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BiSpEem

Bivalve-speleothem compared reconstruction of Eemian climate and environment of the Belgian coast in the context of ongoing global warming

Dr Sophie Verheyden

Koninklijk Belgisch Instituut voor natuurwetenschappen
Belgische Geologische Diest,
Jennerstraat 13, B-1000 Brussel, België
T: +32 (0)2 7887641
@: sophie.verheyden@naturalsciences.be

Detailed description of the research project BiSpEem

1. Problematic

In the current context of global warming, models predict a warming of 2 to 7°C (IPCC, 2007) and a sea-level rise of 40 to 120 cm (Church and White, 2006; Rahmstorf, 2007; Vellinga et al., 2008) by 2100 compared to pre-industrial values. However, current models, which entirely rely on theoretically projections (Church et al., 2001; Rahmstorf, 2007) are not able to fully reproduce the sea-level rise of recent decades and produce generally lower than observed rates (WBGU, 2006; The Copenhagen diagnosis, 2009).

Recent findings of rapid changes in sea level under rapid warming (Waelbroeck et al., 2002; Schneider von Deimling et al., 2006; Thomas et al., 2009) and/or warmer than present conditions (Thompson and Goldstein, 2005; Rohling et al., 2008) feed the current debate on future sea-level changes and suggest a possible instability of polar and Greenland ice sheets under rapid warming and/or warmer than present conditions. Statistical analysis reveals the existence of a close link between the rate of sea-level rise and temperature (Rahmstorf, 2007). Crucial in modelling of sea-level rise is therefore a better understanding of the interaction between temperature increase, ice-volume reduction and sea level (Sidall et al., 2003; Otto-Bliesner et al., 2006; Overpeck et al., 2006; Rahmstorf, 2007; Rohling et al., 2008; Bamber et al., 2009).

The Last Interglacial (LIG) period or marine isotope stage (MIS) 5^{e}, characterized by Global mean surface temperatures that were at least 2°C warmer than present (Otto-Bliesner et al., 2006; Jouzel et al., 2007) and by a mean sea level of 4-6m higher than modern sea level (Chen et al., 1991; McCulloch and Esat 2000; Waelbroeck et al., 2002; Thompson and Goldstein, 2005; Hearty et al., 2007) can provide a base for comparison with the present interglacial and its future evolution. Although the last interglacial period is not an analogue for the current interglacial, regarding the different insolation pattern as explained by A. Berger and co-authors (Berger and Loutre, 1996; Loutre and Berger, 2003), it can provide insights into the climate processes, feedbacks and impacts under warmer than present conditions (Tzedakis et al., 2009). However, lots of uncertainties, heterogeneity and even contradictions still remain (Carr et al., 2009; Rohling et al., 2008). Important in this context are the timing, duration, intensity and variability of temperature and sea-level peaks at higher spatial (downscaling) and temporal resolution (by a better constrained chronology). An unambiguous definition of interglacials based on a single environmental proxy that can be extended throughout the quaternary is not available. Therefore multiproxy and intercalibrated regional data (to feed climate models) as well as more independently dated (rather than astronomically tuned) proxy records (Tzedakis et al., 2009) are essential to adequately respond to ongoing and future climatic and environmental changes linked to warming (Jansen et al., 2007).

Contrary to global sea-level reconstructions, the present coastline in Belgium and the Netherlands was found to be also a near coastal zone during the high stand of the Eemian period (Busschers et al., 2007; Mostaert and De Moor, 1989; Zagwijn 1983). Extensive research on the SW Belgian coastal tidal plain during the Holocene period revealed a complex environmental organisation of tidal subenvironments and peat lands as a direct consequence of gradual sea-level changes (Baeteman et al., 2002; Baeteman and Declercq, 2002; Baeteman, 2008). In the present context of global temperature increase, a detailed understanding of local natural environmental changes in response to global sea-level rise linked to global temperature increase is highly needed. As a basis for comparison to the present-day conditions, we propose to study the climatic and environmental conditions of the SW Belgian coastal area during the Eemian period (closely corresponding to the Marine isotope stage (MIS) 5e period defined in deep-sea sediments) and link it by detailed comparison with independently dated speleothems to global temperature change chronologies.

