

TRACE ELEMENTS IN MARINE ENVIRONMENT : EXTRACTION TECHNIQUES AND RESULTS*

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ABSTRACT

It has long been realised that the geographical and depth distribution of trace elements, both radioactive and stable, hold clues to the understanding of several important physico-chemical and bio-chemical processes. Studies of trace elements, however, involve a contamination-free collection of large volumes of sea water from different depths in the ocean. Whereas the neutron activation technique is suitable for some elements, it is not applicable in others where it becomes necessary to extract the trace elements in large amounts to study them for their isotopic composition or radioactivity.

We discuss in this paper our experiments towards *in situ* extraction of trace elements from few hundreds of tons of sea water. The techniques employed and their results are discussed for waters upto 3500 meters depth in the ocean.

Though one of the techniques seems potential for contamination free extraction of any desired element, most of the results described here involve elements that can be efficiently adsorbed on to ferric-hydroxide dispersed in a matrix form.

The implications of the results of the analyses of isotopes of uranium, thorium, radium, lead, silicon and beryllium are briefly described to show the scope of such studies.

INTRODUCTION

RADIOACTIVE and stable trace elements present in sea water hold clues to the nature and details of a wide variety of physico-chemical and biological processes taking place in the marine environment. In Table 1 are listed several isotopic pairs under three categories, stable/stable, radioactive/stable and radioactive/radioactive, for some geochemically important elements (Turekian, 1956 ; Chow, 1958 ; Goldberg *et al.*, 1958 ; Broecker *et al.*, 1960 ; Lal *et al.*, 1960 ; Merrill *et al.*, 1960 ; Rama *et al.*, 1961 ; Thurber, 1963 ; Moore and Sackett, 1964 ; Koide and Goldberg, 1965 ; Ku, 1966 ; Somayajulu and Goldberg, 1966 ; Lal and Peters, 1967 ; Lal and Suess, 1968 ; Bowen, 1969 ; Moore, 1969). The concentrations of most of the elements/isotopes listed in Table 1 are very small in sea water (Table 2) and their measurement involves the collection and processing of large volumes of sea water in some cases, for example the extraction of Be¹⁰ requires volumes of the order of thousands of tons. Several types of water samplers are used for collecting large volumes (100-5000 litres) of sea water. [For a comprehensive review of the samplers and also the analytical procedures employed for several trace elements, see Riley (1965)].

In view of the difficulties in collection and processing of large volumes of sea water on board the ship it was considered worth-while to develop techniques for *in situ* concentration of the required trace element on to a matrix. Efforts in this

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direction have proved successful and an *in situ* extraction technique was first explored in the coastal regions of the Indian Ocean and Arabian sea, using ferric hydroxide dispersed matrices of jute fibres and natural sponges (Lal *et al.*, 1964). Recently, we have found that synthetic acrylic fibres, after suitable chemical treatment, also serve as ideal matrices for an *in situ* concentration. Since these fibres can be obtained in ultra pure form, the problem of inherent contaminations in the case of some of the elements (e.g. Th) does not arise. With the development of a 'butterfly' trace element sampler (Craig *et al.*, 1971) and using the enriching-matrices discussed above, it has become possible to study most of the ratios belonging to the stable/radioactive and radioactive/radioactive categories (Table 1) in surface and deep ocean waters.

TABLE 1. Some important isotopic ratios and specific activities useful for understanding the marine processes

Stable/Stable	Radioactive/Stable	Radioactive/Radioactive
Sr^{87}/Sr^{86}	Be^7/Be	Ra^{226}/Ra^{226}
Pb^{206}/Pb^{204}	Be^{10}/Be	Th^{230}/Th^{232}
Pb^{207}/Pb^{208}	Si^{30}/Si	Th^{230}/Th^{232}
	C^{14}/C	U^{234}/U^{238}
	Sr^{90}/Sr	
	Pb^{210}/Pb	

