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Uptake of Ni by Marine Bacteria and Algae*

Akira KURATA**, Yoichi YOSHIDA** and Fumio TAGUCHI***

Abstract: The uptake ratios of Ni by marine bacteria and algae were examined. In the medium containing Ni ranging from 1 to 500 mg/*l*, approximately maximum 0.05 % and 0.07 % of added Ni were taken up by two bacterial strains for 6 hr. The uptake ratio of Ni by bacterial strains in the medium was rather higher at lower concentrations of Ni than at higher concentrations. The amount of Ni taken up by two algal strains *Stichococcus* sp. and *Thalassiosira* sp. increased in proportion to the concentration of Ni up to 50 mg/*l* only under the light condition, but it rather decreased at the concentration of 100 mg/*l* of Ni. The maximum amount of Ni taken up by two algal strains was 3.7 % and 3.2 % of added Ni respectively. The uptake ratio of Ni by algae was considerably higher in comparison with that by bacteria. However, in both cases of bacteria and algae, the uptake ratio was highest at the concentration of 10 mg/*l* of Ni. The CO_2 assimilation activity of *Stichococcus* sp. was rather enhanced in the presence of low concentration levels of Ni, while that of *Thalassiosira* sp. was not accelerated at all.

1. Introduction

Heavy metal pollution has proceeded extensively in the coastal areas and it has become a serious social problem in Japan. The distribution of heavy metals in coastal seawaters and bottom sediments has been investigated by many researchers, and the heavy metal content in several kinds of invertebrates in the coastal regions has also been examined by many workers. In spite of these recent studies, the uptake of heavy metals by marine microorganisms and phytoplankton in the coastal environments has not been made clear yet. In the previous paper (KURATA *et al.*, 1977), the authors reported the Ni pollution and the distribution of Ni-tolerant bacteria in water and sediments in the Sea of Aso which has long received industrial waste water containing Ni from a metallurgical factory.

In the present study, an attempt has been made to elucidate the uptake of Ni by marine bacteria and unicellular algae in relation to their nutritional and physiological condition.

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2. Materials and methods

(1) Basal medium for bacterial strains

A slightly modified ZOBELL 2216 medium (ZOBELL, 1946) was used as a basal medium for the bacterial strains, which has the following composition: polypeptone 5.0 g; KH_2PO_4 0.05 g; $FeSO_4 \cdot 7H_2O$ 0.05 g; agar 12 g (except for the liquid medium); in seawater 1000 m*l*; pH 7.6. The bacterial strains used were isolated from the bottom sediments of the Sea of Aso and were Ni-tolerant as described in the previous paper (KURATA *et al.*, 1977).

(2) Uptake of Ni by marine bacteria

The bacterial cells preincubated in the basal medium were harvested and washed by centrifugation several times with sterilized artificial seawater. After the adjustment of cell density, the cells were suspended in the sterilized artificial seawater containing varying concentrations of Ni and incubated for 6 hr at 20°C. Then, the bacterial cells were reharvested and washed again thoroughly several times by centrifugation. After washing, the pellets of bacterial cells were used directly for the determination of Ni.

(3) Basal medium for marine algae

A slightly modified ESP-medium (PROVASOLI, 1964) was used as a basal medium for algal strains. The composition of the basal medium is shown in Table 1. Incubation of algae was carried out at 20°C under the illumination of fluorescent lamps (*ca.* 3000 lux).

(4) Uptake of Ni by marine algae

Preincubated algae in the basal medium were treated in the same way as the case of bacteria. However, the algal cells were harvested finally by filtration with glass fiber filters of 0.45 μm porosity. After drying, Ni was extracted from the algal cells on the filters and determined. Glass fiber filters used for the filtration had been pretreated with HNO_3.

Table 1. Composition of the basal medium for algae

Autoclaved seawater	1000 m*l*	
ES enrichment*	20	pH 7.6
*ES enrichment		
$NaNO_3$	350	mg
Na_2-glycerophosphate	50	mg
Fe-EDTA	2.5	mg
SII metal solution**	25	m*l*
Thiamine	0.5	mg
Biotin	5	μg
Vitamin B_{12}	10	μg
Tris buffer	500	mg
to 100 m*l* of DW		
**SII metal solution		
Br (as Na^+)	100	mg
Sr (as Cl^-)	20	mg
Mo (as Na salt)	5	mg
Rb (as Cl^-)	2	mg
Li (as Cl^-)	2	mg
I (as K^+)	0.1	mg
to 100 m*l* of DW		

(5) Determination of Ni

Ni taken up by bacterial or algal cells was extracted with HNO_3 (10 %) and the amount was determined by an atomic absorption spectrophotometric method described in the previous paper (KURATA, 1974).

(6) Measurement of the CO_2 assimilation activity of algae

After the aseptical adjustment of cell density, the preincubated algal cells were inoculated to the sterilized artificial seawater containing varying concentrations of Ni and 1 μCi of ^{14}C-$NaHCO_3$ was added. After 4 hr incubation at 20°C under the light condition, the algal cells were harvested by filtration, eluted with HNO_3, CO_2 gas was removed by boiling and the radioactivity of the solution was measured with a liquid scintillation counter (Aloka, Model LSC-502).

3. Results and discussion

(1) Effect of Ni on the bacterial growth

The growth of several Ni-tolerant bacteria in the basal medium containing varying concentrations of Ni are shown in Fig. 1. The growth of all of the bacterial strains in the basal medium was affected by the addition of Ni and the cell yield of each strain in the medium after 80 hr

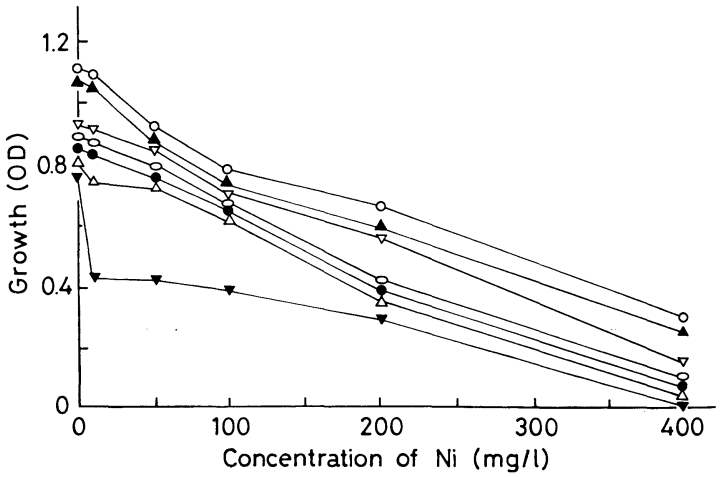

Fig. 1. Growth inhibition of 7 strains of Ni-tolerant bacteria after 80 hr incubation in the ZOBELL 2216 medium containing varying concentrations of Ni at 20°C.

incubation at 20°C was decreased gradually in proportion to the amount of Ni added. One strain failed to grow in the medium containing 400 mg/*l* of Ni, but two strains grew well in the same medium. About 220 bacterial strains isolated from the seawater and the bottom sediments of the Sea of Hiuchi which has long received extensive heavy metals pollution could not survive in the medium containing 300 mg/*l* of Ni, as reported in the previous paper (KURATA and YOSHIDA, 1978). Therefore, these bacterial strains isolated from the Sea of Aso were particularly more tolerant to Ni than those from the Sea of Hiuchi.

(2) Uptake of Ni by marine bacteria

The uptake of Ni by two bacterial strains in the medium containing varying concentrations of Ni was examined and the results obtained were shown in Fig. 2. Uptake of a considerable amount of Ni by the bacterial cells in the cultures of two strains was clearly observed. However, the uptake pattern by two strains in the medium containing Ni ranging from 1–500 mg/ was different. Approximately 24 and 32 μg of Ni were taken up finally by two strains in the period of 6 hr in the medium containing 500 mg/

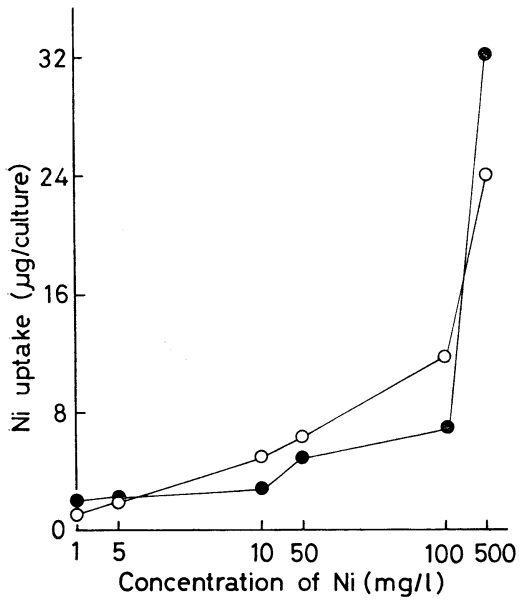

Fig. 2. Ni uptake by two strains of Ni-tolerant bacteria (μg/50 m*l* of culture, OD of which being 0.2) for 6 hr at 20°C.

of Ni and these correspond to 0.05% and 0.07% of the total amount of Ni in the culture, respectively. The uptake ratio of Ni in the medium was rather higher at low concentrations of Ni than at high concentrations in both strains.

WEBB (1970a) reported that the Co-tolerant strain of *Aerobacter aerogenes* was resistant also to Ni in the medium containing adequate amounts of Mg, and that the parent strain of *A. aerogenes* took up about 30 *n* moles/mg dry wt. organisms of Ni for 20 hr at 28°C. Uptake of Ni by the marine bacterial strains shown in Fig. 2 was considerably higher in comparison with that by the strain of *A. aerogenes* reported by WEBB (1970b). Removal of added Zn and Cd from solution by bacteria was reported by MCLERRAN and HOLMES (1974). About 20% of ^{65}Zn added to the cultures was directly associated with the bacterial cells and 85% of ^{65}Zn was removed from solution by the bacteria in the period of 120 hr because of the active production of H_2S. CHOPRA (1971) reported that significant amount of Cd was taken up by the Cd-sensitive strain of *Staphylococcus aureus* but little amount was taken up by Cd-resistant strain. This result is quite different from the results obtained with the Ni-tolerant bacteria in the present study. The difference may be due to the kind of heavy metal as a pollutant or the classificational characteristic of bacteria. Further cytological and taxonomical studies on these resistant strains are desirable.

(3) Effect of Ni on the algal growth and CO_2 assimilation

Inhibition of the growth of algae by varying concentrations of Ni is shown in Figs. 3 and 4. A green alga *Stichococcus* sp. was more tolerant to Ni than a diatom *Thalassiosira* sp. and an obvious growth of the latter was not observed in the presence of 10 mg/*l* of Ni. However, the higher the Ni concentration in the medium, the more elongated the period of lag phase of growth of these organisms. According to the study by ERICKSON (1972), the growth of *Thalassiosira pseudonana* was inhibited markedly by Cu in unenriched seawater and the number of cells of the alga decreased to approximately 1/10 in 72 hr at the concentration of 30 μg/*l* of Cu. According to the study by MONAHAN

(1976), two species of *Scenedesmus* and a species of *Ankistrodesmus* were tolerant to 1 mg/*l* of Pb, and the tolerance of *Scenedesmus obtusiusculus* to Pb in the phosphate-limiting medium was doubled with the supply of phosphate. As shown in Figs. 3 and 4, *Stichococcus* sp. and *Thalassiosira* sp. grew well even in the medium containing 8 mg/*l* of Ni. It may be due to the enough supply of phosphate in the medium or the eminent tolerance to Ni of these algal strains.

Influences of Ni concentrations on the CO_2

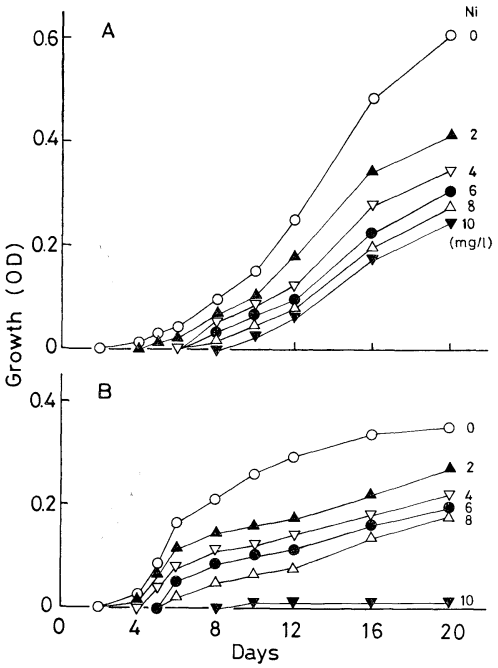

Fig. 3. Growth of *Stichococcus* sp. (A) and *Thalassiosira* sp. (B) in the varying concentrations of Ni at 20°C under the illumination of fluorescent lamps.

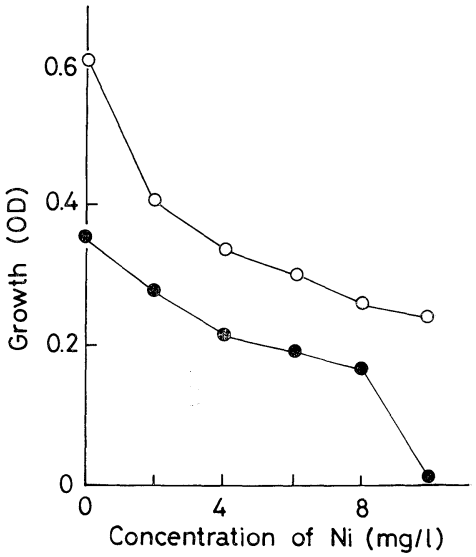

Fig. 4. Growth inhibition of *Stichococcus* sp. (○) and *Thalassiosira* sp. (●) as a function of Ni concentrations in the ES medium at 20°C under the illumination of fluorescent lamps in 20 days.

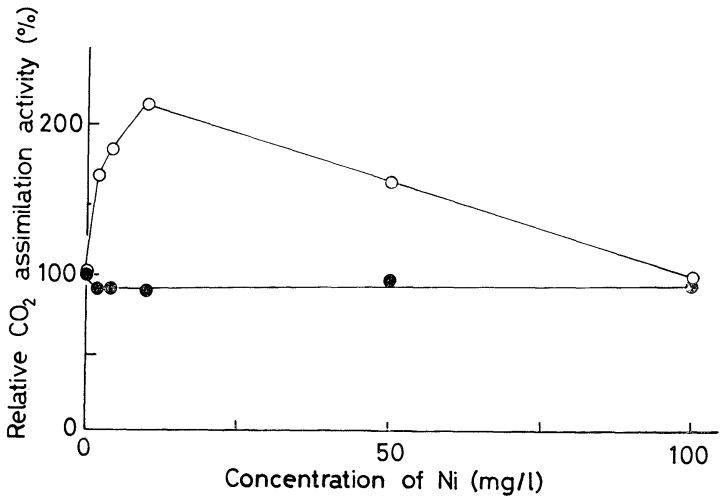

Fig. 5. Relative CO_2 assimilation activities of *Stichococcus* sp. (○) and *Thalassiosira* sp. (●) in varying concentrations of Ni for 4 hr at 20°C under the illumination of fluorescent lamps.

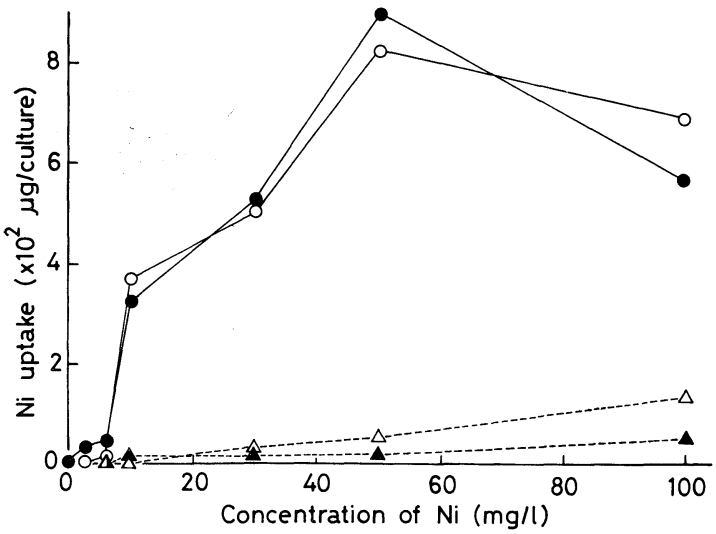

Fig. 6. Ni uptake by *Stichococcus* sp. (○, ▲) and *Thalassiosira* sp. (●, △) (µg/10 m*l* of culture, OD of which being 0.12) in varying concentrations of Ni for 4 hr at 20°C under the light (solid line) and dark (broken line) conditions.

assimilation by the algal strains are shown in Fig. 5. The CO_2 assimilation activity of *Stichococcus* sp. was accelerated in the presence of Ni and it was doubled in the presence of 10 mg/*l* of Ni. On the contrary, the activity of *Thalassiosira* sp. was hardly affected by the presence of Ni.

