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Transferring radiometric dating of the last interglacial sea level high stand to marine and ice core records

C. Waelbroeck [a,*], N. Frank [a], J. Jouzel [a], F. Parrenin [b], V. Masson-Delmotte [a], D. Genty [a]

[a] *LSCE/IPSL, Laboratoire CNRS-CEA-UVSQ, Domaine du CNRS, 91198 Gif-sur-Yvette, France*
[b] *LGGE, 54 rue Molière, Domaine Universitaire, BP 96, 38402 St Martin d'Hères, France*

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Abstract

In order to derive a radiometric age marker for the end of the penultimate glacial–interglacial transition, we compiled published U-series isotope measurements on corals from the period extending from stage 6 to the middle of the last interglacial, and computed the corresponding open-system ages using Thompson et al. model (Thompson, W.G., Spiegelman, M.W., Goldstein, S.L., Speed, R.C., An open-system model for U-series age determinations of fossil corals. Earth Planet. Sci. Lett. 210 (2003) 365–381). We obtain a global mean age of 126 calendar kyr BP (ka) ± 1.7kyr (2σ) for the beginning of the last interglacial sea level high stand. After showing that the phase relationships observed between changes in sea level, North Atlantic benthic and planktonic foraminifera oxygen isotopic records, and atmospheric methane over the last deglaciation were likely also valid over the penultimate deglaciation, we derive an age of 131.2ka ± 2kyr (2σ) for the abrupt increase in atmospheric CH_4 and North Atlantic surface temperature marking the end of the penultimate glacial–interglacial transition. This age is consistent with U–Th dates of the penultimate glacial–interglacial transition recorded in speleothems from sites where speleothems isotopic records are synchronous with North Atlantic temperature records over the last deglaciation. Finally, we show that the phase obtained between the climatic response and northern hemisphere summer insolation is not constant from Termination II to Termination I, implying that northern hemisphere summer insolation alone cannot explain the timing of terminations.

Keywords: last interglacial; open-system ages; sea level; North Atlantic marine cores; ice cores

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1. Introduction

Uncertainty on polar ice and marine cores dating remains very large prior to the time span covered by ^{14}C dating techniques or by layer counting (i.e., approximately the last 15 to 40kyr). Prior to 40 calendar kyr BP (ka), marine cores are generally dated by correlation to SPECMAP reference records (Imbrie et al., 1984; Martinson et al., 1987; Bassinot et al., 1994) which are themselves dated by orbital tuning. This technique assumes constant phases between the obliquity and precession components of insolation and of planktonic or benthic $\delta^{18}O$ throughout the record and produces chronologies with uncertainties of about 5kyr (i.e. roughly a quarter of a precessionnal cycle) along the entire record.

One advantage of central Antarctic ice cores over deep-sea cores is that it is possible to use ice flow and accumulation models to date ice core records (Parrenin et al., 2004). Since snow accumulation processes are

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[*] Corresponding author. Tel.: +33 1 69 82 43 27; fax: +33 1 69 82 35 68.
E-mail address: Claire.Waelbroeck@lsce.cnrs-gif.fr (C. Waelbroeck).

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relatively regular in Central Antarctica and ice cores records resolution is usually very high (typically 100yr), the duration of climatic events (and thus climatic phasing) should be well estimated in ice cores chronologies. It is thus generally accepted that the most promising approach to obtain consistent chronologies for polar ice and marine records is to define a reference ice core chronology and transfer it to deep-sea cores, using markers present in both archives as tie points.