We review here the *in situ* extraction techniques based on adsorption of trace elements on ferric-hydroxide and some of the results obtained employing this technique to show its potentiality for studying several marine physico-chemical processes. For completeness it must be mentioned here that few other extraction techniques based on chemisorption and ion exchange on high purity chemicals like alumina (Silker *et al.*, 1968), basic zinc carbonate and titanium hydroxide (Davies *et al.*, 1964) and potassium cobalt ferricyanide (Folsom and Sreekumaran, 1966), have been reported. Of these, the latter two are specific extraction techniques for U and Cs from sea water. It is quite clear that one can probably dream of a host of chemicals to suit narrow requirements of extraction for a single element from sea water such as ammonium-phospho-molybdate for Cs and $BaSO_4$ for Ra. Even $Fe(OH)_3$, which used in the present experiments, is probably not the most ideal chemical, other systems employing organic functional groups could perhaps serve much better over a wide spectrum of elements.

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MATRIX PREPARATION AND SEA WATER FLUSHING TECHNIQUES

We will briefly discuss the preparation of various types of matrices and techniques for flushing sea water through them. The specific methods used for the measurement of the radioactive and trace elements, will only be referred to. For further details, reference is made to Somayajulu (1969 a).

Though the initial experiments were carried out using jute fibres as the matrix to provide the framework for suspension of ferric hydroxide (Lal *et al.*, 1964),

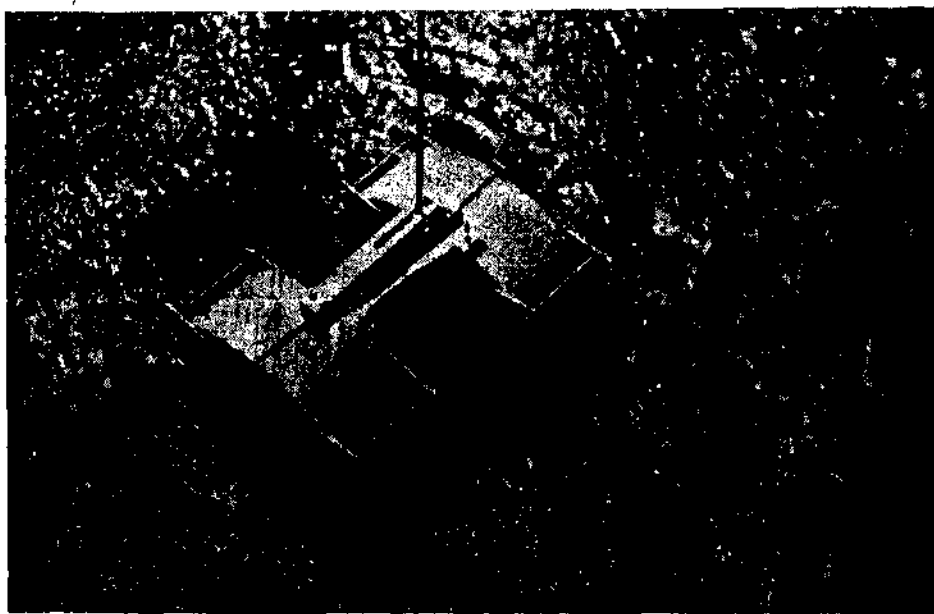


Fig. 1. The 'butterfly' trace element sampler in the descending mode (Craig *et al.*, 1971).

most of the experiments performed to date used natural sponges as the matrix. More recently, synthetic fibres of polyacrylonitrile have also been used and found to be very promising (Krishnaswamy *et al.*, unpublished).

Jute fibres and natural spongin were obtained from Angus Jute Mills, Calcutta and the Sponge Fishing Companies of Florida and Greece, respectively. These materials contain appreciable amounts of silica, U, Th and other trace elements and hence a chemical cleansing becomes necessary before they could be used for extraction of elements. We find that treatment with hydrochloric and hydrofluoric acids is quite adequate. In the case of synthetic fibres a chemical cleansing is not necessary in view of their low intrinsic contents of the elements of interest. They are, however, quite inert (chemically) to begin with and their surfaces have to be chemically activated by alkali treatment to pick up $\text{Fe}(\text{OH})_3$.