(4) Uptake of Ni by algae

The results of the Ni uptake by *Stichococcus* sp. and *Thalassiosira* sp. in the sterilized saline containing varying concentrations of Ni for 4 hr are shown in Fig. 6. The amount of Ni taken up by two algal strains increased in proportion to the concentrations of Ni up to the concentration of 50 mg/*l* of Ni, but it rather decreased at the concentration of 100 mg/*l* of Ni. However, the uptake ratios of Ni were highest at the concentration of 10 mg/*l* of Ni in both algae, and those of *Stichococcus* sp. and *Thalassiosira* sp. were 3.7 % and 3.2 % respectively. The uptake ratios of Ni by algae were considerably highr in comparison with those by bacteria shown in Fig. 2. In the present experiments, the highest uptake ratios of Ni by algae and bacteria were shown at the same concentration of 10 mg/*l* of Ni. It is a very significant problem both for inquiring the biological mechanisms of Ni uptake by different kinds of microorganisms and for trying the Ni removal by using the Ni-tolerant microorganisms from the human living environment. At any rate, Ni was taken up actively by different kinds of marine microorganisms even at relatively high concentrations. From the results, the removal of Ni using various kinds of microorganisms in the polluted environments may be expectable from the commercial point of view in near future.

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海洋性細菌および植物プランクトンの Ni 取込

倉田　亮，吉田陽一，田口二三生

要旨: 阿蘇海およびその付近の海域から分離したNi耐性を示す海洋性細菌ならびに植物プランクトンの Ni 取込について調べた。用いた細菌株は 400 mg/*l* の Ni 濃度においても良好な生育を示した。Ni 濃度が段階的に 500 mg/*l* まで含まれる培地における細菌の Ni 取込は，20°C 6時間で最高 0.07％程度の値を示し，その取込率は概して低濃度において高く，高濃度において低い傾向がみられた。また，用いた植物プランクトン，緑藻 *Stichococcus* sp. およびケイ藻 *Thalassiosira* sp., は 8 mg/*l* の Ni 濃度まで良好な生育を示した。これらの藻類の Ni 取込は光条件下においてみられ，Ni 濃度が 50 mg/*l* までは取込量がほぼ濃度に比例して多かったが，50 mg/*l* 以上ではむしろ減少した。両植物プランクトンの Ni 取込率は，20°C 4時間でそれぞれ 50 mg/*l* Ni の 3.7％ および 3.2％で，細菌の場合よりかなり高かった。細菌の場合にも，植物プランクトンの場合にも，Ni 取込率は 10 mg/*l* の Ni 濃度の時に最も高い値を示した。緑藻 *Stichococcus* sp. では，培地中に低濃度の Ni が含まれた場合，CO_2 同化活性はむしろ促進される傾向がみられ，10 mg/*l* の Ni 濃度の時に最も高い値を示した。しかし，ケイ藻 *Thalassiosira* sp. では，このような傾向は全くみられなかった。

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A Mass-Culture Method for *Artemia salina* Using Bacteria as Food*

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Abstract: The present experiments were carried out to clarify the relative food value of bacteria and to develop a method for the mass-culture of *Artemia* using bacteria as food. By performing screening tests on various bacteria as available food for *Artemia* larvae, the B-9 strain of *Acinetobacter* sp. was found to be effective. Larval culture using the bacterial strain and *Chlamydomonas* sp. as food for estimation of relative food value indicated that the B-9 strain food value is slightly less than that of *Chlamydomonas* sp. Several culture conditions were examined to test the feasibility of utilizing bacteria for mass-culture. The results showed that the most effective culture condition was a food mixture of the B-9 strain at a concentration of 10^8/m*l* and *Chlorella* sp. at 10^6/m*l*, with a density of *Artemia* of 5 indiv./m*l* and a culture temperature of 20°C.

1. Introduction

Nowadays, in many countries, the following live foods are being used for mariculture purposes: *Rotifer*, *Artemia*, *Daphnia*, *Moina*, *Polyphemus*, and *Gammarus* (JHINGRAN and GOPALAKRISHAN, 1974). *Artemia* is the most frequently used and the most convenient form among these organisms, as it is possible to readily obtain various sizes of larvae which can be fed to predators of different size, whenever necessary.

Several studies have attempted to clarify the nutritional preferences of *Artemia*. TERAMOTO and KINOSHITA (1961) fed the shrimp on Wakamoto***, bread yeast, and the dried residue of acetone-butanol fermentation. KUSAKABE (1964) found that wheat flour mixed with soybean powder was a very effective food for the shrimp. Furthermore, cultures of some kinds of unicellular Chlorophyceae, Chrysophyceae, Cryptophyceae, and diatoms have successfully been fed to shrimp (PROVASOLI *et al.*, 1959; GILCHRIST, 1960; NIMURA, 1963; LASKER, 1966; TAKANO, 1967). However, experiments on bacteria as food for the shrimp have been rare (SEKI, 1966).

The purpose of the present investigation was to clarify the relative food value of various strains of marine bacteria and to develop a method for the mass-culture of *Artemia* using bacteria as food. The shrimp used in the experiments was *Artemia salina* LEACH, dried eggs of which were obtained commercially through the Shintoa-Koeki Co, Ltd. from California, U.S.A. The experiments were carried out at the Tamano Marine Station, Japan Fisheries Farming Association (JFFA), and at the Marine Microbiology Laboratory, Ocean Research Institute, University of Tokyo, during the period from May to October, 1977.

2. Materials and methods

Screening of isolates as food Screening tests of potential food for *Artemia* larvae were carried out on isolates of 12 strains of bacteria and one strain of yeast. The isolates were collected from cultures of microbial flock using equipment of the Tamano Marine Station, JFFA.

The culture vessel was a 500-m*l* cylindrical beaker, containing 400 m*l* sterilized seawater,

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*** A commercial drug made of cultures of several types of commonly used molds on cereal germs, and enriched with active lactobacilli and dried yeast.

at room temperature of about 20°C, with aeration. A cylindrical net (100 μm mesh size), sterilized with 70% ethanol, was aseptically placed on the beaker. Then, 100 nauplii of *Artemia* hatched germ-free by the method of PROVASOLI *et al.* (1959) were transferred into the net. The isolates were grown to late logarithmic phase in Medium 2216E broth (OPPENHEIMER and ZOBELL, 1952), and the cultures were harvested by centrifuging at 4,000 ×g for 15 min. Packed cells were added to the culture vessel to obtain a concentration of 10^8/m*l*. After the nauplii had fed on the isolates for 4 hours, the net with the nauplii was removed and held in a beaker containing 400 m*l* sterilized seawater for 20 hours.

This was repeated every 24 hours for one week, and during the experimental period the numbers of surviving larvae were recorded.

Estimation of food value Determinations were made of the food value for *Artemia* larvae of three kinds of food, including the B-9 and P strains confirmed by the screening test as the most suitable foods, and *Chlamydomonas* sp. reported by SICK (1976) to be the most efficient food. The experimental procedure was the same as that mentioned above. Arbitrary concentrations of food were set at 5×10^5/m*l* for *Chlamydomonas* sp. and 10^8/m*l* for the two bacterial strains. 200 newly hatched nauplii were accomodated in each. The experiment was continued for 11 days, and during this period the numbers of survivors, body length and body weight of the larvae were observed.

Mass-culture of Artemia The B-9 strain (confirmed by the screening test as the most suitable food for *Artemia* larvae), the microbial flock (produced by the method of IMAMURA and SUGITA (1972)), and *Chlorella* sp. (cultured at Tamano Marine Station) were used as food for large scale larval culture.

The experiments were divided into four steps. In the first step, arbitrarily chosen culture conditions were set up as follows; culture density of the larvae was 1 indiv./m*l*, water temperature was 20°C, and food species were supplied independently at concentrations of 10^7/m*l* of *Chlorella* sp., 10^8/m*l* of the B-9 strain, and 10^8/m*l* of the microbial flock.

In the second step, to examine whether a combined microbial food was more suitable, four combinations of food concentrations were selected. The B-9 strain (10^8/m*l*) was combined with *Chlorella* sp. at 10^6/m*l* and 10^7/m*l*, and the microbial flock (10^8/m*l*) was also combined with *Chlorella* sp. at 10^6/m*l* and 10^7/m*l*. Water

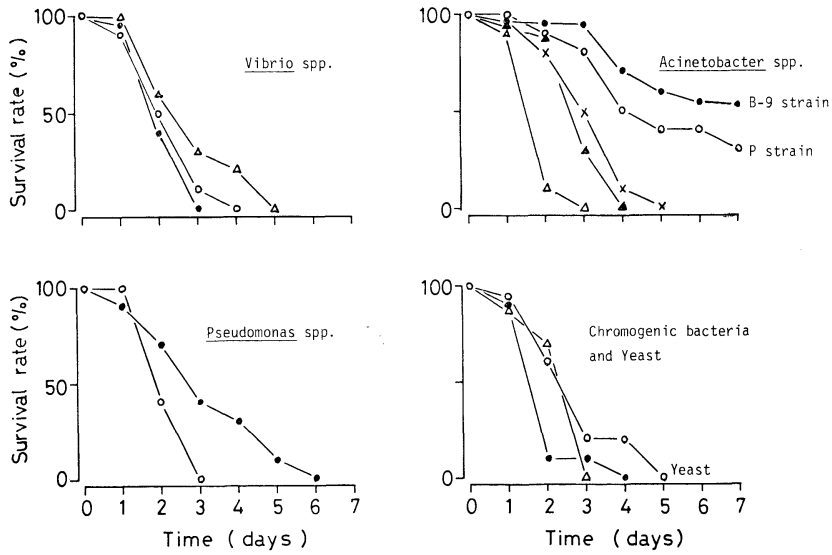

Fig. 1. Effect of different bacterial and yeast strains as food on the survival rate of *Artemia*.

temperature and larval density were 20°C and 1 indiv./m*l*, respectively.

The third step in the investigation was carried out to determine the most suitable density for mass-culture. Four kinds of larval densities were selected at 1, 5, 20 and 50 indiv./m*l*. The larvae were cultured on the mixed food of the B-9 strain (10^8/m*l*) and *Chlorella* sp. (10^6/m*l*) with a larval density of 5 indiv./m*l*, which was confirmed by the third series of experiments as the most suitable.

The culture vessel for the experimental mass-culture of *Artemia* was a 500 *l* capacity square slate tank, into which 500 *l* of sand-filtered seawater was added. A rate of aeration was 1 *l*/min., and a continuous illumination of 200 lux was provided by fluorescent light. Agitation was provided by an agitator in order to prevent precipitation of the food and the larval faecal pellets, and further to raise food value. The cultures of the B-9 srtain, the microbial flock and *Chlorella* sp. were harvested by continuous centrifuging, and washed cells were re-suspended in their respective larval culture tanks. This feeding was carried out every 24 hours. The larval culture was continued for 12 days, and during the experimental period the number of survivors, body length and body weight of the larvae were observed.

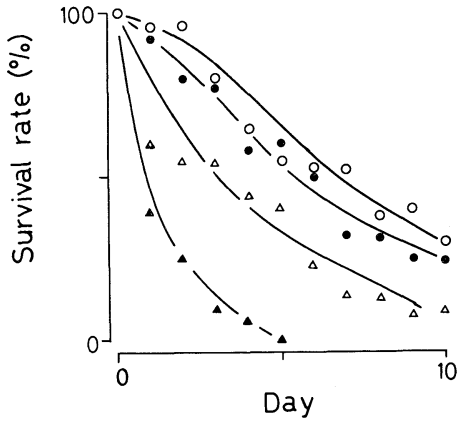

Fig. 2. Comparative effect of two strains of bacteria and *Chlamydomonas* sp. as food on the survival rate of *Artemia*. ○, *Chlamydomonas*; ●, B-9 strain; △, P strain; ▲, blank.

3. Results

Selection of bacterial strain as available food

As a result of the screening tests of the isolates as available food, 2 strains of *Acinetobacter* spp. (P and B-9) were found to be effective (Fig. 1). Especially effective was the B-9 strain, in which the survival rate of the cultured larvae was approximately 60 %. Survival of larvae fed on

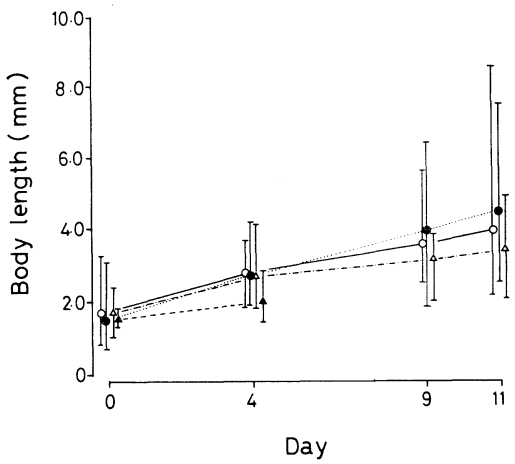

Fig. 3. Comparative effect of two strains of bacteria and *Chlamydomonas* sp. as food on the increase in body length of *Artemia*. ○, *Chlamydomonas*; ●, B-9 strain; △, P strain; ▲, blank.

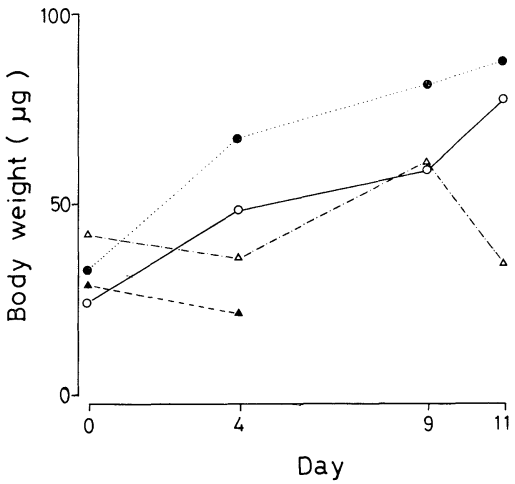

Fig. 4. Comparative effect of two strains of bacteria and *Chlamydomonas* sp. as food on the increase in body weight of *Artemia*. ○, *Chlamydomonas*; ●, B-9 strain; △, P strain; ▲, blank.

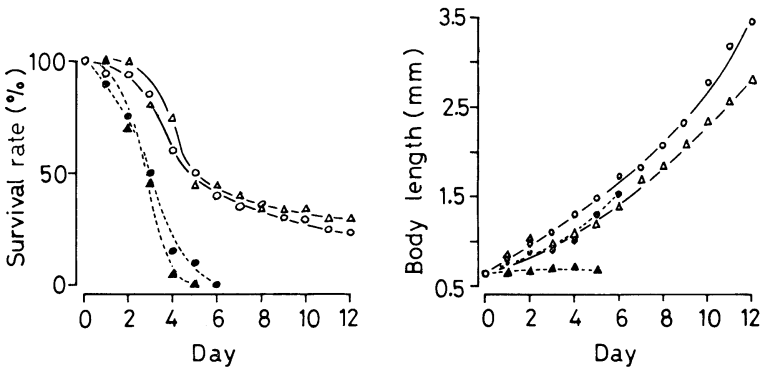

Fig. 5. Effect of different microbial foods, supplied independently, on the survival rate and body length increase of *Artemia*. Initial density of *Artemia* was one individual per m*l*. Cultivation temperature was 20°C. ○, B-9 strain (10^8/m*l*); ●, microbial flock (10^8/m*l*); △, *Chlorella* sp. (10^7/m*l*); ▲, non-addition of food.

Table 1. Effect of different food microorganisms, supplied independently or mixed, on the growth coefficient and survival rate of *Artemia salina*, cultured in a mass-culture tank.

Food density (cells/m*l*)			*Artemia* density (ind./m*l*)	Temp. (°C)	Growth** coefficient	Survival rate (%)
B-9 str.	Microbial flock	*Chlorella*				
10^8	—	—	1	20	0.05897	24
—	10^8	—	1	20	0.05800	0
—	—	10^7	1	20	0.05073	30
—	—	—	1	20	0.01503	0
10^8	—	10^6	1	20	(1) 0.06172*	50
					(2) 0.06375*	48
10^8	—	10^7	1	20	0.06132	45
—	10^8	10^6	1	20	0.04671	24
—	10^8	10^7	1	20	0.05840	40
10^8	—	10^6	5	20	(1) 0.06593*	54
					(2) 0.06941*	58
10^8	—	10^6	20	20	0.03068	20
10^8	—	10^6	50	20	0.02286	9
10^8	—	10^6	5	28	0.07195	38

* Results of the two different experiments.

