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Last glacial maximum glaciers in the Northern Apennines reflect primarily the influence of southerly storm-tracks in the western Mediterranean

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ABSTRACT

During the Local Last Glacial Maximum (LLGM), the Northern Apennines hosted more than 100 valley and mountain glaciers covering collectively more than 260 km^2. Cosmogenic ^{10}Be exposure ages obtained for the first time along the Apenninic range constrain the age of the LLGM to pre-date ca 21 ka. The estimated volumes of these Late Pleistocene glaciers exceeded 9.1 km^3 w.e. Their reconstructed Equilibrium Line Altitudes (ELAs) range from ca. 1200 m a.s.l. for northerly facing compound basin valley glaciers to ca. 1620 m a.s.l. for southerly facing mountain glaciers. Reconstructed ELAs in the western sector of the Northern Apennines were among the lowest recorded for the whole of the Italian peninsula, including the Alps, and also when compared with other mountain chains in the surrounding Mediterranean basin. These probably reflect exceptionally high accumulation rates fed by storm tracks in the western Mediterranean, which in turn has implications for the atmospheric circulation pattern that prevailed in the region at the time.

1. Introduction

During the Middle and Late Pleistocene cold stages most of the mountain ranges facing the Mediterranean Basin repeatedly hosted upland glaciers (e.g., Messerli, 1967; Ehlers and Gibbard, 2004; Hughes et al., 2006a; b; 2010, 2013; Hughes and Woodward, 2008; Ehlers et al., 2011).

Over Europe and the Mediterranean region, present and past climatic conditions are directly related to the position of the oceanic and atmospheric North Atlantic polar fronts that, in turn, respond to fluctuations of sea - ice cover. Thus, the timing of the LGM in Europe is likely to vary locally, as it reflects a gradual migration of the position of the Polar Front, which in turn controls local snow supply (Florineth and Schlüchter, 2000).

The Northern Apennines situated to the south of the Alps and the Po Plain and strongly affected by the proximity of the Ligurian Sea and the cyclogenic centre of the Genoa Gulf are strategically located for establishing how the timing of the Local Last Glacial Maximum (LLGM) in NW Italy compares with that in other Mediterranean regions, and hence for understanding the climatic mechanisms operating at the time.

Relict glacial landforms along the Northern Apennines mountain chain have been recognized and investigated since the end of the 19th Century (De Stefani, 1883, 1887; Sacco, 1893), although there are few age constraints to establish their precise ages, while none of the available dates extend back to the LGM. Most authors therefore relate the ages of the maximal positions reached by former glaciers in a very general sense, for example to the 'recent Würm' (Federici, 1979; Federici and Tellini, 1983; Jaurand, 1998), 'the Würm' (Losacco, 1949, 1982), the 'Late Pleistocene' or to the 'Late Quaternary' (GNGFG, 1988).

Here we present evidence that enables a reconstruction of the former glaciers that occupied the Northern Apenninic Range and of

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their relative ELA elevations. We also constrain the timing of their maximal glacier limits to the LLGM based on the results of ^{10}Be exposure-age dating of fourteen selected erratic boulders located on key geomorphological sites in the area.

A key question for understanding the behavior of the global climate system during the Last Termination (onset at 17.5 ka in the North Atlantic: Stern et al., 2014) is to establish whether the abrupt climatic changes that characterize that interval were regionally synchronous or significantly diachronous (see INTIMATE project recommendations, Lowe et al., 2008; Dominguez-Villar et al., 2013; Hughes et al., 2013; Hughes and Gibbard, 2015; Rodríguez-Rodríguez et al., 2017). Here we provide new data for better constraining LLGM in NW Italy and for evaluating the diachroneity in the timing compared with the Alps and other Mediterranean mountain ranges, and consider the regional climatic factors that may have caused this difference in glacier behavior.

2. The study area

The Northern Apennines (Fig. 1) form the northernmost branch of the Apenninic range, the backbone of Peninsular Italy, and act as the main watershed between the Ligurian and the Adriatic Seas. They are bordered to the north by the Po Plain and to the west by the Maritime Alps, the southernmost portion of the Alpine chain. This study focuses on the Northern Apennines between 44°40′N - 9°12′E and 44°6′N – 10°50′E, extending from the Trebbia River hydrographic basin at the NW margin, to the Panaro River basin at the SE extremity. No glaciers exist at the present time in this area.

The main watershed generally runs parallel to the present coastline of the Ligurian Sea, at a distance of only ca. 20 km from the sea in the vicinity of Mt. Penna and Mt. Gottero, but never exceeding 60 km from the sea (Fig. 1). The hydrographic network is asymmetric (Mazzanti and Trevisan, 1978), with the gentler Adriatic slopes characterized by parallel transverse valleys with basins feeding important tributaries of the Po River. The steeper Ligurian and Tuscan slopes are characterized by longitudinal streams (e.g. by the Magra and Serchio rivers) entrenched into Plio-Pleistocene lacustrine basins, isolating the Apuane Alps to the south. The highest peaks, represented by Mt. Cimone and Mt. Cusna, exceed 2000 m a.s.l.

