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Article spécial n° 5

Marine chemistry or chemical oceanography*

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Is marine chemistry really an independent discipline, with its own goals and its own scientific satisfaction, or is this just a fiction? Whether marine chemistry is a subdiscipline of biological, geological or physical oceanography is little debated, but this question is certainly worth asking. Oceanographic institutes know that when they attract young chemists into the field of marine chemistry, a number of them will sooner or later become disappointed as they experience that they are not carrying out the kind of science for which they thought they had been educated. This happens particularly with chemists who consider chemistry to be the science of synthesizing new chemical products, in connection with the study of the molecular structures of compounds and the determination of their physicochemical properties. Such disappointment seems to occur mostly with newly graduated chemists who not have the slightest notion of what the sea actually is and certainly know nothing about its unstable surface which renders them sea-sick.

Fortunately there remain a few young chemists who stay in their new chosen discipline and become dedicated to the oceans and their marginal seas. Their reason for doing so, however, requires further reflection. They will not go on to synthesize new substances and rarely will carry out research on molecular structures of individual compounds. Hence, the question remains, what their major achievements in chemistry will be, and what the highlights in the general advancement of marine science in fact are.

In the early days of marine chemistry the chemist started as an analytical chemist, whose achievements were connected with the development of analytical techniques and their application in the various conditions encountered in doing and participating in ocean research. Marine chemistry as such was a basic part of either physical, geological or biological oceanography.

In order to avoid being no more than technicians for these disciplines, the chemists called themselves chemical oceanographers, with the emphasis on the second term. Many chemical oceanographers of the first days such as Herman WATTENBERG (G), H.W. HARVEY (UK), Kurt KALLE (G) and Norris RAKESTRAW (USA) were pioniers in the science of understanding the basic processes of water-mass movements and the cycles and budgets of substances in the

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sea. These were essential for oceanography in the early years.

With the improvements of modern analytical techniques and the specialization of education in marine chemistry, the role of chemists has become much more sophisticated. This, however, at the risk of losses for the impact to studies of other oceanographical disciplines.

Marine chemistry has partly become a specialization in itself, and most satisfactory studies can already be done in no more than 1 ml of sea water. Nevertheless these specializations remain almost entirely analytical. The impact of the results of such studies on the functioning and structure of oceanic geochemical and ecological systems remains restricted in value or is indeed absent. The danger of becoming simply a technician in this case of one's own discipline is always present, in spite of the fact that the marine chemist is able to identify dozens of peaks from the computerized read-out of his analytical equipment, and his results and manuscripts may be generously accepted for publication in one of the well-cited journals. Although scientists from other disciplines, in particular biology, may wonder what the value of such studies really is, the reward for the marine chemist is many citations.

For these other marine scientists this is, however, not without concern. Marine biologists, physicists and geologists cannot make progress in their own science without good chemical data. A problem arises when they try to produce these data themselves; this is not the most effective way of working, and there is a loss of accuracy in analysis and interpretation of results. Oceans, marginal seas and estuarine ecology studies require the combined efforts of many disciplines, including those of geochemists, biochemists and microbiologists. In this sense, environmental chemistry is a better term than marine chemistry or chemical oceanography, although each one keeps its own value.

The question remains, however, what is the 'glue' which can bind the efforts of other disciplines with those of marine chemistry, and thus increase the impact of the chemical research carried out in the sea. The answer is the same as that given by the chemical oceanographers of the first days: try to understand processes, on a micro-scale within organisms, sediment and water, or on a macro-scale within water masses, taking into account time, space and state of equilibrium. There is no doubt that this is of multi-disciplinary interest, although the regard in which the articles is held by the scientific world may require more time. Specialists in mono-disciplines are particularly good in self-defence and the citation scores of their publications are usually higher than those of authors who try to broaden their own field of research over the boundaries of different disciplines.

In many instances, where marine chemists have been involved with other disciplines, the initiative for cooperative inter- or multidisciplinary studies has been taken by the other disciplines. Why is this the case? Obviously, as already stated, biological, physical and geological oceanography requires chemical data and the scientists in these disciplines have been forced to take steps to secure it in the best possible manner. But perhaps chemists have been too self-content, or perhaps too shy, to take the initiative themselves to broaden their frontiers over the boundaries of their discipline?

I personally think that it is time for us to take this step, and to venture beyond our boundaries, particularly in the field of aquatic ecological research, studies on diagenesis in geology and sedimentology, and modelling of transfer and transport processes with respect to physics. Overlapping and competition may occur, but is this not always to the profit of science?

Oceanography, in whatever scientific compartment it is carried out, is in its parts as well as in its entirely a tremendous study. Geographically, it concerns 70% of our globe, and the problems of one country with regard to fishery, pollution, ecosystem protection and exploitation are those of the other. This unifies many scientists over the whole world; good scientific articles from their hands are recognized without regard to nationality or creed. Let us trust that it will remain like this and that both marine chemistry and chemical oceanography will have a great future.

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Frequency response of fresh water content in shelf waters[*]

Tetsuo YANAGI[**] and Tetsuya OHBA[***]

Abstract: The frequency response characteristics of the variation of fresh water content in shelf waters to that of river discharge on the shelf is estimated by data analysis in the Bungo Channel, Huga-Nada, Tosa Bay and the Kii Channel in the south western part of Japan. The river discharge has a prominent variability with a period of one year. The amplitude ratios of the seasonal variations of fresh water content to those of river discharge change from 0.5 month to 0.9 month and phase differences of the seasonal variation of fresh water content to those of river discharge change from 0.3 month to 6 months in those areas.

1. Introduction

In recent years human activity spreads its industrial field from the coastal area to the shelf sea area as the coastal area has already no sufficient space. It is urgent to clear the characteristic variabilily of oceanic condition on the shelf sea for the harmonic development with human activity and nature there. The input of fresh water into continental shelf waters alters the physics, chemistry, biology and sediments in the shelf waters. The runoff waters are also the main source of pollution in shelf waters. How-

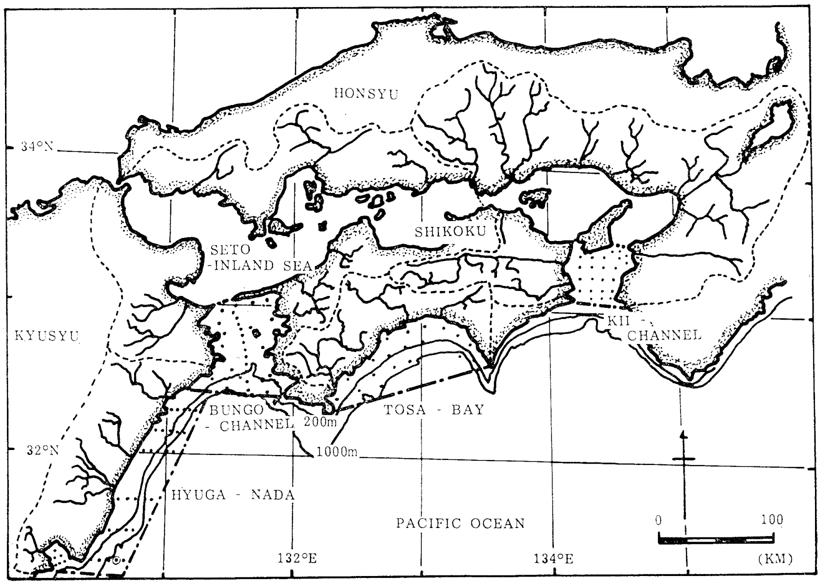

Fig. 1. Map of the Bungo Channel, Hyuga-Nada, Tosa Bay and the Kii Channel. Salinity observed stations are shown by black dottes. Major rivers are also shown. Thin full line shows the bottom contour and numbers the depth in meters. Broken line shows the drainage area.

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ever, the behavior of fresh water flown into the shelf sea has been little known.

This paper is concerned, by data analysis, with the frequency response characteristics of the variation of fresh water content in the shelf sea waters to that of river discharge from the land and backward inner coastal sea in the Bungo Channel, Hyuga-Nada, Tosa Bay and the Kii Channel in the south western part of Japan.

2. Data analysis

The Bungo Channel, Hyuga-Nada, Tosa Bay and the Kii Channel (Fig. 1) situated in the south western part of Japan are classified into two types of continental shelf sea. The Bungo Channel and the Kii Channel have inner coastal sea, Seto Inland Sea, at the back of them, whereas Hyuga-Nada and Tosa Bay abut on the land.

Salinities were observed every month from 1977 to 1981 at 0 m, 10 m, 20 m, 30 m and 50 m depths at 22 stations in the Bungo Channel, at 30 stations in Huga-Nada, at 20 stations in Tosa Bay and at 27 stations in the Kii Channel by Ehime, Ooita, Miyazaki, Kochi, Tokushima and Wakayama Prefecture Fisheries Observatories. Salinities from the sea surface to 50 m depth at each station were averaged by a depth weighting method. The fresh water content F in each area is estimated every month by the equation,

$$F=\sum_i\left(\frac{S_0-S_i}{S_0}\right)\times V_i\,. \qquad (2\text{-}1)$$

Fig. 2. Seasonal variation of representative salinity in the open ocean which is obtained by averaging salinity at 50 m depth at Stn. 4 off Toi in Hyuga-Nada shown by open circle in Fig. 1 from 1977 to 1981.

Here S_0 means the representative salinity in the open ocean, S_i the depth average salinity at the station i and V_i the water volume occupied by the station i. S_0 is made equal to the salinity at 50 m at Stn. 4 off Toi in Huga-Nada, which is shown by open circle in Fig. 1, because it usually showed the highest salinity in these areas. Since the salinity at 50 m at Stn. 4 shows a prominent seasonal variation, monthly values shown in Fig. 2 are used for S_0 in the following analysis.

The river discharge over the coastline is estimated by summing the mothly discharges of the first-class rivers, whose discharge are gauged every day, and those of small rivers. The discharge of small river is estimated by multiplying the discharge of neighboring first-class river by some factor. This factor is determined by the drainage area ratio of small river to the neighboring first-class river. The effects of direct precipitation on the shelf waters and evaporation from the sea surface of shelf wates are neglected, because they have nearly the same volume flux. Moreover the fresh water movements from one area to another area are neglected, because the most fresh water are moved away at the open end of each area by the strong Kuroshio which flows along the coast of Kyushu, Shikoku and Honshu Islands.

River discharge and fresh water content in each area are obtained every month from 1977 to 1981 and the average and standard deviation values are calculated (Table 1). Normalized monthly variations of river discharge and fresh water content with the average and standard deviation values in each area are shown in Fig. 3. River discharge has one prominent peak in a year and the local maximum fresh water

Table 1. Average and standard deviation values of river discharge and fresh water content in each area from 1977 to 1981.

	Fresh water discharge (km^3/month)		Fresh water content (km^3)	
	Ave.	S.D.	Ave.	S.D.
Bungo	2.50	1.71	4.07	2.48
Hyuga	1.51	1.24	2.58	2.91
Tosa	0.88	0.66	1.31	1.58
Kii	2.37	1.20	3.51	0.91

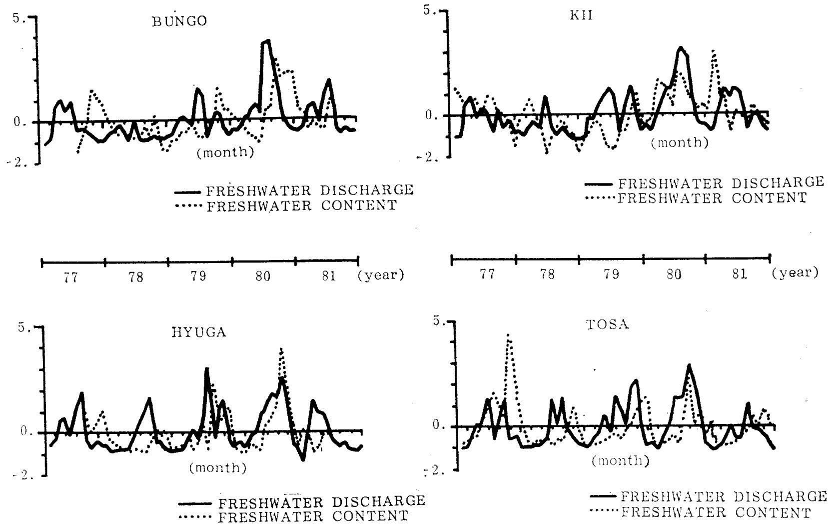

Fig. 3. Normalized monthly variations of river discharge and fresh water content from 1977 to 1981.

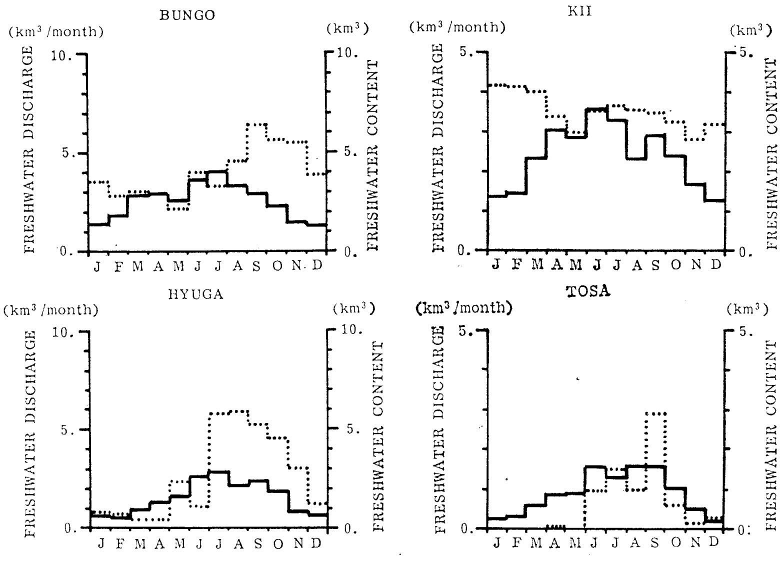

Fig. 4. Average seasonal variations of river discharge (full line) and fresh water content (broken line) from 1977 to 1981.

content occurs several months after that of river discharge. The average seasonal variations of river discharge and fresh water content are obtained by averaging monthly values from 1977 to 1981 and shown in Fig. 4. The maximum river discharges occur in June or July, the rainy season in Japan. On the other hand, the maximum fresh water contents occur in July or September in the Bungo Channel, Hyuga-Nada and Tosa Bay, and in January in the Kii Channel only.

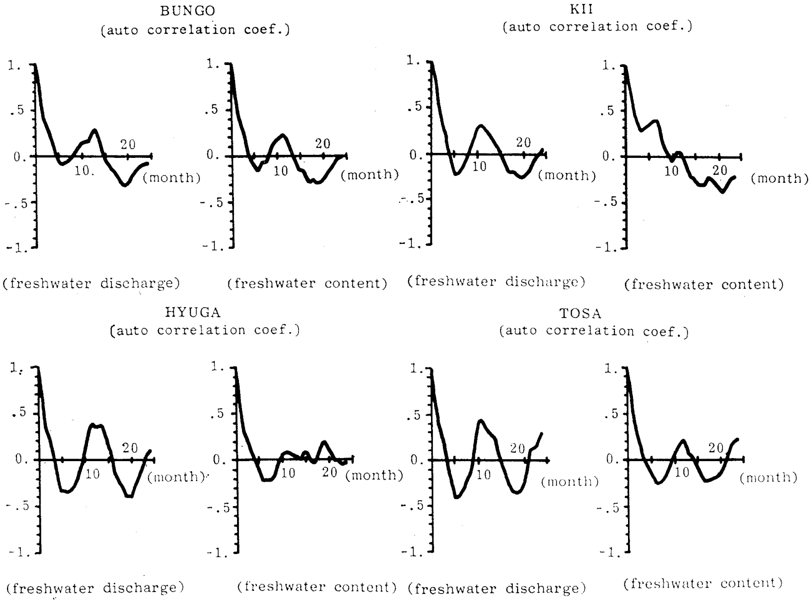

Fig. 5. Auto-correlation coefficients of river discharge and fresh water content variations.

3. Response function

We consider a linear system model which has one input (river discharge) and one output (fresh water content) in each area. The output signal is represented by the following convolution integral of the input signal,

$$y(t)=\int_{0}^{\infty} x(t-\tau)\cdot h(\tau)d\tau \qquad (3\text{-}1)$$

Here, $y(t)$ denotes the fresh water content, $x(t)$ the river discharge and $h(\tau)$ the unit response function of each area. The oceanic characteristics of each area is represented by the unit response function $h(\tau)$. There are four methods to estimate $h(\tau)$; (1) the direct method (*e.g.* HINO, 1977), (2) the correlation method (*e.g.* BOX and JENKINS, 1976), (3) the integral transfer method (*e.g.* FUJITA, 1982) and (4) the cross spectral method (*e.g.* HINO, 1977). Here the correlation method is used for estimating the unit response function for its high precision and simplicity.

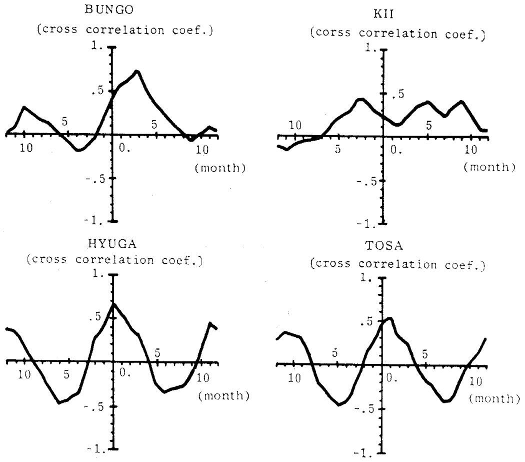

Fig. 6. Cross-correlation coefficient between river discharge and fresh water content variations.

At first the auto-correlation coefficients of variations of river discharge and fresh water content are calculated in each area as shown in Fig. 5. The seasonal variations seem to dominate except for the fresh water content in the Kii Channel. The cross-correlation coefficient between the variations of river discharge and fresh water content in each area is shown in Fig. 6. The correlation is not so high in the Kii Channel only. The unit response function is estimated by the correlation method as,

$$C_{xy}(\tau)=\int_{0}^{T} h(\eta)\cdot C_{xx}(\tau-\eta)\, d\eta . \qquad (3\text{-}2)$$

Here, $C_{xy}(\tau)$ denotes the cross-correlation coefficient between the variations of river discharge $x(t)$ and fresh water content $y(t)$, T the observation period and $C_{xx}(\tau)$ the auto-correlation coefficient of the variation of river discharge. Equation (3-2) in finite difference with unit time of one month is written in matrix form,

$$\begin{bmatrix} C_{xx}(0), C_{xx}(1), \cdots\cdots, C_{xx}(\mathrm{m}) \\ C_{xx}(1), \cdot\ \cdot \qquad , C_{xx}(\mathrm{m-1}) \\ \vdots \qquad \ddots \qquad \vdots \\ C_{xx}(\mathrm{m}), C_{xx}(\mathrm{m-1}), \cdots C_{xx}(0) \end{bmatrix} \begin{bmatrix} h(0) \\ h(1) \\ \vdots \\ h(\mathrm{m}) \end{bmatrix} = \begin{bmatrix} C_{xy}(0) \\ C_{xy}(1) \\ \vdots \\ C_{xy}(\mathrm{m}) \end{bmatrix}, \tag{3-3}$$

where m is taken as 7 months for the Bungo and Kii Channels, 6 months for Tosa Bay and 5 months for Hyuga-Nada from Fig. 5. The unit response function $h(\tau)$ is obtained by solving the linear simultaneous equations (3-3). The estimated discrete unit response function is shown in Fig. 7. The characteristics of frequency response of the variation of fresh water content to that of river discharge, which has the variability with wide range of frequency, is known by the Fourier transform of unit response function. However, it is very difficult to carry out the Fourier transform of the discrete unit response function. Therefore the discrete unit response function is approximated by a simple analytical function. The principle of approximation is as follows: In the Bungo Channel and the Kii Channel which have the inner coastal sea at the back of them, the unit response function is expressed by the summation of exponential functions and solution of diffusion equation as

$$h(\tau)=\sum_{n=1}^{2} a_n e^{-b_n\tau}+\frac{A}{\sqrt{\tau}}e^{-B/\tau}\,. \tag{3-4}$$

In Hyuga-Nada and Tosa Bay abutting on the land, the unit response function is expressed by the summation of exponential functions as

$$h(\tau)=\sum_{n=1}^{2} a_n e^{-b_n\tau}. \tag{3-5}$$

Coefficients a_n, b_n, A and B are obtained by the nonlinear least square method (Quasi Marquart method). The analytical forms of unit response function are obtained as

$$\left.\begin{array}{ll} \text{Bungo} & h(\tau)=0.065\,e^{-0.247\tau}+0.062\,e^{-0.246\tau} \\ & \qquad +\dfrac{0.211}{\sqrt{\tau}}e^{-0.610/\tau}, \\ \text{Kii} & h(\tau)=3.378\,e^{-13.08\tau}-3.049\,e^{-6.523\tau} \\ & \qquad +\dfrac{0.756}{\sqrt{\tau}}e^{-5.111/\tau}, \\ \text{Hyuga} & h(\tau)=0.231\,e^{-0.298\tau}+0.301\,e^{-0.408\tau}, \\ \text{Tosa} & h(\tau)=0.600\,e^{-0.100\tau}-0.349\,e^{-0.900\tau}. \end{array}\right\} \tag{3-6}$$

They are shown by broken lines in Fig. 7. The variation of fresh water content estimated by Eq. (3-1) with the analytical form of unit response function (3-6) and observed river discharge is shown in Fig. 8. The coincidence between the variation of estimated fresh water content and that of observed one is fairly good except for the Kii Channel.

The amplitude ratio and phase difference between the variation of river discharge and that of fresh water content are estimated by Fourier transform of the analytical form of unit response function;

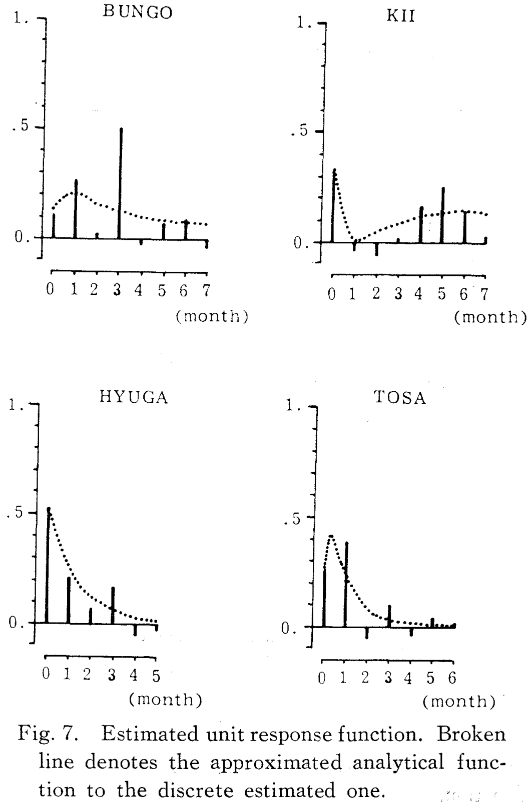

Fig. 7. Estimated unit response function. Broken line denotes the approximated analytical function to the discrete estimated one.

$$h(\tau)=\sum_n a_n e^{-b_n\tau}+\frac{A}{\sqrt{\tau}}e^{-B/\tau}$$

$$H(\omega)=\int_0^\infty\left(\sum_n a_n e^{-b_n\tau}+\frac{A}{\sqrt{\tau}}e^{-B/\tau}\right)e^{-i\omega\tau}\,d\tau$$

$$=\int_0^\infty \sum_n a_n e^{-b_n\tau}\,e^{-i\omega\tau}\,d\tau$$

$$+A\int_0^\infty \frac{1}{\sqrt{\tau}}e^{-B/\tau}\,e^{-i\omega\tau}\,d\tau$$

$$=\sum_n \frac{a_n b_n}{\omega^2+b_n^2}-i\sum_n\frac{\omega a_n}{\omega^2+b_n^2}+\frac{A}{\sqrt{\omega}}e^{-\sqrt{2B\omega}}$$

$$(\cos\sqrt{2B\omega}-\sin\sqrt{2\mathrm{B}\omega}),\qquad(3\text{-}7)$$

where $H(\omega)$ denotes the frequency response function. Therefore, the amplitude ratio $|H(\omega)|$ and phase difference $\phi(\omega)$ are

$$|H(\omega)|=\sqrt{H_R^2(\omega)+H_I^2(\omega)},\qquad(3\text{-}8)$$

$$\phi(\omega)=\tan^{-1}\left(\frac{H_I(\omega)}{H_R(\omega)}\right),\qquad(3\text{-}9)$$

$$\left.\begin{aligned}H_R(\omega)&=\sum_n\frac{a_n b_n}{\omega^2+b_n^2}+\frac{A}{\sqrt{\omega}}e^{-\sqrt{2B\omega}}\\&\quad(\cos\sqrt{2B\omega}-\sin\sqrt{2B\omega}),\\H_I(\omega)&=\sum_n\frac{\omega a_n}{\omega^2+b_n^2}.\end{aligned}\right\}\qquad(3\text{-}10)$$

The estimated amplitude ratio and phase difference in each area are shown in Fig. 9. As for the prominent seasonal variation, the Bungo Channel has the largest amplitude ratio of about 0.9 month; the amplitude of seasonal variation of fresh water content in the Bungo Ceannel is obtained by multiplying the amplitude of river discharge to the Bungo Channel by 0.9 month. The amplitude ratios of seasonal variation in Hyuga-Nada, Tosa Bay and the Kii Channel are 0.8 month, 0.5 month and 0.5 month, respectively. The phase difference of seasonal variation in the Bungo Channel, Hyuga-Nada, Tosa Bay and the Kii Channel are 0.5 month, 0.3 month, 0.3 month and 6 months, respectively. These values will be useful for comparing these areas from the viewpoint of the resistivity of shelf waters against the pollution and of the productivity of shelf waters.

4. Discussion

The difference between full line and broken line in the amplitude ratio and the difference between full line and 90° in the phase difference in Fig. 9 show the openness of each area, because the broken line and 90° represent the amplitude ratio and the phase difference of a closed basin, respectively. The opennes of each area relates to the water exchange ability, which depends on the flow system in each area. For example, the tidal currents are dominant in the

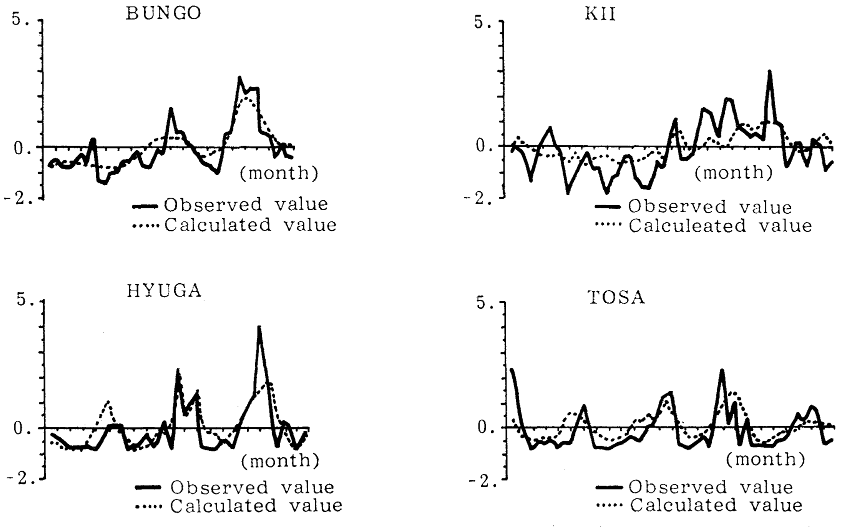

Fig. 8. Observed fresh water content (full line) and estimated one (broken line) with the approximated unit response function.

