NCL
Netherlands Centre for
Luminescence dating

Coastal Development

Application of luminescence dating in coastal studies

NCL Symposium Series, Volume 8
Sytze van Heteren (ed)
August 30, 2011
TU Delft, Science Centre
Mijnbouwstraat 120, Delft

Location and Programme

The symposium takes place on Tuesday August 30, in Room BG 350 at the Science Centre Delft (TU Delft), Mijnbouwstraat 120, Delft (see www.tudelft.nl for directions).

12.00 Coffee and tea

12.25 Welcome by Jakob Wallinga (Director NCL)

12.30 Tony Reimann, Leibniz Institute for Applied Geophysics (p. 3)
Interrelation of Holocene beach progradation and aeolian sand movement at the Baltic Sea and North Sea coast – Insights from OSL dating

12.50 Joep Storms, TU Delft (p. 5)
The impact of rapid sea-level changes on recent Azerbeijan beach ridges

13.10 Sytze van Heteren, TNO - Geological Survey of the Netherlands (p. 8)
Teasing age information out of chance exposures and cores in coastal sand: Cunning tricks of OSL

13.30 Andrew Murray, Aarhus University (p. 11)
Establishing a chronology for Young coastal sediments

13.50 Marcel Stive, TU Delft (p. 13)
From Coastal Genesis to the Sand Engine

14.10 Coffee and Tea

14.30 Alastair Cunningham, TU Delft (p. 15)
PhD thesis: Luminescence dating of storm-surge sediment

15.00 Thesis defence Alastair Cunningham

Interrelation of Holocene beach progradation and aeolian sand movement at the Baltic Sea and North Sea coast - insights from OSL dating

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Holocene coastal plains and coastal barriers along the southern Baltic Sea and southern North Sea coast are made up of shallow marine depositions (e.g. swash-bars, tidal sediments), aeolian depositions (e.g. aeolian cover sands, dune sediments) or sedimentary features, which are a result of a combination of shallow marine and aeolian depositional processes (e.g. foredune ridges). Foredune ridges and swash-bars are cited as sensitive indicators of ancient shoreline positions (e.g. Bristow et al., 2000; Lindhorst et al., 2008) and have thus significance for studies of Holocene coastal evolution. According to Bristow et al. (2000) a basic requirement of a prograding beach or foredune plain is positive sediment budged (i.e. sufficient sediment supply to the beach) and secondly progressive vegetation cover to trap the wind-blown sediment and to stabilise foredunes as well as the beach platform. A beach plain turn into an erosive mode for three main reasons: (i) the sediment supply is significantly reduced, (ii) a significant relative sea-level rise effectively causes erosion of the beach plain and (iii) regressive vegetation cover effectively reduces the quantity of sand being trapped at the beach, which causes an interruption of beach plain accretion and an aeolian sediment transport further inland (e.g. Hesp, 2002). Hence, the development of Holocene coastal barriers and coastal plains results from a complex interaction between variable environmental factors (e.g. sea-level, climate, geomorphology, land-use, coastal protection). The objective of this study is to correlate phases of prograding or erosive beach plains at the southern Baltic Sea and southern North Sea with past environmental changes. Therefore, we applied quartz OSL dating to altogether 46 foredune, swash-bar, wash-over, and coastal aeolian sediment samples taken from the Holocene coastal barriers Świna (southern Baltic, NW Poland) and Sylt (southern North Sea, N Germany).

