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Note

Evolution of pastoralism in Southern Greenland during the last two millennia reconstructed from bile acids and coprophilous fungal spores in lacustrine sediments

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A B S T R A C T

To reconstruct the evolution of livestock in SW Greenland over the last two millennia, we measured the concentration of bile acids in a sedimentary sequence retrieved from Lake Igaliku. Deoxycholic acid (DOC) was the sole bile acid and was present throughout the sequence.

The DOC flux correlated quantitatively with that of coprophilous fungal spores. Maximum DOC and coprophilous fungal spores flux was recorded during the two periods of human settlement and grazing activity in the region (i.e. the Norse settlement during the Middle Ages and the recent Danish agricultural phase since 1920). These flux values were consistent with the presence of recent livestock around the lake and are attested to by way of archeological data relating to the Norse period. In contrast, the DOC and coprophilous fungal spores background during pre-Norse times and the Little Ice Age (LIA), indicated the presence of wild herbivores. Lower DOC and coprophilous fungal spore flux values after the Norse abandonment, compared with pre-colonization conditions, could indicate that Norse activity in conjunction with climate change, altered the pristine wildlife.

Therefore, these quantitative correlations between DOC flux and coprophilous fungal spores flux potentially suggest a quantitative relationship with the livestock grazing in the catchment. The comparison between sedimentary DOC and coprophilous fungal spores provides significant highlights on past pastoral dynamics over the last 2000 yr in SW Greenland.

1. Introduction

Human land use is a driver of the most recent transformations of continental ecosystems but determining the timing, intensity and distribution of human impact remains challenging. Lake deposits are one of the most appropriate archives for tracing recent and past land use, because of their sensitivity to environmental change recorded at high time resolution. However, in only rare cases, may unequivocal tracers of human activity allow disentangling of natural events from human induced impact. Recent studies have proposed new biomarkers for reconstructing the history of agriculture (Oldfield et al., 2003; Jacob et al., 2008; Lavrieux et al., 2013. Concerning pastoralism, coprophilous fungal spores in sediments attest to grazing pressure in the catchment (Van Geel et al., 2003; Gauthier et al., 2010). They do not, however, enable the respective contributions of domestic and wild fauna to be distinguished. Fossil DNA offers a new perspective (Giguet-Covex et al., 2014) but necessitates further development. Thus, there is no indicator which can be used to characterize a livestock population in a lake catchment. Fecal biomarkers, such as sterols and bile acids, may be biomarkers for tracing the presence of humans and grazing mammals. Furthermore, they have proved their relative resistance to degradation and ability to allow identification of domestic mammalian species (Elhmmali et al., 1997; Bull et al., 2002; Jardé et al., 2007; Tyagi et al., 2008). However, they have rarely been applied to sedimentary lacustrine records spanning several millennia (D'Anjou et al., 2012). Here, we have analyzed bile acids in sediments from Lake Igaliku (Southern Greenland), which cover the last 1700 yr. The history of Southern Greenland constitutes an

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exceptional model since the pristine ecosystem was first affected by the Norse settlement during the medieval period. The region was then abandoned before the recent reintroduction of agriculture by the Danes. We tested deoxycholic acid (DOC) stability in sediments and whether or not the flux of DOC allows reconstructing the evolution of domestic and wild fauna during the last 1700 yr in Southern Greenland, considering natural and anthropogenic forcing.

2. Setting

Lake Igaliku [61°00′ N, 45°26′ W, 15 m above sea level (a.s.l)] is a small lake (34.6 ha), with a maximum depth 26 m and catchment area 3.55 km^2. It is in southwestern Greenland, ca. 1.5 km from the village of Igaliku (Fig. 1). It has no major inflow but there is a small outflow into the Tunulliarfik fjord. It is surrounded by relatively low relief and slopes, allowing the establishment of farms, pastures and hay fields (Fig. 1). Southern Greenland has been affected by two phases of agricultural expansion during the last 1700 yr. The first corresponds to the Norse settlement that began in 986 AD and lasted approximately until the middle of the XVth century, coincident with the cooling of the Little Ice Age (Dugmore et al., 2012; Massa et al., 2012). The second corresponds to the modern agricultural expansion since 1920, resulting from the desire of the Danish to favor a new introduction of agricultural activities in a favorable climatic context. Nowadays, husbandry in the catchment is limited to two farms established during the 1970s where only sheep are raised (Massa et al., 2012).

