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The last termination in the central South Atlantic

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ABSTRACT

Lake sediments and peat deposits from two basins on Nightingale Island (37°S), in the Tristan da Cunha archipelago, South Atlantic, have been analyzed. The studies were focused on the time period 16.2–10.0 cal ka BP, determined by 36 ^{14}C dates from the two sequences. A wide variety of proxies were used, including pollen and diatom analyzes, biogenic silica content, C and N analyzes, stable isotopes (^{13}C and ^{15}N), elemental concentrations and magnetic susceptibility measurements, to detect environmental changes that can be related to shifts of the circulation belts of the Southern Ocean. In addition, climate model simulations were carried out. We find that the sediments are underlain by a >2 cal ka BP long hiatus, possibly representing a dried-out lake bed. The climate simulations corroborate that the area might have been exposed to arid conditions as a consequence of the Heinrich 1 event in the north and a southward displacement of the ITCZ. The development on the island after 16.2 cal ka BP is determined by the position of the Subtropical Front (STF) and the Southern Hemisphere Westerlies (SHW). The period 16.2–14.75 cal ka BP was characterized by varying influence from SHW and with STF situated south of Tristan da Cunha, ending with a humidity peak and cooler conditions. The stable conditions 14.7–14.1 cal ka BP with cool and fairly arid conditions imply that STF and SHW were both north of the islands during the first part of the Antarctic Cold Reversal. The most unstable period, 14.1–12.7 cal ka BP, indicates incessant latitudinal shifts of the zonal circulation, perhaps related to climate variability in the Northern Hemisphere and bipolar seesaw mechanisms as the strength of the Atlantic Meridional Overturning Circulation (AMOC) varied. At 12.7 cal ka BP the Holocene warming began with a gradually drier and warmer climate as a result of a dampened AMOC during the Younger Dryas cooling in the north with ITCZ, STF and SHW being displaced southwards. Peak warming seems to have occurred in the earliest part of the Holocene, but this period was also characterized by humidity shifts, possibly an effect of retraction and expansion phases of SHW during AMOC variations in the north.

1. Introduction and background

The vast oceanic areas of the Southern Hemisphere (SH), and especially the Southern Ocean (SO) surrounding Antarctica (Fig. 1A), are in contrast to the Northern Hemisphere (NH), where continents dominate, especially in the Atlantic Ocean. As a result, Quaternary terrestrial records, which have the potential to reconstruct atmospheric conditions through high-resolution dated records, are lacking in the SH. An exception to this are island records from the vast SH oceanic areas. Continuous island archives are ideally made up by lake sediments or peat deposits, which require basin structures. The challenge outside recently glaciated areas is, however, to find such structures that have not already been filled in by pre-Quaternary deposits. Oceanic islands are often part of young, and therefore often still active, volcanic systems. In such settings, caldera/crater lakes are common landscape features and often constitute the only basin type with continuous deposition. In areas with (still) active volcanism the volcanic activity may, however, be an obstacle for coring due to the occurrence of young widespread impenetrable tephra layers covering whole landscapes (cf. Björck et al., 2006). It is therefore essential to find basins whose

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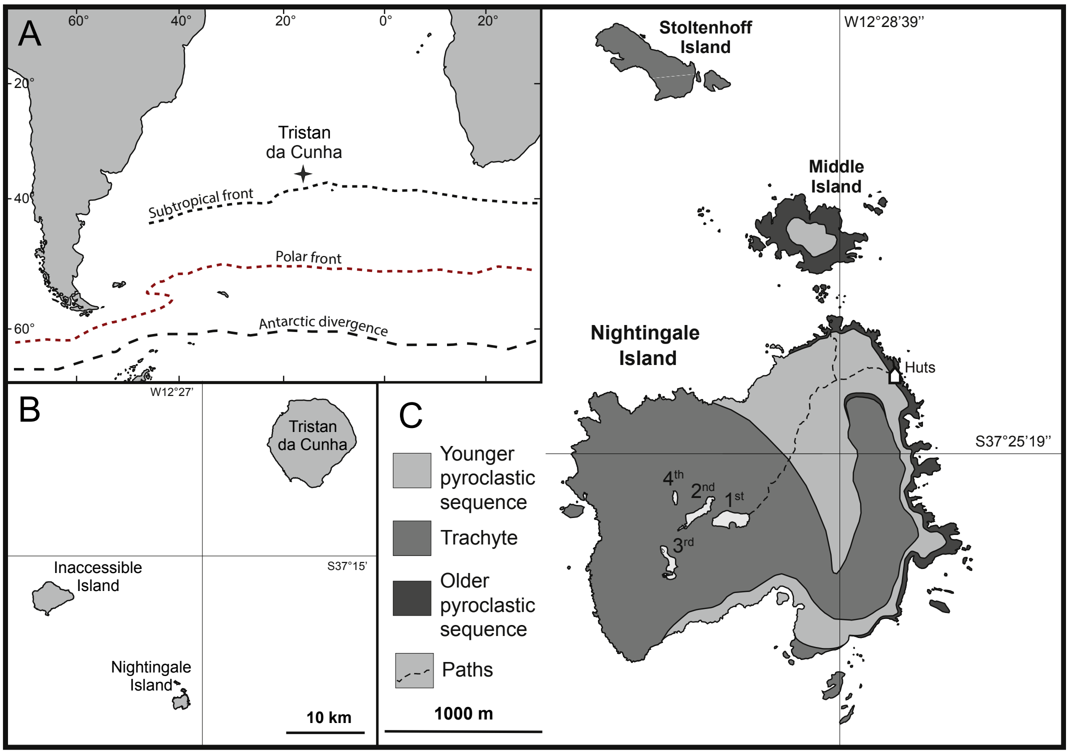

