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Guide for the excursion

MOUNTAINS, HILLS AND PLAINS IN NORTH-WESTERN ITALY

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1th day

GEOLOGICAL SKETCH OF THE PO VALLEY
(A. Carton)

The Po Valley, also defined Po-Venetian Plain, is one of the main morphological units of Italy. It is the largest of all Italian plains and one of the most densely populated and economically advanced regions in the country. It is named after the main river which runs through it from west to east: the River Po. This is the longest river of Italy, 652 km long with a catchment having an area of 74,970 km^2. The plain's area is about 46,000 km^2; i.e. 71% of all Italian plains and 15% of the aggregate national area. It is rimmed, with well defined limits, by the Alps and the northern Apennine. Towards the east, it is open upon the Adriatic Sea, with a maritime front between the city of Rimini and the River Isonzo about 270 km long. Midway on the coast, the broad Po delta fans out. Under a genetic viewpoint, the northern section of the Adriatic can be regarded as the drowned continuation of the plain. The average height of the Po Plain is 105 m, but altitude ranges from 15 m by Porto Tolle, at the mouth of the Po, to about 650 m in the Regione of Piemonte (Province of Cuneo), at the feet of the Maritime Alps. About 2375 km^2 lie under sea level.

The flat morphology of the plain hides complex deep geological structures which can simply be regarded as a buried mountain chain. This deep structure is known especially thanks to borings and geophysical investigations aimed at a search for hydrocarbons, whereby the part of the Po Plain belonging to the Region of Emilia became a focus of interest for the oil industry since 1938. In particular the sedimentary cover which has been accumulating in the last 6-7 million years lies upon deep lying folds and nappes making up the buried appendage of the Apennine. Folds arose out of compression and shortening of the crust due to the collision between the African continental mass and the European. These are ordered in a set of asymmetrical arches with the shortest legs pointing westwards: the Monferrato folded arc, the Emilia folded arc, the Ferrara-Romagna folded arc.

The rocks making up these buried folds were formed during the Mesozoic era and partly in the Tertiary; they have become detached from the crystalline basement and have shifted eastwards. In particular the basement of the Po catchment, as well as that of the southern Alps and of the outer part of the Apennine is a segment of the African continent which, drifting NNW, has become locked into the southern rim of the European continent. The huge compressions brought about by this collision formed the Alps and the Apennines, and caused them to emerge out of the sea, after narrowing and then closing the Tethys Ocean. The ancient basin in which have become sedimented terranes whose origin can be dated to about thirty million years ago, was sited in an area corresponding to the present Thyrrenian and Ligurian seas.

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Geophysical investigations have shown that the tectonic structure of the Apennine continues buried under the plain for about 40 km, reaching somewhat to the north of Ferrara. It appears to be made up by a system of large reverse faults with low angle planes (about 30°) dipping S-SW with a N-NE slip. A system of large asymmetric superficial folds has thereby been created. These have developed during the movement of Apenninic elements N-NE within the Po valley area. Large synclines alternate with narrower anticlines; the latter make up buried ridges linked by single fault plane fronts.

Two large synclines, the one of Piemonte and that of Asti, are located in the western sector of the plain respectively north and south of the Monferrato hills. They are crescent-shaped and have an overall E-W trend. The Asti syncline can be further divided into two depressions: that of Saluzzo to the west and that of Alessandria to the east. The Piemonte syncline and that of Saluzzo are strongly asymmetrical and deeply faulted in their southern reaches. East of Pavia, the buried tectonic belt at the foot of the Apennine folds, often faulted, develops parallel to the emerging structure of the northern Apennine. Its northwards extent varies from 50 km (close to Piacenza and in eastern Emilia-Romagna) to 25 km (Parma area). Also here the folds are strongly asymmetrical. In the section between Piacenza and the Adriatic, folds are broken and made more complex by a sequence of NE-SW trending faults with chiefly horizontal slip. The drainage of many an Apenninic catchment is oriented by these dislocations. Some sections of these folds have a particular geomorphological meaning: in some cases they emerge upon the plain and form isolated ridges. Examples of this kind are the Turin hills and those of Monferrato, the hills of St. Colombano somewhat north of the River Po, east of Pavia, and the Casalpusterlengo terrace, again north of the Po in Lombardy.

The whole Po plain, with the adjacent Venetian plain, represents a predominantly sedimentary area; sedimentation was mainly marine during the Quaternary. This sedimentation was influenced and conditioned by subsidence, which unfolded in a variety of ways both in space and time, due to various kinds of tectonic processes, to the degradation of emerging relief and to eustatic marine cycles. Synclines received, during the Pliocene and the Lower Pleistocene imposing piles of marine sediments. These have reached, in the plain adjacent to the Apenninian margin by Modena and Bologna, thicknesses even of 3-4 km. In particular the base of the Pliocene is over 7 km deep in the plain by Parma and Reggio, within a zone lying between the two main arches of the Po valley folds. The same level is to be found 8 km below the surface within the fold system by Ferrara. Also along the Apennine rim, the base of the Pliocene is consistently very deep.

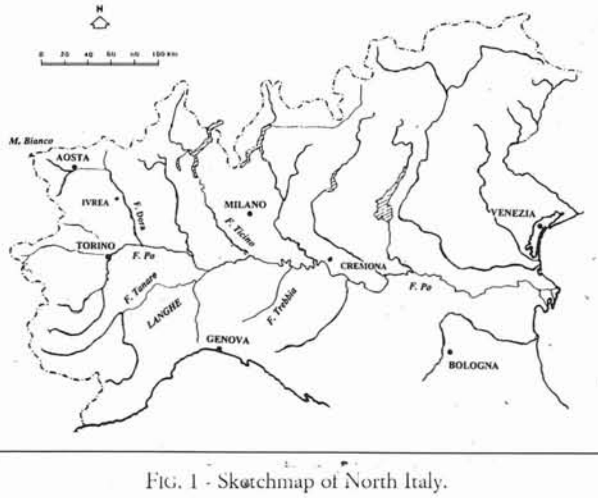

FIG. 1 - Sketchmap of North Italy.

The fact that from the Pliocene to the Lower Pleistocene there is a dominance of neritic marine deposits in the deep sediments of the Po Plain having an aggregate thickness of several kilometres, indicates that subsidence allowed the sea to enter gradually the Po Gulf in spite of the active sedimentation. Part of this sedimentation occurred at the same time as the translational tectonic activity of the deep lying structures. Only towards the end of the Upper Pliocene and in the Lower Pleistocene did such activity decline. This is shown by deposits up to 2 km thick, mostly marine, which follow those of the Lower Pleistocene, sealing the anticlines with usually tabular beddings. As to the dating of the subsidence, a peat sample from a boring in the vicinity of Venice, has enabled geologists to evaluate the average lowering rate between 22,000 and 40,000 years BP at 1.3 mm/year.

After the marine stage, the Po Plain became a continental or alluvial basin at roughly the same time as the great Alpine and Arctic glaciations of the Quaternary. Sea level oscillations during glaciations and the interglacials brought about a sequence of advances and retreats of the coast: at the height of the last glaciation the Po Plain reached out to the entire northern part of the Adriatic sea as far as the site of Ancona. The melting of ice and the attendant sea level rise caused then the coastline to retreat up to a few km inland from the present position. In the last centuries the coastline has been swiftly advancing nearly everywhere, especially at the Po delta. The rims between the nearly flat triangle of the plain and the surrounding mountain ranges are nearly everywhere tectonic in nature. Although more or mess powerful Quaternary covers, linked to the most recent morphogenesis, mask this contact, the contrast at the regional scale between the strongly uplifted areas of the two ranges and the low subsiding one of the plain, is quite striking.

A straightforward analysis of the plain's contours shows two chief morphological units: the upper plain and the lower one. The former, highly developed at the feet of the Alps and narrower belt at the contact with the Apennines, can be identified on account of a more evident slope, as well as the presence of fans and terraces repeatedly formed by streams. The latter's characters are: an extremely gentle slope, low heights, depressions: it is more extensive by the lagoons and deltas of Emilia and Veneto. Structural processes or alluvial siltation distinguish some peripheral areas from the two units mentioned above. This is for example the case of the plain drained by the River Po south of Turin. The upper and lower plain, nearly always easily recognisable, are separated by the so-called spring line or exsurgence belt (*zona dei fontanili or zona delle risorgive*). This provides a limit, sharp in some places, more subdued elsewhere, which divides areas hydrologically and lithologically different. It is a transition belt between rough permeable sediments (mostly piedmont gravels) and finer ones (sand, silt and clay).

The pediplain has some grand structures, especially along the Alps: the broad alluvial fans, often incised by rivers, whose lower reaches extend into the plain for several tens of kilometres. For example we may cite the fans of the rivers of Friuli, of the River Adige and of the Stura di Lanzo in Piemonte. Their continuity is often interrupted by complex glacial till structures dating back to the Pleistocene, sited by the main Alpine valleys and forming barriers still clearly visible. Also the glacial and fluvioglacial depositional forms reach for several tens of kilometres into the plain. Behind these glacial drift structures we find the major pre-Alpine lakes, while at their fronts broad sandurs have developed, with fan shapes still well preserved. Although we shall not be dealing here specifically with till chronology, it is worth recalling that at the base of the Pleistocene till of the morainic complex of Ivrea (see stop. no. 1, 4th day), glaciomarine sediments of the late Pliocene have been found. Several fans are also present on the Apennine side, but their morphological evidence is not always clearly defined.

In the lower plain, the microrelief which in the past appeared at the surface, is nowadays almost entirely absent due to man-made levelling. The only positive or negative forms still preserved seem to be those linked to fluvial and fluvioglacial dynamics. The most evident forms are the slopes of the fluvial terraces, the hanging rivers and the levees. The latter can be found along present day rivers as well as along palaeochannels. The monotony of the plain is broken by some solitary hillocks of different origin made up by pre-Quaternary rocks (Rocca di Cavour, Monti Berici, Colli Euganei) terraces of various origin, hills of Quaternary conglomerates and isolated moraines.

The present drainage network in the Po basin is once more evidence of the important role of tectonics in the morphogenesis of the plain. The main Italian river, in its course in Piemonte, flows repeatedly from areas thickly covered with Plio-Quaternary sediments, regarded as being strongly subsiding, towards buried zones of structural high (confluence Po Dora Baltea at Casale Monferrato and confluence Sesia-Tanaro). Downstream the river flows twice in transverse fashion through another positive structure (at Stradella, between Pavia and Cremona), and then cuts into a broad belt of enormously thick Plio-Quaternary layers prone to subsidence (south of Mantua). By Ferrara the river again flows through an anticline masked by alluvial deposits only 200 m thick. All this suggests a considerable correspondence, even if not invariably present, between the drainage network and the deep structural axis of the plain. Also the secondary drainage pattern takes up peculiar features. In the northern Alpine reaches, the left hand tributaries of the Po and the rivers of Veneto (excluded the Adige) flow in a rather regular fashion. In the southern reaches of the sector of the Piemonte Region, instead, the system of the Po tributaries and of the upper Tanaro, its main tributary, is drained in convergent fashion by two structural depressions. Nearly all the right hand tributaries from the Apennine of Emilia flow through a large belt of the plain, cutting either at right angles or in oblique fashion the different positive structures of the buried Apennine front and the attendant intervening depressions.

We shall now turn our attention upon the southern section of the plain south of the River Po, in which we travel westwards during the first day of the excursion between Bologna and the first stop (fig. 2). This area corresponds to the alluvial plain through which the Po river itself and its Apennine tributaries have been wandering almost exclusively in the last 4000-5000 years. The alluvial cover is represented by fine deposits and grain sizes range from sands to clays as far as the motorway. Grain size distribution follows the classic depositional pattern typical of river beds in flood plain. The distribution of the fine deposits in the first 2-3 m above the surrounding plain level proves to be much more extensive and constant than in the subsurface. This situation may by correlated with the different fluvial dynamics that have characterised these watercourses in the past 500 years due to the intervention of man. The embankments have prevented the rivers from straying as they frequently had in previous periods. In fact, due to this situation, all the oldest deposits have been buried by fine material originating from flooding caused by breaches or overflowing, rather than by changes in the course of the river.

In the piedmont plain sector, sandy and gravely deposits alternate with finer deposits that are linked to the alluvial fans formed by the Apennine rivers. In the Emilian domain, the palaeo-drainage system shows clear evidence of two preferential directions. Moving towards the River Po from the Apennine margin, they clearly change from a SSW-NNE direction to W-E direction starting from the Brescello Ferrara alignment. The ancient Apennine river beds seem to be particularly affected by this deviation of almost 90°, whereas the palaeo-courses of the Po river constantly maintain their W-E orientation. The palaeo-drainage network shows that in the terminal section, the tributaries on the right side hat to run along a long route parallel to the Po river before converging with it. This characteristic was lost only after human interference with the drainage system in the past three centuries. The courses of the ancient river beds are lined by levee ridges 2 to 3 m higher than the surrounding plain level.

As previously stressed, the Apennine margin is dominated by piedmont fans of distinct and well preserved shapes and whose apexes are situated far up the mountain valleys. The fans extend well into the plain, enclosing terraces of the Middle Pleistocene. The analysis of the palaeo-drainage system indicates that starting from the Bronze Age, the Po river on the whole migrated northward and that its Apennine tributaries have been shifting westwards, except for the River Secchia which shows a different tendency.

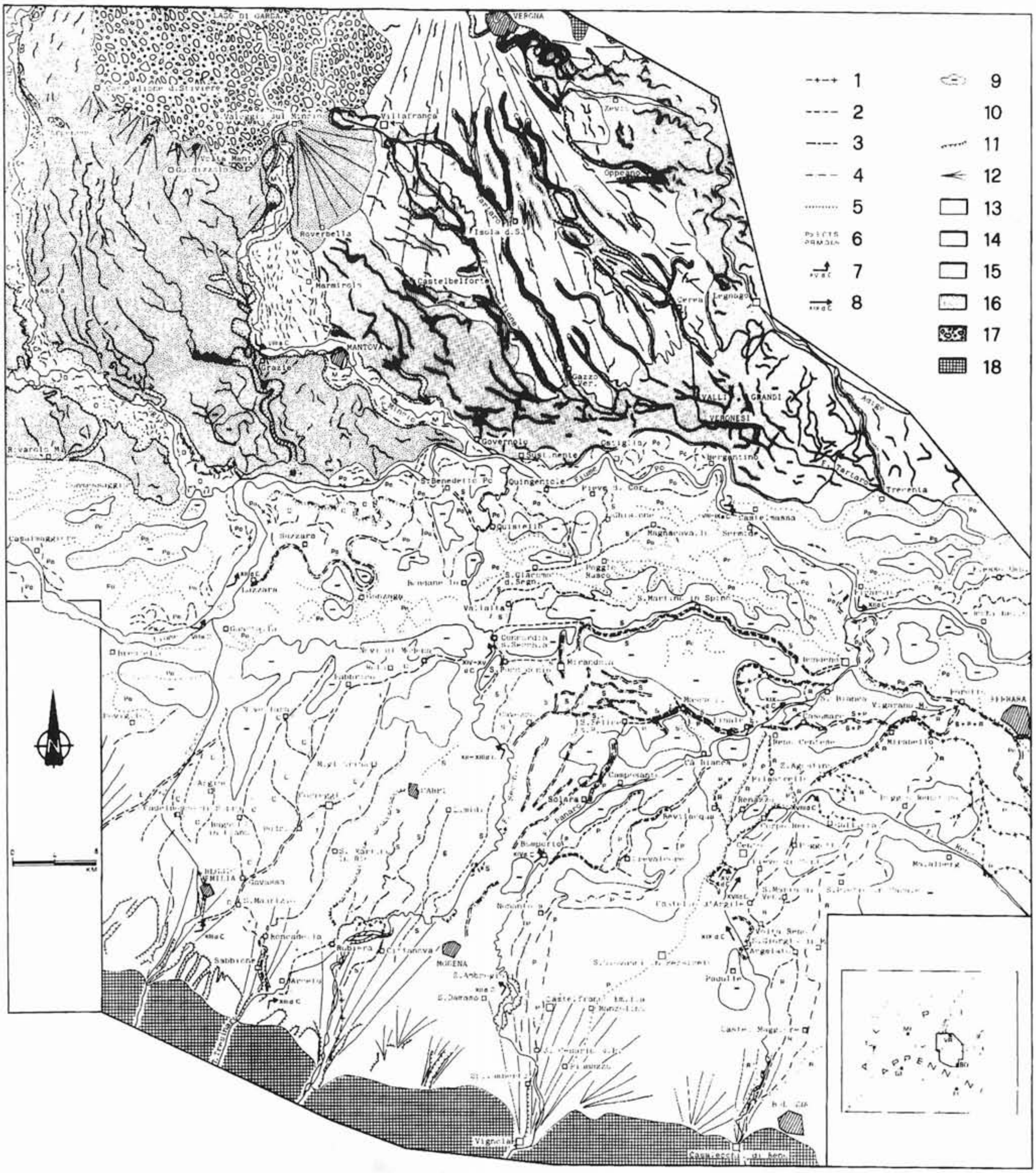

FIG. 2 - Geomorphological map of the central sector of the Po valley (from Castaldini, 1987). *Legend*: 1) Paler river of the modern age; 2) paler river of the late Middle Ages; 3) Paleo river of the early Middle Ages; 4) Paleo river of the Roman period and in some places of the Iron Age (e.g., Mincio); 5) Paleo river of the Bronze Age; 6) Abbreviations of the paleo rivers: Po = Po; E = Enza; C = Crostolo; T = Tresinaro; S = Secchia; P = Panaro; R = Reno; M = Mincio; O = Oglio; Ch = Chiese. No abbreviation: Paleo river of minor importance or unidentified paleo river; 7) Main fluvial deviations with indications as to age (A.D. = Anno Diomini, B:C: = Before Christ); 8)Main fluvial cuts with indications as to age; 9) Depression in alluvial plain; 10) Levee ridge; 11) Scarp; 12) Alluvial fan; 13) Alluvial sediments deposited by the watercourses or paleorivers crossing them and thus of the same age; 14) Sub boreal alluvial deposits (Recent in the vicinity of present beds) of the Mincio, Tartaro, and Adige Rivers with paleo rivers of the same age; 15) late Glacial and early Holocene alluvial deposits of Adige origin with traces of paleo rivers of the same age; 16) Fluvioglacial deposits related to the Garda moraines with traces of proglacial channels; 17) Morainic deposits of the Upper Pleistocene (of the Middle Pleistocene between Carpenedolo and Chiese R.); 18) Mountain reliefs.

