

SEDIMENTARY ARCHITECTURE OF UK WANDERING GRAVEL-BED RIVERS, RIVER COQUET, NORTHUMBERLAND, UK

Loan 1070, GEF report

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Abstract

Ground penetrating radar (GPR) data were collected at three locations on the River Coquet, Northumberland, UK. Locations were selected where there is a known style of channel change revealed by historical data. This project tested published models of sedimentary architecture of wandering gravel-bed rivers and examine the relationship between specific historic river planform change and subsurface sedimentary architecture (e.g. Vandenberghe and van Overmeeren, 1999; Wooldridge and Hickin, 2005). Repeated lines of common offset (CO) survey were performed using the PulseEKKO PRO (50, 100 and 200 MHz) antennas in the first grid (Thropton grid) to assess the most suitable frequency to provide the best depth penetration and image resolution. Velocity analysis of the CMP data ranged from 0.07 and 0.088 m ns⁻¹. Both 50 MHz and 100 MHz frequencies achieved good penetration depth, down to ~14 m and ~11 m, respectively. Continuous reflections were detected from the uppermost units (i.e. 0.5-1.5 m below the surface), while dipping steeply-inclined (10 to 20°) reflection facies were found below this. These reflection facies are typically between 0.5 and 2 m in thickness and extended laterally for 10 to 60 m.

Background

Understanding of the processes and dynamics of wandering gravel-bed rivers has improved over the last two decades (Buffington, 2012; Wooldridge and Hickin, 2005). Passmore and Macklin (2000) used sedimentary data to reconstruct Late Holocene channel stability over the wandering gravel-bed South Tyne River. Although processes within UK wandering gravel-bed rivers have been conceptualised, the relationship between channel pattern change and the subsurface sedimentary architecture of alluvial deposits have yet to be fully quantified. To address this gap, we used GPR to characterise the subsurface sedimentary architecture of the wandering gravel-bed River Coquet, Northumberland, UK, combining GPR-derived sedimentary architecture with changes in surface channel morphology reconstructed for the last 160 years from Ordnance Survey maps. By producing a detailed 3-D model of the system at the reach scale of the river, we characterise the sedimentary architecture associated with different styles of river channel change. We firstly determined historic river channel change by combining detailed topographic surveys with historical maps, aerial imagery and repeat LiDAR analysis. Subsequent GPR

survey and analysis of sedimentary exposures of reach-scale river channel behaviour through time and in three spatial dimensions allowed 4-D quantification of channel change.

As no previous GPR survey had been previously undertaken on the River Coquet, the aims of this project were to: (i) determine the thickness and architecture of the alluvial sedimentary fill of the Coquet valley floor; (ii) provide detailed insights into the relationship between sedimentary architecture and known patterns of reach-scale geomorphological change over time; and (iii) test sedimentary models of the sedimentary architecture of wandering gravel-bed rivers from other river systems.

The GPR survey was undertaken on three 0.5-1 km long reaches of the River Coquet (Thropton, Hepple and Holystone reaches) (Figure 1).

