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OF
THE WHALES RESEARCH INSTITUTE**

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CHANGE OF FORM IN THE SPERM WHALE ACCOMPANIED WITH GROWTH

MASAHARU NISHIWAKI, SEIJI OHSUMI
AND YOSHIHIKO MAEDA*

It is already explained by many authors that in the mammals, all the portions of the body do not extend at the same rate as the length of the body. From this fact the following reversed consideration may be taken. Age may therefore be detected from the data on body proportions by measuring the parts in which growth is apparent. On the other hand, if there are differences in the body proportions of two groups of whales, these differences may be due to hereditary factors. These two groups may be considered to belong to two different populations. An analysis of the data accumulated from investigations carried out at various whaling stations has been made as follows. The ageal changes are given in the figure on relationship between the body length and age computed from teeth lamination reading is attached at the end of this paper.

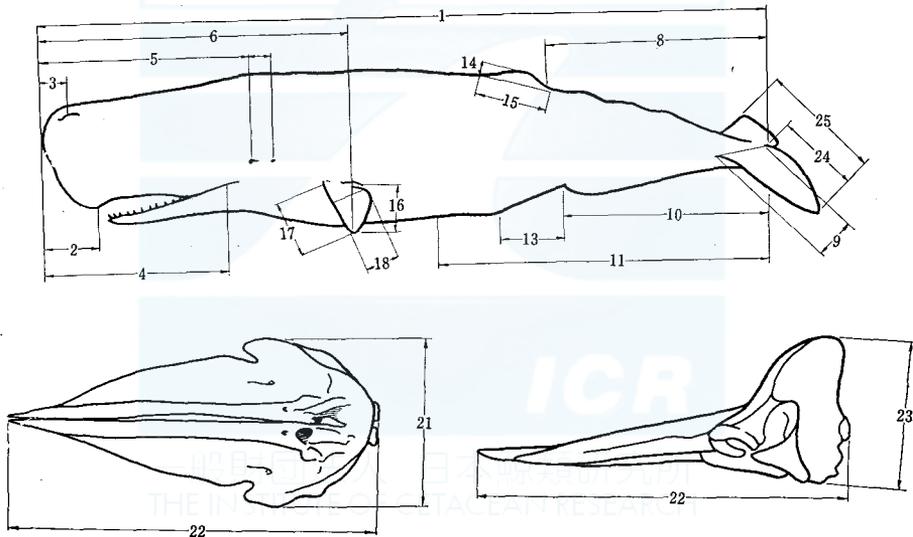


Fig. 1. Measurement points of body proportions of sperm whale.

MATERIALS AND BODY PARTS ON WHICH THE MEASUREMENT IS BASED

The measurements in this paper are based on the data on 227 individuals (199 males and 28 females) of the North Pacific sperm whale (including the data by

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Fujino, 1956), and have been compared with those obtained by Matthews (1938) on the Antarctic sperm whale.

The data are obtained by measuring from the tip of snout or from the notch of tailflukes along a straight line running parallel with the body axis to the objective point. The flippers and the tailflukes have been measured in a straight line at two points.

Fig. 1. outlines the above stated measuring method, and the measurements are numbered mainly in according with the Discovery Reports Vol. 1 (by Mackintosh and Wheeler, 1929) example.

SEXUAL DIFFERENCES IN BODY PROPORTIONS

The greatest sexual difference naturally is most apparent in the genital organs,

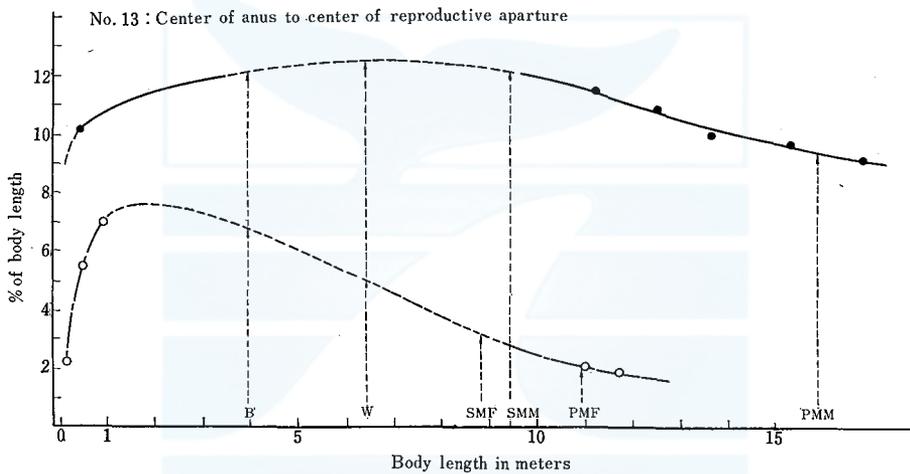


Fig. 2. Sexual difference in genitals.

EXPLANATION OF THE FOLLOWING FIGURES

The abscissa is the body length and the ordinate is the percentage of the body length. In order to avoid complication, data on all the individual points have been eliminated, and have been confined to the indication of the average trend developed through growth of body according to the body length in curves. On the figures attached (2 through 9 and 12), the broken lines indicate facts on which data is scarce and the cross marks indicate the data obtained by Matthews (1938). The letters B, W, SMF, SMM, PMF and PMM in the figures are represent the body length at birth, weaning, sexual maturity of female, sexual maturity of male, physical maturity of female and physical maturity of male, respectively.

that is, the values from the center of the anus to the center of the reproductive apertures are very different in the male and the female. A very interesting trend is noted in the changing of the body proportions according to the part especially in the female. During the period of its embryo, the distance from the anus to the opening of the vagina gradually grows, however, the proportion of the part becomes

gradually smaller from the later stage of its foetal life. In the male, the distance from the anus to the exposure hole of the penis keeps on gradually growing proportionally even after birth till it reaches sexual maturity, after which its growth declines. It is therefore considered that the above distance becomes stable even though the body length keeps on growing.

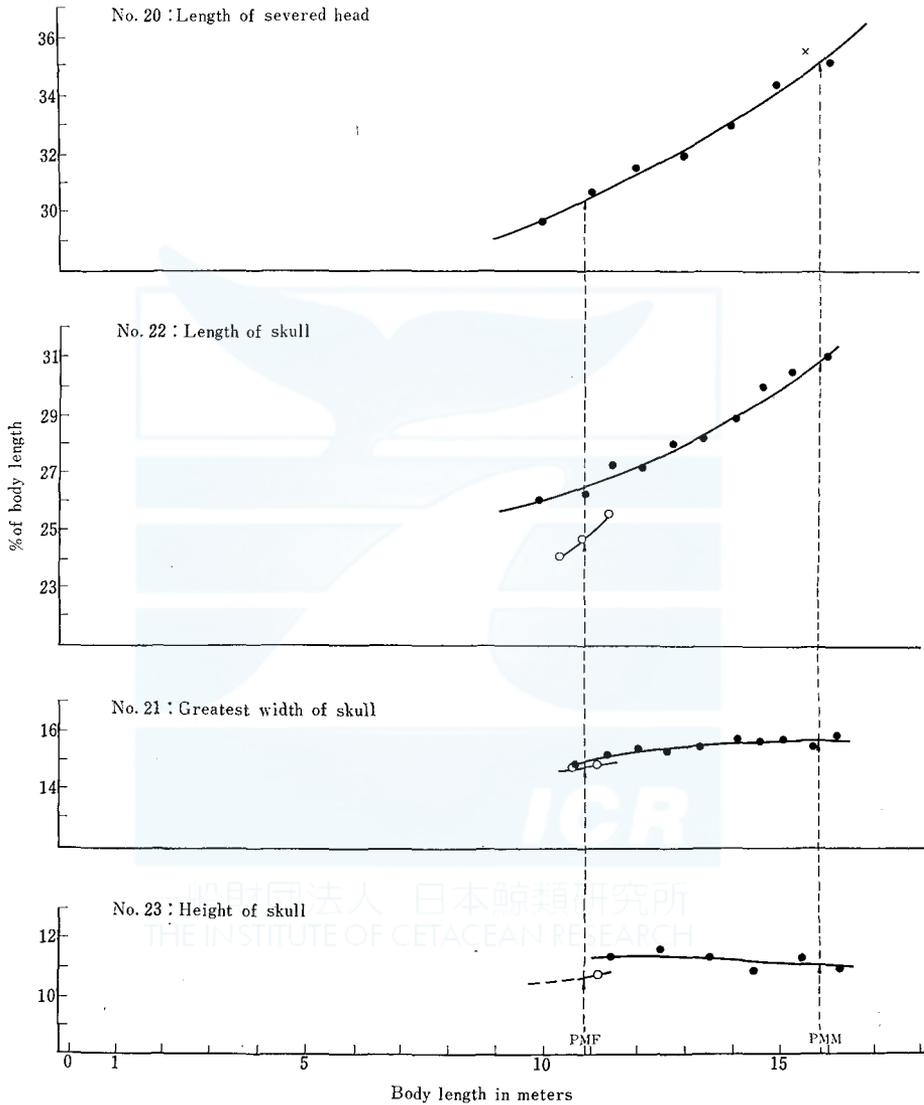


Fig. 3. Sexual differences in skull.

The difference between male and female can also be seen in the skull. The growth of the skull is more remarkable compared with the growth of the body in the male, especially in its length and height. The length of the severed head shows

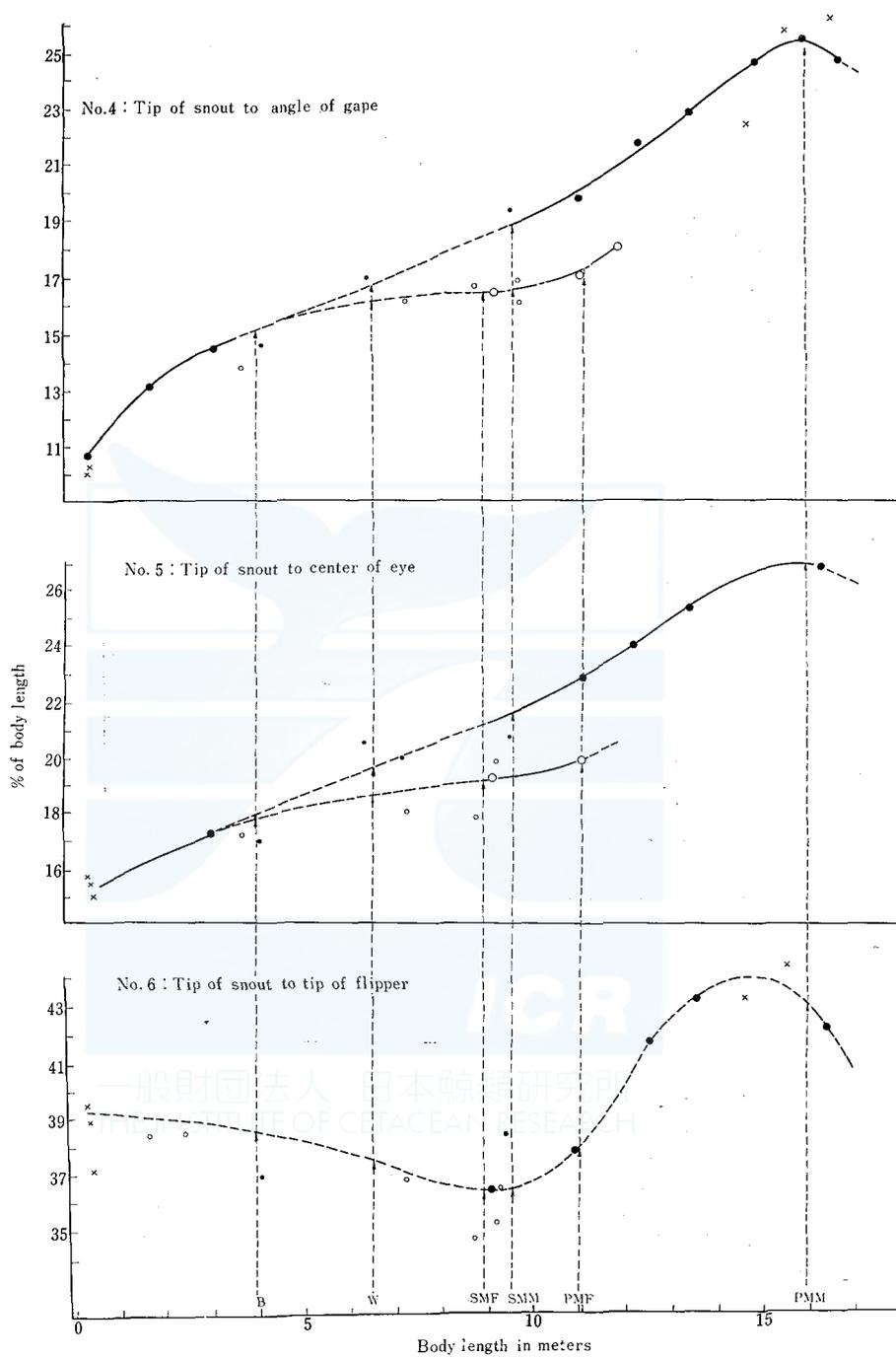


Fig. 4. Growth of forepart of body (1)

growth exceeding the length of the skull at the time of growth. In the male especially, the growth of the distance from the tip of snout to the angle of gape or to the center of eye is greater than that of the skull length, and this means that the soft tissue part in front of the skull grows more than the hard tissue. The consequent argument is that the melon in front of the skull, which not only plays a very important part in the fighting operation of the male to overcome the female but some undefined physical purpose enabling it to dive into the depths, grows at higher ratio than the skull, especially in the male.

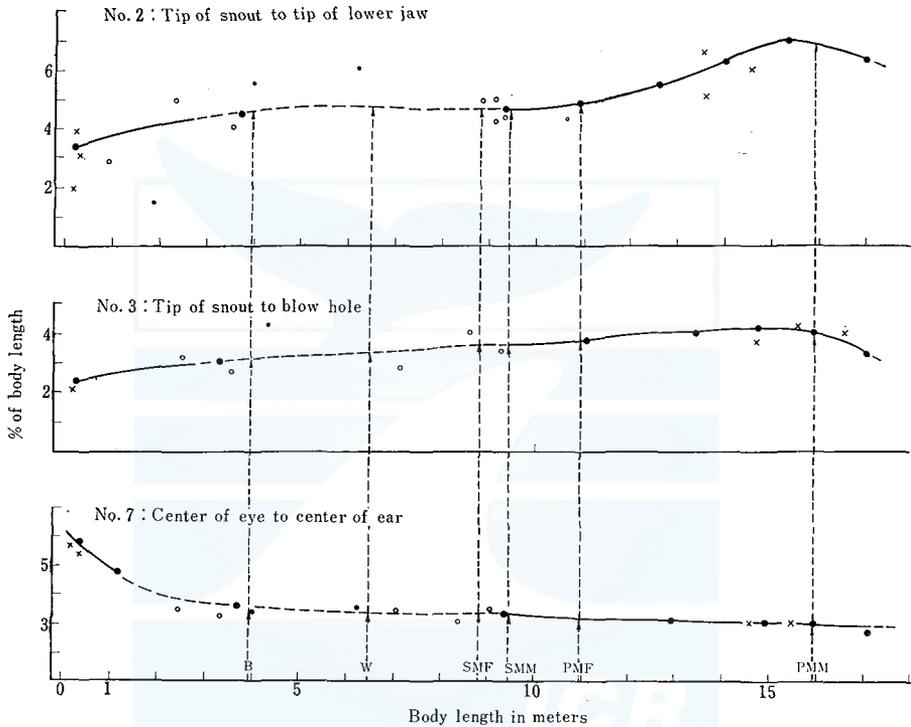


Fig. 5. Growth of forepart of body (2)

The sudden drop in the curves shown in most of the figures do not indicate that the distance between the parts of the body under discussion has become shorter but that this part of the curve is not too reliable due to the fact that data represented here is based on body length and not on age.

GROWTH OF FOREPART OF BODY

The features of the skull are explained in the following paragraph, therefore the other parts of the forepart of the body will be discussed here. As no sexual differences can be observed in these parts, the following changes according to growth are applicable to both male and female.

1. Tip of snout to tip of lower jaw.

Whether the measurements are taken with the lower jaw open or closed, technical errors are in suitable, therefore the actual measurement indicates the distance from the tip of snout to the fore end of the socket into which the lower jaw fits. This part of the head slowly but gradually changes with growth, and the growth of the part becomes proportionate with the growth of the body after sexual maturity is reached (mainly in the male).

2. Tip of snout to blow hole.

Measurements naturally change according to the stage of growth, but as it is well known, the blowhole of the sperm whale opens at a point very close to the tip of the snout, and changes in this particular case are of very little value. As also explained in the foregoing paragraphs, these changes are mainly due to characteristics ensuing from growth of the soft tissue in the forehead.

3. Tip of snout to tip of flipper.

These measurements were taken in accordance with the method employed by Mackintosh and Wheeler (1929). In spite of the fact that this part is considered very important in examining the middle of the body, measurements of this particular area contains considerable errors because the position of the tip of the flipper varies according to the freshness of the carcass as well as the position of the body itself, etc. These measurements therefore are not to reliable.

4. Center of eye to center of ear hole.

This is one of the parts which can be very easily measured. In the earlier stage of the foetal life, the distance between the two points is rather apart, but from the later stage of it this distance becomes very stable and proportionate with the growth of the body length.

GROWTH OF REARPART OF BODY

1. Notch of flukes to anus.

Compared with those of other land mammals, this part of the whale body is very large, and grows at the same ratio as the growth of the body length till it reaches at sexual maturity, however, after this stage is passed, the curve rapidly goes down. As it is well known, ossification advances from both ends of the vertebral column, till physical maturity is reached, but in the Cetacea, the ossification from the rear end advances at heigher speed than from the fore end, so that it may seem that ossification is completed entirely from the rear part of the body. The curve in the figure therefore shows that ossification which commences slightly after sexual maturity is reached advances smoothly.

2. Notch of flukes to posterior emargination of dorsal fin and to umbilicus.

The doral fin of the sperm whale is not conspicuous, moreover, it is accompa-

nied with dorsal humps, so taking measurements is made relatively difficult. The curve of this measurement, however, is comparatively smooth. The curve from the notch of flukes to umbilicus shows a fairly different from the two curves on the abovementioned. In the foetal stage the development of this part is very rapid,

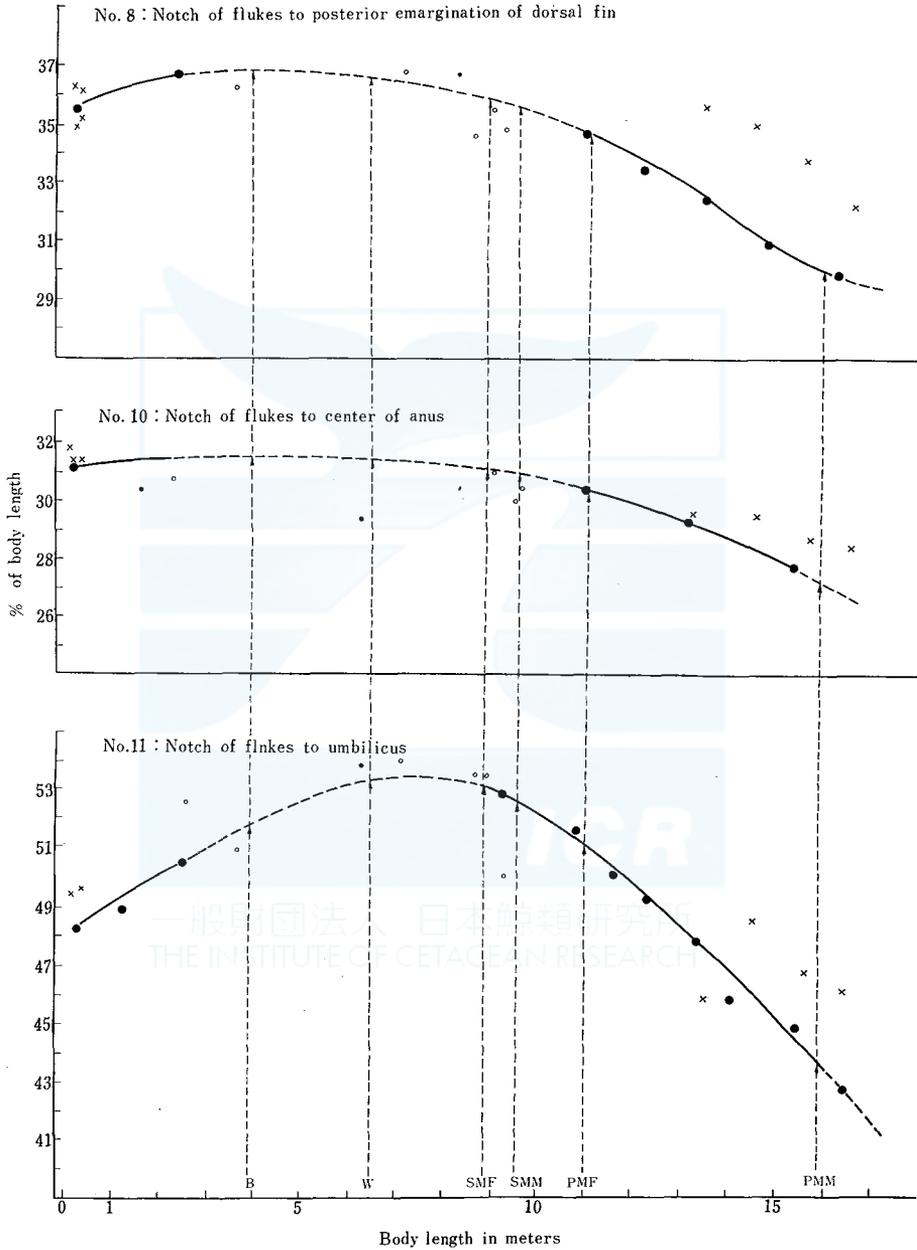


Fig. 6. Growth of rearpart of body.

and this growth continues till the stage slightly before sexual maturity. This is caused by the rapid development of the internal organs. This development stops at the stage of the sexual maturity, thereafter the curve goes down at the same

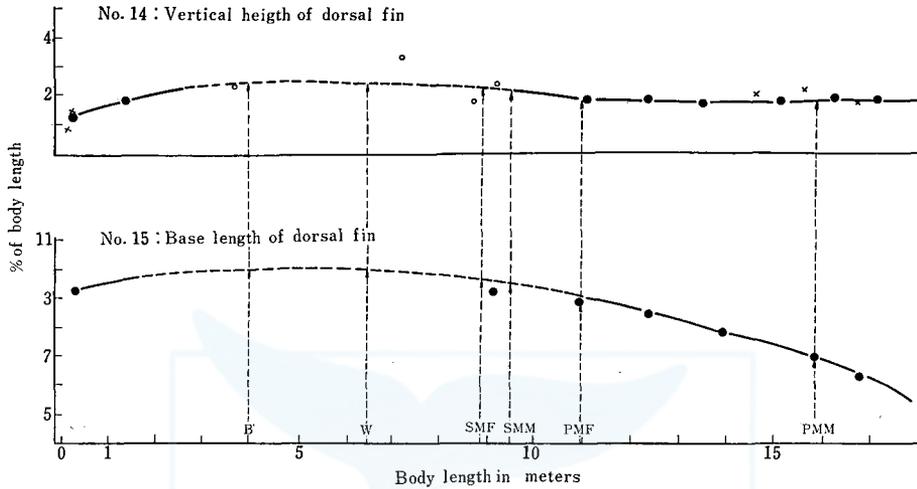


Fig. 7. Change of shape of dorsal fin.

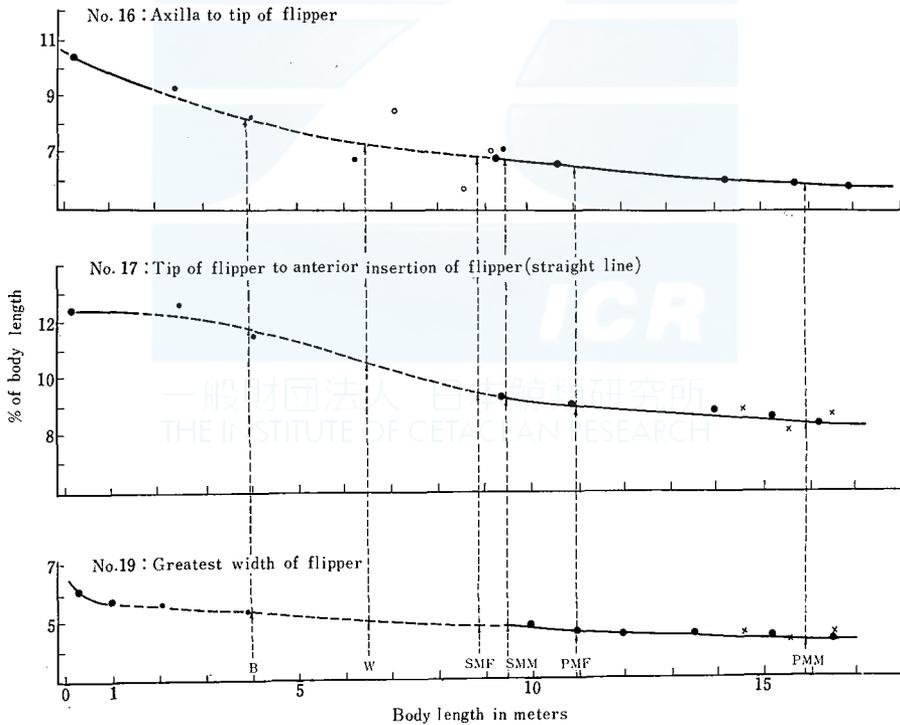


Fig. 8. Change of form of flipper.

rate as the abovementioned curves (from notch of flukes to anus as well as to anterior emargination of dorsal fin). It is understood that this declining tendency of the curves is due to the ossification of the vertebral column.

At the end of these curves, there are "X" marks which clearly disjoins the curves. These phenomena are only observed in the rear part of the body. It is considered from this fact that the tail part of the North Pacific sperm whale is shorter than that of the Antarctic sperm whale. Ivanova (1955) already described this fact.

3. Change of shape of dorsal fin.

The measurements of the dorsal fin had been shown in the figures, although the dorsal fin of sperm whale is very difficult to measure, and the curves are well proportionate with the growth of the body length. The basal length of the dorsal fin is naturally affected and regulated by the ossification of the vertebrae that is situated just under the dorsal fin.

4. Change of form of flipper.

With regard to the shape of the flipper, the distance from the tip to the anterior end of lower border, from the tip to the axilla and the greatest width were measured. The proportions of these lengths follow a fitted ratio in the earlier stage of the foetal life, but this ratio gradually drops in the later stage of it. This trend continues in the later stage of the foetal life till the animal reaches to the high age. From this fact it is considered that the flippers have never played an important role in the swimming life of the sperm whale. Furthermore the paleontological consideration in the long life history of the sperm whale, the foreleg was used in their land life and became atrophied gradually in the swimming life of the sea. The shape of the flipper became smaller and smaller, and the function of the foreleg also changed. This is a very interesting fact in the sperm whale, but is not common in all the species of whales. Though it must be recognized that there is some great difference between the change of the foreleg and the atrophy of the hind leg which does not appear on the outer surface of the body, this is considered as a new phylogenetical opinion.

5. Development of tail flukes.

The measurement of the tail flukes have been taken from the distance between the notch of flukes to the tip, the distance from tip to tip and the length of flukes at insertion.

The tail flukes are first formed at the stage of 3—5 cm body length. The edges of the early flukes rapidly develop to the natural shape. This however is folded in the ventral side of the body until the time of parturition. So it is fairly difficult to obtain accurate results when measuring from tip to tip of flukes in the foetal stage.

In the figure, the ratio of the length of the tail flukes at the insertion is larger in the earlier stage of the foetal life, and this is due to the sudden development.

When the later stage of the foetal life is reached the curve gradually becomes more stable, and the spread of the tail flukes gradually keeps on developing till sexual maturity is reached. This is the stage when the ratio of the spread is largest in the proportion, twice the distance from the notch of flukes to the tip. The ratio of the length of the side of the flukes remains stable while that of the spread becomes shorter, this means that the position of the tip of flukes has moved slightly forward. The figure 11 illustrates tail flukes in their natural shape with equal distance from tip to notch.

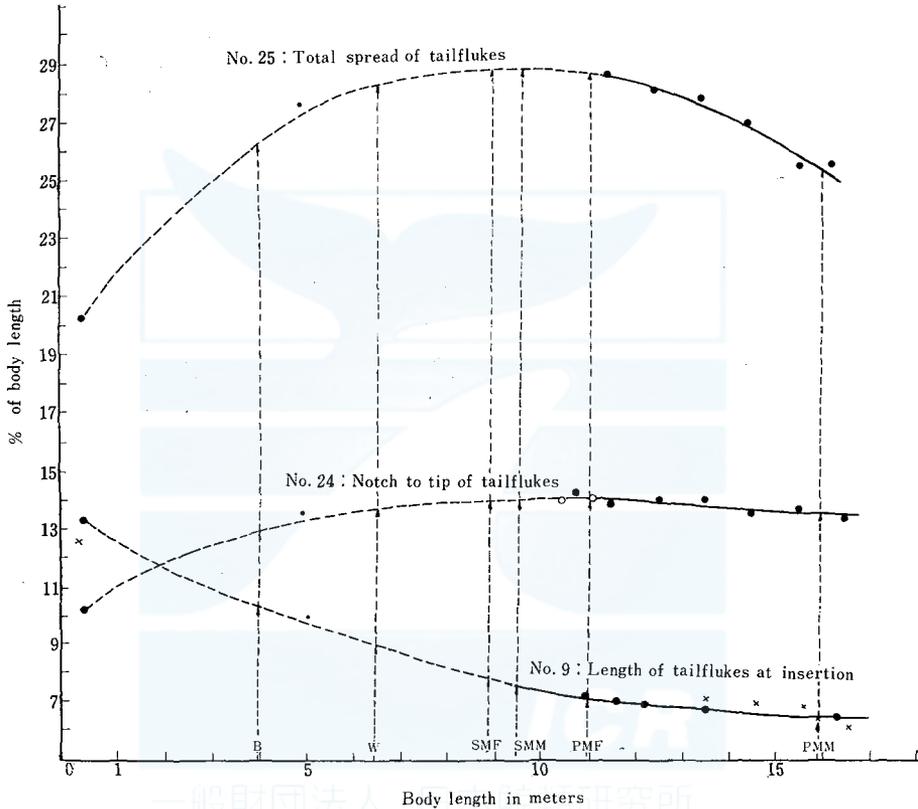


Fig. 9. Development of tail flukes.

RELATION BETWEEN BODY LENGTH AND AGE

It is natural that the body length increases according to age, and the body length of an individual whale is largest at the stage of attainment of physical maturity through sexual maturity. It however is considered recently that the body length decreases very slowly in the older stage. This is shown in Fig. 12 as the relationship between body length and lamination number in the teeth which is the most reliable basis for age determination. This is a general rule of physiological phenomena in the mammals, and can be found in other kinds of mammals including

bented tail part is stretched

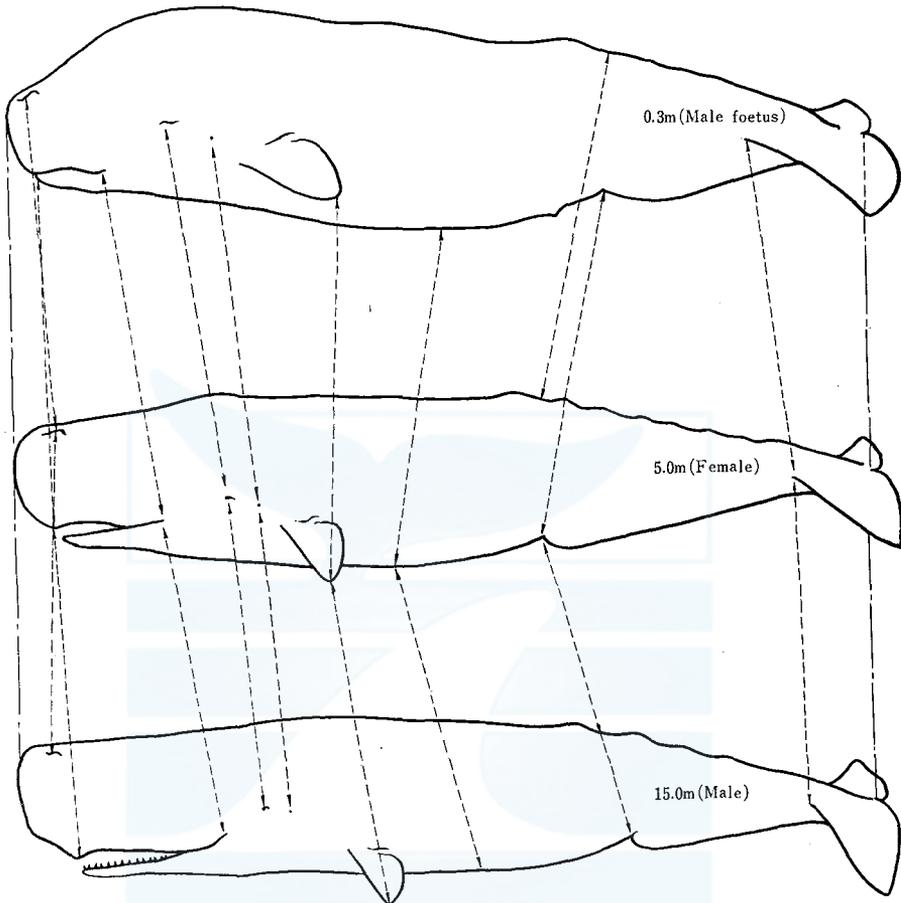


Fig. 10. Pictorial representation on change of body form in sperm whale drawn equal in length.

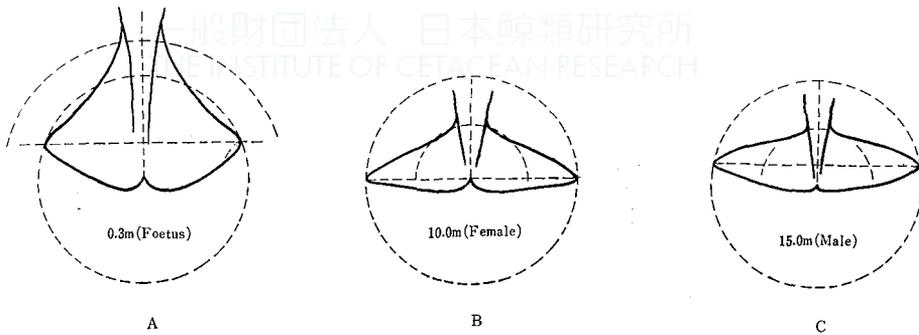


Fig. 11. Pictorial representation on change of tail flukes in sperm whale drawn equal in length.

mankind, which is caused through the contraction of the intervals between the vertebrae, and the bowing of the vertebral column due to age. The head or the skull which occupies a large proportion of the body length of the sperm whale,

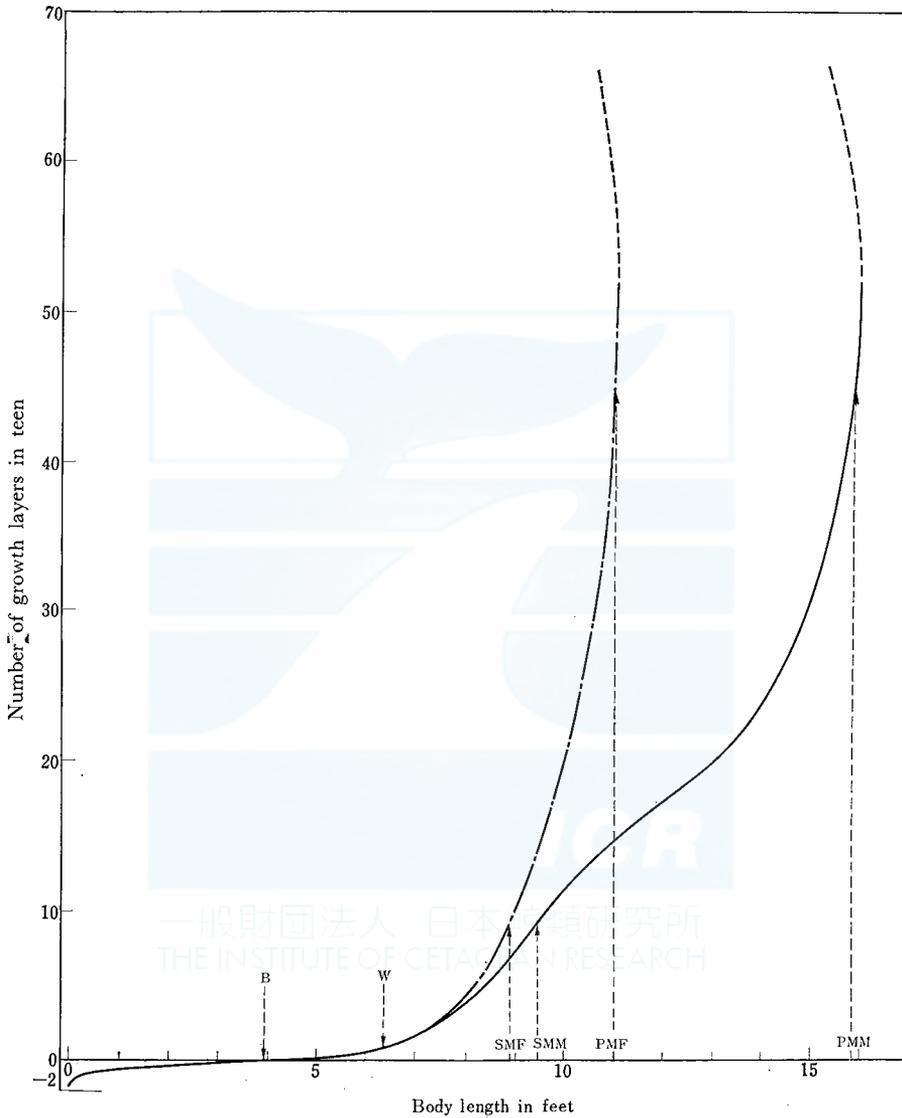


Fig. 12. Growth of body length according to age (represented by number of growth layers in teeth).

however, does not decrease at the same rate. The foregoing facts should not be forgotten when reading the abovementioned figures.

SUMMARY

The above mentioned discussions are summarized as follows.

1. The growth of the head is very remarkable, and it seems that it continues after physical maturity is reached.
2. The sexual differences are naturally observed in the reproductive apertures, but it is interesting to note that it can also be observed in the development of the head part.
3. The phylogenetical data on the development of the shape of the flipper which is large in proportion in the earlier stage of the foetal life has been taken.
4. Some differences in the rear part of the body can be observed in the sperm whale from the North Pacific and the Antarctic, as for instance those from the North Pacific have shorter tail parts. Differences, if any occurring in sperm whales from the same waters, may be considered as technical errors in measurement, therefore such differences are not suitable as data for separating them into groups.
5. The characteristics according to age were observed from body proportions, and they are comparative oldness and not showing the actual age. For more accurate data on age, it is necessary to combine the foregoing with other findings.

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EXPLANATION OF THE PLATES

(The figure number in the plate is given from upper to bottom.)

PLATE I

- Fig. 1. A sperm whale embryo of 3.5 cm in body length, collected from a female caught in the South East off Hokkaido, Japan.
- Fig. 2. A sperm whale embryo of 4.0 cm in body length, collected from a female caught in the South East off Hokkaido, Japan.
- Fig. 3. A sperm whale embryo of 9.1 cm in body length, collected from a female caught in the South East off Hokkaido, Japan.

PLATE II

- Fig. 1. A sperm whale embryo of 30.5 cm in body length, collected from a female caught in the East off Sanriku, Japan.
- Fig. 2. A sperm whale embryo of 19.5 cm in body length, collected from a female caught in the East off Sanriku, Japan.
- Fig. 3. A sperm whale embryo of 26.5 cm in body length, collected from a female caught in the East off Sanriku, Japan.

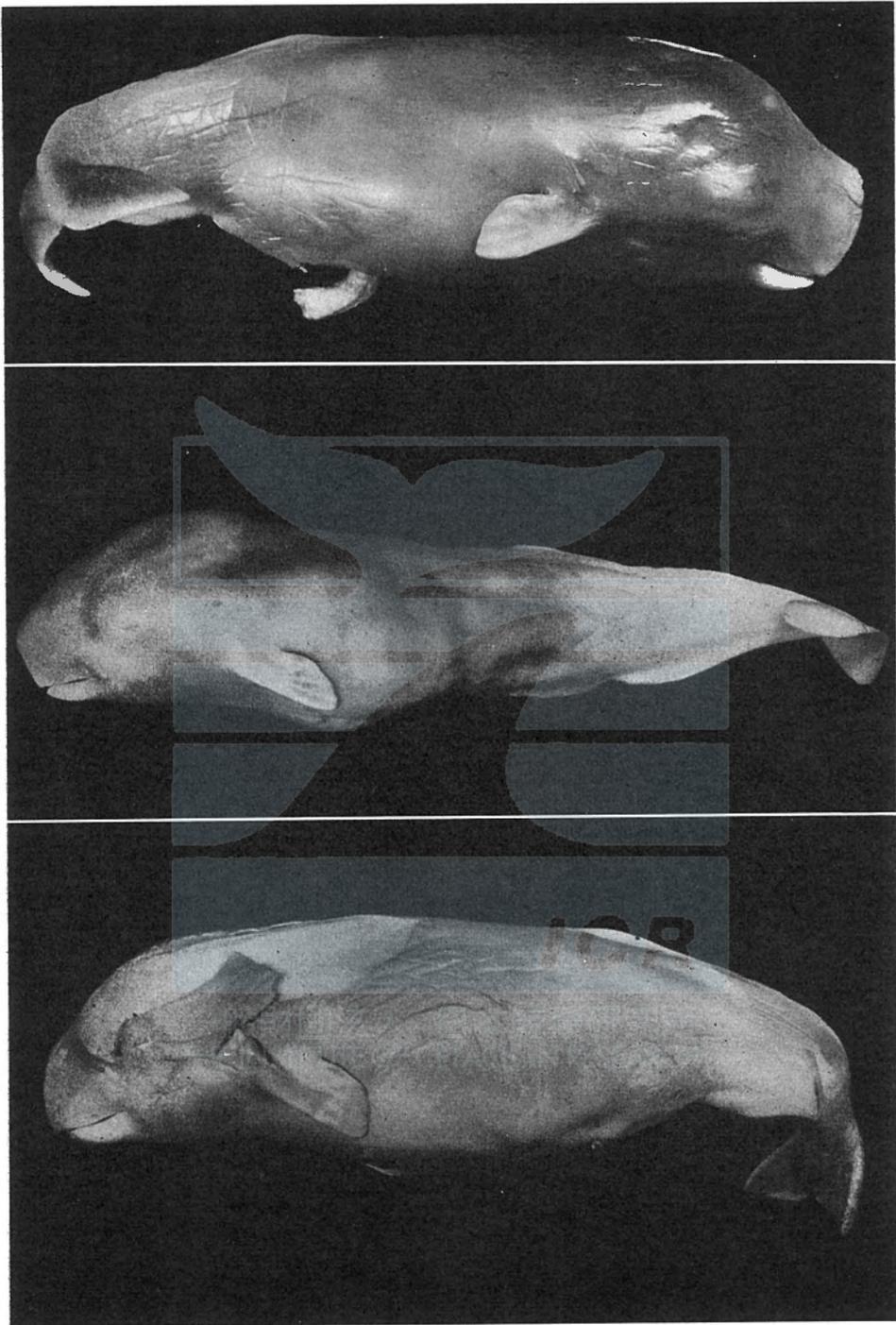
PLATE III

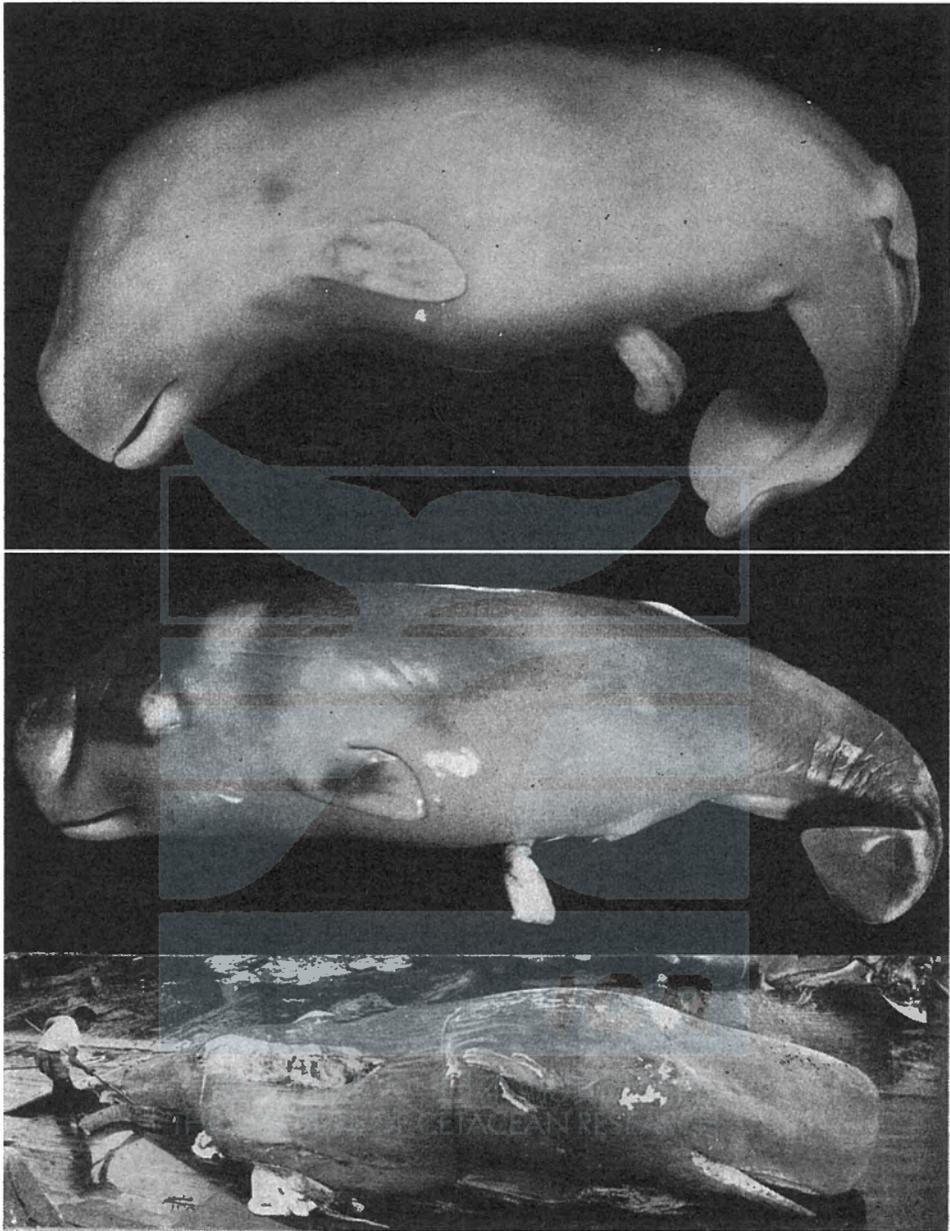
- Fig. 1. A sperm whale embryo of 29.5 cm in body length, collected from a female caught in the South East off Hokkaido, Japan.
- Fig. 2. A sperm whale embryo of 41.0 cm in body length, collected from a female caught in the East off Sanriku, Japan.
- Fig. 3. A young female sperm whale of about 7.5 m in body length, caught in the East off Sanriku, Japan.



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ACCUMULATION RATE OF DENTINAL GROWTH LAYERS IN THE MAXILLARY TOOTH OF THE SPERM WHALE*

SEIJI OHSUMI, TOSHIO KASUYA AND
MASAHARU NISHIWAKI

INTRODUCTION

The growth layers in the dentine of tooth as an age characteristic for the delphinids was first described by Nishiwaki and Yagi (1953). Yablokov (1958) reported the layered growth in the section of teeth of sperm whale. Then, Nishiwaki, Hibiya and Ohsumi (1958) reported that the buried teeth in the maxillary gum are most useful for age determination of the sperm whale. Nishiwaki, Ohsumi and Kasuya (1961) re-examined Laws's report (1960) on the lamination in the mandibular bone of the sperm whale and showed that the accumulation rate of the lamination is equal to that of the growth layers in the dentine of maxillary tooth.

The maxillary teeth have been collected in the coastal waters to Japan and northern part of the North Pacific on many sperm whales, and they have been used to get the age distribution of the sperm whales caught in these waters. Nevertheless, it is necessary to make sure of the interpretation of the dentine growth (accumulation rate of growth layers) for the calculation of mortality rate or fluctuation of the population size from the age distribution of the sperm whale.

Relating with the subject, Nishiwaki and Yagi (1953) tried to make a time mark in the teeth of the blue-white dolphin (*Stenella caeruleo-alba*) by the *intra vitum* staining method consisting of the injection of the lead acetate into the dorsal muscle, but they could not get a expected result, obstructed by the difficulty of the breeding of the dolphin. Sergeant (1959) studied the teeth of the bottlenosed dolphin (*Tursiops truncatus*) which was born at an aquarium and died there, and he got the result that the growth layers are accumulated one every year in the dentine of the dolphin. Recently, Sergeant (1962) reported that the same accumulation rate could be used in the case of the pilot whale (*Globicephala melaena*) studying the stage of dentine deposition.

The teeth of the sperm whale differ from those of delphinid whales in their structure. For example, the pulp cavity is closed in the teeth of old delphinid whales, whereas in the sperm whale it is not closed all over the life. Then, there are some questions in application of the accumulation rate of the growth layer of delphinid whales to the sperm whale. And it is needed to study the accumulation rate of growth layers in the teeth of the sperm whale.

Following methods may be used to investigate on the subject ;

1. Breeding experiment which was used by Sergeant (1959).

* Dedicated to Professor T. Ogawa for his sixtieth birthday

2. Time marking in the teeth of living animal which was used by Nishiwaki and Yagi (1953).
3. Investigation of teeth from the recaptured whales.
4. Study of the seasonal change of the stage of growth layers in the dentine.
5. Comparison of dentine deposition stage with the physiological condition of the whale.
6. Comparison with other age characters and the ecological knowledges.
7. Population dynamical examination on the age distribution based on the number of growth layers.

Among these methods, the first and the second can not be used for the sperm whale because of the difficulty of the breeding at present.

We studied, in this report, chiefly on the seasonal change of the width of growth layer, and examined the result by the teeth of recaptured whales and by the age distribution based on number of growth layers. After then we have got a conclusion on the accumulation rate of the growth layers in the dentine of the sperm whale.

We are very much indebted to the staffs of our Institute, namely Dr. Kazuo Fujino and Messrs. Takahisa Nemoto, Tadayoshi Ichihara and Keiji Nasu, who helped us in collection of tooth samples and the biological investigations of sperm whales. Many thanks are also given to assistant professor Dr. Takashi Hibiya of the Faculty of Agriculture, Tokyo University and to Dr. Fukuzo Nagasaki of the Tokai Regional Fisheries Research Laboratory who kindly discussed on our draft.

MATERIAL AND METHOD

Sperm whales possess about 13 pairs of teeth in their upper jaw. There are some whales whose maxillary teeth are exposed out of the gum in various numbers. In practice, one tooth was collected from each whales, and the tooth was demanded to have been burried in the gum and to have been placed at the nearly central part of the teeth raw.

The collected teeth were boiled for about half an hour, removed from the gum, then they were dried. In the laboratory the teeth were cut longitudinally with a saw and a grinder into a plane which contains the long axis of tooth, and then the surface of the longitudinal halves was polished with a whetstone. The polished surface, which we observe, is not necessarily a flat plane, but need along the longitudinal axis. After the number of the dark band of the growth layers were counted under the binocular dissecting microscope ($\times 8$), the feature of growth layers were projected on the screen by means of reflecting surface projector ($\times 20$) and their width were measured. As shown in Fig. 1 the dark band of the growth layers were measured at two points on the dentine, namely the width from the margin of the pulp cavity to the starting margin of the latest dark band and that from the latest dark band to the dark band formed in the previous season. And on the ten specimens, we measured the width of all growth layers of the teeth. Some teeth were ground to translucency for microscopic sections and stained with

carbol-fuchsin or hematoxylin and their fine structure was observed.

The teeth of 448 sperm whales were used for the study of seasonal accumulation of growth layers in the dentine, and they were collected between the first decade of May and that of November mainly in 1961 and partly in 1960 in the coastal waters to Japan and the northern part of the North Pacific.

The age distribution of the 1226 female sperm whales caught in the coastal waters to Japan in 1960 and 1961 were calculated based on the number of the growth layers in the teeth. We judged the sexual maturity and pregnancy of the female sperm whales from the ovaries, mammary glands and *uterine cornu* which were examined by the staffs of The Whales Research Institute, and we calculated the ratios of pregnant whales to sexually mature females. The pregnancy was decided by the existance of *corpus luteum* in the ovary, because the whales are opened their belly before towed to the land station and fetus is often lost.

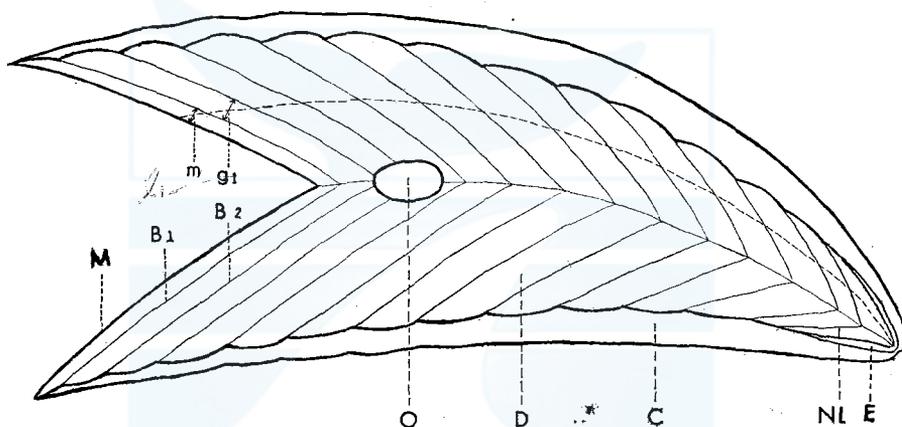


Fig. 1. Semi-diagram of longitudinal section of a maxillary tooth of the sperm whale. B₁, B₂: Dark bands in the dentine, C: Cement, D: Dentine, E: Enamel, O: Osteodentine, M: Margin (pre-dentine), l₁: Lastly formed growth layer, m: Forming growth layer.

We used also the teeth of the eight marked whales which were marked by Japan in the North Pacific and recaptured until 1962.

STRUCTURE OF THE MAXILLARY TOOTH

Sperm whale tooth is composed of dentine, enamel and cement, and enamel is formed in the fetal stage and later it is covered with cement. Laminations are formed comparatively regularly in both dentine and cement, which are observed macroscopically on the ground surface of the tooth with reflex light as a mutually arranged dark and light bands.

When the laminations are observed on the ground transparent section, as the dark band has higher translucency than light band, it changes into clear band, and the light band appears opaque band by the defused reflection. The photographs

of the maxillary teeth of two males and two females are shown in Plates I and II. They are photographed with transparent light from the ground sections. The clear band shows anisotropic character under the polarized light, which is a evidence of the existance of developed crystalline structure. And the opaque band is stained better than the clear band with carbol-fuchsin. So we concluded that the clear band has well developed crystalline structure and is probably better calcified. The width of clear band is smaller than that of opaque band. We used a clear band as the base line of a growth layer and defined one growth cycle as the layer between the beginning of a clear band and the beginning of the next clear band.

TABLE 1. BIOLOGICAL DATA OF THE SPERM WHALES USED TO MEASURE THE EACH WIDTHS OF THE GROWTH LAYERS ACCORDING TO FIG. 2 a, b

Sample No.	Sex	Body length (feet)	Weight of testes, or no. of corpora in ovaries	No. of growth layers	Mean width of growth layer (mm)	Range of width of growth layer (mm)
1	Male	52	8.0, 6.5 kg	55	0.81	0.40-1.30
2	Male	50	7.5, 7.0 kg	38	0.83	0.55-1.25
3	Male	47	3.3, 3.5 kg	30	1.03	0.45-1.30
4	Male	35	0.5, 0.8 kg	18	0.94	0.35-1.20
5	Female	36	0-8, 0-7	51	1.08	0.30-1.30
6	Female	36	lost.	43	0.98	0.35-1.20
7	Female	44	0-6, 0-9	40	0.75	0.30-1.20
8	Female	34	1-4, 0-6	29	0.94	0.30-1.15
9	Female	34	0-1, 0-5	25	0.89	0.55-1.60
10	Female	28	0-0, 0-0	6	0.79	0.60-0.92

Usually one clear band is composed of two parallel and closely situated clear bands, and one or two clear lines are sometimes observed in a opaque band but they are usually very narrow and indistinct. The neonatal line of the sperm whale tooth was already reported by Nishiwaki, Hibiya and Ohsumi (1958). When observed with reflex light, the dentine formed in the fetul stage is one light band and neonatal line is the first dark band in the tooth of which tip is not worn out. Though the width of the growth layer varies in sex and age, the structural difference is not observed. Osteodentine is often found in the various part of dentine, but it is not mentioned here. The microscopical observation of the dentine of the sperm whales reveals, as is shown in Plates V and VI, the many dentinal tubules running parallely through the dentine and the space among these tubules is filled with matrix. The branch of dentinal tubules seems not to develop well in sperm whale maxillary tooth. Though the dentinal tubules are observed well in the opaque band namely light band, some of them are obscure in the clear band (dark band) and appears as if they are discontinued. But there are some tubules which are observed running through the clear line.

The matrix seems to occupy a considerably more space in clear band than opaque band. The well developed interglobular spaces are observed in the dentine formed soon after the birth and some are formed in the fetul stage.

CHANGE OF THE WIDTH OF GROWTH LAYERS ACCOMPANIED WITH AGE, AND ITS FLUCTUATION IN EACH YEARS

Each width of the every growth layers were measured on the 4 males and 6 females. As is shown in Fig. 2 a and b, the width of the growth layers shows a very wide individual and age variation. The mean width of 15 growth layers from 2nd layer to 16th layer fall in the range between 0.75 mm and 1.08 mm (Table 1). In some teeth the fluctuation of the width of the layers is very large and does not show a constant value or tendency to change. Though the width has a tendency to decrease gradually as referred later, there is such a specimen as No. 6 in which width of layers vary from 0.30 mm to 1.30 mm.

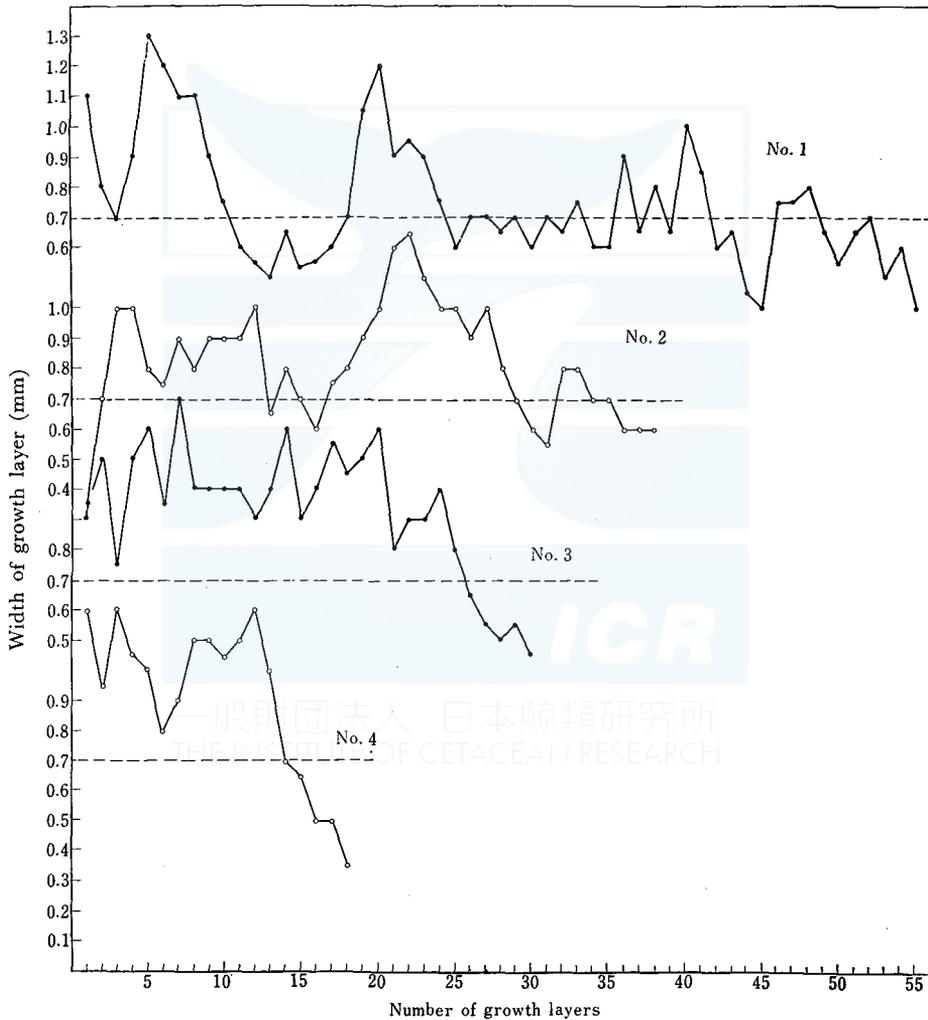


Fig. 2 a Change of width of growth layer with the increase of number of growth layers in the dentine of maxillary teeth. Male sperm whales.

The mean width is lesser in female than in male. It is 0.85 mm in males and 0.75 mm in females. The mean width of each number of growth layers are shown in Fig. 3. Generally speaking, the width of the growth layers shows the tendency to decrease as the age goes by. In the males it shows the maximum width of 1.08 mm at the 5th layer and at the age of 40th layer it decrease to 0.7 mm. In the female shows the maximum width 1.01 mm at 3rd layer and 0.5-0.6 mm at 40th layer.

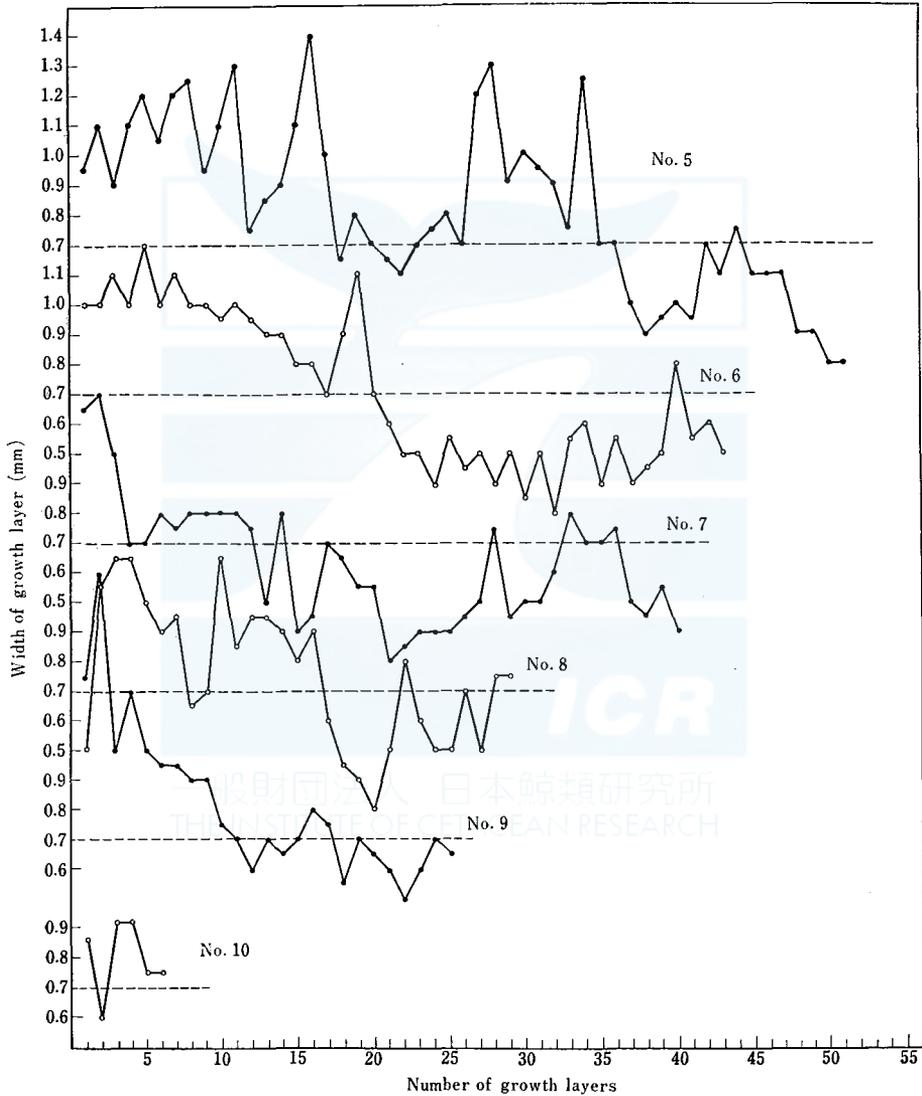


Fig. 2 b Change of width of growth layer with the increasement of number of growth layers in the dentine of maxillary teeth. Female sperm whales.

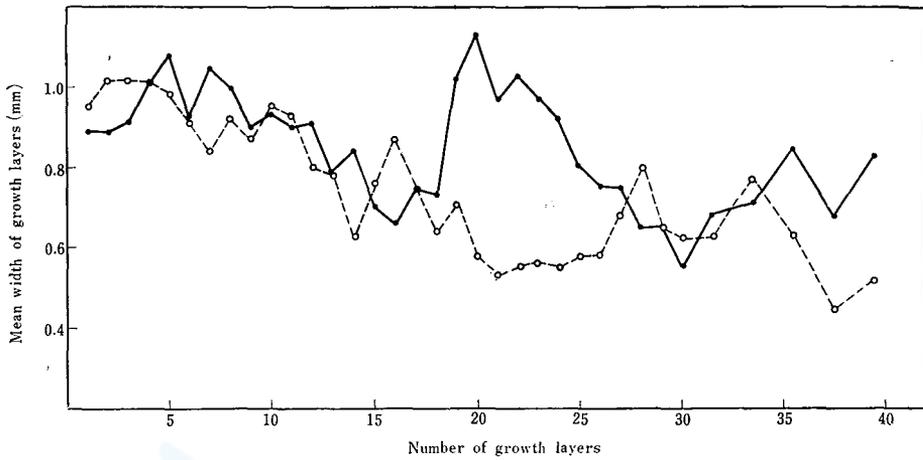


Fig. 3. Change of mean width of growth layers with the increasement of number of growth layers in the dentine. Open circle and broken line: Females, Closed circle and solid line: Males.