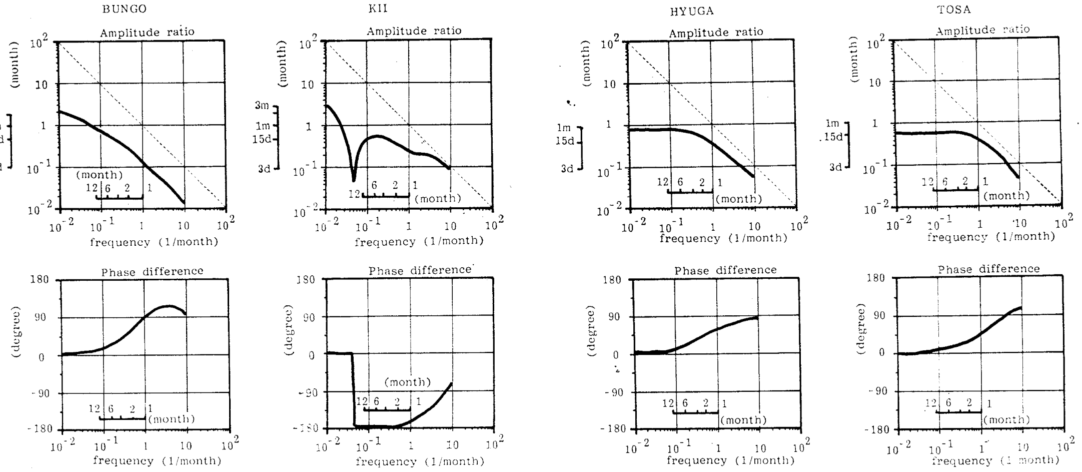

Fig. 9. Amplitude ratio of the variation of fresh water content to that of river discharge (upper) and phase difference of the variation of fresh water content to that of river discharge (lower).

Bungo and the Kii Channels because of their shallowness and of presence of the inner coastal sea at the back of them. On the other hand, tidal currents are not dominant, but flows of other types such as frontal eddies are dominant in Hyuga-Nada and Tosa Bay. The Bungo Channel has the most closed character among the four areas for the input signal with one-year period but Hyuga-Nada and Tosa Bay have more closed character than the Bungo Channel for the input signal with several-month period. The tidal current works as a strong stirrer for the fresh water input with several-month period but does not for the fresh water input with one-year period.

Although the Kii Channel shows the peculiar characteristics of amplitude ratio and phase difference, the cross-correlation coefficient is low as shown in Fig. 5, so that the reliability of frequency response function of the Kii Channel is fairly low. The salinity observation area of the Kii Channel (Fig. 1) is narrow, because the Kii Channel has three large rivers along its coastline while the Bungo Channel has no large river along its coastline. More salinity data are needed in wider area and in longer period for estimating the accurate frequency response function of the Kii Channel.

There are many elementary physical processes in shelf waters such as tidal current, density-driven current, wind-driven current. They are influenced by the irregularities of horizontal geometry and bottom topography of shelf area. Some standard measures are needed for comparing characteristics of continental shelf area governed by different composite physical processes. In this context, the frequency response function is one of useful measures. Moreover, it will be able to predict the time variation of concentration of any man-made contamination from land in shelf waters if the frequency response function is correctly given.

Acknowledgements

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陸棚水中の淡水の周波数応答特性

柳 哲雄・大庭哲哉

要旨：陸棚水中の淡水存在量の変動の河川流出量の変動に対する周波数応答特性を日向灘，豊後水道，土佐湾，紀伊水道での資料解析により明らかにした。河川流出量の変動に卓越する1年周期に対して，陸棚水中の淡水存在量の振幅はこれらの海域で0.5カ月から0.9カ月，変動の位相差は0.3月から6ケ月と異なることがわかった。

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Société franco-japonaise d'océanographie, Tokyo

Distribution of fragile particles in the sea determined by measurements by the Coulter Counter*

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Abstract: In view of fragility of macroscopic aggregates the coefficient of variation (ratio of standard deviation to mean particle number) for disintegrated particles in samples subdivided from a water sampler was obtained. The coefficient was compared with the coefficient for glass powder samples. The ratio of the two coefficients was used to denote the fragility of particles.

Measurements were made on a variety of waters of 23 layers from the Bering Sea and Funka Bay, Hokkaido. Fragility had no relationship to temperature, salinity, or nutrients, but was correlated to the concentration of total volume of particles. The ratio of smaller to the total particle number that was clearly shown in the slope of hyperbolic distribution of particles played an important role in fragility. Fragility was high under oceanographic conditions that seemed to supply fine particles from the seabed as a resuspension. When the concentration of total volume of particles was small, it appeared that fragility was dominated by the composition of materials in aggregates. Comparison of the measured total volume of particles with the assumed volume of macroscopic aggregates suggested that most of particles in the sea is in a state of aggregation.

1. Introduction

Some particulate materials in the sea are formed into aggregates. These aggregates range in size from microscopic (RILEY, 1963, 1970) up to several millimeters (SUZUKI & KATO, 1953; ALLDREDGE, 1972, 1976; TRENT *et al.*, 1978; SHANKS & TRENT, 1979), and occasionally, enormous aggregates are observed (TSUJITA, 1952; JANNASCH, 1973; HAMNER *et al.*, 1975). They have been reported not only in surface layers but also in deep layers (DIETZ, 1959; COSTIN, 1970; MANHEIM *et al.*, 1970; SILVER & ALLDREDGE, 1981; ALLDREDGE & COX, 1982). Primarily because of their chemical compositions and their high sinking rates, the role of large aggregates in the sea as carriers for particulate and dissolved materials (ALLDREDGE, 1979; SHANKS & TRENT, 1979), as a food source (HAMNER *et al.*, 1975), and as a removal of materials by sedimentation (SHANKS & TRENT, 1980), has recently attracted special interest. However, with increasing size, these aggregates become too porous and fragile (KAJIHARA, 1971) to be collected intact by traditional shipboard methods. It is known that aggregates are partly disintegrated when trapped in a water sampler, although no information is available on the relationship between the *in situ* size of intact particles and the size of those trapped in the sampler. The size distribution of particles in sampled water is undoubtedly the result of a balance between two forces, the cohesive force of the aggregates and destructive forces such as pressure variations during the closing of a sampler. However, some of the broken particles in sampled water may still hold the state of aggregates due to the imbalance of the two forces. Since the concentration of aggregate particles is low, the distribution of aggregates in the sampler will not be uniform. In addition, if other unnatural forces such as shock during rinsing of the water sample from the water bottle, are applied, the aggregates will further disintegrate. To determine the amount of aggregates, I obtained the coefficient of variation (ratio of standard deviation to mean particle number) for replicate samples of suspended particles in samplers. The results are discussed with

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respect to the occurrence of fragile particle and dissolved and particulate materials in the sea.

2. Methods

The number of particles counted by a Coulter Counter is not truly representative of the total number present because of coincident passage through an aperture and the subsequent concentration of particles in the water sample (SHELDON & PARSONS, 1967). If the particle is solid or does not disintegrate, however, the precision of reproducibility for the replicated measurements on the same sample, or measurements on some subdivided samples from a well-mixed water, show a definite count fraction that depends on the number of particles counted. If some fragile particles exist in the water sample, and if they are selectively trapped in some bottles of water that are subdivided from the initial sample, then the numbers and sizes of particles in each bottle will show, after their subsequent disintegration, different distributions depending on whether fragile particles are present or not in a given aliquot. The coefficient of variation (CV), or the measure of reproducibility of particle counts in subsamples, will be different from the CV for a sample in which the particles consist of evenly dispersed solids only. Thus, it may be possible to determine the existence of fragile particles in the sea by comparing the CV of suspended particles in seawater with that of solid particles used as a standard for count reliability. As solid particles, glass powder was made by crushing a piece of glass and removing larger particles by water-sieving in electrolyte (ISOTONE).

For obtaining the different concentration of suspended particles, a vertical profile of beam attenuation coefficient was measured and examined before water sampling, and then seawater was collected with a 7-*l* Van Dorn bottle. Seawater in the sampler was split into ten 300-m*l* polyethylene bottles. Before counting particles with the Coulter Counter (model TA-Ⅱ), the bottles were shaken and allowed to stand just long enough to remove bubbles. Measurements were made from a 250-m*l* round beaker, with stirring until just before counting. Particle counts are affected by strong radiated noise, which is not eliminated by using a metal shield around the sample stand of the Coulter Counter. Miscounts also arise both from plugging of the aperture and from the forced displacement of mercury in a manometer due to rolling of the ship. In order to check for miscounts, attention was paid to the total counts and the required time for counting; three or more measurements for each subsample of the bottles were performed. All sets of counts at each station were completed within a few hours in the Bering Sea and within 10 hours at Funka Bay, Hokkaido, after collection of water samples.

The aperture orifice used was 100 μm in diameter and water volume for the measurement sucked into the manometer of the instrument was 0.5 m*l*. The beam attenuation coefficient was measured by an *in situ* transmittance meter (Martek, model XMS), and nutrients and particulate organic materials were analysed by an Auto Analyzer (Technicon) and a CHN Analyzer (Hitachi), respectively.

3. Results

Standardization of the CV. Ten concentrations of glass powder in water (ISOTONE) were prepared, and thirty measurements were performed

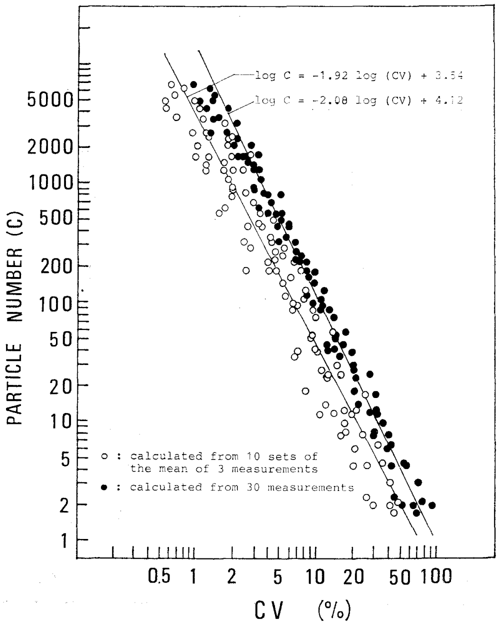

Fig. 1. Standardization of the coefficient of variation for glass powder, determined with the Coulter Counter (model TA-Ⅱ).

for each concentration. The CV was then calculated for two cases, one by the raw measured values in each concentration, and the other by the same data but with ten sets of three measurements. The relationship between the CV and the mean particle number is shown in Fig. 1. The mean counts less than 1 and greater than 10^4 were omitted from the data. Total data points in each case were 110.

When using the mean of three measurements, the CV tended to be smaller than those obtained from $n=30$, as the fluctuations of particle number were diminished. Regression lines calculated from the least squares method were as follows:

$$\log C = -2.08 \log(\mathrm{CV}) + 4.12;\quad n=30, \qquad (1)$$

$$\log C = -1.92 \log(\mathrm{CV}) + 3.54;\quad n=10, \qquad (2)$$

where C and CV are the mean particle number and the coefficient of variation, respectively. Equation (1) was calculated from the raw measured values and equation (2) was from the ten sets of the mean of three measurements. The correlation coefficient for the former was 0.99 and that for the latter was 0.97. The experimental results almost agreed with the error relationship for sample counts theoretically predicted (FRIEDLANDER *et al.*, 1981). The regression line obtained by SHELDON and PARSONS (1967) was located between the two lines in Fig. 1. As the particle number increases over ten, their CV value becomes larger than the present result for $n=10$, and the larger the particle number becomes, the closer their line gets to the present one for $n=30$, which is caused by the high slope of their line.

Description of oceanographic conditions. The nature of suspended particles in seawater depends on the water mass characteristics. As is evident from the temperature-salinity diagram (Figs. 2a and 2b), the stations located in the Bering Sea and Funka Bay are influenced by a variety of water masses. Bering Sea station 79045 was situated in the region of the Alaskan Stream water, with the surface layer diluted by water from the coast. Station 79055 was occupied by coastal water of slightly low salinity, and the vertical profiles of both temperature and salinity show the presence of strong convection. Stations 79065, 79069 and 79075 were situated in the region of the Bering Sea source water (OHTANI, 1973; COACHMAN & CHARNELL, 1979).

The Funka Bay water is characterized by periodical inflowing of two major water masses,

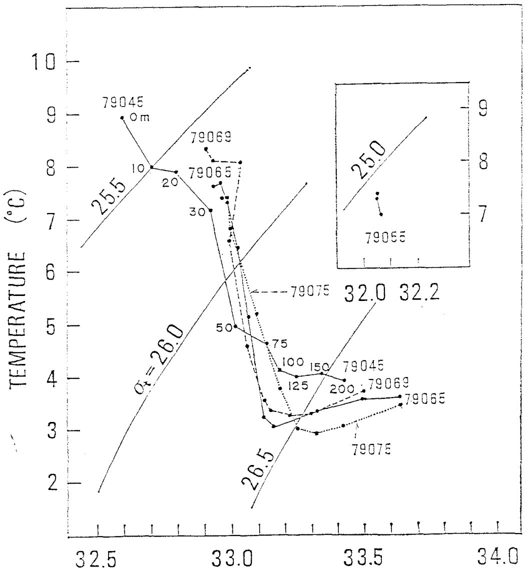

Fig. 2a. Temperature-salinity diagram for the upper 200 m layer in the Bering Sea.

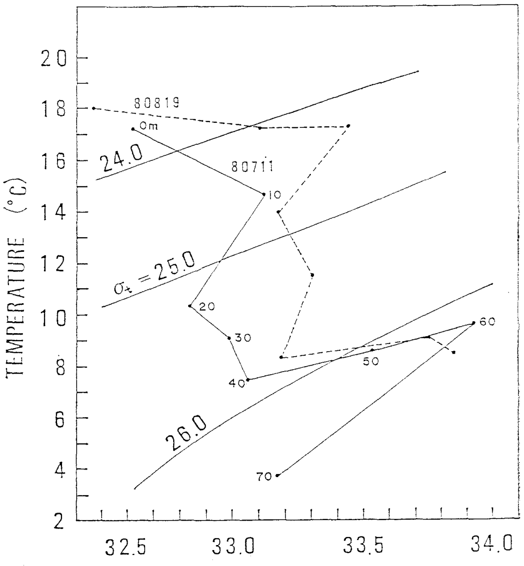

Fig. 2b. Same as Fig. 2a, except for Funka Bay, Hokkaido.

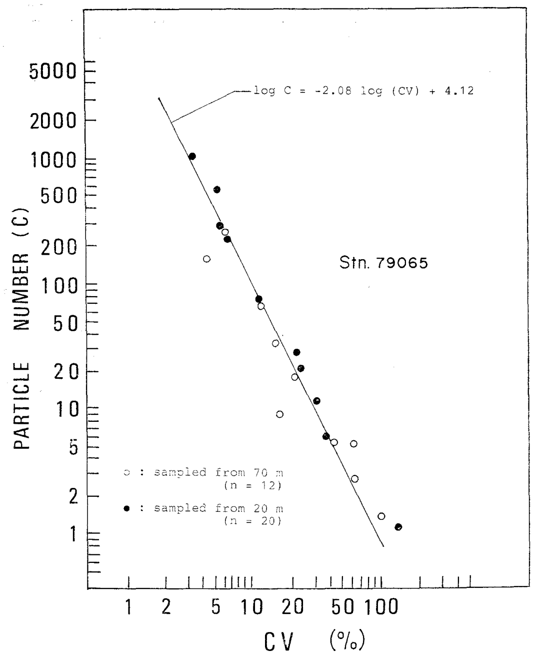

Fig. 3. Relation between the coefficient of variation and the particle number, obtained from replicate measurements for the water in one bottle.

a cold and low saline water mass originating from the Oyashio, and the warm and saline Tsugaru warm water water mass from the Kuroshio. The waters that enter the bay are affected mostly by meteorological effects and runoff from land, while they are resident in the bay (OHTANI, 1979). The measurements were carried out during the inflowing season of Tsugaru warm water. At Stn. 80711, an intrusion of Tsugaru warm water appeared in a layer centered at 60 m depth, just above the resident Oyashio water near the sea bottom. At Stn. 80819, the inflowing Tsugaru warm water spread over the bottom layer under 50 m depth. The intrusion in the upper layer (temperature, 17.23°C, salinity, 33.45 ‰) was stronger than that in July (temperature, 14.62°C, salinity, 33.13 ‰). The contrast of water masses was seen in both the concentrations of nutrients and of particulate organic matters (Table 1).

Field observations. The CV resulting from the replicate measurements for the same subsample from one bottle, sampled from 20 m (n=20) and 70 m (n=12) depths at Stn. 79065, was

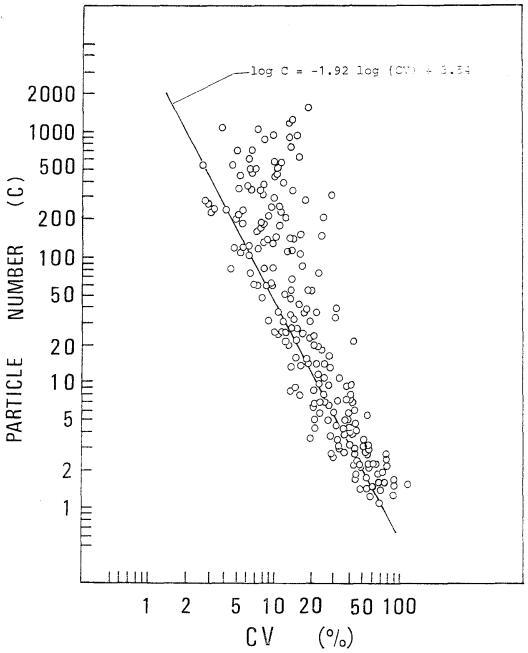

Fig. 4. Deviation of the coefficients of variation from the standard line (n=10) in the Bering Sea and Funka Bay.

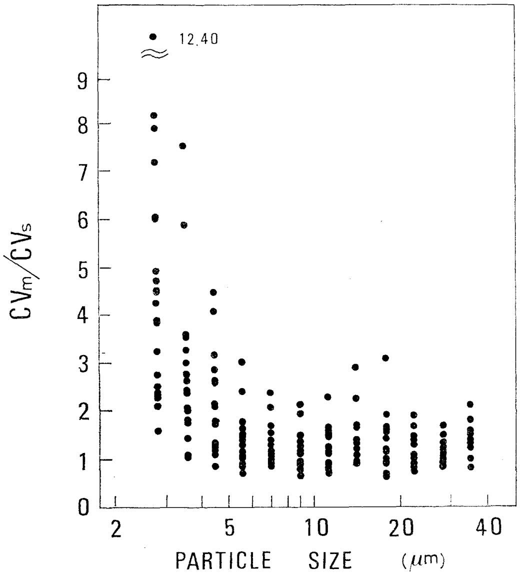

Fig. 5. Relationship between the particle size and the fragility of particles, calculated from the data for Fig. 4.

in fair agreement with the relation in the case of n=30 for glass powder (Fig. 3). This means that the accuracy of the CV in a well-stirred sample was within the mechanical error of the instrument. However, the relation between the particle number and the CV obtained from data for ten subsamples divided from one Van Dorn bottle gave a quite different tendency in the result; *i.e.*, the CV tended to deviate more with increasing particle number (Fig. 4). This figure shows all the data from the Bering Sea and Funka Bay, and the regression line inserted in the figure is for the case of n=10. Each particle number is the mean of three measurements.

To estimate the deviation for the CV for n=10 in each size, the ratio of the measured CV (CV_m) to the CV obtained with glass powder (CV_s) was plotted (Fig. 5). On the whole, the deviation of ratios was greater in the smaller size range, showing that fragile aggregates were trapped selectively in some subsamples and subsequently broken into smaller particles, causing the CV to increase. As an indicator of the fragility of particles, the CV_m/CV_s in the range of 2.52–3.17 μm (the smallest size range in the present measurement, mean diameter 2.82 μm), is given in Table 1.

Although there were wide variations in temperature, salinity and nutrient concentrations in the waters, fragility showed no direct relationship to them. However, fragility tended to increase with the total volume of particles 2.52–40.3 μm (V_1) in size, which were calculated from the sum of particle volume in each size. In this case, the correlation coefficient r was 0.49. Similarly, correlation was weak (r=0.17) between fragility and the beam attenuation coefficient α, and also weak (r=0.26) between fragility and the particulate organic carbon POC. The factors V_1, α and POC are all properties of particulate matter suspended in the sea, but α is a value defined as the sum of the absorption coefficient and the total scattering coefficient of both water and particles suspended in the water (JERLOV, 1976), whereas POC is only the

Table 1. Dissolved and particulated organic matters, beam attenuation coefficient α, mean volume of particles between sizes 2.52 μm and 40.3 μm in seawater per 0.5 ml, and fragility CV_m/CV_s at 2.82 μm.

Station	Date	Depth (m)	Temp. (°C)	Sal.	NO_2^- (μm)	NO_3^- (μm)	PO_4^- (μm)	C (μgC/l)	N (μgN/l)	α (m^{-1})	V_1 ($\times 10^3 \mu m^3$)	CV_m/CV_s
79045	July 12, '79	10	7.95	32.71	0.17	7.1	0.74	196	35	1.26	619.6	5.95
(55°48′N, 168°54′W)		20	7.86	32.80	0.26	9.8	0.94	494	58	0.61	183.1	3.26
		40						427	52	0.23	122.7	4.55
79055	July 15, '79	10	7.32	32.05	0.05	0.2	0.56	755	53	0.53	125.4	7.18
(59°00′N, 168°00′W)		20	7.02	32.06	0.03	0.3	0.50	712	44	0.55	156.6	4.85
		30	6.97	32.02	0.06	0.2	0.61	626	49	0.56	211.7	5.99
79065	July 20, '79	20	7.40	32.98	0.30	18.4	1.63	292	44	0.46	203.3	2.23
(57°00′N, 177°02W′)		30	6.39	33.02	0.17	14.7	1.44	447	55	0.32	176.4	3.82
		70						198	35	0.16	47.9	7.88
79069	July 22, '79	10	7.71	32.96	0.18	13.6	1.14	195	34	0.45	171.9	2.73
(58°00′N, 179°00′W)		30	6.39	33.02	0.27	15.9	1.36	146	22	0.39	137.4	2.15
		100	3.05	33.16	0.08	21.9	1.79	118	24	0.12	36.5	5.44
79075	July 30, '79	10	7.27	32.99	0.18	15.4	1.42	202	42	0.36	82.6	2.34
(52°59′N, 179°01′W)		30	6.76	33.00	0.18	12.0	1.42	190	42	0.32	84.3	2.45
		50	5.13	33.10	0.26	18.8	1.59	133	24	0.32	79.2	3.83
80711	July 11, '80	30	9.09	32.99	0.09	1.4		300	62	0.29	503.7	12.40
(42°06′N, 140°56′W)		50	8.48	32.54	0.33	2.0		301	72	0.27	102.6	1.59
		65	8.50	33.85	0.44	4.2		207	55	0.62	131.7	3.91
		75	5.20	33.40	0.71	10.8		337	84	1.20	184.3	8.16
80819	Aug. 19, '80	0	18.0	32.47	0.03	0.9		174	38	0.30	66.2	2.38
(42°06′N, 140°56′W)		30	13.93	33.18	0.03	0.5		219	45	0.31	49.2	4.57
		50	8.23	33.19	0.19	1.1		184	44	0.27	51.7	2.33
		70	8.17	33.86	0.54	9.9		181	39	1.02	59.0	4.25

concentration of organic carbon in particulate matter. Thus, the correlations might become weak especially in α and POC, depending upon the water mass.

Distributions of finer particles. Since the aperture orifice used was 100 μm in diameter, and counts smaller than 2.52 μm particles were omitted, the particle sizes presented here were confined to those from 2.52 μm to 40.3 μm. However, particles of size less than 2.52 μm are most abundant in seawater, and therefore may contain information about the size composition of fragile particles.

It is known that the size distribution of suspended particles in seawater follows a hyperbolic distribution,

$$\tilde{N}=kX^{-m}, \qquad (3)$$

where $\tilde{N}$ is the cumulative number of particles larger than a given size X, and k and m are constants (BADER, 1970). This relationship also fitted the present data, including disintegrated particles. In this case, $\tilde{N}$ was taken as the cumulative particle number of the mean of ten sets of subsamples; the distributions were then plotted on log-log plots (Fig. 6). The patterns were convex in most cases; however, that at Stn. 79055 located in a region of strong convection, and that near the sea bottom in Funka Bay (Stns. 80711 and 80819), appeared concave. In a few cases, the two segments did not cross each other, if examined in detail, although they were nearly one straight line. MCCAVE (1975) discussed the hyperbolic distribution of particles offered by Sheldon, and noted that in shallow layers above 200 m, the distributions consisted of two or more segments, while below 200 m most of them fitted one straight line. The patterns MCCAVE discussed were convex in shallow layers. Concave patterns were seen in data collected around the Galapagos Island (CARDER *et al.*, 1971).

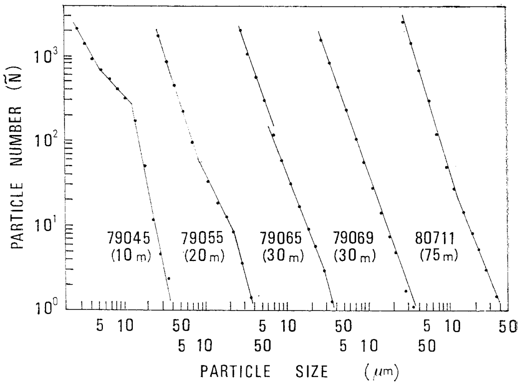

Fig. 6. Selective size distributions of the cumulative particle number. The numbers in parentheses indicate the depth of sample at the station.

