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## THE PUZZLE OF THE OUTER LIMITS OF THE GARDA GLACIER DURING THE LAST GLACIAL MAXIMUM

**ABSTRACT:** SAURO U., *The puzzle of the outer limits of the Garda Glacier during the Last Glacial Maximum.* (IT ISSN 1724-4757, 2005).

The many studies of the Garda morainic amphitheater have led to different interpretations about its history and age. The state of the art of the open debate evidences how the problem is worth to be faced through a multi- and interdisciplinary approach.

The results of a preliminary examination of some environmental aspects never taken into account, considered as a whole together with the already known data, allow to sketch the scenery of the last glacial advance (LGM: Last Glacial Maximum). The position reached by the glacial front nearly agrees with the conclusions of both Penck & Brückner and of Habbe: the maximum extension approximately coincides with the Penck and Brückner limits; the main rest location of the front corresponds with the Habbe extent. Anyway, the glacial tongue occupied an area with a preexisting hilly relief, modifying it only for some characteristics. So, the Garda main morainic amphitheater was not built during the LGM only, it is a very complex structure resulting from several glacial advances.

**KEY WORDS:** Morainic amphitheater, Lake Garda, LGM, Upper Pleistocene, Southern Alps.

**RIASSUNTO:** SAURO U., *L'enigma del limite esterno della lingua glaciale del Garda durante l'ultima grande avanzata glaciale.* (IT ISSN 1724-4757, 2005).

L'edificio principale dell'anfiteatro morenico del Garda è molto complesso e lo studio di numerosi autori ha portato a risultati per vari aspetti discordanti. Lo stato di avanzamento di questi dibattiti dimostra come il problema dell'ultima espansione glaciale meriti di essere affrontata in una dimensione multi- ed interdisciplinare. I risultati dell'esame preliminare di diverse caratteristiche dell'ambiente dell'anfiteatro, mai considerate precedentemente, insieme ai dati già noti, permettono di abbozzare un modello dell'ultima grande avanzata glaciale (LGM) quando la fronte raggiunse una posizione che quasi coincide sia con le conclusioni di Penck & Brückner sia con quelle di Habbe. In particolare la massima estensione corrisponde all'incirca con la ricostruzione di Penck e Brückner, mentre il più importante stazionamento è in accordo con i limiti descritti da Habbe. In ogni caso, la lingua glaciale ha trovato qui un preesistente rilievo collinare che avrebbe soltanto ricoperto e modificato per alcuni caratteri. L'edificio morenico sarebbe pertanto

una struttura complessa risultante da una successione di più avanzate glaciali.

**TERMINI CHIAVE:** Anfiteatro morenico, Lago di Garda, Ultimo Massimo Glaciale, Pleistocene Superiore, Alpi Meridionali.

### A VERY COMPLEX MORAINIC «AMPHITHEATRE»

G.B. Castiglioni in his recent synthesis about the «Quaternary glaciations in the eastern sector of the Southern Alps» (2004) underlines that «it is difficult to find general agreement about the LGM (Last Glacial Maximum) in the Lake Garda area» and emphasizes how «the case of the Lake Garda end-moraines, a very complex «amphitheatre», needs further discussion both for the older glaciations and for the LGM».

The Lake Garda main morainic amphitheater is a very large depositional apparatus with a horseshoe shape, an outer perimeter of nearly 80 km, and both a maximum E-W width and a N-S extension of about 30 km (Castiglioni B., 1940; Sauro, 1974; Sorbini, 1983; Sauro & *alii*, 2001). The difference in elevation between the lake surface and the highest hills varies in the ranges of 200-300 m in the northern part and of 100-150 m in the southern part. In the western sector, besides the main apparatus, there are relicts of outer older rings, as those of Calvagese and of Ciliverghe.

The Authors who have tried to determine the ages of the morainic hills have based their research work on some of the following criteria:

1. freshness of the glacial forms («morphostratigraphy»),
2. degree of evolution of the soils developed on the moraines (pedostratigraphy),
3. stratigraphy of the glacial outwash and löess like deposits (lithostratigraphy),
4. reconstruction of the topography of the old glacial tongues based on both the valley and the terminal moraines («palaeotopography»),

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5. radiocarbon data (isotopic chronostratigraphy),
6. paleomagnetic data (magnetostratigraphy).