2. Aim of the proposal

The aim of this proposal is to reconstruct past climatic and environmental changes of the western Belgian coastal area within a well-dated frame and link these to global and regional climatic variability. We plan to make an intercomparison of two geological archives 1) marine carbonate bivalves from coastal sedimentary cores from the western Belgian coastal tidal plain and 2) independently dated low Mg calcite speleothems (chemical cave deposits) from Belgian and French stalagmites. The combined lithostratigraphic, petrographic and geochemical study (stable oxygen and carbon isotopic composition and Mg^{2+}/Ca, Sr^{2+}/Ca and Ba^{2+}/Ca ratios) of both proxies, will lead to a two-proxy climatic and environmental reconstruction allowing coastal-terrestrial comparison and integration of the environmental changes of the Belgian coastal area, including sea-level changes, into independently dated regional and global climatic and environmental variability during the Eemian period. Special attention will be given to the warmer-then-present period around 125 000 years BP.

3. Tasks and Methodology

The essential characteristic of the proposed reconstruction is that it is based on integrated reconstructions inferred from two different proxies. An innovative approach is to use speleothems to improve the chronology of the environmental reconstructions from coastal cores. Both proxies offer seasonal resolution through growth increments and contain climatic and environmental information through similar and complementary geochemical proxydata. As task 0, a website of the project will be made.

Task1. Carbonate molluscs from the western Belgian coastal plain.

The western Belgian coastal plain is a 15-20km wide embanked lowland at an elevation that varies from +2 to +5m TAW (mean lowest water spring, about 2 meters below mean sea level. Data from about 1250 undisturbed hand-augered gouges and 100 mechanically-drilled cores, covering the entire Quaternary sequence are available. These deposits contain numerous carbonate mollusc shells throughout the LIG-LG-Holocene cycle, including *Scrobularia, Corbicula, Mytilus, Ostrea* and *Spisula* species. The Holocene sequence was studied in detail with numerous datings (Baeteman and Declercq, 2002) inclusive radiocarbon dates obtained from intertidal mollusc shells (Baeteman, 2005, 2008). The coastal sedimentary deposits in Belgium have proven to be reliable recorders of past sea-level changes (Mostaert, 1989; Baeteman and Van Strydonck, 1989; Denys and Baeteman, 1995) partly due to a well-studied and stable eustatic effect (Vink et al., 2007). Also the history of the sedimentary infill of the area (Baeteman, 1999), the driving mechanisms of coastal changes (Baeteman, 2005, 2008; Baeteman et al., 1999, 2002), and a reconstruction of the palaeogeography at different time slices since 9500 cal BP (Baeteman and Declercq, 2002) could be retrieved from these sedimentary studies. An Eemian sequence, generally 3 to 5 meters, sometimes over 10 meters long was observed in approximately 50 sedimentary cores and the lithology was already studied in detail (Baeteman, 1990 unpubl.). Several sequences contain numerous shells or shell fragments.

We will sample mollusc shells along the Eemian sequence at an as high as possible resolution (one sample every 100 to 500 years is possible based on the available lithostratigraphic studies, Baeteman, 1990, unpubl.) (task 1.1.). Raman spectrometry on selected shell fragments will give a first indication of the extent of diagenetic changes (Lecuyer et al., 2004) (task 1.2.). The Pleistocene/Holocene boundary will be precisely determined in the cores using Magnetic susceptibility (task 1.3.). Both techniques are available at the RBINS (see table).

