Pears, B, Brown, A G, Toms, P S ORCID logoORCID: https://orcid.org/0000-0003-2149-046X, Wood, J C, Sanderson, D and Jones, R (2020) A sub-centennial-scale OSL chronostratigraphy and Late-Holocene flood history from a temperate river confluence. Geology, 48 (8). pp. 819-825. doi:10.1130/g47079.1

Official URL: https://pubs.geoscienceworld.org/gsa/geology/article/586485/A-subcentennialscale-optically-stimulated
DOI: http://dx.doi.org/10.1130/g47079.1
EPrint URI: https://eprints.glos.ac.uk/id/eprint/8290

A sub-centennial-scale OSL chronostratigraphy and Late-Holocene flood history from a temperate river confluence

Ben Pears[1], Antony G. Brown[1], Phillip S. Toms[2], Jamie Wood[2], David Sanderson[3], and Richard Jones[4]

[1]Palaeoenvironmental Laboratory, Department of Geography and Environmental Science, University of Southampton, Highfield Campus, University Road, Southampton, UK, SO17 1BJ.

[2]Luminescence Dating Laboratory, School of Natural and Social Sciences, University of Gloucestershire, Swindon Road, Cheltenham, UK, GL50 4HZ.

[3]Scottish Universities Environmental Research Centre, Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride, UK, G75 0QF.

[4]Centre for English Local History, University of Leicester, Salisbury Road, Leicester, UK, LE1 7RH.

Abstract

River confluences can be meta-stable and contain valuable geological records of catchment response to decadal-millennial scale environmental change. However, in alluvial reaches flood stratigraphies are particularly hard to date using ^{14}C. In this paper we use a novel combination of optically stimulated luminescence (OSL) and multi proxy sedimentological analyses to provide a flood record for the Severn-Teme confluence over the last two millennia which we compare with independent European climate records. The results show that by c.2000 BP the Severn-Teme confluence had stabilized and overbank alluviation had commenced. Initially this occurred from moderately high flood magnitudes between c.2000-1800 BP (50 BCE-CE 150), but was followed from 1800-1600 BP (CE 150-350) by fine alluvial deposition and decreased flood intensity. From 1600-1400 BP (CE 350-550) the accumulation rate increased with evidence of large flood events associated with the climatic deterioration of the Dark Age Cold Period.

Following a period of reduced flood activity after c.1400 BP (c. CE 550) larger flood events and increase in accumulation rate once again became more prevalent from c.850 BP (c. CE 1100) coincident with the start of the Medieval Climate Anomaly, a period associated with warmer, wetter conditions and increased land-use intensity. This state persisted until c.450 BP (c. CE 1500) after which increased flood magnitudes can be associated with climatic variations during the Little Ice Age. We demonstrate that from the combination of high-resolution dating techniques and multiple analytical parameters, distinctive phases of relative flood magnitude vs flood duration can be determined to a detailed chronological precision beyond that possible from ^{14}C dating. This permits the identification of the regional factors behind floodplain sedimentation, which we correlate with the intensification of land-use and climatic drivers over the last two millennia.

Keywords: alluviation, Holocene, flooding, climate, river confluence, OSL.

Introduction

River floodplains contain archives of changing climatic and catchment conditions through their extensive sedimentary records. In particular, confluence zones act as nodal points for flooding, as floodplains are generally at their widest and integrate flood peaks from several catchments. Confluence migration can happen through channel belt movement, and also downstream junction yazoo-type, meander migration or through meander cut-offs (Best and Lane, 2004; Camporee et al., 2007; Brown et al., 2013; Dixon et al., 2018). Additionally oscillatory channel behaviour can also occur, stimulated by large floods (Brown et al., 2013). However, some confluences can also be surprisingly stable, becoming fixed or pinned when confined by tall banks created by high rates of levee/overbank deposition (Dixon et al., 2018). It is these large volumes of overbank sediment stored in confluence zones that act as archives of flooding and past catchment conditions.

In upland reaches ^{14}C probability density functions can yield depositional histories from channel and flood deposits (Macklin et al., 2010), but many ^{14}C-derived chronostratigraphies terminate before 1000 BP as a result of sediment reworking and organic translocation leading to problems with the calibration dates. Additionally, in clastic dominated alluvial sequences suitable organic material is only occasionally encountered and, where it is, its reliability for dating is also questionable. These factors have made it difficult to relate the sedimentary record to documentary or instrumental flood histories, which in Europe rarely go back further than 100-250 years (Macdonald et al., 2017; Longfield et al., 2018). In this paper we show how the Severn-Teme confluence has evolved over the last two millennia. We reconstruct overbank sedimentation and a detailed flood history using extensive OSL dating, alongside detailed stratigraphic and sedimentological analyses.

