4. Chemical Studies of the Ocean. (XL) On the Regularities of the Amounts of Elements dissolving in Sea Water (2)

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INTRODUCTION

There seems to be certain relationships between the amount of element dissolved in the sea-water and that of the same elements in the earth's crust, supposing that the salt in the sea-water are the results of dissolution occured in the reaction between water and rock or magna. The amount of elements in the sea-water must be affected by the solubility of their compounds in the earth's crust, as well as by the chemical characters of their ions in water solutions—both in sea-water and in land-water.

Important factors for chemical properties of an element or an ion are ionic radius and ionic charges—speaking more strictry, the ionic potential which is the ratio of ionic charges to ionic radius.[1]

On the assumption that ionic potential expresses itself in the chemical and physical manner of element or ion, it may be imaginable that the ions of similar ionic potential have analogous behaviours in sea-water.

From the above mentioned viewpoint, the appearance of some regularities is expected between ionic potential on one hand, and the ratio of the amount of an element dissolved in sea-water to that of the same element in the earth's crust, on the other.

CONSIDERATION ON THE REGULARITIES

As for the amount of elements dissolved in sea-water, we can obtain good data on principal elements, while some data of trace elements by several persons are more or less different from one another, and some of them, moreover, seem to be inadequate.

The authors made use of the data given by Wattenberg[2] and Sverdrupp *et. al.*[3] as well as those by the authors themselves for completing Table 1 as to the amount of elements in sea-warer. Though the composition of lithosphere should be used for the composion of the earth's crust, the authors, for convenience's sake, take advantage of Clarke Number[4] which is shown in Table 2.

Table 1. Elements in Sea Water.

Element	γ/L	m. mol/L	Element	γ/L	m. mol/L
H	1×10^{8}	1×10^{5}	Ni	0,1	$1,7\times10^{-6}$
Li	120	$1,7\times10^{-2}$*	Cu	3	$4,7\times10^{-5}$*
B	$4,6\times10^{3}$	$4,2\times10^{-1}$	Zn	5	$7,7\times10^{-5}$
C	$2,8\times10^{4}$	$2,3\times10^{0}$	As	15	2×10^{-4}
N	5×10^{2}	$3,6\times10^{-2}$	Se	4	$5,1\times10^{-5}$
O	$8,6\times10^{8}$	$5,4\times10^{4}$	Br	$6,5\times10^{4}$	$8,1\times10^{-1}$
F	1400	$7,4\times10^{-2}$	Rb	200	$2,35\times10^{-3}$
Na	$1,05\times10^{7}$	$4,35\times10^{2}$	Sr	$1,3\times10^{4}$	$1,48\times10^{-1}$
Mg	$1,28\times10^{6}$	$5,25\times10^{1}$	Y	0,3	$3,4\times10^{-6}$
Al	10	$3,7\times10^{-4}$*	Mo	15	$1,56\times10^{-4}$*
Si	2000	7×10^{-2}	Ag	0,3	$2,8\times10^{-6}$
P	50	$1,6\times10^{-3}$	I	50	$3,9\times10^{-4}$
S	9×10^{5}	$2,8\times10^{1}$	Cs	2	$1,5\times10^{-5}$
Cl	$1,89\times10^{7}$	$5,4\times10^{2}$	Ba	50	$3,65\times10^{-4}$*
K	$3,8\times10^{5}$	$9,8\times10^{0}$	La	0,3	$2,2\times10^{-6}$
Ca	$4,1\times10^{5}$	1×10^{1}	Ce	0,4	$2,85\times10^{-6}$
Sc	0,04	9×10^{-7}	Au	0,004	2×10^{-8}*
Ti	0,4	$8,3\times10^{-6}$*	Hg	0,03	$1,5\times10^{-7}$
V	3	$5,9\times10^{-5}$*	Pb	4	$1,9\times10^{-5}$*
Cr	0,06	$1,15\times10^{-6}$*	Ra	1×10^{-7}	$4,4\times10^{-14}$
Mn	3	$5,45\times10^{-5}$*	Th	0,1	$4,3\times10^{-7}$*
Fe	5	9×10^{-5}*	U	1,5	$6,3\times10^{-6}$

* Values from our laboratory.

Table 2. Composition of earth crust (Kimura).

