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Understanding the Effect of Age Uncertainty in Recurrence Analysis of Paleoseismic Records

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The ultimate goal of paleoseismology is to estimate the strength, location and timing of future large earthquakes. Paleoseismic records can deliver an accurate description of past hazards, which is the first step towards that goal. To understand how reliably past events forecast the timing of future events, paleoseismologists characterise the periodicity in earthquake sequences. The periodicity is often expressed by the coefficient of variation (CoV, mean-normalised standard deviation) of recurrence intervals. Depending on the CoV, fault rupture behaviour is called periodic, random or clustered. However, sedimentary records rely on age-models, which have various ways to assign age and age uncertainty to events and thus it is unclear how well the CoV can be estimated.

Most onshore paleoseismic studies rely on sedimentary sequences, where sedimentation rate is highly variable and cannot be used as a constraint (Bayesian prior) in age-depth modelling. In these onshore studies, event ages are often determined by dates constraining the event age to a minimum and maximum age and making use of the stratigraphic order of event deposits. In contrast, marine and lacustrine paleoseismic records benefit from a more stable sedimentation rate, which is a suitable prior for Bayesian age-depth models, effectively decreasing age uncertainty. The sediment thickness between event deposits in subaqueous records can thus form a reasonable estimator of recurrence intervals (RI), i.e., the relative age of the events.

Different approaches are used to calculate RIs affecting the reported CoV. For example, there is the "best" age approach, where a single "best" age (often the median of an age distribution) is assigned to each event and the difference is the RI. In another approach the RIs are calculated based on the age differences within Markov chain Monte Carlo iterations that make up the age model. The latter method draws on more information and gives a mathematically more correct estimate for RIs by keeping the probabilistic nature of the event age. This method can be applied through, e.g., the use of the Difference()-function in OxCal or through the subtraction of iteration ages of consecutive events (Bacon.Age.d()-function) from BACON age-depth models.

To quantify the effect of age uncertainty on CoVs of earthquake sequences, we first describe the uncertainty in CoVs from various synthetic earthquake recurrence patterns without age uncertainty (control). Then we simulate the effects that age uncertainty in paleoseismic records can have on earthquake sequence statistics. We evaluate when ignoring the age uncertainty while calculating the CoV is a convenient and appropriate shortcut and when it can cause considerably different results by discussing various natural cases from literature.