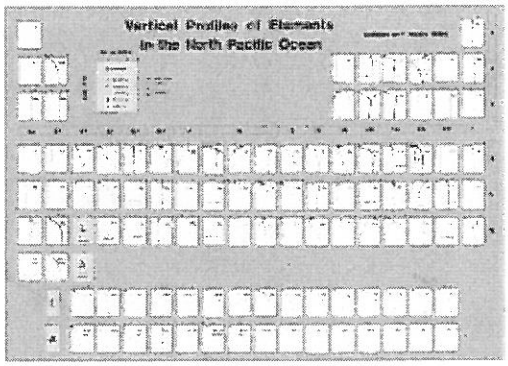
A Fresh Look at Element Distribution in the North Pacific

Yoshiyuki Nozaki, Ocean Research Institute, University of Tokyo, Japan

Figure | Article | Reference List

Figure 1. Vertical Profiles of Elements in the North Pacific Ocean



(~ 70 kB)

Table 1. Estimated mean oceanic concentrations of the elements and the references on which the periodic chart (Figure 1) is based.

Atomic Number	Element	Species	Type of Distribution	Oceanic mean Concentration (ng/kg)	Reference
1	Hydrogen	H_2O			
2	Helium	Dissolved gas	c	7.6	Clarke et al. (1970)
3	Lithium	Li^+	c	180×10^3	Stoffyn-Egli and Mackenzie (1984)
4	Beryllium		s+n	0.21	Measures and Edmond (1982)
5	Boron	Borate	c	4.5×10^6	Noakes and Hood (1961)
6	Carbon	Inorganic ΣCO_2	n	27.0×10^6	Broecker and Takahashi (1978)
7	Nitrogen	Dissolved N_2	c	8.3×10^6	Craig et al. (1967)
		NO_3^-	n	0.42×10^6	GEOSECS Operation Group (1987)
8	Oxygen	Dissolved O_2	inverse n	2.8×10^6	GEOSECS Operation Group

					(1987)
9	Fluorine	F^-	c	1.3×10^6	Bewers et al. (1973)
10	Neon	Dissolved gas	c	160	Craig et al. (1967)
11	Sodium	Na^+	c	10.78×10^9	Millero and Leung (1976)
12	Magnesium	Mg^{2+}	c	1.28×10^9	Carpenter and Manella (1973)
13	Aluminum		s	30	Orians and Bruland (1985)
14	Silicon	Reactive SiO_2	n	2.8×10^6	GEOSECS Operation Group (1987)
15	Phosphorus	Reactive PO_4	n	62×10^3	GEOSECS Operation Group (1987)
16	Sulfur	SO_4^{2-}	c	898×10^6	Morris and Riley (1966)
17	Chlorine	Cl^-	c	19.35×10^9	Wilson (1975)
18	Argon	Dissolved gas	c	0.62×10^6	Craig et al. (1967)
19	Potassium	K^+	c	399×10^6	Culkin and Cox (1966)
20	Calcium	Ca^{2+}	almost c	412×10^6	Horibe et al. (1974)
21	Scandium		(s+n)	0.70	Brewer et al. (1972)
22	Titanium		s+n	6.5	Orians et al. (1990)
23	Vanadium		almost c	2.0×10^3	Collier (1984)
24	Chromium	Cr(VI)	r+n	210	Nakayama et al. (1981)
		Cr(III)	r+s	2	Nakayama et al. (1981)
25	Manganese		s	20	Landing and Bruland (1980)
26	Iron		s+n	30	Martin et al. (1989)
27	Cobalt		s	1.2	Martin et al. (1989)
28	Nickel		n	480	Bruland (1980)
29	Copper		s+n	150	Bruland (1980)
30	Zinc		n	350	Bruland (1980)
31	Gallium		s+n	1.2	Orians and Bruland (1988)
32	Germanium		n	5.5	Froelich and Andreae (1981)
33	Arsenic	As(V)	r+n	1.2×10^3	Andreae (1979)
		As(III)	r+s	5.2	Andreae (1979)

