ACTA GEOLÒGICA HISPÀNICA, t. 18 (1983), n.º 3/4, pags. 217-233

Quaternary Glacial Geology of Alta Ribagorça Basin (Central Southern Pyrenees)

by J. M. VILAPLANA

Dpt. de Geomorfologia i Tectònica. Facultat de Geologia. Universitat de Barcelona.Gran Vía, 585. 08007 Barcelona.

ABSTRACT

This paper is an abstract of the doctoral thesis presented by the autor at the University of Barcelona on September 1983. It constitutes a regional study about the Quaternary Glacial Geology in the Ribagorça high valleys. It is the first work in relation to the geomorphology, sedimentology and stratigraphy of the glacial and related deposits in this zone of the Pyrenees. Several formations of quaternary deposits have been studied in detail (mainly in Llauset Valley and in Taüll area); and the local quaternary stratigraphy is established and finally a correlation with some previously studied areas in the Pyrenees is attemped.

RESUMEN

Este artículo es un resumen de la tesis doctoral que el autor presentó en la Universidad de Barcelona en Septiembre de 1983. Consiste en un estudio regional que trata de la evolución cuaternaria de los Altos Valles de la Ribagorça, el cual tiene como principal objetivo la reconstrucción del glaciarismo cuaternario. Es el primer trabajo que trata, de manera monográfica, la geomorfología, la sedimentología y la estratigrafía de los depósitos cuaternarios de los valles de la Noguera Ribagorçana y de la Noguera de Tor. Las principales formaciones sedimentarias de origen glacial han sido estudiadas con especial interés (principalmente las del Valle de Llauset y las del sector de Taüll). En este artículo se elabora una estratigrafía de los depósitos cuaternarios a nivel de cuenca, a partir de la cual se establece una correlación con los datos estratigráficos y cronológicos más recientes de la vertiente Norte del Pirineo.

RESUM

Aquest article és un resum de la tesi doctoral que presentà l'autor a la Universitat de Barcelona el setembre de 1983. Es tracta d'un estudi regional sobre l'evolució quaternària de les Altes Valls de la Ribagorça que té com a objectiu principal la reconstrucció del glacialisme quaternari. És el primer treball que tracta, de manera monogràfica, els aspectes geomorfològics, sedimentològics i estratigràfics, dels dipòsits quaternaris de les valls de la Noguera Ribagorçana i de la Noguera de Tor. Les principals formacions sedimentàries d'origen glacial han estat estudiades amb especial detall (principalment les de la Vall de Llauset i les del sector de Taüll). En aquest article hom presenta una estratigrafia dels dipòsits quaternaris, a nivell de conca hidrogràfica, a partir de la qual s'estableix una correlació amb les dades estratigràfiques i cronològiques més recentment obtingudes en el vessant Nord del Pirineu.

INTRODUCTION

The Alta Ribagorça Basin is drained by two main valleys: the Noguera Ribagorçana Valley and the Boí Valley which is named Noguera de Tor. Both valleys come from the Northern sector of the Alta Ribagorça, where the highest peaks are found, some of them above or very close to 3000 meters a.s.l.

The highest sector is constituted by Hercinian granites, the Palaeozoic rocks (limestones, schists, shales and quartzites) crop out towards the South. All of these materials are in contact with the Mesozoic rocks near Pont de Suert area.

During the Quaternary, those valleys were occupied by important valley glaciers, which had a length of more than 30 kilometers. These glaciers played an important geomorphologic and sedimentary role, both in the covered areas and in the marginal zones. During the maximum of the glacial extension, the front of Noguera Ribagorçana Glacier went as far as South of Vilaller (940 meters a.s.l.); the Boí Glacier (Noguera de Tor glacier), which had a not much bigger alimentation basin went as far as South of Llesp (890 meters a.s.l.).

The glacial landforms are common in the upper parts of the basin; the glacial deposits are such common than the erosion forms in the lower parts of the basin.

The relief is characterized by important glacial cirques in the valley heads, carved in granitic areas. All these cirques have overdeepened basins (often in staggered progression) presently occupied by small lakes (some of them very close to 100 meters in depth). There are important extensions of polished and striated rocks at the bottom of the cirques.

The valleys have steep slopes, with a U-shaped profile (specially where a crystalline bedrock exists, and where the greatest accumulation of glacial ice –in quantity and time– was produced). There are two big overdeepened basins at the backside of important rock thresholds in the studied valleys. These basins are produced by glacial erosion of the bedrock in the zones of greatest accumulation of glacial ice:

– The Bono basin (Noguera Ribagorçana Valley), about 5 km length and 0.8 km width, presently occupied by an alluvial plain. A maximum depth of 213 meters is calculated for the bedrock (Paleozoic basement).

– The Barruera Basin (a similar model in the Boí Valley), where the palaeozoic basement is found at 150 meters under the alluvial plain.

QUATERNARY DEPOSITS

The most important deposits are of glacial origin (Upper Pleistocene age), and they are represented by some till types and related sediments: glaciolacustrine and glaciofluvial deposits, and some periglacial deposits on the slopes.

There are some fluvial terraces near Pont de Suert, some of them related with the glacial deposits of the upper zones. The lower terraces are generally attributed to a Postglacial period (Goron, 1941 and Sole, 1951). A good sedimentary record of recent Quaternary is found in the present lacustrine sedimentation in the majority of lakes located in the upper parts of the valleys.

Fluvial terraces

The existence and preservation of fluvial terraces in these valleys is determined by several factors. The valley morphology (narrow valleys and steep slopes) makes difficult the sitting up of alluvial plains, which are only present in zones of valley widening. It must be also considered that the intense dynamics on the slopes has degraded most of the terraces.

The better remains of fluvial terraces are found in Pont de Suert area and in the confluence of Boí and Noguera Ribagorçana Valleys (Figure 1).

Five levels of fluvials terraces between 3 and 200 meters above the present river level are distinguished; their relative heights are indicates in Figure 3. These fluvial deposits are mainly constitued by gravels, pebbles and some boulders –often with imbricated disposition– and sandy matrix. There are some interestratified beds and lenses of sand. The clast lithology is mainly granodioritic however schists are also present. The clast shape is rounded and subrounded, but in some cases, typical glacial shapes (faceted, elongated) are also present, which indicates the glaciofluvial origin of these deposits.

Till and related deposits

In such narrow and deep valley of the Alta Ribagorça region we can group tills and related deposits according to their position. On the bottom valley position we find two great families of deposits: *ice-terminal till complexes* and glaciofluvial deposits which are filling the overdeepened basins. On the slopes, quite high with reference to the present river level, we find *ice-lateral till complexes.*

–Ice-terminal till complexes

They don't ocup much extension, and the few outcrops that exist are not good. These deposits are mainly represented by end moraines (Figure 1). The glacial deposits called *terminal morainic complex* were firtsly quoted, in the Pyrenees, by Penck (1881). Later others quaternarists tried to locate the terminal complexes of different valleys in order to

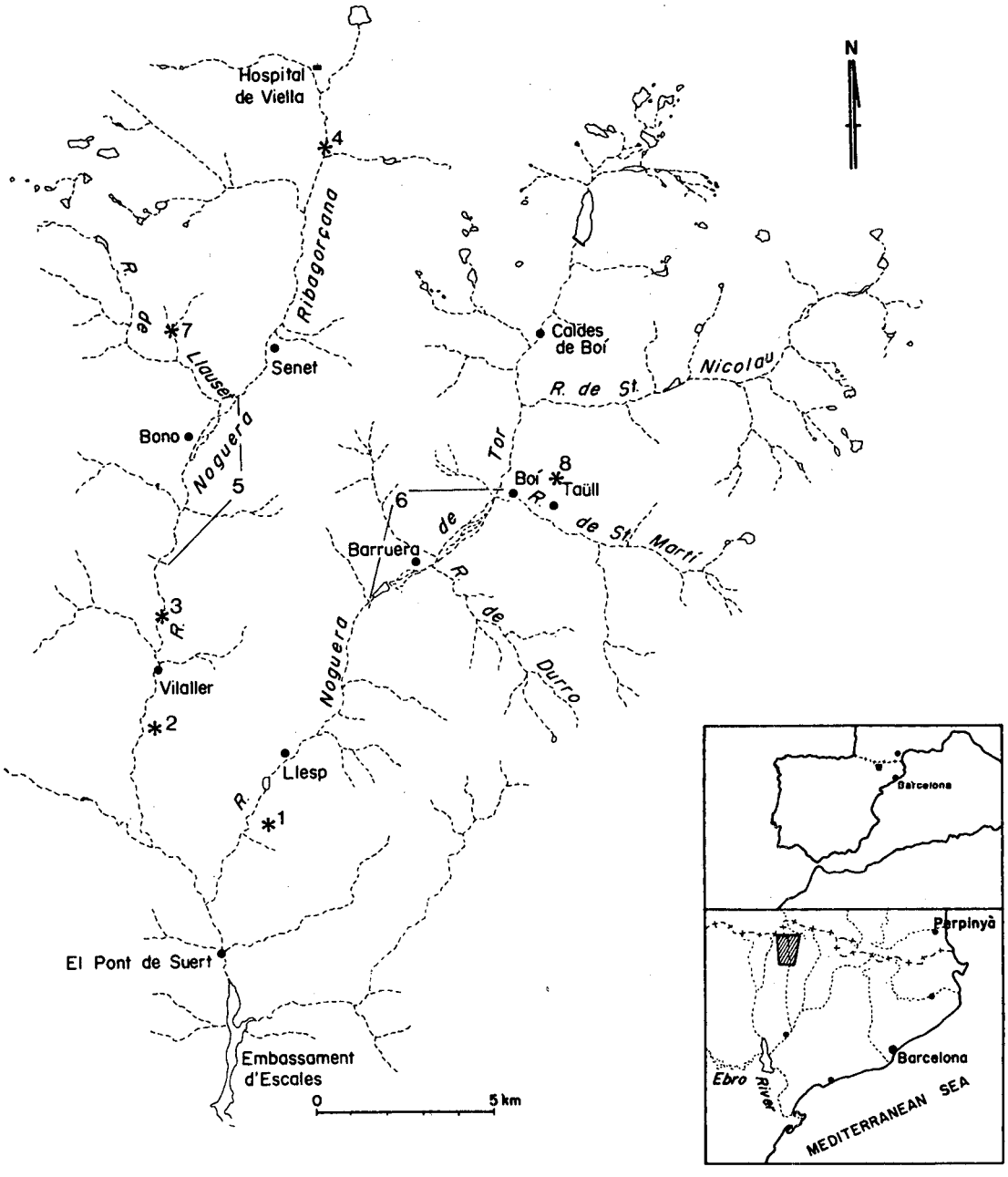

Figure 1. Alta Ribagorça Basin. This map show the studied area and its situation in the Pyrenees Mountains and also the location of the most important sedimentary formations indicated in the text. *Ice-terminal till complexes*: 1. Grilló; 2. Sant Antoni (see Fig. 3); 3. Seminari de Vilaller (see Fig. 4); 4. Barranc de Besiberri. *Bottom-valley deposits.* 5. Overdeepened basin of Bono; 6. Overdeepened basin of Barruera (see Fig. 5); *Ice-lateral till complexes:* 7. Llestui (see Fig. 6); 8. Taüll (see Fig. 7).

delimite the extensión of the quaternary glaciers.

