

RiOMar

Chapter 1: The Role of RiOMar Systems in Global Change

1.1 What are RiOMars?

River-dominated ocean margins (RiOMar) are land-ocean margin systems that are impacted by major rivers. Major rivers (rivers with high sediment and/or water discharge rates) play a disproportionately important role in transporting dissolved and particulate materials from terrestrial environments to the coastal ocean. The world's 25 largest rivers in terms of sediment and water discharge, respectively, account for approximately 40% of the fluvial sediments and 50% of the freshwater entering the ocean (Milliman and Meade, 1983; Meade, 1996; Table 1.1). As Meade (1996) points out, the term “delivery to the oceans” can be misleading when referring to sediment discharge from rivers because fluvial sediments from some rivers are delivered to, and trapped in, enclosed estuaries; whereas sediments from other rivers are delivered to the river's delta, to adjacent coastlines and shelves, and to the deep sea—in varying proportions depending on the river. RiOMar environments are examples of the latter case.

As a result of high freshwater discharge rates, “estuarine” processes associated with major rivers primarily take place on the adjacent continental shelf instead of in a physically confined estuary. This greatly influences the magnitude and selectivity of processes that transform and/or retain materials in these environments, and consequently, their impact on the ocean.

1.2 Global Importance of RiOMar Systems

Terrestrial Storage: The storage of terrestrial organic carbon in river basins may be much more important than

previously recognized (Stallard, 1998), and is directly affected by human influences. This organic carbon reservoir is directly connected, through RiOMar environments, to the ocean. Presently, the timing for mobilization of this enormous pool of terrestrial carbon (equivalent to as much as 100 years of riverine discharge) is not understood. Man, presently heavily impacts many rivers, and their associated coastal margins. A better understanding of carbon cycling in less-impacted and anthropogenically influenced RiOMar environments is needed.

Input and Retention: RiOMars receive large inputs of terrestrial (allochthonous) organic carbon via rivers and marine (autochthonous) organic carbon resulting from high coastal productivity rates. RiOMar environments undoubtedly represent the largest modern repository of particulate organic carbon. During interglacial times, approximately 80-85% of global carbon burial occurs in continental margins, primarily in RiOMar environments (Bernier, 1982; Hedges and Keil, 1995). Terrestrial materials that are supplied to passive margins via rivers appear to be efficiently retained and processed within the margin environment. In contrast, major river systems on collision margins may be sites where a substantial portion of terrestrial inputs bypass the shelf and are discharged onto the continental slope and beyond. It is unclear how the retention of terrestrial materials within the margin affects the fate of autochthonous organic carbon in these environments.

Transformation: Annually, the total organic carbon burial in marine sediments is less than one-third of the riverine organic carbon discharge—indicating that riverine organic matter is either rapidly mineralized

Table 1.1 Characteristics of Major World River Systems

RIVER	Sediment* Discharge 10 ⁶ t yr ⁻¹	Sediment* Discharge Rank	Water* Discharge 10 ⁹ m ³ y ⁻¹	Water* Discharge Rank	Drainage* Basin Area 10 ⁶ km ²
Amazon, Brazil	1150	1	6300	1	6.15
Zaire, Zaire	43	22	1250	2	3.82
Orinoco, Venezuela	150	11	1200	3	0.99
Ganges-Brahmaputra, Bangladesh	1050	3	970	4	1.48
Yangtze (Changjiang), China	480	4	900	5	1.94
Yenisey, Russia	5		630	6	2.58
Mississippi, USA	210	7	530	7	3.27
Lena, Russia	11		510	8	2.49
Mekong, Vietnam	160	9	470	9	0.79
Parana/Uruguay, Brazil	100	14	470	10	2.83
St. Lawrence, Canada	3		450	11	1.03
Irrawaddy, Burma	260	5	430	12	0.43
Ob, Russia	16		400	13	2.99
Amur, Russia	52	20	325	14	1.86
Mackenzie, Canada	100	13	310	15	1.81
Pearl (Xi Jiang), China	80	16	300	16	0.44
Salween, Burma	100	15	300	17	0.28
Columbia, USA	8		250	18	0.67
Indus, Pakistan	50	21	240	19	0.97
Magdalena, Colombia	220	6	240	20	0.24
Zambezi, Mozambique	20		220	21	1.2
Danube, Romania	40	24	210	22	0.81
Yukon, USA	60	19	195	23	0.84
Niger, Africa	40	25	190	24	1.21
Purari/Fly, New Guinea	110	12	150	25	0.09
Yellow (Huang He), China	1100	2	49		0.77
Godavari, India	170	8	92		0.31
Red (Hunghe) Vietnam	160	10	120		0.12
Copper, USA	70	17	39		0.06
Choshui, Taiwan	66	18			0.003
Liao He, China	41	23	6		0.17

* *Data from Milliman and Meade (1983) and Meade (1996)*

or is not recognized as “terrestrial” by the techniques used (Hedges and Keil, 1995). Organic carbon preservation (allochthonous and autochthonous) may not be as complete as previously thought for RiOMar environments (Aller, 1998; Keil et al, 1997). The high rates of remineralization and the great extent to which discharged riverine organic matter is remineralized in these coastal zones has only been appreciated in the last few years. The mechanisms to explain this phenomenon are presently unresolved.

