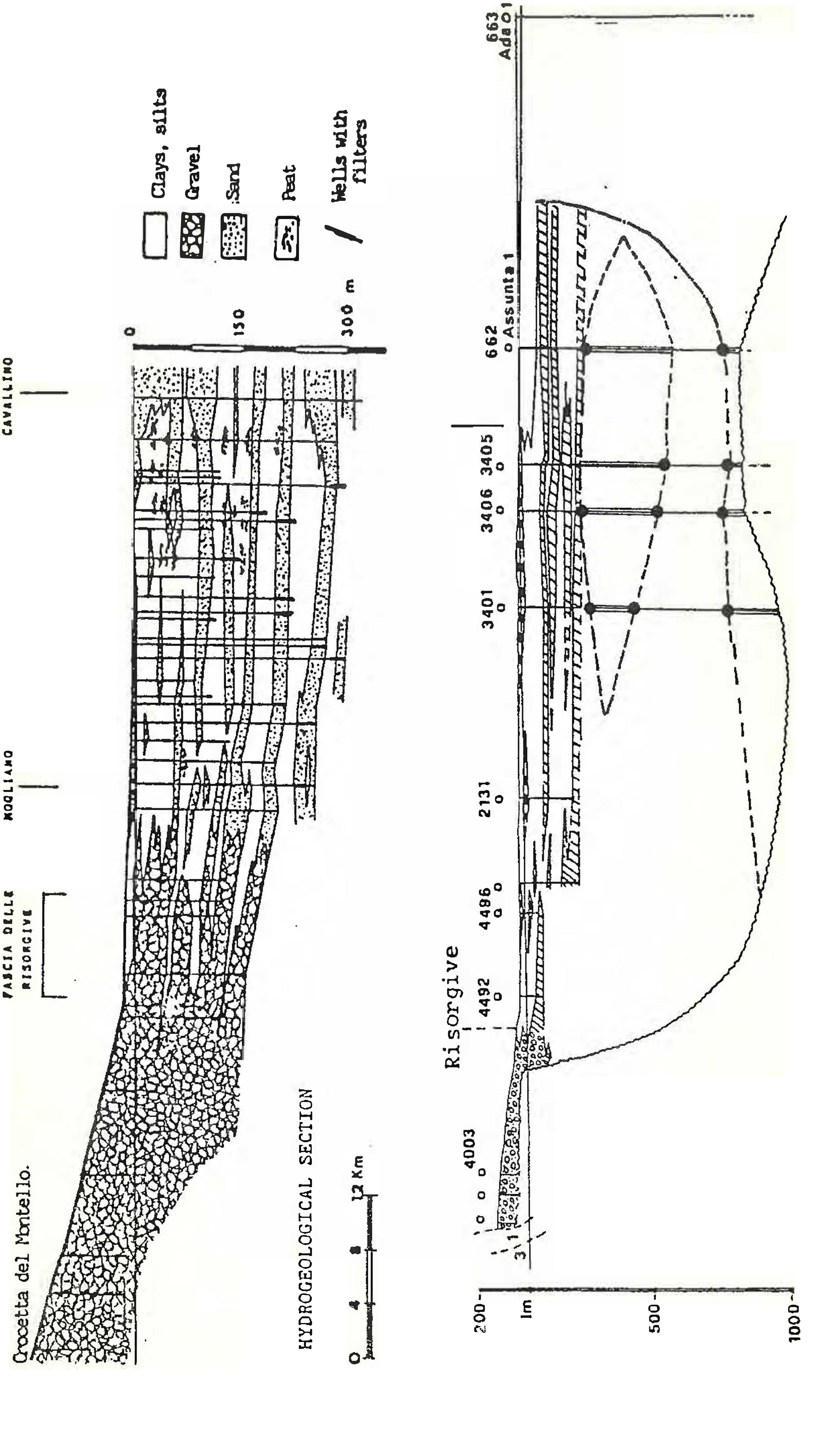
