

## GLACIAL EVOLUTION OF THE UPPER GALLEGO VALLEY (PANTICOSA MOUNTAINS AND RIBERA DE BIESCAS, ARAGONESE PYRENEES, SPAIN)<sup>1</sup>

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**ABSTRACT.**- *Glacial evolution in the upper Gállego Valley has been established by studying erosional and depositional landforms. Ten pulsations, related to five phases are described: Premaximal (F.G. 0), attributed to Middle Pleistocene; Peniglacial, with three expanding pulsations (F.G. 1, 2 y 3), is attributed to the Upper Pleistocene; Finipleniglacial with two phases of dynamic (F.G. 4 y 5) and climatic (F.G. 5) equilibrium associated with the Pleistocene deglaciation; high mountain phase (F.G. 6 y 7), with two morphogenetic episodics; and the Holocene pulses from the Little Ice Age.*

**RESUMEN.**- *Evolución glaciár del Alto Gállego (Montañas de Panticosa y Ribera de Biescas, Pirineo aragonés). Se reconstruye la evolución glaciár del Alto Gállego a partir del estudio de las formas de erosión y acumulación glaciár. Se describen diez pulsaciones, correspondientes a cinco fases mayores: Premáximo (F.G.O.), atribuido al Pleistoceno medio; Pleniglaciár, con tres pulsaciones de expansión (F.G. 1, 2 y 3), del Pleistoceno reciente; el Finipleniglaciár, con fases de equilibrio dinámico (F.G. 4 y 5) y climático (F.G. 5), ligadas a la deglaciación pleistocena; las fases de alta montaña, con dos pulsaciones (F.G. 6 y 7), atribuidas al Tardiglaciár; y las fases holocenas, de la Pequeña Edad del Hielo.*

**RESUMÉ.**- *Évolution glaciaire de Haut Gállego (montagnes de Panticosa et Rivage de Biescas, Pyrénées aragonaises). On étudie l'évolution glaciaire du Haut Gállego à partir de l'étude des formes d'érosion et accumulation glaciaire. On décrit dix pulsations, correspondant à cinq phases majeures: le Prémáximun (F.G. 0), attribué au Pléistocène moyen; le Pléniglaciaire avec trois pulsations d'expansion (F.G. 1, 2 et 3) attribuée au Pléistocène récent; le Pini-pléniglaciaire avec des phases d'équilibre dynamique (F.G. 4 et 5) et climatique (F.G. 5), liées à la deglaciación pléistocène; les phases de haute montagne, avec deux pulsations (F.G. 6 et 7) attribuées au Tardi-glaciaire, et les phases holocènes, du Petit Âge Glaciaire.*

**Key words:** *Pyrenees, glacial geomorphology, Pleistocene, Holocene, glacial phases.*

<sup>1</sup> Received December, 1991.

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The areas shaped by glaciers in the high Gállego basin, include the Ribera de Biescas and the Tena valley. Both areas are natural regions formed by the morphostructural compartimentation of the Pyrenean relief.

The Ribera de Biescas spreads from the Val Ancha depression -made up of Eocene maris to the Inner Ranges (*Sierras Interiores*). It includes a flysch unit, formed by the Eocene turbidites.

The Inner Ranges, Tendeñera and Telera, are formed by limestones with sand and dolomitic intercalations. They are a large morphostructural barrier separating the Ribera of Biescas from the Tena Valley.

The Tena Valley is located in the axil Pyrenees and is surrounded by the Inner Ranges, by the Permotriassic and volcanic materials in the south and west, and by the vigorous relief which forms the Brazato, Araitille, Gran Facha, Balaitous and Ferraturas ridge on north and east.

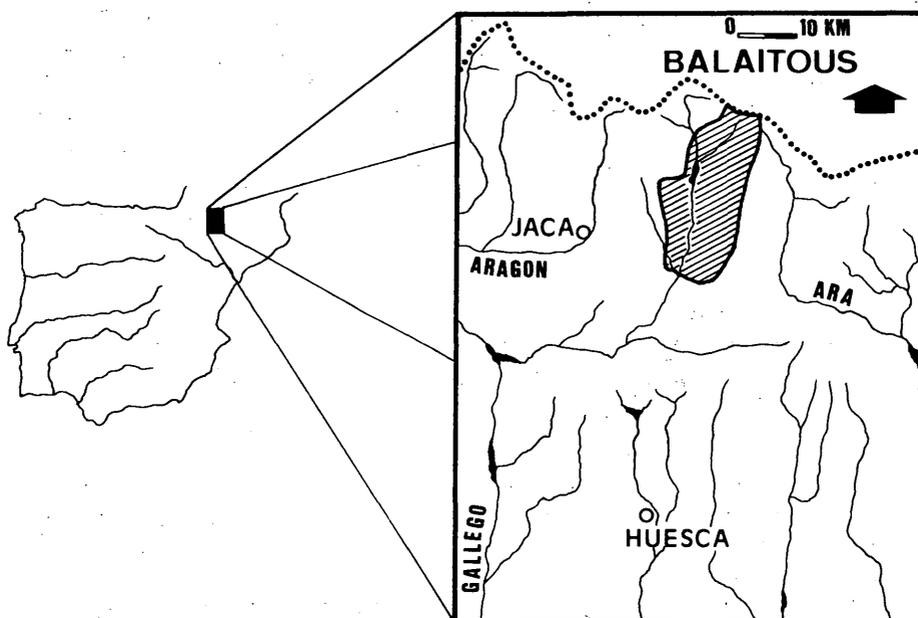


Fig. 1. Location of the study area in the Pyrenean range.

The valley morphology is organized according to material disposition, devonic limestones and shales following the hercinic structures direction. Moreover the Caunterets granitic batholitic, —which includes the highest point in the valley, the Balaitous peak at 3,150 m— and the Panticosa's one, both exhibiting their respective metamorphic aureoles, complicate the relief creating orographic knots which reach 3.071 m a. s. l. in Infierno-Argualas massif, which is formed by metapelites and marbles.

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The Tena Valley is divided into two main basins: the Gállego and Caldarés. The latter descends from the granitic and metamorphic areas of Panticosa and Infierno massifs. Observations on the glacial evolution of Tena Valley have mainly been performed in Caldarés basin.

The contributions to this subject in the Gállego basin began in the last century with SCHRADER (1836) dealing with the upper mountain, while MALLADA (1878) and PENK (1885) dealt with the glacial deposition landforms and the lateral obturation complexes of the Gállego Valley. These works have been followed by VIDAL BOX (1933), PANZER (1948) and SOLÉ SABARIS (1942). The made a first approach within the pluriglaciariist theory. More detailed studies carried out by FONTBOTÉ (1948), CASAS & FONTBOTÉ (1945) and BARRÈRE (1952, 1953, 1966 y 1975) put the Quaternary glaciation problems in perspective. Recently, MARTÍ-BONO (1977, 1978) and MENÉNDEZ & MARTÍ (1973) have worked on chronological problems. Other contributions are the cartographic ones (BARRÈRE, 1966; GARCÍA RUIZ & PUIGDEFÁBREGAS, 1982; GARCÍA RUIZ, 1989), the INEGLA studies on present glaciers (ALONSO *et al*, 1983; MARTÍNEZ DE PISÓN & ARENILLAS, 1988) and others recently made on the upper mountain phases, tardiglacial and Little Ice Age (CHUECA, 1989; SERRANO & AGUDO, 1989; SERRANO, 1990 a).

### 1. Glacial morphology

In the high Gállego the main morphological features are the glacial landforms, which are inscribed in the craggy morphostructural relief. The Pleistocene glaciers have left the most important features and they are responsible for the present glacial morphology.

#### 1.1. *Erosional landforms*

These are the landforms prevailing in the upper Gállego landscape, having caused the sharpest modifications on the preglacial morphology. The latter only stays in the axial divides and in the turbiditic units (flysch area). The preglacial topography and, especially, the structures led the glacial action had conditioned its dynamics. The main factors influencing on the different typologies showed by the depositional landforms are size, altitudinal position and the location of the different morphostructural units. They act on ice status, size, length and endurance.

The glacial cirques show different forms. They are usually wide, with flat and overdeepened bottoms, which show a moderate ice feed. Away from the highest peaks, barely organized landforms, can be found, mainly related to preglacial topography and morphostructures.

Troughs would lead the ice through asymmetrical valleys in the upper stretches, changing to sharper and more perfect troughs in the lower ones.