The bigest extension of the quaternary valley-glaciers and the smaller width of the Marginal Ranges in the northen slope of the Pyrenees allowed the glaciers to reach as far as the Aquitaine Basin where numerous end moraines are found (in french called «vallum morainiques»). We can mention the *terminal morainic complexes* of Aurudy Buzy (Ossau Valley) and Lourdes (Pau Valley), both of them very close to 400 m. a.s.l.

The *terminal morainic complexes* in the southern slope of the Pyrenees are very different to the northern ones. The main differences are the altimetric situation, the position of the deposits, the preservation grade; and even in some cases their existence can be called in question. Penck (1881) had already emphasized the lesser extension of the quaternary glaciers in the southern slope of the Pyrenees, he placed the end moraines about 1000 m. a.s.l. on average, while in the northen slope were placed at 570 m. a.s.l. All the authors, from Penck (1881) to the most recent ones (Marti *et al.*, 1978) have pointed out that not any glacier of the southern slope reached the Ebro Basin, not even the small intramontane basins (excepting the Querol Glacier at Puigcerdà, Cerdanya). This fact made difficult the formation of *terminal morainic complexes*, but through they were formed, the torrential water streams during the retraction of the quaternary glaciers and during the Postglacial period, destroyed most of the terminal morainic deposits.

These deposits are constitued by morainic material in the Alta Ribagorça Basin, but they are not much extended and the morphology is badly preserved. In the Noguera Ribagorça Valley there are three localities with till deposits in relation to terminal moraines, from south to north: *Sant Antoni* till, *Seminari de Vilaller* till and *Barranc de Besiberri* till. In the Boí Valley there is only most external one: *Grilló* till (Figure 1). Some of these deposits were already quoted by several authors (Obermaier, 1921; Frödin, 1927; García Sainz, 1935 and Mey, 1968). The most external end moraines (Sant Antoni and Grilló) are very eroded and only a part of the deposit is preserved. I prefer call these deposits by the term *ice-terminal till complex,* because from the sedimentological point of view it is more realistic. In most cases frontal morainic morphology don't exist because the erosion destroyed it. Till is always present and in some terminal complexes it is related with glaciofluvial and / or glaciolacustrine deposits. It consists in a basal till with an high contents of clayey matrix (> 50%) and it is similar to the «mud till» defined by Schlüchter (1977) in the Alps.

The *ice-terminal till complex* of Seminari de Vilaller shows the best preserved original morphology of terminal morainic ridge. At the bottom of the deposit there is a till with a grey silty-clay consolidated matrix and with striated and subrounded clasts. The upper part is less consolidated and a beige silty-sand matrix is present. From field observations, and according to the model proposed by Boulton and Eyles (1979) for the formation of *dump-moraines,* an interpretative schema of this *ice-terminal till complex* is elaborate in Figure 4.

The Barranc de Besiberri deposits, at the upper part of the Noguera Ribagorçana Valley are remains of two end moraines at 1.530 m. a.s.l. degraded by fluvial erosion. The deposit is mainly constitued by a supraglacial till.

–Bottom-valley deposits

A great number of small lakes exist in the high part of Alta Ribagorça Basin, above 2000 m. They have been formed by glacial erosion and located mainly in the bottom cirques and also on the bottom valley. The sedimentary fill of these basins should contain stratigraphic information since deglaciation to the present time. Lake Llauset represents one of the most important of these lakes; and its lacustrine filling deposits are studied in an specific article in this review (Vilaplana et al., 1984).

The two bigest basins are found in bottom-valley situation in the lower part of two main valleys (Bono and Barruera located at 1000 m. a.s.l.). The deposits that fill these basins have been studied by Vilaplana and Casas (1983). The conventional surficial studies was complement with vertical electrical soundings in order to determine the depth of the paleozoic bedrock and the character of the quaternary filling. The analysis of the resistivity data suggests that the Bono and Barruera depressions are overdeepened basins 200 m and 150 m depth respectively. We have distinguished three different lithofacies of quaternary deposits (Fig. 5):

a) *Bottom deposits,* with low electrical resistivity (from 80 to 200 Ohms.m); interpeted as muddy sediments deposited in lacustrine environement.

b) *Intermediate deposits.* with medium electrical resistivity (from 300 to 800 Ohms.m); interpreted as diamict with a large fine matrix of fluviolacustrine origin.

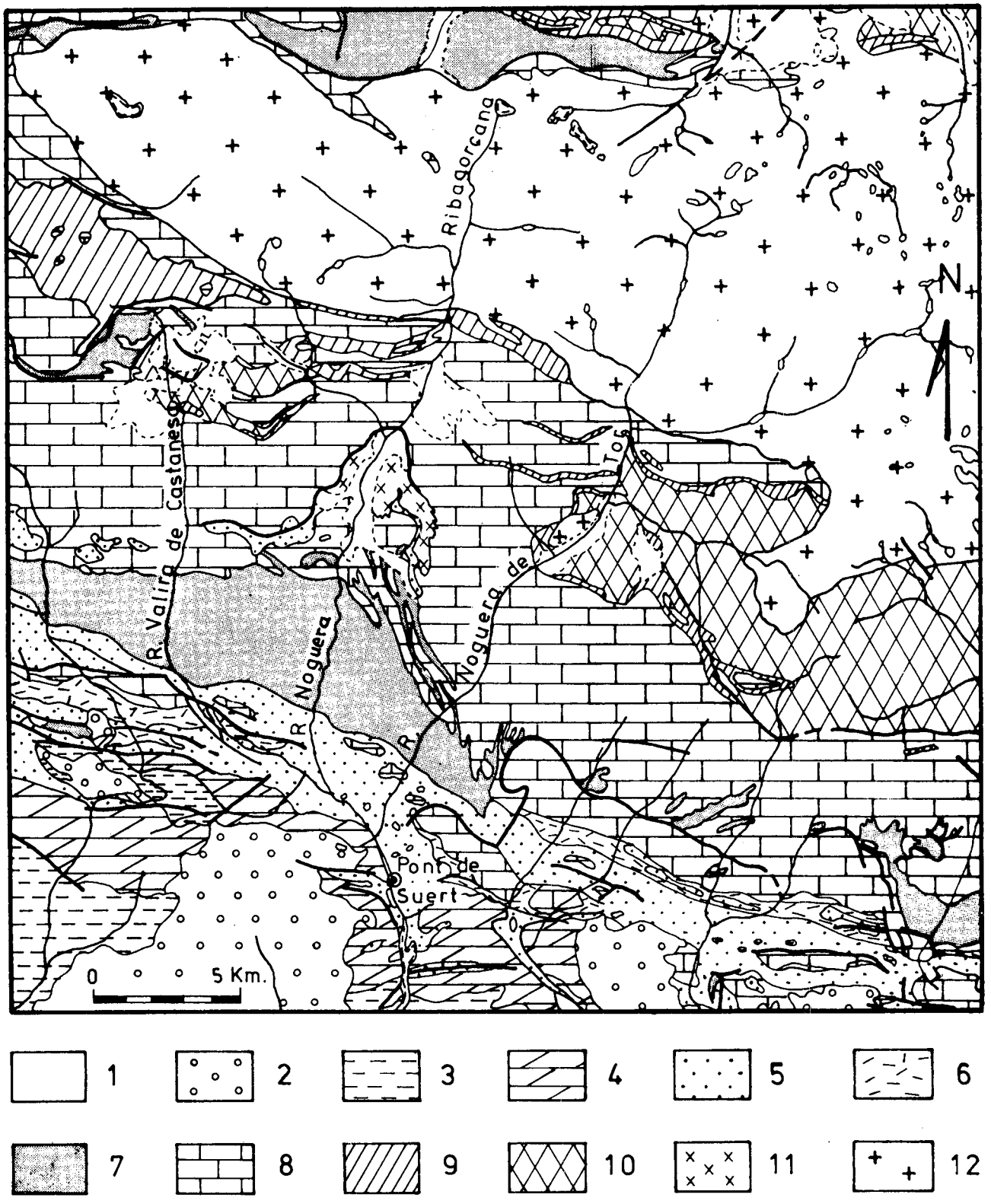

Figure 2. Geological map of Alta Ribagorça region (Southern Central Pyrenees), from ZWART (1972). 1. Quaternary deposits; 2. Oligocene; 3. Upper Cretaceous; 4. Jurassic and lower Cretaceous; 5. Permo-Triassic; 6. Posthercynian Carboniferous; 7. Prehercynian Carboniferous; 8. Devonian; 9. Silurian; 10. Cambro-Ordovician; 11. Silicified hornfels; 12. Granodiorite of Maladeta Massif.

