**Early Medieval Place-Names and Riverine Flood Histories: A New Approach and New Chronostratigraphic Records for Three English Rivers**

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**Supplementary Material**

**Flow Regimes**

Flow regimes for the three rivers have been taken from the National River Flow Archive (<https://nrfa.ceh.ac.uk>) created by the Centre for Ecology and Hydrology, using the nearest station upstream of the sample sites: Knightsford Bridge Station (54029) for Broadwas and the Teme; Buildwas Station (54095) for Buildwas and the Severn; and Belmont Station (55002) for Rotherwas and the Wye. Mean flows are quoted, together with Q95 (5 percentile flow)—the flow in m3/s equalled or exceeded for 95 per cent of the flow record—and Q10 (90 percentile flow) equalled or exceeded for 10 per cent of the flow record, which, when compared, provide an index of the variability or flashiness of the flow regime.

Teme: mean flow: 18.163m3/s. Q95 2.02 m3/s. Q10 42.2 m3/s. The Teme is considered a natural catchment.

Severn: mean flow: 59.74 m3/s. Q95 11.6 m3/s. Q10 146 m3/s. The modern flow regime of the Severn has been significantly modified as a result of upstream reservoir construction.

Wye: mean flow: 48.344 m3/s. Q95 6.428 m3/s. Q10 115.6 m3/s. The current flow regime is moderately affected by high levels of water abstraction for agriculture.

**Topographic, Gradient & Sedimentological Modelling**

Topographic modelling at each site was conducted using high-resolution LiDAR datasets available from the Environment Agency. Initially a Digital Terrain Model (DTM) at 50m resolution was created for the UK and central England and overlain by major rivers (Figure 1). Detailed DTMs at 1m resolution were then created for *c.* 2.5–3km2 areas across each of the floodplains at the three sites and overlain by a colour-shaded elevation model with major watercourses. River gradient models were calculated using the raw elevation data combined along the lengths of the Teme, Severn, and Wye at 50m intervals (Figure 2). In order to contextualize the sequence stratigraphies at each site across the wider floodplain landscape, existing core data held by the British Geological Survey (<https://www.bgs.ac.uk/data/bmd.html>) was gathered and remodelled with the new data in cross sections. At Broadwas, where no existing core data were forthcoming, a programme of coring at 100m intervals using a mechanical percussion auger was undertaken to record the sediment sequence and collect samples from the settlement to the river section (Figure 4). The ground surface topography across each transect was extracted from the raw LiDAR data at 10cm resolution.

**Field Sampling**

In order to analyse the sedimentary sequences at Broadwas, Buildwas, and Rotherwas, river sections were excavated at strategic locations along the banks of the rivers Teme, Severn, and Wye. The sample areas were cleaned, photographed, and recorded, revealing between 3 and 3.75m of alluvium down to the present river level, with terrace gravels identified at the base of each. From each section *in-situ* sediment samples were collected using 30–50-cm-long u-channels with 5-10cm cross-over to enable <1cm to 1cm resolution analysis; these were complemented by larger bulk sediment samples (*c.* 20–50g) collected every 5cm.

**Optically Stimulated Luminescence (OSL) Sampling**

**Sample Preparation**

Fifteen sediment samples were collected in opaque plastic tubing from excavated sections and submitted for optical dating at the University of Gloucestershire Luminescence dating laboratory (Toms, 2017; Toms & Wood, 2018a, 2018b) (Table 1 [main article] and Table S1 [Supplementary Material]). To preclude optical erosion of the datable signal prior to measurement, all samples were opened and prepared under controlled laboratory illumination provided by Encapsulite RB-10 (red) filters. To isolate material potentially exposed to daylight during sampling, sediment located within 20mm of each tube-end was removed. The remaining sample was dried and then sieved. Depending on each sample’s modal grain size, quartz within the fine sand or fine silt fraction was segregated.

