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

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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 Proffessor 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.

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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 containes 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-fucsin or hematoxillin 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.

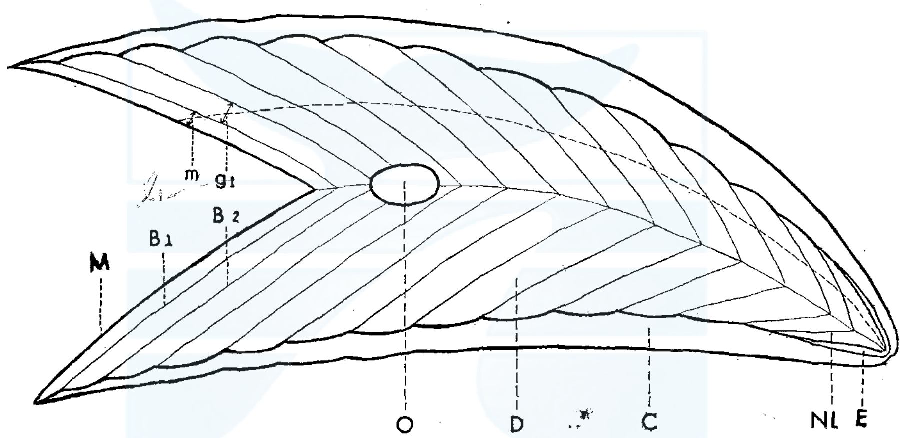

Fig. 1. Semi-diagram of longitudinal section of a maxillary tooth of the sperm whale. B_1, B_2 : Dark bands in the dentine, C : Cement, D : Dentine, E : Enamel, O : Osteo-dentine, M : Margine (predentine), l_1 : Lastly formed growth layer, m : Forming growth layer.

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 fetul 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 anisotrapic 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 parallelly through the dentine and the space among these tubules is filled with matrix. The branch of dentinal tubules seems not to develope 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 refered later, there is such a specimen as No. 6 in which width of layers vary from 0.30 mm to 1.30 mm.