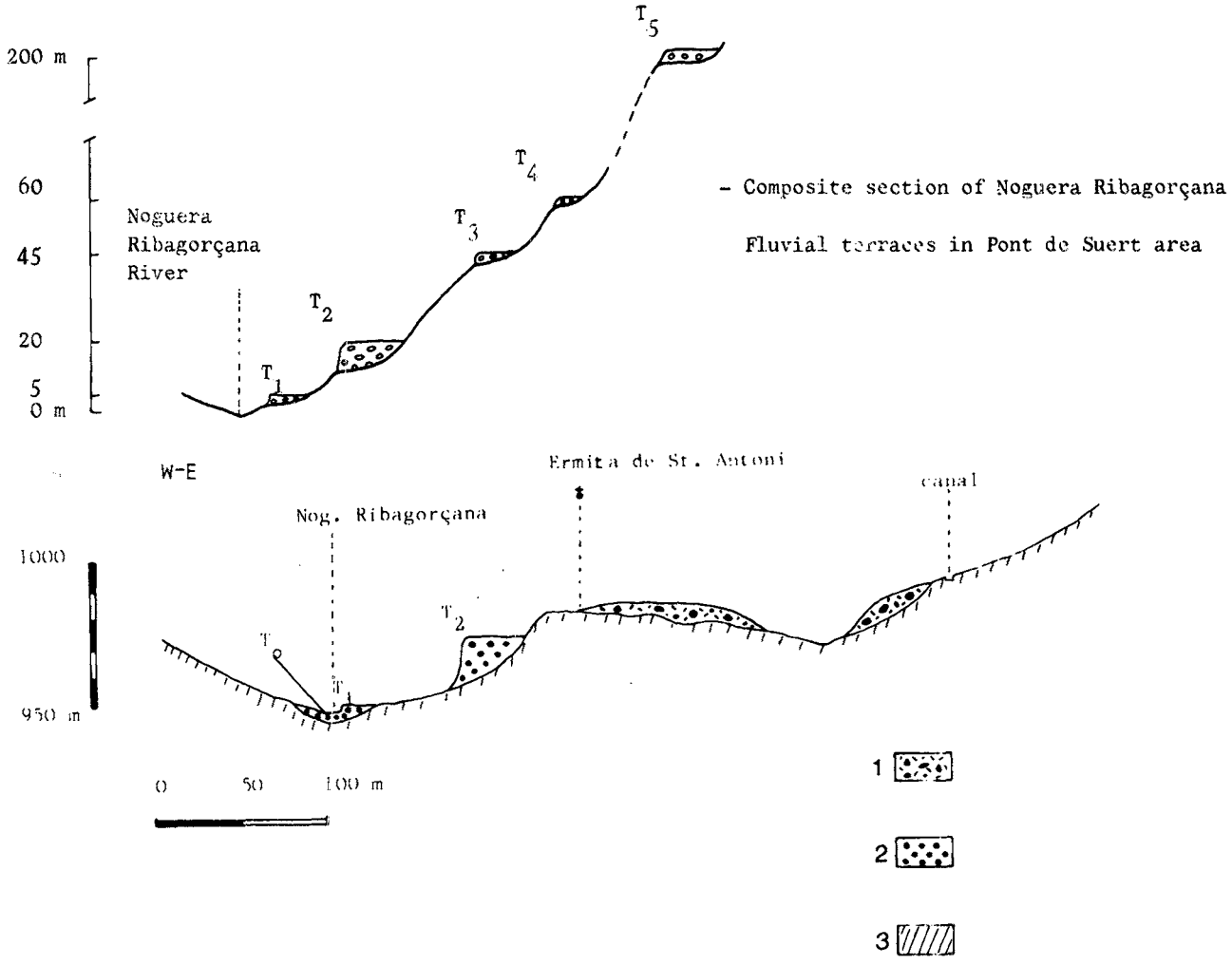

Figure 3. Transversal cross-section of Noguera Ribagorçana Valley near Sant Antoni Church (see location in Fig. 1). 1. Ice-terminal till complex of St. Antoni; 2. Fluvial terraces: recent alluvions (T_0); terrace +3m (T_1); terrace +20m (T_2); 3. Carboniferous bedrock.

c) *Top deposits,* with high electrical resitivity (from 1500-1700 Ohms.m); corresponding to the alluvial sands, gravels and boulders which crop out in the present alluvial plain.

This results suggest that both overdeepened depressions (Bono and Barruera) were eroded by the Ribagorçana and Tor Glaciers respectively, during the maximum glacial phase. And during the retreat of the valley glaciers both overdeepened basins were filled by glaciolacustrine deposits.

–Ice-lateral till complexes

This type of deposits are constituted by lateral moraines with subglacial till sometimes covered by supraglacial till, both in relation to lacustrine, fluvial or slope deposits. One of the best examples is the *Llestui complex* in the Llauset Valley, a tributary of the Noguera Ribagorçana River. A glacial tongue 10 km long, flowed through that valley during the last Quaternary Glaciation, to join on to the main glacier of the Noguera Ribagorçana. At this time, the *ice-lateral till complex* with glaciolacustrine deposits of Llestui was formed on the left margin of the Llauset Glacier by obstruction of a small fluviotorrencial basin. These deposits are reported by Serrat *et al.* (1983) as one of the best examples of ice-marginal lacustrine sedimentation in the Southern Pyrenees. From these autors, the great amount of sedimentary material without hiatus in this marginal lake, indicates a large period of glacial-stabilization. This sedimentary complex was

studied in detail by Vilaplana (1983 a) from both sedimentological and stratigraphical point of view (Fig. 6). There is a clear influence of the lateral expansion of the glacier wich prograded in the lake. The supraglacial till shows a geometry like a dump moraine, but in lateral position, that indicates a glacial lateral advance. The rhythmite (laminated muds) sediments alternate with levels of diamicts produced by mass movements from the lateral moraine into the lake. There is also a progressive incorporation of lacustine mud in the subglacial till matrix.

In relation to the stratigraphy, we atribute these deposits to the stabilization phase after the maximum of the last Quaternary Glaciation, (Vilaplana, 1983). All the radiocarbon dates samples give an age of 34.000 years B.P. (Fig. 6). From the first partial data of the palynological stratigraphy carried out by A. Esteban & Vilaplana, (1984), and the correlation with the lacustrine deposits of Biscaye (Lourdes), in the Northen slope of the Pyrenees, studied by M. Mardones (1982), an age between 65.000 and 31.500 years B.P. is proposed for this formation (See Figure 12).

Glacial deposits in Taüll Valley

Taüll Valley is located in the Noguera de Tor River Basin also named Boí Valley and it is constituted by Sant Martí River (which springs near Port de Rus 2622 meters a.s.l.) and its tributary, Ginebrell Creek (which comes from port d'Ertra 2460 meters a.s.l.). Taüll Valley is bounded by Sant Nicolau Valley to the North and Durro Valley to the South (Fig. 1).

The bedrock is constituted by palaeozoic rocks, mainly the Cambro-Ordovician Serie, formed by shales and sandstones with some conglomerates, quartzites and quartz-veins. There are silurian coal-shales both in Ginebrell Valley and Sant Martí Valley head. A granodioritic band crops out in the Pessó Peak area.

Sant Martí and Ginebrell Valleys have a typical glacial morphology with numerous cirques at the upper parts. There are basal till accumulations at the bottom of the cirques (Coma del Port de Rus). These basal tills are partially covered by rock-glacier moraines.

There is a considerable basin-shaped widening

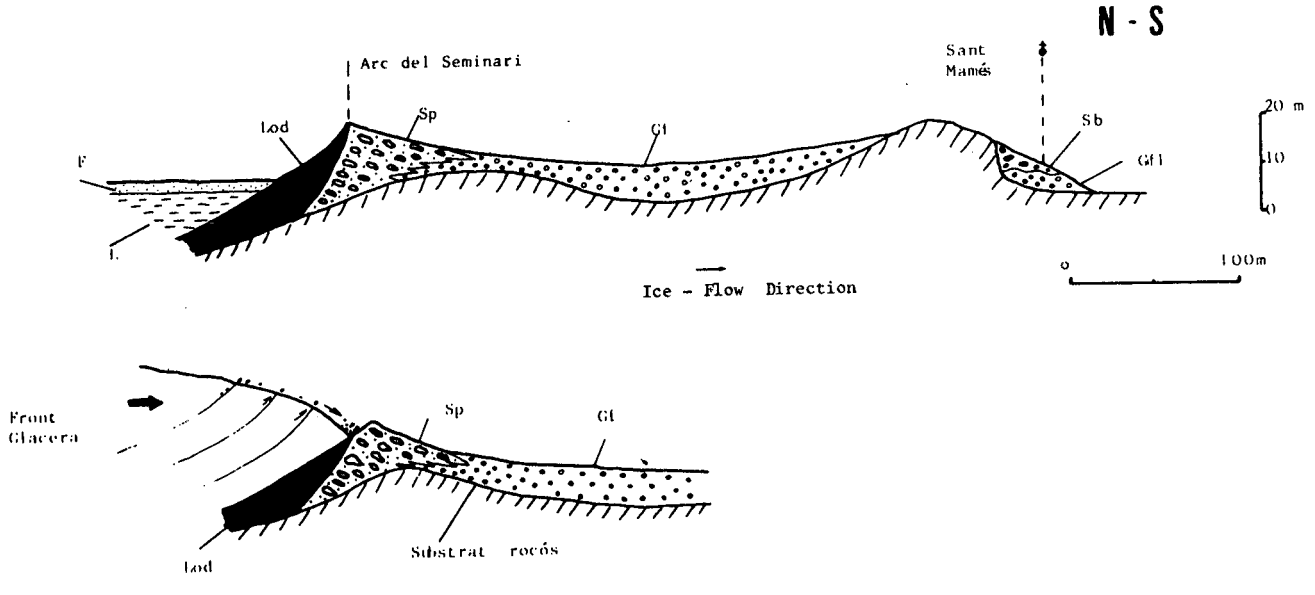

Figure 4. Ice-terminal till complex of Seminari de Vilaller in the Noguera Ribagorçana Valley (see location in Fig. 1).
a) Longitudinal cross-section.
b) Reconstruction of the Ice-terminal sedimentation from a model proposed by BOULTON and EYLES (1979). Maximum glacial deposits (St. Antoni deposition). Gfl: Sant Mamés glaciofluvial deposits; Sb: Subglacial lee-side till. Postmaximum glacial deposits (Seminari de Vilaller deposition); Gf: Glaciofluvial deposits; Sp: Supraglacial till; Lod: Lodgement till, Glacial retreat deposits; L: Lacustrine deposits; F: Fluvial deposits.

in the confluence of Ginebrell and Sant Martí valleys, where an important quantity of sediments (mainly of glacial origin) are found.