Even if the criteria applied by the different Authors are similar, the results are for some aspects in contrast (fig. 1). Penck & Brückner (1909) have recognized in the Garda region different glacial expansions and considered nearly all the main amphitheater as the result of the last glacial advance. Venzo during his research work changed repeatedly his opinions reaching the conclusion (1965, 1969a e b) that the last glacial tongue surpassed only a bit the southern boundary of the Lake Garda. Habbe (1968, 1969) starting from the reconstruction of the topography of the old glacial limits on the slopes of the main valley, based on the lateral moraines, reached the conclusion that the external ring is pre-Würm in age («Young Riss») (fig. 2). Both Chardon (1975) and Cremaschi (1987) agreed that all the main amphitheater is attributable to the last glaciation.

In particular, Chardon writes: «Contrariement a l'opinion de S. Venzo (1957, 1965) de Habbe K.A. (1969) et des chercheurs italiens, il n'y a pas de différence fondamentale, entre les arcs morainiques, du plus externe à celui longeant le lac. Les uns e les autres doivent etre attribués au glacier würmien.» He bases his conclusions on the three main aspects: 1) the continuity of the arches, 2) the

similar drainage properties of the moraines, 3) the nearly identical weathering conditions (from the points of view of both decalcification and of the clay types in the soils).

Cremaschi calls the main morainic apparatus «Solferino moraine», and refers all it to the last pleniglacial period. He writes «South of the frontal moraine of the Garda Lake, referred to the Solferino stage, lies the fluvio-glacial plain (sandur), which developed downstream the Garda Glacier during the last pleniglacial period and of which the shape is still well preserved. It has been deeply cut by the main rivers that cross it from north to south».

The unlike conclusions of the Authors came as a consequence of the different approaches to the complex problem and of the more or less punctual views based on only a few of the most significant elements. Nobody presents an overall coherent group of data of different type useful to support a well grounded model about the paleogeography of the region during the last glacial maximum.

#### THE NECESSITY OF AN INTEGRATED APPROACH

In the recent studies, an approach comprehending all the significant aspects for the reconstruction of the recent glacial history of the Lake Garda is missing. The following

