Reply to comment by Rob Westaway on "Review of tufa deposition and palaeohydrological conditions in the White Peak, Derbyshire, UK: implications for Quaternary landscape evolution."

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We thank Westaway (2012) for his interesting discussion of the uplift rates derived from the Alport tufa and its geomorphological setting. His comments highlight the tentative nature of geological approaches to determining rates of glacio-isostatic and tectonic uplift. In particular, Westaway (2012) questions the validity of the uplift rates that were presented within our original paper (Banks et al., 2012) and we welcome the opportunity to clarify this further. We also welcome the opportunity to comment on the practicalities of determining uplift measurements from karst environments within the wider, long-term, tectonic evolution of the Peak District.

Westaway (2012) makes reference to two (of four) cited incision rates (Banks et al., 2012) that correspond with the Late Ipswichian to Holocene period, and the end of the Anglian to present and compares them with values that span the entire Quaternary (Westaway 2009, 2012). Accordingly, it should be noted that the uplift rates that were presented by Banks et al. (2012) were linked to specific durations, which also included periods of accelerated down-cutting during the Devensian to Holocene (0.165 mm a^{-1}) and for the duration of the Anglian (0.36 mm a^{-1}). Clearly these periods of incision also correspond with periods of uplift, albeit that this may not have been contemporaneous with incision because of the time-lag associated with the isostatic response to glacial loading and unloading. Combining the Anglian and post-Anglian incision rates gives a rate of 0.055 mm a^{-1}, which corresponds reasonably closely with longer term uplift rates, e.g. 0.03 to 0.06 mm a^{-1} (post Late Miocene uplift) determined by Pound et al. (2012), but is clearly lower than the rates suggested by Westaway (2012) for the Quaternary. Banks et al., (2012) presented the incision rates in components, because it was considered that they may contribute to future assessments of crustal movements, operating over differing time-scales and wavelengths of uplift, i.e. both tectonic and glacio-isostatic, (c.f. Maddy et al., 2000). However, it is interesting to note that the Holocene uplift (glacial isostatic adjustment [GIA]) model presented by Shennan et al. (2009) suggests that currently there is no glacio-isostatic relative land- and sea-level change in this part of the UK. Furthermore continuous GPS monitoring data (Bradley et al., 2009) appear to correlate with the modelled results for this part of the UK.

Based on geodynamic modelling Westaway (2009 and 2012) presents a case for on-going hot-spot related lowering of viscosity in the lower crust as the driver for lower crustal flow coupled to surface process and resulting in elevated rates of uplift in northern England. This contrasts with the Shennan et al. GIA model, which assumes an elastic lithosphere and viscous structure within the mantle. Modelling undertaken by Westaway (2009) uses observed uplift that is, in part, estimated from "karstic base-level lowering". Calculation of uplift rates in karst environments is particularly difficult. This is due to the paucity of dated surfaces and the hydrogeological complexity largely due to the solubility of limestones, which facilitates subsurface flow at the expense of surface flow. Accordingly, Westaway (2009, 2012) is forced to draw from an extensive literature review of karstic levels, using speleothem dating as the basis for calculating uplift rates. It is assumed that the dated karstic levels mark the phreatic to vadose transition as a consequence of uplift (Westaway, 2012). Whilst this is an entirely logical approach it is not without its complications. In particular, speleothem dates provide minimum ages for the karstic levels and therefore offer the marked potential to overestimate more recent rates of uplift. Furthermore, the phreatic to vadose transition may occur both as a response to incision, or surface inundation and subsequent recession of glacial meltwater. Consequently, whilst determination of tufa incision rates does have a place in the ongoing quest to determine a chronology of Quaternary uplift rates in the Peak District (Westaway, 2012), it should also be noted that, aside from the possibility that recent uplift rates are lower than suggested by Westaway (2009 and 2012), there are two further reasons why the results presented by Banks et al. (2012) may be lower than anticipated by Westaway (2009 and 2012). Firstly, the incision of the tufa might not have been in hydraulic equilibrium with uplift, and secondly, incision may have been impeded by the extensive volcanic strata of the Fallgate Formation that underlie this area of the Peak District (BGS, 1982).

With respect to tectonic uplift, the contextural evidence remains equivocal. The limestones of the Peak District lie within the Tournquist domain, immediately to the north-east of the Midlands Microcraton (Smith et al., 2005). Travel-time and depth maps of the seismic reflection Moho beneath the UK (Chadwick and Pharaoh, 1998) appear to provide evidence of crustal thinning to the north-west (< 25 km in basins of the north-west margin) with a depth of 30 to 31 km beneath the Peak District. Smith et al., (2005) suggested that the dominant structural influences in the south-west Pennine Basin during the Palaeogene and Neogene were the development of the Iceland Plume and Alpine continental convergence to the south. These uplift processes have also been identified as the major control on Palaeogene uplift and erosion in north-west England and adjacent parts of the eastern Irish Sea (Chadwick et al., 1994). Smith et al. (2005) recognised that Cenozoic uplift (1500 to > 2000 m) comprised two components: a regional uplift and a more local uplift of the basin depocentre. It was speculated that the latter was associated with basin inversion and the reversal of major basin-controlling faults. More recently, sedimentary basins on the Atlantic margin of northwest Britain have been found (Stoker et al., 2010) to record four discrete sedimentary successions derived from four major phases of Cenozoic uplift of the British Isles (Palaeocene, Eocene-Oligocene, Miocene and Pliocene-Pleistocene). This was interpreted as plate boundary compressional stress related, rather than Palaeocene uplift induced by the Iceland plume. However, this area is tectonically differentiated from the Tournquist domain and crustal response to tectonic perturbations, e.g. stress accommodation by faults, differs between tectonic domains and uplift rates are also likely to vary through time.

Evidence that has been presented to date suggests that the causes of uplift are multi-facetted such that detailed understanding requires further analysis of the emerging evidence. We look forward with interest to the publication of the forthcoming monograph (Bridgland et al., in press) on the evolution of the Trent system and the associated approach to the correction of incision rates to determine the rates of uplift of sites that were once outwith the ancestral Trent, but now fall within its catchment.

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