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Martin J-M & Meybeck M. Elemental mass-balance of material carried by major world rivers. *Mar. Chem.* 7:173-206, 1979.
[Laboratoire de Géologie, École Normale Supérieure, Paris, France]

River fluxes to oceans were estimated for about 50 elements, both dissolved and particulate, based on authors' analyses and literature data for 23 major rivers. Although some of the data are outdated, this article is still used when considering the global geochemical cycles. [The *SCI*® indicates that this paper has been cited in more than 170 publications, making it the most-cited paper from this journal.]

Rivers and Global Elemental Cycles

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I started a "geochemical data collection" when I first discovered D.A. Livingstone's master compilation.[1] Later the classic book of R.M. Garrels and F.T. Mackenzie[2] emphasized to me the key position of river fluxes among the exogenic reservoirs—atmosphere, biosphere, hydrosphere, soils, and oceans.

I was, at that time, with Jean-Marie Martin's team on estuarine geochemistry at the École Normale Supérieure. Considering his analyses on a few major rivers, such as the Congo, which he sampled in 1971, and my literature search (I was also reassessing the river budget for major elements[3]), we thought it useful to combine all pieces of the jigsaw puzzle and propose, for the first time, world averages for major and trace elements for both particulate and dissolved material. An earlier version, mainly one big table, was returned from a first journal with a nasty comment of the reviewer, still anonymous, attributing the paper to "the dark ages of aquatic chemistry." This review forced us to polish the paper and extend the discussion to the comparison of river material with parent surficial rocks and ocean sediments.

Soon after, Martin published a modified version of the paper with M. Whitfield[4] focusing on the behavior of elements in oceanic systems. Actually, estimates of average trace elements content in rivers are continuously changing because of the improvement of field and laboratory procedures and the study of more rivers. Based on new data for the Amazon and for Indian, Chinese, and Soviet rivers, parts of which were obtained through the estuarine studies led by Martin, it is clear that dissolved contents of Zn, Pb, Cu, Ni, Al, and As (to name a few) were overestimated by us, sometimes by an order of magnitude. Major element concentrations of particulate matter are more reliable, and our estimates were found to be very similar to those published in the same period by two Soviet oceanographers, V.V. Gordeev and A.P. Lisitzin,[5] mostly based on Soviet rivers. One noted gap in our paper was coverage of carbon, nitrogen, and phosphorus, a topic that I considered later.[6]

There are now plenty of reliable analyses on many world rivers. These could be the basis for a revision of our paper, particularly concerning dissolved trace elements, an area in our early work for which we have been justly criticized.

River geochemistry is now widely recognized as a key component in present, past, and future global cycles. Some major research issues still remain. I am presently working on the environmental factors controlling river geochemistry in major river systems, particularly through the typology of weathering rates. How do we distinguish natural fluxes from anthropogenic ones, and what is the relative importance of atmospheric and riverine fluxes to ocean? These are among the objectives of the major European River Ocean System program, EROS 2000, presently led by Martin.

1. **Livingstone D A.** Chemical composition of rivers and lakes. *US Geological Survey Prof. Paper 440 G*, 1963. 64 p.
2. **Garrels R M & Mackenzie F T.** *Evolution of sedimentary rocks.* New York: Norton, 1971. 397 p. (Cited 405 times.)
3. **Meybeck M.** Concentrations des eaux fluviales en éléments majeurs et apports en solution aux océans. *Rev. Géographie Phys. Géologie Dyn.* 2:215-46, 1979.
4. **Martin J-M & Whitfield M.** The significance of river input of chemical elements to the ocean. (Wong C S, Boyle E, Bruland K W, Burton J D & Goldberg E D, eds.) *Trace metals in seawater.* New York: Plenum, 1983. p. 265-98.
5. **Gordeev V V & Lisitzin A P.** Average chemical composition of suspended matter in world rivers and input of fluviatile sediments to oceans (in Russian). *Dokl. Akad. Nauk SSSR* 238:2255, 1978.
6. **Meybeck M.** Carbon, nitrogen and phosphorus transport by world rivers. *Amer. J. Sci.* 282:401-50, 1982. (Cited 90 times.)

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