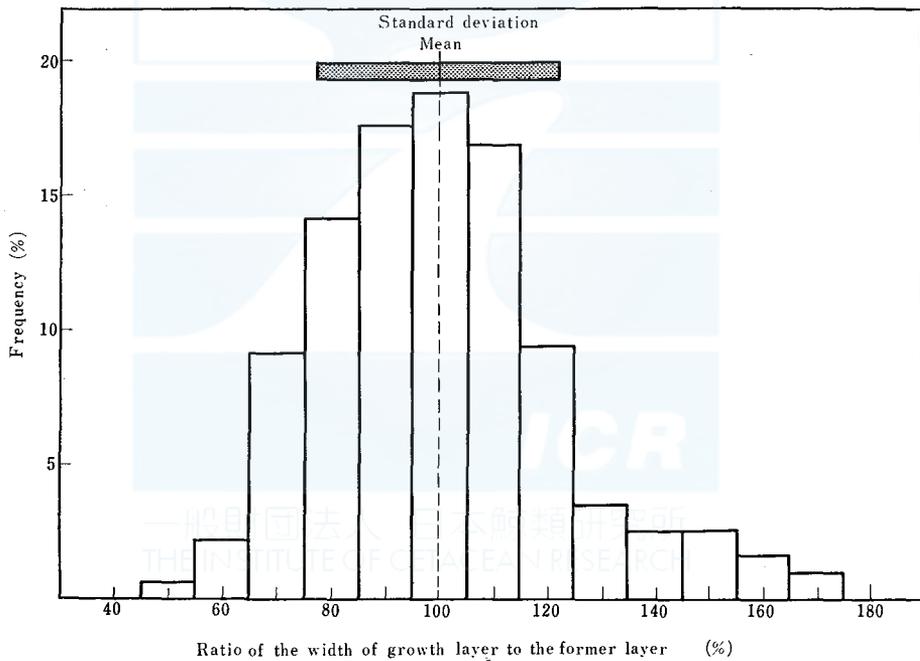


Fig. 4. Frequency distribution of the ratio of width of a growth layer to the former layer, and standard deviation of the ratio.

Though in the tooth of the male, the width of the layers are rather broad, between 19th and 24th layer which differs from that of females, we can not conclude whether it is the general tendency of the male teeth or not, for only three males are measured its all layers in the teeth. In any case, there are fluctuations in the

width of each growth layers and it will show that the accumulation of the growth layers in the teeth vary from year to year and by individuals.

Table 1 will show that the shrinkage of the dentine of old layers does not occur. For example the mean width of a young sample No. 10 of which tooth contains 6 growth layers is 0.79 mm and that of an old sample No. 5 of which tooth contains 51 layers is 1.08 mm. And we calculated the ratio of the width of one growth layer to the width of the former layer, which frequency distribution is shown in Fig. 4. These ratios distribute in the range from 46% to 173% and have a large deviation. The distribution of these ratios nearly fit to the normal distribution, though it has some bias to the side of larger value. Their mean value is 99.9%, which can be thought to be nearly 100%. This shows that as the average the width of a growth layer is nearly equal to that of the former layer. The standard variation is 22.5%.

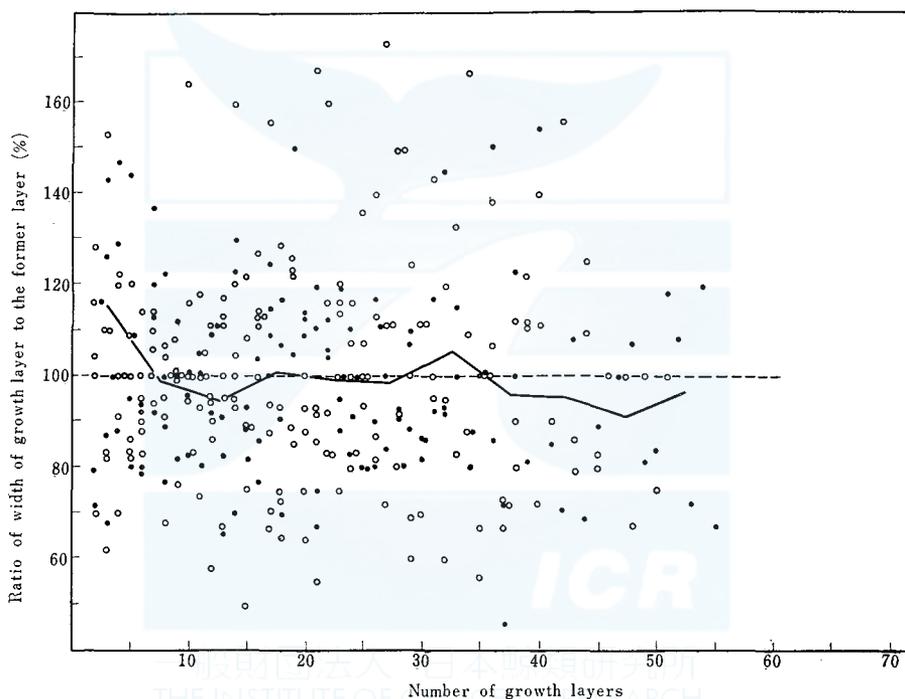


Fig. 5 Change in ratio of width of growth layer to the former layer in the dentine of maxillary teeth. Open circle: Female, Closed Circle: Male.

Fig. 5 is a graph of the relationship between the number of the growth layers and the ratio of each two layers. There seems to be no difference in both sexes. At the age of from 2 to 5 growth layers the mean values of the ratio are more than 100%. This shows that in this stage the width of the growth layer increases with age. After that stage, though there are some fructuations, it shows the tendency to decrease. In the other words, it can be said that the width of the growth layer decrease gradually, after the age more than 5 growth layers.

Though the decrease of the ratio becomes larger in old ages as stated before, when the ratios are not grouped by the age, the mean ratio is nearly 100%, this means that the width of the growth layers have no bias, considering in average.

FORMATION OF THE DARK BAND, ITS SEASON AND PERIOD

Fig. 1. is a diagrammatic figure of an upper tooth of a sperm whale. In this figure M is the margin of the dentine at the pulp cavity. B_1 is the last dark band of growth layer and B_2 is the former dark band. Then, m is the length between B_1 and M, and l_1 is the breadth between B_1 and B_2 . We measured m and g_1 on 447 sperm whales with a reflecting projector of 20 magnification.

When we measured them the base line of the dark band was settled at the border of a dark band and the former light band, which is shown in Plates.

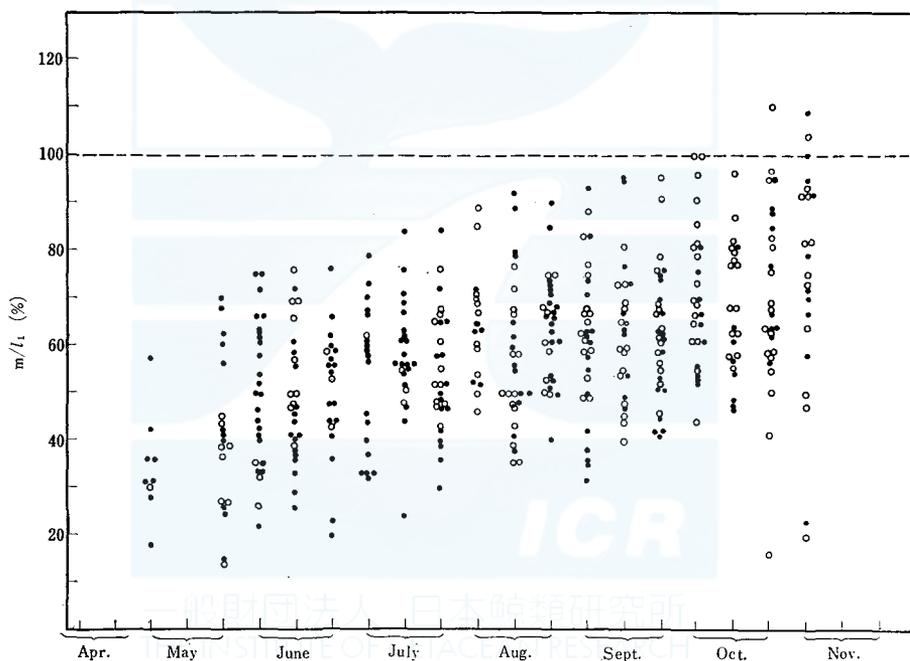


Fig. 6. Seasonal accumulation of growth layer shown by the ratio of accumulating growth layer (m) to the former growth layer (l_1) in the dentine of maxillary tooth of the northern sperm whales. Open circle: Female, Closed circle: Male.

Though the samples were desirable to be of a same age, we could not collect a sufficient number of samples, thus the ages of samples distribute from 5 to 35 layers old (mean 18.7) in the males, and from 4 to 27 layers old (mean 14.4) in the females respectively.

Nearly all of the sample (92%) were collected in 1961, in order to eliminate the influence of the fluctuation by year. The samples were also collected extend-

ing over 6 months from the first decade of May to the first decade of November. We grouped the samples to the first, middle and last decade of each month. Each group contains from 20 to 30 samples.

If the dark band is formed seasonally the value of m will increase with the elapse of time. As shown in the anterior chapter, the width of dentine shows wide individual variation, but the ratio of m to l_1 will show the time passed since the beginning of the accumulation of the recent dark band.

Fig. 6 shows the relation between m/l_1 and the season. It can be easily known from the figure that the ratio (m/l_1) have the tendency to increase as the progress of time. The growth rate of the growth layer does not seem to show the difference between male and female, for there seems not to be efficient difference between the ratio of m/l_1 in both sexes. But the ratio shows wide variation in every decade (the difference of the minimum and the maximum is about 55%).

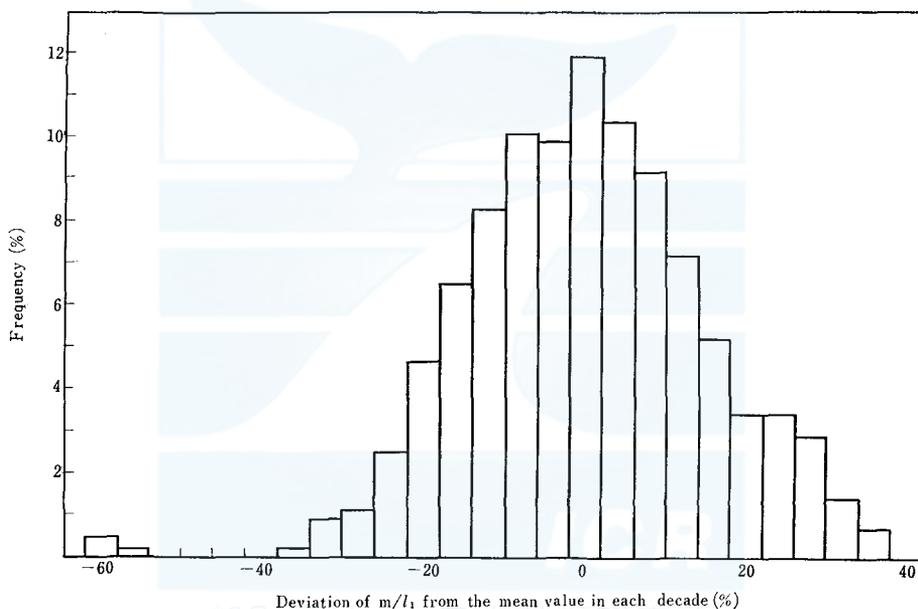


Fig. 7. Frequency distribution of deviation of m/l_1 from the mean value in each decade.

The variation from the mean value of each group is shown in Fig. 7 which nearly fits to the normal curve. This means that the season when dark band is formed is one season, and a next growth layer can not be accumulated on the way of accumulation of a growth layer.

After the first decade of October there happens such a sample which ratio m/l_1 shows more than 100%, and after the last decade of October there is the samples which seems to be soon after the beginning of the formation of a new dark band. These phenomena suggest that in some specimens the formation of the dark band already occurs in the first or second decade of October. When the lower border of Fig. 5 is deduced to April, it is presumed that there is such individuals

of which dark band begins to be formed in April. Accordingly it is supposed that the dark band begins its formation during the 7 months between the first decade of October and the last decade of April with the height of prosperity in January.

Fig. 8 shows the mean value of m/l_1 in each decade. Though the sample covers only 6 months and does not cover the season when dark band is formed in most individuals and we can not definitely conclude, it seems that growth layer does not grow linearly but conversed sigmoidally.

Figs. 7 and 8 show that the cycle of the formation of the dark band is not 6 months as considered in the previous paper. And the growth layer seems to grow more slowly in summer or from July to September than the other seasons. So it is inadequate to apply a straight line to the data which were not covered in all seasons.

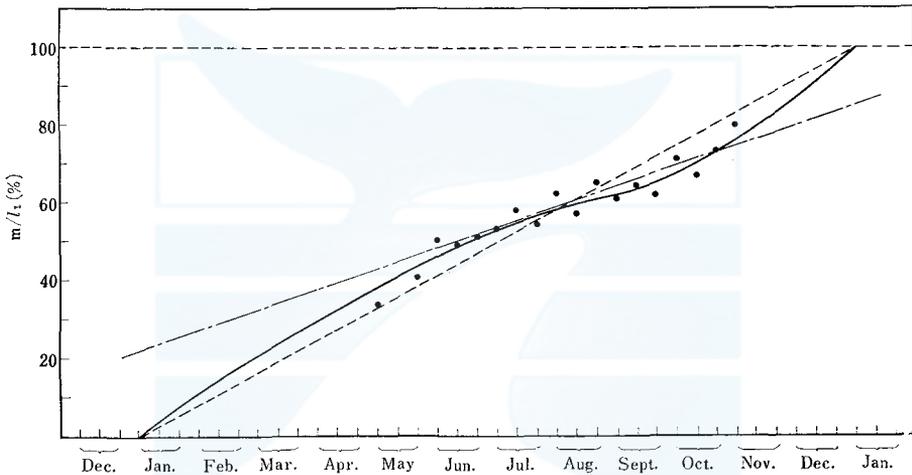


Fig. 8. Three accumulation curves of the growth layer in the dentine of maxillary tooth of the Northern sperm whales. Closed circle: Mean value, of m/l_1 Solid line: Estimated curve, Chain line: Regression line calculated with the mean values, Broken line: Fitted straight line when the accumulation cycle is expected to be one year.

But for a trial, we calculated the regression line from the mean values of each decade groups, which is shown by following formula,

$$y = 1.772x + 21.64$$

$$y: 100 m/l_1$$

$$x: \text{No. of the decade from the first decade of January when } x \text{ is } 0.$$

and this is shown by the chain line in Fig. 8. This does not seem to fit the given data. When the ratio y is 0, the time x is minus 12.2 and this means the first decade of last September. And in the middle decade of March in the next year (x is 44.2) y becomes 100%. By this formula the cycle of the accumulation of growth layer is shown to be 56.4 decade, namely 1.57 year long and it does not fit to the data because if the cycle is 1.5 year long, the samples should separate into two groups.

The broken line in Fig. 8 is made to fit the each mean values best, on the assumption that the cycle of the accumulation of growth layer is one year long. This line less deviates from the data than the chain line which is already explained. On this line the time when y shows 0% is the first decade of January, which fits as a matter of course, with the result already got by us.

EXAMINATION OF GROWTH RATE WITH THE MAXILLARY TEETH OF THE MARKED WHALES RECAPTURED

As shown in Table 2, the teeth of the eight marked whales were collected by 1962 in Japan. In order to examine the accumulation rate of the growth layer by the tooth of marked sperm whales, it is desirable that the age when the whale was marked is as young as possible and that the time elapsed since the time of marking is relatively long, for the elapsed time since marking is desirable to be nearly equal to the whole life of the recaptured whale.

TABLE 2. MARKED SPERM WHALES WHICH WERE RECAPTURED AND COLLECTED THEIR MAXILLARY TOOTH

Mark no.	Date marked	Date recaptured	Elapsed time (A) (year-month)	Sex	Body length at marking (feet)	Body length at recovery (feet)	No. of ovulation	Preg-nancy	Weight of testes (kg)	Growth layers (B)	B/A
J2871	12·IX·52	24·X·62	10- 1 $\frac{1}{3}$	Female	—	35	0-2, 0-1	None	—	18	1.78
J2878	12·IX·52	24·X·62	10- 1 $\frac{1}{3}$	Female	—	35	lost	None	—	39	3.85
J2883 J2984	12·IX·52	24·X·62	10- 1 $\frac{1}{3}$	Female	32 28	38	1-2, 0-3	Male 144 cm	—	20	1.98
J3166	13·IX·52	20·X·61	9- 1	Female	35	36	0-3, lost	None	—	30	3.30
J3237	17·VI·53	30·VIII·61	8- 2 $\frac{1}{2}$	Female	37	35	0-0, 0-2	None	—	14	1.71
J6381	7·VIII·55	13·XI·62	7- 3 $\frac{1}{2}$	Female	25	35	lost	—	—	10	1.48
J6658 J7338	7·VIII·55	18·VIII·62	7- $\frac{1}{3}$	Male	30	36	—	—	0.8, lost	12	1.71
J8278	22·VII·60	11·VI·61	0-10 $\frac{3}{8}$	Male	50	47	—	—	5.2, 5.3	44	49.5

A sperm whale, No. 3237 was marked in Japanese coastal waters in 1953, and recaptured in 1961 also in the almost same region. This whale is a female and the time elapsed since it was marked till it was recaptured is 8 years and 2.5 months. Though whales are apt to be estimated their body length larger than their true length especially in small whales at the time of marking, its estimated body length when it was marked was 37 feet long. Therefore it can not have been so young whale then. When it was recaptured, it was already adult (number of ovulations of this whale was 2), and the growth layers in upper tooth was numbered to be 14. The ratio of the number of the growth layers to the years elapsed since the time of marking till recapture is 1.71. And considering that the age at the time of marking of the individual must have been not so young, the accumulation rate of the growth layers formed after the marking should be less than 1.71 per year.

Similar results were obtained in 1962 from four recaptured whales, namely Nos. 2871, 2883, 6381 and 6658 whales. Elapsed times of them were 10.1, 10.1, 7.3 and 7.0 years respectively, and the number of growth layers of them were also

18, 20, 10, and 12 respectively. Therefore, the number of growth layers divided by elapsed years were 1.78, 1.98, 1.48 and 1.71 respectively for four whales.

Especially the number of growth layers of No. 6381 whale was only 10, when it was recaptured after 7 years and 3 months. Then, the accumulation rate of the growth layer is considered as one per year, the whale would have been about 3 years old ($10 - 7.3 = 2.7$) at the time of marking. Now, according to the growth curve of the sperm whale by Nishiwaki, Hibiya and Ohsumi (1958), the body length at the age of three growth layers is considered to be 22 feet. On the contrary, the body length of the whale No. 6381 at the time of marking was 25 feet. Considering the error of the estimated length, this fairly agrees with the calculated body length from the growth curve.

Above five materials are considered to suggest strongly that the accumulation rate of growth layers must be less than two per year, and considering the age at the time of marking, the rate may be one per year.

A sperm whale No. 8278 had lived less than only 11 months after it was marked and had been estimated its body length to be 50 feet when marked, so it will have been fairly old when it was marked. For these two reasons this whale is not so useful to examine the accumulation rate of the growth layers (44 growth layers is numbered in the upper teeth).

The whale No. 3166 was recaptured after 9 years and 1 month after the marking. Although the time passed from marking till recapture is longer than No. 3237 by 11 months, the dentine of the upper teeth contained 30 growth layers, and 3.30 is the quotient of the number of layers divided by the year elapsed from the time of marking to recapture. This quotient is larger than 2. Though one ovary had been lost, the other ovary contained 3 corpora albicantia. So this whale may have been older than No. 3237 when it was recaptured. If it is assumed that No. 3166 was much older than No. 3237 at the time of marking, the ratio 3.30 of No. 3166 is not inconsistent with the assumed accumulation rate of the growth layers. No. 2878 whale was recaptured after 10.1 years from the time of marking, and the number of growth layers was 39, then the divided value is 3.85. This value is thought to be obtained in the similar case of No. 3166 whale.

EXAMINATION WITH AGE DISTRIBUTION BASED ON THE NUMBER OF GROWTH LAYERS

Fig. 9 shows the age distribution of 1,226 female sperm whales caught in the Japanese coastal waters in 1960 and 1961 based on the number of the growth layers in the dentine of the upper tooth. The age distributions are converted on both assumption that one growth layer is accumulated in a year and that two growth layers in a year.

As shown in Fig. 10, the catch of the sperm whales in the coastal waters to Japan has been increasing gradually and recently it attained more than 2,000 whales and since 1959 the maximum catch was restricted to 2,100 whales, which is about 4 times more than the catch in 1920. But the rate of the catch to the

stock of sperm whales in the coastal waters to Japan calculated from the recovery rate of the marked whales is 0.5% in recent years (Ohsumi, unpublished data).

In spite of the sudden increase of the catch since 1957, the age distribution of the catch, which is shown on the semi-logarithmic graph in Fig. 9, shows to decrease with nearly a straight line in the age groups of 13 to 47 growth layers. This will mean that the rate of catch to the stock of sperm whales is very small in the coastal waters to Japan. So, we consider that the mortality rate calculated from the age distribution of the catch will show natural mortality in the most parts. Even if the natural mortality is affected by fishing, it does not influence to the latter calculations.

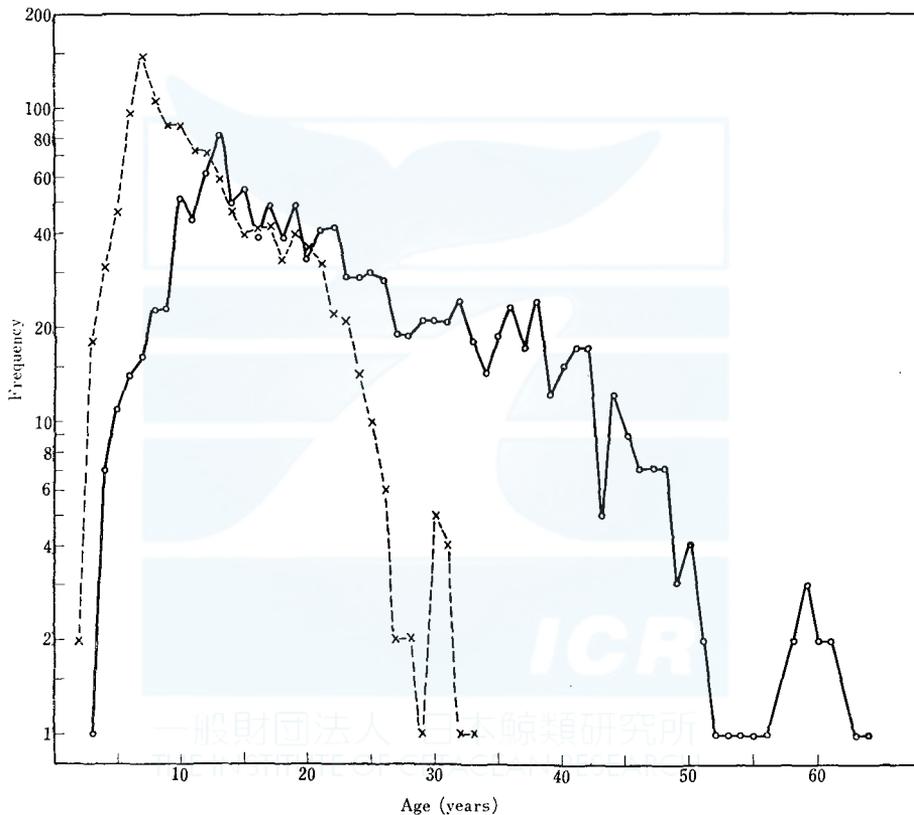


Fig. 9. Age distribution of female sperm whale caught in the adjacent waters to Japan in 1960 and 1961. Ages are based on the number of growth layer. Open circle and Solid line: One growth layer is accumulated in a year, Cross and broken line: Two growth layers are accumulated in a year.

The mortality rate calculated from Fig. 9 is shown below.

Accumulation rate of growth layer	Mortality co-efficient	Mortality rate
One growth layer in a year (one layer age)	0.056	5.3%
Two growth layer in a year (two layers age)	0.121	11.4%

The mortality rate calculated by one layer age largely differs from that of two

layers age.

The reproductive rates are calculated on the assumption that the mortality rate lasts in the same value throughout the life span. Now, the female sperm whales attain the sexual maturity at the age of 9 growth layers according to Nishiwaki, Hibiya and Ohsumi (1959).

And the pregnant rate is given in Table 3, which is based on the biological data collected in the coastal waters to Japan in 1960 and 1961.

Clarke (1957) reported that the gestation period of the sperm whales in the northern waters is 16 months and the maximum of the pairing and parturition occurs in April and in August respectively. Then, from April to August, there should be two groups of pregnant females, one group is the females which become pregnant in the former year and the other group have become pregnant in the next year. And the half of the apparent pregnancy rate must be the true pregnancy rate during the seasons from April to August. In September we used the $\frac{2}{3}$ of apparent pregnancy rate as a true rate. Because in September there are still females to be delivered of a calf.

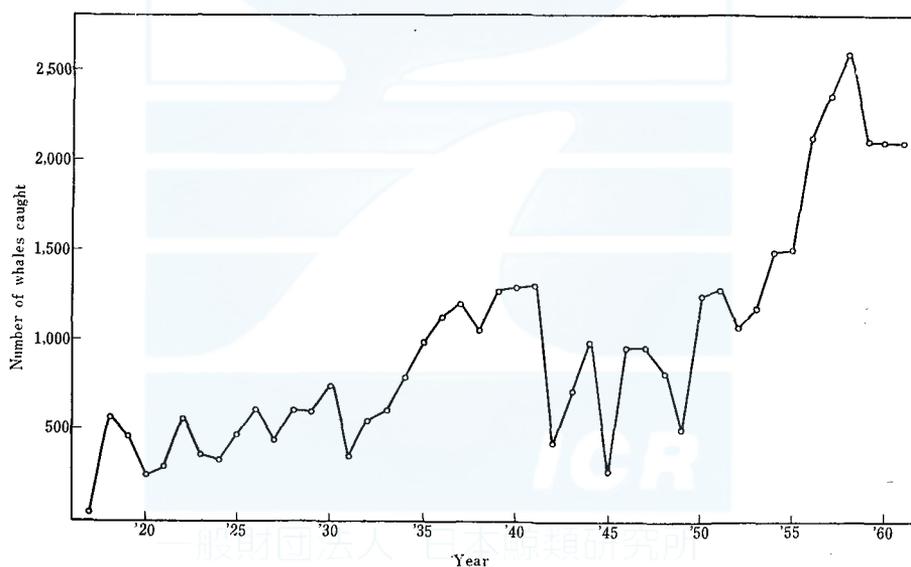


Fig. 10. Variation of catch of sperm whales in the adjacent waters to Japan (after the International Whaling Statistics and Japanese Whaling Statistics).

By these methods we got the conclusion that the true pregnancy rate will be 25~33%, and mean pregnancy rate in the season from May to November is calculated as 28.7%. Clarke (1957) reported the low pregnancy rate of 27% on the North Atlantic sperm whales. This is almost the same value as ours.

In the next place, we calculated the recruitment value "R" corresponding to the varying mortality rate from 0.03 to 0.13, on the two assumptions that the female sperm whales become reproductive from the age of 9 growth layers, namely 9 years old in the case of one layer age and 5 years old in the case of 2 layers age,

and corresponding to the varying mean pregnancy rate of the matured female sperm whales from 0.25 to 0.35 through the reproductive life span.

The R-values calculated from these figures are shown in Table 4. Naturally, when the R-value is lower than 1, the stock of the sperm whales will decrease, and if higher than 1, the stock increases.

And here next two problems come into question.

- (1) The error caused by the assumption that the mortality rate is constant throughout all the life span.
- (2) The ignorance of the high mortality rate soon after the birth, which is usually observed in the population of animals.

TABLE 3. PREGNANT RATE OF SPERM WHALES CAUGHT IN THE ADJACENT WATERS TO JAPAN IN 1960 AND 1961 SEASONS

	May & Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Total
Pregnant whales	24	28	90	205	64	14	425
Resting and lactating whales	15	14	83	291	154	40	597
Total whales	39	42	173	496	218	54	1,022
% of pregnant whales	61.5	66.7	52.0	41.3	29.4	25.9	41.5
Rate	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{2}{3}$	$\frac{1}{1}$	$\frac{1}{1}$	
Possible pregnant ratio (%)	30.8	33.3	26.0	26.8	29.4	25.9	28.7

TABLE 4. R-VALUES OF THE SPERM WHALE

Pregnant rate Survival	0.35		0.30		0.25	
	9 years	5 years	9 years	5 years	9 years	5 years
0.97	4.44	5.02	3.80	4.30	3.17	3.58
0.96	3.03	3.57	2.60	3.06	2.16	2.54
0.95	2.21	2.71	1.89	2.33	1.58	1.93
0.94	1.67	2.14	1.43	1.83	1.19	1.53
0.93	1.30	1.74	1.11	1.49	0.93	1.24
0.92	1.03	1.44	0.89	1.25	0.74	1.03
0.91	0.83	1.21	0.71	1.04	0.59	0.89
0.90	0.68	1.03	0.58	0.89	0.48	0.74
0.89	0.56	0.89	0.48	0.76	0.40	0.62
0.88	0.46	0.77	0.40	0.66	0.33	0.55
0.87	0.38	0.67	0.33	0.58	0.27	0.48

When the mortality rate is presumed from the mature and stabilized ages considering the above mentioned two points, R-value needs to be fairly higher value than 1 in order to keep the stock constant.

If 2 growth layers are accumulated in a year, the R-value can be more than 1, only when the mortality rate is lower than 9%.

But the mortality rate calculated from two layers age is 11.4% and therefore R is 0.75, which prohibits the maintenance of the stock. Even when the pregnancy rate is 35%, R-value is 1.01 which can not be suitable value, for the mortality rate soon after birth is thought to be higher than that of the later stage.

On the other hand, if it is assumed that one growth layer is accumulated in

a year, the mortality rate is calculated to be 5.3%. And when the pregnancy rate is assumed to be 25% and 35%, the R-value is 1.5 and 2.1 respectively. These values surely permit the maintenance of the stock even when other various factors influenced on the stock.

In fact, the stock of the sperm whales in the coastal waters to Japan does not show evidence of decrease and the catch rate is considered to be low. Thus the examination of the growth layer in the maxillary tooth based on the age distribution leads to the conclusion that it does not explain the actual conditions of the stock to assume that two growth layers are accumulated in every one year and it seems to be suitable to consider that less than two probably one growth layer is accumulated in a year.

DISCUSSION

All the results obtained in the preceding chapters seems to show that one growth layer is accumulated in every year in the dentine of maxillary tooth of the sperm whale.

On the accumulation rate of the growth layer in the tooth of the toothed whale, Sergeant (1959) already reported that one layer accumulates in one year on the tooth of the bottlenosed dolphin. This result was obtained from the captive dolphins which lived in an environment largely differed from the natural conditions. But we (Nishiwaki and Ohsumi, unpublished data) got the fact that the number of growth layers in the teeth of the bottlenosed dolphin at the attainment of sexual maturity in natural condition nearly coincides to the age of same stage for the captive bottlenosed dolphin in the report by Tavalga and Essapian (1956). Then Sergeant's result will be considered to be applied for the dolphin in natural environment.

Sergeant (1962) also obtained the same result on the accumulation rate of growth layer for the pilot whale in natural environment.

On the accumulation rate of the lamination in ear plug of baleen whales, Ohsumi (1962) suggested on the biological data of the recaptured fin whales that the ear plug accumulates one lamination in a year.

Although Pinnipedia animals are classified differently from Cetacean animals, one growth layer of tooth is accumulated in a year (Scheffer; 1950, Laws; 1953, etc.). And the feature of growth layers in the dentine of some Pinnipedia looks very similar to that of dolphins.

According to Omura and Kawakami (1956), based on the marking investigation in the North Pacific, the growth of sperm whales may be much slower than that is generally believed. Further biological materials which had been collected later from recovered marked sperm whales also support the result.

Chuzhakina (1961) reported a paper on the ovaries of the sperm whale, and showed a table on the relation between the age and the total ovulation, although we do not know the method of age determination in this study. Then, the above relation coincides fairly well to the figure and formula by Nishiwaki, Hibiya and

Ohsumi (1958) on the relation between the number of growth layers in the maxillary tooth and the total ovulations, when we assumed that one growth layer accumulates in a year.

We think that the formation mechanism of the growth layers in the dentine will be related with the metabolic cycles, and its final solution will depend on the physiological study on the periodicity of the metabolic and reproductive mechanisms of the whale. However, the already known ecological informations on the whale seems to support the assumption that the whales have one year periodicity in the metabolic cycles.

In this report, we examined the seasonal change in the ratio of the width of the last growth layer to that of the former growth layer. But the ratio does not necessarily show a stage of the growth layer period of the animal, for the width of the growth layer has fairly large fluctuations between samples or each layers in one sample. In order to prevent this error, it will be better to divide a growth layer into many stages and to decide the stage to which the samples belong. But, to our regret, this method was not used.

In this report we presumed that the dark (clear or translucent) bands in the dentine begin to form in winter and its prosperous season falls in the first decade of January. The dark band in the dentine is thought as a well calcified tissue and seems to be accumulated as the result of a good nutritious condition of the animal and Mc-Laren (1958) reported on the teeth of ringed seal *Phoca hispida* that the clear band is formed in the season of moult and opaque band is formed in summer.

Sergeant (1959) reported on the teeth of *Tursiops truncatus* that the dark band is formed in the pairing season of early spring.

And he (1962) also reported on *Globicephala melaena* that its pairing season extend over 6 months with its flourishing season in April and May, and the dark band is formed in this season.

The sperm whales in the northern hemisphere have their maximum pairing season in April (Clarke, 1957). We estimate that light (opaque) band is formed in summer and that dark band is formed in about three months proceeding the pairing season.

This result does not coincide with the already published data, but coincides with the report that in the fur seals, the dark band is formed in April proceeding 2 or 3 months to the pairing season (Kubota et al., 1962). Though the change of the seasonal abundance of the food of the sperm whales is not yet known sufficiently, there seems no change between June and November (Clarke 1957).

Omura (1950) reported that the thickness of the blubber begins to decrease in January, and attains the minimum in June and July and then increase rapidly from September to November in the North Pacific sperm whale. If the accumulation of nutrition occur proceeding to the pairing season and the nutrition affect the formation of the dark band, it will be probable that the dark band is formed in the tooth of sperm whales in January. But we think that the season when the dark band is formed would not be concluded now, for our ecological knowledge on the sperm whales in winter is very insufficient and our materials used in this report is

lacking in the samples during the seasons from November to April. We are rather inclined to suppose the influence of some hormones on the formation mechanism of dentine layers.

As one of the means to give solution to this problems, the time marking on the teeth of a living sperm whale will be effective, but this method is now far from the utilization.

SUMMARY

Following results are obtained on the accumulation rate of growth layers appeared in the dentine of maxillary teeth of the sperm whale.

1. The light (opaque) and dark (translucent) bands are found accumulating mutually on the surface of the longitudinally ground section of the dentine of the sperm whale maxillary tooth. The dark band has affinity for carbol-fuchsin and shows a strong anisotropic character to the light. Though some narrow dark lines are ordinary found in a light band, its difference in the sex and age is not found.

2. There are individual variations in the width of growth layers of the dentine, and their yearly fluctuations are also recognized in the same individual. But generally speaking, the widths of layer are larger in male than those in female, and they decrease with the age. However the decreasing tendency is mere, and therefore we may consider that the width of a layer is almost same as the width of the next layer on an average.

3. As the result of the measuring the seasonal growth of latest layer, it is considered that one growth layer will accumulate in a year, and the dark band will be formed in winter.

4. Biological investigation of a recaptured sperm whales suggests that the accumulation rate of growth layer in the dentine must be under two per year and may be probably one per year.

5. Pregnancy rate of the adult sperm female is considered to be 28%, judging from the gestation period of the whale.

6. Age distributions of female sperm whale in the adjacent waters to Japan was shown basing on the number of growth layers of maxillary teeth. And the mortality rates were calculated in the two case of one layer age and two layers age. They are 5.3% and 11.4% respectively.

7. Calculating the recruitment-value with the mortality rates and pregnancy rate, the stock of sperm whale in the adjacent waters to Japan is not able to explain the case of two layer age, but able to explain in the case of one year age.

8. It will be concluded from the above discussion that the accumulation rate of growth layer is considered to be one layer per a year and the dark band may be formed in winter.

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EXPLANATION OF PLATES

PLATE I

Longitudinal ground sections of the maxillary and mandibular teeth of sperm whales.

B: Dark band, C: Cement, D: Dentine, E: Enamel, NL: Neonatal line, O: Osteo-dentine.

Left: Female, 10.8 m in body length, ovaries lost, 11 growth layers, taken in the coastal waters to Japan on July 26, 1961. (×4.4)

Right upper: Female, 5.0 m in body length, immature, no growth layer, stranded in Enoshima Beach on July 27, 1959. (×4.4)

Right lower: Female, 3.7 m in body length, fetus, taken in the coastal waters to Japan on Sept. 27, 1960, mandibular tooth. ($\times 4.4$)

PLATE II

Longitudinal ground sections of the maxillary teeth of male sperm whales.

Left: Male, 13.5 m in body length, 2.0 and 2.2 kg in weight of each testes; 22 growth layers, taken in Aleutian waters on June 16, 1961. ($\times 2.4$)

Right: Male, 13.2 m in body length, 3.0 and 3.3 kg in weight of each testes, 25 growth layers, taken in Aleutian waters on June 21, 1961. ($\times 2.2$)

PLATE III

Longitudinal ground sections of maxillary teeth of sperm whales.

Left: Female, 10.7 m in body length, one corpus luteum and three corpus albicans in the ovaries, pregnant, 17 growth layers, taken in the coastal waters to Japan in July 26, 1961. ($\times 3.8$)

Right: Female, 8.5 m in body length, one corpus luteum and three corpus albicantia in a ovary, pregnant, 11 growth layers, taken in the coastal woters to Japan on July 30, 1961. ($\times 3.5$)

PLATE IV

Longitudinal ground sections of maxillary tooth of a sperm whale. Marks are same as Plate I.

Female, 10.8 m in body length, ovaries lost, 11 growth layers, taken in the coastal waters to Japan on July 26, 1961.

Upper: Tip portion of the tooth ($\times 17.4$)

Lower: Pulp portion of the tooth ($\times 17.4$)

PLATE V

Longitudinal ground sections of maxillary tooth of a sperm whale.

Female, 8.5 m in body length, one corpus luteum and one corpus albicans in a ovary, pregnant, 11 growth layers, taken in the coastal waters to Japan on July 22, 1961.

Upper: Tip portion of the tooth ($\times 18$)

Lower: Pulp portion of the tooth ($\times 18$)

PLATE VI

Longitudinal ground sections of the tip portions of maxillary teeth of sperm whales.

I: interglobular space, other marks are same as Plate I.

Upper: Male, 13.5 m in body length. ($\times 224$)

Lower: Female, 10.8 m in body length. ($\times 134$)

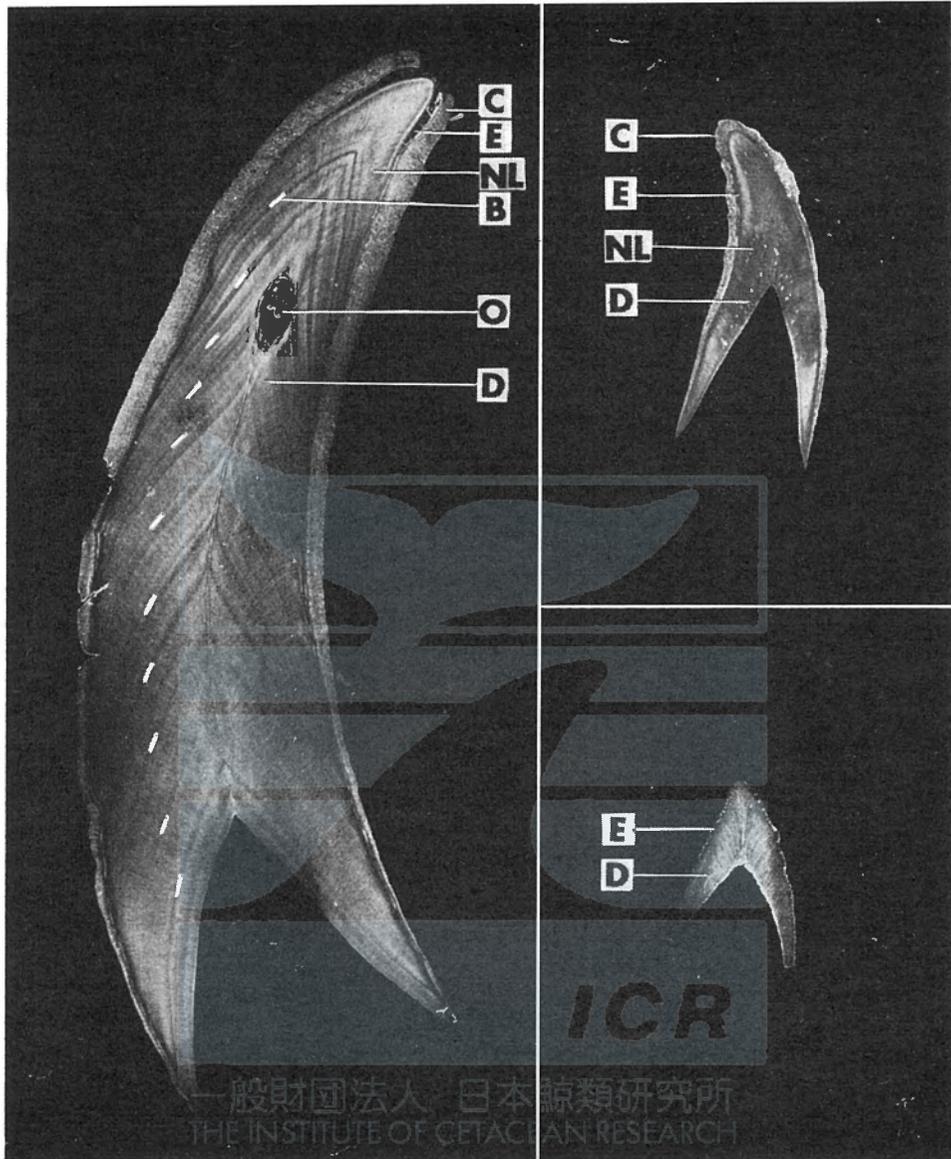
PLATE VII

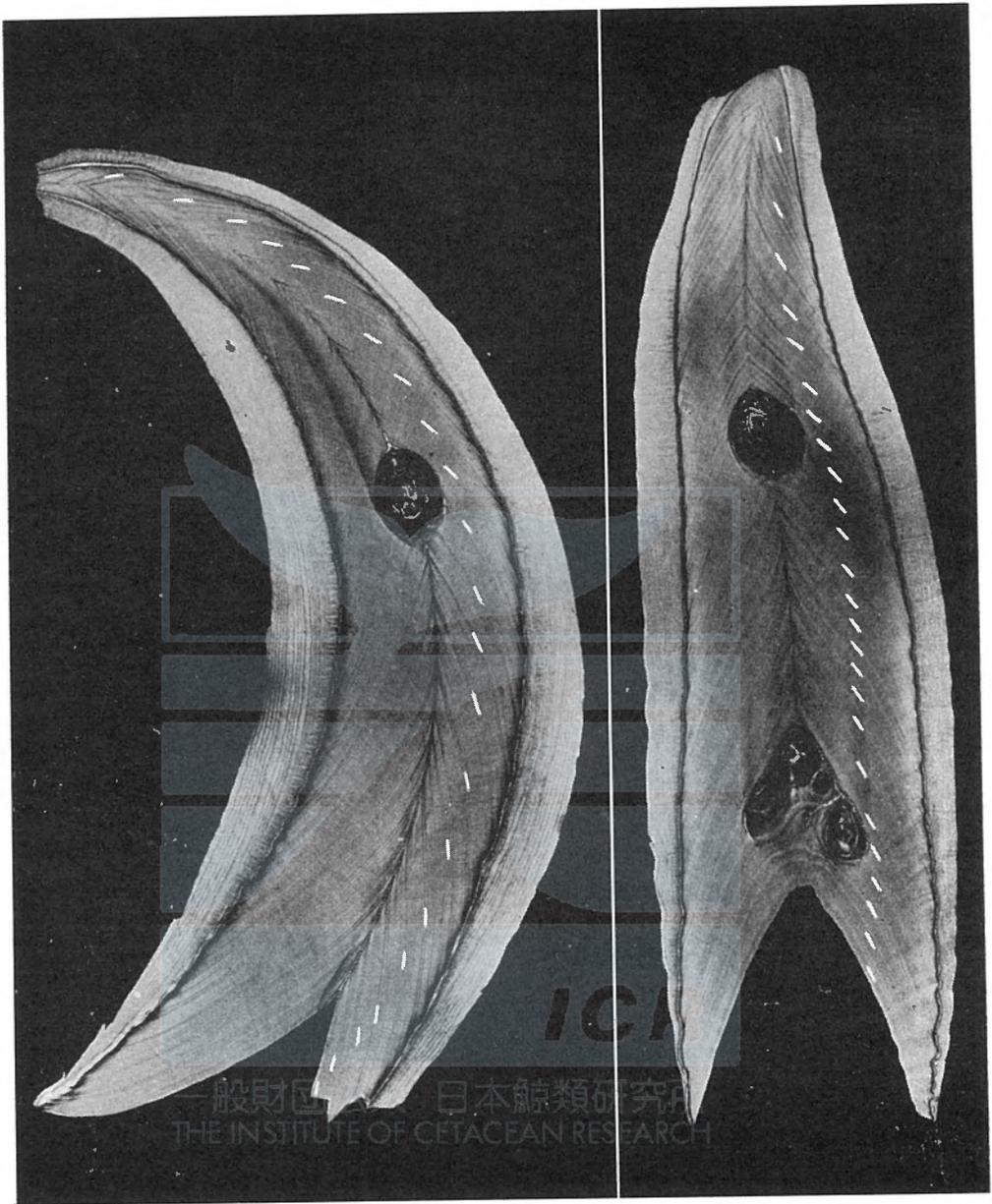
Longitudinal ground sections of a male sperm whale. Dentinal tubules are running through the dentine.

P: predentine, other marks are same as Plate I.

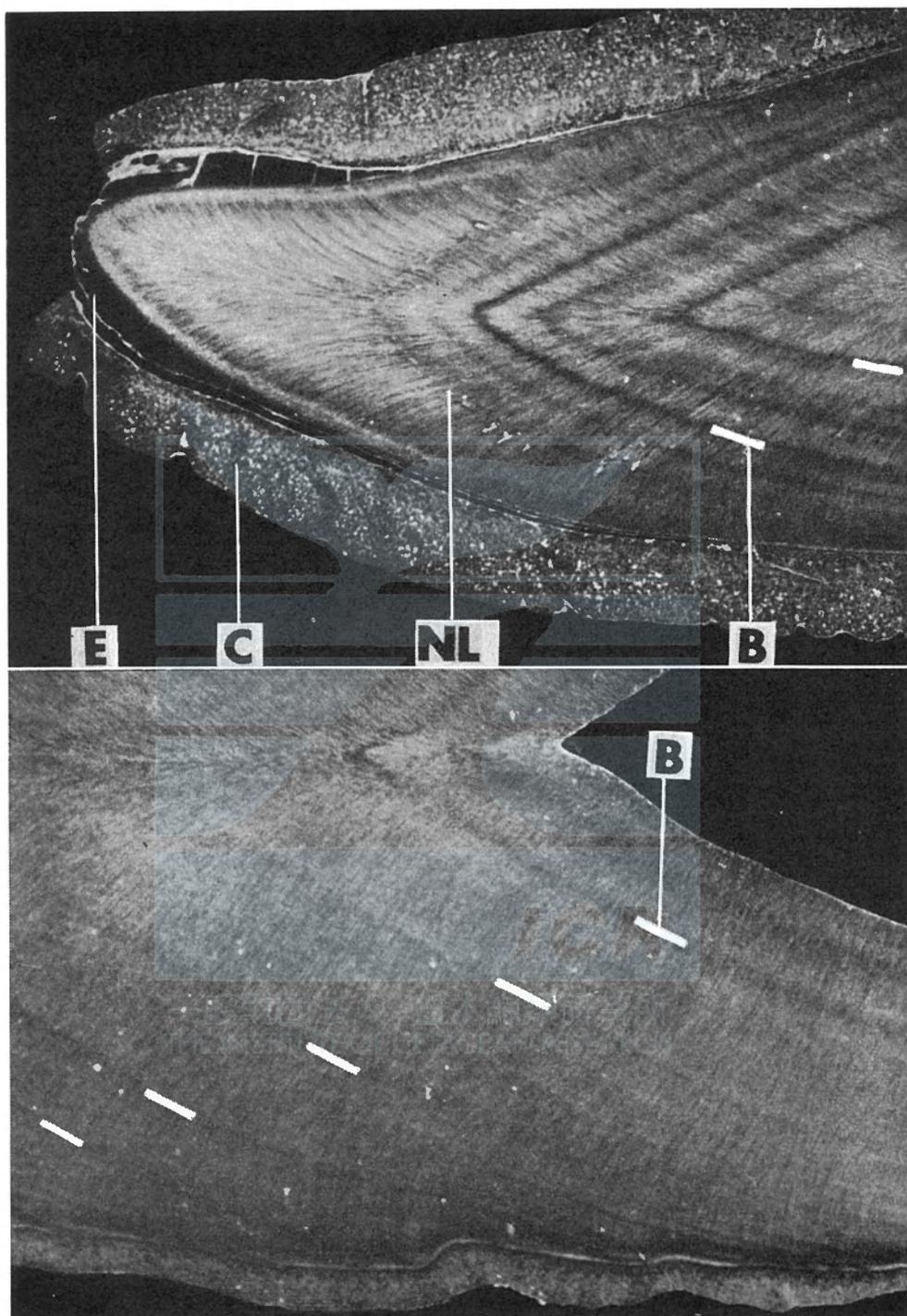
Upper: Male, 12.9 m in body length, 2.4 and 2.4 kg in the weight of each testes, taken in the Aleutian waters on July 4, 1961. ($\times 112$)

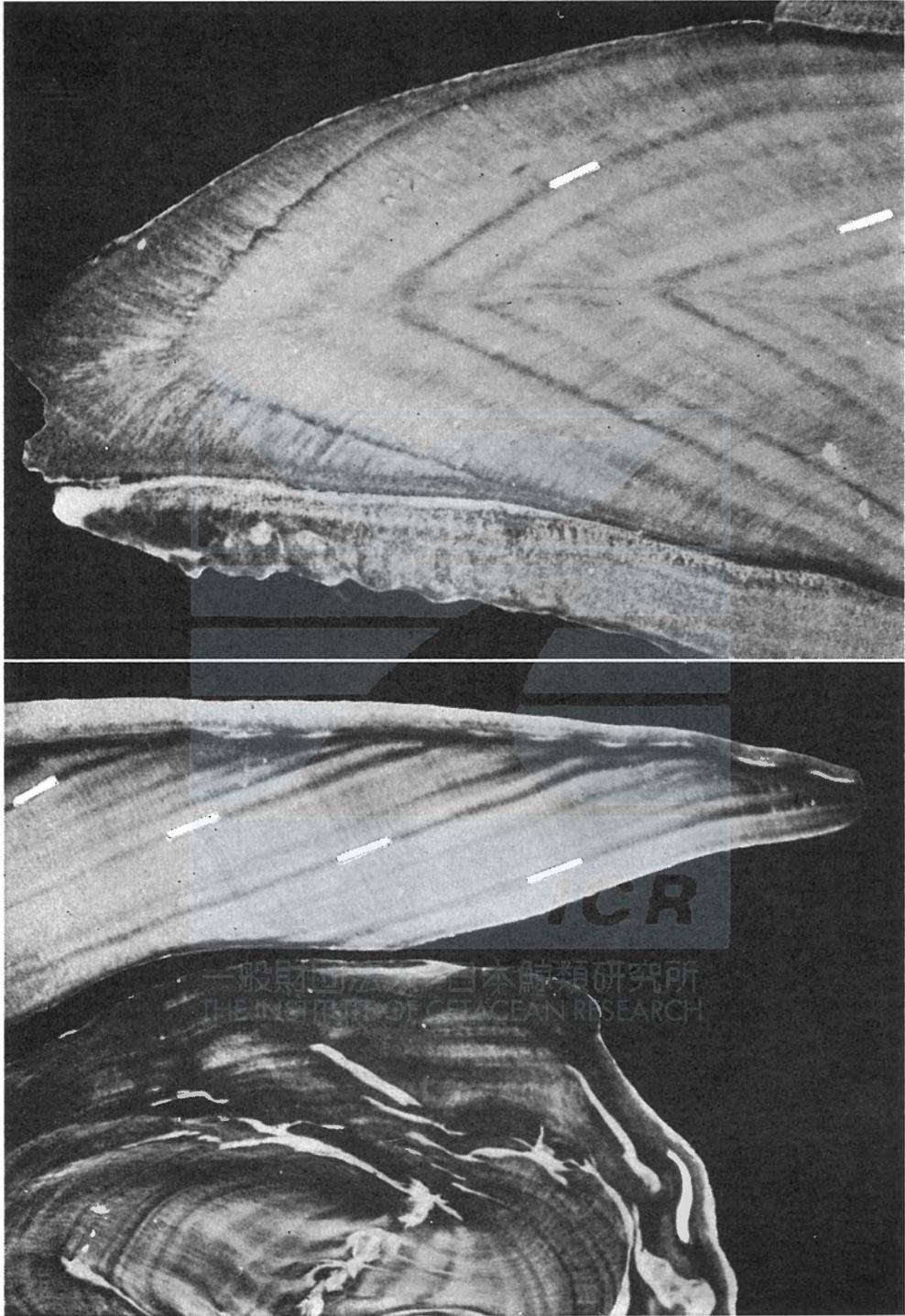
Lower: The same tooth with the upper figure. ($\times 268$)

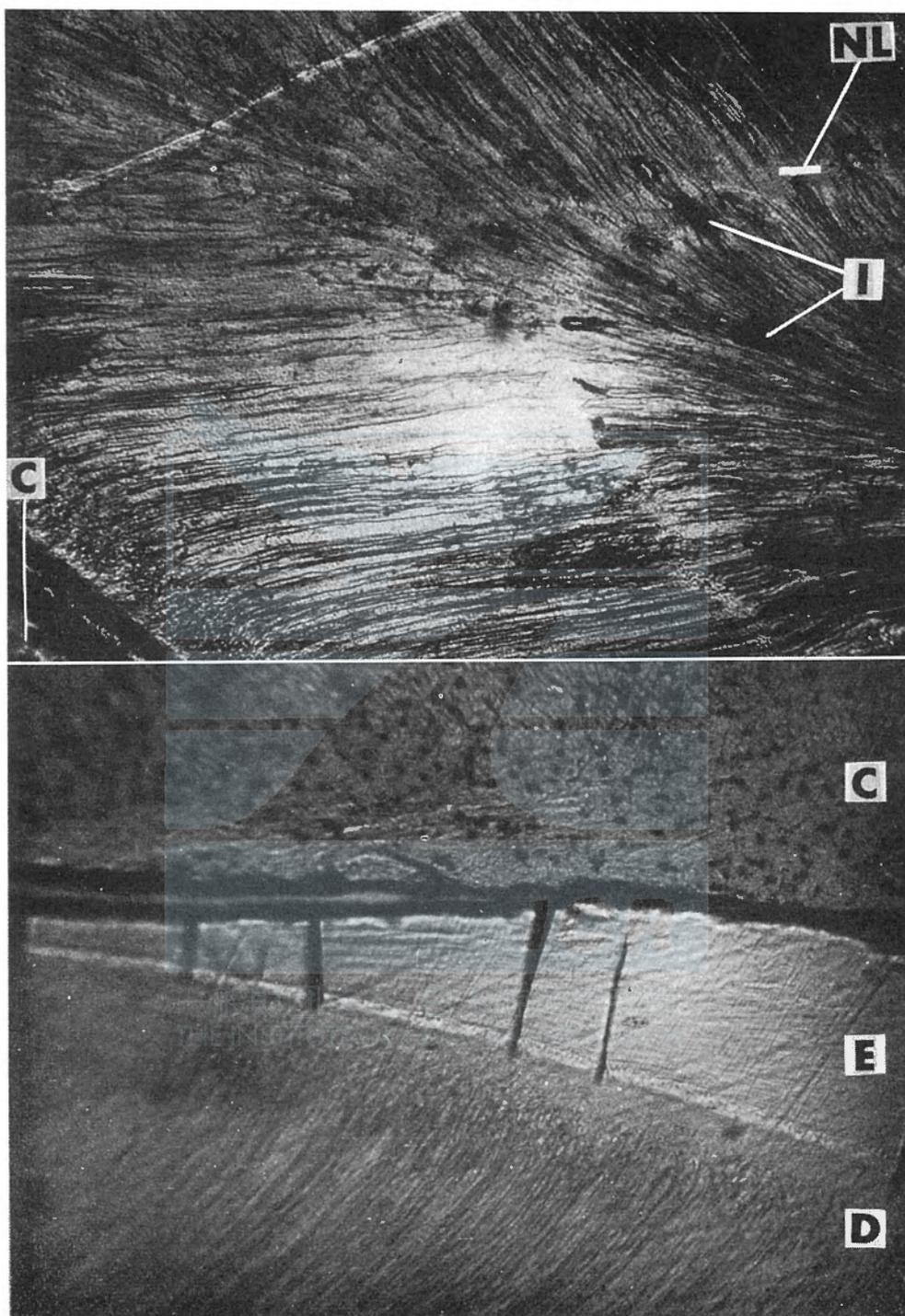


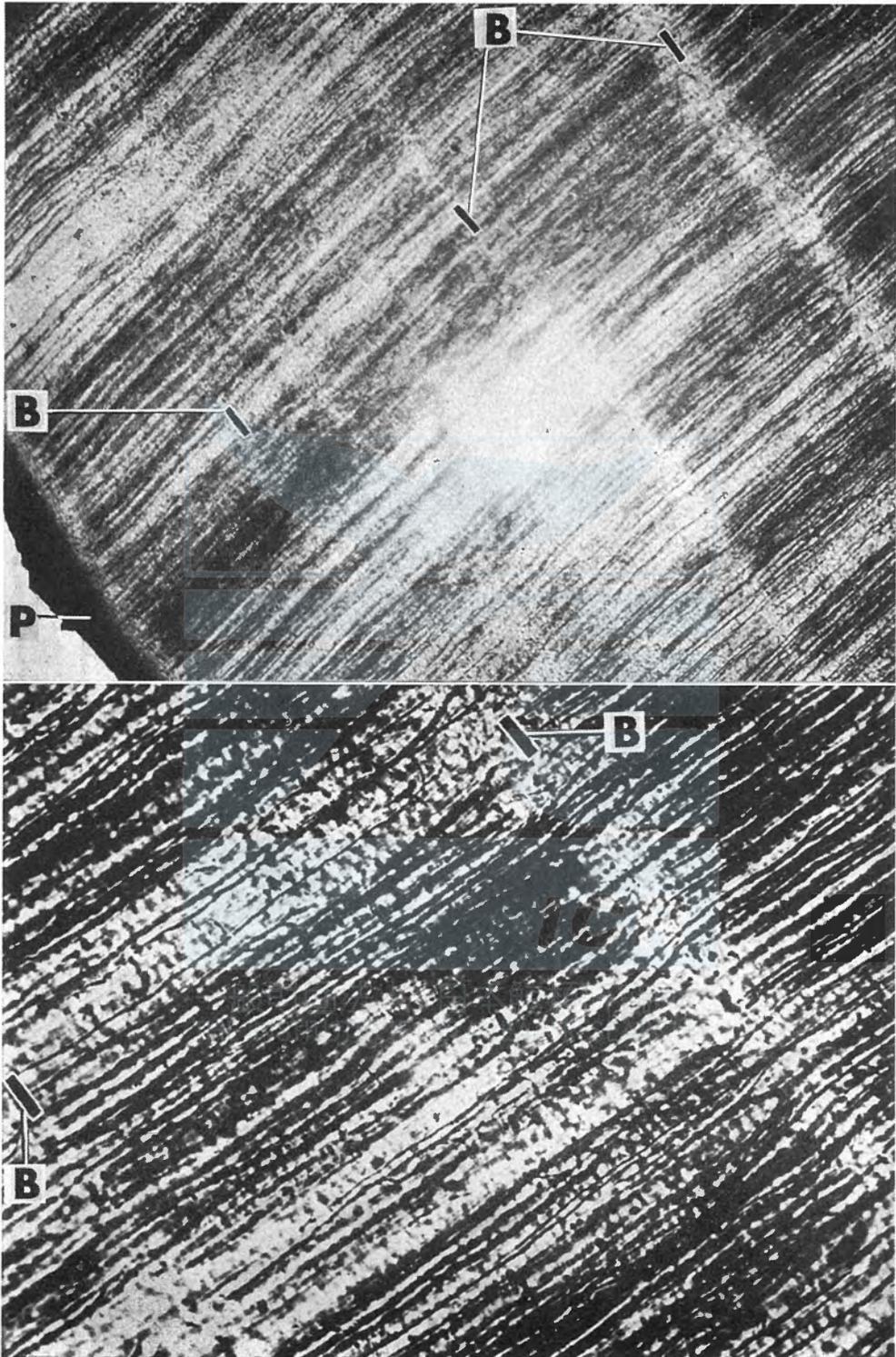












PHOTOMETRIC METHOD FOR COUNTING LAMINAE IN EAR PLUG OF BALEEN WHALE*

TADAYOSHI ICHIHARA

INTRODUCTION

Since Purves (1955) found out the ear plug as a valuable age character of the baleen whale in the course of study on sound conductivity, several scientists have researched for the relation between other age characters appreciated until then and the number of laminae in ear plug. They have concluded that the ear plug is the most valuable character for the age determination throughout the life span of baleen whales. The core of ear plug is formed from the epithelial cell of so-called glove-finger which is closely connected with tympanic ligament and it is constructed by the alternation of bright and dark lamina in the macroscopic observation. Ichihara (1959) concluded in the histological examination that these alternations result from the fatty and keratinized degeneration of the epithelial cells of glove-finger.

It is most important for determining the whale age to count accurately the laminae composed of two different components mentioned above and to avoid the interpretation favoured by individual scientists. Besides, it is desirable that the thickness of each lamina can be automatically measured and recorded. Measurement for the thickness of the most proximal lamina being now constructed is indispensable to study the annual accumulation rate of laminae. In order to attain these purposes, the photometric method for laminae counting should be devised.

My grateful acknowledgements are due to Dr. Moriso Hirata, Department of Physics, Faculty of Science, University of Tokyo, who accomplished the photometric counting apparatus and permitted me to describe its mechanism in this paper. I am also indebted to Dr. Hideo Omura, Director of the Whales Research Institute, for his encouragement throughout this work. My thanks are due to Dr. R. M. Laws, Nuffield unit of tropical animal ecology, Uganda and to Mr. G. C. Pike, Biological Station at Nanaimo, Fisheries Research Board of Canada, who kindly sent me some specimens of ear plugs for standardizing the laminae counting and informed me their counts with other biological data. The personal communications as well as the exchange of ear plug between them and me stimulated the idea for this work. Mrs. Sadako Tsumori assisted me in counting the laminae of ear plug from the fin whale in the North Pacific.

TRIAL FOR STANDARDIZING THE LAMINAE COUNTING IN EAR PLUG

In 1958, I counted the laminae of ear plugs from 408 fin whales caught in the North

* Dedicated to Professor T. Ogawa for his sixtieth birthday.

Provisional paper is submitted to the special Ad Hoc Scientific Committee of the International Whaling Commission held at Rome, 24 April—6 May in 1961.

Pacific expedition. Dissecting microscope with 12 from 8 magnifications is used for the counting. A trained assistant, Mrs. Sadako Tsumori, counted independently the laminae in the same specimens to examine the individual discrepancy in the laminae counting. The discrepancy of counts between both persons occurs for 277 of 408 specimens. The ear plug of vague laminae constitutes most of 277 plugs and its ratio corresponds to 67.9 percentage of total ear plugs examined.

In the course of laminae counting in the ear plug taken from the Antarctic fin whale in 1959/60 season, I separated the ear plugs of female whales captured by a Japanese fleet into two categories; one is the specimens indicating clear laminae which can be counted easily, and the other is that showing vague laminae, whose counting being somewhat arbitrary. In Table 1, the number of specimens in two categories are indicated respectively in area IV and area V-VI. Area IV includes the waters to 130°E from 70°E, area V to 170°W from 130°E and area VI to 120°W from 170°W in the Antarctic Ocean.

TABLE 1. TWO CATEGORIES OF EAR PLUG FROM THE FEMALE FIN WHALE IN THE ANTARCTIC

	Area IV	Area V-VI	Total
1) Specimens of clear laminae	40	39	79
2) Specimens of vague laminae	120	121	241
Total	160	160	320
Percentage 2) to total	75.0	75.6	75.3

Average ratio of specimens of the vague laminae to the total ear plugs examined is 75.3% in the Antarctic and the nearly same ratio is obtained both in area IV and in area V-VI.

Ear plugs in vague laminae are possibly counted at individual option. The occurrence of vague laminae is less frequent in the North Pacific than in the Antarctic as far as the present materials concern. The fact that 84.1% of total ear plugs in the North Pacific expedition in 1958 is from the male whale supports this evidence, because the alternation of laminae is more regular in the male than in the female plugs.

The occurrence of individual discrepancy in the laminae counting is examined further in Fig. 1 & 2 for the ear plugs obtained in the North Pacific expedition in 1958. With the increment of laminae, less count or over count increases for the ear plug. The percentage frequency of ear plugs in which the discrepancy in count occurs is indicated at each 5 laminae in Fig. 1. The frequency increases rapidly until 25 laminae but remains on the same level over 26 laminae. Although the different counts are obtained in most of ear plugs with many laminae, Fig. 1 indicates the evidence that the count for many laminae is coincident between individuals, if the structure of laminae is clear.