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BIOGEOGRAPHY AND MAN-MADE CHANGES
(E. Biagini)

THE FLORA - The Holocene, saw a gradual recolonisation by deciduous vegetation, after an ecological succession from tundra to conifers. As the climate warmed up, conifers and tundra throve at increasingly greater altitudes. At present, for example in the Central Alps (fig. 3), deciduous forests may reach 1300 m, conifers 2000 m and the Alpine tundra 4000 m and over. Two lichen species, *Gyrophora proboscidea* and *Lecidea* sp. were collected at a height of 4700 m on Mount Blanc (GIACOMINI & FENAROLI 1958). Vegetational limits may tend to be somewhat higher on the Apennines, on account of the difference in latitude.

Pollen analysis shows the existence, during the Neolithic, of extensive oak forests in the plain and at the basal alpine level. From the Bronze age onwards, other species (maple, chestnut, beech and lime) also became important, although oak remained dominant. Extensive marshes existed close to the rivers. After the invasions of Iron Age peoples, such as Etruscans from the south and Celts from the north, and therefore around the 5th century BC, when the aboriginal Bronze Age Ligurians began their retreat towards the sea that bears their name, forests were still extensive. Even in the 2nd century BC POLIBIUS described the fields in the Po plain as surrounded by oak forests (*silvae glandariae*).

Only the massive, well planned Roman colonisation, based upon advanced land surveying methods known as *centuriatio*, entailing the subdivision of the land into carefully measured squared allotments, caused a substantial retreat of the forests and marshes in the Po valley: the inner lagoon called Padusa was greatly narrowed by extensive reclamation. Evident traces of the *centuriatio* are still to be seen not only on aerial photographs, but even on the actual groundplan of present-day farmland. Deforestation brought about increased erosion and sediment transport, whereby the growth of the delta accelerated substantially. On the other hand, the Romans had many laws and traditions tending to the preservation of woodland, partly regarded, along with the pastures, as an exploitable resource (*ager publicus*); partly as holy places for the preservation of

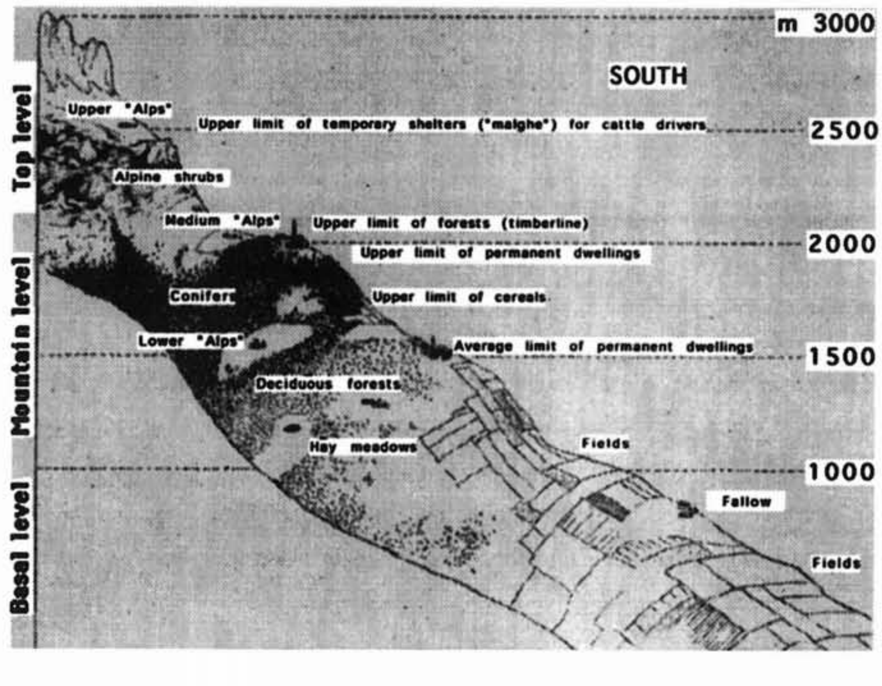


FIG. 3 - Forest cover of the Central Alps as modified by man.(redrafded from Giacomini and Fenaroli 1958). The figure gives a model of the conditions in the Fifties, before the extensive depopulation of mountain areas in Italy.

springs, burial places and temples; and partly as property boundaries (*omnis possessio Silvanus colit*). However, the demise of the Empire and the migration of Germanic tribes from central and northern Europe (*Völkerwanderung* in the northern view, or barbaric invasions according to the southern view), caused a decline of agriculture, so that forests expanded again. Worse than that, the end of hydraulic controls meant that the river could unleash repeated great floods, thereby turning the lower valley into a huge morass again. Forests were protected during the upper Middle Ages as a hunting preserve for the aristocracy of Germanic origin. CHARLES THE GREAT himself, in his decree *De villis*, prohibited the cutting of forests aimed at extending tillage (GIACOMINI & FENAROLI 1958).

Forests and marshes began to decline again, especially thanks to the great work of reclamation by the Benedictine monks, and the process has continued to the present day with the introduction of modern techniques of agriculture and cattle husbandry. The demise of woodland was very great also on the mountains, and gave rise to a chequered patchwork of fields, meadows and abandoned woodland, with seasonal settlements up to about 2000 m for the exploitation of higher pastures by cattle during the summer.

THE FAUNA - The fauna that became established in Padania after the last (so far) glacial event is typically of the Mediterranean Palaeoarctic type (COLOSI 1956, GHIGI 1959, TORTONESE 1949), the most conspicuous species of Mammals being brown bear (*Ursus arctos*), wolf (*Canis lupus*), fox (*Canis vulpes*), marten (*Mustela martes*), stone marten (*Mustela foina*), boar (*Sus scrofa*), roebuck (*Cervus capreolus*), ibex (*Capra ibex*), alpine hare (*Lepus timidus*). Among the Birds, are worthy of notice: eagle (*Aquila chrisaëtus*), various species of hawk (*Falco* sp., *Accipiter* sp.), heron (*Ardea cinerea*), swallow (*Hirudo rustica*), sparrow (*Passer italiae*). Reptiles are represented, among others, by *Vipera ammodytes and Natrix natrix*, and Amphibians by *Triturus alpestris, Salamandra salamandra, Hydromantes italicus, Pelobates fuscus, Bufo bufo, Rana latastei, Rana temporaria.* As in all heavily populated regions, the natural fauna has been largely depleted by human activities and replaced by domesticated species.

The waters of the Po catchment harbour many species of fish, such as *Salmo trutta, Salmo garnerii, Salmo carpio* (the latter typical of the Garda Lake), *Salvelinus salmarinus*, *Coregonus lavaretus*, *Thymallus thymallus*, *Esox lucius*. However, commercial fishing has been largely impaired by chemical pollution, of urban, rural and industrial origin, as well as by the imprudent introduction of unwanted allochtonous species such as *Silurus glanis*, from eastern Europe, which grows to over 3 metres in length and is exceedingly dangerous to the local fish species and even to terrestrial animals bathing in the river.

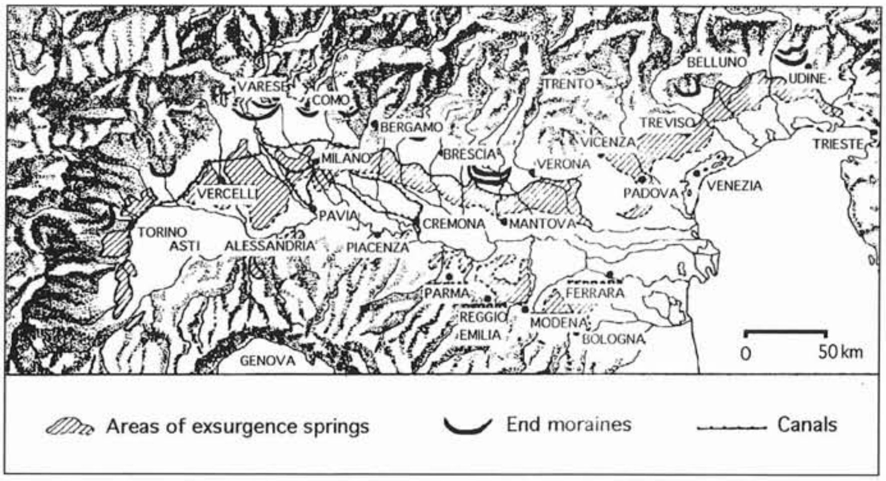
PHYSICAL ENVIRONMENTS AND HUMAN POPULATIONS - The distribution of human populations has constantly been influenced by the natural environment, such as by lithology, geomorphology, climate and soils, while at the same time it has often exercised in its turn a strong impact in modifying the environment. Settlement is either in valley bottoms, if the valley is regarded as large and sunny enough. Otherwise it reaches up to a certain height on the sunniest slopes (see fig. 3). Height and aspect, therefore, are the main factors which traditionally have conditioned the choice of sites in which to settle. People tend to live in villages, as nearness to other families has always been deemed necessary to face the challenges of the mountain environment. In particular, extensive cooperation was necessary in the traditional activity of forestry. Other traditional activities are cattle husbandry, a limited agriculture, as well as handicrafts, chiefly the making of all kinds of objects cut in wood.

Rising emigration after the Second World War has left the upper reaches of the Alps and the Apennines increasingly bereft of a stable population. This depopulation has not by any means brought about desirable environmental impacts. An increase in landslides has been the immediate consequence, especially on the sedimentary slopes of the Apennines and the lower parts of the Alps. Some particularly scenic valleys, such as the Valle d'Aosta, however, have experienced considerable economic conversion from declining primary activities (agriculture and cattle husbandry) to tourism. This has brought about financial rewards, the building of hotels and infrastructure, a better control on landslides, but has also caused more environmental problems.

On the plain, where communications are easier and the environment not so harsh, rural settlement is usually in isolated farms rather than villages. A basic difference in this regard is that between the Upper and the Lower plain. It is hard to perceive the dividing line between the two parts by means of height observations, whereas hydrological conditions reveal a marked difference between the two kinds of areas. The upper plain is the area bordering the mountain amphitheatre of the Alps and the Apennines: it is made up of rough alluvial material, deposited during stages of glacial retreat by the rivers pouring down meltwater from the mountains, bringing about highly permeable yet unconsolidated clastic layers. Accordingly, surface runoff is limited, the water table is low and aridity is widespread, in spite of sizeable precipitation levels (900-1000 mm per year).

The lower plain, instead, borders the Po, and results from fining of sediments in the lower reaches of the rivers which were to become the tributaries of the Po. As it is made up of sands and muds, this part of the plain is impermeable. The contact between the two parts of the plain is therefore characterised by the salience of water which, after, infiltrating the upper plain, comes to light forming the so-called «spring line», made up practically of vast areas of exsurgence springs. Since the Antiquity, the main settlements on the plain have been usually sited within, or close to, areas of exsurgence springs. These areas have attracted the main cities and towns, even before Roman times. The Romans were noted for their technical ability in territorial planning and for their skill in choosing the most favourable locations. It is therefore no surprise if, with the introduction of Roman civilisation into the Po catchment, the urban network became very similar to the present one. In

FIG. 4 - Exurgence springs (*fontanili*) and settlement (from Bonaparte, 1977).



spite of the great social and economic upheavals which followed the Roman age, no significant relocation of urban centres took place; neither was there any appreciable shift in the relative importance of the major centres. The link between exsurgence areas and urban settlement is still quite evident (fig. 4).

Accordingly, also the rural landscape is utterly different between the two parts of the plain. The lower plain is the locus of intensive agriculture and cattle husbandry, with a thick network of canals for navigation and especially for irrigation, notably north of the Po, especially in Lombardy, where the great 'Naviglio Grande' brings the waters of the River Ticino to Milan (see fig. 5). Vast expanses of land have been turned into rice paddies or irrigated meadows, due to the potential for flood irrigation linked to the exsurgence springs. Corn, sugar beet, fruit, vines and horticultural products are widely produced by modern methods in the lower plain. Landscape and productivity levels are quite different in the upper plain, whose spontaneous vegetation is a moorland dominated by *Calluna vulgaris* (it. «brugo», whence the Italian name for moorland, which is «brughiera»). The «brughiera» has been extensively replaced in the past by the cultivation of wheat and vine, but it is now largely depopulated and uncultivated, and is thus reverting to spontaneous vegetational patterns.

A further natural factor of great importance in governing settlement and economic patterns is the presence of mountain passes which, by orienting the routes of communication and transport lines, exercise a decisive influence on the relative importance of towns and cities. The massive urbanisation and industrialisation, which developed from the second half of the nineteenth century onwards, owe a great deal to previous settlement patterns and hence to the physical patterns that affected them, and especially to the availability of water, initially a commodity regarded as well-nigh inexhaustible, whereas nowadays a substantial lowering of the water table has been observed for many years, and pollution problems of different kinds

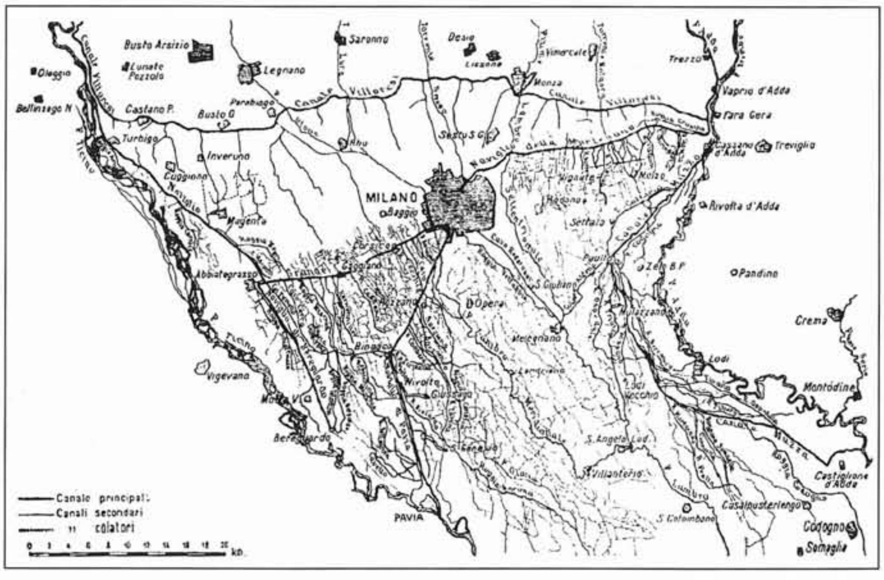


FIG. 5 - Main canals (Main canals (*navigli*) and irrigation system in Lombardy between Ticino and Adda (from Pracchi, 1960).

have emerged, requiring careful environmental studies and effective intervention. Moreover, the intensive development of economic and urban patterns could provide an interesting subject for a study in man-made geomorphology.

It must be stressed that no deterministic relationship can be implied between physical parameters and the socio-economic system. Any influence of the former upon the latter is mediated by cultural attitudes, political systems and technological levels. Yet, for a variety of reasons, human geographers have often gone too far, in their anti-deterministic polemics. Physical geographers are usually more sensitive to these topics, as well as the historians, many of whom, in spite of their training essentially oriented towards the Humanities, have shown a surprisingly sophisticated understanding of physical factors. Leading historians like BRAUDEL (1965), OBOLENSKY (1974) and ZÖLLNER (1984) are cases in point.

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THE RIVER PO FLOOD PLAIN NEAR CREMONA
(F. Maraga, A. Masino, E. Beretta & E. Viola)

The territory under examination is sited in the centre of the Po Plain. It includes a section of the River Po 40 km long, between the confluence of the River Adda, coming from the Alps to the north, and the confluence of the Taro, coming from the Apennines to the south, at a distance of about 300 km from the Adriatic sea. The catchment of the Po downstream from the confluence of the Adda, at the hydrometrographic station of Cremona, covers an area of 50,726 km^2, i.e. about two thirds of the total catchment area of the River Po.