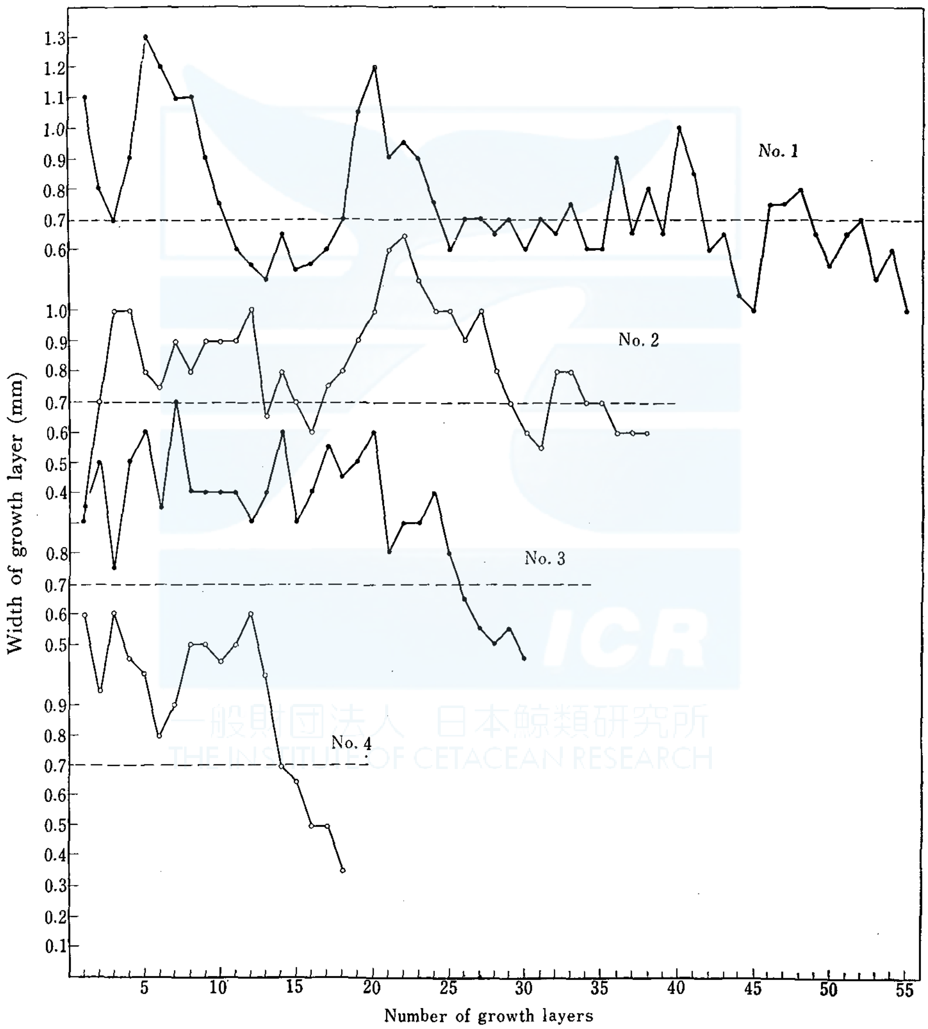

Fig. 2 a Change of width of growth layer with the increasement of number of growth layers in the dentine of maxillary teeth. Male sperm whales.

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.

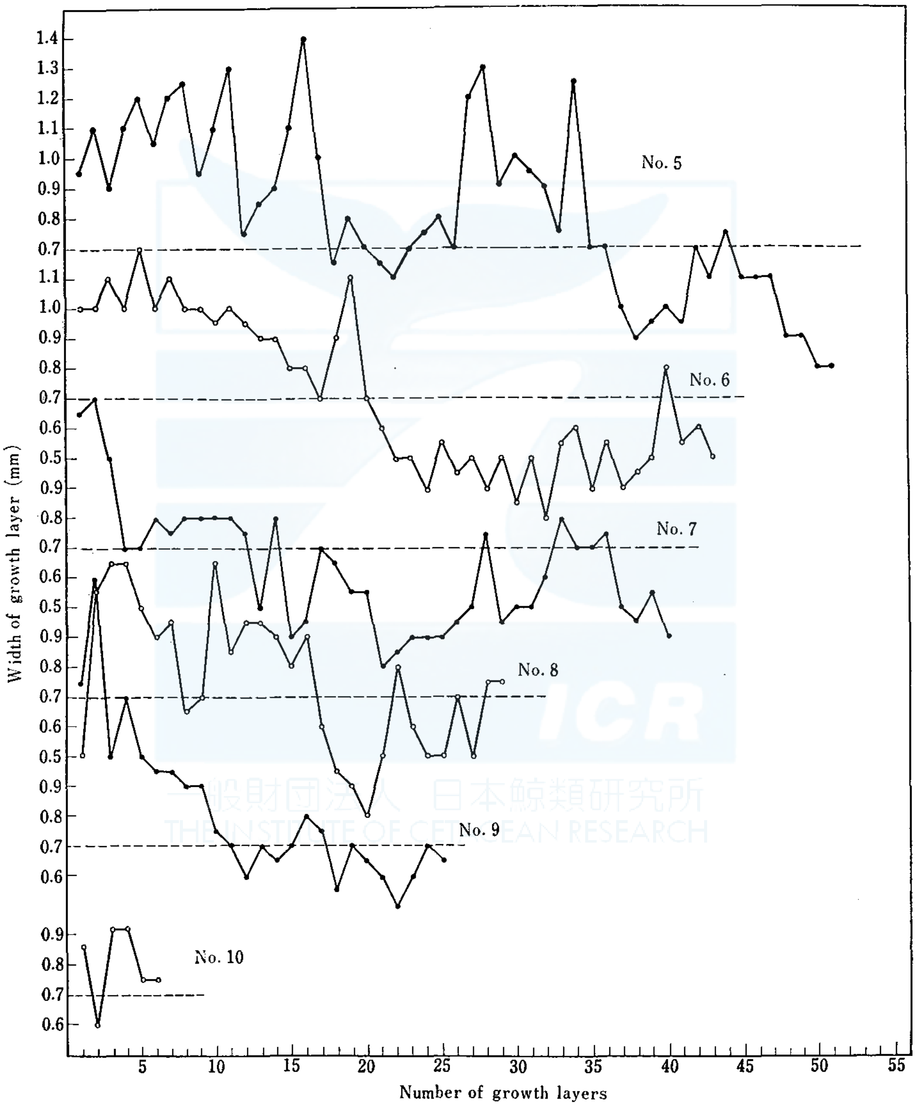

Fig. 2 b Change of width of growth layer with the increasement of number of growth layers in the dentine of maxillary teeth. Female sperm whales.