3. Material and methods

Two cores Iga-2007 (130 cm long) and Iga-2011 (87 cm) were retrieved a few m apart under 21 m water depth, using a gravity corer. The age-depth model of Iga-2007 was based on 14 accelerator mass spectrometry (AMS) radiocarbon dates and on ^{210}Pb and ^{137}Cs measurements using spectroscopy, for the upper 15 cm (Massa et al., 2012; Fig. 2). The model was applied to Iga-2011 by correlating magnetic susceptibility data (measured with a Geotek Multi Sensor Core Logger) with Iga-2007 (Fig. 2). Coprophilous fungal spores, particularly *Sporormiella* spp, were counted in 33 samples spanning the last 1700 yr in Iga-2007, (Gauthier et al., 2010) and were expressed as flux of number of spores ($N/cm^2/an^1$) in order to take into account variation in sedimentation rate. Sediment samples (33; 0.5 cm thick) from Iga-2011 were selected for biomarker analysis.

Lipids were extracted from each sample (ca. 2 g) using an ASE 200 (Dionex©) with CH_2Cl_2:MeOH (9:1 v/v) at 100 °C and 1000 psi. Considering the minor mineralogical changes through the core, we did not use recovery standards for the bile acid. In addition, in-house tests indicated no significant proportion of bound acids, thereby excluding bias due to the proportion of bound vs. free bile acids. The extract was separated into neutral, acidic and polar fractions using solid phase extraction on aminopropyl bonded silica (Jacob et al., 2005). The acid fraction was methylated with anhydrous MeOH/MeCOCl and heating at 55 °C for 1 h. After separation of the fatty acid methyl esters (eluted with dichloromethane, DCM) from the hydroxy acid methyl esters (eluted with DCM:MeOH, 1:1) on activated silica, the latter were silylated by reacting with 100 μl *N,O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA) in 200 μl pyridine at 60 °C for 1 h. Finally, esterified and silylated acidic fractions were analyzed using gas chromatography–mass spectrometry (GC–MS) with a Trace GC Ultra gas chromatograph equipped with an AS 3000 autosampler and coupled to a TSQ Quantum XLS mass spectrometer (both Thermo-Scientific, Bremen, Germany). The GC instrument was fitted with a TG-5 MS column (60 m, 0.25 mm, i.d., 0.25 μm film thickness) from Thermo, Bellefonte, PA, USA. Samples were injected at 40 °C (held 1 min) and the oven was programmed to 120 °C at 30 °C/min and then

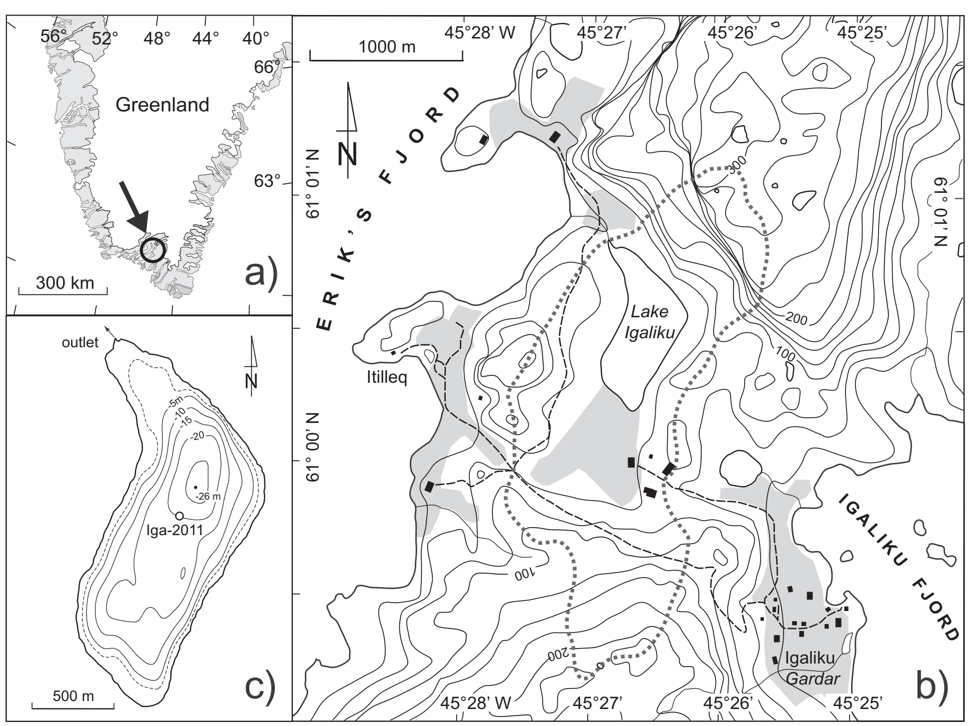

Fig. 1. Location of Lake Igaliku: (a) Map of Greenland with study area in the black circle. (b) Focus on region around the lake including paths (dashed lines), buildings (black rectangles), actual hay fields (gray zone) and the archeological site of Gardar. The catchment delimitation is drawn in dotted lines. (c) Bathymetry of Lake Igaliku and core Iga-2011 location.