In the ear plugs of which the laminae count is lacking in agreement, the individual deviation from the mean count is expressed as follows. If one person counts 19 laminae and another person does 21 laminae for the same ear plug, the percentage deviation from the mean is

$$1/20 \times 100 = 5(\%)$$

Such a calculation is practised for each ear plug and the percentage frequency of deviation is indicated as the histograms in Fig. 2. With the increment of laminae, there is a tendency that the range of discrepancy becomes narrower but much skewness of the histograms appears positively, therefore, the mean value as expressed in the dotted line decreases gradually. The mean value is 6.70% for 1-20 laminae group, 4.11% for 21-40 group, 3.06% for 41-60 group and 3.12% for the group over 61 laminae. For the examined ear plugs, the mean discrepancy is $\pm 4.68\%$ as indicated in the bottom in Fig. 2.

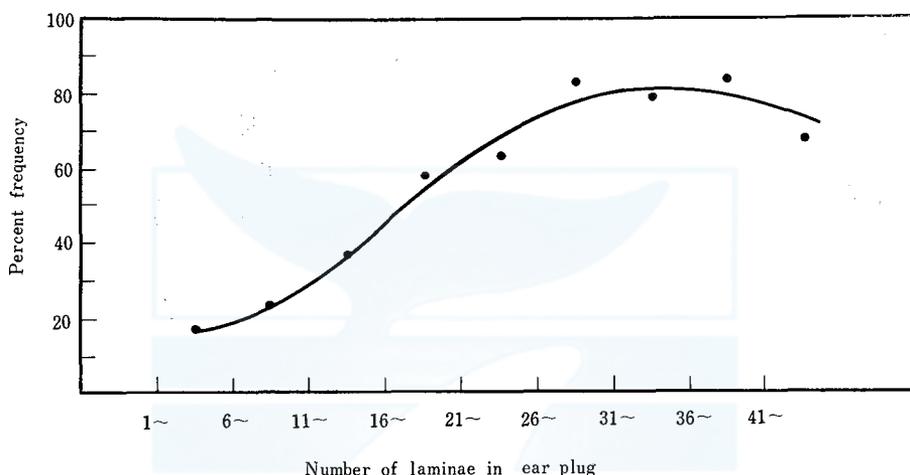


Fig. 1. Percentage frequency of discrepancy in the laminae counting of ear plugs from the North Pacific fin whales.

For standardizing the counting method of laminae, it is a way to exchange some ear plugs among scientists belonging to different countries and to count the laminae with each other. By this way, the individual interpretation can be avoided to some degree. For the advancement of whale biology, the agreement among scientists is of most importance. In 1959, the Whales Research Institute sent ear plugs of 6 fin whales caught in the Antarctic Ocean to Dr. Laws and ear plugs of 11 fin whales captured in the North Pacific to Mr. Pike. Dr. Laws who had then the duty at National Institute of Oceanography in England, sent me 8 ear plugs from Antarctic fin whales. Accepting the program of exchange, Mr. Pike sent me ear plugs of 10 fin whales captured off Vancouver Island. The laminations of these 35 ear plugs were independently counted and checked with each other.

It is concluded from the practice of this program that in the ear plugs of fin whales, if the structure of laminae is clear, the nearly same count is obtained, while, if the structure is vague, the value of laminae count is possibly lacking in agreement. Particularly, the intermediate bright layers are often found between the dense layers in the female ear plug. The presence of intermediate laminae, of which structure is usually vague and in some cases clear, results in the discrepancy in the laminae counting. It is worthy to remind that most of female ear plugs in the

Antarctic are composed of specimens showing vague laminae, as indicated in Table 1.

PHOTOMETRIC METHOD FOR COUNTING LAMINAE

The laminae counting is eventually to count the number of alternations of bright

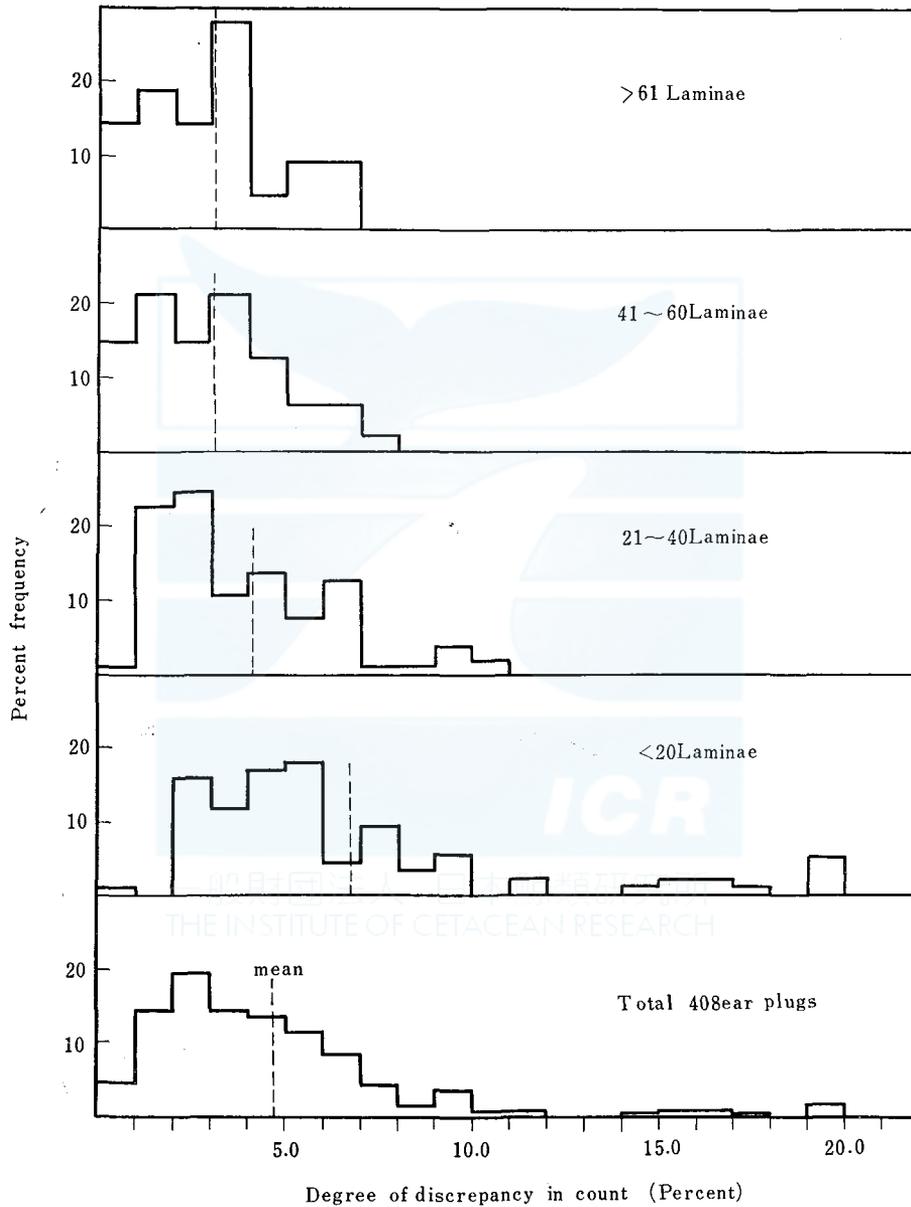


Fig. 2. Percentage deviation of individual counting from the mean count for the laminae of ear plug in the North Pacific fin whale.

and dark layers in the ear plug. The usual method of counting by naked eye observation or by means of dissecting microscope includes some ambiguity for the

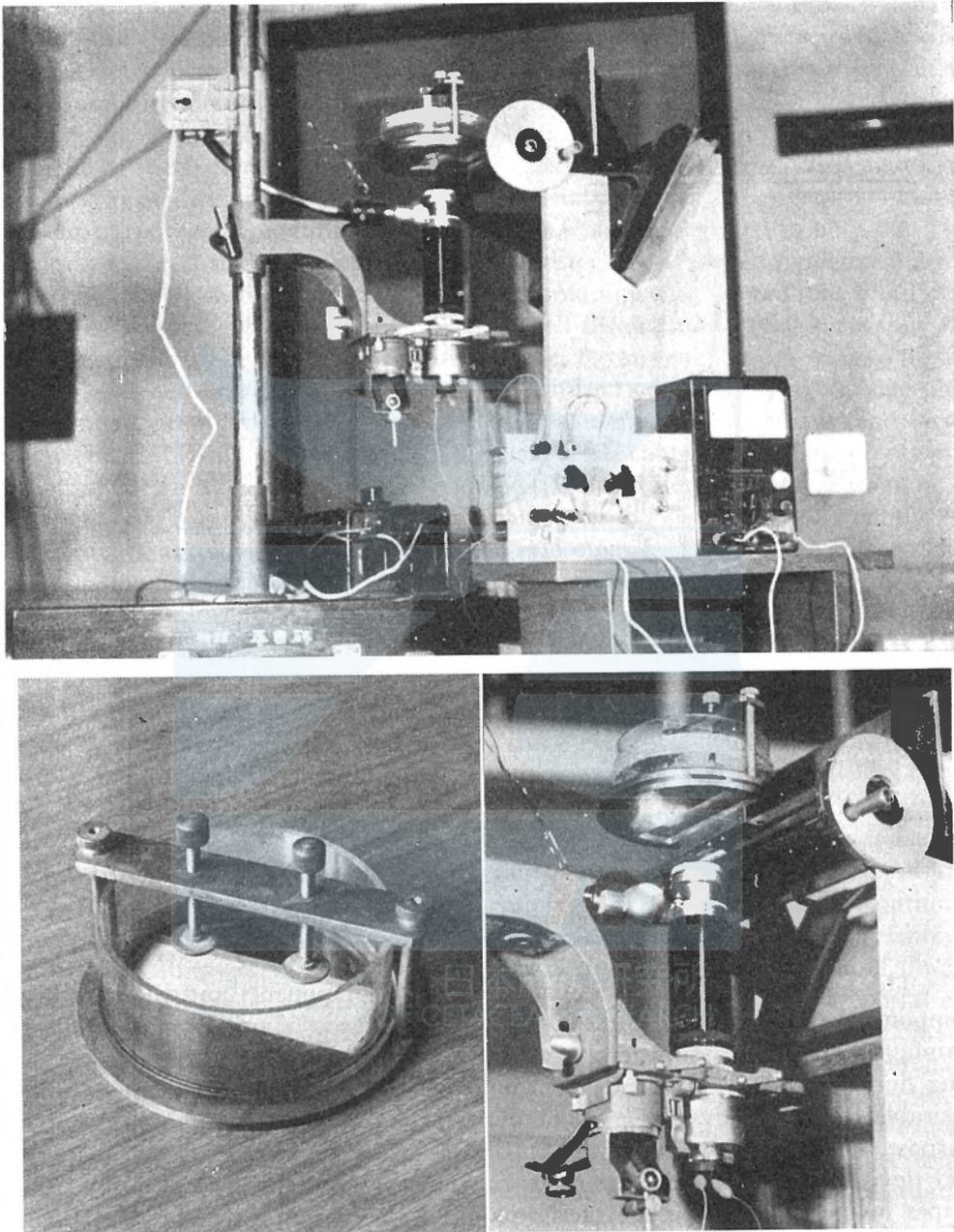


Fig. 3. Photographs of photometric counting apparatus. upper: General view, lower left: Glass vessel with the device of pressing screws, lower right: Upper half of the apparatus.

agreement among individual interpretations by different observers, especially in the case of vague laminae as pointed out in the preceding article. The judgment through our sense of sight is not always reliable.

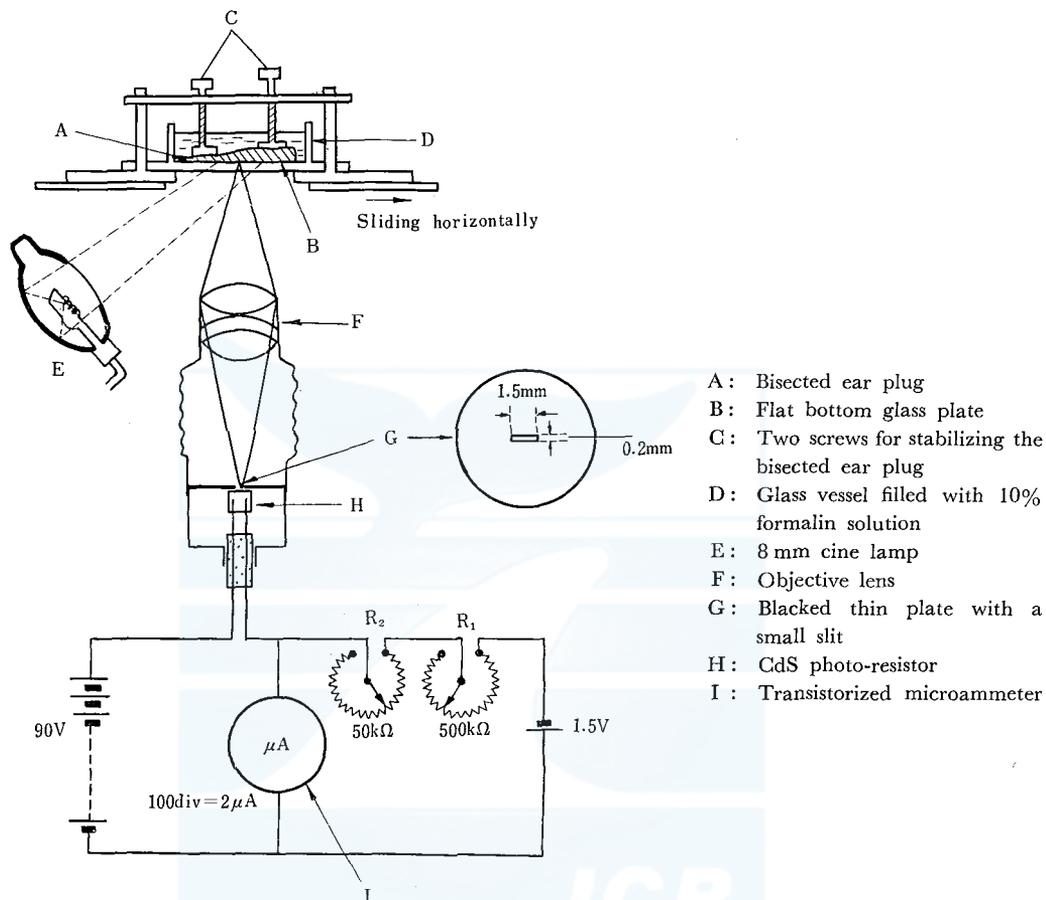


Fig. 4. Schematic diagram indicating the mechanism of photometric apparatus for counting laminae in the ear plug.

The laboratory work for staining the fatty components and the keratinized components respectively in the ear plug after slicing is laborious work, while this staining method is not sufficiently reliable for preserving the records unaltered for long duration. More accurate recordings of laminae in many ear plugs will be desirable for the analysis of age composition in the whale population. For this purpose, I have tried to utilize the apparatus, which had originally been designed and developed by Dr. M. Hirata to measure photometrically the brightness of stripes in the bisected surface of ear plug. A brief outline of this method will be given in the following lines.

Mechanism: The photograph of photometric apparatus is shown in Fig. 3, and its schematic diagram in Fig. 4.

The flat surface of longitudinally bisected ear plug (A) is smoothed with a fine whetstone. This specimen put in a glass vessel (D) containing 10% formalin solution for keeping the ear plug from drying, where the smoothed surface is faced the flat bottom glass plate (B), is pressed downwards by means of two screws (C). This glass vessel is placed on the sliding bench of the comparator and is driven in the horizontal direction by rotating. The flat surface of the plug is illuminated through the bottom glass plate by a 8 mm cine lamp (E). The magnified image of the laminae of the specimen is focused by the lens (F) on the blacked thin plate (G), which is provided with a small slit, 1.5×0.2 mm, opened at its centre. For the present purpose, the magnification ratio of the image is adjusted to about 2. Just behind the slit, a small piece of CdS photo-resistor (H) is placed, which is fed with a 90 V dry cell through a transistorized microammeter. A suitable small compensating voltage is applied from 1.5 V dry cell through the variable resistors (R_1 , R_2) to the microammeter (I) as is shown in Fig. 3, thus enabling us to read the fine variation of the brightness of fatty and keratinized components in the ear plug.

For the first experimental step, the scale of the microammeter is read successively at each 0.1 mm displacement of the glass vessel containing the plug by turning the micrometric screw. It may be more desirable to develop some automatic recording apparatus by connecting the microammeter to a pen-writing system through an adequate amplifier, and by driving the micrometric screw with a tiny synchronized motor. Furthermore, it is possible to conduct the measurement by continual watching the scanning spot on the image of laminae if the optical system can be modified by inserting a thin semi-transparent glass plate below the objective lens in an inclined orientation and projecting the same image to the watching window. Construction of such an automatic recording apparatus is now being planned, but at the present stage, I will describe only some examples of data obtained by the simple apparatus mentioned above.

Records: The method is applied for four ear plugs from the Antarctic fin whales captured in 1959/60 season. The reading of the microammeter is made at each 0.1 mm sliding position of ear plug and plotted in the figure. The pulsating curve in Fig. 5 & 6 is obtained by connecting these plotted spots with continuous line. The scale of ordinate in the figures is an arbitrary one and represents the relative brightness in the surface of the bisected ear plug. The scale of abscissa indicates the distance in mm from the proximal end of ear plug to the distal end. In the fluctuation of brightness in Fig. 5 & 6, the higher brightness represents the bright layer composed of fatty components in ear plug and, on the other hand, the lower brightness indicates the dark layer composed of keratinized epithelial cells of glove-finger in ear plug. Prenatal layer (Ichihara, unpublished) exists in the distal end of individual plug core and appears in the extremely higher brightness. Laminae in ear plug, therefore, can be counted as the number of fluctuations recorded in the paper. Numbers of my own count also are shown in Fig. 5 & 6.

Photographs of ear plugs from the Antarctic fin whales, tested for this photometric method are indicated in Fig. 7. One of these ear plugs is from the male fin whale and the remains are from the female fin whale. The biological data of

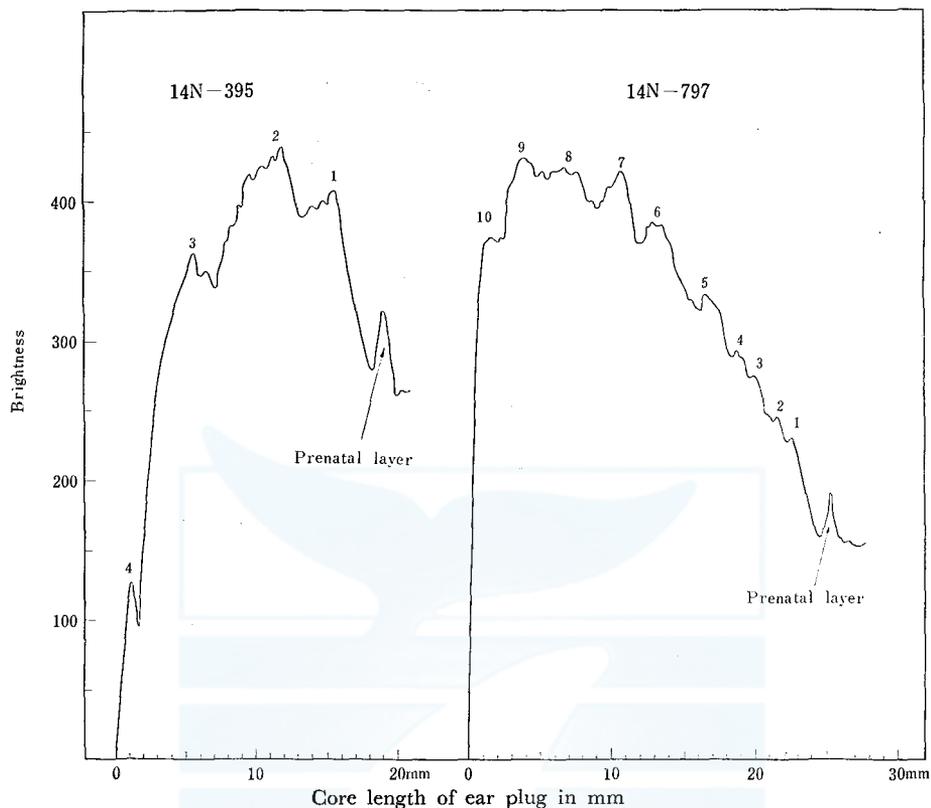


Fig. 5. Photometric records of brightness in the surfaces of bisected ear plugs which were obtained from the Antarctic two fin whales.

TABLE 2. BIOLOGICAL DATA OF FIN WHALES OF WHICH EAR PLUGS ARE USED FOR THE PHOTOMETRIC METHOD

Serial No.	Body length in feet	Sex	Position of capture	Date of capture	Foetus length in feet	Ovary Corpora Number	Testis Weight in Kg	Laminae number in ear plug
14N-395	61	Female	57-19S, 91-29E	11. Jan. 1960	None	0	—	4
14N-797	68	Male	60-38S, 153-56E	25. Jan. 1960	—	—	19.6, 19.1	10
14N-100	69	Female	57-43S, 96-06E	1. Jan. 1960	M 5-4	Mature	—	31
14N-1585	70	Female	62-53S, 150-19E	7. Mar. 1960	F 5-9	18	—	42

these fin whales are tabulated in Table 2 with special reference to the sexual state.

DISCUSSION

In the laminae counting, it is of importance to observe the prenatal layer in the ear plug. In the course of bisection for the ear plug, the prenatal layer is often grinded down, however, without confirming the existence of prenatal layer the total laminae are never counted.

Photometric method records the whole alternation of bright and dark layer

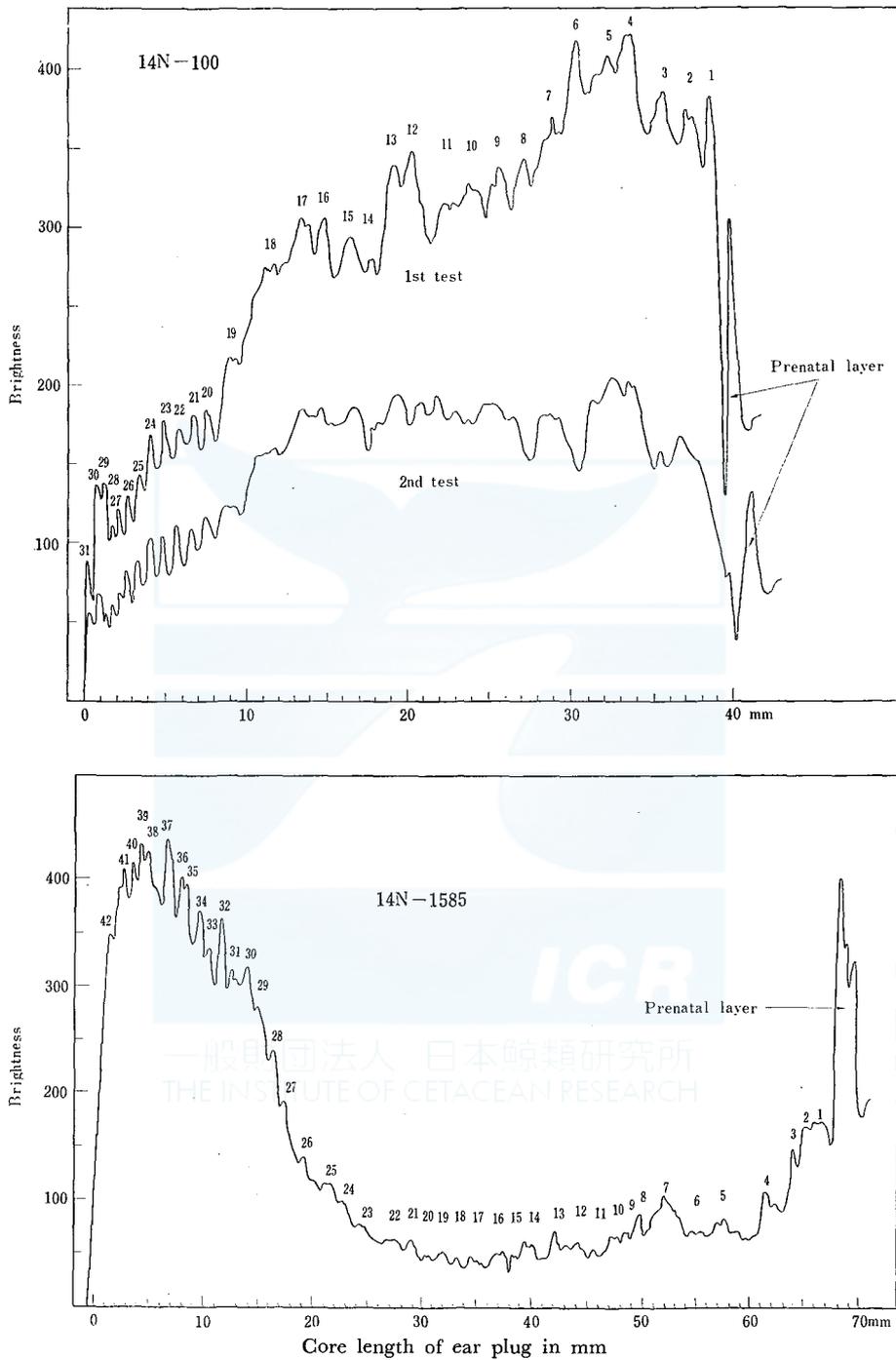


Fig. 6. Photometric records of brightness in the surfaces of bisected ear plugs which were obtained from the Antarctic two fin whales.

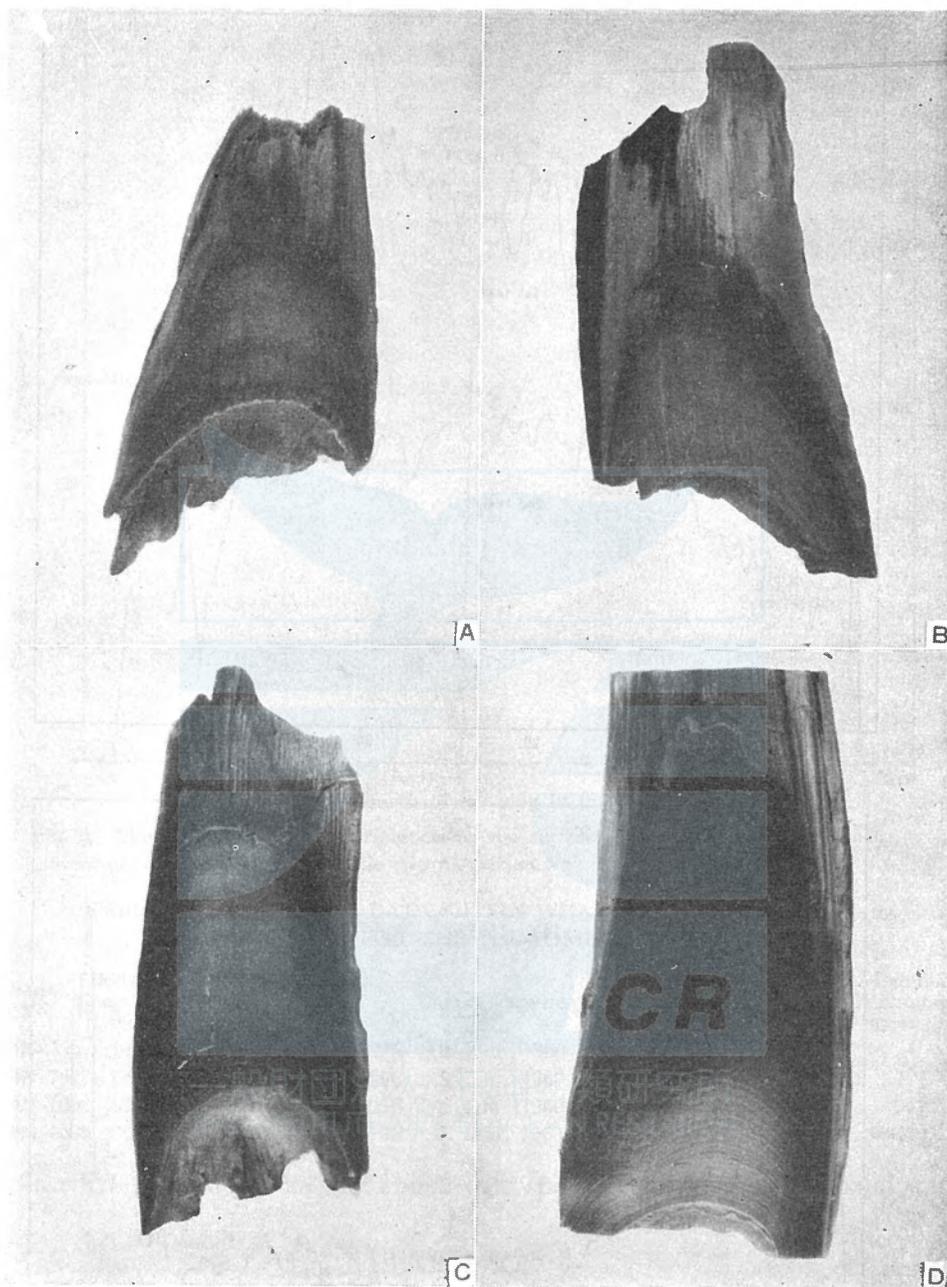


Fig. 7. Photographs of bisected ear plugs from the Antarctic four fin whales, tested for the photometric method. A; Serial no. 14N-395, B; 14N-797, C; 14N-100, D; 14N-1585.

in the ear plug. The dense layer which is supposed to be significant for determining age is possibly selected from the records of alternation. The distance between the higher and the neighbouring lower brightness is suggestive to find out the dense

layer among various fluctuations. In some cases, the dense layer is found in the periodicity in the fluctuation of brightness. On the other hand, whether or not the laminae are clear, it is noteworthy that the histological structure in the alternation of two kinds of layers is similar. The evidence that Walford's formula (1946) is not applied even for the growing layer of the ear plug indicating clear laminae suggests that there is no rigid periodicity in the thickness of each lamina. The alternation of each lamina, therefore, should be understood as the reflexion of the physiological rhythm of whale body, but further anatomical and physiological researches are needed for this study.

The general colour tone of the surface of bisected plug core is indicated in the curve of brightness in Fig. 5 & 6. In the general tendency except 14N-100 specimen, it has the highest brightness near the proximal end of plug core. In the distal half of 14N-1585 specimens in Fig. 6, the clear laminae are not recorded, as compared with the proximal half of that ear plug. This record shows the frequent presence of the intermediate laminae in the distal half of the specimens, in which the arbitrary count is probably made by individuals.

When the bisected ear plug on the glass plate (B) in Fig. 3 is slid along its longitudinal axis, it is presumed that the longitudinal bright band in the ear plug, (See Fig. 7) disturbs the measurements of brightness in the concentric laminae. To examine this disturbance, the second test is tried for 14N-100 specimen at the slight different position and also indicated in Fig. 5. The similar fluctuations of brightness are obtained between such two examinations. Photometric method is one of the most valuable to standardize the laminae counting in the ear plug.

SUMMARY

Accurate counting of laminae in the ear plug is most necessary to determine the age of baleen whales. Interpretation of laminae favoured by individual scientist stands in the way of advancement in the whale biology. Independent counting of laminae by two persons in our institute through naked eyes or dissecting microscope observation indicates that the individual discrepancy in laminae counting is usually 10% to the total laminae number.

For standardizing the laminae counting, the exchange of ear plugs between England and Japan, besides between Canada and Japan were practised in 1959. The results that the laminae were counted independently and checked with each other indicates that the nearly same counting is made in the ear plug showing clear layer but that the discrepancy in counting occurs in the ear plug of vague layer. As two third of ear plugs from female fin whales is composed of vague laminae, the individual discrepancy in counting for them has a great effect on the age determination. To avoid the individual interpretation, the photometric method for counting was devised. By this method, the whole alternation of bright and dark layer in the ear plug can be recorded and the thickness of each layer can be measured. The objective interpretation begins with the record of permanent use.

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THE LAMINATIN OF THE MASSETER OF THE HUMPBACK WHALE*

TETSUO YOSHIKAWA AND TAKASHI SUZUKI**

PREFACE

Basing upon the comparative anatomical study of the masseter of various mammals, which include the marsupial (kangaroo), the insectivore (mole), the chiroptera (macro- and microchiropteras), the primate (monkey, apes and man), the rodent (rat and marmot), the lagomorph (rabbit), the carnibore (dog, cat and bears), the artiodactyl (pig, camel, deer, goat, sheep and cattle), the perissodactyl (horse), Yoshikawa et al (1961, 1962) proposed that the masseter of mammal shows a laminar structure, which consists of the following six elements :

A. The proper masseter,

- 1) M. masseter superficialis, lamina prima,
- 2) M. masseter superficialis, lamina secunda,
- 3) M. masseter intermedius,
- 4) M. masseter profundus, pars anterior and pars posterior.

B. The improper masseter,

- 5) M. maxillomandibularis,
- 6) M. zygomaticomandibularis.

The above laminar pattern is the modification of that of Seiferle (1958) in the dog, in which Seiferle overlooked the second superficial masseter and the maxillomandibular muscle. Although these six elements receive, of course, the various modification as the animal varies, the fundamental principle seems to be applicable through the various animal. Then, how far the laminar pattern described above can be applied to the whale, one of the most specialised forms in the mammal?

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MATERIAL AND METHOD

The male fetus of the humpback whale, *Megaptera nodosa* Bonn., is used, the body length of which measures 17 cm long (Fig. 1).

When the laminar structure is investigated, the tendon of the muscular layer should never be cut through. It is recommendable to cut the muscular substance of the layer along the terminal line. By cutting the indicated line, the blade can reach the tendon of the underlying layer. By scraping along the underlying tendon, the layer can be easily separated. There is the 'reversal relation of the tendon and the muscular substance' between the succeeding layers.

* Dedicated to Professor T. Ogawa for his sixtieth birthday

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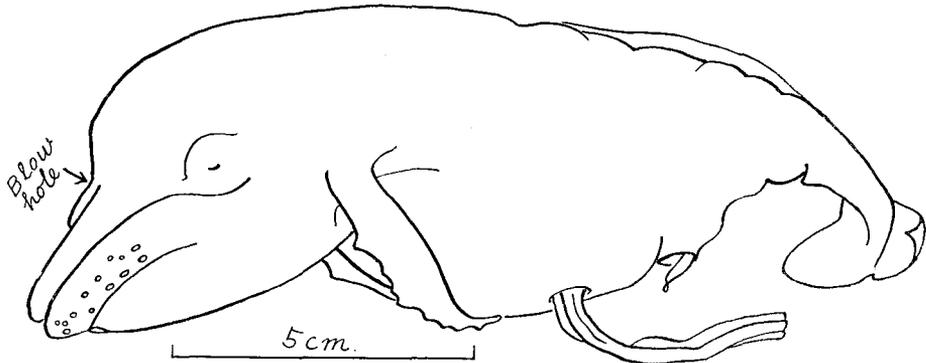


Fig. 1. The fetus of the humpback whale.

DESCRIPTION

The mandible does not yet ossify completely. The posterior part of the zygomatic arch only develops, while the anterior half of the arch presents the tendinous structure, making the ventral border of the orbit.

The first superficial masseter arises from the ventral border of the orbit with the narrow tendon, running ventrocaudally. It terminates along the mandibular angle with the rich muscular substance, spreading in the semicircular form (Fig. 2, A and B). Crossing under this narrow tendon, the slender muscle which takes

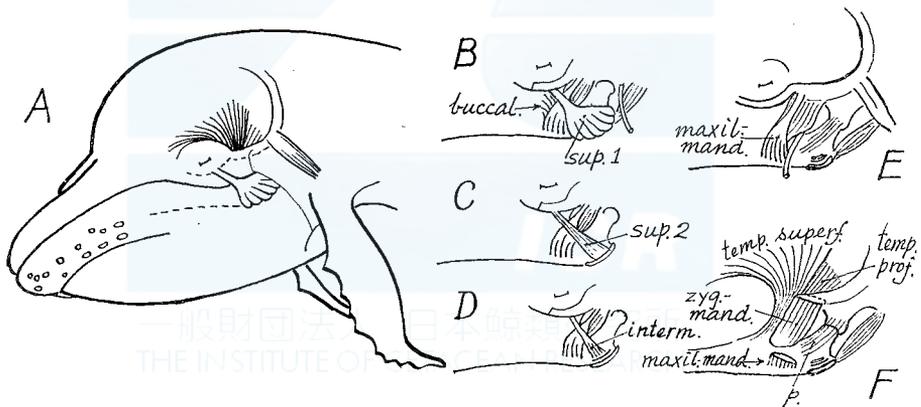


Fig. 2. The laminar structure of the masseter of the humpback whale.

buccal . . . M. buccalis, interm. . . M. masseter intermedius, maxil-mand . . . M. maxillomandibularis, p . . . M. masseter profundus, sup. 1 . . . M. masseter superficialis, lamina prima, sup. 2 . . . M. masseter superficialis, lamina secunda, temp. superf. . . M. temporalis superficialis, temp. prof. . . M. temporalis profundus, zyg-mand . . . M. zygomaticomandibularis.

its origin at the anterior extremity of the zygomatic process of the temporal bone runs anteroventrally. This is the maxillomandibular muscle (side infra). When the first superficial masseter is overturned by cutting its muscular substance along

the mandibular angle, the slender second superficial masseter is found, the direction of which coincides with the narrow tendon of the first superficial masseter (Fig. 2, C). Its tendon is found on the mandibular side and the muscular substance develops on the orbital side. When the muscular substance of the orbital side is cut cautiously, the tendon of the intermediate masseter makes its appearance, the muscular substance of which develops on the mandibular side (Fig. 2, D). Comparing with the first superficial masseter, the second superficial and intermediate masseters are very narrow, overlapping in the same form.

The deep masseter does not make a good development, spreading as a thin sheet between the root of the condyloid process and the glenoid fossa of the zygomatic arch (Fig. 2, E and F).

Making the X-form with the superficial masseter, the thick muscular column develops, connecting the anterior extremity of the zygomatic process of the temporal bone and the mandible. This column can be divided into the medial thick column and the lateral thin muscular plate. The latter is the maxillomandibular muscle, which arises as the thin plate at the anterior extremity of the zygomatic process of the temporal bone, spreading anteroposteriorly (Fig. 2, E). The former is the zygomaticomandibular muscle, which originates from the medial side of the anterior extremity of the zygomatic process and terminates near the root of the small coronoid process (Fig. 2, F).

The temporal muscle can be divided into the superficial and deep muscles (Fig. 2, A and F). The superficial temporal muscle arises from the dorsal side of the orbita and the anterior half of the temporal fossa and terminates on the vestigial coronoid process. The deep temporal muscle is recognised between the posterior margin of the superficial temporal muscle and the zygomatic arch.

CONSIDERATION

In the specialised mammal such as the whale, whalebone or toothed, we expected the modification of the laminar pattern of the masseter. The result of investigation, however, proved that the laminar subdivision after Yoshikawa et al can be also applied to the whale. The proper masseter, however, shows the atrophy as the layer deepens; while the improper masseter makes a good development, especially the zygomaticomandibular muscle.

Such a poor differentiation of the proper masseter coincides well with the loss or weak development of teeth, which does not require the quick and strong mastication. On the contrary, the enormously long mandible requires the strong closure. To this purpose, the development of the improper masseter plays a good role. The analogous model is furnished with the forceps, which is easily closed by pressing the sides with fingers, while it is not easily closed by manipulating the base of the forceps.

Toldt (1905) reported the masseter of the dolphin, *Delphinus delphis*, in which Toldt mentioned only two layers. The superficial layer is piriform and corresponds to the first superficial masseter after Yoshikawa et al. The deep

layer which is covered by the superficial layer corresponds to the intermediate masseter after Yoshikawa et al. The existence of zygomaticomandibular muscle is denied, owing to the incomplete zygomatic arch. If Toldt cuts the muscular substance of the superficial layer along the mandibular terminal line, he would easily succeed to discover the tendon of the second superficial masseter. Toldt mentioned the maxillomandibular muscle in the rodent only and included it in the zygomaticomandibular muscle in the other mammal.

In the dolphin, the zygomatico- and probably maxillomandibular muscles may be hidden behind the zygomatic process of the temporal bone. The complete absence of these muscles can not be imagined in the toothed whale from the result of investigation, not only in the whalebone whale, but also in the general mammal.

SUMMARY

In the fetal humpback whale, one of the mistacoceti, the proper masseter presents the atrophy as the layer deepens, while the improper masseter makes a good development, especially the zygomaticomandibular muscle.

In the proper masseter, the first superficial masseter makes fairly a good development, while the second superficial and intermediate masseters remain narrow and thin muscles. The deep masseter remains rudimentary.

In the improper masseter, the maxillomandibular muscle is a broad but thin muscle. The zygomaticomandibular muscle is the thick muscular column, which plays the most important role to close the long mandible.

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INTRA-UTERINE SELECTION DUE TO MATERNAL-FETAL INCOMPATIBILITY OF BLOOD TYPES IN THE WHALES*

KAZUO FUJINO

Since its discovery, it had been generally considered that blood type was hereditarily neutral characteristics free from natural selection. Thereafter many observations were reported on the correlations between blood types and hemolytic diseases in newborn or erythroblastosis foetalis and differential survival in intra-uterine life such as rate of fertility and of miscarriage and in extra-uterine life for human and some other mammalian species (reviewed in Race and Sanger, 1959, pp. 310-312). These knowledges have led to rise of discussions on natural selections relating to blood groups. Series of recent papers on human blood groups by Matsunaga (1953, 1954, 1959), Matsunaga and Itoh (1953, 1954, 1958), Simmons et al. (1960), Grubb and Sjöstedt (1955), and Jakobowicz et al. (1961) furnish more evidences from these view-points. Basing upon the results of the Antarctic whaling investigation in 1960/61 season, Fujino (1962) describes that differential percentage pregnancies by blood groups were seen in both species of the Antarctic pigmy-blue and the fin whales, and that hemolytic antibodies were positively detected from isoserums of fin whales. Then he states that the facts in these observations strongly suggest incidence of miscarriages of fetuses caused by maternal-fetal incompatibility of blood types in whales and that these frequencies of occurrence will closely relate to gene frequencies of blood types of the population. Results of further observations in 1961/62 Antarctic season (Fujino, unpublished data) confirm the differential rates of pregnancy stated above. In the present paper, at first are described the results of observation, that is a) differential apparent rates of pregnancy by blood groups and b) hemolytic properties of isoserums as the evidences suggesting intra-uterine selection in whales. Secondly, after basing upon knowledges about intra-uterine selection and its compensatory mechanism in human (Matsunaga, 1954), quantitative relationships between selection and fitness are discussed, and the prenatal mortality rate is estimated for actual population of whales.

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MATERIALS AND METHODS

Testing bloods All stages of testing bloods were performed on board for fresh samples, and the methods of typing blood are same as that described in the previous paper (Fujino, 1962). In addition, hemolytic antibodies were detected for isoserums as follows. To each test-tube containing a series of successive dilutions of inactivated fresh isoserum was added equal volume of 2% cell suspension, and mixtures were incubated at 37°C. Thirty minutes later, reading was made. In-

* Dedicated to Professor T. Ogawa for his sixtieth birthday

direct Coomb's Test (I.C.T.) was undertaken as follows (refer Race and Sanger, 1959). To each tube containing two drops of a series of successive dilutions of iso-serum was added equal volume of 2% cell suspension, and mixtures were incubated at 37°C for one hour. After being washed three times with cool saline, two drops of 1:10 diluted immune rabbit antiserum, prepared by injecting fin whale serum, were added to the coated cells. Ten minutes later, results of reactions were observed.

Observing ovary and internal reproductive organ of female whales As it is generally considered that corpus albicans survive on ovary throughout life of female whale even after diminishing in size (Mackintosh, 1929 and Laws, 1961), one can know accumulated number of past ovulation for each individual by counting the ovarian corpora. When carcasses of female whales were treated on board, ovaries were taken out and were observed. Individuals, of which existence of ovarian corpora were positively detected, were recognized as sexually mature. Simultaneous observations on uterine conditions were made to discriminate pregnancy or not. Female, from which fetus was found in their uterus, always possesses functional corpus luteum in the ovaries. Sometimes, however, observation encounters females from which no fetus was found in spite of existence of functional corpus luteum in their ovaries. These are generally interpreted to correspond with one of following three cases, that is, 1) the corpus is originated from mere ovulation without fertilization, 2) tiny embryo at a very younger stage of conception was missed or 3) it has not passed so long time since fetus had been lost because of shock when killed or of physiological factors. For some individuals of females additional observations were made by author himself for intra-uterine conditions especially for degree of congestion of mucous membrane.

EVIDENCES SUGGESTING INTRA-UTERINE SELECTION RELATING TO BLOOD GROUPS

First of all, problems identifying breeding subpopulations should be discussed here. After studying summarized results of marking return including those taken after his previous work (Brown, 1954), Brown (1962) stated as follows. "Marks from fin whales do suggest that fin whales from different breeding-populations may intermingle on the feeding-grounds, and that the 'groups' of whales within the whaling Areas may include animals belonging to more than one breeding population. Thus, sector of area III which lies to the south of South Africa has been shown to contain during the southern summer fin whales from the populations of the South Atlantic and Indian Oceans." Fujino (1962) extends blood typing investigation, which was undertaken to identify breeding population of the North Pacific fin whales (Fujino, 1960), to the Antarctic fin whales, and states that "The frequency of occurrence of Ju blood types of finbacks suggested that a portion of the Atlantic population from area II migrates to area III and mingles with the population there." Frequencies of occurrence of Ju₂-positive types were estimated approximately as 2 per cent for the aboriginal population of the area III and as

30 per cent for the postulated Atlantic population which partly contribute to the stocks in the area III, and estimation of intermingling ratio between both populations were made for the sample taken from area III in 1960/61 season. Results of further investigation in 1961/62 confirm existence of geographical non-random distribution of frequency of occurrence of blood types stated above, and suggest existence of the additional different populations in the area IV of which frequency of occurrence of Ju2-positive types reveals somewhat higher figure than that of aboriginals in the area III (Fujino unpublished data). These might support the already-cited knowledges which was noted by Brown (1962). When various parameters for population study were obtained from area in which migratory ranges of different populations overlapped each other, the figures should be separated into those proper to each pure population. Figures for the postulated Atlantic population in Table 1 were obtained by summarizing data on several days in which daily incidence of Ju2-positive blood types jumped up significantly (refer Fujino, 1962).

TABLE 1. FREQUENCY OF OCCURRENCE OF FIN WHALE Ju MAJOR BLOOD TYPES IN THE AREA III OF THE ANTARCTIC*

Blood type		Postulated Atlantic Population**	Geographical area***		
			B	A	C
Percentage of Ju2-negative type]	Ju1	69.7	91.2	95.4	98.0
Percentage of Ju1-2 heterozygote]	Ju1.2	25.0	7.5	4.0	2.0
Percentage of Ju2 homozygote]	Ju2	5.3	1.3	0.6	0.0
Total numbers of whales typed		132	734	350	104

* Cited from Fujino (1962)

** Sum of the data of days in which the frequency of occurrence of Ju2-positive types jumped to high frequencies of approximately 30 per cent.

*** Arbitrarily divided as follows ; section A : 35 to 70 degrees east of south of 50 degrees south ; section B : 0 to 35 degrees east of south of same ; section C : north of 50 degrees south.

Here some results of observation can be adduced as evidences suggesting intra-uterine selection relating to blood groups. As already reported by Fujino (1962) no significant differences was seen in frequency of occurrence of blood types between both sexes, but marked differences in the percentage of pregnant whales among mature females were recognized between Ju2-positive and Ju2-negative blood groups in the pigmy-blue and the fin whales. These relationships were confirmed with results of further investigation in 1961/62 season (Fujino, unpublished data). Table 2 shows these figures obtained in the season 1960/61 for different geographical areas and for the postulated Atlantic population. Although fin whale bloods were classified into seven types in all by subgrouping Ju2 antigen complex (Fujino, 1962), in Table 2 comparisons of percentage incidence of pregnant female are shown for three major groups alone, because of scantiness of data for subdividing. It can be seen from this table that percentage incidence of pregnant whales among mature

females reveals lower figure in Ju1 group than that in Ju2-positive groups. Similar type of observations were reported for human already. For instance, basing upon his observations on marked differences of rate of miscarriage between compatible and incompatible matings for ABO blood groups, Matsunaga and Itoh (1954) state that there should be differential natality rates between these two types of

TABLE 2. DIFFERENCE OF PERCENT OF PREGNANCY BY BLOOD TYPES AMONG ADULT FEMALE WHALES*

Blood type	Fin whale				Pigmy-blue whales
	Postulated Atlantic population	B	A	Sum of A and B	
Ju2-positives	78.9(19)**	73.3(30)	40.0(5)	68.6(35)	71.4(7)
Ju2-negatives	63.9(36)	61.6(307)	51.5(101)	59.1(408)	32.8(61)

* Cited from Fujino (1962) ** Figures in parentheses show number of samples typed.

matings. Basing upon data collected at maternity hospitals, Boorman (1950) and Bryce et al. (1950) find with regard to compensatory mechanisms against intra-uterine selection that rate of conception in mother population reveals the highest figure in AB group than those in any other three groups belonging to ABO blood group system. According to analogical construction from these phenomena in human being, above-stated observations in whales might suggest that there should be significant differences by blood types in the rates of fertilization or of miscarriage or in both.

As already reported by Fujino (1962) most donors classified as Ju1 type homozygote have anti-Ju2 isoantibodies in their serum, and moreover isoantibodies are positively detected with reference to three kinds of Ju2 specificities in fin whales.

TABLE 3. TITRATION OF ISOAGGLUTININ OF FIN WHALE, NOT INACTIVATED*

cells of:		no. 313 serum**					cells of:		no. 1161 serum***				
type	no.	16	32	64	128	256	type	no.	8	16	32	64	128
Ju1	313	—	—	—	—	—	Ju1	1275	—	—	—	—	—
Ju1·2 ₃	394	##	++	+	—	—	Ju1·2 ₃	1279	—	—	—	—	—
Ju1·2 ₂	403	##	##	##	++	+	Ju1·2 ₂	1301	++	++	+	—	—
Ju1·2 ₁	349	##	##	##	++	+	Ju1·2 ₁	1348	##	##	##	++	+

cells of:		no. 1374 serum**					cells of:		no. 121 serum			no. 368 serum		
type	no.	4	8	16	32	64	type	no.	1	2	4	1	2	4
Ju1	1275	—	—	—	—	—	Ju1	313	—	—	—	—	—	—
Ju1·2 ₃	1279	++	+	—	—	—	Ju1·2 ₃	394	—	—	—	—	—	—
Ju1·2 ₂	1301	##	##	++	+	—	Ju1·2 ₂	403	—	—	—	++	+	—
Ju1·2 ₁	1348	##	##	##	++	+	Ju1·2 ₁	349	++	+	—	##	++	+

* Blood types of these donors are Ju1 (nos. 313 and 1374), Ju1·2₃ (nos. 368 and 1161) and Ju1·2₃ (no. 121).

** Specific hemolysis were observed up to dilutions 1:8 in no. 313 serum and 1:2 in no. 1374 serum against Ju2 positive cells.

*** Specific hemolysis was observed at dilutions 1:1 through 1:4 against nos. 1301 and 1348 cells.

That is, Ju₂₃ subtype donors had isoantibodies for Ju₂₁ and Ju₂₂, Ju₂₂ donors had isoantibody for Ju₂₁, while Ju₂₁ had no isoantibody. Table 3 shows titrating results for several examples of these isoserums. No isoserum for Ju₁ has been discovered. Most fresh isoserums possessing antibodies specific to Ju₂, derived from Ju₁ type donors, agglutinated Ju₂₁ cells at dilutions ranging from 1:2 to 1:256 and hemolysed at dilutions between 1:1 and 1:16 when not inactivated. However, two examples of isoserums taken from Ju₁ type female donors (nos. 301 and 347), which have ovaries with functional corpus luteum and congested uterus but lack fetus, revealed marked high titer. Table 4 shows comparisons of agglutinin

TABLE 4. COMPARISON OF AGGLUTININ TITER OF ISOANTIBODIES OF JU 1 TYPE OF FIN WHALES AT VARIOUS PHYSIOLOGICAL CONDITIONS, EXAMINED BY INDIRECT COOMB'S TEST (I.C.T.)

Physiological condition		no. of samples examined	range of titer*
male	mature	8	1:4~1:512
female	mature, resting	5	1:4~1:512
"	" pregnant	9	1:4~1:1024
"	" non-pregnant, but with functional corp. lutea, excluding nos. 301 & 347	11	1:4~1:1024
"	" " no. 301**	1	1:2048
"	" " no. 347**	1	1:4096

* Tested against Ju₂₁ homozygote cells. The rabbit serum prepared by injecting fin whale serum does not agglutinate whale cells at dilution used.

** Probable abortive 2 females out of 13 samples with a functional corpus luteum in their ovary but lacking fetus.

titer by different physiological conditions for these anti-Ju₂ isoantibodies derived from Ju₁ type donors. Titrations of isoserums were made by means of Indirect Coomb's Test (I.C.T.). These observations suggest that titers of isoantibodies of the Ju₁ mothers have risen by isoimmunization between fetus and mother which followed conception of Ju₂-positive fetus and that subsequently the fetus seemed to be miscarried by hemolytic diseases some time before the mother whale was captured.

No other anatomical observation has been made for this problem at present. While it has not been solved yet how soon do the enlarged and congested uterus regress and do functional corpus luteum diminish into corpus albicans. If these physiological regression would be accomplished in a comparable shorter interval, it might be reasonable to presume that a very limited number of miscarriages are anatomically confirmed at present, even if extensive observations are attempted.

Above-stated facts suggest that intra-uterine selections occur at fairly high frequency in incompatible mating of Ju₁ female × Ju₂-positive male. Though no direct evidence suggesting selection in another incompatible mating of Ju₂ female × Ju₁ or Ju₁·2 male has been obtained, it can be assumed that this selection might

occurs at lower frequency than in the former incompatible mating in the recruiting generation in all, because 1) no isoantibody for Ju1 has been found in the serums of Ju2 donors, and 2) Ju2 homozygote has very low frequency of occurrence in the population.

In the case of human beings, differential natality rates between incompatible and compatible matings can be observed after second conception of each individual for Rh blood group system, but even in first conception already for ABO system. It is thought to closely relate to these facts that natural isoantibodies for Rh factor occur irregularly at low frequency, while those for A or B factor occur always in connection with existence of erythrocyte antigens (Matsunaga, 1959). As already stated, most Ju1 type donors have isoantibodies specific to Ju2 in fin whales, so that it can be surmised that intra-uterine selection in this species occurs already even in first conception, although no available observation has been made so far.

RELATIONS BETWEEN FREQUENCIES OF OCCURRENCE OF BLOOD TYPES AND OF INTRA-UTERINE SELECTION

Fujino (1962) states that prenatal mortality rate due to intra-uterine selection will closely depend upon the frequency of occurrence of Ju blood groups. Analysis of these quantitative relationships will be attempted in this paragraph. First of all genetic relationships should be discussed. After considering far lower figures in relative frequency of occurrence of Ju1·2 heterozygote against those which are expected from hypothetical two allelic system for random mating population and parentages between mother and fetus, Fujino (1960) proposed that three allelic genes including a dominant or recessive gene will be involved in the Ju blood group system for the north Pacific fin whale population. In the results of investigation for the Antarctic fin whale population, however, observed figures of relative frequency for major three blood groups are well consistent with those which are expected from major two equal allelic genes for the random mating population (see Table 1). Furthermore, it became to be obvious that Ju2 antigen was subdivided into three kinds of subtypes, so that it can be assumed so far that four allelic genes including one (j_1) for Ju1 antigen and three (j_{2_1} , j_{2_2} and j_{2_3}) for Ju2 antigen complex equal each other are involved for Ju blood group system of the Antarctic fin whales. According to this hypothesis phenotype-genotype relationships can be expressed as those in Table 5. As shown in Table 3, differential intensity in agglutination reaction is observed among these three subtypes for the same reagent, and some evidences have been obtained which suggest existence of subtypes among Ju2-positive groups for the North Pacific whales also (Fujino, 1960, Table 7). These facts may lead necessity in future to re-consider allelic system and biases in relative phenotypic frequency which may be reflected by existence of subtypes and dosage effect. In Table 5 are shown relative frequencies of three major phenotypes in the random mating population, where summarized frequency of allelic genes j_{2_1} , j_{2_2} and j_{2_3} controlling three specificities of Ju2 antigen complex is q and that of j_1 is p .

Secondly, should be noted definition of compatible-incompatible relationships

of pregnancy or mating in relation to blood groups of whales. According to Matsunaga (1959), incompatible pregnancy means a case which erythrocytes of cow does not possess an antigen, which is hereditarily derived from bull and exists in fetal blood. All other cases belong to compatible pregnancy. Incompatible mating is the combination which may cause incompatible pregnancy, and other combinations

TABLE 5. PHENOTYPE-GENOTYPE RELATIONSHIPS FOR THE ANTARCTIC FIN WHALE JU BLOOD TYPES UNDER A HYPOTHETICAL ALLELIC SYSTEM

Phenotype	Genotype	Frequency of occurrence in* the population at Hardy-Weinberg's Equilibrium
Ju2-negative	Ju1 j1 j1	p^2
Ju2-positive	{ Ju1·2 ₃ j1 j2 ₃	} $2 pq$
	{ Ju1·2 ₂ j1 j2 ₂	
	{ Ju1·2 ₁ j1 j2 ₁	
	{ Ju2 ₃ j2 ₃ j2 ₃	} q^2
	{ Ju2 ₂ j2 ₃ j2 ₂ , j2 ₂ j2 ₂	
{ Ju2 ₁ j2 ₃ j2 ₁ , j2 ₂ j2 ₁ , j2 ₁ j2 ₁		

* Freq. of occurrence of j1 gene is p , summarized freq. of j2₁, j2₂ and j2₃ is q , and amount to 1.

belong to compatible mating. Table 6 shows these compatible-incompatible combinations related to major three phenotypes of Ju blood group system. As available data are not sufficient to analyse the problems under considering for subtypes, following discussions in the present paper will be undertaken in accordance with combinations in Table 6.

TABLE 6. COMPATIBLE-INCOMPATIBLE PREGNANCIES AND MATINGS IN FIN WHALE JU MAJOR THREE BLOOD TYPES

pregnancy				mating			
compatible		incompatible		compatible		incompatible	
mother	fetus	mother	fetus	female	male	female	male
Ju1	Ju1	Ju1	Ju1·2	Ju1	×Ju1	Ju1	×Ju1·2
Ju2	Ju2	Ju2	Ju1·2	Ju2	×Ju2	Ju1	×Ju2
Ju1·2	Ju1	—	—	Ju1·2	×Ju1	Ju2	×Ju1·2
Ju1·2	Ju1·2	—	—	Ju1·2	×Ju1·2	Ju2	×Ju1
Ju1·2	Ju2	—	—	Ju1·2	×Ju2	—	—

Next problems to be considered are compensatory mechanisms against selection for heterozygotes. Phenotype to be selected disadvantageously by maternal-fetal incompatibility of blood types is always heterozygous fetus to be born from incompatible matings. This means that equal numbers of two kinds of major allelic genes controlling antigens Ju1 and Ju2 eliminate from the population in each occasion of selection. If this phenomenon would merely progress, gene frequency of the population should promptly shift and in consequence will be attained monomorphism consisting of one gene which had higher frequency at the ancestral population. In real natural population, however, polymorphism is generally maintained.

Regarding to these facts Matsunaga and Itoh (1954) state that the mortality rate of eliminating heterozygotes is so high that mutation could not sufficiently compensate the losses of genes in each generation. At present following several phenomenon are discussed in population genetics for human blood groups as the possible mechanisms for maintaining polymorphism.

a) Excessive natality rate of heterozygous fetus in compatible mating : After reporting excessive natality of MN type child in the mating of MN mother \times MN father and of AB type child in the mating of AB mother \times AB father in human, Matsunaga (1954) states that heterozygous fetuses are disadvantageously selected in incompatible mating, while in compatible mating number of this type of child which are actually born exceeds expected figure. Though sufficient evidences suggesting these similar phenomena have not been obtained yet in whales because of scantiness of data, it might be interpreted that differential rates of pregnancy between Ju1 and Ju2-positive blood groups which was described in the previous paragraph might consist of two elements of decline by intra-uterine selection in Ju1 group cows and of excessive natality of Ju1.2 heterozygous calves in Ju1.2 heterozygous cows, if similar trends would be involved.

b) Selective interaction between different blood group systems : After partitioning the matings, that had produced miscarriages or stillbirths, by MN and ABO incompatibility jointly of human blood groups, Matsunaga (1960) found a significant excess in the MN compatible, ABO incompatible mating and states that this might suggest that selection of heterozygous child due to ABO incompatible tend to occur more frequently in compatible mating than in incompatible mating relating to MN blood group system. Although no information relating to the similar type of facts has been available yet in whales, it must be important problem to be discussed in subsequent studies. Additional several observations were reported in relation to blood group and span of life for human being (Allan, 1953 a, 1953 b), but sufficient observations have not been available yet in whales.

According to the above-stated discussions, there are some differences of relative fitness in intra-uterine life between different phenotypes especially heterozygote and homozygotes, and then it can be thought that gene frequencies of a population are maintained by counterbalance between selection in incompatible mating and excessive natality in compatible mating for heterozygotes. If interactions between different blood group systems and some other factors could be thought to hardly influence upon selective and compensatory mechanisms, selective value and relative fitness could be calculated as follows. When selective value for heterozygous fetuses in incompatible mating are given as k and k' for two cases of which blood groups of cows are Ju1 and Ju2 homozygotes respectively and relative fitness is given as $1 + K$ for heterozygote in compatible mating, incidence of intra-uterine selection are expressed as $q.k$ and $p.k'$ for the former two cases and excessive natality rate is $K/2$ for the latter case, so that condition maintaining equilibrium for gene frequencies of a population is given by following formula.

$$[\text{Ju1}] k.q + [\text{Ju2}] k'.p = [\text{Ju1.2}] K/2 \dots\dots\dots 1)$$

, where $1 \geq k$, $k' \geq 0$, $K \geq 0$, and $[Ju1]$, $[Ju1 \cdot 2]$ and $[Ju2]$ mean relative frequency of occurrence for each phenotype, and amount to 1 in all. As survivor of fetuses at the end of intra-uterine life are given by :

$$[Ju1] \left\{ [Ju1] + \frac{[Ju1 \cdot 2]}{2}(2-k) + [Ju2](1-k) \right\} \text{ for Ju1 homozygote cows,}$$

$$[Ju1 \cdot 2] \frac{2+K}{2} \text{ for Ju1 \cdot 2 heterozygote cows,}$$

and $[Ju2] \left\{ [Ju1](1-k') + \frac{[Ju1 \cdot 2]}{2}(2-k') + [Ju2] \right\}$ for Ju2 homozygote cows

respectively, ratio between P1 and P2 which mean apparent rates of pregnancy in Ju1 and Ju2-positive types of cows is expressed as follows.

$$P1/P2 = \frac{\{[Ju1 \cdot 2] + [Ju2]\} \left\{ [Ju1] + \frac{[Ju1 \cdot 2]}{2}(2-k) + [Ju2](1-k) \right\}}{\frac{[Ju1 \cdot 2]}{2}(2+K) + [Ju2] \left\{ [Ju1](1-k') + \frac{[Ju1 \cdot 2]}{2}(2-k') + [Ju2] \right\}} \dots\dots 2)$$

As regards relations between k and k' , it seems to be reasonable to assume as $k \geq k'$, judging from the facts that anti-Ju2 isoantibody is positively detected from serums of most Ju1 type donors while no isoantibody for Ju1 has been detected from Ju2 type donors. Then after applying the observed figures, which are shown in Tables 1 and 2, to Formulae 1 and 2, calculations were attempted for five cases of $k' = k$, $1/2k$, $1/4k$, $1/8k$ and $0 \ll k$. Parameters to be used in the present discussions should be those which were obtained from a pure population. For this purpose figures for the postulated Atlantic population of which Ju2-positive types occur in fairly high frequency are most appropriate at present, that is, $[Ju1] = 0.697$, $[Ju1 \cdot 2] = 0.250$, $[Ju2] = 0.053$, $p = 0.822$, $q = 0.178$ and $P1/P2 = 0.639/0.789 = 0.810$. Percentage pregnancies for each blood group used here were obtained during Antarctic pelagic whaling season in which whales migrate there for feeding. It is generally accepted that pelagic whaling season does hardly overlap the seasons for copulation and parturition for the southern whales (Mackintosh and Wheeler, 1942, Laws, 1961). It may be thought therefore that this relative figure of percentage pregnancies between different blood groups obtained during whaling season approximately represent that of real population, even if female whales belonging to a population somewhat segregate by age or some other physiological factors during their migration to feeding grounds. The results of calculation are shown in Table 7. According to this table, figure of k shows an approximate constant of 0.37 for any cases of relations between k and k' . While, figure of k' fluctuates at ranges between 0.000 and 0.373 and K at ranges between 0.368 and 0.500. This figure of k means that prenatal mortality rate of heterozygous fetuses expected from Ju1 type mother whales at incompatible mating reach up to approximately 37 percent for the postulated Atlantic population. This figure corresponds approximately twice as the mortality rate of heterozygous A or B child at the matings of mother O \times father A or mother O \times father B (Matsunaga and Itoh, 1954).

TABLE 7. CALCULATED FIGURES OF VARIOUS PARAMETRES FOR THE INTRA-UTERINE SELECTION OF FINBACK WHALES

	relation between k and k'	k^*	k'^*	$1+K^{**}$
i	$k' = k$	0.373	0.373	1.500
ii	$k' = 1/2k$	0.371	0.186	1.433
iii	$k' = 1/4k$	0.370	0.093	1.401
iv	$k' = 1/8k$	0.369	0.046	1.384
v	$0 \doteq k' \ll k$	0.371	0.000	1.368

* selective values of heterozygous fetuses expected from Ju1 and Ju2 mother whales at incompatible matings.

