

YALE PEABODY MUSEUM

P.O. BOX 208118 | NEW HAVEN CT 06520-8118 USA | PEABODY.YALE. EDU

JOURNAL OF MARINE RESEARCH

The *Journal of Marine Research*, one of the oldest journals in American marine science, published important peer-reviewed original research on a broad array of topics in physical, biological, and chemical oceanography vital to the academic oceanographic community in the long and rich tradition of the Sears Foundation for Marine Research at Yale University.

An archive of all issues from 1937 to 2021 (Volume 1–79) are available through EliScholar, a digital platform for scholarly publishing provided by Yale University Library at <https://elischolar.library.yale.edu/>.

Requests for permission to clear rights for use of this content should be directed to the authors, their estates, or other representatives. The *Journal of Marine Research* has no contact information beyond the affiliations listed in the published articles. We ask that you provide attribution to the *Journal of Marine Research*.

Yale University provides access to these materials for educational and research purposes only. Copyright or other proprietary rights to content contained in this document may be held by individuals or entities other than, or in addition to, Yale University. You are solely responsible for determining the ownership of the copyright, and for obtaining permission for your intended use. Yale University makes no warranty that your distribution, reproduction, or other use of these materials will not infringe the rights of third parties.



This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.
<https://creativecommons.org/licenses/by-nc-sa/4.0/>



SEARS FOUNDATION FOR MARINE RESEARCH
BINGHAM OCEANOGRAPHIC LABORATORY, YALE UNIVERSITY

JOURNAL OF MARINE RESEARCH

VOLUME X

1951

NUMBER 2

COMPARATIVE STUDIES OF MINERAL CONSTITUENTS OF MARINE SPONGES

I. THE GENERA *Dysidea*, *Chondrilla*, *Terpios*¹

By

VAUGHAN T. BOWEN

Brookhaven National Laboratory, and Osborn Zoological Laboratory, Yale University

AND

DORIS SUTTON

Brookhaven National Laboratory

ABSTRACT

Analyses of Al, Ca, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sn, Ti, and V are presented for specimens of five species of marine sponges: *Dysidea crawshayi*, *D. etheria*, *Chondrilla nucula*, *Terpios fugax* and *T. zeteki*; and of F in *D. crawshayi*.

From replicate analyses on unhomogenized material from each specimen, and from comparison with such analyses made on other sponges from the same habitat and on the same species of sponge from other habitats, it is concluded that decision can be made as to whether a given element is truly a constituent of the sponge or of the living or dead extraneous matter which is unavoidably a part of each specimen.

From such comparisons it is concluded that *D. crawshayi* is an accumulator of F, K, and Ti, that *D. etheria* is not an accumulator of any of the elements studied, that *Chondrilla nucula* is an accumulator of Cu and Na, that *Terpios fugax* and *T. zeteki* are accumulators of Ti, and of K to some extent, and that *T. zeteki* may also accumulate Mn, Sn and V.

It is shown that one collection of *D. crawshayi* is characterized by an extraordinary level of Ni accumulation ($F = 5 \times 10^5$ on a wet basis), which may be due to the

¹ Research carried out at Brookhaven National Laboratory under the auspices of the Atomic Energy Commission.

activities of an irregularly occurring microfloral inhabitant. From analyses of preservative solutions of museum specimens, it is concluded that this sort of Ni accumulation is not of infrequent occurrence in these sponge species and that the mass of accumulated material is in extractable form.

INTRODUCTION

As pointed out by Bergmann (1949), it has long been assumed that evolutionary divergence within the phylum Porifera has taken a clearly chemical form. The major divisions of the phylum have been based on the organic and inorganic composition of the skeletal material. Recently Low (1949) has shown evidence for a major division based on divergence in halogen content, and Bergmann (1949) has laid the groundwork for reclassification of some genera on the basis of sterol content. During the latter investigation, Bergmann called the senior author's attention to peculiarities of the ash of many of his sponges. The opportunity to study the mineral composition of a large series of carefully determined animals was a welcome one, especially since many other aspects of their biochemistry were being examined, and since, as an initial assumption, their geochemical environment was taken to be quite uniform.

Reported below are analyses on specimens of the genera *Dysidea*, *Terpios* and *Chondrilla*. This is the first of a planned series of studies of which the next will be a spectrographic survey of each of the specimens studied by Bergmann; work has already begun on this. This work will be followed in turn by detailed quantitative studies of all forms showing unusual features of mineral composition.