Confluence metastability

The Severn-Teme confluence (centred on Lat: 52.166947, Lon: -2.2303104) has over 5m of overbank sediments deposited unconformably on channel-gravels. Both the Severn (4,325 km^2) and Teme (1,648 km^2) catchments drain the Cambrian Mountains, receiving mixed intensity precipitation from W-E cyclonic activity and depression systems. The 3.5 km^2 confluence zone is bounded by Pleistocene gravel terrace deposits with alluvium deriving from the basal Triassic mudstone, siltstone and sandstone lithology (Fig. 1). Deep clastic alluvial deposits of the Severn-Teme confluence were first identified over 30 years ago (Brown, 1985) but were undatable due to a lack of suitable organic material for ^{14}C dating. However, a chronostratigraphy of channel change in the reach was established by dating palaeochannel sediments within the confluence zone (Brown, 1987). The dating of a large meander of the Teme, which must once have been close to the junction with the Severn, shows that it was abandoned, by progressive avulsion to the north between 4826-4407 BP (2876-2457 BCE). The remodelling of borehole data across the confluence shows an undated palaeochannel below the overbank units which most likely demonstrates an intermediate position prior to the creation of the large gooseneck-type meander characteristic of the present Teme channel. Alongside the physical evidence, historical data also confirms channel stability. The earliest detailed cartographic evidence shows that the Teme had adopted its current course by CE 1648, and the permanency of parish boundaries, which continue to follow the present river course, as well as the location of medieval mills, leats and weirs all indicate channel stability from as early as 1188-951 BP (CE 762-999) (Fig.1). The extensive depths of sandy-silts blanketing the palaeochannels can be traced across the confluence and further afield including the Avon catchment to the east. It was originally designated the 'buff red silty-clay' (Shotton 1978) and shown to post-date c.3600 BP (c.1650 BCE) in all locations. The stratigraphy of the sampled Powick section (Lat: 52.169259, Lon: -2.2376946), (Fig.2) consisted of a lower unit of 0.6m of yellowish grey medium to fine sandy silt (Unit A), overlain by 2.3m of dark yellow-reddish brown fine silt (Unit B), covered by 1.1m of reddish brown medium sandy silt (Unit C), capped by 0.8m of dark reddish brown coarse sandy silt and a 0.4m soil horizon (Unit D). Faint, but clear, sand-silt laminations were identified and recorded throughout. These could be traced the entire length of the section (150m) and correspond to a sequence previously recorded c. 500m upstream (Brown, 1985). This confirms that the sequence dated and analyzed here is representative of the confluence as a whole, and that the rate of overbank deposition was high enough to out-pace rare bioturbation by earthworms.

Sampling & analysis

Eight OSL dates and in-situ dosimetry were taken at 0.4-0.8m intervals up-sequence (see Supplemental Material, S3). Sediment u-channels ranging from 0.3-0.4m in length were extracted for detailed sedimentary analysis [Loss on Ignition (LOI), magnetic susceptibility (MS) and particle size], alongside multi-elemental analysis using ITRAX XRF

(Supplemental Material, S5-9; Files 1 & 2). Additional 'dark' bulk samples were taken every 5cm for luminescence profiling using a portable reader (pOSL) (Supplemental Material, S10; File 3). Age-depth Bayesian modelling of the dated alluvial sequence was initially conducted using the OSL settings provided by OxCal, v.4.3 with IntCal^{13} program (Bronk Ramsey 2008; 2009) and then using Bacon v2.2 (Blaauw and Christen 2011) to provide a cross reference of chronological quality as well as improved calendric date output [2σ (95.4%) and 1σ (68.2%) precision] (Fig.2, Supplemental Material, S3-4, Table 1), and sediment accumulation (c.1.8-3.2mm/yr^{-1}). Statistical analysis of data was conducted to clarify depositional processes (Supplemental Material, S11-12; Files 4-5), and sediment index models created to compare against climatic data (Supplemental Material, S14: File 6).

Sedimentary parameters

The sequence is entirely clastic except for the top 0.4m associated with contemporary soil formation and increased organic matter (Fig.2). High temperature LOI shows several peaks within periods of finer sedimentation reflecting carbonate but also small increases in mixed layer clays that are present in the basal Mercia Mudstone geology. MS peaks are most likely due to increases in Fe-minerals associated with ironstones, heavy minerals and coatings of quartz grains typical of the aeolian-derived Triassic sands in the Teme catchment. Particle size fractions are taken to reflect flow velocities delivered to the floodplain and they will reflect flood velocity if the location of the channel is constant relative to the site. The power function combines the coarse sediment fraction (D90), a proxy for flow velocity, with organic matter (an inverse function of sedimentation rate). Measurements of mineralogy were undertaken using an ITRAX-XRF Scanner (Croudace et al., 2006) to calculate LogZr:Rb ratios. This provides a measure of the weathered nature of the sediment and the relative contribution of detrital grains vs clay minerals.

In order to refine the depositionary history and determine flood events pOSL analysis was conducted (Sanderson and Murphy 2010). The technique has proven success in fluvial contexts (Muñoz-Salinas et al., 2010) (Supplemental Material S10), which demonstrate that sudden changes and particularly peaks in accumulated pIRSL dose that diverge from general trends are identifying sources of sediment that are relatively unbleached and derive from eroded bank sediment and mobilized during high energy flow events. Periods of constant flood rate with equally sized events would produce a uniform pOSL curve.