The chronologies of the investigated sedimentary archives indicated that under conditions of a fast sea-level rise (i.e. during the Littorina or Flandrian transgression) no established foredunes or swash-bars were formed. The ages of the oldest foredune ridges at the Świna-barrier revealed that foredune plains can grow even under conditions of a moderate sea-level rise. It is concluded that under conditions of an overall moderate sea-level rise (1.0-1.5 mm/yr) the setting of a beach plain or foredune plain (progradative, or erosive) is highly depending on other controlling parameters, in particular it depends on the relation of sediment supply, accumulation space and sediment trapping, i.e. the local geology, morphology, and vegetation cover. The formation of foredunes and swash-bars was likely correlated to warmer, milder and calmer phases within the mid- to late-Holocene (Fig. 1). At the Świna barrier a phase of intensive foredune plain progradation took place in early Subboreal before ~2100 BC during the Holocene climate optimum (Reimann et al., 2011). Beach samples from Sylt indicate that swash-bars along the western coast were welded at 400 BC to 400 AD and ~1100 AD implying a coincidence with the Roman warm period (RWP) and the Medieval warm period (MWP), respectively (Reimann et al., submitted). Similar phases of beach progradation during the RWP and MWP were also detected in the chronology of the Świna barrier foredune accretion. In contrast, time gaps within the Świna foredune chronology probably indicating a stagnant or erosive foredune plain at ~2100 BC, ~900 BC, 600 AD, and during the time of the Little Ice Age (LIA) at ~1550 AD (Fig.1). These time gaps correlate with well known phases of enhanced aeolian activity along the coasts of West and Northwest Europe (e.g. Wilson et al., 2004; Clemmensen et al., 2009) in coherency with abrupt climate shifts (known as LIA-type events) to cooler and stormier conditions (e.g. Bond et al., 1997). This climate shifts likely caused a regressive vegetation cover and accordingly induced a sediment transport from the beach/foredune plain to the coastal hinterland providing the sediment for transgressive dunes or aeolian sand-sheets. Indeed, the formation of a transgressive dune at the Świna barrier and the deposition of aeolian cover sands in Sylt were dated to ~1500-1600 AD indicating enhanced aeolian activity during the main phase of the LIA.