The choice of the genera *Dysidea*, *Terpios* and *Chondrilla* has a purely historical basis. The ash of *Dysidea rawshayi* from Walsingham Pond, Bermuda, was the first sample shown to us by Bergmann, it having caught his attention by its extraordinary fusibility and bright green color; at that time the only other specimen available from Walsingham Pond was *Terpios fugax*. *Chondrilla nucula* from Harrington Sound, Bermuda, was chosen as a sponge which had no known biochemical peculiarities and which had not been exposed to the peculiar environment of Walsingham Pond. Other specimens and species were added subsequently to provide additional comparisons.

The organic chemists who have studied sponge composition (Bergmann, 1949; Low, 1949) have used the nonspicule ash as an indication of the amount of extraneous material in the sample. But it appears to us that a more detailed consideration of the exogenous components of a sponge sample is justified. It is commonplace in biological thought that the mineral components of organisms play an essential

part in their functioning and that they show, between species or larger groups, variations which are quite as consistent and often quite as inexplicable as those shown by the organic components. It seems evident from such studies as those of Pearse (1950) and de Laubenfels (1950a), coupled with the work of Bergmann and Low, that the mineral elements in a given sponge sample must be thought of as having five sources: the sponge tissue itself, macrodetritus, microdetritus, macro-organisms inhabiting the sponge, and micro-organisms inhabiting the sponge. Gross examination shows that there is considerable irregularity in distribution within each specimen, both of the macrodetritus and of the macroinhabitants. Accordingly, it may be thought that chemical constituents which show the same sort of irregularity between replicate analyses of unhomogenized tissue are to be referred either to macrodetritus or to macroinhabitants.

On the other hand, we should not expect exogenous material that enters as microdetritus (of which coral sand in these sponges is thought to be a major component) to show wide fluctuations between duplicate analyses, nor should we expect the content of micro-organisms to vary widely among specimens of one species caught at the same place and time. However, it does seem reasonable to assume that the composition, and, to a degree, even the amount of microdetritus, will be common to sponges of different species taken at the same place and time, whereas we should not expect the faunae and florae of different genera, or even species, to be highly alike. Thus we are inclined to conclude that elements which show uniform distribution among replicates of the same sample but which are not found in similar concentration in other species from the same habitat are true constituents of the sponge or have been introduced in the bodies of the micro-organism population.

It appears from de Laubenfels' (1905a) detailed description of Bermuda sponges that this discussion may require modification due to the fact that some sponges select their detrital components. Thus, *Dysidea etheria* reportedly accumulates calcareous detritus almost exclusively, whereas *D. crawshayi* accumulates largely silicious spicules of other sponges. Pursuit of extensive field studies, combined with analyses of material which is made available for microscopic examination in fairly fresh condition, will probably have to determine how far this property of selection is general among sponges.

However, there does not appear to be adequate information as to the extent to which the micro-organism population of a sponge species may be subdivided into two portions: one facultative, characterizing only a given habitat, the other obligate, characterizing the species no matter where collected. Although some sponge species have been

regarded as distinct (Verrill, 1907; Topsent, 1929) on the basis of their inhabitants (algae in these two cases), de Laubenfels' (1950a, 1950b) comparisons in the field did not lead him to decide that any of the Bermuda sponges is characterized by a particular micro-organism population. Should such a population be found, we do not discern any mechanism whereby comparison analyses can be used to differentiate its chemical contribution in a sponge sample from that of the sponge tissues *sensu strictu*. Both contributions will be uniformly distributed among replicates, will not be common to other sponge species from the same habitat, and will be common to all collections of the species in question. On the other hand, contributions by the "facultative micro-organism inhabitants" will evidently be characterized by uniform distribution among replicates of the same sample and by dissimilar concentrations in specimens of other species from the same habitat and of the same species from different habitats. This reasoning, of great importance to the conclusions set out below, is summarized in Table IV.

Thus, for maximum elucidation of analytical data on specimens of unavoidably high contamination, it appears that analyses must be made on as many species as possible from each collecting point, on specimens of each species from as many collecting points as possible, and on several replicate samples taken from each specimen without previous attempts to render the sample homogeneous. That this proves to be a difficult regime to follow in the case of tropical sponges is indicated by the few sets of comparison analyses which actually could be made, but we feel that the results set out below justify both the reasoning and the attempt to follow its consequences.

Although some of these conclusions are implicit in the thoughtful discussion by Webb (1937) on the mineral constituents of marine organisms, and although Fox and Ramage (1931) used comparison analyses to confirm the validity of nickel accumulation as a characteristic of the annelid genus *Myxicola* (see p. 163), neither study was planned to take advantage of the approach we have outlined.