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.

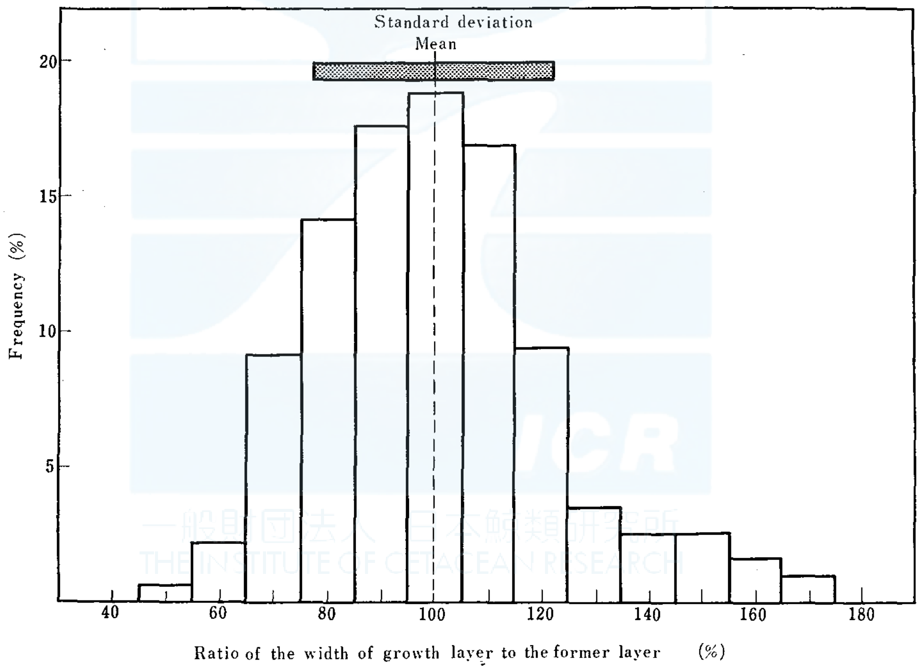

Fig. 4. Frequency distribution of the ratio of width of a growth layer to the former layer, and standard deviation of the ratio.

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 containes 6 growth layers is 0.79 mm and that of an old sample No. 5 of which tooth containes 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 layeris nearly equal to that of the former layer. The standard variation is 22.5%.