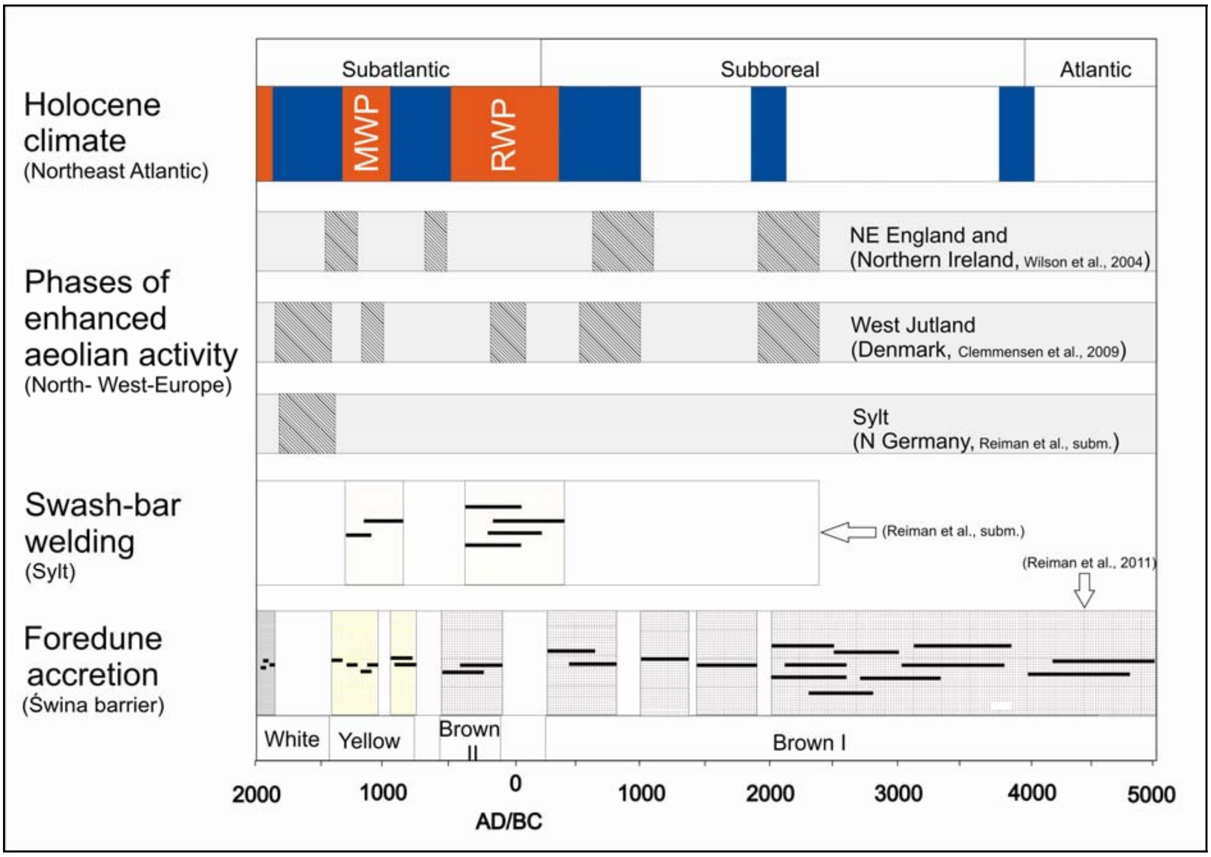

Figure 1. Beach progradation, aeolian activity and Holocene climate.

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The impact of rapid sea-level changes on recent Azerbaijan beach ridges

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Over the past 50 years extensive field studies of Holocene and Pleistocene beach-ridge complexes have been conducted in order to resolve the effect of waves and sea-level variability on the formation of beach ridges (Bristow and Puccillo, 2006; Otvos, 2000; Taylor and Stone, 1996). Several hypothesis have been proposed on the role of low and high-energy waves on the formation of beach ridges but it is realized that different formation mechanisms may exist for at different locations and under different conditions. On coarse clastic beaches, high-wave-energy events appear to be the dominant mode of beach-ridge formation (Carter, 1988). On less coarse beach systems, beach ridge formation is "commonly attributed to the waning phases of storms", according to Wells (1996). However, other studies reveal that, based on the highly complicated internal structures within beach ridges, swash is the dominant process in the construct of beach ridges and that storm waves play no significant role (Tanner, 1995). In case beach-ridge formation is driven by swash processes, this also indicates that sea-level fluctuations are an important parameter in controlling the morphology and orientation of beach-ridge complexes. By assuming that beach-ridge formation relates to sea-level change, several authors have used beach-ridge complexes to reconstruct the Holocene lake levels (e.g. Dott and Mickelson, 1995; Thompson and Baedke, 1997).

The coastlines along the Caspian Sea offer a unique opportunity to elucidate the role of sea level and sediment supply on the formation of beach ridges with minimal tidal influences. The Caspian Sea is a landlocked basin in which mean annual sea-level changes rapidly while tidal amplitude is negligible. The Caspian Sea has a surface area of 393.000 km2 and is the largest inland water body on earth. The northern part of the sea is a shallow shelf region reaching a maximum depth of about 10 m. The southern region is part of an active tectonic zone in which the Great and Lesser-Caucasus are uplifting (Mitchell and Westaway, 1999). Caspian seafloor subsides at a rate of 2.5 mm/y (Inan et al., 1997). The depth of the southern Caspian Sea is approximately 1025 m and the shelf edge is located 20 to 40 km offshore. The Caspian Sea has virtually no tides, its salinity (13 mg/l) is only a third of oceanic seawater and the sea surface is situated about 26 m below global oceanic level. The mean annual Caspian Sea level varies with rates up to 0.34 m/y. However, the interaction between seasonal differences in river discharge (predominantly the Volga), evaporation, precipitation and water temperature (Rodionov, 1994; Kosarev and Yablonskaya, 1994) results in interannual sea-level changes of up to 0.4 m (Cazenave et al., 1997). Caspian Sea level varied between -26 m and -30 m between 1840 and 1999. In 1977 Caspian sea level started to rise (Kroonenberg et al., 2000) which continued for 18 years, totaling 2.5 meters. From July 1995 onwards, Caspian Sea level started to fall again. Between 1995 and 1999 the Caspian Sea level fell about 0.8 m leading to coastal regression and the formation of beach ridges along several sectors of the Azerbaijan coast. Superimposed on the overall sea-level fall is a seasonal change in sea level with an amplitude of about 0.2 m. We used satellite altimetry measurements to create a bi-daily to weekly time series for the level of the Caspian Sea. Ground penetrating radar, combined with detailed topographic measurements, was used to reveal the subsurface structures. A nearby meteorology station provided the storm data.