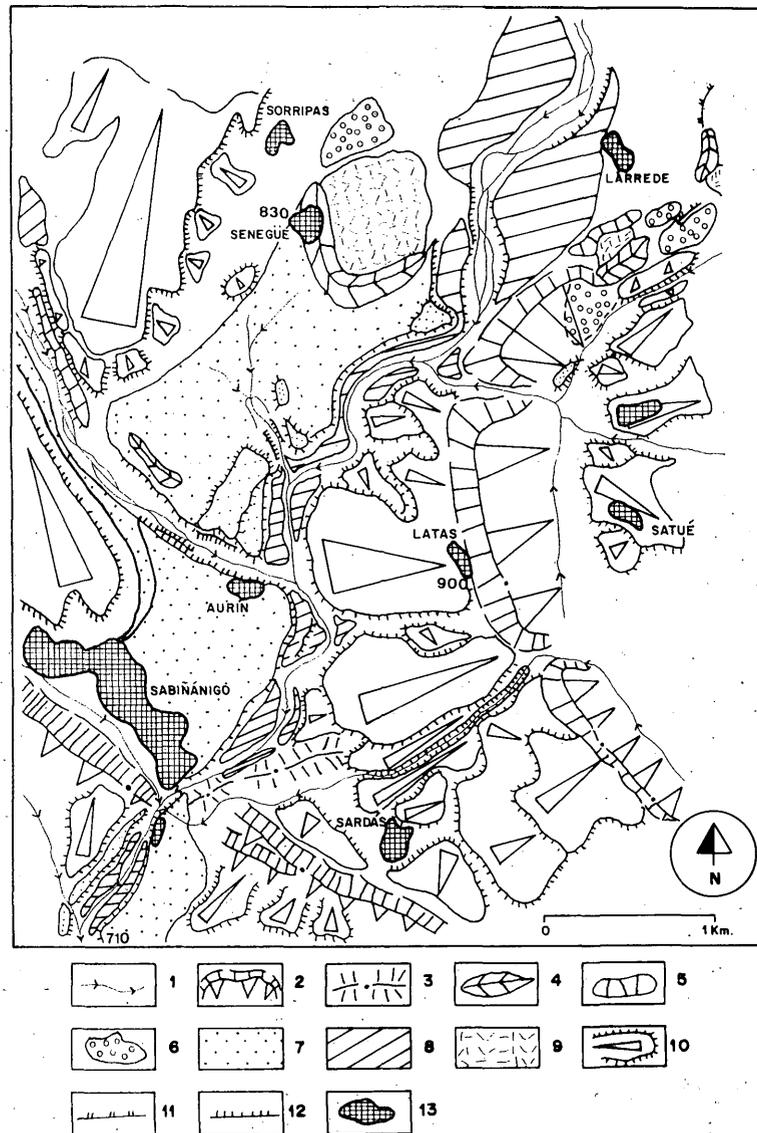


Fig. 2. Geomorphological diagram of the Senegüé-Sabiñánigo frontal morainic complex. 1, rivers. 2, structural hogback. 3, ridges. 4, moraines. 5, till deposits. 6, scattered morainic materials. 7, glaciofluvial terrace. 8, fluvial terrace. 9, obturation terrace. 10, "glacis". 11, trough walls. 12, escarpment. 13, village.

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The erosional landscape is produced by a relatively moderate but persistent feed from the heads. Erosional landforms analysis shows three main different morphogenetic phases:

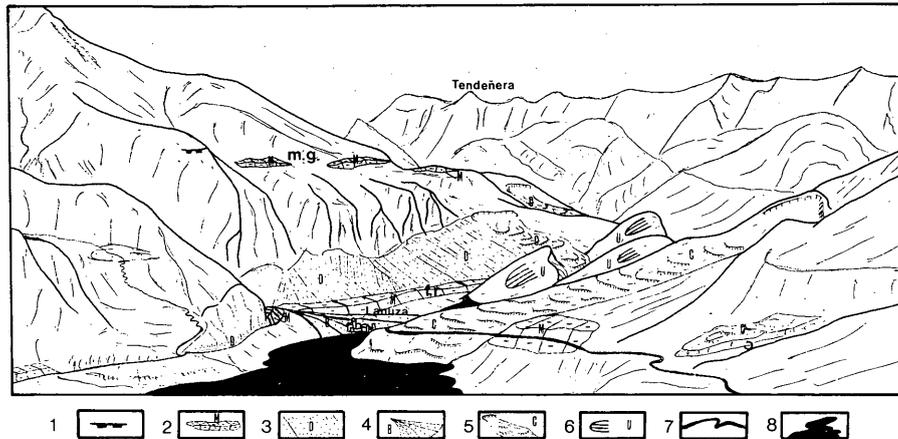


Fig. 3. Geomorphological design of The Gállego trough in Lanuza area. 1, trough walls. 2, moraine. 3, slope screens. 4, alluvial fan. 5, slides. 6, roches moutonnées hills. 6, road. 8, Lanuza reservoir.

—The first stage is only represented by the retouches and truncated ridges in the Sia valley. These are not connected to the major forms, and have been developed by an ice tongue coming from the Gállego Valley and following a disappeared topography, it was a depositional glacial phase previous to that which deposited the lateral moraines and dug the Gállego basin.

—The second stage was the most important one because it created the greatest erosional landforms, the main forms in the present morphology. During this period the glaciers made the Gállego, Bolatica, Ripera, Yenefrito, Caldarés and Gállego troughs. The cirques complex which fed these basins was also organized.

—The last stage acted only in the upper mountain, where the cirques appear overdeepened and remodelated as trough forms (Ibones, Azules, Xuans y Lavaza) and the erosional landforms show important changes in ice dynamics. This phase is very recent and the cirques created during the previous one were remodelated in detail.

### 1.2. *Depositional landforms*

They have little entity on the landscape, appearing as detail landforms which are mainly located in marginal areas.

### 1.2.1. The frontal and frontlateral complexes

The are placed at the bottom of the bottom of the valleys and cirques at different intervals, from 800 m a.s.l. in Senegüé up to 2.600 m in the Infierno massif.

a) *The morainic complex of Senegüé-Sabiñánigo*. This is a group of landforms originated by the glacial front at different stages. It is formed by: the frontal moraine of Senegüé, built by a supraglacial till; the glaciofluvial terrace of Aurin, linked to the moraine to which it is joined beyond Sabiñánigo at a single level + 15 m over the present thalweg; and the moraine of Aurin, damaged, and formed by a supraglacial till. Above this there are some scattered moraine remnants in the Satué depression at 870 m. They are connected to the Lárrede lateral moraine. Such remnants and a glaciofluvial terrace at + 3 m. above the present channel in the Satué depression point out a previous episode linked to the phase which originated the frontal complex.

b) *The morainic complex of Lanuza-Panticosa*. There are lateral moraines and diverse morainic remnants stay in Gállego and Caldarés valleys at 1,300 m. They point out the existence of a glacial front whose frontal parts have been destroyed by the proglacial and postglacial processes.

The Lanuza lateral moraine is formed by a lodgement till which supports a supraglacial till above it. Both are buried by stratified slope screes. In Panticosa the morainic remnants, formed by a supraglacial till, are very damaged. They are deeper and have wide obturation deposits.

c) *Frontal complexes in high mountain*. They appear located at intervals in troughs and cirques. In Arnales, Infierno, Pecico, Punta Zarra, Xuans, Letrero and Espelunz there are complexes at 2,300 m a.s.l. whose features are partially disturbed. In these cirques, above the previous complexes, between 2,400 and 2.500 m a.s.l., there are remnants of frontal moraines. Almost all of them are small and located at the foot of the cliffs. Higher above, there are only morainic complexes in the higher and better exposed cirques. We can find groups formed by two or three arcs in the Infierno, Punta Zarra, Tendeñera and Sabocos. In the lower cirques the morainic landforms have usually been substituted by rock glaciers located at the bottom of the cirques and at the foot of the cliffs.

d) *Lateral complexes*. In the Tena Valley there are lateral moraines at 1,800 m a.s.l. in the Estiviacha and Costera Ordenal. They surround the Panticosa and Lanuza lower complexes and are very damaged. These landforms and deposits involve the largest size reached by the glaciers in the valley.

The Ribera de Biescas lateral complexes are located in Lárrede, Oliván, Barbenuta, La Sía, Los Forcos, Asieso, El Puerto, Sobremonte and Escuer. They are larger than those in Tena Valley and are located in lateral valleys perched over the trough. They are organized as obturation complexes where the subglacial till, supraglacial till and lacustrine obturation deposit succession exists. All of them are covered by hillside deposits. The lateral arcs are well preserved; five in Sía, three in Oliván, three in Escuer and two in Sobremonte. All of them are the most important lateral morainic and obturation complexes

and are located at different heights. The depositional features, sediment weatherings and landforms of the deposits allow us to attribute the main landforms to the same glacial stage. We can relate them to the frontal complex of Senegúe-Sabiñánigo.

In La Sia and Espierre valleys there are erosional features and reworked morainic material scattered on the ancient bottom of the valleys. They are covered by lacustrine and slope materials. These features allow us to identify a glaciation previous to the remnants of erosional and depositional landforms in the Ribera de Biescas.