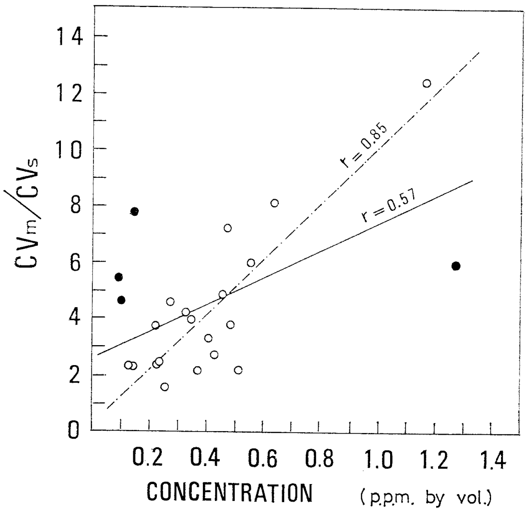

Fig. 7. The fragility of particles as a function of the concentration of total volume of particles (p.p.m. by vol.). Solid line was calculated from all data, and dot-dash line from data excluding solid circles.

Table 2 shows a summary of slopes m in each segment and their applicable sizes. Although the slopes of the lines ranged widely from 1.12 to 6.30, most slopes were within the range 2.0–4.0. Steep slopes in the larger sizes may be spurious due to small particle number. For the hyperbolic distribution of particle number, the volume of particles (assumed spherical) (V) contained between sizes X_0 and X is (BRUN-COTTAN, 1971),

$$\mathrm{V}=-\frac{\pi km}{6(\mathrm{m}-3)}\left[X^{-m+3}\right]_{X_0}^{X} \quad \text{for } m\neq3, \qquad (4)$$

$$\mathrm{V}=-\frac{\pi k}{2}\left[\log X\right]_{X_0}^{X} \quad \text{for } m=3. \qquad (5)$$

Thus, if the slope m obtained in the small size range holds in the range of smaller particles,

Table 2. Slopes of straight line segments m_i and their applicable size ranges in hyperbolic distributions, cumulative number of particles $\tilde{N}$ at a size of 2.82 μm, and mean volumes of particles V_2 between sizes 1 μm and 2.82 μm, calculated from samples of 0.5 ml volumes.

Station	Depth (m)	m_1	Range (μm)	m_2	Range (μm)	m_3	Range (μm)	$\tilde{N}$	V_2 ($\times 10^3 \mu m^3$)
79045	10	1.62	<5.2	1.12	5.2-11.8	4.55	>11.8	1974.5	16.9
	20	2.13	<11.9	3.88	11.9-17.7	6.30	>17.7	1216.8	17.5
	40	2.57	<6.4	2.12	>6.4			614.7	13.5
79055	10	3.66	<8.2	2.34	8.2-23.3	4.78	>23.3	2026.7	119.5
	20	3.05	<9.1	2.01	9.1-23.5	4.03	>23.5	1777.7	60.6
	30	2.91	<8.2	2.26	8.2-22.0	4.08	>22.0	1895.3	56.9
79065	20	2.57	*	2.70	*	4.40	>19.1	2264.6	49.6
	30	2.84	*	2.61	*	3.55	>27.9	2083.9	58.7
	70	2.96	<14.1	4.88	>14.1			569.3	17.9
79069	10	2.84	<28.5	4.10	>28.5			1794.2	50.5
	30	2.88						1531.4	44.7
	100	2.91						377.1	11.3
79075	10	3.04	<18.2	4.13	>18.2			971.8	32.8
	30	3.02	<16.1	3.92	>16.1			1080.5	35.8
	50	2.87	<15.8	3.97	>15.8			956.1	27.7
80711	30	2.47	<14.4	2.86	>14.4			3762.6	75.1
	50	2.82	<14.5	2.37	>14.5			801.8	22.1
	65	3.10	<8.4	2.09	>8.4			1124.1	40.1
	75	3.49	<12.8	2.10	>12.8			2651.4	134.2
80819	0	2.55	<4.1	1.76	4.1-10.2	3.75	>10.2	511.8	11.0
	30	2.49	<19.6	3.30	>19.6			331.8	6.8
	50	2.67	<19.0	3.44	>19.0			549.5	13.2
	70	3.91	<9.1	2.94	6.1-15.5	3.66	>15.5	1482.0	109.2

* Two segments do not cross each other.

the volume of particles ranging from 1 μm to 2.82 μm (V_2) could be calculated as in Table 2, where 2.82 μm is the geometric mean diameter for the size range 2.52-3.17 μm. Although the correlation coefficients between fragility and V_1 and V_2 were 0.49 and 0.45, respectively, the correlation coefficient between fragility and ($V_1 + V_2$) or between fragility and the concentration of total volume of particles ranging from 1 μm to 40·3 μm was 0.57 (Fig. 7).

4. Discussion

According to direct observations of macroscopic aggregates of marine snow by SCUBA diving, concentrations were 1.9-27.7 l^{-1} (longest dimension >0.5 mm) (TRENT *et al.*, 1978). 0-3.2 l^{-1}, 0-8 l^{-1} (longest dimension >3 mm) (ALLDREDGE, 1979), 0.7-14.0 l^{-1} (longest dimension >1 mm) (SHANKS & TRENT, 1980) and 0.1-1.1 l^{-1} (longest dimension >3 mm) (ALLDREDGE & COX, 1982). Thus, it is recommended to sample marine snow by the 7-l Van Dorn bottle. Marine snow is not the only fragile class of particles suspended in seawater; colony-forming phytoplankton, fragile cells and skeletal materials also might be disrupted by the Coulter Counter technique, and thus become a source of smaller particles, although these planktonic particles are undoubtedly one of the main components of marine snow. An increase of smaller particles in seawater is of no necessity for increasing in fragility in the smaller size ranges. Fragility increases only when particles in the sampler in low concentrations are broken apart by stirring prior to measurements by the Coulter Counter, and are disrupted unevenly among the ten subsample bottles.

In the present measurements, the fragility

CV_m/CV_s of 2.52-3.17 μm ranged from 2.15 to 12.40 (Table 1). The average particle counts of ten subsamples per 0.5 ml in each case were 716 and 1528, respectively, *i.e.*, CV_s at these counts were 2.27 and 1.53, as is evident from Eq. (2), and CV_m were 4.48 and 19.00. This means that there are significant differences in the standard deviations of particle numbers among the 250-ml subsamples, which are 9.35×10^3 and 133.5×10^3 in the size range between 2.52 μm and 3.17 μm. If the calculation of standard deviations is extended to the full range of 2.52-40.3 μm, these differences become 23.4×10^3 and 247.9×10^3. Although a major assumption remains that fragile planktonic particles, much more abundant than fragile aggregates, are divided into ten subsamples with even dispersion, macroscopic aggregates and/or their broken pieces at water sampling might contribute as a main cause for the large variation of fragility.

Fragility increases in proportion to the volume of particles contained in seawater. Thus, aggregates are apt to be formed when there are high concentrations of particulate materials; however, the correlation was not as good as expected. This may be due to the fact that fragility is affected not only by the concentration of particulate materials, but also by the nature of the aggregates themselves. Fragility was high in samples at Stn. 79055 and near the seabed in Funka Bay, where the distribution patterns were concave. The pattern signifies that the ratio of the number of smaller particles to total particle number in these samples was high, compared to the ratio in the distribution patterns of convex or one straight line relationships. In view of the oceanographic conditions in the region sampled, some of the smaller particles were possibly transported from the seabed as a result of resuspension. When macroscopic aggregates settle on the seabed, they will be broken by bottom shear stress and by collision with moving particles on the seabed. The particles thus produced are small both in size and weight and are therefore easily transported upward by turbulent diffusion. Some resuspended particles will aggregate onto other aggregates or will aggregate among themselves. In either case, the smaller particles transported from the seabed play an important role in the resulting high fragility. At Stn. 79045 in the Alaskan Stream water region, the fragility at 10 m depth was high, but the increase in values was not as high as expected from the concentration of total volume of particles. At this depth, the slope m_1 was extremely low, which meant that the ratio of the number of smaller particles to the total particle number was very low. I cannot explain exactly why such a low slope occurred, but it appeared to relate to weather conditions. Several days before the present measurements, there were strong winds. Under such weather conditions, rough seas tend to produce organic aggregates due to bubbe dissolution (JOHNSON, 1976), which may adhere to and thus consume smaller particles. If there was an imbalance between removal of smaller particles due to consumption and the supply of them at surface layers, a low slope would be formed. The amount of fragility also might be affected by the concentration of smaller particles in the opposite case.

Fragility was comparatively high at 70 m depth at Stn. 79065, at 100 m depth at Stn. 79069, and at 30 m depth at Stn. 80819, despite the low concentration of total particle volume. These zones of high fragility might be caused by the selective trapping of fragile particles into a limited number of subsamples, or they might relate to higher ratios of POC and PON to the total volume of particles (V_1+V_2). Specifically, fragility might be changed by the composition of materials in the aggregates. Mucous materials produced by zooplankton provide a particularly suitable nucleus for the gradual accumulation of small particles (ALLDREDGE, 1979). If the data from Stns. 79045 (10 m), 79065 (70 m), 79069 (100 m) and 80819 (30 m) different from the other data were excluded from the calculations, the correlation coefficient between fragility and the concentration of total volume of particles increases to 0.85 (Fig. 7).

The total valume of particles ranging from 1 μm to 40.3 μm in size, calculated both from results of the Coulter Counter measurements and with the assumption of hyperbolic distribution was 47.8-636.5$\times10^3$ μm^3 (mean 200.5×10^3 μm^3) per 0.5 ml of seawater, *i.e.*, 9.56-127$\times10^7$ $\mu m^3\ l^{-1}$ (mean 4.01×10^8 $\mu m^3\ l^{-1}$). On the other hand, if there were macroscopic aggregates of marine snow with 3 mm in diameter having 99 % porosity, the volume of solid portion would be $1.4\times 10^8\ \mu m^3$. Consequently, if the total volume of particles is the result of the disintegration of marine snow, its concentration would be $0.7\text{-}9.1\ l^{-1}$ (mean $2.9\ l^{-1}$). Since suspended particles in the sea do not consist only of marine snow, the above calculations overestimate marine snow abundance, whereas, particles larger than 40.3 μm in size were out of the range of my measurements, the above calculations understimate it. Although the technique for estimation of the concentration of marine snow as discussed here is certainly rough, the result agrees well with *in situ* observation described earlier. I thus suggest that most of the particulate matter suspended in the sea is in the form of aggregates. This is supported by measurements by TRENT *et al.* (1978) showing a high ratio of the pigment concentration in aggregates to that in the surrounding seawater.

It is believed that high fragility results from the existence of large aggregates in seawater taken by water samplers. The presence of low fragility, however, does not always imply the reverse situation, because fragility does not increase if the aggregates are broken into a large number of fine particles and are evenly dispersed in the sampler. Consequently, fragility is not an indicator for the concentration of macroscopic aggregates themselves. It is true, however, that the fragility provides information about the existence of aggregates, probably of macroscopic size.

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コールターカウンターの測定から求めた壊れ易い粒子の分布

梶原昌弘

要旨: 大型の凝集粒子が壊れ易いことに注目し，採水器から分水した試水中の，崩壊した粒子による変動係数（標準偏差/粒子数平均）を求めた。この値をガラス粒子の変動係数と比較した。この比を粒子の壊れ易さ（fragility）を表わすのに用いた。

測定はベーリング海，噴火湾の異なる23試水について行なった。fragility は水温，塩分，栄養塩とは相関がなかったが，粒子の全体積濃度とは相関がみられた。双曲線分布の勾配として示される全粒子数に対する微小粒子の割合は，fragility に重要なかかわり合いを持っていた。海底から微小粒子が，再懸濁によって供給されていると考えられる海洋条件のもとでは，fragility は高かった。粒子の全体積濃度が低い時には，fragility は凝集粒子の物質組成に影響されていた。測定された粒子の全体積を，大型の凝集粒子を仮定した体積と比較してみると，海中のかなりの粒子が凝集状態にあると考えられた。

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Société franco-japonaise d'océanographie, Tokyo

Deep water property variations below about 4000 m in the Shikoku Basin*

Hideo SUDO**

Abstract: Time series of spatial distributions of potential temperature and dissolved oxygen concentration below 3800 m in the Shikoku Basin during 1975-1983 are described. It seems likely that there is a steady or unsteady northward flow below about 4000 m along the western boundary of the basin; possibly it circulates clockwise off the continental slope slowly moving upward and renewing the deep basin water. In 1976-1977 an anomalously cold deep or bottom water with corresponding high oxygen values intruded into the basin. However, a remarkable increase in dissolved oxygen that occurred up to 3000 m or less in 1980-1982 was accompanied only by a subtle decrease in potential temperature. The direct source of such an anomalously cold or oxygen-rich deep water can be traced at least 15°N; at 4000 m level it may travel from 15°N to 30°N in about one year. The transient sharp decrease in dissolved oxygen that took place at least below 2000 m in the eastern area north of 20°N during the period of the second half of 1981 to early 1982 must be connected with the occurrence of the southward shift of the Kuroshio path in November 1981.

1. Introduction

The Shikoku Basin is a small basin with depths of 4000 to 5000 m located in the northeastern corner of the Philippine Sea. It shapes like a triangle. It is bounded on the north by the continental slope running from west-southwest to east-northeast. The eastern boundary is the Izu-Ogasawara Ridge of less than 3000 m in depth. On the southwest, though the bottom topography is much complicated, the Kyushu-Palau Ridge extends southward separating the Philippine Basin from the Shikoku Basin. To the south it connects with the West Mariana Basin at 25° to 26°N (Fig. 1).

It is considered that the deep water below about 4000 m in the Shikoku Basin has entered the West Mariana Basin through a rift (about 11°N, 141°E) southwest of the Mariana Ridge and has spread northward. The sill depth is estimated to be about 4500 m. The uniformity in deep water properties below a depth of 4500 to 5000 m in the Shikoku Basin has implied that the water renewal is less significant within a few hundred to a thousand meters of the bottom.

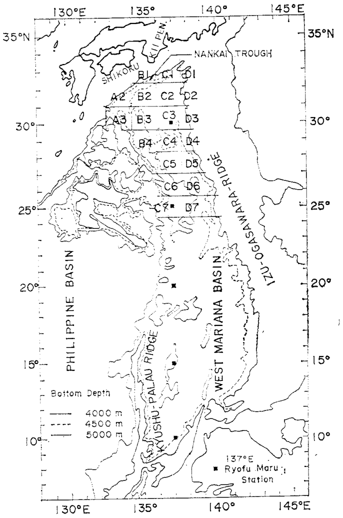

Fig. 1. Bottom topography south of Japan and the division of the Shikoku Basin used in Figs. 2 and 3. Area symbols and boundaries are as follows:
132°40′E [A] 134°20′E [B] 136°00′E [C]
137°40′E [D] Izu-Ogasawara Ridge,
24°20′N [7] 25°40′N [6] 27°00′N [5] 28°20′N
[4] 29°40′N [3] 31°00′N [2] 32°20′N [1]
continental slope.

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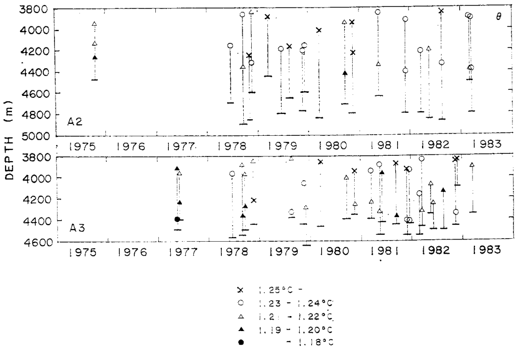

Fig. 2-1. The space-time distribution of potential temperature between 3800 m and the bottom during the period 1975-1983. Short horizontal bars denote bottom depths. Area C6 is excluded because of the complete lack of observations.

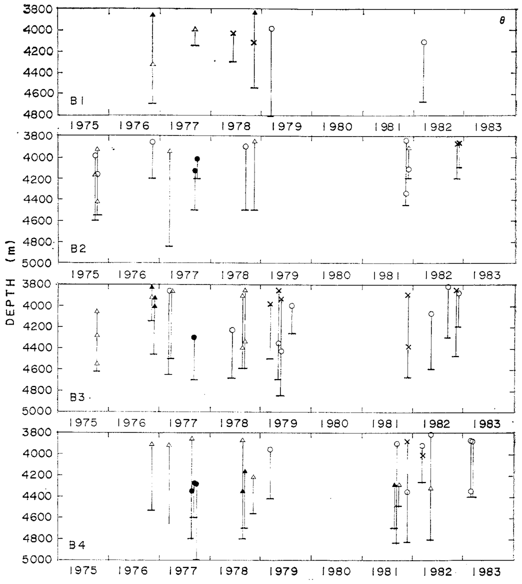

Fig. 2-2.

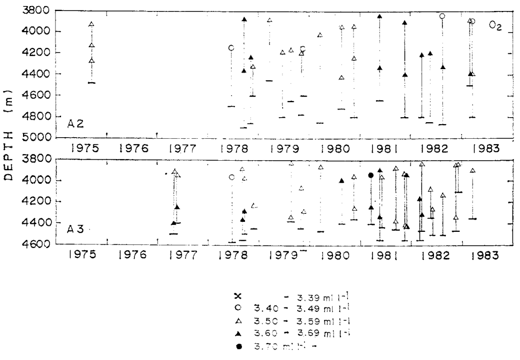

Fig. 3-1. As in Fig. 2. except for dissolved oxygen concentration.

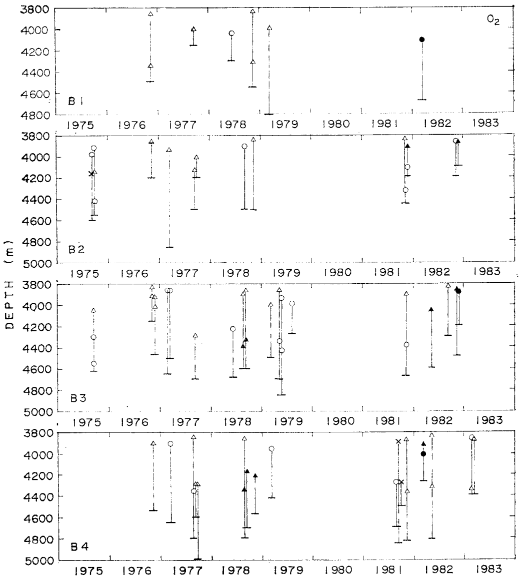

Fig. 3-2.

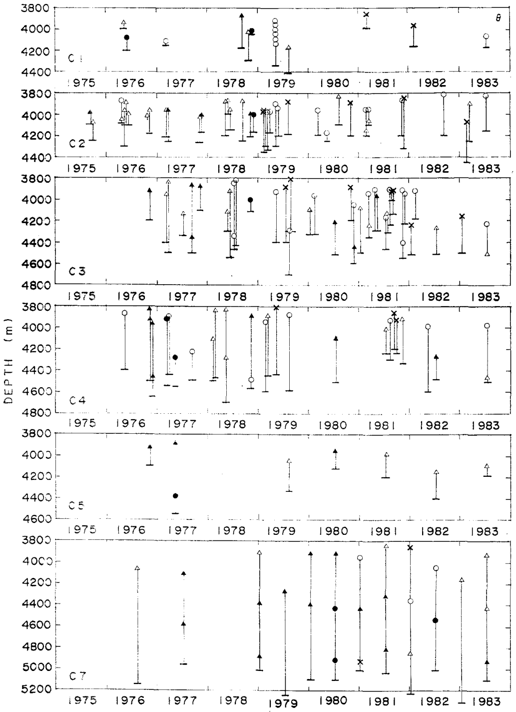

Fig. 2-3.

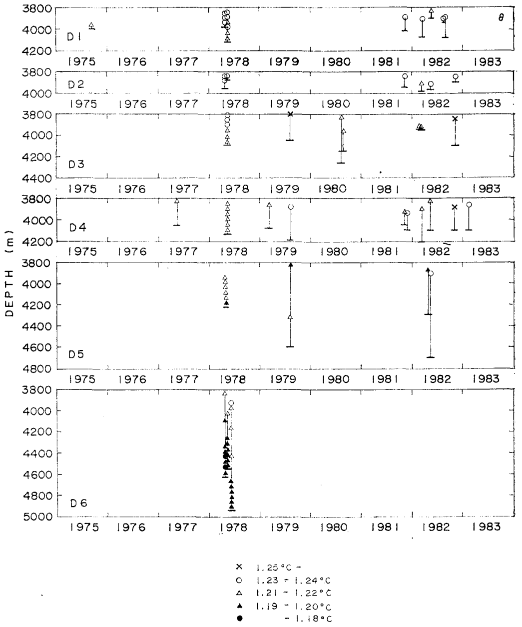

Fig. 2-4.

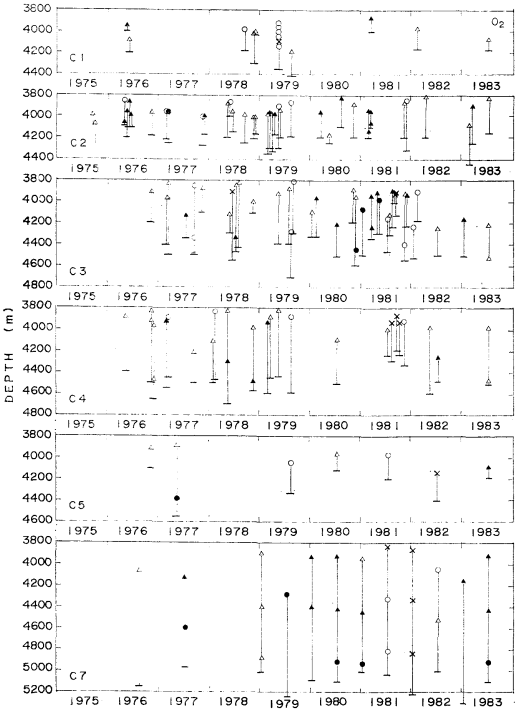

Fig. 3-3.

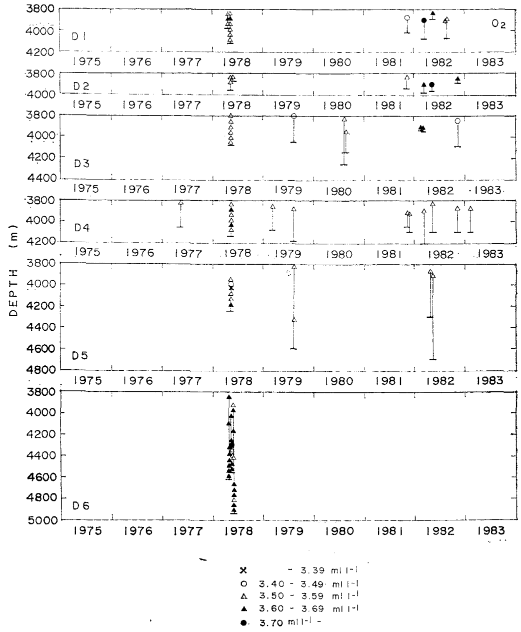

Fig. 3-4.

A few direct current measurements and CTD observations suggest that there is a cyclonic gyre below about 3000 m in the northern part of the Shikoku Basin (FUKASAWA *et al.*, 1985).

In 1976, to cope with the southward detour of the Kuroshio path, the Hydrographic Department, Maritime Safety Agency, started regular hydrographic casts down to about 3000 m or more in the area south of Shikoku and Kii Peninsula. Though the vertical sampling at every 500 m was not adequate to the analysis, it was shown that below about 4000 m the water was apparently cooler for a time in 1976–1977 (SUDO, 1982). Unfortunately, salinities obtained from some cruises might include excessive systematic errors for the deep water. Therefore, in the present analysis, an attempt is made to examine mainly temperature and dissolved oxygen variations below about 4000 m in the Shikoku Basin.

2. Distribution of potential temperature and dissolved oxygen collected below 3800 m

The quarterly hydrographic survey on R. V. *Takuyo* or *Shoyo* of the Hydrographic Department has been carried out in the area north of 28°N between 132°E and 139°E since 1976. Neither fixed sections nor fixed stations have not been set. For every cruise hydrographic casts were made usually on about 30 stations, among which less than 20 had casts extending to depths greater than 3000 m and about ten or less to 4000 m or more. A section along 137°E has been occupied by R.V. *Ryofu Maru* of the Japan Meteorological Agency in winter since 1967 and repeated in early summer since 1973. In general, its deep hydrographic casts down to 4000 m or more were made at every five degrees of latitude and occasionally at every one degree north of 28°N for summer cruises. For both routine observations, vertical spacing was usually 500 m for depths greater than 2000 m. In addition, there are some available hydrographic data: *Hakuho Maru* Cruise KH-75-5 in September–October 1975 (OCEAN RESEARCH INSTITUTE, 1978), INDOPAC Expedition Leg II in May 1976 (SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1978) and *Kaiyo Maru* cruises in May 1978 and May 1979 (SUDO, 1979). These samples were closely spaced in vertical, at every 200 to 300 m or less.

It is advisable to interpolate observed values neither vertically nor horizontally for the present analysis because of sparse samples and of uniformity of properties of the Pacific Deep and Bottom Water (the Common Water). For the examination of the horizontal distribution of water properties, the basin area with bottom depths greater than 3800 m for the north of 24°20′N is divided into 20 parts by every 1°20′ of latitude and every 1°40′ of longitude centered at 31°N, 136°E (Fig. 1). For each of them potential temperatures and dissolved oxygen values sampled at depths of 3800 m to the bottom are shown symbolically according to ranges of observed values (Figs. 2–3).

The reversing thermometer yields the *in situ* temperature to an accuracy of about ±0.02 K in routine use. The conversion of *in situ* temperatures to potential temperatures was made through the table showing adiabatic cooling values against depth ranges (SUDO, 1985, Table 6); it adds the round off error of ±0.005 K to the measurement error. Therefore, the class interval of 0.02 K used in Fig. 2 may be too small for areas or cruises of sparse samples.

An anomalously low potential temperature (≦1.18°C) was detected at 3922 m, 29°04′N, 137°00′E in May 1977 (1.18°C, C4 in Fig. 2) for the first time in the north of 27°N except for 1.18°C at 4083 m, 32°55′N, 137°36′E in May 1976 (C1). The former had a high oxygen value of 3.60 ml l^{-1} (C4 in Fig. 3). In 1976 deep hydrographic observations for the north of 27°N were made only once (along 135°40′E, B areas, in November) or twice (along 137°30′E, C areas, in May and November). In May 1976 the potential temperature was 1.21°C or more below 3800 m along 137°30′E except for the above-mentioned C1 sample. Half a year later all of the samples collected below 3800 m along the same longitude showed a significant drop of 0.02–0.03 K (1.19–1.20°C); along 135°40′E it was 1.19–1.21°C excepting only one sample north of 32°N (B2).

In May 1977 all of the samples taken below 4200 m indicated 1.20°C or less and three of four stations had anomalously low temperatures and high oxygen values: 1.16°C, 3.64 ml l^{-1} at 4393 m, 30°41′N, 133°59′E (A3), 1.17°C, 3.82 ml l^{-1} at 4373 m, 28°00′N, 137°15′E (C5) and

1.18°C (no oxygen value) at 4284 m, 28°40′N, 137°28′E (C4). Because of lack of observations in B areas it is uncertain whether they formed a single cold water mass. In September all of the samples taken below 4000 m along 135°E between 28°N and 32°N had low temperatures of 1.16–1.18°C (B2–B4), while along 136°30′E the temperature below 4000 m was 1.24°C at 29°00′N (C4) and 1.19°C at 29°23′N (C3). The lowest potential temperature observed in the Shikoku Basin during 1975–1983 was 1.16°C that appeared at least twice in 1977. They are the above-mentioned A3 sample in May and at 4123 m, 31°56′N, 135°05′E (B2) in September. In November 1977 samples below 3800 m were taken only at three stations along 136°40′E north of 30°20′N (C2–C3). It is to be noted that none of the stations located north of 29°40′N, east of 136°E (C1–C3) throughout 1977 yielded an anomalously low potential temperature (≦1.18°C).

