Improving age-depth models of fluvio-lacustrine deposits using sedimentary proxies for accumulation rates

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Introduction

Lacustrine fills, including those of oxbow lakes in river floodplains, often hold valuable sedimentary and biological proxy records of palaeo-environmental change. Precise dating of accumulated sediments at levels throughout these records is crucial for interpretation and correlation of (proxy) data existing within the fills. Typically, dates are gathered from multiple sampled levels and their results are combined in age-depth models to estimate the ages of events identified *between* the datings.

Method

A method of age-depth modelling is presented that varies the vertical accumulation rate of the lake fill based on continuous sedimentary data. In between Bayesian calibrated radiocarbon dates, this produces a modified non-linear age-depth relation based on sedimentology rather than linear or spline interpolation.

Geological setting

The method is showcased on a core of an infilled palaeomeander at the floodplain edge of the river Rhine near Rheinberg (Germany). The sequence spans from ~4.7 to 2.9 ka cal BP and consists of 5.5 meters of laminated lacustrine, organo-clastic mud, covered by ~1 meter of peaty clay. Four radiocarbon dates provide direct dating control, mapping and dating in the wider surroundings provide additional control.

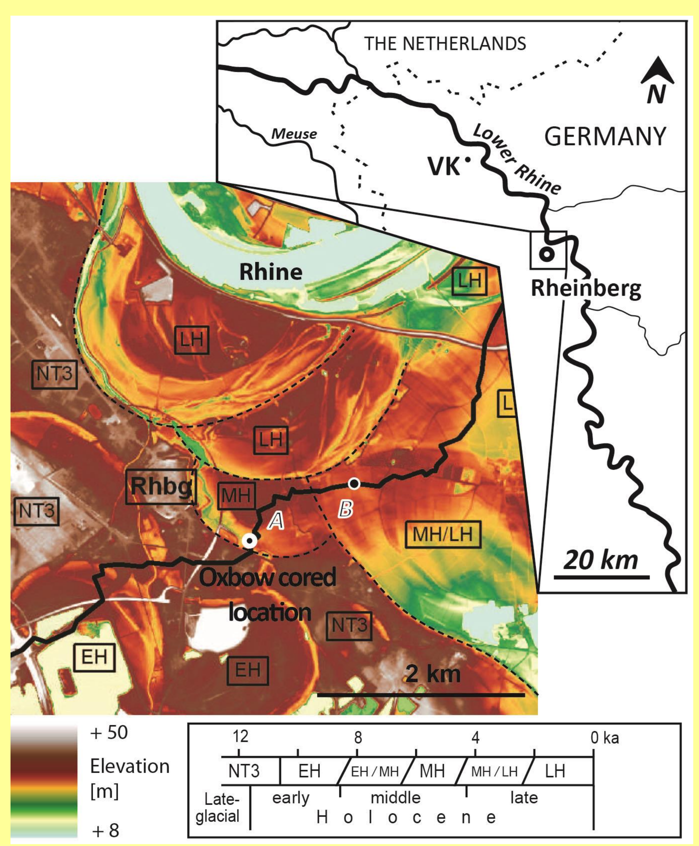

Fig.1: Location of the Rheinberg palaeochannel (A) and its immediate successor (B) in Nordrhein Westfalen, Germany. Dots show sample core locations and the dashed lines mark scarps of former Rhine meanders. Rhbg = village of Rheinberg located on the Lateglacial Niederterrasse 3 (NT3); EH, MH, and LH = Early, Middle, and Late Holocene. Annotated LiDAR imagery after Erkens et al. (2011).