During the maximum glacial phase in the Quaternary, this basin was the confluence point of three valley-glaciers: the great Tor Glacier and the two small glaciers (Sant Martí and Ginebrell) forming the Taüll Glacier (see Fig. 9).

During the last Quaternary glacial maximum, the greatest glacier extension was produced. After the maximum phase both Sant Martí and Ginebrell Glaciers were disconnected from the Tor Glacier, wich obstructed the Taüll Valley drainage. The main consequence of this prolonged obstruction was a sedimentary overaccumulation in Taüll Basin.

–Mulleres deposits

80 meters thickness of quaternary deposits is calculated using geoelectrical studies in the southern part of this basin (Ginebrell area). There is a predominance of tills in surface, but the vertical profiles carried out in the scarce outcrops and the geophysical studies of electrical resistivities, allow us to differenciate several lithofacies.

The vertical profiles (Fig. 8) show a subglacial till at the bottom, covered by fluviolacustrine deposits. Another subglacial till is (with an erosive contact) above the fluviolacustrine deposits. On top of this last till there are glaciofluvial gravels and sands.

We interpret this alternance as a typical ice-marginal environment between Ginebrell and Sant Martí Glaciers, whose advances and retreats are marked by the alternance of tills with glaciofluvial and glaciolacustrine sediments.

–Ice-lateral till complex of Taüll

It is a clayey matrix till with a clear lateral morainic ridge morphology, located 200 m above Taüll village (See figure 7). Alluvial cone deposits and other kind of slope deposits are in contact with glacial deposits. The major part of the glacial deposit is constitued by a lodgement till; in the upper part there is a supraglacial flow till. Both morphology, clast lithology and fabric allow us to assure that it was deposited as a lateral moraine from the Tor Glacier which entered in Taüll Valley upon Taüll Glacier.

–Local glacial chronology

The different glacial phases that we can inter-

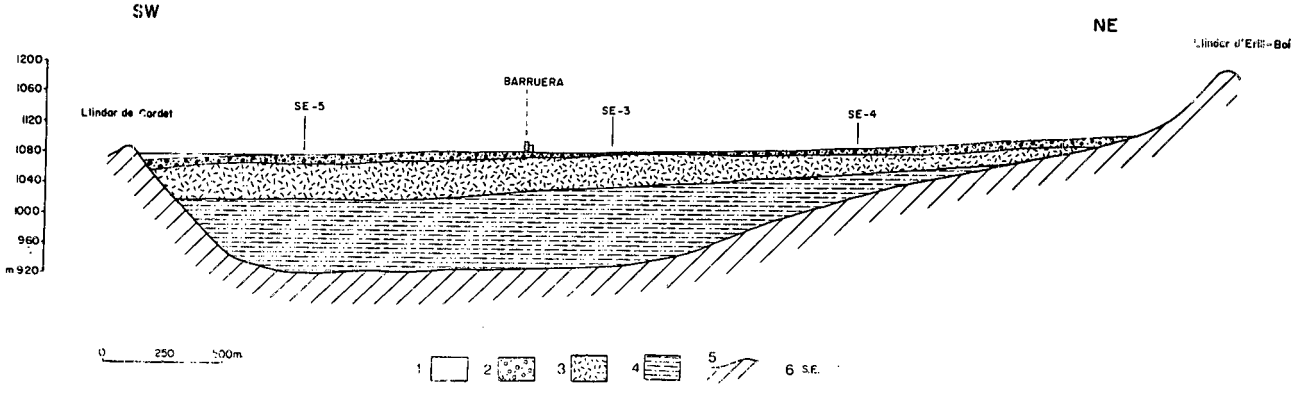

Figure 5. Longitudinal geoelectrical profile of Barruera overdeepened basin. 1. Dam; 2. Top deposits, with resistivities between 1600 and 1700 Ohm-m; 3. Intermediate deposits, with resistivities between 525 and 800 Ohm-m; 4. Bottom deposits, with resistivity of 80 Ohm-m; 5. Paleozoic bedrock; 6. Location of vertical electrical sounding.

pret both from sediments and landforms are:

– A *maximum glacial extension phase* followed by an important *stability phase* of the great glaciers (i.e. Tor Glacier). During the *stability phase* there was an important sedimentation, mainly in marginal environments. Also during this phase, the small glaciers (Sant Martí and Ginebrell Glaciers) had several advances and retreats (two of them well marked), conditioning the alternance of till layers with fluviolacustrine levels deposited in an ice-marginal environement.

After the *stability phase,* the gradual but final retreat of all the glaciers to the cirque areas was produced.

Finally, we detect a last glacial pulsation showing special characteristics and restricted to some cirques (those above 2200 m and northern oriented). This last phase which produced rock glaciers in the Pyrenees Mountains is called Tardiglacial (Serrat,1979). In Taüll area this phase is represented by rock glacier moraines in Coma de Port de Rus (Sant Martí Cirque).

QUATERNARY STRATIGRAPHY AND GLACIAL CHRONOLOGY IN THE ALTA RIBAGORÇA BASIN

A stratigraphy of quaternary deposits of Alta Ribagorça region is established taking into account and correlating the different sedimentary complexes studied by Vilaplana (1983 a).

Pleistocene previous to the Last Pyrenean Glatiation.

The almost totality of glacial quaternary deposits in the Alta Ribagorça are attributed to a last and important glatiation. There are only two sedimentary formations of earlier age –presently difficult to determine it precisely– a high terrace and a colluvial deposit.

The first one is the fluvial terrace level T_5 (180-200 m above the present river level) of the Noguera Ribagorçana River, in Pont de Suert area

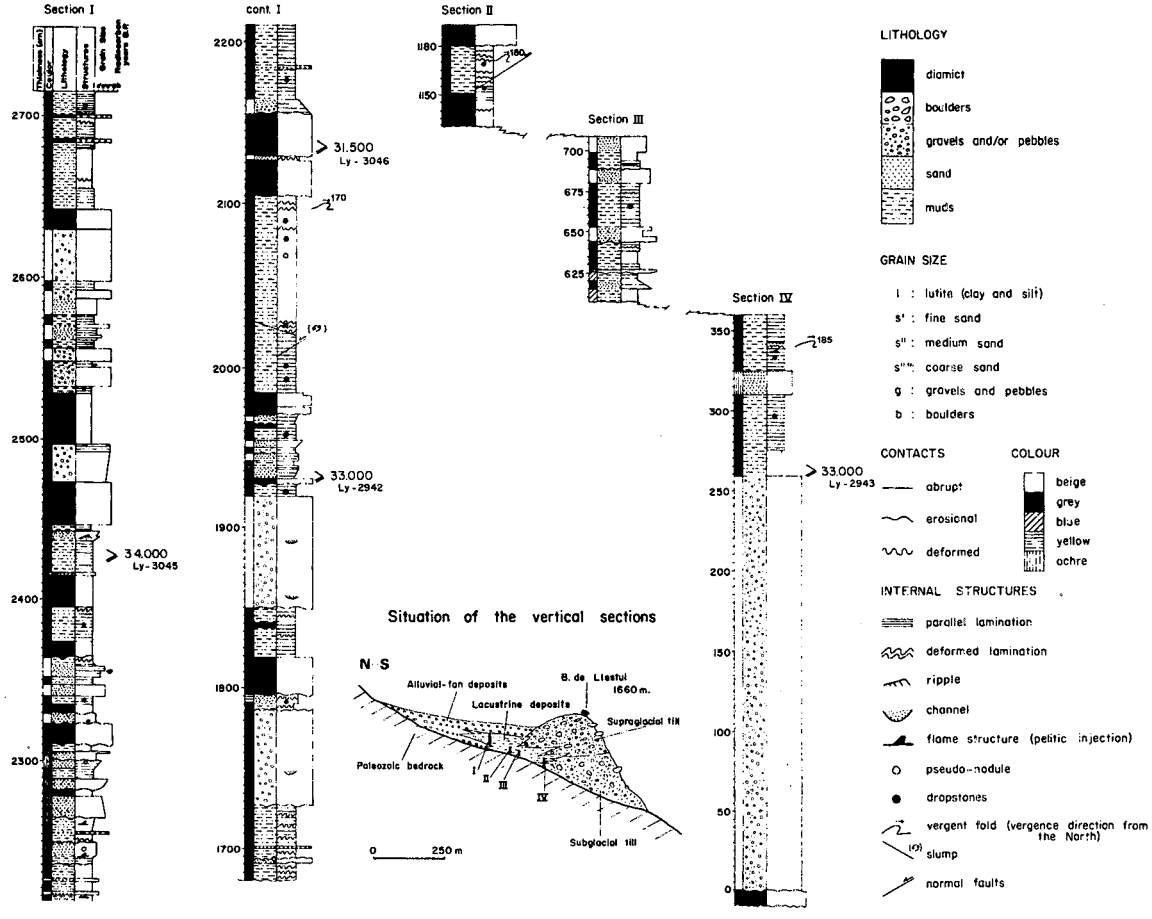

Figure 6. Stratigraphical sections of Llestui.