** relative fitness of heterozygous fetuses expected from Ju1·2 mother whales at compatible mating.

In the next place will be discussed general relationships between gene frequency and rate of intra-uterine selection of heterozygotes at incompatible mating in a population which gene frequencies are given as p and q controlling Ju1 and Ju2 antigens respectively, prenatal mortality rate (d) of heterozygous fetuses can be expressed as the summarized figure for two cases which blood groups of cows are Ju1 and Ju2 homozygotes.

$$d = [\text{Ju1}] q \cdot k + [\text{Ju2}] p \cdot k' \dots\dots\dots 3)$$

As the relations of $p = 1 - q$, $[\text{Ju1}] = (1 - q)^2$ and $[\text{Ju2}] = q^2$ can be adopted to a random mating population, Formula 3 will be arranged for q as follows,

$$d = q \{ (k - k')q^2 + (k' - 2k)q + k \} \dots\dots\dots 4)$$

, where $1 \geq q > 0$. When being differentiated by q , Formula 4 will be

$$d' = 3(k - k')q^2 + 2(k' - 2k)q + k \dots\dots\dots 5)$$

Mortality rate d will take a maximum figure at a point of

$$q = \frac{2k - k' - \sqrt{k^2 - kk' + k'^2}}{3(k - k')} \dots\dots\dots 6)$$

, where $1 \geq q > 0$ and $1 \geq k \geq k' \geq 0$.

Formulae showing relations between gene frequencies (p , q) and prenatal mortality rate (d) and figure of q at which d takes a maximum will be obtained from Formulae 4 and 6 for five cases of relations between k and k' , presented already, as follows.

i)	When $k' = k$	$d = q(1 - q)k$	takes a maximum at $q = 0.500$	} ... 7)
ii)	„ $= 1/2k$,	$= q(1 - q)(2 - q)k/2$	„ $= 0.423$	
iii)	„ $= 1/4k$,	$= q(1 - q)(4 - 3q)k/4$	„ $= 0.362$	
iv)	„ $= 1/8k$,	$= q(1 - q)(8 - 7q)k/8$	„ $= 0.355$	
v)	„ $0 \doteq k' \ll k$,	$= q(1 - q)^2k$	„ $= 0.333$.	

When figures of k in Table 7 are put into Formula 7, relations between d and q will be drawn as Fig. 1. According to Fig. 1 prenatal mortality rate takes a maximum figure at a point of $q = 0.500$ for a case of $k = k'$ (curve 1) and reaches up to more than 9 percent of total recruiting generation of the population. In the postulated Atlantic population ($p = 1 - q = 0.822$) the figure of d is approximately 5 percent for any cases of relations between k and k' . If various parameters in Table 7 could be available for the aboriginal population of area III too, the figure of d might be estimated to not reach up more than 0.3 or 0.4

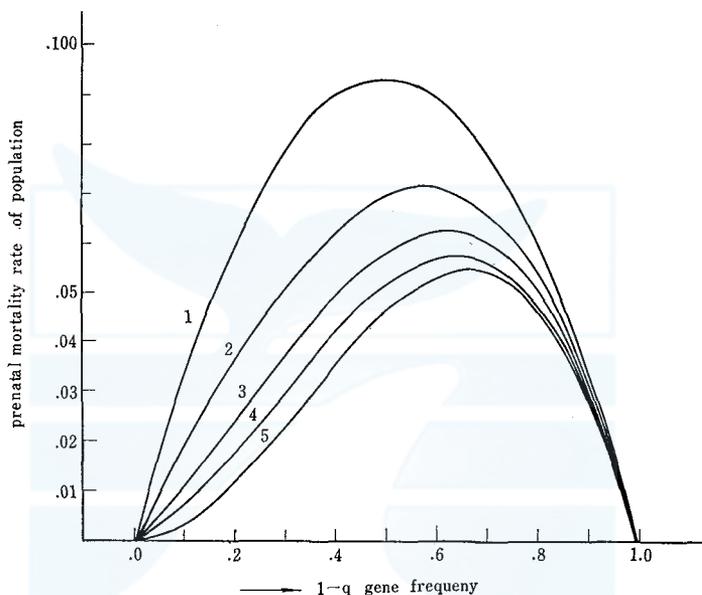


Fig. 1. Relation between blood type gene frequency and frequency of occurrence of intra-uterine selection of heterozygous fetuses in random mating ideal population of whales. Curves 1, 2, 3, 4 and 5 correspond to five cases of which relations between k and k' are $k' = k$, $= \frac{1}{2}k$, $= \frac{1}{4}k$, $= \frac{1}{8}k$ and $= 0 \ll k$ respectively.

percent for the population. These figures include mortality rate at intra-uterine life only. Actually, however, perinatal mortality rate of recruiting generation must be enhanced with postnatal death of infants which is observed in human as fatal hemolytic diseases which follow incompatible pregnancies.

SUMMARY

Basing upon the results of blood typing investigation, the author stated in his previous paper (Fujino, 1962) that in the area III of the Antarctic distribute at least two different breeding populations of fin whales which have different frequencies of occurrence of blood type each other, and that this might support the results of marking investigation reported by Brown (1954). Furthermore after discussing

relations between blood groups and other items of investigation, he described that significant differences were seen in the percentage pregnancy among mature females by blood groups. This suggests that intra-uterine selection caused by maternal-fetal incompatibility of blood types, which has been reported for human beings and some other mammalian animals, takes place in whales also.

In the present paper, at first results of serological observation, that is, existence of natural isoantibodies, their hemolytic properties and marked ascending of titre of the isoantibody which seems to be caused by isoimmunization between fetus and mother are described as evidences relating to intra-uterine selection. Secondly, after basing upon an assumption of compensatory mechanisms for intra-uterine selection, quantitative relationships are discussed between frequency of occurrence of blood types and relative rates of pregnancy by blood groups, and estimation for the rate of incidence of the selection was made. Consequently, the author noted that in the postulated Atlantic population approximate 37 percent of heterozygous fetuses expected from J₁ type females at incompatible mating were disadvantageously selected, and this figure corresponds to approximate 5 percent of the recruiting generation of the population and this does not reach up more than 0.3 or 0.4 percent in the aboriginal population of the area III.

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THE JU BLOOD TYPING SYSTEM OF THE SPERM WHALE AND SPECIFIC SOLUBLE SUBSTANCES

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The use of immunogenetic concepts in marine population research is rapidly expanding (Cushing 1962) and pertinent material on whales has been reviewed (Fujino, 1960). In the case of sperm whales, a "species-specific" antigen resembling the human B antigen has been found on their erythrocytes, and antibodies for the human ABO system occur variably in their serums. Chicken and rabbit antisera prepared against sperm whale erythrocytes have been used to distinguish six phenotypes among twenty-six individuals. One of the antigens designated, Sp, could also be recognized by a natural antibody in sei whale serum (Fujino 1954). The present paper reports additional work on sperm whale antigens that was done in California (Cushing and Calaprice), in the Antarctic (Fujino) and in Peru (Cushing).

CALIFORNIA RESEARCH

Samples of bloods from ten sperm whales taken by San Francisco shore whaling stations were preserved by glycerol-freezing (Cushing et al., 1959). Erythrocytes were recovered by dialysis and compared with those of finback, humpback, and sei whale erythrocytes with respect to their reactions with Fujino's (1956) heteroimmune anti-finback Ju1 (no. 47) and Ju2 (no. 34) serums. These comparisons demonstrated that, as in the humpback, pygmy-blue and sei whales, antigens occur in sperm whales that are very similar in specificity to the Ju1 and Ju2 finback antigens. These antigens behave in finbacks as if determined by a pair of allelic genes (Fujino, 1960).

The normal serums of horses, cattle, sheep and pigs were found to be useful reagents for detecting the Ju2 antigen. Antibodies for this antigen occurring in all serums examined. The serum of the California spiny lobster (*Panulirus interruptus*) was found to contain antibodies capable of agglutinating some Ju2-positive cells, but not others, suggesting that it may prove to be valuable as a Ju2 subtyping reagent (These reactions will be reported in a separate paper).

Isoantibodies in Ju2-negative sperm whales for Ju2-positive erythrocytes were found, as were cross-reactions between the Ju2-positive cells of one species with the isoantibodies of other species. These results suggest that the Sp antigen already referred to may have been Ju2 because of its agglutinability with sei whale serum. No other relations between the sperm whale antigens first described by Fujino and the ones described in this paper as like those of the finback Ju system can be determined, as the earlier anti-sperm whale reagents are no longer available

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for comparison.

The results given in the above section, together with relevant observations reported in earlier papers, establish the possibility of using the readily available reagents in normal serums for comparison of Ju2-positive reactions among sperm and other whale species in different parts of the world. The results of two such studies are given below.

ANTARCTIC RESEARCH

Data on the Ju system of blood types in Antarctic populations of sperm whales was obtained by Fujino while he served as biologist aboard the factory ship, Kyokuyomaru No. 2 during the 1960/61 whaling season. Samples were taken from the heart of all but a few whales at an average time of eight hours post-mortem in sea and air temperatures which fluctuated within a few degrees of zero centigrade. The exceptional samples came from large clots of blood within the body cavity. Nine volumes of sample were added to one volume of the usual collecting solution. This consists of 8.5 gm. NaCl, 50 gm. of sodium citrate and 0.5 gm. of the antimicrobial

TABLE 1. ISOAGGLUTINATION OF VARIOUS WHALE ERYTHROCYTES BY UNDILUTED SERUMS*

Undiluted serums :	Ju2-positive cells													Ju2-negative cells	
	100	6	8	120	124	110	101	111	90	78	152	163	7	95	154
Ju2-neg. serum	95	##	##	##	##	##	##	##	##	##	##	##	±	-	-
	154	##	##	##	##	##	##	##	##	##	##	##	±	-	-
	163	##	##	##	##	##	##	-	-	-	-	-	-	-	-
	152	##	+	+	##	+	##	+	-	-	-	-	-	-	-
Ju2-pos. serum	101	+	+	##	-	-	-	-	-	-	-	-	-	-	-
	110	+	+	+	-	-	-	-	-	-	-	-	-	-	-
	124	##	##	-	-	-	-	-	-	-	-	-	-	-	-
	111	-	-	±	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* See absorptions in Table 2.

These reactions show that subtypes exist among Ju2-positive cells and that the weaker subtypes can contain isoantibodies for stronger ones. Serums and cells of whales 95 and 154 are representative of those of all Ju 2 negative whales ## symbolizes strong agglutination, ranging through ## and + to - for no agglutination.

guanofuracin per liter of water. These samples remained in good condition for thirty days or longer under refrigeration. Serums of such samples showed little hemolysis, and had no opportunity to become mixed with other tissue fluids.

Each sample was tested with the same normal bovine serum, using conventional saline agglutination techniques. Agglutination was taken as evidence of the presence of Ju2 antigen. All Ju2 positive samples, together with various negative ones, were subsequently compared as to their reactions with normal horse serum, the same unabsorbed anti-finback serums used by Cushing and Calaprice, and the

TABLE 2. EXAMPLES OF ABSORPTIONS OF CATTLE SERUM
(NO. 25) THAT SHOW SUBTYPE DIFFERENCES AMONG
JU 2-POSITIVE SPERM WHALES*

Reactions with unabsorbed serum, dilutions:							Reactions with absorbed serums diluted one in eight							
Cells:	1:2	1:4	1:8	1:16	1:32	1:64	Absorbing Cells:	100	124	111	7	95		
Ju2 pos.	100	##	##	##	##	++	+	Ju2 pos.	100	-	-	-	-	
	124	##	##	##	##	++	+		124	##	-	-	-	
	111	##	##	##	##	++	+		111	##	##	-	-	
	7	##	##	+	-	-	-		7	##	##	##	-	
Ju2 neg.	95	-	-	-	-	-	-	Ju2 neg.	95	##	##	##	+	-

* Also see Table 1 for reactions of these red cells with various whale normal serums.

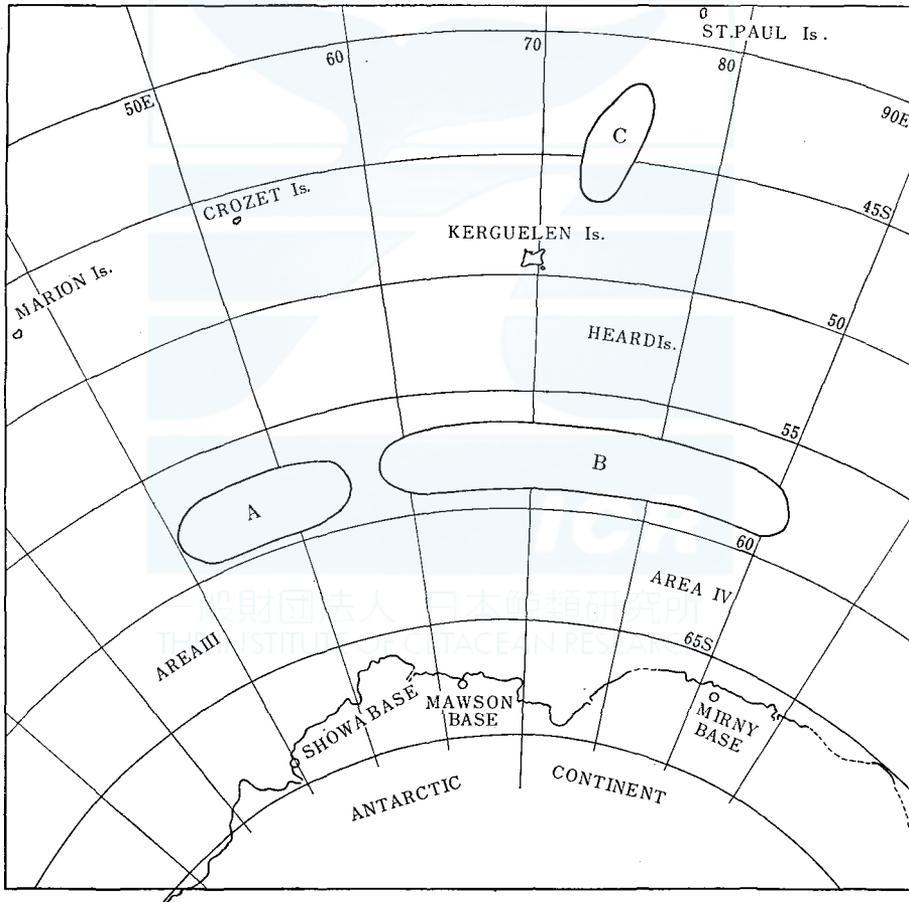


Fig. 1. Localities where sperm whales were taken by Kyokuyo-maru No. 2. in the 1960/61 whaling season.

isoantibodies in a single sperm whale serum. These comparisons continued to confirm the usefulness of normal animal serums as reagents for the detection of the Ju2 antigen on erythrocytes.

Isoantibodies for Ju2-positive cells were found in all Ju2-negative serums examined (one hundred and twenty-seven). In the weaker Ju2-positive subtypes were detected isoantibodies for the stronger Ju2 subtypes as shown in Table 1. Isoantibodies for Ju1-positive cells were not found.

All Ju2-positive samples from areas A and B (see Fig. 1), having been collected within a span of twenty-eight days, were compared with respect to their ability to absorb bovine serum. These absorptions showed that Ju2-positive cells exist as a series of at least four subtypes (Table 2). No subtypes of Ju2-negative cells were found following absorption of anti-finback Ju1 reagent with cells from forty-six negative samples. Experiments were performed on the reactions of antibodies eluted from erythrocytes following absorption of bovine and anti-finback Ju1 serum. These will be reported in detail in connection with other related studies.

One whale was found that appeared to be a blood group chimera in that its cells consisted of a mixture of Ju2-positive and Ju2-negative cells as determined by microscopic examination of agglutinations, and by hemolytic tests.

TABLE 3. FREQUENCY OF OCCURRENCE OF BLOOD TYPES OF THE ANTARCTIC SPERM WHALES*

Blood types	Area A		Area B		Area C		Sum of all whales	
	Act. no.	Freq.	Act. no.	Freq.	Act. no.	Freq.	Act. no.	Freq.
Ju2-negatives	105	0.898	95	0.969	15	0.882	215	0.927
Ju2-positives, separated by subtypes.**	Ju2 ₁	1	1	0	1	0	3	0.073
	Ju2 ₂	2	0	0	0	2		
	Ju2 ₃	8	1	1	1	10		
	Ju2 ₄	1	1	0	0	2		
Sum	117	1.000	98	1.000	17	1.000	232	1.000

* See Fig. 1 for area limits

** Symbols of four subtypes of Ju2-positives were named in accordance with those in finbacks (Fujino, 1962).

The frequencies of Ju2-positive cells in population samples from the different Antarctic areas shown in Fig. 1 are given in Table 3. These are arranged according to subtype differences and suggest that larger samples will show that the sperm whale population of area A may differ from those of B and C.

PERUVIAN STUDIES

Sperm whale Ju blood types were studied in Peru by Cushing during July–August 1960 at the shore whaling station of Cia Balleneria Del Norte, Tierra Colorado

Bay, Paita, Peru. Whales were fished twenty to ninety miles off-shore and usually had been dead twelve to thirty hours before flensing. Blood samples were taken from various flensing cuts in the musculature, it being impractical to obtain heart blood as was done by Fujino. Whales in which decomposition was apparent were not sampled.

The erythrocytes obtained were in good condition, but the serum showed much hemolysis and was subject to mixt with fluids from the muscle tissue. A few milligrams of streptomycin and sulfathiazole were mixed with each 100 ml. sample, which kept well for several days refrigerated.

Conventional slide agglutination tests were used, being scored in a range between — for no reaction through ### for the strongest agglutination. (Note that the score of agglutinations given by Fujino does not extend beyond #. Study of the same materials by both authors while together in Tokyo showed this difference in convention had no effect on interpretations of the data obtained). Reagents used included the same anti-finback and stock of normal domestic animal serums referred to in the foregoing sections of this report. Emphasis on the Peruvian work centers on the reactions of erythrocytes with a pool of horse serum. As in previous work, saline controls were run on all cell suspensions to avoid possible error through autoagglutination.

The horse serum readily distinguished two types of individuals. Cells reacting strongly were classified as Ju2-positive, those at dilutions of serum at one in five or less as Ju2-negative. Reactions with the anti-fin whale heteroimmune serums confirmed this classification.

As the first whale typed gave a strong positive reaction and the next three gave negative reactions, it looked as if the frequency of Ju2-positive cells would be readily obtained. However, a new phenomenon was encountered early in the investigation that showed this would be impossible to achieve within the time available. This phenomenon was the observation that five different samples which initially reacted as Ju 2-negative, changed type over a period of days and became Ju2-positive. In contrast, eight other Ju2-negative cells did not change type, nor did any Ju2-positive cells become negative.

As the changes occurred in spite of refrigeration and the presence of antibiotics, were Ju specific, and took place in samples in good condition, it seemed unlikely that they were due to microbial actions (Stormont et al., 1960).

The possibility that the erythrocytes had acquired a specific soluble Ju2 substance (hereafter Ju2 SSS) from the serum or tissues was therefore investigated. Such substances were first described by Stormont who showed that the J types of cattle erythrocytes are determined by SSS in the blood plasma (Stormont, 1949). They have subsequently been found in man, sheep and other domestic species (An introduction to recent literature on soluble blood group antigens will be found in Sneath et al., 1959, Stone, 1962, Stormont et al, 1960, and Race et al., 1958). Limited observations on sperm whale human B-like antigen and on the finback Ju system have already suggested their occurrence in cetaceans (Cushing et al., 1959, Fujino, 1960).

Table 4 shows the reactions of the whales that changed type. While circumstances did not permit an extensive series of experiments, several kinds of observations were made which indicate that the type of change was actually due to post-mortem coating of erythrocytes with Ju2 SSS.

The first of these observations was the demonstration that Ju2 SSS capable of inhibiting the reactions of horse serum with Ju2-positive cells occurs in the serums of whales that changed types, and in examples of other positive whales (Table 5). The failure of inhibition with respect to certain combinations of cells and serums can be reasonably explained as due to subtype differences among the reactants involved. Serums of four whales typed as Ju2-negative did not inhibit the action

TABLE 4. REACTIONS SHOWING CHANGE IN JU TYPE OF THE ERYTHROCYTES OF INDIVIDUAL WHALES

Whale nos :	Horse serum dilutions						Date tested, 1960
	1:5	1:10	1:20	1:40	1:80	1:160	
3	—	—	—	—	—	—	7-31
3	###	###	##	++	+	—	8-2
*3	—	—	—	—	—	—	8-18
19	+	—	—	—	—	—	8-3
19	###	###	###	###	###	++	8-5
19	###	###	###	###	###	+	8-15
21	—	—	—	—	—	—	8-3
21	—	—	—	—	—	—	8-5
21	++	++	++	+	—	—	8-7
21	###	###	###	##	++	+	8-15
5-5	+	—	—	—	—	—	8-6
5-5	++	++	+	±	—	—	8-7
5-5	##	++	++	++	+	—	8-9
5-5	###	###	###	##	++	—	8-13
4-3	—	—	—	—	—	—	8-5
4-3	###	###	##	##	+	—	8-9

* This sample represents cells recovered from an aliquot of 3 blood frozen in glycerol citrate and recovered by dialysis Aug. 18. The cells had not become positive during this time, in contrast to the change in unfrozen cells.

of horse serum. Account was taken of the occurrence and action of isoantibodies in these and other serums where these antibodies might have complicated results.

Another kind of supporting evidence are the results of some absorptions of horse serum involving the erythrocytes of some of the whales that changed types, and which are shown in Table 5 to have Ju2 SSS in their serums (Table 6). These absorptions show that, as in the inhibition tests, individual variations exist in the reactions of different erythrocytes with different serums. The relations between 19 and 21 are strikingly similar in both kinds of experiments. Cells 4-1 and 5-6 removed antibodies agglutinating some other kinds of cells while not agglutinating to any degree in unabsorbed horse serum themselves; also that the serums of these cells were capable of inhibition (Table 5). This is a situation similar to that reported for certain of the cattle J types (Stormont et al., 1960, Stormont, 1962).

A third kind of experiment further supports the possibility that the type changes

TABLE 5. EXAMPLES OF THE INHIBITION OF HORSE SERUM BY SERUMS FROM JU2-POSITIVE WHALES. THOSE THAT CHANGED TYPE ARE INDICATED BY AN ASTERISK

Test cells	horse serum only	*21	*4-3	*5-5	*0-3	0-1	5-6	4-1	*19
5-5	###	—	+	+	+	+	++	++	###
4-3	###	—	+	+	+	+	++	++	###
21	###	—	++	###	###	###	###	###	###
0-1	###	###	###	###	+	—	++	++	+
19	###	###	###	###	+	—	++	++	++

Horse serum diluted one in ten plus individual whale serums (excepting first column which shows the reactions of horse serum alone). One drop of whale serum was added to one drop of horse serum for each test. Cells were added fifteen minutes later and readings made after an additional twenty minutes. ### indicates strong agglutination and therefore no inhibition, while — indicates no agglutination and therefore complete inhibition. Note that homologous combinations 4-3, 5-5 and 19 did not show complete inhibition. No isoagglutinins for the cells used in the above tests were found in serums 21, 5-5, 0-1, 5-6, and 19. Serums 0-3, 4-3, and 4-5 were not tested for isoagglutinins. Four Ju2-negative serums (0-2, 0-4, 4-5, and 11-7) were found to contain isoagglutinins for the above cells, and did not inhibit the agglutination of these cells by horse serum.

TABLE 6. THE REACTIONS BETWEEN VARIOUS ABSORBED HORSE SERUMS AND ERYTHROCYTES

	Absorbing cells	Test cells										
		5-6	4-5	4-1	19	21	4-3	4-4	8-3	4-2	5-5	6-2
Unabsorbed serum (1 : 10)	none	—	—	+	###	###	###	###	###	###	###	###
	19 Ju2-pos.	—	—	±	+	###	###	###	###	###	###	+
	21 Ju2-pos.	—	—	—	###	—	—	###	###	++	++	++
Absorbed serums (1 : 10)	4-1 Ju2-neg.	—	—	—	++	###	+					
	5-6 Ju2-neg.	—	—	—	###	###	++					
	4-5 Ju2-neg.	—	—	—	###	###	###					

Blank spaces in columns to right show that no tests were made. Serums were absorbed at room temperature with one-third volume of packed cells for thirty minutes. Results show the marked reciprocal relationship between 19 and 21 observed in inhibitions (table 5). Note that absorption with cells of 19 was not complete. Other heterogeneities are revealed suggestive of the subtypes found by Fujino. Note that cells 4-1 and 5-6, while reacting essentially negatively with horse serum, were still capable of removing some of the antibodies or other erythrocytes reacting with this serum.

observed were due to the coating of erythrocytes with Ju2 SSS. One experiment of this kind was performed by placing drops of washed erythrocyte suspensions from two Ju2-negative whales (10-2 and 11-7) in drops of undiluted serum from a Ju2-positive whale (11-11). These mixtures were allowed to stand for twenty minutes, at the end of time which ± traces of agglutination attributed to agglutinins other than those involved with the Ju system were observed. No agglutination occurred in saline controls of the cells or in the mixture of 11-11 cells with their homologous serum.

Drops of horse serum (1 : 5) were then added to the three mixtures of cells with 11-11 serum. At the end of a second period of twenty minutes cells of 10-2 and 11-7 showed strong (###) agglutination while those of 11-11 were negative. In contrast horse serum placed in the saline controls gave only a \pm agglutination with 10-2 cells, none with 11-7 cells, and ### with 11-11 cells. These results can be interpreted as due to the coating of the erythrocytes with Ju2 SSS in the case of cells 10-2 and 11-7, and to the inhibition of horse serum in the case of 11-11. They were confirmed in a second series of experiments that showed the titer of Ju2 SSS inhibitor in 11-11 serum to be one in sixteen with respect to the reactions of horse serum with 11-11 cells; and one in four with respect to ability to coat the cells of 11-7. (The serum of 11-7 contained strong iso-antibodies for 11-11 cells and for all the Ju2-positive cells shown in table 5. It did not inhibit the reactions of horse serum with these cells).

A second experiment similar in kind to the one just described was performed by placing a suspension of human type A cells in the serum of another Ju2-positive whale 5-3. This serum was also known to inhibit the agglutination of its homologous cells by horse serum. No agglutination of the human cells occurred in this serum after twenty minutes. The addition of horse serum (one in ten) to the mixture again resulted in a strong agglutination after a twenty minutes wait. The cells of Ju2-negative whale 0-2 also were affected by 5-3 serum in the same way. Controls showed that the horse serum alone gave only traces of agglutination with the human cells and none with the 5-3 whale cells.

A third experiment was made with the serum of Ju2-positive whale 0-1 also known to contain horse serum inhibitor and not to contain isoantibodies. In this case, however, it was not possible to induce the agglutination of human A cells or those of Ju2-negative whale 0-2. The serum of whale 0-2 did not appear to contain Ju2 SSS as shown by an inhibition experiment which took into account the presence of isoagglutinins in the 0-2 serum.

One set of experiments was made which showed that the serum of Ju2 positive whale 11-11 strongly inhibited the agglutination of its own cells by finback anti-Ju2 serum (no. 34) as well as that of the cells of Ju2 positive whale 0-1.

DISCUSSION

While alternative explanations can not yet be ruled out, the observations reported above support the concept that the changes in type of sperm whale erythrocytes were the result of post-mortem coating with Ju2 SSS. Changes of a similar nature have been produced experimentally with the cattle J antigen, originally reported by Stormont (1949) and more recently by Stone (1962). It is also of some interest that Stone et al (1954 p. 399) comment that occasionally a sample of cattle cells classified as J negative later showed very weak reactions with high concentrations of J reagents, and that these individuals occurred among those whose serum contained J inhibitor. Experiments reported by Kodani (1962) show that the blood group phenotypes of human epithelial cells can also be altered by exposure to

soluble heterologous blood group substances. The occurrence of Ju2-negative whales whose serum contained isoantibodies for Ju2-positive cells, and which were not capable of inhibiting the action of horse serum, show that the two major classes of whales found in California and the Antarctic also exist in the Peruvian population. However, the frequency of individuals whose erythrocytes reacted strongly with horse serum (including the five that changed type) was much higher in the Peruvian sample than in the others. Such whales totaled 25 among a sample of 33 whales that were systematically typed with horse serum and the two antifinback heteroimmune serums. (Whales 4-1 and 5-6 are counted as negative in this instance as they did not agglutinate in horse serum).

The tentative explanation offered for the high frequency of Ju2-positive erythrocytes in the Peruvian material is based on the fact that the blood was obtained from whales in a relative advanced post-mortem condition due to a longer period, in higher temperatures of sea and air, between death and flensing. In addition, the samples, having been taken from superficial cuts rather than the heart, were exposed to mixture with body fluids other than serum. These factors could well provide a reasonable opportunity for Ju2 SSS to coat the erythrocytes after the death of the animal. If this explanation is correct the Ju2 antigen, by comparison with Antarctic data, would seem to occur on the erythrocytes of living individuals with much less frequency than it occurs in the serum and or other tissues as a soluble substance.

The above considerations obviously lead to an evaluation of the usefulness of the Ju antigens in population reaserch. Two points are to be made. First, the phenomenon of type change was not observed by Fujino in his studies on sperm whales. This supports the view that fresh blood samples taken from the heart present an accurate picture of the relations between Ju2 antigen in the serum and attached to erythrocytes. Second, no type changes have been observed in the very extensive research that has been done on finback whales. Here not only are the conditions of sampling significant, but also the fact that this species, being a baleen whale, is very far removed in an evolutionary sense from the sperm whale. This is significant as it is known that the human ABO substances vary with respect to their solubility and occurrence upon erythrocytes among the many species where they occur (see, for example, Mourant 1954 page 175 on the primates). Other points could be made, but enough has been written upon which to base two conclusions from the results of this paper. First, the Ju2 finback-like antigens in sperm whales appear to be soluble antigens with properties akin to the soluble antigens known in other species. Second, samples taken from the heart blood of recently killed whales appear to present valid material for frequency determinations. However, further blood typing studies involving the Ju system will have to consider the possible complexities introduced by soluble components of this system and methods of sampling. That the frequency of the different phenotypes produced by systems involving soluble antigens can be determined is already shown in them literature on the occurrence of cattle J in various breeds (Sprague 1958, Stormont 1959) and by the studies that have been made on the human Lewis system (Race

et al. 1958).

SUMMARY

This paper reports the discovery of a pair of antigens in sperm whales that resemble the Ju1 and Ju2 antigens of finbacks and other species. Reagents for the detection of these antigens include heteroimmune antiferback serums, the normal serums of several domestic animals, and isoantibodies for Ju2 in sperm whale serum. The Ju2 antigen exists as a series of at least four subtypes. The distribution of Ju2-positive individuals was determined in Antarctic samples of sperm whale populations. Observations on sperm whales taken off Peru suggest that the Ju2 antigen can exist as a soluble substance which can cause changes of type in erythrocytes on post-mortem.

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NEW RECORDS OF SPERM WHALES WITH PROTRUDED RUDIMENTARY HIND LIMBS*

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The first record of protruded legs in Cetacea is described by Andrews (1921) on a humpback whale caught in the off waters of British Columbia, Canada in 1919 which has remarkable protruded legs in the abdominal part of the body. As the second case having the pair of protruded hind limbs in Cetacea, a very interesting case of the sperm whale with rudimentary hind limbs is reported by Ogawa & Kamiya in 1957 (Ogawa & Kamiya, 1957). This sperm whale has not such a remarkable protruded legs as the humpback whale reported by Andrews, but the protruded legs are forming protrusions which clearly elevated like a dome. The height of the protrusions measures 5.35 cm in the right and 6.56 cm in the left respectively. There is well developed tibia from the pelvic bone to the dome of the epidermis and the tip of this cartilaginous stick intrudes a little the blubber of the protrusion of the skin. The case is considered as a abnormal retention of the early embryonic state (Ogawa & Kamiya, 1957).

In 1960, a sperm whale having such a protrusion is caught in the northern part of the north Pacific by Japanese whaling operation. The photograph in situ and description are remained but unfortunately the samples are missing and now under search. The sperm whale is caught on 16th July in 1960, at the position 51–52N and 171–22E in the north Pacific. The body length is 15.3 m and male testis weights are 5.3 and 5.1 kg, respectively. The thickness of the blubber is 12.5 cm in the dorsal fin part of the body.

The description says there are two protrusions like the mammae along the anal groove, and three photographs are taken by the observer.

As illustrated in figures and a plate, the protrusions are situated in the side of the anus of the sperm whale. And the protrusions are considered pointing the anterior direction of the body. In this point, the case is different from the former case in which the protrusions point the posterior direction. The protrusions are also considered somewhat higher than the case reported by Ogawa & Kamiya (1957) and curved to the anterior direction.

As it is clearly shown in figures in the plate, the white spot is found in the center of the cut protrusion. It is said the protrusion is easily cut by the flensing halberds, suggesting that the white spot is the soft bone not ossified. Ogawa & Kamiya (1957) state that the cartilaginous stick is present in their case, the top of which is clearly extends to the dome of the protrusion as illustrated in their figures.

From this figure, it may be considered that the cartilaginous stick is also longer than the former case, as the protrusions are longer and the cartilaginous stick is reaching as far as the half of the dome.

* Dedicated to Professor T. Ogawa for his sixtieth birthday.

Another Japanese record is only remained in the biological record of the whales caught and there is a few suspect to the case. This sperm whale is caught at the position 51-07N and 179-29E on 5th July in 1956. The testis weights of which are 5.5 and 6.0 kg respectively and sexually mature. The blubber thickness is 13.0 cm and is moderate for the size of the whale.

Although the specimens and the photograph have not been remained, the note clearly shows the protuberances like mammae along the anus, and it is considered this would be enough to be described as the third case of the sperm whale with rudimentary hind limbs. The aspect of the protuberance is considered the same as the said case, although no detailed description is remained. Further it is considered the case is the highest one among three cases in those sperm whales. Above two cases are reported from the Japanese whaling expeditions in the Bering sea and the adjacent waters to Aleutian Islands, where only male sperm whales are the main constituents of the total sperm whale catch. From 1954 to 1961, some 12761 sperm whales have been caught by the Japanese whaling operations, so the percentage of the occurrence of the sperm whale with rudimentary hind limbs may be about 0.02 for the total catch in the Bering sea and the northern part of the north Pacific.

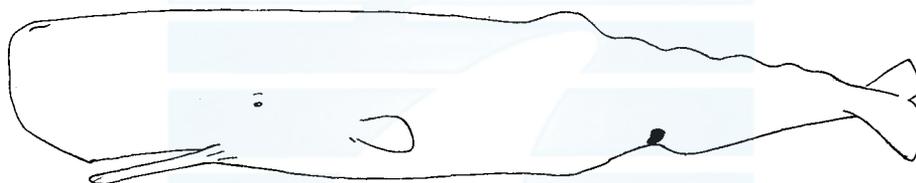


Fig. 1. Position of the protruded rudimentary hind limb in situ in the male sperm whale.



Fig. 2. Shape and position of the protrusion in the side of the anus. An arrow shows the anterior direction.

In the Japanese news paper, ' the Mainichi ' dated 18th May in 1959, a sperm whale with protruded rudimentary hind limbs is reported by AP Kyodo.

This record is based on the broadcast from Moscow and it is said that the one sperm whale has the legs like the other mammals in the abdominal part of the body. In the legs, there exist bones by examination using the X ray. The detail of the case is not clear, however, it is considered the sperm whale has protruded

legs longer than our case.

As the second case, Soviet news published by Soviet embassy in London on 22th May 1962 reports a sperm whale with protuberance which are considered legs, is caught in Kuril waters. The protuberances contain undeveloped thigh bones. The detail of the case is also unknown yet, but the case reinforces the consideration that the occurrence of protruded rudimentary hind limbs is highest in sperm whales.

There are no other record of sperm whales with protruded rudimentary hind limbs in Japanese observation, only 5 cases of sperm whales are available for the consideration. But I suspect the case having the protruded hind limbs in sperm whales shows a little higher percentage if the more strict research were made on all whales caught especially in the land whaling stations flensing many sperm whales in the adjacent waters to Japan.

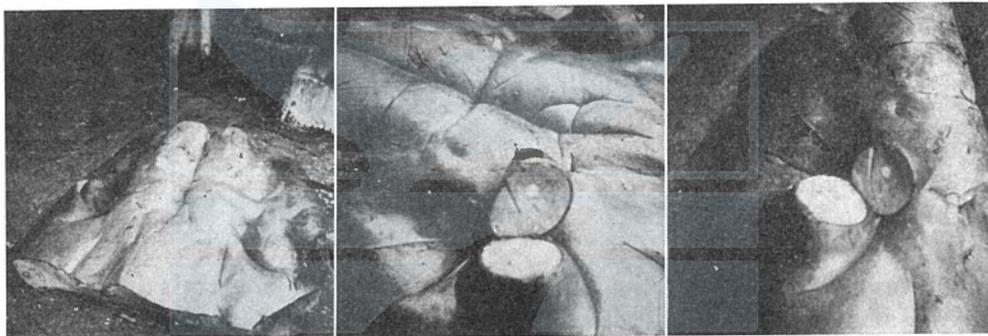


Fig. 1.

Fig. 2.

Fig. 3.

Fig. 1. Two protrusions along the anal groove from the behind.

Fig. 2. The cut left protrusion showing the cut white cartilaginous stick in the center of upper piece. The right protrusion in the upper position of the photograph shows the pointing to the anterior direction of the body.

Fig. 3. The left cut protrusion showing the white cartilaginous stick in the cut surface. From the surface of the root of the cut protrusion, the stick situated a little outer position shifting the center of the protrusion.

When these 5 cases of sperm whales are compared with the baleen whale, only one case of a humpback whale is available. And it is safe to say the percentage of the occurrence of the protruded rudimentary hind limbs is higher in sperm whales than other baleen whales.

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STONES AND OTHER ALIENS IN THE STOMACHS OF SPERM WHALES IN THE BERING SEA

TAKAHISA NEMOTO AND KEIJI NASU

Sperm whales, the largest odontoceti, are very famous for their feeding on large squids in diving in the deeper waters of the open sea. The large deep sea living fish also occupy the considerable part of the diet of the sperm whales according to the research hitherto done (Clarke, 1956).

As a consequence, sperm whales are well known for their deep diving to feed, and they are sometimes entangled by the telephone cable in the deep sea bottom over 1000 meter, and Clarke (1956) also states the sperm whales occasionally visit the sea floor to feed from the records of dents on the forehead part. Heezen (1957) further suggests the digging up the sea bottom with their strong lower jaws to feed causes the entanglement of the cable set on the sea bottom. Sperm whales become entangled while swimming along with their jaws plowing through the sediment in search of foods.

From the observation on sperm whales caught in the Bering sea, stones and rock fragments have been found in the stomachs of whales suggesting that sperm whales are feeding in the sea bottom and swallowed these stones as stated by Heezen and Clarke.

We think also stones and rock fragments found in the stomachs of sperm whales are direct evidence that sperm whales are often feeding in the sea bottom and digging the bottom to swallow their foods, such as deep sea fish octopus and sometimes even crabs. Here we would examine the occurrence of stones and rock fragments with other aliens such as coconuts, sea sponge, shells and glass balls. These aliens would suggest the peculiar feature of the ecology of sperm whales to some extent. For example, in the diving in their feeding, how far they do it may also be suggested by considering the distribution of these aliens.

MATERIALS

The materials treated here have been collected from 1954 to 1961 in the Japanese whaling expeditions in the Bering sea and adjacent waters. Following aliens are found and examined here.

- Stone and rock fragment
- Sand
- Glass bouy (for long line fishing)
- Coconut
- Deep sea sponge
- Cut meat of the baleen whale
- Crab (As stated before crabs are considered as a food of sperm whales.)

Shell of bivalves

Stones and other samples are mostly collected from the first stomachs of sperm whales but some stones are also found in the second stomach.

Stones and rock fragments

It is sometimes observed that stones and gravels are found in the stomachs of gray and little-piked whales (Andrews, 1954; Jonsgard, 1951). These cases suggest that those baleen whales sometimes seek their food in the bottom strata in their feeding. On the other hand, sperm whales are deeper divers and they apparently seek their foods in the deep sea bottom as suggested by Heezen (1957). Sperm whales must have dug the sea bottom or chased the bottom living animals such as crabs and rays and angler fish as considered by Heezen, because considerable many stones and sand are found in the stomachs of sperm whales caught in the Bering sea. The positions where stones and sand are found in the stomachs of sperm whales are illustrated in Fig. 1. As shown in Fig. 1 the positions distribute along Aleutian

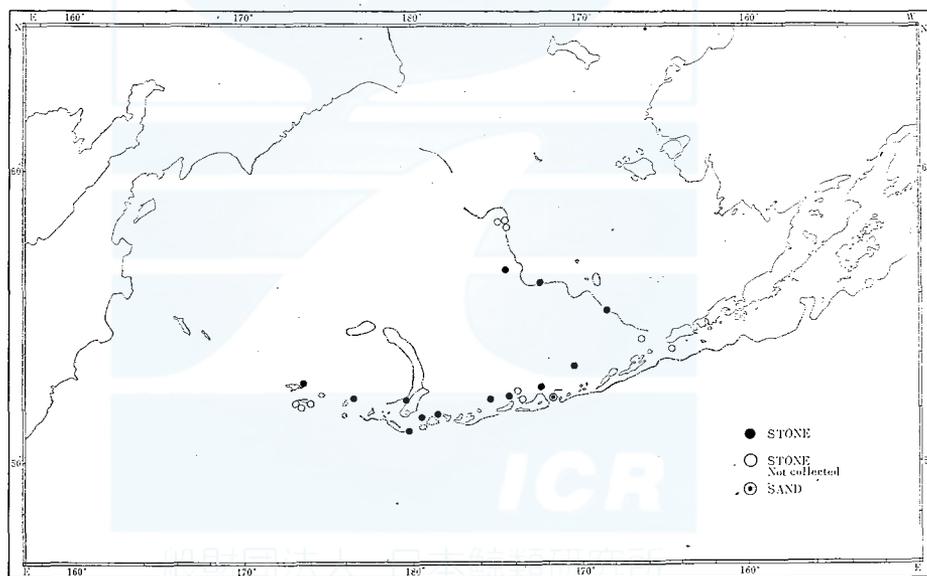


Fig. 1. Distribution of stones and sand found in stomachs of sperm whales caught in the Bering sea.

archipelago and Alaskan continental shelf. We should think the position may have the relation to the distribution of food fish and crabs, which distribute along the shelf waters more abundantly. Although sperm whales have been caught in the waters of Bowers Bank and the center part of the Bering sea, no sperm whale with stones in the stomachs has been caught in the said waters. Considerable many sperm whales have been caught in the deeper waters of the Bering sea, but sperm whales with stones have not been caught in the center waters.

Many sperm whales with one stone in stomachs of whales but some 40 and

50 stones are also found in two sperm whales. The latter cases may prove that the sperm whales digged over again to take their food in the bottom.

The weight of the stones found in the stomachs of sperm whales varies from 20 to 1,400 gram as shown in Table 1. Almost all stones are less than 300 g, but two stones are between 500 g and 1,000 g, and only one stone is 1.4 kg. The weight of the jaws of large squids is also heavy and may be unpleasant for sperm whales. However, jaws of squids are often found in vast number undigested in their stomachs. So stones may be not so uncomfortable for the physical condition of sperm whales like those jaws of squids.

TABLE 1. NUMBER OF STONES FOUND IN THE STOMACHS OF SPERM WHALES

Number of stones									
1	2	3	4	5	6	7	8	ca. 40	ca. 50
14	1	2	—	2	—	—	1	1	1

TABLE 2. WEIGHT OF STONES FOUND IN THE STOMACHS OF SPERM WHALES

Weight of stones in gram						
1~49	50~99	100~149	150~199	200~300	500~999	1000~
4	9	7	1	5	2	1

It is not certain whether these stones swallowed are disgorged again from the mouth or go down to the intestine to be discharged from the anus, however, the sperm whales taking stones are mostly caught along the shelf of the Islands and continent, so it may be considered the swallowed stones are cleaned out fairly speedy in either way above stated. The one case that stones are found in the second stomach suggests that stones are sometimes cleaned out through intestine and anus.

These stones include following species.

- Andesite
- Propylite
- Basalt
- Siliceous shale
- Shale
- Liparite
- Liparitic tuff
- Quartz andesite
- Andestic agglomeratic tuff
- Gray wacke sandstone
- Psolite (in the tuff)

As it is shown in the table, andesite stones are numerous and account 60% of the total stones found in the stomachs of sperm whales, Although the examined samples are rather few, andesite is found in the stomachs of sperm whales caught

from the central part to the eastern part of the Aleutian Islands. In the future investigation, it will be possible to get a little knowledge about geological feature of Bering sea bottom from the stones found in stomachs of sperm whales.

Among the collected stones, the most part of the stones found in the same whales are related each other. Two cases in which 5 stones are found respectively consist of all andesite stones. One liparite stone and liparitic tuff stones make third case, and two stones found in stomachs of a sperm whale are quartz andesite and andesite respectively.

Above cases suggest sperm whales take those stones in the neighbouring position or simultaneously with their foods.

TABLE 3. THE SPECIES OF STONES AND NUMBERS OF STONES AND ROCK FRAGMENTS

Andesite	17
Propylite	1
Basalt	1
Liparite	2
Liparitic tuff	1
Quartz andesite	2
Andestic agglomeratic tuff	1
Siliceous shale	1
Shale	1
Sandstone	1
Gray wacke sandstone	1
Psolite (in the tuff)	1

As stated above, andesite stones show the dominant occurrence, 60.5% for the total, and igneous rocks occupy the almost all part of the stones found in the stomachs of the sperm whales. This phenomenon is surely owing to the distribution of the stones in sea bottom of feeding grounds of sperm whales in the Bering sea to some extent. Distribution of stones in the sea bottom may be drawn from the examination of the stones too. The andesite stones are found in the stomachs of sperm whales caught in the adjacent waters to the middle and east Aleutian Islands as illustrated in Fig. 2.

According to Hess (1948) and Kuenen (1950), the andesite line is drawn on the outer convex side of the arcuate trenches and basaltic central area is divided from the peripheral regions as illustrated by Kuenen (1950). In the landward of the boundary line along the Aleutian Islands where many sperm whales are feeding, the andesites are found.

The basaltic stone is found only one occasion, suggesting that the caught sperm whales have not been feeding in the outer basaltic zone so heavily. This assumption also may be shown by the composition of foods of sperm whales in which the bottom or deep sea living fish occupy the considerable part. Those fish are apparently considered to be living more numerous within the line where the sperm whales are more actively feeding.

It is reported that birds sometimes carry stones to the unexpected area and it is said it makes some confusion in geology, especially in the distribution of rock

fragment and stones. So, if sperm whales swim with stones in the stomachs considerably speedy in a short period, there may be also some confusion in the determination of distribution of stones found in the sea bottom. The delivered sediment stones and rock fragments by sperm whales may be considered as a possible reason if extraordinary occurrence of stones in the sea bottom is observed.

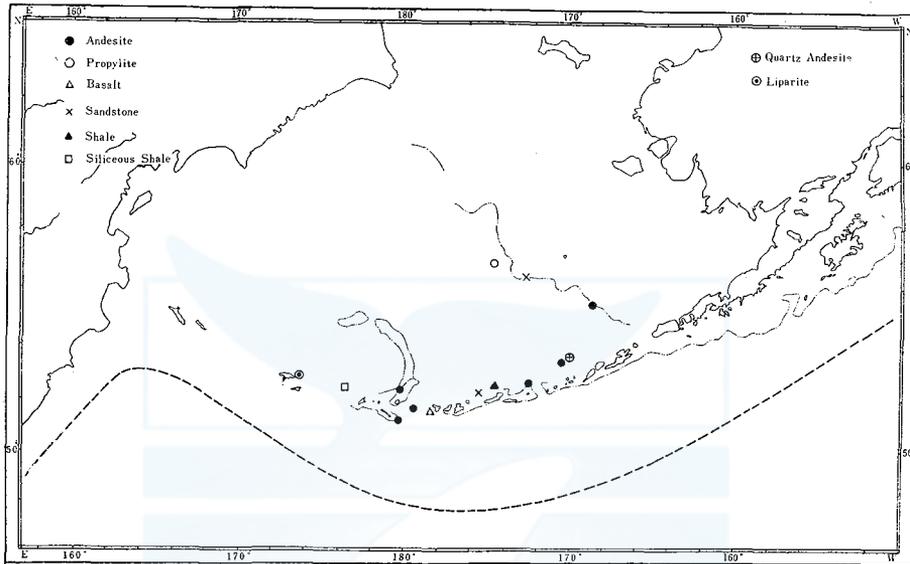


Fig. 2. Distribution of stones found in stomachs of sperm whales caught in the Bering sea. Broken line—Andesite line (Kuenen, 1950)

Sand

It is very interesting to note that a gallon can of sand is observed in the stomachs of a sperm whale. This is also an illustration that sperm whales are usually feeding on the bottom living organisms with digging sand and chasing over again by their jaws as stated by Heezen (1957).

Crabs

As we said in the former part, bottom living crabs are considered to be taken as a food by sperm whales. The occurrence of benthos crabs has been described also in former reports (Clarke, 1956). In the stomachs of sperm whales, crabs are mostly digested, but two species of crabs are identified among the collected legs and carapace fragments of the crabs. Warty crabs and king crabs are them. Those crabs are considered moving in the sea bottom, and sperm whales must have chased them as their foods by some method such as ultrasonic detection. If we examine more carefully the stomachs of sperm whales, more fragments of crabs may be found.

Glass buoy

A glass buoy is found in the stomach of a whale caught at 58–10N and 174–37W

in 1961. This glass buoy is ordinary one and it is usually used as a buoy in the gillnet or longline fishing.

From the finding of glass buoy and many coconuts in the stomachs of sperm whales, it is considered that sperm whales sometimes follow floating substances on the surface of the sea from the under water. But of course it is not certain if sperm whales have fed them as their foods or not. Some curiosity for the floating may cause this swallowing such strange aliens.

Cocunut

Six cases of the finding cocunut in the stomachs of sperm whales are described in the records of the biological survey on the sperm whales caught in the Bering sea and the northern part of the north Pacific. In each case, only one cocunut is found in the first stomachs of those sperm whales, the capture positions of which are illustrated in Fig. 3. From the Fig. 3, the sperm whales taking cocunut in their

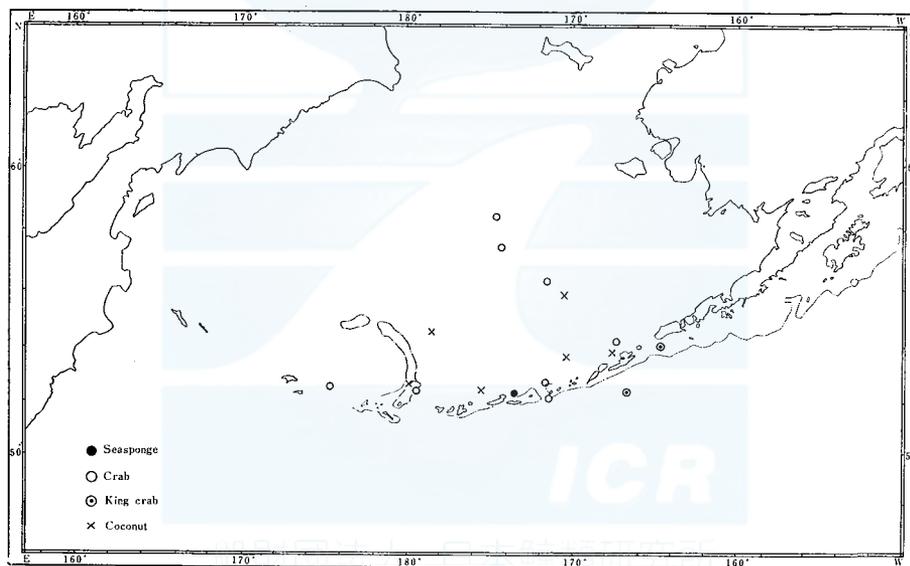


Fig. 3. Distribution of sea sponge, crab, and coconut in stomachs of sperm whales caught in the Bering.

stomachs are caught in the off waters of the Bering sea different from the whales taking stones in their stomachs which distribute along the continental shelf and Aleutian Archipelago. This may suggest that they drifted to the Bering sea and swallowed by sperm whales. From the observations on the external condition of coconuts, the outer covering of coconuts are not so fresh.

We would think these cocunut have not been swallowed directly in the south waters where the cocunut trees are growing, but they have been floating to the northern waters in the currents and swallowed by sperm whales.

Cut meat of the baleen whale

The very interesting case of a sperm whale taking cut meats of the baleen whale are observed in 1960. In the Aleutian waters, Japanese and Russian whaling have been operating in the Bering sea, and the meat of the caught baleen whale is flensed to make the products on the factory ships. These cut meats are considered one of the flensed meats from the factory ship.

The fresh meats of baleen whales sink in the sea, however, fatty meat or rot meat float in the surface of the sea for a while. It is considered the sperm whale follow the meats in the surface stratum like coconuts.

Shells of bivalves

Ten shells of the bivalve are found in a stomach of sperm whale caught in the Bering sea on 19th July in 1960 at 52-30N and 173-59W. Among these shells, two species of bivalves are identified. One is *Chlamys islandicus* Muller. The bivalve distributes from the northern part of the north Pacific to the Arctic sea. It occurs circumpolar in the northern hemisphere also in the Atlantic, and is also found in Puget Sound and adjacent waters to Kamtchatka peninsula. It usually inhabits in the bottom of the sea from 200 to 400 meter depth in above regions.

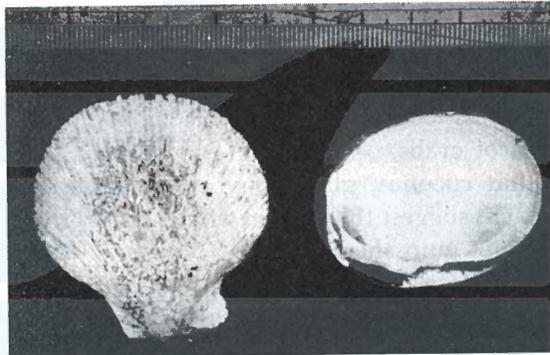


Fig. 4. Two shells swallowed by a sperm whale in the Bering sea. Left—*Limopsis vaginatus* Dall, Right—*Chlamys islandicus* Müller. Photo by T. Okutani.

As the next species, *Limopsis (Empleconia) vaginatus* Dall is found among them. The *Limopsis vaginatus* is firstly described from the shore of Unalaska Islands in the Bering sea from the 600 meter depth. Above two bivalves have remained ligaments considerably fresh especially in the latter. From the stage of the ligaments, it is considered these bivalves were living when they were swallowed by the sperm whale. This also affirms that sperm whales feed actively on the livings on the sea bottom of the Bering sea, and these bivalves may be swallowed in the feeding.

Deep sea sponge

Besides above stones and other aliens, a deep sea sponge is found in the stomach of a sperm whale caught at 52-20N and 173-30W on 9th July in 1960. This sponge

is considered a deep sea living sponge belonging to the order Hexasterophora and it is usually found in 200–400 meter depth or deeper waters. From the skeletons of the body, the sponge was alive when it was swallowed by the sperm whale.

The sponge has tough root and it must have attached to the sea bottom with considerable strong fixing power. So the sperm whale must have dug it with lower jaw and swallowed it with other bottom living food such as crabs and rays etc.

Clarke (1956) already notes the occurrence of a gorgonid in the stomach of a sperm whale caught in the Azores.

ACKNOWLEDGEMENT

We would express sincerely our thanks to Dr. H. Niino of the Tokyo University of Fisheries for his kind identification on the stones and rock fragments collected. The kind examination on the shells of bivalves by Mr. T. Okutani of the Tokai Regional Fisheries Laboratory is also gratefully acknowledged here.

SUMMARY

1. Stones and other aliens found in the stomachs of sperm whales caught in the Bering sea and the northern part of the north Pacific are examined in view of the distribution of aliens and feeding habits of sperm whales. These aliens contain stones, sand, glass bouy, coconuts, sea sponge, cut meat of the baleen whales and fragments of crabs.

2. The cases that coconut, glass bouy and cut meat of the baleen whales are found in the stomachs suggest that sperm whales follow the drifters on the surface of the sea and sometimes gulp them.

3. The finding of deep sea sponge, deep sea crabs, living shells, stones and rock fragments and sand prove that deep diving of sperm whales and their feeding is also active in the deeper layer and the sea bottom.

4. The most part of stone and rock fragments are andesite and almost all stones are igneous, which suggest the bottom distribution of the stones in the shelf of the Bering sea along the Aleutian Islands. The further collection of stones and rock fragments will add something to the study of geology of the Bering sea.

5. From the finding of the many stones and fragments of rocks in the stomachs of sperm whales, they are considered to dive deeper than 200 meter to feed in the Bering sea.

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TAXONOMICAL CONSIDERATION ON GENERA OF *DELPHINIDAE**

MASAHARU NISHIWAKI

INTRODUCTION

There are some difference in the considerations regarding separation and the combination of the various genera of *Delphinidae* according to different authors. According to the checklists by J.E. Gray, he separated them into three families *Balaenidae*, *Catodontidae* and *Delphinidae*, in the suborder *Cete* in 1850, but he corrected it to six families, *Catodontidae*, *Ziphiidae*, *Platanistidae*, *Iniidae*, *Delphinidae* and *Globicephalidae*, in the section *Denticeti* in 1866. Some of the previous authors after Gray have written on separation into families other than already established. The separation considered differ according to the individual author however the reasons given by each are most reasonable, as for instance, some of the previous authors have separated them into *Kogiidae*, *Phocaenidae* and *Monodontidae* (*Delphinapteridae*) as well as *Physeteridae*, *Ziphiidae*, *Platanistidae* and *Delphinidae*. There is very clear reason for these separations, and the author could think it reasonable. None of them however, separated the *Globicephalidae* from the *Delphinidae* in the suborder *Odontoceti*. If a genus of a family has some different characters from another genera of the family, it may be recognized as a subfamily or an individual family. The author if possible does not wish to apply subfamily as a general principle. It is necessary to consider, of cause, the genera is derived from what kind of ancestral animals.

It is easy to understand that in the family *Physeteridae*, the subfamily *Kogiinae* was separated with the subfamily *Physeterinae*, and then the subfamily *Kogiinae* was made an independent family *Kogiidae*. The author would like to induce separations of the family *Delphinidae* as mentioned above.

The following names of the living genera were included in the family *Delphhiidae* by recent authors. *Delphinus*, *Stenella*, *Tursiops*; *Lagenorhynchus*, *Lissodelphis*, *Steno*, *Sotalia*, *Cephalorhynchus*, *Globicephala*, *Pseudorca*, *Feresa*, *Grampus*, *Grampidelphis* and *Orcaella*. These genera have one to ten species, so the family *Delphinidae* is the largest family in the suborder *Odontoceti*. The author already recognized that *Phocaena*, *Phocaenoides* and *Neomeris* were included in the family *Phoocaenidae* independently from the family *Delphinidae*.

It is considered that there are apparently two types in the family *Delphinidae*. One has a pungent beak, numerous teeth and small in size, another has a beakless blunt head, few teeth and moderate in size. The various characters of these types must be studied.

Cephalorhynchus and *Sotalia* are considered in the first type, but the author has no detailed descriptions on these genera, so the author with much regret is unable

* Dedicated to Professor T. Ogawa for his sixtieth birthday

to discuss on these genera.

BODY LENGTH AND NUMBER OF VERTEBRAE

It was clear that the total number of vertebrae, including cervical, dorsal (thoracic), lumbar and caudal vertebrae, were different in each of the genera.

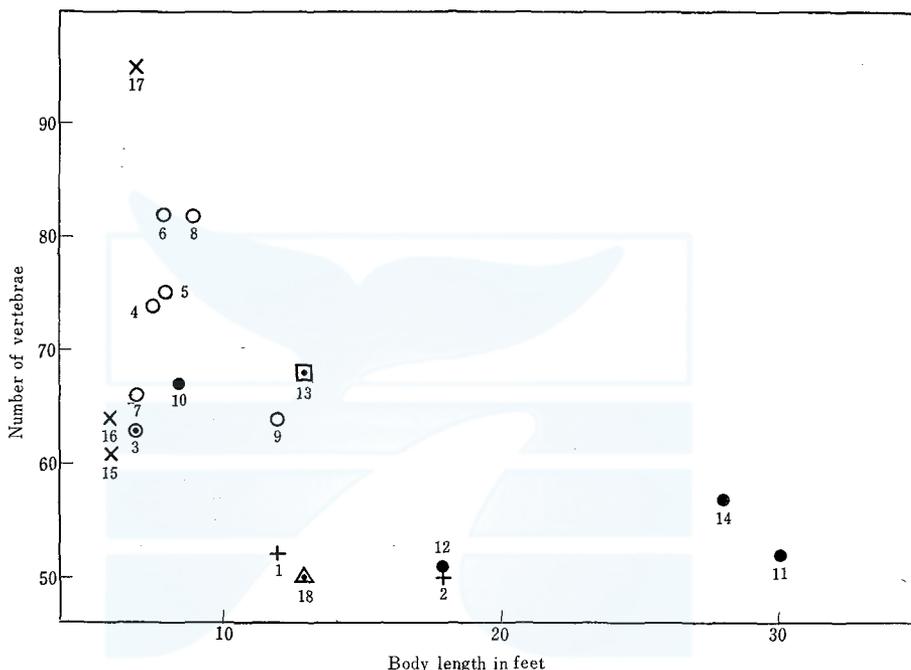


Fig. 1. Relation between body length and number of vertebrae in various genera of smaller toothed whales.

Explanation of the marks in the figures.

The marks ○ are the genera with only the *Atlas* fused to the *Axis*; the marks ● indicate those in which the *Atlas* is fused with more than two other cervicals. The genus *Orcaella* is shown with the mark ⊙, and the mark ◻ shows the genus *Grampidelphis*. The marks × are the genera of the family *Phocaenidae*, and the marks + are the genera of the family *Monodontidae*. The mark Δ shows the family *Kogiidae*. The attached number of marks represent the name of the genera. 1: *Monodon*, 2: *Delphinapterus*, 3: *Orcaella*, 4: *Delphinus*, 5: *Stenella*, 6: *Lissodelphis*, 7: *Steno*, 8: *Lagenorhynchus*, 9: *Tursiops*, 10: *Feresa*, 11: *Grampus*, 12: *Pseudorca*, 13: *Globicephala*, 14: *Glampidelphis*, 15: *Neomeris*, 16: *Phocoena*, 17: *Phocaenoides* and 18: *Kogia*.

Fig. 1 shows that the total number of vertebrae, whether small or large, does not affect the body length. The average of a number of species of each genera are given in the figure, but as for the body length, the measurements of full grown male have been given. Usually male is bigger than female in the suborder *Odontoceti*. According to this figure, the large sized genera have smaller number of

vertebrae, as compared with the larger number of vertebrae in the smaller sized genera. This suggests that each vertebral bone is bigger in the large sized genera.

These figures (Fig. 1–Fig. 3) also show the positions of the genera of the families *Kogiidae*, *Monodontidae* and *Phcaenidae* which are already separated from the family *Delphinidae* by the previous authors.

FUSED BONES IN CERVICAL VERTEBRAE

The very important character is which of the seven cervical vertebrae are fused. (As it is well known, there is no genus which has six or eight cervical vertebrae in the order Cetacea.)

In the family *Physeteridae*, the *Atlas* is free, but the *Axis* to the seventh cervical are all fused, but the all cervicals are fused in the case of the family *Kogiidae*. The family *Ziphiidae* has fused cervicals, from the *Atlas* to the *Axis* or to the fourth. All free cervical vertebrae are observed in the case of the family *Monodontidae* and the *Platanistidae*.

In the case of the genera in the family *Delphinidae*, it is described that at least the first and the second cervical vertebrae are fused together. Some authors mention that “at least two bones are fused” but the author on examining this character have found the following facts.

The names of the genera with only the *Atlas* and the *Axis* fused, are *Delphinus*, *Stenella*, *Lagenorhynchus*, *Tursiops*, *Lissodelphis*, *Steno* and *Orcaella* (*Cephalorhynchus* and *Sotalia* were not studied). The author observed, however, in this genera especially in the *Stenella* or the *Delphinus*, the third cervical became fused with the *Axis* after growth. It seems that these cases have not occurred due to the hereditary nature, but to the ageal changes. These seven genera are small in size and have a pungent beak, except the genus *Orcaella*.

The genus *Orcaella* (Irawaddy dolphin) has a beakless blunt head, moderate number of teeth (15–17/12–14) and small in size. They are very different in character from both types of the *Delphinidae*. Furthermore the *Orcaella* is generally fluviatile and comparatively restricted in distribution. The author would first like to separate this genus *Orcaella* from the family *Delphinidae*.

Another genera in the family *Delphinidae* have not only the *Atlas* and the *Axis* fused but also the third or more cervical vertebrae fused to the *Atlas*. In the case of the genus *Feresa*, the *Atlas* to the third cervicals are fused, and in the genus *Grampus* the cervicals are fused from the *Atlas* to the fourth. The genera in which the *Atlas* is fused to the sixth cervical vertebrae are the *Globicephala*, *Pseudorca* and *Grampidelphis*. These five genera have a beakless blunt head, fewer number of teeth (under fifteen in a tooth row) and some of them reach moderate in size.

SHAPE OF SKULL

The characteristics of the skull are very important, and a most intricate method of measurement is employed, however it would be too complicated to explain the

method here, therefore, in this paper only the length of the skull and the length of the rostrum will be treated as the ratio of their breadth. The length of the skull is the straight length from the middle of the occipital conuyles to the tip of the snout when the skull is situated horizontally. By the breadth of the skull, the greatest width of the skull is meant and this is usually equal to the breadth across the middle of the orbits. The length of the rostrum is obtained by measuring the base, and this is almost equal to the length between antorbital notches.