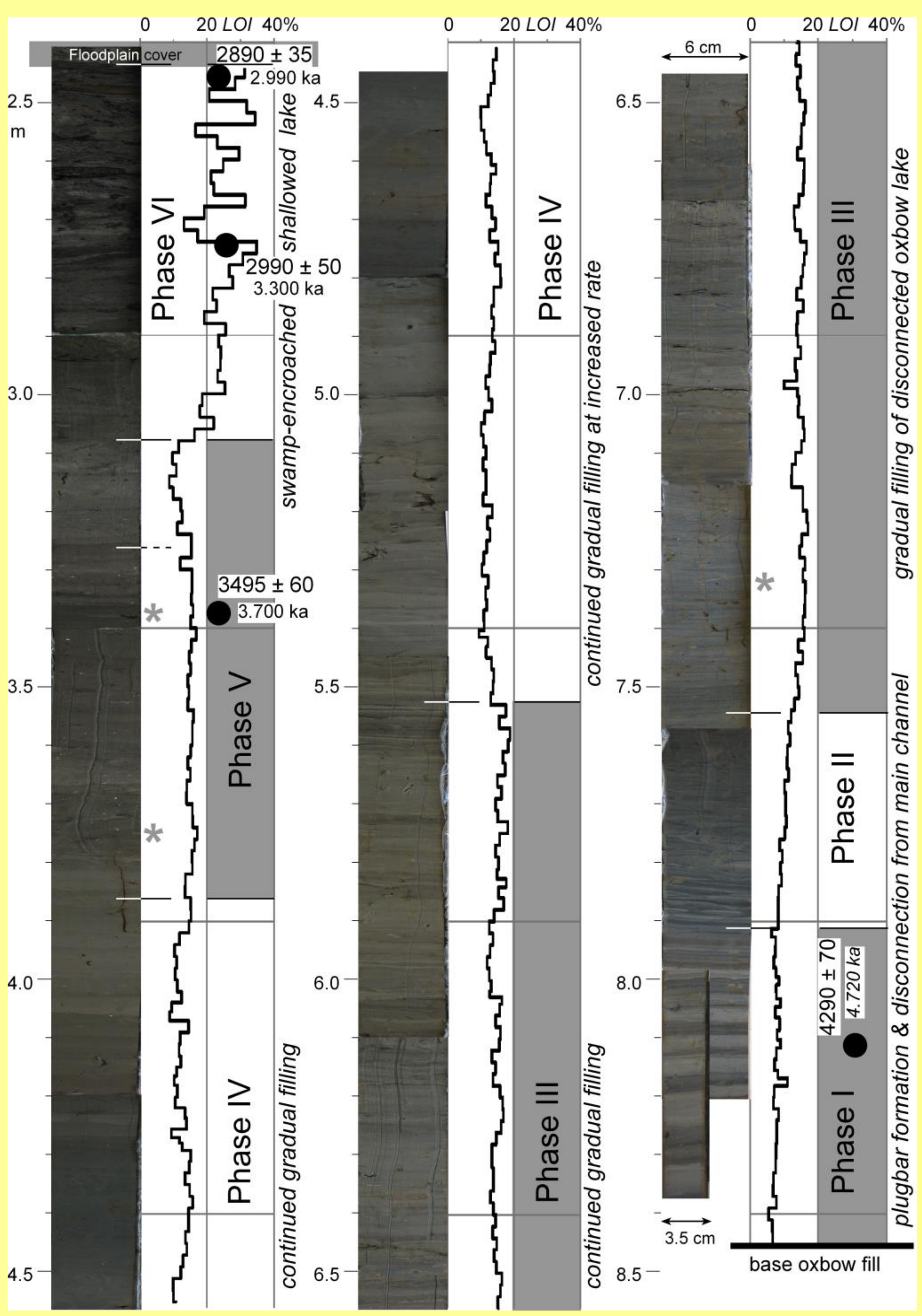

Figure 2. Collated core photos of the freshly cut Rheinberg sequence, with sedimentological subdivision, LOI results, and positions of radiocarbon dates. The bandings in the photograph are the combined textural (silt, clay) and organic (diffuse admixture and concentrations of macrofossils) irregular laminations and oxic-anoxic (ferro-sulfuric) colouring overprint.

LOI as sedimentary proxy for accumulation rate

The laminated, organo-clastic facies of the oxbow fill contains a record of nearby fluvial-geomorphological activity, including meander reconfiguration events and passage of rare large floods, recognized as fluctuations in coarseness and amount of allochthonous clastic sediment input. Continuous along-core sampling and measurement of loss-on-ignition (LOI) provided a fast way of expressing the variation in clastic sedimentation influx from the nearby river versus autochthonous organic deposition derived from biogenic production in the lake itself. This low-cost sedimentary proxy data feeds into the age-depth modelling.