Discharge is significantly seasonal, with summer drought and autumn floods. At Cremona, with average discharges (1971-1985) of 1290 m^3/s, peaks and lows (1932-1985) have been measured respectively in 1951, with 13750 m^3/s, and in 1965 con 200 m^3/s. The 1951 peak occurred during the great flood of 6 November, which hit the whole Po Plain from the River Ticino to the sea. A new historical peak flood occurred in November 1994.

The stops are planned to show: i) the bedform forced upon the river during the 20^{th} century by constraining its channel and causing it to become deeper; ii) relict fluvial forms and the multiple floodbank system on the floodplain (fig. 6).

HISTORICAL INFORMATION ON THE FLOODS - During the Neolithic, the River Po did flow nearly at the feet of the Apennines, about 30 km due south of Cremona, as shown by archaeological evidence from the distribution of cremation and inhumation necropolises, parted by a border identified as an ancient Po channel. After the Climate Optimum in which Neolithic cultures had flourished, the streams from the Apennines deposited broad alluvial fans which, along with the subsidence of the Po Plain, pushed gradually the Po northward, choking with sediments the old channels. In particular, intensive alluvial stages, linked to two climate crises in the 15^{th}-12^{th} centuries BC and in the 10^{th}-4^{th} centuries BC have been identified, by means of stratigraphic studies on proto-historical settlements.

In the 6^{th} century BC, the River Po was very broad and turbulent, not yet constrained by floodbanks and therefore free to wander, divided into several branches with a great number of shoals, in an area of about 10-12 miles, where it stagnated forming highly unhealthy marshes. It also caused huge floods. The Romans found the region covered with forests, broad mires and small clearings, sparsely and irre-

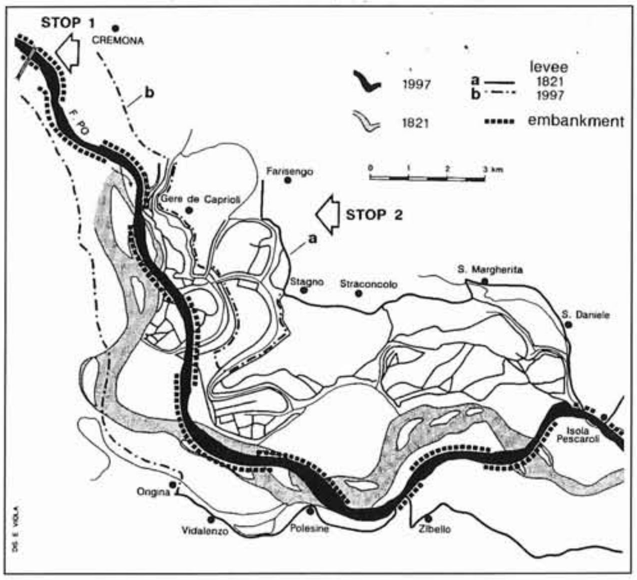

FIG. 6 - The Po River near the town of Cremona in 1997 compared to its watercourse and floodplain. in 1821. The line (a) represents the main levees in conformity with their primordial configuration since XVII century; the dotted line (b) shows the main levees of XX century that continues until Cremona; the squared line indicates the river bed enbankments. A complex configuration of the levees is in evidence by the abandoned channels on the foodplain of the left bank. This settlement allows large flooding corridor and preserve the main levee from breaches. At the stop 1 will be observed the hydrological station of Cremona with an hydrometrer 13 m higth and recording flood levels since 1801. At the stop 2 the floodplain evolution in consequence to the river channelisation will be illustrated.

gularly settled. Settlements were mostly along streams and/or on nodal points. Roman reclamation and systematic colonisation in typical Roman gridiron pattern (*centuriatio*) changed the landscape entirely. They acted on the River Po to constrain it within one single channel, in order to make it navigable.

In the early centuries AD, the River Po touched the present centres of Stagno Lombardo, Ragazzola, Torricella, Colorno, Brescello, with a single channel very much prone to meandering, or with very sinuous ramifications and intervening shoals.

A new cold-humid climate crisis with increasing precipitation and attendant increase of the sediment load in rivers, caused substantial aggradation of the channels. The end of the 5th century saw the so-called «flood of Paolo Diacono», from the name of the historian who described it, which modified the drainage network of the Po Plain extensively. The River Po is cited by historians as reaching the settlements of Pieve d'Olmi, San Daniele, Scandolara, Torricella del Pizzo (on the left bank, nowadays sited up to 5 km from the river), with the hypothesis of a braided rather than meandering pattern. The territory between Adda, Po and Oglio was again prone to forming marshes, among which the Lago Gerundo (*Auctorum*; now disappeared, and whose whereabouts are uncertain), due to the dereliction of the defence and reclamation works undertaken by the Romans, as a consequence of the fall of the Empire.

From the 9th to the 15th century, no significant changes occurred in the drainage pattern in the area of Cremona, in spite of climate oscillations, though of short duration, in the whole Po valley, followed by famines and the Black Death. Historical documents apparently record a migration of the Po towards Cremona in 1100, with the attendant upriver migration of the Adda confluence to reach Castelnuovo, which took the name of «Bocca d'Adda» (i.e. «Mouth of the Adda»). Moreover, the river might have occupied larger areas, touching centres that are nowadays remote from it, such as Busseto in 1130 (on the right bank, whereas the town lies at present 5 km due south from the river), while in the vicinity of Stagno Lombardo (left bank, 3 km from the Po) the documents give some «lakes» (*lacus*) probably corresponding to relict river meanders. In the 1390 «Statutes» of Cremona we can read «Scandolara Ripa Po», whilst Scandolara is at present about 5 km from the river.

In the 15th and 16th centuries, many hydraulic works were carried out in order to contain the waters of the River Po, constraining any future expansion of the floodchannel and the re-activation of old channels. An entry for 1479 relates specifically for Cremona that «91 floodbanks of the Po, were completed, thereby turning the river into one single channel» and in 1589 a decree was promulgated for creating the *Ufficio del Magistrato degli Argini* (Floodbank Authority) for the rivers Po and Adda. In the second half of the 15th century, the River Po took up its present horizontal profile. Thereafter only some bank erosion, occasioned by floods, took place.

During the 17th century, the River Po was flowing very close to Cremona, alternatively approaching the city walls or getting further away from them. In 1622 it was about 1.5 km from them, while between 1672 and 1680 it caused great damage, and this made necessary to build massive protection structures. More lateral erosion is reported in 1687 about 15 km downstream on the right bank, between Pieve Ottoville and Ragazzola.

In 1654 and 1705 the whole plain of Cremona was hit by disastrous floods caused by collapsing floodbanks. The waters flooded the countryside up to 7 km from the river, on the left side of the floodplain, invading ancient channels. The following flood of 1758, instead is remembered for having enhanced erosion by the city walls, continuing a trend already established in the previous century.

The River Po finally got away from the walls of Cremona in the 19th century, moving southwards into the early 17th century channel (in 1821 it was 300 m from the walls; in 1852-58 this distance rises to 900 metres, up to the 1.5 km of 1916). Many floods are documented in official State publications, and for the territory under scrutiny, two floodbanks collapses are reported, with flooding of the plain on the right bank in 1801, and on the left bank in 1868, while erosion is still active, especially in the municipalities of the Polesine of Parma, Zibello and Roccabianca (right bank).

FIRST STOP: THE CHANNELIZATION OF THE RIVER AT CREMONA - The first stop of the itinerary will be on the left bank of the Po, at Cremona, immediately downstream from the railway and motorway bridge which links the town with the Province of Piacenza, built in stone and mortar in the second half of last century to replace the previous boat bridge sited about 300 m downstream. At the Cremona bridge the River Po is 400 m wide: it occupies only one fifth of the structural length of the bridge, which is one kilometre on the left bank, while on the right bank there is agricultural land, only exceptionally flooded. By the town, on a stretch about 10 km long, the channel has narrowed by 50% from 1890 to 1995, and this process has taken place mostly before 1920.

MAN-MADE STRUCTURES - The importance of the River Po as a commercial artery is stressed by Roman historians, and in the 12th century by the document issued by FREDERICK BARBAROSSA in favour of the people of Cremona, whereby the Emperor undertakes to keep the waters of the Po free in order to ease the navigation of rivers and marshes through canals which were to be dug to reach the valleys of the Alps. We also have a description of a «naval battle» that occurred in 1431 between Cremona and the mouth of the Adda, between a Venetian fleet made up of 38 *galeoni* and 48 lesser ships, and the Visconti of Milan, with 28 *galeoni* and many lesser ships.

In the vicinity of Cremona the sedimentary and morphological characters of the Po channel are such that dredging is definitely inadequate. A sufficiently narrow profile of the low water channel was required here, in order to keep the bottom in a stable equilibrium. This could be only achieved by diverting sediment away from the channel, in areas at the ordinary flood level. The projected profile of the low water channel from the mouth of the Adda to that of the Mincio, therefore, envisaged conveying the waters into one single channel by a winding layout excluding the straightening out of the channel, because in flood conditions an overall deepening of the reach thus modified could occur, along with deposition downstream, as it has been observed in other rivers. the breadth of the channel was set at 250 m in the straight stretches and 400 m in bends, in order to keep depth at 2.50 m and runoff at 400 m^3/s. Works were completed in 1970, and achieved a stabilisation of the channel.

The Po reaches in the vicinity of Cremona are characterised by: 1) utilisation of longitudinal works with groynes aligned to the thalweg in order to promote the occlusion of the side channels linked to the shoals; 2) adoption of a breadth for overbank flow 250-300 m broader than for the Po channel in the lower plain. Longitudinal defences are threatened by an increasingly eroded bed, now 4 metres deep in average, so that the stability of their foundations is threatened, while the energy of overflowing waters is enhanced.

GAUGING STATION - The monumental gauge (or hydrometer) of Cremona, built on the left buttress of the bridge, is clearly visible from the water level to that of the road leading to the bridge, for a height over 11 metres, with marks for every major flood in the last two centuries. It also provides information from the three preceding gauges, the first of which dating back to 1823. The present gauge, built in 1891, records the hydrometric null point of the gauges of 1823 and 1876, built close to the fluvial terrace upon which the town is built, with a zero of 6.83 m under the foundations of the walls, corresponding to a height of 34.25 m a.s.l. The gauge is made up of four flights of granite steps from the river bank to the level of the bridge, with marks from 6 m below zero to 5 m above. The highest flood level was measured on 8 November 1994 at the 5.95 m mark, one centimetre above the historical maximum measured in November 1951. The hydrometre for the low waters of 1904 had marks from 2 metres below zero to 1 metre above. In 1913 it was extended down to 2.40 m below zero, and reaches now 6 m below zero.

The early continuous observations of the Cremona gauge date back to 1821, although there are some data since 1801, with interruptions in the periods 1825-1838 and 1847-1850, and with further gaps in 1866-1867. Runoff measures begin in 1932, but are published in irregular fashion until 1972. In that year these data began to be regularly published in the Hydrological Annals (*Annali Idrologici*) of the Italian Gauging Service (*Servizio Idrografico Italiano*).

SECOND STOP: THE FLOOD PRONE AREAS - The second stop takes place downstream from Cremona, still along the banks of the Po, after a bus leg across the floodplain from the historical floodbank of Farisengo (15th century) to the Po, covering 5 km in a heavily humanised landscape. Here, relict forms of ancestral fluvial channels have preserved their identity for the last five-hundred years, thanks to the complex system of submersible and insubmersible floodbanks which in time have developed around them (see fig. 6).

The area was repeatedly flooded, due to collapses of the Farisengo floodbank until the 18th century. Thereafter, frequent floods have occurred, but they have been contained within the present main floodbank, insubmersible, built at about half breadth of the floodplain. The most recent flood events occurred in sequence every year, in October 1992, September 1993 and November 1994.

FLOODBANKS - The term «floodbank» is used to define any hindrance to the water, either running or stagnant, giving protection against flood events, thereby allowing to gain fertile land to agriculture. In the Po Plain floodbanks are earth ramparts to prevent the spreading of floodwaters; they can be either submersible, and insubmersible (i.e. master floodbanks, or *argini maestri*). The size of the latter, dictated by a time-honoured tradition, is the following: 1) breadth at the top from 5 to 7 metres, thereby making the bank fit to be walked upon; 2) height determined by the top flood, plus 0.80 m above that level.

Floodbanks (*argini golenali*) built in the area between the master floodbanks and the low water channel (*golena*) to protect farming land sited on the floodplain from middle-sized floods: these are submersible by major floods; their top must be 0.20 m lower that top flood level. Superimposed floodbanks (*argini in froldo*) are built upon the levees, in direct contact with the water. Particular types of floodbanks are built in emergency to patch up a section of floodbank destroyed by a flood (*argini in coronella*). Floodbanks often follow the banks of relict channels, used as flood relief channels. Sluices (*chiaviche*) are installed to control and manage the waters, but also to prevent the backflow of floodwaters.

RELICT CHANNELS - The left bank floodplain preserves clear traces of meanders of ancient active channels probably from AD 1000 and doubtless reactivated by the great 1705 flood, when the Farisengo floodbank was breached, 5 km from the present fluvial channel. The geometry of relict forms shows different stages of abandonment, caused by meander cuts or relinquishment of braided channels close to a confluence. In fact it is possible that the confluence of the Adda, nowadays well defined 10 km upstream from Cremona in the present monochannel system, might have been sited downstream from the town, or that perhaps it occupied a long stretch of the river, forming a braided pattern. The most recent phase of abandonment of side channels concerns the active Po channel during the last century and was brought about by occlusion of inter-shoal channels, due to channelling works.

The stop by the river is intended to stress the processes of channel deepening, whose effects can be easily observed in correspondence with a branch abandoned after the Seventies. The site used to show a cluster of small shoals till the end of last century, with the Po bank in external position by 1 km *vis-à-vis* the present. Floodbank protection works, after the Fifties, have gradually recovered the channel to cultivation. The confluence of the relict channel with the Po is over 3 metres higher than the average discharge level, and it shows a section of fluvial sediments alternating sands and mud typical of fluvial sedimentation at bankfull level, whereas on the bars and the banks, there are predominantly sands laying on gravel.

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GEOMORPHOLOGY OF THE PIACENZA AND PAVIA APENNINE

(R. Rossetti, P. Boni, L. Laureti, G. Marchetti, C. Ottone & L. Pellegrini)

The western section of the Northern Apennine summarises most of the tectonic and neotectonic events interesting also the relationships between the Alpine and the Apennine chains. Therefore, the foothills and the mountain landscape of the Pavia and Piacenza Apennine provide a good opportunity to inspect the complex history of Quaternary events, strongly influenced by the geomorphic patterns built up both by the older tectonic and exogenetic processes (fig. 7). The «Bobbio tectonic window», in the Trebbia valley, offers a view of the North-Apennine structural frame shaped in two main sheets: external (*Tuscanides*) and internal (*Ligurides*, split into internal and external) with the interposition of the *Subligurides*.

The prevailing rock type is the flysch, more or less calcareous, often with a dominant clay or sandstone component. The ophiolites, associated to a «basal complex», are in the lower part of the series in the internal Ligurides, while in the external ones these masses, embedded in the sediments, are quite allochthonous. Sandstone and conglomerate are present also as formations in the upper Mesozoic, but some conglomerate lenses, generally linked to the ophiolites, can be found in other formations. A piggy-back basin, as the Tpb (Tertiary Piemonte Basin), linking up Alpine and Apennine chains, as well as semi-autochthonous units (*Epiligurides*), are also present.

The relief maps of this area show strong differences on the two sides of the Genoa meridian. Eastward, the Apennine range has a NW-SE direction and it is wide and high (over 30 km and 2,500 m), while westward the mountain range (Alps) has a SW-NE orientation and it is narrower and lower (respectively under 10 km and 1,000 m). The Antola axis (BONI & *alii*, 1996), that flanks the Genoa meridian, seems really to be a physical marker of two different mountain ranges. In the Apenninian part, there is evidence of an ancient divide, lined up to the Apennine axis and over 1,600 m high, while the present one is lower and aligned

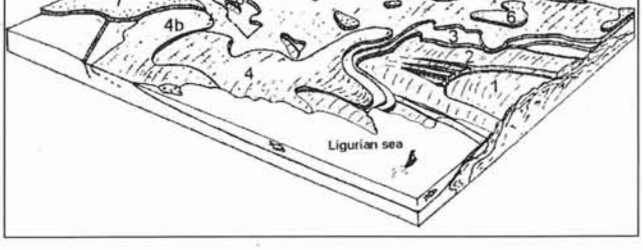

FIG. 7 - Structural sketch of the Northern Apennine. 1 = Apuanes; 2 = Tuscanides; 3 = Subligurides; 4 = Internal Ligurides (4b = M. Antola nappe, lower internal Ligurides); 5 = External Ligurides; 6 = Epiligurides; 7 = TBP (Tertiary Piemonte Basin); 8 = Bobbio Window; 9 = Po plain (redrafted from Zanzucchi, 1994).

about East-West due to tectonic tilting. This old watershed passes through some traces of a wide, gentle, top palaeosurface. A high number of top and slope palaeosurfaces are the result of some strong changes in the drainage system, connected both with tectonic and neotectonic events and also with climatic ones (MARCHETTI, 1979) (fig. 10).