34	Selenium	Se(VI)	r+n	100	Measures et al. (1980)
		Se(IV)	r+n	55	Measures et al. (1980)
35	Bromine	Br^-	c	67×10^6	Morris and Riley (1966)
36	Krypton	Dissolved gas	c	310	Bieri et al. (1968)
37	Rubidium	Rb^+	c	0.12×10^6	Spencer et al. (1970)
38	Strontium	Sr^{2+}	almost c	7.8×10^6	Brass and Turekian (1974)
39	Yttrium		n	17	Zhang et al. (1994)
40	Zirconium		s+n	15	McKelvey and Orians (1993)
41	Niobium		?	<5	Carlisle and Hummerstone (1958)
42	Molybdenum		c	10×10^3	Morris (1975)
43	Technetium				
44	Ruthenium		?	<0.005	Koide et al. (1986)
45	Rhodium		n	0.08	Bertine et al. (1993)
46	Palladium		n	0.06	Lee (1983)
47	Silver		n	2.0	Martin et al. (1983)
48	Cadmium		n	70	Bruland (1980)
49	Indium		s	0.01	Amakawa et al. (1996)
50	Tin		s	0.5	Byrd and Andreae (1982)
51	Antimony		almost c	200	Brewer et al. (1972)
52	Tellurium	Te(VI)	r+s	0.05	Lee and Edmond (1985)
		Te(IV)	r+s	0.02	Lee and Edmond (1985)
53	Iodine	I(V)	almost c	58×10^3	Nakayama et al. (1989)
		I(-I)	(r+s)	4.4	Nakayama et al. (1989)
54	Xenon	Dissolved gas	c	66	Mazor et al. (1964)
55	Cesium	Cs^+	c	306	Spencer et al. (1970)
56	Barium	Ba^{2+}	n	15×10^3	Chan et al. (1977)
57	Lanthanum		n	5.6	Piepgras and Jacobsen (1992)
58	Cerium		s	0.7	Piepgras and

				Jacobsen (1992)
59	Praseodymium	n	0.7	Zhang et al. (1994)
60	Neodymium	n	3.3	Piepgras and Jacobsen (1992)
61	Promethium			
62	Samarium	n	0.57	Piepgras and Jacobsen (1992)
63	Europium	n	0.17	Piepgras and Jacobsen (1992)
64	Gadolinium	n	0.9	Piepgras and Jacobsen (1992)
65	Terbium	n	0.17	Zhang et al. (1994)
66	Dysprosium	n	1.1	Piepgras and Jacobsen (1992)
67	Holmium	n	0.36	Zhang et al. (1994)
68	Erbium	n	1.2	Piepgras and Jacobsen (1992)
69	Thulium	n	0.2	Zhang et al. (1994)
70	Ytterbium	n	1.2	Piepgras and Jacobsen (1992)
71	Lutetium	n	0.23	Piepgras and Jacobsen (1992)
72	Hafnium	?	3.4	Boswell and Elderfield (1988)
73	Tantalum	?	<2.5	Schutz and Turekian (1965)
74	Tungsten	c	10	Sohrin et al. (1987)
75	Rhenium	c	7.8	Anbar et al. (1992)
76	Osmium	?	0.002	Koide et al. (1996)
77	Iridium	?	0.00013	Anbar et al. (1996)
78	Platinum	(c)	0.05	Colodner et al. (1993)
79	Gold	(c)	0.02	Falkner and Edmond (1990)
80	Mercury	(s+n)	0.14	Gill and Bruland (1987)
81	Thallium	almost c	13	Flegal and Patterson (1985)
82	Lead	s	2.7	Schaule and Patterson (1981)
83	Bismuth	s	0.03	Lee et al. (1985)
84	Polonium	s		Nozaki and Tsunogai (1976)
85	Astatine			

86	Radon	Dissolved gas	c		Broecker (1965)
87	Francium				
88	Radium	Ra^{2+}	n	0.00013	Chung and Craig (1980)
89	Actinium		s+n		Nozaki (1984)
90	Thorium		s	0.02	Roy-Barman et al. (1996)
91	Protactinium		s		Nozaki and Nakanishi (1985)
92	Uranium		c	3.2×10^3	Chen et al. (1986)
93	Neptunium				
94	Plutonium		(r+s)		Bowen et al. (1980)
95	Americium		(s)		Livingstone et al. (1985)

***According to Li (1991): c = conservative, n = nutrient type, s = scavenged type, and r = redox-control on only educated guess.**
****Estimated by following the methods of Quinby-Hunt and Turekian (1983).**

A Fresh Look at Element Distribution in the North Pacific

Yoshiyuki Nozaki, Ocean Research Institute, University of Tokyo, Japan

Figure | Table | Article

Reference List for Table 1.