Discussion

From the age-depth model and sedimentary properties it is possible to propose a flood history for the mid-point of the Severn catchment over the last 2000 years (Fig.2). From 2000-1800BP (50BCE-CE150) medium-silt alluvium with elevated proportions of sand and pOSL are present and possibly reflect increased soil erosion from Late Iron Age and Romano-British cultivation, similar to other major UK lowland floodplains (Robinson and Lambrick 1984; Brown 2009). Between 1800-1600BP (CE150-350) there is a reduction in sand and increase in carbonate and fine particulate indicating a reduction in fluvial depositional conditions. After 1600BP, and continuing until 1400BP (CE550) fine alluvial sedimentation continued but an increase in accumulation rate and clear peaks in MS demonstrate large, lower energy flood events at the start of the Dark Age Cold Period, in response to climatic downturn (Lamb 1972). The development of extensive floodplain meadowlands across many river systems at this time may have, in part, been as a result of suitable 'well-watered' conditions (Williamson 2013, 204). There followed from 1400-1100BP (CE550-850) a fall in accumulation rate and lower energy alluviation with increases in carbonate and pOSL after 1250BP (CE700). From 1100-600BP (CE850-1350) the sedimentological evidence suggests higher fluvial activity with an increase in high-magnitude events. The accumulation rate increases markedly alongside more numerous peaks in MS, higher sand content, and increases in pOSL and elemental indicators. This clear change corresponds with the change to warmer, wetter conditions typical of the Medieval Climate Anomaly alongside increased land-use intensity on the floodplain. At this time arable cultivation covered 30-50% total land area in those English counties within the Severn-Teme catchment (Broadberry et al., 2015; Rippon et al., 2015), and beyond (Hey 2004), corresponding to peak medieval population levels in midland England of over 10 persons/km^{2} (Goldewijk, 2010).

From 600-400BP (CE1350-1550) river conditions appear to have calmed and a sharp decrease in accumulation rate alongside increase in carbonate and reduction in other proxy suggest fewer high-energy depositional events. After 400BP (CE1550) and continuing through to the present, there is another rise in accumulation rate alongside a significant increase in grain size to coarse silt, considerably higher sand content, and major increases in pOSL and elemental indicators. Together these demonstrate intensive phases of deposition in the Severn-Teme confluence particularly 400-350BP (CE1550-1600); 250-200BP (CE1700-1750) and c.100BP (CE1850) and appear conterminous with the period of maximum recorded historical flood events (Marsh et al., 2016; Macdonald et al., 2017), and the abandonment of the open-field system. The data support the identification of periods of lower duration but higher magnitude flood dominated regimes caused by increased snowmelt and storminess (Rumsby et al., 1996; Macklin et al., 2012). Statistically there are clear relationships between the key analytical techniques (Fig.3). There is a positive correlation between grain size, sand content and Zr:Rb associated with a higher coarse component within the alluvium. A positive trend is also present for the pIRSL and pOSL, although there is less clear correlation between the overall particle size and pOSL, possibly as a result of variations in sediment provenance. Clear negative correlations are present between aforementioned classes and carbonate, and to a lesser extent with magnetic susceptibility. The stratigraphical variation at the Severn-Teme confluence can now be compared to other recently established deep alluvial sequences along the rivers Teme and Severn (Pears et al., 2020), providing further evidence for flood regimes in other parts of their catchments as well as to European scale climatic models to assess potential drivers (Fig.4). All three fluvial sequences demonstrate predominantly fine-grained deposition to 1450BP (CE350) during the Roman Warm Period associated with warmer, drier conditions across the UK, Ireland and Europe (Charman et al., 2006; Swindles et al., 2013; Wilson et al. 2013; Büntgen et al., 2011). In contrast from 1500-1000BP (CE400-1100) the sedimentary models from the upstream profiles at Broadwas and Buildwas demonstrate much coarser sediment deposition than the Severn-Teme confluence, suggesting that the variable climatic conditions of the Dark Age Cold Period and Medieval Climate Anomaly had more localized effects upon the fluvial activity in the upper reaches of these river systems. The onset of significantly coarser sedimentation in the Severn-Teme confluence from 900BP (CE1000) which accelerated after 400BP (CE1550) is mirrored in the other sequences albeit with longer phases of finer sediment deposition and can be associated with climatic variability during the Little Ice Age (Wanner et al., 2008; Phipps et al., 2013), leading to prolonged phases of wetter conditions across the UK and Ireland (Charman et al., 2006; Swindles et al., 2013; Wilson et al. 2013), cooler European climates (Esper et al., 2014) as well as continued intensification of land-use and sediment erosion across the confluence landscape.

Conclusions

A combination of detailed topographic and sedimentological mapping, OSL dating and stratigraphic modelling show that the river channels forming the Severn-Teme confluence zone have been almost completely fixed for the last 2000 years. This has produced the continuous sedimentological record of levee/overbank flooding. High resolution OSL dating of the sedimentary sequence has produced an alluvial flood record for the last two millennia. The sedimentary record shows distinct variation in depositionary conditions in the late Holocene with phases of low and high magnitude events associated with changing land-use intensity in the surrounding local landscape in the medieval, post medieval and modern periods, and exacerbated by variable climatic drivers especially during the Dark Age Cold Period, Medieval Climate Anolmaly and Little Ice Age.

Acknowledgments

This work was undertaken as part of the Leverhulme Trust-funded ‘*Flood and Flow*’ project (RPG-2016-004). We thank the landowners, British Geological Survey for borehole records and The Environment Agency for Lidar. The pOSL analysis was conducted using equipment owned by the University of Tromsø, Norway.