** Regression coefficient of the curve obtained by plotting the ratio of the logarithm of body length to the time from the start of culture.

the P strain was about 30% up to 7 days, whereas using the other strains, the larvae could not survive during this experimental period.

Estimation of food value Larval culture using these two strains (P and B-9) with *Chlamydomonas* sp. as a control, was carried out. Survival rate of larvae fed on *Chlamydomonas* sp. was 31%, on B-9 was 26%, and on P was 9% (Fig. 2). The increase in body weight and body length of the larvae was greatest for the larvae fed on B-9, followed by *Chlamydomonas* fed larvae, and growth using the P strain was negligible (Figs. 3 and 4). The individuals forming eggs in the ovarium numbered, at 11 days, four with B-9, two with *Chlamydomonas* sp., and none with the P strain.

The above results show that the B-9 strain

is of slightly less value than *Chlamydomonas* sp. as available food for *Artemia* larvae.

Conditions for mass-culture To obtain large yields of *Artemia* larvae for practical mariculture purposes, it is necessary to use a large scale tank with an open system. The present experiments were carried out using a 500-*l* slate tank to examine the possibility of using bacteria as food for further mass-culture of *Artemia*.

Shown in Fig. 5 are the results of the first investigation, in which the survival rate of the larvae fed on *Chlorella* was highest, and increase in body length of larvae fed on the B-9 strain was greatest. Larvae fed on the microbial flock had almost all died by the 6th day, although the growth coefficient was equal to that of the larvae fed on B-9 (Table 1). The growth coefficient is the regression coefficient of the curve obtained by plotting the ratio of the logarithm of body length to the time from the start of culture.

In the second examination, as shown in Fig.

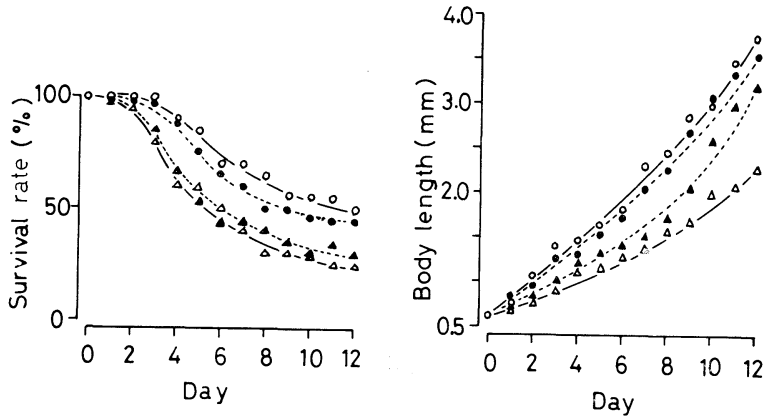

Fig. 6. Effect of combined microbial foods on the survival rate and body length increase of *Artemia*. Initial density of *Artemia* and cultivation temperature are the same as shown in Fig. 5. ○, mixture of B-9 strain (10^8/m*l*) and *Chlorella* sp. (10^6/m*l*); ●, mixture of B-9 strain (10^8/m*l*) and *Chlorella* sp. (10^7/m*l*); △, mixture of microbial flock (10^8/m*l*) and *Chlorella* sp. (10^6/m*l*); ▲, mixture of microbial flock (10^8/m*l*) and *Chlorella* sp. (10^7/m*l*).

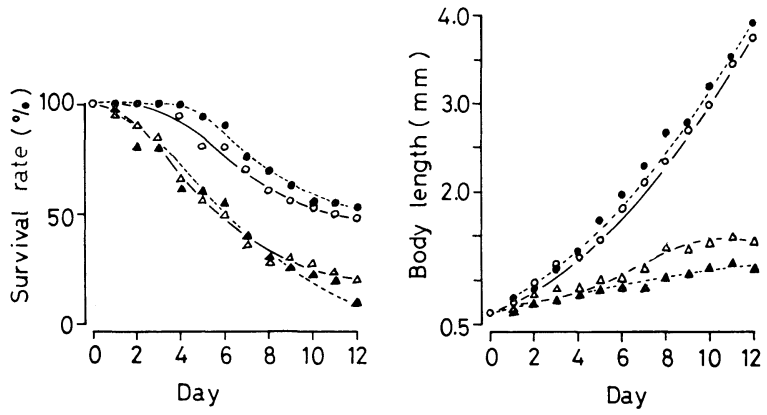

Fig. 7. Effect of *Artemia* density on their survival rate and body length increase. *Artemia* was cultured on a mixture of B-9 strain (10^8/m*l*) and *Chlorella* sp. (10^6/m*l*) at 20°C. ○, 1 indiv./m*l*; ●, 5 indiv./m*l*; △, 20 indiv./m*l*; ▲, 50 indiv./m*l*.

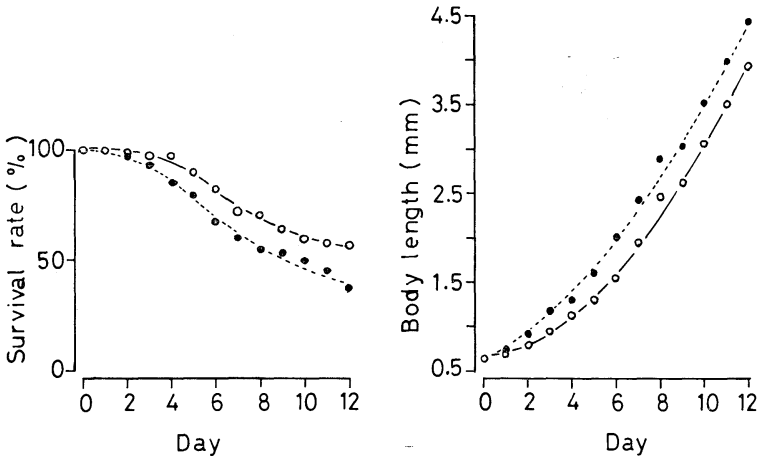

Fig. 8. Effect of cultivation temperature on the survival rate and body length increase of *Artemia*. *Artemia* (5 indiv./m*l*) was cultured on a mixture of B-9 strain (10^8/m*l*) and *Chlorella* sp. (10^6/m*l*). ○, cultured at 20°C; ●, cultured at 28°C.

6, the highest values for survival rate and body length increase were found in the larvae fed on the mixture of the B-9 strain (10^8/m*l*) and *Chlorella* sp. (10^6/m*l*).

From the results of the third examination, it is clear that the culture density of 5 indiv./m*l* produced the highest survival rate and growth coefficient (Fig. 7).

Furthermore, larval cultures at 20°C and 28°C indicated that survival rate was higher at 20°C and growth coefficient was the reverse (Fig. 8). This result suggests that mass-culture of *Artemia* as food for mariculture purposes is better carried out under low temperature conditions to increase survival, especially as *Artemia* eggs are becoming increasingly expensive.

4. Discussion

The results of the screening tests indicate that even in closely related species of bacteria there are differences in availability as food for *Artemia* larvae. This conclusion agrees closely with the data derived from studies of feeding experiments by PROVASOLI *et al.* (1959) in that *Tigriopus* and *Artemia* display a diverse ability to utilized different species of algae as food, and that this selectivity does not depend on the size of the food organism, as one organism may be nutritionally suitable, and the other unsuitable. The B-9 strain, which has a slightly lower food value than *Chlamydomonas* sp., was suitable for the larvae of the brine shrimp. Though our results provide experimental support for the belief that bacteria are available as food for marine animals (REISWIG, 1975; RIEPER, 1978), we consider microbial flocks which are made nutritionally more valuable by attaching an available protozoa or unicellular algae better as larval food for mariculture purposes than aggregates formed by the available bacterium alone.

Concerning the simple food experiments, it is not clear why the larvae fed on the microbial flock produced by the method of IMAMURA and SUGITA had almost all died by the 6th day even though their growth coefficient was equal to that of the larvae fed on the B-9 strain. Although there is no concrete nutritional evidence, we may speculate as to the reason as follows. One hypothesis which is supported by the results of the mixed food experiments is that the growth coefficient and survival rate of the larvae fed on the mixture of the microbial flock (10^8/m*l*) and the *Chlorella* (10^7/m*l*) are higher than those of the ones fed on *Chlorella* or the microbial flock only; that is, the larvae fed on the microbial flock received nutritional supplements from *Chlorella*.

On the other hand, the growth coefficient and survival rate of larvae fed on the mixture of the B-9 strain and *Chlorella* were higher with

a low concentration of *Chlorella* than with a high concentration, in contrast to the microbial flock and *Chlorella*. This result could have two explanations in that i) the relative food value of *Chlorella* is lower than that of *Chlamydomonas* sp. (SICK, 1976) or ii) high concentrations of *Chlorella* prevent the growth of *Daphnia* (RYTHER, 1954). Apart from the nutritional interpretation, the result that the food value was higher in mixed food than in simple food is explained by the finding of HANAOKA (1977) that ammonia accumulated in a closed system of cultivation is absorbed by *Chlorella*; that is, nutrient recycling in the tank was carried out by *Chlorella*.

Although these experiments were intended to provide criteria for the mass-culture of *Artemia* using bacteria as food, the data concerning the culture density, growth and survival rates of the larvae seem as yet insufficient. Hence, to use bacteria or microbial flock practically as food for mariculture purposes, further information about bacterial behavior in the culture tank will be necessary. We anticipate that bacteria will be found to be useful not only as food but also as biological controlers of fish disease and activators of the rate of nutrient regeneration.

Acknowledgements

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餌料細菌を用いるアルテミアの大量培養

安田公昭，多賀信夫

要旨: アルテミア（*Artemia salina* LEACH）の培養に従来用いられてきたクラミドモナス（*Chlamydomonas* sp.）やクロレラ（*Chlorella* sp.）などの餌料に代りうる有効な餌料細菌を選択するため，今村・椙田方式（1972）で生産される微生物フロック餌料から分離された細菌12株と酵母1株とを供試餌料として，アルテミアの培養が試みられた。その結果，*Acinetobacter* 属細菌の2株（B-9 およびP株）に餌料としての有効性が認められた。更に，B-9 菌株とクラミドモナスとを投餌した場合のそれぞれの餌料効果を比較した結果，アルテミアの歩留りは10日間で前者は 26％ であり後者は 31％であったが，その体長および体重の増加は前者の場合優れていることが判明した。

B-9 菌株とクロレラとの単独および混合餌料ならびに微生物フロック餌料を用いて，アルテミアの大量培養（500 *l*）に関する最適条件の検討が行なわれた。その結果，培養温度 20°C で，B-9 菌株とクロレラとの混合餌料をそれぞれ 10^8/m*l* および 10^6/m*l* の濃度割合として添加し，アルテミアの収容密度を5個体/m*l* として培養した場合に，アルテミアの歩留り（10日間で 60％）と体長増加は最良であることが認められた。

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Tome 18, N° 2, pp. 63 à 68, Mai 1980

Determination of Biogenic Silica in Marine Sediment*

Akiyoshi KAMATANI**

Abstract: A technique for determining biogenic silica in sediment was studied by modifying the existing chemical methods. The improved procedure involves the use of 40 m*l* of 5% Na_2CO_3 solution for 100-minute digestion of less than 50 mg of sediment at 100°C. The content of biogenic silica in sediments can be estimated by subtracting non-biogenic silica, calculated from the extracted aluminum concentration, from the total amount of extracted silica. This technique is much simpler and quicker than other techniques. The improved method was applied for demonstrating the vertical distribution of biogenic silica in a core from the central part of the Bering Sea.

1. Introduction

Determination of biogenic silica in seawater and sediments is one of the important factors in studying silica balance in oceans and also in the estimation of paleoproductivity. A number of methods for determining biogenic silica in sediments have been reported, but the methods still remain as a frustrating problem. Included among these are X-ray diffraction (GOLDBERG 1958, CALVERT 1966), infrared spectroscopy (CHESTER and ELDERFIELD 1968) and chemical solution (BEZURUKOV 1955, VAN ANDEL 1968, JONES 1969, HURD 1973) methods. These developed techniques do not given consistent results even for the same sample. EISMA and VAN DER CAAST (1971) disclosed that X-ray method suffered from the disadvantage by the presence of minute amount of clay minerals or cations. The method using infrared spectroscopy is interfered by the presence of more than 5% quartz in sediments, and requires a time-consuming modification to the technique. Moreover, if the biogenic silica : quartz ratio is less than 3 : 1, it is not possible to determine the biogenic silica content by this method. LEINEN (1977) proposed a method; opal content of deep sea sediments could be estimated by subtracting non-biogenic silica, calculated from the aluminum and magnesium contents in the sediment, from the total silica content of the sample. However, he suggested there that the method had not been validated for nearshore sediments which are rich in terrigenous debris and also in such clays having significantly more aluminum than most pelagic deposits.

A more promising approach for determining biogenic silica in sediment is based on a chemical solution method; alkaline solution method provides a simple and quicker substitute, an extracting method of this type has been studied and an improvement was made in the existing chemical methods. In addition, it has provided a method for correcting the amount of silica released from clay minerals. The improved method was applied for demonstrating the vertical distribution of biogenic silica in a core sample from the Bering Sea.

2. Samples and analytical methods

Two kinds of biogenic silica were used to ascertain the most suitable extracting condition; diatomaceous earth which was collected from the bed buried in the upper-pliocene in Makkari, Hokkaido and silicious sponge from the littoral zone of Onagawa, Miyagi Pref. The bulk of the diatomaceous earth, prior to the experiments, was suspended in a solution of 2 N HCl to decompose carbonate in it with slight warming. Clay minerals were separated from the diatom valves by decantation. The refined diatom valves were recovered by filtration, washed with distilled water until free from acid. Finally they were dried at 105–110°C and stored in a desic-

* Received October 29, 1979
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cator. In this sample *Nitzschia* sp. was dominated. Silicious sponge was thoroughly digested at 100°C with concentrated nitric acid and hydrogen peroxide to remove organic matter. The refined silica spicules, after washed with distilled water until free from acid, were preserved for the experiments.

The core sample, which was collected from the central part of the Bering Sea by Hakuho Maru cruise, was cut at suitable intervals (5 cm), dried at room temperature and ground with an agate mortar. The pulverized samples were subjected to the improved analytical method.

Reactive silica extracted by alkaline solution was measured by silica-molybdate colorimetric method as described in the previous paper (KAMATANI 1971). For the determination of the total amount of biogenic silica suspended in alkaline solution, suitable small aliquots of the suspension put into a platinum crucible and the water was evaporated gently. The residue was fused with anhydrous sodium carbonate. After dissolving the cake in distilled water, the solution was used for the determination of reactive silica.

Aluminum extracted by alkaline solution was determined fluorometrically using Pontachrom Blue Blak R (PBBR), which was the original method utilized by WEISSELER and WHITE (1946). A portion of the extracted solution containing suitable amount of Al was neutralized with 0.5 N HCl, and buffered to the optimum pH of 4.9, followed by the addition of hydroxylamine to eliminate iron interference. After the addition of PBBR reagent, the fluorescence measurement was made within the first 2–5 hours using Hitachi Fluorescence Spectrophotometer.

3. Selection of extracting conditions

The amount of silica released from sample must be affected by the extracting conditions such as concentration of alkaline solution, temperature, digestion time and the volume ratio of sample to solution. Alumino-silicates in sediments should also set free silica from their lattices in the course of the treatment with alkaline solution.

Effect of digestion time: To find out the optimum digestion time, a predetermined amount of diatom valves or sponge spicules were put into the alkaline solution and mixed well together. Forty milliliters of the mixture were divided into each 50 ml polycarbonate tube. A series of the tubes, stoppered with caps, was placed in a water bath kept at 100°C. The tube was taken from the bath at intervals, swirled gently by hand and immediately dipped into a running water basin in order to cool to room temperature. After removal of remains by centrifugation, the reactive silica in the supernatant was measured by the above method, and the results are given in Fig. 1. The dissolution rate is greatly influenced by the nature of the extracting solution; 5% Na_2CO_3 solution takes long time for changing the silicious sponge spicule to soluble form, while the strong alkaline solution (1.0 N NaOH) can solubilize quickly the rigidly silicified spicule by 40-minute digestion. Diatom silica dissolves completely even by 60-minute digestion with 5% Na_2CO_3 solution.