After chemical cleansing, the jute fibres were first immersed in molten ferric chloride for a few minutes. The same procedure was followed for spongin and 'activated' synthetic fibres except that a concentrated solution of ferric chloride was used, instead of molten FeCl_3 . Analytical grade reagents were employed throughout. The ferric chloride saturated matrices were then dipped in 10% NH_3 solution. Subsequently, the matrices were washed with distilled water to remove excess ferric hydroxide *i.e.*, not deposited on the matrix. We determined, that jute fibres and spongin retained about 15-20 grams of $\text{Fe}(\text{OH})_3$ per 100 gm of matrix. In the case of activated synthetic fibres, the retention was only about (7-10) g $\text{Fe}(\text{OH})_3/100\text{g}$.

In the initial experiments, perforated stainless steel and PVC samplers, cylindrical in shape, were employed; the samplers were closely packed with about 1-2 Kg of the matrices and towed behind motor launches and naval ships at speeds of 2-3 knots for 8-10 hrs (Somayajulu, 1969 b). Later on, the development of a stainless steel butterfly trace element sampler (Craig *et al.*, 1971) made it possible to flush waters at great depths through the matrices. Sea water is flushed through the sampler containing the matrix, by raising and lowering it through 50-150 m, at speeds of about 10 m/min for 10-15 hrs. Samplers are made to descend to the desired depth in an orientation that does not allow sea water to flow through the matrix. Corrosion of a magnesium strip at the profile depth swung the samplers into a butterfly orientation when up and down motion allowed free flushing of water through it.

TABLE 2. Concentrations of some Important Stable Elements and Radioactive Isotopes in Sea Water*

Element	Average concentration in sea water (gm/liter)	Isotope	Concentration in sea water (dpm)/liter
Be	10^{-10}	Be ⁷	10^{-3-6}
Si	10^{-9}	Be ¹⁰	1×10^{-6}
Sr	8×10^{-9}	Si ³⁰	3×10^{-6}
Pb	$10^{-6}-10^{-4}$	Si ³⁰	$10^{-2}-10^{-1**}$
		Pb ²¹⁰	10^{-1}
		Ra ²²⁶	$10^{-3}-10^{-1}$
		Ra ²²⁸	$10^{-1}-4 \times 10^{-1}$
		Th ²³²	$10^{-3}-10^{-2}$
		Th ²³⁰	10^{-3}
		Th ²³²	$10^{-5}-10^{-4}$
		U ²³⁵	2-3

* Data compiled from Goldberg (1965) for stable elements from Prospero and Koczy (1965) for radioisotopes.

** In near surface waters only.

After flushing of sea water the samples were brought on board the ship, the matrices packed in poly-bags and shipped to the laboratory for chemical analysis. Plain acid-cleansed spongin (*i.e.*, unimpregnated with any hydroxides) was also flushed with sea water in order to evaluate on particulate matter trapped by the matrix and also to check on the possibilities of direct pick-up of trace elements by the organic surfaces of the matrix.

In the laboratory, the sea water treated matrices were soaked in analytical grade 6M HCl (10-15 litres/kg dry wt of matrix) to extract the dispersed hydroxides and associated trace elements. The leachates were filtered through Whatman No. 54 filter paper and the filtrate analysed for various elements. The residue consisted of spongin fibres predominantly and no significant amount of particulates could be seen on the filter papers. Techniques employed for the analysis of radioactive and stable trace elements are summarised with references in Table 3.