Element	Weight %	Wt.%/At.Wt.	Element	Weight %	Wt.%/At.Wt.
H	0,87	0,87	Sr	0,02	$2,2\times10^{-4}$
He	8×10^{-7}	2×10^{-7}	Y	3×10^{-3}	$3,1\times10^{-5}$
Li	6×10^{-3}	6×10^{-4}	Zr	0,02	2×10^{-4}
Be	6×10^{-4}	$6,6\times10^{-5}$	Nb	2×10^{-3}	$2,1\times10^{-5}$
B	1×10^{-3}	1×10^{-4}	Mo	$1,3\times10^{-3}$	$1,3\times10^{-5}$
C	0,08	5×10^{-3}	Tc	1×10^{-7}	1×10^{-9}
N	0,03	$2,2\times10^{-3}$	Ru	5×10^{-7}	5×10^{-9}
O	49,5	$3,1\times10^{0}$	Rh	1×10^{-7}	1×10^{-9}
F	0,03	$1,6\times10^{-3}$	Pd	1×10^{-6}	1×10^{-8}
Ne	5×10^{-7}	$2,5\times10^{-8}$	Ag	1×10^{-5}	9×10^{-8}
Na	2,63	$1,1\times10^{-1}$	Cd	5×10^{-5}	$4,4\times10^{-7}$
Mg	1,96	8×10^{-2}	In	1×10^{-5}	$8,7\times10^{-8}$
Al	7,56	$2,8\times10^{-1}$	Sn	4×10^{-3}	$3,3\times10^{-7}$
Si	25,8	9×10^{-1}	Sb	5×10^{-3}	$7,8\times10^{-9}$
P	0,08	$2,5\times10^{-3}$	Te	2×10^{-7}	$1,6\times10^{-9}$
S	0,06	2×10^{-3}	I	3×10^{-5}	$2,3\times10^{-7}$

Cl	0,19	$5,6\times10^{-3}$	Xe	3×10^{-9}	$2,3\times10^{-11}$
A	$3,5\times10^{-4}$	1×10^{-5}	Cs	7×10^{-4}	$5,3\times10^{-6}$
K	2,40	6×10^{-2}	Ba	0,023	2×10^{-4}
Ca	3,39	$8,5\times10^{-2}$	La	$1,8\times10^{-3}$	$1,3\times10^{-5}$
Sc	5×10^{-4}	$1,1\times10^{-5}$	Ce	$4,5\times10^{-3}$	$3,1\times10^{-5}$
Ti	0,46	$1,0\times10^{-2}$	Pr	5×10^{-4}	4×10^{-6}
V	0,015	3×10^{-4}	Nd	$2,2\times10^{-3}$	$1,5\times10^{-5}$
Cr	0,02	$3,8\times10^{-4}$	Pm	—	—
Mn	0,09	$1,8\times10^{-3}$	Sm	6×10^{-4}	4×10^{-6}
Fe	4,70	8×10^{-2}	Eu	1×10^{-4}	$6,5\times10^{-7}$
Co	4×10^{-3}	$6,8\times10^{-5}$	Gd	6×10^{-4}	4×10^{-6}
Ni	0,01	$1,7\times10^{-4}$	Tb	8×10^{-5}	5×10^{-7}
Cu	0,01	$1,6\times10^{-5}$	Dy	4×10^{-4}	$2,5\times10^{-6}$
Zn	4×10^{-3}	6×10^{-5}	Ho	1×10^{-4}	7×10^{-7}
Ga	1×10^{-3}	$1,4\times10^{-5}$	Er	2×10^{-4}	1×10^{-6}
Ge	$6,5\times10^{-4}$	9×10^{-6}	Tu	2×10^{-5}	$1,4\times10^{-7}$
As	5×10^{-4}	$6,6\times10^{-6}$	Yb	$2,5\times10^{-4}$	$1,5\times10^{-6}$
Se	1×10^{-5}	$1,3\times10^{-7}$	Lu	7×10^{-4}	4×10^{-7}
Br	6×10^{-4}	6×10^{-6}	Hf	4×10^{-4}	2×10^{-6}
Kr	2×10^{-7}	$2,3\times10^{-9}$	Ta	1×10^{-3}	$5,3\times10^{-6}$
Rb	0,03	$3,5\times10^{-5}$	W	6×10^{-3}	$3,5\times10^{-5}$
Re	1×10^{-7}	$5,3\times10^{-10}$	Po	4×10^{-14}	2×10^{-16}
Os	3×10^{-7}	$1,5\times10^{-8}$	At	—	—
Ir	1×10^{-7}	5×10^{-10}	Rn	1×10^{-15}	5×10^{-18}
Pt	5×10^{-7}	$2,6\times10^{-9}$	Fr	—	—
Au	5×10^{-7}	$2,6\times10^{-9}$	Ra	$1,4\times10^{-10}$	8×10^{-13}
Hg	2×10^{-5}	1×10^{-7}	Ac	4×10^{-14}	2×10^{-16}
Tl	3×10^{-5}	$1,5\times10^{-7}$	Th	$1,2\times10^{-3}$	5×10^{-6}
Pb	$1,5\times10^{-3}$	$7,5\times10^{-6}$	Pa	9×10^{-11}	4×10^{-13}
Bi	2×10^{-5}	1×10^{-7}	U	4×10^{-4}	$1,7\times10^{-6}$