METHODOLOGY

The specimens analyzed were mostly in the form of residues after acetone extraction, as described by Bergmann (1949). The analytical figures for these have been restored to a whole dry weight basis, using Bergmann's figures for organic fat. In addition, some specimens, originally donated by Bergmann, were obtained from the Bingham Oceanographic Collection. These had been preserved in alcohol or formalin and were dried before analysis. Some analyses were made on the fluid extracts as well.

Both dry and wet ashing have been employed. In the former process the dry material, in a clean weighed porcelain crucible, was placed in an electric muffle furnace where the temperature was slowly raised to 200° C, held at this point from 6 to 12 hours, then slowly raised to 500° C and held at this point from 4 to 6 hours. Clean ash of low carbon content was obtained.

Wet ashing, in pyrex vessels of suitable size, was effected generally with nitric and perchloric acids, mostly in the following proportions: 5 ml HNO₃ and 3 ml HClO₄ to 1 g dry sponge. Some large samples of *Dysidea crawshayi* had potassium too high for convenient perchloric treatment, and these were treated with nitric and sulfuric acids in the following proportions: 5 ml HNO₃ : 1 ml H₂SO₄ : 1 g dry sponge. Sample sizes varied from 0.5–20.0 grams, and in general ashing proceeded smoothly.

The analytical methods employed have been quite varied. Through the cooperation of Morris Slavin of Brookhaven National Laboratory, survey spectrograms were obtained by arcing dry ash in carbon electrodes with a Baird Associates 1 meter grating spectrograph. The semiquantitative interpretation of these spectrograms is due to Mr. Slavin's long experience, and we take pleasure in extending our thanks to him.

Standard procedures, substantially as described by Hillebrand and Lundell (1929), were used in determining silicon by perchloric acid dehydration; aluminum with ammonia following cupferron separation of other R₂O₃ cations; and calcium as oxalate.

Magnesium was determined, following the other separations, either as the ammonium phosphate or as the 8-hydroxy quinolate.

Sodium and potassium were determined on hydrochloric acid extracts of dry ash with the Beckman flame spectrophotometer.

Iron was determined photometrically as ferrous dipyriddy, substantially as outlined in Sandell (1944). Although the orthophenanthroline method is somewhat more sensitive, the great insolubility of ferrous orthophenanthroline perchlorate proved an overpowering disadvantage.

Copper was determined with diethyldithiocarbamate substantially as outlined in Sandell (1944).

Cobalt was determined with nitrosocresol according to the extremely sensitive method of Ellis and Thompson (1945).

Nickel was determined both gravimetrically with dimethylglyoxime, and colorimetrically with diethyldithiocarbamate, following preliminary extraction with dimethylglyoxime (Alexander, Godar and Linde, 1946). The latter method proved satisfactory and was capable of extreme sensitivity.

