

Mechanisms of organic matter stabilization and destabilization in soils and sediments: conference introduction

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The interest in organic matter continues to gain momentum, mainly through the ongoing concern about increased levels of atmospheric greenhouse gasses (GHG). Since soils contain approximately one-third of the carbon known to exist in all fossil fuel reserves (Scharpenseel and Becker-Heidmann 1990), its potential to act as a sink or source of atmospheric GHGs is of great interest. Changes in soil management, particularly the adoption of low- or no-till systems, can result in increased soil C levels and hence represent a sink for atmospheric C. Increasing soil C stores also improves soil fertility and productivity and so provides a clear win-win situation. On the other hand, the degradation of the world's soils through erosion, salinization, acidification and desertification, which continues apace, generally results in a net release of C to the atmosphere, and is just as clearly a lose-lose situation. However, the biggest concern is that global warming itself will increase rates of organic matter degradation, resulting in a positive feedback loop, where warming releases soil C to the atmosphere,

which in turn causes further warming. Coastal and oceanic sediments also contain substantial organic C stores with annual burial rates estimated to be in the order of 130 Mt (Summons 1993). In order to be able to predict how these C stores will be affected by changes in either climate or management, we need a detailed understanding of C cycling in soils and sediments. Although the basics are well known—most C added to soils and sediments comes either directly or indirectly from photosynthesis in the form of plant and microbial biomass, and most C is lost through microbial decomposition—the fact that substantial stores of non-living organic C exist in soils and sediments is evidence that considerable time can pass between the death of an organism and respiration of its biomass to CO₂. During this time, C is removed from the atmosphere. We clearly need to understand the mechanisms by which this organic matter is stabilized against decomposition and the mechanisms by which it can be destabilized and made available for decomposition, if we ever hope to be able to predict changes in, and perhaps even control, these C stores.

This special issue of *Biogeochemistry* presents some of the results from the Third International Conference on Mechanisms of Organic Matter Stabilization and Destabilization in Soils and Sediments (SOM3), which took place on 23–26 September 2007 at Glenelg, near Adelaide, Australia. As the third conference in what is now recognized as a series of biennial or triennial conferences, it was the first to

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specifically include mechanisms in sediments as well as in soils. The history of this new series of conferences is well documented by Sollins et al. (2007) and need not be repeated here. The conference was attended by 76 delegates from 13 countries, with most from the US, Australia, Japan and Germany. A fourth conference is planned to be held in southern France in 2010 and will be hosted by Professor Claire Chenu and her group from BioEMCo, in Grignon, France.

Conference highlights

In very broad terms, there are three basic mechanisms of organic matter stabilization. They are:

1. the innate stability (recalcitrance) of the organic matter;
2. stabilization of the organic matter through interaction with the soil or sediment matrix, especially with mineral components; and
3. the absence of the required suite of microbial decomposers.

As well, there are combinations of these mechanisms, and many possible manifestations of each, so this ‘simple’ picture is in reality very complicated once you look closely. Nonetheless, if this conference series can be taken as a true gauge of sentiment in the interested community, it is worth noting that at each consecutive meeting the second mechanism—stabilization through interactions with soil minerals—has become more prominent. This time around, three oral presentations (Georg Guggenberger, Ingrid Kögel-Knabner, Klaus Kaiser) directly addressed different aspects of mineral stabilization of organic matter in soils. Much of the material presented was based on a series of recent publications by this group (Kaiser and Guggenberger 2007; Kaiser et al. 2007; Kögel-Knabner et al. 2008). Furthermore, Johann Six presented evidence that soils have a maximum capacity for C storage which is related to “saturation” of mineral association (see: Six et al. 2002; Chung et al. 2008; Gulde et al. 2008; Stewart et al. 2008). We also heard that mineral association is implicated in the stabilization of both marine (Angie Dickens, see: Dickens et al. 2006) and riverine (Anthony Aufdenkampe see: Aufdenkampe et al. 2001, 2007) organic matter. Mineral stabilization of

organic matter is also addressed by Moritz et al. (2008) (this volume), who report significant differences in the stabilization of microbial residues for paired tropical sites that vary mainly in their soil parent materials. They attribute these differences to variations in the iron oxide content of the two soils.