Fig. 1. A) Map of the Southern Ocean and surrounding continents with its main zonal circulation systems, the position of the Tristan da Cunha island group, B) its individual islands and, C) Nightingale Island with its four overgrown "ponds". The geology is adapted from Baker et al. (1964). Note that the westerlies are situated between the Polar Front and the Subtropical Front.

surroundings have not experienced young volcanic eruptions and ash fall-out, but at the same time are not too old to have been infilled with much older deposits. For example, on the Azores only three out of 15 cored sites were not affected by young volcanic activity (Björck et al., 2006), and still the oldest record was only c. 6 cal ka BP old. In the South Atlantic, islands are rare north of 50°S. In addition, north of 30°S the sub-tropical high-pressure cell creates very dry and warm conditions, which mean that, e.g. the volcanic island of Ascension (8°S) has a too small P/E ratio to maintain wetland/lake habitats, and St. Helena (16°S) contains some scattered superficial peaty deposits but the only basin situated in the dry NE part of the island, the Central Basin of Prosperous Bay Plain, is filled in by pre-Quaternary lake sediments. The volcanism is also old without any traces of crater lakes.

The Tristan da Cunha island group (Fig. 1) is comprised of Tristan da Cunha, Inaccessible Island and Nightingale Island (Fig. 1B) found at 37°S, and Gough Island slightly further south (40°S), just at, or north of some important oceanographic and atmospheric frontal systems, namely the Subtropical Front (STF) and the Southern Hemisphere Westerlies (SHW). All these islands are of volcanic origin of varying age, and have been known to hold peat and lake deposits (Hafsten, 1951, 1960; Wace and Dickson, 1965; Bennet et al., 1989), with indications of pre-Holocene age on scattered peat finds. From an expedition to the Tristan da Cunha group in 2003 it was clear for us that young volcanic activity and tephra fall-outs on the main island, Tristan da Cunha (TDC), prevented attempts to reach down to sediments older than 2.3 cal ka BP (Ljung et al., 2006). However, on the near-by Nightingale Island (NI) it was possible to obtain an almost complete Holocene sequence in one of the four "Ponds" (2nd Pond) on the island (Fig. 1B) without reaching the bottom of the basin (Ljung and Björck, 2007). In 2010 three of the ponds - which are made up of basins between lava ridges possibly formed during MIS3 (Bjørk et al., 2011) - were cored with stronger coring equipment. It was possible to reach down into the Last Termination in all three of them (1st, 2nd and 3rd). One of the records, 1st Pond, spans 37 cal ka, and here we present two of the records (1st and 2nd Pond), focusing on the period 11–16.2 cal ka BP.

The concept of a bipolar seesaw climate mechanism (Broecker, 1998) during the Last Deglaciation has been convincingly shown to exist between the two polar areas as recorded in their ice core records (EPICA, 2006). The most distinct, well-dated and striking anti-phase shifts between the polar areas are the onset and warming of GIS-1e in Greenland, corresponding almost perfectly to the start of the Antarctic Cold Reversal (ACR), and the onset of the present interglacial warming in the very south during the early part of the Younger Dryas (YD) cool event in the NH. It has also been shown that the climate in some southerly regions outside Antarctica have responded in the same pattern as many of the Antarctic ice cores do, but they are in general situated south of 40° S in the Pacific (Newnham et al., 2012). Such records are, e.g. from glacial advances in southern New Zealand (Turney et al., 2007; Putnam et al., 2010) and southerly shifts of the SHW in Tierra del Fuego (Björck et al., 2012), and thereby also latitudinal changes in sea ice extent, during the YD. The geographic extent of the effects of the bipolar seesaw in the SH is, however, still not resolved (Newnham et al., 2012). The close coupling between the atmospheric and oceanic circulation in the SH means that latitudinal shifts of the main atmospheric and oceanic fronts play a key climate role. Theoretical studies show that a cooling of the Northern Hemisphere (e.g. cooling of the North Atlantic) leads to a southwards shift of the ITCZ (Chiang and Bitz, 2005; Kang et al., 2008;