TABLE I

Analyses in Terms of Whole Dried Sponge

Species	Sample Place and Date	Ash %	SiO ₂ %	Ca %	Mg %	Na %	K %	Al %	Fe %	Co ppm	Ni ppm	Mn ppm	Ti ppm	Cu ppm	Sn ppm	Mo ppm	Pb ppm	V ppm
Dysidea crawshayi	A-1-1 Dried Specimen Bermuda 1946	34.1	1.08 ^R	4.79 ^R	0.93 ^R	3.29 ^f	4.11 ^f	1.73 ^R	0.067 ^c	--	23 ^c 22 ^c 24 ^c	--	--	22 ^c 21 ^c	--	--	--	--
Dysidea crawshayi	A-1-2 Extracted Specimen Walsingham Pond Bermuda 1946	32.5	1.6 ^s 0.11 ^R 0.31 ^R	1.18 ^R 0.53 ^R	0.77 ^R 0.49 ^R	3.25 ^f 3.25 ^f	7.10 ^f 7.70 ^f	0.29 ^R	0.25 ^c 0.27 ^R	1.6 ^c 2.2 ^c 2.7 ^c	614 ^R av.	31 ^v	127 ^c 137 ^c 150 ^c	298 ^c 281 ^c	nil ^s	--	nil ^s	nil ^s
Dysidea crawshayi	A-1-3 Extracted Specimen Walsingham Pond Bermuda 1947	32.8	1.6 ^s	0.78 ^R	--	2.79 ^f 2.85 ^f	7.56 ^f 7.15 ^f	0.19 ^R	0.35 ^c 0.11 ^c	nil ^c 0.1 ^c	1.8 ^c 2.7 ^c	11 ^c	90 ^c 100 ^c 116 ^c	38 ^c 39 ^c 43 ^c	nil ^s	--	3 ^s	3 ^s
Dysidea etheria	A-1-4 Extracted Specimen Bimini, Bahamas 1948	75.6	0.23 ^R	30.20 ^R	0.32 ^R	9.46 ^f	0.38 ^f	0.59 ^R	0.03 ^c	nil ^c nil ^c	1.8 ^c 2.4 ^c	25 ^c	<10 ^c	10 ^c 15 ^c	7 ^s	0.7 ^s	nil ^s	<1 ^s
Dysidea etheria	A-1-5 Dried Specimen Bermuda 1946	30.8	2.45 ^R	8.04 ^R	0.60 ^R	3.55 ^f	0.39 ^f	1.85 ^R	0.28 ^c 0.34 ^c	0.5 ^c	7.3 ^c 8.0 ^c	59 ^v	215 ^c 270 ^c 300 ^c	60 ^c	nil ^s	--	3 ^s	nil ^s
Chondrilla nucula	A-8-1 Extracted Specimen Harrington Sound Bermuda 1946	30.5	1.72 ^R 1.73 ^R 1.82 ^R	11.35 ^R 8.95 ^R	0.66 ^R 0.75 ^R 0.75 ^R	6.68 ^f	0.77 ^f	0.06 ^R 0.27 ^R 1.24 ^R	0.98 ^c 1.11 ^c	~.1 ^c ~.1 ^c	18 ^c 18 ^R 20 ^c	45 ^c 42 ^v	<10 ^c	385 ^c 397 ^c	--	--	--	--
Chondrilla nucula	A-8-2 Extracted Specimen Bermuda	40.4	1.18 ^R	3.43 ^R	0.73 ^R	7.50 ^f	0.60 ^f 0.61 ^f	0.59 ^R	0.045 ^c 0.057 ^c	1.5 ^c 1.5 ^c 2.1 ^c	67.5 ^c 68.0 ^c	10 ^c 40 ^c	<10 ^c	324 ^c 330 ^c 339 ^c	4 ^s	--	nil ^s	nil ^s
Terpios fugax	A-5-2 Extracted Specimen Walsingham Pond Bermuda 1946	30.1	15.45 ^R	1.15 ^R 2.05 ^R	0.40 ^R	2.10 ^f 2.84 ^f	1.0 ^f 1.2 ^f	0.11 ^R 0.12 ^R 0.70 ^R	0.076 ^c 0.10 ^c	~.1 ^c	18 ^c 20 ^c	15 ^c	88 ^c 97 ^c 100 ^c	56 ^c 61 ^c 62 ^c 66 ^c	--	--	--	--
Terpios zeteki	A-5-3 Extracted Specimen Hawaii 1948	54.5	39.80 ^R	1.52 ^R 2.32 ^R	0.42 ^R	2.55 ^f 2.62 ^f	0.80 ^f 0.93 ^f	0.13 ^R 0.41 ^R	0.14 ^c 0.15 ^c 0.20 ^c	0.1 ^c 0.8 ^c	2.9 ^c 4.9 ^c	253 ^c 200 ^c	96 ^c 120 ^c 180 ^c	50 ^c 60 ^c 72 ^c 84 ^c	50 ^s	--	nil ^s	5 ^s

Superscripts: s = spectrographic c = colorimetric g = gravimetric v = volumetric f = flame spectrophotometric --: not determined

Manganese was determined as permanganate either by arsenite titration after persulphate oxidation (Hillebrand and Lundell, 1929) or spectrophotometrically after periodate oxidation (Sandell, 1944).

In all of the above-mentioned colorimetric methods, a Beckman model D. U. spectrophotometer was employed.

Titanium was determined with peroxide (Sandell, 1944). A preliminary separation with cupferron served to remove interference except for that due to iron. The positive error due to iron in a hydrochloric acid solution was corrected by running blank samples to which iron had been added to equal that of the specimens. For this method a Lumetron electrophotometer with a 440 $m\mu$ medium band filter and 50 mm cells was used.

RESULTS

The main body of data is presented in Table I. In accordance with the arguments outlined above, the replicate figures entered in many places are results of analyses on replicate samples taken without previous attempt to render the sample homogeneous. In many cases the figure entered is actually the mean of two or more analyses made on aliquot portions of such replicate samples, thus reducing to a minimum the possible significance of purely analytical variation.