Figures

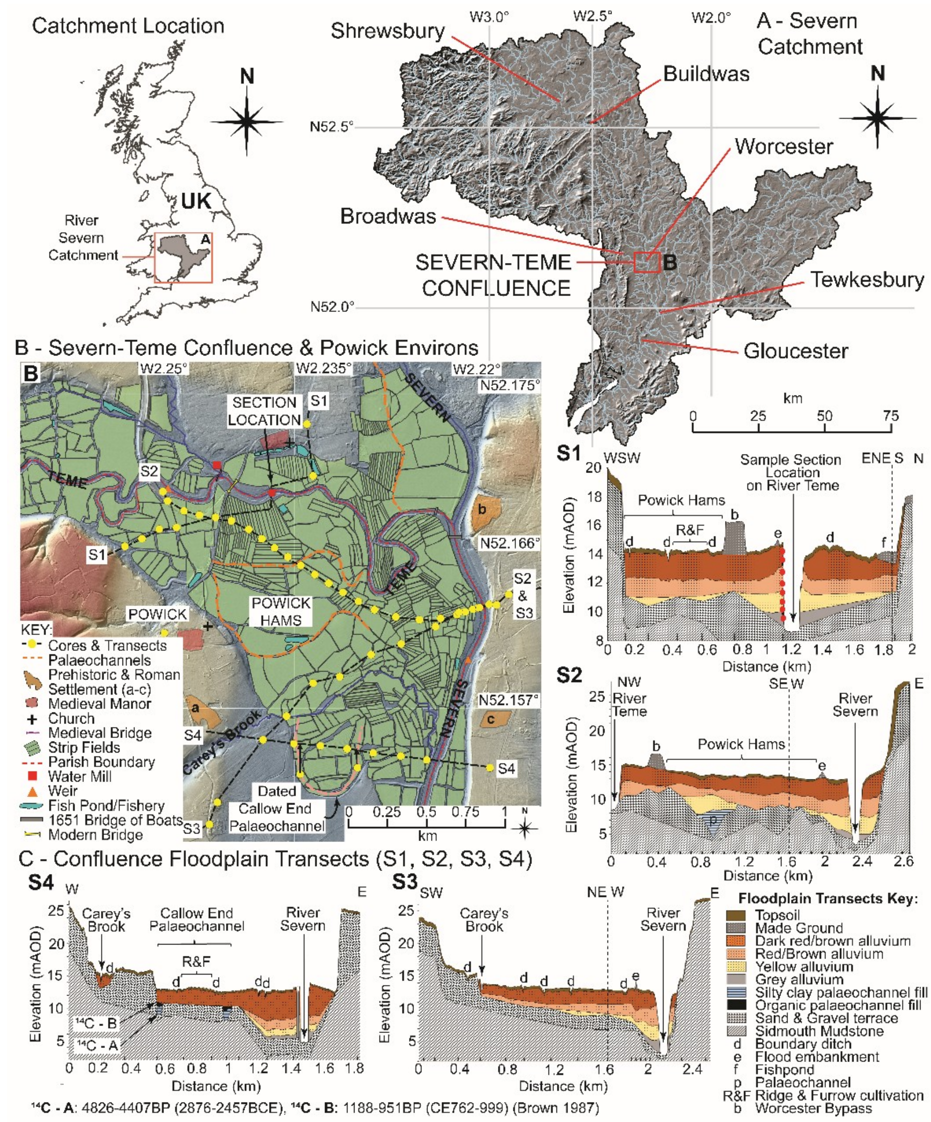

Figure 1. Catchment location; (A) River Severn catchment, major settlements and other sample locations (see Figure 4), basemap 50m resolution Lidar DTM (Environment Agency 2017); (B) Severn-Teme confluence 1m resolution Lidar DTM basemap SO85SW, SO85SE, cores, river sample location and palaeo channels. Historic land use plotted from 1m Lidar, Coventry map (CE1648), 1st Edition Ordnance Survey (CE1886) and Worcestershire Historic Environment Record (WHER). (C) Reconstructed and modelled floodplain cross-sections (S1 – S4) with surface topography from 1m Lidar DTM and WHER.