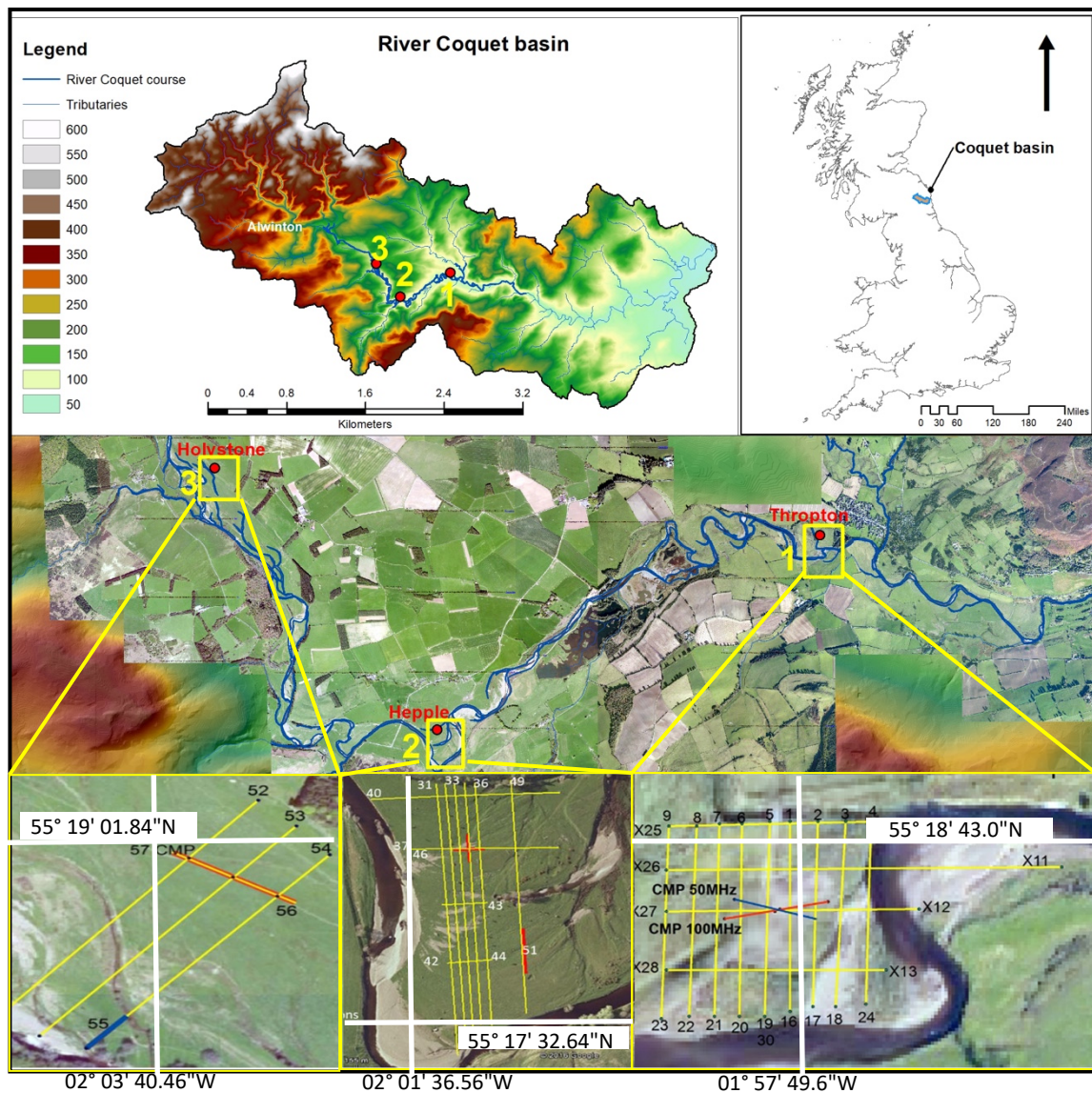


Figure 1. Site locations selected for GPR survey on the River Coquet, Northumberland, UK. (1) Thropton grid (2) Hepple grid (3) Holystone grid. The yellow lines indicate to the common-offset GPR lines and the common-midpoint profiles are marked in red. Background image is the 2009 satellite image from Google Maps.

The choice of these reaches for investigation was based on the presence of different style of river planform adjustment (e.g. channel width, rate and style of migration and channel avulsion processes, and extent of palaeochannel re-occupation and/or instigation of new channels) mapped from the available historical data set.

Survey procedure

GPR and topographic survey (using dGPS) were carried out on the River Coquet between 17th May and 1st June 2018. We used the NERC Geophysical Equipment Facility (GEF) Sensors and Software Pulse Ekko Pro GPR with a 1000 V transmitter, and 50, 100 and 200 MHz antennas (Figure 2). A common offset (CO) survey using three different frequencies of antennas (50, 100 and 200 MHz) was performed along single lines in the first survey grid (Thropton grid) to establish depth of penetration and data resolution, and to determine which antenna set would be most appropriate to address the scientific goals of the project. Subsequent GPR grids at Hepple and Holystone were conducted at frequencies of 50 and 100 MHz (Hepple), and 100 MHz (Holystone). The time window used in the initial survey line was 200 ns but this was then changed to 400 ns for 100MHz data acquisition and 600 ns for 50MHz acquisition, to ensure that all subsurface reflections were acquired. The number of stacks was 16 for all the GPR profiles. To calculate subsurface velocities at