## **2. Glaciomorphological dynamics and evolution**

### *2.1. The Pre-maximum phase*

The blocks and megablocks scattered through the Espierre and La Sia valleys are of glacial origin. They may be classified as remnants of till or proglacial deposits but they are neither related to the main glacial landforms nor to the existing deposits. In Yésero they are all located over the ancient bottom of the valley there is also a lacustrine complex. The valley bottom deposits include scattered granitic blocks and a formation constituted by supraglacial till covered by lacustrine and slope deposits.

These sedimentary records and erosional landforms point to a stage previous to the main glacial landforms. This is mainly deduced from: the multiple processes which have acted on them with reworked morainic material included in recently altered ancient hillside deposits; the lack of well preserved landforms; their uneasy connection with the major glacial phase; and their relationship with the preglacial topography. They are remnants coming from an ancient, previous to the pleniglacial, cold phase. One can assume that they were created on a different morphology to the present and Pleniglacial ones and that they may be related to the Pleistocene and to one of its cold phases.

### *2.2. The Pleniglacial: ice maximal expansion*

The combination of morphostructural characteristics, topography and exposure has produced several dynamic areas, with the most active glaciers coming from the highest divides.

The northern exposure is of great importance in the formation of cirques in every massif. The large morphostructural barrier of the Telera and Tendeñera Ranges is the clearest example, as they show a sharp difference between their southern and northern slopes.

The pleniglacial landforms show deglaciation since the glacial maximum performed by episodes that give it a discontinuous character. During this period, in the stabilization maximum one, the glacier should have been 300 m deep in Ribera de Biescas, 400 m in Santa Elena and 600 m in Tena Valley.

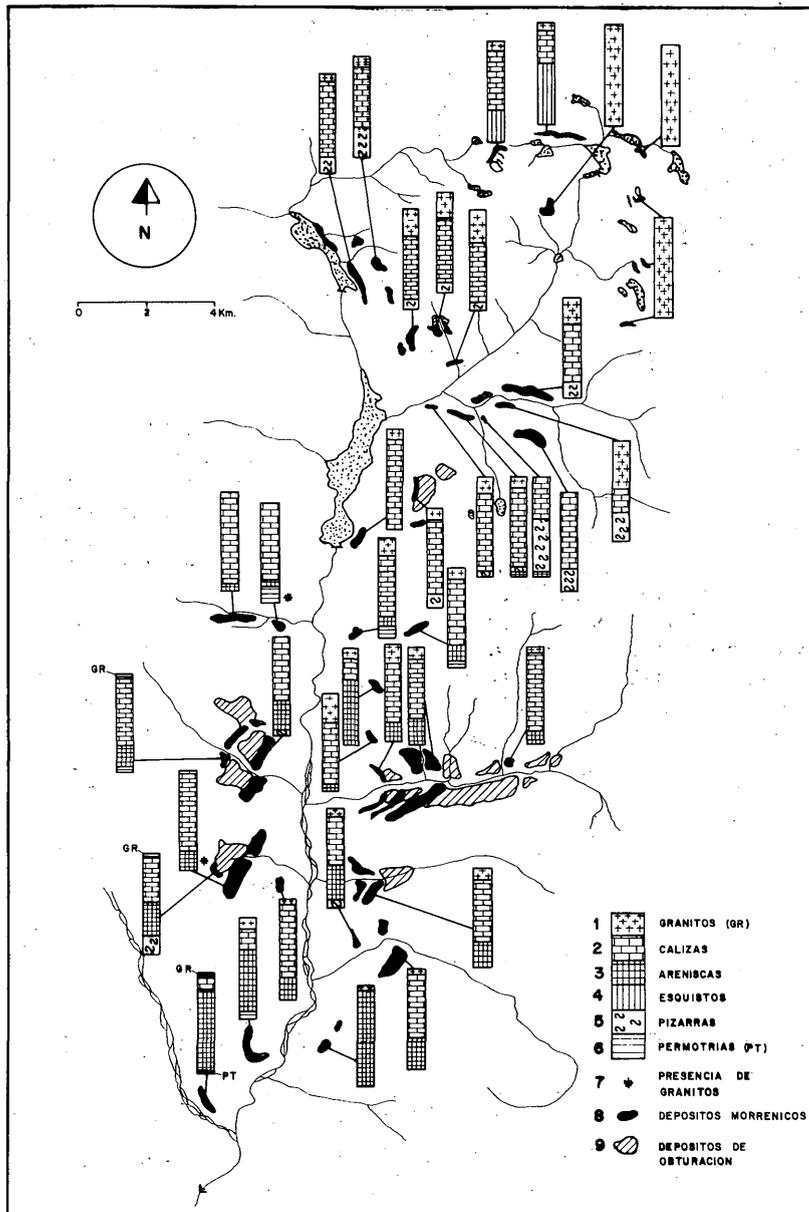


Fig. 4. Lithology of the moraine deposits in the study area. 1, granites. 2, limestones. 3, sandstones. 4, schists. 5, shales. 6, Permotriassic materials. 7, granite presence. 8, morainic deposits. 9, glaciolacustrine deposits.

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The study of the sediments in the tills provides information on the ice tongue dynamics and its origin. So we can distinguish between the landforms associated with the Gállego materials and those related to the Inner Ranges, mainly in El Puerto valley. Sediment analysis also shows the relationships between the Panticosa ice lateral complex and the Bolatica and Travenosa ice frontal complex (fig. 4).

The autochthonous materials play a major role, though always lower in the supraglacial till. The presence of granites in the east side of the glacier and the absence or very little presence on the western is a very important factor. Moreover, it shows the poor mixture kept by the different masses inside the glacier. This fact, very common in the glacial tongues all over the world, decreases in the glacier front. Here ice melting processes encourage the mixing of the sediments, confirming the morainic character of the Aurin frontal deposits (Fig. 5).

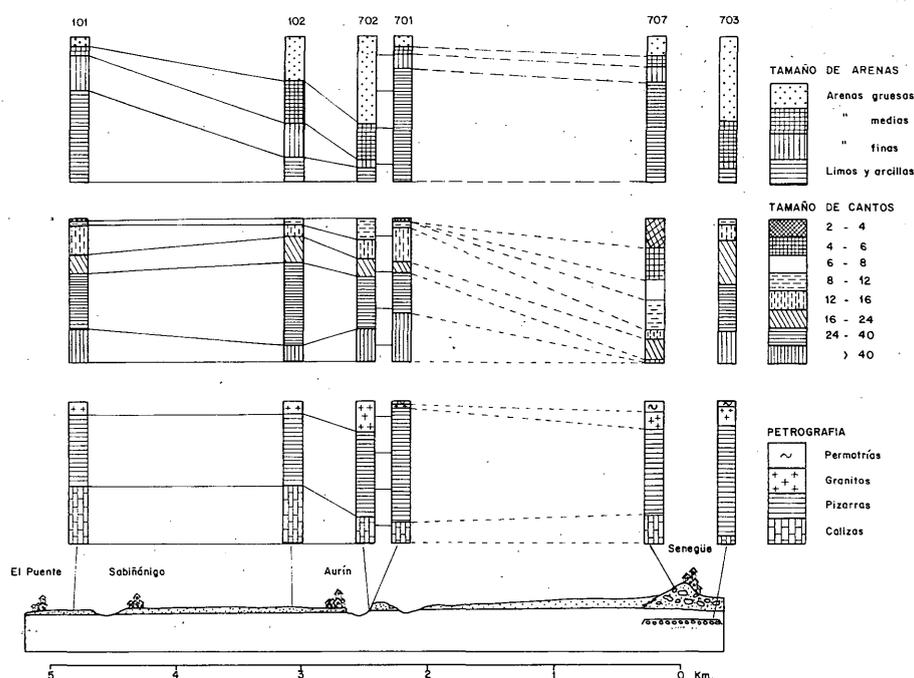


Fig. 5. Cross-section of the Senegüé fluvioglacial plain and sedimentological data.

The landforms related to the pleniglacial phase are the most important ones in glacial morphology. They are most representative in the upper Gállego basin. They constitute a large number of deposition and erosion landforms. We can differentiate: A maximal expansión pulse (F.G. 1) marked

by the external moraines in the lateral complexes of La Ribera de Biescas and Tena Valley, and by the sedimentary records in Satué depression; an intermediate regressive one (F.G. 2), related both to the Aurín moraine and to the intermediate moraines located in the Ribera de Biescas lateral complexes; and the inner stabilization one (F.G. 3), represented by the Senegüé frontal moraine and the inner lateral ones in Escuer, Oliván and Gavin. All of them belong to the same phase being the result of smaller pulsations in the pleniglacial (F. A.).

### 2.3. *The Finiglacial: the finipleistocene retraction*

After the maximal glacial stage a continuous and complex retraction took place. It had small pulsations that created deposition landforms.

