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Comparison between scarp and dip-slope rivers of the Cotswold Hills, UK

Jonathan D. Paul[a,*,1], Nick Watson[b], Edward Tuckwell[a]

[a] Department of Earth Sciences, University College London, Gower St., London, WC1E 6BT, UK
[b] Gloucestershire Wildlife Trust, Robinswood Hill Country Park, Reservoir Road, Gloucester, GL4 6SX, UK

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ABSTRACT

The Cotswold Hills, southwest UK, are properly described as a cuesta, with a steep, west-facing scarp slope and a plateau-like dip slope. Drainage reflects this surface morphology, with most rivers flowing southeast along topographic and stratigraphic dip. Here, we compare two superficially highly similar rivers – the Frome and Churn – whose sources are nearly coincident, but whose behaviour dramatically diverges thereafter. We examine longitudinal profiles, channel steepness, predicted discharge, and valley shapes, using digital topographic data. River discharge and water hardness/temperature values were obtained at seven sites on the Churn and nine on the Frome over a two-year sampling campaign, delineated into summer and winter phases. Nearly 100 borehole records were interrogated from the two catchments in order to assess groundwater level variations. The Frome, flowing west against regional dips, develops a steep course and has carved a deep and wide valley that exposes the full sequence of Cotswold Jurassic stratigraphy. On the other hand, discharge and channel gradients are lower for the dip-slope Churn, whose valley exposes less stratigraphy and fewer springs. Our measurements of river water hardness and temperature suggest that a greater proportion of groundwater flows into the Frome, regulating discharge and maintaining baseflow over summer. We suggest that flank uplift of the Cotswolds is at least part of the reason for the higher incision rates of the River Frome, leading to its intersecting a greater number of highly transmissive fractures that contribute to its discharge. In turn, the increased discharge could positively impact local incision rates.

1. Introduction

1.1. Regional geology and physiography

The general geological structure of the Cotswold Hills, southwest UK (Fig. 1a,b), is relatively simple: laterally extensive beds of essentially northeast to southwest-striking Jurassic oolitic limestone and clay formations, which extend across England from Dorset to Yorkshire (Witchell, 1882; Barron et al., 1997). The superposition of these strata, especially the striking differences in permeability, is the root cause of many other phenomena, such as valley bulging, extensive mass movement, cambering, and intense spring discharge (Ackermann and Cave, 1967; Goudie and Hart, 1975; Goudie and Parker, 1996; Farrant et al., 2015). This geological simplicity, however, belies a wealth of local lithological and structural detail. Gaps in the record, the effects of intense localised faulting, and changes in the thickness and local dip of the strata, contribute to the complicated geological situation (e.g. Buckman, 1901; Barron et al., 1997).

The Cotswolds form a rather flat dip slope (topographic dip of about 0.5° to the southeast: Fig. 1c). However, the regional dip of the Jurassic strata, due to tectonic activity that commenced in Cretaceous times, is only about 0.2–0.3°. As a result, progressively older beds crop out on the plateau surface in a northwest direction (Barron et al., 1997). This surface has experienced multiple episodes of rapid flank uplift and intense erosion, which could be associated with flexural unloading following the excavation of large quantities of soft sediments from the English Midlands by late Pleistocene meltwater-charged rivers (Watts et al., 2000, 2005; Lane et al., 2008). This suggestion is supported by the observation of a highly incised drainage pattern on the plateau surface, which includes both dip and scarp streams (Fig. 1d). Alternatively, Gale and Lovell (2017) suggest that initial tilting of the Cotswolds probably occurred much earlier, at the beginning of Paleogene times, related to incipient North Atlantic rifting, thermal

* Corresponding author.
E-mail address: jdp06@ic.ac.uk (J.D. Paul).
[1] Current address: Department of Civil and Environmental Engineering, Imperial College London, London, SW7 2AZ, UK.