Bulk shell $\delta^{18}O$, $\delta^{13}C$, Sr/Ca, Mg/Ca and Ba/Ca will be measured (task 1.4.) by respectively Isotope Ratio-Mass Spectrometry, available at the Vrije Universiteit Brussel (VUB) (laboratory of Dr E. Keppens) and by ICP-Mass Spectrometry through close collaboration with Dr L. André (Royal Museum of Central Africa, RMCA, Belgium). Results will be interpreted as paleoclimatic and environmental signals (task 1.4.b) in close collaboration with Dr D. Gillikin from Vassar College (NY-USA) and Dr L. André (RMCA, Belgium). Bivalve shells have been well studied (cfr Shöne and Surge, 2005; Calmars Project, 2006; Calmars Project II, in press; Gröcke and Gillikin, 2008) and, despite a significant impact of physiology on proxy data recorded in the shells (Shöne and Surge, 2005; Gillikin et al., 2005; 2007; Shöne et al., in press), several studies demonstrated their potentiality to record environmental and climatic changes through climate related isotopic and chemical characteristics (Gillikin et al., 2006, 2006b; Gröcke and Gillikin, 2008; Elliot et al., 2009; Shöne and Fiebig, 2009; Nielsen and Nielsen, 2009; Johnson et al., 2009; Poirier et al., 2009). Recently (Black, 2009; Black et al., 2009) used the growth increments to start the development of a long-term marine chronology which relates to tree-ring chronologies on the NE American coast showing a major perspective for the development of long-term reconstructions from bivalves.

A main challenge will be the correlation of the reconstructed environmental record with other existing data of Eemian climatic and environmental variability, since precise direct dating of the shells is difficult because the Eemian period lies out of the time range of ^{14}C dating methods and U-series datings suffer from uranium migration (Innocent et al., 2005) and variable initial U-ratios due to their variability in seawater (Kaufman et al., 1971; Schwartz et al., 2005). However, determination of malacological assemblages can give a first idea of different subperiods within the Eemian period (Meijer and Preece, 2000; van Leeuwen et al., 2000) through close collaboration with the Malacology section of the RBINS (task 1.5.). We propose to use independently dated speleothems to tune the bivalve records to refine the chronology and increase time resolution of the coastal record (in close collaboration with D. Genty and the 7th FP-EU_RTD project Past4future).

Task 2. Speleothems

Speleothems or chemical cave deposits, mostly calcite deposits, are formed by CO_2 degassing of the cave water arriving in an open space containing less CO_2 than the surrounding limestone cracks. These deposits have proven to be excellent datable material through the U-series datings with a precision of up to 0.5% (Li et al., 1989; Fairchild et al., 2006) as well as recorders of climatic variability (Bar-Matthews, 1996; Verheyden et al., 1999, 2000, 2006, 2008; Genty et al., 1997, 2003, 2006;.Fairchild, 2006; Wang et al., 2008, 2009; Trouet et al., 2009). It is an increasingly used tool in the refinement of chronologies (Waelbroeck et al., 2008; Almogi-Labin et al., 2009). An already roughly dated Eemian speleothems sequence (Quinif, 1991; Quinif and Bastin, 1990, 1994) is available in the Cave of Han-sur-Lesse. The sequence will be sampled again for study in the context of the starting FP7 *Past4future* project. A second Eemian speleothem from the Vilaine source, nearby Namur, Belgium, a cave where the geochemical functioning was already well studied (Verheyden, 2001) will be sampled (task 2.1.a) and analysed in the context of this proposal, also in close collaboration with the Belgian karst specialists community through the FNRS-Contact group CBEK (Centre belge d'étude karstologique). After dating with the U-series method by Multicollector ICP-MS at the laboratory of Dr. R.L. Edwards, University of Minnesota (and if possible by layer counting) (task 2.2.), and a detailed petrographical description by optical and SEM microscopy available at the Geological Survey, RBINS (task 2.3.), mid-to-high resolution sampling (every 200 to 500 years) (task 2.1.b) and measurement of $\delta^{18}O$, $\delta^{13}C$, Mg/Ca, Sr/Ca and Ba/Ca ratios by similar methodologies as for bivalves (task 2.4.) will be done with special attention to the period around 125 000years.

Task 3. Tuning of the bivalve record with the speleothem record.