RESULTS AND DISCUSSION

In order to compare the figure of merit of different matrices for enrichment, we define a parameter called the 'enrichment factor' of matrix for a given element as the equivalent volume in cc of sea water from which the element has been extracted per gram of the matrix. It is assumed that in all our experiments saturation pick-up has been reached in flushing of water which has been carried out for 8-15 hrs. In the case of silicon we have determined that at a towing speed of 3 knots, the

TABLE 3. Techniques used in various analyses

Element/Isotope	Technique	Reference
Be ⁷	Gamma ray spectrometry	Goel <i>et al.</i> , (1959)
Si	Colorimetry	Strickland and Parsons (1960)
Si ²⁸ (P ³²)	Beta assay	Kharkar <i>et al.</i> , (1963)
PO ₄ ⁻³	Gravimetry	Somayajulu (1969a)
		Longinelli and Somayajulu (1968)
Ni } Co } Cu }	Atomic absorption Spectrophotometry	Pandey (1965)
Pb	Mass spectrometry	Chow and Mckinney (1958)
Pb ²¹⁰ (Bi ²¹⁰)	Beta assay	Rama <i>et al.</i> , (1961)
Ra ²²⁶	Radon emanation	Broecker (1965), Bhat (1970)
Ra ²²⁶ (Th ²³⁰)	Alpha spectrometry	Moore (1969)
Th isotopes	Alpha spectrometry	Somayajulu and Goldberg (1966)
U isotopes	Alpha spectrometry	Bhat <i>et al.</i> , (1969)

matrix of Fe (OH)₃ dispersed spongin gets saturated in about 8-9 hrs; the half pick-up time is about 2 hrs. The Si to Fe ratio in the Fe (OH)₃ spongin matrix (treated with sea water for 8-10 hrs) was about 0.05 which is in good agreement with the ratio of 0.06 at saturation, obtained by Schink (1962) using Fe(OH)₃ dispersed cation exchange resin column. It is clear from all these experiments that at least Si is nearly saturated in the Fe (OH)₃ matrix and it may be reasonable to assume an approximate saturation in the case of other elements also.

The enrichment factors of all elements analysed in this study are given in Table 4 for 'plain spongin' and Fe (OH)₃ and Ti (OH)₄ impregnated spongin. For completeness, the enrichment factors of the hydroxide dispersed matrices are given in two ways (i) cc/g matrix and (ii) cc/g hydroxide (ferric or titanium).

It becomes clear from the results in Table 4 that except for Pb, plain spongin is not effective in picking up trace elements from sea water: the values of 25-100, which represent upper limits (due to uncertainties in estimating inherent levels present in the matrix (Table 5) before sea water treatment) may represent a real pick-up but one cannot exclude this much being a result of trapping particulates since our experiments were carried out in near shore waters. Furthermore the enrichment factor for Pb²¹⁰ is about the same for plain as well as hydroxide impregnated spongin. This presumably indicates the extreme chemical activity of Pb in sea water for concentrating on organic and inorganic surfaces.

The enrichment factors of the $\text{Fe}(\text{OH})_3$ dispersed synthetic fibre matrix for various elements (values are not given here) are found to compare very favourably

TABLE 4. Measured Enrichment Factors for Some Elements in Different Matrices

Element or Isotope	Enrichment Factor for				
	$\text{Fe}(\text{OH})_3$ Spongin matrix		$\text{Ti}(\text{OH})_4$ Spongin matrix		Plain acid cleansed Spongin matrix
	cc/g matrix	cc/g $\text{Fe}(\text{OH})_3$	cc/g matrix	cc/g $\text{Ti}(\text{OH})_4$	cc/g matrix
Be ⁷	5×10^3	5×10^4	N.M.	N.M.	N.M.
Si	3×10^3	3×10^4	10^3	1.4×10^4	10^3
P	10^3	10^4	N.M.	N.M.	N.M.
Mn	10^3	10^4	10^3	1.4×10^4	10^3
Ni	N.M.	N.M.	10^4	1.4×10^5	N.M.
Cu	10^3	10^4	10^3	1.4×10^4	10^3
Sr	10	10^3	10^3	1.4×10^3	1
Pb ²¹⁰	10^3	10^4	10^3	1.4×10^4	5×10^3
Ra ²²⁶	10^3	10^4	10^3	1.4×10^4	10^3
Th	2×10^4	2×10^5	N.M.	N.M.	N.M.
U	10^3	10^3	5×10^3	7×10^3	25

N.M.—Not measured.

with those of the hydroxide dispersed spongin matrix. Recent experiments have shown that synthetic fibres converted to a cationic form resin can be used for selective extraction of certain elements.