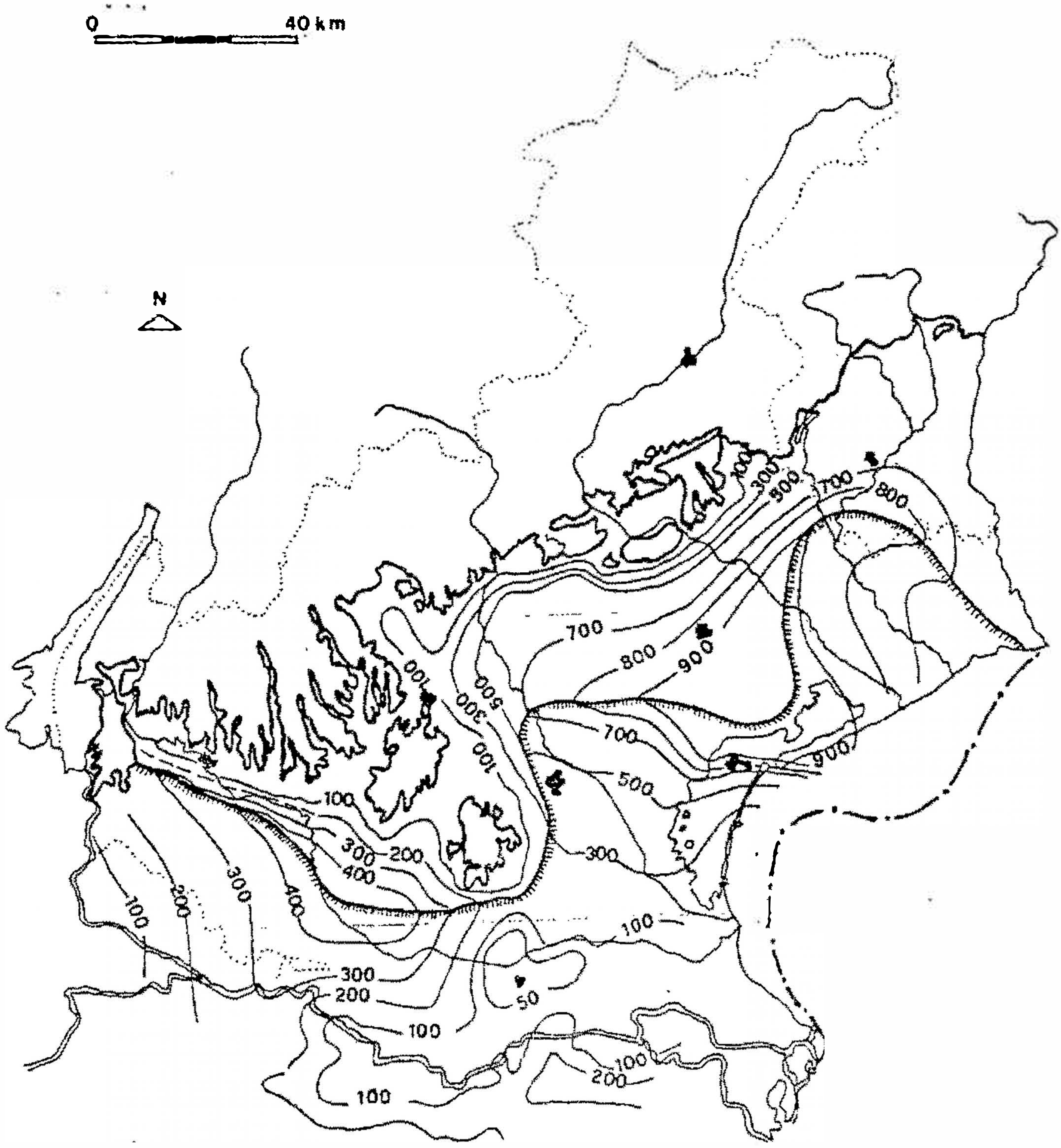