1. Relation between Atomic Number and the Amount of Element

Illustrating absolute values of the amount of elements in sea-water or the earth's crust against each atomic numbers, the tendency is well shown in both cases that the amount generally decreases in proportion to increasing atomic number. And in case of sea-water, if we take log. millimol/L for ordinate and atomic number for abscissa, the amounts of elements which belong to the same groupe of the periodic table—in case of halogen, for example, Cl, Br and I with exception of F—diminish in a regular manner with increasing of atomic number. In such instances as halogene-, alkali- and alkali earth elements are seen in linear relationship. And this was already reported in our previous paper[6].

As seen in Fig. 1 which is the illustration of the relation between atmic number and logarithm of the ratio of the amount of an element in sea-water to that of the same element in the earth's crust, there would be, as in the following,

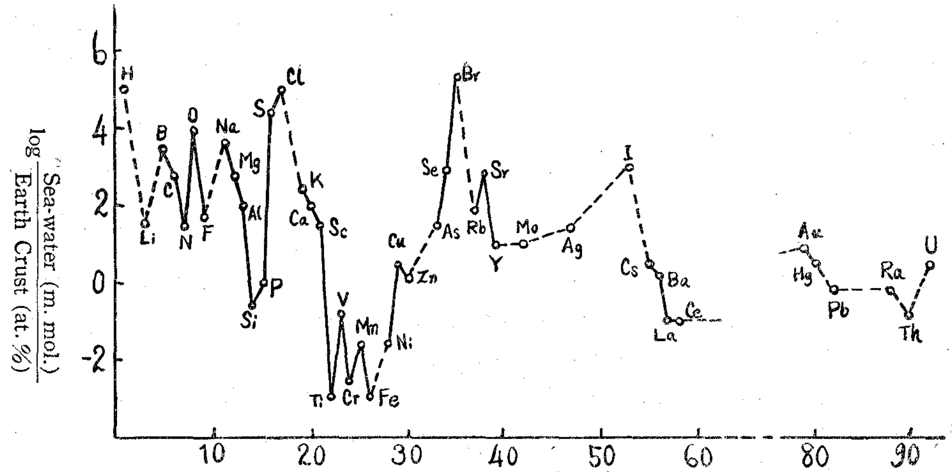
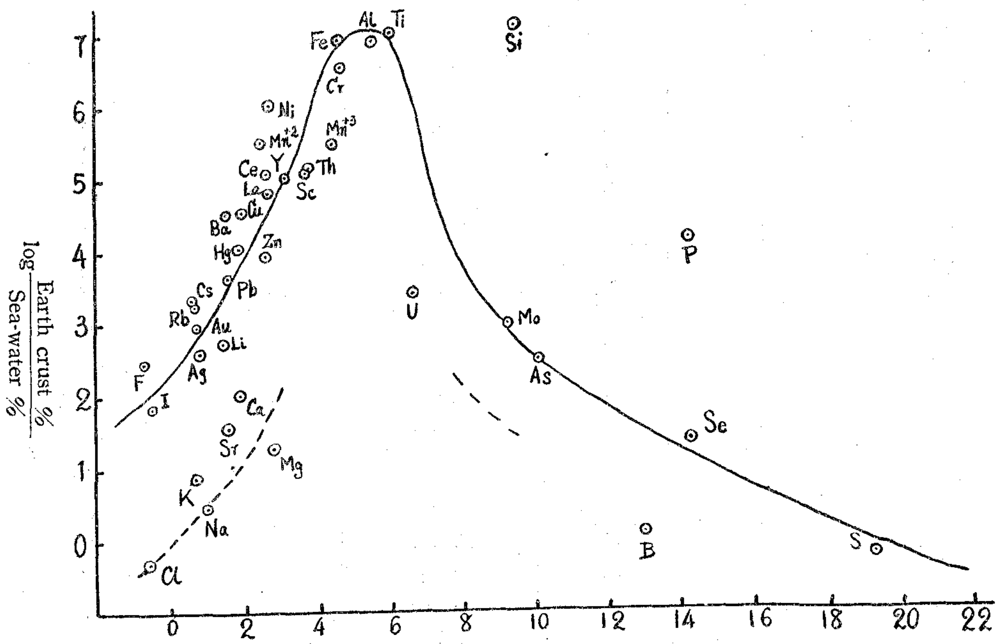