As shown in Table 5, spongin which is a marine product, of course, already has several elements in its structure and the chemical and isotopic composition of trace

TABLE 5. Inherent levels of Si, Pb, Th and U in spongin and synthetic fibres [Units are microgrammes/gm except for Pb²¹⁰ (dpm/g)]

Element ^t (Isotope)	Inherent concentration in matrix	
	Spongin	Synthetic fibres
Si	200(6)	4(10)
Pb ²¹⁰	5×10^{-3} (10-10 ³)	4×10^{-3} (10 ²)
Th ²³²	5×10^{-3} (3)	8×10^{-4} (—)*
U ²³⁸	10^{-3} (10-10 ²)	10^{-3} (10 ²)

Number in parenthesis indicates the ratio of amount of element picked up by $\text{Fe}(\text{OH})_3$ impregnated matrices to the internally present for some experiment carried out in surface waters of Bombay coast.

* No measurable excess Th²³² activity was found although a clearly measurable signal of Th²³² activity was present.

elements present can be studied for an evaluation of the marine environment where the sponges grow. In the present context, the inherent amounts are merely treated

TABLE 6. Measured Isotope Concentrations for Radionuclides of Si, Pb, Ra, Th, and U in sea water

Isotope (s)	Specific activities/Activity ratios based on		Applications
	<i>in situ</i> matrix method	direct processing of sea water	
^{32}Si (dpm/Kg SiO_2)	72 ± 7 (Somayajulu <i>et al.</i> , 1972)	99 ± 32 (Schink, 1962)	Large scale circulation of water in the oceans
^{210}Pb (dpm/microgram Pb)	14 ± 5	10^*	Mixing in the upper layers of the ocean Vertical eddy diffusion in the surface as well as bottom waters
$\text{Ra}^{226}/\text{Ra}^{228}$ (Activity Ratio)	1.6	0.8 (Moore, 1969)	
$\text{Th}^{230}/\text{Th}^{232}$ (Activity Ratio)	10-25 (Somayajulu and Goldberg, 1966)	15 (Moore and Sacket, 1964)	Near surface rapid ad- sorption processes
$\text{Th}^{230}/\text{Th}^{232}$ (Activity Ratio)	6-11 [†]	2-5 [‡]	
$\text{U}^{235}/\text{U}^{238}$ (Activity Ratio)	1.14 ± 0.02 (Krishnaswamy <i>et al.</i> , 1970)	1.14 ± 0.02 (Koide and Goldberg, 1965)	Material balance studies of Uranium

* Based on the measured Pb^{210} concentration of 0.1 dpm/litre (Rama *et al.*, 1961) and stable Pb concentration of $0.01 \mu\text{g/litre}$ (Tatsumoto and Patterson, 1963) for Pacific deep waters.

[†] Pacific deep waters (Somayajulu and Goldberg, 1966).

[‡] Atlantic deep waters (Moore and Sackett, 1964).