Amakawa, H., D. S. Alibo, and Y. Nozaki, Indium concentration in Pacific seawater, Geophys. Res. Lett., 23, 2473-2476, 1996.

Anbar, A. D., R. A. Creaser, D. A. Papanastassiou, and G. J. Wasserburg, Rhenium in seawater: Confirmation of generally conservative behavior, *Geochim. Cosmochim. Acta* , 56, 4099-4103, 1992.

Anbar, A. D., G. J. Wasserburg, D. A. Papanastassiou, and P. S. Andersson, Iridium in natural waters, *Science* , 273, 1524-1528, 1996.

Andreae, M. O., Arsenic speciation in seawater and industrial waters: The influence of biological-chemical interactions on the chemistry of a trace element, *Limnol. Oceanogr.*, 24, 440-452, 1979.

Bertine, K. K., M. Koide and E. D. Goldberg, Aspects of rhodium marine chemistry, *Mar. Chem.* 42, 199-210, 1993.

Bewers, J. M., G. R. Miller, D. R. Kester, and T. B. Warner, Rapid changes in the fluoride to chlorinity ratio south of Greenland, *Nature* , 242, 142-143, 1973.

Bieri, R. H., M. Koide and E. D. Goldberg, Noble gas contents of marine waters, *Earth Planet. Sci. Lett.*, 4, 329-340, 1968.

Boswell, S. W., and H. Elderfield, The determination of zirconium and hafnium in natural waters by isotope dilution mass spectrometry, *Mar. Chem.*, 25, 197-209, 1988.

Bowen, V. T., V. Noshkin, H. Livingston, and H. L. Volchok, Fallout radionuclides in the Pacific Ocean: Vertical and horizontal distributions, largely from GEOSECS stations, *Earth Planet. Sci. Lett.*, 49, 411-434, 1980.

Brass, G. W., and K. K. Turekian, Strontium distribution in GEOSECS ocean profiles, *Earth Planet. Sci. Lett.*, 23, 141-148, 1974.

Brewer, P. G., D. W. Spencer, and D. E. Robertson, Trace element profiles from the GEOSECS II test station in the Sargasso Sea, *Earth Planet. Sci. Lett.*, 16, 111-116, 1972.

Broecker, W. S., The application of natural radon to problems in ocean circulation, in *Symposium on Diffusion in Oceans and Fresh Waters* , edited by T. Ichiye, Lamont-Doherty Geological Observatory, Palisades, N.Y., p. 116-145, 1965.

Broecker, W. S. and T. Takahashi, The relationship between lysocline depth and in situ carbonate ion concentration, *Deep Sea Res.*, 25, 65-95, 1978.

Bruland, K. W., Oceanographic distributions of cadmium, zinc, nickel and copper in the North Pacific, *Earth Planet. Sci. Lett.*, 47, 176-198, 1980.

Byrd, J. T., and M. O. Andreae, Tin and methyltin species in seawater: Concentrations and fluxes, *Science* , 218, 565-569, 1982.

Carlisle, D. E., and L. G. Hummerstone, Niobium in seawater, *Nature* , 81, 1002, 1958.

Carpenter, J. H. and M. E. Mannella, Magnesium to chlorinity ratios in seawater, *J. Geophys. Res.*, 78, 3621-3626, 1973.

Chan, L. H., J. M. Edmond, R. F. Stallard, W. S. Broecker, Y. Chung, R. F. Weiss, and T. L. Ku, Radium and barium at Geosecs station in the Atlantic and Pacific, *Earth Planet. Sci. Lett.*, 32, 258-267, 1976.

Chen, J. H., R. L. Edwards, and G. J. Wasserburg, 238U, 234U and 232Th in seawater, *Earth Planet. Sci. Lett.*, 80, 241-256, 1986.

Chung, Y., and H. Craig, 226Ra in the Pacific Ocean, *Earth Planet. Sci. Lett.*, 49, 267-292, 1980.

