Available online http://amq.aiqua.it
ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, Vol. 31 (Quaternary: Past, Present, Future - AIQUA Conference, Florence, 13-14/06/2018), 225 - 229

https://doi.org/10.26382/AIQUA.2018.AIQUAconference

THE LATE PLEISTOCENE MULTIFOLD GLACIATION IN THE ALPS: UPDATES AND OPEN QUESTIONS

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ABSTRACT: The stratigraphic record of Late Pleistocene glaciations in the Alps is well defined for the Last Glacial Maximum (LGM) thanks to recent chronological and stratigraphic studies. These allowed to compare the spread of the glaciers to the global climate models for the LGM, whereas, the amplitude of glacial advances in the pre-LGM Late Pleistocene needs further investigation in chronostratigraphic archives, with emphasis on the dynamics of Alpine glaciers during cold stages MIS5d, MIS4, and the several MIS3 stadials. In this perspective, the stratigraphic archives bearing finite ages close to the radiocarbon method limit could be tested for improvements of the available chronological methods.

KEYWORDS: Late Pleistocene, Alps, glaciations

1. INTRODUCTION

According to the isotopic record from ice-cores, the Late Pleistocene was marked by at least four major cold stages (MIS5d, MIS5b, MIS4 and MIS2, the latter culminating in the Last Glacial Maximum, LGM). The global LGM is a climate-stratigraphic concept defined as the last period framed in the last glaciation when global ice sheets reached their maximum integrated volume, currently between 27 and 19 ka BP (Clark et al., 2009) or 30 and 17 ka BP (Lambeck et al., 2014).

Recent climate-models investigated the interaction among atmospheric circulation, oceanic circulation and ice-sheet waxing (e.g., Beghin et al., 2015; Liakka et al., 2016). First LGM proxy reconstructions in the Alps allowed first validation of these models (Luetscher et al., 2015). In the Alps, recent stratigraphic investigations expanded the dataset of the Late Pleistocene glacial events, especially the time constrains for glacier spread during the LGM.

The development of Alpine valley glaciers during the Pleistocene has been the topic of a large number of studies since the 19th Century and especially after the milestone work by Penck & Brückner (1909), in which the multi-glaciation theory was illustrated. During the 20th Century the application of this subdivision acted as a postulate, adopted in all the stratigraphic works within the Alpine realm, including geological mapping. Only after Bowen (1978) and Šibrava (1986) this subdivision was suggested to be abandoned and substituted by an array of stratigraphic approaches including allo-, chrono-, bio and isotopic stratigraphy. The development of dating methods in the last forty years improved the chronological assessment of glacial units, especially for those related to the LGM and those marked by a reverse paleomagnetic signal.

2. HISTORICAL BACKGROUND

In the Alps, the last glacial cycle has been related to the Würm glaciation (Penck & Brückner, 1909) and its three-phases subdivision formalized by reference sections and type localities of regional value in the Austrian Alps (Chaline & Jerz, 1984; see also Spötl et al., 2013). This regional scheme distinguishes the “lower” (broadly encompassing the post-Eemian MIS5), the “middle” (MIS4 and 3) and the “upper” Würm (MIS 2). The designation of stratotypes and / or reference sections and type localities for continental units is prescribed by the International Stratigraphic Code currently in use (Murphy and Salvador, 1998). However, until recent times, the use of this Alpine regional stratigraphy in correlating end-moraine systems was mostly supported by criteria based on field properties of weathering profiles. These field criteria were poorly checked by laboratory calibration analysis, while their chronological implications were poorly tested by independent dating methods. Finally, most of the field weathering profile criteria failed the proof of geochronometric dating. Indeed, several glacial bodies forming the Italian end-moraine systems, identified by their weathering profiles, and classified into several distinct Middle or Late Pleistocene “glaciations” (e.g. Venzo, 1965; 1977; Petrucci, 1970; Bini & Zuccoli, 2004) were resettled to the LGM whenever radiometric dating has been successfully applied (Ravazzi et al., 2014; Gianotti et al., 2015; Monegato et al., 2017; Ivy-Ochs et al., in press). It turned out that the largest end-moraine systems, formed during the LGM at the Italian fringe, consist of several acme moraine complexes staked by millennial climate events (Monegato et al., 2017; see Fig. 1). Further investigation is needed in other large end-moraine systems including glacial units ascribed to Middle Pleistocene on the base of weathering profiles (e.g. the Besnate Allogroup in the Ticino and