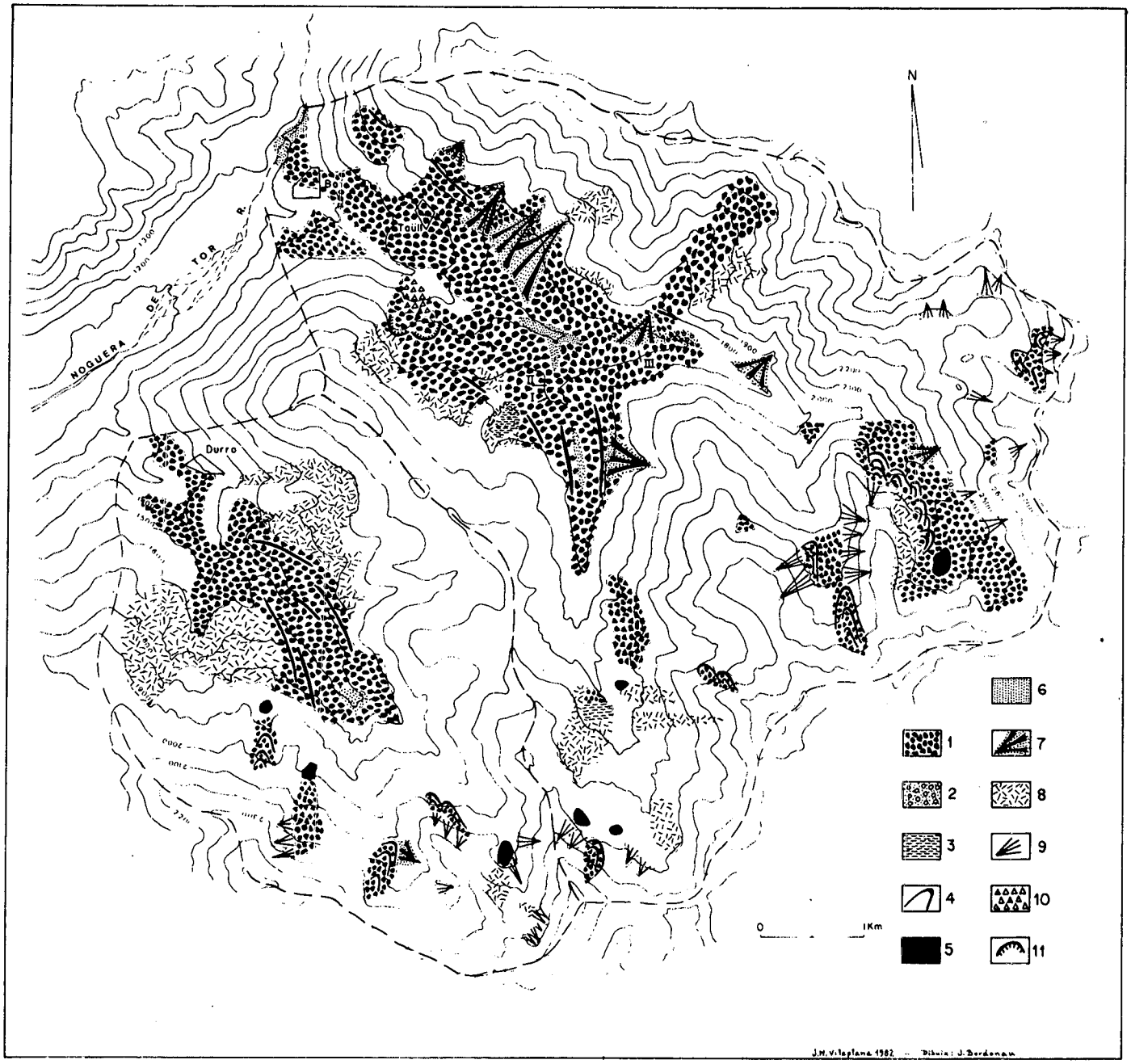

Figure 7. Map of quaternary deposits of Taüll and Durro Valleys (both tributaries of Noguera de Tor Valley). 1. Glacial deposits; 2. Glaciofluvial deposits; 3. Glaciolacustrine deposits; 4. Rock glacier moraines; 5. Recent lake deposits; 6. Alluvial deposits; 7. Alluvial cone deposits; 8. Periglacial slope deposits; 9. Debris cone; 10. Land-slide deposits: 11. Land-slide scar.

(Fig. 3). We have two objective criteria to atribute these deposits to an old glaciation: the glaciofluvial characteristics of the deposit and its altimetric position. In relation to the age of the T_5 level, we can try to use the altimetric stratigraphic criteria proposed by the classical authors in the Pyrenees. Goron (1941) established a stratigraphy for the fluvial pyrenean terraces and he attributed Günz age to the higer terrasses located between 90 and 120 m. a.r.l. Solé Sabarís (1951) ratified the same interpretation. According to other authors who worked in Puigcerdà area (South-eastern Pyrenees) taking into account both weathering and altimetric criteria (Chevalier, 1906; Panzer, 1932; Boissevain, 1934

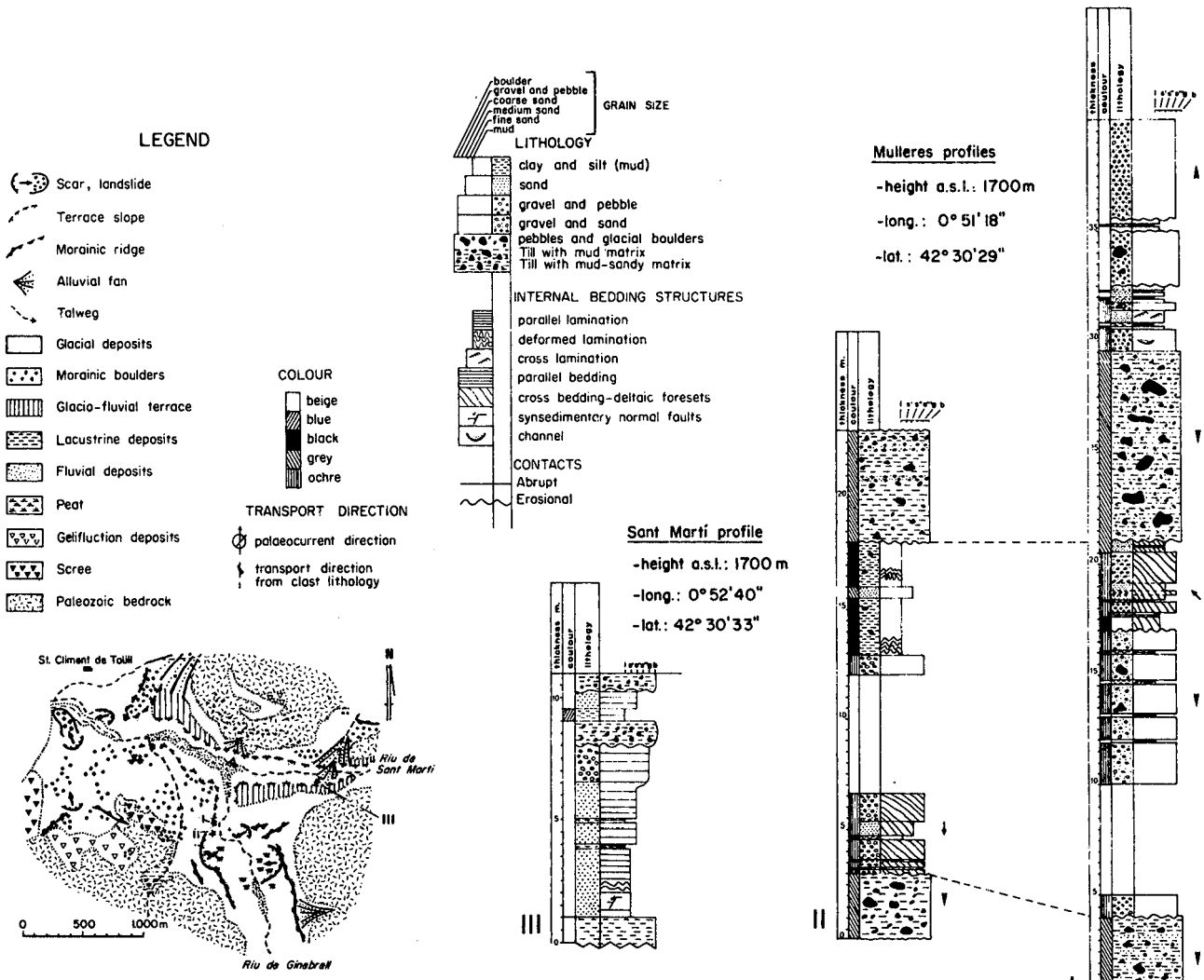

Figure 8. Quaternary deposits of the Taüll area: vertical sections.

and Nussbaum, 1946), the terrace T_5 ought to have a pre-Mindel age. According to the stratigraphy proposed by Serrat (1980) in the Ter Basin (Southeastern Pyrenees) the correlation with the T_5 terrace give also a pre-Mindel age. In spite of my reservations to use the alpine stratigraphical terminology for the pyrenean glaciations, before the establishment of a good correlation between the pyrenean valleys, I prefer say that the age of the T_5 terrace is atributable to an old pyrenean glaciation. Without present data is impossible to establish exactly if it correspond to the Middle or Lower Pleistocene.

The other old deposit is a colluvial formation constitued by periglacial slope material and which includes reworked morainic material. It is covered by the lateral moraine of Artiga (Bono area), clearly atributable to the last glaciation (Vilaplana, 1983). Two things must be considered in relation to the age of this deposit: The existence of the morainic material included in the slope deposit which attests an anterior glaciation (which might correspond to the glaciation indicated by T_5 terrace); and the age of the colluvion which is earlier to the position of the lateral moraine of l'Artiga (last glacial maximum; see Fig. 12). As an hypothesis, we can think that this deposit is the consequence of an important slope erosion between two glacial periods.