In a talk considering the importance of recalcitrance as a stabilization mechanism for soil organic matter, Bernt Marschner reported that there was little evidence for it, except in the case of black carbon and fossil carbon (see: Marschner et al. 2008). The recalcitrance of black carbon was further discussed by both Michael Schmidt (see: Preston and Schmidt 2006) and Johannes Lehmann (see: Nguyen et al. 2008), with the latter providing evidence that even here interactions with minerals may play an important role in retarding degradation. The only oral presentation in which mineral associations were not considered important, was that of Boris Koch, who discussed the recalcitrance of some marine DOM components (see: Koch et al. 2005). The influence of soil biology on stabilization and destabilization of organic matter, whilst recognized implicitly in many presentations, was not addressed explicitly except in the study of Crow et al. (2008) (this volume), who report on the influence of earthworm activity on C cycling in forest soils.

An emerging topic at the previous conference in the series was C cycling at depth (Sollins et al. 2007). At this conference, presentations by Troy Baisden and Steven De Gryze directly addressed this issue. Troy Baisden showed how passive and decadally-reactive C pools in subsoils can be distinguished and quantified through radiocarbon measurements of soil profiles sampled decades apart (see: Prior et al. 2007), whilst Steven de Gryze discussed the development of a depth-explicit version of the CENTURY model of C turnover. The study of Sanderman and Amundson (2008) also deals with carbon cycling at depth, and in particular the role that DOC plays in the movement of soil C to depth and its subsequent fate.

As mentioned above, this was the first conference of the series to specifically include sediments as well as soils. This seemed very fitting, given that it marked a decade since the publication of the seminal review by the late John Hedges and Malcolm Oades, “Comparative organic geochemistries of soils and marine sediments”, which resulted from John Hedges’ sabbatical in Adelaide (Hedges and Oades

1997). Oral presentations covered aspects of organic matter in a range of aquatic environments from rivers (Anthony Aufdenkampe) to floodplains (Darren Baldwin, see: Howitt et al. 2007) to estuarine lakes (Krull et al. 2008 this volume) to the ocean (presentations by Angie Dickens and Boris Koch). The study of Petrone et al. (2008) also addresses organic matter cycling in aquatic systems, and in particular an apparent uncoupling of DOC and DON cycling in an estuarine system.

A pre-requisite for understanding the mechanisms of stabilization and destabilization of organic matter is having the tools to characterize organic matter, and the development and refinement of these tools remains an important area of research. Several oral presentations discussed advances in this area. Alain Plante presented analyses of soil organic matter using pyrolysis-molecular beam mass spectrometry (Py-MBMS) and chemometric analysis (Plante et al. 2008). This technique offers high throughput (up to 300 samples per day) and requires minimal preparation; chemometric analysis facilitates the interpretation of the information-rich, but difficult to interpret datasets produced. Dan Murphy presented results using nano-secondary ion mass spectroscopy (NanoSIMS), a technique that enables mapping of elemental and isotopic compositions at resolutions of 50 nm or better (see: Herrmann et al. 2007). Equally important to introducing new techniques is refining and improving existing ones. Three oral presentations discussed how commonly used techniques can be more complicated than is often appreciated. Chris Swanston—in an oral presentation delightfully titled “How to ruin a perfectly good date”—discussed the challenges of obtaining and interpreting radiocarbon dates on soil organic matter. These include the complications brought about by the increase in ^{14}C due to atmospheric atomic bomb testing in the 1950s and 1960s and its subsequent dilution through mixing with marine and terrestrial C pools, the lag between C fixation through photosynthesis and the transition from living to non-living organic matter (e.g., through organism death or turnover of leaves, wood or roots), and the difficulties in interpreting a single measurement derived from a sample consisting of several heterogeneous organic matter pools. In another presentation, Claudia Czimeczik addressed the issues associated with another commonly used

method—density and size fractionation. In a similar vein, Troy Baisden discussed the complications of modeling C and N turnover when there are multiple mechanisms at work.

Established analytical techniques were also put to new uses. Sylvie Derenne discussed the use of traditional analysis of soil lipids using GC/MS to understand the changes in organic matter composition that occur during podzolization (Bardy et al. 2008). The study of Feng et al. (2008) used analysis of soil saccharides and amino acids to follow litter decomposition in subtropical forests. They report that saccharide concentrations are mainly controlled by litter input, whereas amino acid concentrations reflect microbial activity.

