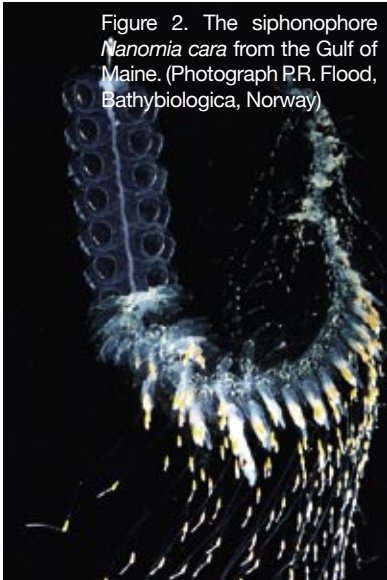


Figure 2. The siphonophore *Nanomia cara* from the Gulf of Maine. (Photograph P.R. Flood, Bathybiologica, Norway)



ers, and general audiences, as well as peer-reviewed scientific publications.

CMarZ will require international collaboration and coordination, through a distributed network of program centres, field project participants, students and laboratory technical staff and taxonomic specialists. CMarZ will establish project offices in North America, Europe and Asia to provide scientific leadership, planning and implementation of field activities, and coordination of proposals and fund raising activities. For more information, the CMarZ Science Plan can be downloaded from the CoML portal (www.coml.org)

or the CMarZ project website (plankton.unh.edu).

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GEOTRACES Gathers Speed

R.F. Anderson and G.M. Henderson

Since the late 1990s there has been a growing impetus for a comprehensive global study of the marine biogeochemical cycles of trace elements and their isotopes (TEIs). This has led to the development of a research programme known as GEOTRACES.

GEOTRACES is motivated by the fact that TEIs play critical

roles in many aspects of oceanography, and by the incomplete-

ness of our understanding of their marine biogeochemical cycles. Better knowledge of the distribution and behaviour of TEIs in seawater will provide insights into a wide range of oceanic processes. It will provide, for example, understanding of the role that micronutrients play in regulating ecosystem structure and productivity, and will elucidate the mechanisms that control the fate of pollutants in the oceans. Some TEIs, particularly radionuclides, constrain rates

of key processes regulating the carbon cycle. Other TEIs can be used to study mixing processes in the ocean. TEI distributions in marine sediments provide many of the proxies used to reconstruct past environmental conditions (e.g. productivity, circulation, ecosystem structure, weathering, hydrothermal activity, anoxia).

Despite these important roles and uses of TEIs, our knowledge of their cycles is limited. For example, the distributions, sources and sinks of micronutrients are so poorly known that their sensitivity to global change and the resulting changes in marine ecosystems and the carbon cycle cannot be meaningfully predicted. Similarly,

although it was established decades ago that many TEIs are removed from seawater by sedimentation, we still lack quantitative rate and process understanding. It is also clear that sediment TEI distributions relate to climate variability, but our ability to use TEIs as reliable proxies is limited by incomplete characterisation of their current biogeochemistry. This in turn, limits our ability to test ocean models against past conditions, and therefore limits our ability to forecast future changes.

Marine geochemists are poised to make significant progress in TEI biogeochemistry. Advances in clean sampling protocols and analytical techniques provide unprecedented

capability for measurement of a wide range of TEIs. The potential afforded by these advances has not however, been realised, largely because of a lack of coordinated research since the GEOSECS programme of the 1970s. New analytical methods that allow high density sampling, and new modelling strategies (as applied successfully during WOCE and JGOFS), make this the right time to mount a major international research programme to study the global marine biogeochemical cycles of TEIs.