Fig. 2 shows the relation between the length/breadth ratio of the skull and the length/breadth ratio of the rostrum. In the figure the plotted points are arranged from underleft to uppright. The open circles are the genera in which are *Atlas*

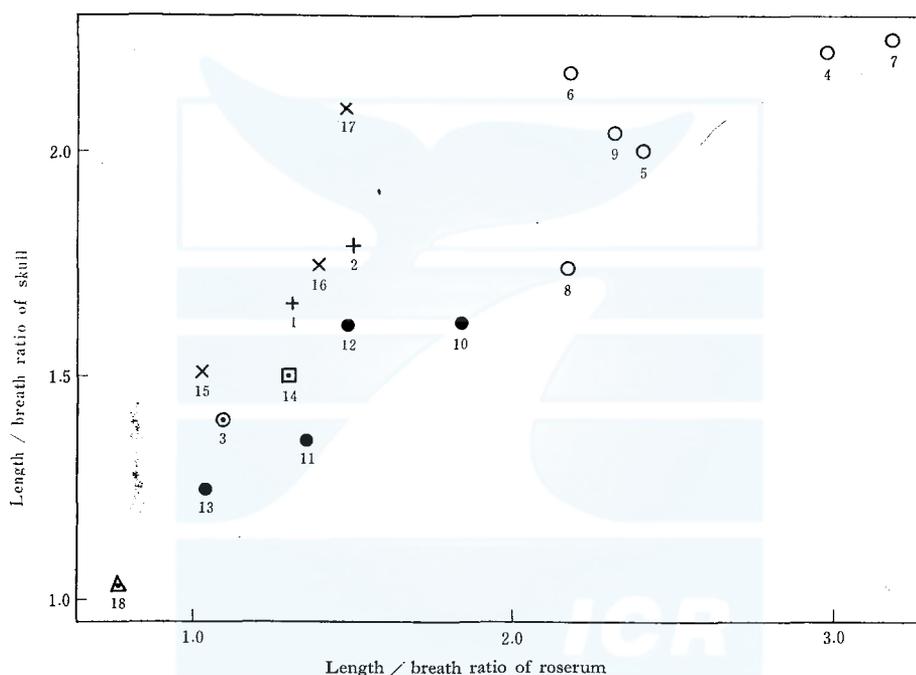


Fig. 2. Relation between skull and snout on their slenderness in various genera of smaller toothed whales.

only is fused to the *Axis*, and the closed circles indicated those in which the *Atlas* is fused more than three cervicals. There is one exception however and that is the genus *Orcaella* shown with an open circle with a point. It is clearly separated into two groups, the open circle group is the *Delphinus* type which have long slender rostrum (over twice the breadth in length), and the closed circle group is the *Globicephala* type which have short broad rostrum (1.5 times of breadth or less in length). The long skull length of the *Delphinus* type group is mainly due to its rostrum length, but in the *Globicephala* type group the brain case is wider. In this figure the genus *Orcaella* occupies a special position near the genus *Neomeris* of the family *Phocaenidae*.

NUMBER OF MAXILLARY TEETH AND LENGTH OF ROSTRUM

It can be considered that the longer rostrum has more teeth than the shorter rostrum. Fig. 3 shows the relation between the number of maxillary teeth and the length/breadth ratio of the rostrum. In the figure the long rostrum generally has more teeth. The genus *Steno* has the longest ratio of the rostrum but surprisingly the number of teeth are relatively small (20–27 in each tooth row). This is caused by the following reason. The teeth size is relatively large and the rostrum is comparatively slender. In this figure also the open circled genera have formed a group (relatively widely diffused) and the closed circle genera have formed another group.

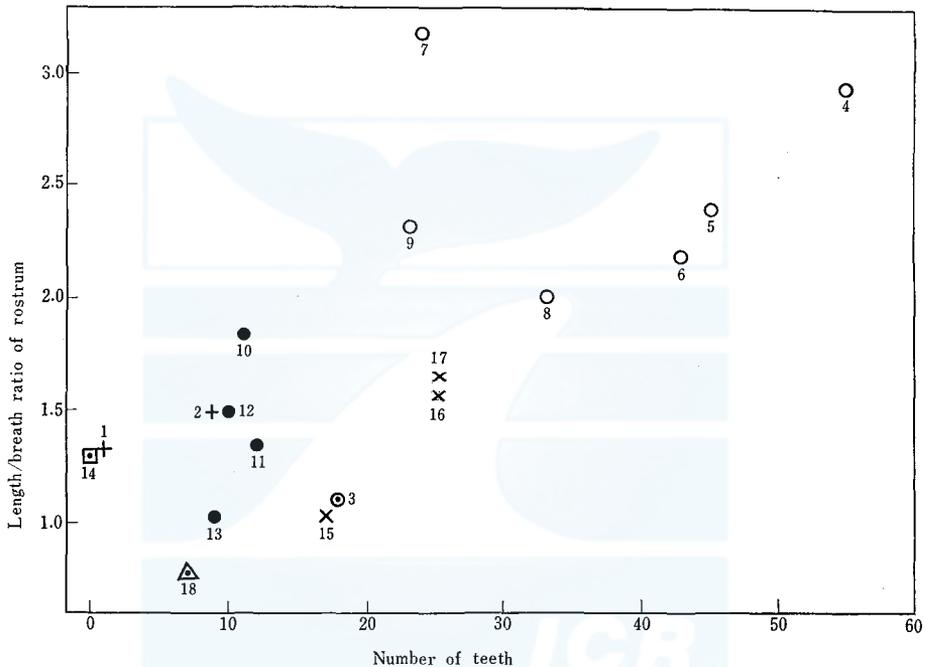


Fig. 3. Relation between number of teeth and length breadth ratio of snout in various genera of smaller toothed whales.

However the genus *Grampidelphis* has no maxillary teeth and does not belong to either of the groups. This may be a reason for separating it into an individual group.

The genera of the family *Monodontidae* and the *Phocaenidae* each form a different group. The genus *Orcaella* also occupies a special position near the genus *Neomeris*. In these two genera (*Orcaella* and *Neomeris*), the shape of the teeth are quite different, but no discussion on the matter will be taken up here.

It is possible to discriminate them into groups by elaborating on the relationship of the foregoing elements, however the author has refrained from illustrating them in figures, because it would be too difficult to explain their connection.

CONCLUSION

Some taxonomical considerations are made on the reasons already mentioned above.

In the fourteen genera of the family *Delphinidae*, the six genera are accepted as the *Delphinus* type, and the five genera are considered as the *Globicephala* type. The genus *Orcaella* is being separated from the two types. The author considers that the family *Phocaenidae* is already separated from the family *Delphinidae* by the previous authors. The *Delphinus* type genera generally have a long slender beak (over twice the breadth in length of rostrum), numerous teeth (over 20 teeth in each tooth row) and relatively small in size (under 13 feet). This type also has the cervical vertebrae with only the *Atlas* fused with the *Axis*. The genera of the *Delphinus* type are *Delphinus*, *Stenella*, *Lagenorhynchus*, *Tursiops*, *Lissodelphis* and *Steno* (*Sotalia* and *Cephalorhynchus* may be included in this type, but these two genera are excluded from this study because the available data was scanty). The author considers these genera should be included in the family *Delphinidae*.

The genus *Orcaella* should be separated from the family *Delphinidae* and independently form the new family *Orcaellidae*.

The *Globicephala* type genera generally have a beakless blunt head (under 1.6 breadth in length of skull), fewer teeth (under 15 in each tooth row) and some of them reach moderate in size (over 25 feet). Furthermore the cervical vertebrae of this type are recognized as having the *Atlas* fused not only with the *Axis*, but also with the third or more cervicals. The genera of the *Globicephala* type are *Globicephala*, *Feresa*, *Pseudorca*, *Grampus* and *Grampidelphis*, and these genera should be separated from the family *Delphinidae*. The author would like to propose that the family *Globicephalidae* has come to the fore again and that these genera should belong to this family.

Though the morphological characters should be examined very carefully, differences which are too minor should not be considered in making. Nevertheless the separation should be made with confidence, if the feature can be clearly differentiated. In the taxonomical consideration of animals, making too many species, genera or families may be indiscreet, but using subfamilies are not an adequate way also.

Each genus of the family *Globicephalidae* has its own special characters, but the most distinct feature in the majority of them is no teeth on the upper jaw. The genus which has this feature is the *Grampidelphis*. The author would like to venture to set up the new family *Globidelphinidae*.

As a conclusion, the author considers that the genera of the foregoing family *Delphinidae* should be separated into the *Delphinidae*, *Orcaellidae*, *Globicephalidae* and *Globidelphinidae* families.

The author in the following table shows a key to the living families of *Odontoceti* through his examination of the characters of the genera.

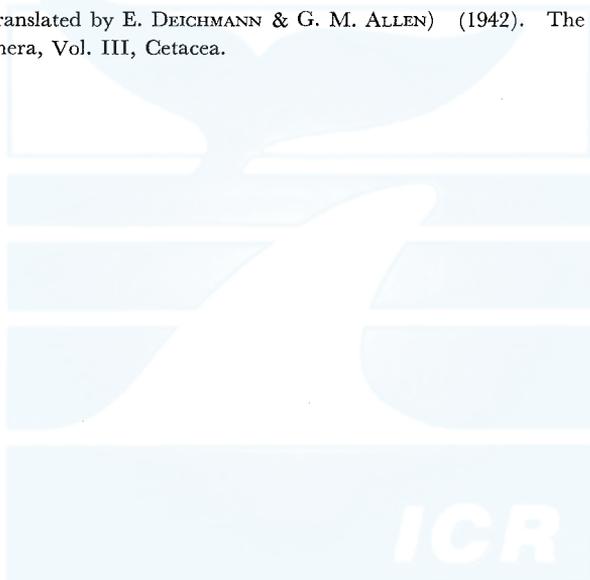
KEY TO THE LIVING FAMILIES OF *ODONTOCETI*

- 1₁ Tip of lower jaw ending an appreciable distance behind foremost part of head ; blowhole far forward on head.
- 2₁ Head massive, 1/4 to 1/3 of body length ; functional teeth large, 18 to 28 pairs in number, confined to lower jaw ; dorsal fin an ill-defined lump ; flipper rounded ; size large (30 to 60 feet). *Physeteridae*
- 2₂ Head 1/6 of body length ; functional teeth small, slender and curved, 9 to 16 pairs confined to lower jaw ; dorsal fin well developed ; flippers tapering ; size small (9 to 13 feet). *Kogiidae*
- 1₂ Lower jaw extending at least as far as tip of snout ; blowhole some distance from tip of snout.
- 3₁ Two conspicuous grooves forming a V-shape on the surface of throat blubber ; dorsal fin present, considerably behind middle of body ; no notch in middle of hinder margin of flukes. *Ziphiidae*
- 3₂ No grooving on throat ; dorsal fin when present at or near middle of body ; notch in middle of hinder margin of flukes.
- 4₁ Seven cervical vertebrae all separate from one another.
- 5₁ Dorsal fin absent or rudimentary ; beak absent ; inhabits Arctic region. *Monodontidae*
- 5₂ Dorsal fin present but almost low ; beak extremely long (1/6 to 1/7 of body length) ; inhabits tropical fresh water ; teeth very numerous in upper and lower jaws. *Platanistidae*
- 4₂ Two or more cervical vertebrae fused.
- 6₁ Only atlas and axis fused.
- 7₁ Beak long and narrow (length of snout less than 1/2 of its length) ; more than 20 teeth in each row of upper jaw ; size small (less than 13 feet). *Delphinidae*
- 7₂ Beak absent ; less than 20 teeth in each row of upper jaw ; size small. *Orcellidae*
- 6₂ Not only atlas and axis fused, but also third or more cervical vertebrae fused.
- 8₁ Head without distinct beak ; each row of upper teeth more than 15 ; body length less than 8 feet. *Phocaenidae*
- 8₂ Head without distinct beak ; each row of upper teeth less than 15 ; body length more than 8 feet.
- 9₁ Teeth present in upper jaw. *Globicephalidae*
- 9₂ Teeth absent in upper jaw. *Globidelphinidae*

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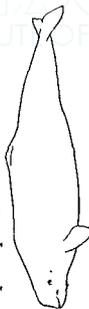
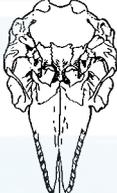
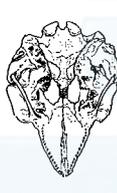
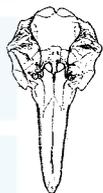
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Appendix: Body form and osteological characters on the various genera of smaller toothed whales.

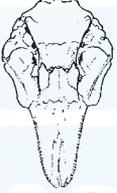
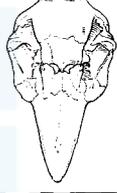
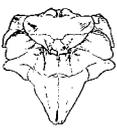
Genus name and out line of typical body form	Body length in feet	Ventral view of skull of typical species	Number of vertebrae (Detailed number with number of fused cervical & number of two headed ribs)	Number of phalangeal bones (Included metacarpals)	Dentition Upper of a side Lower	Length/breath ratio	
						(in typical species) of rostrum	of skull
<i>Monodon</i> 	12		50~55 C : 7 D : 11~12 (?) L : 6~10 Ca : 26~27	I: 1~2 II: 5~8 III: 4~6 IV: 2~4 V: 2~3	$\frac{1}{0}$	1.31	1.66
<i>Delphinapterus</i> 	18		50~52 C : 7 D : ~ L : ~ Ca : ~	I: 1~2 II: 6~9 III: 4~5 IV: 2~4 V: 2~4	$\frac{8 \sim 10}{8 \sim 10}$	1.50	1.79
<i>Orcella</i> 	7		62~63 C : 7 D : 13~14 (2) L : 13~14 (8) Ca : 27~28	I: 2 II: 8 III: 6 IV: 3 V: 0~1	$\frac{15 \sim 17}{12 \sim 14}$	1.10	1.41
<i>Delphinus</i> 	7 1/2		73~76 C : 7 D : 14~16 (2) L : 21~23 (4) Ca : 31~34	I: 1~2 II: 7~9 III: 6~7 IV: 2~4 V: 1~2	$\frac{47 \sim 65}{47 \sim 65}$	2.93	2.22
<i>Stenella</i> 	8		68~81 C : 7 D : 14~16 (2) L : 21~24 (4) Ca : 31~35	I: 1 II: 9 III: 7 IV: 4 V: 1	$\frac{34 \sim 56}{34 \sim 56}$	2.40	2.00
<i>Lissodelphis</i> 	8		88~90 C : 7 D : 14~15 (2) L : 29~30 (5) Ca : 37~39	I: 1~2 II: 8 III: 6 IV: 3 V: 2~3	$\frac{40 \sim 43}{42 \sim 46}$	2.18	2.17

Appendix (continued)

Genus name and outline of typical body form	Body length in feet	Ventral view of skull of typical species	Number of vertebrae (Detailed number with number of fused cervical & number of two-headed ribs)	Number of phalangeal bones (Included metacarpals)	Dentition		Length/breath ratio (in typical species) of rostrum of skull
					Upper	Lower	
<i>Steno</i> 	8		66 C : 7 (2) D : 13 (4~5) L : 15~16 Ca : 30~31	I: 3 II: 8~9 III: 6~7 VI: 3 V: 2	20~27 20~27	3.18	2.25
<i>Lagenorhynchus</i> 	9		73~92 C : 7 (2) D : 14~15 (6) L : 18~22 Ca : 38~41	I: 1~2 II: 10 III: 6 IV: 2~3 V: 2	22~45 22~45	2.02	1.74
<i>Tursiops</i> 	12		61~66 C : 7 (2) D : 12~14 (5) L : 17~19 Ca : 26~29	I: 1~2 II: 7~9 III: 5~8 IV: 2~3 V: 1~2	20~26 20~26	2.32	2.04
<i>Feresa*</i> 	8		67~68 C : 7 (3) D : 12 (6) L : 16 Ca : 32~33	I: 2~3 II: 8~9 III: 7~8 IV: 3~5 V: 2~3	10~12 10~13	1.84	1.62
<i>Grampus</i> 	30		50~52 C : 7 (4) D : 11~12 (6) L : 10 Ca : 21~24	I: 2 II: 6~7 III: 4~5 IV: 3~4 V: 2~3	10~13 10~13	1.36	1.36
<i>Pseudorca</i> 	18		50 C : 7 (6) D : 10 (6) L : 9~10 Ca : 22~24	I: 1 II: 6 III: 5 IV: 2 V: 1	8~11 8~11	1.49	1.62

* A herd of *Feresa* (seven males and seven females) was caught in the Sagami Bay of the Pacific coast of Japan, on 28 January 1962. All of them are being examined at the Whales Research Institute, Tokyo.

Appendix (continued)

Genus name and outline of typical body form	Body length in feet	Ventral view of skull of typical species	Number of vertebrae (Detailed number with number of fused cervicals & number of two-headed ribs)	Number of phalangeal bones (Included metacarpals)	Dentition Upper of a side Lower	Length/breath ratio (in typical species) of rostrum of skull
<i>Globicephala</i> 	28		57~60 C : 7 (6) D : 11~12 (6) L : 12~14 Ca : 28~29	I: 3~4 II: 9~14 III: 9~11 IV: 2~3 V: 1~2	0 2~7	1.30 1.50
<i>Grampidelphis</i> 	13		68~69 C : 7 (6) D : 12~13 (6) L : 17~18 Ca : 30~31	I: 2 II: 8~10 III: 5~8 IV: 3~5 V: 1	7~12 7~12	1.04 1.25
<i>Neomeris</i> 	6		58~63 C : 7 (5) D : 13~14 (11) L : 12~13 Ca : 25~31	I: 2 II: 5~7 III: 5~6 IV: 3 V: 2	15~19 15~19	1.03 1.51
<i>Phocaena</i> 	6		62~66 C : 7 (6) D : 12~14 (10) L : 14~17 Ca : 27~32	I: 1~3 II: 5~10 III: 5~8 IV: 2~6 V: 1~3	23~27 23~27	1.39 1.75
<i>Phocaenoides</i> 	7		92~98 C : 7 (7) D : 15~18 (12) L : 24~27 Ca : 44~49	I: 1 II: 6 III: 4~5 IV: 1~2 V: 0~1	23~27 23~27	1.47 2.10
<i>Kogia</i> 	13		50~51 C : 7 (7) D : 12~13 (8) L : 10~12 Ca : 24~27	I: 2 II: 5~8 III: 4~8 IV: 4~8 V: 2~7	6~8 9~16	0.79 1.03



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OCEANOGRAPHY AND WHALING GROUND IN THE SUBARCTIC REGION OF THE PACIFIC OCEAN

KEIJI NASU

INTRODUCTION

Oceanographic observation in the whaling grounds have been conducted for some years past on board the whaling factory ship "Kyokuyō-maru" and whale marking research boats. The work is carried out in the Chukchi Sea, Bering Sea and northern part of North Pacific Ocean with temperature by bathy thermograph and some serial observations.

Some aspects of the data obtained by these surveys were discussed in previous papers (Nasu 1957, 1958). Uda and Nasu (1956) discussed the whaling grounds in relation to meteorological and oceanographic conditions. Nemoto (1957, 1959) also had reported in detail on the subject from the point of the food of baleen whales and the ecology of plankton. The present paper gives the oceanographic structure in the whaling grounds and on the physical and chemical environment connected with the distribution of whales, using data obtained by whaling expedition cruises as well as sources.*

In this paper the vertical and horizontal distribution of water mass in the whaling grounds were examined.

The author is of the opinion that the vertical stability of sea water is also an important element for the formation of the whaling grounds.

ACKNOWLEDGEMENT

Grateful acknowledgement is made to the Japanese whaling inspectors and the staff of the whaling company who co-operated in the observations.

Acknowledgement is also made to my colleague Mr. Takahisa Nemoto, Mr. Seiji Ohsumi and Mr. Tadayoshi Ichihara who assisted in the collecting of the oceanographic data.

The author is greatly indebted to Dr. Michitaka Uda, Prof. of the Tokyo Univ. of Fisheries, who gave me kindly advices.

Sincere thanks are also expressed to Mr. J.E. Pearce who assisted in editing the paper.

DISTRIBUTION OF WHALES

As already reported by several scientists (Townsend 1935, Matsuura and Maeda 1942, Nikulin 1946, Sleptsov 1955) the larger whales in the northern part of North Pacific, Bering Sea and Chukchi Sea are blue, fin, humpback, sei, right,

* Other data were collected by Oshoro-maru and H.M.C.S. Ste Therese in the summer of 1955.

greenland, grey and sperm whale.

Blue whale (*Balaenoptera musculus*)

In general, blue whales are found in the northern part of North Pacific except the Bering Sea. According to Sleptsov (1955), blue whales are found in the south off Cape Olyutorski, the east off Cape Navarin and the Chukchi Sea. The result of Japanese whaling operations indicate that blue whales in the Bering Sea are scarce and are found mainly in the southern water of the Aleutian Islands. It appears, therefore, blue whales in the southern hemisphere have migrated to comparatively high latitude (Mackintosh and Wheeler 1929), but those in the Pacific sector of the northern hemisphere are found in relatively lower latitude. The blue whales seem to be found dominantly of about 50°N, 170°W.

Fin whale (*Balaenoptera physalus*)

Fin whales in the Sub-arctic Pacific sector are the most prevalent species for the stock of whale as is true for Antarctic whaling and its distribution ranges from the North Pacific to Bering Sea and Chukchi Sea. In the Chukchi Sea (a part of the Arctic Ocean), Japanese research vessel, Yūki-maru found many fin whales (number of whales are unknown) near 66°40'N, 170°W. on August, 22, 1937 and a Japanese pelagic expedition caught 74 fin whales there in 1940. According to Nikulin (1946), in C. Serdzekamen and the Bering Sea, 177 fin whales (July:70, September: 57, October: 50 respectively) were found in 1937. Consequently, as already stated (Nasu 1960), many fin whales seem to migrate into the Siberian waters of the Chukchi Sea at least from the early summer to October.

During the summer season, fin whales in the Bering Sea have been observed in all areas except the central part about 58°N, 177°E and the east of 200 m depth contour line (extending north-west from Unalaska I). Moreover, fin whales were abundant to the north of Unalaska I., (center about 54°39'N, 160°W), near 59°30'N, 170°-00'W and Cape Navarin. Especially, to the north of Unalaska I. as already shown by Kawakami and Nasu (1956), fin whales were most concentrated. Many fin whales were captured in the waters of Cape Navarin and from some previous reports, it is considered that the fin whales migrate to the Chukchi Sea. Some whales were also captured to the west of St. Mathew Island, near 60°N, 178°W.

To the south of the Aleutian Islands, many fin whales are distributed in a belt situation centering around 50°N, 170°W, where blue, sei, and humpback whales have been caught, too. Therefore, this sea region is important for whaling operations, but the annual whaling condition there is unstable.

As already shown by Nemoto (1959), many fin whales are found in the waters around the Komandorski Islands, to the east of Kamchatka Peninsula. In the northern region of the Komandorski Islands, many fin whales were caught in 1956 and 1959.

In the area south-east of Kamchatka, it is considered that the fin whales already had migrated in the middle ten days of May. Fin whales were also captured in

the waters off Cape Olyutorski, near 60°N, 170°E, but the whaling area and catch are both small.

Sei whale (*Balaenoptera borealis*)

In general, sei whales have been caught in the south region of the Aleutian Islands, but some whales were observed in the mouth of Anadyr Gulf in August of 1958. Sei whales are distributed mainly in the waters from the east of Kamchatka Peninsula to the south of Komandorsky Is. and from 180° to 170°W along the 51°N line.

Humpback whale (*Megaptera novae-angliae*)

Humpback whales are most prevalent in the waters south of the Aleutian Islands (especially, east of 170°W) and are also found in the area north of Unalaska Island. From the record of operations of the Japanese expedition in 1940 (101 humpback whales were captured) and data obtained by the research vessel "Yukimaru" in 1937 (many humpback whales were found, but total number is unknown), as Tomilin (1935) stated, it is clear that the humpback whales migrated to the Chikchi Sea. Humpback whales of the Ryūkyō waters have close relation to those of the eastern Aleutian sea area. (Kawakami and Ichihara 1958). Kellogg (1929) advanced the opinion that humpback whales in the west coast of Canada move as far north as Alaska. However, this has never been substantiated.

Sperm whale (*Physeter catodon*)

Many sperm whales were captured along the Aleutian Islands, and the most dense area is situated near longitude 180°. Sperm whales were also captured in the region centered at 56°N, 170°W. According to data obtained by Japanese expeditions, few sperm whales have migrated as far as 61°–62°N latitude. Tomilin (1935) stated that the sperm whales did not migrate to the region north of Cape Navarin. Matsuura and Maeda (1942) determined that the northern limit of the distributional region of sperm whale had existed from 50°N to 60°N latitude by analyzing where whales were sighted and caught.

In general, sperm whales in the Bering sea are considered to migrate as far north as 60°N latitude. In addition, sperm whales have also migrated to the Kuril Is., the west of Kamchatka peninsula, and the central area of Okhotsk sea (Sleptov 1955).

WHALING GROUND OF BLUE AND FIN WHALE

1) Blue whale

The author can not discuss in detail the blue whaling grounds because the catch number have been restricted to 70 whales since 1955; however, the whaling grounds may be roughly divided into east and west longitude areas. Moreover, as stated by Nemoto (1959), blue whales have not been captured in the Bering sea. The whaling ground in east longitude is located in the vicinity of latitude 52°N and

a narrow area along 51°N. In general, the center of whaling grounds existed in the vicinity of 52°N, 166°E. Catch in the west longitude was dominant in the area between 50°N and 49°N and its bound roughly covered from 178°W to 160°W (its center may be considered to locate near 50°N, 170°W). The densest area of catch was in the Aleutian waters from 170°W to 166°W, centered at 53°N, 165°W. A few blue whales were captured near 55°N, 157°W in 1960. Moreover, the rate of catch on east and west longitude was about 3:7 respectively.

2) Fin whale

Number of fin whales caught in the Subarctic Pacific area consist of more than 80 per cent of all whales caught.

Whaling ground of fin whale covered the greater part of the Bering Sea and the North Pacific Ocean north of 48°N, 12,998 fin whales were captured in the year 1952 to 1962, and prior to World War II 221 were caught in 1940 and 370 in 1941, respectively (catch in 1940 included 74 fin whales captured in Chukchi sea). Number of catch in the vicinity of 54°-30'N, 167°W, north of Unalaska I. was more than 500 whales in every one degree area for latitude and longitude. Number captured in one degree square area shows fin whales captured since 1952, and area more than 100 whales present the favorable ground for convenience and those named as follows.

- 1) Off Kamchatka Peninsula
- 2) Off Unalaska Island
- 3) Off Cape Navarin
- 4) Southern region of the Aleutian Island

GENERAL BATHYMETRY

Pelagic whaling in the Subarctic Pacific operates around north of latitude 48°N, in the Bering sea, and the Aleutian Is. The Aleutian Islands form a perfect arc of a circle, and divide the Bering Sea and the North Pacific. The Bering Sea forms roughly a scalene and its area is about 878,000 square miles (Barnes and Thompson 1938).

Fig. 1 is drawn by use of a bathymetric chart published by U.S. Navy Hydrographic office.

In general, the depth of Pacific side is deeper than that of the Bering sea, and the deepest area lies parallel to the Aleutian Islands at latitude 52°N, longitude 173°E, where it attains a maximum depth of more than 4,000 fathoms.

The 3,000 fathom contour line lies 60 sea miles off the south of Aleutian Islands and extends from 170°E to longitude 157°W. Consequently, there are steep continental slope lies in the area from 170°E to 157°W, the south of Aleutian Islands.

The 2,000 fathoms contour line lies to the north of the 3,000 fathoms lies and it extends from the central part of Kamchatka Peninsula to the Alaskan Continent, a distance of About 2,000 sea miles east and west. Therefore, the southern con-

tinental shelf of Aleutian Islands is very narrow. The maximum depth of the Aleutian Ridge lies to the northwest of Attu Island and its depth attains about 1,000 fathoms.

The deeper areas, those exceeding 2,000 fathoms, lie in the southwest part of the Bering Sea and the maximum depth is more than 2,200 fathoms at 54°N 175°W. The Bowers bank is located at the central part of Aleutian Islands, near long. 180° and extends to the north and northwest. The north edge of the 500 fathoms contour line lies along 55°N, and is 12 fathoms at the shallowest point 54°16'N, 179°30'E. The topography in the eastern and northern part of Bering Sea has a depth of at least 1,000 fathoms, and an extensive continental shelf exists. The 100 fathoms contour line extends from the Unimak Pass in the northwest direction to the south of Cape Navarin.

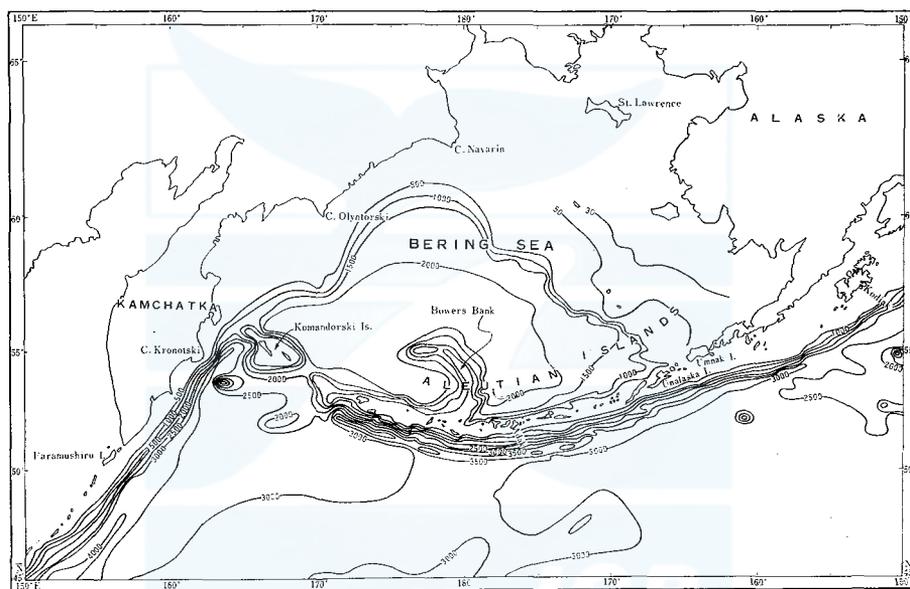


Fig. 1. Bathymetric chart, based on chart published by the U.S. Navy Hydrographic Office. (Soundings in fathoms)

Bering Strait is less than 50 sea miles wide at its narrow point and is from 20 to 30 fathoms deep. The depth in the Chukchi Sea is almost entirely less than 30 fathoms and has a minimum depth of 8 fathoms in 66°-30'N, 168°-30'W.

TEMPERATURE STRUCTURE

Horizontal distribution

Fig. 2-6 show monthly mean distribution of surface temperature during 1955-1959 every 1 degree latitude and longitude.

May:

In the east off Kamchatka, as already stated by Taguchi (1956), we can recognize

cold current (coastal water) which is southerly flowing along the Kamchatka coastal line and warm current (offshore water) which is flowing from the southeast off Kamchatka Peninsula to the northwest. Taguchi (1956) divided coastal and offshore water in May and June by surface temperature as follows.

$$\begin{aligned} \text{coastal water} &> \theta \quad 4.0^{\circ}\text{C} \\ \text{offshore water} &< \theta \quad 3.0^{\circ}\text{C} \end{aligned}$$

Fig. 2 shows the distribution of mean surface temperature in May.

Whaling ground in this season, in the off Kamchatka Peninsula is in general isotherms 1.0° to 3.5°C distributed from NNE to SSW. The isotherm of 1.0°C extends to the east of Onekotan Island ($49^{\circ}\text{--}30'\text{N}$, 155°E) near the 158°E longitude, and isotherms of 2.0° , 2.5° and 3.0°C lie parallel to the isotherms of 1.0°C and the 3.0°C line reach to 161°E longitude. Moreover the distribution of these isotherms must be influenced by the cold water mass which is transported from Okhotsk Sea.

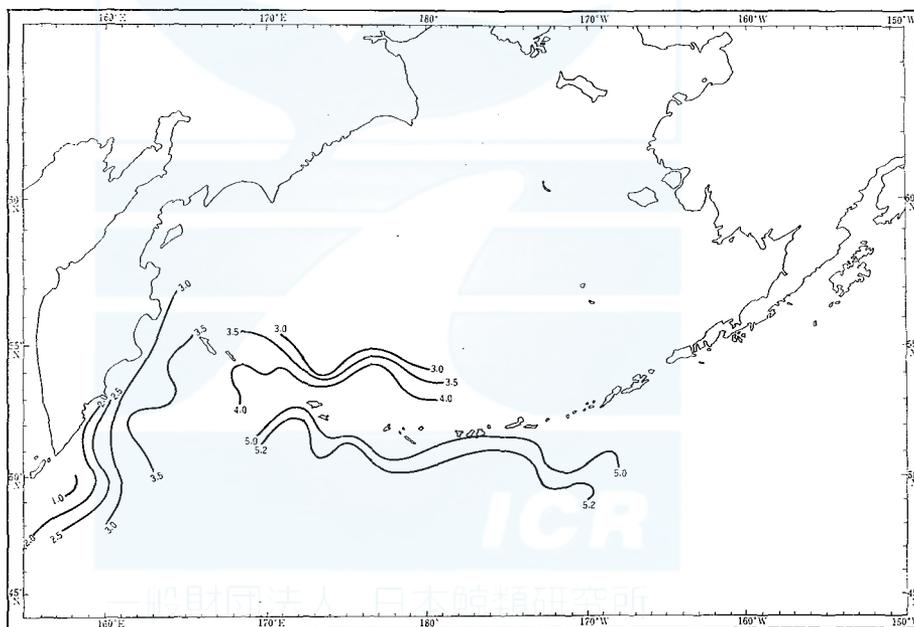


Fig. 2. Distribution of average sea surface temperature ($^{\circ}\text{C}$) in May.

The coastal water which is characterized by less than 3.0°C approaching to the Kamchatka in the northern area and the coastal water at near Cape Africa reaches to only 15 sea miles off the shore.

To the east of the 3.0°C line, the 3.5°C line meanders from the Komandorski Islands to the southwest nearly parallel to the Kamchatka Peninsula and the water mass is characterized by 3.0° to 4.0°C at surface temperature covers on extensive area. From the determination of coastal water mass by Tagauchi (1956), mixing area consisted of coastal and off shore water must be extensive.

Oceanographic variation to the east off Kamchatka Peninsula, as stated by

Taguchi (1956), may be considered as due to the influence of those two water masses. Near 52°N, 162°E the 3.5°C isotherm extends to the west. This is a consequence of the returning flow (Kitano 1958) which is flowing to the west along the south of the Aleutian Islands.

On the southern side of the Aleutian Islands, isotherms (5.0° and 5.2°C) run towards the east and west nearly parallel to each other and the distribution of sea temperature is characterized by a decrease from the west to the east. In the northern side of the Aleutian Islands, the 4.0°C-isotherm extended to the east of the Komandorski Islands with meandering.

The 3.5° and 3.0°C isotherms lie to the north of 4.0°C isotherm and extend roughly parallel of it.

June

Surface temperature in the east of Kamchatka Peninsula was comparatively

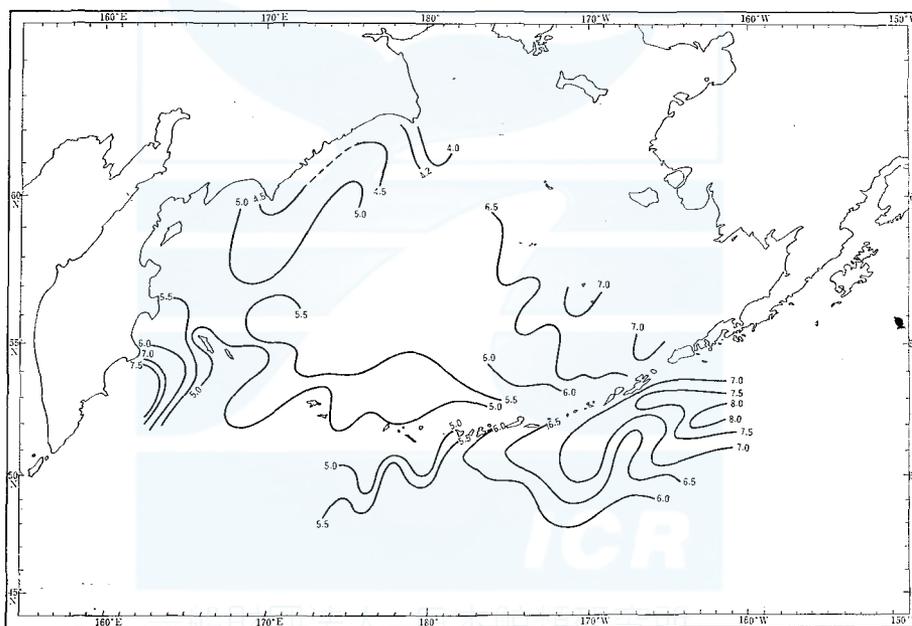


Fig. 3. Distribution of average sea surface temperature (°C) in June.

higher than that of May. The isotherm of 7.0°C extended towards the east and its eastern edge attained in 53°-30'N, 163°E. The water mass which extended towards the east is characterized by low water color and coastal water mass. Moreover, surface temperature was higher in coastal water and lower in offshore water mass.

Temperature at 0 and 30m depth in July of 1957 was as follows.

Depth (m)	Coastal water (θ_c)	Off shors water (θ_o)
0	θ_c	$> \theta_o$
30	θ_c	$< \theta_o$

Higher temperature in coastal water may be influenced by geographical difference of surface heating by solar radiation.

In the vicinity of the Komandorski Islands the 5.0°C-isotherm is located and largely meanders along the northern side of the Aleutian Islands. The southern side of the Aleutian Islands isotherms (5.0° and 5.5°C) run to east and west, and at the south of the Aleutian ridge there is cold water mass which is characterized by less than 5.0°C.

To the south of Aleutian Islands the main flow is from east to west and it was named the returning flow (Kitano 1958), which approaching longitude 180° with high temperature and low salinity at the surface.

The 6.0°C-isotherm reaches to 51°N, 178°W and at 178°W horizontal inclination of temperature increased to the west. Consequently, the extreme point of the returning flow in June may be considered to locate in the vicinity of 178°W longitude.

At 170°W longitude the isotherm of 7.0°C penetrated from the north-east to the southwest and at 167°W longitude isotherms (6.5° and 7.0°C) extended towards the northeast. From these phenomena, each water masses in this area were conjectured to formed complicated movement which was formed between the returning flow and the current with easterly component. The 6.5°C-isotherm locates in the north side of Unalaska Island, on the continental shelf to Alaska relatively high temperature 7.0°C-isotherm is tongue-shaped, extending towards the south. This is the water mass which is heated on the shallow waters of Alaskan continental shelf. At area from Cape Navarin to Cape Olyutorski isotherms run nearly parallel to Siberian Continent and temperature within 20 sea miles off the coast found less than 4.5°C.

July

The 8.5°C-isotherm covers most of the south waters of the Aleutian Islands. At near 53°N, 163°W isotherms lie with a complicated situation like that of June. The 8.0°C-isotherm lies at the north of the 8.5°C isotherm and it also lies along the Aleutian Islands like the 8.5°C-isotherm. In the neighborhood of the Bowers bank, there is a cold water area (below 8.0°C). This is a consequence of the upwelling which is formed by the bank, and it seems to him that the upwelling had developed in July. North side of the eastern Aleutian Islands the 7.0°C isotherm lies along the Islands and to the north of it the 7.0°C-isotherm extends towards the north-northwest mostly like the distribution of the 6.5°C-isotherm in June. The the water mass which penetrated from the Alaskan sea area is higher about 1.0°C than that in June.

Off Cape Navarin the 5.0°C-isotherm lie nearly parallel to Siberian Continent. Near 57°N, 178°E 10.0°, 9.5° and 9.0°C-isotherms run tongue-shaped.

August

The surface temperature attained the maximum value in the Bering sea and the northern part of the North Pacific. For instance, temperature at the east of Paramushiru Island run about 1.0°C-isotherm in May and the 11.0°C-isotherm in August respectively. To the southeast of Cape Kronotski 13.0°, 12.0° and

11.0°C-isotherms extend towards the northeast and the 11.0°C isotherm approaches to the south of Attu Island through the Komandorski Islands. North side of the Aleutian Islands in the neighborhood of Attu Island the 10.0°C-isotherm runs from the northwest to the southwest. The temperature value was generally higher 10.0°C off Kamchatka and 5.0–6.0°C at the adjacent waters of Attu Island than that of May.

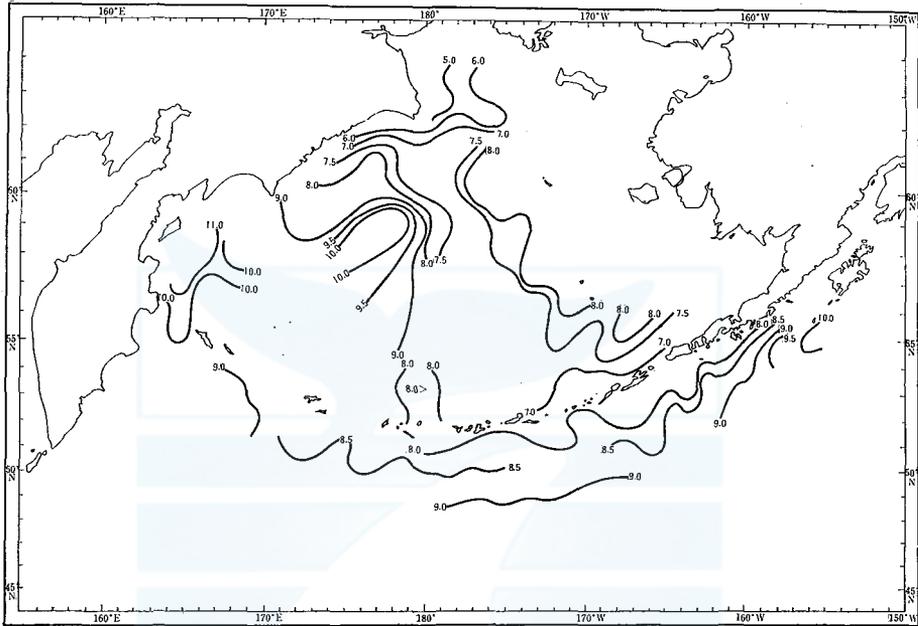


Fig. 4. Distribution of average sea surface temperature (°C) in July.

At the shallowest part of the Bowers bank 8.0° and 8.5°C-isotherms run parallel to each other and from these temperature distribution, it is clear that the upwelling area exists. And the isolated cold water area also is found due to the upwelling by the ridge at the central part of the Aleutian Islands, near of longitude 180°. Off Navarin Cape surface temperature is about 2.0°C higher than that of June and 7.0°, 8.0° and 8.5°C-isotherms run, and the inner part of Anadry Bay is supposed to have a cold water area formed by melted-ice.

In the neighborhood of St. Lawrence Island the 8.0°C-isotherm lies and off Cape Chaplina the 4.0°C-isotherm is found. In addition, temperature within 3.0°C were observed in August of 1958 (Nasu 1960).

Temperature distributions in the Chukchi Sea are summarized as follows.

Temperature at surface in the Chukchi Sea ranged from 3.7°C minimum to 11.2°C maximum (in August).

In general, in the eastern area of Chukchi Sea, the surface sea condition tends to higher temperature and the isotherms run parallel with the Alaskan coast line. In addition the distribution of temperature at surface is characterized by a decrease from the east to west.

September

In the Subarctic Pacific temperatures are decreasing. Near 45°N, 155°E there is tongue-shaped area with the 11.0°C-isotherm extending easterly and the 10.0°C-isotherm extending almost to Attu Island. Surface temperature in the sea area from 45°N, 155°E to Attu Island is higher at the west side and lower at the east side.

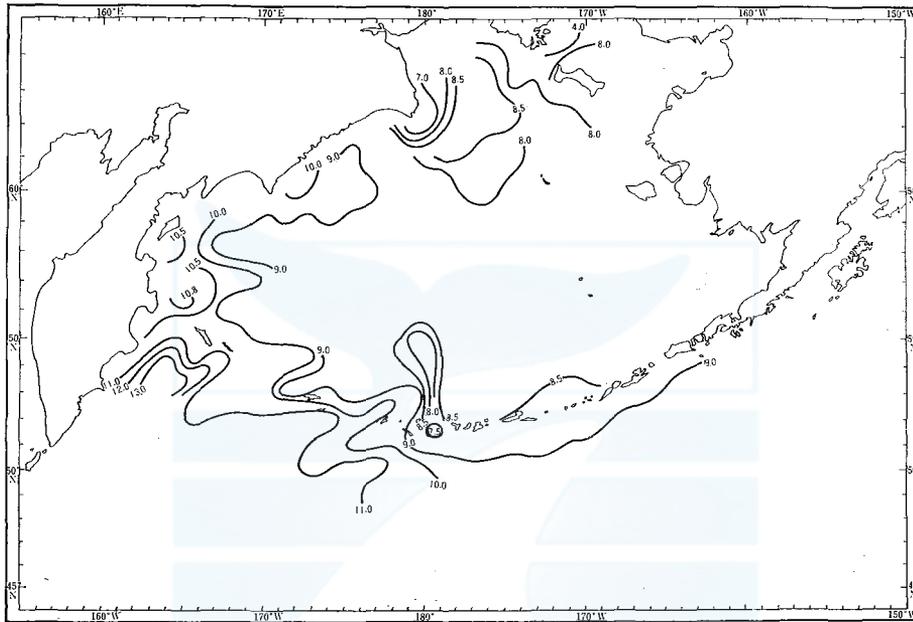


Fig. 5. Distribution of average sea surface temperature (°C) in August.

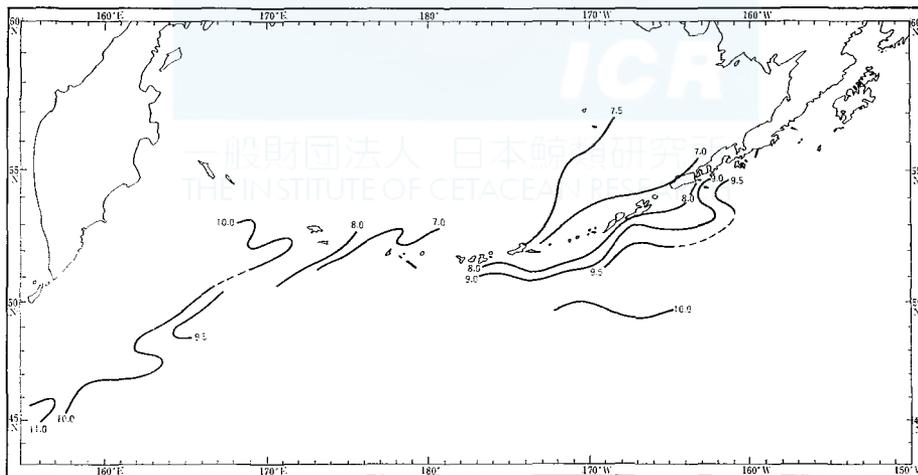


Fig. 6. Distribution of sea surface temperature (°C) in September.

Vertical distribution

Figs. 8-14 show the vertical distribution of temperature along the C,D,E, F,G,H and I (see Fig. 7).

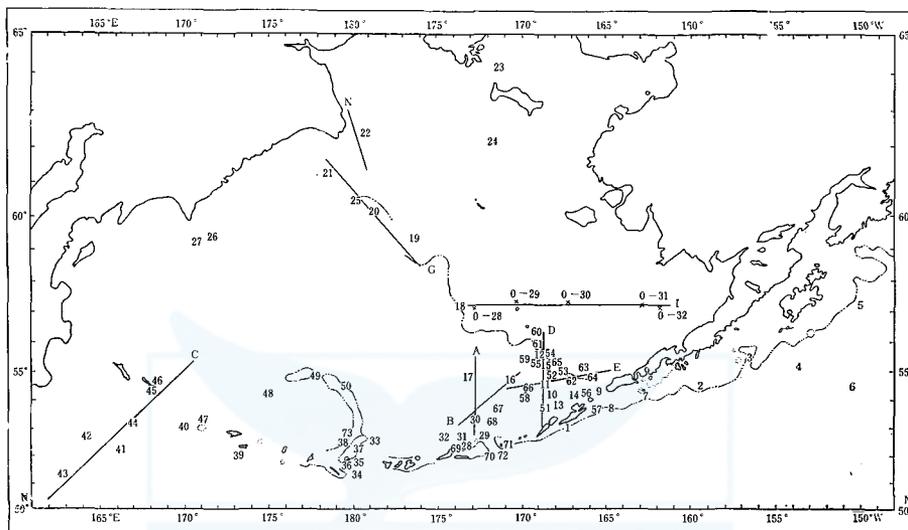


Fig. 7. Station positions obtained by Kōnan-maru no. 5 in the summer of 1955.
(O-28 → O-32: Data by Oshoro-maru)

C-line

Fig. 8 is the southeastward section of the Komandor Is. The cold water area found between Station 44 and 45. The thermocline lies in the upper 50 m in depth and its $\Delta\theta/\Delta D$ is about $0.5^\circ\text{C}/50\text{ m}$. The intermediate cold water lies below the 100 m and its core temperature shows below 1.5°C . Besides, the discontinuous zone was formed at the intermediate cold water layer.

D-line

Fig. 9 shows the vertical section of D-line. Near $54^\circ\text{-}30'\text{N}$, $168^\circ\text{-}30'\text{W}$, the author shows the warm water mass which existed at 50 m with a 30 m layer and was characterized by more than 7.0°C (the maximum temperature was 9.3°C at 25 m at Station 51). In the upper layer of the warm water mass, there is cold water which is characterized by less than 7.0°C and the reversal layer was formed. Moreover, the warm water mass appeared near $55^\circ\text{-}10'\text{N}$.

At $55^\circ\text{-}10'\text{N}$, $169^\circ\text{-}00'\text{W}$, the author recognized the remarkable upwelling and at the upper layer of upwelling, there was the warm water mass, where were formed the thermocline. It seems to him that there were not intermediate cold water.

E-line

Fig. 10 shows the vertical profile of temperature along the E-line. The warm

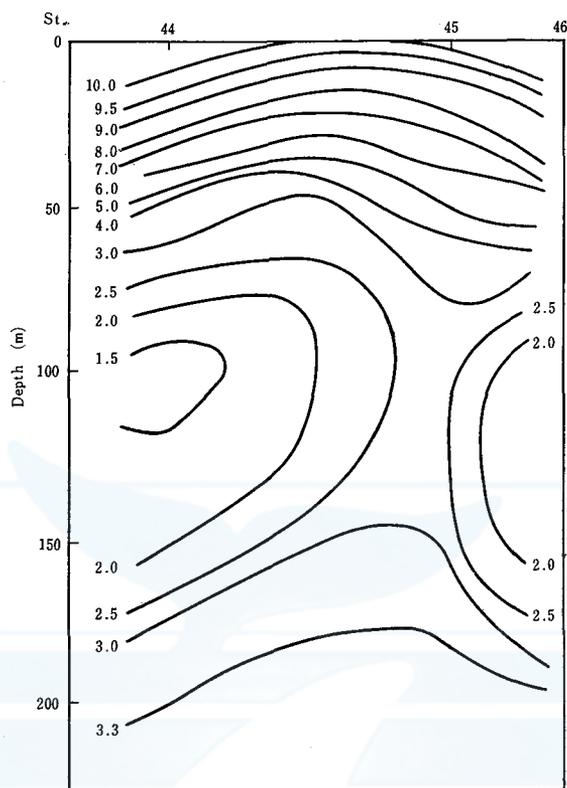


Fig. 8. Vertical Profile of temperature ($^{\circ}\text{C}$) along the C-line.

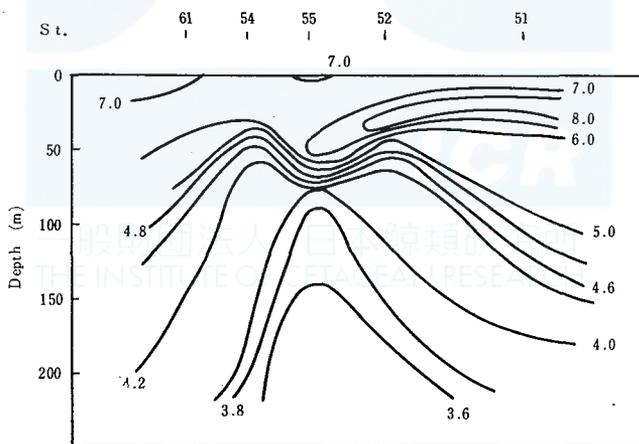


Fig. 9. Vertical profile of temperature ($^{\circ}\text{C}$) along the D-line.

water mass which was characterized by more than 7.0°C existed northwards at a shallow layer less than 50 m at St. 66, near $54^{\circ}\text{-}20'\text{N}$, $169^{\circ}\text{-}30'\text{W}$. At the warm water mass (about 25 m in depth), the inversion layer was formed and its tem-

perature was 7.6°C (the surface water was 7.0°C). The water mass seems to be same one which was found in vertical section along the D-line. At $54^{\circ}\text{-}30'\text{N}$, 166°W the temperature distribution at less than 30m suggest the warm

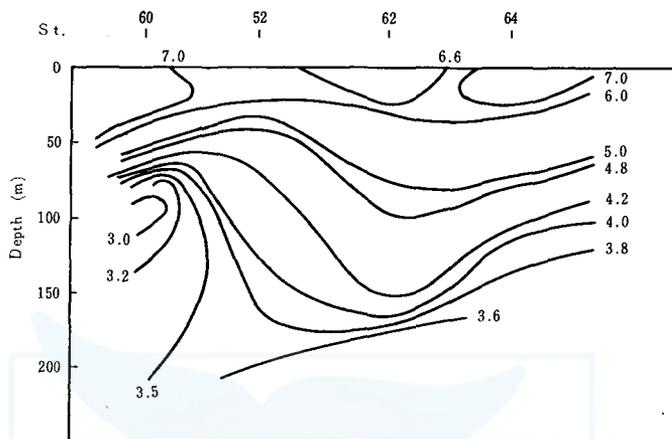


Fig. 10. Vertical profile of temperature ($^{\circ}\text{C}$) along the E-line.

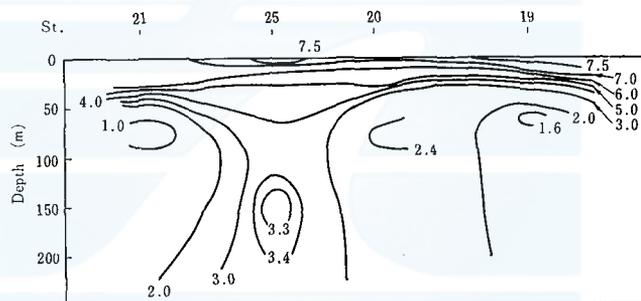


Fig. 11. Vertical profile of temperature ($^{\circ}\text{C}$) along the G-line.

water mass which was characterized by more than 7.0°C and has a westward tendency. The spreading of the isotherms is probably an indication of Bristol waters. Moreover, at $167^{\circ}\text{-}168^{\circ}\text{W}$ the stratum less than 30 m the boundary was formed between the Bering Sea water (towards the east) and the Bristol Bay water (towards the west). At $54^{\circ}\text{-}30'\text{N}$, $169^{\circ}\text{-}30'\text{W}$, there is intermediate cold water, which has 3.0°C at the core, and it is clear that the small scale thermocline is formed near the upper layer of the cold water mass (about 70 m in depth). Below 100 m, the isotherm of 3.5°C climbs steeply. Generally the horizontal distribution of temperature at the layer below 50 m depth, decreases towards the west and increases towards the east.

G-line

Fig. 11 shows the vertical section of temperature along the G-line which was located from about 60 sea miles off Cape Navarin to the south-east. At 25 m

depth, the 5.0°C and 6.0°C lines showed similar depth in every station and it may be considered that stable layer was formed at the surface.

At St. 21, the dichothermal water located near the 75 m depth (temperature minimum shows 0.6°C) and the comparatively remarkable thermocline was formed between the dichothermal water and upper layer of that. Below the dichothermal water, the temperature varies little towards the deep and its difference was 0.5°C from 100 to 200 depth.

St. 19, 59°–20'N, 176°–15'W, the dichothermal water lies at about 60 m in depth and its core water temperature shows 1.6°C, and the temperature below 75 m is mostly homogeneous. The 3.0°C line which extends from the 40 m depth at St. 19 and was very similar in depth to St. 20. At St. 25, the water mass with 3.0°–4.0°C in temperature exists below 60 m depth and the temperature was low on the both sides of that water mass. From the vertical section, it is clear considered that the vertical boundary was formed at St. 25.

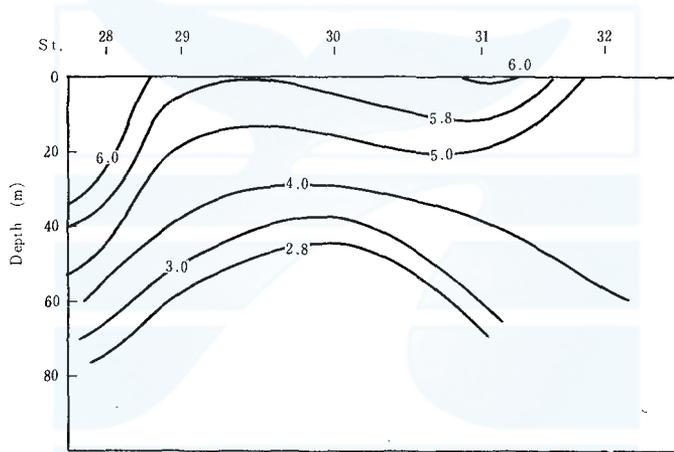


Fig. 12. Vertical profile of temperature (°C) along the I-line.

I-line

Fig. 12 shows the vertical profile of temperature along the I-line by use of data obtained by Oshoro-maru. Each thermoclines rise at St. 0–28. East of St. 0–29 the comparatively cold water was characterized by less than 3.0°C in temperature below the 50 m depth and the cold water layer becomes deeper towards the west. The comparative warm water was characterized by more than 6.0°C in temperature located upper the 30 m in depth near St. 0–28 and the warm water layer becomes deeper towards the west, and at St. 0–28, the water masses are of two types, east area of St. 0–28 is cold and west area is warm.

Thermocline

It is well known that in the northern part of North Pacific and Bering sea the thermocline in summer season has been formed by the heating of surface layer. According to the observations at Ocean Weather Station (lat. 60°N, long. 145°W),

the thermocline develops between 10 and 50 m in April (Tully et al 1960).

In order to analyze of the thermocline conditions, Fig. 13 and 14 show the station curves of temperature at each station in July and August. Then the thermocline located in almost all the northern part of the North Pacific Ocean, Bering Sea and a part of Chukchi Sea, but their depth and temperature gradient ($\Delta\theta/\Delta D$: $^{\circ}\text{C}/\text{m}$ where θ is temperature and D is depth) differ with sea area. On the thermocline, Tully (1957) has been discussed as follow. "Surface waters were warmed by vernal heating and continues to increase through summer to mid-September."

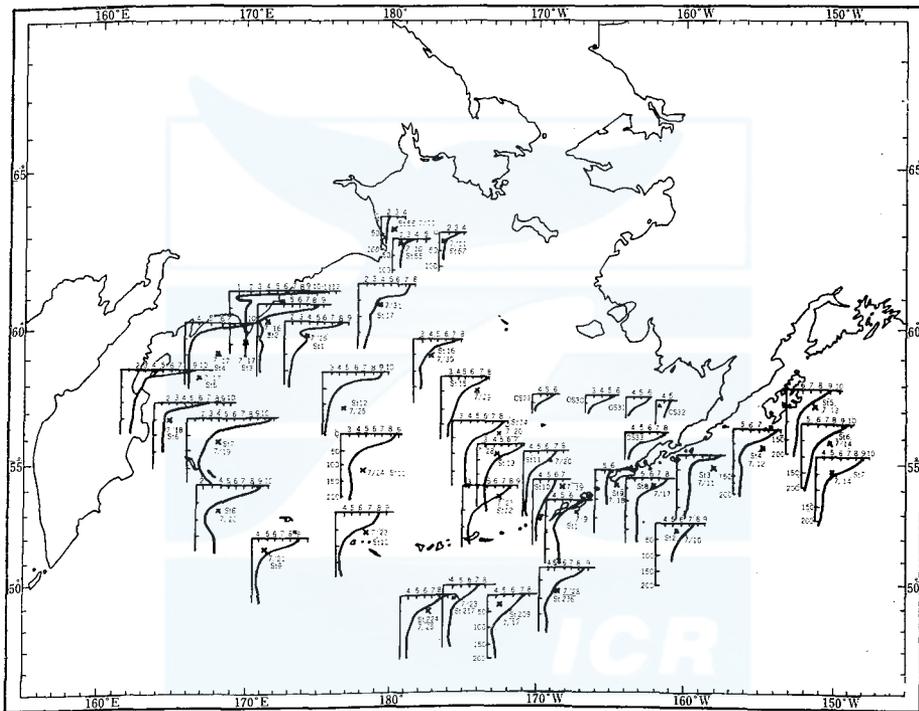


Fig. 13. Station curves of temperature in July.

St. 1~12, 55, 56, 57: 1957

St. 209, 224, 236 : 1959

In July, the most remarkable thermocline exists about 20 sea miles south off Cape Olyutorski, where the temperature gradient is about -1.0°C and that layer is shallow depth. Such a remarkable thermoclines appeared from off Cape Olyutorski to Kamchatka Peninsula, and the sharp variation layer of temperature were roughly from surface to 25 m depth. The depth of thermocline have a tendency to downward in the south sea regions, i.e. to the east of south Kamchatka, near $51^{\circ}\text{--}30^{\circ}\text{N}$, $162^{\circ}\text{--}30^{\circ}\text{E}$ the observed depth were 50–70 m (see Fig. 14). From Komandorski Island to Attu I., there were also comparatively remarkable thermocline which lied similar to that off south Kamchatka slightly deeper than that of Cape

Olyutorski.

Central part in the Bering Sea the thermocline near 59°N, 175°W, especially was conspicuous in August and its depth was shallow, from surface to 25 m depth and temperature gradient was about -0.28°C . The temperature gradient observed on 29 and 30 July were about $-0.09^{\circ}\sim-0.18^{\circ}\text{C}$ and those depth were deep. From that fact, it may be considered that the thermoclines in the central part of Bering Sea develop conspicuously since the beginning of August. North-north-east of C. Navarin, lat. $63^{\circ}\text{--}20'\text{N}$, long 180° the thermocline was not observed in July, and below 20 m depth, there is a thermocline which might cause a sinking due to melting ice. To the east of C. Navarin, in July, the thermocline exists in the upper 20 m depth, below that was formed the homogeneous layer similar to the area north-north-east of C. Navarin. From the data collected on 2 and 3 August around St. Lawrence I. where the thermocline develops conspicuously similar to

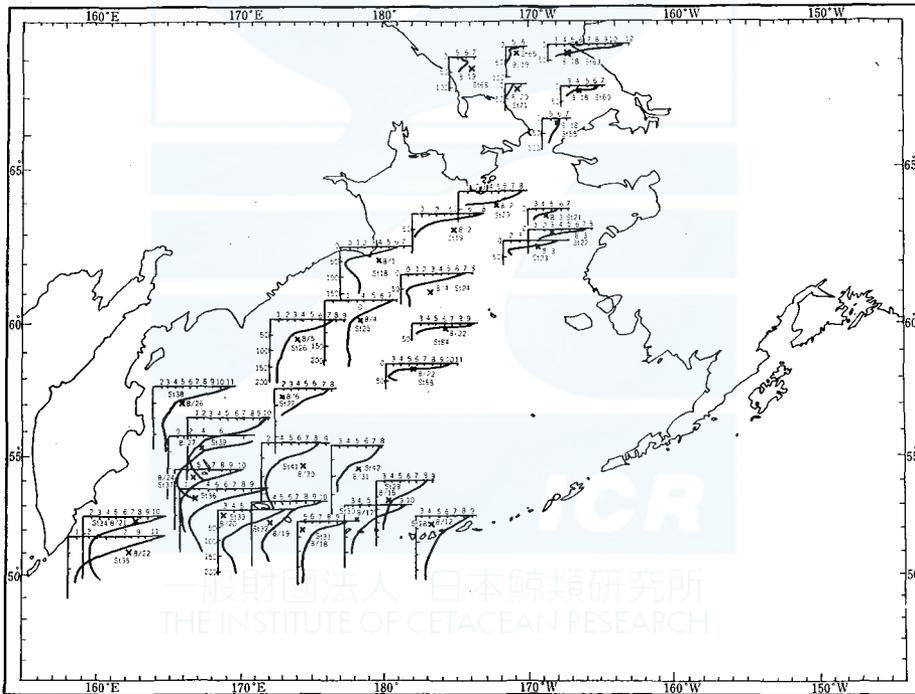


Fig. 14. Station curves of temperature in August of 1955 (St. 58, 60, 63, 65, 68, 71, 84 and 88 were carried out in 1958)

that off Cape Olyutorski and depth of that is shallow (about 20 m). The thermocline east of St. Lawrence was more developed than that of the west. (It is assumed that the thermocline at the east of St. Lawrence Island has already formed in July.) At the Chukchi Sea, north of the Bering Sea, the thermoclines were found on the side of Alaskan waters, but were not found on the side of Siberian waters (Nasu 1960).

The data obtained by Oshoro-maru during July of 1955 (Motoda et al 1956), the thermoclines in the Bristol Bay existed in the sea area west of 57°–16'N, 161°–40'W where the eastern most station in the observed region, and those depth were from surface to 50 m at each station. The temperature gradient increases to the Aleutian Is. To the north of Unalaska I. near 54°–05'N, 168°–10'W the thermoclines were not found and it may be caused by the vertical movement which took place due to physical action.

South of Unimak I. thermocline exists at the surface layer, and the temperature at the 10 m depth was perfectly homogeneous, which seems to represent upwelling by bottom topography. At the southern side of Aleutian Is. the vertical temperature gradient at the west longitude area was larger than that found east of southern Kamchatka Peninsula.

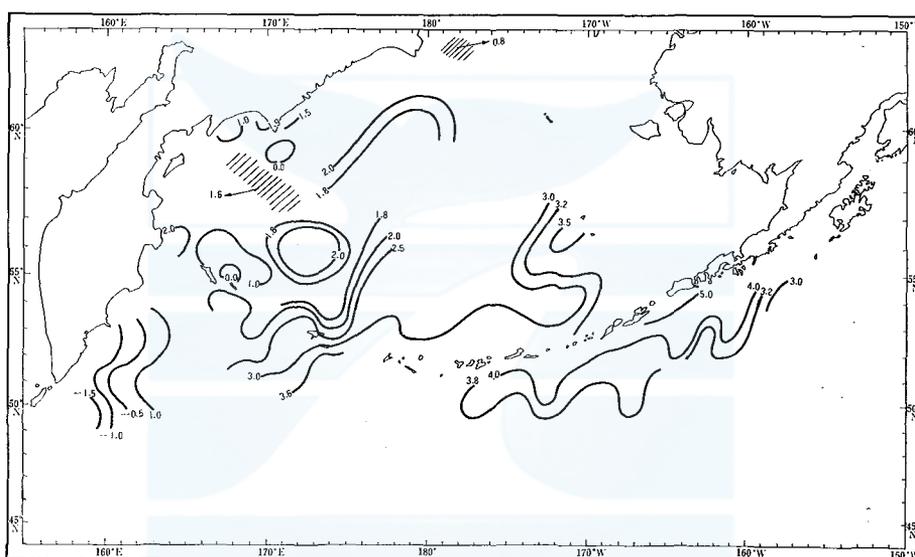


Fig. 15. Isotherm on the temperature minimum surface in summer of 1955, 1957 and 1958.