Dissolution of clay minerals and quartz: To evaluate the amount of silica and aluminum that could be released from clay minerals in the course of digestion, four common clay minerals–montmorillonite, kaolinite, illite and chlorite–were subjected to the above digestion procedure. The amount of silica and aluminum released are different among the clay minerals (Table 1). In the case of 40-minute digestion with 1.0 N

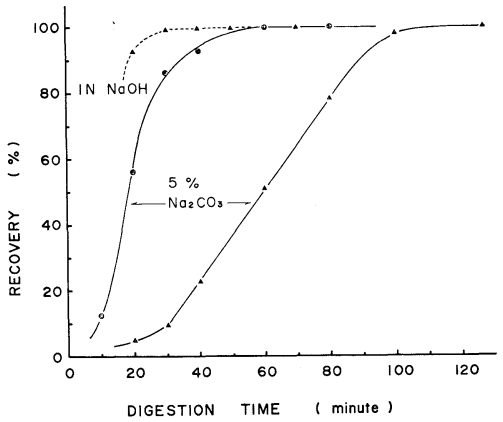

Fig. 1. Dissolution of biogenic silica as a function of digestion time. Biogenic silica of 40 mg was suspended in 40 m*l* of alkaline solution. -▲-, sponge spicule; -●-, diatom wall.

Table 1. Chemical analysis, and SiO_2 and Al_2O_3 extracted from clay minerals by alkaline digestion.

	Kaolinite	Illite	Chlorite	Montmorillonite	Quartz
Chemical analysis* (%)					
SiO_2	46.29	44.92	29.09	51.62	99.99
Al_2O_3	37.66	36.19	21.82	24.31	—
SiO_2/Al_2O_3	1.23	1.24	1.33	2.12	—
40-minute digestion with 1.0 N NaOH (mg/g)					
SiO_2	80.1	22.4	2.5	35.2	8.1
Al_2O_3	117	32.4	1.9	16.9	—
SiO_2/Al_2O_3	0.7	0.7	1.3	2.1	—
100-minute digestion with 5 % Na_2CO_3 (mg/g)					
SiO_2	5.78	6.43	1.64	6.75	3.96
Al_2O_3	3.21	3.94	0.93	1.92	—
SiO_2/Al_2O_3	1.8	1.6	1.8	3.5	—

* These components were determined by the current method used for mineral analysis (e.g. EASTON 1972).

NaOH solution, one gram of chlorite releases only 2.5 mg SiO_2 and 1.9 mg Al_2O_3, whereas the amounts of the both components released from the other three clays are about one order of magnitude higher than those released from chlorite. Quartz also releases 8.1 mg SiO_2 per one gram. On the other hand, the digestion method with 5 % Na_2CO_3 solution is showed to be mild and the amounts of the released silica and aluminum from clays are far smaller than those obtained by the treatment with 1.0 N NaOH solution. Accordingly, the mild method using 5 % Na_2CO_3 solution is a more promising approach to the problem of determining biogenic silica in sediments.

Effect of volume ratio: The following experiments were carried out to ascertain the optimum amount of sediment for 40 m*l* of 5 % Na_2CO_3 solution. The tube, which contained the accurately weighed sediments mixed with 40 m*l* of the solution, was subjected to 100-minute digestion at 100°C. The relation between the amount of extracted silica and the amount of suspended sediment shows good linearity when up to 50 mg is suspended in 40 m*l* of the solution (Fig. 2). For each regression line, the correlation coefficient between the extracted SiO_2 and the sediment suspended in the solution is $r=0.999$. The same trend

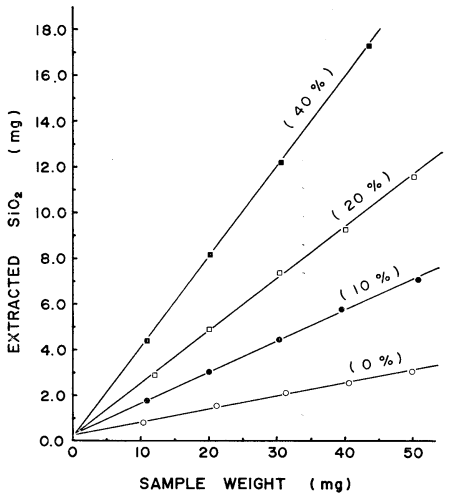

Fig. 2. Relations between sample weight and extracted silica. Each per cent in the parentheses shows the weight per cent of biogenic silica added in sediment.

was also observed for the extracted aluminum.

In order to test the reproducibility of this method five portions of a mixture sample (10 % of biogenic silica in sediment) were used for the analytical procedure. When the mixture sample of 50 mg was subjected to 100-minute digestion in 40 m*l* of the solution, the coefficient of variation obtained from these analyses was 2.1 %.

Method of estimating biogenic silica: The diatomaceous earth used here was diagenated (KAMATANI 1971, 1974) but dissolved completely into the solution by 60-minute digestion, from which most kinds of diatom silica walls in sediments are expected to be extracted quantitatively by this method. Even in the case of sediments rich in sponge spicule, the recovery of silica is also belived at the level of 97 % by the 100-minute digestion (refer to Fig. 1).

The amount of silica released from clay minerals and quartz cannot be ignored for estimating biogenic silica in sediments (Table 2). It is therefore necessary to provide a suitable method for correcting the amount of silica extracted from non-biogenic silica minerals.

The SiO_2/Al_2O_3 ratio in the extract by the 100-minute digestion with 5 % Na_2CO_3 solution ranged from 1.6 to 3.5. The range was fairly

Table 2. Silica and aluminum extracted from sediment, and biogenic silica (mg/g of dry sediment).

Depth	Total*	Extracted		Biogenic
(cm)	SiO_2	SiO_2	Al_2O_3	SiO_2
5- 10	682.7	428	0.34	427
15- 20	655.9	435	0.89	434
25- 30	655.8	430	0.75	428
55- 60	632.0	421	0.69	419
75- 80	630.7	335	0.53	334
105-110	670.8	324	0.67	322
135-140	634.9	376	0.64	374
216-221	670.8	144	0.60	142
271-276	634.9	78.5	1.14	75.7
310-316	632.9	220	0.75	218
351-356	558.1	156	2.69	149
376-381	513.0	99.6	3.16	91.7
396-401	474.6	61.4	3.72	57.6
416-420	434.9	94.6	2.79	87.9
446-451	445.3	93.5	3.18	85.6
471-476	437.8	84.0	3.89	74.3
491-496	447.4	62.4	3.78	53.0
511-516	444.1	62.0	3.29	53.8
541-546	444.3	58.4	3.34	50.1
564-569	453.9	61.3	3.78	51.9
594-599	448.1	57.6	4.28	46.9
614-619	451.9	78.4	4.18	68.0
644-649	454.9	79.3	3.09	71.6
679-684	463.7	60.4	4.07	50.2
719-724	452.7	51.7	4.29	41.0
739-744	449.4	46.2	2.84	39.1
774-779	459.0	45.9	3.52	37.1
799-804	451.7	47.0	4.73	35.2
839-844	467.0	62.6	4.84	50.5
864-869	455.6	36.5	4.41	25.5

Sampling location: Latitude 57°07′00″N, Longitude 176°56′40″W.

* It was determined by the loss in weight that occurred when the sample was treated with HF and H_2SO_4 (e.g. EASTON 1972).

in good agreement with those of the clay minerals used in this experiment, and also the similar ratios were found in oceanic suspended matter (COPIN-MONTEGUT and COPIN-MONTEGUT 1972, BAKER and PIPER 1976) and in continental crusts (KRAUSKOPF 1965). From this, the amount of silica released from silica minerals can be estimated approximately by multiplying the amount of the extracted Al_2O_3 by a factor of 2.5. The method is given by

$$SiO_2\,(\text{biogenic silica}) = SiO_2\,(\text{extracted}) - 2.5\,Al_2O_3$$

where $2.5\,Al_2O_3$ is the non-biogenic silica estimated from the extracted Al_2O_3.

Biogenic silica in a core sample: Table 2 shows the vertical distributions of total silica, extracted silica and aluminum, and biogenic silica. The total silica shows slightly higher values in the upper parts of the core than in bottom parts, while the extracted silica content decreases sharply with depth and the extracted aluminum content increased gradually with depth. As a result, the vertical profile reveals that the content of biogenic silica decreases exponentially with depth. The relationship between the biogenic silica content, C, and depth of core, Z, is given by the following equation;

$$\ln C = 5.974 - 0.003\,Z$$

where C is represented in mg per one gram dry sediment and Z in cm. The decrease of biogenic silica with depth is ascribed to upward flux after dissolution.

For calculation of the dissolution rate constant from the vertical profile of biogenic silica, the following assumptions were made: 1) the sedimentation rate of biogenic silica was constant throughout past years; 2) the decrease in biogenic silica with depth in the core will balance the dissolution rate; and 3) the deposition rate of sediment was ca. 20, 40, and 80 cm per 1000 years (from the data of LISITSYN 1969). The dissolution rate constants corresponding to the above deposition rates were calculated to be 6.9×10^{-9}, 1.4×10^{-8} and 2.7×10^{-8} per hour, respectively. The values of these rate constants are at least 4 to 5 orders of magnitude smaller than those obtained from the acid-cleaned silica walls (KAMATANI and RILEY 1979).

Easily soluble biogenic silica walls disappear in the course of sinking through the water column, so that we may expect the silica walls deposited in sediments to be more resistant to solution than those from the water column. In addition to this, the very small rate of dissolution in sediments must be influenced by the low upward flux rate (HURD 1973, FANNING and PILSON 1974, SCHINK *et al.* 1975) and by the formation of protective matters by some

metal ions which counteract solubilization effects for solution (LEWIN 1961, DIGGER *et al.* 1964). Probably, the degree of protection increases with time (or depth). The mechanism and its rate of formation require further study.

Acknowledgement

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堆積物中の生物体珪酸の定量法

鎌　谷　明　善

要旨: 堆積物に含まれる生物体珪酸の抽出と定量法について検討した。風乾泥 50 mg 以下をポリカーボネート製遠心管にとり，これに 5 % Na_2CO_3 50 m*l* を加え，湯浴上 (100°C) で 100 分間処理をおこなうのが抽出に最適であった。この抽出液について珪酸とアルミニウムの分析をおこない，アルミニウム濃度から非生物体珪酸量を見積った。抽出された全珪酸から非生物体珪酸を差引いた残りを生物体珪酸とした。本法に基づいてベーリング海中央部で採取した柱状堆積物中の全珪酸および生物体珪酸の分布を調べたところ，生物体珪酸含量は深さの増大にともない指数関数的に減少する傾向がうかがわれた。

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大阪湾の固有振動と高潮・津波との関係 (1)*

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Normal Modes of Oscillation in Relation to Storm Surge and Tsunami in Osaka Bay, Japan (1)*

Shigehisa NAKAMURA** and Harold G. LOOMIS***

Abstract: In order to study normal modes of oscillation of Osaka Bay, Japan, the authors applied numerical scheme of finite difference method. An Osaka Bay model in this study has an opening at Tomogashima Passage, and Akashi Strait and Yodo River are considered to be closed. The bathymetry is taken from a nautical chart. The result suggests that the initial three modes are possible to appear in case of storm surge in Osaka Bay. The twelfth mode is quite similar in pattern to the resonant mode which was induced by an incident tsunami, though it is accepted as a general that any of the higher modes can be scarcely expected in a bay.

1. 緒言

著者らの知るかぎりにおいて，閉じた水域として大阪湾の自由振動に関する理論的研究は多いが，湾としての大阪湾の固有振動モードについては従来検討された例がないようである。ここでは，大阪湾の湾口を節とするような固有振動モードを LOOMIS (1970[1], 1973[2], 1975[3]) の方法によって求め，そのようなモードの可能な場合として，高潮および津波を考えた。

大阪湾の固有振動に関する研究を歴史的にふりかえると概略つぎのようになる。大阪湾の固有振動に関する研究は，高谷 (1930a, b)[4,5], 日高(1931 a, b[6,7]; 1937a, b[8,9]; 1937-38[10]), 和達 (1938)[11], 中村・荻原 (1938)[12], 市栄 (1949)[13] がある。このうち，高谷[4,5]は深江と神戸の検潮記録を解析して，3つの卓越周期として 65.2 min, 117.6 min および 272.9 min がみとめられることを示した。日高は，閉じた海盆と考えた大阪湾の単節たて振動の周期は 118.3 min, 双節たて振動の周期は 69.6 min であるとし[6]，さらに，彼は Ritz の方法を用いて同様な解析をし，大阪湾の自由振動を論じた[8,9]。また，和達[11]は，Chrystal の方法を応用して，単節・双節静振と基本副振動および副振動の周期がそれぞれ 112.3 min, 60.5 min, 240 min, 940 min という結果を得た。さらに，中村・荻原[12]と市栄[13]とは，地震によって生じた大阪湾内の津波の模型実験を行ない，湾内波高分布を論じている。気象庁(1961)[14] は大阪湾の潮汐や高潮の解析に有限差分法を応用した結果を発表したが，そのなかではとくに大阪湾の固有周期にふれてはいない。また，YAMADA らは大阪湾の高潮の共振と関連した一連の理論的研究をすすめ，1次元的に移動する高潮として問題をとらえている (YAMADA *et al.*, 1965[15]; YAMADA and OKABE, 1965[16]) が，実際現象との対応づけには注意が必要である。中村 (1979)[17]は，Lee の方法を応用して，大阪湾の数値モデルについて研究し，大阪湾の応答関数を求め，単節および双節のたて振動モードは

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それぞれ 1.68 hr および 1.01 hr であることを示した。また，双節たて振動モードの周期は1960年チリ津波および1944年南海道沖地震による津波の津波スペクトルのピークに対する周期によく対応していることも示した。しかし，この場合，湾内水深を一定ととったことに注意しなくてはならない。NAKAMURA and LOOMIS (1979)[18] は非常に簡単なモデルによって，最低次（0次）のモードも大阪湾の津波の初期には重要な役割を演ずることを示した。

ここでは，海図で与えられた水深条件に対してLOOMIS の方法を適用し，湾としての大阪湾の固有振動を求め，それらが高潮や津波の時にあらわれる可能性の高いことについて検討する。

2. 理論的基礎

LOOMIS (1970)[1] は，任意形状の海岸線をもち任意水深の湾や港における線型浅水波動方程式に対する固有値問題を解く方法を考え，ハワイ周辺の港湾の固有周期をもとめるのに応用した。その後，この解法は改良されて現在にいたっている (LOOMIS, 1973[2]; 1975[3])。その理論的基礎はそのまま大阪湾の固有振動をもとめる場合にもあてはまるものである。以下にはその要点を記す。

線型浅水長波に関する方程式は，たとえば，STOKER (1957)[19] にしたがえば，

$$\nabla\cdot(h\nabla\phi)=\frac{1}{g}\frac{\partial^2\phi}{\partial t^2}. \qquad (1)$$

ただし，

$\phi=\phi(x,y,t)$ ：速度ポテンシアル

$h=h(x,y)$ ：点 (x,y) における水深

$$\nabla=i\frac{\partial}{\partial x}+j\frac{\partial}{\partial y}.$$

境界条件は境界 B_1 および B_2 に対して

$\phi=0$ ：境界 B_1 上で

$\dfrac{\partial\phi}{\partial n}=0$ ：境界 B_2 上で

とし，$B_1\cup B_2$ は水が海岸線あるいは海底としての境界に接している部分である。

いま，速度ポテンシアルについて

$$\phi(x,y,t)=e^{i\omega t}\phi(x,y) \qquad (2)$$

とすると，これを (1) に代入することによって，次式が得られる。すなわち，

$$\nabla\cdot(h\nabla\phi_1)=-\frac{\omega^2}{g}\phi_1. \qquad (3)$$

ここに，(3) を与えられた周波数 ω に対しての固有値問題として解くことによって，包絡面関数 $\phi_1(x,y)$ が求まることになる。以下において ϕ_1 を ϕ と書くことにする。