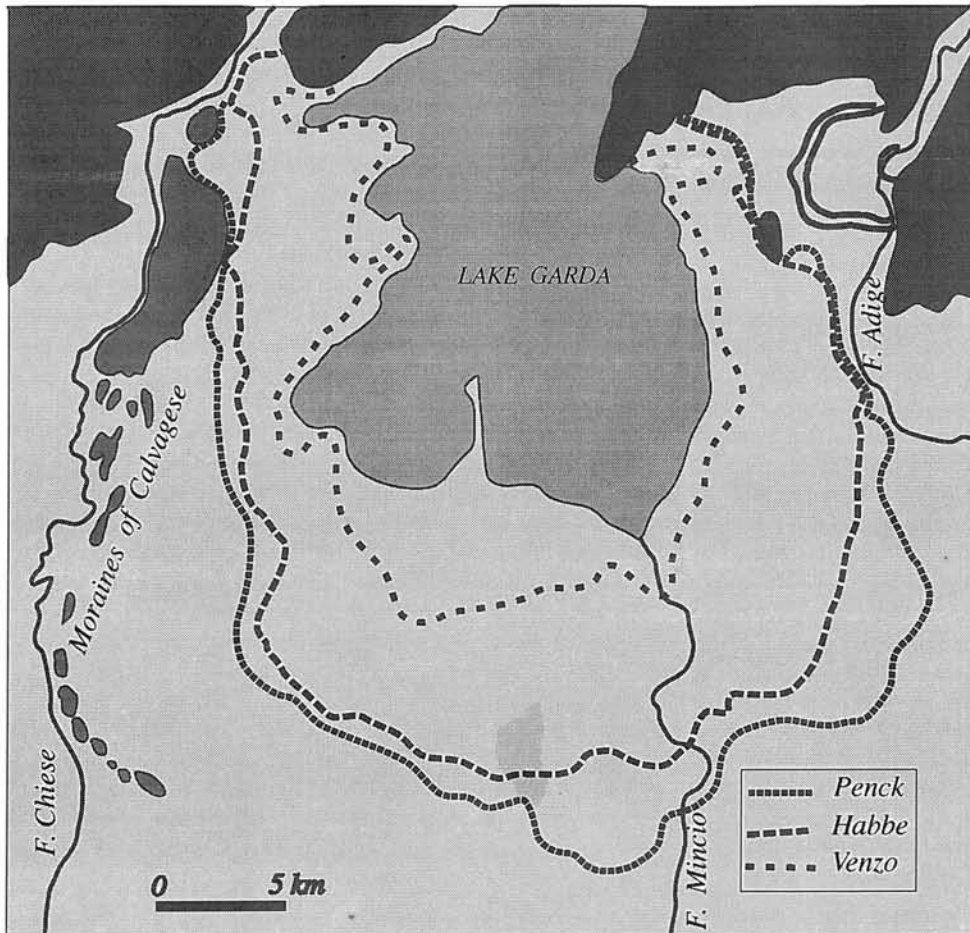
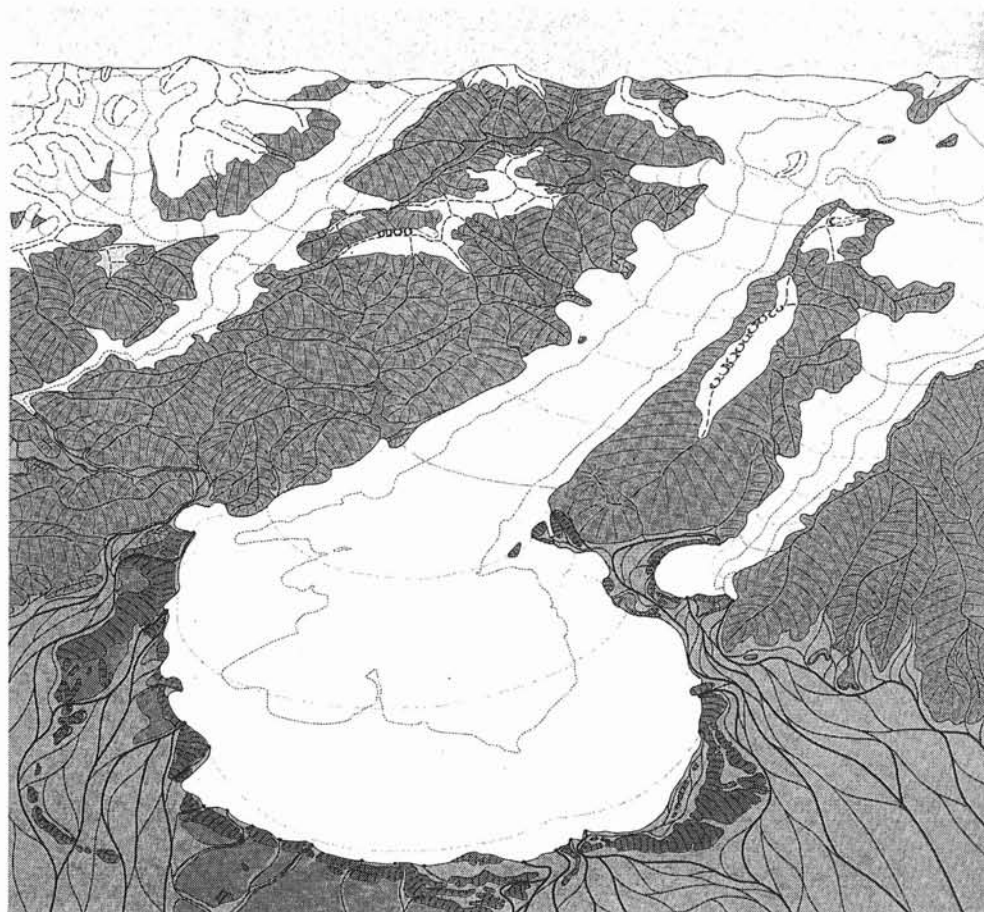


FIG. 1 - The limits reached by the Garda glaciers during the Last Glacial Maximum after Penck, Habbe and Venzo. After Chardon and Cremaschi, the limits nearly correspond with those indicated by Penck.

FIG. 2 - The large Garda glacier during the Last Glacial Maximum after the reconstruction of Habbe (1972). The outer limits correspond here to the inner slope of the most external ring of hills of the morainic amphitheater.



criteria have never been applied in an integrated way in the study of the Lake Garda main morainic amphitheater (Sauro, 2001, 2004):

- a) «structural» characters and interrelations between the main morainic hills composing the amphitheater,
- b) research and recognition of landforms and of other evidences resulting from processes of ice-contact on the slopes of the morainic ridges,
- c) presence and distribution of the small lakes and swamp areas in the depressions between the different morainic rings,
- d) presence of intermorainic plains evolved from lacustrine basins formed during the glacial tongue retreat,
- e) existence of important depressions crossing the main morainic rings, referable to old streams fed by the glacial melting,
- f) position of the apexes of the proglacial fans of sandur type.

