Lithological controls on soil formation rates and the implications for soil sustainability

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Introduction and Main Question:

The long-term provision of soil ecosystem services is controlled by rates at which soils form and erode.

Our knowledge of soil formation is not commensurate with that of soil erosion.

Developments in cosmogenic radionuclide analysis have enabled soil scientists to more accurately constrain rates of soil formation.

Soil formation rates have been measured and compared between major rock types (igneous, sedimentary, and metamorphic) but the role of porosity and matrix mineralogy on these rates has seldom been explored.

To what extent does the lithological variability and, in particular, the porosity and the nature of the interstitial matrix of sandstone, govern rates of soil formation.

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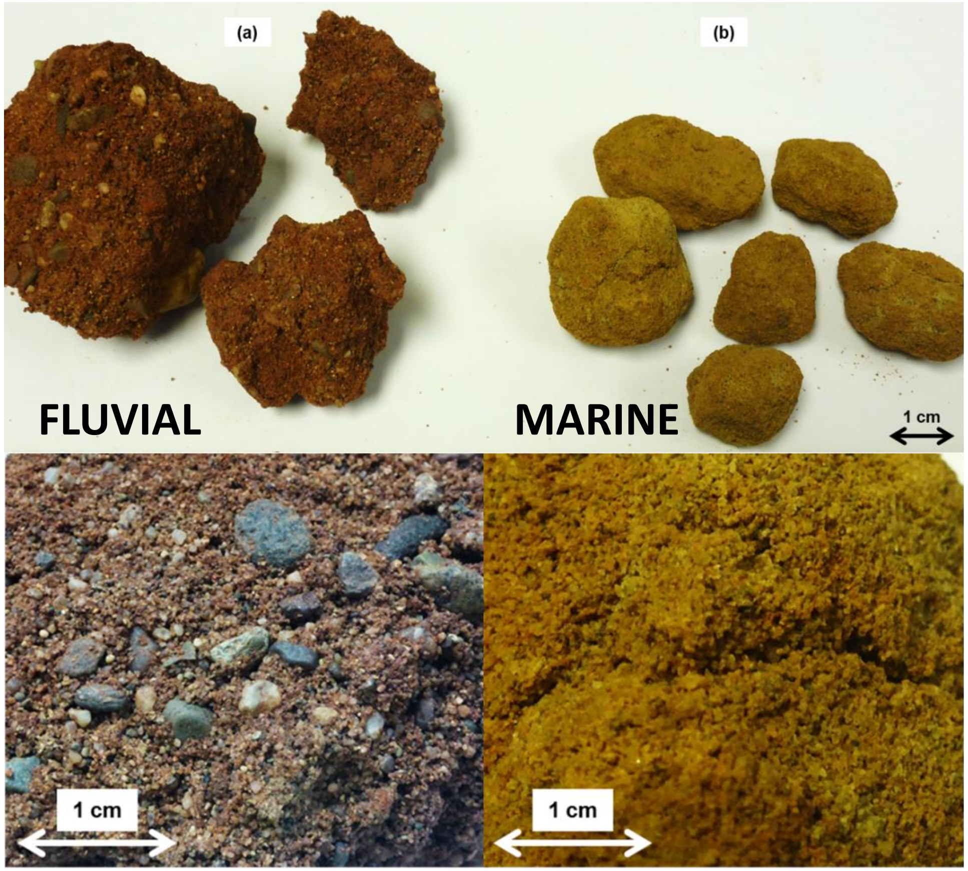


	HILTON	WOBURN
Parent Material	Helsby Sandstone	Woburn Sandstone
Provenance	Fluvial/Aeolian	Marine
Matrix	Detrital mica, illite-smectite, authigenic clays	Nearly matrix free, uncemented, negligible clay content
Porosity (%)	6 – 27 %	35 %
Burial Depth (m)	1000	300

Methods:

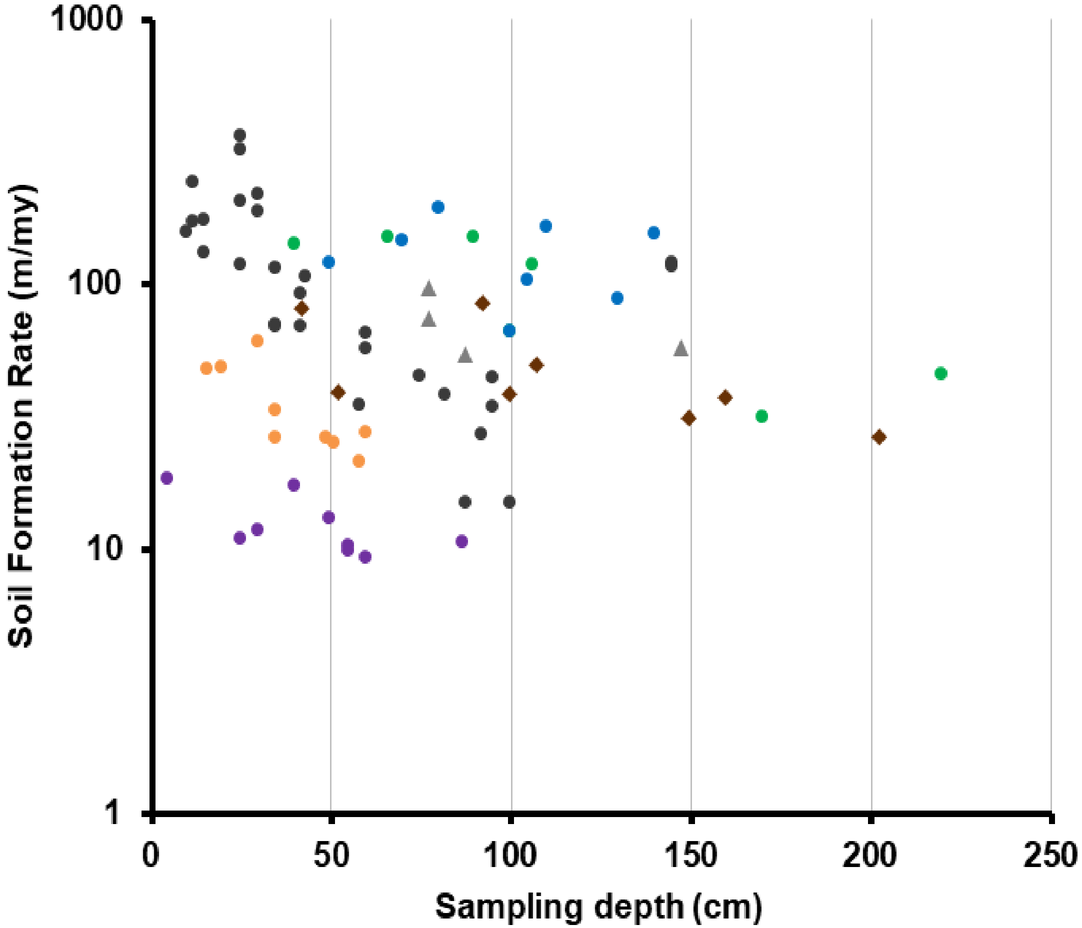
Two arable hillslopes in the UK were selected, underlain by two different sandstone formations (left).

Samples at soil-saprolite interface were subject to Cosmogenic Radionuclide Analysis.