Starting from Piacenza, the excursion heads southward in the Trebbia valley (fig. 8). The first morphological evidences are the alluvial fans of the Nure and Trebbia rivers and the wide Würmian and pre-Würmian alluvial terraces (MARCHETTI, 1990) that cover a system of narrow anticlines and synclines parallel to the Apennines. The evolution of the terrace system is due to some rejuvenation phases associated with recent uplift events.

Near Rivergaro sited at the top of the most recent alluvial fan of the River Trebbia, there is an example of the regular morphological connection between the higher alluvial level ground and the true Apenninian boundary. Here, the Trebbia changes his direction flowing from SW-NE to SSE-NNW due to a river digression. Upstream from Rivergaro, both valley sides show a large number of landslides, some very wide as the old landslide of Donceto on the left-hand bank, and those, on the right bank, of Fabbiano, Statto (densely populated during the Roman Age) and Cognazzo (4.5 km long, reactivated some decades ago). Top and slope palaeosurfaces can be found by Freddezza, Vei, Brugnello and Caverzago. Good examples of selective erosion are the ophiolitic masses outcropping on the surrounding landscape such as those of Pietra Marcia, Pietra Parcellara and Pietra Perduca.

In the Trebbia valley, the resistance of the ophiolitic rocks to erosion is well shown by the impressive Barberino canyon. These rocks were for long time the base level of the Trebbia River. This fact is underpinned by the width of the valley, the thick alluvial terraced deposits and the

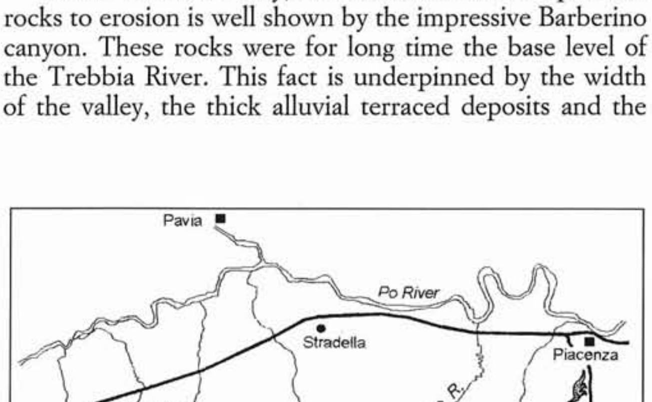

FIG. 8 - Trip path of the escursion.

gentle slopes of the Bobbio basin. Just facing Bobbio, a settlement of Roman origin particularly important in the Middle Ages, there is an old meander edge suspended on the valley bottom and an old alluvial fan cutting the right side, witnessing many stages in the valley evolution.

Upstream from Bobbio, inside the core of the aforementioned geological window (BELLINZONA & *alii*, 1968), the landscape changes suddenly: the valley becomes narrow, with high sub-vertical slopes. The Trebbia forms some spectacular confined meanders, like that of San Salvatore, cut in an impressive series of thick sandstone strata (San Salvatore sandstone of the Lower Miocene, Tuscanide nappe). Further upriver, the middle and the higher part of the River Trebbia show a very complex evolution, chiefly due to tectonic and neotectonic events, as proved by its very complex pattern bearing evident traces of an ancient southward flow.

Of note is also the previously mentioned existence of two sub parallels divides in the NW Apennine (BONI & *alii*, 1996): one, the present watershed of the Apennine, very close to the sea (divide between the Tyrrhenian and the Adriatic Sea), and the other higher and internal, which is likely to be the original one, showing important palaeosurfaces. Today, this last divide is strongly carved by the rivers Trebbia and Aveto (a tributary to the Trebbia) flowing northward to the Po valley. Probably, this means that the tectonic tilting of the old southern rim, complicated by an SE-NW fault system, was slower than stream erosion.

Rising to the Penice Pass along the Bobbio valley (left-hand side of the Trebbia), we can see on the left hand wall frequent landslides and some palaeosurfaces shaped in the argillaceous-calcareous flysch of the Coli-Sanguineto complex (*Tuscanides*). In the upper valley, these units are overlapped by the Monte Penice limestone, the upper unit of the Penice flysch (*Subligurides*) that forms the western frame of the Bobbio window. In this formation, some rock cut-terraces are evidences of palaeosurfaces linked to the early morphological evolution of this area. South- and south-eastward from the Penice Pass the mountain tops provide evidence of the large palaeosurface including the old Apenninian divide.

The road from the Penice Pass to the Brallo Pass, running on the watershed between the Trebbia and Staffora valleys, is an excellent view over different geological and morphological landscapes. To the East, those linked to the Bobbio window, to the Southwest those of the External Ligurides overlapped by the Antola flysch (lower Internal Ligurides), while to the West the major features are those of the arenaceous plate (Monte Vallassa sandstone) of the right-hand watershed of the middle Staffora Valley.

Near to the Scaparina Pass, the Penice flysch is tectonically covered by the Scabiazza sandstone, and in its turn covered by the «Palombini» clays (*Argille a palombini*, both of the basal complexes of the external Ligurides). Into those are embedded many ophiolites, sometimes granitic, olitostromes and some breccias. A scenic view to NE shows the typical features of the Trebbia Valley in the Bobbio area. Terraced palaeosurfaces, deeply incised by a fast geomorphological evolution, flank both sides of the road. Close to the Brallo Pass, an ophiolitic outcrop shows evident selective erosion: it is one of the SE-NW aligned masses, truncated in the Staffora Valley.

It has been hypothesised that the whole network of the rivers Avagnone and Montagnola, today tributaries respectively of the Trebbia and the Staffora, is the track of the old Trebbia bed once passing by Brallo, before the Trebbia was captured by the River Aveto. Tectonic events and, perhaps, extreme climatic conditions are the background for the subsequent accelerated erosion both in the Trebbia drainage network and in the upper Staffora valley, shown by their sharply and deeply incised slopes.

Coming down from Brallo to Varzi, the landscape of the Staffora catchment shows an impressive number of landslides in the few coherent rocks of the valley bottom, underlying the resistant tectonic cap.

The spectacularly parallel elbows of the three major rivers of this area: Staffora, Curone and Grue, change their early S-N flow first to W-E, as under the influence of the Villalvernia-Varzi, and after their turn to SSE-NNW. For the River Staffora, this pattern is quite evident coming down from Brallo Pass to Varzi, from here to Bagnaria and downward from Bagnaria into the alluvial plain. This last part and the equivalent ones of the rivers Curone and Grue are strongly conditioned by a NNW-SSE fault system including the «Staffora fault», very active during the Messinian. This structural layout is evident in some faults and in the recent geomorphological evolution of the river system, but the major fold axes of this western part of the Apennine have a quasi-perpendicular direction. A West, or South-west tilting of this area is underpinned by the strong asymmetry of the valleys that have the right-hand side much more developed that the left-hand one. For example, the rivers Ardivestra and Nizza, the two major tributaries of the Staffora, are about 14 km long each, while those on the left-hand bank normally are shorter than 3 km.

Typical of the Pavia Apennine is the presence of two high tectonized formations as the «Undifferenziated» and the «Chaotic», frequently at the core of the «*rughe*» (= wrinkles), and interested by many mass movements including badlands, earthflows, and landslides. Noteworthy is the arenaceous cover of the Monte Vallassa sandstone, lying on an *epiliguride* formation (*Marne di Antognola* = Antognola shales), that forms all the top of the right-hand watershed from Varzi up to Bagnaria, as well the relief face to Bagnaria on the left-hand side. Near this site, the erosion activity of the Staffora cuts this very resistant sandstone shaped as a syncline of these sandstone with an evident angular unconformity. Very likely, this resistant mass had be for a long time the Staffora base level, as can be surmised from the steep bed profile of this river compared with the much more flat one of its tributary Nizza, inflowing downstream from the arenaceous plate.

Downward from Bagnaria, the River Staffora cuts perpendicularly the morphostructures built in the folded and faulted Cretaceous, Oligocene and Miocene formations. On the left-hand side, the morphostructural landscape downstream from Godiasco shows the «ruga» of Buscofà interposed between the gentle Gomo and Nazzano syncline with a core of Pliocene conglomerates. Also in this part of the valley there are many examples of landslides and palaeosurfaces.

The last stop will be at Salice Terme, a thermal centre with high mineralised waters (fixed residual among 23 and 104 g/l). Known since Roman times, its ancient name was *Locum salis* («salt site», in Latin), owing to the salt deposition from the bromo-iodine and sulphurous waters. In many surrounding sites, as by Monte Alfeo, the sulphurous water is rich not only in hydrogen sulphide, but holds also a high percentage of magnesium salts (sulphates), because of their relationships with the Miocene chalk-sulphur formation (*formazione gessoso-solfifera*: a Cenozoic evaporitic formation with gypsum and sulphur), to be found along the whole Apennine chain.

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NOTES ON THE RECENT AND PRESENT EVOLUTION OF THE LANGHE HILLS
(A. Biancotti, L. Motta & M. Motta)

The Langhe hills are the southernmost part of the Tertiary Piemonte Basin (Tpb), characterised, in this area, by a monoclinal fold tectonic setup, trending NW and dipping 10-15°. The western margin of the region is marked by the River Tanaro, which, at the outlet of its middle valley, at Bastia Mondovì, shifts from a SE-NW trend, cataclinal *vis-à-vis* the layout Tertiary sediments, and therefore consequent, to a S-N one, and parts the terraced plain of Cuneo, to the west, from the Langhe, to the east. The northern limit is again marked by the Tanaro, which, slightly northwards from Cherasco, after the confluence of its largest left hand tributary, the Stura di Demonte, turns to the NE, flowing through a large and deep valley cut among the hills between the Langhe and Monferrato, then reaches the plain of Alessandria and finally joins the Po. The southern limit of the region is marked by the Ligurian Alps, the eastern one by the River Scrivia.

The geomorphological history of the Langhe begins in the Quaternary, when an extensive pediment (*glacis*) was formed in this area, between the Pliocene and the Pleistocene (fig. 9). At present this structure, almost entirely eroded during the Quaternary, is revealed by the long straight ridges forming the external watersheds, and part of the internal ones, of the main basins of the Langhe. These are aligned approximately S-N in the north-central and eastern part of the region, corresponding to the catchments of the rivers Belbo, Bormida di Millesimo and Bormida di Spigno, whose longitudinal axes are aligned as pointed out above; in the south-western areas, corresponding to the Rea catchment and to that of middle Tanaro, with axes aligned SE-NW, while ridges are also likewise oriented. Divides behave differently in different areas: they slope gently northwards (Belbo and Bormide), or in a NW-W direction (Tanaro and Rea). In the first zone, moreover, the height of the divides decreases gently from E to W, in the second they do likewise from S to N. As a whole, therefore, they are tangent to a plane, trending NW, and dipping from 3° to 6°. This plane is the reconstruction of the ancient Plio-Villafranchian pediment.

A few tens of metres lower *vis-à-vis* the average heights of the ridges, windgaps are recognisable in the whole area. These allow us to figure out an ancient river network which did flow SE-NW, parallel to the present one of middle Tanaro and Rea. An early set of terraces is linked with the windgaps. This palaeo-network has been created when changing climate conditions after the Villafranchian, have replaced a system of areal erosion, that had formed the pediment, with a model of linear incision. These streams we-

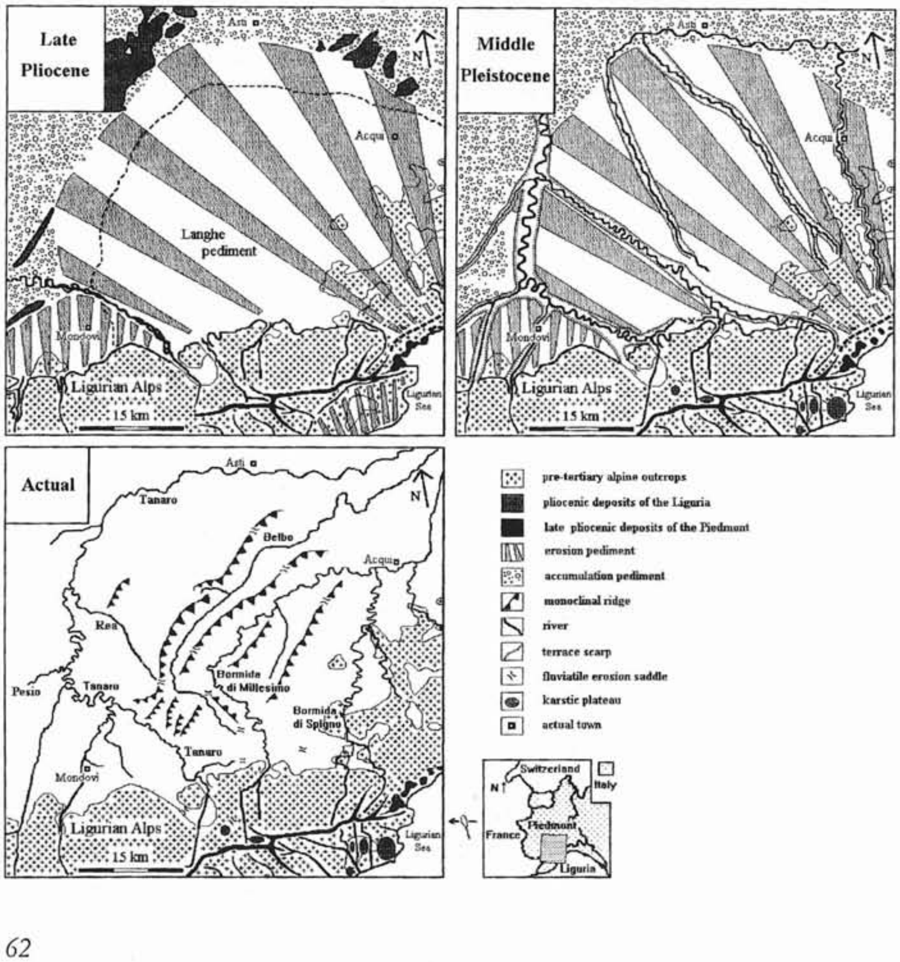

FIG. 9 - Geomorphological history of the Langhe Hills between Late Pliocene and Actual.

re consequent, and their provisional base level was the plain of Cuneo. They kept developing throughout the Middle Pleistocene.

Between the Upper Pleistocene and the Lower Holocene, the Langhe underwent a massive uplift event, with unequal intensity in the different areas: stronger in the Southwest of the region, corresponding to the catchments of the River Rea and the upper Belbo, while decreasing towards NE, and therefore towards the valleys of the Bormida di Millesimo and the Bormida di Spigno. This is confirmed by the different height of Lower and Middle Pleistocene palaeoforms, higher in the SW, gradually lowering towards NE. As a whole, the tectonic movement has taken up the characters of an oscillation, and it has caused a whole set of important consequences for the geomorphic structure of the Langhe.

Firstly, the river network has changed direction from SE-NW to roughly NS. This deviation has taken place in different ways in the various rivers: in the easternmost ones (the present Bormidas) it has occurred gradually. To the west, the Middle Pleistocene headwaters, made up by the upper Belbo-Rea, have been captured by a stream coming from the NE and engaged in active regressive erosion on account of a particularly intensive uplift of the area. A trace of this palaeo-network is windgap of the Bossola Pass, which at present links the River Rea valley with the upper Belbo valley. This capture, of which the great bend of the Belbo by Mombarcaro is an evident trace, took the changed drainage system to a new base level, the Alessandria plain, 100-150 m below the previous base level, the Cuneo plain. Then followed intense erosion which reshaped the morphology and deeply incised the head of the Belbo valley. In the Rea valley, by now separated from the upper Belbo, erosion created new shapes and brought about a deep incision of the thalweg. In particular, where the direction of the secondary network was subsequent, it created a cuestas morphology. This erosional stage has not reached the heads of some secondary dales sited at the northern rim of the basin: here the shape of the thalweg, a deeply incised «V», dominant in the remainder of the catchment, is replaced by poorly incised, gently sloping channels: relics of the Middle Pleistocene morphology.

After a quiescent period, uplift has resumed in the Middle Holocene: a new stage of erosion has incised the thalweg, creating on the slopes of the present valleys of the Bormida di Millesimo and the Bormida di Spigno a second order of terraces. In the Belbo catchment this stage, which is still active, has reshaped the middle valley, but has not yet reached the head of the basin. Roughly to the north of St. Benedetto Belbo the thalweg is deeply incised, and slopes are considerably steep. To the South shapes are more subdued, resulting from climate-driven morphogenetic processes lasting from the Lower Holocene to the present. While during the Lower Holocene the great tectonic movements outlined above were taking place in the Langhe, with their attendant geomorphic effects, another important morphological process was unfolding in the nearby plain of Cuneo: the capture of the Tanaro.

Throughout the Lower and Middle Quaternary, and probably already in the Upper Pleistocene, the River Tanaro, after draining the Cuneo plain, met the Po south of Turin, roughly by the present built-up area of Carignano. During this long time, the Tanaro shifted gradually eastwards, creating a complex system of Mindelian and Rissian terraces, clearly visible in the eastern area of the Cuneo plain. Later, due to the uplift of the hills of the area and, probably, also to contemporary subsidence of the present plain of Alessandria, the river was captured in the vicinity of Bra by a river coming from the NE, which eroded regressively the lower Langa. An alternative explanation is that the deviation of the Tanaro could rather be linked to the strong differences in the uplift of the hills on both sides of the flexure making up the SE rim of the Poirino highland. It also possible that both causes did contribute to the process. The new lower base level brought about regressive erosion which again incised the valley, so that the main level of the Cuneo plain, of Würmian age, is now suspended 80 to 100 m upon the present thalwegs of the Tanaro and its tributaries.