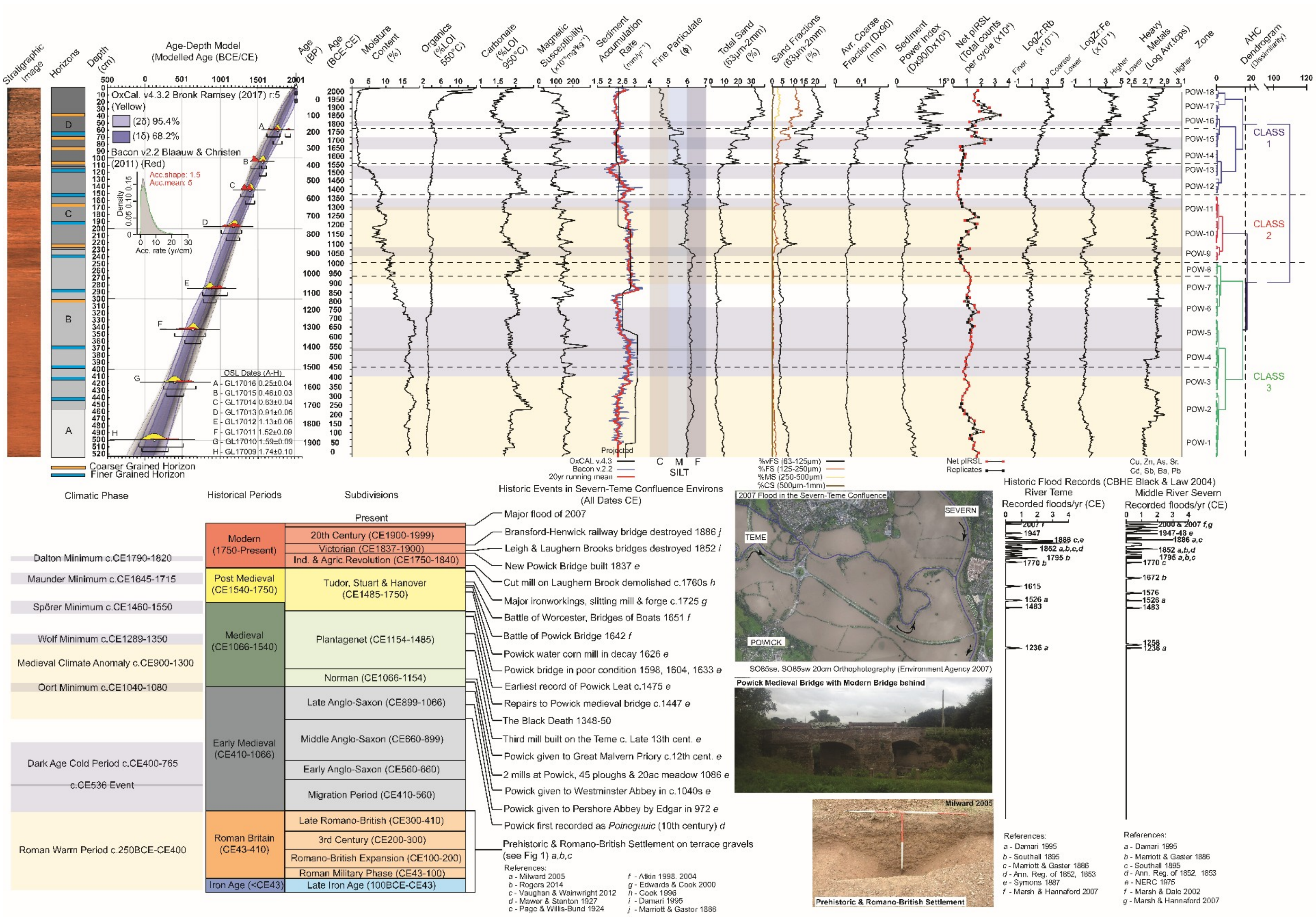

Figure 2. Chronostratigraphy of the Severn-Teme confluence at Powick, Worcestershire.

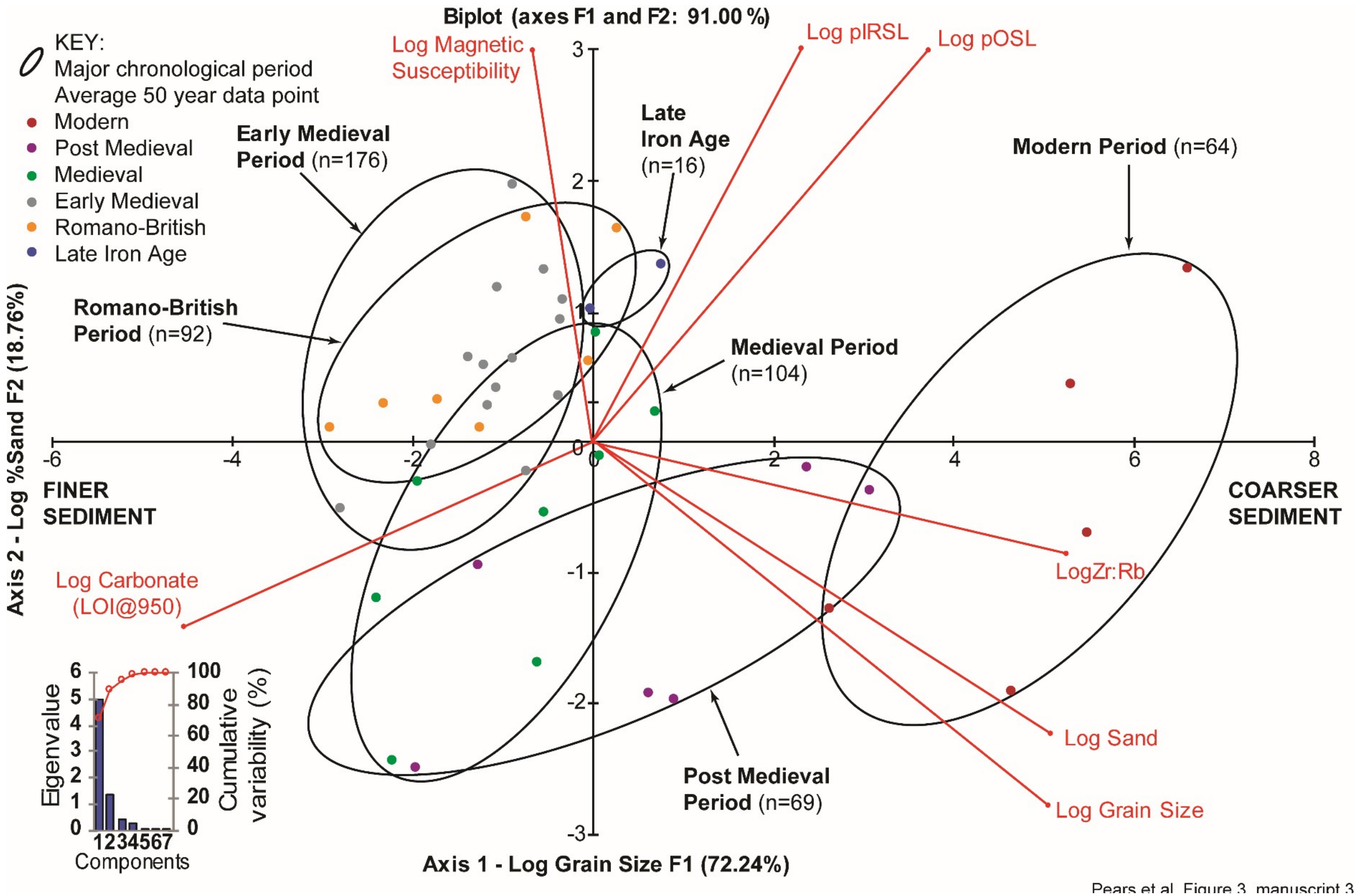

Figure 3. Principal Component Analysis (PCA) using XLStat (2019.2.3) conducted across key variables. 521 observations were clustered across 50-year timespans from 20BCE-Present, classed into six time-periods of the Holocene (solid black lines).