Fig. 1. Atomic Number

a general regularity except the Li-Ne period; the logarithm value begins to decrease in proper sequence from alkali elements toward the fourth group and transition elements, from where it, by contraries, begins to increase and show the maximum value at the halogen group. This will be well explained as hereunder; negative and positive elements are fairly dissolved out into sea-water in connection with their amounts in the earth's crust, while the intermediate elements are not dissolved much as in the case of the formers.

Generally speaking, the ratio of the amount of element in sea-water to that



Fgi. 2. Ionic potential

of that element in earth's crust has some relation with the periodic system of elements.

2. Relation between Ionic Potential and the Amount of Elemets

Setting forth the amount of an element in the sea-water or in the earth's crust with weight percentage, and the taking the logarithm of ratio of two weight percentages as to the same element for ordinate and ionic potential for abscissa, we obtain the graph of the relation as shown in Fig. 2. As seen in it, the ratio is presented with a curved line relation against ionic potential. And it should be taken into consideration that almost the principal elements of sea-water, namely alkali-, alkali earth- and halogen-elements, are deviated from the curve.

In addition another curved line relation, which is shown by the dotted line in Fig. 2, parallel to the former line, is observed among Cl, Na, K, Mg, U, B, and so on. And this will be discussed later.

3. Assumption for the Amount of Element in Sea-water

If we assume that the relation shown in Fig. 2 always holds good the amount of elements dissolved in sea-water as well as yet undermined amount of some

Table 3.

Element	Calculated from the regularity γ/L	Element	Calculated from the regularity γ/L	Element	Calculated from the regularity γ/L
Si	2.9×10^5	Al	8	Fe	8.5
Ca	3.5×10^3	Na	2.4×10^4	K	3.08×10^4
Mg	5.64×10^2	Ti	0.65	Cl	1.65×10^4
Mn^{+2}	28.8	P	5.2×10^4	S	4×10^5
Mn^{+3}	0.25	Rb	3.78×10^2	Ba	80
F	2.2×10^3	Sr	78	Ni	1.5
Cr	0.03	Cu	8(5.6)	Li	19
V^{+4}	0.3	Zn	1.2	Yt	0.3
V^{+5}	11	Pb	3.2	Mo	14(3)
Ce	0.8	B	400	Cs	9.8
La	0.3	Sc	0.02	U	0.002
Th	0.04	Hg	0.03	Ag	0.1
As	16	Au	0.006	Be	0.0006
I	2	Co	1	Ga	0.001
Se	7	Nb	0.002	Pd	0.00001
Zr	0.02	Sn	0.004	Sb	0.015
Ge	0.2	Pr	0.16	Nd	0.5
Cd	0.045	Gd	0.06	Dy	0.05
Te	0.009	Hf	0.0005	Ta	0.01
Ra	2.5×10^{-7}	Re	0.01	Os	3×10^{-7}
Lu	0.007	Tl	0.003(0.03)	Bi	0.0003
W	0.4	Eu	0.6	Yb	0.025
Ir	1×10^{-7}				
Pt	1×10^{-6}				

elements are computable by contraries. And these calculated values are shown in Table 3. Though some differences between the quantified values and the calculated ones may be well explain, the explanation is not be reported in this paper.

