In situ occurrence of organic matter in marine sediments: Processes and preservation

B. Ransom

Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0220, USA

Continental margin sediments are the largest sink for organic carbon in the carbon cycle. Recently, it has been demonstrated that much of the sedimentary organic carbon on the margins is intimately associated with the surfaces of detrital minerals, generally with < 10%, occurring as separable particles. After the removal of such particles, the amount of organic carbon remaining approximates that of a monolayer coating of organic compounds on the surfaces of the remaining clastic material (Mayer, 1994; Keil *et al.*, 1994). It has been proposed that this matrix-linked organic matter is sequestered inside surface roughness features on detrital clastic grains (Mayer, 1994), enhancing its preservation. The 'monolayer' hypothesis was investigated using transmission electron microscopy (TEM) to examine the natural distribution and micro-textural associations of organic matter in continental margin sediments and their marine snow precursors (see below). Theoretical considerations, calculations, and data reported by Keil *et al.* (1994) were used to assess the 'surface roughness' hypotheses. Results of this latter investigation show that the specific surface area of most continental margin sediments, regardless of grain size, is controlled by the presence of clay minerals and bioclasts with high surface area-to-volume ratios, not by frame work grain surface roughness. Augmenting data from Keil *et al.* (1994) with that collected from continental slope sediments along two widely spaced transects on the California margin, an intriguing relationship between clay mineral suite and organic carbon content was discovered, with smectite-rich assemblages appearing to be associated with higher organic carbon contents than chlorite-rich assemblages.

Results of the TEM studies of the *in situ* distribution of organic matter in continental margin sediments and investigation of possible likely mechanisms for the observed relations show that, opposed to occurring evenly distributed over sediment grains or interred inside surface roughness features of framework grains, most organic matter in marine snow and surface sediments (i.e. those buried less than 1 meter below the seafloor) is patchy and occurs as: (1) localized smears, generally associated with clays and particle junctions in clay-rich flocs; (2) discrete, discontinuous blebs and micro-blebs of amorphous organic matter and cellular protoplasm, and (3) microbial cells and associated polysaccharide slimes and networks.

To better understand the distribution and character of the organic matter residing in continental margin sediments, the composition and textures of their precursors, pelagic (upper water column) and nepheloid layer marine snow, were examined. Pelagic aggregates have an open architecture, are bioclast rich, and held together by amorphous organic matter and exocellular polysaccharide fibrils and slime. Those from the nepheloid layer are clay-dominated, compact, and contain what appears to be more highly aged organic matter. Comparison of these two classes of aggregates indicate that pelagic aggregates undergo repeated episodes of disaggregation, aggregation, and mixing with the comparatively large volume of terrigenous detritus traveling in the nepheloid layer or associated with nepheloid processes. It is this release of abundant and insecurely bound, pelagic organic matter that provides a likely mechanism by which clay particles and organic matter become closely associated during nepheloid aggregation. Textural relations similar to those in the nepheloid aggregates examined have been noted between clays and organic matter in seafloor sediments (Lavoie *et al.*, 1997; Ransom *et al.*, 1997). This suggests that the association of organic matter with terrigenous clastic material in continental margin sediments and the distribution of a potentially significant percentage of the organic matter in such sediments happens prior to its permanent deposition and burial. It also provides a means by which the observed close association between clay minerals, thus the specific surface area, and organic matter in continental sediments is obtained. In addition, because the flocculation behaviour of clay minerals differs with particle size and layer charge, this may also provide a mechanism that explains why smectite-rich clay assemblages appear to be associated with more organic carbon than chlorite-rich assemblages, all other things being equal.

With regard to the cycling of carbon and its exchange between both surface and crustal reservoirs, and the effective modelling of this exchange, it would appear that aggregate interactions in the nepheloid layer and the periodic resuspension and deposition that result from nepheloid layer-surface sediment interactions may be considerable. If so, the residence time of organic matter at, or near the sea floor in oxic or suboxic aerobic conditions may be extensive. During such intervals, organic matter would be repeatedly cycled between surface sediments and the overlying bottom water, being moved down slope from its initial point of impact with the seafloor to its site of ultimate burial and removal from the carbon cycle. It seems likely that such a process would increase significantly the refractory character of the organic matter, thus negatively impacting its bioavailability.

An additional impact of the distribution of organic matter in continental sediments that affects the modelling of carbon fluxes, is that this material can impede fluid flow and clog pore fluid pathways in the uppermost few meters of the sediment. The impact of this has been little studied. Organic matter dehydrates and releases H_2O when sediments in which it is present are dried for physical property studies. The H_2O released is indistinguishable from pore water and its contribution will be reflected in measurements of water content, thus porosity: a variable important for the calculation of the flux of dissolved biogeochemical species between pore waters and the overlying water column. Calculations were made to investigate this effect using a Redfield Ratio model to reconstruct the volume of organic matter in sediments in their natural settings from measurements of organic carbon. Results show that organic matter, present as 2 wt.% or more organic carbon in the dry sediment, can occupy a substantial amount of pore space for sediments with porosities less than 75%. This occlusion of pore spaces undoubtedly influences the transport of fluid and other chemical species during diffusion and convection processes in fine-grained marine sediments.

References

Keil, R.G., Tsamakis, E., Fuh, C.B., Giddings, C. and Hedges, J.I. (1994) *Geochim. Cosmochim. Acta*, **58**, 879–93.

Lavoie, D.M., Lavoie, D.L., Pittenger, H.A. and Bennett, R.A. (1996) *Geo-Mar. Lett.*, **16**, 226–31.

Mayer, L.M. (1994) *Geochim. Cosmochim. Acta* **58**, 1271–84.

Ransom, B., Bennett, R.H. and Baerwald, R. (1997) *Marine Geology*, **138**, 1-9.