A ground penetrating radar survey of a newly formed series of beach ridges along the southern Azerbaijan coast, Caspian Sea, illustrates rapid coastal response to the most recent Caspian Sea-level fall of 0.8 m between 1995 and 1999. Effects of seasonal sea-level fluctuations as well as individual storm occurrences can be linked to depositional beds on the ground penetrating radar profiles. The beach ridge system is swash-built and formed primarily under fair-weather conditions. Ridge and swale topography can be related to seasonal sea-level change. The rapid Caspian sea-level change combined with surface and subsurface data on coastal beach ridges provides a unique opportunity to observe and reconstruct coastal evolution at a resolution not possible along other oceanic coasts.

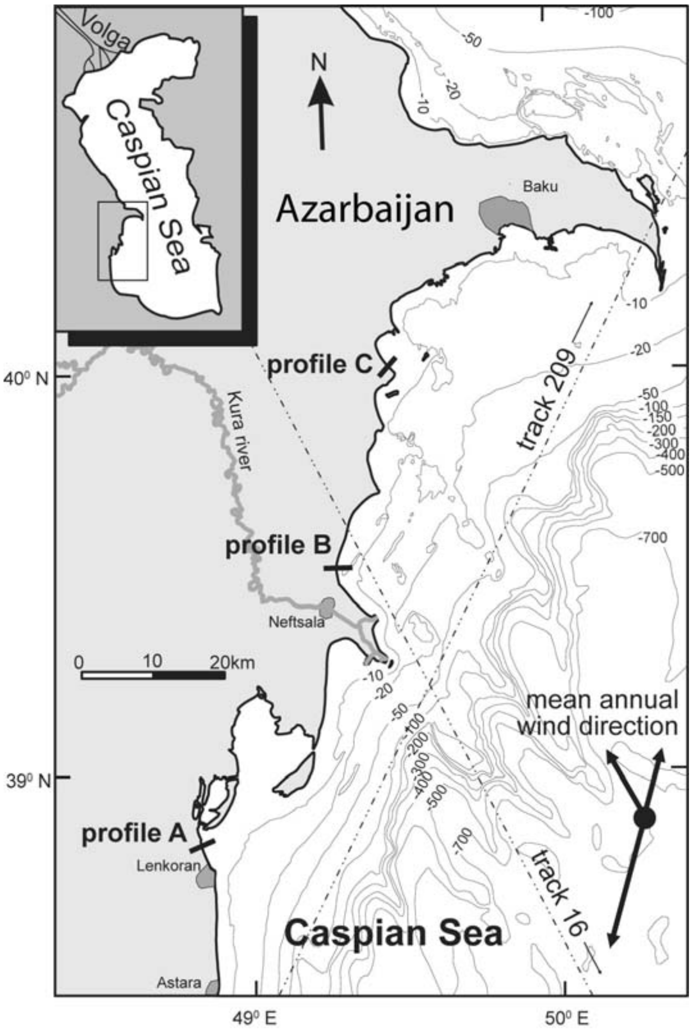

Figure 1. Study area along the Caspian Sea.

Figure 2. Caspian coastline.

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Teasing age information out of chance exposures and cores in coastal sand: Cunning tricks of OSL

Sytze van Heteren (TNO – Geological Survey of the Netherlands, PO Boc 80015, NL-3508 TA Utrecht, the Netherlands, e-mail: sytze.vanheteren@tno.nl)

It has been almost ten years since the first coastal sand samples from the Netherlands were collected for OSL dating. Although these samples from the island of Texel were dated at the Nordic Laboratory for Luminescence Dating in Denmark, they also marked the starting point of the Netherlands Centre for Luminescence dating. Despite the success of this first study, which established the potential of OSL for dating young coastal sediment, relatively few additional coastal samples have been dated by the NCL since that time (Table 1).