The analyses for silica on *Dysidea crawshayi* are complicated by the extraordinary fluorine content of this species. Detailed consideration of sponge fluorine must await a later report, but all specimens of this species encountered thus far show fluorine in the neighborhood of one per cent of the dry sponge. It is thought that this may interfere less with the spectrographic silicon estimations which are included and which do indeed show a much higher figure than has been obtainable chemically.

The calcium figures include strontium. According to present plans, we intend to present data for the Ca : Sr ratios of these and of other sponges at a later date.

As noted previously, the green ash of *D. crawshayi*, taken from Walsingham Pond in 1946, was the starting point of this investigation. The nickel concentration in this specimen was so extraordinary that when the same species taken from the same place in the following year was found to be low in nickel, some consternation was experienced. As discussed hereafter, replicate analyses on the high nickel specimen did not support the possibility of contamination in handling; however, it was thought that this possibility might be discounted further by examination of the preserved specimens which had been deposited in the Bingham Oceanographic Collection, since their treatment had not included drying or acetone extraction, the two

TABLE II. ANALYSES OF MUSEUM SPECIMENS

Species	Place and Date	Preservative	Preservative		Specimen		
			Ash as % Dry	Ni as ppm Dry	Ash as % Dry	Ni ppm Dry	Cu ppm Dry
<i>Dysidea etheria</i>	Virginia Key, Florida, 1945	Formaldehyde	64.2	<1	—	—	—
<i>Dysidea etheria</i>	Mulletts Bay, Bermuda, 1946	Alcohol	48.2	nil	63.9	2.0	—
<i>Dysidea fragilis</i>	Plymouth, England	Alcohol	47.3	nil	75.5	4.6	—
<i>Dysidea crawshayi</i>	Walsingham Pond, Bermuda, 1946	Alcohol	23.6	nil	34.6	2.5	—
<i>Dysidea crawshayi</i>	Harrington Sound, Bermuda, 1946	Alcohol	23.5	nil	28.5	3.4	—
<i>Dysidea crawshayi</i>	Virginia Key, Florida, 1945	Formaldehyde	64.6	<0.5	—	—	—
<i>Terpios fugax</i>	Walsingham Pond, Bermuda, 1946	Alcohol	38.1	4	27.7	13.6	20.3
<i>Chondrilla nucula</i>	Harrington Sound, Bermuda, 1946	Alcohol	32.8	~1	48.6	8.9	22.2

principal manipulations to which the main sample had been subjected. In Table II are presented the analyses made on the group of museum specimens chosen at this time. Although interesting, these certainly gave no indication of the high nickel that was so characteristic of the 1946 *D. crawshayi*.

As a consequence of curatorial aesthetics, however, the preservative on marine specimens is changed regularly until no more alcohol-precipitable material is extracted. We could obtain no estimate of the number of changes and extractions to which this material had been subjected, but it was known that the *Terpios* and *Chondrilla* preservatives were at least one change behind the others, and these showed the highest nickel content. To check further on the interesting hypothesis that nickel in sponges may be largely in extractable form, another series of solutions was obtained from the museum specimens. This series of fluid preservatives or extracts represented material which had been replaced by fresh preservative on the samples of Table II. The analyses of these preservatives are presented in Table III. As ex-

TABLE III. ANALYSES OF PRESERVATIVE FROM MUSEUM SPECIMENS

<i>Species</i>	<i>Place and Year</i>	<i>Solution</i>	<i>Ash%</i> <i>Dry Wt.</i>	<i>Ni ppm</i> <i>Dry</i>	<i>Cu ppm</i> <i>Dry</i>
<i>Dysidea crawshayi</i>	Walsingham Pond, Bermuda, 1946	Alcohol	24.3	8.0	323
<i>Dysidea crawshayi</i>	Harrington Sound, Bermuda, 1946	Alcohol	21.3	18.3	470
<i>Dysidea crawshayi</i>	Virginia Key, Florida, 1945	Formalin	64.6	2.3	51
<i>Dysidea etheria</i>	Harrington Sound, Bermuda, 1946	Alcohol	52.5	8.0	1288
<i>Dysidea etheria</i>	Mulletts Bay, Bermuda, 1946	Alcohol	50.7	2.2	494
<i>Dysidea etheria</i>	Virginia Key, Florida, 1945	Formalin	57.3	19.4	289
<i>Chondrilla nucula</i>	Harrington Sound, Bermuda, 1946	Alcohol	39.9	7.0	1010
<i>Terpios fugax</i>	Walsingham Pond, Bermuda, 1946	Alcohol	38.0	7.0	435
<i>Terpios fugax</i>	Walsingham Pond, Bermuda, 1947	Alcohol	32.5	3.5	750
<i>Terpios fugax</i>	Harrington Sound, Bermuda, 1946	Alcohol	30.7	15.0	1330

pected from the earlier position of these samples in the extraction series, their content in nickel is considerably higher. Further discussion of the significance of these preservative analyses will be found in the following discussion.

