Rhine-Meuse delta studies

Universiteit Utrecht

Deltaic subsidence due to compaction, isostasy and tectonics: Rates at syn-depositional time-scales (Holocene, Netherlands)

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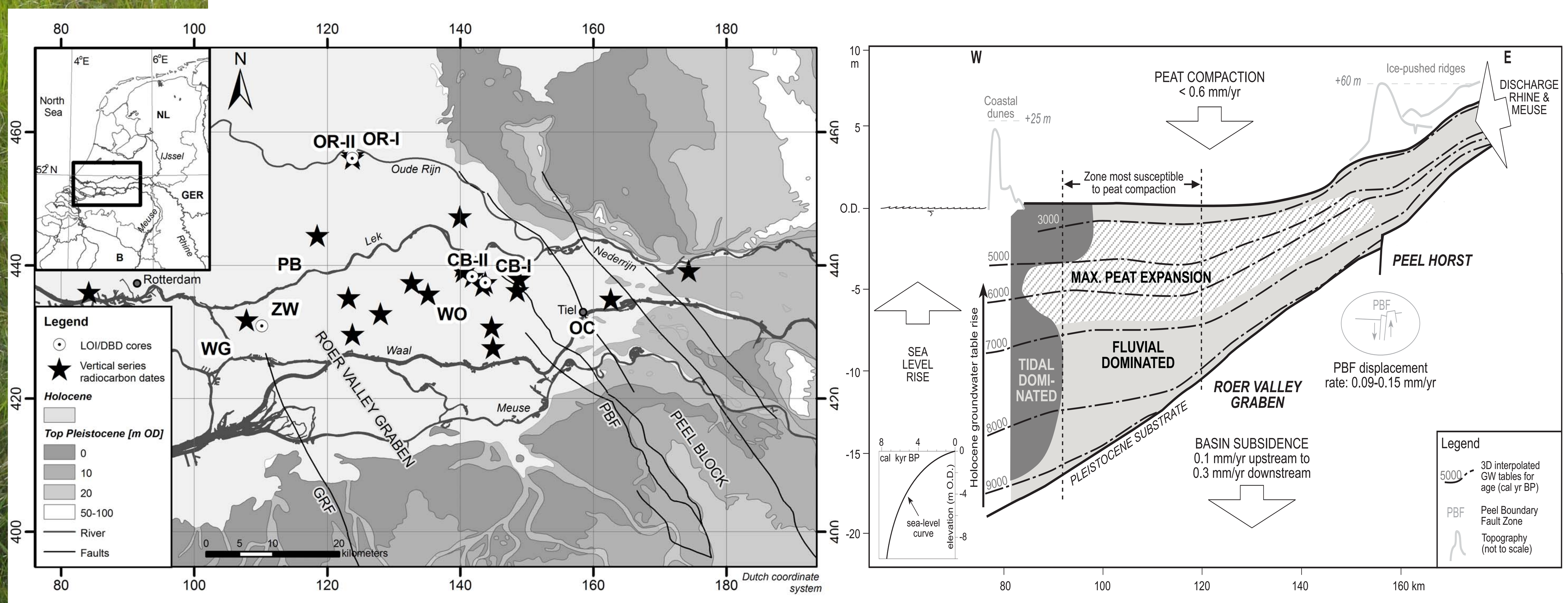
Why time scales matter and what we offer…

Stratigraphical architecture and lithological variability of deltaic deposits are principally determined at syn-depositional time-scales. During delta aggradation, the properties of strata (thickness, consistency, depth, geometry) change rapidly, with strong feedbacks on successive sedimentation patterns. Subsidence comes from two principal sources: compaction of fresh deposits ('autocompaction', 'syn-sedimentary compaction') and (2) substrate lowering due to tectonics, isostasy and compaction of deeply buried deposits. For parameters describing the rates of subsidence (whether due to compaction, tectonics or both) it is especially important to have these determined *at appropriate time-steps,* that match time-scales at which creation of accommodation space is considered.

We determined rates over time-steps of 10^2 to 10^3 years, for flood basins of the Rhine-Meuse delta in the Netherlands. These results come from combining field data and numerical modelling, facilitated by unique datasets that fully cover the sizable river-fed barrier-lagoon system that is the Rhine-Meuse delta in the Netherlands. The poster presents the outcomes and the implications for accommodation space.