数値計算については，以下のような考え方にしたがって計算プログラムを作成し，用いるものとする。

考える領域内で格子点を考え，格子点 (x_i,y_j) における量をたとえば $\phi(x_j,y_j)=\phi_{ij}$ と書く。水域中の格子点 (i,j) に対する (3) の差分式については，つぎのようにする。$h\,\partial\phi/\partial x$ に対する差分商については，(i,j) を中心として右・左に格子間隔の 1/2 を考え，したがって，$\partial/\partial x(h\,\partial\phi/\partial x)$ は (i,j) を中心として考えることになる。h については $h_{ij-1/2}$ とか $h_{ij+1/2}$ という形で値が与えられることになり，差分式の中では ϕ_{ij} のかわりに ϕ_{ij-1} を考えたり，ϕ_{ij-1} のかわりに ϕ_{ij} を考えることになる。y 軸方向についても，上述の x 軸方向の場合と同様である。かくして，差分式は対称性を有することになる。この対称性はとくに固有値問題で有用であり，数値計算において便利である。ここでは，ORTEGA (1967)[20] にしたがって，固有値問題に対する Householder-Givens の方法を用いることにする。

境界条件もそれに応じて適用する。ここで，h と $\partial\phi/\partial x$ との組み合せはつねに $h\,\partial\phi/\partial x$ としてあらわれ，$h\,\partial\phi/\partial y$ についても同様であるので，この値は，境界 B_2 では $h=0$ とおくことによって0となる。また，節となる点については，方程式系中の ij に対応した行列要素を消去するのみで $\phi_{ij}=0$ を得る。この操作は，対象水域内で節とならない点に番号を 1, 2, ..., n とつけ，番号 (n

+1) を ij につけることにおきかえられる。

ここに，固有値問題 (3) はマトリックス形式で書けることになり，

$$A\vec{\phi}=\lambda\vec{\phi}. \qquad (4)$$

ただし，A は対称マトリックスであり，$\vec{\phi}=(\phi_1, \phi_2, \ldots, \phi_n)$。そして λ は固有値である。

3. 大阪湾の地形と計算条件

大阪湾周辺の海岸線は概略 Fig. 1 のようになっている。本文で数値計算の対象としてえらんだ領域は Fig. 1 の中の格子点図で示された部分で，これを大阪湾と考える。海岸線は水の通過しない境界と考え，また，淀川河口および明石海峡も閉めきった場合を考えた。この場合，友ケ島水道のみが外洋に通じているものとする。そして，ここでは，大阪湾口を節とする固有振動モードを求めることを考える。

大阪湾の水深分布は，ここでは，U. S. Naval Office の海図 No. 5317 にもとづいた。大阪湾を含む計算対象領域は，東西方向・南北方向に 15×16 の格子点をとるようにし，各格子点における水深を海図から内挿してもとめたのが Fig. 2 である。ここでの格子間隔は $\Delta x=\Delta y=12320.25$ ft (1 ft=30.48 cm) ととった。

4. 大阪湾の固有振動モード

数値計算は，ハワイ大学の計算センターの IBM 370/158 によった。計算の結果にもとづき，初めの 3 つの固有振動モードを図示すると，Fig. 3(a), (b), (c) のようになる。そのうち Fig. 3(a) は第 1 モードで，その周期は 4.49 hr である。湾口に節があり，湾奥が腹となっている。Fig. 3(b) は第 2 モードであり，その周期は 1.87 hr である。湾口のほかに湾内にひとつの節がみとめられるたて振動であり，湾奥は腹である。Fig. 3(c) は周期 1.38 hr の第 3 モードであり，湾口のほかに湾軸沿いの節がひとつみとめられる。これは明石海峡とその対岸とを腹とするよこ振動であるが，これに類似のモードは中村 (1979)[17] が Lee の方法によって

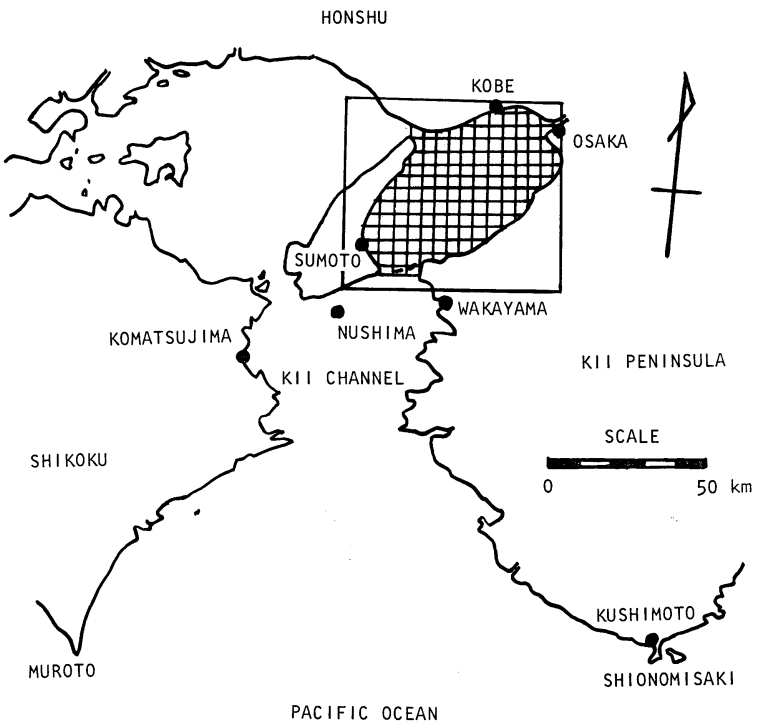

Fig. 1. Location of Osaka Bay covered by a grid system.

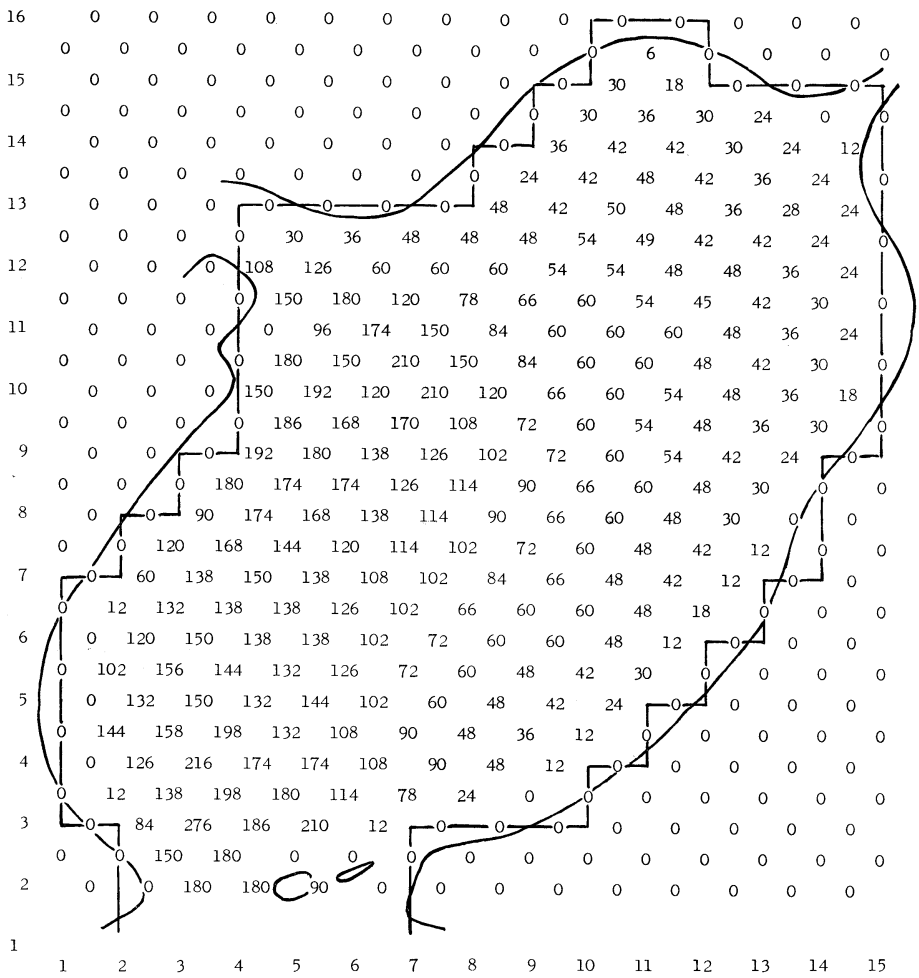

Fig. 2. Bathymetry of Osaka Bay (in feet, 1 ft=0.3048 m).

一定水深の大阪湾モデルについて計算した場合にはみとめられなかった。さらに高次のモードでは湾内の節の数が増す。一般に，このような高次のモードが実際現象として現われるとは考え難い。ここに示した3つのモードは1979年宮崎正衛博士(神戸海洋気象台，私信)が指摘した大阪湾固有の湾水振動の周期およびモードとよく対応している。

高谷 (1930a, b)[4,5] の解析結果とここで得られた結果とを比較してみると，高谷の 272.9 min の卓越周期は Fig. 3(a) の第1モードに対応するものであろう。また，117.6 min の周期は Fig. 3(b) の第2モードに対応するとみられる。これに対応すると考えられるのは，日高 (1931a, b[6,7]; 1937 a, b[8,9]) が閉じた水域としてみた大阪湾についての 118 min を周期とするたて式単節振動や，和達 (1938)[11] の 112.3 min 周期の単節静振と名づけられているものである。第3モードに対応づけられるものとしては，高谷[4,5]の卓越周期のうち 65.2 min のもの，日高[6~9] が大阪湾を閉じた楕円湖として考えた場合の周期 67 min のよこ式単節振動に対応すると考えられ，また，和達[11]が双節静振として与えた 60.5 min の周期によこ振動が考慮されていなかったようにみえる。

ここで数値計算によって得られた固有振動モードのうち，はじめの3つのモードは，これまでの高潮の記録をみてもわかるように (岩垣・中村，

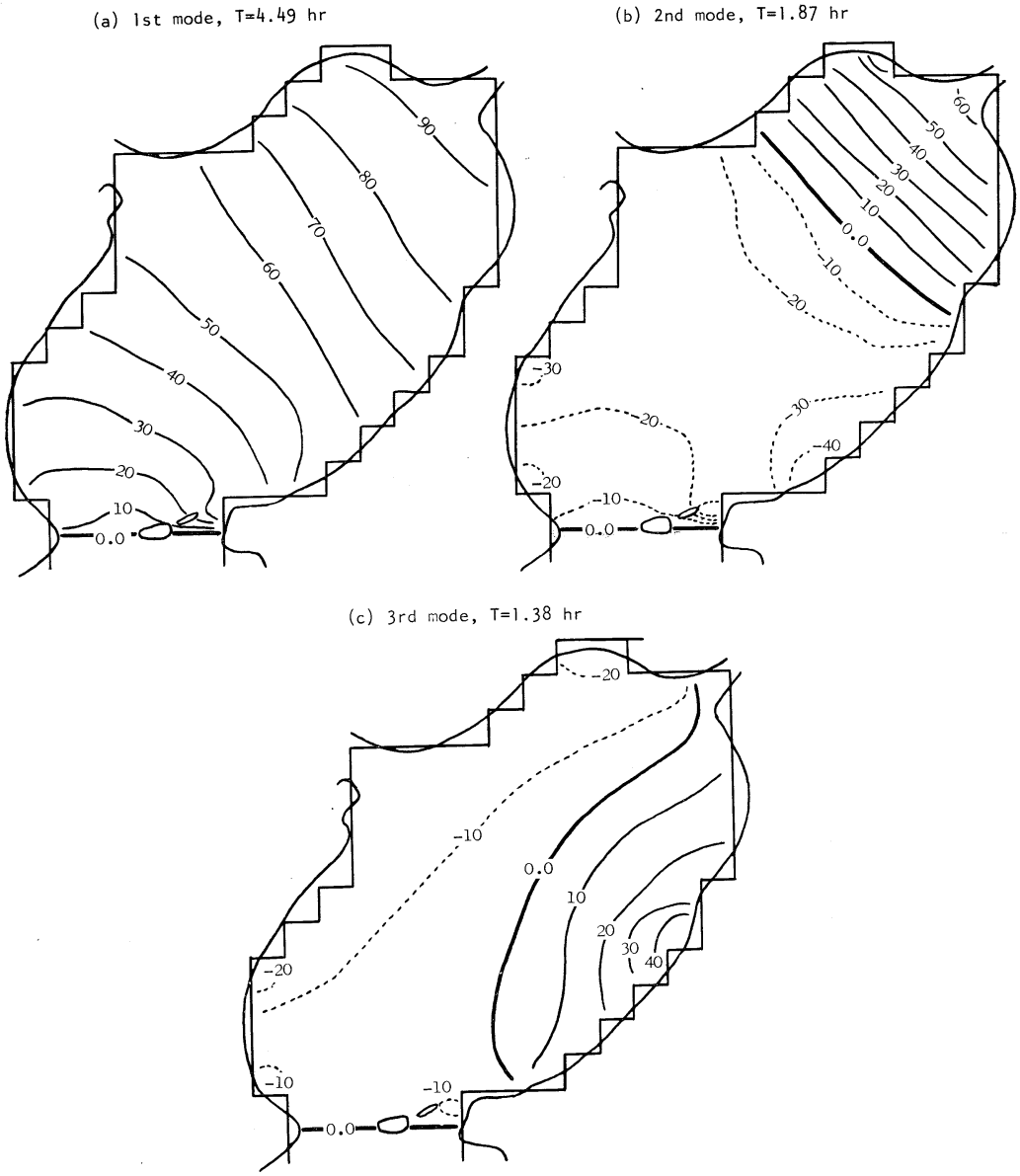

Fig. 3. The lowest three modes of oscillation of Osaka Bay.
(a) the first mode; (b) the second mode; (c) the third mode.

1967[21])，大阪湾付近を通過する台風によって生ずる高潮擾乱に含まれている可能性が高いと考えられる。それぞれのモードが成分波としてどのような波高をとるかは個々の場合に応じて異なるであろう。大阪湾の高潮の検討にあたっては，台風の移動速度と長波の伝播速度との相互関係を考慮することも必要である（YAMADA *et al.*, 1965[15]; YAMADA and OKABE, 1965[16]）が，あわせて，固有周期や固有振動モードも考慮にいれる必要がある。

中村・荻原 (1938)[12] は，水平縮尺 1/135 000，鉛直縮尺 1/1000 として，大阪湾における地震津波の模型実験を行ない，湾中央部の振動は湾軸両端とは大変異なっていたと述べている。また，市

栄（1949）[13]も大阪湾内での津波の模型実験を，2×2.5×0.7 m³ の大きさの水槽で，水平縮尺1/2000，鉛直縮尺1/30000の模型を用いて行ない，20 m等深線を境として振動特性が異なることを見出している。このような模型実験では，縮尺および縮尺の歪の効果にも留意しなくてはならないが，実験結果にあらわれた特長の一部は，Fig. 3 (b), (c) の第2, 3モードあるいはさらに高次のモードに関連づけられるであろう。模型実験では波を人為的に発生させていることを忘れてはならない。

中村（1979）[17]は，1960年チリ津波および1944年南海道沖地震の津波の大阪における記録から得た津波スペクトルを，Lee の方法で得られた大阪の応答関数と比較して，大阪湾内の津波は湾外からの擾乱のうち，とくに，津波の侵入にともない紀伊水道に誘起された単節よこ振動によるものと考えた。その時の振動モードとしては周期1.01 hrの双節たて振動に近いとしている。一般に，高次のモードは実際の現象としては考え難いといわれているが，周期 1.01 hr に近い周期 53.04 min をもつ第 12 モードをみると，Fig. 4 に示したように，湾口のほかに湾内に2つの節をもったたて振動の特長が顕著にあらわれていて，その特長はさきに中村（1979）[17]が示した周期 1.01 hr の双節たて振動とほぼ共通しているとみてよい。これからみて，とくに湾外から波が侵入するなどの作用がある場合には，湾内での振動は強制振動あるいは誘起振動と考えられ，その周期が固有周期に近ければ，たとえ高次のモードでも顕著にあらわれうるというひとつのよい例とみてよい。

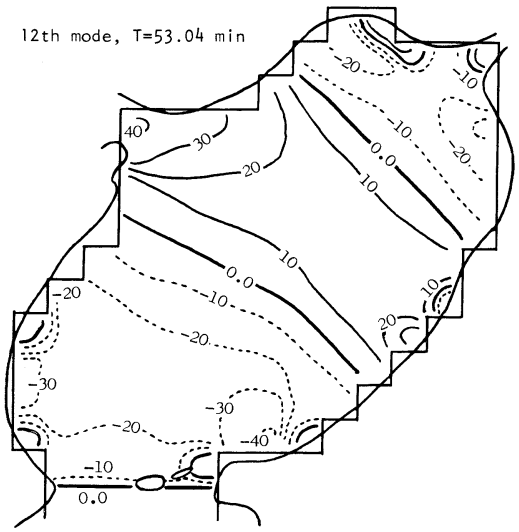

Fig. 4.　A possible mode of tsunami in Osaka Bay.