DISCUSSION

If we now apply the conclusions reached in the INTRODUCTION (summarized in Table IV) to an analysis of the data in Table I, we find certain patterns in each of the five species selected.

Dysidea crawshayi, presently assigned to a genus characterized by lack of silica accumulation, shows rather consistently that there is more silica than seems reasonable. We have already discussed the reason for our rejection of the low silica figures generally obtained gravimetrically for this species. In addition, a high potassium content is shown uniformly, even by specimen A-1-1 which was air dried

TABLE IV. USE OF COMPARISON ANALYSES TO ELUCIDATE ORIGIN OF CHEMICALS ANALYZED IN SAMPLES HAVING HIGH AMOUNTS OF EXOGENOUS MATERIAL

Origin of Chemical Component analyzed	Constancy among replicates of one specimen	Constancy among specimens from one habitat	Constancy among samples of one species from different habitats
Sponge tissue, <i>sens. str.</i>	high	low	high
"Obligate micro-organism population"	high	low	high
"Facultative micro-organism population"	high	low	low
Macro-organism population	low	low	low
Microdetritus	high	high	low
Macrodetritus	low	low	low

and probably had lost much of this element. The two specimens analyzed show agreement in that they gave consistent and rather high titanium. Most other elements show variations indicating origin from detritus or from "macroinhabitants" or "facultative microinhabitants." For these specimens the case of nickel is discussed fully.

Dysidea etheria, whose variable silica figures indicate that this element is of exogenous origin, differs also from its congener above in being low in potassium. The great variability of the other constituents apparently indicates that this species possesses an unusually high content of exogenous matter.

Chondrilla nucula, which gives the consistent silica figures that are to be expected of a silicious skeleton, has uniformly high sodium, moderate potassium and magnesium, uniformly high copper, and very low titanium. The iron of our two samples shows an amazing variation.

The genus *Terpios*, of which we have only a single specimen for each of the two species, shows the high SiO₂ of a very silicious sponge. Also, it shows moderately high and quite consistent potassium and titanium,

and rather low but consistent copper. *T. zeteki* shows a high manganese content, whereas *T. fugax* is among the low manganese samples.

For these five species then, we may add the following observations in addition to the well-known fact that sponges accumulate calcium and silicon. One species, *D. crawshayi*, may be characterized by an accumulation of titanium and potassium, and of fluorine as mentioned previously. Another, *C. nucula*, may be characterized by accumulation of much copper, and both species of *Terpios* may be characterized by accumulation of titanium and of moderate but significant amounts of copper. We conclude that all of these elements are accumulated by the activities of the sponge itself or of any "obligate microinhabitants."

In addition, accumulations which appear to be due to the activities of "facultative microinhabitants" are found for aluminum, iron, copper, nickel and titanium. High levels of manganese, tin and vanadium were found, but insufficient data prevent assignments of origin.

Nickel. The best previous nickel determination in a marine sponge (Noddack and Noddack, 1939) gave 22 ppm of the dry specimen for *Halichondria* from the North Sea. Fox and Ramage (1931), in their examination of two specimens of *Clathrina coriacea*, evidently found no nickel. In polychaete worms and mollusks, Fox and Ramage (1931) found nickel quite generally, with evidence that *Myxicola* of the former group is characterized by nickel accumulation that runs from 80 to 100 ppm dry regardless of the locality; however, in *Haliotis* foot only, high nickel (40 ppm) was found in the absence of high cobalt. Our finding of 614 ppm nickel (the mean of several highly concordant replicate analyses) in dried *Dysidea crawshayi* from the 1946 collection at Walsingham Pond evidently indicates something quite new in nickel metabolism. The possibility that this nickel may be due to contamination introduced in handling seems contraindicated both by what is known of the manipulations involved and by the extreme uniformity with which nickel is distributed through a specimen of about two kilograms. At present we are inclined to conclude that the *D. crawshayi* population of Walsingham Pond, in 1946, was infested by a microflora characterized by an extraordinary level of nickel accumulation. The reasoning that leads to this conclusion is as outlined previously, plus the added assumption that plant accumulation of nickel is more likely in view of the general tendency toward nickel selection by the plant kingdom (Hutchinson, 1949). It is seen in our analyses (Table I) that there is no strong tendency for cobalt to vary in relation to nickel.