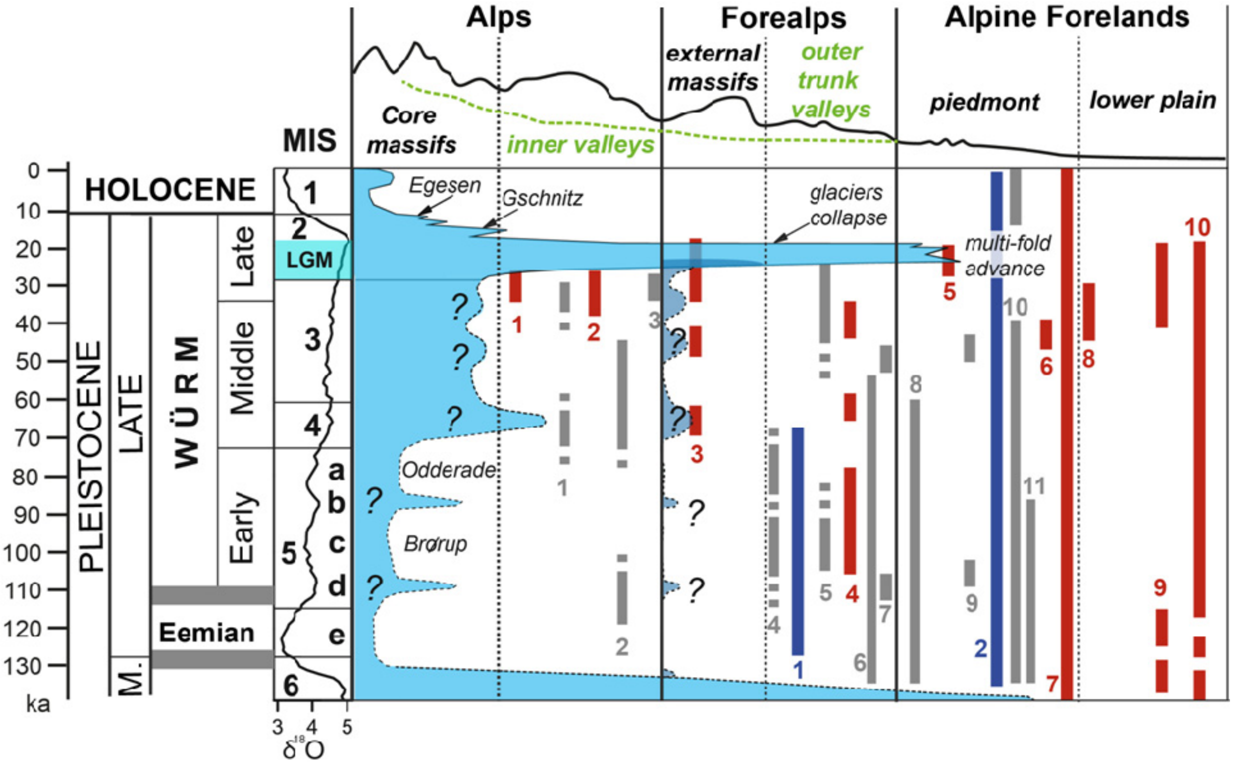

Fig. 1 - Schematic overview of the temporal development of the extent of the glaciers from the Alpine core massifs (pale blue) and external massifs (dark blue) compared to the stratigraphic ranges of important and well dated Würm palaeoclimatic, sedimentary and palaeoenvironmental archives (vertical bars) in the Alps and their foreland (see also Mayr et al., 2017). Western Alps (in blue): 1) North Grésivaudan (Guiter et al., 2008), 2) Les Echets (de Beaulieu & Reille, 1984). Northern Alpine sector (in grey): 1) Baumkerchen (Spötl et al., 2013; Barrett et al., 2017), 2) Unteragenberg (Starnberger et al., 2013), 3) Gossau (Preusser et al., 2003), 4) Hopfgarten and Kitzbüel (Reitner & Draxler, 2002), 5) Nesseltalgraben (Mayr et al., 2017), 6) Samerberg (Grüger, 1979), 7) Thalgut (Preusser & Schlüchter, 2004), 8) Mondsee (Drescher-Schneider, 2000), 9) Niederweningen (Dehnert et al., 2012), 10) Füramoos (Müller et al., 2003), 11) Jammertal (Müller, 2000). Southern Alpine sector (in red): 1) Albeins (Fliri, 1971), 2) Spormaggiore (Avanzini et al., 2012), 3) Vilminore (unpublished data), 4) Valeriano (Monegato et al., 2010), 5) Garda and Tagliamento (Monegato et al., 2007, 2017), 6) Castelnovate (Orombelli, 1986), 7) Fimon (Monegato et al., 2011), 8) Casaletto Ceredano (Ravazzi et al., 2018), 9) Piancada (Hippe et al., 2018), 10) Azzano Decimo (Pini et al., 2009). The stacked northern Atlantic 18O record from benthic foraminifera and the marine isotope stages (MIS; from Lisiecki and Raymo 2009) are shown for comparison.