On the drainage network of the western rim of the Langhe, a direct tributary of the Tanaro, the Rea system, regressive erosion linked to the capture of the Tanaro has strengthened the erosional effects due to Holocenic uplift: an intense cutting followed, which reshaped the cuestas and the valley bottoms. The effects of the morpho-tectonic processes pointed out above are not yet at an end: even today the landscape is very actively evolving, while Holocenic geomorphic processes have not yet been felt either by valley bottoms, where Middle Pleistocene forms linger on, or by the external watersheds and part of the inner ones, which still bear traces of the Villafranchian pediment.

Geomorphic shaping of the slopes develops differently according to the interference of the bedding of Tertiary sediments with the slope. On mesas, corresponding, in subsequent valleys, to the front of cuestas, a rapid incision of the thalwegs causes slumps linked to basal erosion, evidently favoured by bedding. The process, therefore, tends to get verticalised, and thereafter to cause a front retreat. Upon hogback slopes, corresponding, in subsequent valleys, to the back of cuestas, great slumps occur, in particular where Tertiary sediments are made up by alternating marls and sandstones. Discontinuities caused by alternating lithologies, become, in moist periods, potential slumping planes along which big gravitational movements tend to become active and to cause the dip of the topographic surface to agree with the bedding. Also in this case, thalweg incision, affecting slope balance, contributes to trigger the process.

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THE TERRACES OF SOUTHERN PIEDMONT PLAIN
(R. Ajassa)

GEOGRAPHY AND GEOMORPHOLOGY - The three terraces here studied are located in the Eastern part of the plain, about 6-8 km from the Langhe, beside Tanaro River. They are the highest in altitude among the adjacent plains, thereby forming plateau («islands» in the plain) oriented for the most part NW-SE. The shortest distance from the border of the Alps is about 12 km. The Southernmost of these terraces will herein be called Bainale, the traditional name as it is known in the region. It has at times been called the Terrace of Magliano, and the Terrace of Isola, from the names of near villages. The only industry present on the terrace top is agricultural. To the North, separated by the Plain of Benevagenna, is the Terrace of Salmour. Moving once more towards Torino, crossing the deep incision of the Stura di Demonte River, we find the Terrace of Fossano.

Together, the three terraces form part of a sedimentary basin, active since the lower Oligocene. Between the end of the Pliocene and the beginning of the Pleistocene, the plain formed. The Quaternary was therefore a period primarily of erosion, even if altering with periods of sedimentation. This back and forth created the formation of a very complex group of terraces, of which the three studied here form part.

Lower Pliocene - The lower Pliocene is primarily composed of azure marl (Pliocene in facies Piacenziana). The depth is very varied, (in this area, it is over 80 m). The strata emerge toward the NW with a modest incline, and appear directly under the quaternary deposits of Bainale.

Upper Pliocene - The Upper Pliocene is primarily composed of the yellow sands (Pliocene in facies Astiana). The depth here reaches a maximum of 70 m, and rapidly decreases moving South.

Villafranchiano - This term is used for the sake of simplicity, even though today it only refers to the formation site. The term includes terrain of the upper strata of the Pliocene and the lower strata of the Pleistocene. Concerned are deposits of different natures originally deposited in a marine setting, then in a continental setting (sand, gravel, and marl clay).

Quaternary - Here represents conglomerate river deposits mixed with a fine sand, and completely covers the tops of the terraces. In the more recent strata the amount of gravel decreases, as does the depth. On the surface of each terrace is present a loam-clay layer, with very deep soils.

THE PROCESS OF TERRACING - The processes that have brought about the formation of these terraces is complex.

BIANCOTTI and to some degree even GABERT affirm that in discussion are the remains of the alluvial fun of the past of Tanaro River. SACCO, on the other hand, based on the lithologic types present, states that the deposit process is due to all the west tributary rivers of the Tanaro, all the way to the Mellea River. GABERT himself admits that the Northern part of the Terrace of Fossano could only be formed by a river from the West.

Even on the causes of erosion, there exists differences among the various authors. SACCO maintains there existed a contemporary tectonic motivation (the rising of the region) and a climactic one (the reduction of river flow at the end of the Ice Age and a shift from a period of deposit to one of erosion). GABERT also sees the involvement of tectonic and climactic forces. The erosion would have been due to both the rising of the Alpine Chain, and to the lowering of the central plain with the ensuing adaptation of the drainage system to a lower point. The primary causes of the surface incisions, however, would be climactic: in Ice Age there were periods of intense sedimentation and periods of intense erosion. There remains, therefore, a close direct relationship between the climate and the various terrace layers. For BIANCOTTI, on the other hand, erosion would have been due to the contemporary effect of the lowering of the central plain, and the rising of the western most region of the plain (delineated by a tectonic line running N-S and passing through Fossano).

DATING - Dating the terraces of the Southern Plain presents a complex problem, and no definite answer has yet been given.

SACCO attributes the higher regions of the Terraces of Fossano, Salmour, and Bainale to the Ancient Pleistocene (or Diluvium), the lower regions to the Recent Pleistocene (or Diluvium); and the principle plain to the Ancient Olocene (or Alluvium). PENCK confirms SACCO'S dating, however applying for the first time a dating based on the glacial periods of his own conception. VENZO considers, in his dating, only the terraces located in the Stura river valley. As for the three terraces in question, he dates both levels to the Mindel (Middle Pleistocene). GABERT equates the Mindel (Middle Pleistocene) with the upper level, but his thoughts have never been clear about the dating of the lower level. Carraro & Petrucci attribute to both levels the same characteristics as the prealpine terraces studied by Sacco, but date the first level to Villafranchiano and the second one to the Mindel (Middle Pleistocene). BIANCOTTI, on the basis of the existing soils of the various levels, finds distinction among the three terraces. He considers Mindel the Terraces of Salmour and of Bainale , both in their upper level as in their lower level; the Terrace of Fossano to be Mindel in the upper level and Riss (Middle upper Pleistocene) in the lower level. He also attributes to the Riss both the prealpine terraces and the Plain of Benevagenna, which lies between the Terraces of Salmour and Bainale.

Notwithstanding the significant differences in thinking among the various authors, it is possible to discern certain common ideas: 1) there exists four main terraced levels, each in turn divided into sub-levels. The causes of these single terraces at the various levels, however, as does the dating, remain controversial; 2) the various phases of erosion that caused the terraces to form are attributed to the combined actions of tectonic and climactic forces. Knowledge of tectonic structures has grown through the years, and has allowed for an ever-more detailed and complex explanation of the geologic history of the Plain. Likewise, the understanding of the glacial movements is today more refined, even though differences exist as to the glacial relevance to erosion. For example, GABERT considers these to be the principle causes, while BIANCOTTI considers the tectonics much more relevant.

THE SOILS - As has already been noted, the soils present in these terraces have never been studied in depth. There is a traditional sub-division in «red soil» and «white soil» based on the colour of the exposed soil surface: red or dark red in the first case, light brown or yellowish brown in the second. This difference has never been directly addressed by any author.

SACCO obviously doesn't speak about soils pre se, but only alterations of deposits. He limits his remarks to the observations that in general, the surface or the area is reddish; and that the deposits present on the two principle levels are very similar, often indistinguishable. He also notes some black concentrations of over 30% magnesium oxide that serves to cement together yellow limonitic iron, sandy white clay, and often gravel. Sacco attributes this to the presence of ancient swamps. Today, it is known to be attributed instead to the underground water level present in the soils. GABERT also speaks about surface alterations of the deposits. He afirms that the higher levels of the three plateaux have a *ferretto* facies, containing many ferrous nuggets. The only gravels present are quartz. The sandy clay base is red and reaches sometimes a depth of many meters. The lower levels have a very altered covering, but less so than the higher ones. In particular, the former have a yellow hue to them, while the latter a more reddish one. CARRARO & PETRUCCI affirm that the soils of upper levels (Villafranchiano) and those of lower levels (Mindel) are covered with an identical *ferretto*, and are therefore to be distinguished only based on altitude. BIANCOTTI affirms that the entire surface of the Terraces of Salmour and of Bainale, as is the higher level of Fossano, are covered with a soil similar to the one he noted on the glacis of Roracco. He describes, therefore, the same cross-section he observed at Roracco (in Southern part of the plain), where the characteristics are: a very intense red hue, varying between 2.5 YR and 5 YR (pages of Munsell Soil Color Chart); very advanced argilification; very evident remains of the lower layers; the presence of both plinthitic and clay-skins, and the absence of carbonates. His hypothesis is that this region passed through a humid tropical or subtropical period, with a probable forest covering. For the lower level of the Terrace of Fossano, on the other hand, he identifies a less evolved soil, not attributable to the same bio-climactic period as the proceeding. This soil is, however, analogous to that which he observed on the Terrace of Pianfei (in Southern part of the plain, near Roracco). The characteristics here are: a significantly lesser depth than the soil at Roracco; a color variant between 5 YR and 7.5 YR (pages of Munsell Soil Color Chart); the presence of a orizon Bt with illuvial clay, but not plinthitic; less evident pseudogley; lack of solubility traces of crystalline gravel.

Present on the two highest surfaces are two distinct pedologic units. These two units correspond respectively to the above-mentioned «white soil» (upper) and «red soil» (lower). They are present in the internal of the same profiles, but form two different soils, where the lower unit can be defined as a buried soil. The reason the more evolved unit has surfaced is due to secondary erosion. Regions where «red soil» is present on the surface for the most part are located in close proximity to cliffs or areas that have an even erosion, usually areas that have a significant slope. In these areas, erosion has cut through the soil, and has often carried away the higher unit, and this causes the observable phenomenon of the surface soil changing colour.

The distinction between the two units is not, of course, linked to colour. The lower, most ancient unit has a loam-clay or clay texture, with an abundance of clay-skins. In the more recent higher units, instead, the texture is loam. There are no clay-skins, nor traces of ferrous-manganese, and cementations are notably more scarce. As for the values of the interchangeable bases, there are no differences between the two units: this is associated with the process of leaching where these bases consistently migrated from the upper to the lower strata, including those buried. The degree of saturation in the lower depths is on average over 60%: these soils (lower units) are therefore cataloged in the order of Alfisoils. They are leached soils, (in the French classification, they are dark, pseudogely leached) with partially saturated B clay (had they a saturation values less than 35%, these soils would be classified Ultisoils). In both units, there is an almost complete lack of calcium carbonate. These characteristics would suggest there past a rather long time between the first and the second periods of deposit, and that this second period is relatively ancient, as is evidenced by the total decarbonatation and the degree of leaching.

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USING GIS FOR MORPHOLOGICAL ANALYSIS OF WATERSHEDS

(R. Ajassa, E. Bonansea & R. Ferrari)

November's 1994 flowage showed the incorrect management of Piedmont land, both in mountai and in plains. Some of the damages depended on planning process had not been carried out, but other causes of them are difficulties in previding such phenomena. If forecasting is quite simple, it is very difficult to model its resulting effects. The future management of natural disasters, like flowages, should be based on the research and development of new instruments wich can support the prevision of land evolution in order to set up a correct planning process.

Watershed analysis is very important for the land knowledge and management, both under physical and the socio-economic point of view. On the other hand, since reference is made to geographic rather than political and administrative land unities, all the existing information (most of it dealing with administrative limits) should be at hand for a watershed analysis, that can include or be included in more than one administrative land unit. The role of the Sit (Sistema Informativo Territoriale) is very important for informatic management of data and for their geographic and administrative analysis; Sit is also important for creating new knowledge about land especially under the physical point of view.

All watershed's morphological or hydrological paramethers are important elements to be token into account. While their estimate with traditional instruments and methods is difficult and expensive, it is possible to obtain it with Gis in an immediate and automatic way, because estimates are geometrical calculation of geographic entities belonging to the same system of topological information management. Moreover, the calculation of these parameters is useful for hydrogeological estimates in order to manage the soil and the land assessment.

There are two major approaches to the watershed hydrogeologic study: the first referring to flowage risk, the second concerning landslides. Both are depending on many natural and anthropic factors, that are hard to analize together and difficult to understand. Neverless there is a common interpretation about the most important causes of risk, about hydrology and geomorphology of the territory. As far as flowages are concerned much has been done in listing events such as meteorological data, flooded areas and damages, the prevision model of future events, however, is still difficult to draw. This is a consequence of the difficulties involving the scientific comprehension of complex phenomena and of the difficulty in creating geographical previsional models.

REA BASIN - In order to test the chances offered by the Gis Arc/Info system for morphological and hydrological analysis, a possible pilot area has been located. Since the morphological analysis should be carried out in an automatic way and these elaborations had to be tested to identify an area of study in such a way as to place this pilot-project in an ambit wich had already been analysed with classic methodology. In this way it is possible, in first place, to verifyi the efficiency of the system and to check the results in the light of previous knowledge on the area; secondarily, it is possible an useful comparison of the data those obtained through classic methods of analysis and elaboration by informatic instruments, in order to verify the differences of analysis functionality and results. Since the purpose of these analysis is to model the risk of accident, it has also been necessary to choose an area whose caracteristics, from this point of view, could give back a significant model for such a study.

In the light of these remarks the area of the Rea torrent basin, located in western sector of Langhe (Piedmont, Italy), has been chosen as a sample area. In fact this basin has the right dimensions, a typical morphology and has been widely studied with classic methods; moreover, it is geographically situated in a critical land under the point of view of the hydrogeological risk of accident. The analysis of the Rea torrent basin has been achieved for methodological purposes,in order to set up systems of automatic representation wich can contribute to the elaboration of proposals for the organization of territory.

Among the possible cartographic models, which will be flanked by the necessary quantitative analysis related to the specific purpose that will be chosen, the following have been individuated and analysed: 1) elevation pattern; 2) surfaces pattern; 3) hydrography; 4) percentage slopes; 5) aspect of slopes. Every map produced has got its own capability of use and one that derives from compared analysis and from the interaction with the other documents. The fields of possible application can be individuated between the following: 1) slope dynamics; 2) slope stability; 3) primary use of territory; 4) other possible uses of territory.

The terms «dynamics» and «stability» of slopes are employed in the meaning established by project «Progetto Finalizzato 'Conservazione del suolo' (Soil Conservation) del

Consiglio Nazionale delle Ricerche». The Rea torrent basin has been retained indicative enough of a general situation of Piedmont hill environment for the following reasons.

– The Rea torrent is an effluent of The Tanaro river, like most of the collector basins of the Langhe and Monferrato, and was therefore subject to dynamics and to geological events that have interested the whole southern Piedmont in Pleistocene age.

– The Rea torrent is modelled in the «Bacino Terziario Piemontese», which is the dominant geology substratum in the whole hill district of Piedmont. Many of the slope evolution patterns can therefore be extrapolated in the whole area of middle relief of Piedmont.

– The Rea torrent flows between the low hills, still strongly urbanized, and the high ones, by now marginal zones of the regional territory. The relationship between physical space and human space can therefore be studied as an example that reappears in many other similar contexts.

– The organization of the territory in the hills of the Bacino Terziario Piemontese will probably represent one of the main golas for the development of the whole regional realities, being a sector where autonomous choices will be done by local administrations, given the «banality» of plain, whose development is by now well individuated, and conditioned by the evolution of the urbanization in the «Pianura Padana», and the «immaturity» of mountain, wich is intended as present like a transit or like the «garden» of Europe, always in relation to the use that the strong areas of the continent do of it.

– The Rea torrent, besides, was already investigated by scholars of different sciences, aiming at comparing their opinions and physical and anthropic dynamics of territory; the first results where elaborated thanks to the collaboration of the Ires with the Institute of geology, paleonthology and physical geography of Turin's university.

INPUT DATA - Input data for morphological analysis are represented by the necessary parameters for a digital terrain model. The subsequent procedures of analysis are based on it; they use a tridimensional model of the territory for calculation of the morphological parameters. The necessary information for the surface model are essentially altimetrical, and have been obtained by Ctr (technical regional map) in scale 1:10.000. The Ctr supplies, besides raster information, also altitude data in Arc/ Info format coverages. These are the coverages of contour lines, of quoted points, that is significant points obtained from the map and quoted, and of the file Dtm (Digital Terrain Model) that gathers information of the altitude for a net of points with vest of 50 metres of side.

ELEVATION MODEL - For a geomorphological analysis of the territory, the altimetrical data can be elaborated to generate a tridimensional model of the territory, such as to consent an analysis of the surface morphology. In Arc/Info various procedures for generation of tridimensional model of ground are available, that will represent a basis for elaborations and analysis that take into account not only the topographic localization of points but also their elevation. A digital model of ground is generated in such way contains new information referring to altitude. This new variable, related with the spatial location, gives way to a detailed morphological analysis, wich maintains all characteristics and capabilities of Gis analysis.

For the production of a tridimensional model of territory various procedures can be followed; they differ both for the input data and for the use of altimetric base datas; thanks to the Grid modality, the analysis of the topographic surface permits the necessary hydrological correctness of ground model. Starting from verified and corrected data, the digital model of ground by module Grid has been produced, by obtaining a first model with cells of breadth of 10 m containing altitude values, utilizable for the following elaborations. This grid base supplies a 3-dimensions visualization, beside a plant; any cell is associated to a value of altitude that can be obtained by video interactive questions. These values are collected in a list of values of attribute (Vat), a file of data associated to the Grid and useful for analysis, description and statistical elaborations.