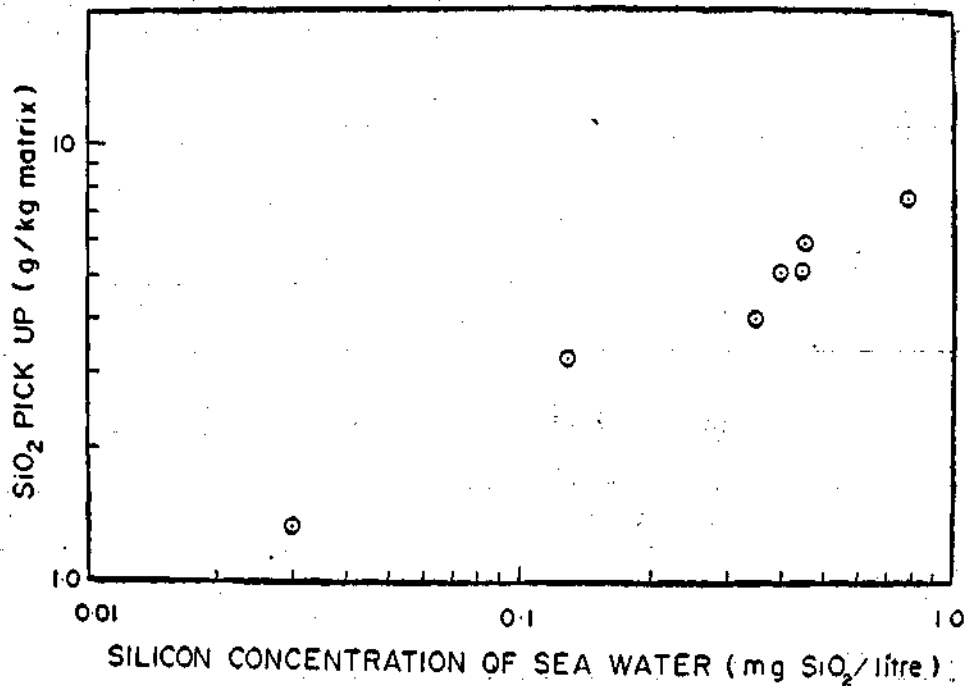


Fig. 2. Enrichment factor of ferric hydroxide dispersed spongin matrix for pick-up of silica from sea water as a function of concentration of silica in sea water; the matrix was treated identically in each case to correspond to near saturation pick-up.

[7]

as 'contamination'. In Table 5 we list the amounts of Si, Pb^{210} , Th and U present in the spongin (after fairly thorough cleansing with HCl and HF) and synthetic fibres (without cleansing). The latter are seen to be free from contamination.

Mechanism of pick-up

In a general way the mechanism responsible for the pick-up of most of the elements reported here can be termed 'adsorption' (physical, chemical or ion-exchange). In view of the fact that the elements studied have quite different chemical behaviours in sea water, the pick-up mechanism for one element may not be the same as for another. However, in specific cases where the behaviour of the elements in sea water is well understood it is possible to indicate the pick-up mechanism. For example, Th and Be should exist as highly hydrated ions in solution (Saccioni, 1949) and form the least soluble hydroxides. These will be effectively picked up by the $Fe(OH)_3$ which will be a negative sol in alkaline solutions (Krauskopf, 1967).

As indicated by laboratory experiments (Lal *et al.*, 1964), chemical adsorption appears to be the mechanism for Si. This can be supported by a series of pick-up experiments performed in 'surface' sea waters. Separate lots of about 2 kg $Fe(OH)_3$ dispersed spongin matrix were flushed with sea waters of different silica concentrations under identical experimental conditions and analyzed for silica. The results are shown in Fig. 2 as a log-log plot of SiO_2 picked up (g per Kg matrix) as a function of silica concentration of sea water. At least square line drawn through the points would have a slope of <1 which is in accordance with an empirical adsorption isotherm for the adsorption of elements in solution on solid surfaces put forward by Freundlich (1906).

Similarly for U, Davies *et al.* (1964) have pointed out that in the case of $Ti(OH)_4$ adsorbent, formation of a uranyl complex with the adsorbent is the mechanism. As a further step towards understanding the enrichment mechanism, we have tried to correlate several well known properties of the elements such as ionic radius, ionic charge, reactivity in sea water etc. and the best correlation appears to be between the enrichment factor and the last mentioned property viz., reactivity. Reactivity of elements which is a relative term, would be expected to be inversely related to their residence times in sea water (see Goldberg and Arrhenius, 1958 and Goldberg, 1965, for data on residence times). Elements like Th and Be which have low residence times (of the order of 50-100 years) are highly reactive in sea water and get quickly removed to sediments by adsorption on to particulate matter present in sea water. This would be quite consistent with the high enrichment factors observed for Th and Be (Fig. 3).

Elements like U and Sr which are relatively inert as evidenced by their long residence times (5×10^5 and 6×10^7 yrs) in sea water do not get attached to matrix surface. In the case of elements with intermediate residence times (i.e. 10^3 - 10^5 yrs) there seems to exist no good correlation and this is an area where further work is needed for a better understanding.

