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Mid-Late Pleistocene glacial dynamics in the Valira valleys (Principality of Andorra). Asymmetries within the Pyrenees and correlation across the westernmost European mountain ranges

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Valenti Turu i Michels

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Universitat de Barcelona

Escola de Doctorat

Benvolgut/da Dr./a.

Em plau convocar-vos a l'acte de defensa de la Tesi Doctoral "Mid-Late Pleistocene glacial dynamics in the Valira valleys (Principality of Andorra). Asymmetries within the Pyrenees and correlation across the westernmost European mountain ranges" del Sr. Valentí Turu i Michels.

Dia: 24 d'abril de 2023
Hora: 11.00
Lloc: Aula Magna Carmina Virgili de la Facultat de Ciències de la Terra (UB)

Cordialment,

Dr. Santiago Giralt
secretari del Tribunal
Barcelona, 27 de març de 2023

SUMMARY:

Many sediment-covered mountain areas affected by the growth of Pleistocene glaciers are over-consolidated. Palaeoglacial conditions are deduced from glacial consolidation and site investigations. Geomorphological evidence on the glacial extent and history is in this Thesis used as a framework for hydro-mechanical flow simulations in the valley glacier of Andorra and the lower Isère glaciated valley. From the effects observed within the fossil record of ancient glaciated valleys, a reliable reconstruction of palaeo-glaciers thickness is possible when former ice-tonges overlayed porous aquifers, because subglacial erosion was mitigated by the subglacial water pressure and limited subglacial till formation. Records of minimum preconsolidation values indicate a buoyant surging glacier. For palaeoglacier reconstruction, the glacial valley geomorphology is clue providing the palaeogeographical calibration for further hydrogeomechanical calculations, especially at successive glacial stages during the deglaciation. A modern analogue, the Hansbreen sub-polar glacier, helps to set up a conceptual model allowing a better understanding of the glaciology of the two studied former valley glaciers, comparable to a polythermal glacier type.

Tills and glaciolacustrine deposits from Andorra's main valley and its principal tributary of La Massana allow for reliable local deglaciation patterns between GS-9 (40 ka b2k) and the Holocene Optimum (9.3–5.5 b2k). However, from the palaeoenvironmental data of the Pyrenees, deglaciation started sooner, and aridity affected the size of the glaciers from GS-10, resetting the valley glacier conditions ahead of GI-7. This affected the mainly prominent glacier-ice transfluence pass in the Pyrenees and the extension of the ice tongues on both sides of the mountain belt between GI-9 and GI-7, also during GS-5.2 and GI-5.1. During and posteriorly Heinrich event H4, aridity did not favour the development of valley glaciers in Andorra until stadial GS-7; however, glaciers in the Pyrenees progressed during the following Heinrich event (H3).

Using geochemical data (Al, Ti, Ca, K, P), a basic limnological study permits a palaeoenvironmental interpretation in Andorra by adding data from stable carbon isotope ($\delta^{13}C$) from bulk carbon samples and AMS dates. Results show four unreported inland $\delta^{13}C$ cycles linked to low water levels in the ice-dammed

lake of Andorra (La Massana palaeolake). At the beginning of each cycle, enhanced $\delta^{13}C$ bulk carbon values are found (> -23‰), a proxy of abrupt shifting from Type-C3 to Type-C4 vegetation. The beginning of the LGM and Heinrich events H3 and H2 were marked by enhanced $\delta^{13}C$ values interpreted as a product of strong climate change that boosted aridity. The retrieval period towards $\delta^{13}C$ depleted values (< -23‰) spans 4,500±500 years.

In Andorra, the beginnings of H3 and H2 events were relatively dry, and the second half of the climate was moist. The first evidence of sediments coming from the motion of a temperate-base glacier in the Pyrenees was from stadial GI-3. Moist conditions suddenly stopped at the beginning of Heinrich event 2 and returned at the end of H2. This moisture behaviour during H2 on the southern slopes of the Pyrenees is the opposite of the wet-to-dry conditions described in NW Iberia. Conversely, the H1 event had a wet-to-dry structure coast to coast of Iberia, including in the SE Pyrenees (Andorra).

A transition from single-phase-like glacier advances (NW Iberia) to multiphase glacier advances (SE Pyrenees) was due to a change from cold-based glaciers to temperate-based glaciers. However, glacier sensibility to global changes increases through time toward NW Iberia. The Last Maximum Ice Extent and the Global LGM did not concur in places experiencing multiphase glacier advances. Indeed both extreme behaviours do not correspond to the same type of glaciers. Polar-type glaciers in NW Iberia are in this Thesis invoked, while tempered or polythermal were frequent in NE Iberia.

