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High-resolution age-depth chronology from tropical montane minerotrophic peat in the Sandynallah valley, Western Ghats, southern India: Analytical issues and implications

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ABSTRACT

Radiocarbon (^{14}C) dating remains the predominant method to build robust chronologies from peat deposits for paleoclimate reconstruction. Although it is widely known that the ^{14}C content of different chemical fractions in peat varies, this heterogeneity is not fully accounted for while constructing age-depth models. Since peat is a complex and heterogeneous matrix, we tried to characterize this uncertainty on our ^{14}C dates by experimenting with pre-treatment procedures on peat sampled from a high elevation site in southern India, where reliable and continuous records of paleoenvironments are scarce. Dated to ~40 kyr, the Sandynallah peat accumulation in valleys >2000 m asl in the Nilgiris, Western Ghats, remains an important source of paleoenvironmental information. We subsampled 2 peat cores (labelled Cores 1 and 2) from this site at 1 cm and 2 cm resolution, respectively, and obtained ^{14}C dates using Accelerator Mass Spectrometry (AMS) for 73 Core 1 and 40 Core 2 samples. The results indicate that the uncertainty (possibly due to sample heterogeneity; henceforth called **external error**) for each date is at least tenfold the **internal error** (reported from the AMS). When this external error estimate was included as an added variance to the internal error on the radiocarbon dates, the numerous minor date reversals on deposits up to about 30 kyr were better explained for by the age-depth model than when only the internal error was used. The remaining large date reversals on deposits older than about 30 kyr are consistent with previous studies from the Sandynallah basin and, hence, could correspond to large deposit level changes/fluctuations. Based on these results we argue that using internal error as the total uncertainty associated with a date given by AMS is insufficient, resulting in models of high precision over accuracy. The internal error should be used in conjunction with a reliable estimate of external error in an age-depth model for more realistic dating of paleoclimatic events.

1. Importance of peat chronology in the tropical context

Peat from the temperate regions, specifically from ombrotrophic bogs that are exclusively fed by atmospheric input, has been used for over a century to study climatic changes in the past (Bindler, 2006). Terrestrial paleoenvironmental archives of changing climate, vegetation, weathering and other related phenomena are scarce in the tropics, and high elevation peat formations, one of the rarest and severely understudied archives for paleoenvironmental reconstruction, are valuable sources for this purpose. The Asian monsoon is one of the dominant rain-bearing systems of the world. The South Asian monsoon accounts for about 80% of the rainfall over the Indian subcontinent and comprises two distinct phases, the southwest (SW) or summer monsoon and the northeast (NE) or winter/retreating monsoon (Das, 1968; Kumaran et al., 2013). It is the most economically important weather phenomenon in India and yet, is only partially understood owing to its complex interactions with phenomena such as the El Niño - Southern Oscillation (ENSO) and the Equatorial Indian Ocean Oscillation (EQUINOO) (Gadgil et al., 2004, 2007). Our understanding of present-day climatic phenomena has been aided by

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paleoenvironmental studies; in the case of the South Asian monsoon, several studies have tried to reconstruct the intensity and distribution of the monsoon in the past (Cai et al., 2006; Fleitmann et al., 2007), its interactions with oceanic phenomena such as ENSO (Charles et al., 1997, 2003) and EQUINOO (Abram et al., 2007, 2008) and associated dynamics reflected in the vegetation (Demske et al., 2009; Kumaran et al., 2013).

The Nilgiris are situated at the junction of the southern Western Ghats with the Eastern Ghats, and receive rainfall from both the SW and NE monsoons. A montane (~2200 m asl) peat formation in the Nilgiris has been found to preserve global climatic fluctuations, inferred through an investigation of the carbon isotope signatures of bulk peat samples (Sukumar et al., 1993; Rajagopalan et al., 1997). At a radiocarbon age of >40 kyr BP, this is one of the oldest deposits in the world and hence, valuable as a paleoclimatic archive. Late Quaternary global climatic fluctuations such as the Last Glacial Maximum (LGM) and the Holocene Optimum seem to have been captured in these studies (Sukumar et al., 1993; Rajagopalan et al., 1997) and the chronology was built using conventional radiocarbon dating. Reversals in the radiocarbon profile after a certain depth are observed in these peat profiles sampled. However, finer timescale fluctuations could have been obscured given the low sampling resolution of the earlier studies. In this study we aimed to obtain a reliable higher resolution paleoenvironmental record from this region and this necessitated re-sampling of the same peat deposit.

