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Fundamental considerations of water repellancy in soil, and related effects on other natural and man-made materials

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This presentation will concern the understanding of soil water repellancy and wettability at a fundamental level, and the difficulties of relating the very small, micron scale at which the repellancy and wettability characteristics are produced to the much larger, field scale at which they are normally observed. The presentation will not be a review of past work, but rather will concentrate on recent publications, publications in press, and speculative considerations which may lead to future work in this area.

There are three fundamental components of water repellancy – the nature of the soil surfaces themselves, the effect of organic matter and microbiologically produced substances, and the topology of the resultant surfaces. The effects of hydrophobic surfaces will be illustrated by a consideration of the wettability of substances such as commercially produced talc grades. The faces of these platey mineral particles are hydrophobic, whereas their edges are hydrophilic, and the combination not only causes water repellency in itself, but also causes unusual adsorption effects from aqueous solution.

The effect of organic matter on soil wettability has been widely studied, often by core-scale wettability experiments. It will be shown how a consideration of micro-wetting effects has led to a more robust data analysis method for such studies (Matthews, G. P. et al, European J.Soil Sci., 2008). Traditionally wetting fronts are assumed to advance in proportion to the square root of time (as predicted by the Washburn equation), but micro-modelling shows that, once inertial effects are taken into account, low-volume fingers of wetting fluid track through porous substances in advance of the observed Washburn wetting front (Bodurtha, P. et al, J.Colloid Interface Sci., 2005). The effects of micro-topology are also well known (Ridgway, C. J. et al, J.Colloid Interface Sci., 2001), but need to be integrated and upscaled, as described below.

Soil water repellency is not only dependant on the soil mineral characteristics, surface topology and organic matter content, but is also influenced by microbiological activity. The production of hydrophobic microbial biomass and exudates alter the hydrological characteristics of soil (Chan, K. Y., Soil Sci.Soc.Am.J., 1992) and strengthen the bonds between soil particles. Amongst these are extracellular polymeric substances (EPS), which are produced as a result of microbial activity and increase during periods of substrate utilisation and microbial growth (Hallett, P. D. et al, European J.Soil Sci., 1999). They form part of a wide spectrum of soil organic species, many produced by the soil's bacterial and fungal biomass. EPS provides a living protective membrane between changing hydrological conditions and the micro-organisms. It comprises polysaccharides and smaller amounts of protein, lipids and humic substances, with masses ranging from 103 to 108 kDaltons (Allison, D. G. et al, Fems Microbiology Letters, 1998). The small amounts of EPS in soil have a disproportionately large effect on soil hydraulic properties, and the response of EPS to major perturbations, such as wetting and drying cycles, has recently been well characterised (Or, D. et al, Vadose Zone J, 2007). Therefore, as will be described, the use of EPS as an analogue to the wider range of organic species can lead to an understanding of climatic effects on soil wettability.

The upscaling of the effects from micron to field scale requires a highly detailed modelling approach, using a dual –porous void structure model (a modification of the previous 'Pore-Cor' model) which takes into account both the soil micro-matrix and the macroscopic percolation and wetting pathways (Laudone, G. M. et al, European J.Soil Sci., submitted).

Super-hydrophobicity in natural materials (the 'lotus' effect) and man-made materials (micro-structured arrays) will also be explained and illustrated, and the condition under which super-hydrophobicity can flip to super-wettability. Super-hydrophobicity gives an unusual insight into the less extreme examples of water repellancy found in many soils.