

Ocean trace element cycles

Gideon M Henderson, Department of Earth Sciences, University of Oxford

The oceans are salty. Each litre contains about 35 grams of dissolved salts, resulting from the balance between inputs and outputs to the ocean over geological time. The constituents of common salt – Na and Cl – make up more than 90% of this dissolved mass, and together with Mg, S, and Ca, represent 99%. Add only three more elements – K, Br, and C – and you have more than 999 parts in a 1000 of the dissolved mass in seawater. Yet there are 82 other naturally occurring elements, and all are found dissolved in seawater, sometimes at extremely low concentration.

It is tempting to think these other elements are at such low concentration that they simply don't matter. It's particularly tempting when trying to measure them. It can be a phenomenal analytical challenge to measure at such low concentrations, in a matrix with high ionic strength, on samples recovered in hostile ocean environments from kilometres below the ocean surface, and on ships that represent a huge potential source of contamination. But these low concentration elements – the trace elements – are fundamental to the functioning of the ocean and its ecosystems.

Iron, for instance, makes up only one billionth of the dissolved mass in seawater, but is an essential nutrient, required for all life in the ocean, and is often the nutrient that limits life when Fe concentrations fall close to zero in surface waters. Without knowledge of the cycle of Fe, we cannot understand the controls on ecosystems in the ocean, nor their role in the global cycling of carbon and other elements.

Another example, mercury, makes up one trillionth of the dissolved mass in seawater, only one part in 10^{12} . Hg is highly toxic, naturally bioaccumulated so that it enters the human food chain in seafood, and prone to significant anthropogenic contamination. Assessing safe diets, and setting policy on future use and release of Hg, relies on accurate understanding of the oceanic Hg cycle.

A further three orders of magnitude lower in concentration, radium makes up just one quadrillionth of the dissolved mass in seawater; one part in 10^{15} . The four radioactive isotopes of Ra, however, provide powerful tracers of ocean processes including the rates of mixing, and of groundwater input.

These three elements – Fe, Hg, and Ra – epitomise the importance of trace elements in the oceans as nutrients, contaminants, and tracers. Despite this recognised importance, significant areas of ignorance have remained about the sometimes complex ocean cycles of such trace elements, often related to the difficulty posed by in their measurement. In recent years, however, improved analytical capabilities, and the ability to sample the ocean cleanly, have enabled a step change in the amount of high-quality concentration data for trace elements. The front cover of this volume, for instance, shows dissolved iron concentrations measured since 2008 in the Atlantic, and is based on approximately a hundred times more data than were available prior to 2008. The use of tracers to provide rate information, and powerful new computational approaches to modelling ocean physics and biogeochemical cycles, are also allowing quantitative assessment of trace element fluxes and of the processes responsible for the observed pattern of concentration.

The oceans are large, and the processes responsible for cycling trace elements are many. Research efforts in one country alone could not hope to create a comprehensive understanding of trace element cycles in the global ocean. Much new understanding has come, instead, from global programmes that link together the efforts of many countries. For trace element cycling, the international GEOTRACES programme (<http://www.geotraces.org/>) has enabled the transformation in understanding that we have seen in recent years, and which is reflected in the papers that follow.

These papers arise from lectures and discussion during four days in December 2015. A two day meeting at the Royal Society in London was a show-case for recent advances in understanding ocean trace element cycles, delivered by leading experts from around the world. It was arranged in four sections: quantifying the oceanic cycles of trace elements; the biological impact of these cycles; the use of trace elements and isotopes as tracers; and the human impact on trace element cycles. The first fourteen papers in this volume are arranged following these sections, in the order in which they were presented.

A following two-day workshop, held at Chicheley Hall, synthesised the state of knowledge about fluxes at the four ocean boundaries: with the atmosphere; the continents; marine sediments; and the ocean crust (Figure 1). Breakout groups at this workshop discussed present knowledge, identified gaps in understanding, and suggested research directions for the future. Amongst the questions these groups considered were: how can trace element fluxes best be incorporated into models of ocean chemical cycles? And, can we predict changes in boundary fluxes in the past and future under changed environmental conditions? The outcome of discussions in these breakout groups are captured in the final four synthesis papers in this volume; one for each of the ocean boundaries.

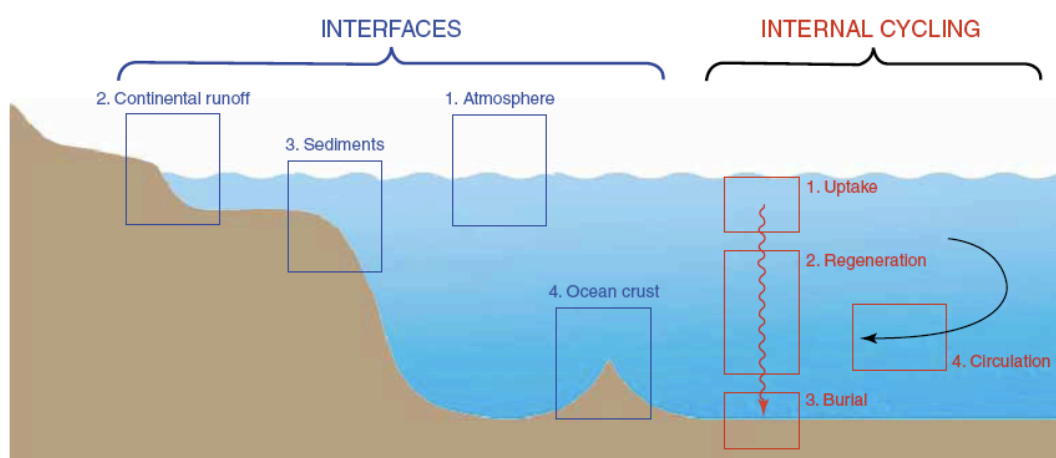


Figure 1: Schematic figure showing the four ocean boundaries or interfaces at which trace elements can enter or be removed from seawater, and the major processes involved in internal cycling of trace elements in seawater (Figure taken from the GEOTRACES Science Plan, ISSN 1932-7951)

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success. We thank the GEOTRACES programme, the results of which are so widely reflected in the following papers. And we thank the Scientific Committee on Oceanic Research (SCOR; <http://www.scor-int.org/>) which, through its critical role in international coordination, allows major programmes of ocean research to flourish. We also thank SCOR and US-NSF for funding that allowed some participants to attend the meetings.

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