Samples were then segregated and subjected to acid and alkaline digestion (10 per cent HCl, 15 per cent H2O2) to attain removal of carbonate and organic components respectively. For fine sand fractions, a further acid digestion in HF (40 per cent, 60 minutes) was used to etch the outer 10–15µm layer affected by α radiation and degrade each sample’s feldspar content. During HF treatment, continuous magnetic stirring was used to effect isotropic etching of grains. To remove acid soluble fluorides, 10 per cent HCl was then added. Each sample was dried, re-sieved and quartz isolated from the remaining heavy mineral fraction using a sodium polytungstate density separation at 2.68 g.cm-3. Twelve 8mm multi-grain aliquots (*c*. 3–6mg) of quartz from each sample were then mounted on aluminium discs for determination of De values. Fine silt sized quartz, along with other mineral grains of varying density and size, was extracted by sample sedimentation in acetone (<15µm in 2 min 20s, >5µm in 21 mins at 20°C). Feldspars and amorphous silica were then removed from this fraction through acid digestion (35 per cent H2SiF6 for 2 weeks, Jackson et al.,1976; Berger et al.,1980). Following addition of 10 per cent HCl to remove acid soluble fluorides, grains degraded to <5µm as a result of acid treatment were removed by acetone sedimentation. Twelve multi-grain aliquots (*c.* 1.5mg) were then mounted on aluminium discs for De evaluation. All drying was conducted at 40°C to prevent thermal erosion of the signal.

**De Measurements**

All minerals naturally exhibit marked inter-sample variability in luminescence per unit dose (sensitivity). Therefore, the estimation of De acquired since burial requires calibration of the natural signal using known amounts of laboratory dose. De values were quantified using a single-aliquot regenerative-dose (SAR) protocol (Murray & Wintle, 2000, 2003) facilitated by a Risø TL-DA-15 irradiation-stimulation-detection system (Markey et al.,1997; Bøtter-Jensen et al.,1999). Within this apparatus, optical signal stimulation is provided by an assembly of blue diodes (5 packs of 6 Nichia NSPB500S), filtered to 470±80nm conveying 15mW.cm-2 using a 3mm Schott GG420 positioned in front of each diode pack. Infrared (IR) stimulation, provided by 6 IR diodes (Telefunken TSHA 6203) stimulating at 875±80nm delivering ~5mW.cm-2, was used to indicate the presence of contaminant feldspars (Hütt et al., 1988). Stimulated photon emissions from quartz aliquots are in the ultraviolet (UV) range and were filtered from stimulating photons by 7.5mm HOYA U-340 glass and detected by an EMI 9235QA photomultiplier fitted with a blue-green sensitive bialkali photocathode. Aliquot irradiation was conducted using a 1.48 GBq 90Sr/90Y β source calibrated for multi-grain aliquots of 5–15μm, 125–180μm and 180–250μm quartz against the ‘Hotspot 800’ 60Co γ source located at the National Physical Laboratory (NPL), UK.

The propensity of feldspar signals to fade and underestimate age, coupled with their higher sensitivity relative to quartz, makes it imperative to quantify feldspar contamination. At room temperature, feldspars generate a signal (Infrared Stimulated Luminescence; IRSL) upon exposure to IR whereas quartz does not. The signal from feldspars contributing to OSL can be depleted by prior exposure to IR. For all aliquots the contribution of any remaining feldspars was estimated from the OSL IR depletion ratio (Duller, 2003). If the addition to OSL by feldspars is insignificant, then the repeat-dose ratio of OSL to post-IR OSL should be statistically consistent with unity, as is the case in this study for the majority of the samples. The exception is sample GL16138, which returns a post-IR OSL ratio of 0.78±0.03 and, thus, the associated age should be treated as a minimum estimate.

Preheating aliquots between irradiation and optical stimulation is necessary to ensure comparability between natural and laboratory-induced signals. However, the multiple irradiation and preheating steps that are required to define single-aliquot regenerative-dose response leads to signal sensitisation, rendering calibration of the natural signal inaccurate. The SAR protocol (Murray & Wintle, 2000, 2003) enables this sensitisation to be monitored and corrected using a test dose, here set at 5 Gy preheated to 220°C for 10s, to track signal sensitivity between irradiation-preheat steps. However, the accuracy of sensitisation correction for both natural and laboratory signals can be preheat dependent.

The Dose Recovery test was used to assess the optimal preheat temperature for accurate correction and calibration of the time dependent signal. Dose Recovery attempts to quantify the combined effects of thermal transfer and sensitisation on the natural signal, using a precise lab dose to simulate natural dose. The preheat chosen for each sample was that where the ratio between the applied dose and recovered D**e** value was consistent with unity. Further thermal treatments, prescribed by Murray and Wintle (2000, 2003), were applied to optimize accuracy and precision. Optical stimulation occurred at 125°C in order to minimize effects associated with photo-transferred thermoluminescence and maximize signal to noise ratios. Inter-cycle optical stimulation was conducted at 280°C to minimize recuperation.