Abrupt glacier advances and quick glacier recession in Andorra are interpreted as surges from a mass-imbalanced glacier. Two kinds of surge events are distinguished from available data in the Pyrenees, those surges produced by overfed ice tongues fed by short-lived cold spells (in GS-2b and H1) and those surges produced by buoyant melting ice tongues within the glaciated valley (between stadials GS-5/GI-4, stadials GI-3/GS-3 and stadials GS-2.1b/GS-2.1a) by a warm moist climate. The winter solar rate increase (GI-3 and GS-5.1) and the evidence of polythermal-type glaciers matched. Conversely, summer insolation increases and wet-ice type oversaturated glaciers and surges at GS-2a concurred. In Andorra the snow-overfed glacier surges correlate with the decreasing winter insolation during GS-2b. In Iberia, the LGM would be placed between 23-17.5 ka and glaciers spread, linked to both wet westerlies from the North Atlantic and moisture supply of Mediterranean influence, reaching almost the eastern side of the Central Pyrenees, leading us to suppose an NW-NE seesaw climatic relationship across Iberia almost since GS-5.1. The oscillations of the oceanic thermal front promoted wet/dry westerly winds crossing over the Pyrenees, pushing back the Mediterranean influence towards the East.

By classifying glacial phases of the northern Iberian Peninsula fringe, four common glacial phases arise for the last glacial cycle:

A An early LGC starting at MIS 5d having a recessional period during MIS 5c. Cold-type glaciers are expected to have existed in some of the extreme NW of the Iberian mountains until Termination 1.

B The Last Maximum Ice Extent occurred mainly during MIS 5a – MIS 4. An asymmetrical glacier recession during MIS 3 was related to an increase in eastward aridity.

C Significant glacier fluctuations during the MIS 3 – MIS 2 hinge, the appraisal of temperated-polythermal type of glaciers accompanied by a generalised moisture increase entailing valley glaciers to surge.

D Side-to-side mountain range-scale deglaciation dissymmetry in MIS 2. The widespread expansion of tempered-polythermal type glaciers during the LGM period and Termination 1 had a proportional expansion to the available moisture.

The final deglaciation is characterised by relictual cirque glaciers disappearing during GS-1. In Andorra, a general rise in local river base levels occurred until the Holocene Optimum.

Unravelling the afore-cited glacial phases and unexpected research allows for a tesselated mapping of the SW continental Europe concerning part, or all of the LGC glacial phases outlined above:

1 – Areas where glaciers were prevalent during MIS 2, like the Iberian Central System, the NW and S French Massif Central, the NW Jura and the maritime Alps.

2 – Areas having a far-flung end moraine produced in a previous glacial phase (MIS 6 or posterior) showing stability until the MIS 2, as for ice caps/fields from the southern half of the Galicia mountains.

3 – Areas of pseudo-pleniglacial or apparent-pleniglacial condition, despite previous glacier recessions phases (albeit challenging to identify), as in most of the northern slope of the Pyrenees.

4 – Areas of multiphase glacier advances, like most of the southern slope of the Pyrenees, most of the Cantabrian Mountains, the half north of the Galicia mountains, the High Atlas, Sierra Nevada and the SW French Massif Central, the western Alps and the Vosges.

5 – Areas where glaciers were present from the LGM until Termination-I, like the northern Iberian range and Sanabria in Iberia. Nevertheless, other mountain ranges have a Type 5 glaciation scenario, like the southern Black Forest in Germany.

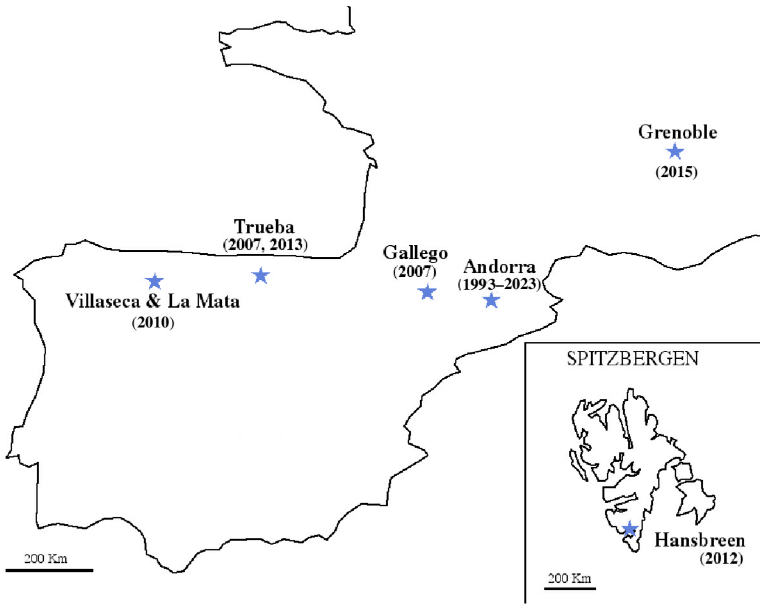

Figure: Extended studied areas away from Andorra, like SW Spitzbergen as a modern analogue, are referred to distant glaciated valleys like the SW Alps and the Cantabrian Mountains until the Pyrenees. References are Turu et al. (1993, 2002, 2007, 2016, 2023), Jalut et al. (2010), Turu (2012), Serrano et al. (2013), Ménard (2014).

Keywords: Pyrenees, glaciations, glacial dynamics, Late Quaternary chronology, glacial valley deposits, over-consolidation, glaciolacustrine, palaeoenvironment, polythermal glaciers, sub-Milankovich cycles, glaciation types, SW Europe.