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UK Position Paper on Joint UK-USA Research on Weathering Systems Science

Background

The National Science Foundation supported a USA community meeting in autumn 2003 to explore the need for a concerted research programme in the area of Weathering Systems Science[1]. UK scientists, with support from the Worldwide Universities Network, convened a round table discussion in London on 15th October 2004 that included programme managers from NERC and NSF and the Principle Investigator from the USA. The outcome from that meeting is the following position paper that establishes the scientific framework for a joint UK-US research programme in Weathering Systems Science.

Weathering Systems Science

Weathering describes a core set of earth systems processes that help create and maintain the "critical zone" for life that exists between the bedrock and the canopy of the biosphere. A key concept inherent in Sustainable Management is that of the "*whole system life cycle*". Weathering science addresses the whole life of soil; where inputs from the uplifting bedrock and atmosphere are internally cycled and eventually removed as the products of chemical, biological and physical erosion that feed the geological cycling of the earth's crust and contribute to the long-term evolution of the physical and chemical environment. For example, atmospheric CO_2 and global temperature are regulated on geological time scales by a negative feedback involving the weathering of silicate minerals. On much shorter time scales the processes of this *weathering engine* are also central controls on the cycling of biomass, nutrients and pollutants; their accumulation and release. These are key factors in the productivity and long-term viability of cultivation and harvesting within the critical zone. They play a central role in water quality and in environmental impacts on human health. A crucial challenge is to place the rates of these processes that dictate the mass stocks and fluxes of soil components, within the context of anthropogenic disturbance to soil sustainability.

Through unsustainable cultivation practices, mining and deforestation, global erosion loss is now much faster (100 times or more) than formation - and soil has become a *finite resource*[2]. Despite its importance for the sustenance of the biosphere and its 6 billion human inhabitants, our knowledge of the weathering engine and its response to human activity is remarkably poor. This is because various scientific approaches are not sufficiently integrated to tackle the many, complex interactions that occur. A multi-disciplinary approach is needed to study soil formation rates and processes and to address the whole life cycle of soil. Weathering Systems Science provides the temporal framework for the analysis of soil processes and evolution. Modern anthropogenic forcing of soil systems is placed in the context of earth systems on geological time scales. This allows an understanding of the role of human impacts on the evolution of modern soils and predictions of future changes that must be managed. It integrates across the broad array of disciplines from geology, soil science, ecology and hydrology and has the potential to combine these with novel molecular and imaging science and powerful numerical modelling methods.

The key scientific questions that need addressing include:

- How can the dominant factors governing weathering be quantified, and what is their context dependency?
- How are the biological, chemical and physical processes driving weathering coupled, across spatial scales from molecular to global and temporal scales from human through glacial to geological?
- How can we predict such processes – particularly those governing soil formation - over pertinent scales?
- How can this knowledge be used to inform and manage soils systems in a sustainable manner?

Innovation Potential

The vision is to develop a General Circulation (Solute) Model (GCSM) that describes in considerable detail the linkages between key biological, chemical and physical processes, developed at the scale of the soil profile, and with the capability to link with regional and global models of hydrology and climate. The model structure would be strongly process-based and supported with substantial fundamental understanding of mechanisms based on molecular-scale observations. There is tremendous potential to move from ecosystem-specific, empirical approaches to predictive capabilities that are established much more firmly from first principles and that can be transferred across a wide range of temporal and spatial scales. This is brought about by the innovative incorporation of extant knowledge with exciting new tools such as cosmogenic isotope profiling, advanced spectroscopy, tomographic imaging, reporter genes, micro-electrodes and other sensors to collect field data at high spatial resolution and environmental informatics. Powerful new computational methods such as parallel load balancing of numerical codes can now incorporate fully coupled descriptions of solute transport and detailed reaction mechanisms while accounting for spatial variability in soil properties. These modelling approaches provide a platform to develop a much more detailed description, particularly of the functional role of soil biology and it's interaction with hydrological transport and geochemical processes. A key requirement for this development is broad international collaboration to develop critical data sets. This includes detailed, comprehensive field studies at highly instrumented sites using agreed common methodologies applied to the full depth of soil profiles; termed *node sites*[1]. For example, well-constrained chronosequences in glacial forefields are

[1] Anderson et al. (2004). Proposed initiative would study earth's weathering engine. EOS, Vol. 85(28), 265-272.
[2] Pimentel D. (1993) *World Soil Erosion and Conservation*. Cambridge University Press.

excellent candidate sites for a field observatory to design experiments that address the temporal evolution of soils over 1-10^5 y time scales. At the same time, a wider range of conditions; biota, climate, latitude, elevation, lithology, etc. can be studied with a common set of protocols; e.g. at globally- distributed *network sites*.

Links to the NERC Strategy for Sustainable Soils Management

These data and the integrated models derived from them would provide an important new resource to assess the entire life cycle of soil systems and thus underpin their sustainable management. There is exceptional potential to address a wide range of soil management problems such as:

- Resolving the scale dependency of soil properties and processes
- Quantifying biological drivers of soil properties and processes
- Assessing pollutant lifetimes and fluxes; e.g. solute budgets that govern the life cycle of contaminants in soils
- Carbon sequestration and anthropogenic forcing of climate; e.g. process models of the soil organic carbon life cycle
- Formation and weathering of carbonate minerals in soils in response to anthropogenic forcing of the carbon cycle
- Soil loss through human impacts – replenishment through the weathering engine; e.g. a whole-life model of soil mineral matter
- Improving urban and brownfield soil quality
- Element and Isotopic mass and flux balances in soil-groundwater weathering systems; i.e. to elucidate transport pathways and deconvolute solute source terms for water resource management

Members of the UK academic community championing the potential for a joint NERC-NSF programme in Weathering Systems Science have presented the above framework to the NERC Working Group on Sustainable Management of Soils and to the EU working group on a European Soils Research Strategy for PF7. The 15th October meeting in London established a commitment between the UK and US researchers to pursue a possible joint directed programme between NERC and NSF. We envision this initiative as a longer-term strategy to build a truly international Weathering Systems Science Consortium that could contribute substantially to the delivery of NERC research on the Sustainable Management of Soils.

Participant List for the 15th October London Workshop

Steve Banwart	U. Sheffield - convenor
Enriqueta Barrera	USA National Science Foundation
Liane Benning	U. Leeds
Sue Brantley	Penn State University, PI WSSC
Andy Dixon	U. Sheffield - organiser
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Mike Henderson	U. Manchester
Andy Hodson	U. Sheffield
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Alan Jenkins	CEH/Wallingford
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Tim Lenton	Tyndall Centre, UEA
David Pilsbury	Executive Director, World Universities Network – meeting sponsor
Catherine Pomies	Cambridge U.
Don Porcelli	Oxford U.
Vala Ragnarsdottir	U. Bristol
Karl Ritz	Cranfield U. – Chair, NERC working group on Sustainable Soils Management
Richard P Shaw	British Geological Survey
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Apologies – forwarded to convenors with expression of interest

Mike Bickle	Cambridge U. (represented by C. Pomies)
Graham Leeks	CEH/Wallingford (represented by A. Jenkins)
Eva Valsami-Jones	Natural History Museum (represented by M. Hodson)