FIRST ELABORATIONS - The first group of parameters obtained is referring to the description of morphological characteristics of idrographic basin, such as area measures, those connected to shape factors and parameters regarding to relief. The second great group of territorial data involves morphological details derived from altitude models, like slopes and aspect, directions of flow, hydrography, automatic hyerarchization. Furthermore, the hydrologic correctness of the model has permitted the identification of basins, utilized as a significant land unity, on which morphological elaborations and parametrizations are possible.

The application of automatic procedures of calculation to the flow model has offered also an example of corrivation model, by estimating corrivation times and water apports. The themes that can be obtained through the instruments of analysis supplied by the module grid have been grouped in categories, according to the type of analysis and to results. For the purposes of the present study two main kinds of analysis can be underlined both connected to a morphological exam of basins: the morphological and the hydrological ones. Morphological themes obtained in such way have been used for the realization of as many tematic maps.

CONCLUSIONS - In the first part of this work the importance of Gis instruments for morphological analysis of basins has been pointed out. The developments offered by modules of Arc/Info, opportunely related and used, supply remarkable hints to further work, both in the field of new applications, and for an extension of the analysis to wider areas. As far as the morphological analysis is concerned, this kind of automatized and standardized analysis of the territory suggests a wide range of applications both for environmental purposes and for the land use, under different points of view.

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4th day

GEOMORPHOLOGY OF THE IVREA MORAINIC AMPHITHEATRE
(M. Giardino)

The onset of the Quaternary glaciations caused the development of typical landforms in the Alpine regions of Europe. The interaction of glacial and periglacial processes produced either constructional morphologies or erosional landforms both in intermontane areas and at valley mouths. Glacial landforms in the central part of the Italian North-Western Alps were strictly controlled by the glacial evolution in the region of Valle d'Aosta. The advances and retreats of the principal body (Balteo Glacier) of this glacial system gave rise to the Ivrea Morainic Amphitheatre, a complex of end moraines extending at the mouth of the Aosta Valley.

The Ivrea Morainic Amphitheatre (Ima, from now on) is the third largest end-morainic complex of the inner side of the Alps, stretching over an area of about 600 square kilometres. Despite of their conspicuous appearance beyond the surrounding drift-covered plains, ridges of Ima end moraines are generally composed of relatively thin glacial ablation deposits (up to some tens of meters): often they appear to be rock-cored.

As different glacial phases developed different end moraines in the area, geological and geomorphological studies (see below) identified 3 groups of end-moraines of the Ima (fig. 10), from the outer to the inner: (i) the Borgo group; (ii) the Serra group; (iii) and the Bollengo group.

The complexity of these landforms is due not only to multiple depositional stages: but also reflects lithological

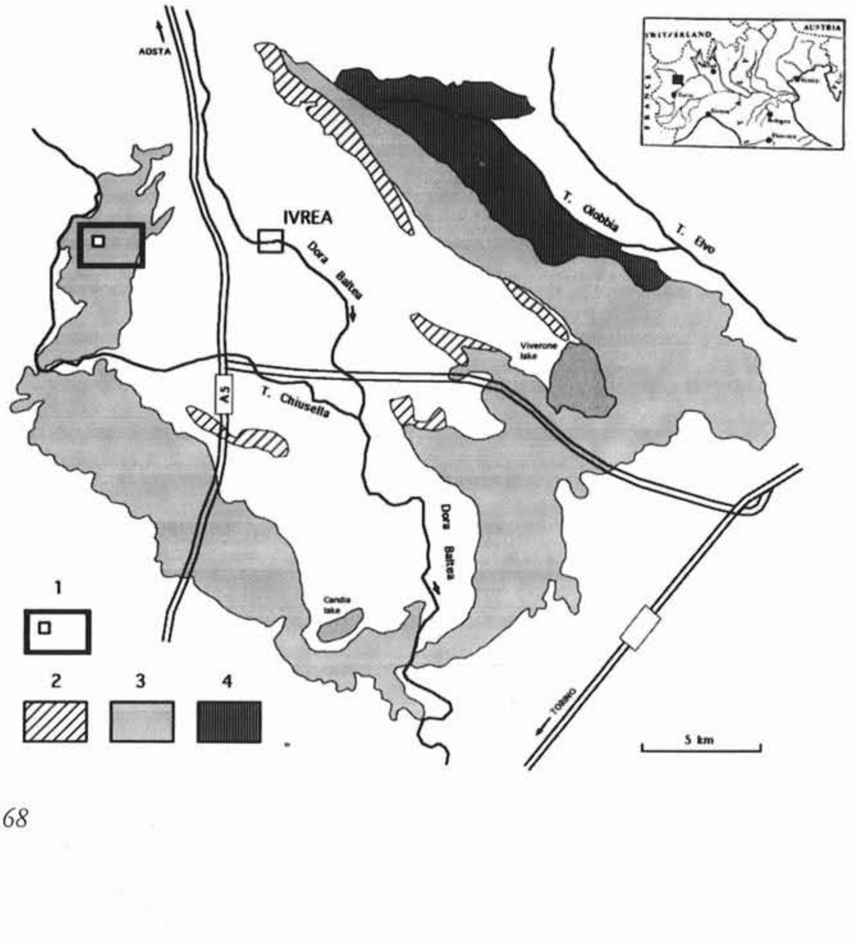

FIG. 10 - Geographic location and geological sketch-map of the Ivrea Morainic Amphitheatre. 1: Alice site and studied area for isotopic age estimates. 2: Bollengo-Albiano Group of terminal moraines. 3: Serra Group of terminal moraines. 4: Borgo Group of terminal moraines. Dora baltea river and other local streams are in bold lines. Double lines (A4 and A5) are the main highways of the Piemonte Region.

and structural patterns of bedrock and the previous morphological setup of the area. The bedrock geology of the Ima is made up of pre-Cenozoic basement rocks, Pliocene deltaic and shallow marine sediments, and Early Pleistocene river deposits. The basement rocks belong to three main structural domains of the Alpine chain: the Europe-vergent Australpine System (polycyclic micaschists and metabasites with HP assemblage: Sesia-Lanzo Zone; VENTURINI, 1995, with references), the Southern Alps (lower-crust mafic rocks of Ivrea-Verbano Zone; VOSHAGE & *alii*, 1990, with references) and the Canavese Zone (Pre-Permian metamorphic basement rocks, Permo-Mesozoic covers and Tertiary ryolites; see BIINO & COMPAGNONI, 1989) lying in between. In the area of Ima, the boundaries between these structural domains are marked by tectonic contacts belonging to the Canavese fault system, which is a part of the Periadriatic-Insubric lineament.

While Alpine basement domains are the substrate for the most part of the inner Ima, Pliocene deltaic and shallow-marine sediments occur in the central and right-lateral sectors. In the outer area of Ima, glacial deposits overlie highly altered sands, gravels and coarser deposits; they are alluvial-fan deposits of Early Pleistocene age whose source-areas are shown by the lithology of the clasts: very heterogeneous for those at Valle d'Aosta mouth (Dora Riparia drainage network), comparatively homogeneous for those from minor valleys. Remnants of the original landforms are preserved only out of the left-lateral sector of the Ima.

On the basis of the pieces of field evidence sketched above, it can be argued that the complex setting of the Ima bedrock shows a differential uplift of the area. This process seems to be active also after the emplacement of the Ima, since post-glacial rivers are rapidly cutting into the Ima, through both glacial deposits and the underlying bedrock. Some anomalies of the present-day drainage network (e.g. the stream Chiusella) could also be related to fluvial deviation phenomena enhanced by differential uplift.

In order to figure out a plausible model of the morphological and geological evolution of the Ima we have to consider that climate change (glaciations and stadials) acts, along with other factors (geodynamics, relative resistance to erosion of outcropping formations) to cause depositional and erosional episodes in the area. Among the studies carried out in the Ima, only the most recent (CARRARO & *alii* 1991; CARRARO, 1992; GIANOTTI, 1993; ENRIETTI, 1996; AROBBA & *alii*, in press) follow correlation criteria based on a multivariate interpretative model. A review of the whole previous literature is at present in progress at the «Dipartimento di Scienze della Terra» (Earth Sciences Department) of the University of Turin. These studies, together with geological field analysis following the allostratigraphic criteria, are devoted to locate and to trace accurately unconformities between units; the stratigraphic relationships between the 3 groups of end-moraines of the Ima (fig. 12) were established by means of comparisons of the heights of basal surfaces of single units. The relative chronology of the different allostratigraphic and geomorphic positions was then enriched by analysing the development of soil profiles in different units; a few data about palaeomagnetically correlated ages and isotopic ages contributed to establish a geochronology of the three groups of end-moraines of the Ima, as hereby set out.

BORGO GROUP - This is the outer and older group of end moraines, whose remnants of the original landforms and sediments are preserved only on the left side of the Ima. Stratigraphic relationships show that older glacial deposits of the Borgo Group are contemporary to lake deposits formed by the damming of River Elvo by the Balteo glacier. Palaeomagnetic studies on lake deposits (CARRARO & *alii*, 1991) showed a reverse polarity (Matuyama Chron, Early Pleistocene as correlated age). Long-term physical and chemical weathering of land surfaces on the outer part of the Ima produced thick weathering profiles and darkening of soil colours (red to dark-reddish brown). Erosional processes and mass movements contributed to bring about strong modifications in the morphology of end moraines. However, the original landform trends are still preserved due to fluvial dissection deepening into original meltwater channels parallel to the ridges. Outwash deposits of Borgo Group often outcrop below a thick cover of loess deposits.

Stratigraphic and geomorphic evidence shows at least two stadials during the glacial phase of the Borgo Group. As mentioned above, the outer and older deposits belong to the Lower Pleistocene. Dominant outcropping sediments of this earlier stadial are: (i) a dense massive diamicton with abundant polished and faceted clasts; (ii) a matrix of clast supported diamicton with subangular to rounded clasts, often altered by soil forming processes. The facies of these deposits are can be interpreted respectively as lodgement and ablation tills.

The inner and more recent end moraines of the Borgo Group are interpreted as deposits of a later stadial of the same glaciation (CARRARO & *alii*, 1991). They show a great variety of facies, such as diamicton with silt and clay beds, sand and gravel, stratified and deformed clay and silts. The type and the internal features of deposits and the association of facies suggest a predominant ice-marginal deposition of tills by subglacial flows interbedded with glacial lacustrine and/or by mass movements with intermittent fluvial sedimentation.

SERRA GROUP - The name of this Group comes from the «Serra» moraine, the most impressive landform in the whole of the Ima, which is made up of two linear (NW-SE trending) parallel ridges up to 18 km long. The majesty of this landform is due to its sharp longitudinal profile rising up to 600 m (at the mouth of the Aosta Valley) over the present-day alluvial plain of the River Dora Baltea.

As shown in the map of fig. 1, the «Serra» moraine is only the inner part of a large group of end-moraines. Geomorphic position and soil stratigraphy allow to separate it from an outer and older part of the Serra Group which is characterised by a ticker soil profile (up to some meters) and darker soil colour (up to yellowish red) than those developed in the inner «Serra» moraine. Typical sedimentary successions of anaglacial fluvioglacial deposits, lodgement and ablation till, cataglacial, fluvioglacial and lake deposits witness the glacial expansions and retreats in an inner position than the previously formed Borgo Group end-moraines, which are partially constraining the end-moraines of the Serra Group. Fluvioglacial deposits of the Serra Group make up terraced units in the inner part of the Ima and a wide apron from the Ima to the Po Plain. Breaks in the longitudinal profile of outer moraines of Serra Group are due to former meltwater valleys. Spill-way channel between ridges of terminal moraine hosted firstly sediment accumulation, then terrace formation due to a lowering of the local base level.

The interaction of fluvial processes with glacial landforms and deposits produced accumulation of placer gold at the Bessa region, on the left hand side of the IMA. As is well shown in the monographic paper by Gianotti (1996) gold minerals from Ayas Valley (left tributary of Aosta valley) had been eroded from bedrock lode sources and concentrated through eluvial-colluvial processes, then carried by the Balteo Glacier up to the left hand side of the IMA. Re-concentration of the older placer of glacial origin was operated by local streams (Viona and Olobbia Creeks) generating the Bessa terrace (8 km-long, 0,6 km-wide). Almost complete depletion of placers was operated by Roman miners (II-I century BC).

The traditional Serra Group chronological interpretation as Middle Pleistocene in age (Riss *auctorum*) used to be a debatable attribution, especially during the field survey carried out in occasion of the second edition of the Geological Map of Italy (BORTOLAMI & *alii*, 1967) because some authors indicated the Serra group as belonging to the last glaciation, some others to the penultimate. Therefore, in the current chronology, the possible interpretations for the Serra group were either Middle Pleistocene or Upper Pleistocene. Recent palynological and isotopic studies (AROBBA & *alii*, in press) were carried out on silty clayey and peaty deposits sampled at –52 m from ground level (585 m a.s.l.) in a core drilled near Alice superiore (right lateral sector of the Ima). The pollen taxa indicate a forested environment characterised by a mesophilous formation typical of a cooler climate than those associated with the actual Querceto-carpinetum. A sample of the deposit yielded an *ante quem* radiocarbon conventional age of >43.000 y. BP. The age estimates and the stratigraphic location of the sampled layer (above and below bounded by glacial-fluvioglacial deposits) are in agreement with an Upper Pleistocene dating of the whole Serra Group, being the silty clayely and peaty deposits of an early interstadial.

BOLLENGO GROUP - As shown by the field survey data on the Borgo and Serra Group, the allostratigraphic units corresponding to inner and younger ridges are based on erosional surfaces at gradually lower elevation. These pieces of evidence show that a sequence of entrenchment and terrace formation episodes has taken place in the area. Also the erosional surfaces related to the emplacement of glacial units of the Bollengo Group, the inner and more recent group of end-moraines in the Ima, are located at gradually lower heights in the bedrock. This indicates that, in the same way already identified for older units of the Ivrea Amphitheatre, the glacier continued the erosional process also during last glaciation and subsequent retreat phases.

The Bollengo Group is proof of an important recessional stage of the last glaciation. Stratigraphic relationships, inner geomorphic position and lower elevation of end moraines uphold the age to be estimated as recent. This is in agreement with the light colour (up to yellowish brown) and thin profile (less than a meter) of the soils.

The fluvioglacial deposits of the Borgo Group make up terraced sequences that cut and fill glacial and fluvioglacial deposits of older groups. Widespread lacustrine deposits witness the formation of a proglacial lake in between the glacial front and the previously formed terminal moraines. The Candia and Viverone lakes are the remnants of this ancient basin. The ancestral effluent stream followed a NW-SE trending depression up to the meltwater channel connecting to the outwash area of Serra Group apron: the palaeochannel of «Dora Morta» is due to entrenching of this water course in the previously formed fluvioglacial apron.

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THE AOSTA VALLEY: GEOGRAPHY, GEOMORPHOLOGY AND CLIMATE

(R. Ajassa & G. Brancucci)

The Aosta Valley is an important valley of the alpine chain. It takes its name from the principle city of the Administrative Region, which again bears the same name, and was founded in the Roman period of Agustus. The Region of the Aosta Valley has an area of 3260 km^2, and a population of just over 100,000. It is the smallest of the Italian Regions and it is classified as a Region of Special Status.

Aosta Valley extends along the entire mountainous tract of the Dora Baltea River basin, which continues to the Padana Plain near Ivrea, and then join the River Po. The valley is delineated on all sides by impressive mountains, except in the South-Western sector, where the lower valley opens towards the Plain of Ivrea. On the Northern extreme, the valley ends with various Alpine peaks: Monte Bianco (4810 m), Matterhorn (4468 m) and Monte Rosa (P. Doufour 4659 m). To the South, the valley border touches the the Gran Paradiso (4061 m). To the East and West, by the dividing crests which separate a number of secondary valleys from the Sesia Valley (Western Piedmont), and the Alta Savoia Valley (Val d'Isere), respectively.

The geology of the valley is schematically represented by a succession of metamorphic rock, enclose which large crystalline massifs: the faces of which seem simple, but in actuality are very complex and intermixed. They are the result of the piling up and settlement of the alpine strata, caused by, according to ARGAND, the strong tangental forces that originated the Alpine Chain at the beginning of the Tertiary Era, when many intense metamorphic processes are said to have occurred.

In the first tract, starting from Pont, we can see the appearance of the crystalline rock of Sesia-Lanzo. Following this, until just past Verres, we see the formations of Mont Avic. Between Verres and St. Michele, in the tract where the Valley narrows slightly, the prevalent litological type is Gneiss from both the Gran Paradiso and Monte Rosa (internal crystalline massif), here smoothed and significantly eroded from the wide glaciers of Pleistocene.