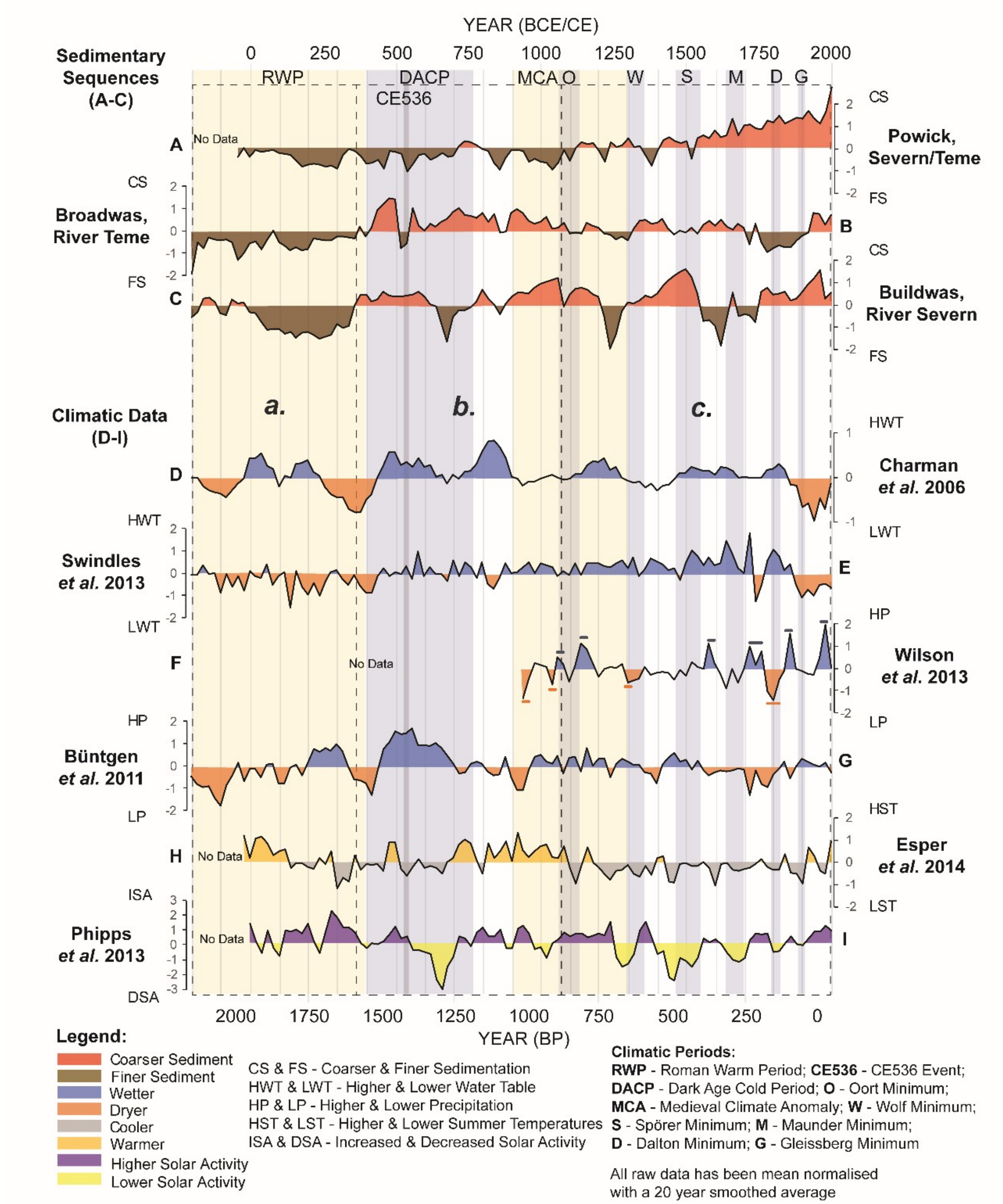

Figure 4. Sediment Deposition Models from the Severn-Teme confluence at Powick (A) with comparative models from sites upstream at Broadwas (Teme) (B) and Buildwas (Severn) (C). Also modelled against upland peatland water table depth and proxy wetter/drier conditions in the UK (D) and Ireland (E); Precipitation in Southern and Central England (F) and Central and Southern Europe (G); summer temperatures in Northern Europe (H) and solar variation (I).

References cited

Best, J.L., and Lane, S.N., 2004, Confluence, channel, and river junctions, in Goudie, A.S., ed., Routledge Encyclopedia of Geomorphology: New York, Routledge, p. 180–183.

Blaauw, M., and Christen, J.A., 2011, Flexible palaeoclimate age-depth models using an autoregressive gamma process: Bayesian Analysis, v. 6, no. 3, p. 457-474, https://doi.org/10.1214/11-BA618.