Efthymiadis et al. (2007) include the Northern Apennines within the southwestern climatic sector termed the Greater Alpine Region (GAR). The spatial distribution and amount of precipitation along the Tuscan - Emilian range are strongly influenced by proximity to the Ligurian Sea, and altitude, with the highest amounts generally exceeding 2000 mm yr^{-1} above an altitude of 1200 m (Rapetti and Vittorini, 2012, 2013). On the Ligurian sector some of the highest annual precipitation totals for the whole of the Italian Peninsula are recorded, exceeding 2584 mm in the high Trebbia Basin (1951–1975 time interval, Rapetti and Vittorini, 2013).

Along the Tuscan - Emilian range the highest mean annual values are recorded in the northernmost valleys (1921–1972 time interval, GNGFG, 1988), where 2500 mm are exceeded at Paduli Dam (Passo del Lagastrello, Val Cedra, 2560 mm) and at Lagdei in Val Parma, (2650 mm).

The main source of precipitation in the western Mediterranean region is presently the westerlies driven by Atlantic perturbations that find their way through the corridors of France and Spain, but are deviated by Corsica towards the NE (Kuhlemann et al., 2008; Rapetti and Vittorini, 2013). In particular, the Gulf of Genoa constitutes one of the important cyclogenesis centres in the entire Mediterranean region and one of the most persistent throughout the whole year (Trigo et al., 1999, 2002). In the framework of the Northern Apennines, outbreaks of polar air masses cause convection of moist air over the Ligurian Sea, fuelling considerable amounts of precipitation along the Ligurian coastal mountains, the first major orographic obstacles that they encounter.

A decrease in annual precipitation moving towards the SE along the Tuscan – Emilian Apennines is mainly due to orographic factors. The Apuane Alps constitute the westernmost coastal barrier that induces forced uplift of the Atlantic air flows with consequent discharge of precipitation that can exceed 4000 mm/yr (Rapetti and

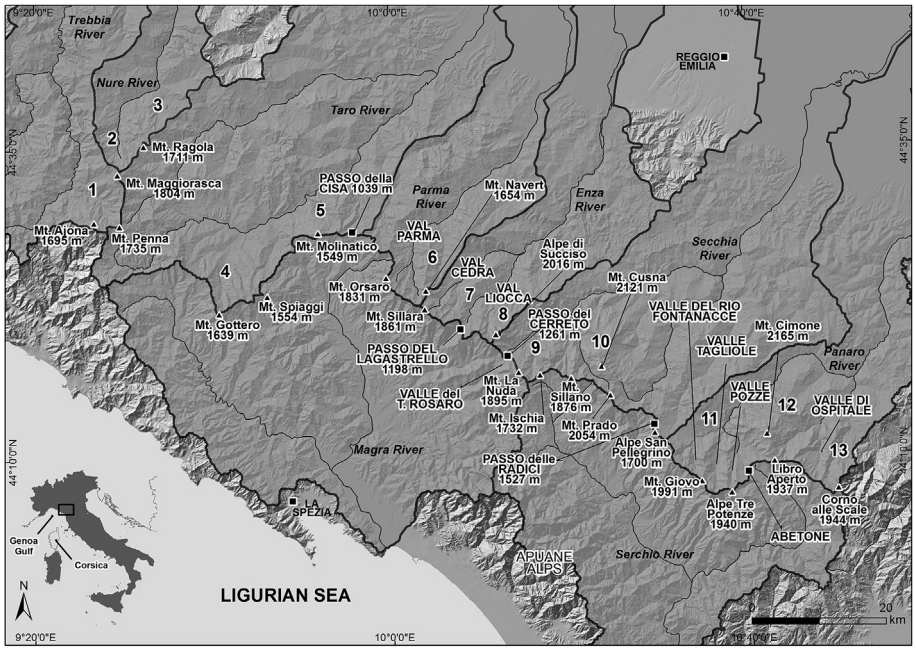

Fig. 1. Location map of Northern Apennines hosting glaciers during LLGM. Marked by numbers are the different mountain groups: 1) Mt. Penna-Mt. Ajona; 2) Mt. Maggiorasca; 3) Mt. Ragola; 4) Mt. Gottero-Mt. Spiaggi; 5) Mt. Molinatico; 6) Mt. Orsaro-V. Parma; 7) Mt. Sillara-V. Cedra; 8) Alpe di Succiso (Val Liocca); 9) Passo del Cerreto-Mt. La Nuda; 10) Mt. Sillano-Mt. Cusna-Mt. Prado-Dolo; 11) Alpe San Pellegrino-Mt. Giovo-Alpe Tre Potenze; 12) Mt. Cimone; 13) Libro Aperto-Corno alle Scale.