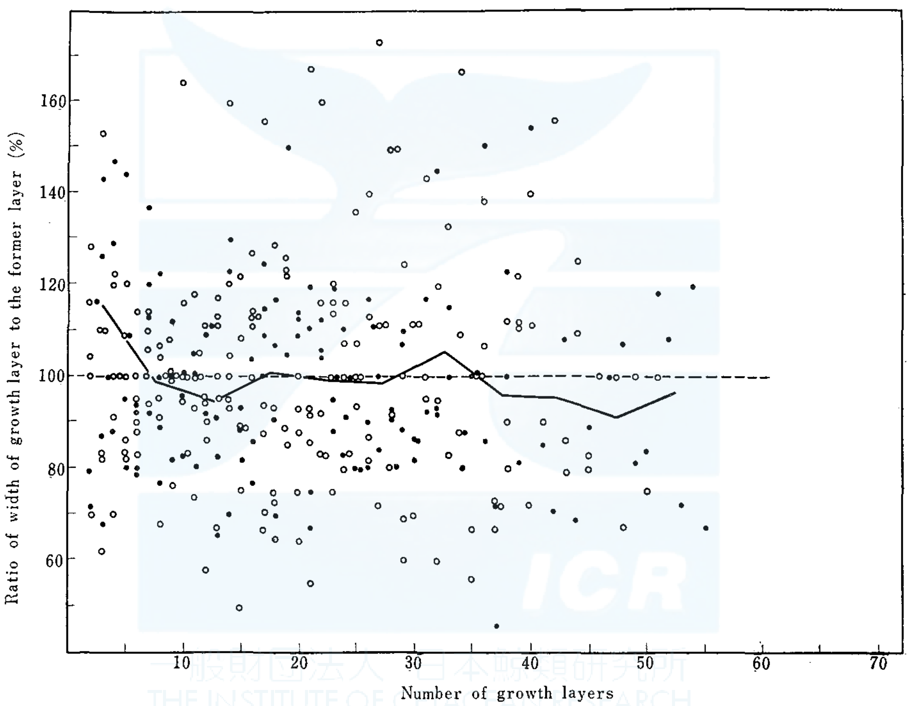

Fig. 5 Change in ratio of width of growth layer to the former layer in the dentine of maxillary teeth. Open circle: Female, Closed Circle: Male.

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, concidering 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.

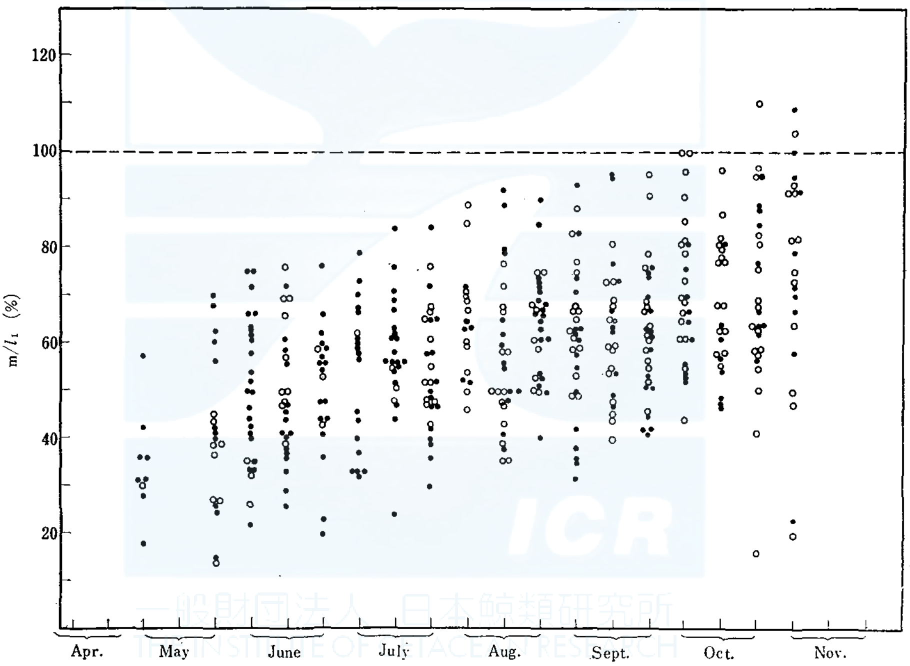

Fig. 6. Seasonal accumulation of growth layer shown by the ratio of accumulating growth layer (m) to the former growth layer (l_1) in the dentine of maxillary tooth of the northern sperm whales. Open circle: Female, Closed circle: Male.

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 extending 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%).