A combination of 1) stratigraphical indications in the coastal sedimentary cores, 2) malacological assemblages, 3) interpretation of the geochemical signals in terms of climate and environment done in the light of current knowledge from the literature with comparison of the general trends of the obtained records in both proxies, 4) comparison of geochemical signals from present-day bivalves and speleothems sampled in the studied sites to use as present-day reference (available), 5) if necessary, rough U-series dating of bivalve shells can be tempted and 6) precise U-series dating in the speleothems will allow us to tune the bivalve record to the independent chronology obtained with the U-series dating of speleothems using basic statistical tools in collaboration with Dr. M. Vandiepenbeeck from the RMI, specialised in climatological statistics (task 3.1.) and correlate with literature data and through discussions with the international (paleo)climate (Pages, IPCC) and Quaternary (Inqua) researchers community (task 3.2.).

In a second phase and for selected periods i.e. close to nowadays conditions, sampling and geochemical analysis ($\delta^{18}O$, $\delta^{13}C$, Sr/Ca, Mg/Ca and Ba/Ca) (task 3.3.) of individual growth increments in both proxies will give additional information on changes in seasonality.

The used methodology will on one hand mutually validate and complement the obtained climatic and environmental information from both proxies with strengthening of their chronology and on the other hand serve as a basis for widespread intercalibration possibilities for coastal and inland paleo-reconstructions. The information on environmental changes, inclusive sea-level changes, of the coastal Belgian plain available at the geological survey will be placed in a wider context of global climatic and environmental changes and in the context of possible future changes due to ongoing global warming (task 3.4.).

4. Expected results and milestones

The project will lead to the elaboration of well-dated records of Eemian climatic (temperature and rainfall) variability based on two independent proxies and of additional environmental variability (sea-surface temperature, nutrient availability and salinity and terrestrial vegetation activity). Very high resolution records will be obtained for specific periods, in particular the period of Eemian sea-level high-stand around 125000 years BP (rank A scientific paper, presentation in the frame of the FP7 project past4future, valorisation of the results through database websites cfr NOAA, pages.). Moreover, the study on seasonal changes, possible in both proxies will give additional information on the strength of seasonal changes during the selected periods (rank A scientific paper).

The proposal will valorise the sedimentary cores collection of the RBINS by placing the information obtained by the geological survey on environmental changes, inclusive sea-level changes, of the coastal Belgian plain in a wider context of global climatic and environmental changes. (paper in Belgian Journal or report + rank A scientific paper)

The reconstructed information from the Eemian period, a warmer-than-present period, will serve as base for a better insight in possible future changes of the Belgian coastal plain in the context of current global warming and associated sea-level rise (paper in Belgian Journal or report + rank A scientific paper). All the information will be available on the project website.

We will work on the shell records mainly during the first year and on the speleothem records mainly during the second year. The third year, we will focus on the comparison of both proxies, on the elaboration of an integrated record and on the study at seasonal resolution. During the fourth year, the obtained records and chronologies will permit to place available information of the environmental changes (s.s.) of the Belgian coastal plain into a broader context of regional and global climatic and environmental variability.

Workplan	**Year 1**		**Year2**		**Year3**		**Year4**	
semester	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Task 0 - website of the project								
Task 1.1. - sampling of bivalve shells in the sedimentary cores								
Task 1.2. - test for diagenetic changes								
Task 1.3. - Pleistocene/Holocene boundary determination								
Task 1.4. - bulk shell $\delta^{18}O$, $\delta^{13}C$, Sr/Ca, Mg/Ca Ba/Ca measurements and elaboration of time-series								
Task 1.5. - determination of malacological assemblages								
Task 2.1. - sampling Eemian speleothem								
Task 2.2. - U-series dating (sending of samples to Univ Minnesota and making of the growth model)								
Task 2.3. - detailed petrographical description								
Task 2.4. - $\delta^{18}O$, $\delta^{13}C$, Sr/Ca, Mg/Ca Ba/Ca measurements and elaboration of time-series								
Task 3.1. - building of integrated records of temperature and rainfall								
Task 3.2. - correlate records with international literature								
Task 3.3. - seasonal resolution study with additional dating if needed - calibration towards present-day values								
Task 3.4. discuss Belgian coastal plain information into a global climatic and environmental context, inclusive sea-level in the frame of ongoing warming and related possible future coastal changes								