Broadberry, S., Campbell, B.M.S., Klein, A., Overton, M. and van Leeuwen, B., 2015, British economic growth 1270-1870: Cambridge, Cambridge University Press.

Bronk Ramsey, C., 2008, Deposition models for chronological records: Quaternary Science Reviews, v. 27, no. 1-2, p. 42-60, https://doi.org/10.1016/j.quascirev.2007.01.019.

Bronk Ramsey, C., 2009, Bayesian analysis of radiocarbon dates: Radiocarbon, v. 51, no. 1, p. 337-360, https://doi.org/10.1017/S0033822200033865.

Brown, A.G., 1985, Traditional and multivariate techniques in the interpretation of floodplain sediment grain size variations: Earth Surface Processes and Landforms, v. 10, no. 3, p. 281-291, https://doi.org/10.1002/esp.3290100310.

Brown, A.G., 1987, Holocene floodplain sedimentation and channel response of the lower river Severn, U.K.: Zeitscrift fur Geomorphologie N.F., v. 31, p. 293-310.

Brown, A.G., 2009, Colluvial and alluvial response to land use change in Midland England: An integrated geoarchaeological approach: Geomorphology, v. 108, no. 1-2, p. 92-106, https://doi.org/10.1016/j.geomorph.2007.12.021.

Brown, A.G., Toms, P., Carey, C. and Rhodes, E., 2013, Geomorphology of the Anthropocene: Time-trangressive discontinuities of human-induced alluviation: The Anthropocene, v. 1, p. 3-13, https://doi.org/10.1016/j.ancene.2013.06.002.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J.O., Herzig, F., Heussner, K-U., Wanner, H., Luterbacher, J. and Esper. J. 2011, 2500 Years of European Climate Variability and Human Susceptibility: Science, v. 331, no. 6017, p. 578-582, https://doi.org/10.1126/science.1197175.

Camporeale, C., Perona, P., Porporato, A., and Ridolfi, L., 2007, Hierarchy of models for meandering rivers and related morphodynamic processes: Reviews of Geophysics, v. 45, no. 1, p. 1001, https://doi.org/10.1029/2005RG000185.

Charman, D.J., Blundell, A., Chiverrell, R.C., Hendon, D. and Langdon, P.G. 2006, Compilation of non-annually resolved Holocene proxy climate records: Stacked Holocene peatland palaeo-water table reconstructions from northern Britain: Quaternary Science Reviews, v. 25, no. 3-4, p. 336-350, https://doi.org/10.1016/j.quascirev.2005.05.005.

Croudace, I.W., Rindby, A., and Rothwell, R.G., 2006, ITRAX: description and evaluation of a new multi-function X-ray core scanner: Geological Society Special Publications, v. 267, no. 1, p. 51-63, https://doi.org/10.1144/GSL.SP.2006.267.01.04.

Dixon, S.J., Sambrook Smith, G.H., Best, J.L., Nicholas, A.P., Bull, J.M., Vardy, M.E., Sarker, M.H., and Goodbred, S., 2018, The planform mobility of river channel confluences: Insights from remotely sensed imagery: Earth Science Reviews, v. 176, p. 1-18, https://doi.org/10.1016/j.earscirev.2017.09.009.

Esper, J., Düthorn, E., Krusic, P.J., Timonen, M. and Büntgen, U. 2014, Northern European summer temperature variations over the Common Era from integrated tree-ring density records: Journal of Quaternary Science, v. 29, no. 5, p. 487-494. https://doi.org/10.1002/jqs.2726.

Goldewijk, K., Klein, A., Beusen, X., and Janssen P., 2010, Long-term dynamic modeling of global population and built-up area in a spatially explicit way, HYDE 3.1: The Holocene, v. 20, no. 4, p. 565-573, https://doi.org/10.1177%2F0959683609356587.

Hey, G., 2004, Yarnton: Saxon and Medieval settlement and landscape. Results of excavations 1990-96: Oxford Archaeology, Thames Valley Landscape Monography No. 20.

Lamb, H.H., 1972, Climate present past and future: London, Routledge.

Longfield, S.A., Faulkner, D., Kjeldsen, T.R., Macklin, M.G., Jones, A.F., Foulds, S.A., Brewer, P.A. and Griffiths, H.M., 2018, Incorporating sedimentological data in UK flood frequency estimation: Journal of Flood Risk Management, v. 12, no. 1, p. 1-19. https://doi.org/10.1111/jfr3.12449.

MacDonald, N., and Sangster, H., 2017, High-magnitude flooding across Britain since AD 1750: Hydrology and Earth System Science, v. 21, p. 1631-1650, https://doi.org/10.5194/hess-21-1631-2017.

Macklin, M.G., Jones, A.F., and Lewin, J., 2010, River response to rapid Holocene environmental change: Evidence and explanation in British catchments: Quaternary Science Reviews, v. 29, no. 13-14, p. 1555-1576, https://doi.org/10.1016/j.quascirev.2009.06.010.

Macklin, M.G., Lewin, J., and Woodward, J.C., 2012, The fluvial record of climate change: Philosophical Transactions of the Royal Society A, v. 370, p. 2143–2172, https://doi.org/10.1098/rsta.2011.0608.

Marsh, T.J., Kirby, C., Muchan, K., Barker, L., Henderson, E., and Hannaford, J., 2016, The winter floods of 2015/2016 in the UK - a review: Centre for Ecology & Hydrology, Wallingford.

