Small things considered: Understanding how spatial micro-heterogeneities affect the response of soils and sediments to environmental change

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Despite the global significance of soils to climate change, understanding of the effect of environmental factors on the dynamics of carbon and nitrogen in soils is still in its infancy. This is particularly the case for the consequences of possible temperature rises and changes in precipitation patterns in years to come, or with respect to the appropriateness of various strategies to sequester carbon in soils. More and more sharply, in recent years, it has become clear that the current lack of understanding of soil C and N dynamics in soils arises because available models and routine measurements do not take into account the spatial heterogeneity of soils at a range of scales, particularly at the micrometric scale typical of many bacteria.

Until just a few years ago, observation techniques were almost entirely lacking to probe soils at these micrometric scales in 3 dimensions. Now, however, a number of table-top X-ray computed tomography machines are available from several manufacturers, affording resolutions down to hundreds of nanometers (in small soil samples), and more commonly of the order of a few microns in larger samples. The first table-top XRF CT machine is currently being commercialized, and provides, non-destructively, 3-dimensional information about soil chemical composition.

These amazing technological advances in recent years have been paralleled by several very interesting simulation efforts, showing that micro-scale heterogeneities in the physical- and chemical properties of soils lead to macroscopic behaviors that are not adequately captured by traditional volumetric averages and mean-field approximations, traditional in the study of soils and sediments, and require a very different type of upscaling.

This convergence of novel measurement techniques and innovative modelling approaches, at scales previously inaccessible to researchers, is causing a revolution in the way we look at biogeochemical processes in soils and sediments. In this invited presentation, I will describe in detail how this convergence is currently unfolding, what are the logical next steps in the novel direction it opens, and what challenges will likely be found along that path.

Detrital garnet Sm/Nd geochronology

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The record of detrial minerals (zircons have received considerable attention) in the sedimentary record provides valuable information about the tectonic evolution of the early Earth both regionally and globally. Detrital garnets are also found within Precambrian (and more recent) sediments and can preserve in their major element and isotopic chemistry a direct record of tectonometamorphic processes that may not necessarily be recorded by other detrital minerals. Detrital garnets could therefore form a complimentary tool in detrital analysis of ancient tectonic processes, if only they can be dated. Here, we explore both theoretically and experimentally the potential for a direct detrital garnet geochronometer.

The Sm/Nd isochron method is well established for dating garnet growth within their metamorphic rock hosts. However a detrial garnet grain is no longer associated with the parent rock from which it crystallized. To overcome this problem, detrital garnets may be crushed and treated with strong acids (including HF) to partially dissolve out micro-mineral inclusions which should in most cases adequately represent the original garnet host assemblage with which it grew in equilibrium. The inclusion rich 'leachate' (with lower Sm/Nd) and the residual pure garnet (with higher Sm/Nd) may then be analyzed and placed on an isochron to generate an age. The accuracy of this age will depend on 1) the assumption of initial garnet-inclusion equilibrium, 2) the spread in the isochron, and 3) the sample-to-blank ratio. The precision of the age will depend on 1) the analytical precision of $^{143}Nd/^{144}Nd$ and $^{147}Sm/^{144}Nd$ analysis on very small aliquots, and 2) the spread in the isochron.

We have established the feasibility of detrital garnet geochronology through theoretical and experimental means. First, assuming attainable laboratory blanks (1pg), attainable spread in the isochron ($\Delta^{147}Sm/^{144}Nd > 1$), and estimated analytical precision for very small Nd aliquots (based on counting statistics and documented 10ppm capability for 4ng Nd loads), theoretical calculations show that individual garnet grains >500 microns diamater could potentially be dated with <10 Myr age precision. Second, test garnets extracted from New England (USA) sediments have been successfully dated with this approach, yielding Acadian ages (as expected given constraints on local provenance) with age uncertainty as low as ±4 Myrs.