The GEOTRACES mission can be expressed in two principal goals (i) to determine global oceanic distributions of selected TEIs, and (ii) to evaluate the

The value of studying multiple TEIs, and the general value of high-resolution TEI data on ocean sections, is illustrated by recent results from the North Atlantic Ocean. Distributions of dissolved iron and aluminium measured at 1° resolution (Figure 1) reveal first-order features of the sources and internal cycling of these trace elements. High surface concentrations of aluminium between the equator and 20°N define the location of dust deposition in the months prior to sampling. Dissolved iron concentrations are low in surface waters, but increase in the thermocline under the region with high surface aluminium concentrations. Dust deposition supplied both iron and aluminium to surface waters, but whilst iron was removed from surface waters in sinking biogenic detritus, and regenerated subsequently in the thermocline, aluminium has a longer residence time and remains at the surface as a tracer of the dust deposition. Examining the two elements together tells us more about their biogeochemical cycles than could be inferred from one element alone. The sharp boundaries of the high-iron region in the thermocline also informs us that the regeneration of iron is sufficiently rapid to prevent substantial dispersion by lateral mixing.

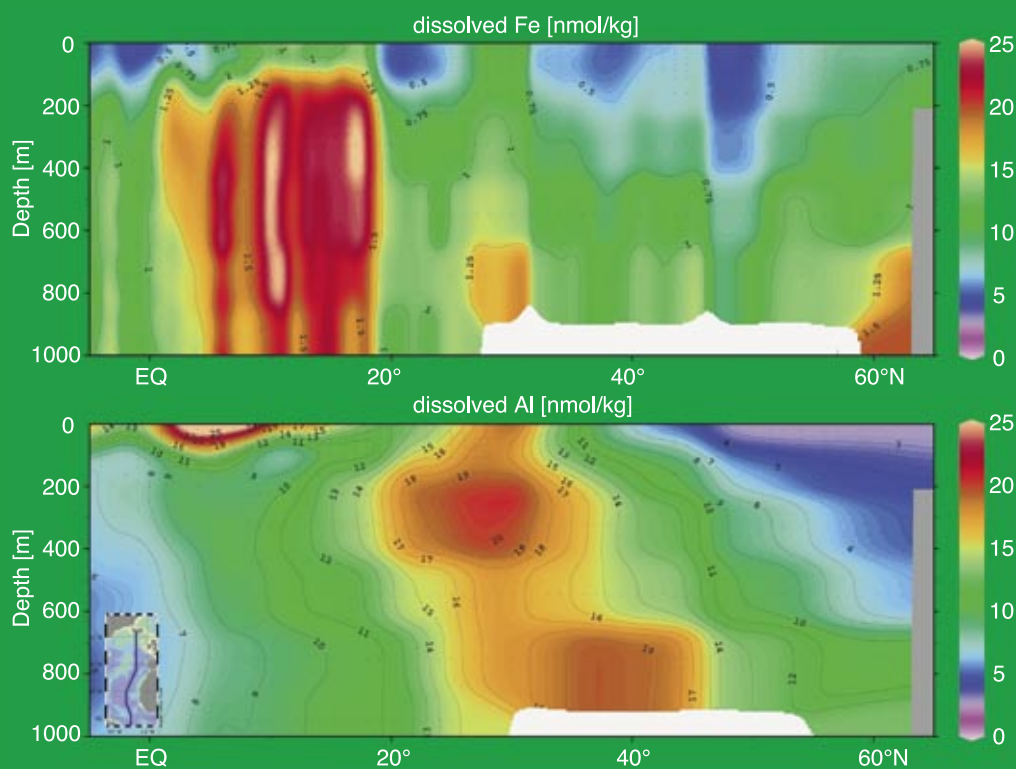


Figure 1. Distributions of dissolved iron (upper panel) and aluminium (lower panel) in the upper 1000 m along the CLIVAR A16 cruise track May 19 to August 11, 2003 (see inset for location). Courtesy of Chris Measures (University of Hawaii) and Bill Landing (Florida State University).