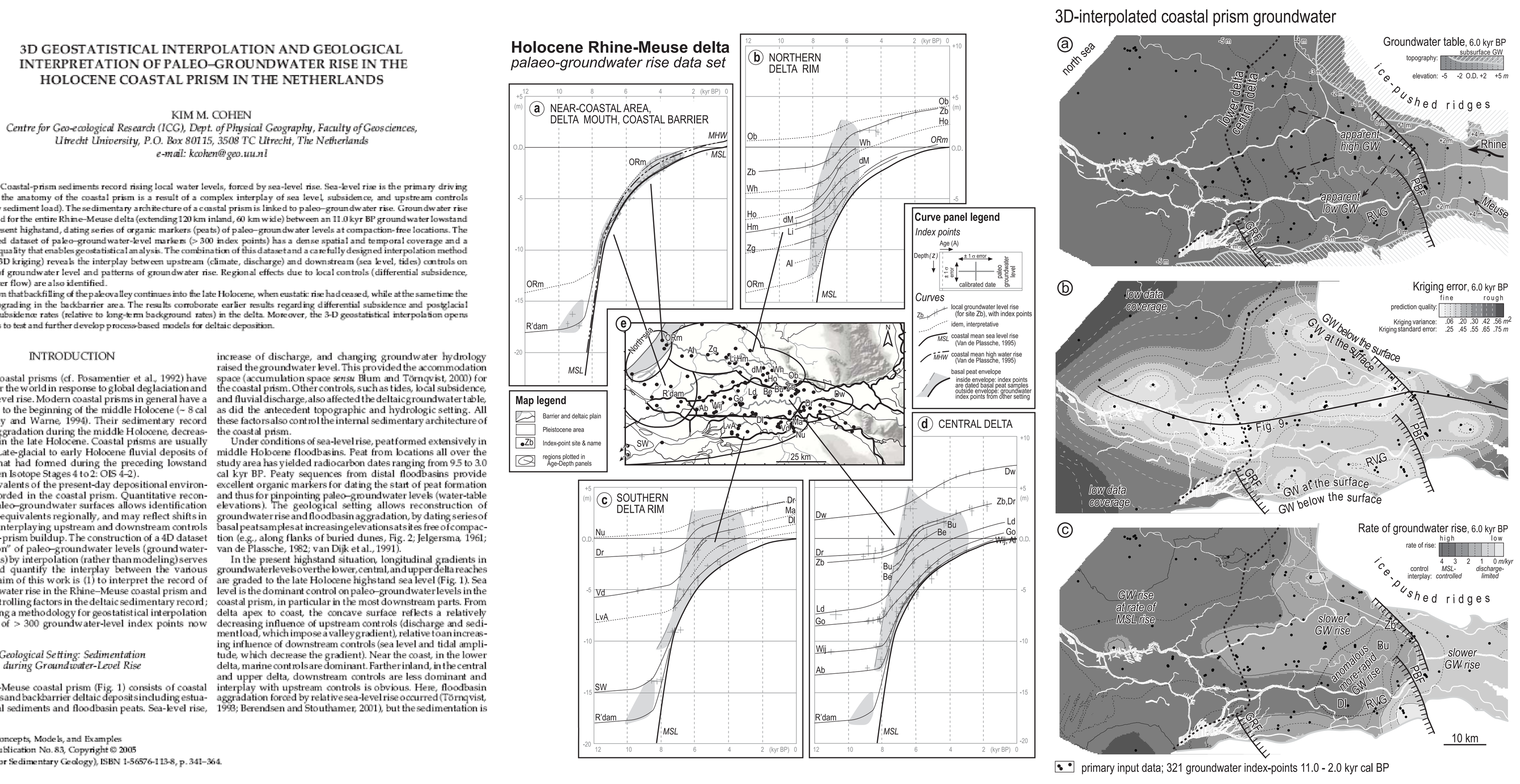


Study area location, high resolution accommodation and compaction reconstruction sites, cartoon longitudinal section through the coastal prism. Van Asselen (2010)