In any case, these are the only sedimentary records found in these valleys related to glacial period earlier to the last one and, by now, they do not

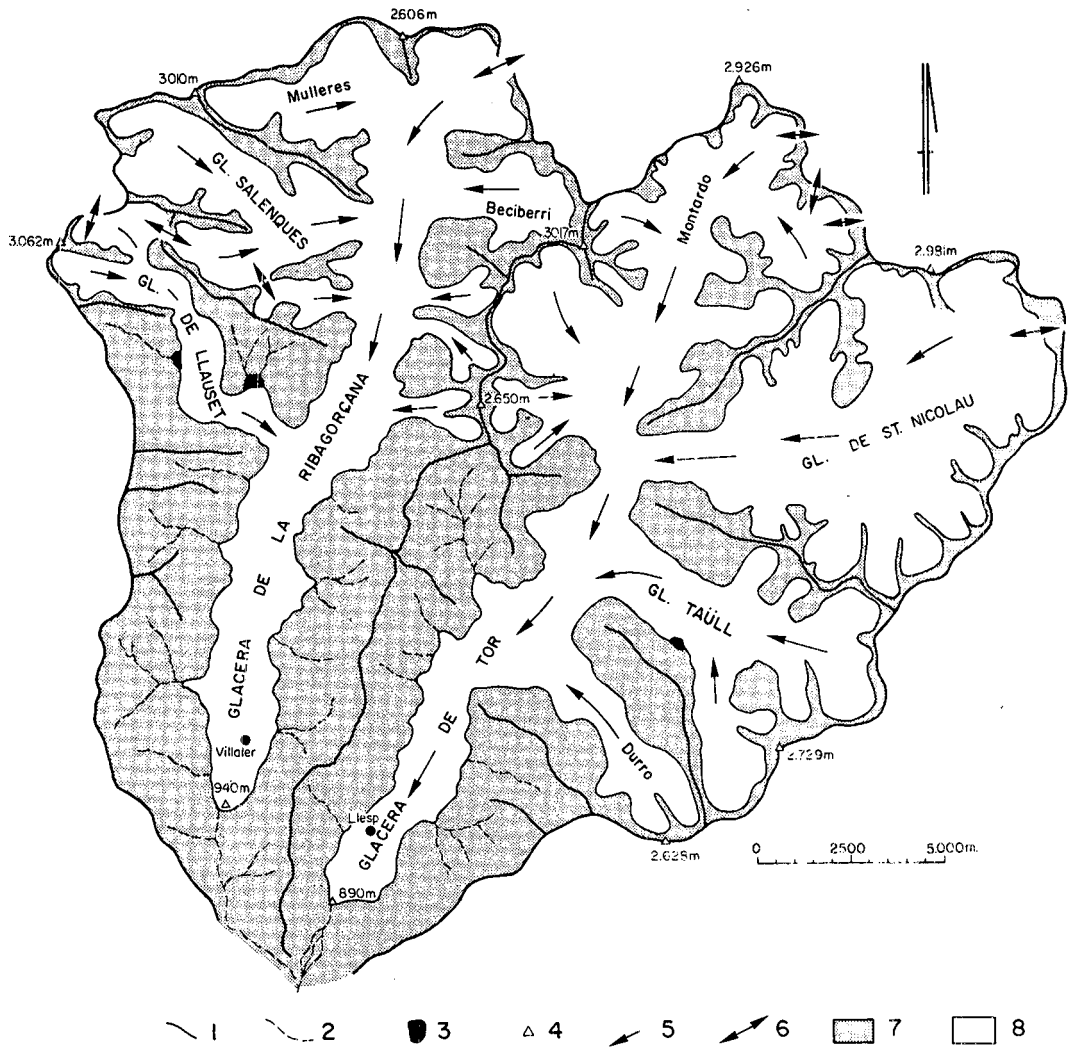

Figure 9. Glacial extension during the last glacial maximum (Phase I) in the Alta Ribagorça Basin. 1. Glacial basin boundary; 2. Water streams; 3. Obstruction lake; 4. Height point; 5. Ice flow; 6. Glacial transfluence; 7. Bedrock; 8. Glacier.

give any information with reference to the extension and characteristics of this or these old quaternary glaciations.

Last Pyrenean Glaciation

During the Upper Pleistocene a very important glaciarisation occurred in the Alta Ribagorça Basin. This glaciation had an important extension (Figure 9) and destroyed almost all the remains of the earlier glaciations.

A stratigraphy of the different Late Pleistocene sedimentary units of the Alta Ribagorça Basin is established; and it is also correlated with the cronostratigraphy and the glacial chronology proposed by Mardones (1982) and by Mardones and Jalut (1983) in Lourdes area (Northen slope of the Pyrenees). The synthesis is given in the figure 12. Three great phases have been differentiated within the last glaciation in the Alta Ribagorça Basin.

–Glacial Maximum Phase

The maximum expansion of the valley-glaciers (Fig. 9) took place, followed by a prolonged stabilization of them. During this phase the great excava-

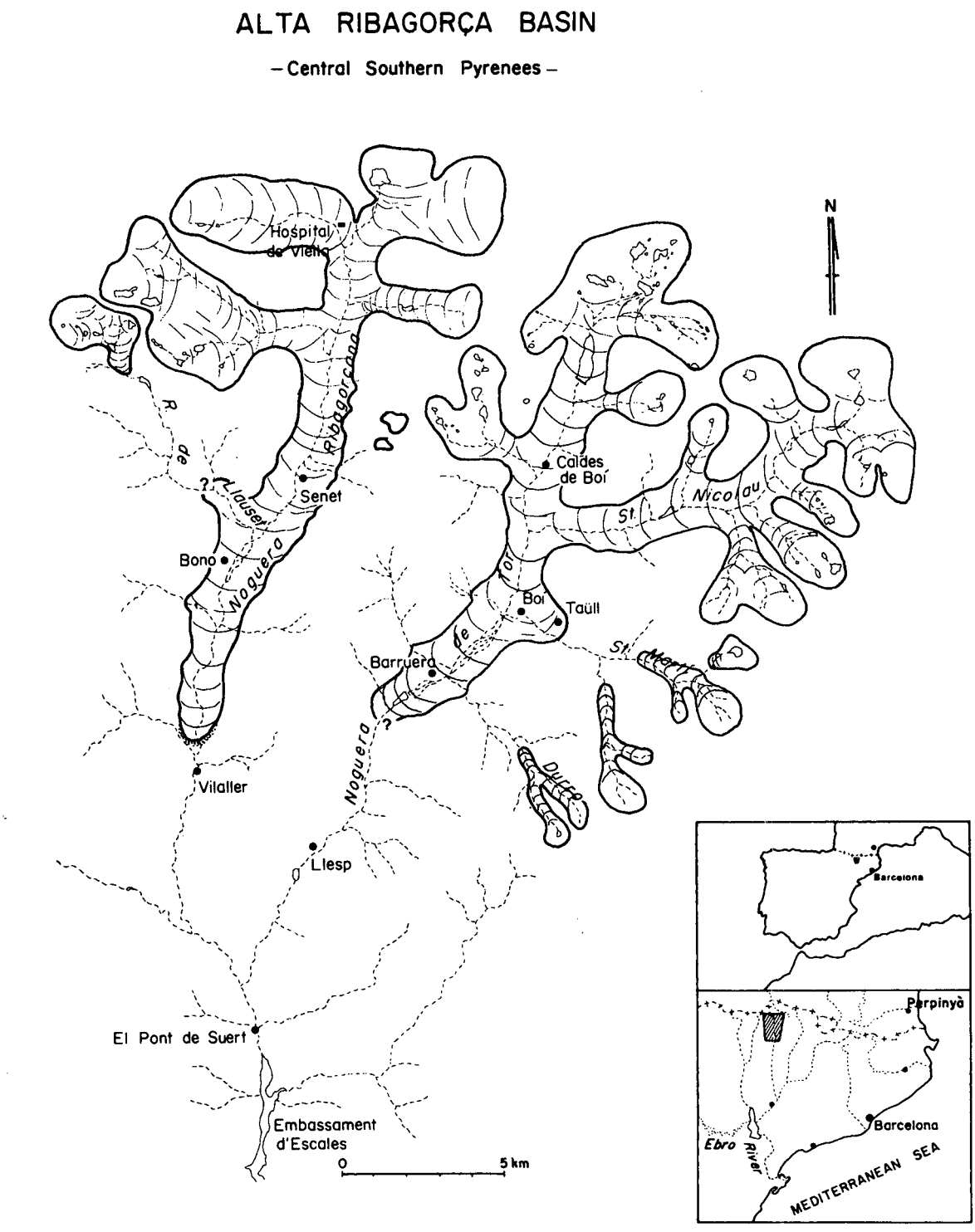

Figure 10. Glacial extension during the second phase (Phase II Postmaximum) of the last Pyrenean Glaciation in the alta Ribagorça Basin.

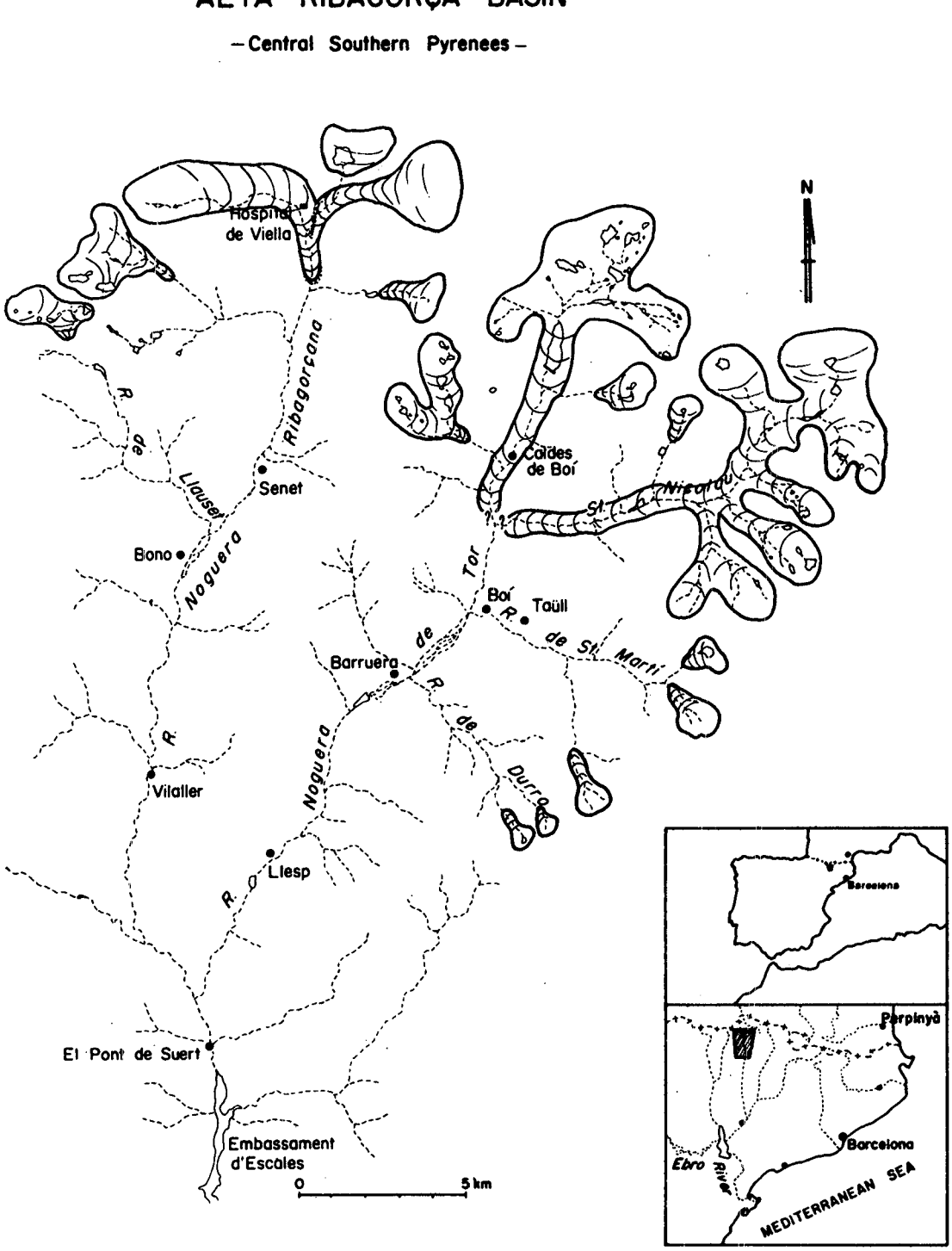

Figure 11. Glacial extension during the third phase (Phase III Final) of the last Pyrenean Glatiation in the Alta Ribagorça Basin.