—Finiglacial I or Búbal phase. It contains small landforms set in a confused disposition. These may be signs of a smaller equilibrium related to a dynamic variation of the glacial tongue itself, resulting in a local morphogenetic phase in Santa Elena. Nevertheless, it does not mean a stable climatic phase.

—Finiglacial II, disjunction of Lanuza phase. This phase is a well-defined one and it can be found in the Gállego river, Lanuza and Escarrilla complexes, as well as those at Panticosa. By that time, the glaciers have left the main valley and they only remain in Panticosa basin -the Caldarés tongue-, and in Lanuza -the Aguas Limpias-Gállego one-. These disconnected tongues - responsible for the deposition of two lateral morainic independent complexes during a long period of equilibrium and standstill-, show the climatic character of this pulsation.

A well-fed tongue in Ripera-Boltaica, coming from Travenosa, is the result of peculiar dynamics present on the northern side of the Inner Ranges (F.G. 5'). Here, a deglaciation occurred during of the late phases of the glaciation following the exposure and the great difference of level.

### 2.4. *Glacial phases in high mountain*

Almost the whole of the deglaciation was produced after the finiglacial retraction. Afterwards, three morphogenetic phases entirely different from the previous retraction occurred in the upper mountain.

#### 2.4.1. High mountain glacial maximum

In upper mountain areas a glacial phase is observed. It is characterized by the existence of small glaciers, of less than one Km in length and located in the highest cirques.

In this episode the glaciers extended around the highest peaks, so The Infierno, and Argualas areas are widely occupied by ice. In the Ibones Azules cirque (SERRANO & AGUDO, 1988) there are several glacial front locations which reflect the different episodes.

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Well-developed glaciers can be found in other mountain areas, but their importance is lesser. In Xuans cirque, a glacier nearly one Km in length created a small trough N-S direction and has left a morainic frontal complex at 2,300 m a.s.l. Another small frontal complex is located at 2,600 m a.s.l. and a fossil rock glacier occupies the bottom of the present cirque.

Remnants of depositional glacial forms can also be found in other cirques, but they are not as important as the former ones (Fig. 6). So, the Espelunz cirque develops a 1,500 m length tongue, a frontal moraine above it and a fossil rock glacier; Arnales, has a 1,400 m length glacier; the cirques

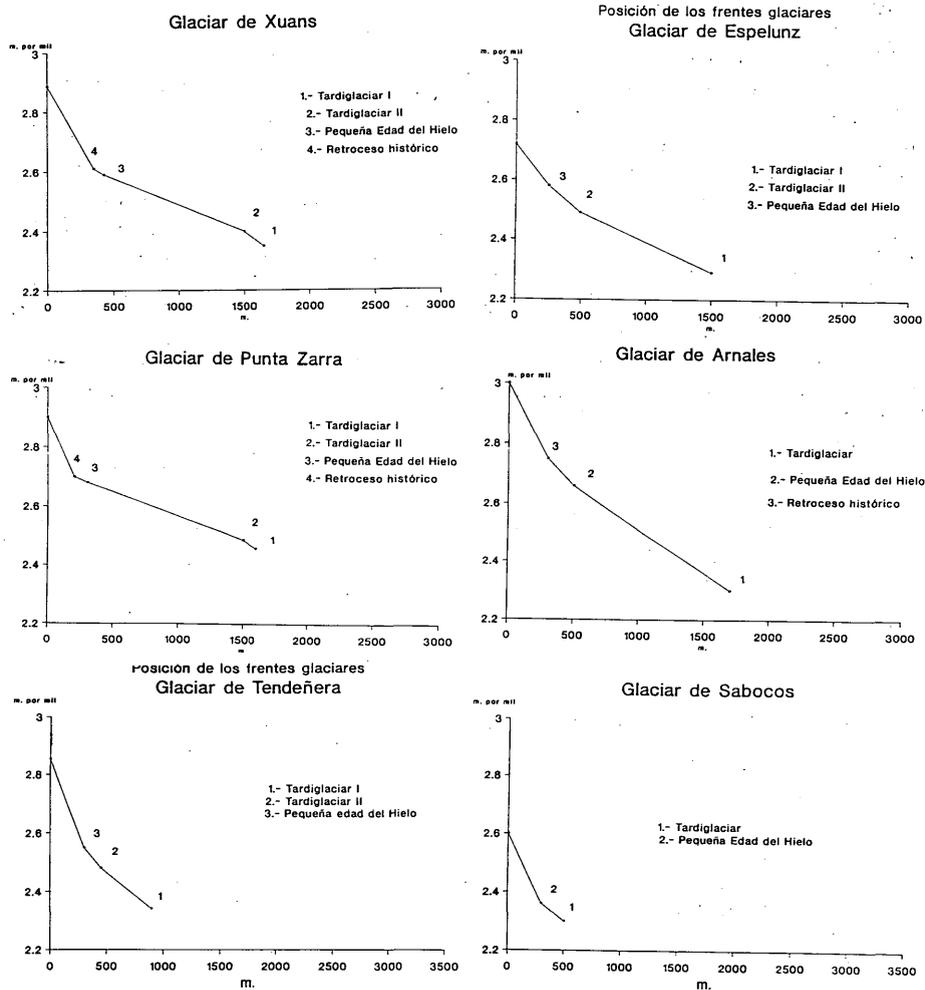


Fig. 6. Upper mountain glacier front position.

between Lana Cantal (2,956 m) and Punta Zarra (2,947 m) peaks show many glacial remnants that imply a tongue which was 1,750 m in length; finally, there are remnants of diverse magnitude in Pondiellos, Pecico, Brazato and Hoyas de Brazato, Letrero, Batanes, Baldairán-Ferreras and Tendeñera Range, as well as in the rock glacier complexes of Espelunz, Piniecho and Baldairán. All of them prove the existence of both a maximum period and a delayed one of stabilization. The distance between them is 1 Km and about 100 m in height.

Three areas with different behaviours can be established according to their location, lithology and height. The largest glaciers are found in the metamorphic aureole, better fed because of their exposure to the cold fronts and their greater height. In the granitic zone the ice feed is less encouraged, and so glaciers are associated with northern exposures. Here, the evolution towards two periods, pointed out in the metamorphic zone, is of morphological importance. It is shown in nearly every basin. Both in the southern zone and in Tendeñera there is a single period again because of the little importance that glaciaticism had on that areas.

The morphological evidences show two main phases:

–High mountain pulse I, an expansive one.- The morphogenesis is basically glacial, with glaciers close to 1 Km large. There are also rock glaciers -the only ones that show great development-, accompanied by an intense periglacial activity (SERRANO, 1990).

–High mountain pulsation II, external.- The most important morphological evidence of this phase is found at a greater altitude than the previous ones; moreover, it is scarcer. These circumstances imply the existence of glacial processes encouraged by altitude and exposure conditions, as well as periglacial processes creating a lot of rock glaciers.

#### 2.4.2. High mountain phase III, historical advance

This phase is the last cold pulsation having morphogenetical importance in our study area. The remnants found in the Infierno massif northern slope belong to this stage. They constitute a morainic complex showing frontal, lateral and retraction accumulations. These remnants have been described and analyzed previously (SCHRADER, 1936; BARRÈRE, 1952; ALONSO *et al*, 1983; MARTÍNEZ DE PISÓN & ARENILLAS, 1988; SERRANO & AGUDO, 1988), and they prove the existence of a glacier that reached 1 Km in length. A first glacial period with the front at 2,580 m a.s.l. and three retraction arcs spaced on the slope, have been observed.

In Tendeñera Range two different zones are located. They are in Tendeñera Peak northern face -with a more complex evolution than that in The Infierno-, and in the northern cirque in Sabocos Peak, N.E. face. Here, the ice has left three very clear and well-preserved arcs. They mean three pulses, there being not any doubt about the existence of a last and very recent equilibrium period.

During this period the glacial morphogenesis had a limited importance. It is only located on very local places where conditions were most suitable. The

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main features are: steep walls, peaks above 3,000 m a.s.l. and cirques above 2,600 m a.s.l. exhibiting N and NE exposures.