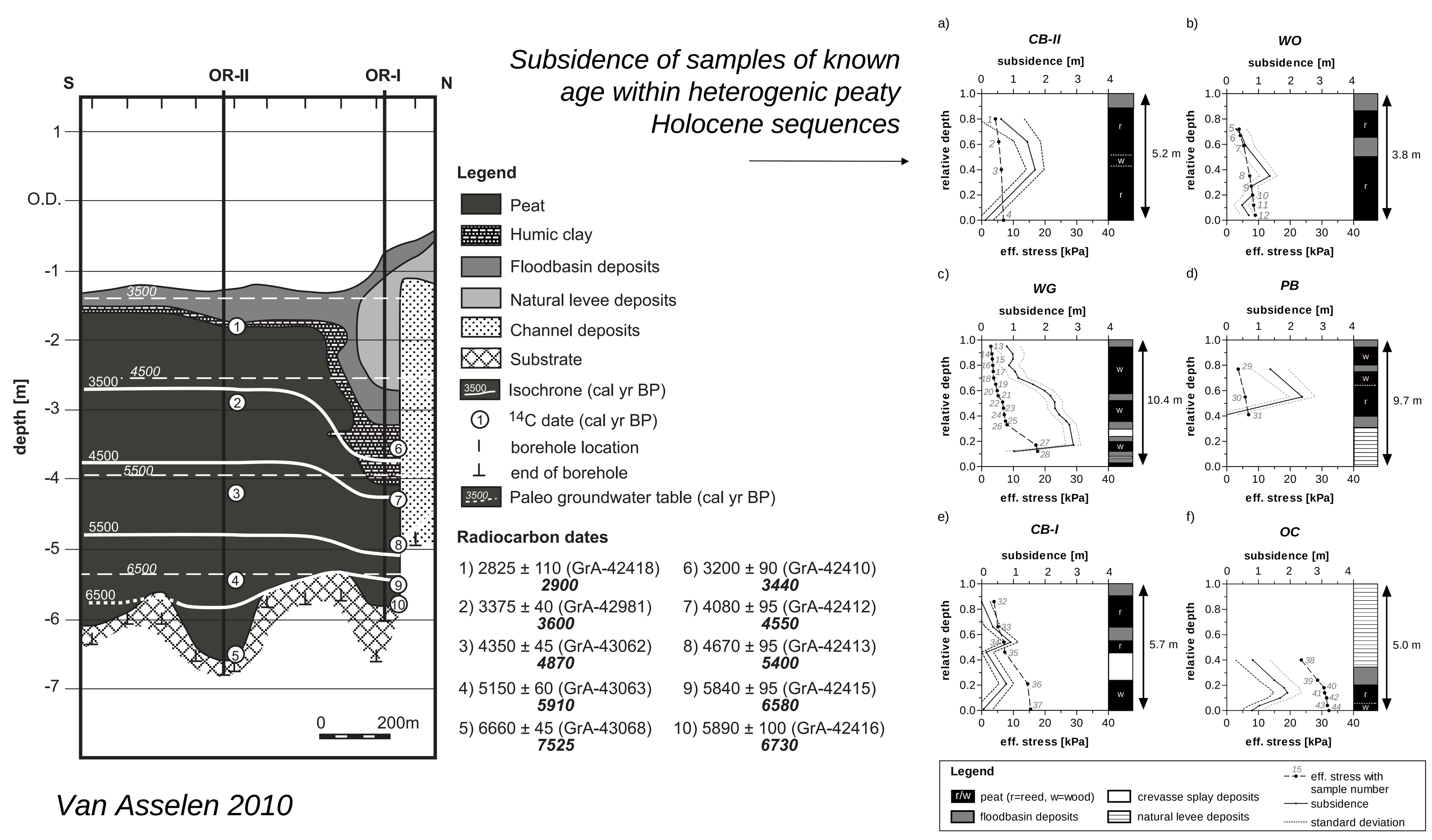
SAMPLING AND DATING HOLOCENE PEATS - INTERPOLATION OF PAST GROUNDWATER TABLES

BASE OF PEAT OVERLIES UNCOMPRESSIBLE SUBSTRATE, REST OF PEAT SEQUENCE IS AUTOCOMPACTED

Rhine-Meuse delta, The Netherlands



Cohen 2005



Van Asselen 2010

Subsidence due to substrate lowering is quantified from groundwater rise reconstructions. Similar to relative sea-level rise reconstructions, dates of begin of peat formation overlying pre-deltaic sandy strata (notably vertical series of dates collected along the flanks of isolated inland dunes (figs. above) provide index-points for past groundwater table rise. Many sites with vertical series of index-points exist, sufficient for geostatistical interpolation (3D universal block kriging). The interpolation shows anomalies that match known neotectonic depocentre and faultzones. The depocentre (40 km^2) sank 0.05-0.10 mm/yr faster than downstream parts, and 0.10-0.15 mm/yr faster than upstream blocks, measured for the period 9000-3000 yr BP.

Interpolated stacks of palaeo-groundwater tables are used to break down accommodation into components 'due to absolute sea level rise and regional tectonic dip', 'due to local subsidence'. It also identifies 'overfilling of accommodation space' as occurs in the upper part of a delta that aggrades and protrudes under increased sediment supply in the last 3000 years. Subsidence rates were higher in the period 20,000-6,000 than in the last 6000 yrs, in agreement with isostatical geophysical predictions, Scandinavian deglaciation and North Sea transgression history.

Crevassing and avulsion cause sediment-loading and floodbasin-filling histories to differ per location and affect the degree of compaction in delta subregions. The effect of autocompaction, i.e. compaction due to loading of peaty strata, is quantified at 15 sites in the central delta. We compared actual depth of peats of known age with the palaeo-groundwater table heights at their time of formation (figs. above). Data on bulk-density, peat composition and organic matter content was also gathered, and used to hindcast compaction at the 15 sites. These two methods reproduced each other and resolve compaction-driven subsidence at centennial to millennial timescales. Shorter timescales are not possible because of resolution limits of the ^{14}C-dating method.