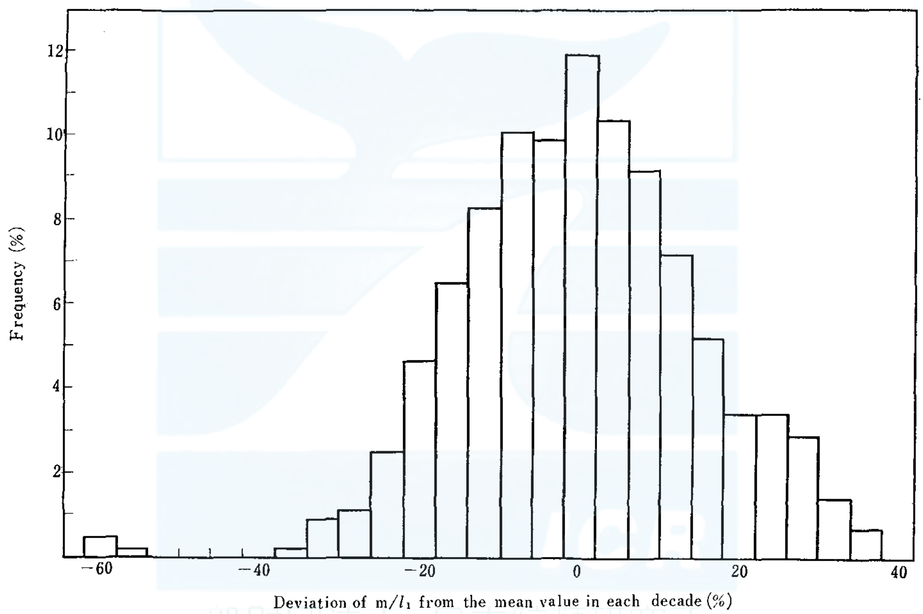

Fig. 7. Frequency distribution of deviation of m/l_1 from the mean value in each decade.

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 inadequite to apply a straight line to the data which were not covered in all seasons.

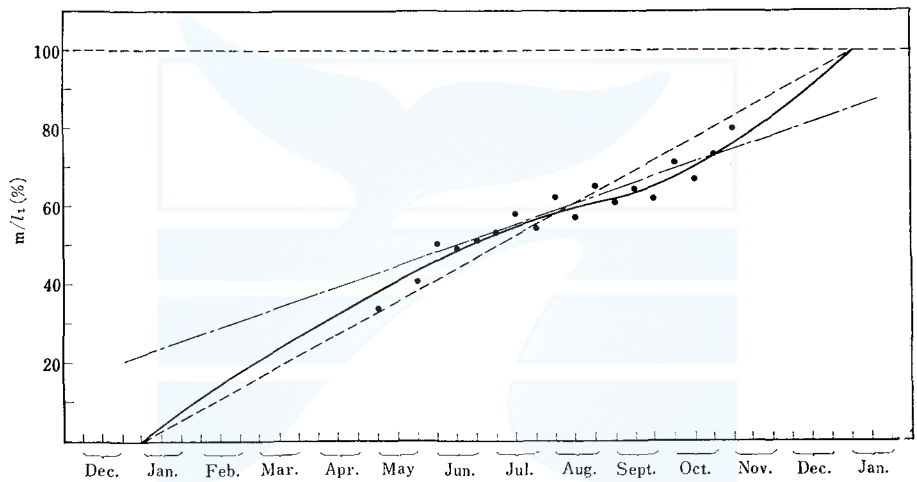

Fig. 8. Three accumulation curves of the growth layer in the dentine of maxillary tooth of the Northern sperm whales. Closed circle: Mean value, of m/l_1 Solid line: Estinated curve, Chain line: Regression line calculated with the mean values, Broken line: Fitted straight line when the accumulation cycle 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: No. of the decade from the first decade of January when x 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- 1⅓	Female	—	35	0-2, 0-1	None	—	18	1.78
J2878	12·IX·52	24·X·62	10- 1⅓	Female	—	35	lost	None	—	39	3.85
J2883 J2984	12·IX·52	24·X·62	10- 1⅓	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- 2½	Female	37	35	0-0, 0-2	None	—	14	1.71
J6381	7·VIII·55	13·XI·62	7- 3⅓	Female	25	35	lost	—	—	10	1.48
J6658 J7338	7·VIII·55	18·VIII·62	7- ⅓	Male	30	36	—	—	0.8, lost	12	1.71
J8278	22·VII·60	11·VI·61	0-10⅔	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 devided 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 contrally, 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 devided 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.