Crocetta del Montello.
FASCIA DELLE RISORGIVE
MOGLIANO
CAVALLINO
HYDROGEOLOGICAL SECTION
0 4 8 12 Km
0 150 300 m
Clays, silts
Gravel
Sand
Peat
Wells with filters
Risorgive
4003
4492
4496
2131
3401
3406
3405
662
Assunta 1
663
Ada 01
200-
Im
500-
1000-

FIG. 5.6

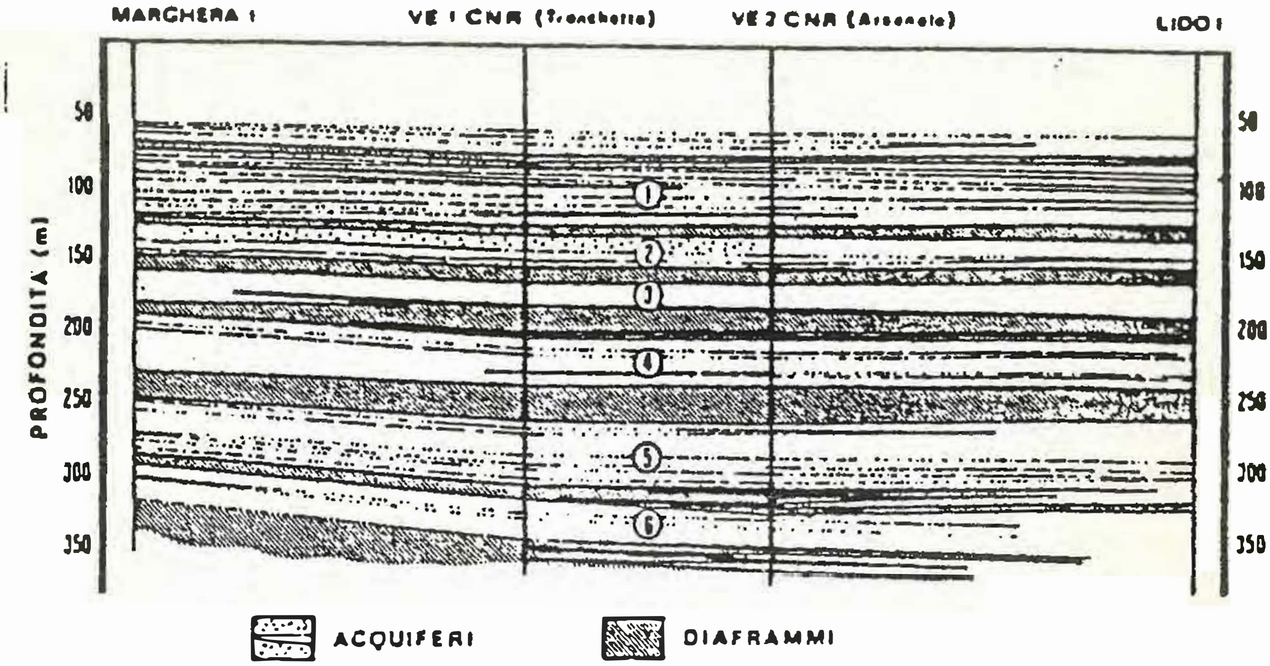
limite montagna-pianura
limite in mare del potenziale zero
900 curva isobata in m sotto il lm

a = base al tetto del Pliocene
b = base all'interfaccia acqua dolce-acqua salmastra