CONCLUDING REMARKS

We have summarised results on determinations of activities of isotopes of Si, Pb, Ra, Th and U, using $Fe(OH)_3$ dispersed spongin and synthetic fibre matrices, in Table 6 along with the values directly determined in sea water; the usefulness of such studies is also indicated in the same table. The fact that elements like Si, Th

and Be can be concentrated from a few hundreds of tons of sea water from different depths, in the oceans makes the *in situ* extraction technique a unique one.

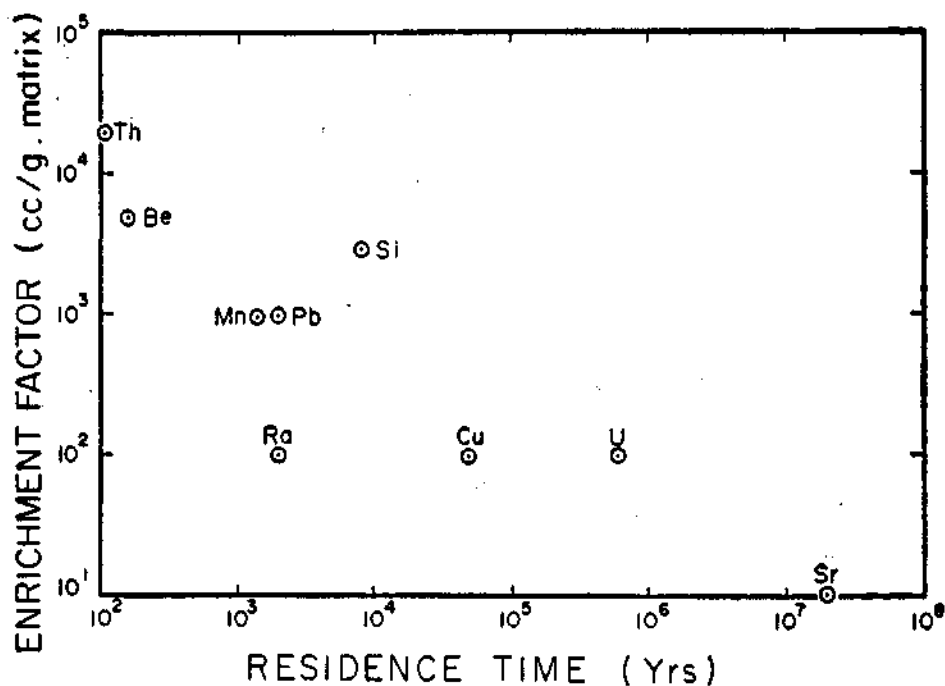


Fig. 3. Plot showing the correlation between enrichment factors and residence times for different elements picked up by $\text{Fe}(\text{OH})_3$ spongin matrix.

For the sake of completeness, it may be mentioned here that the activity of cosmic ray produced Be^7 in sea water has been measured utilising a somewhat similar technique in which sea water is pushed through alumina cakes under pressure (Silker *et al.*, 1968). Folsom and Sreekumaran (1966) have also developed an *in situ* extraction technique for concentrating Cs and Cs^{137} from sea water to study the downward penetration of bomb Cs^{137} in oceans. However, such techniques besides being specific for one or two elements do not lead to routine extraction from large volumes of sea water, as becomes possible with the matrices discussed here.

DISCUSSION

Y. HIYAMA : What is the scientific name of the sponge used?

B.L.K. SOMAYAJULU : The sponges come under the general name 'Porifera'. Most of the sponges used were calcareous type. We have not selected any particular species.

ANILL LYALL : What is the average time (duration) of towing this magnificent sampler?

B.L.K. SOMAYAJULU : On station the ship remains stationery and the samplers move up and down at speed of about 10 m/min for 12-15 hours.

A.K. GANGULY : How do you ensure you are not picking up terrestrial particulate materials in the matrix?