Table 1. Coastal sand samples processed and/or dated by the NCL.

year	number of samples	area	type of deposit
2003	28	Texel	eolian dune
2005	20	Castricum and Heemskerk	eolian dune and beach
2007	5	Castricum and Rijswijk	eolian dune and beach
2008	12	IJmuiden	eolian dune and beach
2009/10	32	Heemskerk	eolian dune and storm-surge beach
2011	15	Balgzand and Plouescat (France)	tidal flat (B); eolian dune and storm-surge beach (P)
total	**112**		

The first systematic dating study of Dutch coastal sand, on Texel (Ballarini et al., 2003), focused on the calibration of OSL ages, using historical documents on coastline position. To maximize the likelihood of success, all samples were collected from similar positions on the seaside of preserved dune ridges that mark a period of coastal accretion on the southwestern side of the island. By sampling dune sand, key problems of partial bleaching and heterogeneity of the beta dose were minimized. The resulting chronology matched that of the independent age control (Figure 1).

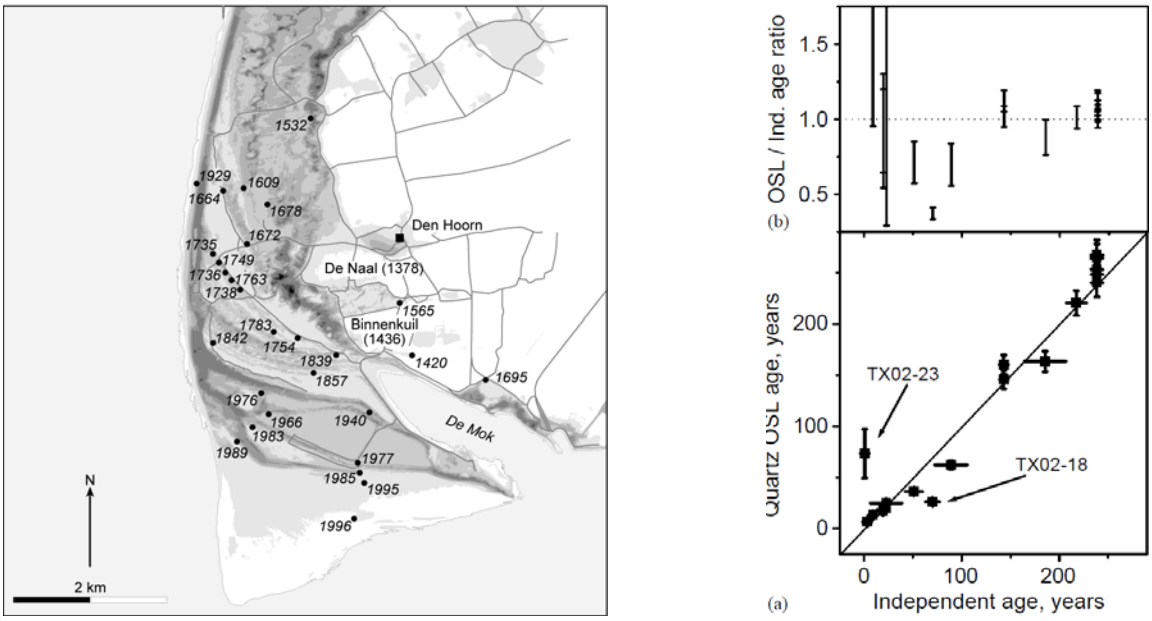

Figure 1. OSL ages (years AD) of Texel samples, and OSL versus independent ages.