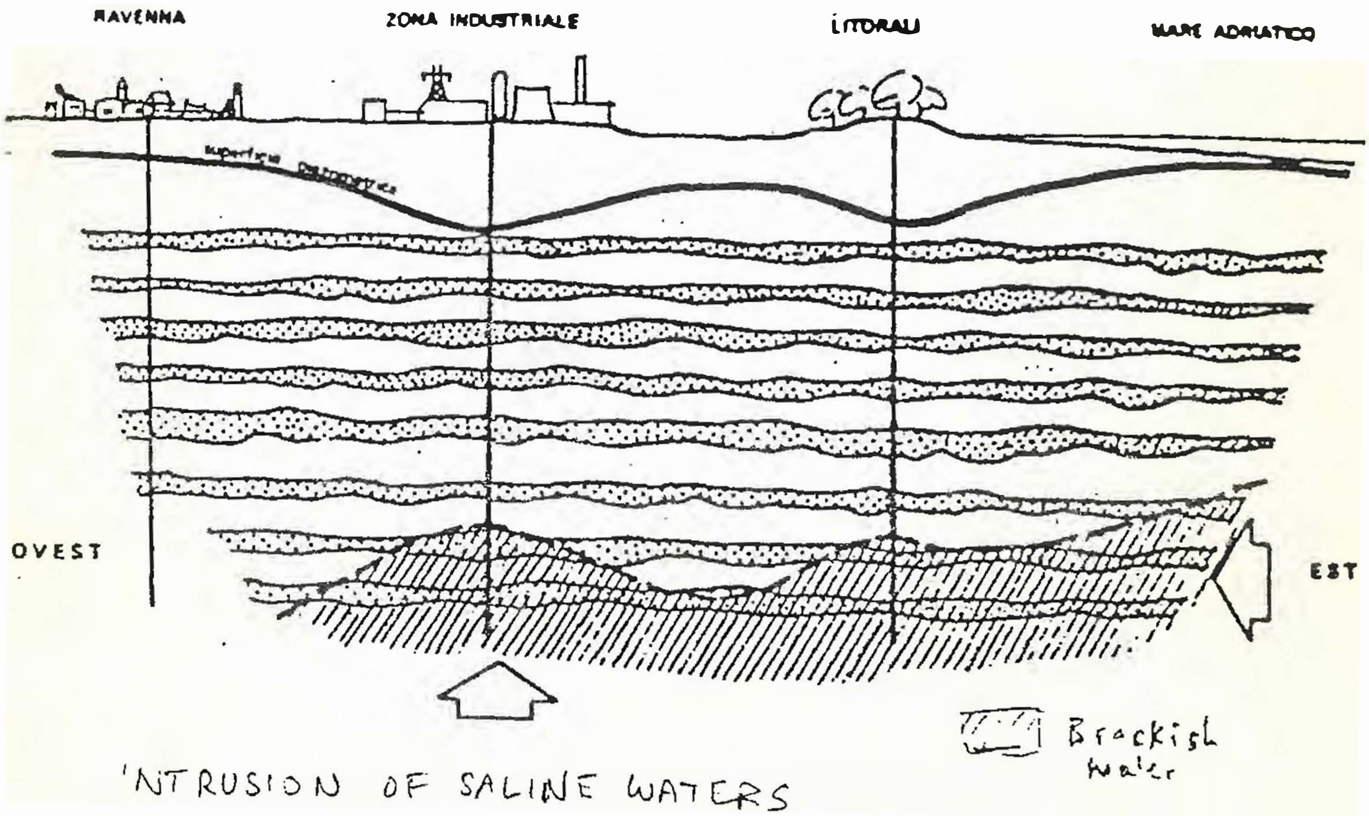


5. 7