[9]

- B.L.K. SOMAYAJULU:** A very important question. It should be pointed out that there is no direct way of ascertaining the amount of terrestrial particulate matter filtered by the matrix. However, when visually examined under microscope, the filter papers through which the acid leachates were filtered showed no appreciable particulate material. Besides, the U^{235}/U^{238} activity ratios obtained from the matrix leachates was 1.14 ± 0.02 , identical with the sea water values. If particulates are present in significant amounts this ratio should be lower.
- A.K. GANGULY:** Comment. Some particles trapped by the $Fe(OH)_3$ may alter the S^{32}/SiO_2 ratio considerably and the reproducibility of the results may be, because of the steady content of particulates at depths explored.
- B.L.K. SOMAYAJULU:** From whatever data we have at hand there is no indication that the particulate matter in the sea contributes significantly towards altering the Si^{28}/SiO_2 ratio. Open ocean waters where these experiments were carried out contain only a few tens of micrograms of particulate per litre and our samples represent about 100 tons of sea water which means about a gram of particulate matter might have been present in the matrix. In the case of a matrix which by accident hit the ocean bottom and trapped substantial amounts of particulate matter only very small amounts of silica could be recovered. Besides, the ratios measured by this technique agree very well with those directly measured from sea water (Table 6). These results only mean that because of the very low concentration of the particulates and their resistance towards giving out silica, the Si^{28}/SiO_2 ratios cannot be significantly altered by the particulate matter of the sea, trapped by the matrix.
- M. SUBBARAO:** Have you used, throughout your investigations, the same type of sponge material?
- B.L.K. SOMAYAJULU:** As far as possible we have tried to buy the same commercial variety of sponges which showed similarity in appearance and texture. All samples were cleansed in acids and were found to retain 15-20% of $Fe(OH)_3$ by weight. As long as the blanks are low and the hydroxide retention is high it is not important whether we use the same type or not. Besides we measure the isotopic ratios or specific activities, which are independent of pick-up efficiency, amount of water flushed, etc.
- B. PATEL:** It will be worth collecting and trying *Adosia so* (sponge) from Tarapur waters during January-March.
- B.L.K. SOMAYAJULU:** Thank you for the suggestion. We will be happy to experiment with the specimens you are recommending.
- S.Z. QASIM:** It is certainly a very ingenious method, but I was wondering whether you could also use the synthetic sponges. Also, is there any method by which you could close your apparatus when you are hauling it up from great depths? Do you precisely know how much water the sponges have filtered?
- B.L.K. SOMAYAJULU:** Synthetic sponges do not retain ferric hydroxide and hence are not useful. Your second question is an important one. The butterfly sampler we have used descends to depths in the closed position but comes up only in the open position. This technique has recently been improved so that the sampler can come up in the closed position. For elements like Si whose concentrations in deeper waters are one to two orders of magnitude higher than in the surface waters, bringing the sampler up in the open position does not in any serious way introduce any 'contamination'. As for your third question, the answer is 'No'. We do not know directly how much water is filtered by the matrix. However, in specific cases, where one can collect a few litres of water sample and measure these elements for example Si, Th^{232} etc., we can compute the effective amount of water from which the element has been extracted.
- R. VISWANATHAN:** The suggested towing method (using sponges) is considered suitable for the extraction of trace elements from the sea. How does it compare with the Folsom technique used recently for survey of Cs^{137} and Cs in the oceans?
- B.L.K. SOMAYAJULU:** The Folsom technique using potassium cobalt ferricyanide matrix is used for extracting Cs from relatively small volumes of water (few 100 litres). We are using 10 kg matrices and trying to concentrate elements from 10-100 tons of sea water

- K.C. PILLAI: (Suggestion) Perhaps for studying upwelling, Cs^{137} is much better than S^{35} because you can use small columns and simpler method for estimation. Once you know the Cs^{137} levels in one area we can easily study the upwelling.
- B.L.K. SOMAYAJULU: It would be ideal to study as many radioisotopes as possible, for example, Cs^{137} , S^{35} and C^{14} (man-made).

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