During the next five years, all coastal sand samples submitted to the NCL for OSL dating were collected in a geo-archeological context. They provided a chronological framework for the habitation history of coastal regions during the past few thousand years, and increased our understanding of the closure of the former IJ estuary about 2,000 years ago. Systematic OSL dating of coastal sand resumed after a storm surge in November 2007 exposed older storm-surge deposits in the eroded frontal dune at Heemskerk. The deposits consisted of shell beds intercalated with sand, providing methodological challenges of varying degree related to partial bleaching and to heterogeneity of the dose rate. By tackling these challenges, Cunningham et al. (2011) were able to assign the deposit to the historical storm surges of 1775/1776 (Figure 2), and simultaneously opened up a new (geological) source of information for understanding long-term storm-surge risk.

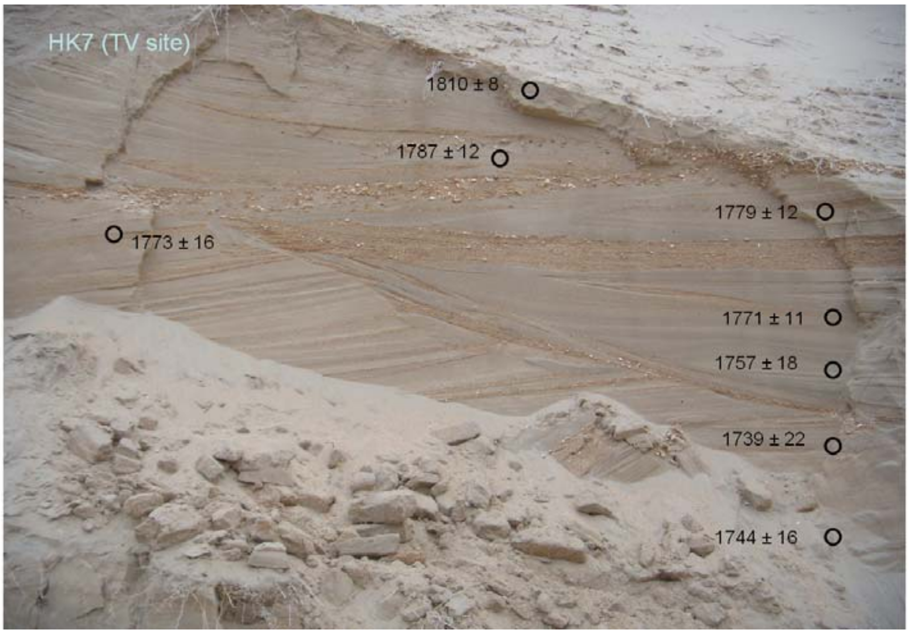

Figure 2. OSL ages (years AD) of a Heemskerk storm-surge section.

As a follow-up of the Heemskerk study, superimposed storm-surge layers exposed on the north coast of Brittany (France) (Figure 3) have recently been dated with OSL. These layers described by Lindstrøm (1979) were the first deformed sedimentary structures associated with storm surges. The setting of this site differs from that of Heemskerk, with high-energy open-Atlantic hydrodynamic conditions and a weathered granite source rather than semi-mature, partly recycled quartz-feldspar sands. Aside from this different setting, with its specific challenges for OSL dating, the Brittany site offers an opportunity to look at the potential for interregional correlation of storm-surge layers. All storm-surge units were formed during the 18th and 19th centuries, but differences in ages calculated using the Central Age Model and Minimum Age Model preclude detailed conclusions at this time.

Building on experiences from Danish Wadden Seas research, a final systematic OSL-dating study is being carried out on the Balgzand tidal flat south of Texel (Figure 4). A 60-cm-long core with intertidal sand was sampled every 5 cm. The associated OSL ages show steady accretion of about 1 cm per year, with a possible hiatus between 1980 and 1992. The most likely cause of this hiatus is the major storm of February 1990, which destroyed many of the mussel beds in the Dutch Wadden Sea.

Thus far, 'Dutch' OSL-dating studies of coastal sand have focused on calibration aspects, on methodological improvements, and on specific environmental issues related to foredune formation, storm-surge events and tidal-flat accretion. Several challenges remain in coastal research, given that quantification of long-term process-response relationships to predict 21st-century barrier behavior is only possible when accurate volume and flux estimates are complemented by reliable age constraints.