From an overview of the system of the morainic hills constituting the complex amphitheater, it is easy to recognize that the «structure» of the amphitheater is much more complex than one could expect (fig. 3). There is not a simple system of concentric rings of ridges, but a rela-

tively disordered pattern made up by discontinuous ridges varying in width and in height. Most of the ridges are very short; only a few are more than 2 km long. Some ridges are oriented obliquely or perpendicularly with regard to the ideal concentric rings. In particular, the outer ring is articulated in short ridges separated by deep gaps; in planimetry this ring draws a multi-lobate figure composed by a succession of arches with different radiuses. The main lobes are the western «Castiglione delle Stiviere lobe» and the eastern «Sommacampagna lobe». Between these, the central «Volta Mantovana lobe» represents an evident bulge to the south of the complex form. The intermediate and inner rings are not so deeply dissected but show irregular arrangements and areas with a highly articulated relief made up by groups of hundreds of relatively small hills.

Some of the glacial hills are clearly imprinted by ice-contact forms, difficult to be recognized in the field, but easily distinguishable in the aerial photographs and satellite images (fig. 4). In the black and white photos these forms are often evidenced by the darker color of the wood growing on the steeper slopes, especially on those exposed to the north.

The remote sensing allows to hypothesize the presence of two main types of ice-contact forms: 1) the ice-contact slopes, relatively steep and with sinuous contours, 2) the