実際の大阪湾の水位変動には，ここで考えたモード以外の水位変動もあると考えられ，湾口が節となるようなことは事実上ありえないことと考えられる。

本研究の一部は，著者のひとり中村が1978年ハワイ大学客員上級研究員として滞在中に得た成果である。

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大阪湾の固有振動と高潮・津波との関係 (2)*

中村重久**, H. G. ルーミス***

Normal Modes of Oscillation in Relation to Storm Surge and Tsunami in Osaka Bay, Japan (2)*

Shigehisa NAKAMURA** and Harold G. LOOMIS***

Abstract: Normal modes of oscillation in the area including Osaka Bay and Kii Channel were studied numerically by using Loomis' method for determining normal modes of irregular bodies of water with variable depth. The lowest four modes are 7.34, 3.43, 2.97 and 2.51 hours respectively, and those modes are illustrated to show their patterns of wave height distribution in the area. Any one of these modes might appear if an incident disturbance has an approximately same period to that of the mode, especially in case of a landfall storm inducing a storm surge in the area of Kii Channel and Osaka Bay. Adding to the above, a possible mode, which might be produced by an incident tsunami, is also considered in order to have an understanding of the period at the peak of the tsunami spectra at Osaka.

1. 緒　言

中村・ルーミス (1980)[1] は，さきに，大阪湾の固有振動について，LOOMIS (1970, 1973, 1975)[2-4] の方法を利用して数値的に解析し，その固有振動と高潮・津波との関連について検討した。その解析では，大阪湾は，その南端の友ケ島水道で外洋につながっているものとし，明石海峡と淀川とは閉じているものとした。そして，大阪湾の湾口を節とするような固有振動を考えた。しかし，実際の現象では湾口に節があらわれるような現象はない。波が外から侵入して湾内に誘起される振動は，たとえば，一定水深として単純化した大阪湾モデルの場合には中村 (1979)[5] が示したようになる。たまたま，大阪湾口が非常にせまいため，その湾水振動の周期は，閉じた水盆としてみた大阪湾での固有周期によく対応することになったものと考えられる。

ところで，NAKAMURA *et al.* (1975)[6] が 1960 チリ津波の記録を解析した結果から明らかにしたように，紀伊半島南端の串本の津波スペクトルのピークは周期約 33 min と約 17 min とにみとめられるのに対して，大阪湾では周期約 55 min に顕著なピークがある。これは，津波が紀伊水道で誘起した振動が大阪湾の水位変動に作用したと考えざるを得ない。

本報では，大阪湾と紀伊水道とをあわせた系を考え，蒲生田岬と日の岬とを結ぶ線を節とする固有振動を Loomis の方法で数値的に解析し，固有振動モードの特性を大阪湾の高潮・津波と関連づける立場から検討した。

2. 数値解析の理論的背景と条件

Loomis の方法を利用して，さきに大阪湾の固有振動をもとめた (中村・ルーミス, 1980)[1] と同じ手法によって，数値計算をすることにした。数値計算にあたっては，ハワイ大学の計算センター

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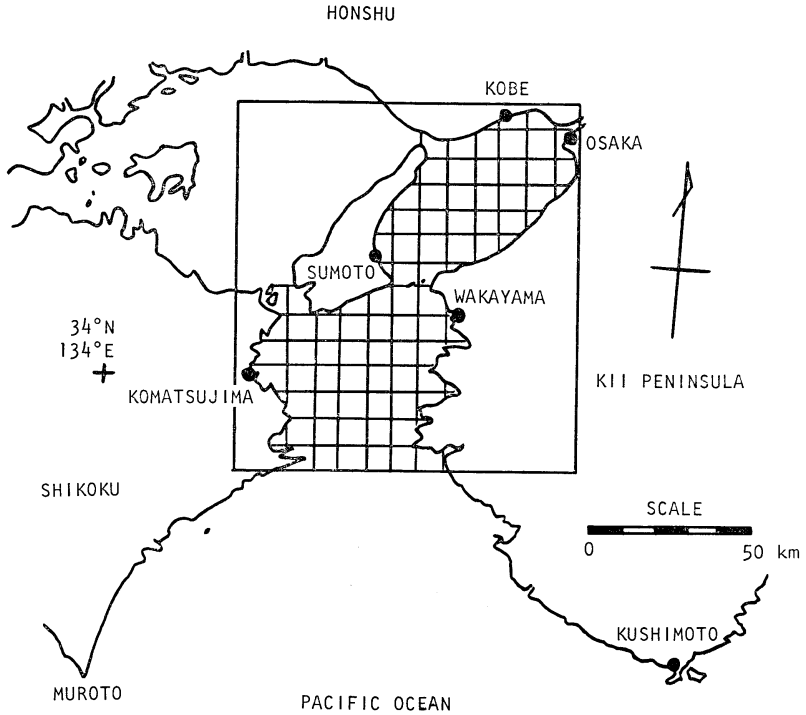

Fig. 1. Location of Osaka Bay and Kii Channel covered by a grid system.

の電子計算機 IBM 370/158 を用いた。

大阪湾・紀伊水道付近の海岸線は概略 Fig. 1 のようになる。そのうち，図中格子点でおおわれた部分が，本文での数値計算の対象領域である。海岸線は水の通過しない境界と考え，また，淀川河口，明石海峡および鳴門海峡は閉じているものとし，友ケ島水道のみが外洋に通じる唯一の開口部であるとした。そして，ここでは，とくに，四国の蒲生田岬(G)と紀伊半島の日の岬(H)とを結ぶ線(G-H 線）を節とするような固有振動モードを検討することにした。海岸線の形状をみると，このG-H線は紀伊水道の振動を特長づけるのに重要な役割を果しているようにみえるし，また，G-H線のすぐ沖では水深は急速に深くなっている。このような地形条件は，G-H線を節とする大阪湾・紀伊水道の固有振動を検討することが有意義であることを示唆しているものと考えた。

計算にあたって，対象水域の水深は U.S. Naval Oceanographic Office の海図 No. 5317 によってもとめた。計算に用いた水深のデータは Fig. 2 に示した。ここで，格子点の間隔は，$\Delta x=\Delta y=$ 24640.5 ft (1 ft=30.48 m) ととった。

3. 固有振動モード

ここで与えた条件のもとでの数値計算によれば，固有振動モードは総数99個あらわれることになるが，この数は数値計算における格子点間隔の選び方によって定まるものであり，格子点の数をさらに多くとれば第99次よりも高次のモードが求まる。しかし，実際の現象においては，低次のモードがあらわれることはあっても，一般に高次のモードがあらわれるとは考え難い。

ここに得られた初めの4つの固有振動モードは，Fig. 3(a)～(d) のようになる。そのうち，Fig. 3(a) は第1モードで，その周期は 7.34 hr であり，G-H線を節とし，大阪湾奥を腹とするたて振動である。もし，なんらかの原因でこのようなモードの振動が誘起されている場合に，中村・ルーミス (1980)[1] のように，大阪湾単独の現象としてのみとらえようとするかぎり，うまく説明がつ

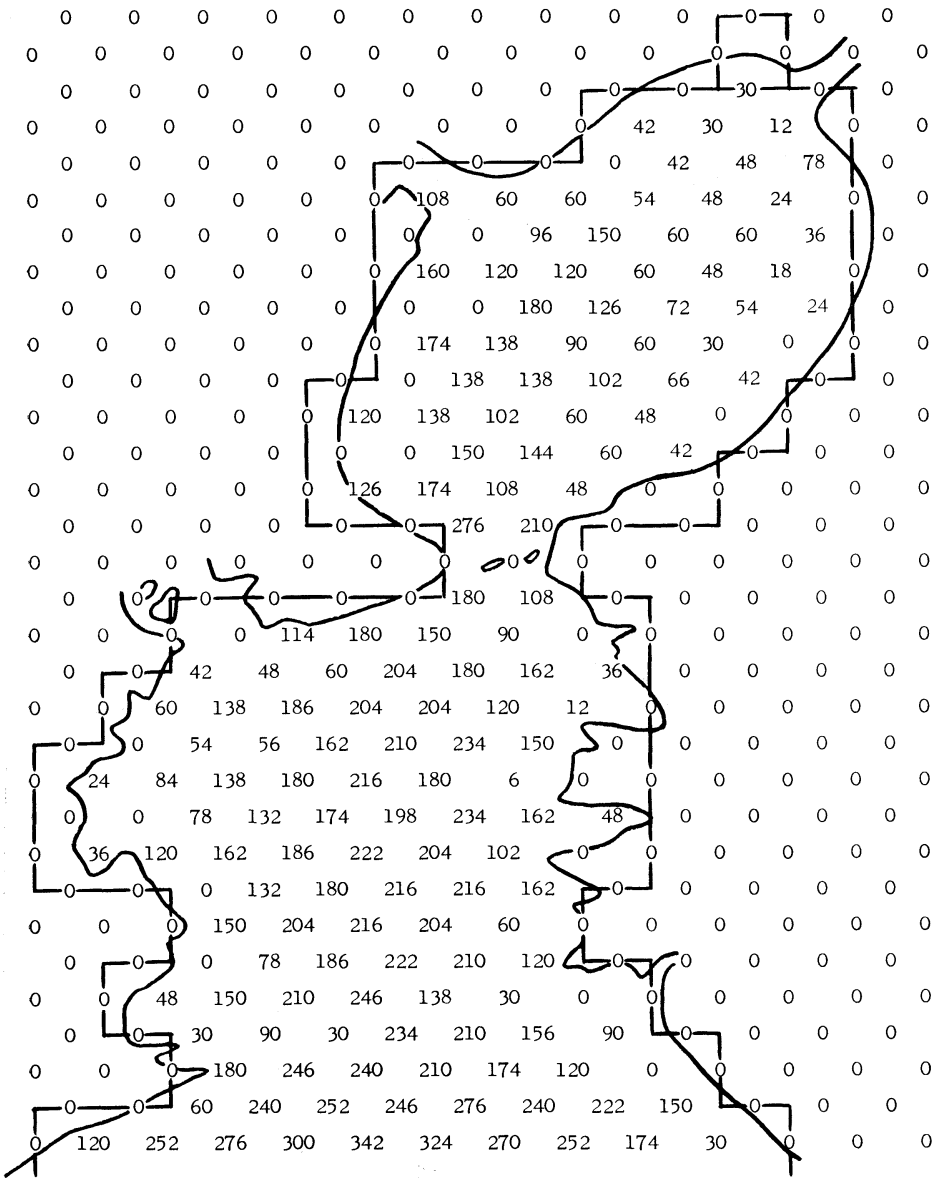

Fig. 2. Bathymetry of Osaka Bay and Kii Channel (in feet, 1 ft=0.3048 m).

かないということもありうる。Fig. 3(b) は第2モードであり，節は G-H 線のほかに大阪湾を横断するものがひとつみられる。その周期は 3.43 hr である。この第2モードの波高分布のパターンは，友ケ島水道の付近を除けば，中村・ルーミス (1980)[1]の第2モード（周期 1.87 hr）にかなりよく似ている。さらに，Fig. 3(c) の第3モードは，周期は 2.97 hr であり，第2モードの周期とは異なるが，その大阪湾内の波高分布は，友ケ島水道付近を除けば，中村・ルーミス (1980)[1] の第2モードに非常によく似ている。Fig. 3(c) でこのほかに注意すべきことは，和歌山で −41 の振幅に対して，小松島で17の振幅をとり，沼島付近での振幅は8であることである。この場合，節線は和歌

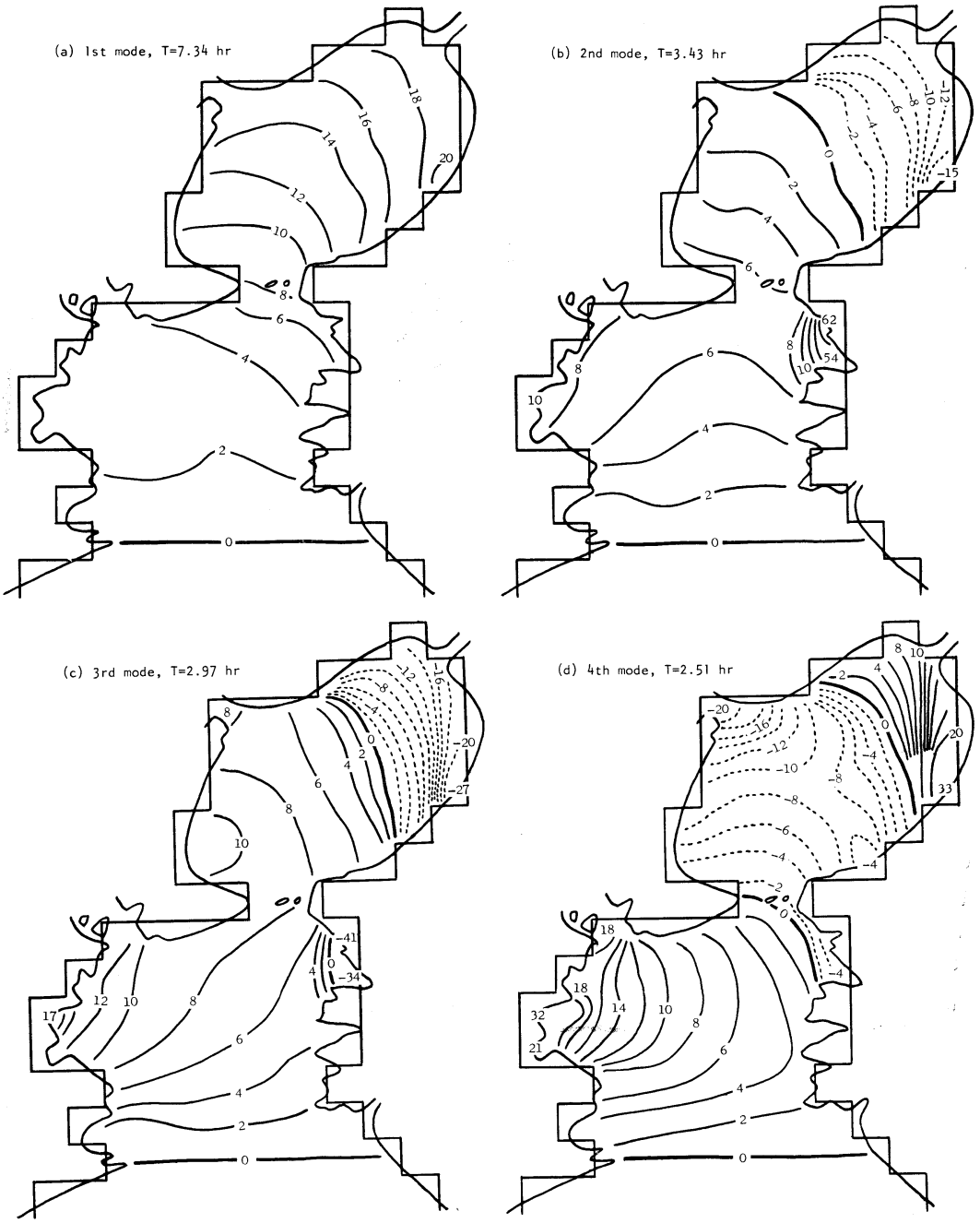

Fig. 3. The lowest four modes of oscillation in Osaka Bay and Kii Channel.
(a) the first mode; (b) the second mode; (c) the third mode; (d) the fourth mode.

