OCEAN AND CLIMATE CHANGE INSTITUTE PROGRESS REPORT

Project #25051225: Coastal Dunes as Archives of Climate Change

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Environmental changes recorded in coastal dune stratigraphy: Preliminary Results

Holocene coastal dunefields in southern New England and along southeast Baltic Sea coast are ideally situated for a comparative study of the climatic effects on coastal environmental change. Whereas their early Holocene sea-level histories differ, coastal deposition at both sites began after 7,000 yBP and the dunefields have the potential of recording 3,000-6,000 years of landscape dynamics. It has been suggested that the most recent phase of dune activation on the Curonian Spit, Lithuania (Fig. 1A) was the result of deforestation prior to the "Little Ice Age" (before 700 yBP); however, to date only a handful of studies have addressed the evolution of this coastal region. To date, no attempts have been made to address the role of climate change as a driving mechanism in coastal dune evolution.

In the fall of 2005, with the funding from the Ocean and Climate Change Institute at the, I have conducted preliminary field studies (GPR surveys, sediment cores, dendrochronology) along the southeast Baltic Sea coast (Fig. 1) and at Aquinnah dunefield on Martha's Vineyard, Massachusetts. Curonian Spit, a UNESCO World Heritage Site, has the highest coastal dunes in northern Europe (up to 67 m above sea level) which are part of the Great Dune Ridge. Exposures of relict dunes on the northern part of the spit reveal a number of mappable paleosol horizons, which have been recently dated at NOSAMS to 5,690±80, 3,355±115, 1,255±85, and 700±40 cal years BP (Figs. 1B-D). The first set of optical dates from another site to the south dates the dune activity phase at <500 yBP (Bitinas, 2004), which represents the most recent period of dune migration. The geometry and extent of these paleosols allow reconstruction of dune morphology and migration direction similar to some examples of relict dunes along the Polish coast. These paleosols are also clearly identifiable in GPR records, which provide a more complete picture of their spatial relationships and extend below the water table (Fig. 1C, D). The working hypothesis is that periods of dune re-mobilization following each stability episode are related to North-Atlantic climate change possibly through changes in the NAO-mediated storminess and subsequent human-induced changes.

Similarly, recent surveys on Martha's Vineyard indicate that periods of temporary landscape stability alternated with dune activity. Reconnaissance GPR profiles and sediment cores indicate that relict dunes are characterized by highly weathered brown sands, reach 5-12 m in thickness, and contain organic-rich horizons. The next stage in this research is a comprehensive sampling strategy to determine optical (OSL) ages of various parts of the dune sequences to reconstruct the timing of dune activity.

Another example of paleo-environmental information archived in coastal dunes is a sedimentological record of past wind climate. Along with wind frequency and direction, the velocity of near-surface winds is one of the most important factors governing aeolian sediment transport and is itself one of the proxies for NAO-related variability. Reconstructing this component of the atmospheric circulation system based on coastal dune sediments has not been previously addressed and is one of my research initiatives. Just as a heavy-mineral concentration (HMC) is diagnostic of storm erosion in beach sediments, the HMCs in dunes sands are likely related to substantial increases in wind velocity thereby causing preferential winnowing of light minerals (quartz, feldspar, muscovite) and increase in the proportion of denser minerals (garnet, magnetite, ilmenite, etc.) in a given grain-size fraction. HMCs are common on modern dunes and in dune exposures and produce prominent reflections in GPR records. These observations indicate substantial fluctuations in wind intensity and show great potential for reconstructing for

the first time both the timing of various wind intensity phases (based on ^{14}C-dating of bounding paleosols and OSL dating of dune sands) and the threshold shear velocities that produced them. The latter is possible due a direct relationship between wind velocity and sediment texture and density, thus providing a means of quantifying the wind speed responsible for transport and deposition of dune sediments with various proportions of heavy minerals. This approach will provide additional constraints on the centennial-to-millennial scale climatic variability in the North Atlantic and can be extended to coastal and continental dunefields in other parts of the world.