In 1978 only two deep stations were occupied along 137°E (C4 in February) before May. In May–July every deep water sample taken below 3800 m north of 27°N was warm (1.21–1.25°C) except one near the bottom in the southeastern part (1.20°C at 4186 m, 28°01′N, 138°01′E, D5). In September 1978 a low temperature of 1.19–1.20°C was observed at five of ten stations. In November an anomalously low potential temperature (1.17°C) was obtained at about 4000 m along 137°E north of 30°N (C1–C3). It should be kept in mind that all of the deep waters sampled below 4200 m were considerably warmer (1.22–1.27°C) than those at a depth of about 4000 m or less. It is probable that a single cold water mass a few hundred meters thick, centered at about 4000 m depth, was embedded in the deep water north of 30°N. This was the first appearance of the anomalously cold water to the north of 29°40′N, east of 136°E except for that in C1 area in May 1976.

For the area north of 27°N the occurrence of the anomalously cold water with a potential temperature of 1.18°C or less was limited in the period 1976–1978. As for the cold water sampled in May 1976, it is impossible to give any interpretation because of a small number of observations throughout 1975 to 1976.

It seems unlikely that the anomalously cold water entered the northeastern part of the basin (C1–C3) directly from the south. A possible explanation is that the area north of 29°N with bottom depths exceeding 4500 m, the northern part of which is called the Nankai Trough, is mostly limited to the area near the western periphery of the basin (Fig. 1). Its northeastern end reaches about 32°40′N, 136°40′E (C1). This suggests that the deepest basin water circulates clockwise and the old near-bottom waters found in November 1978 must have invaded from the north.

North of 27°N the cold water with a potential temperature of 1.21°C or less was not found in 1979 with the exception of two stations (1.20°C at 3817 m and 1.21°C at 4312 m, 28°01′N, 138°10′N, August, D5; 1.21°C at 4282 m, 29°51′N, 133°50′E, November, A3).

Few deep stations were taken in 1980. In July–September the potential temperature observed below 3800 m north of 27°N was all 1.19–1.22°C. Four of eight stations showed a low value of 1.19–1.20°C (three at 28–30°N along 137°E, C3–C5; one in the western part, 31°19′N, 133°41′E, A2). Though it is uncertain whether they formed a single cold water mass, this seems to indicate the second intrusion of the cold water mass into the basin. This is not so intense as the previous one in 1976–1977. In November the potential temperature below 3800 m was 1.22°C or more except for one sample (1.19°C at 4443 m, 30°00′N, 137°31′E, C3).

In 1981–1982 seven samples for the area north of 27°N had a low potential temperature of 1.19–1.20°C; three were at 30–31°N along 133°40′E (A3, at 3950 m, May 1981, at 4370 m, September 1981 and at 4126 m, August 1982); the other four were discretely distributed south of 30°N (at 3962 m, 30°00′N, 137°21′E, May 1981, C3, at 4276 m, 28°59′N, 135°37′E, September 1981, B4, at 3875 m, 28°20′N, 138°00′E, May 1982, D5 and at 4262 m, 29°02′N, 136°58′E, July 1982, C4). The two which occurred in May 1981 may be the remnants of the cold water inflow in 1980.

The deep hydrographic casts carried out in the Shikoku Basin by the Hydrographic Department ended with the cruise in February–March 1983. For the period after that only the *Ryofu Maru* data along 137°E were available. From these fewer observations, a cold water with a potential temperature of 1.20°C or less was not detected after November 1982.

The accuracy of dissolved oxygen values is estimated to be about $\pm 0.05\,\mathrm{ml\,l^{-1}}$. High oxygen concentrations ($\geqq 3.70\,\mathrm{ml\,l^{-1}}$) were observed in the deep water of the Shikoku Basin at least twice for the period 1975–1983 (Fig. 3). In 1977 those high values were obtained separately along 137°E: $3.75\,\mathrm{ml\,l^{-1}}$ at 3949 m, 31°12′N, March (C2), $3.82\,\mathrm{ml\,l^{-1}}$ at 4373 m, 28°00′N, May (C5) and $3.72\,\mathrm{ml\,l^{-1}}$ at 4593 m, 25°00′N, July (C7). The second one of the above, which had an extremely high value, was taken at 177 m of the bottom, accompanied by an anomalously low potential temperature (1.17°C). Nine of ten samples of high values ($\geqq 3.60\,\mathrm{ml\,l^{-1}}$) had low potential temperatures ($\leqq 1.20$°C). This suggests that the above oxygen-rich waters were the fresher, cold bottom waters invaded from the south.

The second increase in deep water oxygen concentration occurred corresponding to the intrusion of the cold deep or bottom water in the second half of 1980 to the first half of 1981. Its beginning was presented by the *Ryofu Maru* station at 25°N, 137°01′E in July 1980: 1.20°C, $3.62\,\mathrm{ml\,l^{-1}}$ at 3927 m, 1.18°C, $3.65\,\mathrm{ml\,l^{-1}}$ at 4422 m and 1.17°C, $3.72\,\mathrm{ml\,l^{-1}}$ at 4918 m (at 192 m of the bottom). Though deep stations occupied in January-May 1981 were limited to two areas north of 30°N, along 133°40′E (A2–A3) and along 137°00′E or 137°20′E (C1–C3), only one of 17 samples for the north of 29°N was a little poor in oxygen concentration ($3.54\,\mathrm{ml\,l^{-1}}$) and three showed high values (3.71–$3.76\,\mathrm{ml\,l^{-1}}$); all of the values below 4000 m were $3.64\,\mathrm{ml\,l^{-1}}$ or more. This oxygen increase on a large scale did not continue until summer. Only one of 13 stations taken north of 28°20′N in July–September 1981 yielded a high oxygen concentration ($\geqq 3.60\,\mathrm{ml\,l^{-1}}$) and four out of 16 did in November-December.

In March 1982 ten stations were made along 133°50′E (A2–A3), along 135°50′E (B1–B4) and along 137°50′E (D1–D4); high oxygen values (3.63–$3.80\,\mathrm{ml\,l^{-1}}$) were obtained except for the southernmost one (29°12′N, 137°48′E, D4). For the major part of the northern area (*e.g.*, A2, B3, and D2) high values of 3.60–$3.71\,\mathrm{ml\,l^{-1}}$ were continuously or intermittently observed until November 1982 or March 1983. In particular, in the northwesternmost area (A2) all of the measurements below 4000 m in 1981–1982 were more than $3.60\,\mathrm{ml\,l^{-1}}$. On the contrary, none of three hydrographic casts carried out at 25°N, 137°E during July 1981–July 1982 showed such a high oxygen concentration. Therefore, it seems unlikely that the oxygen increase in March 1982 was due to the deep water invasion directly from the south. Possibly the oxygen-rich bottom water having entered the basin in the spring of 1981 ascended by several hundred meters and appeared in the northeastern area of the basin at some time of the autumn of 1981 to the spring of 1982. However, available hydrographic data fail to give definite and reliable information on the cause of this oxygen increase.

In 1983 the deep water below 3800 m at 25°N, 137°E (C7) indicated a significant increase in dissolved oxygen, but its effect on the Shikoku Basin water is unknown.

It is shown from a comparison between Fig. 2 and Fig. 3 that higher oxygen values are not always accompanied with lower potential temperatures for the deep basin waters. Each of divided areas given in Fig. 1 mostly has only one to three samples for the same cruise. Therefore, if for each of divided areas the potential temperature-dissolved oxygen relation is plotted by the present data from various cruises, it must be widely dispersed because of systematic errors, even if they are small. Nevertheless, in the southernmost part of the 137°E section (C7) both properties have some inverse correlation.

Though stations are limited to the northern area of the basin, the data taken from R.V. *Thomas Washington* in June–July 1971 (SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1977) are very useful to examine the relation for the deep water of the Shikoku Basin because of a large number of samples. There is a distinct relation between both properties for the area of 31°00′–32°20′N and 134°20′–136°00′E (B2); north of it (B1) the correlation is discernible as well (Fig. 4). For other three areas (A2, C1 and C2) the relation hardly exists. Besides, about half of the B2 samples had low potential temperatures of less than 1.20°C and all of them showed high oxygen values of more than $3.60\,\mathrm{ml\,l^{-1}}$. The

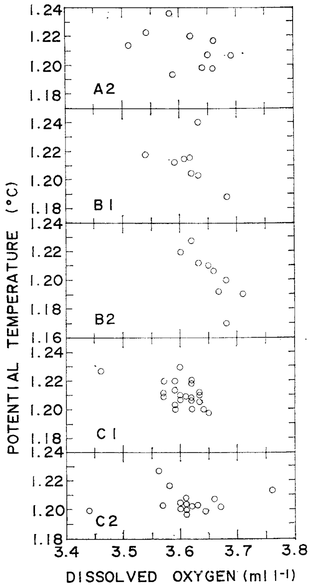

Fig. 4. Potential temperature-dissolved oxygen relation for samples taken below 3800 m from *Thomas Washington* in June-July 1971. Area symbols are shown in Fig. 1.

distribution is most scattered in A2 area and most concentrated in C1 area. These imply that the deep or bottom water mass which has entered the Shikoku Basin from the south will reach the northwestern part of the basin at an early stage. After that it slowly spreads clockwise in the northern area at least north of 31°N splitting into cold or oxygen-rich water patches (B1, A2 and C2) and mixing mainly with the overlying basin water (C2 and C1).

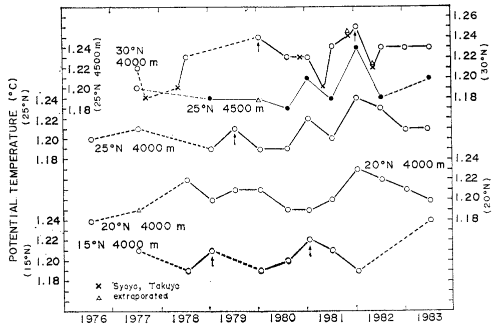

Fig. 5. Time series of potential temperature interpolated for 4000 m depth at 30°N, 25°N, 20°N and 15°N and for 4500 m depth at 25°N along 137°E. Stations were taken from *Ryofu Maru* unless specified.

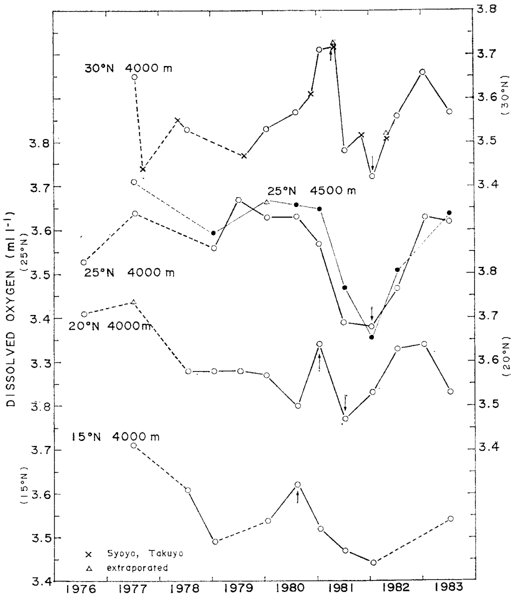

Fig. 6. As in Fig. 5 except for dissolved oxygen.

3. Deep water property variations along 137°E

To trace the origin of the anomalously low temperature and the high oxygen concentration in the deep water of the Shikoku Basin, both property values interpolated for the 4000 m depth at 30°, 25°, 20° and 15°N along 137°E are plotted as a time series during 1976-1983 (Figs. 5-6). At 25°N interpolated values for 4500 m are also plotted because the bottom depth is several hundred meters geater than that at 30°N or 20°N. In addition, vertical distributions of properties below 2400 m at four stations along 137°E are depicted (Figs. 7-9).

The 4000 m potential temperature at 30°N, 137°E, which was usually 1.22-1.23°C, dropped to 1.18-1.19°C in September 1977-May 1978 and in May 1981, while it rose to 1.25°C in January 1982 (Fig. 5). Though the rise seems to have occurred concurrently at stations of 30° to 20°N, temperature falls were not always clear at 25°N and south. The 4500 m temperature at 25°N was usually 1.19°C, occasionally rising to more than 1.20°C, but it was not below 1.18°C. The 4000 m temperature fluctuated with a range of about 0.05K at 25°N and south.

It is a surprise to find that there appears to be a definite inverse correlation between the

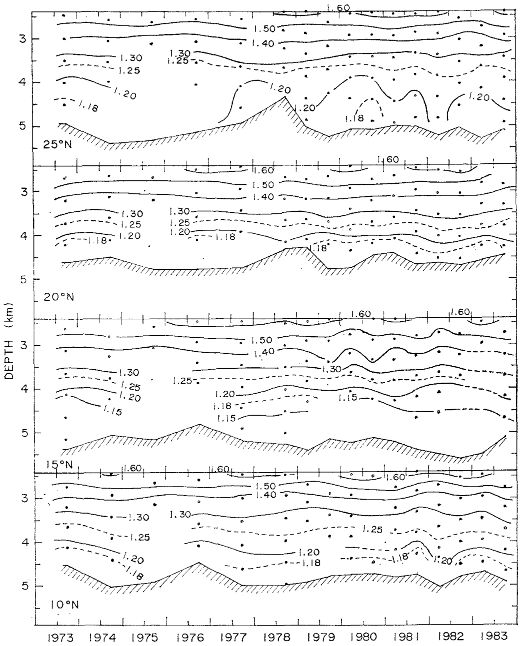

Fig. 7. Depth-time diagram of potential temperature below 2400 m at 25°N, 20°N, 15°N and 10°N along 137°E. Stations were taken from *Ryofu Maru* usually in July and in addition, in January for 1979 and after.

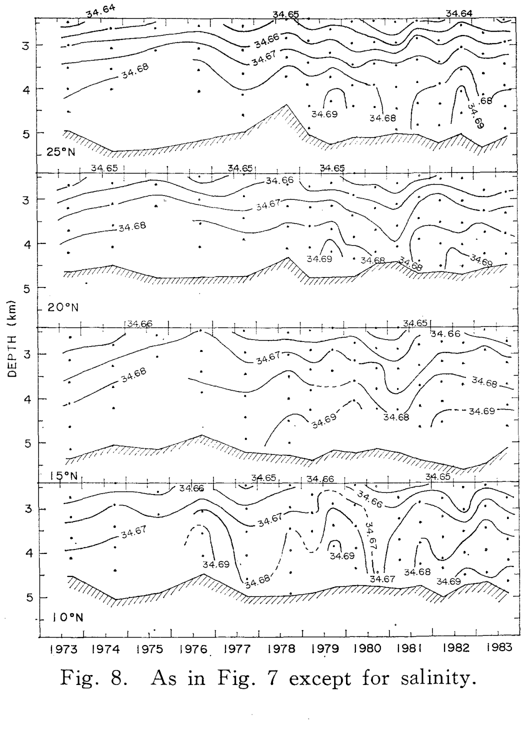

Fig. 8. As in Fig. 7 except for salinity.

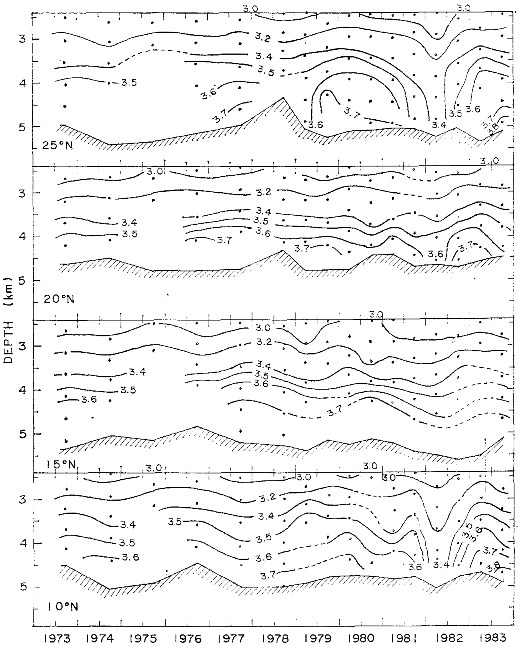

Fig. 9. As in Fig. 7 except for dissolved oxygen.

4000 m potential temperature at 20°N and that at 15°N. The sea bottom at 15°N, 137°E and vicinities, where a depression is formed, is several hundred meters greater than that at 20°N and vicinities. Figure 7 shows that a cold bottom water mass with a potential temperature of 1.15°C or less always lay to a thickness of more than several hundred meters at 15°N, 137°E, though observations were scarce below 4000 m. Its thickness varied greatly. Therefore, the upper portion of the water mass accumulated on the depression may be forced periodically or sporadically to move and be replaced by a warmer water mass. This is a plausible explanation of the inverse correlation of 4000 m potential temperatures between at 20°N and 15°N shown in Fig. 5, but it cannot be verified owing to the insufficiency of observations. A noticeable undulation of isotherms is illustrated below 4000 m at 25°N, 137°E; however, its potential temperature rarely dropped to less than 1.18°C. It is probable that the cold bottom water flows northward on the western flank of the basin, west of 137°E, at 25°N.

The time series of dissolved oxygen concentration for 4000 m at 30°N, 137°E resembles that at 20°N rather than that at 25°N (Fig. 6).

As mentioned above, the northward flow of the deep water must have avoided the station at 25°N, 137°E where the bottom depth is greater than that at both sides (20°N and 30°N) along the longitude. The inverse correlation of 4000 m oxygen values between at 20°N and at 15°N is not so conspicuous as that for potential temperatures. The peak presented at 15°N in July 1980 seems to have propagated northward and to have reached 30°N in May 1981, being away from 137°E at 25°N. If the case occurred, it travelled from 15°N to 30°N at a rate of about 0.06 m s^{-1}. For the potential temperature both of maximums shown in January 1979 and in January 1981 at 15°N seem to have reached 30°N a year later (Fig. 5); the average travelling speed was about 0.05 m s^{-1}, if the movement existed. A layer of more than several hundred meters of the bottom at 15°N, 137°E was occupied by an oxygen-rich bottom water with a value of 3.70 ml l^{-1} or more as well as the cold bottom water (Fig. 9).

The salinity variation seems to be much complicated (Fig. 8). It may be to a certain extent due to systematic measurement errors, because isohalines undulate greatly in the upper waters as well. A noteworthy feature in Fig. 8 is the salinity decrease that occurred concurrently at 15°N and north in January 1981.

4. Salinity and dissolved oxygen variations on the isothermal surface

Since the oxygen variation did not always correlate with the temperature variation in the deep or bottom water of the Shikoku Basin, the temperature-oxygen relation must have varied appreciably in the basin. But this is difficult to examine because water property ranges are small and measurement errors are relatively large at greater depths. To find variations in property relation, isothermal surfaces for potential temperatures of 1.3°C and 2.0°C were selected (Figs. 10 and 11).

For 1.3°C surface (at a depth of about 3000-3300 m), both salinity and dissolved oxygen distributions show similar periodical variations after 1978, being maximum values from late 1979 to early 1980 and in 1982. For 2.0°C surface (at a depth of about 1700-2000 m), the salinity variation is similar to that for 1.3°C; though dissolved oxygen values were dispersed after 1981, they were generally high in 1982-1983 except for the southeastern part (29-30°N, 137-138°E).

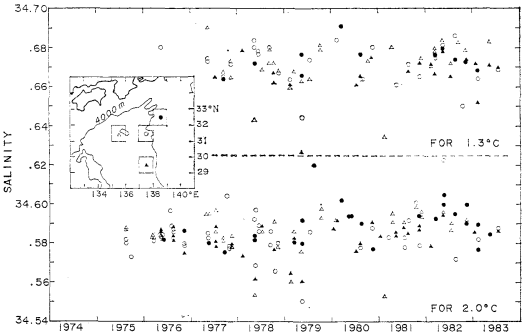

Fig. 10. Salinity on the isothermal surfaces for potential temperatures of 2.0°C and 1.3°C in selected 1°×1° areas shown in the inserted chart.

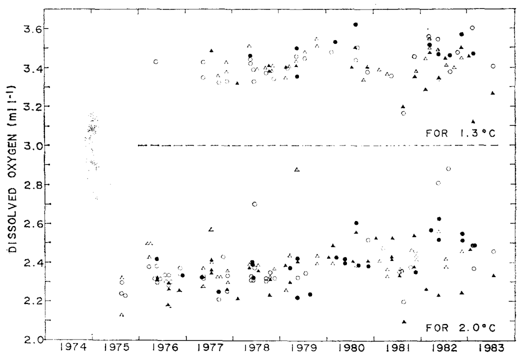

Fig. 11. Dissolved oxygen on the isothermal surfaces for potential temperatures of 2.0°C and 1.3°C in selected 1°×1° areas shown in the inserted chart in Fig. 10.

The dissolved oxygen maximums in 1982 for 1.3°C surface occurred early in 31-32°N, 135-136°E area (included in B2 area shown in Fig. 1) and late in 32-33°N, 138-139°E area (included in D1-D2 areas). Therefore, it may be concluded that they were brought through the oxygen increase in the lower water, probably the marked oxygen increase in January-May 1981 (A3 and C3 in Fig. 3). If it had propagated from the south, it took about two years to get to a depth of 3000 m in the northeastern corner of the Shikoku Basin from a depth of 4000 m at 15°N, 137°E. It seems likely that this oxygen increase had an effect on the upper water up to 2000 m or less in the northeastern part of the basin.

On the contrary, a sudden drop in the second half of 1981 on both isothermal surfaces took place down to the bottom north of 20°N at the same time (Figs. 6 and 9). The decrease was remarkable east of 137°E. Though Fig. 6 indicates the 4000 m oxygen minimums at 30°N and 25°N in January 1982, the differences from the preceding values are small. This transient sharp decrease in dissolved oxygen for fixed potential temperature values on an extensive scale both horizontally and vertically may be related to the occurrence of the southward detour of the Kuroshio path in November 1981.

5. Discussion

Normal property values of the deep water of the Shikoku Basin are not known definitely. Prior to the deep hydrographic casts made by the Hydrographic Department starting in 1976, three special cruises for the survey of the Kuroshio were carried out in the northern part of the basin during 1965-1975. For this reason a comparison of historical data is made for the north of 30°N (Table 1).

Within 250 m of the bottom or below 4500 m the above three surveys indicates low mean potential temperatures of 1.20-1.21°C with small dispersion because of single cruises. The mean for 1977 is slightly lower than the earlier means. However, for the upper water, the difference between the mean for the early three surveys (1965-1975) and that for the late observations (1979-1982) is only 0.01-0.02 K; in 1976-1977 the upper water was remarkably cooler. The lowest potential temperatures were 1.187°C (doubtful) or 1.200°C in 1965, 1.17°C in 1971 and 1.20°C in 1975.

In the deep water below 3800 m there was a considerable year-to-year variation in dissolved oxygen concentration. Though it is difficult to determine the normal absolute values, under the normal condition the value within 250 m of the bottom or below 4500 m seems to be about 0.04 ml l^{-1} higher than that for the overlying water. This difference was occasionally reduced with larger increase in the upper water than in the lowest water. Therefore, it may be reasonably concluded that the state was normal in 1965, 1977, 1978 and 1983. The 1971 values were apparently higher in dissolved oxygen and somewhat lower in potential temperature; possibly a fresh bottom and deep water had flowed into

Table 1. Potential temperatures and dissolved oxygen concentrations below 3800 m north of 30°N in the Shikoku Basin.

	Potential temperature						Dissolved oxygen					
Year	Within 250 m of the bottom or below 4500 m			Above 4500 m and above 250 m of the bottom			Within 250 m of the bottom or below 4500 m			Above 4500 m and above 250 m of the bottom		
	No. obs.	Mean (°C)	Std. dev. (K)	No. obs.	Mean (°C)	Std. dev. (K)	No. obs.	Mean (ml l^{-1})	Std. dev. (ml l^{-1})	No. obs.	Mean (ml l^{-1})	Std. dev. (ml l^{-1})
1965[1]	16	1.210	0.011	13	1.222	0.014	7	3.569	0.032	8	3.526	0.038
1971[2]	34	1.202	0.008	36	1.216	0.010	31	3.624	0.047	34	3.607	0.052
1975[3]	6	1.207	0.005	8	1.221	0.006	5	3.518	0.058	8	3.488	0.059
1976	8	1.210	0.016	7	1.204	0.016	7	3.583	0.089	7	3.573	0.038
1977	9	1.199	0.021	10	1.203	0.019	8	3.575	0.064	10	3.538	0.084
1978	30	1.217	0.022	24	1.225	0.015	30	3.570	0.041	22	3.538	0.067
1979	5	1.236	0.011	22	1.238	0.013	5	3.532	0.077	23	3.495	0.055
1980	7	1.223	0.019	13	1.235	0.021	7 (6	3.664 3.585	0.214 0.045)*	13	3.561	0.047
1981	18	1.231	0.016	24	1.237	0.015	18	3.546	0.115	24	3.599	0.077
1982	13	1.228	0.011	18	1.237	0.018	13	3.641	0.074	19	3.571	0.096
1983	2	1.220	0.014	7	1.231	0.013	2	3.590	0.028	7	3.544	0.057

* a doubtful value of 4.14 ml l^{-1} is excluded.

[1] CSK 31K001 (*Atlantis II*) (JAPAN OCEANOGRAPHIC DATA CENTER, 1966),

[2] ARIES Leg VI (*Thomas Washington*) (SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1977),

[3] KH-75-5 (*Hakuho Maru*) (OCEAN RESEARCH INSTITUTE, 1978).

the Shikoku Basin in the year or shortly before. Such an oxygen-rich water intrusion occurred in 1976 and in 1980–1982 as well, but the latter was complicated owing to a transient decrease in 1981. The reason why the oxygen value decreased in 1975 and 1979 cannot be understood.

The direct source of the anomalously cold or oxygen-rich water occasionally found below about 4000 m in the Shikoku Basin can be traced at least to 15°N (Figs. 7 and 9). However, the mechanism of its formation and spreading to the north is still unknown. Such a shift in the potential temperature-dissolved oxygen relation as observed in the Shikoku Basin in 1980–1982 must have originated in the south. The significant hydrographic response to modest short-term climatic forcing has been pointed out for the northern North Atlantic (*e.g.*, BREWER *et al.*, 1983; SWIFT, 1984). However, the origin cannot be found in the North Pacific because neither the deep water nor the bottom water is not formed there.