山のごく近くに位置しているが，紀伊水道内でのよこ振動が計算対象水域のたて振動に重なっているとみてもよいであろう。第4モードは周期2.51 hr で，節はG-H線，友ケ島水道付近，大阪湾内にそれぞれひとつずつあらわれ，紀伊水道内ではさらによこ振動の傾向は強くなるが，大阪湾内はたて振動のパターンを示している。このようにみてくると，紀伊水道では第1，2次モードではたて振動型であるが，さらに高次のモードではよこ振動型の傾向が強くなることがわかる。また，大阪湾内では，いずれのモードについてみてもたて振動型があらわれ，とくに，2次より高次の場合，大阪湾の単節たて振動のあらわれる傾向が強いことがわかる。

Fig. 3(a)-(d) にあらわれた固有振動モードの周期 $T=7.34$ hr, 3.43 hr, 2.97 hr および 2.51 hr は台風による高潮の持続時間に対応してあらわれる可能性が高いものと考えられるが，具体例については，いろいろの条件を考慮にいれた上であらためて検討する必要がある。いずれにしても，周期が長いかどうかにかかわらず大阪湾内には単節たて振動型のパターンがあらわれやすいと考えて差支えないであろう。ただ，ここで注意したいことは，中村 (1979)[5] の大阪湾で誘起された振動の計算からみると，ここに示した Fig. 3(a)-(d) に対する周期のモードは共振モードとは考えられないということである。

中村 (1979)[5] は大阪湾のみに着目した場合，誘起振動の第2モードとしては周期 1.01 hr を考えるべきことを示し，これが，1944 南海道沖地震による津波は1960チリ津波のスペクトルのピークの周期約55minに近いことから，共振に近い状態がみられるのではないかと考えた。NAKAMURA *et al.* (1975)[6] の解析例をみてもわかるように，紀伊半島南端の串本では約 55 min の周期成分の存在は顕著とはいえない。それにもかかわらず大阪で約 55 min の周期成分のみが卓越しているという事実を理解するためには，大阪湾の，たとえば大阪の応答関数の共振周期が約 55 min に近いことのほかに，入力関数で約 55 min の周期成分がかなり主要なものでなくてはならない。それは，

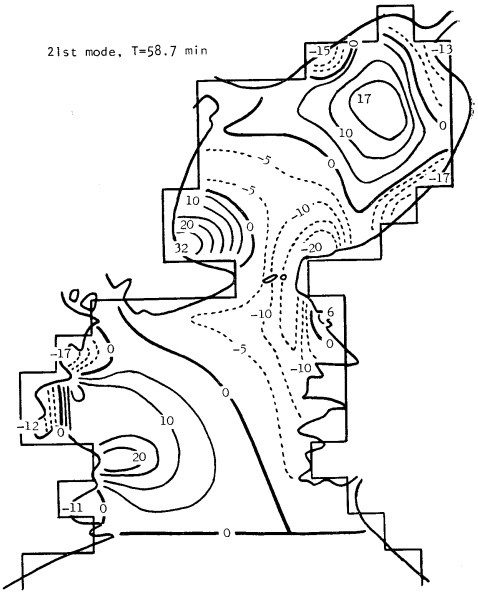

Fig. 4.　A possible mode for tsunami in Osaka Bay and Kii Channel.

津波スペクトルが，いわば，出力関数であり，入力関数と応答関数のコンボリューションとして与えられると考えられるからである。もともとの入力関数でその周期成分がごく小さければ，その成分の出力は顕著なものとはなりえないはずである。そして，すでに述べたように，約 55 min の周期成分が串本でとくにみとめられないことから，津波が串本から大阪へ至る間にその成分を誘起したとしか考えられない。

外から侵入する波の周期が着目する水域の固有周期に近ければ共振を起しうるという考えからすれば，津波スペクトルのピークの周期に対応する固有振動モードについて検討するのもあながち無益なことではないであろう。ちなみに，第21モードを Fig. 4 に示した。水域内に多数の節線があって，一見複雑にみえるが，紀伊水道内では，沼島付近を節としたよこ振動の特長がみとめられる。和歌山で振幅6に対して沼島で振幅は2程度，小松島では−12である。

1960チリ津波について，和歌山，沼島，小松島の検潮記録を比較すると，振幅は沼島が他の2つの検潮所より小さく，しかも，和歌山と小松島とでは周期はほとんど同じで位相は逆になっている

ことがわかった。この限られた検潮記録から，中村（1979）[5]は，津波の侵入にともない紀伊水道で単節よこ振動が誘起され，それが外力となって大阪湾内の約 55 min という周期成分の振動をひきおこしたものと考えた。Fig. 4 の紀伊水道内の節線は，その特長の一端に力学的根拠を与えたものと考えてよいであろう。

このようにみてくると，大阪の津波スペクトルのピークに代表される約 55 min を周期とする大阪湾内の水位変動は，大阪湾のみの固有振動の問題としてとらえると同時に，大阪湾と紀伊水道とをあわせた水域をひとつの振動系として考えるのが力学的にみて適切であると考えられる。

本研究の一部は，ハワイ大学の援助のもとに，著者のひとり中村が1978年ハワイ大学 JIMAR に客員上級研究員として滞在中に得られたものである。

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La mer (Bulletin de la Société franco-japonaise d'océanographie)
Tome 18, N° 2, pp. 82 à 88, Mai 1980

Subsurface Chlorophyll Maximum in Winter at a Station in the Western North Pacific Ocean*

Yukuya YAMAGUCHI** and Shun-ei ICHIMURA***

Abstract: A marked subsurface chlorophyll maximum was detected in winter at the subsurface layer between 90 and 150 m in oligotrophic oceanic water of the western North Pacific Ocean. Chlorophyll concentration of this layer consisted about 50 % of the total chlorophyll in the upper 150 m. Phytoplankton in the chlorophyll maximum layer exhibited high photosynthetic activity and they contributed about 28.5 % of the primary production in a 150 m-deep column.

1. Introduction

The presence of the deep chlorophyll maximum in the open ocean has long attracted attention of marine biologists. The chlorophyll maximum layer is usually found at the depth of 50 to 100 m near or below the compensation depth in the seasonal pycnocline and distributed over a wide region of temperate and tropical oceans. The concentration of chlorophyll in the maximum layer is often several times higher than in the upper mixed layer and its contribution to the primary production could be significant.

Several researchers have proposed some processes to explain the formation of the chlorophyll maximum (e.g. RILEY *et al.* 1949, STEELE and YENTSCH 1960, STEELE 1964, ANDERSON 1969, 1972, LORENZEN 1965, VENRICK *et al.* 1973, JAMART *et al.* 1977) but the problem still re-

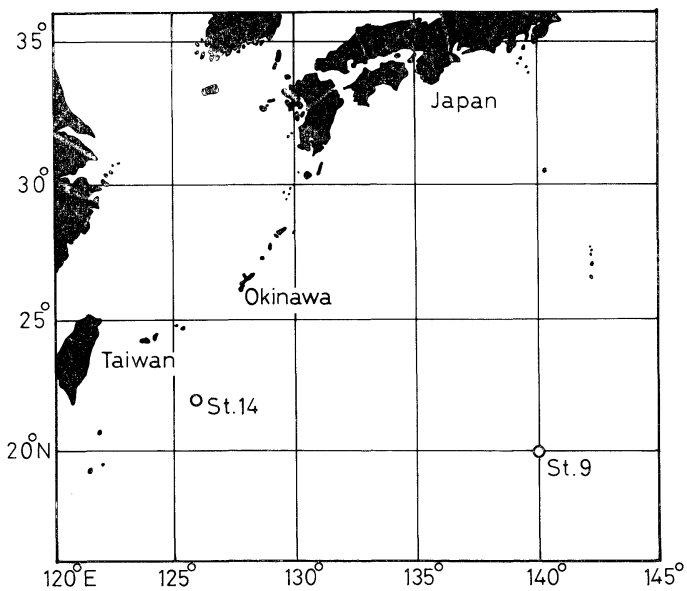

Fig. 1, Location of sampling stations in the western North Pacific Ocean.

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mains unsettled and further information is required for understanding the deep living phytoplankton dynamics.

This paper reports some properties of a subsurface chlorophyll maximum found at one station in the western North Pacific Ocean during the cruise of R.V. Hakuho-Maru, Ocean Research Institute, University of Tokyo, from January to February in 1973.

2. Materials and methods

The data presented here were obtained on 18 and 31 January at St. 9 (19°58′N, 139°50′E) and St. 14 (22°00′N, 125°51′E), respectively

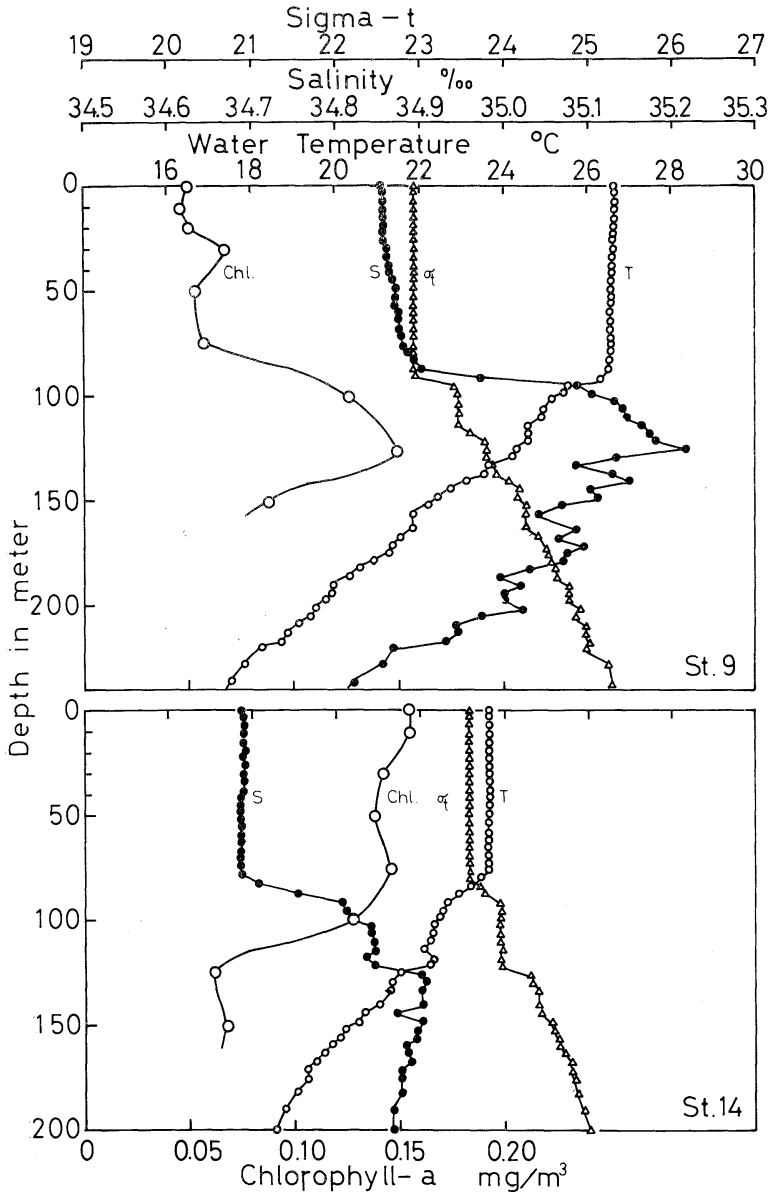

Fig. 2. Vertical profiles of temperature, salinity, density (sigma-t) and chlorophyll *a* concentration at St. 9 and St. 14.

(Fig. 1). The seawater samples were collected by standard hydrographic casts with 10 liter Van Dorn samplers from 9 depths at St. 9 and 8 depths at St. 14. Further samples were taken by Rosette Multi Samplers (RMS-13) combined with a Hytech 9006 STD system. The samplers were attached 1.7 m above the STD sensor. Water samples were collected at 39 depths from 98 to 190 m at St. 9 and 27 depths from 65 to 176 m depth at St. 14. The concentrations of chlorophyll *a* in the water samples collected by Van Dorn samplers were measured according to the UNESCO procedure (SCOR-UNESCO 1966). The samples for analyses of nutrients were collected by general hydrographic casts using Nansen samplers and measurements were made of ammonia, nitrite, nitrate, phosphate and silicate (OCEAN RESEARCH INSTITUTE 1975).

Photosynthetic activity of phytoplankton was measured by the ^{14}C method. Water samples were incubated for 3 hours in 100 m*l* Pyrex glass bottles in a waterbath at a light intensity of about 14 klux for Van Dorn samples and about 1.8 klux for Rosette samples from daylight fluorescent lamps at 20±1°C. Dark carbon assimilation was measured simultaneously to correct the photosynthesis. After incubation the samples were filtered through HA Millipore filters, dried and their radioactivity determined with a liquid scintillation counter (Beckmann LS-3155T). *In situ* primary production was measured in the samples suspended at respective depths from where the water samples had been taken by Van Dorn casts. Incubation lasted for a half day from midday to dusk. Half day photosynthesis for each sample was multiplied by two to obtain the whole daytime photosynthesis (mg C/m^3/daytime). Daily total primary production was obtained from a photosynthesis-depth curve by graphic integration.

3. Results

The profiles of temperature, salinity and density (sigma-t) are shown in Fig. 2. As can be seen from the figure, the water columns were well stratified and there was similar trend between the stations. Sharp pycnocline developed from the depth of 90 m at St. 9 and 80 m at St. 14. The water temperature and salinity within the upper mixed layer were 26.6°C and

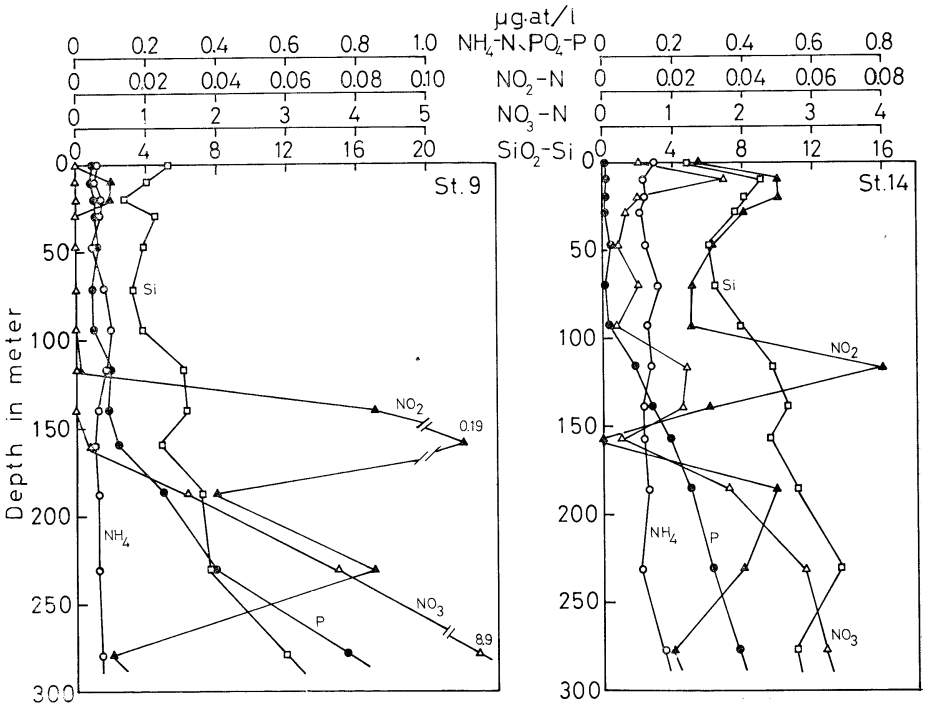

Fig. 3. Vertical distributions of nutrients at St. 9 and St. 14.

34.85‰ at St. 9 and 23.6°C and 34.69‰ at St. 14, respectively. At St. 9 water masses with high salinity of more than 35‰ were interposed in the thermocline and formed clear pycnocline. The vertical distribution of ammonia, nitrite, nitrate, phosphate and silicate are shown in Fig. 3. Except phosphate, nutrient concentrations in the upper mixed layer at St. 14 were higher than those at St. 9. The concentrations of nitrite and nitrate in the mixed layer were below the detection limit of the method at St. 9, but increased rapidly with depth at about 120 m in nitrite and at 150 m in nitrate, where nitrite showed a noticeable peak. The concentration of nitrite in the water immediately below the mixed layer was much higher at St. 9 than at St. 14. The water in the upper 100 m at the oceanic station 9 was very low in nutrients but temperature and salinity at St. 9 were higher than those at St. 14. Vertical distributions of chlorophyll *a* at both stations are shown in Fig. 2. A marked subsurface chlorophyll maximum was located in a layer between 100 and 150 m with the maximum value of 0.15 mg/m^3 at St. 9, whereas no maximum was detected at St. 14. The depth of the chlorophyll maximum layer at St. 9 was closely related to the depth of nitrite maximum in the pycnocline. The total chlorophyll *a* in the upper 150 m was 12.9 mg/m^2 at St. 9 and 18.3 mg/m^2 at St. 14. Chlorophyll *a* for depth from 90 to 150 m was 6.4 mg/m^2 at St. 9 and it constituted about 50% of the total chlorophyll *a* for upper 150 m.