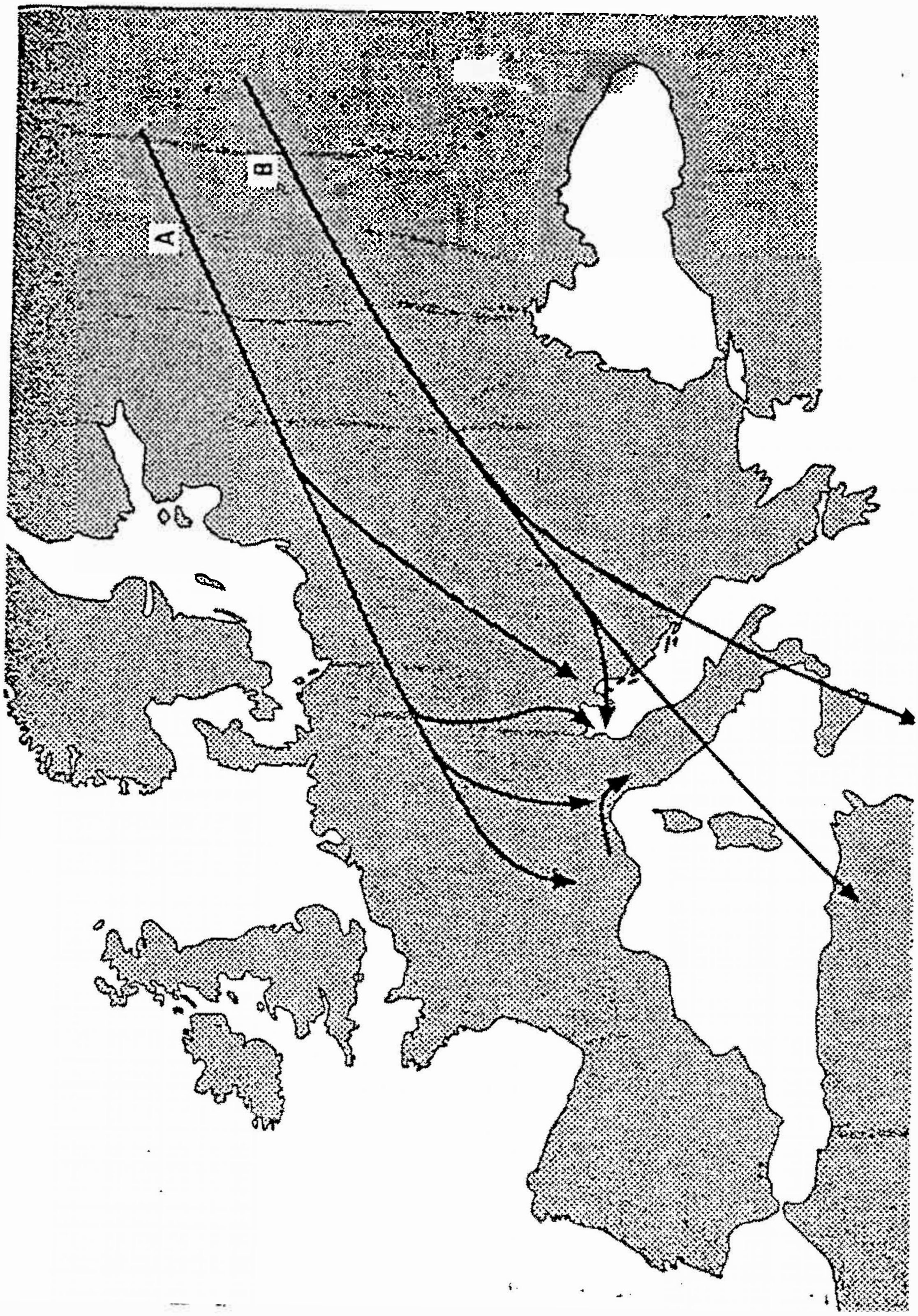
· Base del sistema Acquifero Quaternario