To bridge the gap between reconstruction and modelling approaches, additional measurement and quantification of natural load-induced peat compaction on decadal to centennial scales was needed. Such data was collected in the Cumberland Marshes (Canada), an inland-delta that developed over the last 135 years, where river clastics buried peats of similar composition as in the Rhine delta in the Middle Holocene. Parameters calibrated on Canadian peats were used to simulate local natural compaction histories for synthetic delta successions.

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SAMPLING FRESH PEAT

Cumberland marshes, Canada

Journal of Sedimentary Research

Journal of Sedimentary Research, 2009, v. 79, 918–922
Research Methods
DOI: 10.2110/jsr.2009.091

SEPM Society for Sedimentary Geology

A NEW METHOD FOR DETERMINING THE BULK DENSITY OF UNCOMPACTED PEAT FROM FIELD SETTINGS

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ABSTRACT: A new method for determining the bulk density of uncompacted surficial peat from field settings is presented. Most importantly, a new peat sampler was developed to ensure minimum disturbance of the peat sample. The main benefits of the new device are (1) from the moment of field sampling, the peat sample remains undisturbed in an inner collecting liner, which has a fixed volume and fits perfectly in an outer cutting tube, until the sample is ready to be analyzed in a laboratory, (2) the risk of fracturing or disturbing the sample during lifting it to the surface is significantly reduced by using a vacuum pump or hose to reduce suction at the base of the peat core, and (3) the razor-sharp cutting edge of the outer tube easily cuts through all kinds of fibers by short rotational movements. Furthermore, sufficiently large samples can be extracted, thereby accounting for the heterogeneous character of peat. The device is relatively light and easy to operate, which is a great advantage in the often remote and difficult-to-access peatlands. The sampler was successfully used during test trials on different types of fen peat in the Biebrza National Park, Poland.