Dating of sedimentary sequences and event markers will become increasingly important, and sediment budgets for entire coastal tracts must be improved. For some records still present today, time is running out as coastal erosion is slowly removing valuable geological evidence of past coastal change.

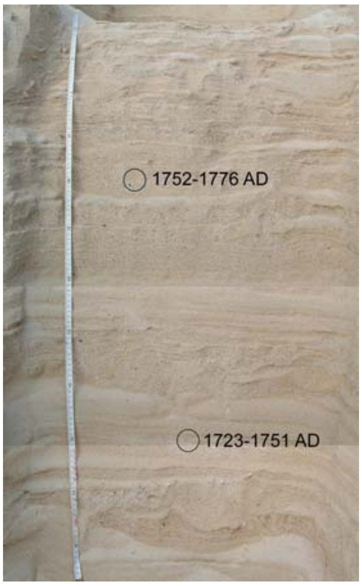

Figure 3. Narrowing coastal spit at Plouescat (Brittany), and OSL ages of storm-surge units.

Figure 4. The Balgzand tidal flat and associated dated core (ages in years AD).

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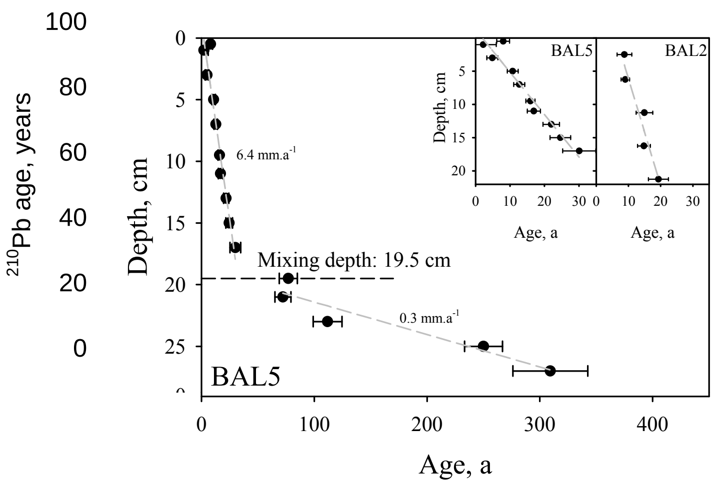
Establishing a chronology for young coastal sediments

Andrew Murray (Nordic Laboratory for Luminescence Dating, Department of Geoscience, Aarhus University, Denmark, e-mail: anmu@risoe.dtu.dk)

Young coastal sediments archive the history of, inter alia, recent sea level change, extreme events of direct relevance to modern society, and the environmental effects of industrialisation and land use changes. They have the potential to become very important tools in land use, coastal and estuarine management and conservation. But, as with all archives, the data cannot be interpreted without a chronology. Until about 10 years ago, the methods available to establish a chronology for recent sediments were very limited: ^{210}Pb and ^{137}Cs could, in the right circumstances provide a model-dependent chronology in fine-grained sediments for about the last 100 years, but apart from chance finds of anthropogenic material ('bottles and boats') there was essentially no way to date sand accumulation retrospectively. Luminescence dating has completely changed this picture.

Optically stimulated luminescence (OSL) provides burial ages for sediments that were daylight exposed prior to sedimentation. This light exposure emptied trapped charge within the luminescent mineral (usually quartz) and so reset, zeroed or bleached the luminescence signal. For many years it was thought that this process could never be sufficiently complete to allow OSL ages younger than ~1000 years, although a few individual results from both quartz and feldspar suggested that this might not always be true. More recently, beginning with the collaborative work between Delft and Aarhus (Ballarini et al., 2003), it has become clear that many types of coastal sediment are sufficiently exposed to daylight to allow dating on a decadal, perhaps even annual, time scale, even without the complexities of analysis grain by grain..