Figure 2. *The use of the 100 MHz antenna to collect a profile at Thropton grid.*

each site we collected a number of common midpoint (CMP) profiles (Figure 1). CMP surveys were acquired with both 50 MHz and 100 MHz antenna sets to obtain an accurate estimate of the depth by calculating the velocity of the subsurface radar wave. The average velocity calculated for subsurface hyperbola reflections ranged between 0.07 and 0.088 m ns⁻¹.

Palaeo-flow parallel and palaeo-flow transverse longitudinal and cross-sectional GPR profiles were acquired at each field site (Table 1). Line number 5 in Thropton grid (Figure 3) was repeated using the three antennas (50, 100 and 200 MHz) to test depth penetration and vertical resolution.

Table 1. Details of acquired CO GPR data collection at Thropton, Hepple and Holystone, River Coquet.

Grid	Freq. (MHz)	No. of lines	Orientation relative to channel		Total length (m)	Trace sampling (m)
			longitudinal	cross-sectional		
Thropton	50	13	4	9	1, 368	0.5
	100	13	4	9	1368	0.25
	200	1	-	1	89	0.1
Hepple	50	9	4	5	2, 341	0.5
	100	6	3	3	1, 251	0.25
Holystone	100	4	1	3	1, 053	0.25

Data quality

Repeat GPR surveys showed that the 50 and 100 MHz frequencies provided significant depth penetration and good resolution, while the high frequency antennas (200 MHz) provided greater resolution but less depth penetration (Figure 3). The quality of data collected was very good, although some profiles in the Hepple grid were affected by above surface reflections from nearby telegraph poles and tree logs. The location of these objects was mapped using hand-held GPS.