Intermediate cold water.

It is wellknown that in the Subarctic region a temperature minimum was observed at some depth in the summer. The structure which is associated with the temperature minimum is termed dichothermal structure (Uda 1935, 1955, 1956).

As Hirano (1961) also stated, the intermediate cold water is one of the characteristics of the Subarctic Pacific.

Fig. 15 shows the isotherm on the temperature minimum surface in summer of 1955, 1957 and 1958. The minimum temperature was -1.5°C and occurred east of Paramushiru I. near 50°N , 159°E . The intermediate cold water extends to the Kuril Is. and exists in about 150 m in depth. The maximum value of the minimum temperature is 5.0°C isotherm and exists near 53°N , 165°W about 40 sea miles

south of the Unimak Pass. Judging from the map of Bennett (1959) and Uda (1960), the 5.0°C-isotherm may extend south of Kodiak I. And in this region the depth of the minimum temperature existed at 60 m and increased from this area towards the south. Near 53°N, 161°W the minimum temperature covered a wide area at 75 m depth. The 3.5°C-isotherm occurred in a tongue near the Pribilof Islands north of Unalaska, and to the west of this area there were 3.2° and 3.0°C isotherm. The 3.2°C isotherm is notably meandered as far as 53°N, 171°W and the 3.0°C isotherm extents from 53°N, 172°W to south of Attu Island 52°N, 172°E.

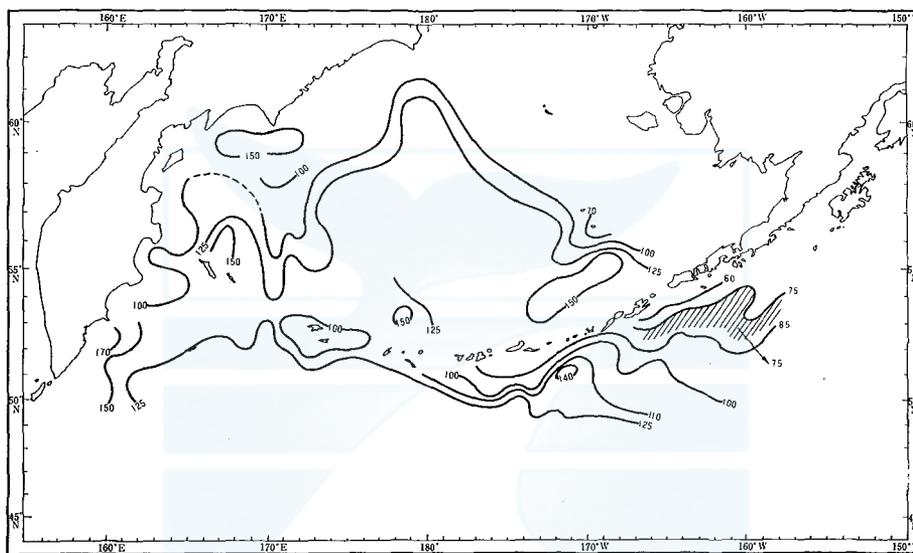


Fig. 16. Depth of temperature minimum (meters) in Summer (1955, 57, 58, 59)

The depth of minimum temperature north of Unalaska I. the 100 and 125 m line lie mostly similar to the contour line of 200 m and extent from near 61°N, 180° longitude to near 55°N, 170°E. In the northern-side of the Aleutian Is. the intermediate cold water increased in temperature and decreased in depth towards Bristol Bay. East of Cape Navarin, there was a minimum temperature which was characterized by comparative low -0.8°C at 73 m in depth. At the south of Cape Olyutorski, intermediate cold water exists at 150 m in depth and has 0.0°C in temperature. At very small area, the distribution of minimum temperature waters differed with the east and west of Cape Olyutorski. That is:

	Temp. ($^{\circ}\text{C}$)	Depth (m)
At the east	1.5	50
At the west	1.9	80

Near Cape Govenia, the intermediate cold water existed, and was 0.7°C in temperature and 25 m in depth.

At the north of the Komandorski Is. the cold water area (less than 1.0°C in temperature) was found and was 0.0°C at its minimum temperature at the area close to the island. South of the Komandorski Is. the 1.8°C isotherm lies at the layer more than 100 m in depth. To the north of the Bering Sea, the minimum temperature around St. Lawrence I. in general, existed near the sea bottom.

Generally, the temperature minimum of intermediate cold water in the northern part of the North Pacific and the Bering Sea in summer vary from -1.6°C at its minimum to the highest value 5.6°C , and its core extents from 175m to 25m in depth.

There is an indication that the depth at the core of intermediate cold water is deep at the cold area and shallow at the warm area.

SALINITY STRUCTURE

As the data of salinity are very few compared with that of temperature, it is not suitable for analysis concerning monthly mean. Consequently, in this paper the distribution by year's were shown. Moreover, the general distribution of ice in February and April shown in Fig. 17 cited from the pilot chart which was published by U.S. Navy Hydrographic office.

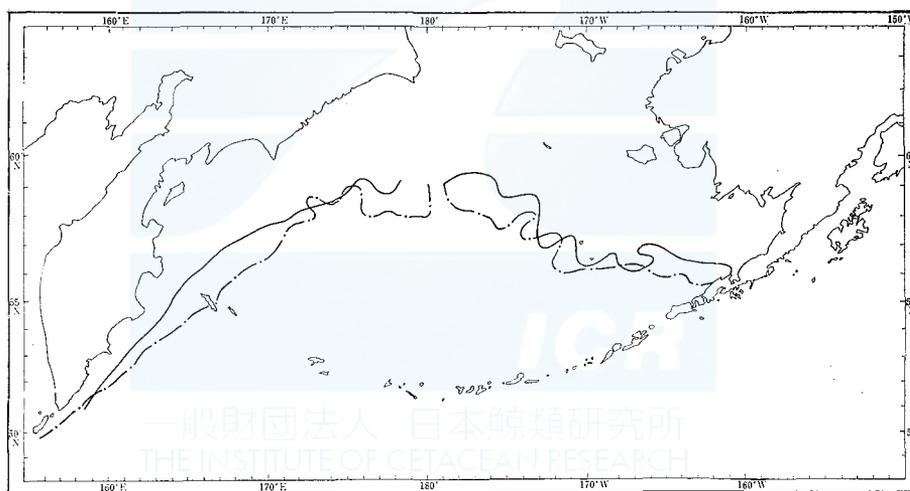


Fig. 17. Distribution of ice area, Solid line : April, Chain line : February

Horizontal distribution

June

Fig. 18 shows the horizontal distribution of salinity at the surface to the east of 170°W , the southern side of the Aleutian Is. At the north of Unalaska, 33.00 , 32.80 and 32.50‰ located roughly parallel to one another and the 200 m contour line and those values decrease towards Bristol Bay. As shown by Fig. 17, it is

clearly due to melted-ice. From the surface, the waters to Bristol Bay is characterized by high salinity and low temperature.

The surface distribution of salinity south of the Aleutian Is. was drawn by use of data in 1958. At latitude 52°N south of Unalaska I. the 32.65‰ isohaline existed to the east and west, and the low salinity area located north of the isohaline. South of 32.60‰ isohaline 32.70 , 32.75 , 32.80 and 32.85‰ isohalines locate from southwest to northeast, and it is supposed that the water mass which is characterized by high salinity extends from southwest to north with anticyclonic pattern.

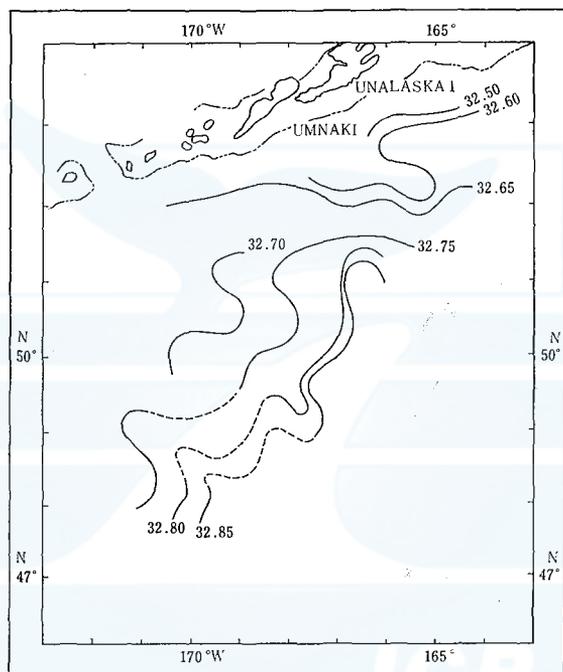


Fig. 18. Horizontal distribution of salinity at the surface in June of 1958.

July

Fig. 19 shows the horizontal distribution at the surface in July of 1957. The variation of salinity near 32.80‰ is scarcely changed, and 33.00‰ moved about 40 sea miles westward compared with that of June. It may be considered as due to influence of lateral mixing by advection of melted-ice in and near Bristol Bay. The distribution of salinity at the west longitude area south of the Aleutian Is. was drawn by use of data in 1958. At 50°N , 170°W , 32.70‰ isohaline in the form of tongue extends toward the southeast, and 32.70‰ isohaline runs in general from east to west within the range from 177°W to 169°W . At the north of 32.70‰ isohaline, there was 32.65‰ isohaline which seems to be extended towards the east.

At the sea region to the east of Cape Navarin there was distinguished low temperature and salinity water mass which is characterized by less than 4.0°C in temperature and 24.60‰ in salinity. In addition, at this sea region melting pack ice was observed in June of 1957 (information from Mr. Ichihara), therefore, it may be considered that the low temperature and the salinity water mass which was already mentioned was formed in the immediate melted pack-ice.

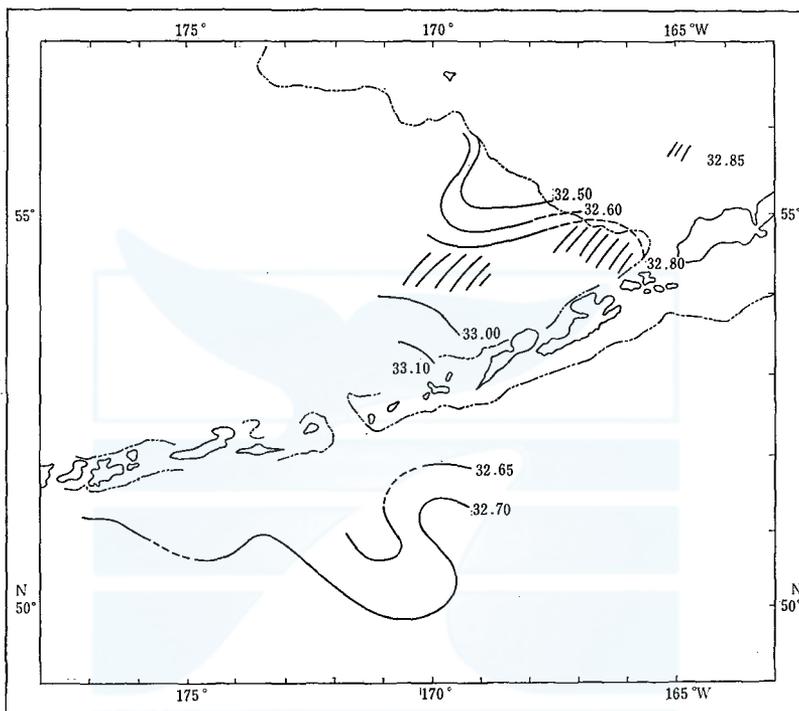


Fig. 19. Horizontal distribution of salinity at the surface in July of 1958.

To the East of Kamchatka, at the sea region between the Komandorski Island and Attu Island 32.90‰ isohaline located from south to north, and the salinity was low at the east and high at the west of the isohaline. Moreover, during the summer west of Kronotski low salinity water mass extended to the east (Kitano 1958).

August

As shown in Fig. 20, near Cape Navarin, 31.50‰ line was found parallel 30–50 sea miles off the coast of Siberian Continent, 32.50‰ line extends further north-east through the vicinity of 60°N , 168°E and locates south of Cape Navarin.

The warm area which is characterized by more than 10.0°C was similar to the area of 32.50‰ .

The location of the 33.50‰ isohaline was also found near $61^{\circ}\text{--}62^{\circ}\text{N}$ $179^{\circ}\text{--}30^{\circ}\text{W}$. However, compared to the western area of this region (vicinity of 60°N , 168°E) it is noted that relatively cold water (less than 10.9°C) extends. Conse

quentry, it can be concluded that the cold and fresh water mass exists from Cape Navarin to the east. While the warm and high salinity water mass exists from Cape Navarin to the west.

In addition, in July of 1957 the high salinity water mass at the surface had closed with the land compared to that of August, it may indicate that the oceanic water mass had grown from July to August. The surface salinity in the Chuckih Sea in August of 1958 varies from 27.00‰ to 32.50‰. The high salinity region existed in the central part of the Chukchi Sea east and west of this region the low salinity region existed (Nasu 1960).

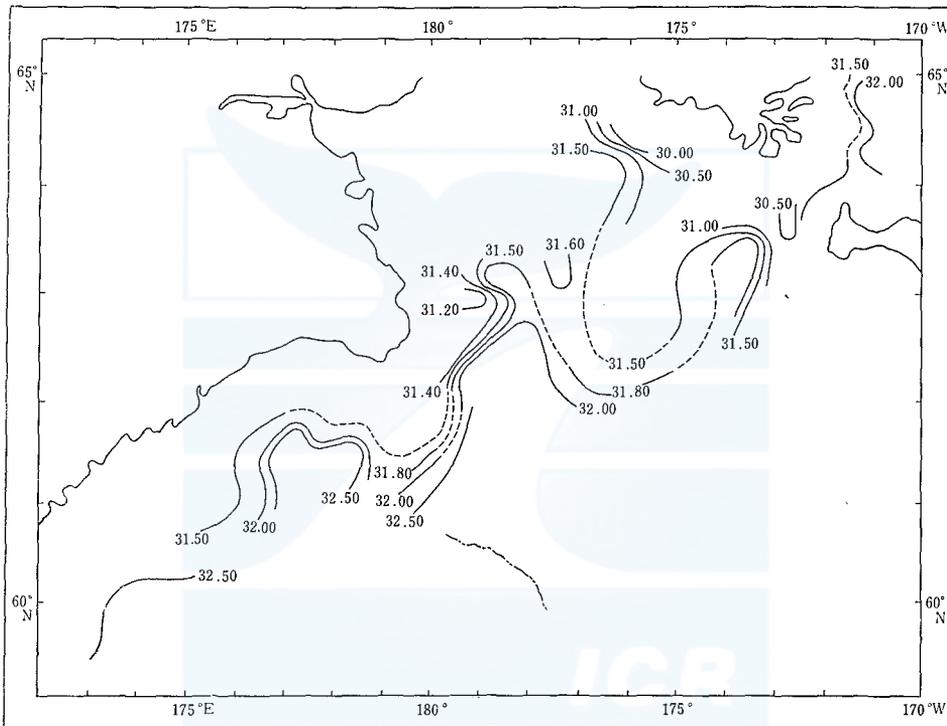


Fig. 20. Horizontal distribution of salinity at the surface in August of 1958.

The data of 1955, the separated salinity area (33.30‰ located near 52°N, 170°-30'W, and it shows 33.42‰ at the maximum. The surface temperature was less than 7.0°C and there was the separated cold and high salinity area, which is clearly formed by the influence of sea bottom topography.

Vertical distribution

C-line

Fig. 21 shows the vertical profile of salinity along the C-line. Below the surface salinity was high at St. 45 and low at St. 46 respectively. This tendency was prominent in layer less than 30 m in depth.

That is, the (isohalin) distribution decreases towards St. 46 and from the vertical (isohaline) distribution shown in Fig. 22 the pattern of distribution evidently varied with stations (St. 45 and 46) at layers more than 50 m in depth. In this region, the distribution of temperature also was divided into two types the 9.0°C and 11.0°C line, and the difference of temperature was clearly found below 50m in depth (Fig 23).

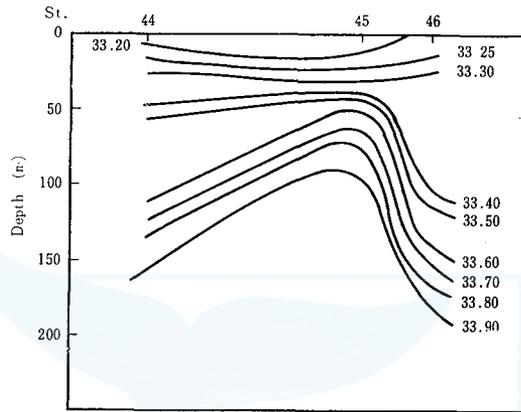


Fig. 21. Vertical profile of salinity along C-line.

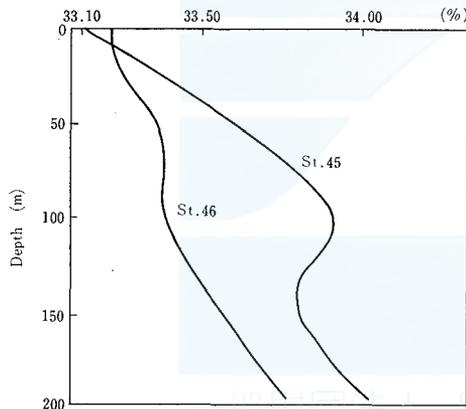


Fig. 22. Station curves of salinity.

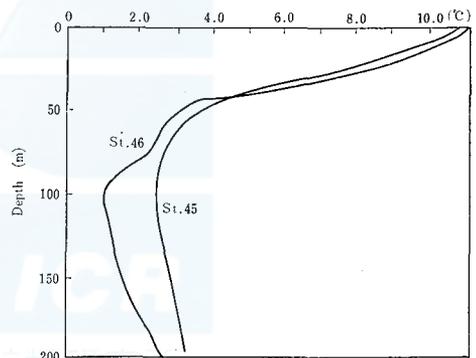


Fig. 23. Station curves of temperature.

Consequently, at the southeast of Medni I, it may be concluded that the notable structure of discontinuity was formed below the 30 m depth between the southern warm saline and the northern cold, low-salinity water mass.

At St. 46 the layer which was characterized by 33.70‰ existed at 50–100 m in depth and at St. 45 there was low salinity layer at about 140 m in depth.

D-line

Fig. 24 shows the vertical section of salinity along the C-line. At St. 54 the isohalines rise suddenly towards the surface similar to the isotherms. St. 45 is located

at just the edge of 200 m contour line and the bottom topography from this station to the west became abruptly deeper. Accordingly, the sudden rise of these isolines are probably caused by the influence of some irregularity of the bottom topography. At the surface layer, the low salinity area (33.00‰) was found to the south

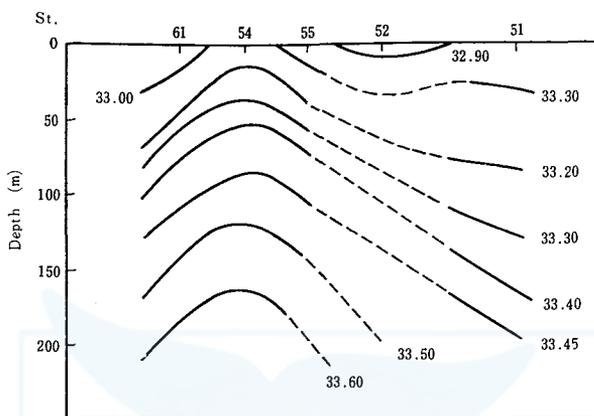


Fig. 24. Vertical section of salinity along the D-line.

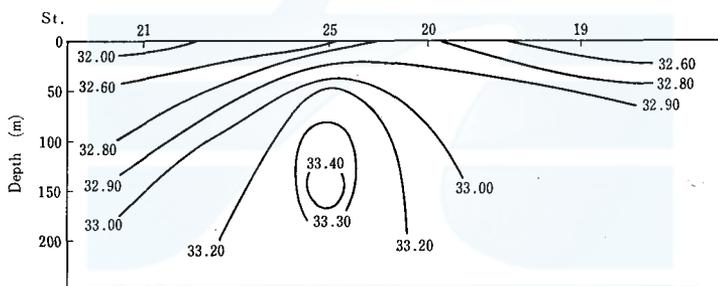


Fig. 25. Vertical section of salinity along the G-line.

of latitude 55°N where the temperature was more than 6.0°C . To the north of St. 54 the water mass is more than 6.8°C and less than 33.00‰ extended. Below 50 m the structure of discontinuity was formed on both the northern and the southern side of the cold, saline water mass which rose from a deeper layer. The warm low-salinity water which was located less than 50 m depth may be transported from Bristol Bay.

G-line

The vertical section of salinity along the G-line shown in Fig. 25. 32.80‰ line was found as far as of St. 20 with the salinity being high in the southeastern side and low on the northwestern side of this line. Consequently, it was evident that in the layer above 25 m depth the warm, saline water mass existed to the southeast, and the cold, low salinity water mass existed to the northwest of St. 20. At St. 25, a local high salinity area which was characterized by more than 33.40‰

existed to about 150 m in depth with 3.3°C temperature, indicating dichothermal water. Moreover, as already stated, the vertical section of the temperature along the G-line showed that the cold water mass existed both southeast and northwest of St. 25 warm area. Accordingly, below 50m depth it is evident that the cold saline water mass was formed to the north and south, respectively.

I-line

Fig. 26 shows the vertical section of salinity along the I-line. The low salinity water mass (32.00‰) extends from near 20 m in depth at St. 31 to the east in the form of sinking. From the distribution of temperature it may be assumed that the deep water had risen near St. 28 and 29. In the surface layer of St. 28 there

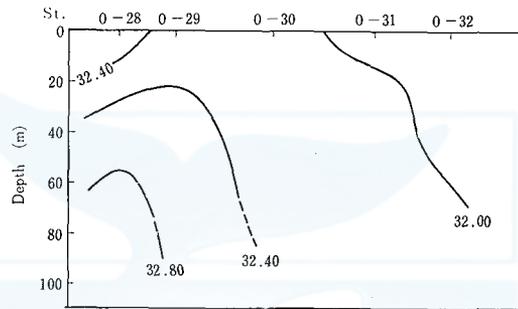


Fig. 26. Vertical section of salinity along the I-line.

is a zone of high salinity (32.40‰) which coincided with the warm water ($6.0^{\circ}\text{C} <$). Generally, at St. 28 the water masses can be divided into two types.

Low temperature, low salinity water mass: Easter of St 28.

High temperature, saline water mass: Wester of st. 28.

THE ANALYSIS OF WATER MASS

The analysis of water mass was made by using temperature and salinity diagrams.

J-line

Fig. 27 and 28 show a vertical section of temperature and salinity along the J-line. A relatively warm water mass was rising near the island to the north. This phenomena was conspicuous, and this water mass, which is characterized by more than 5.0°C in temperature, was found uniformly. At St. 11 the cold water of the deep layer was found as shallow as 100 m depth. High salinity water was also found above the deep layer. From the distribution of temperature and salinity, it can be assumed that the water mass which flows from the Aleutian Islands to the north was isolated by the rising of deep water at St. 11.

Fig 29 shows the temperature-salinity relation near J-line. Surface water which was characterized by more than 5.0°C in temperature and salinity of less than 32.66‰ was found at St. 10 and 12, and was clearly divided from the relatively high temperature saline water mass of more than 5.0°C and 32.80‰ found St. 11.

To the Aleutian Islands at St. 13 and 14 water mass which was characterized by about 6.0°C and 32.50‰ located, and seems similar character for that of St. 10 and 12. Dichothermal water of minimum temperature was found at St. 11, 15 and 16, at about 150m in depth. Dichothermal water was not found at St. 10, 13 and 14, near the Aleutian Islands.

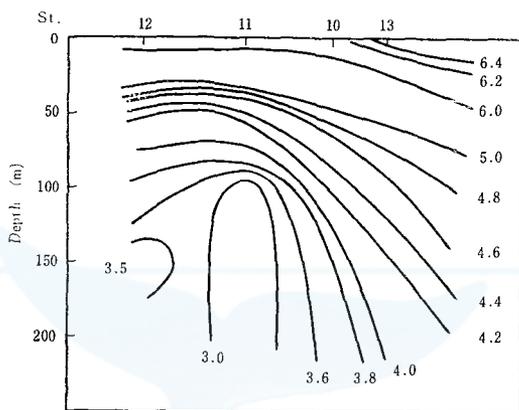


Fig. 27. Vertical section temperature along the J-line.

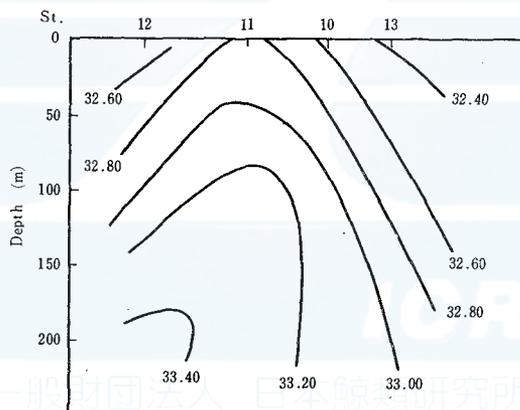


Fig. 28. Vertical section of salinity along the J-line.

Near the layer of 200 m depth, the water masses characterizing St. 13 and 14 were found to be quite similar At St. 11 there was a relatively high-salinity water mass which may have been mixed with the deeper water mass by upwelling. Consequently, the water masses at near 200 m depth are divided into two types. Those are water mass along the Aleutian Islands (St. 13 and 14) and the mixing zone (St. 10). The water mass near St. 15 also seems to be a mixing zone and was characterized by the low-salinity (33.00‰). It may be due to the advection of the waters of Bristol Bay. The water masses near the J-line can be divided as follows:

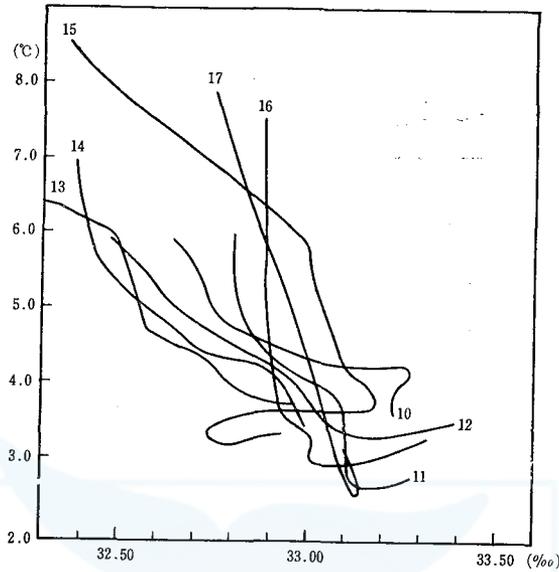


Fig. 29. Temperature and salinity at St. 10, 11, 12, 13, 14, 15, 16 and 17.

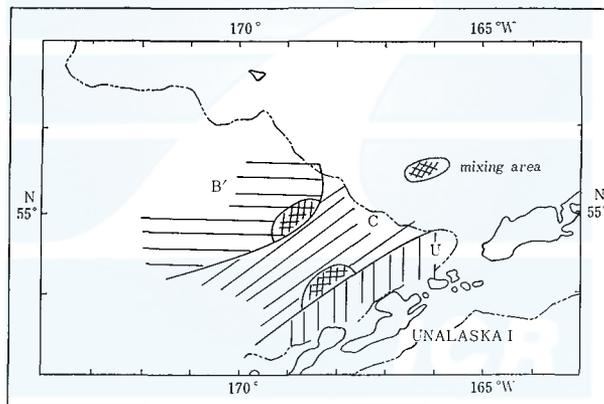


Fig. 30. Water types in the north area of Unalaska I.

That is, B'—type
 C—type
 U—type
 Mixing type

C-line

Fig. 31 shows the T—S characteristics of the water masses along the C-line. These are separated by three zones; an upper zone of warm, low-salinity water (above 25 m in depth): a intermediate cold zone characterized by a temperature minimum (near 100 m in depth): and a lower zone in which the temperature and salinity

are both high. From the vertical section shown in Fig 8, the rising phenomenon of deep water was found at St. 45 and was more apparent from Fig. 21. It is theorized that the deep water was raised by the ridge located between St. 45 and 46. By analysis of the T—S diagram shown in Fig. 31, there were uniformly surface

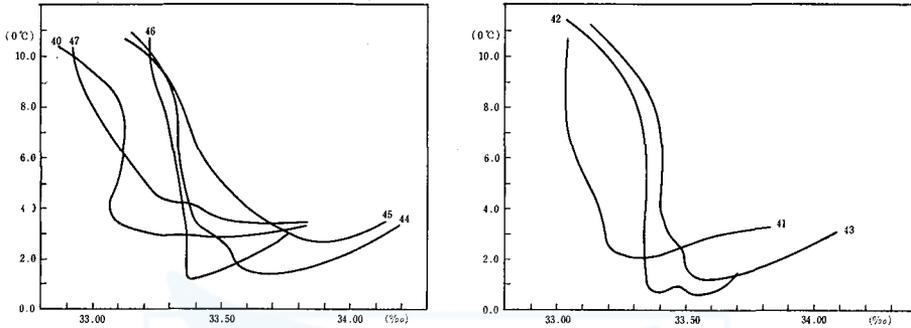


Fig. 31 Temperature and salinity at St. 10, 11, 12, 13, 14, 15, 16 and 17.

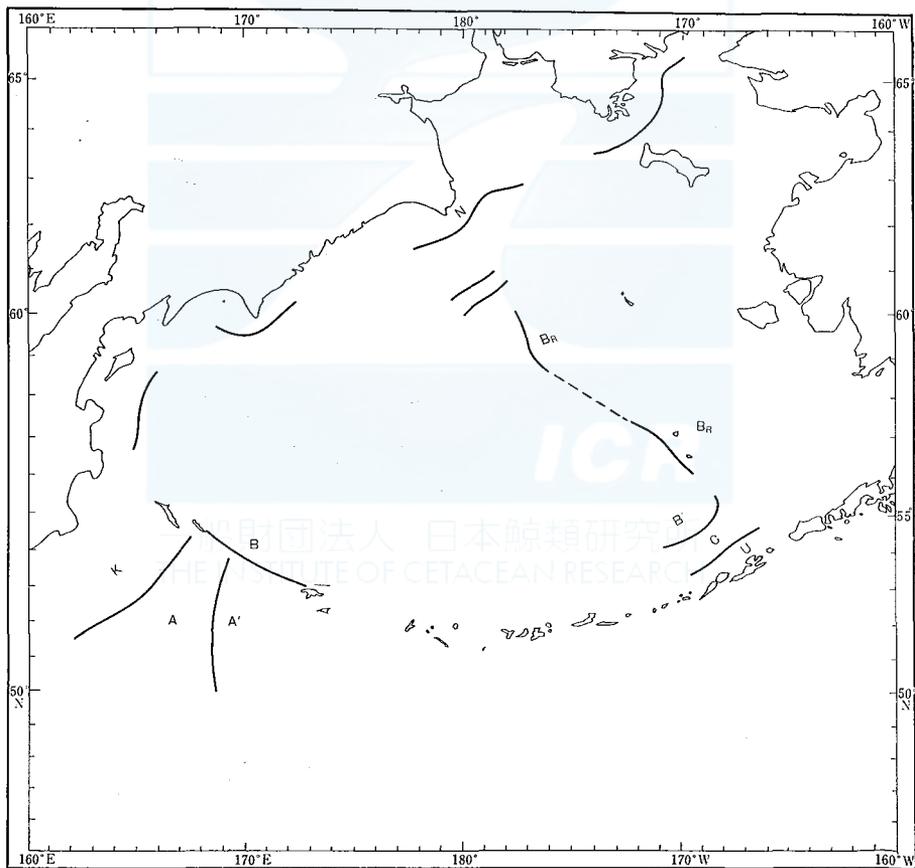


Fig. 32. Distribution of water mass.

waters in salinity about 33.30–33.40‰). To the west of Attu Island, near 53°N, 170°E, low salinity water was, of which the salinity was lower than that of the water mass along the C-line. Near 50 m of St. 45 high salinity water mass ($>33.60‰$) was found, and suggested the rising of deep water. At St. 42 the temperature from surface to 50 m varied remarkable, however the salinity was homogeneous. This water mass may be considered that of coastal water off Kamchatka, in which the intermediate cold water exists at relatively shallow depth. Near 100 m the water mass which is characterized by less than 1.5°C and 33.50–33.60‰ located at St. 42, 43 and 44 respectively, and water masses at St. 40 and 47 were relatively warm and low salinity. At St. 46 there are cold and low

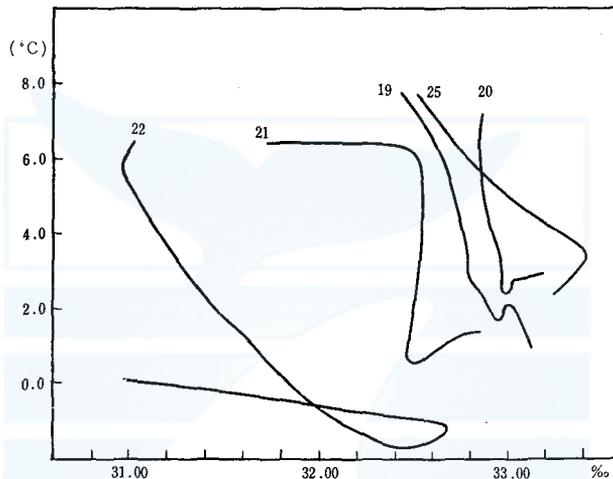


Fig. 33. T-S characteristics of the water masses at vicinity of the G-line.

salinity waters (temperature: about 1.2°C, salinity: about 33.40‰). Near 200 m depth, both temperature and salinity were higher than those at 100–150 m depth at each station. Analyzed water masses are termed A, A', B and K for convenience, and the distribution of those is shown in Fig. 32. The summary for water masses are as follows.

- A: Intermediate cold water developed, with the core at about 100 m, with warm and high salinity water near 200 m.
- A': As stated by Kitano (1958), A' is a subtype of A, and is generally warmer and more saline than A below 50 m depth.
- B: From surface to near 100 m depth, temperature varied anomalously with depth. Salinity was homogeneous, and the temperature minimum was found near 100 m. According to Kitano (1958), the B-type extended to the central area of the Bering Sea.
- K: The core of intermediate cold water is located in shallow layer, with a temperature of less than 1.0°C.

G-line

Fig. 33 shows the T—S characteristics of the water masses at the vicinity of the G-line. In general, from 10 to 75 m depth at St. 22, near Cape Navarin, there is a prevalent cold water ($<-1.0^{\circ}\text{C}$) which is apparently established by vertical convection during the period of cooling. At 100 m depth there is a low salinity water mass (30.99‰) which is quite different from that observed at 75 m depth. At surface layer of St. 19, 20, 21 and 25 warm and high salinity water masses are found which may be divided with the water mass near St. 22. At the 25 m layer of St. 21 there is a relatively cold and low salinity water mass which must be influenced by the Siberian coastal area water mass. At St. 25 in general it was evident that the warm and high salinity water mass had intruded. At St. 19, generally, salinities are low at each depth layer, it was probably established by the convection between the low salinity of Alaskan coastal area and other. From Fig. 32, near Cape Navarin cold and low salinity water mass located in the vicinity of Siberian Continent where in the south, there was a warm and high salinity area near $60^{\circ}\text{--}30'\text{N}$, 180° longitude where salinity in the east decreased again. Consequently, water masses near Cape Navarin may be divided into three types. General distribution of water masses in the Subarctic region was shown in Fig. 32 which included Kitano's figure (1958), too. The water masses near Cape Olyutorski, St. Lawrence Island and the Chukchi Sea were examined by use of data obtained at sea surface.

HYDROGEN-ION CONCENTRATION (PH)

The hydrogen-ion concentration was determined by a comparator for sea water which consists of two series of color standard solutions, one was Cresol Red and

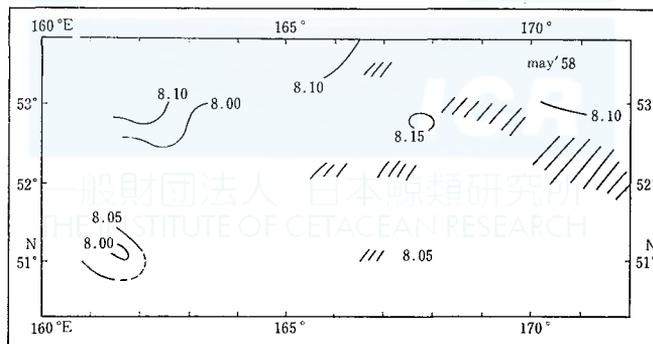


Fig. 34 a).

the other was Tymol Blue. The horizontal distributions of pH at the surface are shown in Fig 34 a) b) c) d). The pH values varied from 8.25 maximum to 7.95 minimum at the south of the Komandorski Is. and the adjacent waters of the Aleutian Is. The waters of high concentration of pH at the surface located in the northern area of Unalaska I., where the value was 8.15, and increased toward

Bristol Bay (8.20–8.25). The pH value in Bristol Bay was 8.4 to 8.5 according to data obtained by Oshoro-maru. In July of 1959, the eastern-most part of the 8.20 line was located more westerly than in 1958 and it may be deduced that the Bristol water mass is to be characterized by a pH of less than 8.25 extended towards the west. Moreover, it may be assumed that the annual variation on the distribution of pH is quite large. It may be influenced by the expansion and decay between the Bristol Bay and Bering Sea water mass.

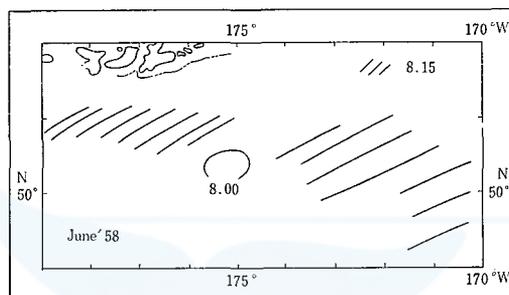


Fig. 34 b).

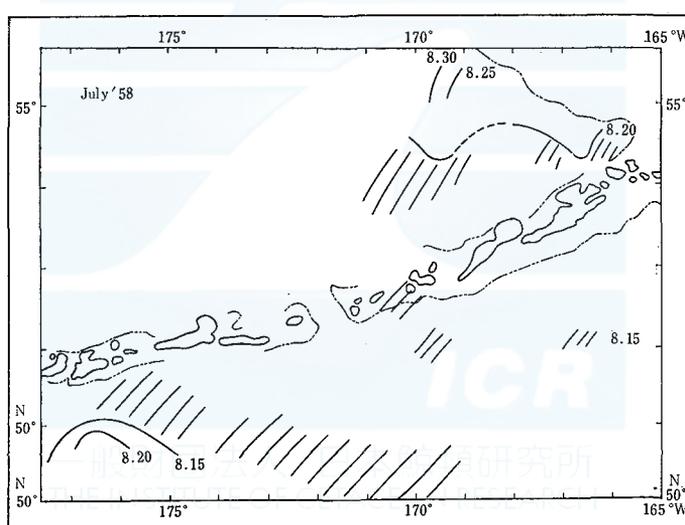


Fig. 34 c).

TRANSPARENCY

Fig. 35 a) b) show the isoline of transparency which were obtained by Secchi disc. In June 1958, near 50°–30'N, 172°–30'W where the transparency generally was high compared with that of the surrounding area and those value varied 7 to 18 m. The transparency was observed to vary between stations. That is, near 50°N, 178°W and 51°N, 172°W, high value area extended towards the north. This may

be a significant factor in causing the branch of extension of the Kuroshio water mass. Near 50°N, 170°W, to the south there was an isoline of 7 m. From the distribution of transparency it is assumed that a discontinuous zone may be formed near 168°W to 172°W. The transparency at the northern side of Unalaska

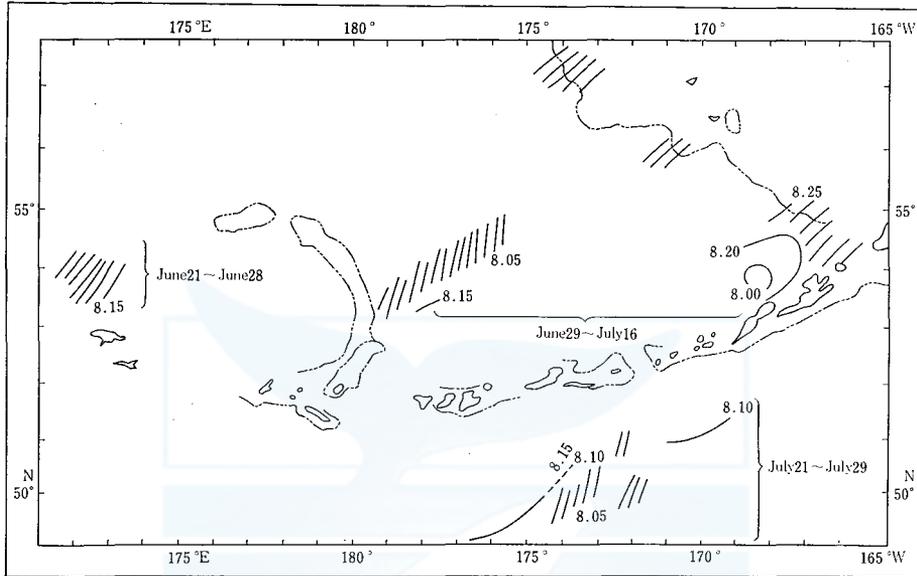


Fig. 34 d).

Fig. 34 a)~d). Horizontal distribution of pH at the surface.

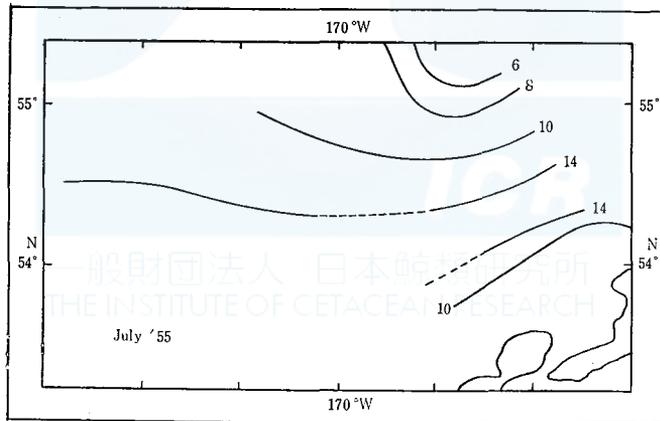


Fig. 35 a).

I., from 6 to 16 m, decreased towards the north, near 200 m contour line. The highest area which was characterized by more than 16 m, coincide with the C-water mass area (see Fig. 32), and it is probably due to the intrusion which flowed from the western area. In addition, the transparency near Unalaska I. was less than 10 m.

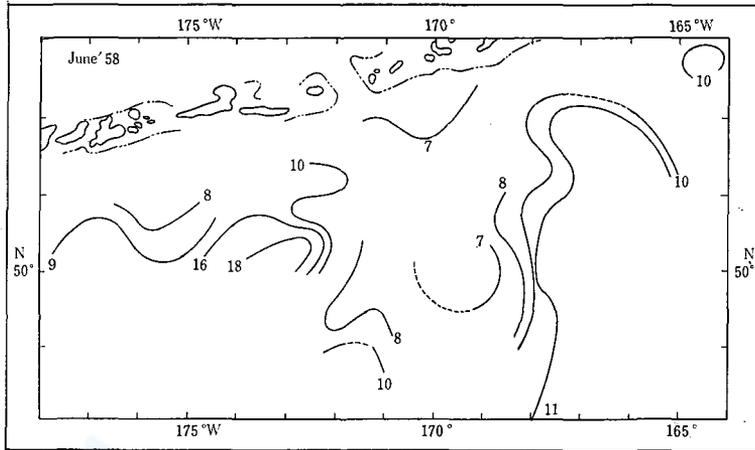


Fig. 35 b).

Fig. 35 a)~b). Transparency in summer (reading-meters).

DISSOLVED OXYGEN

Horizontal distribution

In general, from the data obtained by our observations the dissolved oxygen at the surface in the Bering Sea ranged from 4.43 to 11.05 CC/L and it decreased along

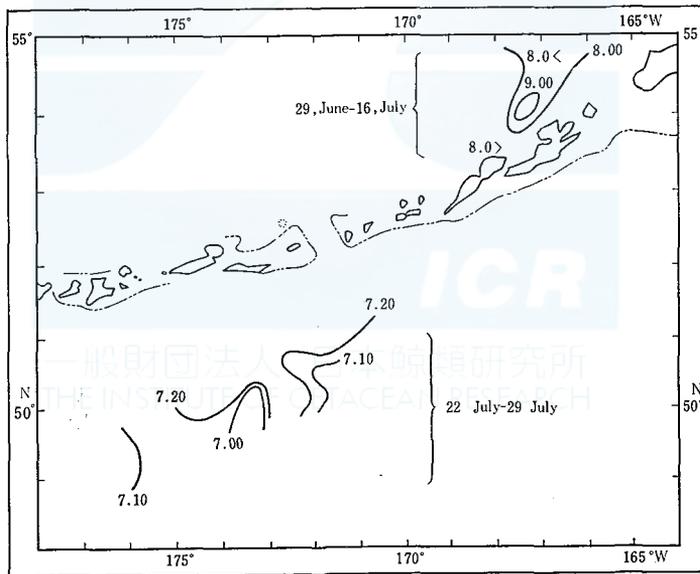


Fig. 36. Horizontal distribution of dissolved oxygen at the surface in June and July of 1959.

the Aleutian Is. (the dissolved oxygen was decreased near Bowers Bank also) and increased towards the east region of Kamchatka Peninsula and Bristol Bay (Nasu

1957).

In the Chukchi Sea, the dissolved oxygen varied from 9.03 to 7.17 CC/L in August of 1958, and generally was less along the Alaskan coast and the higher along the Siberian coast (Nasu 1960). Fig. 36 shows the distribution of dissolved oxygen at the surface. To the northern side of Unalaska I. the 8.0 CC/L line is tongue-shaped and intrudes from Bristol Bay to the southwest. As already mentioned above, the dissolved oxygen is higher in the water mass of Bristol Bay and is lower along Unalaska I. where there is sea area, which is covered by less than 8.0 CC/L. Moreover, at 49°–50°N, 170°–176°W there is the isolated region where the dissolved oxygen was greater than 9.00 CC/L. It may be considered due to the influence of some biological elements. To the south of the Aleutian Is. near 49°–51°N, 170°–176°W, the dissolved oxygen ranged from about 7.00 to 8.00 CC/L and generally is lower compared to that in the northern side of Unalaska I. 7.00 and 7.10 CC/L line extend from the south to the northward. On the other hand, 7.20 CC/L line locates from the north to the southward and is mostly tongue-shaped at 50°N, 172°–30'W. From the data of sea temperature, salinity and transparency, at 50°N, 172°W the author can be assumed that the oceanic front is formed between the cold and warm water mass.

Vertical distribution

C-line

Fig. 37 shows the vertical profile of the dissolved oxygen along the C-line. In general, as shown in the profiles of temperature and salinity, there is a boundary at St. 45. That is, the dissolved oxygen is higher at the northern side (B-water mass) and is lower at the southern side of the boundary (A-water mass), and the

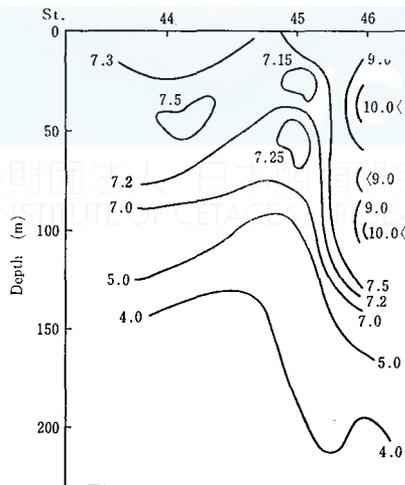


Fig. 37. Vertical profile of dissolved oxygen along the C-line.

isoline of it abruptly changes. The rising of low dissolved oxygen at St. 45 may be caused by upwelling formed by the ridge extending from the Komandorski Is. to the southeast. At St. 46, from the surface to near 100 m depth, there is high dissolved oxygen layer in which the value was over 9.0 CC/L (the value at 150 m depth was about 7.0 CC/L). It may be assumed that the marine productivity is high in the B-water mass of Bering Sea water. Above 100 m depth at St. 44 and 45 there is a water mass which is characterized by having water of about 7.5 to 6.0 CC/L. dissolved oxygen. From each station curves of the dissolved oxygen vertical change develops abruptly below 100 m depth, at St. 44 and 46, and are small at St. 45.

D-line

The vertical profile of the dissolved oxygen along the D-line is shown in Fig. 38. Below 50 m depth between St. 65 and 61 there is a transition layer which characterized by a abruptly change of the dissolved oxygen. The isolines of the

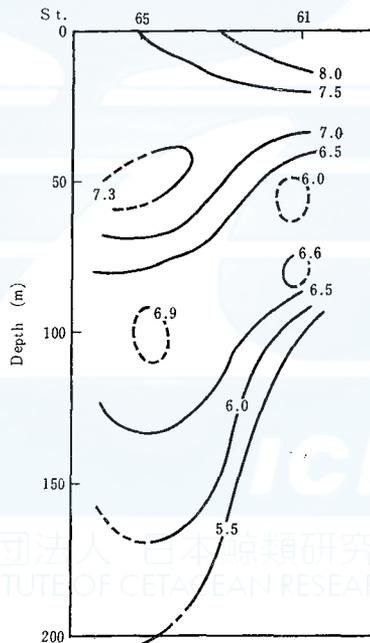


Fig. 38. Vertical profile of the dissolved oxygen along the D-line.

low dissolved oxygen rise from south to north. The phenomenon may be considered that the upwelling is formed by the marine topography in which the contour line is steeply change from 200 m to downward. The existence of upwelling is also apparent from the vertical distribution of the dissolved oxygen at St. 61 and 65. To the very surface the intrusion of the high dissolved oxygen is found.

I-line

Fig. 39 shows the vertical profile of dissolved oxygen along the I-line. The water mass is characterized by more than 11.00 CC/L below 20 m to the east of St. 0-29. From the surface to 30 m between St. 0-28 and St. 0-29 11.00 CC/L, of which

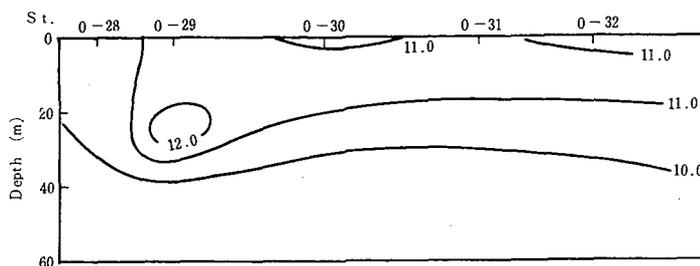


Fig. 39. Vertical profile of dissolved oxygen along the I-line.

the distribution at a relatively shallow layer coincides with the water mass of more than 6.0°C in temperature and 32.40‰ in salinity. Such a distribution leads to a definition of two distinct water masses as a boundary to St. 0-28: the Alaskan water mass of low temperature and salinity with high dissolved oxygen, and the Bering Sea water mass (high temperature and salinity with dissolved oxygen).

ANNUAL VARIATION OF WHALE CATCH

Table 1 shows the number of whale caught by Japanese whaling expeditions in the Bering Sea and the northern part of the North Pacific. The fin whale is the most important specie in the waters, as mentioned in Table 1. Fig. 40 shows the daily catch of fin whale per a catcher boat. In the Fig. 40 we must be careful on the catch of fin whale during the operation of blue whale, because the catch of

TABLE 1. NUMBER OF WHALE CAUGHT BY JAPANESE WHALING EXPEDITIONS IN THE BERING SEA AND THE NORTHERN PART OF NORTH PACIFIC

Year.	Blue	Fin.	Hump.	Sci.	Total.	Sperm.	Right.
1940	34	295	108	3	440	182	
41	40	370	6	7	423	162	
52	55	213	37	14	319	0	
53	90	470	42	98	700	0	
54	145	1,316	136	129	1,726	490	
55	70	1,360	117	21	1,568	1,084	
56	70	1,415	37	48	1,570	1,598	
57	70	1,405	6	166	1,641	1,700	
58	70	1,331	24	330	1,755	1,500	
59	70	1,450	0	32	1,552	1,800	
60	70	1,393	0	203	1,666	1,800	
61	70	1,452	9	4	1,535	1,600	3
62	48	1,193	17	260	1,518	2,549	3
	902	13,663	539	1,315	16,413	14,467	6

fin whale decrease by the catch of blue whale. The daily variation of catch has increased in recent years. However, the catch in 1959 and 1960 was relatively stable. Such a problem must be examined from the point of oceanography, meteorology, catch effort and other elements. From the catch tendency of each year, the fluctuation of daily catch off Kamchatka is relatively large, but that of 1959 shows a small daily variation. The whaling location in this year was a little different from that of other years. Whaling was carried out in the region north of the Komandorski Islands.

When compared to 1953 the catch off Kamchatka has a tendency to become better in the first half and worse in the latter half of the season.

As already stated, the whaling ground on the southern side of the Aleutian Islands (West longitude) shifted to the southward around on 50°N latitude from 1957. In this ground, the operation in 1957 and 1958 were holding out a stable catch, but the catch in 1959 and 1960 decreased. The operation carried out from middle to last decade of July in 1957 and from middle to last decade of June 1958 and from July 1959 and 1960. Whaling operation at the west region of St. Mathew Island carried out in 1957 and 1960. In 1957 and 1958 there were also whaling ground off Cape Navarin, where many fin whales were captured and the detail of whaling season is obscurity as there is lack of data in June and July, but it should be late (may be from last decade in July).

Operation in the northern ground of Unalaska Island commenced in 1954 and has carried out there ever since. The number of daily catch always stable condition every year in this ground, but the total caught whale are relatively small quantity in some years which is because of unnatural influence for the commercial production. From the yearly operation it may be considered that the whaling season lasts from June into September. The variation of sperm whale caught did not show in Figure. From yearly operation the whaling ground is formed around the Aleutian Islands during the summer season, whose yearly fluctuation is very small, but 1960 many whales were captured at the vicinity of 57°N, 175°W.

It is convenience to use the center of whaling ground for the analysis of fluctuation of that at sea region off Kamchatka Peninsula and the northern region of Unalaska Island where the whaling operation are carried out at every year. A primary factots what the whaling grounds are formed consist mainly of meterology, submarine topography, oceanographic condition and others, in which the oceanographic condition is the most important factor. The oceanographic condition, namely, the physical, chemical and biological element in each year do not shown always stationary distribution.

CENTER OF WHALING GROUND

Off Kamchatka Peninsula

In order to obtain the center of whaling ground the author used following formula which was shown by Uda (1930).

$$\bar{X} = \frac{\sum nix_i}{ni} \quad \bar{Y} = \frac{\sum niy_i}{ni}$$

, where x and y are location of caught whale. n is number of caught whale. \bar{X} and \bar{Y} are the center of whaling ground.

Fig. 41 shows the average center in the years 1952 to 1960 and the yearly center of ground. Next, Fig. 42 shows the yearly caught whale number of latitude and longitude respectively at each grounds.

On the longitudinal variation, two peaks were found in 1952, 1953 and 1954, of which the operations were carried out during long time (the operation in 1956 and 1959 were carried mainly out at the northern region of the Komandorski Islands). Those peaks are generally near 164°E and 174°E, and the most peak

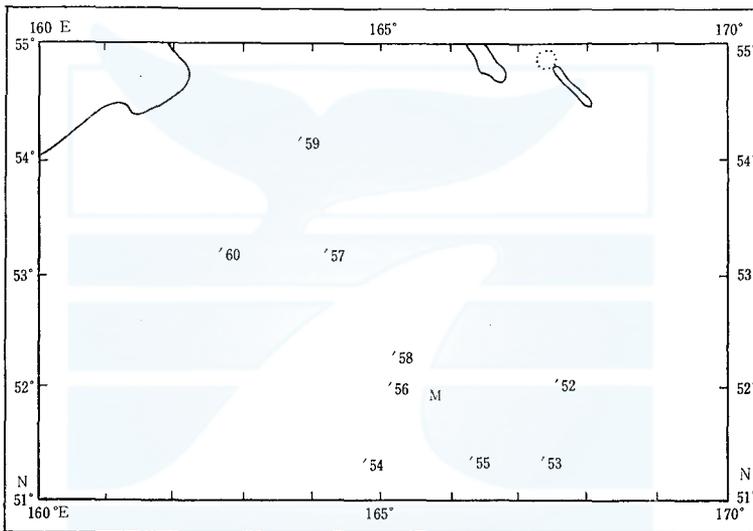


Fig. 41. Yearly center of fin whaling ground.

Ⓜ shows the average center in the years 1952 to 1960.

longitudinal catch was found near 164°E. The peak of latitudinal catch generally is at 52° to 53°N, and has a tendency to move more towards the north. Such in 1956 and 1959 when the whaling ground was formed at the northern region of Komandorski Islands coincides with relatively higher sea temperature. The problem of movement of ground must be analyzed from the point of migration of whales and whaling season.

The operation in this area is carried out recently at the beginning of the whaling season in the Subarctic Pacific area. The peak of latitudinal catch generally is near 52°-30'N and the average center of whaling ground in the years 1952 to 1960 is located near 52°N, 165°-30'E.

Off Unalaska island

As mentioned on the whaling operation in the region off Unalaska I. by Japanese

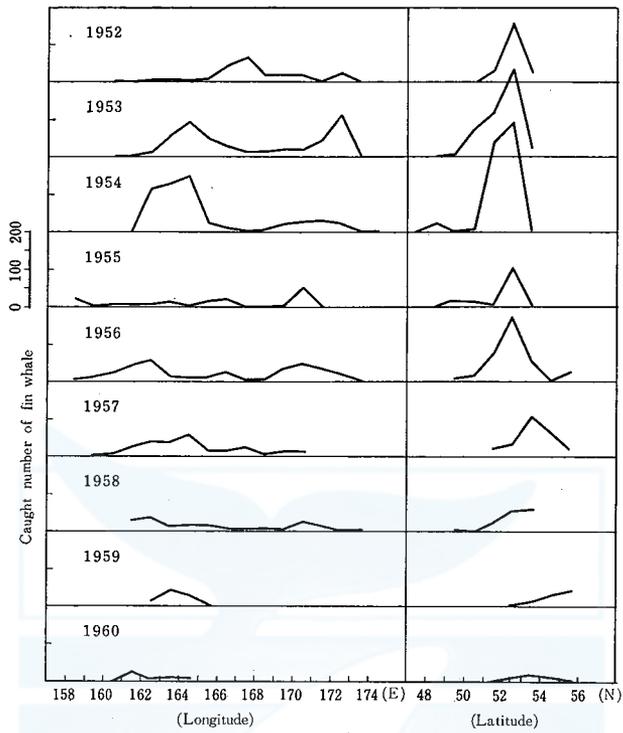


Fig. 42. Yearly caught number of fin whale in the ground off Kamchatka.

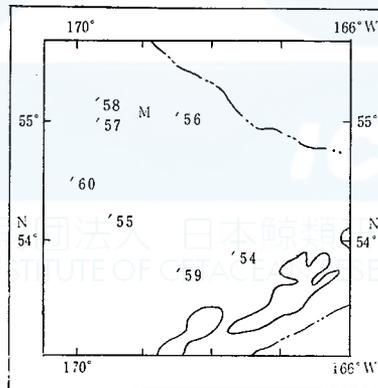


Fig. 43. Yearly center of fin whaling ground.
 (M) shows the average center in the years 1954 to 1960.

expeditions are began since 1954. From Fig. 43 the center of ground fluctuates in a small range. The average center of ground in the years 1954 to 1960 locates at 54°N 169°W and the peak of the latitudinal catch was found between 54°N

and 55°N latitude (see Fig. 44). On the longitudinal between 169°W and 171°W, there are the center of catch.

In general, the whaling ground off Unalaska Island fluctuates in a smaller compared with that off Kamchatka Peninsula.

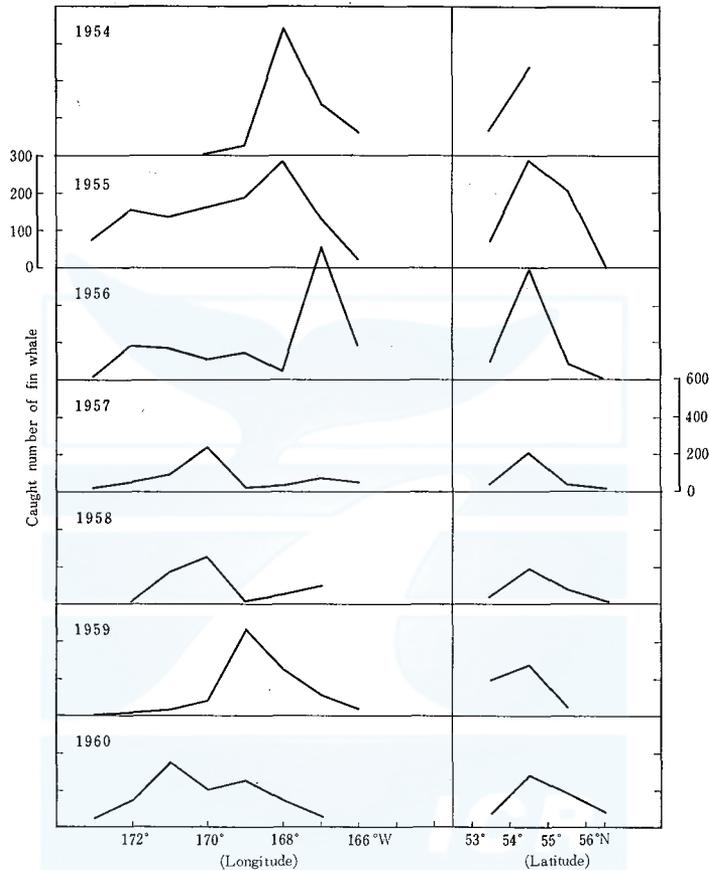


Fig. 44. Yearly caught number of fin whale in the ground to the north of Unalaska Island.

SPERM WHALING GROUND

Sperm whales are mainly captured along the Aleutian Islands 1960 was an exception. Fig. 45 shows the latitudinally number caught in the ground along the Aleutian Islands. The latitudinal range of ground covers from 170°E to 160°W indicates that the annual fluctuations are very small. The number caught at each latitude section varies somewhat each year, and in general, is more abundant in the region west of 177°W and is most abundant in the vicinity of 180° longitude.

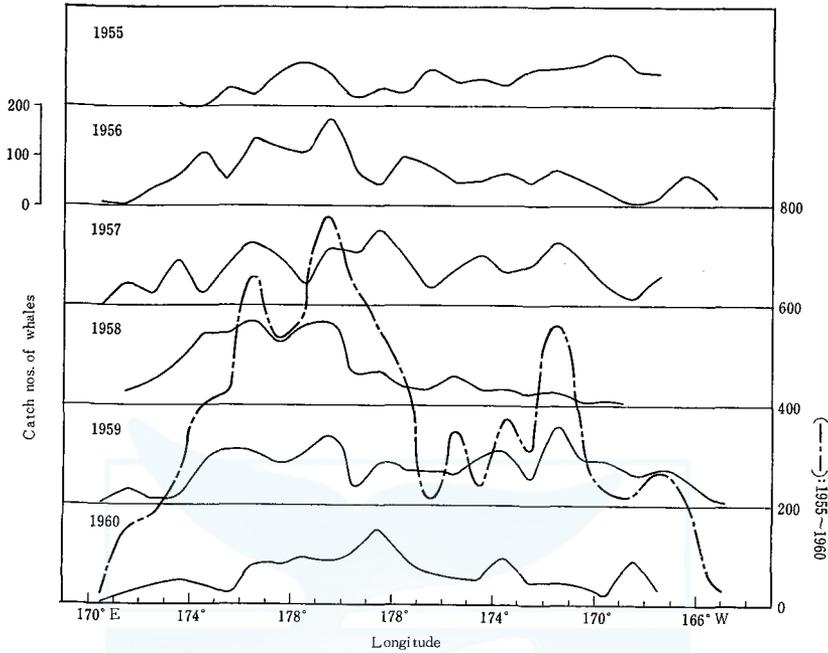


Fig. 45. Latitudinal number of sperm whale in the ground along the Aleutian Island. (except to the north of 55°N)

STRUCTURE OF WHALING GROUND

Fig. 46 shows the schematic hydrographic structure of the ground off northern region of Unalaska Island along the D-line. In the Fig. 46 black circle shows the number of fin whale caught in 1955 season. The hydrographic structure in this ground has formed the discontinuous zone at subsurface between the water mass which intrudes from the southern region of the Aleutian Islands and the Bering Sea from the water mass, which there also is upwelling zone. The quantity of dissolved oxygen, is lower along the Aleutian Islands and almost shows super-saturation at the head of the water mass which is transported from the southern region.

Uda (1960) stated that $Q = \int_{(A)} \int_{(Z)} \Delta O_z' dz dA$ (where A : area, Z : depth, O_z : quantity of dissolved oxygen at Z m. in depth, O'_z : super-saturation quantity of dissolved oxygen at Z m.) is directly proportional to the quantity of marine life, and Matsudaira et al (1956) reported that the marine production relationship is shown in following formula, based on the quantity of dissolved oxygen.

$$P = (O_z - O'_z)$$

Where P is marine production,

O and O' are similar to Uda's formula.

Consequently, $O_z - O'_z$ may be considered for the indirect index of marine

production. The source of the oxygen supply is air, phytoplankton etc. The oxygen which is supplied from air is transported to the deep layer by vertical turbulence of sea waters, etc, and is consumed there.

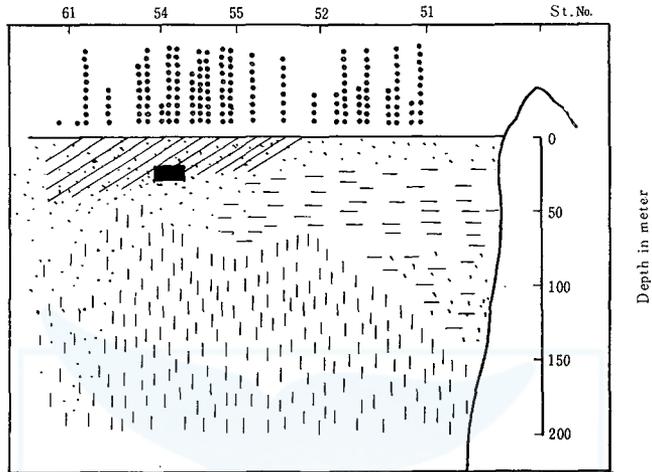


Fig. 46. Schematic hydrographic structure of the ground off region of Unalaska Island.