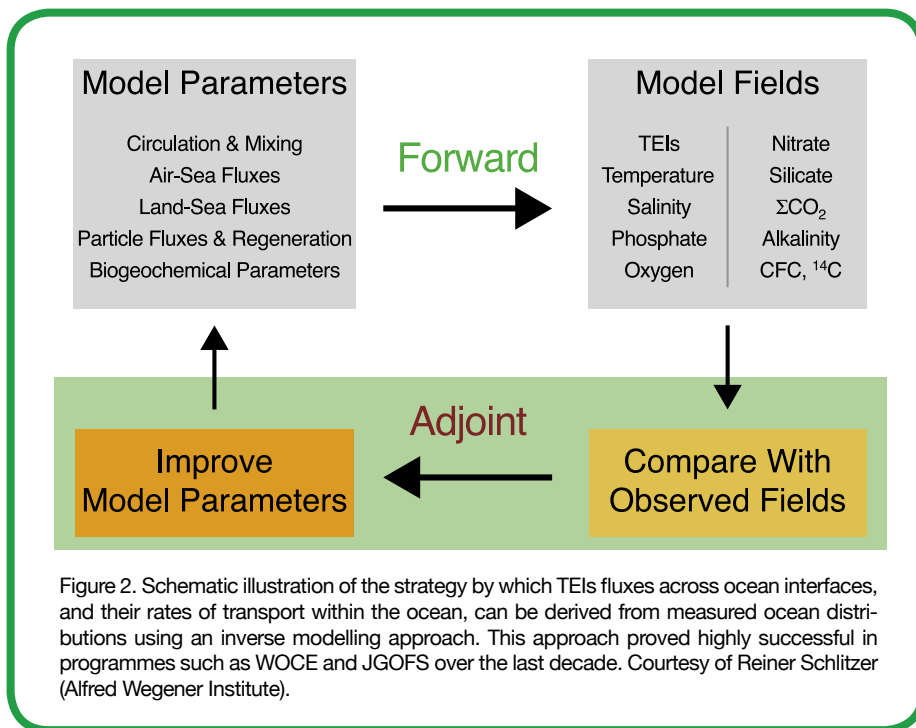


Figure 2. Schematic illustration of the strategy by which TEIs fluxes across ocean interfaces, and their rates of transport within the ocean, can be derived from measured ocean distributions using an inverse modelling approach. This approach proved highly successful in programmes such as WOCE and JGOFS over the last decade. Courtesy of Reiner Schlitzer (Alfred Wegener Institute).

sources, sinks, and internal cycling of these TEIs, and thereby characterise the physical, chemical and biological processes regulating their distributions. Research in pursuit of these goals will be organised under two themes. The first theme will examine the modern cycling of TEIs by quantifying fluxes at the principal ocean interfaces (e.g. atmosphere, continental margins, mid-ocean ridges), and by determining the rates of internal cycling of TEIs within the ocean (e.g. biological uptake, chemical scavenging, physical transport). The second theme will focus on TEIs that serve as palaeoceanographic proxies, to understand the factors controlling proxy distributions in the water column and sediments. A natural outcome of this work will be to build a community of marine scientists who understand the processes regulating TEIs sufficiently well to exploit them reliably in interdisciplinary studies. Another outcome will be the ability to incorporate TEI cycles into models to predict responses to future global change.

GEOTRACES will be global in scope, consisting of ocean sections complemented by regional process studies. Sections and process studies will combine fieldwork, laboratory experiments and modelling. Sections will cross regions that provide most information about sources, sinks and internal cycling of TEIs. Although commitments have not yet been made to particular sections, priority will be given to regions of prominent TEI sources or sinks, such as dust plumes, major rivers, hydrothermal plumes and continental margins. Sections will also sample the principal end-member water masses, as well as the major biogeographic provinces.

A fundamental principle underlying GEOTRACES is that measurement of multiple TEIs with varying behaviour will provide insights into processes not attainable from study of a single TEI (see box). GEOTRACES will also go beyond qualitative descriptions of sources, sinks and internal cycling of TEIs. Numerical models will be used to evaluate

the relative importance of physical and biogeochemical processes, and to calculate TEI fluxes from measured distributions. GEOTRACES will apply a hierarchy of model resolutions and complexity. Examples include coupled physical/biogeochemical general circulation models, box models, chemical speciation models and inverse models. Recent advances in data assimilation and inverse modelling, for example, now allow direct data utilisation methods not yet applied for determination of TEI fluxes. Inverse models promise to be an important element of ongoing and future studies of ocean circulation (e.g. CLIVAR). Expanding those activities to the assimilation of TEI distributions offers a strategy to quantify TEI flux terms in marine biogeochemical cycles, including the vertical fluxes associated with TEI uptake and regeneration by sinking particles (Figure 2). GEOTRACES will allow intercalibration and standardisation of the analytically-challenging TEI measurement methods, and provide for technology transfer and capacity building in nations that presently lack TEI measurement capability.