2.5. The present glaciers

The period between the last expanding phase and the present day is characterized by the nearly complete upper mountain deglaciation. A slow but constant retraction is produced. It has known occasional periods and

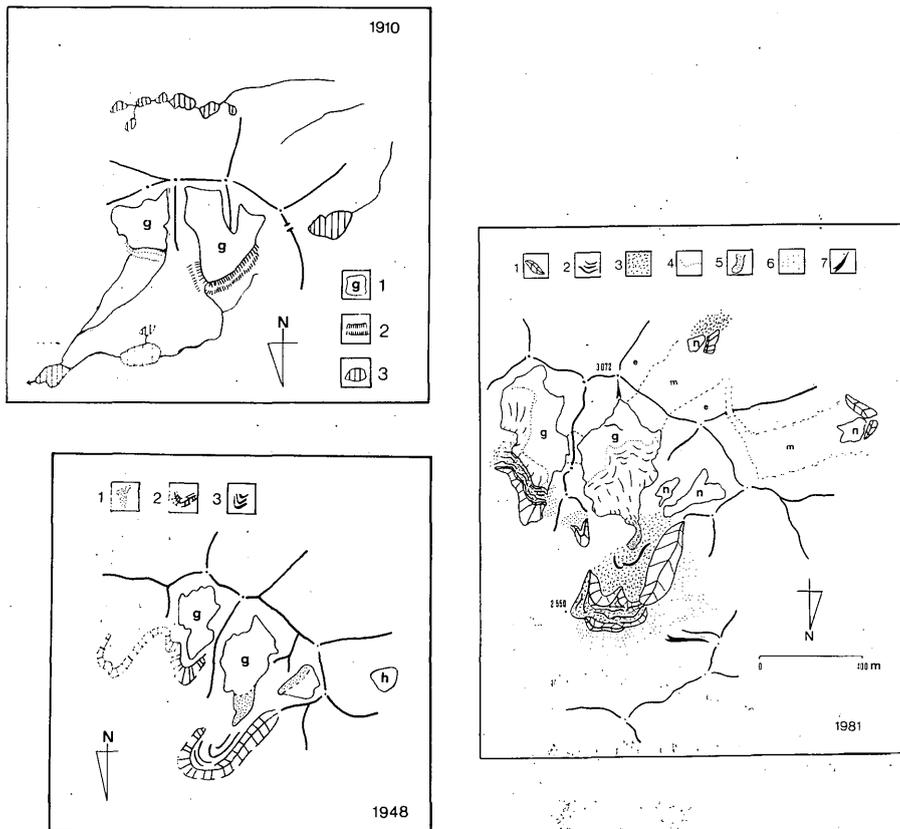


Fig. 7. The Infierno glacier evolution. a, in 1910 (from Gaurier, 1910, modified). 1, glacier. 2, moraines. 3, lakes. b, In 1948 (from Barrère, 1957, modified). 1, supraglacial morainic deposits. 2, moraines. 3, smaller morainic arcs. c, In 1981-1989. 1, moraines. 2, smaller morainic arcs. 3, scattered morainic material. 4, actual permanent snow limit. 5, supraglacial morainic deposits. 6, slopes. 7, avalanches channel. g, glacier. n, relict ice. e, schists. m, Infierno marbles.

annual variations until it has reached a certain calm in recent decades (EQUIP DE GEOMORFOLOGÍA, 1980; ALONSO OTERO *et al.*, 1983; MARTÍNEZ DE PISÓN & ARENILLAS, 1988). The glaciers have suffered a strong retraction, also recorded in the whole chain, during the last decade (MARTÍNEZ DE PISÓN *et al.*, 1991). The landforms may be considered belonging to previous periods as they are in many cases in the late phase.

Nowadays, the latest period of retraction is occurring. This retraction seems to be in its final phase. There only remains a single glacier with landforms showing some movement; it is located in Western Infierno. The others are only residual ices located in certain cirques. This marks the end of the morphogenesis caused by ice and glacial dynamics in the studied area. It is only present through an active periglacial dynamic.

### 3. Gállego glacial phases: a chronological approach

#### 3.1. *Pre-maximal*

We have associated both the phase characterized by the scattered granitic blocks and La Sia glacial erosion traces with a cold pleistocene crisis. This was previous to the Pleniglacial period and it is related to the Val Ancha's main glacial level and also to hydrographic network II (R.H. II). If we correlate it to the fluvial landforms previous to the Pleniglacial (SERRANO, 1991 b) this phase can be located in the Middle Pleistocene.

Traditionally, several glaciations are supposed to have taken place in the Pyrenees, but at most only two glaciations have recently been established (see SERRANO, 1989). A "recent" glaciation is observed. It may be associated with the Pleniglacial period in the Gállego, though it is also present in nearly every studied valley. It involves what was previously considered as Riss and Würm. An ancient glaciation has been identified in Lannemezan plane (HUBSCHMANN, 1984), where some evidences have recently been attributed to the Lower Pleistocene (HETU & GANGLOFF, 1989), High Ribagorza (VILAPLANA, 1983), Ariège (TAILLEFER, 1985; HERAIL *et al.*, 1982; MARDONES & JALUT, 1983; HERAIL *et al.*, 1987; ANDRIEU *et al.*, 1988).

In the same way, the Pleniglacial would have its maximum before 38,000 B.P., with retraction and equilibrium periods dated between 25,000 and 24,000 B.P.. It would include the quiet retraction phases. From this point on the deglaciation starts in the lower areas.

#### 3.2. *Pleniglacial period*

The largest ice extension in Gállego Valley is performed by the three pulsations registered in the lateral morainic complexes and in the frontal one in Senegüé-Sabiñánigo. In the northern slope the glacial maximum has been established before 38,000 B.P. with some retraction and stability periods until 26,000-24,000 B.P. when the definitive retraction and deglaciation began (MARDONES, 1982; JALUT *et al.*, 1982; MARDONES & JALUT, 1983; HERAIL *et al.*, 1987; ANDRIEU *et al.*, 1988).