However, glaciological models alone do not yield accurate absolute ages because of poorly known parameters (e.g. glacial accumulation rate, basal melting and sliding). This is why Parrenin et al. (2001) developed an inverse method in order to derive model parameters that give optimal agreement with independent absolute age markers. This method provides ice core chronologies that are accurate with respect to both absolute ages and events durations. Published age scales for Dome C, Dome Fuji and Vostok were derived using no accurate ages markers prior to 41ka but wide orbital control windows instead. As a consequence, there are currently large discrepancies between the timing of the penultimate glacial–interglacial transition in these three East Antarctica ice cores age scales, although the shape of the records is very similar from one site to another. More specifically, the mid point of the penultimate deglaciation is dated at about 135.3ka in Dome F ice oxygen isotopic (δ^{18}O) record (Watanabe et al., 2003), whereas it takes place around 133.9ka in Vostok ice deuterium (δD) record (Parrenin et al., 2004), around 130.6ka in Dome C δD record on the EDC2 time scale (EPICA, 2004) and around 132.4ka in Dome C δD record on the latest EDC3 time scale (Parrenin et al., 2007). The discrepancies amount to roughly 5 ky, consistently with the wide orbital windows used for each age scale.

This large uncertainty on polar ice and marine cores dating around 130ka contributes to maintain debate on the mechanisms responsible for deglaciations: it is currently still unclear if changes in summer northern hemisphere insolation are the main forcing factor triggering deglaciations as proposed by (Milankovitch, 1941).

There is thus a need for an absolute reference age scale for marine and ice cores records. The purpose of the present paper is to provide a radiometric age marker for the beginning of the last interglacial in polar ice and North Atlantic deep-sea cores.

2. Method

Our approach is to examine whether the phase relationships observed between sea level, North Atlantic (benthic and planktonic) foraminifera δ^{18}O records, and atmospheric CH_4 over the last deglaciation may also be valid over the penultimate deglaciation. After showing that it is likely the case, we derive a radiometric age for the abrupt increase in atmospheric CH_4 and surface temperature in the North Atlantic region marking the end of the penultimate glacial–interglacial transition, from corals U–Th ages of the beginning of stage 5e sea level high stand.

2.1. Preliminary remark on the timing of benthic δ^{18}O and sea level

Benthic δ^{18}O can be decomposed into a global term reflecting changes in global ice volume or sea level, and a local term reflecting changes in local deep water temperature and δ^{18}O. There are currently two sources of deep waters in the North Atlantic basin: (1) relatively warm (2°C) and saline (> 34.9 practical salinity units) North Atlantic deep water (NADW) formed at high northern latitudes; (2) colder (< 0°C) and less saline (< 34.7psu) deep waters formed around Antarctica. At depths of more than ~ 2500m, past deep-water temperature at a given site of the North Atlantic basin depends on the proportion of each of these water masses reaching the site, so that deep water temperature increases when NADW formation intensifies (e.g., Skinner et al., 2003). Changes in surface conditions and ocean circulation during the Younger Dryas and the 3kyr time interval preceding the Bolling–Allerod in the North Atlantic resulted in the formation of brine-generated intermediate waters characterized by low δ^{13}C and δ^{18}O (Labeyrie et al., 2005; Waelbroeck et al., 2006). Therefore, benthic δ^{18}O signals from North Atlantic cores are strongly influenced by changes in deep water temperature and δ^{18}O, that in turn depend on changes in ocean circulation occurring during glacial–interglacial transitions (Skinner et al., 2003; Skinner and Shackleton, 2006). These changes in circulation have been shown to occur rapidly with respect to the slow decrease in mean ocean δ^{18}O resulting from ice-sheets melting (Elliot et al., 2002; McManus et al., 2004; Gherardi et al., 2005). As a consequence, the timing of benthic δ^{18}O signals from North Atlantic cores can not be assumed to follow that of global ice volume or sea level changes across glacial–interglacial transitions. Note that this conclusion is valid for the entire world ocean since benthic δ^{18}O signals from other regions of the world ocean are also sensitive to changes in deep water temperature and δ^{18}O resulting from circulation changes across deglaciations (e.g., Labeyrie et al., 2005; Skinner and Shackleton, 2005).

When examining the sequence of events during the last deglaciation in well-dated North Atlantic marine records, we indeed see that the beginning of the Holocene benthic