INTRODUCTION

Recently formed peat has a very loose and heterogeneous structure; it often contains different kinds of plant remains and may consist partly of a living root mat. Therefore, sampling modern peat without disturbing the peat structure or inducing compaction is difficult. Extracting undisturbed and uncompacted peat samples is needed, however, for determining physical (e.g., bulk density, porosity, organic-matter content, fiber content) and chemical properties (e.g., nutrient concentrations) of peat (Clymo 1988; Buttler et al. 1998), which is important information for, e.g., carbon storage, ecological, and hydrological studies. Furthermore, determination of physical properties of peat is essential with regard to understanding and predicting compactional behavior of peat soils (e.g., Lefebvre et al. 1984), from both a geological and an engineering perspective. Peat is most compressible of all natural soils, and hence, peat compaction potentially leads to vast amounts of subsidence. In populated areas, this may lead to damage to constructions and land inundation. In natural environments, subsidence due to peat compaction creates accommodation space for either fluvial deposition or peat accumu-

prevents fracturing of the core during lifting it to the surface, and (3) the razor-sharp cutting edge of the outer tube easily cuts through all kinds of fibers by short rotational movements. Further details of the sampler are described in the next sections.

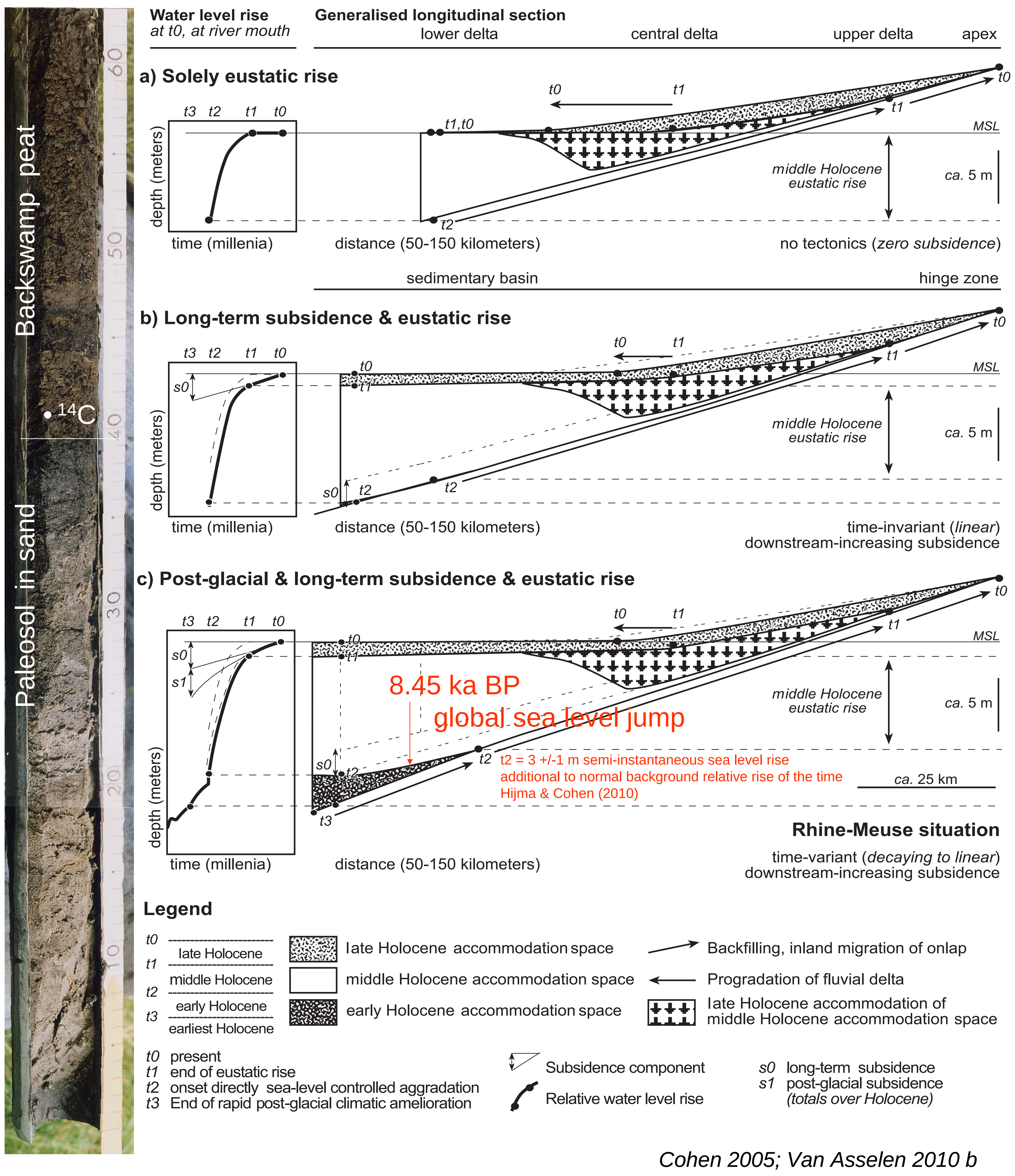
CONSTRUCTION AND USAGE