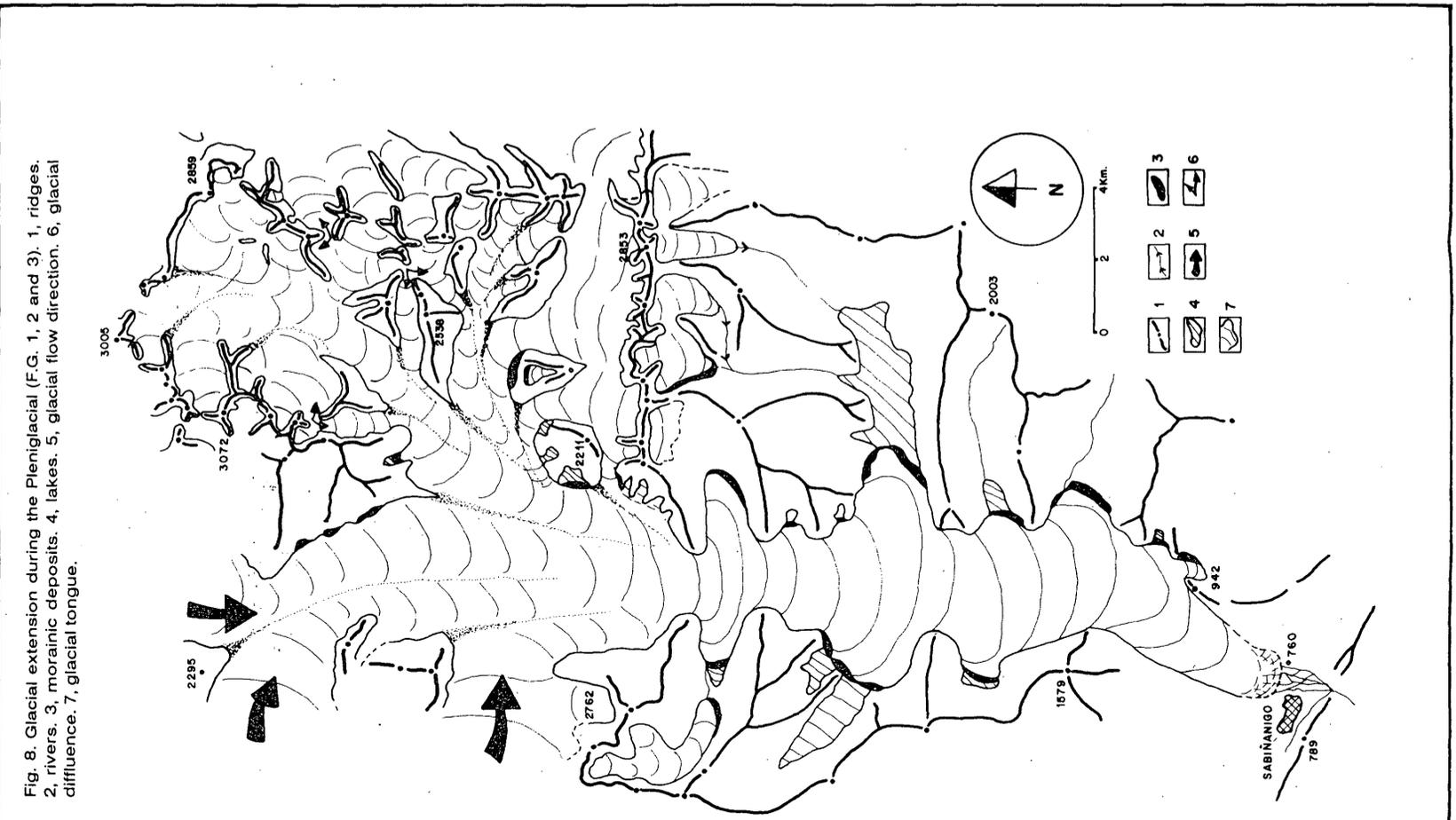
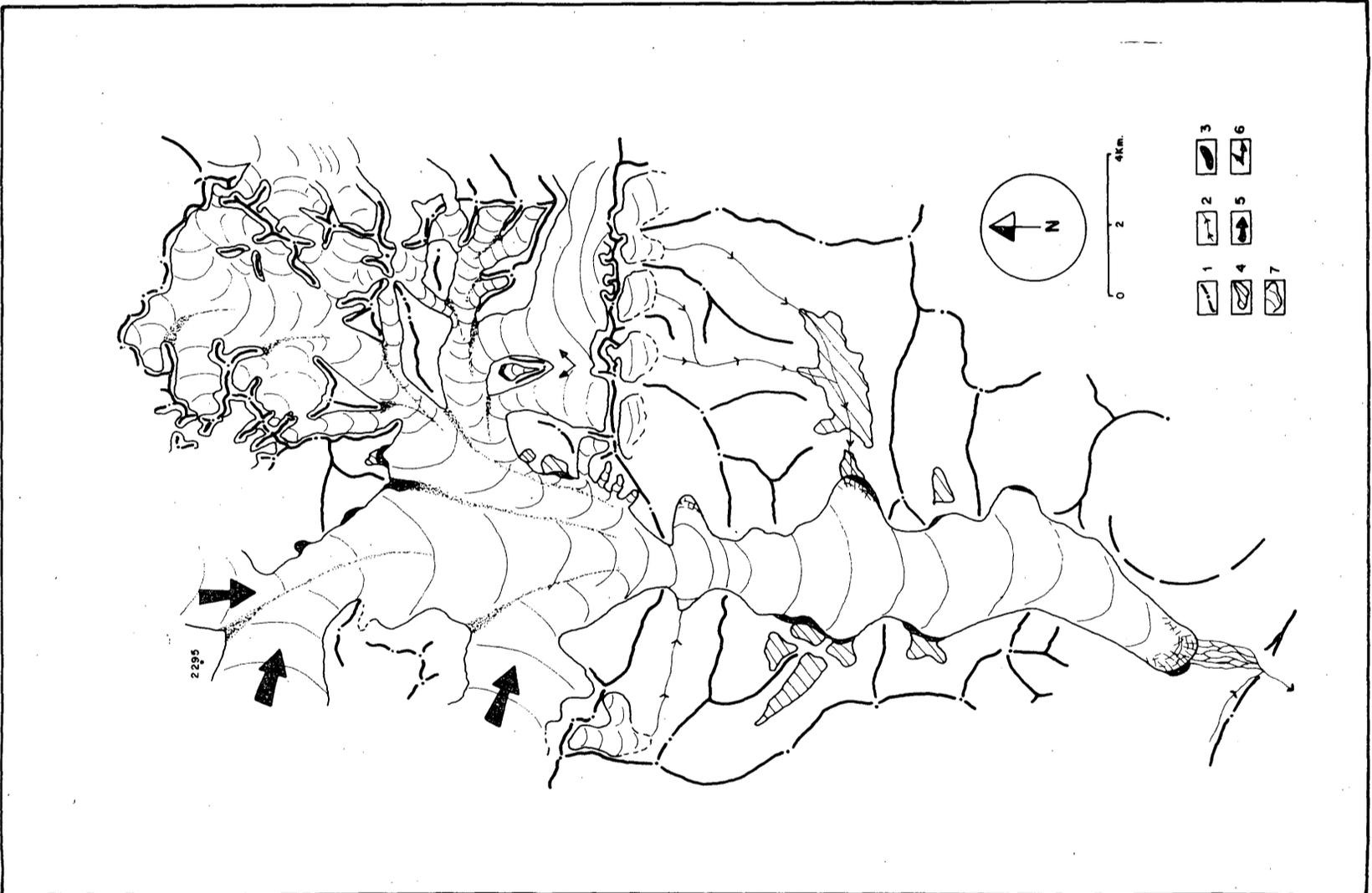
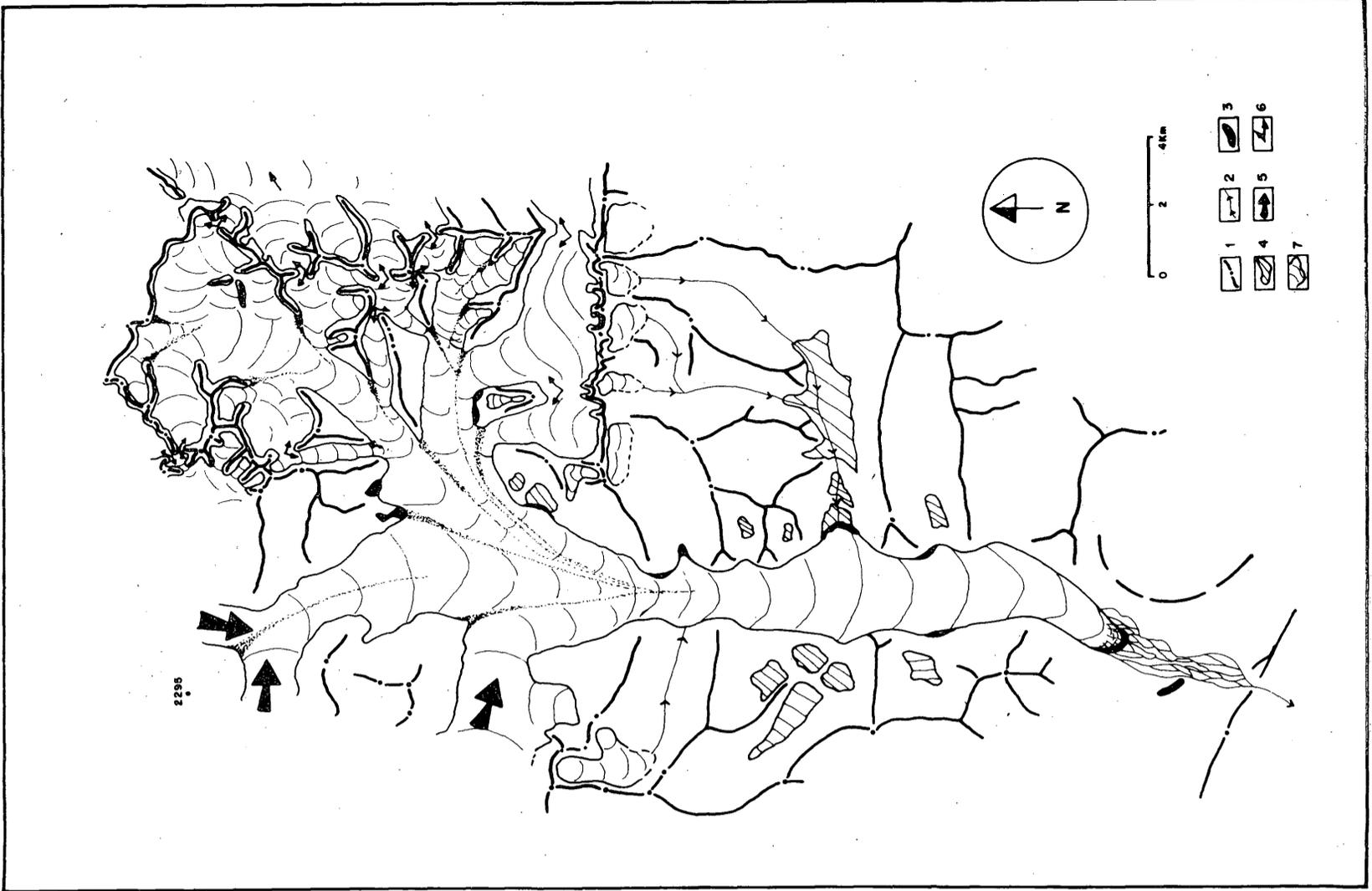


Fig. 8. Glacial extension during the Pleniglacial (F.G. 1, 2 and 3). 1, ridges. 2, rivers. 3, morainic deposits. 4, lakes. 5, glacial flow direction. 6, glacial diffluence. 7, glacial tongue.

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In the same way, the Pleniglacial would have its maximum before 38,000 B.P., with a retraction and equilibrium periods dated between 25,000 and 24,000 B.P. It would include the quiet retraction phases. From this point on the deglaciation starts in the lower areas.