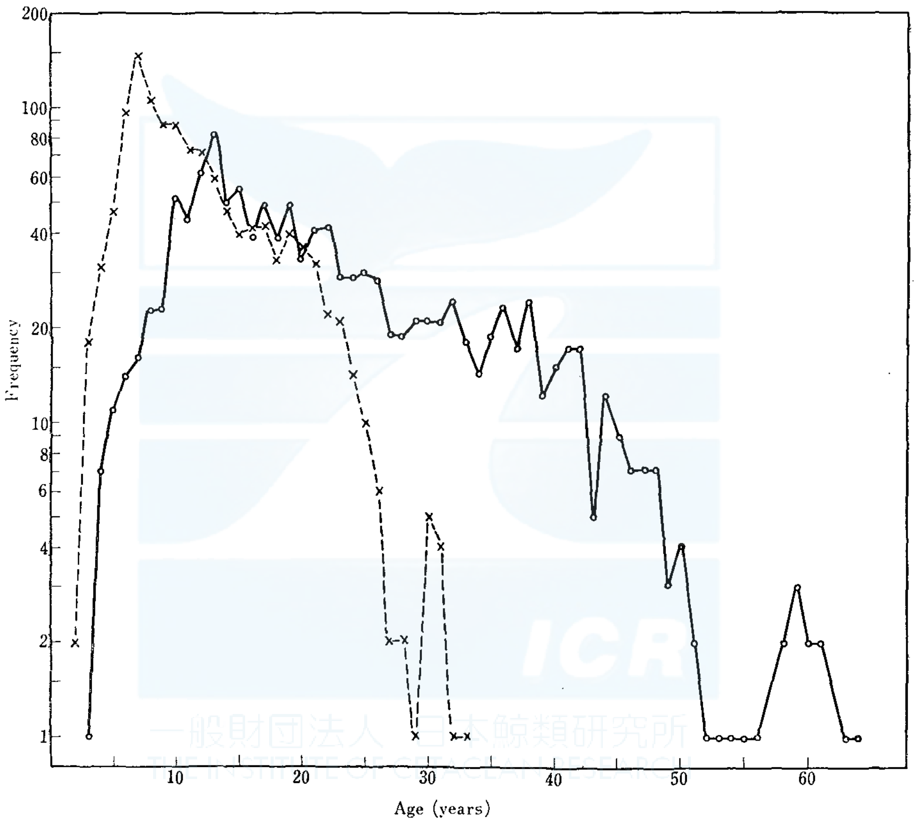

Fig. 9. Age distribution of female sperm whale caught in the adjacent waters to Japan in 1960 and 1961. Ages are based on the number ot growth layer. Open circle and Solid line: One growth layer is accumulated in a year, Cross and broken line: Two growth layers are accumulated in a year.

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 2/3 of apparent pregnancy rate as a true rate. Because in September there are still females to be delivered of a calf.

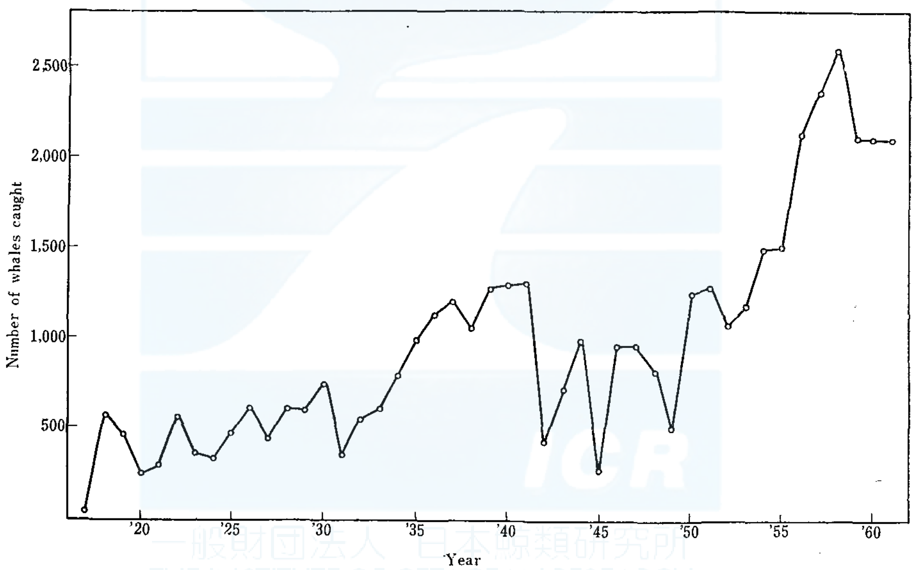

Fig. 10. Variation of catch of sperm whales in the adjacent waters to Japan (after the International Whaling Statistics and Japanese Whaling Statistics).