The authors made use of the data mentioned in Table 1 as for the amount of elements in the sea-water and it must be taken into account that caraful to some extent, many a more or less different value is available to us as for the trace elements.

4. On the Anomaly of Alkali-, Alkaliearth-, and Halogen-Elements

It is proper for the study of the relation between the earth's crust and sea-water to take marine sediments—which are thought to have been deposited out of sea-water in consequence of some reactions—into our consideration. And to our regret we do not know as yet much about marine sediments, for they have been little studied. But judging from the composition of marine sedimentary rocks, alkali- and alkali earth- elements should be considered to have been dissolved out and concentrated into sea-water.

Halogen elements are under different circumstances from the former elements and other—that is, they are atmophile elements, and so may be codsidered to have had cousiderable occurrences since the birth of sea-water.

As for most of the other elements it can be considered that the amount carried into sea-water and the deposit amount from it have reached to an equilibrium state with each other in a comparatively early era. And these elements do not deviate from the curved line relation as shown in Fig. 2.

Besides these calculations of the age of the ocean seems to be possible from the difference between the continuous line and the dotted line in Fig. 2, as well as from the amount carried into sea-water, but this problem will be discussed on another occasion.

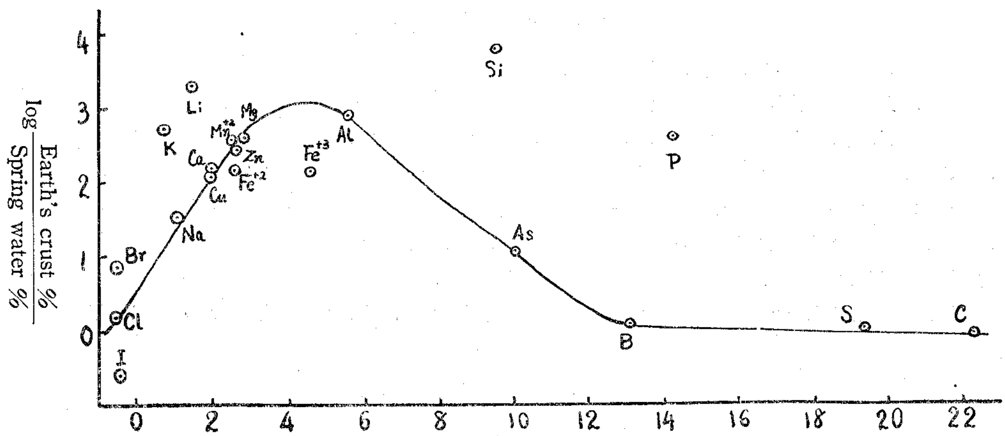


Fig. 3. Ionic Potential

5. On the similar Regularity in other kinds of Water

A similar regularity is expected to be in other kinds of waters than sea-water, which have connection with the composition of the earth's crust. Mineral water is not so much of definite nature as sea-water and too much attention must not be paid to its relation to Clarke Number, but to its relation to the rock composition near at its gushing point.

If we use the mean composition of many sorts of mineral water in various places, a regularity similar to to that of sea-water is observed. Fig. 3 shows this similar regularity, and the mean compositions of mineral water in Japan[7] are treated as in the instance of sea-water.

SUMMARY

1. The relation between the ratio of the amount of an element dissolved in sea-water to that of the same element in the earth's crust and its atomic number was considered, and moreover its relation to the periodic system of elements was given interpretation at the same time.

2. Assuming that ionic potential presents, on the whole, the characters of an element, the authors found a regularity between the ratio of the amount of an element in sea-water to that of the same element in the earth's crust, and ionic potential.

3. The amount of some as yet undermined elements in the sea-water were calculated from the regularity explained herein.

4. The reasons why some sorts of element deviate from the aforesaid regularity were also discussed.

5. By exemplifying with the mean composition of mineral water in Japan, the authors could verify that the similar regularity was also observed in other sorts of water than sea-water, and the appropriateness of its regularity was reaffirmed.

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