Adda Rivers glacial systems, Bini et al., 2004).

3. RECENT UPDATES OF THE UPPER PLEISTOCENE UNITS IN THE ALPS

Regarding the three subdivisions of the Würm glaciation, in the Austrian stratotype of Baumkirchen the upper Würm onset, marked by the advance of the Inn glacier over the middle Inn valley, was recently chronologically constrained at 32-33 ka cal BP (Spötl et al., 2013). At the same site, the occurrence of lower-middle Würm advances has been investigated in recent years (Barrett et al., 2017). Studies on lacustrine records around the Alps yielded climatic and environmental information which show an overall agreement with glacier build-ups before LGM, i.e. during MIS5d and MIS4, but also MIS3 stadials (Drescher-Schneider et al., 2000; 2007).

The sedimentary traces of advances predating the upper Würm are scattered and scarce in some sectors (Fig. 1). In the Austrian sector of the Alps a few outcropping sections and core records document upper Pleistocene pre-LGM glacial and glaciolacustrine deposits (Starnberger et al., 2013; Barrett et al., 2017). In the Swiss sector of the Alps the occurrence of three different advances was highlighted in the definition of Birrfeld Glaciation (e.g., Preusser et al., 2011; Buechi et al., 2017) through OSL and radiocarbon dating on glaciofluvial and glaciolacustrine deposits. As in the Austrian part, the lower-middle Würm advances were recognized in cores and stratigraphic sections generally buried by the LGM deposits, whereas moraines of relevant age were not documented in piedmont amphitheaters.

On the Italian side of the Alps, pre-LGM cold / continental phases are represented by subtle alluvial sediment piles in the Late Pleistocene lower plain successions (Pini et al., 2009; Hippe et al., 2018), suggesting a scarce sedimentary delivery from the mountains or, alternatively, that most of the deposits related to cold stages were stored within the valleys. In the Friulian piedmont plain the Valeriano Creek succession, related to a small foothill catchment, shows gravel aggradation during the MIS5d, and, after fine-grained deposition ascribed to MIS5c-a, another coarse-grained unit occurs before 36.0±2.2 cal ka BP (Monegato et al., 2010). Similar situations, with ages close to the radiocarbon method limit, are reported for the Ticino system in the Alpine foreland (Castelnovate site, Orombelli, 1986). These sites indicate active aggradation of fluvial systems belonging to glaciated catchments at least during cold phases of MIS3.

4. THE LGM RECORD AND INFERENCES ON GLOBAL CIRCULATION MODELS

The culminations occurring in the late Würm are now commonly associated to the LGM thanks to a robust chronology available for several sector of the Alps including end-moraine systems (e.g., Monegato et al., 2007, 2017; Ivy-Ochs et al., 2008; Ravazzi et al., 2012; Federici et al., 2016) and the related outwash plains (Fontana et al., 2010). The spread of the Alpine glaciers reached its maximum at about 26-24 ka (Fig. 1) in correspondence to the insolation minimum (Laskar et al., 2004) and the Greenland Stadial 3 (Andersen et al., 2006), considered to be the peak in global ice volume (Hughes and Gibbard, 2015). Comparing the LGM development of Alpine glaciers to the waxing of the boreal ice-sheets, it is interesting the in-phase relationship with the North American Ice-Sheet (NAIS) at 26-24 ka. According to the atmospheric circulation models (e.g., Beghin et al., 2015; Liakka et al., 2016) the topography of the NAIS controlled the circulation and the development of the European ice-sheets, including mountain glaciers (Monegato et al., 2017). According to these models, during the MIS5b and MIS4 the European ice-sheet experienced a larger expansion towards the north, due to the lesser extension of the NAIS and the circulation track delivering moisture northwards. During these phases, the Alps were mostly interested by westerlies and the glaciers of the western French Alps likely reached sizes similar to the LGM ones. Different circulation tracks could have meant changes in distribution of the precipitations in the Alps, with consequence of spread of local glaciers, especially in the forealpine sector and the western French Alps, where elevated plateaus could have developed large glaciers during pre-LGM cold phases. This possible large extension of glaciers in the western Alps has been modeled by Seguinot et al. (2018), but sedimentary evidence needs to be confirmed, starting from those sections where wood remnants are dated close to the radiocarbon limit.

ACKNOWLEDGEMENTS

The authors are grateful to Giuseppe Orombelli and Paolo Mozzi for their essential comments.

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Ms. received: May 7, 2018
Final text received: May 18, 2018