tion both in the cirques and valleys was produced by the glaciers. Important overdeepened basins were formed at the bottom of the main valleys –1000 m. a.s.l.– (Bono and Barruera). These erosive processes were conditioned by both the important rock thresholds and the confluence of several glacial tongues (ice-overaccumulation). The sedimentation on the bottom of the valleys and cirques was not much important. The main deposition took place in the ice-marginal zones: ice-terminal till complexes (Sant Antoni till and Grilló till) and ice-lateral till complexes (Llestui formation and Taüll moraine). During this phase of ice-marginal deposition, it must be emphasized the setting up of lacustrine environments due to the destruction of the tributary valleys by the main glaciers (Serrat *et al.*, 1983). From both the absolute dates carried out in the Llestui formation and the correlation with the stratigraphy proposed at Lourdes (Mardones, 1982 and Mardones & Jalut, 1983), the phase of maximum extension was between 70000 and 50000 years BP and the later stabilization lasted until 31.900 years BP (see fig. 12).

–Postmaximum Phase

The second phase of the last glaciation was also characterized by valley-glaciers, though lesser extensives than those during the maximum phase (Figure 10). The erosive and sedimentary capacities are very lower with reference to the first phase. The main sedimentary unit of this phase is represented by the Seminari de Vilaller ice-terminal till complex in the Noguera Ribagorçana Valley. No absolute dates have been established for this deposit, if a correlation with the stadial I of Mountain glaciers (Mardones, 1982 and Mardones & Jalut, 1983) is accepted, it would be placed between 25000 and 14820 years B.P. (see fig. 12).

–Final Phase

It was the last phase of the last quaternary glaciation, restricted with referente to the other two phases (Figure 11). The glacial tongues were

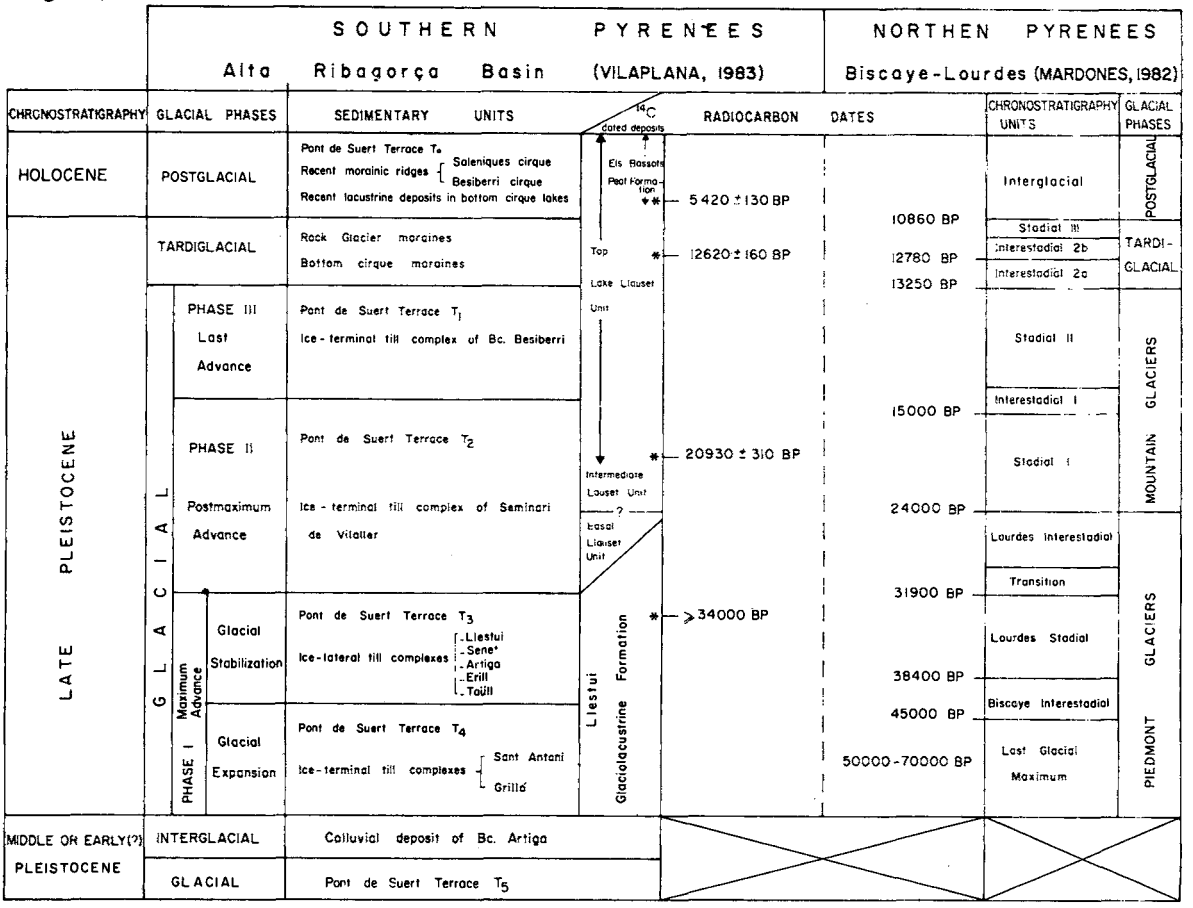

Figure 12. Quaternary stratigraphy and glacial chronology of Alta Ribagorça Basin and its correlation with the glacial chronology of Lourdes area (Pyrenees Mountains).

shorter than 10 kilometers in leghth at the main valleys, while only cirque glaciers ocupied the small valley-heads. During this phase of small erosive capacity, tills were deposited on te bottom of some cirques, and the terminal moraine of the Ribagorçana Glacier was deposited in the Barranc de Besiberri. During the glacial retreat of phase 2 and during this last phase, the in-filling of the lakes at the overdeepened basins (Bono and Barruera) according to the correlation with the stratigraphy proposed by Mardones (1982) and Mardones & Jalut (1983), this last phase, of brief duration, would be placed between 14820 and 13000 years B.P.

Tardiglacial: Rock-glaciers Phase

Once the pleistocene glaciers retreated, a cold and dry pulsation was produced. This pulsation was defined by Serrat (1979) at the Eastern Pyrenees as Tardiglacial episode; this phase was placed at the Pyrenees between 13000 and 10000 years B.P. Mardones (1982) dated this cold phase at Biscaye between 11200 and 10860 years B.P. Jalut *et al.* (1983) dated this cold, dry and brief phase at Freychinède (Ariège Pyrenees) a little earlier than 11200 years B.P.

The Pleistocene period in the Alta Ribagorça ended with this Tardiglacial phase, and the Holocene or Postglacial period started.

Holocene Period

The most complete stratigraphy of the Holocene has to be searched in the high lakes, at the upper part of the valleys and the bottom-cirques. In fact, some of these lakes already started their sedentary record during the final part of the Last Pleistocene Glaciation.

The most important example of these lakes is Llauset Lake which is being studied from sedimentological and stratigraphical view-points. The first results of this study are presented in a paper within this review (Vilaplana, Schlüchter & Verdaguer, 1984).

With reference to the glacial dynamics in the Alta Ribagorça basin during the Holocene, it can be said that there are evidences of glacial dynamics at the upper parts of the mountains. There are well-preserved morainic ridges containing very fresh materials at the uppermost zones (between 2.600 and 3.000 m. a.s.l.). Acording to several observations carried out in other basins of the Central and Western Pyrenees, the small cirque-glaciers which caused these deposits were placed during historical times. Concretly, Martí *et al.*, (1978) quoted a cold pulsation between the XVII-XIX centuries, and correlated it with the little-Ice-Age in the Alps.

At present, there are no glaciers in the Alta Ribagorça Basin. The only present evidences of glacial dynamics are found in the nearby Maladeta Massif (NW of the studied area) where five small cirque-glaciers occur with a total area of 2.6 square kilometers. (Serrat *et al.*, 1980).

ACKNOWLEDGEMENTS

I wish to thank the following Institutions and people for making possible the present work with their support and their active collaboration.

Servei Geològic de Catalunya (Dpt. Obres Públiques i Política Territorial de la Generalitat de Catalunya). CIRIT de la Generalitat de Catalunya. ENHER (National Hydropower Company).

Dr. Christian Schlüchter (ETH - Zürich). Dr. David Serrat (Dpt. Geomorfologia i Tectònica-Univ. Barcelona). Josepa Brú (Dpt. Geografia-Univ. Barcelona). Jaume Bordonau (Dpt. Geomorfologia i Tectònica-Univ. Barcelona). Dr. Juan R. Vidal Romaní (Laboratorio Xeoloxico de Laxe). Dr. Jacques Evin (Laboratoire de Radiocarbone; Univ. Claude Bernard-Lyon I).