As mentioned previously, precise interpretation of the analyses set out in Tables II and III is difficult because of the uncertainty as to the

number of extractions that preceded the extractives. It does appear highly probable, however, that a large fraction of the nickel present in *D. crawshayi* from Walsingham Pond, 1946, was alcohol-extractable. If we accept this conclusion, such analyses as those on *D. crawshayi* from Harrington Sound, 1946, on *T. fugax* from Harrington Sound, 1946, and on *D. etheria* from Virginia Key, 1945, may indicate that similar infestations of nickel-accumulating plants characterized these populations. Similar conclusions for copper are indicated from Table III. Collections now being made by the personnel of the Bermuda Biological Station under conditions conducive to the most precise control of mineral content are expected to provide confirmation of this variable in nickel uptake by marine sponges. In time we hope that concomitant water collections will even reveal whether the nickel organisms are inhabitants of the sponge or whether they are planktonic and appear in selected sponges as a result of the sort of differential predation postulated by Bertrand (1950) in the case of vanadium accumulation by tunicates.

Accepting the figure of 0.5×10^{-9} for the nickel content of sea water, as given by Noddack and Noddack (1939), the concentration factor of approximately 5×10^5 on a wet basis for the high nickel *D. crawshayi* appears to indicate extreme intervention of this element in the metabolism of some organisms. For comparison we may cite the accumulation of vanadium by tunicates, which involves concentration factors in the range of 1 to 3×10^5 (Bertrand, 1950).

Here it may be worth pointing out that no rational program for marine disposal of radioactive waste is possible in the absence of data much more detailed than that presented here. In the case of strontium, the studies of Spooner (1949), coupled with those of Odum (1950), indicate that high concentration factors are rare among marine organisms; furthermore, they indicate that the high content of strontium in sea water may be expected (1) to provide an immediate reduction to a safe level in specific activity of released strontium isotopes and (2) to prevent the operation of any local geochemical isotope concentration mechanisms. In the case of almost no other long-lived radioisotopes which present a disposal problem do we have sufficient analyses of sea water or of biological concentration phenomena to permit an adequate judgment of safe levels.

Further, it appears evident that too much thinking on waste disposal problems has viewed the ocean as a continuum and has assumed that the entire mass of a given element in the ocean is to be viewed as immediately effective as a diluent. Scott (1950) indicates local bottom accumulations as the prime exception. That this is not a reasonable assumption is indicated by such studies as those of Cooper

(1935) and Harvey (1947) which show that locally high fractions of the available iron or manganese may be present at times in the bodies of plankton. The local massive accumulations of nickel and of some other elements which are suggested in the present study pose an even more disturbing problem, since we are uncertain how general they may be, both with respect to the elements and to the species concerned. Data must be accumulated in this direction as soon as possible, as well as in the direction of ascertaining how such accumulations affect uptake of elements by organisms associated environmentally with the accumulator. In the case of nickel, this is made especially interesting by the solubility of the accumulated element, bringing to mind the toxicity-enhancing properties of those selenium accumulators which release soluble selenium compounds to the soil (Trelease and Beath, 1949).

ACKNOWLEDGMENT

It is a great pleasure to acknowledge the interest and cooperation of Professor Werner Bergmann, who has supplied generous samples from his collection and through whose good offices the taxonomic assistance of Professor Max W. de Laubenfels of Oregon State University was obtained. Dr. Willard Hartmann has been generous in procuring museum specimens from the Bingham Oceanographic Collection and from Peabody Museum of Yale University and has provided much stimulating discussion of sponge biology and museum practice.

Throughout this study Professor G. E. Hutchinson has been a source of support and stimulation. The investigation was begun at Yale University during the senior author's appointment as Research Assistant in Biogeochemistry under the auspices of the American Museum's Survey of Contemporary Knowledge of Biogeochemistry, whose support is gratefully acknowledged. The present study has been completed at Brookhaven National Laboratory under the auspices of the U. S. Atomic Energy Commission.

SUMMARY

Analyses of Al, Ca, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sn, Ti, and V are presented for specimens of five species of marine sponges: *Dysidea crawshayi*, *D. etheria*, *Chondrilla nucula*, *Terpios fugax* and *T. zeteki*; of F in *D. crawshayi*.