At St. Vincent, the lower valley widens and takes a decisive turn to the East - West. The slopes are less extreme, and woods uniformly cover the inside slope exposed to the North, while the number of cultivated areas increase on the slopes with southern exposure. We enter in the zone of «Calcescisti con pietre verdi». Between Avise and Courtmayeur, the valley narrows once more and we find in the structural unity of Subbrianzone and Brianzonese, the first constituted of flysh formation (sandstone, conglomerate, and shale), the second of gneiss, various shale and slightly metamorphic formations from Permo-Carboniferous (the Permo-Carbonifero Assiale). The Dora River of both Val Veny and Val Ferret run at the foot of Monte Bianco, where granite of external massif touches its sedimentary covering.

In this valley quaternary formations are also very frequent. Besides the deposits brought by the waters of the Dora, we find consistent morenic accumulations, left by the main glacier at the end of the Pleistocene period (traces of the most invasive glaciers of the era are to be found outside the Valley, near Ivrea, in the Ivrea Morenic Anphyteatre. This is mentioned further in another part of the Guide). The glacial deposits of Olocene characterize the head of the secondary valleys, will be discussed later. The consistent deposits (scree slope) especially in the which link the slope with the plain above all in the intermediate tract of the valley, are still to point out.

The glacial morphology include small scale observable formations and larger formations, easily recognized throughout the Valley. The most typical manifestation of the morphogenic glacial action is primarily characterized by a transversal cross-section «U», which is maintained in the terminating part of the Valley. Here in fact, we can note very steep walls whose height is proportional to the depth and size of the glacier, upon which we note typical mountonne rock: asymmetrical cross sections, rather rough surfaces toward the bottom of the valley, rounded, and with carvings and ravines towards the upper sides. Locally, (Settimo, Bard, Montjovet) at the base of the mountain walls, we also see evidence of quarrying. The bottom of the valley is generally flat, with a irregular longitudinal cross-section, variable width and a thin sedimentary covering. The ancient glacial borders, rounded with mountonnè rock on the upper sides, steeper and rougher on the bottom sides, are often on these carved by river erosion and form rather narrow gorges (Bard, Montjovet, Entreves), and hereupon have been carved epigenetic river-beds. The major resistance to erosion along the glacial edges has created locally a upward gradient. Edges and rocky barres of glacial valleys are explained, in this case, principally by litological and structural causes and, secondly, by irregular glacial erosion.

The smaller tongues of the lateral glaciers, converging into the principle glacier, could not form their valleys to reach the depth of the river bed. For this reason, with the glacial fusion, these are known as suspended valleys, where they join the main valley, there is a difference in altitude. These are visible throughout the valley, and today, remain deeply cut by the tributaries of the Dora. Historically, as these steps are difficult to cross, they have been used as strategic points of defense to control the crossing, building fortifications and castles. The Castle of Verres, situated at the opening of the Val d'Ayas, and the Napoleonic fortification at Bard are of particular beauty.

Further up from the narrowing at Montjovet, the valley changes direction, from NNW-SSE to W-E. Higher in altitude, typic glacial formations are present. In this part of the valley, both on the plain and on the slopes facing the south, with this favorable condition of the terrain, a high quality of agriculture has developed, and vineyards are common.

Farther up from the conca of Aosta, the valley is interrupted by other borders and narrows once again. At Entreves, the Dora runs in a deep gorge carved in the Brianzones and Subbrianzones terrain. The river get to a much higher altitude at the conca of Courmayeur.

The climate of the Aosta Valley is very much conditioned by the continous chain of mountains, as well as the morphology of the area.

Because of these logistics, the precipitation lessens with a certain regularity from the extreme end of the valley to the mouth, with the highest annual rainfall average at the Colle del Gigante (the Crest of the Giant, Monte Bianco) with over 2000 mm (this rainfall is mostly snow). The lowest annual average instead is at the mouth of the valley, at St. Marcel, just below Aosta, with less than 500 mm of precipitation. In these surrounding areas, as can be testified by the vegetation, there exists a surprisingly arid ground, rendering artificial irrigation a necessity for agriculture. For the Region the average annual rainfall is 740 mm. The course of precipitation cames into the category of climate «*sublitoraneo alpino*» (MENNELLA 1967). It shows a high in spring, a secondary high in autumn, and a significantly accented minimum in the winter.

The average annual temperature is proportional to altitude, varying between –5 °C at Plateau Rosa (3480 m), 10.6 °C at Aosta (590 m) and 12.1 °C at Pont St. Martin (330 m) at the opening of the valley. The average temperature of 0 °C is at about 2750 m. Generally, both the daily and yearly range of temperature is large, associated with the long periods of sun and the clear, dry air of a region whose climate is so favorable. Local climate is marked by significant differences along the slopes, according to the direction they face.

All in all, we can speak of a continental climate, ever if this does not correspond to the course of precipitation.

THE GLACIERS OF THE VAL VENÌ (A.V. Cerutti)

The Val Venì is, among all the valleys of the southern Alps, that which has by far the highest level of glaciation. The 1975 aereophotogrammetric survey showed that, on a length of 15 km and an area of 91,420 hectares, 30,483 were covered by glaciers, that's to say over 33 % of the territory. In Val Ferret, the kindred valley by the eastern sector of Mount Blanc, the glaciation rate is a mere 13 % (16,561 hectares).

Moreover, the highest sector of Mount Blanc overhangs this valley. This sector is constantly over 4000 m and rises considerably higher than that with several peaks. It is known that the winds from the Atlantic are moisture-laden even at great heights. French researchers have ascertained that an amount of snow equivalent in average to 2800 mm of water accumulates every year upon the highest ice cap of Mount Blanc, at 4,735 m a.s.l. At those heights, all precipitations are solid. As no meltwater can exist, the snow remains constantly dry, and its temperature, even at a depth of 10 metres, is in average –20°. Glaciers there have the same characters as polar glaciers: they are «cold glaciers». This fact accounts for a great many anomalies in the two major Mount Blanc glaciers: the Miage glacier (fig. 11) and the Brenva glacier, which flow down the highest ice caps of the mountain, the former from the west, the latter from the east. They make up together two thirds of the glaciated surface in Val Venì.

The area of the Miage glacier is 1300 hectares, of which 700 make up the accumulation area. The latter is at average height of 3600 m. The area of the Brenva glacier is 305 hectares, of which 300 belong to the accumulation area at a height of 3450 m in average. No other glacier of the Italian side of Mount Blanc has comparable parameters. The Miage glacier flows in a narrow and deep tectonic depression about 5 km long and just six hundred metres broad. It is increased by five tributaries, of which the two bigger ones (glaciers of Bionassey and the D™me) come from the ice caps of Mount Blanc. The various tributaries turn this glacier into the only Himalayan type glacier on the south side of Mount Blanc.

The long ablation tongue is entirely covered by shifting glacial till, but the cover is not very thick and allows the underlying brown ice, with transverse crevasses, to be seen. After flowing through the narrow and regular tectonic depression, the glacial mass, which at this stage is still much thicker than a hundred metres, flows into the Val Venì and, turning the same way as the latter's flow, occupies it almost entirely for about 3 km. In the last thousand metres the tongue splits into three lobes: the central one is very short and the other two keep flowing downwards. Between them is an extensive wood called *Jardin du Miage*.

FIG. 11 - The Brenva glacier at the end of the 17th century in a watercolour by Jean-Antoine Link.

The morainic deposits of this glacier are particularly thick and complex. In it we find two intra-morainic lakes and a periglacial one, enclosed among ancient drumlins and the present tongue of the glacier which makes up its northern shore. The outer arches of this morainic complex show that the position reached by the terminuses at their historical peak was at 1600 m a.s.l. The glacial peak was reached, like all other Mount Blanc glaciers, around 1818, when the Miage reached a length of 11,000 m.

At the aereophotogrammetric survey of 1975, the Miage glacier appeared to be 10,350 metres long, and its terminus was at 1720 m a.s.l. The length of the glacier, from the maximum length of 1818 did therefore decrease by 650 m. It is a far smaller variation than that of nearly all other glaciers on the Italian side of Mount Blanc. The nearby glacier of Lex Blanche in Val Venì, for example, after a long sequence of retreats and advances, has lost 1230 m from 1818; that of Pré de Bar, in Val Ferret, has retreated by 1330 m. It is therefore quite surprising to find today the Miage glacier so similar in size to its historical maximum. This may be accounted for by the great height of its accumulation area. Actually a part of it remains above 0 °C even in the warmest months of the climatic stages less favourable to glaciation.

From calculations by the author on the basis of average temperatures recorded at midday by the observatory of the Italian apron of the Mount Blanc tunnel, it appears that the midday isotherm 0 °C in the month of July during the last thirty years has always risen above 4000 metres but has reached 4300 and 4400 only in the five-year periods 1981-85 and 1991-95. It follows that, during the last thirty years, and probably earlier as well, only sections above 4500 m of accumulation areas have entirely escaped fusion, and have constantly received solid precipitations. At those heights, the glacier, functioning as «cold» glacier, has been able to accumulate ice even when this process was not possible, or occurred in very limited fashion, in lower accumulation areas. For this reason, I believe that, *vis-à-vis* other glaciers, the accumulation area of the Miage has been able, during periods unfavourable to glaciation, to compensate better the losses of the ablation area, and therefore it retreated far less.

The same applies to the Brenva glacier. In 1818, at the peak of its advance, the terminus reached as low as 1380 m, and the length reached 8000 m. Its terminus today is at 1490 m, being the lowest terminus among all those of the other Italian glaciers. The Brenva, however, has had a far more dynamic history than the Miage, duly recorded in the scientific literature. The glacier flows from the top ice caps of Mount Blanc with one single grand and steep tongue. It is therefore a glacier of the «alpine» type, with a broad and high accumulation area and a well developed tongue flowing down from Val Venì, damming the valley bottom and filling it up with its mass for about 2 km.

So described it DE SAUSSURE in 1784: *This glacier has, in its upper part, a very steep slope, where the ice is topsy-turvy, in mounds and crevasses, and looks dreadful. Two holes, put there as two huge eyes in the middle of the terminus of this glacier, let the blackish rock to be seen through, and make it possible to gauge the thickness of the ice. If the upper part of this glacier has something majestic and terrible, the lower one possesses, on the contrary, a rare and singular elegance. The moraine crosses in slanting fashion the bottom of the valley and rises a great deal from it. This whole rampart is covered with larches which accompany the glacier, and form a half-trasparent curtain through which one can see the live and brilliant colour of the ice.*

DE SAUSSURE, in his beautiful description, stresses the «live and bright» colour of the ice which appears through the green curtain of the larches. At his times, therefore, the Brenva had no till cover: it was a «white glacier», and as such it was painted by contemporary artists: Teodore Bourrit e Antoine Link (fig. 11). But De Saussure describes one more interesting detail of the glacier: two «holes», located in the upper part, like huge eyes which «let the blackish rock to be seen through, and make it possible to gauge the thickness of the ice». The landscape today has changed entirely. As the ice cover has much decreased, the two black «holes» similar to eyes have broadened hugely and have caused a big rocky «window» to open between 2400 and 2150 metres by a notch which divides the upper glacier from the underlying tongue.

Like the other Mount Blanc glaciers, the Brenva between 1818 and 1920 had seven alternating stages of positive and negative variations of the order of several hundreds of metres. But the event which marked in a peculiar way the history of this glacier are the big landslides of 14 and 19 November 1920. A volume of rocks of about 6 million m^3 broke off in those days from the north-west walls of the cirque, from a height slightly below 4200 m; by a sequence of slumps, having a speed over 100 km/h, it invaded the whole glacier basin, overflowing by many hundreds of metres the lateral moraines. The material reached the valley bottom and part of it went up the opposite side of the Val Venì damming the River Dora and knocking down many thousands of trees.

The glacier had been expanding then for seven years and lengthening by about 25 metres a year. The load of rocks weighted upon the ice, causing the speed of flow to increase. In the following year, the tongue lengthened by 70 metres and 50 metres the following year. The advance then became stabilised at lower amounts, but went on for twenty years, in spite of a climatic phase highly unfavourable to glaciation which set in immediately after the landslide, a circumstance which caused all other Mount Blanc glaciers to undergo a sharp retreat. Only in 1941, the glacier, having discharged in the moraines most of the rocky material, put an end to its anomalous progress. In that year it had reached a length barely 135 m less than the historical maximum.

The Brenva was then certainly longer than at the time of De Saussure's visit, but it had become a «glacier noir», because a massive till cover lay over the whole tongue. Higher up, the fury of the great landslide had taken the glacial cover off most of the steepest section. There were no longer «black holes» similar to eyes, but a rocky step from which ice slumps were taking place all the time; the «Pierre à Moulin». After 1941, the glacier began to retreat, by about 25 metres per year. In the Fifties, a climatic trend favourable to glaciation set in. The average temperature of the summer months at Courmayeur decreased by about a half degree and this caused a lowering of the snow line by 70 metres; accumulation areas broadened significantly and the glaciers, better fed, began to expand in volume and length.

On the Brenva, the trend inversion began in 1962, and ten years later Lesca observed that the ice flowed from the accumulation area to the tongue with a speed of 50 metres a year. The terminus flowed downwards recovering about 20 metres a year and becoming steadily broader. In 1972, according to calculations by the author cited, the glacier surged up to 12,600,000 m^3. The growth continued for 17 more years, and at the end of it the length of the glacier had topped that of 1941 by far, reaching 7940 metres, that's to say hardly 60 metres less than the historical maximum. Its volume had grown further, up to about 40,000,000 m^3.

Such a massive growth has been possible, according to me, due to two factors: in the accumulation area, the most important contribution was from that sector of «cold glacier» which, even in the most unfavourable years had been able to keep producing considerable amounts of ice; in the tongue, the advance of the glacial mass was eased by the presence of fossil ice belonging to the previous advance that had been buried by the massive till cover.

In the last eight years, a new phase of swift retreat began, more in terms of volume rather than of length. Nowadays it looks rather like a regenerated glacier than like a tongue of a great glacier as it appeared in 1898.

On 18 January 1997, the Brenva basin has been again the scene of a landslide detached, this time, from the so-called «Spur of Brenva» (*Sperone della Brenva*) at 3500 m a.s.l. The volume of the rocks involved in this slump was far smaller than that of the 1920 landslide, a mere million of m^3, but the event occured in mid-winter, when the glacier was under a thick snow cover. The latter was dislodged by the impact and turned into a huge snow and ice avalanche which, together with rock debris, crashed into the valley bottom of Val Venì with a front of about 1 km. The size of the mass and its extremely high velocity caused an imposing aerosol phenomenon which uprooted thousands of trees on the opposite slope, where there was a ski track. Two skiers died. Compressed air and the extremely fine snow and rock debris formed a column nearly a thousand metres high and fell many kilometres away in the trough of Entrèves and in the Val Ferret.

A very similar episode had taken place on 29 January 1995. The avalanche had formed then an aerosol column which had knocked down more than six thousand trees and had risen up to 2200 m. However, the 1995 episode had been labelled a simple snow avalanche, since the cursory survey made at the time had failed to trace any rocky component. Facts have unfortunately upheld the hypothesis by OROMBELLI & PORTER, who, in his 1981 paper, maintained that the landslides of the Brenva cirque were likely to occur more than once, and therefore were to be regarded as indicators of-continuing geological hazard.

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5th day

THE MOUNT BLANC
(A.V. Cerutti, L. Motta & M. Motta)

FIRST STOP: MONT FRÉTY (2174 M) - Mont Fréty offers a splendid view of the Italian side of Mount Blanc: from the imposing western flank of Mount Blanc (4810 m) to the splendid glacial Venì and Ferret valleys, to the thin «Dente del Gigante» (4013 m). It is also possible to observe from a short distance westwards the rugged Glacier de la Brenva, partially hidden by the Rochers de la Brenva (topping with the Aiguille de la Brenva, 3269 m) from which broke off in January 1997 a grand avalanche that reached the bottom of the valley. Towards the north are the extremely steep ravines descending from the ridge running from the Colle del Gigante to the Grandes Jorasses (4208 m), among which in the foreground can be seen the gully of Praz Moulin (see below), topped by the Glacier du Mont Fréty, farther away is the ridge which hosts the Glacier of the Grandes Jorasses, from which in January 1997 a huge mass of ice broke off. The latter had been monitored for some time, due to the fear of damages downvalley.

THE WEST FLANK OF MOUNT BLANC - The majestic and dangerous Brenva flank of the Mount Blanc was climbed long after the first climb of the mountain from the French side, thanks to the doggedness of the Englishman Moore, who, by climbing the three more evident spurs, in climbs stretching the human capabilities to the utmost *vis-à-vis* the technology of the time, put an end to mountain climbing viewed as geographic exploration to pave the way to mountain climbing as a sport.

The morphology of the mountain flank is strongly controlled by the faults along which the Mount Blanc massif (formed by allochtonous tectonic chips of granite and metamorphic rocks) is still rising nowadays. Since prevailing faults are very inclined or vertical, the geologic structure enhances glacial activity, which tends to create sharp pyramids and thin ridges: the attendant landscape is typically made up by rocky peaks and exceedingly sharp ridges in the granite areas, such as that of the Aiguille de la Brenva, where the extremely thin Père Eternel (3224 m) is particularly evident: this is 40 m high, and so sharp that two people cannot stand together on its puny summit. Areas of schists correspond instead in general to glacial basins, except where cleavage planes are very inclined or vertical, as in the Aiguille Blanche de Peuterey.