It is uncertain whether there exists a steady deep circulation in the basin showing a wide variation in water property or the basin flow is sporadic and every time it happens the property distribution is disturbed. Possibly both movements coexist. One of the most probable deep currents based on direct measurements in the Shikoku Basin is a westward current above several hundred meters of the bottom at the northern edge of the basin along 136°15′E (FUKASAWA *et al.*, 1985) or 136°30′E (TAFT, 1978). But TAFT (Table 2 and Fig. 14a) presented an eastward bottom current of about 0.05 m s^{-1} at 32°40′E. The result of the present analysis indirectly confirms the eastward current below about 4000 m in the northern part of the basin.

6. Conclusion

Below about 4000 m in the Shikoku Basin there seems to be a steady or unsteady northward flow along the western boundary; it circulates clockwise off the continental slope slowly moving upward and renewing the deep basin water. In 1976–1977 an anomalously cold deep or bottom water with a corresponding high dissolved oxygen concentration intruded into the basin. However, a remarkable increase in dissolved oxygen that occurred below about 3000 m in 1980–1982 was accompanied only by a subtle decrease in potential temperature. The direct source of such an anomalously cold or oxygen-rich deep water can be traced at least to 15°N; at 4000 m level it may travel from 15°N to 30°N in about one year. The transient sharp decrease in dissolved oxygen that took place at least below 2000 m in the eastern area north of 20°N during the second half of 1981 to early 1982 must be connected with the occurrence of the southward shift of the Kuroshio path in November 1981.

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四国海盆約4000m以深の深層水の特性の変動

須藤英雄

要旨: 四国海盆内3800m以深のポテンシャル水温と溶在酸素の分布の，1975年から1983年の間における変動を調べてみた。海盆の西縁の約4000m以深には定常あるいは非定常の北上流があり，海盆北部では，大陸斜面の南側を時計まわりに循環しながらゆるやかに上昇し，海盆内の深層水を更新しているらしい。1976年から1977年にかけては，著しく低温で溶在酸素の多い底深層水が海盆内に流入した。1980年から1982年にかけても，3000m以浅にまで及ぶ深層水での溶在酸素の著しい増大がみられたが，底深層における水温の低下はごく僅かにとどまった。これらの低温高酸素水は15°N以南に直接の起源があり，4000m深では15°Nから30°Nまで約1年で到達するとみられる。なお，1981年後半から1982年初めにかけて，20°N以北の東部では少なくとも2000m以深の全層にわたり，溶在酸素の一時的な急低下がみられたが，これは1981年11月の黒潮大蛇行の発生と関連があるらしい。

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Early developmental stages of some marine fishes from India

1. Nematalosa nasus, Sardinella clupeoides, S. fimbriata, S. sirm and S. albella[*]

Pathrose BENSAN[**]

Abstract: Among certain early developmental stages of twenty-five species studied during 1977-79, those of five Clupeiformes are described, most of them for the first time. These are eggs, larvae and postlarvae of *Nematalosa nasus*, *Sardinella clupeoides*, *S. fimbriata* and postlarvae of *S. sirm* and *S. albella*. Salient taxonomic features which may be of diagnostic value are commented upon.

1. Introduction

Among about 1,800 species of marine fishes known to occur in India, the early developmental stages of not even 10% is reported in sufficient detail. Since an adequate knowledge on this aspect is an essential prerequisite in judicious management of the resources, it was found essential to study and document them. In this connection, eggs, larvae, postlarvae and/or juveniles of twenty-five fishes were studied during 1977-79 at Porto Novo on the southeast coast of India, most of them for the first time. In the present paper the early developmental stages of five Clupeiformes are described. This Order contributes to about 25% of total marine fish production for India, from about sixty-five species. But, the early developmental stages of most of these species are either unknown or imperfectly known.

2. Materials and methods

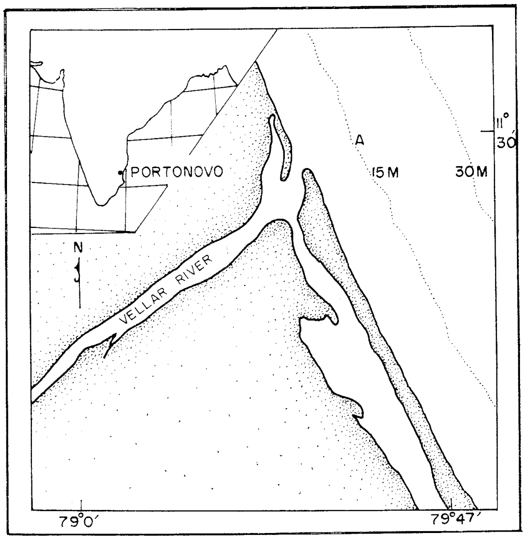

Fig. 1. Location (marked A) off Porto Novo on the southeast coast of India from where eggs, larvae, etc. of fishes in the plankton were collected.

Material for the present study was drawn from plankton collections off Porto Novo, at 11°30′N 79°46′E (Fig. 1), about 2 km off Vellar Estuary. Plankton net used was 1.5 m long and 0.5 m wide at its mouth. Each type of egg was separated based on diameter, presence or absence of oilglobules, nature of yolk, pigmentation, etc. Representative stages were studied and sketched with the aid of a mirror type camera lucida, in living condition. While rearing eggs and larvae, growth of microorganisms was minimised by adding Streptopenicillin at a concentration of 25 mg/100 ml of water. All larvae, postlarvae etc. were measured and sketched after fixing. Total length was measured from tip of snout or lower jaw to the tip of caudal fin end or larval finfold.

Guidelines used for identifications are as

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[*] Received September 18, 1985.

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followed by AHLSTROM and MOSER (1976, 1980, 1980). Some of the more important of these are: similarities between ripe ovarian eggs and planktonic eggs, oilglobules, nature of yolk, extent of perivitelline space, pigmentation of embryo, number and disposition of myomeres in larvae in relation to adult vertebral condition, etc. BLAXTER (1957) and HEMPEL and BLAXTER (1961) have pointed out that in larvae of *Clupea harengus* there were three or four myomeres more than adult vertebral number. In such cases, caution was applied to cross check identifications made, in relation to spawning season, egg size, etc. The urostyle was counted as the last vertebra/myomere in adults and larvae. The terminology used to denote early developmental stages is that by RUSSEL (1976).

3. Results and discussion

3.1. *Nematalosa nasus* (Bloch)

This fish is distributed all along Indian coasts. It is also invariably met with in fish catches from estuaries, lagoons, backwaters, etc. Apart from a report of KOWTAL (1970) on the eggs and early larvae of this species from Chilka Lake (northeast India), nothing is known on early developmental stages.

(a) Eggs (Fig. 2, A–C)

Eggs were collected in February and March 1978. These were pelagic, spherical, transparent and ranged in diameter from 0.94 to 1 mm in living condition. Each egg contained eight golden yellow oilglobules ranging in diameter from 0.036 to 0.081 mm. The oilglobules were usually found near the tail end of the embryo. A narrow perivitelline space was present all around the yolk. The yolk was spherical and vacuolated, the vacuoles being fairly large in size. In an egg ready for hatching (Fig. 2, C), a few black pigment spots were noted on the dorsal side of the embryo.

(b) Larvae (Fig. 2, D and E)

A just hatched larva measured 3 mm (Fig. 2, D) with a globular yolksac, prominent finfold and ventrally placed oilglobules. The body tapered towards caudal end, yolksac was rounded off posteriorly and alimentary canal was almost straight except at the vent. A series of black pigment spots was present at the base of the finfold dorsally. Thirty-five myomeres were present in the preanal region. Precise number of myomeres in postanal region could not be ascertained due to imperfect nature of myosepta there.

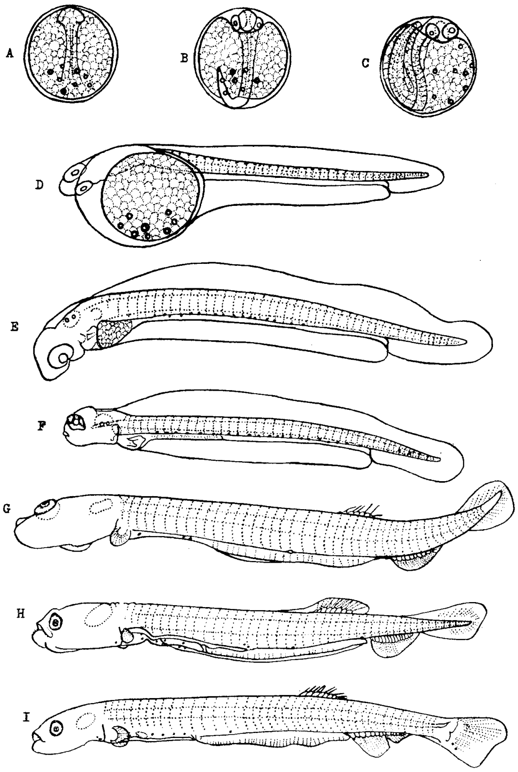

Fig. 2. Eggs, larvae and postlarvae of *Nematalosa nasus*. A, B and C: Eggs in three stages of development. D: Newly hatched larva. E: 4 mm larva. F: 4.8 mm postlarva. G: 6.7 mm in total length. H: 9 mm. I: 10.6 mm. All eggs were drawn in live condition. All larvae and postlarvae were drawn from preserved specimens.

A second larval stage obtained by rearing and measuring 4 mm (Fig. 2, E) had many progressive features such as reduction of yolksac, formation of pectoral finbud and movement of dorsal pigments to above alimentary canal. Position of the mouth was marked below eye region. Eyes were unpigmented and anus opened below 35th myomere in this stage also. Myosepta have become more organised than in the previous stage in postanal region where about ten myomeres could be counted.

(c) Postlarvae (Fig. 2, F–I)

The earliest postlarva was reared in the laboratory, 24 hours old and measured 4.8 mm (Fig. 2, F). Yolk was fully utilised, mouth was formed and eyes were partially pigmented. Pectoral fin has become larger, pigmentation along dorsal aspect of alimentary canal has become more pronounced and opercular cleft has developed. There were 34 preanal and 11 postanal myomeres.

Three postlarvae were collected from plankton in March 1978. In 6.7 mm stage (Fig. 2, G), the body has become broader and larval finfold has disappeared. Jaws have developed, eyes were pigmented and pectoral fins had indications of rays. Dorsal fin has developed between 23rd and 27th myomeres with about six rays. Anal fin was between 31st and 38th myomeres with about ten rays. Caudal region also showed indication of rays. There were 30 preanal and 15 postanal myomeres, the number and disposition corresponding to adult vertebral condition. Pigmentation has become slightly reduced from the previous stage, with only a few spots in foregut region.

In a 9 mm postlarva (Fig. 2, H), the progressive changes were further development of all the fins, an increase in pigmentation and development of minute conical teeth in the jaws. Eight rays were present in dorsal fin and about fifteen in anal fin. One pigment spot was present in front of opercular cleft, two posterior to pectoral fin and six in foregut region. Besides, two spots were present above midgut anteriorly, one posteriorly and one above vent.

In 10.6 nm stage (Fig. 2, I), about sixteen caudal and fifteen anal rays could be counted. Pigmentation has increased; two pigments have appeared at the base of lower caudal region, two in front of operculum ventrally, two in pectoral region, a series of four in foregut region, one large pigment above midgut and another above anus.

(d) Remarks

Identification of the present material as those of *N. nasus* is based on coincident occurrences of the eggs and postlarvae in plankton as well as mature and spent specimens in fish catches at Porto Novo; characters of the eggs and larvae; and rearing of postlarvae in ponds at Porto Novo. DELSMAN (1926b) assigned certain eggs to this species from Java coast; but later (DELSMAN, 1933a) changed his view. KOWTAL (1970) identified the free eggs at first from Chilka Lake, based on characters of ripe ova. The two larval stages given in the present account show overall similarities to those described by KOWTAL (1970). Eggs of the closely allied species *Anodontostoma chacunda* (DELSMAN, 1933a) have a diameter of about 1 mm and contain 6–12 oilglobules. Besides, its larvae have a lesser number of myomeres than in those of *N. nasus*, in accordance with adult vertebral number namely 41.

Postlarvae of *N. nasus* may be distinguished from those of *A. chacunda* by the difference in number and disposition of myomeres, the total of which in the former is 45 and in the latter is 41 (BENSAM, 1971). Postlarvae of *Sardinella gibbosa* (*S. jussieu*, BENSAN, 1970) have a total of 45 myomeres; but could be distinguished from the postlarvae of *N. nasus* by difference in pigmentation pattern and delayed bifurcation of caudal fin in *N. nasus* when compared to *S. gibbosa*. Postlarvae of *S. fimbriata* which have 45–47 vertebrae, differ from those of *N. nasus* in the disposition of myomeres and pattern of pigmentation *vide* section 3.3. of present paper. Postlarvae of *Chanos chanos* (DELSMAN, 1926c; 1929b; CHAUDHURI, *et al.*, 1978; LIAO, *et al.*, 1979) differ from those of *N. nasus* in having a parallel arrangement of muscle fibres, as against crossed arrangement in the latter.

3.2. *Sardinella clupeoides* (Bleeker)

This species is observed in small quantities in sardine fisheries of southeast and southwest coasts of India. Till now no information is available on the early developmental stages of this fish.

(a) Eggs (Fig. 3, A and B)

Planktonic eggs were collected during February and April 1978. These were pelagic, spherical, transparent and ranged in diameter from 0.91 to 0.95 mm in living condition. Yolk was spherical, colourless and vacuolated with diameters ranging from 0.50 to 0.52 mm in living condition. A large perivitelline space was present and there was no oilglobule. The embryo and yolk had no pigmentation.

(b) Larvae (Fig. 3, C and D)

By rearing eggs in the laboratory, two stages

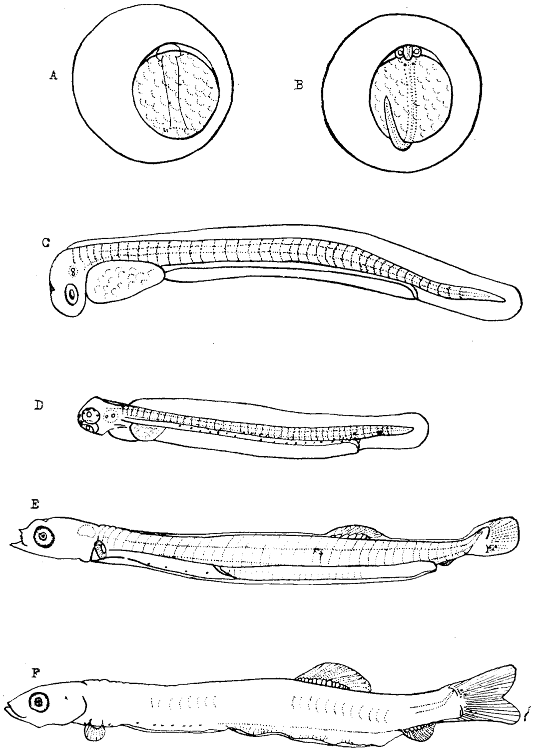

Fig. 3. Eggs, larvae and postlarvae of *Sardinella clupeoides*. A and B: Eggs in two stages of development. C: 3.6 mm larva. D: 4.5 mm. E: Postlarva of 10.2 mm total length. F: 13.1 mm. Both the eggs were drawn in live condition. All the larvae and postlarvae were drawn from preserved specimens.

in larval development were studied. In an earlier stage measuring 3.6 mm (Fig. 3, C), the body had a uniform depth behind yolk. There were 38 preanal and about 5 postanal myomeres. The larva was devoid of pigmentation. In a later stage measuring 4.5 mm (about 32 hours old) (Fig. 3, D), pigmentation has appeared in the form of two series of spots along the alimentary canal, one above the other. The lower series was more prominent and almost continuous from behind the yolksac till vent. The upper series was at the dorsal aspect of the alimentary canal and was discontinuous. A pigment was present midlaterally above the vent and a partly branching pigment about half way in postanal region. In the snout a couple of pigments was present and on the dorsal side of eyes a few pigments have appeared. Mouth was not yet formed although yolksac was very much reduced. There were 43 myomeres of which 37 were preanal and 6 were postanal.

(c) Postlarvae (Fig. 3, E and F)

Both the postlarvae were collected from plankton during February 1978. In 10.2 mm stage (Fig. 3, E), the upper jaw showed minute conical teeth and the lower jaw was slightly longer than the upper. Pectoral fin has developed and eyes were pigmented. In the foregut four pigment spots and in the lower caudal region three spots were present. Dorsal fin has developed between 24th and 31st myomeres with about 7 rays. Caudal fin was somewhat club shaped with about 12 rays. Anal fin was indicated behind vent. There were 38 preanal and 5 postanal myomeres. In 13.1 mm postlarva (Fig. 3, F), the body has become slightly cylindrical, head has become pointed and caudal fin was forked. About 15, 18 and 7 rays could be counted in dorsal, caudal and anal fins respectively. Pigmentation consisted of a short series of black spots in the foregut, a few spots at the base of upper and caudal lobes and a single pigment above vent. Disposition of myomeres has changed to 35 preanal and 8 postanal.

(d) Remarks

The size of ripe ovarian ova in comparison with the size of yolk in early stages of embryonic development has aided the identification of planktonic eggs. As pointed out by MILLER (1952) and AHLSTROM and MOSER (1980), in sardine eggs the egg capsule develops only after the ova come into contact with water and increases in size thereafter. This is confirmed by the presence of 43 myomeres in the larvae hatching out of the eggs, tallying with adult vertebral number. Eggs assigned by JOHN (1951) to *Sardinella sirm* had a diameter of 2.12 mm and did not have oilglobule. Eggs of *S. clupeoides* differ from those of *S. fimbriata* (DELSMAN, 1926a; this paper, 3.3) in that the latter have a diameter of 1.4–1.55 mm, yolk measured 0.8 mm in diameter and an oilglobule is present. Eggs assigned by DELSMAN (1926a) to *S. leiogaster* ranged in diameter from 1.42 to 1.63 mm with yolk measuring about 1 mm; and those assigned by DELSMAN (1933b) to *Clupea perforata* (*S. albella*, WHITEHEAD, 1972) did not exceed 1.1 mm and had an oilglobule. An oilglobule is reported in the eggs of *S. longiceps* (NAIR, 1960) and *S. gibbosa* (BENSAM, 1970), apart from other differences.

While comparing the postlarvae of *S. clupeoides* with those of *S. gibbosa* (BENSAM, 1970), lesser pace of development in *S. clupeoides* than in *S. gibbosa* becomes apparent. In early postlarvae of the former species there are 37 myomeres as against only 33 in early postlarvae of the latter species. In later stages, preanal myomeres become 35 in *S. clupeoides* and only 30 in *S. gibbosa*. When compared to postlarvae of *S. dayi* (BENSAM, 1973) also, the rate of growth in *S. clupeoides* appears slower. This may be seen from the fact that although almost the same developmental features could be seen in 18.7 mm postlarva of *S. dayi* (BENSAM, 1973) and 13.1 mm postlarva of *S. clupeoides*, there is about 5 mm difference in linear growth. Besides, there is a progressively developing anal fin in the former which is absent in the latter.

3.3. *Sardinella fimbriata* (Valenciennes)

It is found in sardine catches off both east and west coasts of India. DELSMAN (1926a) described eggs, larvae and postlarvae presumed to be of this species from Java Coast. BAPAT (1955) and VENKATARAMANUJAM (1975) have reported on the eggs from India. The present section deals with a few eggs and postlarvae.

(a) Eggs (Fig. 4, A-D)

Eggs were collected in April 1978. These were pelagic, spherical, transparent and varied in diameter from 1.36 to 1.41 mm. Yolk was vacuolated and ranged in diameter from 0.80 to 0.89 mm. Perivitelline space was wide. A single golden yellow oilglobule of 0.102-0.109 mm diameter was present. None of the eggs reared in the laboratory has hatched out; but all were found dead on the next morning.

(b) Postlarvae (Fig. 4, E-G)

In 11.4 mm postlarva collected during October 1977, larval finfold has disappeared, lower jaw was a little longer than the upper and the latter was provided with a few conical teeth (Fig. 4, E). Dorsal fin has appeared above 28th to 33rd myomeres, with about 11 rays. Caudal fin showed an early stage of bifurcation with about 24 rays. Anal fin had about 7 rays. A series of black pigment streaks was present above alimentary canal, three spots ventrolaterally towards the end of foregut, a single one towards the vent, a few at the base of lower caudal lobe and a couple of spots at the middle of caudal base. There were 39 preanal and 7 postanal myomeres. In a 12.3 mm stage collected in February 1978, the pigments in the mid and hind gut regions have moved to a ventral positions (Fig. 4, F), but those in the foregut region and the one above anus have remained in the same position. About 15 dorsal and 24 caudal rays could be counted. Number and disposition of myomeres remained the same as in the previous stage. A much longer postlarvae measuring 21.5 mm (Fig. 4, G) was collected during August 1977. The body has become massive and deeper. There were about 21 dorsal, 28 caudal and 18 anal rays. Pelvic fin has appeared below midgut in the form of a few rays. Pigmentation was in the form of black spots along ventral side of alimentary canal, at the bases of upper and lower caudal

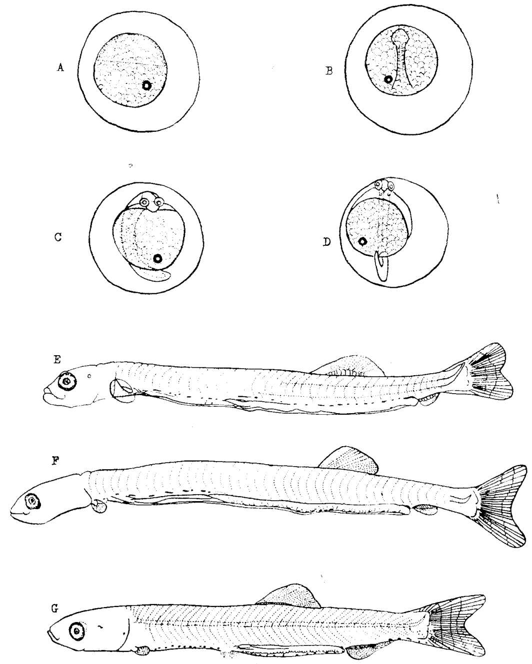

Fig. 4. Eggs and postlarvae of *Sardinella fimbriata*. A-D: Eggs in four stages of development. E: Postlarvae of 11.4 mm in total length. F: 12.3 mm. G: 21.5 mm. All the eggs were drawn in live condition. All the postlarvae were drawn from preserved specimens.

lobes and at the base of lower caudal peduncle. In head region there was a sunken pigment behind eye and another one in front of operculum. Disposition of myomeres has changed to 33 preanal and 13 postanal.

(c) Remarks

The only other Indian sardine which has an overall egg diameter similar to that of *S. fimbriata* is *S. longiceps*. But, the latter was not observed at Porto Novo during the present study and is in fact rarely reported from the southeast coast of India. This fact minimises the possibility of the present eggs as belonging to *S. longiceps*. Besides, diameter of yolk in the eggs of *S. longiceps* is not less than 1 mm as observed by DEVENESAN (1943), while it is only in *S. fimbriata* that the yolk diameter is about 0.8 mm, as pointed out by DELSMAN (1926a). Yolk in the eggs assigned by DELSMAN (1933b) to *S. albella* measured about 0.57 mm in diameter and in the eggs identified as of *S. gibbosa* by BENSAN (1970) measured 0.58–0.74 mm in diameter. Such features aid in segregating the eggs of *S. fimbriata* from those of allied species.

While describing some postlarvae from Java Coast, DELSON (1962a) has opined that the number of myomeres in them does not correspond with adult vertebral number of *S. fimbriata* and hence these could not belong to the above species. But, the 22 and 27.5 mm postlarvae described by the above author had 34 preanal and 12 or 13 postanal myomeres, the total number corresponding with adult vertebral number of *S. fimbriata* and thus confirming his identification. The 21.5 mm postlarva in the present section when compared to the 22 mm stage described by DELSMAN (1926a) shows lack of preventral pigmentation in the latter. Such a condition exists in the 27.5 mm stage also described by the above author. The total number of myomeres in *S. fimbriata*, *S. gibbosa*, *S. dayi* and *S. longiceps* being overlapping one another, may not be of much use in separating their postlarvae. But, differences in disposition of myomeres between postlarvae in somewhat same stages of development may be of some use in species discrimination. Thus, the 11.4 mm postlarva of *S. fimbriata* which is in the same stage of development as 9.92 mm postlarva of *S. gibbosa* (BENSAM, 1970) differs in having 39 preanal and 7 postanal myomeres as against 30 preanal and 15 postanal myomeres in the latter. A comparison of the postlarvae of *S. fimbriata* with those of *S. dayi* (BENSAM, 1973) shows that in some developmental features the latter are quicker than the former, such as appearance of ventral fin and rate of growth. Between the postlarvae of *S. fimbriata* and those of *S. longiceps* described by UNDP/FAO (1976), distribution of pigments may be of use in their segregation because in the 12.3 mm stage of the former pigment spots in the mid and hind gut have occupied a ventral position, whereas even in the 13.1 mm stage of the latter species, pigment spots have still occupied a dorsal position.

3.4. *Sardinella sirm* (Walbaum)

It is one of the three species belonging to the subgenus *Amblygaster*, the other two being *S. clupeoides* and *S. leiogaster*, *vide* WHITEHEAD (1972). It is widely distributed in the Indo-Pacific; and in India it is particularly found off the southeast coast. DELSMAN (1926a) opined that the egg "f" collected from Java coast belonged to this species. JOHN (1951) identified the eggs from India. No information is available so far on its postlarval history. In the present section three postlarvae are described.

(a) Postlarvae (Fig. 5, A–C)

The earliest stage measuring 10.4 mm (Fig. 5, A) was collected during September 1977. Preanal width of the body was almost uniform. Lower jaw was slightly longer than upper jaw, the latter showing a few conical teeth. Two pigment spots were present in auditory region. Dorsal

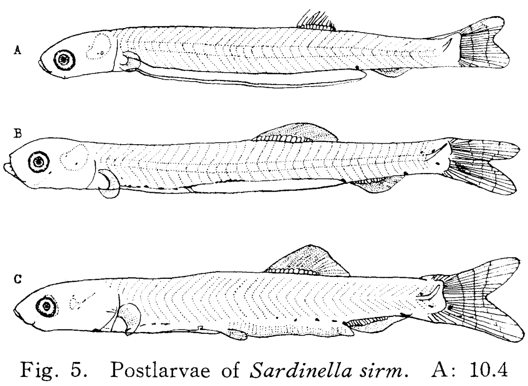

Fig. 5. Postlarvae of *Sardinella sirm*. A: 10.4 mm in total length. B: 13.4 mm. C: 14.1 mm. All the postlarvae were drawn from preserved specimens.

fin has developed above 23rd and 28th myomeres, with about 12 rays. Bnal fin showed about 8 rays and caudal about 20 rays. A pigment spot was present above anal region. There were 42 myomeres of which 31 were preanal and 11 postanal. A 13.4 mm postlarva was collected during September 1978 (Fig. 5, B). The major change observed was an increase in pigmentation. Posterior to the lower margin of eye a pigment has developed; also a series of seven streaks in the post-pectoral region. In the dorsal aspect of midgut, behind the anal fin, in the caudal peduncular region and in the base of the lower caudal lobe, pigmentation has appeared. Dorsal and anal fins showed about 15 and 12 rays respectively. The myomere disposition has changed to 28 preanal and 14 postanal. A slightly longer stage of 14.1 mm (Fig. 5, C) was collected in July 1977. Apart from a slight increase in pigmentation, no progressive change was visible in this stage over the previous one.