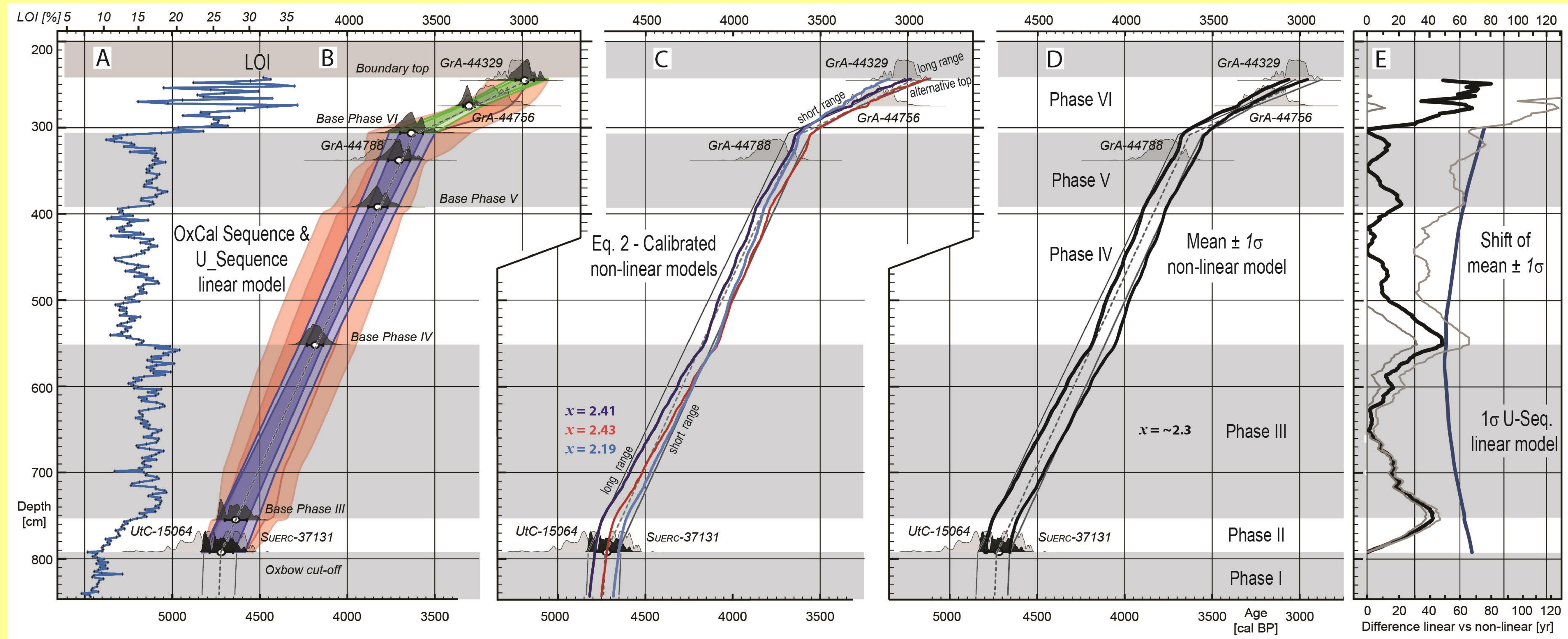

Fig.3: Figure 3. Age-depth models for the Rheinberg oxbow fill sequence. a) Loss-on-ignition (%) curve with 2 cm resolution. b) Calibrated age models; Blue: Oxcal's depositional U_Sequence linear model, with a pre-defined facies boundary at 309 cm depth (Bronk Ramsey, 2008); Red: Oxcal's Sequence model. c) Non-linear age models incorporating variable sedimentation rate based on the LOI data (a). Dark blue: long range model; light blue: short range model; Red: 'alternative top' model. d) Combined non-linear age model; mean of the short and long range models (c) and the uncertainty range (± 1σ) of Oxcal's linear model (b). e) Absolute difference between mean of the linear (b) and the non-linear, variable sedimentation rate (d) models in years including the range of the short and long range model. Blue line: uncertainty range (± 1σ) of the linear (b) model.

Age-depth modelling results

The sedimentology-modelled age-depth relation (re)produces the distinct lithological boundaries in the fill as marked changes in sedimentation rate. Especially the organo-clastic muddy facies subdivides in centennial intervals of relative faster and slower accumulation. For such intervals, sedimentation rates are produced that deviate 10 to 20% from that in simpler stepped linear age-models. For irregularly laminated muddy intervals of the oxbow fill – from which meaningful sampling for radiocarbon dating is more difficult than from peaty or slowly accumulating organic lake sediments – supplementing spotty radiocarbon sampling with continuous sedimentary proxy data creates more realistic age-depth modelling results.

The model uses the following equations:

$$\Delta t_i = LOI_i^{\,x} D_i \times \frac{T_N}{\sum_{j=1}^{N} LOI_j^{\,x} D_j} \qquad (1)$$

$$Age_i = Age_{j=1} + \sum_{j=1}^{i} \Delta t_j \qquad (2)$$

where *i* and *j* identify individual sampled layers, *N* is the total number of samples in the interval to which the model applies, T_N is the time duration covered by the interval (in years) and Age_i is the age of sample layer, with *i*=*j*=1 for the lower most layer. For more organic samples (relative higher LOI), decelerated sedimentation rates are expected and Δt_i should be larger than for less organic instances in the sample series. Exponent *x* was solved by regression, minimizing the deviations between Eq. 3-modelled and independent-dating mid-point estimates for Age_i for the few layers where independent age estimation (radiocarbon date) was available.

Highlights

- Oxbow lake fills contain flood-induced event-stratigraphies indicating high fluctuations in sedimentation speed
- Standard age models are unable to reproduce the spasmodic behaviour of oxbow lake fills
- Sedimentological analysis of an oxbow fill reveals high-resolution insight in accelerations and deceleration of sedimentation
- Combining sedimentology with C-14 calibration creates a more realistic (oxbow) lake fill age-depth model

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