The depth profiles of primary production expressed per cubic meter at both stattions are indicated in Fig. 4. At St. 9 production was relatively high in the surface layer with a maximum value of 0.91 mg C/m^3/daytime at 20 m and below this depth it dropped rapidly. In the subsurface layer a secondary maximum was found at the depth of 125 m. This peak coincided well with a peak of subsurface chlorophyll maximum. Productivity at St. 14 increased gradually in the upper mixed layer and reached a highest value of 0.88 mg C/m^3/daytime at the depth of 75 m, but in the pycnocline it decreased from 0.5 mg/m^3/daytime at 100 m to 0.09 mg C/m^3/daytime at 150 m. The daily total primary production in a 150 m-deep column was 54.9 mg C/m^2/daytime at St. 9 and 85.3 mg C/m^2/daytime at St. 14. The primary production in the subsurface chlorophyll maximum

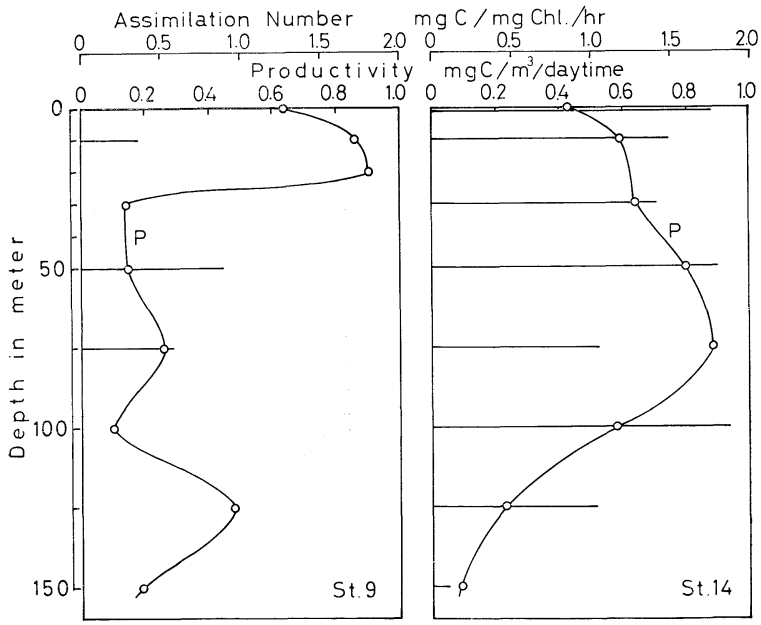

Fig. 4. Profiles of primary productivity at St. 9 and St. 14. The horizontal bars indicate assimilation number measured in a waterbath under 14 klux.

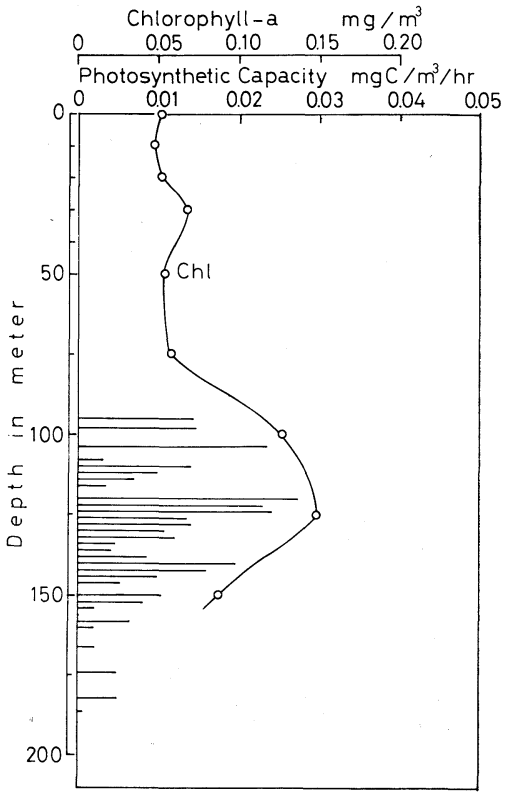

Fig. 5. Photosynthetic capacities of Rosette samples measured under 1.8 klux at St. 9. Vertical profile of chlorophyll *a* is also indicated.

layer (100–150 m) at St. 9 was 15.6 mg C/m²/daytime, thus it appears to contribute about 28.5 % of the total production. Assimilation number measured in a waterbath ranged between 0.37 to 0.90 mg C/mg Chl. *a*/hr at St. 9 and 1.05 to 1.87 mg C/mg Chl. *a*/hr at St. 14 for samples from the mixed layer but it was only 0.09 mg C/mg Chl. *a*/hr for sample from 125 m at St. 14. It is interest to note that the samples from the bottom of mixed layer at St. 9 indicated a relatively high photosynthetic capacity under the low light condition. For water samples collected at St. 9 by the Rosette Samplers we measured photosynthetic capacity in a waterbath and the results are indicated in Fig. 5 with the vertical distribution of chlorophyll *a*. The values ranged mostly from 0.005 to 0.02 mg C/m³/hr with the highest value of 0.028 mg C/m³/hr. Chlorophyll concentrations in the Rosette samples could not be determined because of the limited volume of water, so that we were not able to evaluate assimilation number for individual samples. However, the vertical pattern of photosynthetic capacity in the region of the subsurface layer was roughly proportional to that of chlorophyll concentration measured in Van Dorn samples. This suggests that phytoplankton of subsurface chlorophyll maximum are photosynthetically active even under low light conditions.

4. Discussion

Since RILEY *et al.* (1949) had discussed the mechanism for formation of subsurface chlorophyll maximum, possible processes have been presented by several investigators; accumulation of phytoplankton settling from overlying water (STEELE and YENTSCH 1960), increase in chlorophyll content in cells adapted to low light intensity (STEELE 1964), differential grazing pressure by zooplankton (LORENZEN 1965), combination of several biological and physical processes (VENRICK *et al.* 1973). ANDERSON (1969, 1972) has shown that the chlorophyll maximum layer consists of photosynthetically active cells adapted to low light and is most likely a result of phytoplankton growth at this depth. Data from the present study suggest the view of JAMART *et al.* (1977) wherein subsurface chlorophyll maximum may be explained by two processes; one is *in situ* growth of photosynthetically active phytoplankton and the other is differences in the buoyancy and sinking rate of phytoplankton caused by variations in their nutrient conditions.

In the present study, a well-developed pycnocline is formed at both stations, St. 9 (oligotrophic water) and St. 14 (mesotrophic water), and the concentration of chlorophyll *a* in the water column of upper 100 m at St. 14 is at least two times greater than that at St. 9. Under such conditions, if the chlorophyll maximum is assumed to be developing in pycnocline by simple accumulation process of senescent phytoplankton sinking from overlying water, a more pronounced maximum may be found at St. 14. Nevertheless, a striking subsurface chlorophyll maximum was present at St. 9 whereas a maximum was absent at St. 14. Such difference

in the vertical distribution of chlorophyll is presumably attributed partly to difference of nutrient conditions in the surface water. Depletion of nutrients, especially inorganic nitrogen, in the surface layer may have brought a decrease in buoyancy of phytoplankton cells and consequently cells would have to sink downwards (STEELE and YENTSCH 1960). When cells reached nutrient-rich pycnocline, buoyancy is probably increased and cells may be retained at this depth. This process seems partly contribute to formation of chlorophyll maximum. Assimilation number for phytoplankton from the mixed layer at St. 9 was very low compared with the values at St. 14. Lower activity may be associated with nutrient depletion.

Photosynthetic capacity of the water samples collected by the Rosette samplers from the subsurface layer below 100 m showed relatively high value at St. 9, while we could hardly detect any activities at St. 14, except for a few layers around 100 m depth. This fact suggests that the subsurface chlorophyll maximum layer at St. 9 consists of shade type phytoplankton.

The daily *in situ* production was estimated to be 54.88 mg C/m^2 at St. 9 and 85.33 mg C/m^2 at St. 14. These values are less than one third or half of those reported in the Kuroshio regions (e.g. SAIJO and ICHIMURA 1960, ARUGA and MONSI 1962). Contribution of the chlorophyll maximum layer to primary production is about 28.5 % of the total production. This value coincides fairly well with those reported by ANDERSON (10-15 %, 1972), VENRICK *et al.* (7-20 %, 1973) and SAIJO (20 %, 1973). As pointed out by ANDERSON (1972) the chlorophyll maximum layer appears to contribute significantly to the primary production of the open ocean.

Acknowledgements

We wish to thank Professor A. HATTORI, the chief scientist, and all members of the Hakuho-Maru KH 73-1 cruise and the crew of R.V. Hakuho-Maru, Ocean Research Institute, University of Tokyo, for their co-operation during the cruise.

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冬季における西部北太平洋の亜表層クロロフィル極大

山口征矢，市村俊英

要旨：冬季の西部北太平洋の貧栄養海域の1測点で 100～150 m の深度に表層の約3培の濃度をもつクロロフィル極大層が認められた。この層の植物プランクトンは弱光条件下でも相当高い光合成能を有し，水柱全体の日生産量の 28.5% がクロロフィル極大層中で生産されていることが明らかになった。表水層が比較的栄養塩に富む測点ではクロロフィル極大層はみられず，亜表層の植物プランクトンは弱光条件下ではほとんど光合成活性を示さなかった。亜表層のクロロフィル極大は水柱の栄養状態と植物プランクトンの光合成能の微妙なバランスの上に形成されるものと思われる。

学 会 記 事

1. 昭和55年3月1日，東京水産大学において編集委員会が開かれ，第18巻第2号の編集を行った。

2. 昭和55年4月5日，東海大学代々木校舎において，シンポジウム「海洋の物質循環にかかわる微生物過程—その研究の現状と展望—」（コンビーナー 関 文威（筑波大生物））が，日本海洋学会との共催で開かれた。

概観の試み（キーノートアドレス）
西沢 敏（東北大農）
炭素の循環 半田暢彦（名大水圏科研）
窒素の循環 小池勲夫（東大海洋研）
生物生産過程における微生物
高橋正征（筑波大生物）
従属栄養過程における微生物
関 文威（筑波大生物）
物質循環に関するモデル解析
角皆静男（北大水産）

総合討論（座長 市村俊英（筑波大生物））では，活発な論議が行われた。

3. 新入会員

氏 名	所 属	紹介者
安田公昭	名大・水圏科学研究所	有賀祐勝
関 晋	日本原子力研究所 環境安全研究部	橋本 淳
山口征矢	埼玉大学教養部	有賀祐勝

4. 会員の住所・所属の変更

氏 名	新住所または新所属
小長俊二	〒305 茨城県筑波郡谷田部町長峰1番1 気象研究所海洋研究部
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守安実己郎	〒165 中野区野方 6-39-3

5. 正会員赤築敬一郎氏および平泉泰氏は逝去されました。御冥福を御祈りいたします。

6. 退会者
正 会 員 荻野珍吉，宮崎千博，佐々木信男
賛助会員 日本海洋産業(株)

7. 交換及び寄贈図書
1) なつしま 第44号，45号
2) 国立科学博物館研究報告 A類（動物学） 第5巻
3) 国立科学博物館彙報 第12号
4) 理化学研究所第2回科学講演会記録
5) 季刊 海洋時報 第16号
6) 横須賀市博物館資料集 第3，4号
7) 英国産業ニュース 2月号，3月号
8) 広島県水産試験場研究報告 第10号
9) 須田皖次先生寄贈図書目録（東海大附属図書館）
10) 海洋汚染防止法制の比較研究 第2号
11) 鯨研通信 第332号，333号
12) 広島日仏協会報 No. 75
13) 海洋産業研究資料 Vol. 11 No. 2
14) 1979年第4回国際海洋シンポジウム報告書
15) 研究実用化報告 Vol. 28 No. 12, Vol. 29 No. 1, 2
16) 神戸海洋気象台彙報 No. 198
17) 海洋資料センター（JODC）ニュース No. 20
18) 理化学研究所60年の記録
19) 東海大学紀要海洋学部 第13号
20) 東海大学海洋学部業績集 第10集
21) 昭和50年水産試験研究機関海洋観測資料(水産庁)
22) Annales de l'Institut Océanographique Tome 55
23) Boletim Instituto Nacional de Investigação des Pescas
24) Bulletin de l'Institut de Geologie du Bassin d'Aquitatine N° 26
25) La Gazette N° 31, 32, 33
26) Scienece et Pêche, Bull. Inst. Pêches Marit. N° 293, 294, 295, 296
27) Israel Oceanographic & Limnological Research, Haifa, Collected Reprints Nos. 2, 3

日仏海洋学会役員

顧　問　ユベール・ブロッシェ　ジャン・デルサルト　ジャック・ロベール　アレクシス・ドランデール　ベルナール・フランク　ミシェル・ルサージュ　ロベール・ゲルムール

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（五十音順）

監　事　久保田　穣，岩崎秀人

評議員　青山恒雄，赤松秀雄，秋山　勉，阿部宗明，阿部友三郎，新崎盛敏，有賀祐勝，石野　誠，石渡直典，市村俊英，井上　実，今村　豊，入江春彦，岩崎秀人，岩下光男，岩田憲幸，宇田道隆，宇野　寛，大内正夫，小倉通男，大村秀雄，岡部史郎，岡見　登，梶浦欣二郎，加藤重一，加納　敬，川合英夫，川上太左英，川村輝良，川原田　裕，神田献二，菊地真一，草下孝也，楠　宏，国司秀明，久保田　穣，黒木敏郎，小泉政美，小林　博，小牧勇蔵，西条八束，斎藤泰一，斎藤行正，佐伯和昭，坂本市太郎，佐々木忠義，佐々木幸康，猿橋勝子，柴田恵司，下村敏正，庄司大太郎，杉浦吉雄，関　文威，多賀信夫，高木和徳，高野健三，高橋淳雄，高橋　正，谷口　旭，田畑忠司，田村　保，千葉卓夫，辻田時美，寺本俊彦，鳥羽良明，冨永政英，鳥居鉄也，中井甚二郎，中野猿人，永田　正，永田　豊，奈須敬二，奈須紀幸，西沢　敏，新田忠雄，根本敬久，野村　正，半沢正男，半谷高久，樋口明生，菱田耕造，日比谷　京，平野敏行，深沢文雄，深瀬　茂，福島久雄，淵　秀隆，星野通平，増沢譲太郎，増田辰良，松生　洽，松崎卓一，丸茂隆三，三浦昭雄，三宅泰雄，宮崎正衛，村野正昭，元田　茂，森川吉郎，森田良美，森安茂雄，安井　正，柳川三郎，山路　勇，山中鷹之助，山中一郎，山中　一，吉田多摩夫，渡辺精一

（五十音順）

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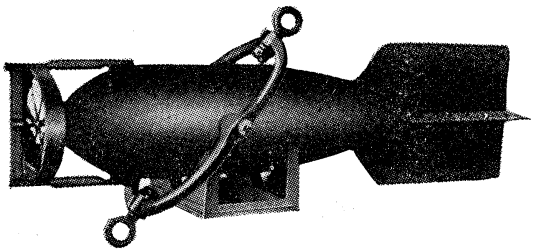
株式会社渡部計器製作所	東京都文京区向丘 1-7-17

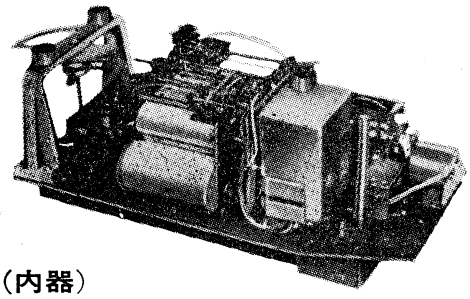
長期捲自記流速計

(NC-Ⅱ)

本流速計は海中に設置し、内蔵した記録器に流速流向を同時に記録するプロペラ型の流速計で約20日間の記録を取る事が出来ます。但し流速は20分毎に3分間の平均流速を又流向は20分毎に一回、共に棒グラフ状に記録しますから読取が非常に簡単なのが特徴となって居ります。



(外器)

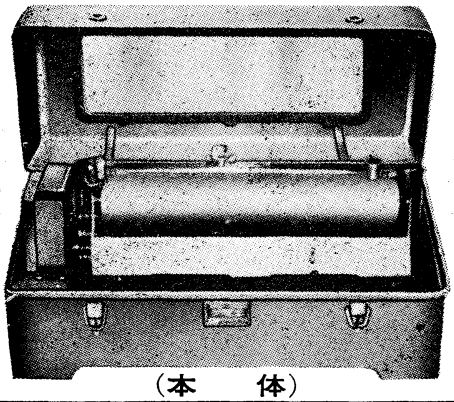


(内器)

プロペラはA，B，C三枚一組になって居り
A(弱流用)……1m/sec
B(中流用)……2m/sec
C(強流用)……3m/sec
迄で一枚毎に検定してあります。
弱流ペラーに依る最低速度は約4cm/secです。

フース型長期捲自記検潮器

(LFT-Ⅲ)



(本　体)

営業品目

階段抵抗式波高計
ケーブル式波高計
フース型検潮器
小野式自記流速計
自記水位計
港施型土圧計
理研式水中カメラ
その他海洋観測諸計器

協和商工株式会社

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