The resources needed for this research require international cooperation. Formal planning of GEOTRACES was launched with an international workshop in April 2003 involving 85 scientists from 15 nations. This workshop was followed by regional/national planning workshops in Europe, North America and Japan. Plans are advancing for additional workshops in Canada, China, and elsewhere. In 2003, the SCOR agreed to provide oversight for GEOTRACES, and a SCOR-sponsored planning group that first met in June 2004 was tasked with preparing a science plan. A draft science plan

will be released for comment early in 2005, leading to revisions by the planning group during their May 2005 meeting.

On completion of the Science Plan, the planning group will be replaced by a Science Steering Committee (SSC) to oversee implementation of the programme. Early tasks for the SSC, in preparation for the main field programme, will include the creation of a data submission and management

strategy, the development and distribution of standard reference materials, and the initiation of inter-calibration exercises. These activities will be organised under the direction of an International Programme Office, overseen by SCOR. GEOTRACES will collaborate closely with other ocean research initiatives, including CLIVAR, IMBER, SOLAS, LOICZ, GLOBEC, IMAGES/PAGES, INTERRIDGE, MARGINS, and

various modelling programmes, to ensure synergy between the different programmes and to avoid unnecessary duplication of effort.

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Land Use/Cover Change on the Indo-Gangetic Plains: Implications for the Terrestrial Carbon Cycle

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The Indo-Gangetic Plains – one of the most extensive fluvial plains of the world, consists of rich fertile alluvium from the Indus and the Ganges river systems. Agriculture probably began over 7000 years ago on the Plains in the form of settled cultivation. It has been suggested that the first human intervention in the Indo-Gangetic Plains Region (IGPR) occurred when agropastoralist Aryans colonised the middle Gangetic Plains [1]. The Vedic Aryans are believed to have always been a settled agrarian people, reliant on the tending of domestic animals as well as cultivation [2]. However, the oldest written account – preserved in the Rigveda (Hindu scriptures dated to 1200-1500 BP), tells of ancient agrarian practices by Indo-Aryans. The IGPR cuts across Pakistan, India, Nepal and Bangladesh, and is a globally important agricultural area, often referred to as the ‘food bowl of the Indian sub-continent’.

The Indian portion of the IGPR extends over an area 1600 km by 320 km, reaching from the Indus delta in the west, to the Ganges delta in the East, and comprising around 21% of the total area of the country (Figure 1). It broadly includes the states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal, and is home to 40% of India’s population. More than 70% of most districts of the Indian IGPR are under agriculture. The dominant rice-wheat cropping system in this

sub-region has been a major contributor to the ‘Green Revolution’ in India, providing close to half the Indian food grain production. Average rainfall and humidity increase from west to east; dryness typifies the northwest, whereas places in the east record very high rainfall. The soils developed in the IGPR alluvium under arid, semi-arid and sub-humid environments are therefore very important for India’s agricultural production (Figure 2).

The major historical land cover changes in the IGPR include conversion of fallow and scrub to agriculture, agriculture and wasteland to settlements or urban areas, and both creation and loss of wetlands. The major landuse intensifications relate to cropland, and include: (i) an increase in irrigated cropland, (ii) an increase in the area under high yielding variety cultivars, (iii) an increase in cropping intensity, (iv) an increase in fertiliser application, (v) changes in cropping patterns and dominance of wheat-rice rotation and marginalisation of kharif and rabi coarse cereals and pulses, (vi) increased mechanisation, involving tractors, planters and combine harvesters, and (vii) crop residue/biomass use for fodder and fuel, and recently, *in situ* burning of crop residues. Many of these changes are interlinked and have been driven by a number of technological, policy, socio-economic and biophysical factors [3]. Prior studies include a description of the major agricultural developments between 1757 and 1947 [4], a description of agricultural expansion in India since independence [5] and a summary of the major landuse changes from 1880 to 1980 in IGPR states [6] based on data from [7] and [8]. Agriculture is the dominant

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