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Asynchronous Little Ice Age glacial maximum extent in southeast Iceland

Marie Chenet [a,*], Erwan Roussel [b], Vincent Jomelli [a], Delphine Grancher [a]

[a] CNRS Laboratory of Physical Geography, 1 place Aristide Briand, 92195 Meudon cedex, France
[b] CNRS GEOLAB, 4 rue Ledru, 63057 Clermont-Ferrand cedex, France

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ABSTRACT

The Little Ice Age (LIA) maximum glacial extent of 13 glaciers located in SE Iceland was dated by lichenometry to check for intraregional variations. Different lichenometric approaches were applied to date maximum LIA moraines, and they all showed high variability between glaciers. According to the Extreme Value Theory and Bayesian approach, LIA advances in the region occurred in or around A.D. 1740–1760, A.D. 1810–1820 and A.D. 1840–1880 with confidence intervals of between 8 and 21 years. The dates were correlated with geomorphic characteristics of glacier tongues: hypsometric and slope parameters can be considered as determining factors in the variability of glacier timing during the LIA, as previously observed in Norway and in the Alps. In terms of timing, results obtained in SE Iceland were similar to those obtained for other glacier regions around the North Atlantic.

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1. Introduction

The term "Little Ice Age" is commonly used to describe the most recent period of glacier extension in both hemispheres. In Iceland, which is located between cold polar and warm subtropical water and air masses, migration of the Polar Front during the Little Ice Age (LIA) led to significant environmental changes and glacial fluctuations. A notable feature of the established Icelandic glacial history is the uncertainties surrounding the timing of the glacial maximum extent of the LIA and the accuracy of lichenometric dating (Kirkbride and Dugmore, 2001).

Previous lichenometric studies concluded that Icelandic glaciers reached their LIA maximum during the late nineteenth century (Ives, 1956; Jacksch, 1970, 1975; Gordon and Sharp, 1983; Sharp, 1984; Sharp and Dugmore, 1985; Thompson and Jones, 1986; Thompson, 1988; Gudmundsson, 1997, 1998; Evans et al., 1999). More recently, improvements in lichenometry resulted in the timing of the LIA maxima being shifted from the late eighteenth and early nineteenth century (Bradwell, 2001, 2004a,b) to the mid-nineteenth century (McKinzey et al., 2004). These results contrast with tephrochronological evidences pointing to the maximum LIA glacier extent in the early eighteenth century (Kirkbride and Dugmore, 2006, 2008), in mid-eighteenth century (Kirkbride and Dugmore, 2001), in the late eighteenth century (Bradwell et al., 2006) or in the early nineteenth century (Casely and Dugmore, 2004).

The key question is the extent to which the variability of lichenometric results is linked to a problem of dating methodology (previous authors used several different procedures to build lichen growth curves) or reflects possible asynchronous glacier advances during the LIA. To answer this question, moraine ridges corresponding to the LIA maximum glacial extent of 13 glaciers located in SE Iceland were investigated and dated by lichenometry based on the statistical analysis of either the largest lichen diameters recorded on geomorphic features or on the frequency of all lichens. Southeast Iceland enables dating a large number of glaciers located in a limited area with a homogeneous climate, whereas previous studies dated a few glaciers located in different parts of Iceland. Jomelli et al. (2007) have recently demonstrated that the Bayesian approach, by fitting an extreme value distribution to the largest lichen diameters, offers the most reliable estimates of moraine dates for methods based on the measurement of lichen maxima and enables uncertainties to be generated.

In this context, the aims of this paper are i) to date the LIA maximum extent of 13 glaciers in SE Iceland applying different lichenometric approaches to check for intraregional variations, ii) to establish whether the LIA maximum depends on geomorphic characteristics, iii) to compare Icelandic chronology with other well-known chronologies around the North Atlantic.

2. Study area

The study site is located in the Öræfi region in SE Iceland (ca. 64° N., 17° W.) and was chosen because of the concentration of glaciers and the climatic similarity between them. This subpolar oceanic environment is characterized by a mean annual precipitation of 1800 mm and a mean annual temperature of 4.8 °C (Fig. 1).

* Corresponding author. Laboratoire de Géographie Physique, 1 place Aristide Briand, 92195 Meudon Cedex France. Tel.: +33 16 99 81 71 70.
E-mail address: Marie.Chenet@cnrs-bellevue.fr (M. Chenet).

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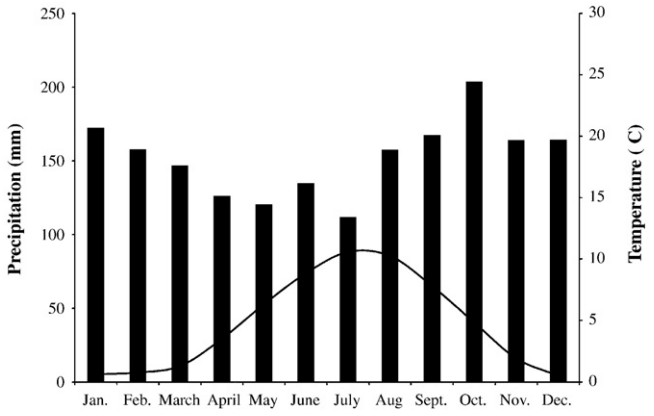

Fig. 1. Climatological data from Fagurhólsmyrí meteorological station for the period 1961–2006. With high precipitations every month and relatively mild temperatures for the latitude (64°N.), the climate of SE Iceland is a subpolar type.