(b) Remarks

Since the vertebral number in *S. sirm* (42) is only one lesser than that in *S. leiogaster* and *S. clupeoides* (43), this character alone may not be of much use in segregating their postlarvae. However, since spawning stock of *S. sirm* alone was observed at Porto Novo during the period when the above postlarvae were collected and not spawning stock of *S. leiogaster*, it appeared most probable that the present postlarvae belonged only to *S. sirm*. This is strengthened by the one lesser number of myomere in this species when compared to *S. leiogaster*. The present postlarvae showed vital differences from comparable stages of *S. clupeoides* given in the present paper. Although the 10.2 mm stage of *S. clupeoides* and 10.4 mm stage of *S. sirm* are almost of equal length, the former has a slender body, club shaped caudal fin and is in a much earlier condition of development than the latter. Besides, the number of preanal myomeres in the former is 38 but in the latter only 31. Similarly, the 13.1 mm postlarva of *S. clupeoides* comparable to 13.4 mm stage of *S. sirm* in size, differs from it in having 35 preanal myomeres as against only 28 in the latter. Besides, pelvic fin was quite prominent in 14.1 mm stage of *S. sirm*, but not even indicated in 13.1 mm stage of *S. clupeoides*, both of which showed many other features in common. Postlarvae of *S. sirm* could be segregated from those of *Thryssa* and *Stolephorus* (DELSMAN, 1929a; 1931) in having a terminal mouth and a lower jaw slightly longer than the upper, when compared to a prominent snout and inferior mouth in these two genera.

3.5. *Sardinella albella* (Valenciennes)

Like many other species of *Sardinella*, *S. albella* is widely distributed in the Indo-Pacific and supports coastal fisheries at many centres in India. DELSMAN (1933b) gave an account of its eggs and larvae from Java Coast. CHACKO and MATHEW (1956) reported on its embryonic and larval development from the southwest coast of India. In the present section, a few postlarvae and an early juvenile are described, all collected during September–October, 1977.

(a) Postlarvae (Fig. 6, A–C)

A 6.6 mm postlarva (Fig. 6, A) showed remnants of larval finfold. Jaws were pointed, the lower one longer than the upper. Eyes were pigmented black and pectoral fin was membranous. Dosal fin has developed above 23rd to 30th myomeres, with about 14 rays. Caudal fin was paddle shaped, with many rays. Pigmentation was sparse and consisted of a spot in the oesophageal region, a group of three sunken ones above midgut and three spots in the hindgut region, of which two were above and one below anal region. There were 34 preanal and 9 postanal myomeres. In an 8.4 mm postlarva, anal

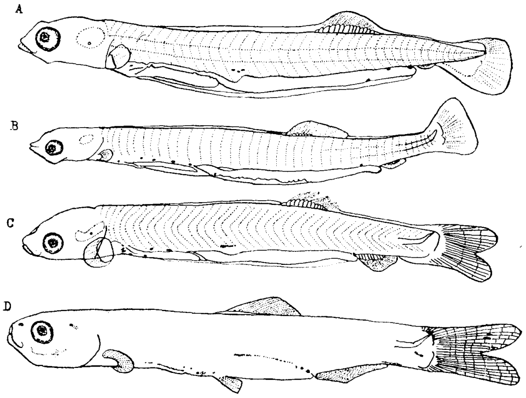

Fig. 6. Postlarvae and a juvenile of *Sardinella albella*. A: Postlarvae of 6.6 mm in total length. B: 8.4 mm. C: 11.0 mm. D: Juvenile of 19 mm in total length. All the postlarvae and the juvenile were drawn from preserved specimens.

fin has become more prominent and pigmentation has increased in the foregut, as a series of six spots. Preanal myomeres have decreased to 32 and postanal ones have increased to 11 (Fig. 6, B). In a transitional stage between postlarva and juvenile measuring 11 mm (Fig. 6, C), the body has become wider and more massive. There were about 14 dorsal, 10 anal and 20 caudal rays; and the caudal fin has become forked. A pigment has appeared in the auditory region; and a patch of sunken pigments is present above midgut. Number and disposition of myomeres remained the same as in the previous stage.

(b) Juvenile (Fig. 6, D)

A single early juvenile measuring 19 mm was collected from the mouth of Vellar Estuary in September 1977. Body has become massive and assumed a sardine like appearance. About 15 rays could be counted in the pectoral fin. Caudal fin showed about 28 rays, many of which were segmented. Anal fin has become longer and showed about 21 rays. Pelvic fin has developed at a level below the origin of dorsal fin, with about six rays. Pigmentation was in the form of a sunken patch behind the eye, a series behind pectoral region, two small spots slightly above the hind end of the series, a sunken spot in front of pelvic region and two branching chromatophores in front of it. On the dorsal aspect of the alimentary canal, behind the pelvic region, a series is present, ending with three chromatophores in the anal region. Behind the anal fin a sunken patch of pigments and behind the urostyle a group of four closely placed pigments could be seen. Caudal fin showed a few pigments at the base. Preanal myomeres have further decreased to 29 and postanal ones increased to 14, although the adult disposition of 27 preanal and 16 postanal has not yet reached.

(c) Remarks

S. albella was observed to spawn off Porto Novo during April/May to September/October period. The present postlarvae differ from those of *S. gibbosa* (BENSAM, 1970), *S. dayi* (BENSAM, 1973), *S. clupeoides* (section 3.2 of present paper) and *S. fimbriata* (section 3.3), in having a lesser number of myomeres. It may be noted in this connection that UNDOP/FAO (1976) have given a vertebral number of 45 for *S. albella* from the southwest coast of India. But, from the southeast coast centres of Tuticorin (BENSAM, 1973) and Porto Novo in the course of 1977–79, specimens of *S. albella* showed only 43 vertebrae. This is in agreement with the observation of DELSMAN (1933b) that *S. perforata* (=*S. albella*, vide WHITEHEAD, 1972) from Java Coast had 32–43 vertebrae only. In having a total of 43 myomeres, the early postlarvae of *S. albella* resemble those of *Hilsa kelee* described by RAO (1973). But, in the postlarvae of the latter, pigment series are present along dorsal and ventral aspects of the alimentary canal. But, such a condition is absent in the postlarvae of *S. albella*.

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インド産魚類の初期発生段階

1. Nematalosa nasus, Sardinella clupeoides, S. fimbriata, S. sirm and S. albella

Pathrose BENSAN

要旨： 1977年から1979年にかけて採取したいわし型魚類6種の初期発生段階を記述した。*Nematalosa nasus*, *Sardinella clupeoides*, *S. fimbriata*, *S. sirm*, *S. albella* の卵，幼生である。同定に役立つ顕著な分類形質について註釈を加えた。

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日本南岸の黒潮流域付近における海洋音速場について*

中村重久**

A note on sound speed fields around the Kuroshio south of Japan

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Abstract: A theoretical model is presented for describing the vertical profile of sound speed in the sea. Some examples are given from temperature and salinity data obtained in waters around the Kuroshio area south of Japan. A striking difference in sound speed is found between a cold water mass and the axis of the Kuroshio. Vertical profiles of sound speed in shelf and coastal waters are also presented. In shallow waters the sound speed becomes fast in August to September and slow in February to March.

1. 緒言

海洋中の音波とその利用の歴史はそれほど古くない。1912年汽船 Titanic 号が氷山と衝突し，数百人の死者をだした後約1カ月で，L.R. RICHARDSON は航空機搭載用音響測距の特許を英国でとり，5月10日には疎密波を用いて海中の巨大物体の存在を調べる方法について特許をとった。米国では1913年1月29日同様な方法について R.A. FESSENDEN が特許をとり，1914年4月27日には2マイルの距離の氷山を発見するのに成功している。それ以来，諸国の活発な開発研究がみられた（CLAY and MEDWIN, 1677)。英国漁船船長 R. BALL は1930年代初期音響反射計を利用し，ノルウェーの O. SUND (1935) は音響測深の漁業への利用について記している。日本では KUWAHARA (1939) が海水中の音速について研究した成果を発表したのが最初とみられ，これが現在でも国の海底測量に利用されている（友田，1985)。また，外洋における海洋観測での音響式切りはなし装置の使用に関連して，音の鉛直伝ぱについては松山・高野 (1975) が Snell の法則を応用して数値的研究を行った。また，別に，沿岸域の流速計測にも海中音波の利用がみられた (MIDDLETON, 1955; 海象(流氷)観測グループ，1983)。

CLAY and MEDWIN (1977) によれば，水中音速の最初の測定は COLLADON・STURM によって1826年11月スイスのジュネーヴ湖で行なわれた。実際には，音速は，水温・塩分・圧力が増すと速くなり，また季節・時刻・水深・地理的位置・河川周辺・融水などの条件によっても大きく異なる。実用的な音速計算式として CLAY and MEDWIN は次式を与えている。

$$C=1449.2+4.6\,T-0.005\,T^2+0.00029\,T^3+(1.34-0.010\,T)\,(S-35)+0.016\,Z \quad (1)$$

ここに，C: 音速 (m/s)，T: 水温 (°C)，S: 塩分 (‰)，Z: 水深 (m)。

本文では，まず，海洋中の音速の鉛直分布の特性を理論的モデルによってとらえ，つぎに，太平洋北西部の黒潮流域，とくに本州南岸の紀伊半島周辺を例として，深海・沿岸陸棚域・浅海域の記録によって，それぞれの海域の音速の実態をとらえる手がかりとした。

2. 海洋中の音速の鉛直分布に関するモデル

海中の音速は，すでに述べたように，水温 (T)，塩分 (S)，水圧 (P) によって定まる。すなわち，C は T, S, P の関数であって，

$$C=C(T,\ S,\ P). \qquad (2)$$

このとき，第1近似として，2次以上の微分を無視できるものとすれば

$$\frac{\partial C}{\partial z}=\frac{\partial C}{\partial T}\cdot\frac{\partial T}{\partial z}+\frac{\partial C}{\partial S}\cdot\frac{\partial S}{\partial z}+\frac{\partial C}{\partial P}\cdot\frac{\partial P}{\partial z} \qquad (3)$$

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深海での水温は断熱的分布をし，その変化は，

$$\frac{\partial T_A}{\partial z}=g\frac{(\bar{\gamma}-1)}{aC^2}\sim 0.10\ {}^{\circ}\mathrm{C/km}. \qquad (4)$$

ここに，$\bar{\gamma}=1+0.0035$ は相対比熱である。(MUNK, 1974)。また，深海での T が十分小さい値として，(3) はつぎのように書きかえられる。

$$\frac{\partial C}{\partial z}=\alpha\frac{\partial T'}{\partial z}+\beta\frac{\partial S}{\partial z}+\gamma_A \qquad (5)$$

ただし，

$$\alpha=\frac{\partial C}{\partial T},\quad \beta=\frac{\partial C}{\partial S},\quad \gamma=\frac{\partial C}{\partial P},$$
$$\gamma_A=\gamma\frac{\partial P}{\partial z}+\alpha\frac{\partial T_A}{\partial z}\quad T=T'+T_A. \qquad (6)$$

一方，海水密度の鉛直こう配について

$$\frac{1}{\rho'}\frac{\partial\rho'}{\partial z}=\frac{\partial\rho'}{\partial T'}\cdot\frac{\partial T'}{\partial z}+\frac{\partial\rho'}{\partial S}\cdot\frac{\partial S}{\partial z}$$
$$\equiv -a\frac{\partial T'}{\partial z}+b\frac{\partial S}{\partial z} \qquad (7)$$

と書くことにする。ところで，Turner 数は塩分と温位とが水柱の安定度に対する寄与の程度を示すものであり，(7) の a および b を用いて

$$Tu=\left[b\frac{\partial S}{\partial z}\right]\Big/\left[a\frac{\partial T'}{\theta z}\right]. \qquad (8)$$

さらに，Brunt-Väisälä 周波数は，

$$N(z)=\left[g\frac{1}{\rho'}\frac{\partial\rho'}{\partial z}\right]^{1/2} \qquad (9)$$

と定義される。ここで，(5) と (8) とから

$$\frac{\partial C}{\partial z}=\alpha\frac{\partial T'}{\partial z}\left(1+\frac{\beta}{\alpha}\cdot\frac{a}{b}\cdot Tu\right)+\gamma_A \qquad (10)$$

が得られる。ところで，(7) より

$$\frac{1}{\rho'}\cdot\frac{\partial\rho'}{\partial z}=-a\left(\frac{\partial T'}{\partial z}\right)\left(1-\left[b\frac{\partial S}{\partial z}\right]\Big/\left[a\frac{\partial T'}{\partial z}\right]\right)$$

である。したがって，

$$\frac{1}{\rho'}\cdot\frac{\partial\rho'}{\partial z}=-a\left(\frac{\partial T'}{\partial z}\right)(1-Tu). \qquad (11)$$

この (11) と (10) とから $\partial T'/\partial z$ を消去すると，

$$\frac{\partial C}{\partial z}=-\frac{\alpha}{a(1-Tu)}\cdot\frac{1}{\rho'}\cdot\frac{\partial\rho'}{\partial z}$$
$$\times\left(1+\frac{\beta}{\alpha}\cdot\frac{a}{b}\cdot Tu\right)+\gamma_A. \qquad (12)$$

ここで (9) を使うと，

$$\frac{\partial C}{\partial z}=-\frac{\mu}{g}N^2(z)+\gamma_A. \qquad (13)$$

ただし，

$$\mu=\frac{\alpha}{a}\frac{\left(1+\frac{\beta}{\alpha}\cdot\frac{a}{b}\cdot Tu\right)}{(1-Tu)} \qquad (14)$$

すなわち，(13)が海水中の音速の鉛直こう配を与えることになる。

一般に，浅いところでは N^2 を含む項が大きいが，深海では $N^2\rightarrow 0$ となり，音速は γ_A の割合で深さとともに大きくなる。

とくに，ある水深 $z=z_1$ において $\partial C/\partial z=0$ であるとすると，このとき，(13) より

$$N(z_1)=\left(\frac{\gamma_A g}{\mu}\right)^{1/2}. \qquad (15)$$

水深 z における音速 C は (13) を z について積分することによってもとまる。すなわち，

$$C=\int_{z_0}^{z}\left(-\frac{\mu}{g}N^2(z)+\gamma_A\right)dz;\ z_0=\mathrm{const}. \qquad (16)$$

いま，もし，(14)に示される μ の値が一定値をとる場合には (16) は

$$C=-\frac{\mu}{g}\int_{z_0}^{z}N^2(z)dz+\gamma_A(z-z_0). \qquad (17)$$

と数式の変形として書きかえられるが，実在の海洋での Turner 数 Tu はかならずしも一定値をとるわけではないから，μ を一定値とみなせる場合も限られた条件の下でしか考えられない。

ここで，N_0 および B を定数として，たとえば外洋でサーモクラインより深い層のみに着目したとすると，

$$N=N_0\exp(-z/B)$$

と書くと解析に好都合である (MUNK, 1974)。この場合には (17) はさらにつぎのように書きかえられる。

$$C=-\frac{\mu N_0^2}{g}\int_{z_0}^{z}\exp(-2z/B)\,dz+\gamma_A(z-z_0)$$
$$=\frac{\mu N_0^2 B}{2g}\exp(-2z/B)+\gamma_A z+z_0'. \qquad (18)$$

ただし，

$$z_0'=-\frac{\mu N_0^2 B}{2g}\exp(-2z_0/B)-\gamma_A z_0 \qquad (19)$$

すなわち，(18)が海中の音速の鉛直分布を特性づけるこ

とになる。

MUNK (1974) は (18) の指数関数を z の級数展開近似によって表わした。しかし，実用的には，(18)のかわり (1) にのように水温，塩分および圧力の級数展開の部分による近似的表示による記述の方が便利である。

3. 深海の音速場

すでにみたように，海洋中の音速は水温・塩分・圧力によって定まる。その特性は，基本的には前節の (18) によってあらわされていると考えられるが，実際には，その他の条件によって異なることが多い。

いま，神戸海洋気象台の海洋速報によって，測点の塩分・水温・水深のデータを実用式 (1) に代入すれば音速の鉛直分布を知ることができる。たとえば，Fig. 1 には，測点 u_3 (32°56′N, 137°02′E) において 1983年10月12日23時の例を黒丸と実線で示した。また，白丸と点線は測点 u_8 (30°30′N, 137°04′E) で1983年10月14日 0 時の例である。測点 u_3 は紀伊半島南東方に位置し，当時，いわゆる冷水塊の中にあった。Fig. 1 の水温の鉛直分布をみても，50-1000 m 深で測点 u_8 よりも u_3 の水温が低いことがわかる。海中の音速に対する水温の効果はとくに顕着であり，それは Fig. 1 の音速の鉛直分布について，測点 u_8 と u_3 の例を比較するだけでもよくわかる。海面下 1000 m 以深では，測点 u_3 も u_8 も，同一水深に対する水温・塩分はほぼ同じとみられる。ちなみに，測点 u_3 および u_8 を含む測線 137°E に沿って 30-34°N の音速鉛直断面分布をもとめた結果は Fig. 2 のようになる。これからみて冷水塊の部分では音速はその周囲より小さい値であり，また，深海での鉛直分布は緯度によって顕著な差がないといえる。

海中の音速について $\partial C/\partial z=0$ (音速極小) の位置を Fig. 1 では矢印によって示した。これに対応したものが Fig. 2 では1点鎖線で示されており，これは axis of sound channel とよばれる (CLAY and MEDWIN, 1977)。

黒潮流路には大きく分けて直進型と蛇行型との1つのパターンがあることはよく知られている。1981年7月の直進型の時期の 135°E 測線の音速分布を Fig. 3 に示した。これに対して 1983 年 7 月の蛇行型の時期の 135°E 測線の音速分布は Fig. 4 のようになっていて，1000 m 以浅の等音速線群が蛇行型は直進型に比較して約 60 km 南へずれているようにみえる。このように，音速の鉛直分布は，黒潮の流路の相違によって大きく異なる。しかし，たとえば直進型の期間では，音速鉛直分布の季節的変化は表面付近を除けばそれほど顕著ではない。

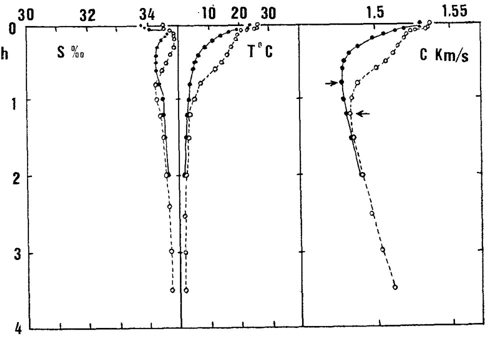

Fig. 1. Salinity, temperature and sound speed at stations in and out of a cold water mass around which the Kuroshio was meandering (arrows show minima of sound speed). The data was obtained on 12 to 14 October 1983 by Kobe Marine Observatory: solid circles are for the station U3 in the cold water mass (32.56N, 137.04E) at 23h on 12 October 1983 and open circles are for the station U8 outside of the cold water mass (30.31N, 137.04E) at 00h on 14 October 1983.

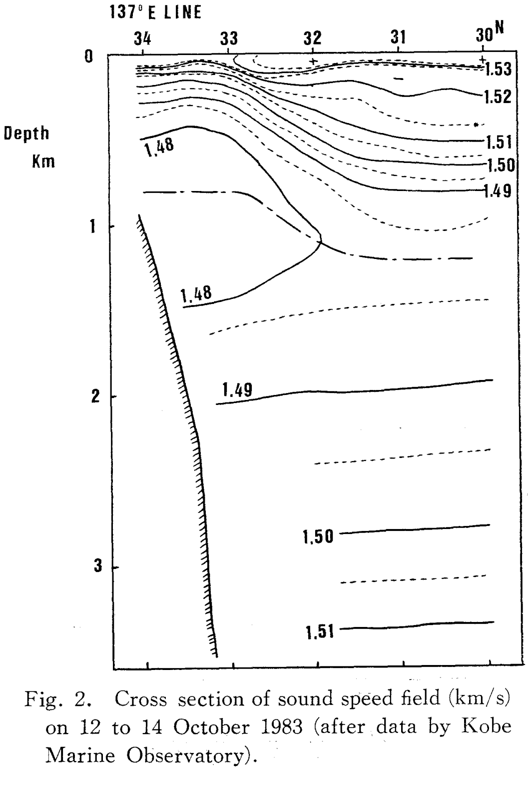

Fig. 2. Cross section of sound speed field (km/s) on 12 to 14 October 1983 (after data by Kobe Marine Observatory).

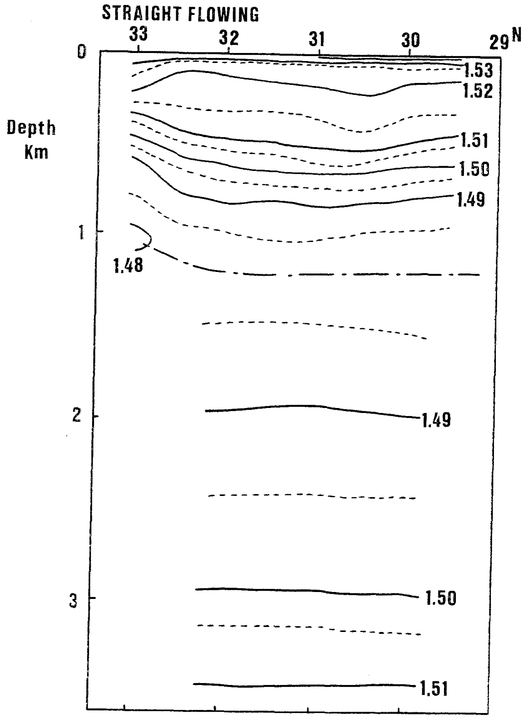

Fig. 3. Cross section of sound speed field (km/s) along 135E on 6 to 8 July 1681 (after data by Kobe Marine Observatory).

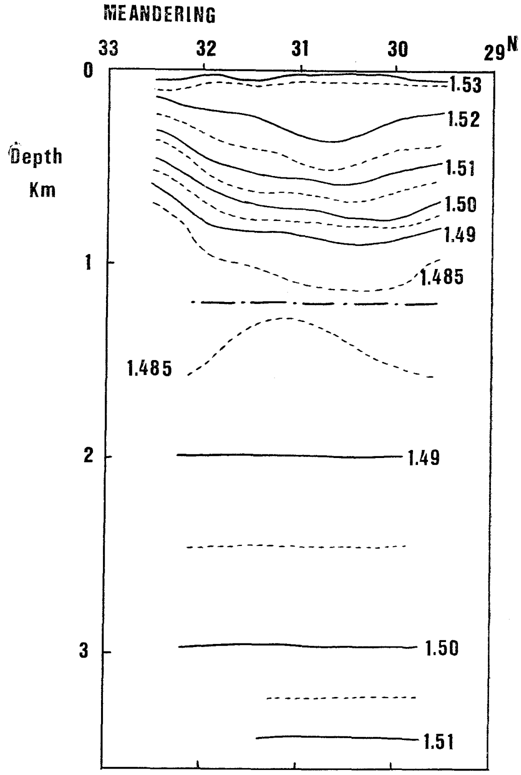

Fig. 4. Cross section of sound speed field (km/s) along 135E on 8 to 9 July 1983 (after data by Kobe Marine Observatory).

上に述べた特徴は，過去において得られたデータについても同様である。

4.　沿岸域の音速場

海洋の水温や塩分の変動は，表面に近いほど大きい。それに対応して，音速の変動も大きいものと考えられる。とくに，沿岸域では陸での熱的環境条件による効果が加わって，その変動はかなり複雑なものとなってくる。

いま，例として，田辺湾沖ノ島（33°43′7N，135°20′1E）および潮岬（33°24′1N，135°44′7E）における音速の鉛直分布を，和歌山県水産試験場の観測による水温・塩分・水深を（1）に入れてもとめた結果を Fig. 5 に示す。図中，黒丸は1983年9月，白丸は1983年3月の例である。沖ノ島では，Fig. 5 上段のように，9月には海面下6mまでは塩分が小さいが，音速には水温の効果が顕著にあらわれている。3月には，音速は水温と同様，深さに対してほぼ一様な分布をしている。潮岬では，Fig. 5 下段にみるように，水深 20m までについては，沖ノ島とよく似た傾向を示しているが，Fig. 5 からみて顕著な年周変動は大体海面下 50m 位までに認められる。すなわち，海面付近の変動の大きい場合をとってみると，塩分にして年間4‰程度の変化はみられるが，これには陸からの河川水や降雨などの影響も考えなくてはならない。また，水温については，年周変動幅は14°C程度であり，これに対応して，音速の変動幅は高々 30m/s 程度である。海面下 50m 以深 200m までの範囲では，その年周変動幅は，塩分にして高々 0.3‰程度，水温にして高々 1°C 程度，そして，音速にして高々 4m/s 程度となっている。

上述と同様なことは，同一測点の過去の記録からもうかがうことができる。

5.　白浜海洋観測塔の音速場の年周変動

紀伊半島南西部の田辺湾湾口部付近に位置する白浜海洋観測塔（33°41.63′N，135°20.88′E）では，サーミスタを用いて水温を，電気伝導度用コイルを用いて塩分を連続記録してきた（1985年6月30日，台風6号接近時，遂にセンサー折損落失）が，とくに，塩分の記録にはセ

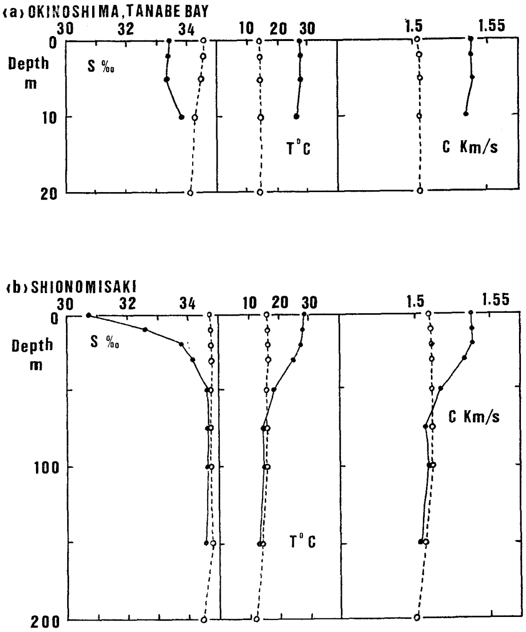

Fig. 5. Vertical profiles of salinity, temperature and sound speed in a coastal zone of (a) Okinoshima, Tanabe Bay and (b) Shionomisaki. Solid circles for September 1983 and open circles for March 1983 (after data by Wakayama Fisheries Research Station).