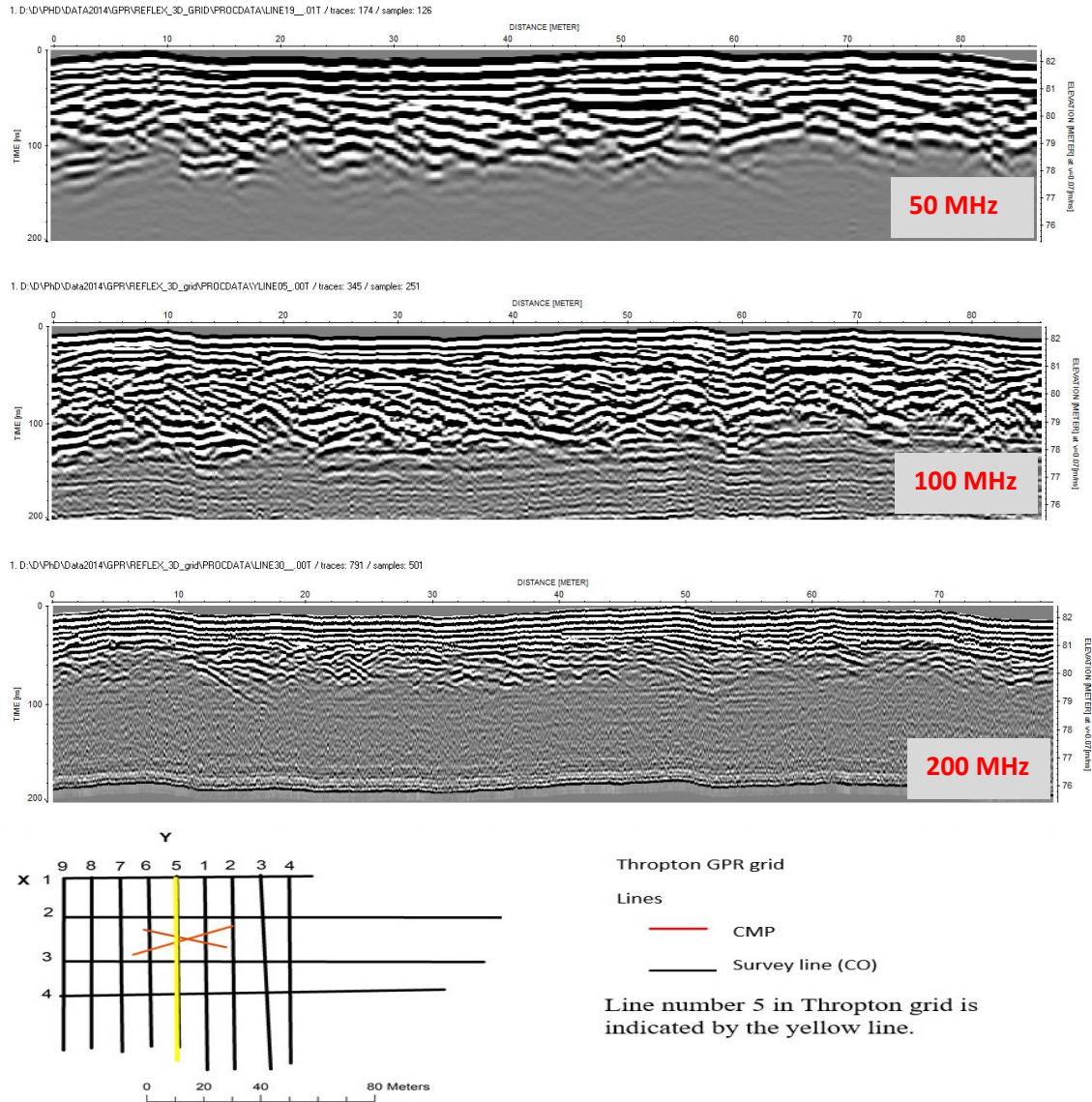


Figure 3. Post- processed results of the repeated line (line number5) using the three antennas (50, 100 and 200 MHz) to test depth penetration and vertical resolution.

Data Processing

Following data acquisition, all GPR profiles were processed using the Sandmeier software REFLEXW (version 8.5). The main aim of this was to improve the data quality and to get a more realistic image of the subsurface data by enhancing the signal-to-noise ratio (Neal, 2004). Basic processing steps were applied to all GPR lines to improve the data, with variations in processing applied to data acquired at different frequencies. Processing included: (a) move start time to change the arrival time signal; (b) dewow to remove very low frequency components from the data (Annan, 2002); (c) bandpass filter: different parameters were tested, with the most optimal parameters found to be 35-70-150-225 MHz for the 50 MHz transmitter, while the frequency band chosen for filtering the 100 MHz were 35-70-200-325 MHz; (d) stack traces (number of traces = 3); and (d) gain function to enhance the amplitude of deeper reflections (Cassidy, 2009). Finally, topographic correction was applied to correct the subsurface

reflection position. Since the GPR profiles were acquired in alternate directions, every second profile was flipped in the x-direction to provide a comparable view of all profiles. The CMP data were processed using CMP-velocity analysis within REFLEXW to provide an accurate estimate for the subsurface radar velocity.