The peat sampler consists of an outer stainless steel tube and an inner PVC liner which collects the peat sample (Fig. 1). The liner fits perfectly in the outer tube, and the inner surface is perfectly smooth (Fig. 2A). The sharp cutting edge of the outer tube has sinuous teeth, which easily cuts through all kinds of plant remains without disturbing the internal peat structure of the sample. Fibers like wood and thick reed stems do take a little more sawing time. The sampling device is brought downward into a peat substrate by small back-and-forth rotational sawing movements (± 1 cm), without exerting any extra downward pressure. During coring, displaced air inside the peat sampler is ventilated through hollow extension rods (Fig. 1).

ACCOMMODATION AND SYN-SEDIMENTARY TIME

There are two ways to look at accommodation space on syn-depositional time-scales. Depending on the view point, compaction contributes to accommodation space creation or compaction allows storing sediments in earlier-created accommodation space (e.g. figure below). This difference is not trivial when modelling internal alluvial architecture of deltaic wedges at time-steps of 50, 100 or 1000 years. It is insightful to intercompare quantifications of 'compaction subsidence' and 'substrate-lowering subsidence' with the total amount of accommodation space created and filled during Holocene transgression and high stand, i.e. the not-eustasy-driven part of delta accommodation.

Subsidence due to peat compaction has locally (re)created up to 40% of the Rhine delta's accommodation space, in inner parts of the delta. In transgressive tidal floodbasin areas this may have been even more (more work needed!). Substrate subsidence in the last 9000 years has created at least 3 meters (12.5%) of 24 meters of total vertical accommodation (22%) at the river mouth and 20% (1 meter) of a total 5 meters in the last 7000 years over the inland tectonic depocentre.