Murray and Wintle (2000, 2003) suggest that ratios from repeat-dose measurements indicate the success of sensitivity correction, whereby ratios ranging across 0.9–1.1 are acceptable. However, this variation of repeat-dose ratios in the high-dose region can have a significant impact on De interpolation. In this study, these ratios are based on repeats of low and high dose measurements. Most repeat-dose ratios are consistent with the range 0.9–1.1, though some data are relatively scattered owing to poor signal to noise ratios. However, the recycling ratios for sample GL16092 from Buildwas are not consistent with the range 0.9–1.1; the corresponding age estimate is therefore rejected.

**Dr Measurements**

Lithogenic Dr values were defined through measurement of U, Th and K radionuclide concentration and conversion of these quantities into α, β and γ Dr values (Table S1). Contributions of α and β were estimated from sub-samples by laboratory-based γ spectrometry using an Ortec GEM-S high purity Ge coaxial detector system, calibrated using certified reference materials supplied by CANMET. Rates of γ dose were estimated *in situ* with an EG&G μNomad portable NaI gamma spectrometer (calibrated using the block standards at RLAHA, University of Oxford); these reduce uncertainty relating to potential heterogeneity in the γ dose field surrounding each sample. The level of U disequilibrium was estimated by laboratory-based Ge γ spectrometry. Estimates of radionuclide concentration were converted into Dr values (Adamiec & Aitken, 1998), accounting for Dr modulation forced by grain size (Mejdahl, 1979), present moisture content (Zimmerman, 1971) and, where De values were generated from 5–15 μm quartz, reduced signal sensitivity to α radiation (a-value 0.050 ± 0.002). Cosmogenic Dr values were calculated on the basis of sample depth, geographical position, and matrix density (Prescott & Hutton, 1994). No samples exhibited pronounced (226Ra/238U>50 per cent) U disequilibrium.

**Age-Depth Modelling**

The determination of the OSL dates allowed detailed age-depth modelling of the alluvial sequence (Figure 3). This was conducted using OxCal, version 4.3 with IntCal13 program (Bronk Ramsey, 2008, 2009). Outliers were identified by running statistical analyses on all the dates, including reversals, and analysed against a run without reversals (Figure 3, in red). This demonstrated that all but one of the dates (GL16092) were statistically viable for the calculation of precise calendrical dates at 2δ (95.4 per cent confidence) and 1δ (68.2 per cent confidence). The development of a sequence chronology then enabled the calculation of the average sediment accumulation rate at each of the sites.

**Loss on Ignition**

Alongside the chronological determination, samples were also subjected to a range of sedimentological analyses to interpret the depositional history of the sequence (Figures 5, 6, and 7). Loss on Ignition (LOI) at 1cm resolution was conducted by combusting samples at 105oC for 12 hours to determine moisture content, an additional particle size proxy. A second burn at 550oC for a further 2 hours provided the percentage organics, conducted to determine the presence of *in-situ* soil horizons and/or sudden deposition from flood events. A final burn at 950oC for 4 hours determined the calcium carbonate (CaCO₃) content, essential for further elucidation of the fine-sediment fraction through the preservation of flocculated structure, and the binding of organics to the fine particulate in alluvium (e.g. Bullinger-Weber et al.,2007).

**Magnetic Susceptibility**

Magnetic susceptibility (MS) was measured in order to identify high-resolution variations in texture, and changes in depositional conditions, possibly as a result of flooding events (Figures 5, 6, and 7). The process was also used to determine variations in landuse on the floodplain. This has previously been shown to demonstrate changes in anthropogenic activity on archaeological sites (Tite & Mullins, 1971). MS was undertaken with a Bartington MS2 meter using the MS2B dual sensor equipment at 1cm resolution. Volume magnetic susceptibility in SI unit (κ) was determined using a fixed frequency of 3.41kHz and a periodicity of 15 seconds, and precision was determined with randomly selected repeatability of samples. The methodology and interpretation of results followed Dearing (1999).

