Microbial iron reduction: From bacteria to cement

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Context

Diagenetic iron cements are prevalent in many sediment profiles. In marine environments where sulphate is the dominant terminal electron acceptor, iron preferentially reacts with biogenic sulphide to produce the precursors to pyrite (Berner, 1981). Freshwater systems are depleted in sulphate, so cements may be dominated by iron carbonates precipitated by Fe(III)-reducing bacteria. Iron carbonates may even dominate in marine and brackish waters if the loading of organic matter is low, and utilised completely to drive more energetically favourable processes (aerobic respiration and Fe(III) respiration (Froelich et al 1979)). Thus, effectively starving sulphate-reducing bacteria of the reducing power to generate sulphide, and hence pyrite (Lovley and Phillips, 1987). The formation of siderite in this setting has received relatively little attention.

Shell beds are commonly associated with stratal surfaces (Kidwell, 1985). In such situations there is time for early microbially mediated cements to precipitate. Within shell beds organic matter present is normally well degraded and so where iron is present in such environments siderite would be expected to precipitate at the expense of pyrite.

Discussion of data

The Rutland Formation at Ketton, U.K. contains abundant shelly material and was deposited in a marginal marine setting. This succession was investigated utilising optical and electron optical methods and was found to contain early siderite cements that precipitated in close proximity to rootlets. The microbial controls on siderite precipitation in this ancient sediment system, however, could not be investigated easily. An analogous environment was needed to clarify the processes occurring in modern sediments. The Machair of the Outer Hebrides is a specialised shell bed and peat forming habitat that experiences both fresh and marine water influences. Sediment samples taken from these deposits contained abundant iron and a diversity of active Fe(III)-reducing bacteria. Laboratory experiments have shown these bacteria to be capable of precipitating siderite.

Conclusion

Thus, processes demonstrated by these bacteria can provide a model for the precipitation of the ancient cements.

References

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Studying fluid interactions by inverse modeling of noble gas data

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The partitioning of noble gases between fluids such as air, water, and hydrocarbon gas, oil, or hydrates depends on gas solubilities and diffusivities in the different phases. Because the relevant physical properties vary systematically with the mass of the different noble gases, the interaction between fluid phases leads to characteristic elemental (and to a lesser degree also isotopic) fractionation patterns. The systematics of noble gas concentrations has been used in many studies to investigate interactions between crustal fluids.

The noble gas abundance patterns in the different phases are often expressed in terms of fractionation factors relative to the atmospheric composition and displayed and examined in graphical form. While very useful for a qualitative analysis, such approaches do not easily allow the quantitative determination of physical system parameters such as volume ratios of the different phases or temperature during the exchange.

An alternative approach to the interpretation of noble gas data is to set up an explicit model of the expected concentrations in the studied fluid as a function of the physical parameters of interest. If the number of model parameters is smaller than the number of observables, a best estimate of the parameters can quantitatively be obtained by inverse modeling. In this approach, the model parameters are varied until the best fit between predicted and observed concentrations is found. This method of interpretation has been developed for the case of groundwater – air interaction, but it can be applied to any other problem where the final noble gas pattern depends on only a few parameters.

In the case of water – air interaction during groundwater infiltration, the relevant system parameters are the water temperature and the initial and final volume ratios between water and entrapped air, assuming that solubility equilibrium between the two phases is established. This model describes the observed concentrations of dissolved noble gases in many aquifers with high precision. It thus provides a basis for a reliable determination of (palaeo-) recharge temperatures, as well as for the study of the entrapment and dissolution of air during infiltration.

The same model can be generalised to describe the effect of any contact between water and a gas phase . Irrespective of the origin of the gas phase, such a contact leads to the typical signature of degassing, i.e., preferential depletion of the light noble gases in the water. Using the inverse approach, the gas/water volume ratio and the temperature during the contact can be estimated from degassed groundwater samples.