Small black circle : catch no. of fin whale.
 Oblique : super saturation of dissolved oxygen.
 Black : the most dense stratus of dissolved oxygen.
 And other notations show water mass.

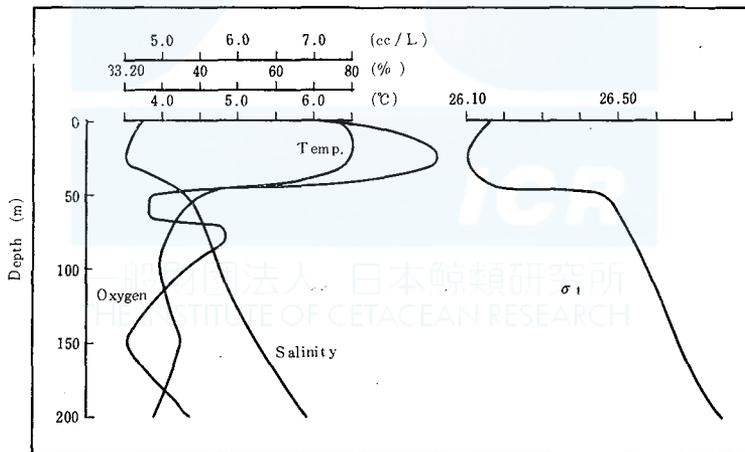


Fig. 47. Vertical distribution of temperature, salinity, dissolved oxygen and σ_t at St. 54.

When the dissolved oxygen is supplied from air, the quantity is the maximum at sea surface. As shown in Fig. 47, at St. 54 the quantity of dissolved oxygen is very large. Its saturation ratio is 122.40%, and mainly be produced

by photosynthesis. At St. 54 the vertical stability ($E = 10^{-3} \frac{d\sigma_t}{dz}$, where E is vertical stability, σ_t is density of sea water and Z is depth) is the most stable condition between 25 and 50 m. in depth, where the typical thermocline is formed also (see Fig. 47). This may be explained by an upwelling water mass during the winter season supplying the surface layer, where it is well known that phytoplanktons increase. Halse (1956) stated that in the Antarctic zone, with its pronounced stability, the large phytoplankton population were confined to a surface layer of 25–50 m. According to Mackintosh & Wheeler (1929), Hardy & Gunther (1935), Mizue (1951), Peters (1955), Marr (1956) and Nemoto (1957, 1959, 1962), it is well known that the staple food of baleen whale in the Antarctic and North Pacific Ocean is euphausiids, and Kemp et al (1932) stated that the distribution of blue and fin whales in the Antarctic waters is closely correlated with the euphausia distribution. It is also reported that these euphausiids feed mainly on phytoplankton (Barkley 1940, Einarson 1945, Ponomareva 1959) and zooplankton organisms (Ponomareva 1959). But Hardy (1935) described that the zooplanktons are distributed away from the concentration area of the phytoplanktons, in general, such an area is not always plenty area of zooplankton.

It also is known that the high concentration layer of the diatom exists less than about 50 meters of depth (Moberg 1928, Phifer 1934a, 1934b, Kokubo and Tamura 1934). The high concentration layer of the phytoplankton seems to the feeding depth of baleen whale. Consequently, as stated by Marr (1956) and Nemoto (1962), baleen whales seem to feed at relatively shallow depth, but the problem on the feeding depth must be examined from the ecology of zooplanktons and other marine life, also.

Southern region of the Aleutian Is. in West longitude

In this region mainly fin whales were captured but some blue and sei whales were also captured. The whaling ground extends to east and west as a center to lat. 50°–51°N, and locates in the water mass of returnig flow (Kitano 1958). From the distributions of surface temperature in June and July (some whales were sighted in the season) the ground seems to be closely with the oceanic front which is formed between the northerly branch of Kuroshio Extention and the Aleutian Gyral. In order to analyze the structure of the whaling ground, the auther tried study of the upwelling and sinking, whose computation was based on the formula devised by Saito and Kanari (1961).

Fig. 48 shows the distribution of upwelling and sinking between 25 and 200 meters in depth along 50°N latitude. At 177°W, sinking exists as deep as 200 m. at least. In the area between 171°W and 176°W there is upwelling at relatively shallow depth which seem to extend toward the west, according to Kitano (1958). Between 174° and 176°W sinking is formed to depth of 100 to 200 m. Near 171°W upwelling exists as deep as at least 200 m. At 170°W sinking generally is formed as far as 200 m, condition being similar to those found at 177°W. From these conditions fin whale generally were captured in the area where the upwelling exists

from relatively deep layer, being especially plentiful near the boundary zone which exists between the sinking and upwelling areas. Vertical structure along 167°-57'W is shown in Fig. 49, where the fin whale catch between 168° and 169°W, was totaled. Thermocline exists between 20 and 40 m depth, with isopycnal rises between 50° and 51°N.

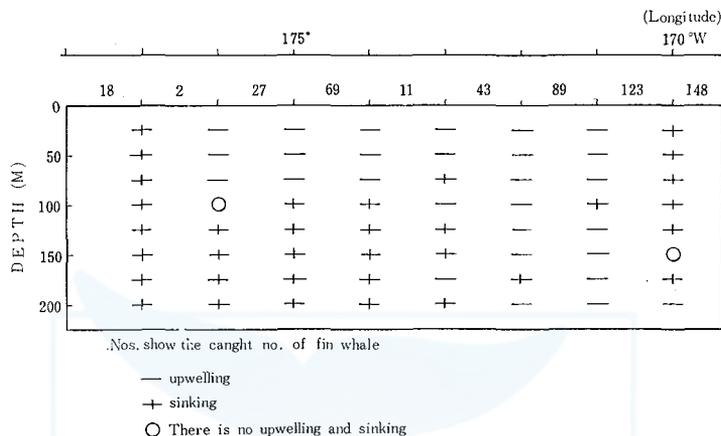


Fig. 48. Vertical distribution of upwelling and sinking along 50°N Latitude.

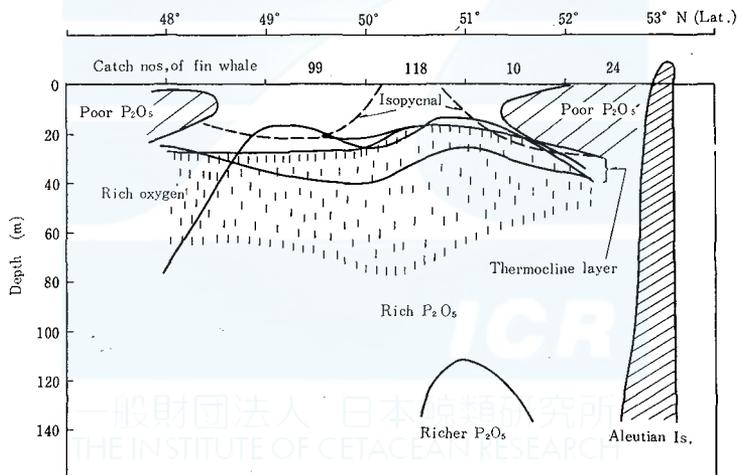


Fig. 49. Schematic structure in the fin whaling ground along 167°57'W.

The maximum layer of dissolved oxygen is found between 20 and 80 m, with thickness being larger where the quantity of phosphate is low at relatively shallow depth, and especially is lower south of 48°-30'N and north of 51°-20'N.

The water mass which is characterized by having water of relatively high concentration of phosphate rises north of 49°N, and zone of the highest concentration is found near 110 m depth at 51°N. Many fin whales were captured between 49° and 51°N, where an upwelling region exists in which the waters in the deep

layer have rich phosphate waters and the maximum layer of dissolved oxygen is most thick.

Off Cape Navarin

This whaling ground is located near the mixing zone formed between the water mass along the Siberian continent, characterized by low temperature and salinity, and the oceanic water mass of relatively high temperature and salinity. Fig. 50 shows the schematic figure of water masses and the distribution of fin whale caught (nos. is shown in the Fig. 50). In the Fig. 50 oceanographic data used is that of middle July, and the whaling season is shown from the last of August.

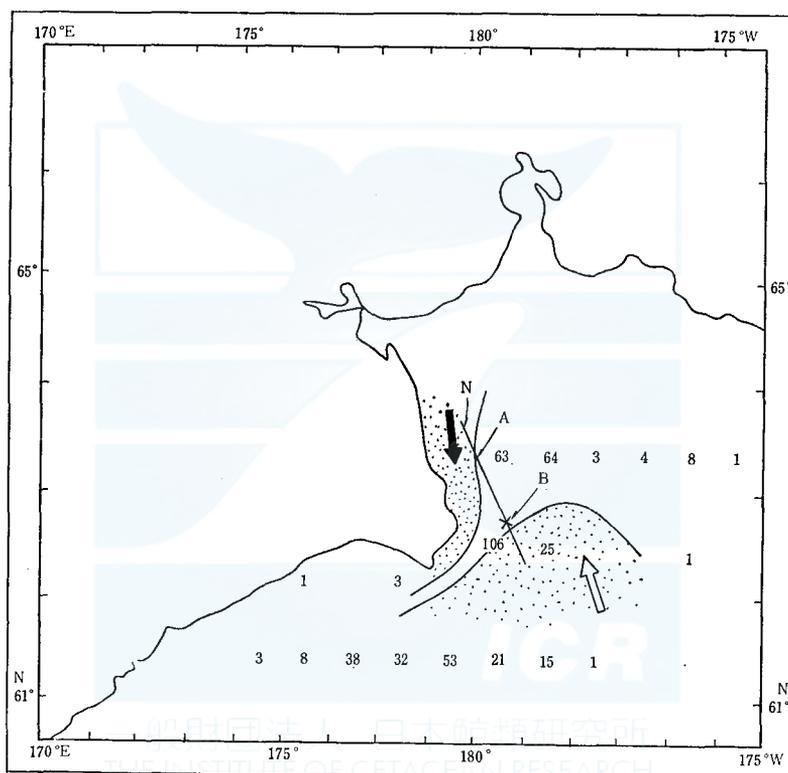


Fig. 50. Schematic picture of water masses and the distribution of fin whale caught. Solid lines show the boundary of water mass.

Moreover, the vertical section of temperature along the N-line is shown in Fig. 51. The water mass off Cape Navarin further can be defined to three zones (it was defined to two zones in the article of water mass analysis), as follows:

1. Pure melted-ice water: is characterized by marked cold (less than 2.2°C) and low salinity (less than 26.00‰).
2. Zone off Cape Navarin: is characterized by relatively warm (more than 6.0°C) and high salinity (more than 30.00‰).

3. Mixing zone: locates between the pure melted ice-water and water mass off Cape Navarin.

These water masses are termed conveyentry N, ON and M-type, respectively. From Fig. 51, it is seen that a typical discontinuous zone is formed between N-type and M-type, and is considered the vertical boundary as Tsujita (1954) described it in his treatise on the mackerel fishing grounds of Tsushima. Such a vertical boundary can also be assume to form near pack-ice in the Antarctic.

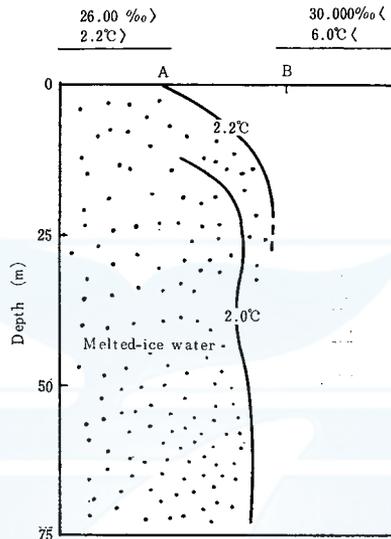


Fig. 51. Vertical section of temperature along the N-line.

From the distribution of surface temperature as shown on current chart (Uda 1960, Fleming 1955), it is clear that the water mass of N-type is moving towards the south along the Siberian continent and the ON-type is flowing towards the north. In addition, many fin whales were captured in the mixing zone (especially narrow area).

SUMMARY

1. In this paper the oceanography and whaling grounds are discussed based on the data obtained by whaling factory and whale marking boats.
2. The monthly mean distributions of surface temperature during 1955—1959 were examined.

May: Temperature distribution to the east off Kamchatka Peninsula, in general, may be considered as due to the influence of coastal and off shore water mass.

On the both side of the Aleutian Islands, isotherms run towards the east and west roughly parallel to each other.

June: Isotherms in the vicinity of the Aleutian Islands run similar to those

of May. On the continental shelf to Alaska relatively high temperature 7.0°C-isotherm is tongue-shaped, extending towards the south.

July: In the neighborhood of the Bowers bank there is a cold water area which is characterized by below 8.0°C.

Temperature in the Alaskan Sea area is high about 1.0°C than that in June. In the vicinity of the Cape Navarin the 5.0°C and 6.0°C isotherms lie nearly parallel to Siberian Continent.

August; The surface temperature in the northern part of the North Pacific and the Bering Sea attained the maximum value in August.

September; Temperatures in this season are decreasing.

3. Thermocline located in almost all the northern part of the North Pacific Ocean, Bering Sea and a part of Chukchi Sea, but their depth and temperature gradient ($\Delta\theta/\Delta D$) differ with sea area and season.

4. The temperature minimum of intermediate cold water in the Subarctic Pacific region vary from -1.6°C at its minimum to highest value 5.6°C, and its core extents from 175 m to 25 m in depth.

5. As the data of salinity was very few compared with that of temperature, it is not examined concerning monthly mean. However, the distribution of some months by year's were shown and discussed.

6. The analysis of water mass was made by using temperature and salinity diagram.

a) Northern sea area of Unalaska Island can be divided into four water masses as shown in Fig 30.

b) Water mass off Kamchatka Peninsula can be divided into four types. That is,

A: Intermediate cold water developed, and saline water near 200m.

A': Subtype of A.

B: From surface to 100 m in depth, temperature varied anomalously with depth. Salinity was homogeneous.

K: Intermediate cold water was located in shallow layer, with a temperature of less than 1.0°C.

c) Near Cape Navarin cold and low salinity water mass located in the vicinity of Siberian Continent where in the south, there was a warm and high salinity. Water mass near Cape Navarin may be divided into three types.

7. The waters of high concentration of pH at the surface located in the area of Unalaska Island and increased towards Bristol Bay.

8. The transparency shows the higher in the C-water mass (see Fig. 32) and lower near Unalaska Island.

9. The dissolved oxygen at the surface in the Berig Sea range from 4.43 CC/L to 11.05 CC/L and it decreased along the Aleutian Islands and increased towards the east region of Kamchatka Peninsula and Bristl Bay.

10. According to catch distribution from 1952 to 1960 in general, fin whale grounds divided in to five area.

That is,

a) Off Kamchatka Peninsula

Whaling grounds off Kamchatka Peninsula located from the east area of Kamchatka Peninsula to the vicinity of Attu Island. Such in 1956 and 1959 when the whaling ground was found at the northern region of the Komandorski Islands coincided with relatively higher in sea-temperature.

b) Southern side of the Aleutian Islands

Whaling ground on the southern side of the Aleutian Islands (west longitude) shifted to the southward around on 50°N longitude since 1957. The whaling ground extends to east and west as a center to lat. 50°–51°N, and located in the water mass of returning flow (Kitano 1958).

c) Off Unalaska Island

Whaling operations in the northern ground of Unalaska Island commenced in 1954 and has carried out there ever since. The center of ground fluctuates in small range.

d) Off the west of St. Mathew Island

Whaling operations in this area carried out in 1957 and 1960.

e) Off Cape Navarin

Whaling in this area carried out in 1957 and 1960. This ground is located near the mixing zone formed between the coastal water mass along the Siberian Continent and the oceanic water mass of relatively high temperature and salinity.

11. The results of Japanese whaling expeditions indicate that blue and sei whales are found mainly in the southern waters of the Aleutian Islands.

12. Humpback whales are most prevalent in the waters south of the Aleutian Islands (especially east of 170°W) and are also found in near Cape Navarin and in Chukchi Sea.

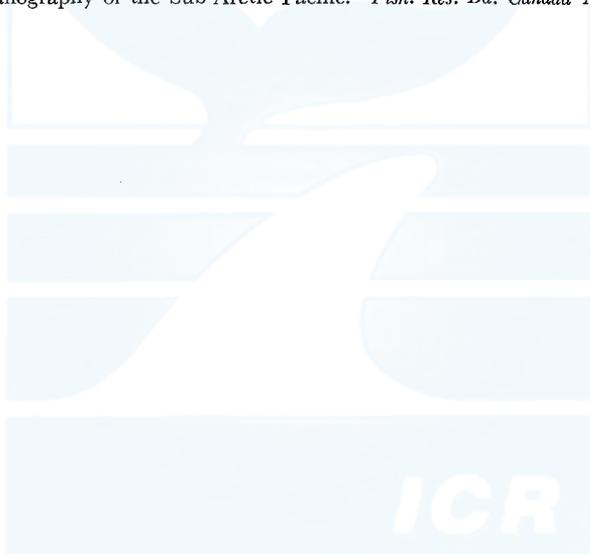
13. Sperm whales are mainly captured along the Aleutian Islands.

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SOME ASPECTS OF THE DISTRIBUTION OF *CALANUS*
CRISTATUS AND *C. PLUMCHRUS* IN THE BERING
AND ITS NEIGHBOURING WATERS, WITH
REFERENCE TO THE FEEDING OF
BALEEN WHALES

TAKAHISA NEMOTO

Generally speaking, copepod crustaceans are one of the most important foods for some baleen whales as well as other marine fish. They occupy the most part of the abundance of the zooplanktons in the sea. In the Bering sea and in the northern part of the north Pacific, copepods are one of the most important foods for baleen whales along with euphausiids and fish. Among baleen whales, fin whales usually take *Calanus cristatus* besides euphausiids, and right and sei whales are feeding on *C. plumchrus* favorably (Nemoto, 1959). These selections of their foods are closely related to the feeding apparatus of baleen whales (Tomilin, 1954 : Nemoto, 1959). The distribution of the copepods as a food of baleen whales is examined here from the observation of stomach contents of baleen whales in relation to their feeding.

MATERIALS

The materials treated in this paper have been obtained from the collected samples of stomach contents of baleen whales caught from 1952 to 1961. Plankton samples collected in 150 and 200 meter vertical tows with 45 cm diameter and 0.33 mm net have been also included with other data published by Anraku (1954) and Minoda (1958). The measurements of cephalo-thorax length are only made on the fresh unbroken specimens in plankton net samples or stomachs of baleen whales saved from digestion. Oceanographical materials of the Bering sea and adjacent waters are based on following data.

Data collected by Whales Research Institute.

Data record of oceanographic observations and exploratory fishing. No. 1—5 by Hokkaido University.

Oceanographic data on the northern part of the north Pacific. No. 1—3.

DISTRIBUTION OF FIN AND SEI WHALES

The distribution of baleen whales in the Bering sea and its adjacent waters is considered from the charts of the catch distribution to some extent. As already discussed by Nemoto (1959) sei whales belong to *Ocean denizen type* and comparatively rarely penetrate into the marginal sea. The observation of sei whales has scarcely been recorded in the Bering sea in the whaling these days except some Japanese

records. The number of sei whales found by the whale searching is also very few in the Bering sea in high latitudes (Nemoto, 1959). On the other hand fin whales are considered to be *Ocean* and *Marginal sea denizen* which distribute widely in the Bering sea and even penetrate into the Arctic sea. From the catch statistics in Japanese operations in recent 10 years, 8 main whaling grounds for fin whales have been drawn in the Bering sea and adjacent waters. As illustrated in Fig. 1, the most heavy catch is observed in the north waters of the east Aleutian Islands, where euphausiids *Thysanoessa inermis* and *T. longipes* are very abundant. *Thysanoessa inermis* distributes along the Alaskan continental shelf and *T. longipes* in the off waters of the north waters of the east Aleutian Islands. In this off waters of the said area, *Calanus cristatus* also appears as a food for fin whales (Nemoto, 1959).

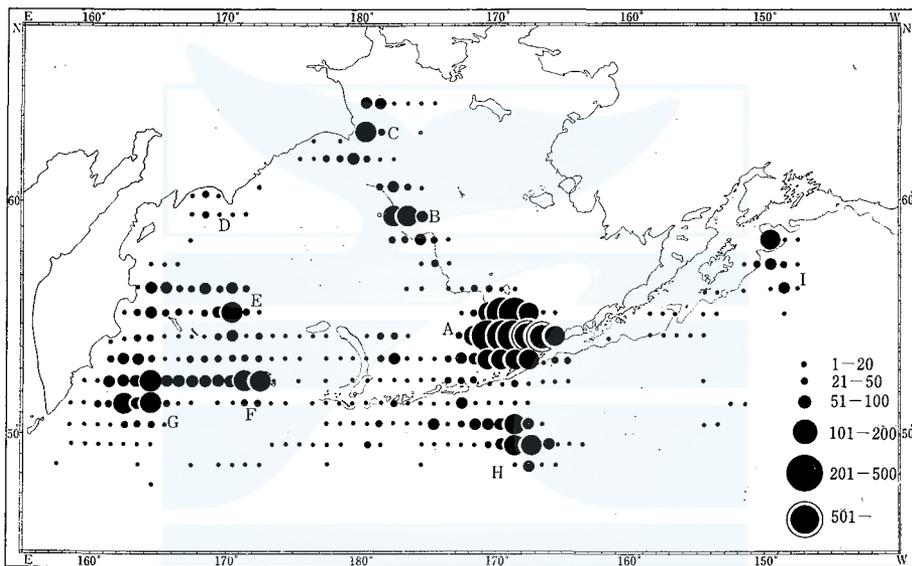


Fig. 1. Distribution of fin whales caught by Japanese whaling from 1952 to 1961.

It has occurred very often in the stomachs of fin whales in 1955 and 1956 seasons, and many fin whales have swarmed to feed *Calanus cristatus*. In the northern part of the Bering sea, there have been observed three regions of the concentration of fin whales as illustrated in Fig. 1. Along the Alaskan continental shelf waters, considerable number of fin whales have been taken where Alaska pollack is the food for fin whales (Fig. 1-B.) In other grounds C and D, fin whales sometimes have fed on *Thysanoessa raschii* and caplin which distribute in the waters off Cape Navarin (Fig. 1-C). A few catch of fin whales is also observed in Olyutorskiy Bay, where the abundant crop of *Calanus cristatus* for baleen whales was already reported by Brodsky (1950). But fin whales which have been caught by Japanese whaling expeditions in the Olyutorskiy bay in June in 1960 have scarcely taken *Calanus cristatus*. Fin whales caught in Olyutorskiy bay have fed on herring (*Clupea pallasi*) and caplin (*Mallotus catervarius*). It is safe to say that fin whales feeding in the said areas feed mainly on fish or euphausiids and few occurrences of *Calanus*

cristatus. In the southern Kamtchatka side of the Bering sea, *C. cristatus* is one of the important food for fin whales as illustrated in Fig. 2. In the adjacent waters to Attu Islands (Fig. 1-F), fin whales swarm to feed on *C. cristatus* every year from June to July especially in the late of July. The stage of the *C. cristatus* is copepodite 5 in general and it coincides with the cycle of it in the waters as established by Heinrich (1957). The considerable part of the copepodite stage 5 *Calanus cristatus* distributes in the surface strata of the north Pacific. (Vinogradov, 1955). In the southern waters of Sagami Bay of Japan, the immature *C. cristatus* also inhabits in the intermediate layers between 300–500 meter and adult specimens are usually found in the depth deeper than 500 m (Tanaka, 1956).

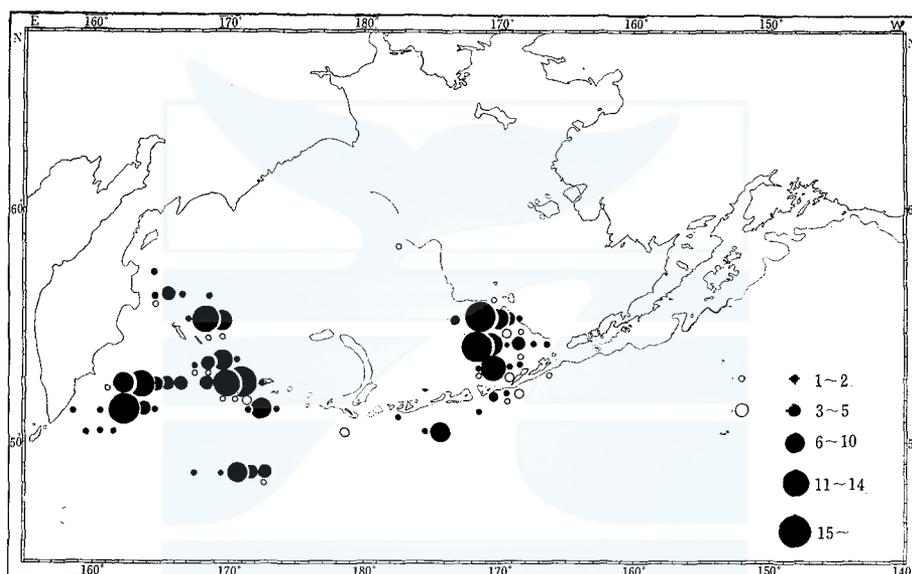


Fig. 2. Distribution of *Calanus cristatus* and *C. plumchrus* in the stomachs of fin whales in the Bering sea and Adjacent waters. Black—*C. cristatus*, Open—*C. plumchrus*.

The swarm of *C. cristatus* is considered to sink to the deeper waters to attain their growth and to spawn. Generally, *C. cristatus* spawn in the waters deeper than 500 m in the Bering sea and adult *C. cristatus* is also found in the deeper waters in Kuril-Kamtchka region (Vinogradov, 1955). Fin whales can dive as far as about 300 m (Scholander, 1940), and it is considered usual feeding range of the baleen whales do not exceed 300 m. Thus swarms of adult *Calanus cristatus* escape the swallowing of baleen whales. In other two waters, Copepodite 5 stage of *C. cristatus* stay in the upper layer waters later than July. As a second important copepoda, *Calanus plumchrus* occurs in the south waters of the Aleutian Islands from June to August. The occurrence is also observed in July and August in the north waters of the east Aleutian Islands (Fig. 2).

The whaling grounds formed by *Calanus cristatus* extinct as soon as the subsiding of *C. cristatus* to reproduce in the unattainable depth of fin whales. In the 'Calanus

year' (Nemoto, 1959), fin whales heavily swarm in the area F and E in Fig. 1 in June and July, however, blue whales usually do not come to the areas by the late of August and September. On the other hand, fin whales have not been attracted by *C. cristatus*, and feeding on the heavy shoals of euphausiids in the waters E, in 'Euphausiid year'. In 1954, many fin whales were feeding in waters along the Alaskan continental shelf but they were feeding in the off waters of the shelf on *Calanus cristatus* in 1955 when euphausiids were rather scarce along the shelf.

The second *Calanus* feeder is the sei whale in the northern part of the North Pacific. Sei whales are the *Ocean denizen* and majority of them come only as far as the Aleutian archipelago. The catch of sei whales, however, usually have been done in the south of the Aleutian Islands as the main herd of sei whales do not penetrate into the Bering sea. As it is shown in Fig. 3, the main concentrations of sei whales catch are observed in the waters off Kamtchatka and along the Aleutian Islands.

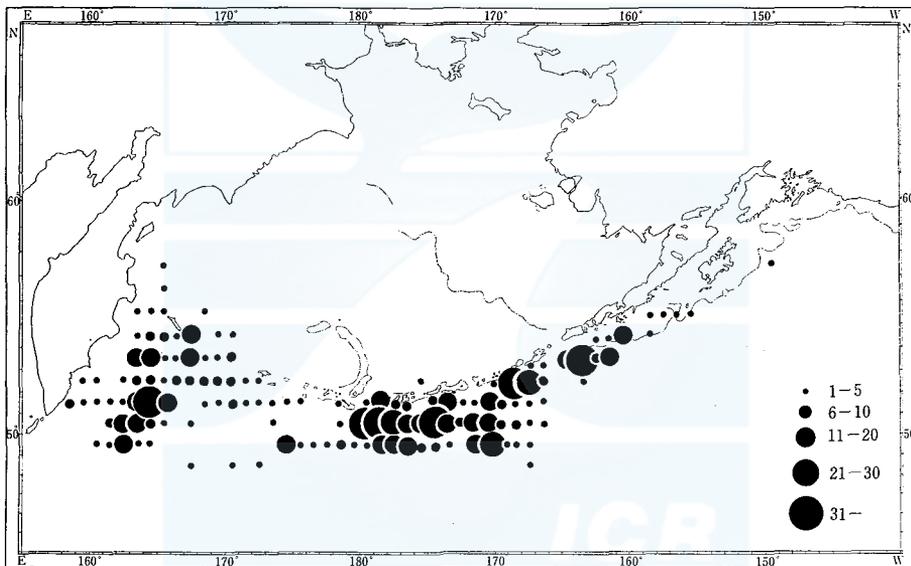


Fig. 3. Distribution of sei whales caught by Japanese whaling from 1952 to 1961.

As a general tendency, sei whales come to the waters off Kamtchatka in summer when the height of *Calanus plumchrus* is observed (Heinrich, 1957), Heinrich shows two groups of *C. plumchrus* in the waters and sei whales mainly feed the group which attains their copepodite stage 5 in August. But sei whales are already feeding in the south waters of the east Aleutian Islands in June. This also suggests that *C. plumchrus* is abundant in this area in June.

In the stomachs of sei whales, the majority of *Calanus plumchrus* is in copepodite 5, and a few specimens of copepodite 4 are also found among copepodite 5. This differs the case of *Calanus cristatus* found in stomachs of fin whales in which very few copepodite 4 is found in the mass of *Calanus cristatus*.

The food of sei whales in the northern part of the north Pacific is already discussed by Nemoto (1959), and the most sei whales have been feeding on copepods.

The number of sei whales fed on other foods, euphausiids and squids are rather scarce when the data are compared with the one in the adjacent waters to Japan. The distribution of *Calanus* copepoda identified in the stomachs of sei whales are illustrated in Fig. 4. Although the collected number is not so many, the main part of the food *Calanus* is *Calanus plumchrus*. It is suggested these main concentrations of sei whales fairly coincide with the waters where *Calanus plumchrus* are abundant.

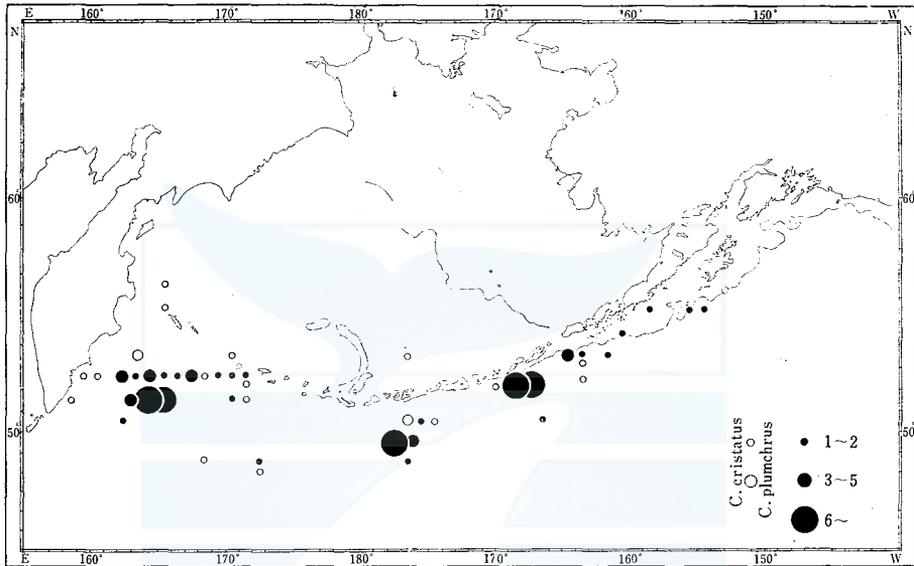


Fig. 4. Distribution of *Calanus cristatus* and *C. plumchrus* in the stomachs of sei whales in the adjacent waters to Aleutian Is. Black—*C. plumchrus* Open—*C. cristatus*.

DISTRIBUTION OF *CALANUS CRISTATUS* AND *C. PLUMCHRUS* IN THE SURFACE STRATA

According to Bogorov & Vinogradov (1960), *Calanus cristatus*, *C. plumchrus* and *Eucalanus bungii* occupy the 80 per cent of biomass of the Kuril-Kamtschatka region. In the surface collections of copepods by the vertical plankton net, both *Calanus cristatus* and *C. plumchrus* are found most commonly in the waters investigated. These occurrences of both species show, however, some interesting features as discussed following.

Calanus cristatus found in the stomachs of fin whales usually consists of copepodite stage 5, and adult *C. cristatus* has not been found in the stomachs of baleen whales. The positions where copepodite stage 5 of *C. cristatus* is found in the net collections are plotted in Fig. 5. As it has been considered, *C. cristatus* distributes mainly in the waters which have depth deeper than 500 m and naturally it is found in the deeper waters in the Bering sea. *Calanus cristatus* has not been found in some plankton net towed along the Alaskan continental shelf and Chukchi sea as shown in

Fig. 5. *C. cristatus* has not been collected in the stations within the Alaskan shelf and 5 station in the Siberian side of the Chukchi sea. Of course both areas are little influenced by the Bering sea current which may bring *C. cristatus* from the off water. In the Chukchi sea, Johnson (1956) already reports the occurrences of *C. cristatus* as the visitor from the southern fauna in the Alaskan side of the Chukchi sea. The clear segregation in occurrences of *C. cristatus* in the Chukchi sea is apparently affected by the sea current through the Bering strait and shore waters along the Siberian side.

The number of *Calanus cristatus* in the shallower waters of Chukchi sea is very scarce in the vertical net from the bottom, and adult specimens have not been collected. The adult *Calanus cristatus* has not been collected by surface plankton nets in other waters of the Bering sea (Anraku, 1954; Minoda, 1958), and it is considered it usually distributes in the waters lower than 500 m.

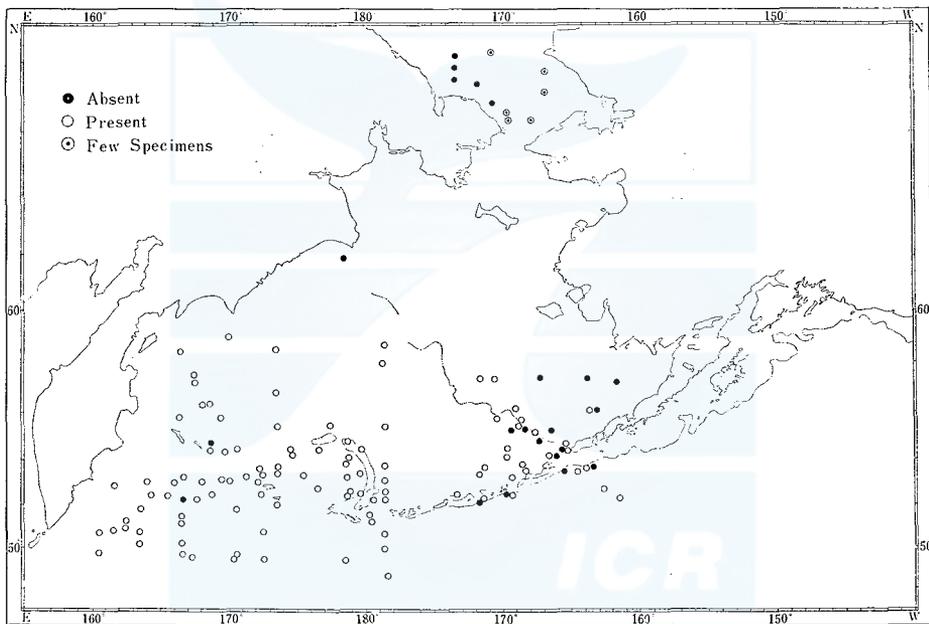


Fig. 5. The occurrences of *Calanus cristatus* in the vertical plankton Net in the surface strata above 150 m and 200 m in the Bering sea and Chukchi sea.

The general distribution layers of the two *Calanus* species are different. Copepodite 5 stage of *C. plumchrus* distributes shallower waters than *C. cristatus* (Vinogradov, 1956). This coincides with the swimming depth of fin and sei whales in their usual feeding. (Nemoto, 1959).

The occurrences of *Calanus plumchrus* in the vertical plankton nets towed in surface layer in the Bering sea are plotted in Fig. 6. Both adult and copepodite 5 stage of *C. plumchrus* are more commonly found in the Bering sea and the latter appears in the almost all collections in the investigations. It also occurs in the Chukchi sea in several stations. Especially adult *C. plumchrus* is observed in shallow stations

of Chukchi sea and Alaskan shelf as shown in Fig. 6. Adult *Calanus plumchrus* has been found only three net collections towed in stations in the deeper waters off the Alaskan shelf and the west waters, however, it occurs in several shallower stations in Alaskan shelf and Chukchi sea. The adult *Calanus plumchrus* is found in the deep waters of the Bering sea and usually deeper than 200 m (Anraku, 1954). This suggests that *Calanus plumchrus* becomes adult in the shallower waters if it can't subside to deeper waters, although the adult *Calanus plumchrus* spawns like *Calanus cristatus* in the deeper waters. Anraku (1954) reports the adult *Calanus plumchrus* distributes usually in the waters deeper than 150 m or 200 m in the west side of the Bering sea.

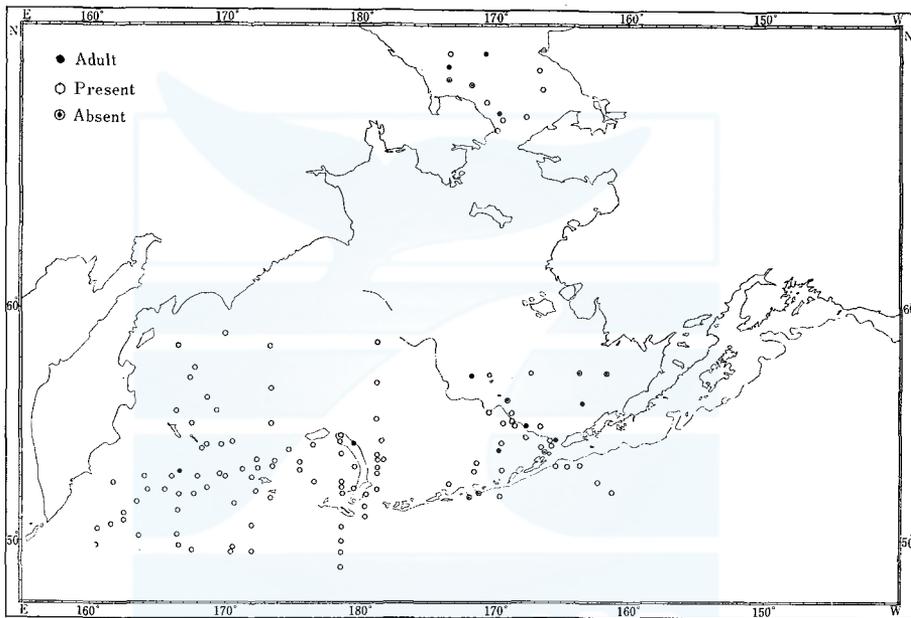


Fig. 6. The occurrences of *Calanus plumchrus* in the vertical plankton net in the surface strata above 150 m and 200 m in the Bering and Chukchi sea.

In the stomach contents of fin and sei whales caught, there has been no record of adult *Calanus plumchrs* not to say *Calanus cristatus*. It may be reasonable to consider that those baleen whales usually not to feed in the deeper waters where the adult *Calanus plumchrus* and *Calanus cristatus* are reproducing. The number of adult *Calanus plumchrus* sometimes amounts considerable number in the plankton net towed in the Alaskan shelf waters (Minoda, 1958). *Calanus plumchrus* has been collected in almost all stations in the Bering sea as stated above, but it has not occurred in 3 stations along the east Aleutian Islands, 3 stations in the Alaskan continental shelf and 2 stations in the Siberian side of the Chukchi sea. These waters are also shallower and the number of *Calanus plumchrus* is restricted by the environmental conditions.

BODY LENGTH VARIATION

The variations of body length of *Calanus plumchrus* and *C. cristatus* are discussed by Heinrich (1957). The materials collected in Whales Research Institute during 1952 to 1956 are measured, the positions of collections of which are also illustrated in Fig. 7.

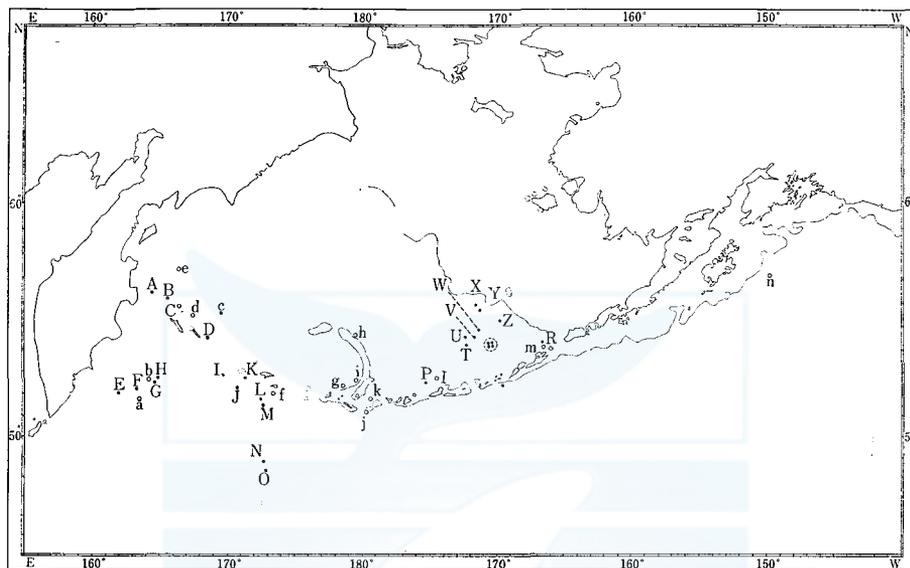


Fig. 7. Stations where *Calanus cristatus* and *C. plumchrus* have been collected in the Bering sea and adjacent waters to Aleutian islands. Black symbols and capitals—*C. cristatus*, Open symbols and *C. plumchrus*.

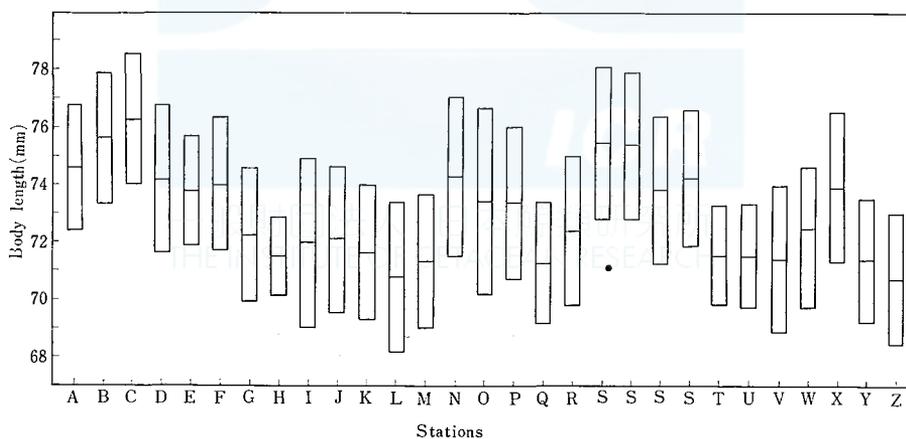


Fig. 8. Cephalothorax length of *C. cristatus* in the Bering sea and adjacent waters. Rectangles represent means, plus or minus two standard errors.

The average body length (cephalothorax length) of *Calanus cristatus* in copepodite stage 5 is plotted in Fig. 8 with two standard deviations. From the figures, it is

suggested that there are 4-5 size groups in the waters around the Aleutian Is. Off Kamtchka group, South-west Attu Is. group, North-east Aleutian Is. group, and Adjacent waters to Aleutian Is. groups are them. Following points are noticed from the illustration of the body length.

1) *Calanus cristatus* distribution in the off water of Kamtchatka Islands, has the character of cold water form and has larger body length. This may be attributable to the intermediate cold waters where *Calanus cristatus* develops from naupli to copepodite stage. In the very adjacent waters to stations E and F, the small sized *Calanus cristatus* occurs in G and H stations. This would suggest complicated oceanographic conditions in the waters where the Kamtchka shore waters, Aleutian current and waters from the south meet one another.

2) From I to M stations, *Calanus cristatus* shows also comparatively smaller values. As it is shown in Fig. 9, the water temperature in J-M waters is higher than the waters A-B, C-D and D-F.

3) The length of *C. cristatus* in N-O waters is larger than the specimens in J-M waters of the north. The reason may be attributable to the fact that those specimens of cold water origin come from Kamtchatkan side

4) *Calanus cristatus* collected in the water Q-R stations has the smaller body length and water temperature is higher as shown in Fig. 9. But station P has a rather larger size *Calanus cristatus* in spite of the lower water temperature than stations Q-R. This reverse correlations should be examined again in the further investigation.

5) In the north waters of the east Aleutian Islands stations T-Z, the intermediate cold waters do not so develop. The surface water temperature is also high and this tendency coincides with the small size of *Calanus cristatus* in these waters except stations X and S. It is interesting to note, further, the large sized *Calanus cristatus* specimens are found in the station S and X in the very neighbouring waters. *Calanus cristatus* in station S groups are collected from the stomachs of fin whales caught in the neighbouring waters.

Although plus and minus standard errors overlap one another as a series distribution from the west to the east, there are some correlations between the water temperature and body length of *Calanus cristatus*, as it has been established (Wiborg, 1954).

These groups of *Calanus cristatus* constitute fin whales feeding ground from spring to summer. And it has been observed that the prosperity of *Calanus cristatus* in each whaling grounds is different in every season.

When the relation between the body length of *Calanus cristatus* and water temperatures is examined, the water temperatures below 500 m depth do not show so much difference among stations. They are nearly constant values about 3°C at 800 m depth, however, the water temperatures at 300 m depth show lower values at the stations where the larger *Calanus cristatus* has been collected. The water temperatures at stations A-B. and E-F are lower than the values at J-M and T-X stations. It is more likely that if the development of *Calanus cristatus* affected by the intermediate cold waters in the Bering sea, then it is affected by the slight difference

of water temperatures at 300 m level. The intermediate cold water generally develops in the west waters of the Bering sea especially in the A-B and E-F areas.

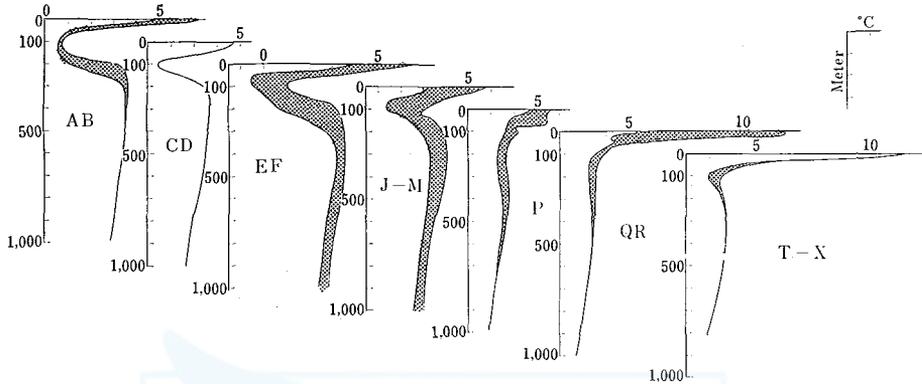


Fig. 9. Water temperature profile in the Bering sea and the adjacent waters. Alphabet shows the position in Fig. 7.

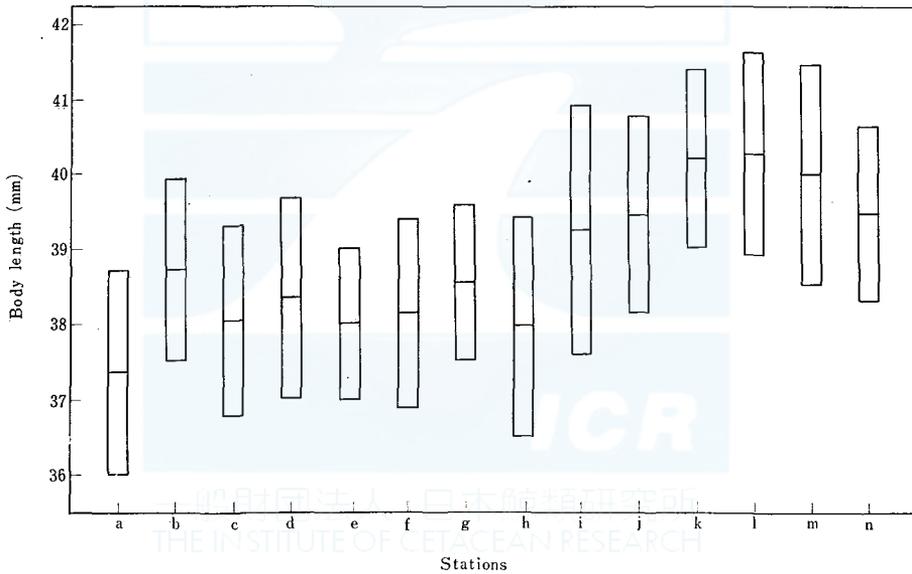


Fig. 10. Cephalothorax body length of *Calanus plumchrus* in the Bering sea and adjacent waters. Rectangles represent means, plus or minus two standard errors.

The body length of *Calanus cristatus* found in J-M stations is smaller than those in C-D stations, although the coldest point of intermediate cold waters is the nearly the same. In the stations Q-R and T-X where the small length *Calanus cristatus* is found, the intermediate cold water does not so develop. Further, the surface water temperature shows 10°C or more. The body length of copepodite stage 5 *Calanus plumchrus* in the collected specimens is illustrated in Fig. 10. The different body size in each *Calanus plumchrus* group is already discussed by Heinrich (1960).

According to his description, the cephalo-thorax length ranging 3.3 and 4.1 mm is obtained in the west Bering sea.

Calanus plumchrus specimens in the adjacent waters to the east Aleutian Islands and Kodiak Is. have rather large body size than the west groups in general. This tendency is attributable to the fact that the *Calanus plumchrus* treated here may be the second group in Heinrich's materials, which attains to their copepodite stage 5 in the summer when the surface water temperature is considered higher. They propagate and distribute in the surface in the western side of the Bering sea and constitute feeding grounds of sei whales in summer.

SWARM OF *CALANUS CRISTATUS* AND *C. PLUMCHRUS*

In the feeding ground of the Bering sea and its neighbouring waters, fin whales like *Calanus cristatus* as their food. But those fed on *Calanus plumchrus* are rather scarce in number when compared with other food taken. On the other hand, sei whales feed usually on *Calanus plumchrus* (Nemoto, 1959). It is reasonable to consider that two *Calanus* copepods have different attractions for fin and sei whales. Some examples of the weight of stomach contents found in fin and sei whales are given in Table 1. This table shows a fairly good correlation between weight of stomach contents and feeding quantity stage observed by naked eyes.

TABLE 1. THE WEIGHT OF COPEPODS CONTENTS
IN STOMACHS OF FIN WHALES

Species	Weight	Stage
<i>Calanus cristatus</i>	107 kg	rrr
	87 "	R
	75 "	rrr
	45 "	rr
	30 "	rr
	30 "	rr
	26 "	rr
	18 "	rr
<i>Calanus plumchrus</i>	72 "	R
	64 "	rrr
	25 "	r
<i>Metridia lucens</i>	16 "	rr
	80 "	rrr

Generally speaking, the quantity of *Calanus plumchrus* found in baleen whales is smaller than *Calanus cristatus*, which suggests the patch of *Calanus cristatus* is heavier than that of *Calanus plumchrus* in the sea. Fin whales usually take their food by swallowing method, which needs the food plankton patch to be in suitable density and mass in the sea. Of course, *Calanus plumchrus* also sometimes may make heavy swarms.

From the digestion stage of the stomach contents, it is considered the swarm of *Calanus cristatus* and euphausiids are sometimes swallowed instantaneously or successively in the short period. In the stomachs of baleen whales, *Calanus* copepods

sometimes have been found along with other euphausiid *Thysanoessa longipes*. *Calanus cristatus* is also found with *Thysanoessa inermis* and *Euphausia pacifica*, however, the number of occurrences is far small as given in Table 2. The shore living euphausiids *Thysanoessa raschii* and *T. spinifera* have scarcely been found with *Calanus cristatus*. It is attributable to the fact that the main distribution of *Calanus cristatus* has been restricted in the region of the sea where the bottom is deep as it is discussed in the former part. *Thysanoessa longipes* is only a off shore euphausiids in the north Pacific, the annual cycle of which has no relation to the shelf or the shallower sea. The possibility of the constituting mingled swarms of *Calanus cristatus* and *Thysanoessa longipes* is also probable.

TABLE 2. MIXED SWARM FORMATION IN *CALANUS* COPEPODS AND EUPHAUSIIDS IN THE BERING SEA AND ADJACENT WATERS

	Thysanoessa			Euphausia pacifica
	longipes	inermis	spinifera	
<i>Calanus cristatus</i>	38	10	—	3
<i>C. plumchrus</i>	3	1	1	—
<i>C. cristatus</i> & <i>C. plumchrus</i>	4	—	—	—

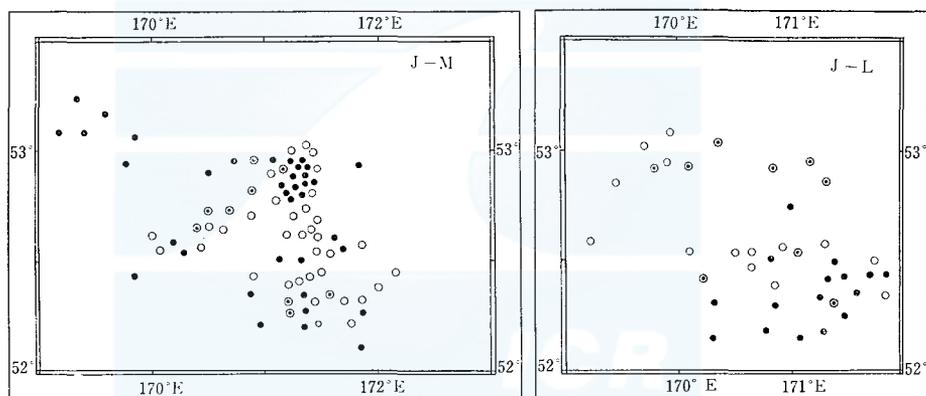


Fig. 11. Distribution of the foods of fin whales in the adjacent waters to Attu Is. in 1953. Black—*Calanus cristatus*, with dot—Euphausiids, Open—Vacant stomach.

On the other hand, few cases of *Calanus plumchrus* have been found in the stomachs of baleen whales as a mingled swarm with other euphausiid as given in Table 2. Only three cases of *Calanus plumchrus* are found in the stomachs of baleen whales along with *Thysanoessa longipes*, and each one case with *Thysanoessa inermis* and *T. spinifera* respectively.

As an example of the distribution of *Calanus cristatus* and euphausiids, the feeding chart of fin whales is given in Fig. 11, which shows the stations where fin whales caught with or without plankton contents in their stomachs in 1953. In the southwest waters of Attu Is. in 1953, the most part of fin whales had been feeding on *Calanus cristatus* by the first in July. In the middle of July, there are concentrations

of *Calanus cristatus* and euphausiids in certain areas from the distribution of the catch of fin whales with them in their stomachs. *Calanus cristatus* in the waters where the dominant occurrences of *Calanus cristatus* were observed in the middle had extincted in the late of July as shown in Fig. 11. The swarms of *Calanus cristatus* must have subsided down deeper waters for reproduction. The surface water temperature is considered to be the direct reason for the subsiding of *Calanus cristatus* in this case (Nemoto, 1959). The southern groups of *Calanus cristatus* appeared in the same waters still in the late of July as shown in Fig. 11. This would suggest that the subsiding of *Calanus cristatus* occurs successively by physical condition of *Calanus* and environmental factors.

SUMMARY

1. Based on the data of stomach contents of baleen whales and plankton nets, the distributions of *Calanus cristatus* and *C. plumchrus* are discussed. The probable correlation between the distribution of fin and sei whales in their feeding grounds and the distribution of *Calanus cristatus* and *C. plumchrus* is given. The main concentration of *Calanus cristatus* in spring and summer seasons of the Bering sea coincides with the feeding grounds of fin whales, and *Calanus plumchrus* with sei whales.

2. Adult specimens of both species have not been appeared in the stomachs of baleen whales as their food. Some occurrences of adult *C. plumchrus* in the net collections are observed mainly in the shallower waters of the Bering and Chukchi seas.

3. The cephalo-thorax body length of two *Calanus* is examined. The fairly close correlations between water temperature and body length are observed in *Calanus cristatus*, and the related body size groups are found in the neighbouring waters. But the different types of size groups are sometimes found in the very near position in the sea where the sea condition is rather complex.

4. *Calanus cristatus* sometimes may make mingled swarms with euphausiids *Thysanoessa longipes*, or *Calanus cristatus* which often distributes in the very near waters to the swarm of *Thysanoessa longipes*.

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STUDIES ON THE OIL OF BLACK RIGHT WHALE IN THE NORTHERN PACIFIC OCEAN

HIDEO TSUYUKI* AND UHEI NARUSE**

INTRODUCTION

A number of studies have been made in whale oil from olden time. However, the oil of black right whale, *Eubalaena glacialis*, has almost remained unexplored to this day. Because, our ancestors had caught a number of black right whales, so that we have all the world over been stopped to catch them for keeping of their resource.

The works studied on whale oils were chiefly concerned with its physical-chemical properties. But only a little work was made in the study of the oils contained in various parts of a whale body and component fatty acids. These works seems to be important from the view points of fat metabolism in whale bodies and the utilization of whale oils.

Regarding the differences in the characteristics of the oils contained in various parts of a whale body, Drs. M. Saiki and T. Mori¹⁾⁻³⁾, and Messrs. H. Watanabe and K. Suzuki^{4), 5)} studied several kinds of whales. Reviewing the works done on the black right whale oil, we have merely been reported by Dr. M. Saiki.⁶⁾ He studied the chemical characteristics of the oils contained in some blubbers of black right whale, which had been caught 102 miles 80° off "Kinkazan" (Miyagi prefecture in the north-eastern part of Japan) on 23rd May, 1956. However, this work was very simple, so that we can say that we have no sufficient work on the differences in the characteristics of the oils contained in various parts of a black right whale body. Further, as to the study on the component fatty acids of the black right whale oil, we have not been reported yet.

The writers were fortunate enough to obtain the oils in various blubbers, meats and viscera of three black right whales and examine their properties including component fatty acids.

The authors wish to express their thanks to the Whales Research Institute for presenting the experimental materials of three black right whales and for kind co-operation and assistance. They also wish to express their appreciation to President Dr. H. Ōmura, Dr. M. Nishiwaki, Mr. S. Ōsumi in the Whales Research Institute and Prof. Dr. A. Shionoya in Nihon University for their kind advices.

EXPERIMENTS AND RESULTS

I

The present experiment was carried out with three black right whales⁷⁾, which were

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caught in southern sea of Kodiak Island (N $55^{\circ}53' \sim 54'$, W $153^{\circ}4' \sim 6'$) on the 22nd August, 1961 by the "Kyokuyōmaru" Fleet (Fig. 1). Sex, presumptive age and body length of three whales are shown in Table 1.

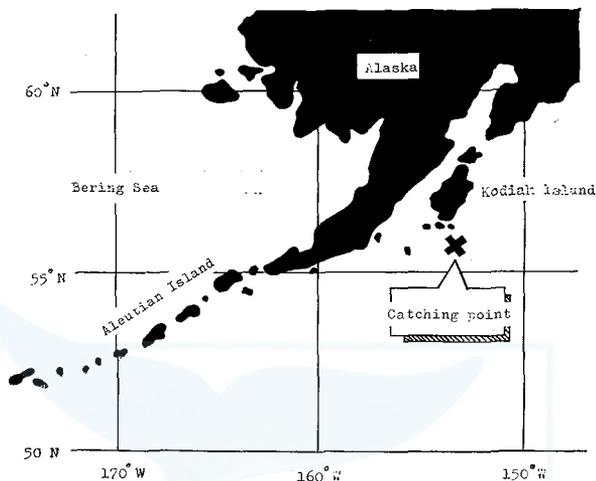


Fig. 1. Catching place of black right whale in the Northern Pacific Ocean

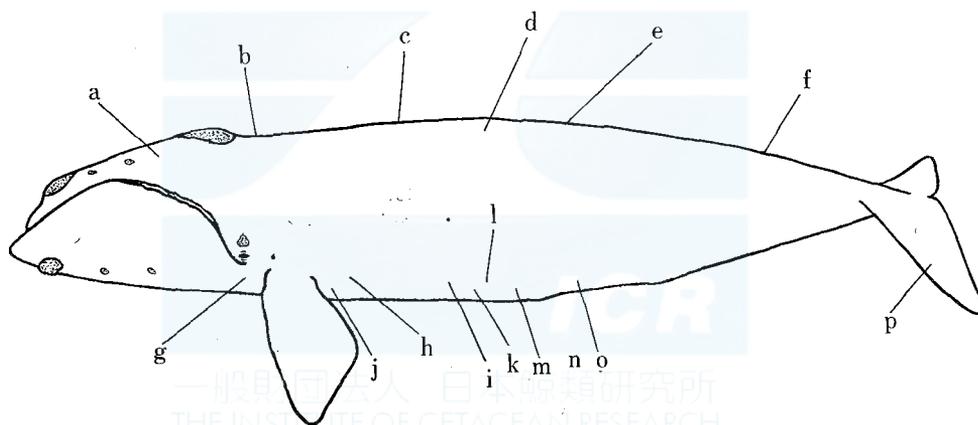


Fig. 2. Various blubbers and meats of black right whale

a) Brain blubber. b) Blow-hole blubber. c) Blubber of hind part of blow-hole. d) Back meat. e) Middle back blubber. f) Posterior back blubber. g) Blubber of "Dendō" in Japanese. h) Thoracic meat ("Munaita" in Japanese). i) Anterior abdominal blubber. j) Thoracic blubber. k) Umbilicus blubber. l) Abdominal blubber. m) Blubber of fore part of genital aperture. n) Genital aperture blubber. o) Anus blubber. p) Tail flukes blubber.

These whales were treated on the boat immediately after catching as follows: At first, they were dissected and divided into various meats, blubbers (Fig. 2) and organs. Each portion was immediately refrigerated at -20°C . Returning to port,

these materials described above were sent to the laboratory. In the laboratory, the oils contained in various blubbers were obtained by boiling these blubbers in water. On the other hand, the oils in various meats and organs were extracted with acetone in an atmosphere of nitrogen gas.

The specific gravity, refractive index, acid value, saponification value and unsaponifiable material content (%) of the obtained oils were measured in the usual manner and the iodine value was determined by the Wijs method. The results obtained are shown in Tables 2~10.