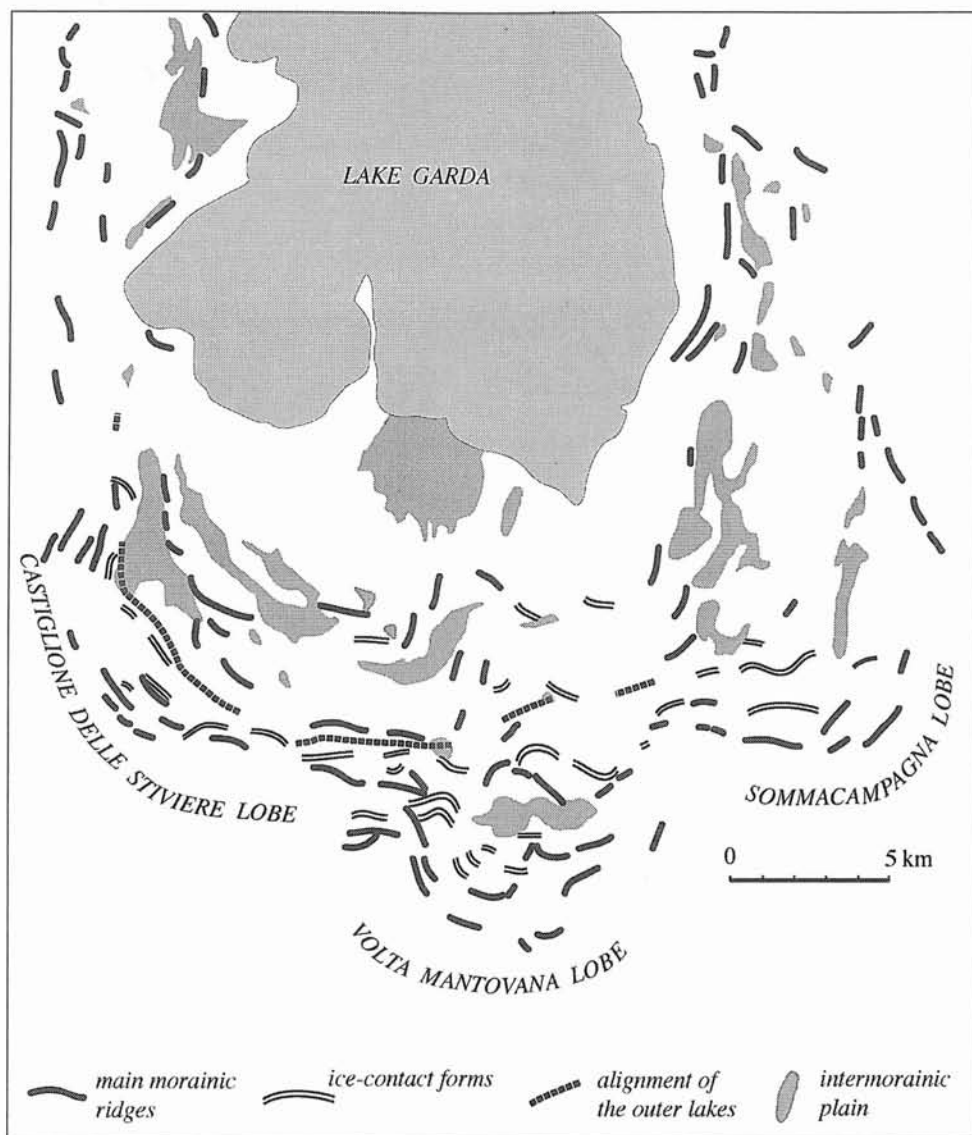


FIG. 3 - Geomorphological sketch of some of the most significant features, as the main morainic ridges, the more evident ice-contact features, the alignment of the outer intermorainic lakes. The main intermorainic plains are drawn as represented in the Locchi plaster.

ice-contact terraces of «kame» type. The forms of the first type could be linked with the pushing action of the glacial front against the slope of a preexisting morainic ridge; those of the second type with the standing position of the glacial margin close to a morainic slope and with the actions of the melting and running waters. Examples of the first type seem to be the northern slope of the ridge of Cavriana; of the second the northern slopes of the hills SW of the depression of Castellaro Lagusello. The ice-contact slopes are well developed in the western sector especially along the inner slopes of the outer ring; in the central sector there are not very typical kame-type terraces but intermediate forms between the ice-contact slopes and the ice-contact terraces. Anyway, these forms, here only preliminarily outlined, need further research work and morphometric analysis.

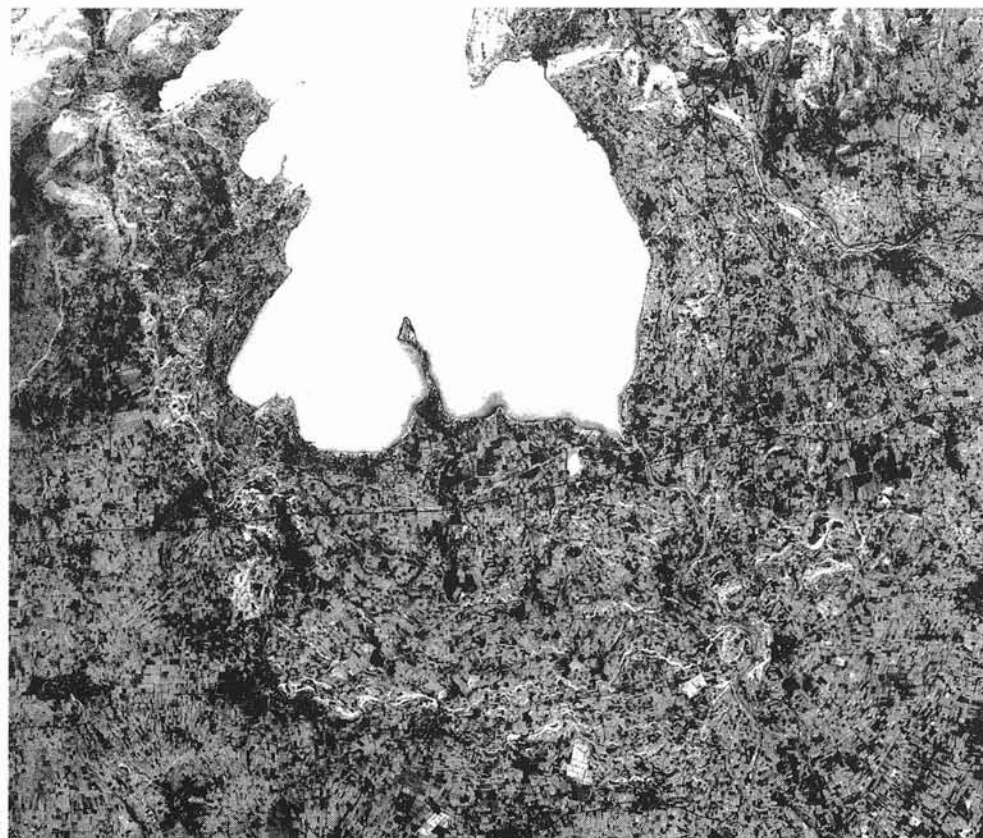
From an overview it is possible to see how the ice-contact forms are well developed along a W-E line south of

the lake of Castellaro Lagusello. A few forms seem recognisable to the north of Volta Mantovana, in the most southern part of the amphitheater; some small groups are visible also to the north of the main alignment. In general the ice-contact forms appear to be present especially in the western and central part of the amphitheater; they are nearly lacking in the eastern part.