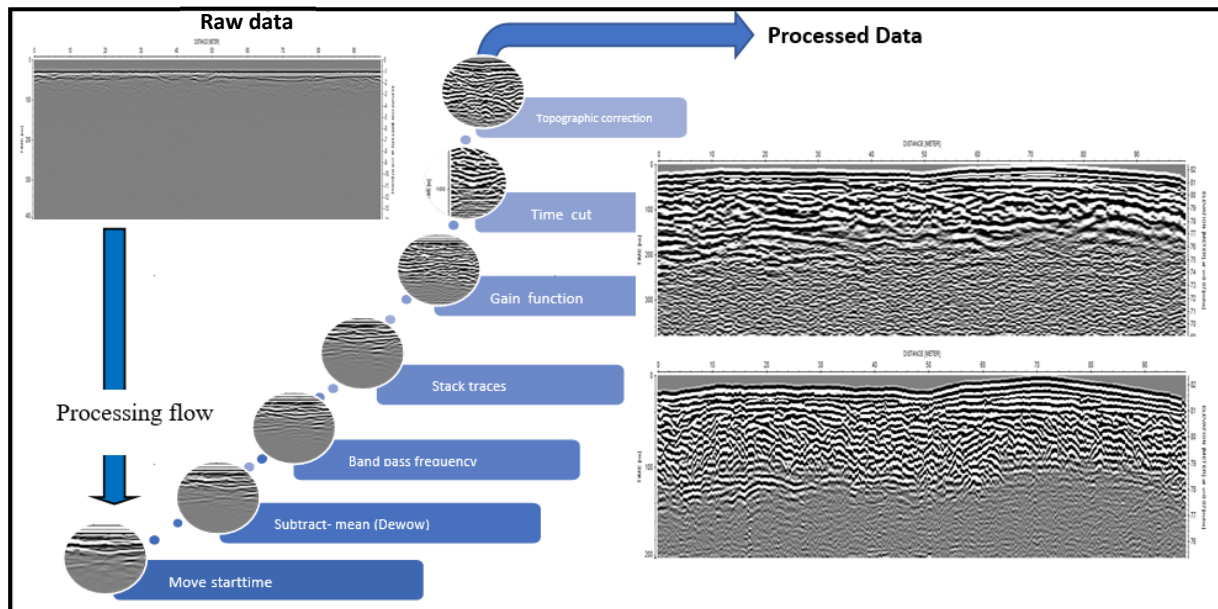


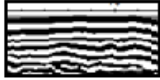
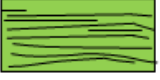





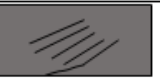








Figure 4. Summary of flow processing applied on the GPR (50 and 100 MHz frequencies) using Reflexw.

Interpretation to date

GPR data were analysed and interpreted by identifying reflection patterns based on the shape, amplitude, continuity and reflection configurations, following approaches used in a variety of previous studies of fluvial sedimentary architecture (e.g. Ekes and Hickin, 2000; Skelly et al., 2003; Wooldridge and Hickin, 2005; Kostic and Aigner, 2007; Hickin et al., 2009; Rice et al., 2009; Vandenberghe and van Overmeeren, 1999). The subsurface architecture and stratigraphy of the River Coquet were described from the GPR data. Eight key radar facies were identified to a depth of 7 m in the River Coquet alluvial fill, based on the reflection patterns outlined in Table 2.

RF1 consists of horizontal to subhorizontal, continuous and parallel to subparallel reflections. It is characterised by high amplitude reflections that are gently inclined ($0-4^{\circ}$) with an overall lateral extent that is typically in the range of 50 to 100 m. Reflections of this facies were detected at variable depths in the GPR profiles but are mostly found and better-defined in the uppermost units (0.5 - 1.5 m). RF1, commonly observed in the upper units of GPR profiles, represents planar bedding associated with either a lower- or transitional-flow fluvial regime. RF1 is interpreted as upper stage plane beds with horizontal stratification produced by aggradation (vertical accretion) of gravel sheets (Ekes and Hickin, 2001).

Table 2. Radar facies used to classify and interpret the processed GPR profiles for the River Coquet.

Radar facies	Description	Example pattern	Average scale			Interpreted pattern	Interpretation
			Length	Thick	Angle		
RF1	Horizontal to subhorizontal, continuous, subparallel		50-100m	0.5-1.5m	0 to 4°		Plane beds, vertical accretion of gravel sheets.
RF2	Low-angle cross-stream dipping, subparallel reflection		10-50m	Up to 1m	2 to 10°		lateral accretion surfaces.
RF3	complex sigmoidal, moderate to high-angle, cross-stratification		10-60m	0.5-2m	10-20°		downstream accretion or foreset deposits, bed- or barform migration.
RF4	oblique, highly inclined cross-stratified reflection		2-10m	~ 1.5m	15-30°		downstream dipping slipface (bar-margin slipface)
RF5	trough-shaped (concave up) reflection pattern		10-30m	0.5-1.5m	—		channel and chute basal boundaries
RF6	trough infill facies		—	0.5-1.5m	—		channel and chute fill deposits
RF7	Hummocky, discontinuous, trough cross-stratification and diffractions.		<10m	<0.5m	—		bedform accumulations and/or small, subaqueous 3-D dune. Diffraction interpreted as buried woody debris
RF8	reflection free areas		—	—	—		attenuation of the electromagnetic wave signal due to presence of fine-grained materials such as clays or diamicton.

