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Chapter “dating techniques”, subchapter “relative dating techniques », section Lichenometry

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Lichenometry is a relative dating technique based on the presence of lichen thalli on exposed rocky surfaces, taking advantage of the lichen slow radial development; the conception is from Beschel (1950). Species within the *Rhizocarpon* subgenus, yellow-green crustose lichens, are the most used, with most studies focussing on *Rhizocarpon alpicola* and *Rhizocarpon geographicum* (Karlén and Denton, 1976), mais non exclusivement (Calkin and Ellis, 1980). The aim of lichenometry in geomorphology is to date surfaces exposed following various earth surface processes and events building up related landforms. It proposes a relative dating technique, inexpensive, by comparing the presence and size of lichens from one deposit to another. It also developed into assigning numerical ages to rocky surfaces, therefore to landforms created by various geomorphic processes.

Several reviews, even debates, have been produced over the last decades, demonstrating the enthusiasm of geomorphologists for lichenometry, highlighting both the proxy lichens represent, and the limits of the method (*e.g.*, Beschel, 1973; Mottershead, 1980; Worsley, 1981; Innes, 1985ab; Matthews, 1994; McKinze et al., 2004; O’Neal, 2006; Jomelli et al., 2007; Bradwell, 2009; Benedict, 2009; Chenet et al., 2010; Matthews and Trenbirth, 2011; McCarthy, 2013; Osborn et al., 2015; Decaulne, 2016). The technique has been extensively used in arctic and alpine environments (Golledge et al., 2010; Wiles et al., 2010; Hansen, 2010; Trenbirth and Matthews, 2010; Roberts et al., 2010), however not exclusively (Jacob et al., 2002; Gob et al., 2008). The longevity of the *Rhizocarpon* subgenus in cold environments (around 500 years, Innes, 1985b) makes it a suitable proxy to reconstruct past geomorphological dynamics, over periods that lack documentary sources or other dating techniques such as dendrochronology or  $^{14}\text{C}$ . That’s why its application is commonly done on moraines and hillslopes.

Over time, the field technique has remained identical: it consists into measuring diameters of thalli directly on the rocky supports with rulers or calipers, with a measuring precision from 0.01 (McCarthy, 2002) to 0.5 mm (*e.g.*, Innes, 1983b; Caseldine and Baker, 1998; Roussel et al., 2008); the number of measurements can change considerably according to the analyses to be done on the data obtained. Mathematical and statistical tools have been added through time to analyse the collected data, in an attempt to propose a more robust method that must approach better dating results with larger cohorts of measured individuals on specific landforms. Many studies used the diameter of the largest lichen (one single measurement retained on each surface; *e.g.*, Beschel, 1950; Jaksch, 1970); another technique is to use the measurements of the five largest lichens on each surface, measuring either the long axis or the short axis (*e.g.*, Gordon and Sharp, 1983; Guðmundsson, 1998). As these two methods only consider a few specimens, the data set is statistically weak (McKinsey et al., 2004); as a result, the size-frequency approach considers all thalli of *Rhizocarpon* on multiple surfaces within a specific area (at least 300 lichens) and describes the structure of the lichen population mathematically (Bradwell, 2009), enabling the identification of anomalous large lichen growth that could have been mistaken by applying the largest, or the five largest lichens methods. Other statistical models have been used, such as the generalized extreme value distribution (Cooley et al., 2006; Jomelli et al., 2007), or the goodness-of-fit (Orwin et al., 2008). However, most authors have neglected one or several aspects of the lichen biology and ecology, leading to interpretation shortcomings (*e.g.*, Jochimsen, 1973; McCarthy, 1999; Armstrong, 2001; Osborn, et al., 2015; Rosenwinkel et al., 2015).

Researches using lichenometry have nonetheless proven interesting results over short terms. For instance, they have shown that *Rhizocarpon* lichens ecesis interval varies from 5 to 30 years on stable surface to develop (*e.g.*, McCarthy, 2002; Decaulne et al., 2005), therefore lichenometry is useful as a

relative dating tool for events older than this establishment time span. Lichenometry approaches quite accurate dating over the last dozen decades or so (therefore very short periods of time), when the size of the measured thalli on a substrate is extrapolated from the mean annual growth rate of the same lichen individuals that develop on surfaces of known ages, within spatially constrained areas (Decaulne, 2016). Nevertheless, the established growth curve should not be extrapolated beyond data, *i.e.*, should not overpass the older control point measured (Osborn et al., 2015). Moreover, the variety of lichen growth curves produced by different researchers using various lichenometric techniques within the same area, sometimes even at a regional scale (Decaulne, 2016), show large variability, at all lichen stages of development, from juvenile to mature should encourage caution about the scope of the results obtained. The lichen's growth rate is obviously not linear, while most growth curves are presented so ((e.g., Bradwell, 2001, Decaulne, 2016). Lichens of the same species are useful to provide relative dating within a constrained area (*e.g.*, a slope, maybe a valley), on consistent rock-surface orientation (solar radiation and snow-cover influence its growth), providing a reference growth can be established locally; a time span is necessary to check the growth of specific lichen individuals on specific surfaces, meaning that a site needs to be revisited and the very same lichens repetitively measured.

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