Global Change Record: Rivers provide a continuous integrated recording of terrestrial vegetation and climate that is uniquely recorded in RiOMar sediments. Although the stored sedimentary information is multidimensional, the entrained organic compounds provide an unparalleled wealth of structural and isotopic information. These telltale patterns are first imprinted within soil profiles, where climatic conditions and local bedrock determine the types and amounts of vegetation and minerals that are formed. Erosion eventually translates this cumulative record to the river, through the floodplain, and into adjacent continental margin sediments. Since long-term

preservation of any materials on eroding landscapes is rare, we must ironically turn to coastal marine sediments to understand the extremes of climatic history, which are typically most strongly expressed on land.

On longer (Quaternary) time scales, RiOMar regions may switch from being reactors and transformers of organic matter during high sea-level stands to being a direct conduit for terrestrial organic matter, shunting it directly into the open ocean during low sea-level stands. The role of RiOMar environments in the global carbon cycle would be markedly different under these two scenarios.

High sedimentation rates in RiOMar environments may provide a high-resolution record of (a) changes within drainage basins over the past 300 years, as influenced by human activities (this represents a large portion of the terrestrial realm) and, (b) changes within the margin during the onset of the present interglacial. The insights that these sedimentary records can provide concerning organic carbon cycling during interglacial (and perhaps transgressive) times are indeed exciting.

1.3 Rationale for RiOMar Workshop

Over a decade ago, two national and international workshops did an excellent job summarizing the global biogeochemical importance of ocean margin environments (in general)—emphasizing the different material fates possible in ocean margins. These workshop documents are:

Ocean Margins in GOFS. Report of the workshop on The Impact of Ocean Boundaries on the Interior Ocean. Chairman: G.A. Knauer. March 1987.

Ocean Margin Processes in Global Change. Report of the Dahlem Workshop (Editors: R.F.C. Mantoura, J.-M. Martin and R. Wollast) 1991.

The Dahlem Workshop Report (1991) suggested that “Globally representative and socially relevant ocean margin systems now need to be typologically identified and investigated by coordinated multidisciplinary teams...” We believe that the best approach to understanding ocean margins is through interdisciplinary studies of representative margin ‘classes’. Arguably, the most important class of margins (in terms of oceanic influence and human

impact) is river-dominated ocean margins (RiOMars). Rivers are the primary interface between terrestrial and ocean environments and play a central and multifaceted role in linking the terrestrial and marine cycles of bioactive elements—carbon in particular. The magnitude of weathering and erosion processes on land, sediment storage within the river system, and cycling and burial processes in adjacent ocean margins collectively support the premise that rivers and RiOMar environments play an important role in global change.

The initial planning document prepared for the U.S. Global Change Research Program (“A U.S. Carbon Cycle Science Plan”) provides an integrated and comprehensive overview of global carbon cycle issues, and stresses the importance of examining both the terrestrial and oceanic sinks for organic carbon. In RiOMar, we seek to understand the influence of river-dominated ocean margins (the primary connection between terrestrial and oceanic environments) on global carbon cycle processes and global change. To achieve such an understanding will require successfully dealing with many cross-cutting issues that require interdisciplinary cooperation between the earth and ocean science communities.

The central goal of RiOMar is to evaluate the role of rivers and associated ocean margins in the global cycles of carbon and other bioactive elements, and to better characterize the processes that govern the cycling and fate of bioactive elements in these environments.

Workshop Objectives

(1) To assess the current state-of-knowledge regarding the role of rivers and associated margins in the global cycles of carbon and other bio-relevant materials.

(2) To identify the major unresolved questions regarding RiOMar environments and their role in these global cycles. Outstanding “burning questions” were prioritized as a means to focus future research efforts.

(3) To identify salient areas of research in which interdisciplinary and/or cross-cutting research approaches will be needed, and to evaluate the manner in which these various research approaches can be facilitated.

1.4 Workshop Format and Terminology

Research Themes:

Discussions were organized around three research themes, which correspond to Chapters 2-4 in this workshop document:

- **Drainage Basin and Riverine Processes: Riverine inputs to the margin (Chapter 2)**
- **Plume and Upper Water-Column Processes: Transformation and export (Chapter 3)**
- **Benthic Boundary Layer and Seabed: Transformation, transport and burial (Chapter 4)**

Organizing Questions:

The workshop activities were centered on three organizing questions:

- (1) *Current State of Knowledge: What do we currently know about the cycling of carbon and bio-relevant materials in RiOMar environments?*
- (2) *Global Impact/Key Questions: Based on current knowledge, what is the impact of RiOMar systems on the global carbon cycle? Which processes or sets of processes are key?*
- (3) *Interdisciplinary and Crosscutting Issues: What are the important interdisciplinary and cross-cutting questions that need to be addressed in the future?*

Terminology:

The term “bio-relevant materials” is used to represent a group of biogeochemical constituents that are important to carbon cycling in river-ocean systems. This term is preferred to the term ‘bioactive elements’, because there are non-bioactive materials generated during weathering, and transported by rivers, that have a substantial impact on cycling of carbon and bioactive elements in the coastal ocean. For example, weathered aluminosilicate debris may act as a substrate for sorption of carbon and other bioactive elements, enhancing their transport and in some cases enhancing preservation of labile components.