Here the luminescence characteristics required for successful dating of young sediments are first outlined, and the apparent residual ages in a selection of recently deposited sediments from around the world presented. It is shown that under the most favourable circumstances, ages as small as ~1 year can be measured on sediments still undergoing transport, although residual ages of a few years are more common.



The application of the technique to recently deposited intertidal sediments is then discussed using the considerable body of work (mainly Madsen and coworkers) from the Danish Wadden Sea. These dated profiles have an age range from decades to thousands of years, and compare well with independent age control (e.g. Figure 2, from Madsen et al., 2005). In many ways the most remarkable thing about these results is the smooth variation with depth within the 20 cm deep mixing zone at the surface. An example of such data is given in Figure 3 (Madsen et al., 2011); these data provide a direct estimate of the rate of bioturbation, of about 6 mm.a^{-1} at this location.

The various age/depth profiles are discussed in terms of their precision and accuracy, and in particular in terms of completeness of bleaching.

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From Coastal Genesis to the Sand Engine

Marcel J.F. Stive (Department of Hydraulic and Environmental Engineering, Delft University of Technology)

This contribution is on the history of "Building with nature" in the Netherlands. It is a personal view implying that it will not necessarily comply with the view of the many other people involved in this history.

With the design of the seaward extension of Rotterdam's Port via Maasvlakte 1 in the 1970s, the concept of integrating natural processes into human interventions became manifest. The greater part of the seaward defence of Maasvlakte 1 consisted of a dune coast. The creation of the Van Dixhoorn "Triangle" just north of the harbour entrance with sand extracted from the new navigation channel can be seen as a nature compensation "avant la lettre". Svasek and Waterman became known as the promotors of the concept.

In the mid 1980s the academic institutions upon instigation of Rijkswaterstaat became involved with the concept of working with nature in the Coastal Genesis project. Through a multidisciplinary collaboration engineering time scales were connected with historical and geological time scales. Many results were used in the context of the first Coastal Policy document of 1990, in which it was decided to maintain the coastline position primarily by sand nourishment. One of the concepts was that of using foreshore nourishment as an alternative to beach or dune nourishment. This first innovation in soft engineering was realized for the first time in the Nourtec project on Terschelling. Many foreshore nourishments have followed since.

Meanwhile Ronald Waterman kept promoting extending the Van Dixhoorn Triangle into a large scale lineair extension along the coast between Hoek van Holland and Scheveningen. While there existed political support the realization was obstructed by the general public. In 2008 an alternative to a lineair extension was suggested in the form a the Sand Engine. This was recently completed and can be considered as a second innovation in "Building with Nature".

The Van Dixhoorn Triangle (source: Ronald Waterman).

The Sand Engine at Delfland in August 2011 (source: Rijkswaterstaat/Joop van Houdt).

Embryo dunes on the Sand Engine in August 2011 (source: Leo Linnartz).

Luminescence dating of storm-surge sediment

Alastair C. Cunningham (Delft University of Technology, Netherlands Centre for luminescence dating)

The analysis of storm-surge sediment has the potential to provide new information on storm-surge risk, and give an understanding of how storm-surges affect the coastal zone. While reliable measurements of storm surges have been collected over the last hundred years or so, the data that can be obtained from the geological archive has two particular benefits. Firstly, storm-surge deposits can be created from high-magnitude events over a period of hundreds or thousands of years. The low frequency of these events means they are unlikely to occur during the relatively short time-span of instrumental measurements. Secondly, high-magnitude events of the past may have occurred under subtly different climatic conditions. Studying palaeo storm surges allows a better appreciation of how storm surges respond to climate parameters, vital information given the changes in climate patterns and sea level that are likely in the near future.

Storm-surge sediment found within coastal sand dunes near Heemskerk, North Holland. Left: OSL sampling at a section containing the storm-surge unit, visible across the middle of the photo. Upper right: Sampling a frozen bluff-face section. The storm-surge unit truncates the whole section, just above head-height. Lower right: Detail of the shell-rich storm-surge deposit.