A major highlight of the conference was the increasing use of a combined range of techniques that are now being used to gain insight into mechanisms of protection of OC in both aquatic and terrestrial systems. There were many such presentations and the papers of Krull et al. (2008) and Sandermann and Amundsen (2008) are good examples.

Finally, two oral presentations covered the influence and implications of management on C cycling. Charles Rice (see: Fabrizzi et al. 2008 this volume) discussed further refinement of our understanding of the effects of tillage on C and N cycling, whilst Roland Bol addressed the implications of widespread amendment of soils with manure.

Future research

Quantification will clearly be a key future issue. Up until now, much of our research has been directed towards showing a particular stabilization mechanism exists, often under particular circumstances, either in real soils or model systems. However, to have an impact in the ‘real’ world, we need to be able to do more than just identify mechanisms of stabilization and destabilization, we need to be able to quantify them with some degree of accuracy. In a greenhouse world, managing the stores of carbon in soils and sediments could play an important role in GHG mitigation, but this will only happen if we can provide reliable predictions of how soil and sediment C stores will respond to given management options in a range of environments.

This process is already well advanced in the case of the effect of agricultural practices, especially tillage (see for example Lal et al. 2007). However, this should be considered a special case, because the main driver for these changes in management practices is not GHG abatement, but improved soil fertility and sustainability. As a consequence of widespread uptake, it has been possible to quantify the effect on soil C stores across a wide range of environments, and from that we attempt to determine mechanisms. This is very different to driving management changes specifically for GHG abatement.

The “biochar” concept (<http://www.biochar-international.org/>) provides an example where GHG abatement through increased soil C storage is an important, though not sole, consideration. The biochar concept is to pyrolyse biomass to produce both clean energy and char which is then used as a soil amendment. The benefits are threefold: the production of non-fossil energy, fertility benefits of the added char, and increased soil C storage through the innate stability of char toward microbial degradation. The feasibility of the biochar concept in part depends on being able to quantify how stable biochar is in soil. One of the largest impediments to this is the lack of consensus on methodology for identifying and quantifying char in soil. A number of ring trials have been conducted (Schmidt et al. 2001; Hammes et al. 2007) that demonstrate the large differences between different techniques. For char research to progress, these differences urgently need to be rationalized.

As discussed above, there is a growing acceptance that interactions with soil minerals may be the most important overarching stabilization mechanism for soil organic matter. A number of potential mechanisms have been identified, but most studies have involved model or manipulated systems. The need clearly exists to develop techniques for identifying mechanisms and quantifying these effects in real soils. Part of the problem is that there are few techniques that can simultaneously characterize soil organic matter and soil minerals. Mid-IR, especially when combined with chemometrics, shows potential in this regard, and has the added advantage of being rapid and cheap (Janik and Skjemstad 1995). At the other end of the cost scale, synchrotron-based X-ray microscopy (Lehmann et al. 2008) probably represents the most direct way to observe organic matter-mineral interactions. We are a long way from being

able to increase carbon storage directly through manipulation of organic matter-mineral interactions, but given the strength and ubiquity of this stabilization mechanism, it is a worthwhile long-term goal.

Another area that requires more attention is the interface between organic matter chemistry and microbiology. As discussed above, this latest conference included few papers on the role of microbiology on C cycling. As a community, we need to go beyond considering microbial decomposition as a ‘black box’ and be more inclusive of soil biologists. This is an area of rapidly increasing analytical power and this power needs to be harnessed.

Finally, a note of caution on the development and application of new techniques. It is all too easy to get too excited by the potential of exciting new methods and the new insights they can provide. However, every new technique comes with its own set of pitfalls. Due to their extreme complexity, soils and sediments are amongst the most challenging substrates to analyze. We need to be prepared to do the basic, often difficult and time consuming testing and calibration required when adapting new techniques to soil and sediment analysis and not simply assume that what works for less complex substrates such as plant materials will also work for soils and sediments. Furthermore, there is great power in applying multiple techniques to the analysis of such complex materials, but each technique must be applied expertly and with a full appreciation of its biases and limitations. In view of these issues, there is perhaps a need for greater collaboration within the organic matter community to bring together our diverse expertise on joint projects more often.

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