**Particle Size Analysis**

Further analysis of micro-variant sediment texture was conducted using particle size analysis (Figures 5, 6, and7), following the methodology set out by Konert and Vandenberghe (1997). To remove organic material, 2–5g of sediment was heated to 550oC for 2 hours in a furnace and the remaining sediment sieved through a <2-mm sieve and then mixed with a deionized water and Calgon solution to disaggregate remaining components. A subsample of this was then placed in a petrie dish with more Calgon and gently agitated with a pestle before being added to a Malvern Digisizer until an optimal obscuration of 5–20 per cent had been achieved. Background and sample measurement time was set to 90 seconds and each sample was analysed five times in order to get a good statistical dataset as determined by the international standard ISO-13320-1. All samples analysed had a standard deviation lower than 2 per cent for the fine-grained percentile (<Dx10), less than 3 per cent for the median percentile (<Dx50) and less than 5 per cent for the coarsest percentile (<Dx90).

**Multi-element ITRAX analysis**

Multi-element determination was calculated using an ITRAX XRF scanner (Croudace et al., 2006). *In-situ* sediment samples were collected in 30–50cm-long ‘u channels’ from the river section and scanned at 0.2cm resolution using 30kV, 30mA settings and a 15-second count time at the British Ocean Sediment Core Research Facility (BOSCORF) at the National Oceanography Centre, Southampton (NOCS). In total, 39 elements were identified including lithogenic indicators (Si, Al, K, Ti, Zr, Rb) and anthropogenic and heavy metal indicators. The resultant elemental intensities, measured in counts per second (cps), were vetted to remove unreliable results which occurred at the boundaries of samples, in particular within exceptionally coarse sediment horizons. The resultant dataset was then scrutinized and specific combinations of elemental ratios created in order to determine proxy coarse-grained indicators (Zr:Rb) (Thompson & Oldfield, 1986; Jones et al., 2010,2012), flood events and depositional conditions (Zr:Fe) (Wilhelm et al.,2013), redox conditions, waterlogging and/or elevated water tables (Fe:Mn) (Vepraskas, 2002), and combined heavy metals (Cu, Zn, As, Sr, Cd, Sb, Ba, Pb) in the fine and coarse sediment fraction (Croudace & Rothwell, 2015). Results from the multi-element ITRAX analysis are presented in Figures 5, 6, and 7 as log-ratios following the work of Aitchison (1981), Weltje and Tjallingii (2008), and Weltje et al.(2015).

**Sediment Power Index**

In order to further understand the variations in sediment concentration, size, distribution, and presence/absence of void space within the alluvium at the three sites, a Sediment Power Index was calculated (Figures 5, 6, 7). This was achieved by dividing the coarse sediment fraction (Dx90) by the finest sediment fraction (Dx10) to the power 3. The organic fraction was initially removed from the calculation; however, the LOI@550 results were so negligible that in the end this was not calculated in the equation.

**Agglomerate Hierarchical Clustering (AHC)**

To analyse statistically sedimentological variations within the alluvial sequences from the three sites, a programme of Agglomerative Hierarchical Clustering (AHC) analysis was conducted using the XLStat, which enabled the detailed zonation of horizons (Figures 5, 6, 7). For each site, series dissimilarity was determined of data z-scores at 1cm resolution using the Euclidean distance between six variables, percentage organics, percentage carbonate, magnetic susceptibility, fine particulate, percentage sand, and Zr:Rb. Agglomeration was calculated using Ward’s Method (Ward, 1963). The results were presented in horizontal dendrograms demonstrating cophenetic distance between variables and horizons, with major classes defined by class colour variation and individual horizon zonation defined by changes at the most similar level.

**Flood Magnitude Models**

Flood magnitude models were created for each of the sites using the coarse-grained sediment indicators Zr:Rb determined during the ITRAX multi-element analysis, detailed by Jones et al.(2012: 91 & 93). This methodology was chosen because the original work had also been conducted in the River Severn catchment where comparable basal geologies exist. The original ITRAX data were statistically tested using polynomial regression, which enabled the determination of a flood threshold value, and remodelled where there was threshold exceedance above average LogZr:Rb (Figure 8). The filtering out of ‘noise’ from the original dataset and addition of a 50-year moving average, enabled the identification and refinement of flood-rich phases of deposition at each site between ad 300 and 1150.

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