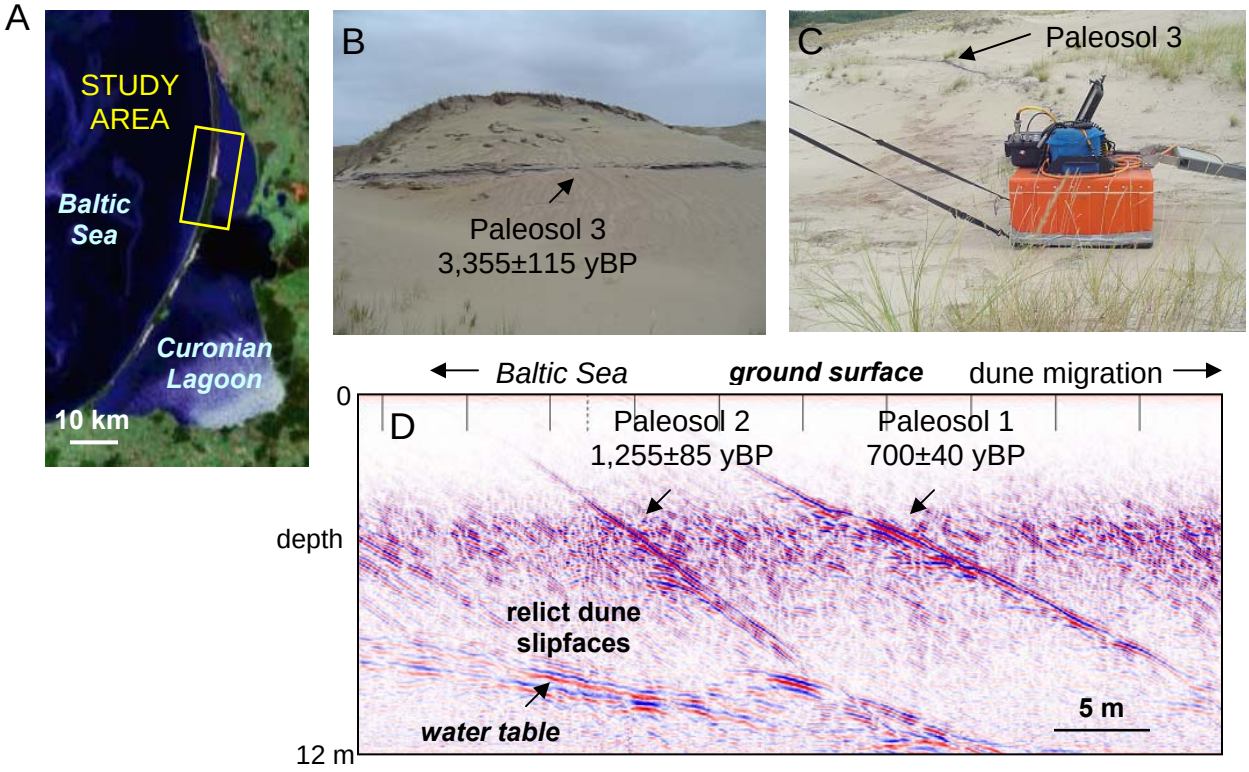


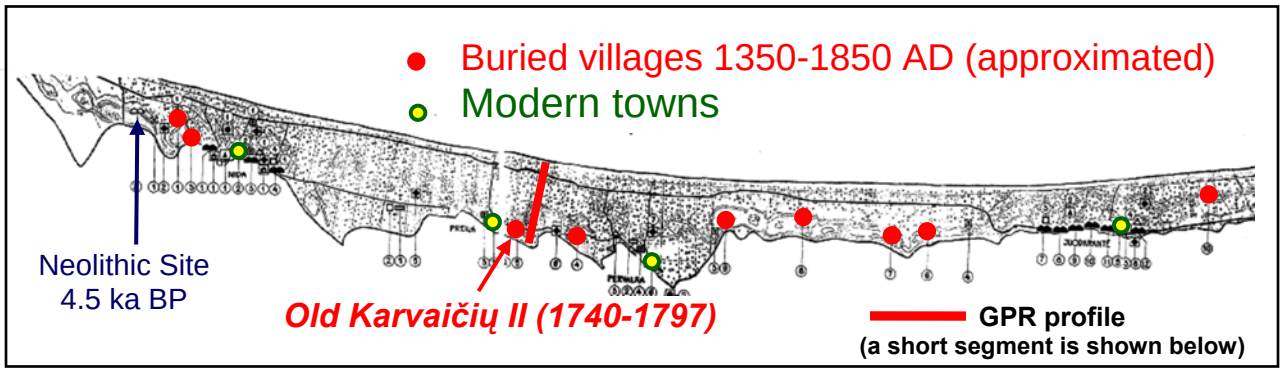
Figure 1. A) Satellite image of the Curonian Spit, Lithuania; B) paleosol exposed along an erosional remnant of a relict Holocene dune at Naglių Nature Reserve was formed during a period of relative landscape stability (age in calendar years BP); C) SIR-2000 GPR antenna and control unit over the same paleosol exposed on a horizontal deflation surface; D) GPR image over an exposed deflation surface (east of location in 1B) reveals the internal structure of a migrating dune, including prominent reflections from two buried paleosols.

Human-landscape interaction

The role of human activity (deforestation, grazing, controlled burning, etc.) has been an important factor in altering the coastal dune landscapes and is a parallel focus in the ongoing research. The interaction between people and the coastal landscape along the southeast Baltic Sea coast began as early as 4,500 years ago (Neolithic dune sites), but the impact on the landscape was evident during medieval times when the spit was a transit area for the Teutonic Order during the Northern Crusades (12-15th centuries A.D.). The scale and speed of geological impact on local population have reached their peak during the 15-19th centuries. During this time, a number of communities were established along the Curonian lagoon seeking protection from the Baltic winds behind the high dunes (Fig. 2). A preliminary review of the existing documents and charts reveals that this time was also marked by several mobilization episodes of large dunefields, triggered largely by land clearance. During this period, at least twelve Curonian fishing villages were buried by migrating dunes (Fig. 2, top).