All these ice-contact forms seem to be relatively fresh features. In fact, the survival through several glacial stages of old ice-contact forms seems improbable. So, these forms may be considered as clear evidences of the most recent glacial boundaries in the area.

The peculiar hydrography of the morainic amphitheater is another environmental aspect useful for the understanding of the history of this complex form. Unfortunately the situation of the water bodies has deeply changed during the Holocene. Important modifications occurred

FIG. 4 - Negative of a space image in which the ice-contact forms are easy to be identified as narrow and sinuous, light colour figures. In the positive they are darker because correspond to steeper slopes mostly covered by the wood.



also in the last century. The hydrographic pattern at the end of the 19<sup>th</sup> and at the beginning of the 20<sup>th</sup> centuries have been described by Locchi, in a plastic model (1898) (fig. 5), and by Stegagno (1905) in a paper and a map. These Authors evidence the presence and distribution of the many small lakes and swamp areas in the depressions between the morainic ridges. In general, these features have formed during the last glacial retreat in the intermorainic depressions created by the glaciers. In fact, in time, these depressions are filled by fluvial and colluvial sediments and the lakes evolve to swamps and to open plains. So, likely, all the small lakes formed before the last glacial advance have been completely filled in and the external limit of the surviving lakes is indicative of the position reached by the glacial tongue during the last glacial phase. In the Locchi model and in the Stegagno map it is easy to recognize an evident chain of small lakes situated just behind the most distinct alignment of the ice-contact forms. Outside of this alignment there are nearly no lakes or humid areas; inside there are many.

Most of the intermorainic plains are located in the middle belt of the amphitheater within the ring of the outer lakes. They are mainly elongated after the concentric pattern of the ridges and depressions and host swamp areas. These depressions and plains probably evolved from lacustrine basins formed during the stands of the glacial front, and have been later naturally filled or artificially drained.

The most southern intermorainic plains are north of Volta Mantovana but they lack of humid areas.

In the outer main morainic ring it is possible to recognize about 20 depressions corresponding to ancient melt-water channels (Habbe, 1972; Castiglioni, 1997). The bottoms of most of these depressions lack of water streams also because their altitudes are greater than the intermorainic plains backward.

The sandur type fans have their apexes inserted in the depressions of the morainic ring and are coalescing together to constitute a complex form, a kind of sandur plain encircling the amphitheater. In the southwestern sector there are small dry valleys entrenched in the apical part of the fans, as the Valle Sorda south of Solferino, and surfaces with evident traces of braided streams. After Habbe (1972) in this area it is possible to recognize relicts of the older sandur slightly elevated above the surrounding surfaces. In Castiglioni (1997) a similar distinction is not applied.

#### TOWARDS THE RECONSTRUCTION OF A MODEL OF THE LAST GLACIAL ADVANCE

The preliminarily outlined analysis allows some considerations about the recent glacial history of the Garda area (fig. 3). The complex morphologic «structure» of the main amphitheater is indicative of the fact that it repre-