### 3.3. Finiglacial retraction

We have divided this phase into different episodes: Búbal and Ripera have a dynamic character while Lanuza, has a climatic one. This last phase is the so-called "disjunction phase" by BARRÈRE (1963) because the glacial

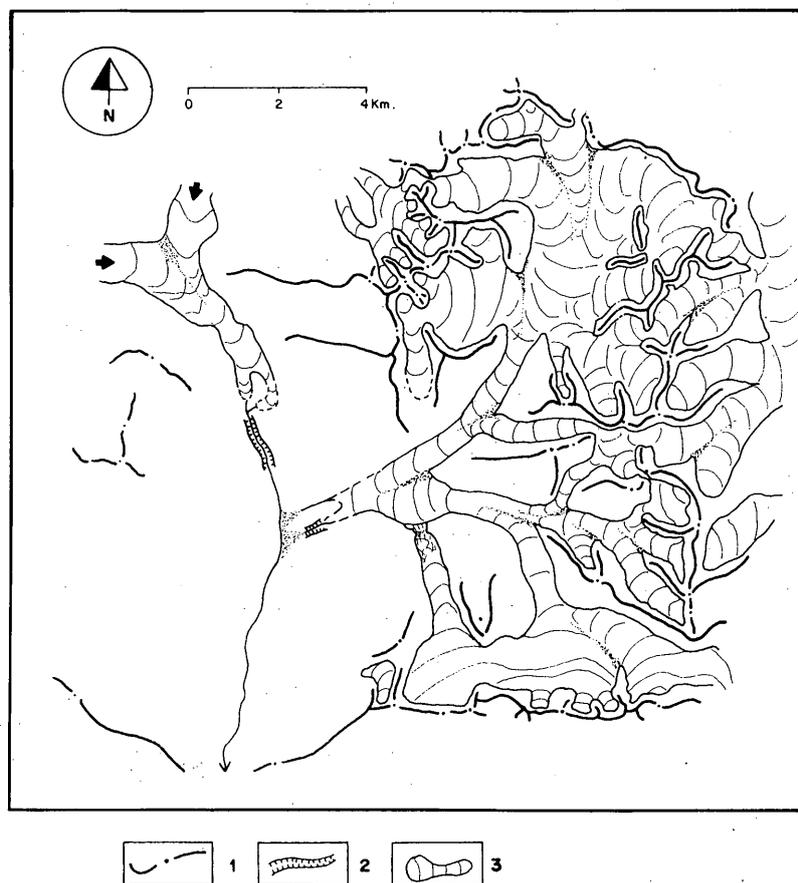


Fig. 9. Glacial extension during the Finipleistocene retraction, Lanuza phase (F.G. 5). 1, ridges. 2, outwash flow channels. 3, glacial tongue.

tongues stayed definitely separated and enclosed inside the mountains. Some similar retraction periods have been pointed out in the Ariège (TAILLEFER, 1985), Andorra (VILAPLANA, 1985), PALLARS (BRU *et al.*, 1985), Ribagorza (VILAPLANA, 1983) and Benasque Valley (MARTÍNEZ DE PISÓN, 1989).

The finiglacial retraction was produced after the last stopping period, dated about 26,000-24,000 B.P. (MARDONES, 1982; ANDRIEU *et al.*, 1988). These authors believe that a progressive retraction until its retreat to the upper valleys was produced about 16,000-15,000 years B.P.

### 3.4. High mountain phases

#### 3.4.1. High mountain expansion

The moraine presence is widely detected in the high mountain areas of the Pyrenees. Starting from the glacier extension and situation, we attribute these landforms, to the Tardiglacial, making an extrapolation from the existing bibliography (TAILLEFER, 1968; SERRANO, 1989). Its chronology has been established between 13,000 and 10,000 B.P. (MARDONES & JALUT, 1983; TAILLEFER, 1985, VILAPLANA, 1983; MONTSERRAT & VILAPLANA, 1987).

Palinologic analysis only detect a cold phase in the Tardiglacial. There is no trace of it (JALUT *et al.*, 1982) in Lourdes (MARDONES, 1982), Ribagorza (MONTSERRAT & VILAPLANA, 1987), the Tena Valley (MARTI-BONO, pers. comm.) and even in Ariège, in Freychinede peat bog. However, the geomorphological analysis allows us to establish a difference among several morphogenetic phases attributed to this period by some authors (BRU *et al.*, 1985; SERRANO, 1991a; MARTÍ & SERRAT, 1990).

We include the high mountain I and II episodes into the Tardiglacial because studying the morphological position of the moraines and the lichen cover, we have established that they are very close in time (SERRANO, 1991a; 1991 b). Taking into account palinological analysis we hypothetically assign the first episode to the Old Dryas, between 15,000 and 13,000 B.P. with cold characteristics (DUPLESSY *et al.*, 1981; RUDDIMANN & MCINTYRE, 1981; JALUT & MARDONES, 1984); the second one is located in the recent Dryas. The "tardiglacial interstate" would be located between them (JORDA, 1985).

#### 3.4.2. Historic growth: The Little Ice Age

This phase represents the last cold pulsation of some morphogenetic importance in the high Gállego basin. It is located in the Little Ice Age, the glacial reappearing between the XVIth and XIXth centuries.

In Infierno Massif, from historical papers, MARTÍNEZ DE PISÓN & ARENILLAS (1988) have checked the existence of a tongue glacier which started its retraction in the eighties of the XIXth century. Some large and cracked tongues were located and described by scientists and climbers like Rüssel

GLACIAL EVOLUTION OF THE GALLEGO VALLEY

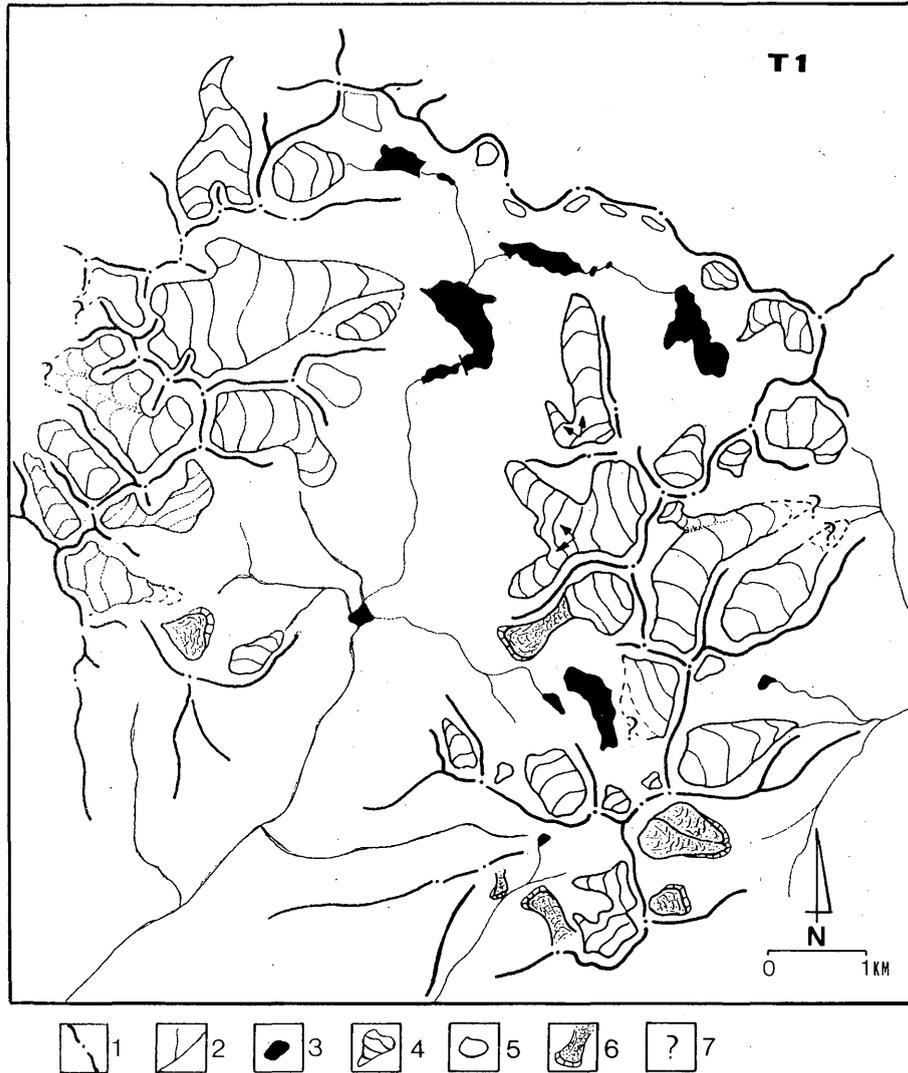


Fig. 10. Glacial extension during the upper mountain expansion phase (F.G. 6). 1, ridges. 2, rivers. 3, lakes. 4, glacial tongues. 5, relict ice. 5, rock glaciers. 7, not fixed glacial fronts.

in 1867 and Lequeutre in 1874. LUCAS-MALLADA (1878) also studied both distanced "ices" and SCHRADER (1936) pointed out in 1898 two glaciers in the Infierno and a third one in Pondiellos.