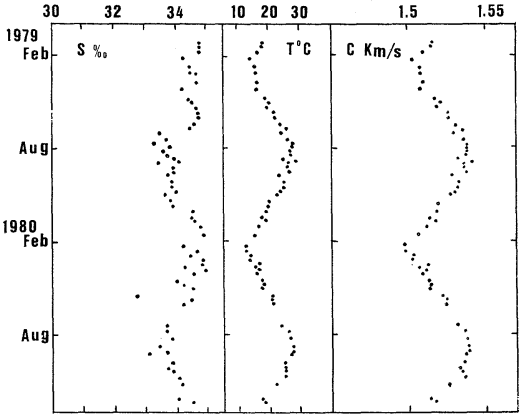

Fig. 6. Annual variations of salinity, temperature and sound speed at Shirahama Oceanographic Tower Station (33°41.63′N, 135°20.88′E).

ンサー部位の付着生物の影響が顕著であり，その記録の補正は難かしい。この補正の目的で不定期にサーミスタ設置位置での採水・測温を北原式採水器によって行っている。いま，例として，1979年1月から1980年12月までの2年間について，その塩分・水温およびそれらを (1) に入れて得られた音速をもとめ Fig. 6 に示した。

観測塔における水温の変動をみると，2-3 月に1年間の最低水温がみられ，8-9 月に最高水温がみられる傾向がとらえられる。1年間を通して，平常の水温の日周変動幅は 0.7°C 程度である。このような水温の年周変動や日周変動の原因は主に海面への太陽輻射によるものと考えられる。ただ，フロントの通過によると考えられる不規則な顕著な変動も認められる（海象(流れ)観測グループ，1983)。

観測塔における塩分の変動をみると，全般的傾向として，2-4 月頃に塩分は最高であり，7-9 月頃に塩分は最低となっていることがわかる。とくに，7-9 月頃の低塩分は，この時期が梅雨期から台風期に対応し，沿岸域は多雨の条件下にあり，陸からの河川流出量も増大することによるものと考えられる。とくに，観測塔での採水・測温直前に強い降雨があり，雨水を多量に混合した沿岸水パッチがサーミスタ付近を通過すると，たとえば，1980年5月17日（11時10分）の測定例のように一時的に顕著に小さい塩分値が記録される。観測塔の記録をみても，塩分には日周変動があるようにはみえないが，フロントの通過に対応すると考えられる不規則な変化はしばしばとらえられている。

上に示したような水温と塩分とからもとめた音速にも年周変動がとらえられる。その特徴は Fig. 6 によって示されるように，2-3 月には音速も最小値をとり，8-9 月には最大値をとる。

海中の音波に関連した問題を検討する場合には，単純化したモデルによってその基本的特性をとらえることも必要であるが，海中の音速がいろいろの条件によって時間的・空間的に一様ではなく変動していることも忘れてはならない。

謝　辞

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巨大津波の前駆異常音について*

中村重久**

On an acoustic precursor of the big tsunami

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Abstract: According to ancient manuscripts, a big tsunami arrives at the coast, sometimes following a boom as an acoustic precursor. A hypothetical interpretation of the boom pathway is proposed; there are combinations of the bottom geometry of the continental slope, the vertical profile of sound velocity and the epicenter location favorable for the boom production and its arrival to the coast.

1. 緒言

海底で大地震が発生した場合，かならず津波をともなっている。地震発生から津波到達までにどのようなことがみられるかは，津波の予警報や対策のあり方とも関連して興味のあるところである。ここでは，とくに，わが国の沿岸での巨大津波に関する過去の記述的資料を整理し，津波に先だって大砲のような音響が聞かれたという記事に注目し，その科学的意味づけの可能性をさぐろうとした。すなわち，地震発生と同時に音波として水中を伝わること，あるいは空中を伝わることが考えられるかどうか仮説をたててみた。

2. 史料における前駆現象

大地震の発生にともなう前駆現象については，とくに最近50年間の例については記述を見出すことができない。これは，そのような現象は認められないということを意味しているのであろうか。過去の歴史的大地震については数多くの前駆現象の記述がある。ただ，江戸時代より以前の記述は被害の範囲に限定され，詳細は不明である。前駆現象としては大別して光と音とがあるが，このうち，ここでは音についてのみ考えることにする。以下に，津波来襲までの経過についての記述を抜き出してみた。これをみると，対象となった地震の地域などに共通したところがあることに気がつく．ここに紹介できなかったもので現在までのところその共通性をはずれるものはなかった。表現はできるだけ原文の記述あるいはそれにできるだけ近いものとするよう努めた。

（1） 宝永4年（1707）[1] 南海道沖地震

(i) ‘地震海溢考’大阪大地震津浪之事より

′宝永四年……十月四日昼未の刻より地震半時計ゆる（中略）此地震に而桿ニ打れ死する人々を知らず大阪に而は大津は大潮西之方と思しくて鳴音しければ又地震のゆりかつしかと心も空に成し処ニ西海夥しく鳴渡りて大山の如く大潮さし込……′（和田義翁の坐右録に同文の記述あり）。

(ii) ′南北堀江誌′ 大阪府より

′宝永四年十月四日大地地震之事……然るに申の上刻頃から海底どうどうと鳴出し，何事ならんと驚く折しも，木津川に一の洲の海底から，俄かに大潮湧き上り来ること凡そ二十丈許り……′。

（2） 安政元年（1854）東海道沖地震

(i) ′熊野年代記′（那智勝浦町史 p. 93）[2] より

′安政元年十一月四日の朝四ツ半時（午前11時）震動し……凡そ半時（今の1時間）其後海鉄砲と申して洋中にて鉄砲の音聞え，西の方に当り，雲中に折々ドンドンの甚しく，……′。

（3） 安政元年（1854）南海道地震

(i) 大阪屋定次郎より園部弾次郎宛書状の一部（大阪市）[3] より

′昨五日朝より七ツ時半迄震不申，漸安心仕候程之儀

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に御座候処，風も無之，快晴に御座候処，近海沖，雷鳴之如く，五ケ度程相聞候に付，不審に奉存候，無間も津波潮押寄，……'。

(ii)　名屋浦鑑4) より（現在の御坊市）

'今日（五日）申下刻又大地震，西南海大に震動すること数万之雷一時に落る如し。暫くして大津浪来り地震は尚止まず海中鳴ること炮の如し，地震頻りに震，大なるもの世の常ならず次第に相減じて両三年にして止む炮の如く鳴るもの俗名海鉄炮といふ。……'。

(iii)　山本清七記 'つなみ心得咄' 5)（現在の御坊市）より

'当日（五日）七ツ時大地震誠に諸人心配致し候処，未申の間にて山もくずる様にどんどん鳴り，此上鳴り止り候節津波上り，……'。

(iv)　中岩家文書（和歌山県白浜町富田）6)7)

'同日（五日）申刻頃烈敷大地震良暫良くの間不止……小し大ゆりも静まりしより，西南の方へ当り，大砲を打つごとくドンドンと鳴り出し，……'。

(v)　出羽島貞之助 '嘉永七年寅年十一月五日津波一巻書記'（牟岐町史より）8)

'……（十一月五日）七ツ半時（午後5時）頃俄ニ大地震無程海中鳴出シ其厳き事無譬方，大木は如顚，大地如破，海中より鳴出ス。其音如大筒切ニぼんぼんと鳴出し半時余りにして海中波の高き事如大山暫時大潮渦巻来り，……'。

（4）　明治29年（1896）三陸沖地震

(i)　岩手県大船渡市盛町洞雲寺 '大海嘯記念碑'（明治35年6月15日建立）（山下の著 p. 37 より）9)

'明治 29 年6月15日……午後7時を過ぎし，大砲の如き音，聞えければ，怪しみて耳欹つる程こそあれ。……'。

(ii)　山下の著 p. 144 より9)

'（田老村にて）15月は午後3時頃からにわか雨が大いに降り，7時 30 分頃，1-2度地震があった。いずれも強いものでなかったが，普通の地震に比べると振動している時間を長く感じた。ところが8時12分と覚しき頃となり，東北の方であたかも空砲でも発するような音が前後3回つづき，人びとはこれを怪しみかつ恐れて，みな戸外に出て佇んだ。……'。

(iii)　山下の著 pp. 145-146 より9)

'（田老村にて）津波の来襲前，東北の方向で大砲のような音が前後3回あって，三百余間ほど潮が引くと共に，「朗月の如き光」が海面を照し，同時に数丈の波が押し寄せて，全村が洗いさられるように流失した。……'。

(iv)　山下の著 pp. 146-147 より9)

'田老の漁師六〇名は津波の当日十五隻の小舟で東北の方向，二里ばかりの沖合で鮪漁をしていた。波は比較的静かで潮流にも特に異常なかったが，突然，北の方で砲声のような大きな音がきこえ，岸の方では汽車の走るような怪音がした。異変が起ったのかと急いで網をあげて，港をめざして漕ぎ戻った。

途中で二，三の大波に出会い，辛うじて港の口まで来たが，全村が真暗で一つも灯火が見えないばかりか，木材などが大量に流れ出て来た。波浪も激しく，しかたなく港口で一夜を過した。夜が明けてからはじめて陸上の荒涼たる様子を目撃し，大津波のあったことを知ったという'。

（5）　昭和8年（1933）三陸沖地震

(i)　田老村津浪誌（山下の著 pp. 283-284）9)

'3月3日の午前2時半頃，突然風の吹いてくるような地鳴りがして，大地が揺れ出した。……そのとき，遠く沖のかなたで大砲を打ったような音が2つつづけさまにした。だが人びとは道路工事の夜業のハッパぐらいに考えてあまり気にとめなかった。……'。

(ii)　山下の著 p. 270 より9)

'（釜石町にて）三日午前二時三十五分頃突然激しい上下動がしたとみる間に，沖合の海面に稲妻のような怪しい光がかがやき，物凄い海鳴りが始まった。あっという暇もなく海水は急に引き去り，人々が津波だ，逃げろ！と叫び出したときには海は小山のように盛りあがり，……'。

(iii)　山下の著 p. 276 より9)

'（山田町にて）山田郵便局電話交換手沼崎ツイさん(21)，内館アキさん(20)，湊チヤさん(19)の三名は，大槌局から"ただ今，沖が鳴っているから津波が来ましょう"という警告をうけて，しばらくのあいだ警戒していたが，いっこうその様子もないので，念のため大槌局に問い合わせると，音波に乗って，津波だ，津波だ！という声がかすかに聞こえてきた。三人は，すぐさま百余の加入者に対し，"津波が来るから避難するように"と警告したので，町民は時を移さず龍昌寺，小学校，小倉山，八幡神社などの高所へ避難した。……'。

3.　地震に伴う擾乱の伝播として可能な型態

海底地震が発生した場合，震源から沿岸まで擾乱がどのような型態で伝わるかを考えてみると，つぎのようになる。第1に，地震波として，P波が最初に到達する。津波は海底地震にともなう海底地殻の変動がつくった重力長波である。また，地震時の擾乱が音波として水中を

Table 1. Propagation time of disturbances accompanied by an underwater earthquake.

category	speed	propagation time for 100 km distance
seismic wave (P wave)	8 km/s (for 100 km depth)	12.5 sec
acoustic wave in water	1500 m/s	67 sec
acoustic wave in atmosphere	331.45 m/s (for 0°C, 1 atm. pres.)	303 sec
long gravity wave as tsunami	100 m/s (for about 1000 m depth)	1999 sec

伝わることも可能であるし，震源の直上から空中を音波として伝わることも考えられないことはない。いずれの型態も可能であるとして，その伝播の特徴をとらえるために，大ざっぱではあるが，水平距離約 100 km を伝わるのに要する時間の比較を試みた (Table 1)。

この比較によると，地震波が10数秒であり，その後，水中音波は約1分，空中音波は約5分である。津波としての重力長波は地震後約15分経過しないと到達しない。

前節に示した史料の記述では，時間的にどの程度の精度で上の例に対応づけられるのかについては相当の主観的判断が介入する可能性が高い。一方，いづれの史料の記述にも共通しているのは，地震につづいて海中又は沖合で音が聞え，その後津波が来襲したということである。記述が事実を記しているとみるかぎり，この共通のパターンには物理的特性としての意味づけが可能であることを予想させる。

さて，大気中の音響の異常伝播の研究については藤原 (1911)[10] があるが，この異常伝播が超高層大気（地上 30-60 km）の高温によって起ることは WHIPPLE (1923) によって明らかにされた。戦争中に観測された砲声やダイナマイトの爆発の聞こえる地域は音源を中心としてドーナツ型にひろがっている。音響は音源をはなれるにつれて一様に減衰するのではなくて，途中に音の聞えない区域（半径約 200 km）があって，さらにその外側には音響の伝わる区域がリング状（半径約 400 km）にとりまいている[10]。地震によって生じた擾乱が音波として大気中を伝わることは可能性として考えられるが実際の現象として存在しうるのであろうか。今後の検討をまたねばならない。あるいは，数百キロメートル距ったところで津波に原因する音を聞くことができるであろうか。これも興味ある問題である。さらに，前節の史料の記述にあったような，一回の海底地震に対して数回大砲のような音がくりかえされることを説明できるであろうか。

ここで，水中を伝わる音波として海底地震による擾乱が伝わる可能性についても検討してみよう。

海洋中の音場をみると，海中音速の鉛直分布には，2つの典型的なパターンが考えられる（たとえば，CLAY and MEDWIN, 1977)[11]。すなわち，海面から鉛直下方に軸をとるとき，海中音速 $c(z)$ の鉛直分布として (a) $dc/dz<0$ と (b) $dc/dz>0$ とが考えられる。一定水深の海で，震央位置を原点として水平方向に x 軸をとることにし，海底地震を音源とする擾乱音の伝播経路は模式的に Fig. 1 のようになるものと考えられる。図中 (a) の場合には，震央から出た音は矢印のような経路で海中を伝わるが，いづれの経路も上に凸である。とくに，海面上の点 x_a に接するような経路に注目しよう。$x>x_a$ の海域で海面と経路 R_a との間には音源から直接音波は到達しない。この区域は音場の影 (shadow zone) である。そこでは，海底で反射したものが，海面で一度反射した後海底で反射したものを感知されることになる。ただし，反射時に音のエネルギーは一部失なわれ，また，経路の長さも長くなるため伝播の途中の音の減衰も考えられる。他方，図中 (b) の場合には震央から出た音波は矢印のように上に凹な経路をとる。音源で海底に接するように出た音波は経路 R_b を経て海面の点 x_b に到達するが，音源からの直接の音波はこの経路 R_a と海底との間の区域に入ることはない。これも影の区域 (shadow zone) である。この区域では，海面で反射した音波が伝わることは考えられる。しかし，実際の海洋中の音場は

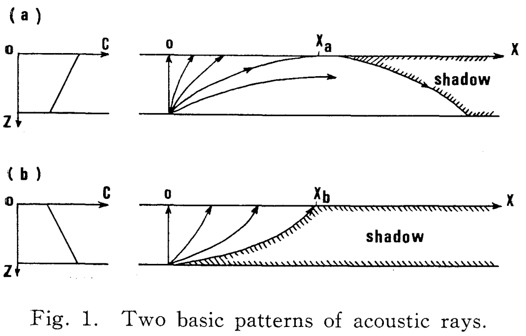

Fig. 1. Two basic patterns of acoustic rays.

一般に複雑である（たとえば，中村，1985）[12]。さらに，海底地震が起りやすい場合は，たとえば環太平洋地震帯といったように，海洋でも特定の場所に限られている。前節の例にみたような日本周辺で起った巨大津波地震の震央では水深は 1000 m から 4000 m 程度と考えられ，そこから海岸線までには陸棚があり，海底地形は岸に近づくほど複雑となり，さきに Fig. 1 で考えたような単純なものではなくなってくる。

ここで，Fig. 1 よりさらに実際の海洋の音場に近い模式的例として Fig. 2 を考えることにしよう。

いま，ここで，約 4000 m の水深に対して音速の鉛直分布は Fig. 2 左のように与えられているとする。このとき，音源から経路 R_b あるいは R'_b を経た音波は 500m 以浅で $x<x_b$ の区域の一部に直接伝わる。これは，もし海底断面形状が R_b あるいは R'_b に近いもので与えられたとしても十分考えられる。一方，経路 R_b を経て（水深 500 m で $x=x_b$ を通り），海面に $x=x_a$ で接するような場合には，$x>x_a$ の影の区域（shadow a）では音源から直接到達する音波はとらえられない。そして経路が R_b と R'_b との中間である場合には，経路は $x_a<x<x_c$ なる区間内で海面に最も近づき，その後，方向を下にとって，海面下 500 m では $x_c<x<x'_c$ なる区間内を通ることになる。このとき，海面上の点（x_a，0）を起点として，$x_a<x<x'_c$ の区間の音波の経路の集中による caustics が形成される。音源から 20～30 km の距離にこのような caustics があらわれれば，30 km 以上音源から距った位置で海中から衝撃波的な音が聞こえても不思議ではない。このことは，仮に海底断面が Fig. 2 の shadow のようであったとしても考えられうることである。

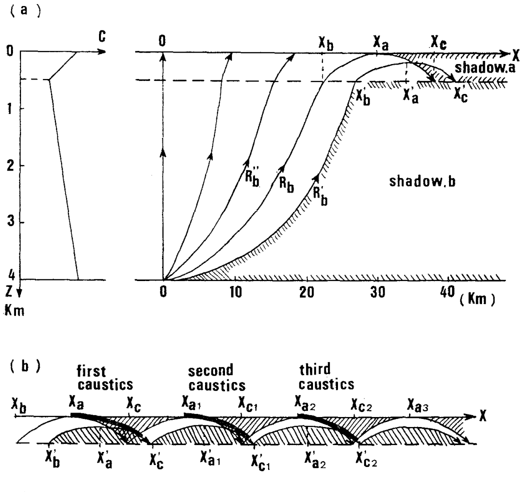

Fig. 2. Hypothetical interpretation of the boom arrival. (a) vertical profile of sound velocity and acoustic rays. (b) resulting boom formation on the continental shelf.

以上は音源から直接伝わった音波についての検討であるが，同様なことは海面で反射しさらに海底で反射した音波についても考えられる。したがって，$x>x_a$ なる区間でいくつかの caustics が形成され，そこでいくつかの衝撃波的な音が何回か聞こえることも十分考えられる。

Clay and Medwin[11] は大西洋の典型的海中音場についての図（Figs. 3. 2. 7）を示した。基本的には，その音場の特性は日本太平洋沿岸[12]でも同じであると考えられる。深海で水平に進む音波はその経路を次第に上向きに変える。概略の傾向として 3000–5000 m の深さで水平に進む音波の経路はそこから 25–35 km 距った海面に接する。深さが 3000 m 以浅で水平に進む音波ははじめ上向きに進んで海面に接近するが，海面下およそ数百メートルで向きを下向きに変える。このようなことから，caustics が海面あるいは海面のごく近くに形成されるのは，音源が海面下 3000–5000 m の場合に限られるものと推定される。したがって，海底地震の震央が海面下 3000–5000 m であれば，津波来襲前に沖合で海中異常音として，大砲のような音が数回聞こえることは，物理的にみてもありうることである。

いま，もし，海底断面が Fig. 2 の R''_b のように急峻である場合には，音波の経路はすべて海面へと向かい，海面で反射することになるが，海底断面が R'_b の場合のように海面付近に音波の経路の集中による caustics があらわれる可能性は高いとはいえない。つまり，たとえ音源が海面下 4000 m であっても海底が急峻ならば，衝撃波的な音が聞こえる可能性は考え難い。ただ，音源での擾乱に相当する擾乱が海面で認められるにすぎないであろう。

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6) 中村重久（1984）: 田辺・白浜における津波について. 京都大学防災研究所年報，No. 27B-2, 591-610.

7) 楠本慎平（1965）: 近世における富田郷の災害対策に関して―宝永の「津波警告板」の意味するもの―. 田辺文化財和 No. 9, 和歌山県田辺市教育委員会, 42-47.

8) 猪井達雄・澤田健吉・村上仁士（1982）: 徳島の地震津波―歴史資料から―. 徳島市民双書16, 徳島市立図書館, 235 pp.

9) 山下文男（1984）: 哀史三陸大津波. 岩手文庫, 青磁社, 413 pp.

10) 気象学ハンドブック編集委員会編（1959）: 気象学ハンドブック. 技報堂, 1321 pp.

11) CLAY C.S. and H. MEDWIN (1977): Acoustic Oceanography. Wiley-Intersci. Pub., N.Y., 544 pp.

12) 中村重久（1985b）: 日本南岸の黒潮流域付近における海洋音速場について. La mer, **24**, 42-47.

学 会 記 事

1. 昭和60年11月1日，日仏会館フォワイエにおいて海洋水産用語辞典増訂版（仮称）編集委員会（第2回）が開かれ，事業計画の具体化について協議した。

2. 昭和60年11月21日，東京水産大学において幹事会が開かれ，評議員選挙について協議した。評議員の選挙事務は高木常任幹事が担当することとした。

3. 昭和60年11月21日，東京水産大学において編集委員会が開かれ，La mer 第24巻第1号の編集が行われた。

4. 昭和60年11月21日，東京水産大学において学会賞受賞候補者推薦委員会（第1回）が開かれ，委員長に中村重久氏を選出し，推薦方法および日程を決めた。

5. 昭和60年12月13日，日仏会館フォワイエにおいて海洋水産用語辞典増訂版（仮称）編集委員会（第3回）が開かれ，事業計画の具体化，とくに出版方法および出版経費などについて検討が行われた。

6. 昭和60年12月23日，東京水産大学において学会賞受賞候補者推薦委員会（第2回）が開かれ，評議員からの推薦をもとに審議の結果，柳哲雄氏を推薦することとし，その旨会長宛に報告された。

7. 昭和61年2月17日，東京水産大学において幹事会が開かれ，評議員選挙開票の際の得票同数の者の扱い方について原則を協議した結果，開票担当者の抽せんにより順位をつけることとした。また，1988年に予定される日仏学術シンポジウムについて協議し，組織委員会をつくる方向で更に検討することとした。

8. 昭和61年2月17日，東京水産大学において評議員選挙の開票が行われ，次の50名が昭和61・62年度評議員として選出された。

青木三郎，青山恒雄，阿部友三郎，有賀祐勝，石野誠，市村俊英，井上 実，岩井 保，宇野 寛，岡市友利，岡部史郎，岡見 登，小倉通男，加藤重一，梶浦欣二郎，鎌谷明善，川合英夫，川原田裕，久保田穣，黒木敏郎，西条八束，佐伯和昭，坂本市太郎，坂本 亘，須藤英雄，関 文威，平 啓介，高木和徳，高野健三，高橋 正，谷口 旭，辻田時美，寺本俊彦，鳥羽良明，冨永政英，永田 豊，奈須敬二，奈須紀幸，西沢 敏，根本敬久，畑 幸彦，半沢正男，日比谷 京，平野敏行，増沢譲太郎，松生 洽，丸茂隆三，三浦昭雄，村野正昭，森田良美

（五十音順）

9. 昭和61年2月28日，日仏会館フォワイエにおいて海洋水産用語辞典増訂版（仮称）編集委員会（第4回）が開かれ，事業計画の具体化，とくに商業ベースでの出版の可能性を探ることとし，採録用語の原稿提出期限を6月末とすることを決めた。

10. 下記の方が第23巻第4号掲載の名薄からもれていました。お詫びいたします。

関根義彦　〒239 横須賀市走水1-10-20
防衛大学校数物教室

11. 逝去　山中 一

12. 交換・寄贈出版物

1) Bull. Ocean Res. Inst., Univ. Tokyo	No. 20
2) ライフサイエンス講演会記録	
3) 日本学術会議月報	第26巻第10～12号， 第27巻第1～2号
4) 研究実用化報告	Vol. 34 No. 10～12., Vol. 35 No. 1～3
5) 鯨研通信	第360～362号
6) 養殖研研究報告	第8号
7) 養殖研ニュース	No. 10
8) 測量・地図年鑑	昭和60年度
9) しおさい	No. 2
10) 神奈川県立博物館研究報告，自然科学	第16号
11) 海洋科技センター年報	昭和59年度
12) 海洋時報	第39，40号
13) 東海大学海洋学部紀要	第21号
14) 広島大学生物生産学部紀要	第24巻第1・2号
15) 海洋産業研究資料	Vol. 16 No. 6, Vol. 17 No. 1
16) 日本航海学会論文集	第73号
17) なつしま	No. 79，80
18) 高知大学海洋生物教育研究センター研究報告	No. 7
19) 国立科学博物館専報	第18号
20) Bull. Nat. Science Museum	Vol. 11 No. 3
21) 海洋牧場ニュース	Vol. 1，2
22) 航海	第86号
23) 農林水産省報告・技術論文要約集	第12号
24) JODC ニュース	No. 31
25) 水産庁海洋観測資料	昭和57年
26) 日本海洋協会ニュース	No. 2，3
27) 広島日仏協会報	No. 92
28) 日本プランクトン学会報	第32巻第2号
29) 東海大学海洋研究所研究報告	第6号

30) 東海大学海洋研究所年報 第6号
31) 日本海区水研研究報告 第36号
32) Inst. Nac. Invest. Pescas Publ. avulsas N° 3, 4
33) Bol. Inst. Nac. Invest. Pescas N° 10
34) 科学通报 Vol. 30 Nos. 10～12, Vol. 31 Nos. 1～4
35) Israel Oceanogr. & Limnol. Res. Vol. 8
36) Revista Cubana Invest. Pesqeras Vol. 5 No. 4, Vol. 6 No. 1
37) Equinoxe N^os^ 2, 3
38) The Ocean Surface
39) Multidiciplinary Studies of the Eastern Mediterranean Basin 1984-1985
40) Bull. l'inst. géol. bassin d'aquitaine N° 38
41) 韓国海洋学会誌 第20巻第2, 3号
42) Marine Microbial Food Webs Vol. 1 No. 1
43) Revue des travaux de l'institut des pêches maritimes Fasc. 3, 4
44) American Museum Novitates No. 2823-28

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 ジャック・マゴー レオン・ヴァンデルメルシュ

名誉会長 オーギュスタン・ベルク

会長 冨永政英

副会長 高野健三，森田良美

常任幹事 有賀祐勝，宇野 寛，佐伯和昭，関 文威，高木和徳，松生 洽

幹事 青木三郎，阿部友三郎，石野 誠，井上 実，岩下光男，岡見 登，川原田裕，菊池真一，草下孝也，斎藤泰一，佐々木幸康，佐藤孫七，高橋 正，奈須敬二，根本敬久，半沢正男，丸茂隆三，三浦昭雄，山中鷹之助