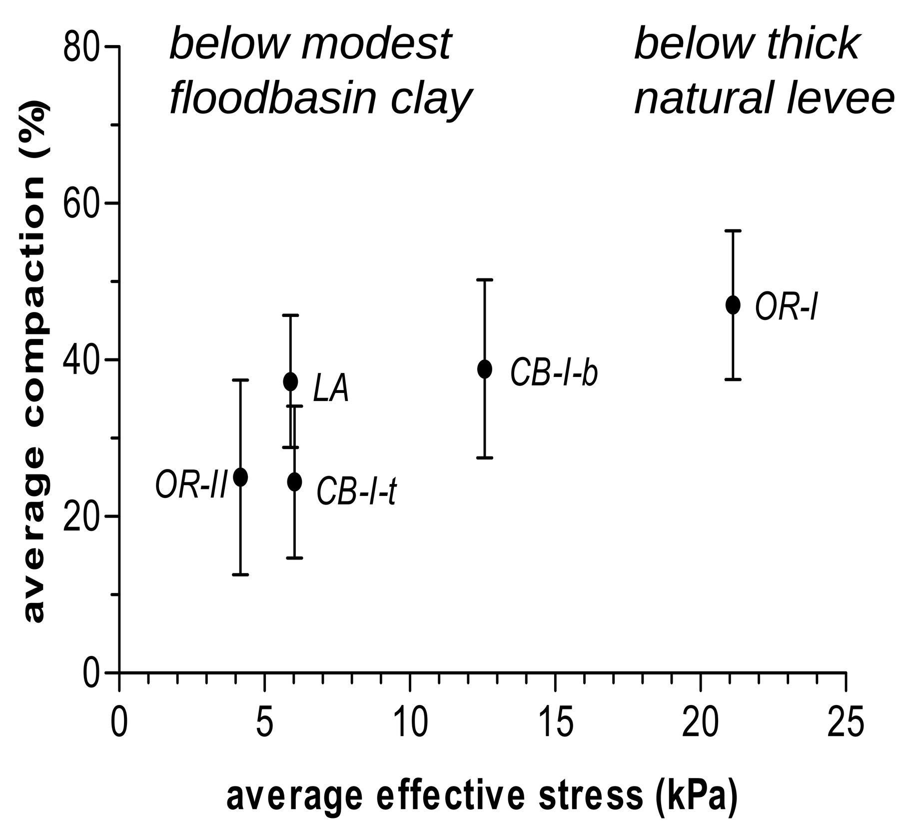


Cohen 2005; Van Asselen 2010 b

1999.05.012

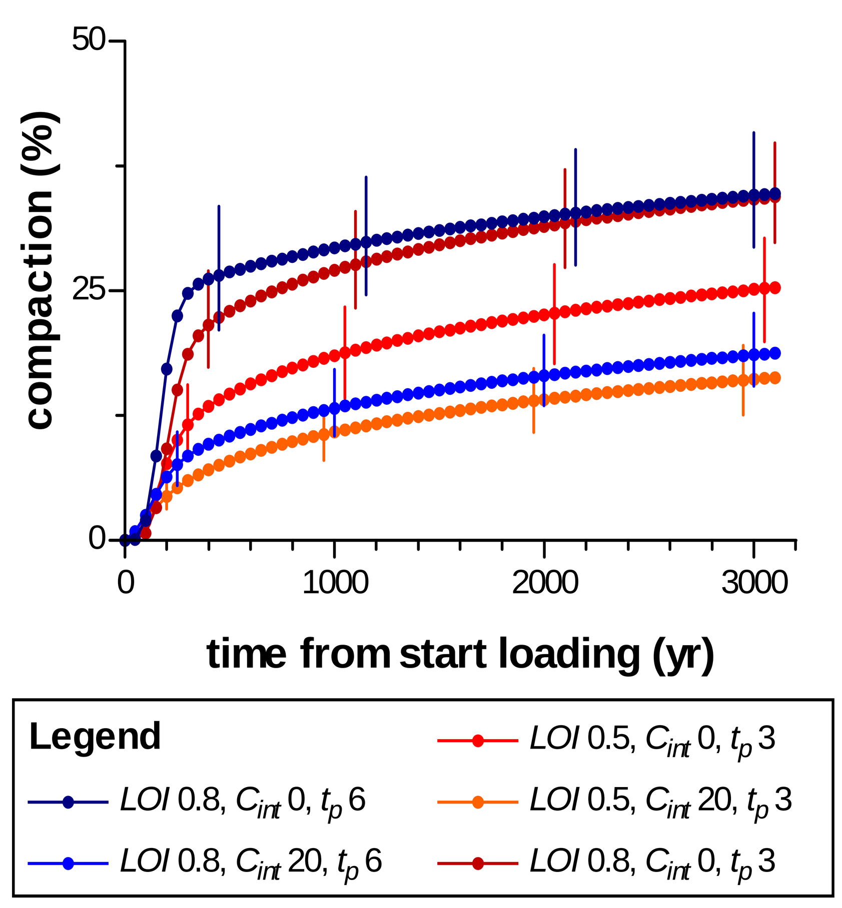
COMPACTION MODELLING: BACKWARD, FORWARD

Field data



Van Asselen 2010

Synthetic Sequence



Autocompacted floodbasin sites in the Rhine delta show peat surfaces to have locally lowered up to ~3 meters within 10-m-thick successions. The associated compaction rates were up to 0.62 mm/yr, averaged over multiple millennia (figs..above). Higher rates of a few mm/yr occurred over decades to centuries, shortly after loading. Subsidence rates measured in the Cumberland Marshes: up to ~6 mm/yr, averaged over ~135 years.

Forward modelling predicts compaction to occur most rapidly in the first decades after loading a peat sequence. Simulations for ranges of natural conditions yield subsidence rates that successfully reproduce field observations. They predict rates up to 15 mm/yr (averaged over 50 years = time step in model) in 8-m-thick high-organic peat (LOI=0.8), representative for the most compaction prone areas in the delta.

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Thanks: E. Stouthamer, C. Roosendaal, I. Bos, W.H.J. Toonen, D. Karssenberg, N. Smith W.Z. Hoek, M. van Ree, J.J.A. Bos, N. van Asch, T. van Asch, M.P. Hijma, G. Erkens