From replicate analyses on unhomogenized material from each specimen, and from comparison with such analyses made on other sponges from the same habitat and on the same species of sponge from other habitats, it is concluded that decision can be made as to whether a given element is truly a constituent of the sponge or of the living or

dead extraneous matter which is unavoidably a part of each specimen.

From such comparisons it is concluded that *D. crawshayi* is an accumulator of F, K, and Ti, that *D. etheria* is not an accumulator of any of the elements studied, that *Chondrilla nucula* is an accumulator of Cu and Na, that *Terpios fugax* and *T. zeteki* are accumulators of Ti, and of K to some extent, and that *T. zeteki* may also accumulate Mn, Sn and V.

It is shown that one collection of *D. crawshayi* is characterized by an extraordinary level of Ni accumulation ($F = 5 \times 10^5$ on a wet basis), which may be due to the activities of an irregularly occurring microfloral inhabitant. From analyses of preservative solutions of museum specimens, it is concluded that this sort of Ni accumulation is not of infrequent occurrence in these sponge species and that the mass of accumulated material is in extractable form.

BIBLIOGRAPHY

- ALEXANDER, O. R., E. M. GODAR AND N. J. LINDE
1946. Spectrophotometric determination of traces of nickel. *Industr. Engng. Chem., Anal. Ed.*, 18: 206-208.
- BERGMANN, WERNER
1949. Comparative biochemical studies on the lipids of marine invertebrates with special reference to the sterols. *J. Mar. Res.*, 8: 137-176.
- BERTRAND, DIDIER
1950. The biogeochemistry of vanadium. *Bull. Amer. Mus. nat. Hist.*, 94: 407-455.
- COOPER, L. H. N.
1935. Iron in the sea and in marine plankton. *Proc. roy. Soc. London*, 118B: 419-438.
- ELLIS, G. H. AND J. F. THOMPSON
1945. Determination of cobalt in biological materials with nitrosocresol. *Industr. Engng. Chem., Anal. Ed.*, 17: 254-257.
- FOX, H. M. AND H. RAMAGE
1931. Spectrographic analysis of animal tissues. *Proc. roy. Soc. London*, 108B: 157-173.
- HARVEY, H. W.
1947. Manganese and the growth of phytoplankton. *J. Mar. biol. Ass. U. K.*, 26: 562-579.
- HILLEBRAND, W. F. AND G. E. F. LUNDELL
1929. *Applied inorganic analysis*. J. Wiley and Sons, New York. XIX + 929 pp.
- HUTCHINSON, G. E.
1949. Unpublished notes in biogeochemistry.
- LAUBENFELS, M. W. DE
1950a. The *Porifera* of the Bermuda Archipelago. *Trans. zool. Soc. Lond.*, 27: 1-154.
1950b. An ecological discussion of the sponges of Bermuda. *Trans. zool. Soc. Lond.*, 27: 155-201.

- LOW, E. M.
1949. Iodine and bromine in sponges. *J. Mar. Res.*, 8: 97-105.
- NODDACK, I. AND W. NODDACK
1939. Die Häufigkeit der Schwermetalle in Meeres Tieren. *Ark. Zool.*, 32A: 1-35.
- ODUM, H. T.
1950. The biogeochemistry of strontium. Doctoral dissertation, Yale University.
- PEARSE, A. S.
1950. Notes on the inhabitants of certain sponges at Bimini. *Ecology*, 31: 149-151.
- SANDELL, E. B.
1944. Colorimetric determination of traces of metals. Interscience Publishers, New York. XVI + 487 pp.
- SCOTT, K. G.
1950. Radioactive waste disposal—How will it affect man's economy? *Nucleonics*, 6: 18-25.
- SPOONER, G. M.
1949. Observations on the absorption of radioactive strontium and yttrium by marine algae. *J. Mar. biol. Ass. U. K.*, 28: 587-625.
- TOPSENT, E.
1929. Phénomènes de Styloprothèse chez des Poecilosclérines. *Arch. Zool. exp. gén.*, 68: 19-32.
- TRELEASE, S. AND O. A. BEATH
1949. Selenium. New York. X + 292 pp.
- VERRILL, A. E.
1907. Porifera of the Bermuda Islands. *Trans. Conn. Acad. Arts Sci.*, 12: 330-344.
- WEBB, D. A.
1937. Studies on the ultimate composition of biological material. II. Spectrographic analyses of marine invertebrates, with special reference to the chemical composition of their environment. *Sci. Proc. R. Dublin Soc.*, 21: 505-539.