TABLE 1. DETAILS OF BLACK RIGHT WHALES,
EUBALAENA GLACIALIS

Whale No.	Sex	Presumptive age	Body length (m.)
A	Male	More than 12	17.1
B	Male	More than 12	17.0
C	Male	More than 9	15.1

TABLE 2. PROPERTIES OF THE OILS CONTAINED IN VARIOUS
BLUBBERS AND MEATS OF BLACK RIGHT WHALE A

Parts	Oil content (%)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Brain blubber	56.31	1.4765	0.9183	0.3	188.3	134.7	0.64
„	54.48	1.4715	0.9175	0.6	189.5	131.2	0.81
Blubber of hind part of blow-hole	55.57	1.4755	0.9216	0.1	194.1	125.9	0.84
„	57.95	1.4745	0.9230	0.2	193.6	123.7	0.79
Middle back meat	66.73	1.4745	0.9246	0.7	188.2	137.3	0.98
„	70.80	1.4735	0.9231	1.0	187.9	143.7	0.91
„	68.21	1.4760	0.9229	1.2	188.4	139.1	1.12
Posterior back meat	60.31	1.4706	0.9119	0.7	193.5	124.7	0.73
„	63.42	1.4745	0.9190	0.5	194.3	122.4	0.77
„	66.59	1.4735	0.9182	0.5	193.5	126.6	0.88
„	64.87	1.4725	0.9189	0.3	191.9	129.9	0.91
Thoracic meat	42.98	1.4740	0.9233	0.7	192.7	121.4	0.62
„	45.56	1.4723	0.9249	0.9	194.1	122.2	0.80
Anterior abdominal blubber	53.39	1.4751	0.9255	0.3	192.2	130.3	1.02
Abdominal blubber	54.99	1.4749	0.9243	0.7	191.9	126.3	0.89
„	52.19	1.4768	0.9259	0.5	191.7	130.6	1.27
Blubber of "Dendō"	38.61	1.4739	0.9218	0.4	191.4	126.1	0.94
„	35.62	1.4745	0.9239	0.5	190.9	128.3	0.97
Blubber of fore part of genital aperture	73.80	1.4745	0.9187	0.9	188.6	142.6	1.09
„	73.01	1.4740	0.9195	1.1	187.9	139.9	0.89
Tail flucks blubber	40.49	1.4755	0.9203	0.9	190.5	123.6	0.81
„	38.47	1.4704	0.9229	0.7	194.3	119.7	0.69
„	37.75	1.4713	0.9215	0.9	192.7	124.1	0.98
Back meat	0.68	1.4738	0.9259	1.9	190.8	128.0	1.15

TABLE 3. PROPERTIES OF THE OILS CONTAINED IN VARIOUS ORGANS OF BLACK RIGHT WHALE A

Parts	Oil content (%)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Tongue	30.71	1.4757	0.9241	0.2	195.1	116.2	1.08
Oesophagus	14.56	1.4735	0.9218	0.4	192.0	129.1	0.59
„	13.97	1.4746	0.9233	0.7	193.4	124.3	1.17
„	11.83	1.4720	0.9209	0.6	194.1	126.7	1.06
Lung	28.19	1.4745	0.9211	0.7	190.6	133.2	1.28
„	25.23	1.4715	0.9232	0.5	188.3	137.1	1.09
Stomach	7.89	1.4725	0.9189	0.6	193.2	123.2	1.03
„	8.46	1.4725	0.9197	0.7	193.6	125.6	1.21
Small intestine	8.03	1.4720	0.9208	0.8	187.9	138.1	1.32
„	7.61	1.4729	0.9221	0.9	189.2	135.9	1.18
Large intestine	3.06	1.4725	0.9233	0.8	190.4	127.8	1.10
Liver	10.41	1.4740	0.9219	1.5	190.5	129.4	1.72
Pancreas	9.37	1.4718	0.9203	0.5	190.9	128.7	1.31
„	8.76	1.4700	0.9218	0.6	192.5	127.2	1.09
„	7.91	1.4745	0.9226	0.8	194.1	123.7	1.22
Heart	2.48	1.4733	0.9191	1.1	193.6	124.1	1.48
Kidney	5.14	1.4740	0.9236	1.0	192.8	126.9	1.16
„	7.28	1.4725	0.9220	1.3	190.9	129.7	1.28
„	10.06	1.4700	0.9241	1.3	193.1	128.5	1.02
Testicle	8.13	1.4745	0.9251	2.2	196.0	116.7	1.33

TABLE 4. PROPERTIES OF THE OILS OF BLACK RIGHT WHALE A

Kind of oils	Oil contents (%)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Blubber oils (23 samples)	35.62	1.4704	0.9175	0.1	187.9	119.7	0.62
	73.80	1.4768	0.9259	1.2	194.3	143.7	1.27
Meat oil (1 sample)	0.68	1.4738	0.9259	1.9	190.8	128.0	1.15
Organ oils (20 samples)	2.48	1.4700	0.9189	0.2	187.9	116.2	0.95
	30.71	1.4757	0.9251	2.2	196.0	138.1	1.72

TABLE 5. PROPERTIES OF THE OILS CONTAINED IN VARIOUS BLUBBERS AND MEATS OF BLACK RIGHT WHALE B

Parts	Oil content (%)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Blubber of hind part of blow-hole	56.71	1.4735	0.9233	0.6	190.7	131.4	0.81
„	57.44	1.4735	0.9221	0.6	193.9	124.0	0.68
Middle back meat	66.36	1.4740	0.9197	1.0	187.3	137.9	0.77
Posterior back meat	64.39	1.4699	0.9208	0.4	191.9	123.5	0.55
Thoracic blubber	47.03	1.4745	0.9190	0.7	193.1	127.2	0.73
Anterior abdominal blubber	61.78	1.4715	0.9209	0.8	190.3	135.0	0.73
„	58.53	1.4762	0.9227	0.6	190.7	137.4	0.88
„	56.91	1.4745	0.9215	1.2	188.1	141.2	0.76
Abdominal blubber	53.43	1.4755	0.9188	1.0	189.5	137.2	0.82
„	56.22	1.4760	0.9201	1.4	187.8	142.1	0.95
Blubber of "Dendō"	36.11	1.4718	0.9239	0.4	189.8	134.5	0.78
Blubber of fore part of genital aperture	70.85	1.4753	0.9241	0.5	190.9	137.1	0.84
„	68.57	1.4725	0.9229	0.5	190.6	133.5	0.69
Tail flucks blubber	40.89	1.4697	0.9208	0.5	195.1	116.9	0.76
„	42.52	1.4743	0.9220	0.3	194.0	122.7	0.85
„	38.35	1.4701	0.9231	0.9	195.4	117.8	0.70
Back meat	0.93	1.4735	0.9190	1.2	193.5	126.3	0.99
Thoracic meat	0.83	1.4730	0.9222	0.9	190.9	130.5	1.16

TABLE 6. PROPERTIES OF THE OILS CONTAINED IN VARIOUS ORGANS OF BLACK RIGHT WHALE B

Parts	Oil content (%)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Tongue	31.85	1.4747	0.9208	1.0	194.0	113.3	1.06
Oesophagus	11.98	1.4769	0.9238	0.3	194.2	120.9	1.13
„	14.32	1.4748	0.9218	0.5	192.9	125.8	0.97
Stomach	7.42	1.4750	0.9238	0.8	191.4	129.9	1.31
„	6.55	1.4766	0.9245	0.9	191.1	125.6	1.24
Small intestine	8.02	1.4745	0.9229	0.6	187.3	143.2	1.40
Large intestine	5.88	1.4729	0.9201	0.4	193.5	126.2	1.52
„	6.31	1.4761	0.9227	0.7	193.1	123.2	1.30
„	6.95	1.4725	0.9191	0.3	192.7	122.3	1.44
Liver	10.49	1.4715	0.9233	1.7	191.8	127.6	1.66
Heart	2.82	1.4759	0.9227	0.7	192.2	127.1	1.79
Kidney	9.74	1.4750	0.9206	1.3	190.9	131.8	1.26
„	10.97	1.4761	0.9221	1.1	190.6	130.3	1.47
Testicle	7.92	1.4733	0.9209	1.5	194.9	120.2	1.23
Epididymis	4.41	1.4740	0.9211	0.7	196.4	116.4	1.44

TABLE 7. PROPERTIES OF THE OILS OF BLACK RIGHT WHALE B

Kind of oils	Oil content (%)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Blubber oils (16 samples)	36.11	1.4697	0.9188	0.3	187.3	116.9	0.55
	70.85	1.4762	0.9241	1.4	195.4	142.1	0.95
Meat oils (2 samples)	0.83	1.4730	0.9190	0.9	190.9	126.3	0.99
	0.93	1.4735	0.9222	1.2	193.5	130.5	1.16
Organ oils (15 samples)	2.82	1.4715	0.9191	0.3	187.3	113.3	0.97
	31.85	1.4769	0.9245	1.7	196.4	143.2	1.79

TABLE 8. PROPERTIES OF THE OILS CONTAINED IN VARIOUS BLUBBERS AND MEATS OF BLACK RIGHT WHALE C

Parts	Oil content (%)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Blubber of hind part of blow-hole	58.98	1.4735	0.9208	0.7	193.1	124.6	1.08
	55.66	1.4735	0.9219	0.3	192.8	122.4	0.89
Middle back meat	68.46	1.4760	0.9193	0.5	189.7	135.3	0.73
	65.33	1.4715	0.9180	0.8	189.4	133.3	1.11
	70.80	1.4720	0.9201	0.4	188.5	137.5	0.85
Posterior back meat	60.37	1.4765	0.9227	1.3	192.6	127.6	0.94
	64.78	1.4751	0.9205	1.7	193.2	129.1	0.78
Thoracic blubber	46.47	1.4740	0.9211	0.5	195.0	119.9	1.06
	45.69	1.4733	0.9203	0.4	193.7	124.6	0.81
	44.62	1.4722	0.9225	0.9	195.2	122.8	0.96
Anterior abdominal blubber	63.52	1.4749	0.9208	0.4	188.3	137.5	0.85
	60.31	1.4725	0.9223	0.4	190.4	133.2	0.97
Blubber of fore part of genital aperture	72.42	1.4743	0.9238	0.8	189.3	138.5	1.12
	70.97	1.4754	0.9225	0.6	188.5	136.2	0.79
	69.12	1.4736	0.9227	0.5	187.1	140.9	0.84
Tail flukes blubber	40.58	1.4753	0.9211	0.5	196.2	119.2	0.83
	44.42	1.4745	0.9206	0.4	194.1	125.0	0.97
	42.71	1.4740	0.9227	0.8	196.0	117.4	1.03
	39.53	1.4729	0.9201	0.9	193.9	123.6	0.69
Thoracic meat	0.80	1.4731	0.9192	0.9	190.6	133.1	1.28

TABLE 9. PROPERTIES OF THE OILS CONTAINED IN VARIOUS ORGANS OF BLACK RIGHT WHALE C

Parts	Oil content (%)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Oesophagus	13.07	1.4736	0.9197	0.6	193.7	125.9	1.11
„	12.39	1.4721	0.9208	0.8	192.9	128.4	1.02
Stomach	6.98	1.4744	0.9245	0.9	194.1	124.4	1.15
Large Intestine	7.21	1.4754	0.9233	0.5	191.0	129.5	1.37
„	7.98	1.4763	0.9221	0.7	190.7	131.5	1.19
„	6.18	1.4760	0.9246	0.9	191.5	127.3	1.30
Liver	11.52	1.4749	0.9208	0.5	190.2	134.9	1.82
„	13.73	1.4745	0.9227	0.8	189.9	131.5	1.48
„	11.04	1.4729	0.9236	0.6	190.6	132.4	1.68
Heart	2.87	1.4753	0.9196	1.2	194.6	122.2	1.56
„	2.36	1.4738	0.9209	1.0	192.9	120.8	1.39
Spine	4.03	1.4751	0.9248	0.7	194.6	122.9	1.61
Kidney	6.97	1.4740	0.9233	0.5	190.9	132.4	1.31
„	8.19	1.4754	0.9218	0.5	191.4	133.5	1.19
Bladder	12.88	1.4732	0.9228	0.3	194.1	125.3	0.73
Testicle	9.02	1.4762	0.9209	1.9	195.7	117.1	1.06
„	7.21	1.4738	0.9211	1.7	196.4	119.7	1.29
Epididymis	2.28	1.4761	0.9241	0.6	194.6	122.3	1.27

TABLE 10. PROPERTIES OF THE OILS OF BLACK RIGHT WHALE C

Kind of oils	Oil content (%)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Blubber oils (19 samples)	39.33	1.4715	0.9180	0.3	187.1	117.4	0.96
	72.42	1.4765	0.9255	1.7	196.2	140.9	1.12
Meat oil (1 sample)	0.80	1.4731	0.9192	0.9	190.6	133.1	1.28
Organ oils (18 samples)	2.36	1.4721	0.9196	0.3	189.9	117.1	0.73
	13.73	1.4763	0.9248	1.9	196.4	134.9	1.82

TABLE 11. PROPERTIES OF THE OIL CONTAINED IN MIDDLE BACK BLUBBER OF BLACK RIGHT WHALE C

Appearance (15°C.)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Light yellowish orange, opaque cohesive liquid	1.4760	0.9193	0.5	189.7	135.3	0.73

II

The oil contained in middle back blubber of the black right whale C (Table 1) was prepared by boiling the material with water and refined with a centrifugal separator. Chemical characteristics of the obtained oil are shown in Table 11.

Next, to some 200 g. of the sample oil was added 200 c.c. of absolute alcohol and further potassium hydroxide solution (KOH 87 g. and H₂O 148 c.c.) and heated in an atmosphere of nitrogen gas for two hours on a water bath, after which the majority of ethanol was distilled off and the resulting soap solution was cooled and diluted with water. It is preferable to risk the chance of slightly incomplete saponification rather than to incur the rearrangement of some of the highly unsaturated components. The unsaponifiable material was removed from the soap solution with ethyl-ether, and 190 g. of the conjugated fatty acids were recovered after decomposing the soap solution with 10% sulfuric acid solution.

180 g. of the mixed fatty acids (I.V. 148.3) thus recovered was subjected to the lead-salt alcohol separation method as modified by Hilditch,⁸⁾ whereupon 49.32 g. of solid fatty acids (I.V. 9.4) and 130.68 g. of liquid fatty acids (I.V. 199.2) were obtained.

120 g. of the liquid fatty acids was then subjected to the lithium-salt acetone separation method,⁹⁾ when 84.96 g. of lowly unsaturated fatty acids (I.V. 153.3) and 35.04 g. of highly unsaturated fatty acids (I.V. 305.5) were obtained.

Finally, the total mixed acids consist of 27.4% solid acids, 51.4% lowly unsaturated acids and 21.2% highly unsaturated acids.

Each group of the fatty acids (solid, lowly unsaturated and highly unsaturated) was separately converted into methyl esters by the usual method¹⁰⁾. Some properties of the fatty acids and methyl esters are shown in Table 12.

TABLE 12. PROPERTIES OF FATTY ACIDS AND THEIR METHYL ESTERS
(MIDDLE BACK BLUBBER OIL)

Fatty acids	%	Neuter. value	Iodine value	Methyl esters	
				Sapon. value	Iodine value
Mixed fatty acids	—	199.1	148.3	—	—
Solid fatty acids	27.4	205.9	9.4	196.1	8.5
Lowly unsaturated fatty acids	51.4	198.6	153.3	190.1	149.2
Highly unsaturated fatty acids	21.2	186.5	305.5	178.4	299.8

Each ester was fractionated as usual through E.H.P. column modified by Tsuyuki.¹¹⁾ The iodine value and saponification value of each of the subfractions of all the groups of methyl esters were determined in the usual manner. The most unsaturated fraction, HU, was taken up first without any loss of time, then the less unsaturated fraction LU, and lastly the least unsaturated fraction S. The ester-fractionation date, along with the saponification values and iodine values, are given in Tables 13~15.

The composition of each of the ester fractions was calculated from the saponification values and iodine values according to the method described by

Hilditch.¹²⁾ The mean unsaturation expressed as the fractional number of hydrogen atoms short of saturation, for example, -2.0 H (monoethenoid), was determined by the usual method. The component acids in three ester fractions are given in Table 16 along with the final fatty acids composition of the original oil calculated from these figures (Fig. 3).

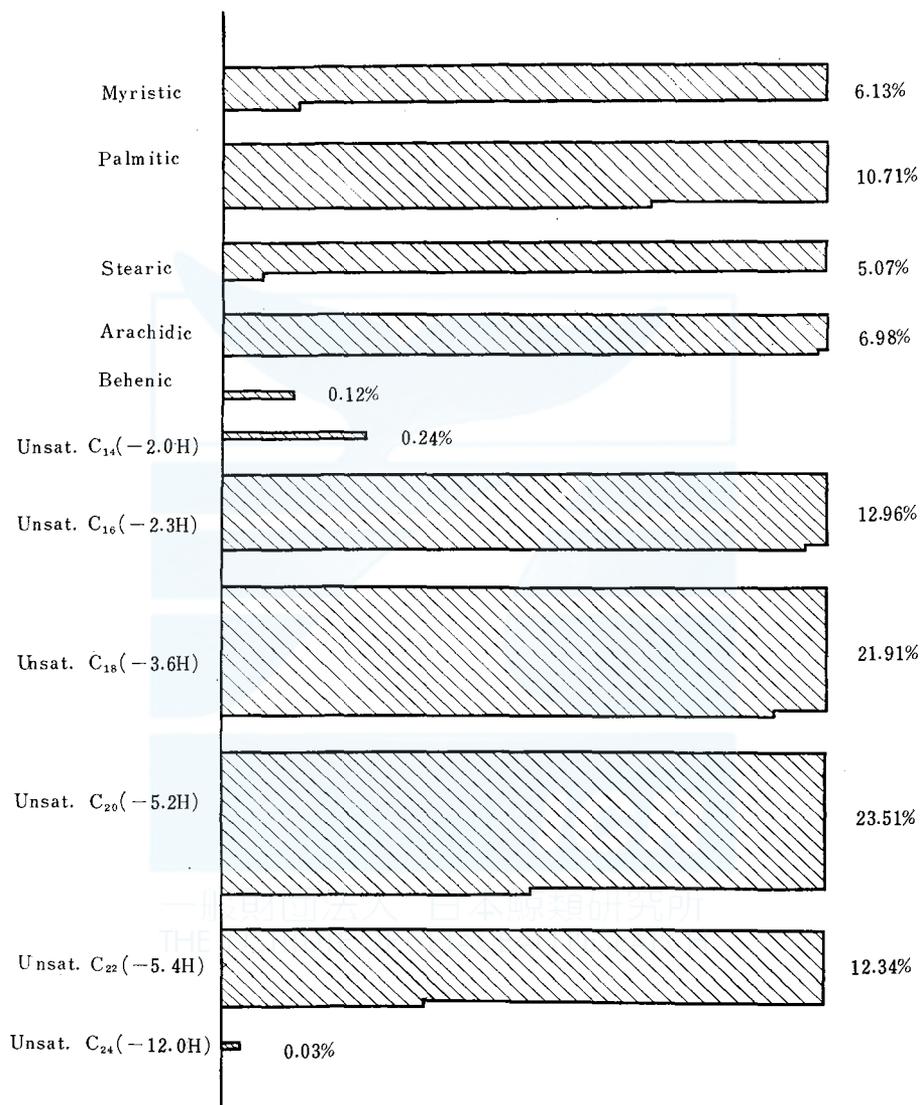


Fig. 3. Calculated composition of total acids in middle back blubber oil of black right whale C

III

The oil contained in spine of the black right whale C was extracted with acetone

in an atmosphere of nitrogen gas. Chemical properties of the obtained oil (acetone-soluble lipid) are given in Table 17.

TABLE 13. FRACTIONAL DISTILLATION OF METHYL ESTERS OF SOLID FATTY ACIDS

Fraction	g.	%	Boiling point (°C/3.5 mmHg)	Sapon. value	Iodine value
S—1	2.18	14.55	—148	218.7	0.6
S—2	2.03	13.51	148—154	212.4	1.5
S—3	2.17	14.52	154—160	208.5	2.7
S—4	2.29	15.23	160—170	193.1	3.8
S—5	1.86	12.42	170—190	185.3	7.9
S—6	1.74	11.59	190—195	179.7	10.8
S—7	1.83	12.16	195—	174.1	24.1
S—8	0.90	6.02	Residue	170.1	33.2
Total	15.00	100.00			

TABLE 14. FRACTIONAL DISTILLATION OF METHYL ESTERS OF LOWLY UNSATURATED FATTY ACIDS

Fraction	g.	%	Boiling point (°C/2mmHg)	Sapon. value	Iodine value
LU— 1	2.97	9.91	—146	212.3	79.7
LU— 2	2.82	9.41	146—154	208.7	92.2
LU— 3	2.05	6.82	154—156	199.4	114.4
LU— 4	3.13	10.43	156—158	197.5	135.5
LU— 5	3.53	11.75	158—160	192.2	148.2
LU— 6	2.84	9.46	160—163	188.8	160.8
LU— 7	2.52	8.40	163—166	185.1	168.1
LU— 8	2.72	9.06	166—171	179.4	176.3
LU— 9	1.79	9.30	171—175	176.5	182.8
LU—10	1.73	5.78	175—180	175.1	186.2
LU—11	1.34	4.47	180—185	172.4	189.2
LU—12	1.08	3.59	185—	170.2	193.4
LU—13	0.48	1.62	Residue	167.8	198.2
Total	30.00	100.00			

TABLE 15. FRACTIONAL DISTILLATION OF METHYL ESTERS OF HIGHLY UNSATURATED FATTY ACIDS

Fraction	g.	%	Boiling point (°C/1mmHg)	Sapon. value	Iodine value
HU—1	2.28	15.21	—175	199.2	232.1
HU—2	2.56	17.06	175—185	189.0	271.3
HU—3	3.87	25.81	185—192	174.1	298.7
HU—4	3.36	22.40	192—200	166.2	326.8
HU—5	1.53	10.21	200—207	165.5	356.5
HU—6	0.90	5.98	207—	163.4	388.1
HU—7	0.50	3.30	Residue	162.2	235.4
Total	15.00	100.00			

TABLE 16. COMPOSITION OF FATTY ACIDS OF MIDDLE BACK BLUBBER OIL OF BLACK RIGHT WHALE C

Acids	Solid fatty acids (27.40%)	Lowly unsaturated fatty acids (51.40%)	Highly unsaturated fatty acids (21.20%)	Total (100%)
Saturated acid :				29.01
Myristic	2.17	3.96	—	6.13
Palmitic	10.38	0.33	—	10.71
Stearic	4.80	0.27	—	5.07
Arachidic	6.98	—	—	6.98
Behenic	0.12	—	—	0.12
Unsaturated acids :				70.99
C ₁₄	—	0.24(-2.0H)	—	0.24(- 2.0H)
C ₁₆	0.24(-2.0H)	11.57(-2.2H)	1.15(-2.7H)	12.96(- 2.3H)
C ₁₈	0.55(-2.0)	16.66(-4.0H)	4.70(-5.7H)	21.91(- 3.6H)
C ₂₀	2.01(-2.0H)	15.61(-4.2H)	5.89(-7.9H)	23.51(- 5.2H)
C ₂₂	0.51(-2.0H)	2.76(-5.6H)	9.43(-9.1H)	12.34(- 5.4H)
C ₂₄	—	—	0.03(-12.0H)	0.03(-12.0H)

TABLE 17. PROPERTIES OF THE OIL CONTAINED IN SPINE OF BLACK RIGHT WHALE C

Appearance (15°C)	n_D^{20}	d_4^{15}	Acid value	Sapon. value	Iodine value	Unsapon. material content(%)
Light brownish yellow, non-opaque cohesive liquid	1.4751	0.9248	0.7	194.6	122.9	1.61

To the same oil was added a minimum quantity of potassium hydroxide (44 g. per 100 g. of the oil) dissolved in alcohol solution (absolute alcohol 100 c.c. and H₂O 80 c.c. per 100 g. of the oil) and heated for two hours on a water bath, after which nearly 80% of alcohol was distilled off and the resulting soap solution was cooled and diluted with water. The unsaponifiable material was removed from the soap solution with ethyl-ether, and the mixed fatty acids were recovered after decomposing the soap solution with 10% sulfuric acid solution. The mixed acids obtained were resolved into different fractions according to varying degrees of unsaturation, first by the lead-salt alcohol method modified by Hilditch,⁸⁾ and then by the lithium-salt acetone method.⁹⁾

Finally, three groups of the fatty acids (solid, lowly unsaturated, highly unsaturated acids) were obtained. The total fatty acids consist of 30% solid acids, 46.8% lowly unsaturated acids and 23.2% highly unsaturated acids. Each group of the fatty acids was separately converted into methyl esters taking the precautions suggested by Hilditch.¹⁰⁾ Some characteristics of the fatty acids and their methyl esters are summarized in Table 18.

Each group of the methyl esters was fractionated through the same column¹¹⁾ as described in II. The iodine value and saponification value of each of the subfractions were determined, and the data are given in Table 19~21.

The composition of each of the ester fractions was calculated from the saponifi-

TABLE 18. PROPERTIES OF FATTY ACIDS AND THEIR METHYL ESTERS (SPINE OIL)

Acids	%	Neutr. value	Iodine value	Methyl ester	
				Sapon. value	Iodine value
Mixed fatty acids	—	203.2	136.2	—	—
Solid fatty acids	30.0	214.4	8.3	203.1	7.6
Lowly unsaturated fatty acids	46.8	200.3	132.1	191.4	127.8
Highly Unsaturated fatty acids	23.2	188.7	300.6	180.4	295.1

cation values and iodine values by the method of Hilditch.¹²⁾ The component acids in the ester fractions are shown in Table 22 along with the composition of the original oil calculated from these figures (Fig. 4).

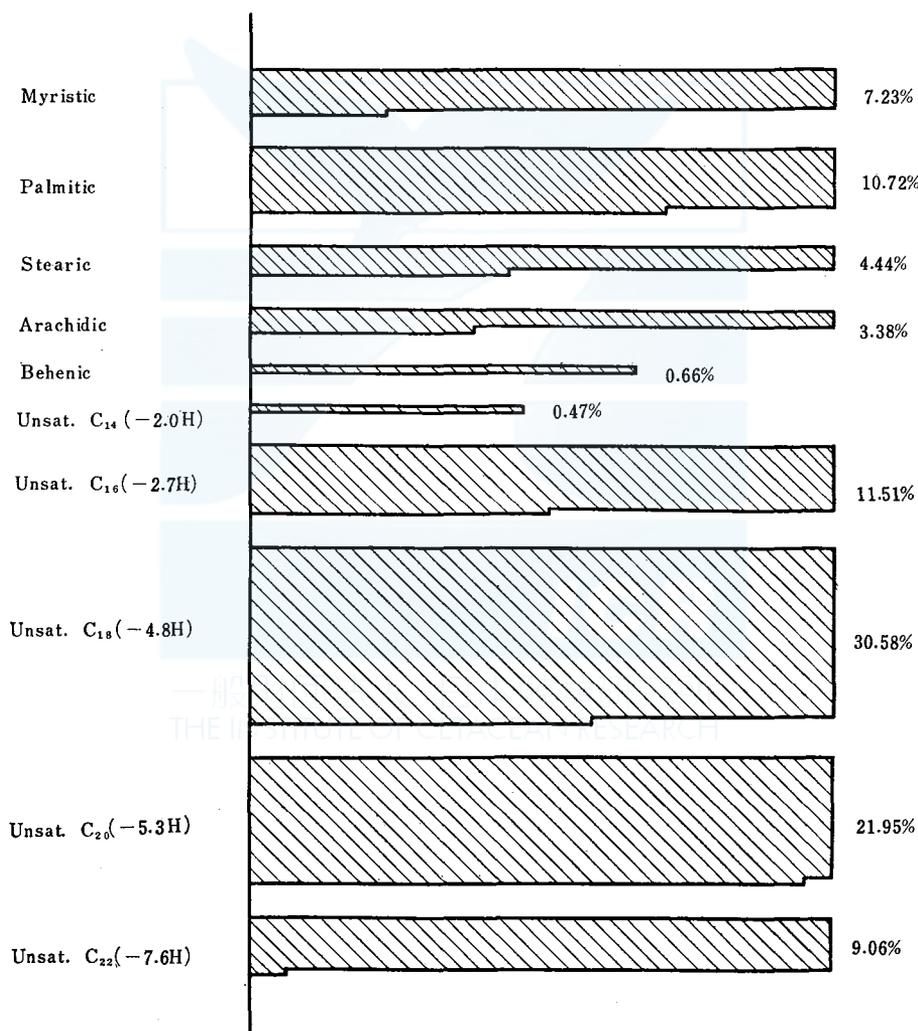


Fig. 4. Calculated composition of total acids in spine oil of black right whale C

DISCUSSION

The properties of some blubber oils of a black right whale caught in 1956 were studied by Dr. Saiki⁶⁾ and the results are shown in Table 23. The differences between the Saiki's results and the writer's results in this work on the properties of the blubber oils of the black right whale are not clear.

The properties of various baleen whale oils studied by many workers are shown in Table 24 in order to discuss the differences in the properties of the black right whale oil and other baleen whale oils.

From Table 2~10, in the properties of the oils contained in the black right whale bodies, the individual difference can not be found clearly. The reason seems to be due to that the above three whales are almost same not only in sex but also in living circumstance and age. The differences in the properties of the oils contained in various parts of each whale body were comparatively clear, but the regularities can't be observed in this differences.

TABLE 19. FRACTIONAL DISTILLATION OF METHYL ESTERS OF SOLID FATTY ACIDS (SPINE OIL)

Fractions	g.	%	Boiling point (°C/3.5mmHg)	Sapon. value	Iodine value
S-1	2.42	16.12	-147	227.1	0.4
S-2	2.57	17.13	147-153	223.4	1.2
S-3	3.02	20.16	153-165	216.7	3.0
S-4	2.43	16.22	165-180	194.3	5.3
S-5	2.40	16.01	180-196	181.6	11.6
S-6	1.55	10.31	196-	175.9	20.8
S-7	0.61	4.05	Residue	168.2	32.6
Total	15.00	100.00			

TABLE 20. FRACTIONAL DISTILLATION OF METHYL ESTERS OF LOWLY UNSATURATED FATTY ACIDS (SPINE OIL)

Fractions	g.	%	Boiling point (°C/2mmHg)	Sapon. value	Iodine value
LU- 1	2.61	8.69	-145	212.9	63.2
LU- 2	2.84	9.48	145-155	209.3	77.9
LU- 3	3.17	10.56	155-160	199.7	94.8
LU- 4	3.30	11.02	160-164	194.5	112.2
LU- 5	3.64	12.14	164-168	190.9	131.5
LU- 6	4.01	13.35	168-172	187.8	142.1
LU- 7	2.91	9.70	172-177	183.0	157.6
LU- 8	1.87	6.23	177-182	178.9	162.9
LU- 9	2.47	8.23	182-187	177.6	166.8
LU-10	2.55	8.49	187-	174.7	170.3
LU-11	0.63	2.11	Residue	170.3	174.5
Total	30.00	100.00			

TABLE 21. FRACTIONAL DISTILLATION OF METHYL ESTERS OF HIGHLY UNSATURATED FATTY ACIDS (SPINE OIL)

Fractions	g.	%	Boiling point (°C/1mmHg)	Sapon. value	Iodine value
HU—1	2.12	14.15	—180	203.4	212.3
HU—2	1.98	13.17	180—190	191.6	265.3
HU—3	3.01	20.04	190—200	181.0	310.1
HU—4	4.68	31.21	200—210	171.1	339.5
HU—5	1.90	12.68	210—	170.7	362.2
HU—6	1.31	8.75	Residue	168.3	206.7
Total	15.00	100.00			

TABLE 22. COMPOSITION OF FATTY ACIDS OF SPINE OIL OF BLACK RIGHT WHALE C

Acids	Solid fatty acids (30.0%)	Lowly unsaturat- ed fatty acids (46.8%)	Highly unsaturat- ed fatty acids (23.2%)	Total (100%)
Saturated acids:				26.43
Myristic	6.82	0.41	—	7.23
Palmitic	8.82	1.90	—	10.72
Stearic	3.16	1.28	—	4.44
Arachidic	3.38	—	—	3.38
Behenic	0.66	—	—	0.66
Unsaturated acids:				73.57
C ₁₄	—	0.47(-2.0H)	—	0.47(-2.0H)
C ₁₆	2.28	8.27(-2.0H)	0.36(-3.6H)	11.51(-2.7H)
C ₁₈	2.76	21.21(-4.3H)	6.61(-6.1H)	30.58(-4.8H)
C ₂₀	1.36	11.64(-4.6H)	8.95(-8.3H)	21.95(-5.3H)
C ₂₂	0.62	1.62(-7.6H)	7.28(-9.0H)	9.06(-7.6H)

TABLE 23. PROPERTIES OF BLUBBER OILS OF BLACK RIGHT WHALE
(Dr. M. Saiki)

Part	Oil content (%)	Acid value	Sapon. value	Iodine value	Unsapon. material content (%)
Anterior abdominal blubber	60.6	0.98	189.7	141.2	0.68
Abdominal blubber	54.3	1.90	191.3	129.2	0.83
Middle back blubber	69.7	0.94	190.5	140.9	0.81
Blubber of fore part of genital aperture	74.1	0.61	187.9	142.7	1.23
Posterior back blubber	65.1	0.86	187.1	138.8	0.80
Umbilicus blubber	59.4	1.01	189.0	130.9	0.85
	54.3	0.61	187.1	129.2	0.68
Range	74.1	1.90	191.8	142.7	1.23

TABLE 24. PROPERTIES OF VARIOUS BALEEN WHALE OILS

Kind of oils	d_{4}^{20}	n_D^{20}	Acid value	Sapon. value	Iodine value	Unapon. material content (%)	Remark
Black right whale							
Blubber oil	0.9175~0.9259	1.4697~1.4768	0.1~1.7	187.1~169.2	116.9~143.7	0.55~1.27	
Meat oil	0.9190~0.9259	1.4730~1.4738	0.9~1.9	190.6~193.5	126.3~133.1	0.99~1.28	Tsuyuki, Naruse,
Viscerous oil	0.9189~0.9251	1.4700~1.4769	0.2~2.2	187.3~196.4	113.3~143.2	0.73~1.82	
Bone oil			0.6~1.0	187.1~191.8	129.2~142.7	0.68~1.23	Saiki
Fin whale							
Blubber oil	0.9137~0.9236	1.4705~1.4769	0.4~4.5	190.3~200.0	95.2~155.8	0.32~1.98	
Tongue oil	0.9200~0.9222	1.4711~1.4750	0.5~1.2	193.3~200.7	93.6~110.7		Toyama, Uozaki
Viscerous oil	0.9225~0.9250	1.4736~1.4761	0.5~0.9	191.5~200.0	109.2~134.3		Tsujimoto, Tamimura
Bone oil	0.9150~0.9219	1.4694~1.4724	0.6~5.0	195.1~200.0	82.7~110.0		Saiki <i>et al</i>
Blue whale							
Blubber oil	0.9208~0.9222	1.4700~1.4726	0.5~2.1	192.8~200.0	100.0~110.0	1.0~2.0	
Tongue oil	0.9200~0.9260	1.4700~1.4800	0.5~1.0	190.0~195.2	100.0~110.0	1.0~2.0	
Viscerous oil	0.9200~0.9265	1.4685~1.4750	0.8~5.0	190.0~195.0	68.0~110.0	1.0~2.0	
Bone oil	0.9250~0.9254	1.4700~1.4727	0.4~1.0	190.0~195.0	100.0~110.0		Tsujimoto
Meat oil		1.4648	0.4	194.3	122.3		Ueno, Iwai <i>et al</i>
Head blubber oil		1.4640	0.4	198.2	116.3		
Humpback whale							
Blubber oil	0.9154~0.9234	1.4690~1.4772	0.3~1.5	183.5~195.2	100.0~159.4	0.31~1.09	
Meat oil		1.4763	0.7	195.5	134.1	0.68	Ueno, Iwai
Viscerous oil	0.9200~0.9217	1.4650~1.4737	0.3~5.0	190.0~195.2	113.5~126.4	1.00 2.00	Tsujimoto
Tongue oil	0.9175~0.9200	1.4700~1.4706	0.2~1.0	189.2~190.0	90.0~100.0		Toyama, Uozaki <i>et al</i>
Bone oil	0.9176~0.9251	1.4700~1.4735	0.5~6.1	187.7~192.9	98.9~110.0	1.00~2.00	
Head blubber oil		1.4663	0.3	195.5	130.7	0.89	
Sei whale							
Blubber oil	0.9150~0.9250	1.4700~1.4785	0.2~3.3	181.5~193.1	115.0~161.5	0.56~2.70	Ueno, Tamimura
Tongue oil	0.9150~0.9211	1.4700~1.4735	0.5~2.0	190.0~200.0	90.6~115.0	1.00~2.00	Toyama, Uozaki
Bone oil	0.9202~0.9400	1.4737~1.4753	11.3~16.4	190.0~200.0	108.3~121.7	1.00~2.00	Saiki <i>et al</i>
Viscerous oil	0.9250~0.9276	1.4700~1.4702	0.5~5.0	190.0~190.7	90.0~90.7	1.00~2.00	
Grey whale							
Blubber oil	0.9250~0.9280	1.4767~1.4800	0.5~3.0	190.0~192.7	134.2~150.0	1.86~2.00	Ueno <i>et al</i>
Viscerous oil	0.9300~0.9330	1.4780~1.4800	0.5~5.0	190.0~195.9	140.0~155.0	1.00~2.00	
Bone oil	0.9300~0.9350	1.4750~1.4800	0.5~7.0	190.0~195.0	130.0~150.0	1.00~2.00	

Appearance Color of the black right whale oils, generally, was dark and light yellow, or dark and light yellowish orange. However, color of the viscera oils rarely was brown or brownish red. Color of the blubber oils is more fainter than that of the viscera oils. The viscosity of the sample oils is different accordingly to the parts of the whale body.

Oil content Oil content in the blubbers is very high. For example, the oil content in the blubber of "Dendō" of the whale A is the lowest (32.62%), whilst that in the blubber of fore part of genital aperture of the whale A is the highest (73.80%). The oil content in the back blubber and in the blubber of fore part of genital aperture is comparatively high with the range of 60~70%. On the contrary, the oil content in the thoracic blubber, "Dendō" blubber and tail flukes blubber is rather low with about 40%, respectively. The oil content in the back meat and thoracic meat is very low with the range of 0.68~0.93%, though many material meats were not obtained. The oil content in the viscera is lower than that in the blubbers, but higher than that in the meats. For example, the oil content in the heart of the whale C is 2.36% and that in the tongue of the whale B is 31.85%. The oil content in the lung and tongue is comparatively high with the range of 25~30%, whilst the oil content in the heart is about 2% and that in the epididymis and spine is 3~4% respectively and that in these three samples is very low.

Refractive index Refractive index of various black right whale oils is different accordingly to the parts of the whale body. However, the regularity is unable to be seen in the difference of refractive index of various sample oils. Observing the refractive index of the sample oils at 20°C, that of the blubber oils is from 1.4697 to 1.4768, that of the meat oils is from 1.4730 to 1.4738 and that of the viscera oil from 1.4700 to 1.4760.

Specific gravity Specific gravity of the sample oils is different with the parts of the whale body. But the writers can't find the regularities in the difference of specific gravity of the sample oils. Observing the specific gravity of the sample oils at 15°C, the range of specific gravity is from 0.9175 to 0.9259 in the case of the blubber oils, 0.9190 to 0.9259 in that of the meat oils and 0.9189 to 0.9251 in that of the viscera oils.

Acid value Acid value of the sample oils is generally low, being considered to be from 0.1 to 1.7 in the case of the blubber oils, 0.9 to 1.9 in that of the meat oils and 0.2 to 2.2 in that of the viscera oils. If the authors dare to discuss the difference in the acid value of the sample oils, the acid value of the former oil is lower than that of the latter two oils. The reason why the acid value of the sample oils is generally low seems to be as follows: As the materials had been refrigerated in the range of -20~-30°C., the decomposition of the oils in the materials with lipase and the rancidity of the oils in the materials with oxygen had not almost been

happened.

Saponification value The authors can not find the regularity in the differences of the saponification values of the blubber oils, meat oils and viscera oils. The saponification value is 187.1 to 196.2 in the case of the blubber oils, 190.6 to 193.5 in that of the meat oils and 187.3 to 196.4 in that of the viscera oils.

Iodine value The writers can not find the regularity in the differences of the iodine values of the blubber oils, meat oils and viscera oils. The iodine value is in the range of 113.9~143.7 in the case of the blubber oils, 126.3~133.3 in that of the meat oils and 113.3~143.2 in that of the viscera oils. If the authors dare to discuss the differences in these iodine values, the blubber oils with lower iodine value were the tail flukes blubber oil (117~125), posterior back blubber oil (122~130) and thoracic blubber oil (120~125). The viscera oils with lower iodine value were testicle oil (110~120), epididymis oil (116~122), stomach oil (123~130) and tongue oil (113~116). Whilst the blubber oils with higher iodine value were the middle back blubber oil (133~144), anterior abdominal blubber oil (130~141) and the blubber oil of fore part of genital aperture (134~143). The viscera oils with higher iodine value were the small intestine oil (136~143) and lung oil (133~137).

Unsaponifiable material content As to the unsaponifiable material content (%) in the black right whale oil, that of the blubber oils were 0.55 to 1.27, meat oils 0.99 to 1.28% and viscera oils 0.73 to 1.83%. If the authors dare to discuss the differences in the unsaponifiable material content of various sample oils, the content of the blubber oils is lower than that of the meat oils and viscera oils. Considering of the unsaponifiable material content, it seems that the content of the black right whale oil is essentially different with that of the toothed whale oil such as the sperm whale oil and is similar to the baleen whale oil such as the fin whale oil. The relation of the characteristics of the black right whale oil and those of other baleen whale oils are shown in Table 24. Being shown in Table 24, the unsaturation of the oil of the black right whale caught in the Northern Pacific Ocean seems to be higher than that of the oils of the fin whale, blue whale, humpback whale and sei whale caught in the Antarctic Ocean. Because, the unsaturation of the oil contained in *Calanus*¹³⁾ which is the diet of whales in the Northern Pacific Ocean is higher than that of the oil contained in *Euphausiacea* which is the diet of whales in the Antarctic Ocean. Dr. Saiki¹³⁾ had mentioned that the difference between the unsaturation of the oils of the whales in the Northern Pacific Ocean and that of the oils of the whales in the Antarctic Ocean seems to be due to the diet. The authors also think that the diet of the whale effects to the characteristics of the whale oils. The unsaturation of the black right whale oil seems to be higher than that of other baleen whale oils, but is lower than that of the grey whale oil.

Saponification value of the black right whale oil is lower than that of the fin whale oil and blue whale oil, and is near to that of the humpback whale oil and

grey whale oil.

The unsaponifiable material content in the black right whale oil is near to that in the fin whale oil and humpback whale oil, and is lower than that of the blue whale oil, sei whale oil and grey whale oil.

That the acid value of the sample oils in the present work is generally lower, seems to depend on that the rancidity of the oil with oxygen and decomposition of the oils with lipase had hardly been occurred because of keeping the materials in such low temperature as $-20\sim-30^{\circ}\text{C}$.

Component fatty acids The two sample oils, the middle back blubber oil and the spine oil, from the black right whale C, had iodine values 135.3 and 122.9, respectively. This difference in their unsaturation is somewhat clear when the writers compare the component fatty acids of the two oils (Tables 16 and 22).

The fatty acid composition of the middle back blubber oil is shown in Table 16 and Fig. 3. It is noticed that the total saturated fatty acid content is 29.01% (myristic acid $\text{C}_{13}\text{H}_{27}\text{COOH}$: 6.13%, palmitic acid $\text{C}_{15}\text{H}_{31}\text{COOH}$: 10.71%, stearic acid $\text{C}_{17}\text{H}_{35}\text{COOH}$: 5.07%, arachidic acid $\text{C}_{19}\text{H}_{39}\text{COOH}$: 6.98%, behenic acid $\text{C}_{21}\text{H}_{43}\text{COOH}$: 0.12%) of the total. The unsaturated fatty acid content is 70.99% (C_{14} acids: 0.24%, C_{16} acids: 12.96%, C_{18} acids: 21.91%, C_{20} acids: 23.51%, C_{22} acids: 12.34%, C_{24} acid: 0.03%) of the total. In this case, the degree of unsaturation are as follows: C_{14} acid: -2.0H , C_{16} acids: -2.3H , C_{18} acids: -3.6H , C_{20} acids: -5.2H , C_{22} acids: -5.4H , C_{24} acid: -12.0H . The chief component acids belong to the unsaturated C_{20} series (23.51%), the next most prominent are those of the unsaturated C_{18} series (21.91%), unsaturated C_{16} series (12.96%), unsaturated C_{22} series (12.34%) and palmitic acid (10.71%). Whilst the saturated acids including myristic (6.13%), stearic (5.07%) and arachidic (6.98%) are present in somewhat lower proportions. Behenic acid (0.12%), unsaturated C_{14} acid (0.24%) and unsaturated C_{24} acids (0.03%) are trace.

On the other hand, the fatty acid composition of the spine oil is given in Table 22 and Fig. 4. It is noticed that the total saturated fatty acid content is 26.43% (myristic acid: 7.23%, palmitic acid: 10.72%, stearic acids: 4.44%, arachidic acid: 3.38%, behenic acid: 0.66%) of the total. The unsaturated counterpart is 73.57% (C_{14} acid (-2.0H): 0.47%, C_{16} series (-2.7H): 11.51%, C_{18} series (-4.8H): 30.58%, C_{20} series (-5.3H): 21.95%, C_{22} series (-7.6H): 9.06%) of the total. The component acids of the spine oil studied by the writers show the following tendency: The chief component acids belong to the unsaturated C_{18} series (more than 30%) and the next prominent is the unsaturated C_{20} series (about 22%). The next component acids are those of the unsaturated C_{16} series (11.51%), palmitic acid (10.72%), the unsaturated C_{22} series (9.06%) and myristic acid (7.23%), whilst the saturated acids such as stearic and arachidic are 3~5% respectively and behenic acid is less than 1%.

The saturated fatty acid content (%) was lower in the case of the spine oil

than in that of the middle back blubber oil, and on the other hand the unsaturated acid content (%) was higher in the case of the former oil than in that of the latter oil. However, the highly unsaturated fatty acid content was rather lower in the case of the former oil than in that of the latter oil. Therefore, the former oil seems to contain a large amount of the lowly unsaturated fatty acids consisted mainly of C_{18} series. In the case of the spine oil, the total of the unsaturated C_{18} series (more than 30%) and C_{20} series (about 22%) is nearly 52%. Whilst in the case of the middle back blubber oil, the total of the unsaturated C_{20} series (about 24%) and C_{18} series (about 22%) is about 46%. It is remarkable that the content (%) of the unsaturated C_{18} series which is the main component acid of the spine oil is very high (more than 30%). In spite of that the middle back blubber oil contains the unsaturated C_{24} acid ($-12.0H$) trace, the spine oil seems to not contain the unsaturated C_{24} series at all.

Considering that the saturated fatty acid content in the fish oils is generally about 20%, that in the black right whale oil is about 30% and nearly 10% higher than that in the fish oils. Generally, in the case of the component fatty acids of the fish oils, the content (%) of the unsaturated C_{22} and C_{24} series are respectively rather high. Therefore, comparing the component fatty acids of the black right whale oil with those of the fish oils, it seems that the unsaturated C_{22} series content is somewhat lower and the unsaturated C_{24} series content is much lower in the case of the former oil than in that of the latter oil.

Reviwing the report (Drs. Saiki and Mori¹³) studied on the component fatty acids of the oil contained in *Calanus cristatus* obtained from the stomach of the fin whale caught in the Northern Pacific Ocean, it was noticed that the total saturated fatty acid content is about 16% (myristic: 9%, palmitic: 7%, stearic: trace) and the total unsaturated fatty acid content is about 84% ($C_{14}(-2.0H)$ acid: 3%, $C_{16}(-2.2H)$ series: 10%, $C_{18}(-4.7H)$ series: 14%, $C_{20}(-4.2H)$ series: 29%, C_{22} (more than $-4.2H$) series: 38%). From the result mentioned above, it is notable that the saturated fatty acid content is only 16%. *Calanus plumchrus*⁷⁾ was contained in the stomach of three black right whales in this work. The authors presume that the properties of the oil contained in *Calanus plumchrus* are near to the properties of *Calanus cristatus* oil. Thinking that the component fatty acids of the black right whale oil contain 30% saturated acids, it seems that the saturated acids are contained in larger amount in the case of the black right whale oil than in that of *Calanus plumchrus* oil.

SUMMARY

1) Chemical properties of the oils contained in various parts of three black right whales, *Eubalaena glacialis*, caught in the Northern Pacific Ocean were studied. The results obtained are as follows:

[Blubber oil] d_{4}^{15} : 0.9175~0.9259, n_D^{20} : 1.4697~1.4768, Acid value: 0.1~1.7, Saponification value: 187.1~196.2, Iodine value: 116.9~143.7, Unsaponifiable material content: 0.55~1.27%.

[**Meat oil**] d_{4}^{15} : 0.9190~0.9259, n_D^{20} : 1.5730~1.4738, Acid value: 0.9~1.9, Saponification value: 190.6~193.5, Unsaponifiable material content: 0.99~1.28%.

[**Viscera oil**] d_{4}^{15} : 0.9189~0.9251, n_D^{20} : 1.4700~1.4769, Acid value: 0.2~2.2, Saponification value: 187.3~196.4, Iodine value: 113~143.2, Unsaponifiable material content: 0.73~1.82%.

2) Middle back blubber oil from the black right whale contains 29.01% saturated fatty acids (myristic: 6.13%, palmitic: 10.71%, stearic: 5.07%, arachidic: 6.98%, behenic: 0.12%) and 70.99% unsaturated fatty acids { $C_{14}(-2.0H)$: 0.24%, $C_{16}(-2.3H)$: 12.96%, $C_{18}(-3.6H)$: 21.91%, $C_{20}(-5.2H)$: 23.51%, $C_{22}(-5.4H)$: 12.34%, $C_{24}(-12.0H)$: 0.03%} of the total.

3) Spine oil (acetone-soluble) from the black right whale contains 26.43% saturated acids (myristic: 7.23%, palmitic: 10.72%, stearic: 4.44%, arachidic: 3.38%, behenic: 0.66%) and 73.57% unsaturated acids { $C_{14}(-2.0H)$: 0.47%, $C_{16}(-2.7H)$: 11.51%, $C_{18}(-4.8H)$: 30.58%, $C_{20}(-5.3H)$: 21.95%, $C_{22}(-7.6H)$: 9.06%} of the total.

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A PRELIMINARY STUDY ON THE METHOD OF TIME MARKING WITH LEAD SALT AND TETRACYCLINE ON THE TEETH OF FUR SEAL

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Few studies have been so far reported on the technique of the age determination of fur seal. Scheffer (1950) described that the number of growth ridges appearing on the root of the canine tooth indicated the age of fur seal. Matsumoto (1958) developed the age-reading technique on the basis that the number of the transparent zones of the dentine corresponds to that of the growth rings on the surface of the teeth.

Kubota *et al.* (1961) stated that the transparent zone observed in the longitudinal ground section of the dentine terminates at the top of the growth ridge on the dental root. After histological studies, they have also found that the interglobular spaces, the granular layer of Tomes, and the transparent zone are formed in regular turn every year in the dentine.

The method of counting the number of annual rings of the contour or of the transparent bands of the dentine is rather easy and this is in practical use for the young animal. But the method is more difficult in the case of older animal, because the annual rings deposited become closer together with age. In addition, some thinner transparent zones of the dentine appear occasionally between two annually formed transparent dentines in many specimens especially of female. One of the practical difficulties and confusions in determining the age comes mainly from these zones in the case of the ground section of the dentine.

The present paper is a preliminary study to clarify the developmental process of the dentine by recording the time by the following two methods of intravital staining for hard tissues. The first is the modified method with lead acetate devised by Okada and Mimura (1938) and the second is with tetracycline adopted by Milch *et al.* (1957). Nishiwaki *et al.* (1953) reported that the method using lead acetate (dose of 5 mg of lead acetate per kg. of body weight by intramuscular injection) is applicable for the time-marking of the dolphin-tooth.

As to the method using tetracycline, many studies so far reported show that this antibiotic tends to combine with calcium when deposited. After administration of tetracycline to an animal an induced fluorescence can be detected in the tissues where tetracycline is distributed.

MATERIAL AND METHODS

In the present experiment a female fur seal of 25 kg. in body weight caught on

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June 16, 1959 in the water off Ozuchi, Iwate Prefecture, Japan, was used for this purpose.

The animal received the injections on August 27, 1959, after rearing about two-month period in the pond of the Enoshima Marineland (an aquarium). An injection containing lead complex salt was prepared by mixing lead acetate with sodium citrate in the rate of 1 : 3 and was administered intramuscularly into the nates. The dose was 5 mg of lead acetate per kg. of body weight. Tetracycline hydrochloride prepared commercially was administered by a single muscular injection in the dose of 4 mg per kg. of body weight, followed for seven days by the same dose contained in each of the twice daily diet. Therefore, the animal received the total amounts of 1500 mg of tetracycline administered orally or parenterally.

The animal survived for 162 days after the initial injection. The canine teeth which were removed from the dead animal were fixed in a 10% neutralized formalin solution. The teeth were decalcified in the 0.2 N hydrochloric acid saturated with hydrogen sulfide, and then cut into frozen sections. They were next immersed in a 0.1% solution of gold trichloride then in a 5% sodium thiosulfate solution to obtain a gilded lead line.

In order to observe the localization of tetracycline undecalcified ground sections of the teeth, approximately 50 μ thick, were put to microscopic examination for induced fluorescence under ultraviolet illumination. The microphotographs were taken with the aid of an orange filter.

RESULT AND DISCUSSION

The line made by the deposition of lead was found in the sections of the teeth prepared by the procedure given above. Fig. 1 shows the deposited line in the middle of the developing dentine. The fluorescent structure characteristic to the deposition of tetracycline is shown in Fig. 2 in which the structure is apparently demonstrated as bright yellow line or band under the ultraviolet light.

As shown in these figures the lines, both of lead acetate and tetracycline, are located in the position of the growth layer of the dentine which is formed practically at the same time as the development of the dentine. This portion of the dentine confined between the marked line and the predentine corresponds to the increase during a five-month period from August 27 to February 2. The longitudinal ground section of the tooth shows that the age of the fur seal is identified as approximately four years by counting the contour growth ridges or transparent zones of the dentine (PLATE II-A).

In the sections of the dentine some peculiar lines presumably caused by metabolic disturbances in the development of the dentine were observed. The first line, the outermost of the dentine, was recognized as the neonatal line. The last one, coincided in position with the marking line, seemed to be caused by the administration of tetracycline (PLATE III). It is already known that the administration of tetracycline depresses the calcification either in skeleton or in tooth, while lead acetate in the appropriate doses shows no effect in development of the calcified

tissues. In the tetracycline method a ground section must be prepared, since the drug is removed by the delayed treatment for decalcification.

In the present experiment tetracycline was given to the animal by separate administration for seven successive days in the dose of 60 mg per kg. of body weight. From the result obtained, a single dose of tetracycline possibly less than 60 mg per kg. may produce a detectable fluorescence in the area where calcification takes place. It was noted that an adequate amount of tetracycline available for the ultraviolet examination persisted within the dentine over 24 months after the death of the animal.



Fig. 1. Transverse section of right mandible canine, 162 days after the injection of lead complex salt. Pb: Line of deposited lead.

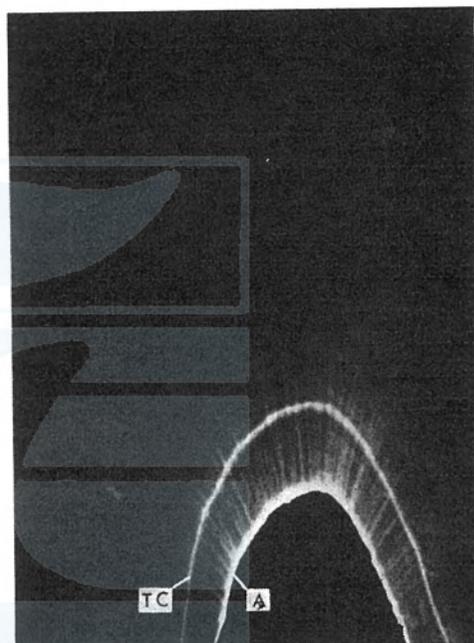


Fig. 2. Transverse section of left mandible canine, around 158 days after the administration of tetracycline, under ultraviolet light. TC: Fluorescent line of deposited tetracycline. A: Line of autofluorescence.

Further study is in progress for marking the time with lead salt and tetracycline on the fur seal dentine so as to clarify the mechanisms of annual ring formation and to establish the method of the age determination.

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of Mr. Izumi Morisaki in the course of studying fluorescence.

SUMMARY

Intravital staining after the modified lead acetate method and tetracycline for marking the time on the dentine of the fur seal was carried out, in order to establish a reliable method for the age determination of this animal. A female fur seal received the drugs and survived for 162-day period.

1. Lead acetate was given intramuscularly in the dose of 5 mg per kg. of body weight. The injection containing lead complex salt by adding sodium citrate to lead acetate, produced deposited line of lead in the area of the dentine in which matrix calcification took place. The lead line was demonstrable histochemically in the decalcified sections.

2. Tetracycline was given in the dose of 60 mg per kg. of body weight orally and parenterally. The administration of this was divided into seven successive days and given practically at the same time as the lead injection. The line of tetracycline-induced fluorescence was evident in the ground section of the dentine under the ultraviolet illumination.

3. Two lines produced by deposition of lead and tetracycline were localized in the same position of the dentine. The width of dentine enclosed by the marked band revealed the increase of the dentine during a five-month period from September to January.

4. It was estimated that the fur seal was about four years old both from those results and from the annual rings on the root and the dentine.

5. The methods described here may be adopted as a technique for the age determination especially in the older animal in which the pattern of the annual rings is not well defined.

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EXPLANATION OF PLATES

PLATE I

Ventral view of the skull (A), dorsal view of the mandible (B), the left mandible canine (C) and the left maxillary canine (D) of the fur seal, 25 kg. weight female, used in this observation.

PLATE II

Longitudinal ground section of left maxillary canine of the fur seal (A) compared with a specimen of 4-year-old female (B).

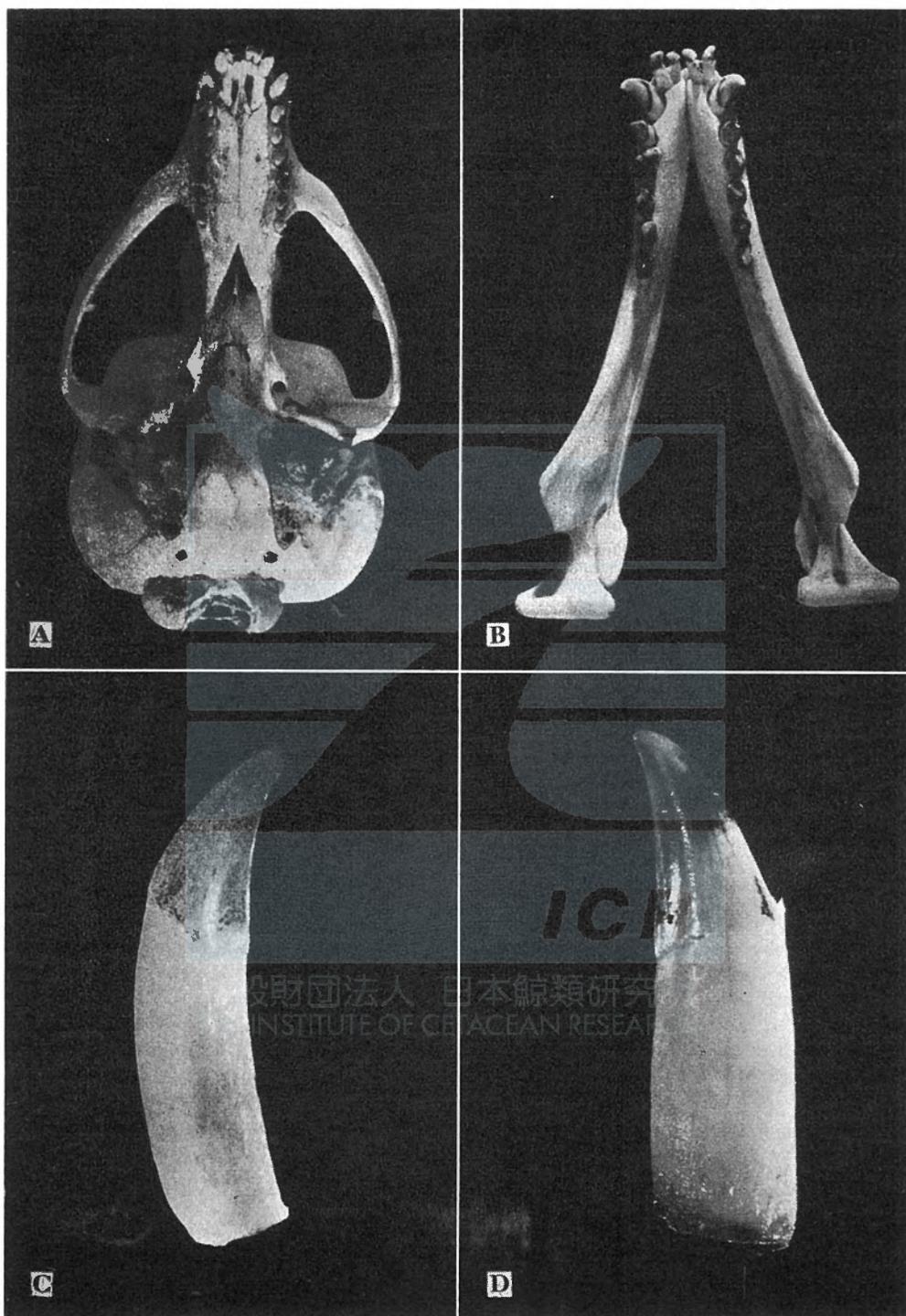
N: Neonatal line. T-1, 2, 3: Transparent zone of the dentine.

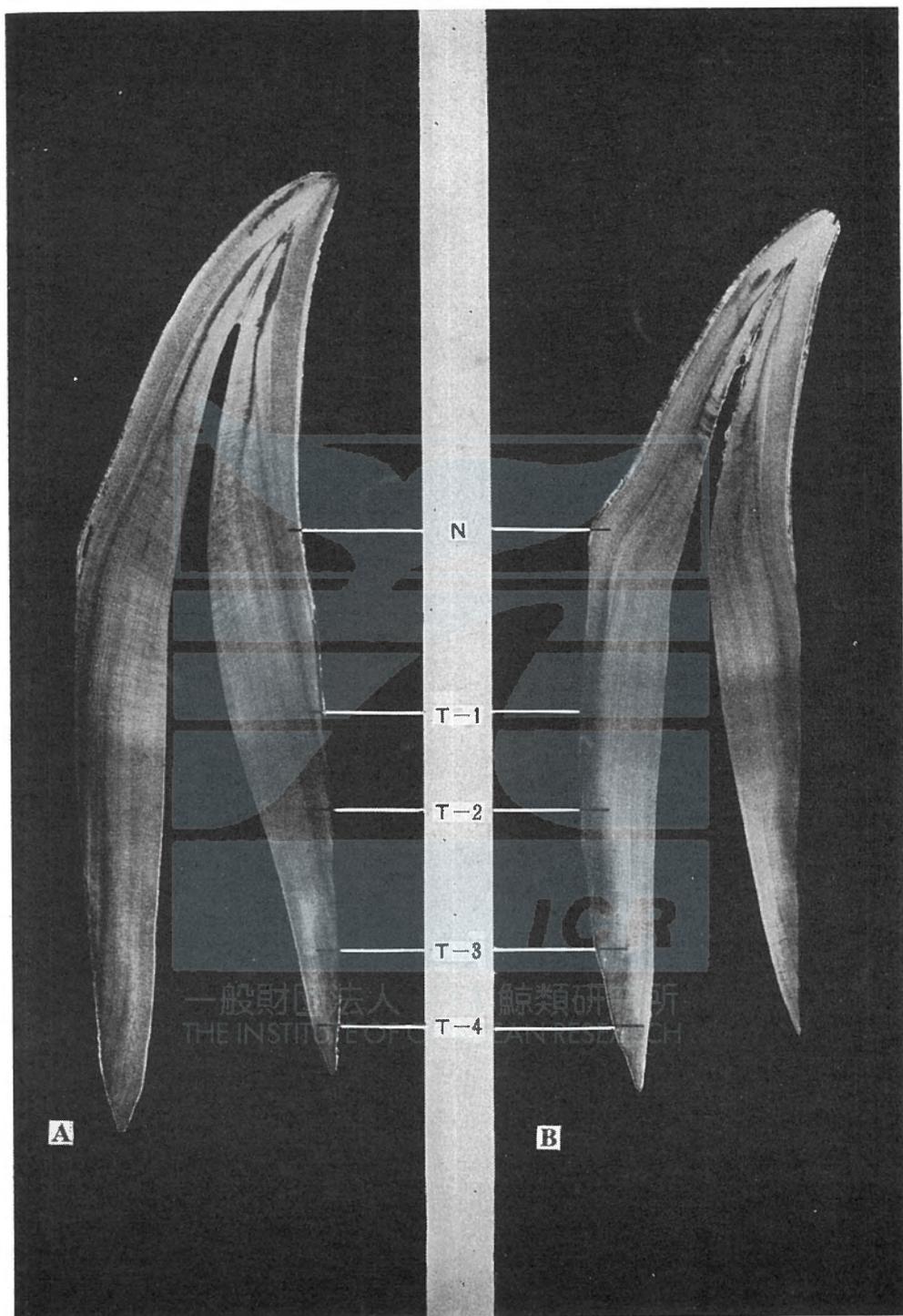
PLATE III

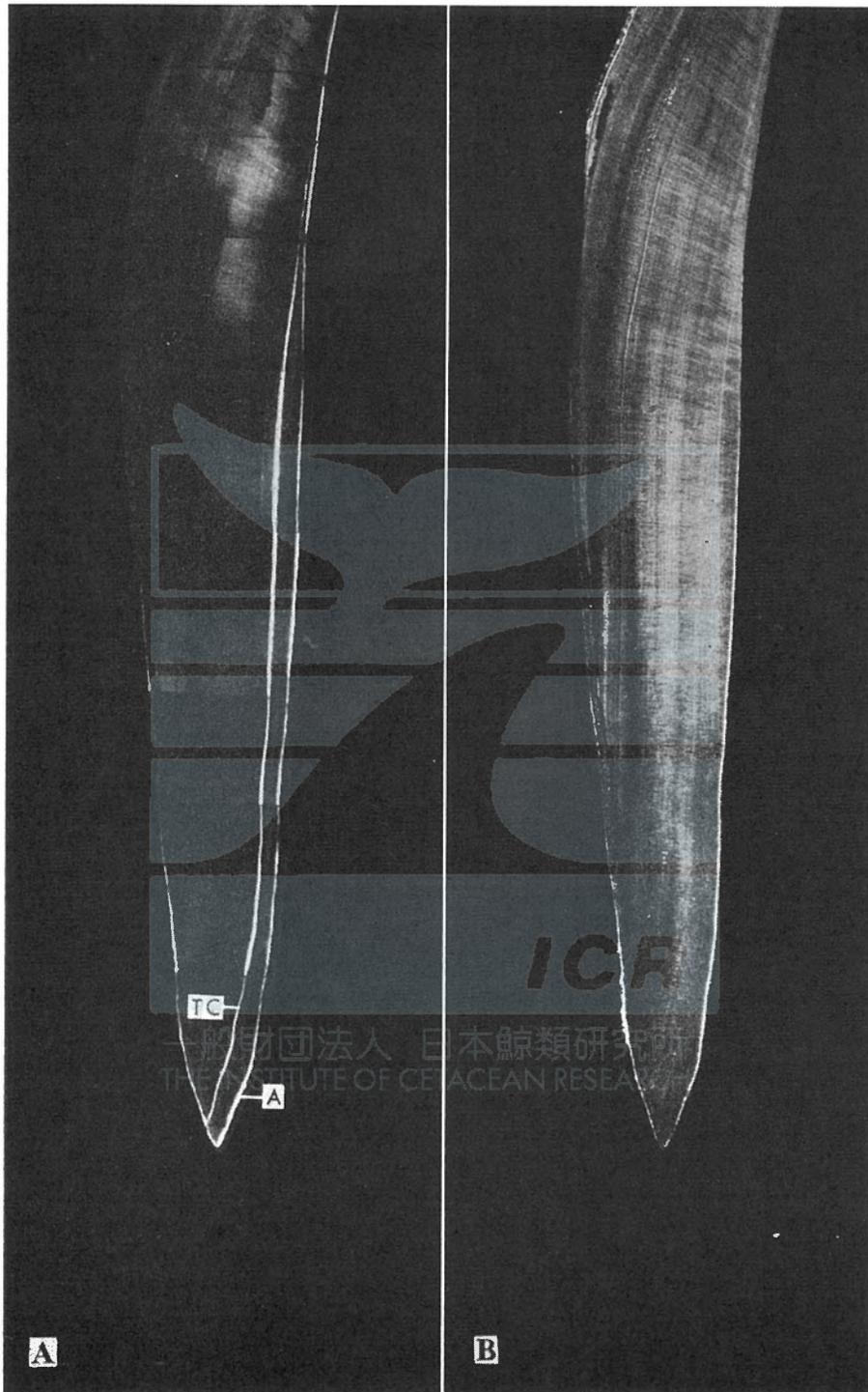
Longitudinal ground section of left maxillary canine of the fur seal, around 158 days after the administration of tetracycline, under ultraviolet light (A) and under tungsten light (B).

TC: Fluorescent line of deposited tetracycline.

A: Line of auto-fluorescence.







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