The pulsations responsible for the inner arcs may be related to those described by PLANDE (1947), BRUNET (1956) and BARRÈRE (1953). The claimed

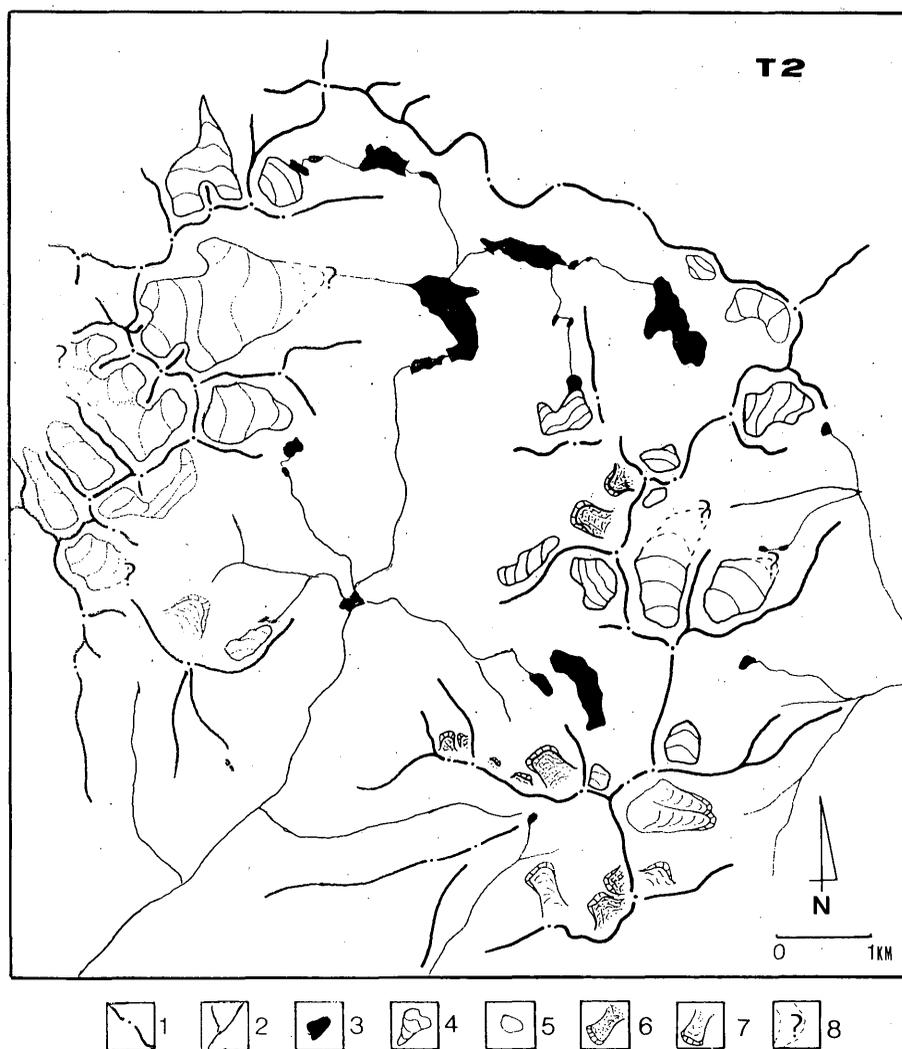


Fig. 11. Glacial extension during the upper mountain retraction phase (F.G. 7). 1, ridges. 2, rivers. 3, lakes. 4, glacial tongues. 5, relict ice. 6, rock glaciers. 7, ancient rock glaciers. 8, not fixed glacial fronts.

a stabilization beginning in 1905 and a maximum last pulsation between 1910 and 1915.

In the studied area the Little Ice Age is characterized by the existence of two pulsations: a first phase till the middle of the XIXth century produced a maximum expansion. It is followed by a retraction that finishes in the first

GLACIAL EVOLUTION OF THE GALLEGO VALLEY

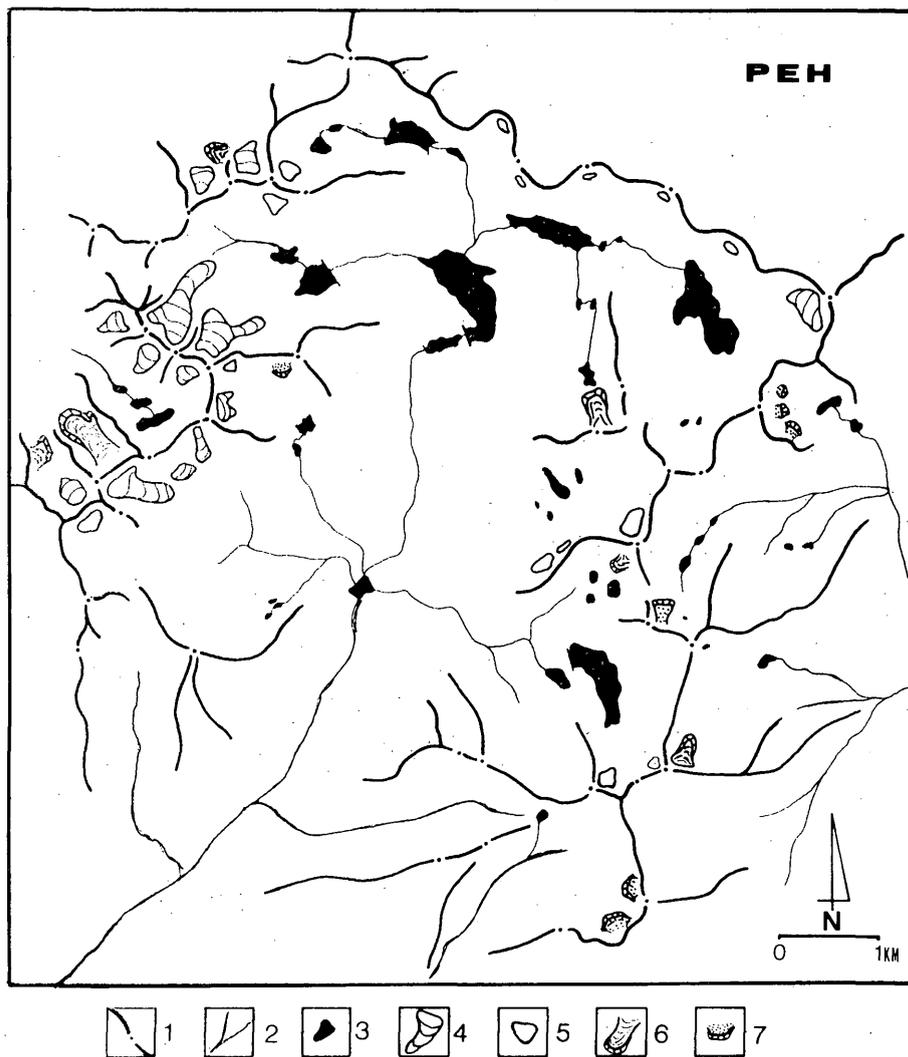


Fig. 12. Glacial extension during the Little Ice Age. 1, ridges. 2, rivers. 3, lakes. 4, glacial tongue. 5, relict ice. 6, rock glaciers. 7, Flowing debris.

decade of the XXth century. The glacier retraction up to its present state began at the beginning of this century. It marks the end of this phase.

It must be pointed out, finally, the absence of Holocene pulsations, although they are present in most of the temperate mountains in the world (LE ROY LADURIE, 1967; GROVE, 1977; ROTH LISBERGER *et al.*, 1980; ZIMBUHL &

HOLZHAUSER, 1988). This subject constitutes a difference between the Panticosa mountains and the Alpine ones.

#### 4. Conclusions

Climatic evolution, altitude and exposure have controlled the glacial dynamics in the study area. These factors, together with the morphostructural one, explain the differences of Pleistocene and Holocene glacial features and dynamics. The upper areas are dominated by erosion features, with well-developed cirques and troughs. Here, ice accumulation was the most important factor and the glacial history is more complex. Lowlands are also dominated by erosion features, but depositional ones are very frequent. Here, the confluence of tongues caused ice masses to enlarge, and erosion and deposition landforms are well performed by Gállego trough, as well as lateral and frontal moraines complexes.

In the high Gállego basin five main glacial phases have occurred: The pre-maximal (F.G. 0), Pleniglacial, Finipleistocene retraction, Tardiglacial and Little Ice Age. Such main phases are divided into different episodes of dynamic and climatic character spaced at the bottom of the troughs and slopes: Three main episodes during the Pleniglacial (F.G. 1, 2 and 3), with other features scattered in the Gállego trough walls; three more episodes during the Finipleistocene retraction, one climatic event (F.G. 5) and two dynamic ones (F.G. 4 and 5'); two morphogenetic phases from the Tardiglacial (F.G. 6 and 7); and several small ones during the Little Ice Age (F.G. 8) pulsations. All of them, together with the present glaciers and relict ice, are the Pleistocene and Holocene history of glacial features in the Tena Valley and Ribera de Biescas.

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