By these mathods we got the couclusion 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 polulation 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	$1/2$	$1/2$	$1/2$	$2/3$	$1/1$	$1/1$	
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	0.35		0.30		0.25	
Survival rate	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 Tavolga 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 simmilar 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 cicles, 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 phemisphere 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 proceding 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 whould 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. (×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. (×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. (×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 corupus albicans in the ovaries, pregnant, 17 growth layers, taken in the coastal waters to Japan in July 26, 1961. (×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. (×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 (×17.4)

Lower: Pulp portion of the tooth (×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 (×18)

Lower: Pulp portion of the tooth (×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. (×224)

Lower: Female, 10.8 m in body length. (×134)

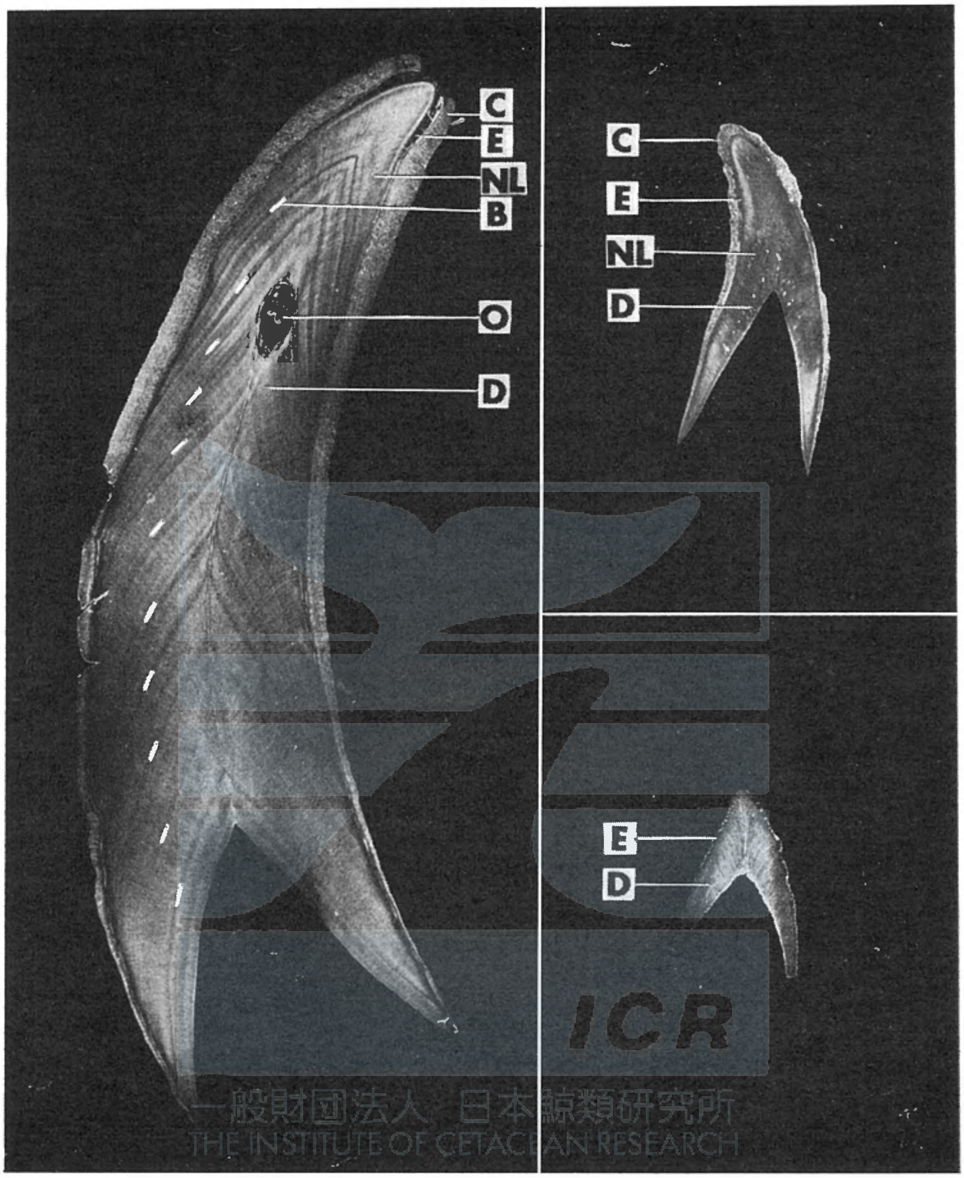
PLATE VII

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. (×112)