Rates of soil formation were calculated using the CoSOILcal model

Main Take Home Messages (1)

Fluvial-based Helsby Formation	Marine-based Woburn Formation
Soil formation rate at zero soil thickness: 0.164 mm/yr	Soil formation rate at zero soil thickness: 0.229 mm/yr
Smaller porosity: sandstone would store a smaller proportion of precipitation that infiltrates down soil profile. Less mineral surfaces in contact with water, reducing chemical weathering processes.	**Greater porosity**: sandstone would store a greater proportion of precipitation that infiltrates down soil profile. More mineral surfaces in contact with water, amplifying chemical weathering processes.
Deep burial: Overburden compaction at depth reduced porosity (more rotation, re-orientation, and plastic deformation of ductile particles). Greater grain-to-grain contact	**Shallow burial**: A smaller degree of overburden compaction, so less porosity reduction. Smaller gain-to-grain contact.
Cementation: Greater temperatures at deeper burials can lead to quartz dissolution, resulting in precipitation of quartz cements. These cements grow as overgrowths which coat quartz particles, and strengthen their integrity. Iron oxides (hematite) also observed coating quartz particles.	**Cementation**: Shallower burial, and less quartz overgrowth cementation observed on this site. Lack of iron oxides may be legacy of marine conditions in which sandstone was laid (seawater has a relatively low concentration of iron). Evaporitic minerals would have been prevalent, but these almost immediately dissolved due to their high solubility.



Main Take Home Messages (2)

Rates from the arenite sandstones at Woburn and Hilton are, in some cases, **up to nine times faster than those previously obtained** by scholars working on wackes.

Here, we suggest that these **matrix-abundant wackes** reduce the transmission of water and **slow the process of bedrock weathering**.

By **supporting a denser matrix**, the rock inherently has a **lower porosity**, which can **reduce the rate of weathering** and soil formation processes.

Soil formation rates from Hilton (**blue**; *n* = 8) and Woburn (**green**; *n* = 7), together with those from Rufford Forest Farm (**brown** diamonds; *n* = 8), Comer Wood (**grey** triangles; *n* = 4) and those from a globally compiled inventory of soil formation rates on sandstone geology from Heimsath et al., 1997 (**orange** circles; *n* = 9), Heimsath et al., 2001 (**grey** circles; *n* = 30), and Wilkinson *et al*., 2005 (**purple** circles; *n* = 9).

Note from the authors:

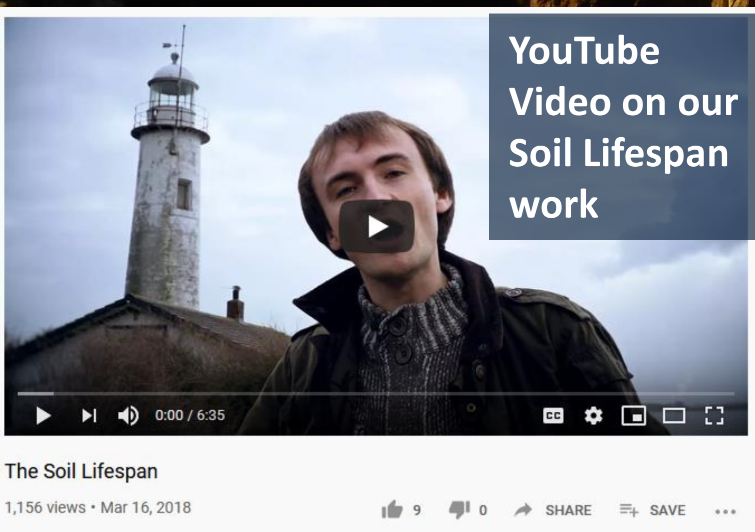
The data and findings of this investigation are currently being prepared for publication. We would be very interested in your comments, questions, or suggestions. Please don't hesitate to contact Dan Evans to discuss further d.evans3@lancaster.ac.uk or @DanEvansol on Twitter.

Meanwhile, please find below some highlights from our latest research into UK soil formation.

Arable soil formation and erosion: a hillslope-based cosmogenic nuclide study in the United Kingdom

Daniel L. Evans et al.

Cosmogenically-derived rates of soil formation for soils currently supporting arable agriculture, the first of their kind globally. Click the box on the left to open the paper.



YouTube Video on our Soil Lifespan work

The Conversation article about our work on UK soil formation.