Paleoclimate studies using peat samples have largely relied on radiocarbon for building age-depth relationships (Piotrowska et al., 2010). Peat is a complex matrix fraught with difficulties for dating purposes (Brock et al., 2011). The appropriate material and methods to recover the *in situ* carbon for dating from various kinds of substrates has been a much deliberated topic of research (e.g. Goh, 1978; Shore et al., 1995; Turney et al., 2001; Nilsson et al., 2001; Brock et al., 2011; Wüst et al., 2008). It is evident from the literature that a paleoclimatologist has to deal with at least four sources of uncertainties: 1. Sample heterogeneity, 2. Pre-treatment procedure, 3. Sample preparation for making target and 4. Measurement on the AMS. The first uncertainty arising due to heterogeneity is due to the various organic fractions in the matrix and the differences in their ages, the second is from the pre-treatment protocol followed for removing 'contaminants' and extracting *in-situ* carbon and the third, from the combustion, purification and conversion techniques used to prepare the target for measurement. The AMS-related uncertainty is routinely calculated by the laboratory in which the measurements are being made, but the other three uncertainties do not have standardized methods for addressing them. Several authors have reported considerable variation among the several datable peat fractions and have called into question various pretreatment methods (e.g., Shore et al., 1995; Nilsson et al., 2001; Turetsky et al., 2004; Brock et al., 2011). Plant macrofossils are considered to be the best datable fraction from younger peats whereas, for more humified peats, laboratories resort to either measurements of radiocarbon on the 'bulk' sample or chemical fractions such as humin, humic/fulvic acid or their combination from the bulk material or from a specific physical fraction (e.g. <250 μ size class) (Piotrowska et al., 2010). Wüst et al. (2008) carried out detailed experiments on the various organic fractions from a tropical peat deposit in Indonesia and concluded that the pollen fraction is the most suitable fraction for dating deeply rooting vegetation. They found that the bulk samples were often the youngest among other fractions and the discrepancy was as high as ~16 ^{14}C kyr at the deepest section. In pre-treatment procedures, Acid-Alkali-Acid method for extraction (described in Gupta and Polach, 1985; Brock et al., 2010) of the desired *in situ* carbon from peat is the most widely used method (Piotrowska et al., 2010). Uncertainty arises because the treatment method is far from standardized and is highly variable in terms of the concentration of reagents, time duration and temperature for each reaction step (Santos and Ormsby, 2013). Given that such large inconsistencies have been reported, it is essential that paleoclimate studies incorporate these uncertainties in the dates in building chronologies with improved accuracy. Telford et al. (2004) have shown that uncertainties calculated from the error on the radiocarbon dates underestimate the true uncertainty of the age–depth model. For example, if a peat sample was divided and sent to two different laboratories for AAA pre-treated measurement, how likely is it that these values will overlap within their uncertainties? This study tries to address this gap by experimenting with extraction methods and including errors arising from these to determine their influence on age-depth models for paleoclimate reconstruction from peat.

2. Methods

2.1. Study site

Our study site, the Sandynallah valley, is located between 11°26′32″N, 76°38′6″E and 11°26′37″N, 76°38′8″E (Fig. 1) at an elevation of ~2200 m asl., in the southern Western Ghats, India. This site receives annual average precipitation of about 1240 mm of which ~52% is from the South West and ~28% from the North East monsoon (Von Lengerke, 1977, Rajagopalan, 1996). The valley is underlain by charnockite of age ~2527 ± 14 Ma (Samuel et al., 2014 and references therein) and the natural vegetation is a mosaic of stunted montane evergreen forests (locally known as "*sholas*") along the folds of the hills and extensive grasslands on the slopes (Sukumar et al., 1995). The valleys feature peat deposits dated to >40 kyr (Sukumar et al., 1993; Rajagopalan et al., 1997). Due to prevailing climatic factors such as cool temperatures (annual average 13.5 °C, mean maximum 18.5 °C and mean minimum 8.5 °C), precipitation and water logging in the valleys, the study site and its neighbouring locations feature peat accumulations that have been used to reconstruct late Quaternary vegetation and climate (Vasanthy, 1988; Sutra et al., 1997). All previous publications are based on samples taken from trenches, with the exception of Sutra et al. (1997).

Our aim through this study was to build a high resolution paleoenvironmental record which necessitated the resampling of this site using a contemporary method of sampling. It was observed that radiocarbon dates from previous profiles could not be used to date our cores because of poor lateral correlation of stratigraphy. Two sites were chosen from a relatively less disturbed broad valley at Sandynallah for coring. The first site was close to the edge of the hill surrounding the valley and the second site was ~200 m along the length of the valley from the first site, with a slightly elevated part at the centre, drier and possibly less disturbed than the earlier site (Fig. 1).

2.2. Sampling and sub-sampling

For obtaining an undisturbed high resolution chronology, peat sampling was carried out using a Belarussian Peat corer (Jowsey, 1966). This is a D-type corer, 5 cm in width and 50 cm in length. The corer was graduated and peat sampled from the Sandynallah basin during the dry season in the months of January–February 2012 at different depths according to a predefined sampling strategy (De Vleeschouwer et al., 2010). Each master core comprises of 9 core units, with 10 cm overlap between successive core units at either ends, procured from bore holes ~30 cm apart to account for lateral variation and to ensure non-disturbance from the coring head (see Fig. 2 for sampling design). Two master cores were obtained from 2 pairs of boreholes ~170 m apart and spanning a depth