The walls of the *aiguilles* are shaped in upright spurs (Fr. *piliers*, It. *pilastri*), parted by deep ravines corresponding to secondary fractures (*goulottes*), whilst the main faults correspond to the saddles between the various peaks and the major gullies (*couloirs*). It is a morphology wonderfully contrasting with the gentle forms of the nearby mountains of Val d'Aosta, where there is a dominance of monoclinal relief, shaped in the tectonic units «Piemontesi-Vallesane», made up of soft metamorphic rocks (limestone schists and green schists) with isoclinal bends. The limit between the two zones is an extremely important Alpine geological limit, the Pennidic Front, which parts the tectonic units of the European continent, nearly autochtonous, from those of the European margin and the African ones, strongly allochtonous. The Pennidic Front can be morphologically visualised by the deep cuttings of the valleys Venì and Ferret.

THE AVALANCHE OF PRAZ MOULIN - On 17 February 1991 on the Mount Blanc massif, the snow cover was not sufficiently stable, because of its thickness and too high a temperature, and also because of the recent evolution of the snow itself. Between 7 and 10 February 165 cm of snow had fallen on Courmayeur. In the following days low temperature had favoured constructive metamorphism. Between 15 and 17 February the temperature had suddenly risen, and further 30-50 cm of snow had fallen at great heights. Moreover, during the previous night, a strong NW wind had created dangerous snow ridges and mounds by the «Colle del Gigante». However, in spite of a decidedly alarming bulletin of the Centre for the prevention of avalanches of Chamonix, as it was a Sunday, the Mount Blanc S.p.A., the society which manages the ski tracks, requested the local manager to evaluate the opportunity of reopening the track of the Pavillon, which descends from the dell underlying the «Colle del Gigante».

The local manager had a talk with a consultant of the «Monte Bianco» whose task was to check the outside-track itinerary descending the valley from the hut «Torino». The latter, although he had not been in the area recently, said ironically that «there was no danger of avalanches, unless the glacier itself would slip as a whole». The track was therefore opened at 11.30. A quarter of an hour later, by the «Colle del Gigante», a huge slab 250 m broad, 200 m long and 2 m thick broke off, probably due to the fall upon it of a part of the ridge which surrounds the col. The slab fell along the knick point linking the glacier of the «Colle del Gigante» to the Mont Fréty glacier, disintegrating to dust and running down the snow layer in an area of 1,600,000 m^2, and a small step faulted crevasse. The initial 100,000 m^3 became thus 500,000 m^3: they stormed ski track at a speed of about 250 km/h, coming to a halt a mere hundred metres from the road at the bottom of the valley. Fourteen people were at that moment upon the track. One of them was thrown 200 m downwards, into a thicket, and found in a bewildered condition at the bottom of the track; another was unhurt, while the remaining twelve people, together with eight ibexes, a fox and a hare, were killed.

In the inquest which followed the accident, the legal representatives and managers of the Mount Blanc were accused of having failed to insure the safety of the track, as were also the Mayor of Courmayeur and the President of the Regional government, the legal subjects who ought to have supervised the opening of a track in avalanche hazard areas or, at least, ought to have kept the management of the track under the control. The public administrators were acquitted, on the grounds that the responsibility for the opening of a track belonged entirely to its managers, and that at the time of the accident no law existed which explicitly forbade to open ski tracks in areas subject to avalanche hazard (sic).

The trial hinged upon the question whether it might have been possible to foresee the event or not. Although it was undeniable that the Praz Moulin gully was subject to avalanches every year, and of such a size as to cause damages or casualties in the years 1902, 1959, 1961, 1981, 1984, 1985, 1986,1990, the expert of the defendant F. VALLA maintained that the avalanche had been caused by a fall of step faulted crevasses: «a natural and unforeseeable event». This defensive thesis, however, was not upheld, after further appraisals which made clear that the avalanche was essentially due to the overloading of the snow cover, easily foreseeable, and bearing in mind that, even accepting VALLA'S hypothesis, if the precise moment of the fall of a step faulted crevasse is unforeseeable, however, an occasional fall of step faulted crevasses is to be expected, as shown by the fact that the feeding of the Mont Fréty glacier depends mainly upon the fall of step faulted crevasses from the overhanging glacier of the «Colle of the Gigante». The trial, therefore ended up with the conviction of the managers of the «Monte Bianco».

SECOND STOP: NEW HUT «TORINO» AT THE «COLLE DEL GIGANTE» (3371 m) - In times of minimum glaciation, a practicable track crossed the Mer de Glace, the glacier of the French side, up to the Col du Géant (3365 m), from which it reached Courmayeur. At the end of the 19th century, the col was still crossed by sheep flocks going to Valle d'Aosta.

The peaks nearest to the «Colle of the Gigante», which dominate the landscape towards the NW, are the Aiguilles Marbrées, mountains of limited climbing interest, but among the most fruitful for those still practising a typical Mount Blanc profession: the crystal hunter. The rocks of the massif have been affected by a widespread hydrotermalism, which has turned many tectonic fractures into quartz lodes, in which there are splendid individuals of fumé and maidenhair quartz, masses of pink quartz and also large individuals of translucent quartz of the highest purity, once actively sought for the construction of optical equipment. Within the lodes, splendid druses of collection minerals can be found, such as adularia, titanite (sphene), bissolite and, in economically uninteresting amounts, even gold (in Courmayeur's museum is preserved a nugget from the Italian side of Mount Blanc, the size of a nut) and uranium minerals (in the area between the «Colle del Gigante» and Mount Fréty). The crystal hunter is expected to be able to spot open fractures on the basis of the noise of the rock to percussion, and to reach lodes in steep mountain walls and above all to bring back crystals unbroken. It is therefore not surprising if a crystal hunter was one of the first two climbers of Mount Blanc in 1786, attracted not so much by the promise of a prize offered by Geneva scientist De Saussure, but rather by the eternal dream of the crystal hunter: to find «the» lode, that with the biggest and clearest crystals.

THIRD STOP: HELBRONNER PEAK AND THE GLACIERS OF THE GRANDES JORASSES - The Grandes Jorasses group is a part of the Mount Blanc chain. Its highest peaks have taken their names Whymper (m 4184) and Walker (m 4208) from the climbers who first conquered them. Both are covered by glacial caps and from them starts a steep ice fall on the Italian side, which, by becoming welded with those coming from the nearby cirques, originates two glaciers linked with each other in their upper parts: the glacier of the Grandes Jorasses to the east and that of Planpincieux to the west.

At a height of about 4000 m the glacier under the Whymper peak has a rock window breaking the continuity of the steep glacial flow. When the glacier is well fed, the window is fairly small and the underlying mass supports the overlying one, giving the complex a good equilibrium. The thinning out of the glacial masses, therefore, broadens the rock window. So the top glacier protrudes from the threshold of the rock window with a suspended lobe, constantly in unstable equilibrium due to the gravitational attraction to which it is subject. In the upper part, between 4050 and 4150 m large crevasses are visible: these are true traction fractures. These, from time to time, by yielding all of a sudden, cause massive ice slumps.

During the winter, when the underlying slopes are mantled in thick snow, these ice crashes are very dangerous as they can trigger big snow avalanches. This is what happened in December 1952, almost at the height of the stage of glacial retreat typical of the years 1925-1980. A huge snow mass plunged downvalley in the Val Ferret destroying a century-old forest. The slump front was more than thousand metres broad, but luckily the avalanche split into two branches, sparing by a hair breadth the village of Planpincieux. The phenomenon has never occurred again on that scale since, also because from 1980 to 1985 the Mount Blanc glaciers experienced a phase of advance which narrowed the dangerous «window» at 4000 m greatly.

The danger, however, is lurking again, due to the renewed glacial retreat that began in the second half of the Eighties. This has again made the lobe of the upper ice cap a hanging one. In the summer of 1993 an ice avalanche from that lobe caused the death of eight mountain climbers who were ascending the underlying ravine. A greater worry is caused by the possibility of a similar events in winter, because, since a few years, the val Ferret, which still in 1952 was empty of people in winter, has become a prestigious Nordic ski resort.

In order to prevent such a disaster, the Courmayeur municipality and the Regional administration of the Valle d'Aosta have entrusted to the Politecnico of Turin the topographic monitoring of the top glacier of the Grandes Jorasses. The operation is directed by Prof. Martin Funk, a noted glaciologist, and is carried out with the cooperation of the high mountain guides and local technicians. The daily movement of reflecting poles infixed into the glacier, is read by means of a laser-theodolite, sited at great height. The different readings allow the elaboration of mathematical models allowing to predict slumps in time to evacuate the valley.

The first «monitored» slump occurred between 23 and 24 January 1997, and had been announced by Martin Funk three days before on the basis of the acceleration of the slumping velocity, which in the last days had increased sevenfold, reaching 45 cm per day. The slump involved about 15,000 m^3 of ice, but luckily the impact did not cause the feared break-up of the underlying snow cover. Everything took place in a val Ferret already evacuated days earlier, in the silence of a moonless night, without hurting anyone.

OVER THE MER DE GLACE FROM HELBRONNER PEAK (3462 m) TO THE AIGUILLE DU MIDI (3842 m) - The Mer de Glace is the longest glacier (12 km), as well as the largest (38 km^2, 4 billion m^3, a maximum thickness reaching 400 m) and the best known in the French Alps. It is said moreover to be the most beautiful in the Alpine amphitheatre; and if esthetic parameters are inevitably at least in part subjective, the Mer de Glace has in any case always been the most frequently visited glacier in the whole Alps.

The earliest visit to the Mer de Glace marks exactly the beginning of the tourist discovery of the Alps. On 18 June 1741, eight gentlemen followed by five servants, all of them duly equipped, left Geneva for a *Voyage aux Glacières de Savoie, dans the Vallée de Chamouny*. The leaders of this strange expedition were two Englishmen, Mr. Windham and the Rev. Pococke, who was disguised as a Turkish Emir and armed to the teeth. On 28 June 1741, after a ten days journey, the group reached the terminus of the Mer de Glace. The doughty «mountain climbers» felt the curiosity to get down to the glacier and reached it, half tumbling down and half slipping on their feet and hands. In 1744 Windham related his adventure in *An Account of the glaciers or icealps in Savoy in two letters*, which is perhaps the earliest work of glaciology. Concerning the Mer de Glace, which at the time was still named *Glacier de Bois* (from the name of the village of *Bois*, reached by the glacial tongue), he wrote: «One has to figure out a lake made rough by a great northern wind and suddenly frozen». It is this very impression that accounts for the present name of the glacier. Windham's account attracted pretty soon to the valley of Chamonix many onlookers, and in 1751 inhabitants of the village were already volunteering to lead the «foreigners» to the Mer de Glace.

When in 1760, de Saussure, the father of mountain climbing, came for the first time to Chamonix and discovered the Mont Maudit (the present Mount Blanc), he set his mind to climbing it. He made several explorative excursions to the Mer de Glace. In 1798, on the rim of the Mer de Glace was built the first shelter hut in the Alps, the «Temple of Nature». Another small hut was built in 1840, a hotel in 1880. For the poor inhabitants of Chamonix it was the beginning of a golden age. The building of the cog railway marked the inception of mass tourism. The summer inflow of visitors in the Seventies run to over 600,000 people, with peaks of 20,000 daily in high season. The present installations are suited to the requirements of mass tourism.

About 1,400,000 tourists in average discover every year the Mer de Glace, either by the railway, or the cableway from Helbronner Peak to the Aiguille du Midi. To the latter belongs a record: that of being the earliest telpherway partly supported by a «suspended pylon», a support made up of cables anchored to the Grand and the Petit Flambeau. It also has a negative record, as it has become the symbol of the «trivialisation» of Mount Blanc, and has therefore been the target of several protest demonstrations, among which those of the renowned mountain climber REINHOLD MESSNER and his friends who have occupied the breath-taking pylon between Helbronner Peak and the l'Aiguille du Midi, aiming at the creation of a park whereby the massif might become a wilderness again. The Mer de Glace is in its turn witness of protests: the Aiguille du Midi was first climbed not by mountain climbers, but by the count De Bouillé, who, after a failed attempt on 14 July 1846, the anniversary of the taking of the Bastille, wished to raise the white oriflamme of the monarchy, on 31 July 1856, on «la cime infranchissable, dont les hommes ne pourront jamais l'enlever».

The Mer de Glace, though still imposing, has known better days. Even today the glacier is ornamented with the most beautiful and extraordinary decoration of ogives. These girders, or bands of Forbes, in the form of perfectly regular chips, give the glacier the outlook of a reptile. They are produced starting from the step faulted crevasses formed at the projection linking the tongue to its accumulation area. In the ogives, the gray girders are covered by detritic particles deposited in the summer on the huge surface of the accumulation area, and form an impressive contrast with the whiteness of the live ice. Their crescent shape is caused by the fact that the ice flow is slower on the sides *vis-à-vis* the central line.

The quickness of movement of the glacier is highly variable. In the area of the step faulted crevasses, at 2700 m an average yearly speed of 830 m has been measured. At the foot of the ice fall, the progression speed is still 300 m per year. The speed decreases further towards the terminus, where it reaches a mere 50 m per year. Several measurements of the glacier speed are by no means the result of planned activity. In 1832, the remains of a ladder left by de Saussure on the glacier in 1788 showed an average yearly speed of 76 m. The rucksack lost by a mountain climber in 1846 in the accumulation area, was substantially faster, as it was found in 1896 at the terminus: it had made it at an average speed of 131 m per year. Anyway, the middle zone of the step faulted crevasses is the quickest: in the accumulation area, the corpse of a Belgian mountain climber fallen in 1973 of the north-east wall of the «Dente del Gigante» had made only 800 m in 16 years.

The wavy outlook to which the glacier owes its name is due to a glaciological process not yet fully understood. Cinematic waves, in the case of the Mer de Glace, appear particularly evident. These waves, whose height can reach several metres, arise, like the ogives, from the fall of step faulted crevasses. They run one after the other, increasingly subdued, on the terminal tongue, till they become confused with other surface irregularities. The rapidity of progression of the waves must correspond from four to thirteen times to the movement of the ice. That's to say the propagation speed of a cinematic wave is of 1400-1500 m per year, while the speed of the glacier is of 120-150 m per year: therefore the waves are not carried by the glacier, but are rather the result of glacier volume changes. On the other hand, the same phenomena cause swift advances of the front, true growth waves of the glacier. In 1605, the glacier reached the village of Bois, destroyed twelve houses at Chàtelard and two in the hamlet of Bonneville. Eleven years later, a renewed advance razed a part of Bois, as well as a large area of precious cultivable lands. In the following centuries, the glacier again reached many times the villages of the valley of Chamonix, for example in 1716, 1740, 1770, 1818, 1825, 1840, until the mid 19th century, when the glacier withdrew entirely into the gorge of Arveyron.

The advance of the front was not the only threat to man. At the confluence of the Tacul and Leschaux a small lake was formed, the Tacul lake, whose floods have often caused alarm in the Chamonix valley. The decline of the glacial mass has caused it nowadays to dry up entirely. Floods did not come from Tacul lake only. Also the break up of interglacial water pockets have caused floods, in 1610, 1716 and 1878. In the night between 24 and 25 September 1912, one of these glacial collapse flooded the forest of Bouchet, where the water reached a height of 1.5 m, and invaded several cellars and ground floors at Chamonix. Ice blocks wrenched from the glacier were found even at Annemasse, a town 70 km away.

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TABLE 1 - Front heights

Year	Lex Blanche	Brenva	Frebouzie	Triolet	Pré de Bar
1818	1990	1380	1733	1780	1850
1961	2400	1485	2400	2400	2085
1975	2065	1415	2350	2350	2075
1988	2040	1390	2300	2300	2070
1996	2070	1400	2380	2370	2075

TABLE 2 - Glacier heights

Years-Stages	Lex Blanche		Brenva		Frebouzie	Triolet	Pré de Bar	
	lenght	Δ	lenght	Δ	lenght	lenght	lenght	Δ
1810-18 a	4320	—	8000	+125	3600	5200	5140	—
1819-42 r	—	—	7750	- 11	—	—	—	—
1843-60 a	4280	—	7900	+ 9	—	—	—	—
1861-82 r	—	—	6980	- 43	—	4100	3910	—
1883-97 a	—	—	7300	+ 23	—	4350	4360	+32
1898-10 r	3750	—	7080	- 21	—	4150	4240	–10
1911-21 a	4050	+30	7310	+ 23	2400	4250	4390	+15
1922-39 r*	3900	–09	7795	+ 54	—	2550	4165	–13
1940-42 a	3940	+20	7865	+ 35	—	—	4228	+32
1943-61 r	3090	–47	7440	- 24	2100	2400	3813	–23
1962-88 a	3830	+29	7940	+ 19	2250	2500	4060	+ 9
1989-96 r	3590	–34	7912	- 4	2150	2450	3970	–13

Abbreviations and notes:

a = advance, r = retreat. Lenght: maximum in metres reached during the stage, Δ = average yearly variation in metres during the stage. Authors sources of the data: Carrel, Forbes, Sacco, Silvestri, Revelli, Capello, Lesca, Cerutti.

* Stage of overall massive retreat, but the Brenva is advancing. The strongest historical advance of the glaciers of the south side of Mount Blanc occurred around 1818. The position then achieved by the terminuses is ascertained on the basis of the end moraines formed by that event. The glaciated area of the Italian side of Mount Blanc was 4670 hectares, as measured by photogrammetry in 1975.