監事 久保田 穰，辻田時美

評議員 青木三郎，青山恒雄，赤松英雄，秋山 勉，安達六郎，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，岩井 保，岩崎秀人，岩下光男，岩本康三，宇野 寛，大内正夫，小倉通男，岡市友利，岡部史郎，岡見 登，岡本 巌，梶浦欣二郎，梶原昌弘，加藤重一，加納 敬，鎌谷明善，川合英夫，川原田裕，菊池真一，草下孝也，久保田 穰，黒木敏郎，小池勲夫，小泉政美，小林 博，西条八束，斎藤泰一，斎藤行正，佐伯和昭，坂本市太郎，坂本 亘，佐々木幸康，佐藤孫七，猿橋勝子，柴田恵司，庄司大太郎，須藤英雄，関 文威，平 啓介，隆島史夫，多賀信夫，高木和徳，高野健三，高橋淳雄，高橋 正，高橋正征，谷口 旭，田村 保，辻田時美，寺本俊彦，鳥羽良明，冨永政英，鳥居鉄也，中野猿人，永田 豊，奈須敬二，奈須紀幸，西沢 敏，西村 実，根本敬久，野村 正，畑 幸彦，半沢正男，菱田耕造，日比谷 京，平野敏行，深沢文雄，深瀬 茂，淵 秀隆，前田昌調，増沢譲太郎，松生 洽，丸茂隆三，三浦昭雄，三宅泰雄，宮崎龍雄，村野正昭，元田 茂，森田良美，安井 正，柳川三郎，山口征矢，山路 勇，山中鷹之助，山中一郎，吉田多摩夫

（五十音順）

マルセル・ジュグラリス，ジャン・アンクティル，ロジェ・ペリカ

日仏海洋学会会則

第1条　本会は日仏海洋学会と称する。

第2条　本会の目的は日仏海洋および水産学者の連絡を密にし，両国のこの分野の科学の協力を促進するものとする。

第3条　上記の目的を実現するため本会は次の事業を行なう。

(1)　講演会の開催
(2)　両国の海洋学および水産学に関する著書，論文等の相互の翻訳，出版および普及
(3)　両国の海洋，水産機器の技術の導入および普及
(4)　日仏海洋，水産学者共同の研究およびその成果の論文，映画などによる発表
(5)　両国間の学者の交流促進
(6)　日仏海洋，水産学者の相互の親睦のために集会を開くこと
(7)　会報の発行および出版
(8)　その他本会の目的を達するために必要な事業

第4条　本会には，海洋，水産学の分野に応じて分科会を設けることができる。

分科会は評議員会の決議によって作るものとする。

第5条　本会の事務所は日仏会館（〒101 東京都千代田区神田駿河台2丁目3番地）に置く。

第6条　本会に地方支部を置くことができる。

第7条　本会会員は本会の目的に賛成し，所定の会費を納めるものとする。

会員は正会員および賛助会員とする。

第8条　正会員会費は年額6,000円，賛助会員会費は一口年額10,000円とする。

第9条　本会は評議員会によって運営される。

評議員の定数は50名とし，正会員の投票によって選出される。選挙事務は別に定める選出規定による。

会長は評議員会の同意を得て5名までの評議員を追加することができる。

評議員の任期は2年とする。ただし，重任を妨げない。

第10条　評議員はその内より次の役員を選ぶ。ただし，幹事は評議員以外からも選ぶことができる。

会長　1名，副会長　2名，幹事　10名，
監事　2名

役員の任期は2年とする。ただし，重任を妨げない。

役員の選出方法は別に定める選出規定による。

第11条　本会に名誉会長，顧問および名誉会員を置くことができる。名誉会長，顧問および名誉会員は評議員会の決議により会長これを委嘱または推薦する。

日仏会館フランス人学長を本会の名誉会長に推薦する。

第12条　会長は本会を代表し，総会および評議員会の議長となる。会長事故あるときは副会長がこれに代わる。

会長，副会長および幹事は幹事会を構成し，本会の庶務，会計，編集，研究発表，渉外などの会務を行なう。

監事は本会の会計を監督する。

第13条　年に1回総会を開く。総会では評議員会の報告を聞き，会の重要問題を審議する。会員は委任状または通信によって決議に参加することができる。

会長は必要に応じて評議員会の決議を経て臨時総会を招集することができる。

第14条　本会則の変更は総会の決議による。

日仏海洋学会評議員・役員選出規定

1.　本規定は日仏海洋学会会則第9条および第10条に基づき本会の評議員および役員の選出方法について規定するものである。

2.　評議員は正会員の50名連記無記名投票により選出する。

評議員の選挙事務は庶務幹事が行なう。ただし，開票にあたっては本会役員以外の会員2名に立会人を委嘱するものとする。

3.　会長は評議員の単記無記名投票により選出する。

会長選挙の事務は庶務幹事が行なう。ただし，開票にあたっては本会役員以外の会員2名に立会人を委嘱するものとする。

4. 副会長，幹事，および監事は，会長の推薦に基づき評議員会で決定する。
5. 本規定の改正は評議員会の議を経て行なう。

日仏海洋学会賞規定

1. 日仏海洋学会賞（以下学会賞という）を本学会に設ける。学会賞は本学会員で，原則として本学会誌に発表した論文の中で，海洋学および水産学において顕著な学術業績を挙げた者の中から，以下に述べる選考を経て選ばれた者に授ける。
2. 学会賞受賞候補者を選考するため学会賞受賞候補者推薦委員会（以下委員会という）を設ける。
3. 委員会の委員は13名とする。
   委員は毎年春の評議員会で選出し，委員長は委員の互選により定める。
   会長は委員会が必要と認めた場合，評議員会の同意を得て２名まで委員を追加委嘱することができる。
4. 委員会は受賞候補１件を選び，12月末までに選定理由をつけて会長に報告する。
5. 会長は委員会が推薦した候補者につき無記名投票の形式により評議員会にはかる。投票数は評議員総数の３分の２以上を必要とし，有効投票のうち４分の３以上の賛成がある場合，これを受賞者として決定する。
6. 授賞式は翌年春の学会総会において行ない，賞状，メダルおよび賞金を贈呈する。賞金は５万円とする。
7. 本規定の改正は評議員会の議を経て行なう。

覚　書

1. 委員は各専門分野から選出されるよう十分配慮すること。
2. 受賞者は原則として順次各専門分野にわたるよう十分配慮すること。

日本学術会議だより

第13期活動計画決まる

昭和60年10月　広報委員会

日本学術会議法の改正によって，従来の科学者による直接選挙によるものから，学術研究団体（学協会）を基礎とする「推薦制」となった新しい会員選出制度の下に選ばれた「第13期日本学術会議」は，去る７月22日発足しました。そして，このたび開かれた第99回総会（10月23日～25日）において，第13期における活動の基本的立場と具体的な課題を明らかにした「第13期活動計画」を決定するとともに，実際の活動の舞台となる常置・特別委員会の設置を決定しました。その概要は，次のとおりです。

第13期日本学術会議は，「第13期活動計画」に盛られた課題の具体化に当っては，今後とも学協会と密接な連携を保ち，逐次お知らせしていく考えでいますので，広く多くの科学者の御理解を賜るようお願いいたします。

活動計画

戦後40年，我が国における科学・技術は目覚しい発展をとげ，経済の高度成長とともに，国民生活の向上に多大の貢献をしてきた。しかしながら，近年経済・社会環境の激しい変化を背景に，様々な問題が科学・技術のあり方のうえに生じている。その中には，科学と人間との係わり方の根源を問い直すようなものも含まれている。また，国際社会における我が国の地位の向上も加わって，科学の面における我が国の貢献への期待は国際的に強まっている。

日本学術会議は，創設以来，学術研究団体や科学者との連携のもとに，その目的・職務の遂行に努力し，我が国の学術研究体制の整備についての重要な勧告等を行い，研究所の設立などを含めて数々の業績をあげてきた。また，国際協力事業への参加をはじめとして世界の学界と提携しつつ，科学の進展に貢献してきた。しかしながら，創設後36年余を経た現在，科学を取り巻く情勢は，国際的にも国内的にも著しい状況の変化を生じた。学術研究団体を基礎とする新しい会員選出制度のもとに発足した第13期日本学術会議は，本会議の創設以来の基本的精神を堅持しながら，改むべきは改め，一層の成果をあげるべく努力するものである。

日本学術会議は，総合的な科学政策に関する重要事項を自主的に調査・審議し，その実現をはかる機関としての使命と役割を確認したうえで，会員の科学的知見を結集し，時代の要請に即応しつつ将来を見通した基本的理念を確立し，我が国における学術研究の一層の推進をはかるために，本会議の本来の目的を，次の視点から実現することが必要であると認識した。

人文・社会および自然科学を網羅した日本学術会議は，全学問的視野に立ち，学術研究団体を基盤とする科学者の代表機関であることを認識して，全科学者の参加と意見の集約を真摯にはからなければならない。さらに，本会議が集約した科学者の意見が政策に反映するよう，他の学術関係諸機関と協議のうえ，その役割分担を明確にしつつ，これらとの連携の強化をはかる必要がある。

また，学術研究団体を基盤とする日本学術会議は，このたび法制化された研究連絡委員会の重要性を認識しその活動を強化するとともに，学術研究団体の活動を助長し，研究基盤の強化をはかり，高度化する科学の発展に貢献する必要がある。

我が国の科学者を内外に代表する機関である日本学術会議は，国際社会における我が国の地位の向上と海外諸国の期待に応えて，学術の分野における国際協力を飛躍的に拡大する必要がある。

日本学術会議は，真理を探求するという理念に立脚し，科学の将来への展望をひらいていくため，科学の開かれたあり方と国際性を重視し，学問・思想の自由の尊重と研究の創意への十分な配慮のもとに，長期的かつ大所・高所の視点に立ち，創造性豊かな研究を発展させることが必要である。

日本学術会議は，以上の諸点を踏まえ，科学者の総意を代表して科学の精神を高揚し，21世紀に向けて望ましい科学のあり方を検討して，総合的な科学政策に指針を与えることにより，国民の期待に応えるとともに人類の福祉と平和に貢献することを期するものである。

1　重点目標

第13期活動計画の重点目標は，次のとおりとする。

(1)　人類の福祉・平和および自然との係わりにおける科学の振興

科学・技術の著しい発展は，人間生活を豊かにすると同時に，現代社会の高度の複雑化とあいまって，人間社会に新たな緊張をもたらし，人類の福祉・平和および自然環境を脅かすのではないかとの疑念を招いている。人類の福祉・平和および自然との係わりを十分に考慮しつつ，科学の総合的振興をはかることは，21世紀へ向けての極めて重要な課題である。これは，人文・社会および自然科学を網羅した本会議の特長を十分に発揮してこそ可能となるものである。科学の振興・発展の人間・社会への望ましい貢献および自然界への好ましくない影響の防止への具体的構想を樹立し，あわせてこれに対応する社会の体制整備に明確な指針を提示する。

なおまた，今日の社会的現実が提起している複雑な問題を解決するには，既成の個別的学問領域のみでは十分に対応し得ない。多くの学問領域が，その独自性を保ちつつ，共同の努力を行い，学問の内容・体系の変革にまで進むことによって，総合的な研究のあり方を追求することが必要である。人間性の尊重を基礎とした科学の発展のための条件整備，学際・複合領域および総合的学問研究の的確な方向づけ等を明らかにすることは必須条件である。

(2)　創造性豊かな基礎的研究の推進と諸科学の整合的発展

科学・技術の発展には，基礎的研究の推進が不可欠であることは言をまたない。我が国の科学の国際的地位の確立をめざし，その発展に向けた長期展望・指針・将来計画の策定についての基盤となる創造的な基礎的研究の推進に積極的に取り組む必要がある。

また，学術の領域は広範多岐であり，それぞれの領域ごとに方法論も異なり研究者の求めるものに大きな違いがあることに思いをいたし，それぞれの研究者の声を聞き，それぞれに適した育成策を講ずることにより諸科学の整合的発展をはかる必要がある。

まず，創造性の基礎となる個人の着想を重視し，革新的研究の強化等を積極的にはかる。一方においては，学術研究体制や社会・産業構造等に内在する創造性をはばむ負の要因の解消に向けて建設的提言を行うなど基礎的研究推進のための条件整備のあり方について，根本的検討を加える。

とりわけ，他の先進諸国に比較して我が国の学術情報・

資料の整備は著しく不備である。創造的な学術を振興するための基盤整備の一環として，絶えず我が国の学術情報・資料の全般にわたる状況を把握し，その蓄積・処理・利用の方策を審議，提言していくことが必要である。

(3) 学術研究の国際性の重視と国際的視野の確立

我が国の学術研究の国際交流・協力のあり方について，これまで本会議が築いてきた実績の評価を踏まえつつ根本的検討を加える。さらに，相互理解と互恵を基礎とした発展途上国に対する共同研究の推進，技術協力・技術移転・共同開発のあり方等を検討する。このようにして，先進国・発展途上国双方との国際交流・協力の基本姿勢およびその抜本的充実方策を明らかにする。

また，科学・技術の急速な発達に伴って重大な影響を受けつつある国際的な政治・経済・社会関係を諸科学の学際的研究によって分析し，そこで生じた諸問題についての解決の方策を究明する。

そのためには，学術研究の国際性を重視して，その国際交流の諸条件を整備し，全世界の科学者と協力して科学の望ましい発展に貢献するための努力を払っていくことが必要である。

2 課題

上述の重点目標にのっとり，現下の最重要課題に対応し，第13期中に，報告・提言等の形での成果を得べき課題を選定する。

これらの課題については，研究連絡委員会の協力を求め多数の学術研究団体と密接な連携を保ちつつ，広く英知を結集して総合的に審議し，適切な報告・提言等を行うものである。

なお，これらの課題の審議に当っては，必要に応じ中間報告又はその他の形で随時報告を行うものとする。

(1) 人類の福祉・平和および自然との係わりにおける科学の振興

この課題の重要性については，既に述べたとおりであるが，本課題については直接に関係する学問だけでなく広く諸科学が積極的に関与すべきであることを十分に考慮し，その方法と課題を検討する。当面，次のサブテーマ等についての問題点および今後の展望をはかろうとするものである。

＜サブテーマ＞

① 人類の福祉・平和および科学
② 科学者の倫理と社会的責任
③ 医療技術と人間の生命
④ 生命科学と生命工学
⑤ 高齢化社会
⑥ 生物資源・食糧と環境
⑦ 資源・エネルギーと文化・経済・環境
⑧ 高度情報社会
⑨ 平和研究機構

(2) 創造性豊かな基礎的研究の推進と諸科学の整合的発展

本課題は，日本学術会議が恒常的に取り組むべき課題であるので科学者の創造性を最大限に発揮するため，研究の自由を保障し，科学者の地位を高めるための努力をするとともに，創造性に富んだ研究者の養成，研究基盤の強化と研究の活性化，我が国の研究費のあり方，創造的研究醸成のために必要な条件整備の課題等について問題点を明らかにし，積極的提言等を行うものである。

＜サブテーマ＞

① 研究者の養成
② 研究基盤の強化と研究の活性化
③ 学術動向の総合的分析と長期研究計画の検討
④ 研究費のあり方

(3) 学術研究の国際性の重視と国際的視野の確立

我が国の国際的地位の向上に伴い，学術研究の面においても我が国に対する国際社会からの期待が増大してきている。世界の科学者と提携して人類の平和と福祉を促進するよう努力するとともに，特に発展途上国に対する学術的な協力の方策について検討を行うものである。

＜サブテーマ＞

① 学術研究の国際交流・協力のあり方
② 国際協力研究事業
③ 国際的な学術研究機構のあり方
④ 技術協力・技術移転・共同開発問題
⑤ 国際関係問題

3 第13期日本学術会議の具体的活動の重点

各委員会の審議を通じて，あるいは個別に日本学術会議の業務を円滑にするため，下記の具体的活動を重点的に行う。

(1) 国際交流・協力事業の拡充を行う。
(2) 研究連絡委員会の見直し，活動の活発化をはかる。
(3) 重点目標について，諸科学の協力のもとに整合性のとれた審議の促進をはかり，その成果を講演会・シンポジウムの開催等により広く一般に公表する。
(4) 重要にして緊急性のある勧告等を建設的に行う。
(5) 広報活動の充実をはかるなど学術研究団体との連携強化に努める。

4 委員会

常置・臨時（特別）の委員会は，現会員の意見を反映させ前期の申し送り事項をも踏まえて次の基本方針に基づいて設置する。

(1) 常置委員会設置の基本方針

目的・任務に即して日本学術会議として恒常的に調査・審議を進めていく必要がある事項について，個々の委員会の職務を明確にしたうえで設置する。

(2) 特別委員会設置の基本方針

重点目標，課題に即して，長期的展望を踏まえて今任期中に調査・審議の結果，勧告・要望・諮問答申として取りまとめることが望ましい事項について設置する。

常置委員会

第１常置委員会――研究連絡委員会活動活性化の方策及び日本学術会議の組織等に関すること。
第２常置委員会――学問・思想の自由並びに科学者の倫理と社会的責任及び地位の向上に関すること。
第３常置委員会――学術の動向の現状分析及び学術の発展の長期的動向に関すること。
第４常置委員会――創造的研究醸成のための学術体制に関すること及び学術関係諸機関との連携に関すること。
第５常置委員会――学術情報・資料に関すること。
第６常置委員会――国際学術交流・協力に関すること。

特別委員会

医療技術と人間の生命
生命科学と生命工学
高齢化社会
生物資源・食糧と環境
資源・エネルギーと文化・経済・環境
高度情報社会
国際的学術研究機構
国際協力事業

多数の学協会の御協力により，「日本学術会議だより」を掲載していただくことができ，ありがとうございます。

なお，御意見・お問い合わせ等がありましたら下記までお寄せください。

〒106　港区六本木７－22－34
日本学術会議広報委員会
（日本学術会議事務局庶務課）
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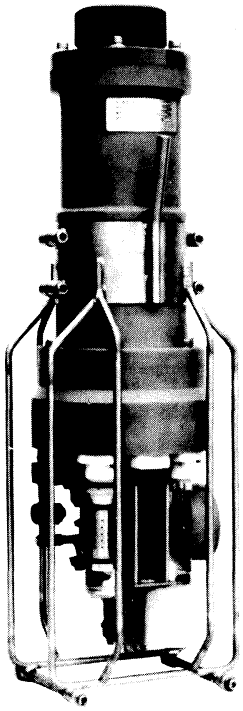

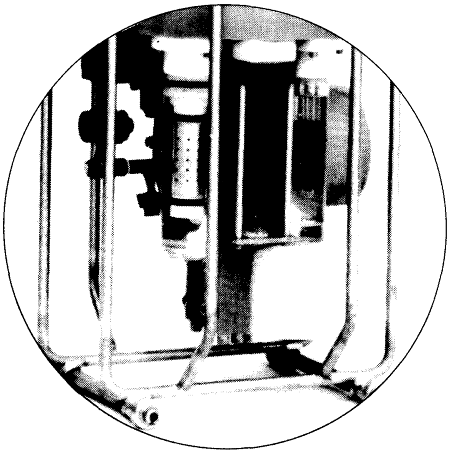

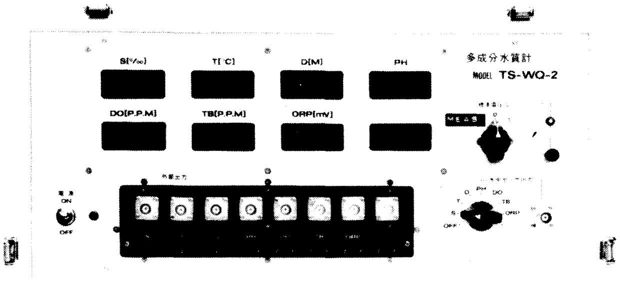

項目 要目	水温	塩分	深度	水素イオン濃度 (PH)	溶存酸素量 (DO)	濁度	酸化還元電位 (ORP)	(ブランク)
測定方式	白金抵抗体	電磁誘導	ストレン・ゲージ	複合ガラス電極	隔膜電極	透過光, 散乱光 比較式	白金電極	—
測定範囲	0～32℃	10～35‰	0～50m	4 ～ 12	0 ～ 20 ppm	0～20ppm オプション (0～100ppm) (0～500ppm)	−500 ～ +500mV	—
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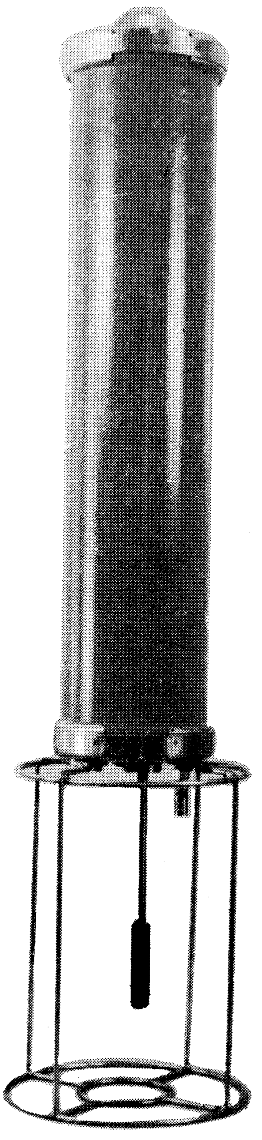

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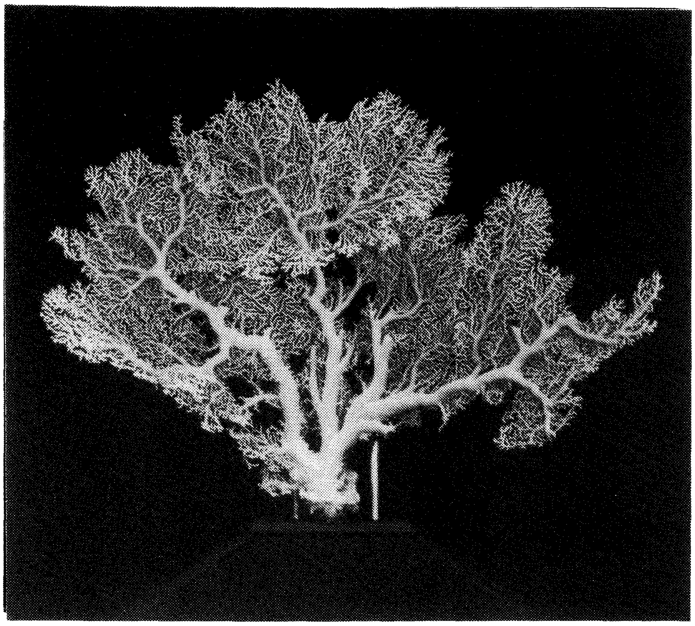

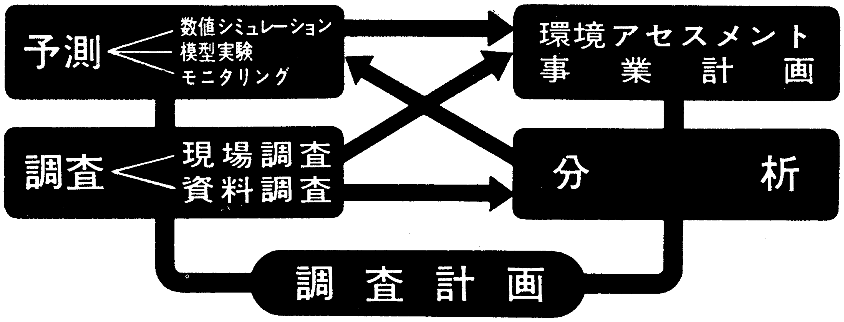
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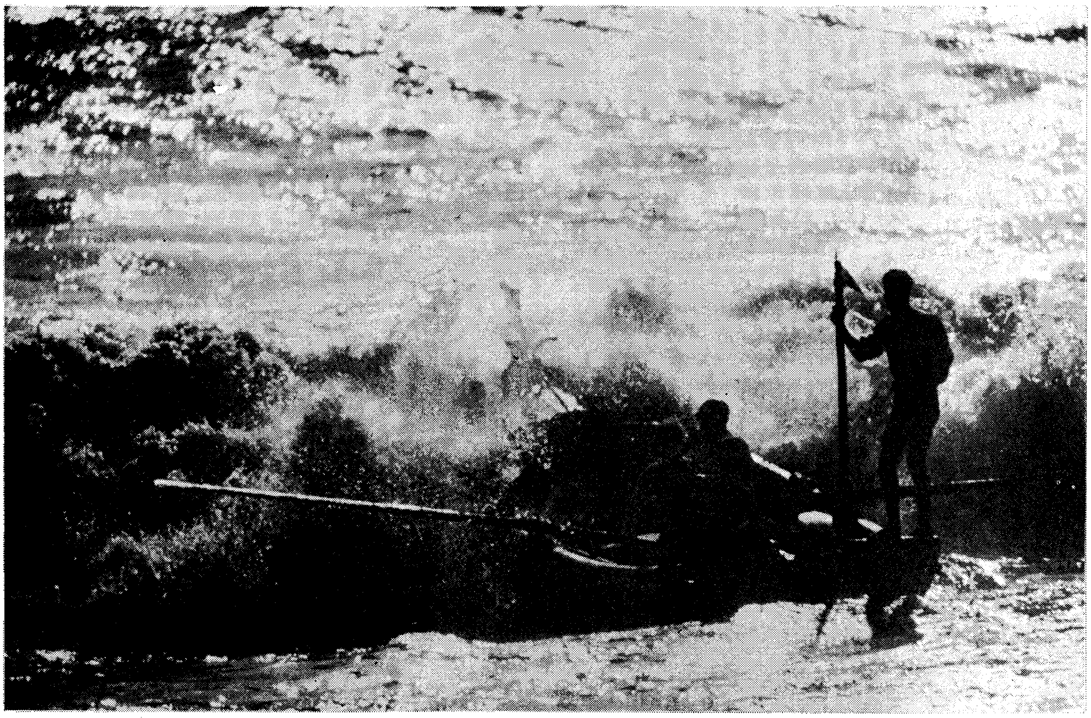

国際会議のお知らせ

第16回太平洋学術会議
(XVI PACIFIC SCIENCE CONGRESS)

1. 日時 1987年8月20～30日
2. 場所 韓国 ソウル
3. メインテーマ： 太平洋における科学・人間・資源の新次元 (New Dimensions of Science, Manpower and Resources in the Pacific)
4. シンポジウム

1) Development of Science and Technology for the Pacific Countries; 2) Population and Food for the Pacific Basin; 3) Perspectives on the Major Resources of the Pacific Region

5. 部会（何らかの形で，太平洋圏に関するすべての分野が含まれています）

A. Ecology, Conservation and Environmental Protection; B. Solid Earth Sciences; C. Geography; D. Museum and Similar Institutions; E. Marine Sciences; F. Coral Reefs; G. Botany; H. Forestry; I. Freshwater Sciences; J. Entomology; K. Social Science and Humanities; L. Economics; M. Public Health and Medical Sciences; N. Nutrition; O. Science Communication and Education

6. そのほか，会議前・中・後に，多くのツアーが企画されています。
7. 1989年の第6回中間会議は，南米チリのサンチアゴで開催予定，91年の第17回太平洋学術会議開催地は未定。
8. 参加資格： 制限なし．ただし，会議用語は英語．また，同伴者プログラムもあります。

First Circular（ソウル会議）申込み先：

Organizing Committee, XVI Pacific Science Congress, K. P. O. Box 1008, Seoul 110, Korea

国内連絡先： 丸茂隆三（日本学術会議太平洋学術研究連絡委員会）

賛助会員

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