To date, very little is known about the exact locations of the former villages, and much of the historical heritage of a once prominent maritime culture has been lost. The hypothesis to be tested in the future studies addresses the period of intensified anthropogenic influence combined with climate-driven changes during the Little Ice Age to trigger an unprecedented massive dune deflation and eastward migration. A pending proposal involves the first attempt to locate and map former settlement surfaces (and possibly remains of old structures) using geophysical imaging (Fig. 2, bottom) as part of an overall goal to investigate the human-landscape interaction in this part of the world.

Similarly, no comprehensive studies exist on the archaeology of Aquinnah dunefield on Martha's Vineyard. In the early Holocene, the area between the island and Cape Cod was exposed and there is evidence of human habitation as early as Middle Archaic period (8,000-6,000 yBP) on the island. However, it is unlikely that prehistoric populations had any impact on coastal dunes in this area, with limited land use beginning only during European settlement. Future work will shed light on this issue.



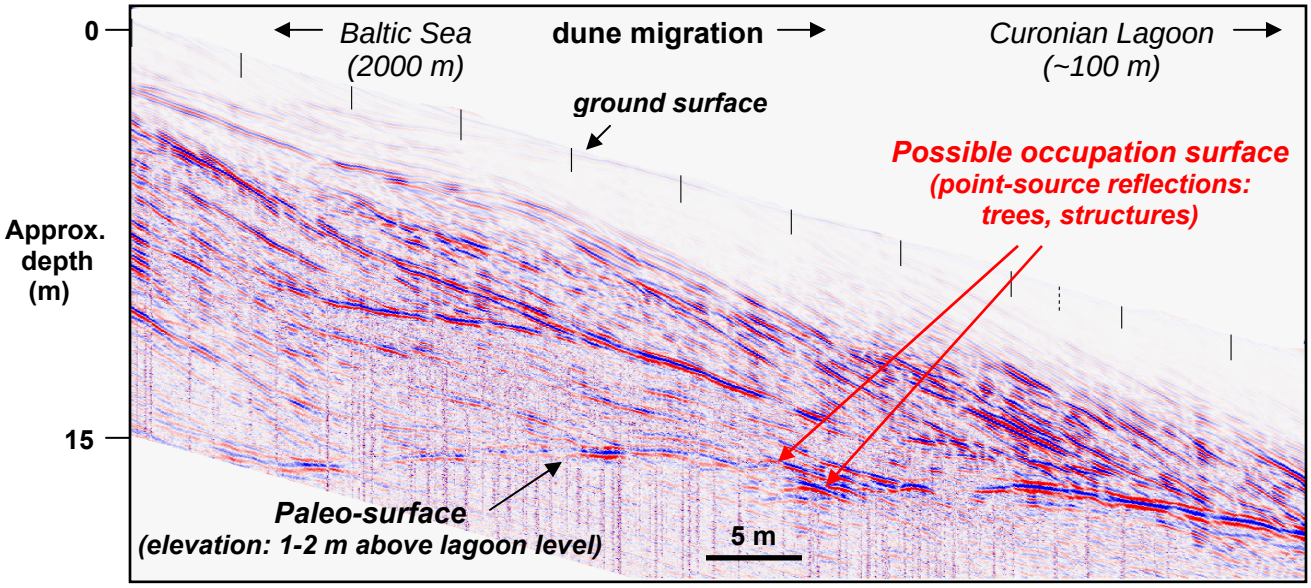


Figure 2. Top: Approximate locations of buried villages, based largely on historical descriptions. Bottom: Ground-penetrating radar record over a large dune (landwardmost segment of red line in Fig. 2, top). Note hyperbolic reflections (possible structures) on a buried horizontal surface just above the lagoon.

Further Funding and Dissemination of Results

The results of the OCCI-funded study have been integrated into proposals to leverage government funding (2006 NSF-EAR - pending; 2006 National Geographic Society - pending). The preliminary findings from the project were presented at the 2005 OCCI Annual PI seminar and Geology & Geophysics Department science feature. The research will be also featured in the 2005 WHOI Annual Report. As data are being analyzed, abstracts are being submitted to international conferences and new findings will be published in several peer-reviewed journals.

Buynevich, I.V., Bitinas, A., and Pupienis, D., 2006. Geological perspective on human-landscape interaction: Curonian coastal dunes, SE Baltic. *International Geological Correlation Programme Project 521, Second Plenary Conference Extended Abstracts*, Odessa, Ukraine, accepted.

Buynevich, I.V., Bitinas, A., and Pupienis, D., Timing of regional dunefield stability along the southeast Baltic Sea coast, in prep.

Buynevich, I.V., Bitinas, A., and Pupienis, D., Diverse lithological origin of GPR reflections in a relict coastal dune, in prep.