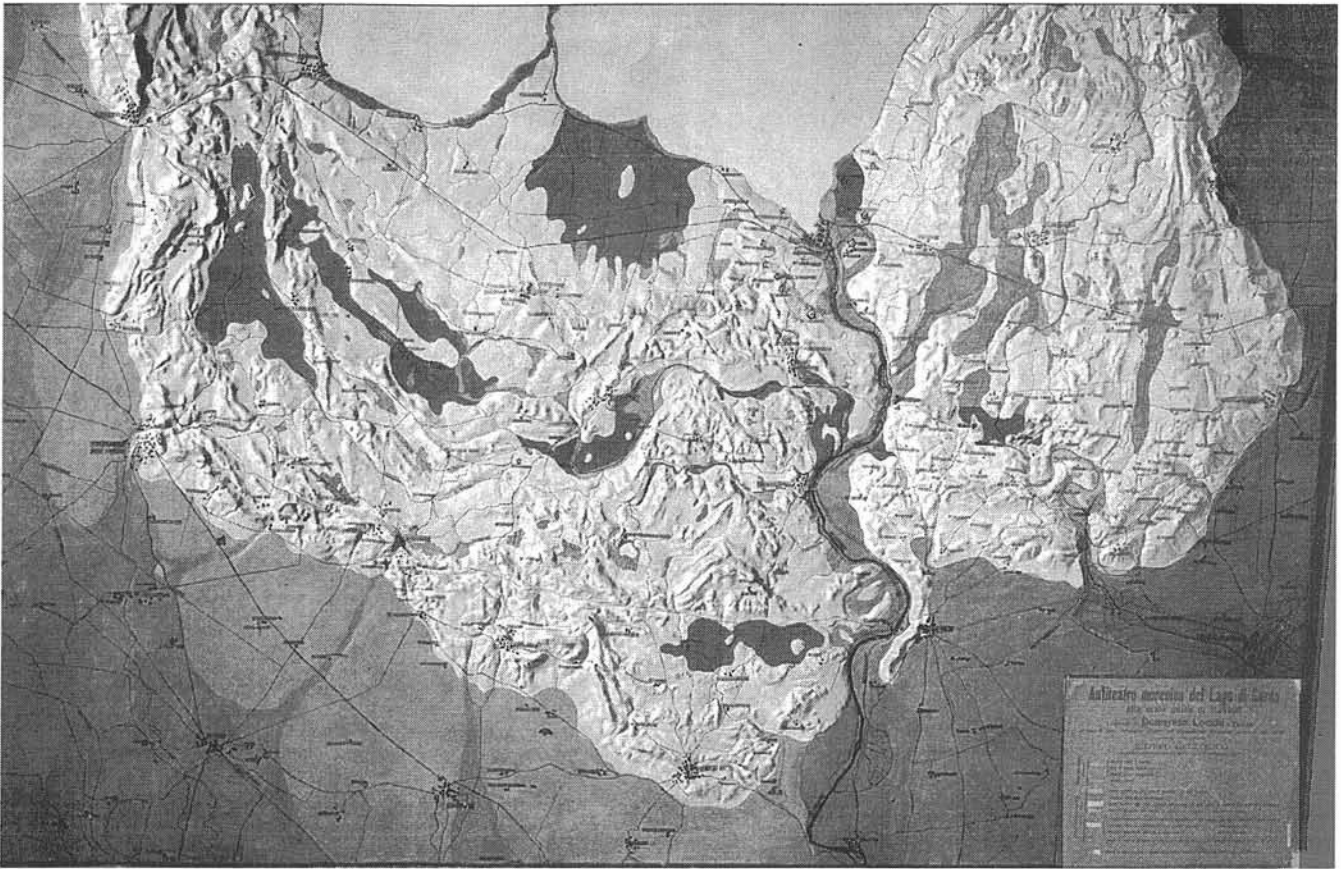


FIG. 5 - Detail of the plastic model of Locchi (1898) in which the small lakes, swamps and humid areas of the morainic amphitheater are evidenced.

sents not a simple sedimentary building. If it would have been deposited entirely during the last glacial advance, we should expect to find a system of regular rings made up by long morainic ridges. But it is not so, and consequently the history and the age of the complex form is not easy to be defined.

The ice-contact forms evidence some of the most significant positions of the glacial fronts during the last stage. The most external ice-contact features seem to suggest that the glacial tongue reached the outward ring pushing on the inner slopes of the ridges. Some not so evident ice-contact forms seem to be present also in the Volta Mantovana lobe, constituting clues of an advance episode interesting this area. Anyway, the most distinct ice-contact forms are slightly rearward and are expression of a longer stay of the glacial front.

The main chain of lakes and swamps, now mostly drained, is somewhat back the arch of the most distinct ice-contact forms, delineating an other element to support the previous interpretation. Also, the disposition of the intermorainic plains agrees with such a reconstruction.

These elements allow to sketch a dynamic scenery of the last glacial advance.

The front of the Garda valley glacier occupied and overran the lake depression and expanded outside of the

mountain borders. Here the glacier stayed on the hilly area made up during previous glacial stages, covering the mounds, smoothing and modifying their shape. According with the modest thickness of the glacier, mainly less than 200 m, the glacier movement was strongly influenced by the floor morphology, and was characterized by zones of extending and compressive flow and by preferential currents. During the maximum extension the glacier reached the external hills of the south-western sector (Solferino lobe) pushing against their slopes and perhaps spread southward covering a part of the Volta Mantovana lobe.