Clarke, W. B., M. A. Beg, and H. Craig, Excess helium-3 at the North Pacific Geosecs station, *J. Geophys. Res.*, 75, 7676-7678, 1970.

Collier, R., Particulate and dissolved vanadium in the North Pacific Ocean, *Nature* , 309, 441-444, 1984.

Colodner, D. C., E. A. Boyle, and J. M. Edmond, Determination of rhenium and platinum in natural waters and sediments, and iridium in sediments by flow injection isotope dilution inductively coupled plasma mass spectrometry, *Anal. Chem.*, 65, 1419-1425, 1993.

Craig, H., R. F. Weiss, and W. B. Clarke, Dissolved gases in the equatorial and south Pacific Ocean., *J. Geophys. Res.*, 72, 6165-6181, 1967.

Culkin, F., and R. A. Cox, Sodium, potassium, magnesium, calcium and strontium in sea water, *Deep-Sea Res.*, 13, 789-804, 1966.

Falkner, K. K., and J. M. Edmond, Gold in seawater, *Earth Planet. Sci. Lett.*, 98, 208-221, 1990.

Flegal, A. R., and C. C. Patterson, Thallium concentrations in seawater, *Mar. Chem.*, 15, 327-331, 1985.

Froelich Jr., P. N., and M. O. Andreae, The marine geochemistry of germanium: Ekasilicon, *Science* , 213, 205-207, 1981.

GEOSECS Operation Group, *GEOSECS Atlantic* , Pacific and Indian Ocean Expedition, Vol. 7., National Science Foundation, Washington, D.C., pp. 200, 1987.

Gill, G. A., and K. W. Bruland, Mercury in the Northeast Pacific, *Eos, Trans. AGU* , 68, 1763, 1987.

Horibe, Y., K. Endo, and H. Tsubota, Calcium in the South Pacific and its correlation with carbonate alkalinity, *Earth Planet. Sci. Lett.*, 23, 136-140, 1974.

Koide, M., M. Stallard, V. F. Hodge and E. D. Goldberg, Preliminary studies on the marine chemistry of ruthenium, *Nether. J. Sea Res.*, 20, 163-166, 1986.

Koide, M., E. D. Goldberg, and R. Walker, The analysis of seawater osmium, *Deep Sea Res. II* , 43, 53-55, 1996.

Landing, W. M., and K. W. Bruland, Manganese in the North Pacific, *Earth Planet. Sci. Lett.*, 49, 45-56, 1980.

Lee, D. S., Palladium and nickel in northeast Pacific waters, *Nature* , 305, 47-48, 1983.

Lee, D. S., and J. M. Edmond, Tellurium species in seawater, *Nature* , 313, 782-785, 1985.

Lee, D. S., J. M. Edmond, and K. W. Bruland, Bismuth in the Atlantic and North Pacific: A natural analogue to plutonium and lead?, *Earth Planet. Sci. Lett.*, 76, 254-264, 1985-1986.

Livingston, H. D., V. T. Bowen, S. A. Casso, H. L. Volchok, V. E. Noshkin, K. M. Wong, and T. M. Beasley, Fallout nuclides in *Atlantic and Pacific water columns: GEOSECS data. Tech. Rep. WHOI-85-19* , Woods Hole Oceanographic Institution, Woods Hole, Mass., 73 pp., 1983.

Martin, J. H., G. A. Knauer, and W. R. M. Gordon, Silver distributions and fluxes on north-east Pacific waters, *Nature* , 305, 306-309, 1983.

Martin, J. H., R. M. Gordon, S. Fitzwater, and W. W. Broenkow, VERTEX: Phytoplankton / iron studies in the Gulf of Alaska, *Deep-Sea Res.*, 36, 649-680, 1989.

Mazor, E., G. J. Wasserburg, and H. Craig, Rare gases in Pacific ocean waters, *Deep-Sea Res.*, 11, 929-932, 1964.

McKelvey, B. A., and K. J. Orians, Dissolved zirconium in the North Pacific Ocean, *Geochim. Cosmochim. Acta* , 57, 3801-3805, 1993.

Measures, C. I., and J. M. Edmond, Beryllium in the water column of the central North Pacific, *Nature* , 297, 51-53, 1982.