REFERENCES

ALIMEN, M.; SOLÉ SABARÍS, L.; VIRGILI, C. 1957. «Comparaison des formations glaciaires des versants N et S des Pyrénées». *Res. Com. Vème Congrès INQUA*, Madrid-Barcelona.

BOISSEVAIN, H. 1934. «Etude géologique et géomorphologique d'une partie de la haute vallée du Segre». *Bull. Soc. Hist. Nat. Toulouse.* T. LXVI, p. 32-170. 27 fig. 1 mapa Toulouse.

BOULTON and EYLES, N. 1979. «Sedimentation by valley glaciers; a model and genetic classification». In: Schlüchter, Ch., ed., «Moraines and varves», A.A. Balkema, Rotterdam, p. 11-23.

BRÚ, J., MARTÍ, C., SERRAT, D. and VILAPLANA, J.M. 1983. «Symposium and field trip on glacial pleistocene deposits in Southern Pyrenees: Excursion guide». INQUA Comission on Genesis and Lithology of Quaternary deposits. Universitat de Barcelona and Instituto de Estudios Pirenaicos. 53 p.

CHEVALIER, M. 1906. «Sur les glaciers pléistocènes dans les vallées d'Andorre et dans les hautes vallées espagnoles environnantes». *C.R. Acad. Sciences*, t. 142, p. 662-910. Paris.

DALLONI, M. 1930. «Etude géologique des Pyrénées Catalanes» *Ann. Fas. Soc. Marseille.* T. XXVI, Fasc. III, 1 vol. 373 p., 65 fig., 12 làm., 1 mapa. Argel.

DREIMANIS, Aleksis. 1976. «Tills: Their origin and properties». In R. Legget, editor: «Glacial till». *Special publication n.º 12 of the Royal Soc. of Canada*, p. 11-49.

ESTEBAN, A. & VILAPLANA, J.M. 1984. «Premiers résultats d'analyses polliniques dans des sediments et tourbières du Bassin de la Noguera Ribagorçana (Pyrénées Centrales, Lleida)». Com. Symposium: *Modifications de l'environement à la fin du Pleistocène et pendant l'Holocène dans le bassin Méditerranéen Occidental.* INQUA– Stra. Subc. Sept– 1983 Toulouse.

FONTBOTÉ, J.M.; SOLÉ SABARÍS, L., ALIMEN, H. 1957. «Livret guide de l'excursion N. PYRENEES». *INQUA, V^ème Com. Inter.* 107 pp. Madrid-Barcelona.

FRÖDIN, J. 1927. «GLaciala Forner i Pyreñenna». *Meddelanden Fran Lunds Universitets Geografiska Institution.* Ser. C., n.º 26, 156 p. Lund.

GARCÍA SAINZ, 1935. «Morfología glaciar y preglaciar de la región de la Noguera» (C. Cinca-Segre). *Bull. Soc. Geogr. Nacional,* n.º 54 TLXXV, p. 64-110. Madrid.

GORON, L. 1941. «Le rôle des glatiations quaternaires dans le modelé des vallées maîtresses des Pré-Pyrénées ariégeoises et garonnaises et de leur avant-pays». *Edit. Privat,* 400 p., 56 fig. 15 lam. phot. 6 lam. Toulouse.

JALUT, G.; DELIBRIAS, G.; DAGNAC, S.; MARDONES, M. & BOUHOURS, M. 1982. «A palaeoecological approach to the last 21.000 years in the Pyrenees: the peat bog of Freychinède (alt. 1350 m, Ariège South of France)» *Palaeogeography, Palaeoclimatology, Paläeoecology,* vól. 40. p. 321-359.

MARDONES, M. 1982. «Le Pleistocène Supérieur et l'Holocène du piémont de Lourdes: Le gisement de Biscaye. (Hautes Pyrénées, France)». Étude palynologique, Thèse de 3.ème Cycle, 96 p., *Université de Toulouse.*

MARDONES, M. & JALUT, G. 1983. «La tourbière de Biscaye (Alt. 409 m, Hautes Pyrenées): Approche paléoécologique des dernières 45000 années». *Pollen et Spores,* Vol. XXV, n.º 2, p. 163-212.

MARTÍ BONO, C.E.; SERRAT CONGOST D.; GONZÁLEZ, M.C. 1978. «Los fenómenos glaciares de la vertiente meridional de los Pirineos». *«Medio físico, desarrollo regional y geográfico, V. Col. Geogr.,* Granada 1877 p. 67. 73. Univer. Granada.

MARTÍ I RIBA, J. 1980. «Morfologia glacial i periglacial de la Ribera de Sant Nicolau. (Alta Ribagorça). Iniciació a l'estudi de la dinàmica actual». Tesi de Llicenciatura. Departament de Geografía. *Universitat de Barcelona.* (inèdita).

MARTÍ I RIBA, J. 1981. «Estudio del glaciarismo cuaternario de un sector del Alt Ribagorça». *Notes de Geografia Física,* 5, p. 33-47, Dpt. de Geografía. Barcelona, Juny 1981.

MARTINEZ DE PISÓN, E. y ANTÓN BURGOS, J. 1981. «Repertorio bibliográfico sobre morfología glaciar de la Península Ibérica». *Cuadernos de Invest. Geogr.,* Fasc. 1-2, T VII, p. 3-49, Mayo-Diciembre 1981.

MEY, P.H.W. 1968. «The geology of the Upper Ribagorzana and Baliera Valleys, Central Pyrenees, Spain». *Leidse Geol. Mededel.* 41- p. 153-220. Leiden.

MEY, P.H.W. 1968. «The geology of the Upper Ribagorzana and Tor Valleys, Central Pyrenees, Spain». *Leidse Geol. Mededel.* 41- p. 229-292. Leiden.

NUSSBAUM, F. 1946. «Orographische und morphologische Untersuchungen ir der östlichen Pyrenäen». *Jahresb. Geogr. Gess. Ben.,* Bd XXXV-XXXVI, 345 p., 94 fig., 4 lam. fot. Berna.

OBERMAIER, H. 1921. «Die Eiszeitiliche Verglerscherung Spanien». *Peternanss Geogr. Mitt.* t. 67, p. 158-162, Gotha.

PANZER, W. 1932. «Die eiszcitilichen Endmoränen von Puigcerdà (Ostpyrenäen)». *Zeitschr. f. Glets-cheik.* Berlin. Traducció de Ll. Solé «Geleres quaternàries dels Pirineus». Butll. C.E.C., t. XLIV, pp. 153-162, 1 fig. Barcelona (1934).

PENCK, A. 1881. «Die Eiszeit in der Pyrenaen». Erdk. Leipzig. Trad. Francesa per L.B. «La période glaciaire dans les Pyrénées». *B.S.M.N.* t. XIX, p. 105-200. Toulouse (1885).

SCHLÜCHTER, Ch. 1977. «Grundmoräne versus Schlammoräne –two types of lodgement till in the Alpine Foreland of Switzerland». *Boreas,* vol. 6, p. 181-188. Oslo.

SERRAT, D. 1979. «Rock glacier morainic deposits in the Eastern Pyrenees». In: SCHLÜCHTER, Ch. ed.: *«Moraines and verves. Origin, genesis, classification».* p. 93-100, A.A. Balkema, Rotterdam.

SERRAT, D. (coordinador) & EQUIPOS de Geomorfología Alpina (Fac. Geografía y Geología de Barcelona) 1980. «Catálogo de los glaciares de la Península Ibérica (1979)». *Notes de Geografia Física:* 3 p. 35-55, Dpt. de Geografía, Universitat de Barcelona.

SERRAT, D.; VILAPLANA, J.M. and MARTÍ, C. 1983. «Some depositional models of glaciolacustrine environment in Southern Pyrenees». in: EVENSON et al. Editors: *Tills and related deposits,* p. 132-144. A.A. Balkema, Rotterdam.

SOLE SABARÍS, L. 1951. *Los Pirineos. El medio y el hombre.* Biblioteca española de Cult. General. t. 8, 627 p. Barcelona.

TAILLEFER, F. 1957. «Glaciaire Pyrénéen. Versant Nord et versant Sud». *Rev. Géog. Pyr. et Sud-Ouest.* t. XXVIII, p. 221-224, 8 fig. Toulouse.

TOMAS QUEVEDO, S. 1979. «Diatomeas de las aguas epicontinentales de España: Géneros *Cymbella y Gomphonema,* Dpt. Ecologia Univ. de Barcelona. Tesi Llicenciatura (inèdita).

VILAPLANA, J.M. 1981. «El método de estudio del glaciarismo cuaternario en el Pirineo y sus posibles aplicaciones en las Sierras Galaico-Portuguesas». *Cuad. Lab. Xeol. de Laxe,* n.º 2, vol. I, p. 275-288. O. Castro.

VILAPLANA, J.M. 1983 a. *«Estudi del glaciarisme quaternari de les altes valls de la Ribagorça».* Tesi Doctoral, Departament de Geomorfologia i Tectònica. Facultat de Geologia. Universitat de Barcelona, 322 p., 1 annex amb 10 map.

VILAPLANA, J.M. 1983 b. «Sobre la Geomorfologia de la Vall de Llauset». *Revista d'Investigacions Geológiques.* Vol. 36.

VILAPLANA, J.M. & SERRAT, D. 1979. «Els dipòsits d'origen glacial de la cubeta de la Massana-Ordino/Andorra: llur significació paleogeogràfica». *Acta Geol. Hisp.* Vol. XIV homenatge al Dr. Ll. Solé Sabarís, p. 433-440, Barcelona, 1982.

VILAPLANA, J.M. & CASAS, A. 1983. «Las cubetas de sobreexcavación glacial de Bono y de Barruera (Alta Ribagorça: Pirineo Central)». *Cuadernos de Lab. Xeol. de Laxe.* n.º 6, p. 283-309. O Castro.

VILAPLANA, J.M. SCHLÜCHTER, Ch. & VERDAGUER, A. 1983. «Sedimentological and Stratigraphical approach to lacustrine Late Pleistocene environement of Lake Llauset (Southern Pyrenees).» *Acta Geológica Hispánica:* 3-4, vol. 18.

ZWART, H.J. 1972. «Geological Map of the Pyrenees» 1: 200.000, Leiden, Geological Institut of Leiden University.