AQUIFERS OF THE VENICE LAGOON

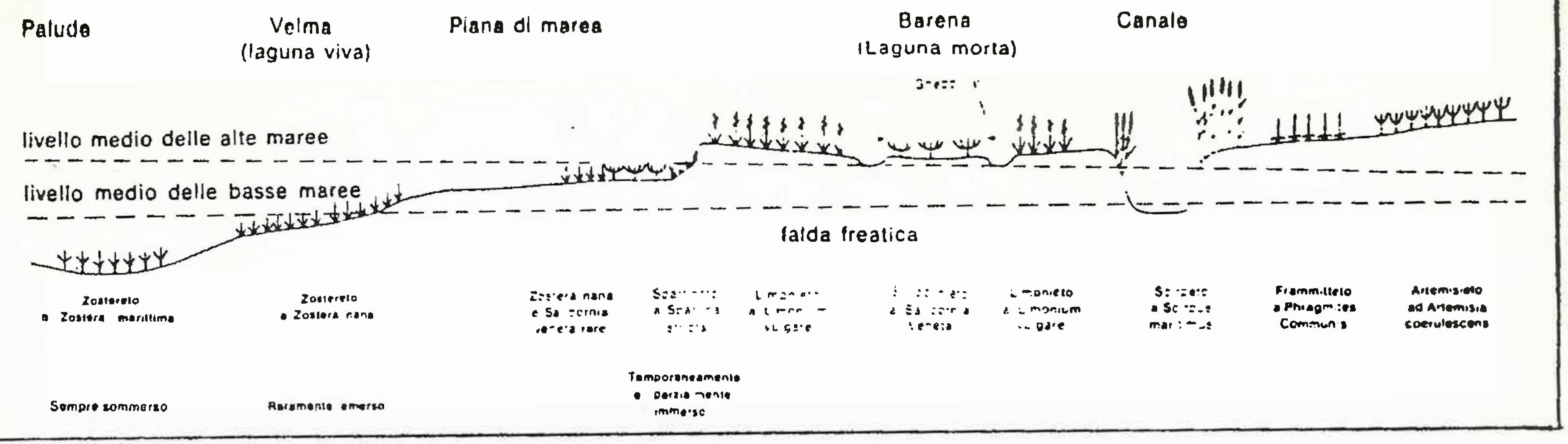


5.8

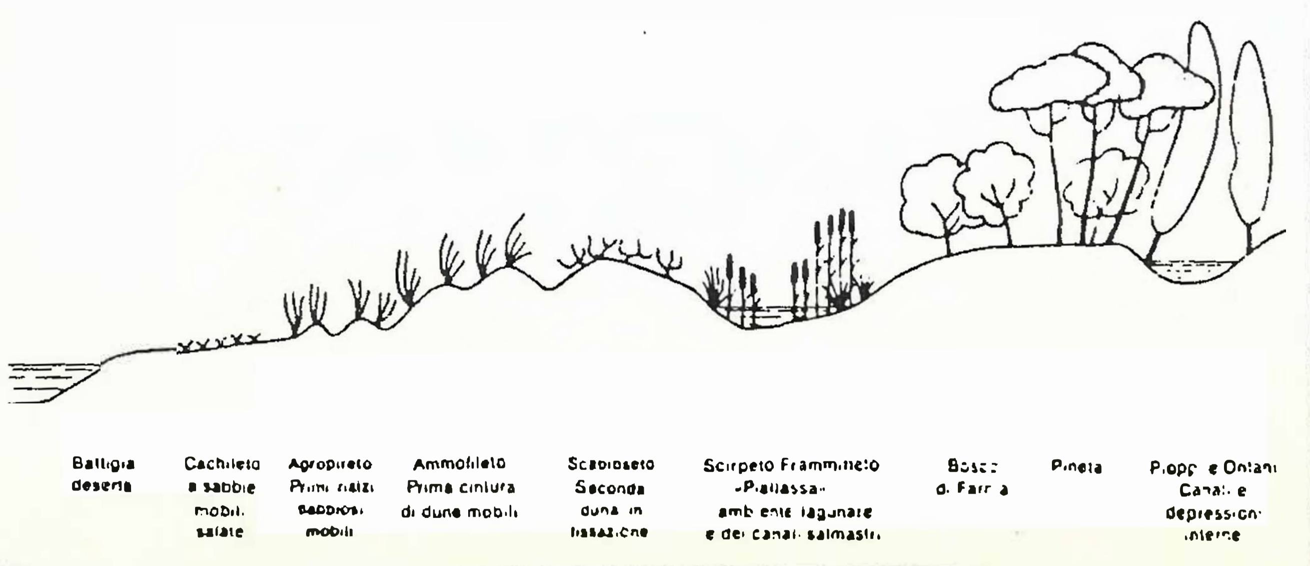


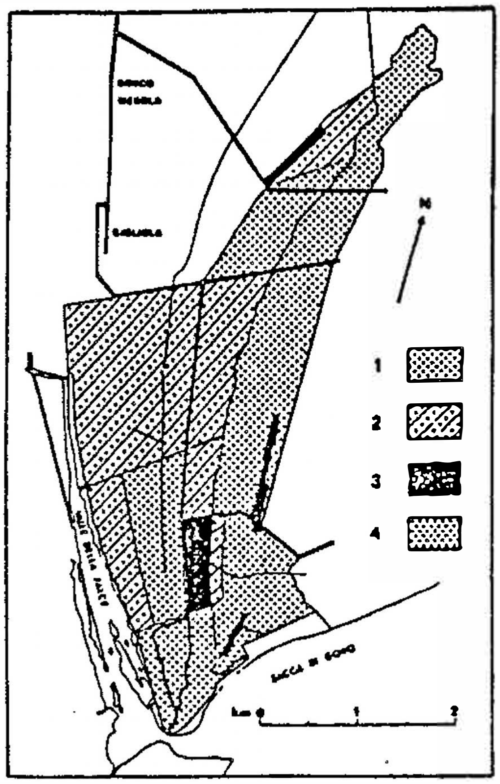
63

PROFILO DELLA VEGETAZIONE SULLA LAGUNA DI VENEZIA

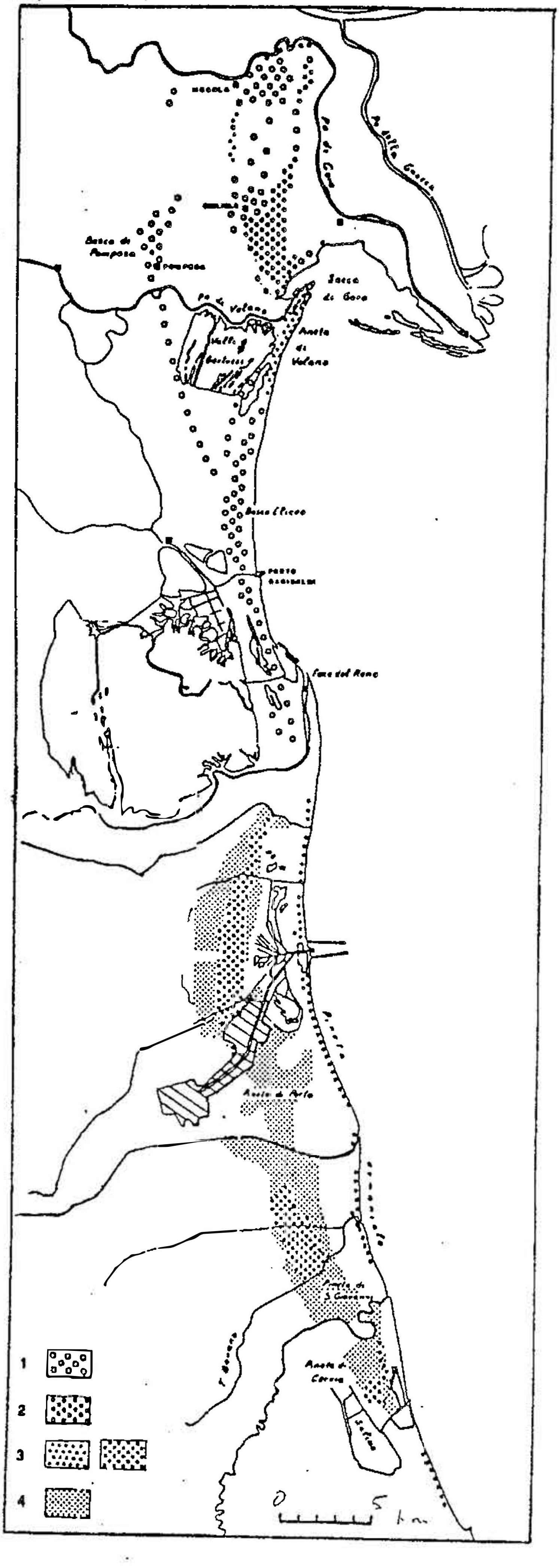


PROFILO DELLA VEGETAZIONE NELLA PINETA DI RAVENNA





The Mesola Wood



Probable extent of evergreen oak XII–XVII C

Present extent of evergreen oak

Present extent of pine woods

Extent of pine woods XVIII century

6.5