The scarcity of hydrographic features, such as small lakes and swamps, supports the thesis that this latter lobe was already present. The shape of this lobe is probably explainable with the constraints to the glacial flow represented by some relatively high and massif morainic hills (M. Paga and M. Il Cio to the NW and M. Croce to the NE). M. Paga, M. Il Cio and M. Croce were, thus, preexisting the Volta Mantovana Lobe. But, if the Volta Mantovana Lobe was built earlier than the last advance, which imprinted on it only a few ice-contact forms, the «constraining» hills are older than this arch. So, three «morphostratigraphic units» are recognizable: a) the older morainic ridges of M. Paga, M. Il Cio and M. Croce,

b) the Volta Mantovana «lobe», c) the ice-contact features in the Volta Mantovana lobe. Each of these «morphostratigraphic units» could be correlated with a different glacial stage.

The last advance interesting the Volta Mantovana lobe, if happened, seems to have lasted a very short time because the ice-contact forms are badly defined and there are no fresh hydrographic features.

After the maximum advance, the glacial front retired slightly and rested for a longer time nearly along the contours marked by the finely preserved ice-contact forms. The following retreat was relatively slow and favoured both the deposition of morainic sediments and the development of intermorainic lakes and plains. The lacking of evident ice contact forms in the eastern part of the amphitheater could, perhaps, be explained with the different dynamic of this part of the glacier due to the shelter effect of the ridge M. Luppia-San Vigilio, prolonged as an underwater chain toward the Sirmione peninsula.

The outlined scenery seems to fit with most of the known characters of the morainic amphitheater. Some pictures of the reconstruction agree with the conclusions of both Penck & Brückner (1909) and of Habbe (1969): the maximum extension of the Last Glacial Maximum (LGM) nearly coincides with the Penck & Brückner limits; the main rest position of the front corresponds with the Habbe limit. In the opinion of Castiglioni (2004) the «old reconstruction given by Penck is not far from reality». The model of Habbe (1969, 1972) is strongly based on the positions of the lateral moraines on the valley slopes and it is natural that these features match with the main standing of the glacier front. The conclusions of Chardon (1975) and Cremaschi (1987), based mainly on the freshness of the forms of the moraines and on the pedological characters, may be partly justified with the action of rejuvenation operated by the glacier front that reached the most external ridges, pushing on some slopes and inducing strong periglacial conditions on the others.

The illustrated model certainly needs further improvements but stimulates some reflections.

The first reflection is that the goal to define the outer limit reached by the glacial tongue of Garda during the last glacial stage needs a wide approach aiming for the reconstruction of the complex kaleidoscope of environments and landscapes evolved before, during and after the last advance of the huge Garda glacial tongue. A second related reflection is that it is not correct to link a complex sedimentary building, as the main morainic amphitheater of Garda, with the last glacial advance only. An earlier amphitheater, even if somewhat different, has surely represented the background of such an advance. So, the present sedimentary building is the result of a long history, it is a complex structure shaped during several glacial phases. The few lithostratigraphic data, as those of M. Fajta, of Valsorda (Bardolino) and of Val dei Molini (Garda) (Cremaschi, 1987, 1990), support the view of a depositional body made up by the overlapping of several stratigraphic unit.

Another related reflection is that it is relatively easy to study and to date a lateral moraine on a valley slope and

hence to choose it as a reference for the definition of a stratigraphic unit (e.g.: see in Castiglioni, 2004, the one called «Alloformazione del Garda»). But it is not proper to correlate such «Alloformazione» with a complex edifice as the main morainic amphitheater. Even single morainic ridges, as those cited above (M. Paga and M. Il Cio and M. Croce), referred by Cremaschi (1987) to the so called «Solferino stage», even if built during a specific stage seem to have survived over the successive stages as relicts more or less modified by glacial, periglacial and other processes.

The sentence: «the case of the Lake Garda end-moraines, a very complex «amphitheatre», needs further discussion both for the older glaciations and for the LGM», written by Castiglioni (2004) is really striking.

The model presented above is only a preliminary contribution to such a further discussion. It is surely possible to give a better organisation to all the available data, improving the integrated approach suggested in this paper through both remote sensing, field investigations and G.I.S. analysis. But, to obtain key elements it is also necessary to promote special surveys such as drillings in the bottom sediments of the Lake Garda and in the intermorainic depressions. It is fundamental to get a better knowledge of the stratigraphy as a base to improve the structural and paleogeographical models. Only multi- and interdisciplinary research works could allow to delineate sufficiently deepened and well grounded models.

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