RF2 is characterised by low- to moderate-angle dipping (2-10°, typically 5° more common) reflections representing lateral accretion. This is interpreted as the primary depositional product associated with the process of point bar growth. RF2 is commonly observed in the upper units of GPR profiles. Steeply inclined GPR reflections (RF3 and RF4) are interpreted as bar-margin slipface deposits that document downstream bar progradation, where sediments have avalanched down the distal face of high-relief amplitude bars into deeper water, associated in the Coquet with high stage flows. The high-amplitude reflections in these facies reflect contrasting dielectric properties associated with the internal size and sorting of foreset beds composed of sand and gravel. RF5 and RF6 represent trough-shaped (concave-up reflections) reflection patterns and trough infill facies. These facies are interpreted as the basal contact of channels and chutes, and the subsequent channel infill structures. RF7 is characterised by individual high- to moderate-amplitude reflections that dip in different directions. This radar facies is the most frequently occurring and is characterised by short, discontinuous irregular subparallel and wavy reflections. In fluvial systems, hummocky reflections consisting of planar and trough cross-stratified sets comprised of poorly-sorted sand and gravel are interpreted as 3-dimensional dune bedforms (Mumpy et al., 2007). RF8, found at depths greater than 7 m, is a zone where no or few reflections arise, or is a zone of noise and enhanced attenuation of the radar signal. This likely indicates

the presence of clay-rich material, possibly subglacial till, that prevents further penetration of the GPR signal.

Conclusions and recommendations

The upper ~2 m of the stratigraphic succession, associated with ‘known’ channel pattern change over the past 160 years, is dominated by lateral accretion facies which represents point bar accretion associated with progressive lateral channel migration. Although the GPR-derived sedimentary architecture of the River Coquet is broadly comparable with other models of wandering gravel bed rivers (e.g. Wooldridge & Hicken, 2005), structures related to individual unit bars and sand sheets are harder to identify due to the Coquet having a lower relief amplitude. Work is in process to generate a three-dimensional interpretation block of depositional units using OpendTect software. GPR has proved very effective in characterising the sedimentary architecture of one of the UK’s most active wandering gravel-bed rivers.

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Location of archived data

The data has been backed up and archived in the institutional data repository, data.ncl ([Newcastle University research repository - Browse](https://doi.org/10.25405/data.ncl.28351814)), which is powered by Figshare <https://doi.org/10.25405/data.ncl.28351814>.

PhD Thesis

Al Zerouni, S. (2021) Controls on decadal morphological change and sedimentary architecture of the wandering gravel-bed River Coquet, Northumberland, UK. PhD thesis, School of Geography, Politics and Sociology, Newcastle University, UK

Conference presentations

- Al Zerouni, S., Russell, A.J., Large, A.R.G., Ross, N. (2022) Controls on morphological change within wandering gravel-bed rivers over decadal time scales: River Coquet,

Northumberland, UK. British Society for Geomorphology Annual Meeting 5th-7th September 2022. Northumbria University (poster presentation).

- **Al Zerouni, S., Russell, A.J., Large, A.R.G., Ross, N. (2018)** Quantifying 3-D morphological change within wandering gravel-bed rivers over time: the River Coquet, Northumberland, UK. European Geosciences Union General Assembly. 8th-13th April 2018. Vienna, Austria (oral presentation).
- **Al Zerouni, S., Russell, A.J., Large, A.R.G., Ross, N. (2017)** Controls on morphological change within wandering gravel-bed rivers over decadal time scales: River Coquet, Northumberland, UK. 56th BSRG annual meeting, 16th-19th December 2017. Newcastle University (oral presentation).

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