Measures, C. I., R. E. McDuff, and J. M. Edmond, Selenium redox chemistry at GEOSECS I re-occupation, *Earth Planet. Sci. Lett.*, 49, 102-108, 1980.

Millero, F. J., and W. H. Leung, The thermodynamics of seawater at one atmosphere, *Am. J. Sci.*, 276, 1035-1077, 1976.

Morris, A. W., Dissolved molybdenum and vanadium in the northeast Atlantic Ocean, *Deep-Sea Res.*, 22, 49-54, 1975.

Morris, A. W., and J. P. Riley, The bromide/chlorinity and sulphate/chlorinity ratio in sea water, *Deep-Sea Res.*, 13, 699-705, 1966.

Nakayama, E., T. Kumamoto, H. Tokoro, and T. Fujinaga, Dissolved state of chromium, *Nature* , 290, 768-770, 1981.

Nakayama, E., T. Kimoto, K. Isshiki, Y. Sohrin, and S. Okazaki, Determination and distribution of iodine- and total-iodine in the North Pacific Ocean by using a new automated electrochemical method, *Mar. Chem.*, 27, 105-116, 1989.

Noakes, J. E., and D. W. Hood, Boron-boric acid complex in sea water, *Deep Sea Res.*, 8, 121-129, 1961.

Nozaki, Y., Excess ^{227}Ac in deep ocean water, *Nature* , 310, 486-488, 1984.

Nozaki, Y., and S. Tsunogai, ^{226}Ra, ^{210}Pb and ^{210}Po disequilibria in the western North Pacific, *Earth Planet. Sci. Lett.*, 32, 313-321, 1976.

Nozaki, Y., and T. Nakanishi, ^{231}Pa and ^{230}Th profiles in the open ocean water column. *Deep Sea Res.*, 32, 1209-1220, 1985.

Orians, K. J., E. A. Boyle, and K. W. Bruland, Dissolved titanium in the open ocean, *Nature* , 348, 322-325, 1990.

Orians, K. J., and K. W. Bruland, Dissolved aluminium in the central North Pacific, *Nature* , 316, 427-429, 1985.

Orians, K. J., and K. W. Bruland, Dissolved gallium in the open ocean, *Nature* , 332, 717-719, 1988.

Piepgras, D. J., and B. Jacobsen, The behavior of rare earth elements in seawater: precise determination of variations in the North Pacific water column, *Geochim. Cosmochim. Acta* , 56, 1851-1862, 1992.

Roy-Barman, M., J. H. Chen, and G. J. Wasserburg, 230Th-232Th systematics in the central Pacific Ocean, *Earth Planet. Sci. Lett.*, 139, 351-363, 1996.

Schaule, B. K., and C. C. Patterson, Lead concentrations in the northeast Pacific: Evidence for global anthropogenic perturbations, *Earth Planet. Sci. Lett.*, 54, 97-116, 1981.

Schutz, D. F., and K. K. Turekian, The distribution of cobalt, nickel and silver in ocean water profiles around Pacific Antarctica, *J. Geophys. Res.*, 70, 5519-5528, 1965.

Sohrin, Y., K. Isshiki, T. Kuwamoto, and E. Nakayama, Tungsten in North Pacific waters, *Mar. Chem.*, 22, 95-103, 1987.

Spencer, D. W., D. E. Robertson, K. K. Turekian, and T. R. Folsom, Trace element calibrations and profiles at the GEOSECS test station in the north-east Pacific Ocean, *J. Geophys. Res.*, 75, 7688-7696, 1970.

Stoffyn-Egli, P., and F. Mackenzie, Mass balance of dissolved lithium in the oceans, *Geochim. Cosmochim. Acta* , 48, 859-872, 1984.

Wilson, T. R. S., Salinity and the major elements of sea water, in *Chemical Oceanography* , Vol. 1, 2nd ed., edited by J. P. Riley and G. Skirrow, Academic Press, New York, pp. 365-413, 1975.

Zhang, J., H. Amakawa, and Y. Nozaki, The comparative behavior of yttrium and lanthanides in the sea water of the North Pacific, *Geophys. Res. Lett.*, 21, 2677-2680, 1994.