Use of the term “bio-relevant” thus not only provides us with a useful shorthand for discussion purposes, but also encompasses other key materials that are not included under the term ‘bioactive elements’.

1.5 Over-Arching Workshop Questions

Previous integrated studies of rivers and adjacent margins (ex. AmasSeds, STRATAFORM) have provided a solid foundation (particularly geological framework) from which a carbon cycle program can be launched. There are many unanswered questions about organic carbon inputs, cycling and fates in RiOMar environments. New initiatives, as well as ongoing and recently initiated programs such as MARGINS, can provide additional research opportunities and infrastructure to address many of these questions in a truly interdisciplinary manner. Representative general questions, concerning the role of RiOMar environments in global change, are listed below. A specific goal of the RiOMar workshop was to refine and amend these questions and to generate a list of specific questions for each research theme (see Chapters 2-4) by community consensus.

- *Are RiOMar environments net global sources or sinks for organic carbon, on annual, decadal, and millennial time scales? What roles do the marginal seas associated with RiOMars play in terms of CO₂ and organic carbon exchanges (source / sink)?*
- *How does the role of RiOMar environments (as global carbon sources or sinks) change over time as a result of long-term climatic forcing (i.e., glacial-interglacial changes) as well as due to short-term human activities (e.g., land-use changes, dam construction)?*
- *Are RiOMars environments highly efficient “filters” and/or transformers of organic matter? The flux of terrestrial organic matter from the continents to the oceans can alone account for the radiocarbon-based residence times of organic carbon in the oceans (almost exclusively as dissolved organic carbon, DOC). Yet we find only trace amounts of analytically identifiable terrestrial material in any part of the ocean, including its margins.*
- *How will climate variations (eg. El Niño / La Niña) affect carbon cycling in RiOMar environments? How do significant changes in rainfall rates within the*

drainage basin, and the frequency of catastrophic floods and discharge events affect the magnitude of organic carbon sequestration and transformation.

- *How do changes in marine biological community structure influence the fate of organic carbon in RiOMar environments?*
- *Is the response of RiOMar regions to global change similar to or different from open ocean environments? How does this influence the oceanic and global carbon cycles?*

1.6 Approaches for Future RiOMar Research

A two-pronged approach is suggested to address global carbon cycle issues within a RiOMar initiative. These are: (1) an **intensive approach** focusing on North America and (2) an **extensive approach** that targets representative RiOMar environments globally. The relative timing of research related to each approach depends on co-ordination with research in other Carbon Cycle Science Plan (CCSP) initiatives and interactions with other international efforts (e.g., MARGINS program, International JGOFS program) so as to optimize financial resources and scientific yield.

(I) Intensive Approach

As recommended in the CCSP, an initial phase should focus on a continental/regional scale—North America. The Northern Hemisphere (and the United States, specifically) has been implicated as a significant site for terrestrial CO₂ uptake and storage (Schimel et al., 2000 and references within). The Mississippi River and its RiOMar environment is one logical candidate for an intensive study examining the connections between the terrestrial and oceanic carbon sinks of North America. The Mississippi River is one of the world's 10 largest rivers (7th in water and sediment discharge and 2nd in drainage basin size). Its drainage basin covers approximately 40% of the conterminous U.S. and parts of Canada. Over 65% of the total suspended matter and dissolved solids transported from the conterminous U.S. to the ocean is carried by the Mississippi. In addition, smaller rivers in North America, and their associated RiOMar environments should be considered for study. Research on a spectrum of river sizes will be

needed so that insights from specific research sites can be scaled appropriately when extrapolating to a global scale.

(II) Extensive Approach

This approach would examine key carbon cycle processes in a few selected global RiOMar environments (other top 25 largest rivers and a spectrum of smaller river systems). Other rivers would be chosen based on several factors (latitude, lithology, drainage and receiving basin types, size). As with the North American rivers, a selection / prioritization of rivers should result from discussion during early planning stages that involve appropriate members of the community.

A partial (but certainly not all-inclusive) list of possible candidates is:

- **Papua New Guinea—several large rivers (ex., Fly) originating within a common drainage basin but discharging into very different types of RiOMar environments (this would benefit synergistically if coordinated with proposed work in this region under the NSF-MG&G MARGINS program)**
- **MacKenzie and Yukon—high latitude; the dominant sources of particulate material to high latitude ocean environments.**
- **Yangtze and Ganges-Brahmaputra—Himalayan source, but contrasting RiOMar environmental conditions such as climate (temperate vs. subtropical) and margin type (broad shelf vs. intersecting canyon). The Yangtze River RiOMar environment is an International JGOFS site and a prominent focus for future studies.**
- **Amazon, Orinoco or Zaire as tropical RiOMar environments**

A combination of these two approaches promises to yield new and significant insights for an important area of global carbon cycle research.

1.7 References

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