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Devising quality assurance procedures for assessment of legacy geochronological data relating to deglaciation of the last British-Irish Ice Sheet

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ABSTRACT

This contribution documents the process of assessing the quality of data within a compilation of legacy geochronological data relating to the last British-Irish Ice Sheet, a task undertaken as part of a larger community-based project (BRITICE-CHRONO) that aims to improve understanding of the ice sheet's deglacial evolution. As accurate reconstructions depend on the quality of the available data, some form of assessment is needed of the reliability and suitability of each given age(s) in our dataset. We outline the background considerations that informed the quality assurance procedures devised given our specific research question. We describe criteria that have been used to make an objective assessment of the likelihood that an age is influenced by the technique specific sources of geological uncertainty. When these criteria were applied to an existing database of all geochronological data relating to the last British-Irish Ice Sheet they resulted in a significant reduction in data considered suitable for synthesis. The assessed data set was used to test a Bayesian approach to age modelling ice stream retreat and we outline our procedure that allows us to minimise the influence of potentially erroneous data and maximise the accuracy of the resultant age models.

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1. Introduction

Numerical ice sheet models provide insights into the response of ice sheets around the globe to various global warming scenarios, but these models have to be validated through comparison with field evidence relating to the evolution of former ice sheets (Stokes et al., 2015). The accurate reconstruction of rates and patterns of deglaciation is, in turn, fundamentally dependent on the quality of the geochronological data that provides a temporal framework. As early as the 1950s advances in radiocarbon (^{14}C) dating permitted glacial events to be constrained in absolute time (e.g. Flint, 1955; Godwin and Willis, 1959). In the subsequent decades, palaeo ice sheets around the world became better constrained by steadily rising numbers of absolute geochronometric ages, firstly by ^{14}C and then by luminescence (e.g. Berger and Eyles, 1994; Duller et al., 1995) and cosmogenic dating (e.g. Phillips et al., 1990, 1994). When age measurements were scarce glaciological reconstructions of entire sectors often hinged on a small number or even individual ages. A classic example for the British-Irish Ice Sheet (BIIS) were the Dimlington ages for maximum ice advance in East England (Penny et al., 1969). As more ages became available it became apparent that ice sheets did not reach their maximum extents or retreat synchronously. Subsequently, ice sheets became a focus for investigation to improve understanding of global climatic teleconnections (e.g. Denton and Hendy, 1994; Gosse et al., 1995; Osborn et al., 1995; Ivy-Ochs et al., 1999, Barrows et al., 2007; Moreno et al., 2009)

The ever-increasing accumulation of legacy geochronological data is spread across hundreds of different publications, making it difficult to address regional or ice sheet scale reconstruction; this can be termed the Compilation Problem. It has recently been addressed for many ice sheets including the Laurentide Ice Sheet (Dyke et al., 2002), the British-Irish Ice Sheet (Hughes et al., 2011), the Antarctic Ice Sheets (Bentley et al., 2014) and the Eurasian Ice Sheets (Stroeven et al., 2015; Hughes et al., 2016). These geochronological compilations reveal how numerous age constraints have become. However, they can also reveal incompatibility or direct conflicts between ages. Such conflicts are not surprising for two reasons. Firstly, dating techniques and their robustness have vastly improved over time (Lowe and Walker, 2015). Secondly, the geological context of the material sampled for dating might have more than one interpretation, or the strength of the association between an age and the event that is of interest may vary. Both factors yield conflicts in specific regions that have often forced authors of a reconstruction to rely on some ages but argue against others. It is apparent that not all legacy ages are equally-robust with respect to addressing a specific research question; this can be termed the Quality Problem.

The issue of quality assurance of geochronological data has received considerable attention in various areas of science including the archaeological (e.g. Pettitt et al., 2003; Blockley et al., 2008; Graf, 2009) and paleoclimatological (e.g. Lowe and Walker, 2000; Brauer et al., 2014) communities with the radiocarbon technique specifically receiving much attention. These studies have highlighted a range of issues that can influence the quality of geochronological data and many have gone on to define set criteria for assessing the reliability of data (e.g. Pettitt et al., 2003; Graf, 2009; Blockley and Pinhasi, 2011). Within archaeology and paleoclimatology much of the focus has been on assessing data that exists in very close association with other data (e.g. ^{14}C dates from a sequence) and more rarely with sparsely distributed data. Additionally, the resolution that is sought is often on the order of 10^1–10^2 years. For the reconstruction of past ice sheets this concentration of data from a single location and achievable resolution is desirable but also generally rare. While some glaciological compilations have been provided with internal quality assurance, the DATED project (Hughes et al., 2016) being a recent and commendable example, little has yet been published in the ice-sheet literature about the underpinning decision making criteria and pragmatic approaches to the task.

A large consortium of researchers (>45) are currently working on the BRITICE-CHRONO project to better constrain the retreat history of the BIIS (Clark, 2014), acquiring new ages and appraising the existing legacy data (Hughes et al., 2011). In order to inform ice sheet reconstructions, and to feed into future numerical modelling, a systematic approach to how all ages are to be used has been devised to address the 'Quality Problem'. It is the purpose of this paper to outline the guidelines used to assess a legacy data set and the criteria devised for doing so. A review is provided of the issues that can introduce geological uncertainty into dating deglaciation by the most commonly applied techniques. We outline how consideration of these was used to create technique-specific guidelines and criteria for assessing geochronological data for constraining rates and patterns of deglaciation. We integrated the assessed data with Bayesian age modelling and outline a procedure for maximising the confidence that can be achieved in the results.

2. Dating deglaciation

Observations of current ice margins (e.g. in Antarctica) can robustly and directly constrain the timing of ice advance and retreat on annual timescales (Rignot et al., 2014), but such observations are limited to the last few decades over which we have aerial photographs and satellite images. The need to understand the longer-term significance of observed changes in modern ice sheets demands a means to reconstruct changes in ice sheets over timescales relevant to deglaciation; i.e. 10^2–10^5 years (Stokes et al., 2015). However, beyond the limits of direct observations there is no geochronological technique that can directly constrain the timing of glacial advance or retreat, rather we date features within the geomorphological and sedimentary record (Fig. 1) that are formed before, during or after deglaciation, and can thus be directly (e.g. an exposed glacial surface) or indirectly (e.g. fluvioglacial outwash) linked to past ice extents. Geochronological control on such features can represent minimum or maximum ages for deglaciation depending on the geomorphic and/or stratigraphic context of the sample collected and the quality of the ages fundamentally influences subsequent interpretation (Fig. 2).

Within any compilation of geochronological data an unknown proportion of measured samples will be affected by factors that can make the resulting ages inaccurate. Ages obtained from chronological methods are derived from the measurement of specific physical properties (e.g. the ratio of $^{10}Be/^{9}Be$ in cosmogenic nuclide dating). The actual measurement of a physical property has a set of defined systematic and random uncertainties associated with processing and measurement which are reflected in the quoted error term that accompanies the reported result. The measured physical property(s) are used to calculate an equivalent calendar age that is then assumed to be contemporaneous with, or constrain, the age of the event of interest. Wrapped up within these assumptions of equivalence are other sources of uncertainty