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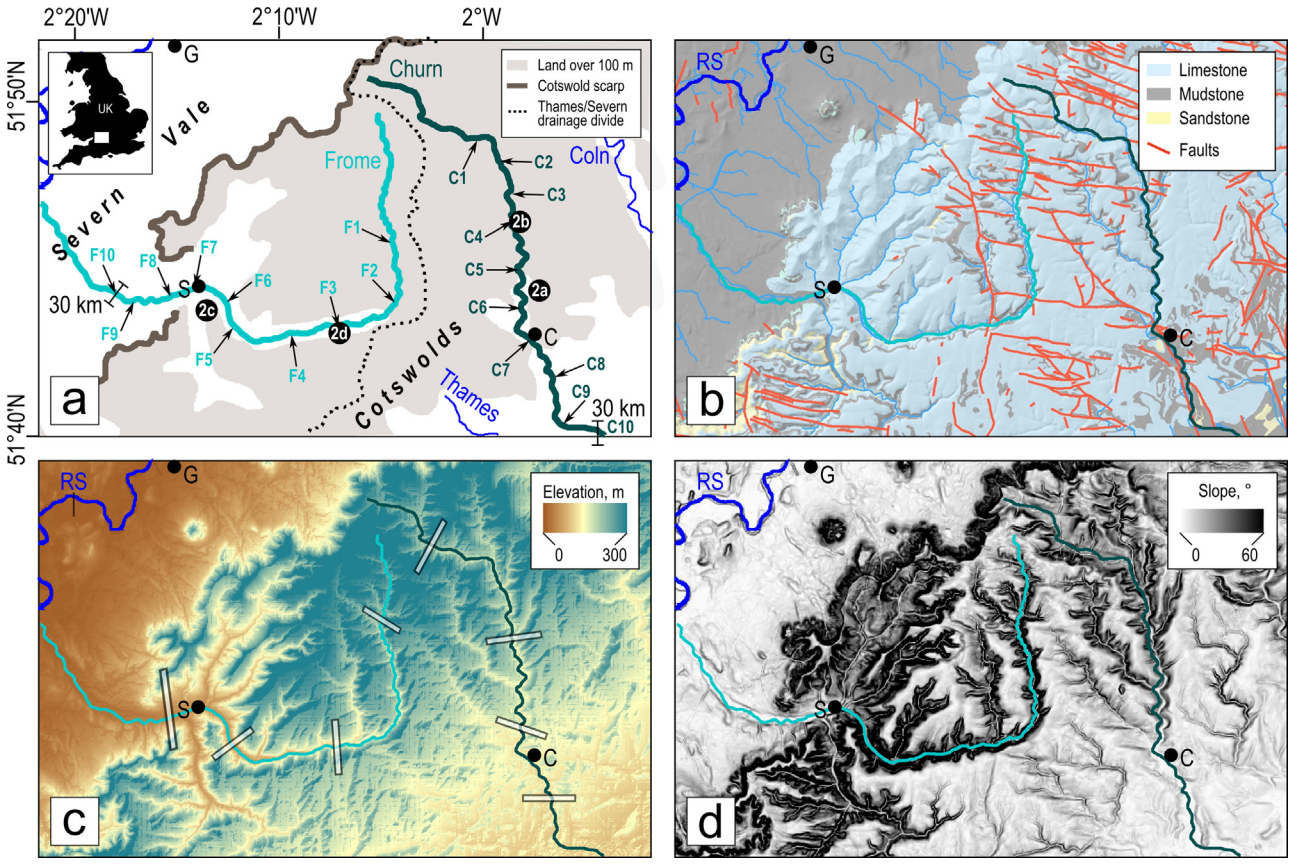

Fig. 1. Maps of study area. RS = River Severn; G = Gloucester; C = Cirencester; S = Stroud. (a) Location map. Labelled arrows = sites of discharge, water temperature and hardness measurements (Table 1; Figs. 5 and 6). Black labelled circles = location of photographs in Fig. 2. 30 km marker = end of longitudinal profile in Fig. 3. (b) Simplified geology, based on BGS's 25 km UK geology data (DiGMapGB-25). (c) Topography (OS Terrain-50). White bars = extent of six valley transects taken at 5, 15, 20, 25 km downstream from the source of each river (Fig. 4). (d) Slope (derived from (c)). Note irregularly indented and deeply incised Frome valley, and steep slopes of the Cotswold scarp.

uplift of the Irish Sea region, and activity of the Iceland mantle plume.

The Cotswolds are therefore a classic cuesta terrain, developed on gently dipping Jurassic strata. Small (1970) discusses the disposition of drainage over cuestas, noting that

> " . . . the continuity of most cuestas is broken at some point by large through-valleys occupied by permanent streams. The latter are usually, though not always, major, dip-slope consequents which – for one reason or another – have resisted encroachment by neighbouring consequent streams, or have had their own catchments ahead of the escarpment, through subsequent stream growth or river capture."

There are, however, other hypotheses to explain differences in valley morphology between scarp and dip-slope rivers of the Cotswold cuesta. These include the capture of rivers and/or underground drainage from fractures, leading to increased discharge. There is geomorphological evidence for the former (e.g. a wind gap at the position where the Frome's course swings west towards the Severn suggests that it once ran southeast towards the London Basin, but was captured and beheaded by a river running towards the Bristol Channel (Goudie and Parker, 1996). On the other hand, although the proliferation of springs along the steep hillsides of the Frome's middle course suggests capture of aquifer drainage, further evidence is limited by the relative paucity of subsurface structural data (e.g. Bricker et al., 2014). Another important hypothesis concerns the relative base-levels to which each river flows: while the Frome drains to the Severn floodplain at ~10 m above Ordnance Datum (OD), the Churn is graded to the upper Thames floodplain, which is significantly higher at ~70 m OD. The Frome therefore has a base-level advantage and thus a higher gradient, irrespective of flank uplift (Fig. 1c). Moreover, as the Frome drains west down the stratigraphy (Fig. 1b), it will always flow through a different geology to the Churn, which flows stratigraphically up-sequence.

The Cotswold escarpment is remarkable in its continuity, lacking a large number of permanent (obsequent) streams that flow in the opposite direction of consequent drainage and topographic dip (i.e. through water gaps). This is in contrast to many other escarpments in the UK; for instance the North York Moors, where several water gaps are to be found. In the Cotswolds, the three major obsequent rivers that incise, unusually, against the dip slope, are (from south to north) the Bristol Avon, River Frome (Fig. 1), and River Chelt.

1.2. Geomorphological history

The stratigraphic framework of the Cotswolds has been progressively revised and is discussed in detail elsewhere (e.g. Buckman, 1901; Arkell, 1933; Barron et al., 1997; Paul, 2014). The number of papers concerning (fluvial) hydrology and geomorphology published from this region, relative to other regions of the UK, remains sparse. Many workers have focused on the high concentration of landslip and other mass movement phenomena on valley slopes (e.g. Ackermann and Cave, 1967; Small, 1970;