Muñoz-Salinas, E., Bishop, P., Sanderson, D.C.W., and Zamorano, J-J., 2010, Interpreting luminescence data from a portable OSL reader: three case studies in fluvial settings: Earth Surface Processes and Landforms, v. 36, no. 5, p.651-660, https://doi.org/10.1002/esp.2084.

Pears, B., Brown, A.G., Carroll, J., Toms, P., Wood, J., and Jones, R., 2020, Early medieval place-names and riverine flood histories: a new approach and new chronostratigraphic records for three English rivers: European Journal of Archaeology.

Phipps, S.J., McGregor, H.V., Gergis, J., Gallant, A.J.E., Neukom, R., Stevenson, S., Ackerley, D., Brown, J.R., Fischer, M.J. and van Ommen, T.D., 2013, Paleoclimate Data-Model Comparison and the Role of Climate Forcings over the Past 1500 Years: Journal of Climate, v. 26, no. 18, p. 6915-6936, https://doi.org/10.1175/JCLI-D-12-00108.1.

Rippon, S., Smart, C., and Pears, B., 2015, The Fields of Britannia: Oxford, Oxford University Press.

Robinson, M.A., and Lambrick, G.H., 1984, Holocene alluviation and hydrology in the upper Thames basin: Nature, v. 308, p. 809-814, https://doi.org/10.1038/308809a0.

Rumsby, B. and Macklin, M.G., 1996, River response to the last neoglacial (the 'Little Ice Age') in northern, western and central Europe: Geological Society, London, Special Publications, v. 115, no. 1, p. 217-233, https://doi.org/10.1144/GSL.SP.1996.115.01.17.

Sanderson, D.C.W. and Murphy, S., 2010, Using simple portable OSL measurements and laboratory characterisation to help understand complex and heterogeneous sediment sequences for luminescence dating: Quaternary Geochronology, v. 5, no. 2-3, p. 299-305, https://doi.org/10.1016/j.quageo.2009.02.001.

Shotton, F.W., 1978, Archaeological inferences from the study of alluvium in the lower Severn-Avon valleys: in Limbrey, S., and Evans, J.G., eds, The effect of man on the landscape: The lowland zone: Council for British Archaeology Research Report, no. 21, p.27-32.

Swindles, G.T., Lawson, I.T., Matthews, I.P., Blaauw, M., Daley, T.J., Charman, D.J., Roland, T.P., Plunkett, G., Schettler, G., Gearey, B.R., Turner, T.E., Rea, H.A., Roe, H.M., Amesbury, M.J., Chambers, F.M., Holmes, J., Mitchell, F.J.G., Blackford, J., Blundell, A., Branch, N., Holmes, J., Langdon, P.G., McCarroll, J., McDermott, F., Oksanen, P.O., Pritchard, O., Stastney, P., Stefanini, B., Young, D., Wheeler, J., Becker, K. and Armit, I., 2013, Centennial-Scale Climate Change in Ireland During the Holocene: Earth-Science Reviews, v.126, p. 300-320, https://doi.org/10.1016/j.earscirev.2013.08.012.

Wanner, H., Beer, J., Bütikofer, J., Crowley, T.J., Cubasch, U., Flückiger, J., Goosse, H., Grosjean, M., Joos, F., Kaplan, J.O., Küttel, M., Müller, S.A., Prentice, I.C., Solomina, O., Stocker, T.F., Tarasov, P., Wagner, M., and Widmann, M. 2008, Mid- to late Holocene climate change: An overview: Quaternary Science Review, v. 27, no. 19-20, p. 1791–1828, https://doi.org/10.1016/j.quascirev.2008.06.013.

Williamson, T., 2013, Environment, Society and Landscape in Early Medieval England. Time and Topography: Anglo-Saxon Studies 19, The Boydell Press, Woodbridge.

Wilson, R.J.S., Miles, D.W.H., Loader, N.J., Melvin, T.M., Cunningham, L.K., Cooper, R.J. and Briffa, K.R. 2013, A millennial long March-July precipitation reconstruction for southern-central England: Climate Dynamics, v. 40, no. 3-4, p. 997-1017, https://doi.org/10.1007/s00382-012-1318-z.

[1] GSA Data Repository item 201Xxxx, Supplemental Date File 1 includes the raw data for the modelled calendric dates, sediment accumulation rate and sedimentological analyses including % moisture, % organics (LOI@550º), % carbonate (LOI@950º), magnetic susceptibility and particle size data (coarse & fine components, sediment power index, sand fractions and total % sand illustrated in figure 2. Supplemental Data File 2 includes the raw and log normalized data for ITRAX XRF analysis and key elements Zr, Rb, Fe, Mn and heavy metals illustrated in figure 2. Supplemental Data File 3 includes the individual raw data sets for each 5cm pOSL run alongside a background sediment sample. The file also includes a summary sheet of all data and replicates (Figure 2). Supplemental Data File 4 provides the raw data, log normalized data and statistical analysis used in the Agglomerative Hierarchical Cluster analysis illustrated in figure 2. Supplemental Data File 5 includes the calculated log data of sedimentary analyses by 50-year period and the statistical analysis used in the Principal Component Analysis (Figure 3). Supplementary Data File 6 includes the 20-year grouping for the Sediment Deposition Models for the Severn-Teme confluence at Powick, Broadwas and Buildwas, and climatic datasets (Figure 4). The files are available online at www.geosociety.org/pubs/ft20XX.htm, or on request from editing@geosociety.org.