The 13 glaciers investigated are southern outlets of the big Vatnajökull ice cap (Fig. 2). They have all undergone a retreat of their margins since the end of the LIA. On most of the glacier forelands, the outermost moraines were assumed to be the maximum LIA moraines. But we know that some moraines built in prehistoric times have been preserved, especially in front of Hólárjökull and Svínafellsjökull (Thorarinsson, 1956). These pre-LIA moraines are easily recognizable in the field by their aspect and were not included in our sampling plan. Moreover, the locations of the maximum LIA moraines are well known for most of the glaciers we explored and have already been examined and mapped by several authors, based on tephrochronological evidence (Thorarinsson, 1956; Evans et al., 1999; Bradwell, 2004a).

The selected glaciers differ in size, orientation, altitude, and distance to the sea (Table 1). The area of the glaciers varies from ca. 5 km^2 (Hólárjökull) to 213 km^2 (Fláajökull), with the same variability in length and width. Most of the glaciers are oriented SW and SE, but some are oriented west, south, or east. The glaciers' altitude varies considerably depending on their distance from the Atlantic Ocean from minima between 26 and 258 m to maxima between 1380 and 2070 m asl.

The terminal moraines are all located below 150 m asl, except Kotárjökull (ca. 190 m), and their distance to the sea ranges from 2.5 (Kviárjökull) to 30 km (Morsárjökull). Glaciers are nonsurging, at least since the end of the LIA. They have all undergone a retreat of their termini since the end of the LIA and are characterized by series of well-defined moraines ridges. Moraines are mainly made of basalt, hyaloclastite, and rhyolite. But basalt boulders dominate because of the rapid destruction of hyaloclastite and rhyolite, especially by frost shattering.

3. Methodology

Thirteen glaciers were selected in a limited area (SE Iceland) to guarantee climatic homogeneity. Conversely, geomorphic and glaciological parameters differ between glacier tongues we investigated. Each moraine corresponding to the LIA maximal extent was dated following standard lichenometric procedures.

3.1. Previous lichenometric methods applied in Iceland and their limits

Several different lichenometric approaches have already been applied in Iceland to date LIA moraines.

The original approach consisted in measuring several large lichens and selecting the largest for dating purposes. Based on the assumption that the largest lichens were among the first to colonize a surface, a lichen growth curve was built based on regression line plots. To reduce errors linked to the choice of only one lichen per moraine, the average of the 5 or 10 largest lichens diameters was computed for each moraine. Applying these methods, numerous lichen growth curves have been built in Iceland (Jacksch, 1970, 1975; Gordon and Sharp, 1983; Maizels and Dugmore, 1985; Thompson and Jones, 1986; Thompson, 1988; Gudmundsson, 1998; Evans et al., 1999). However, this approach is limited by the small data set that is not statistically robust (McKinzey et al., 2004). Furthermore, Jomelli et al. (2007) have demonstrated that the distribution of maxima cannot be normal but instead must follow a specific distribution (the Generalized Extreme Value distribution) whenever the sample size is large enough. Consequently, averaging maxima is not robust from a statistical point of view, and estimates of confidence intervals based on this average are not reliable.

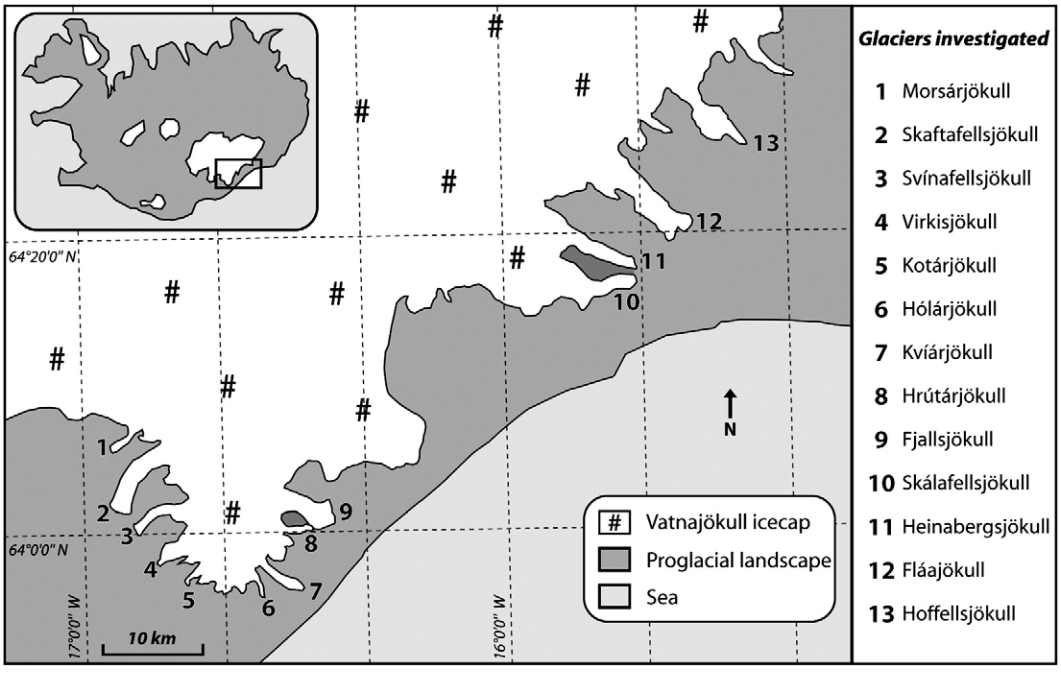

Fig. 2. Location of the glaciers investigated in SE Iceland.

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