Lower: The same tooth with the upper figure. (×268)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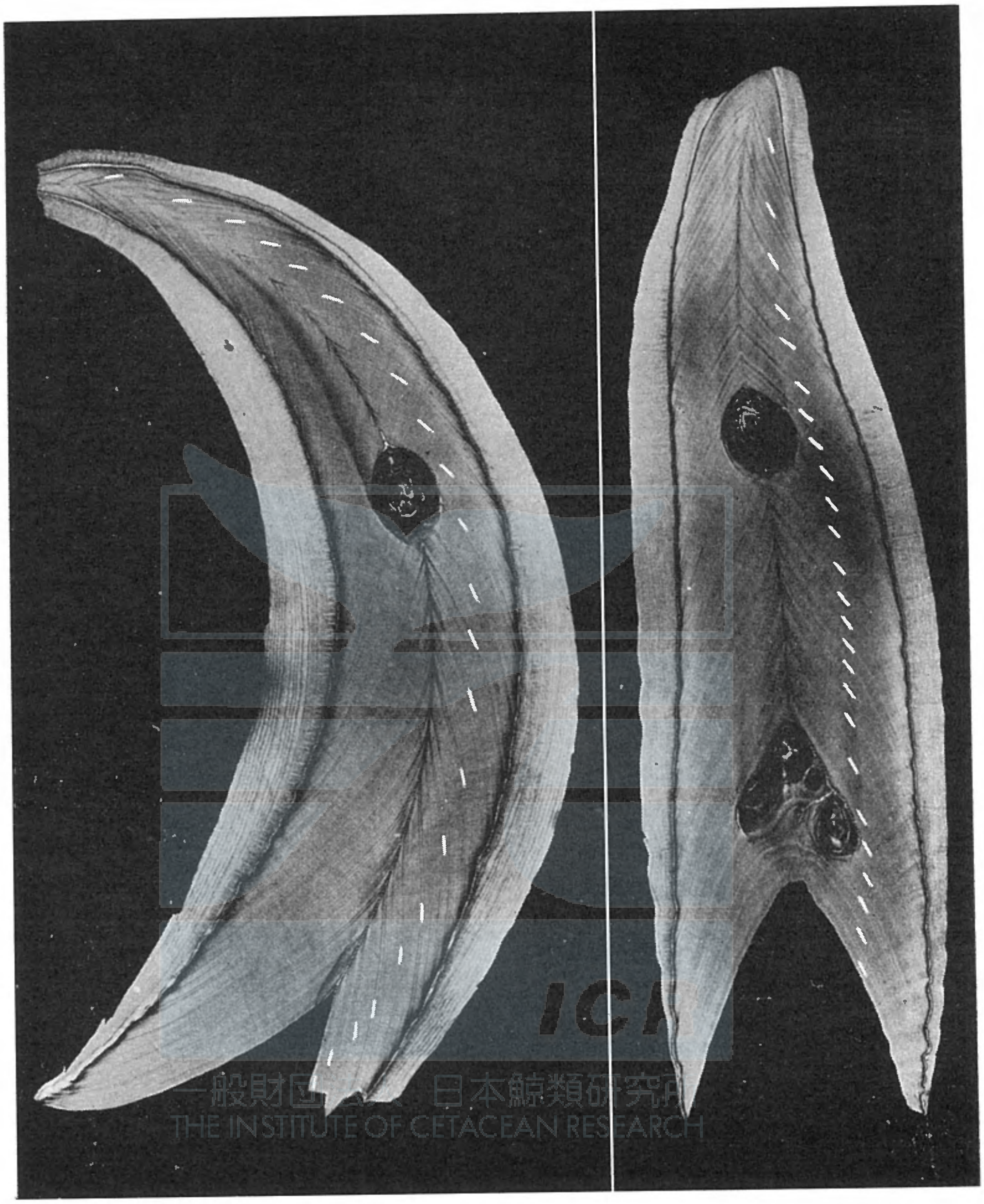

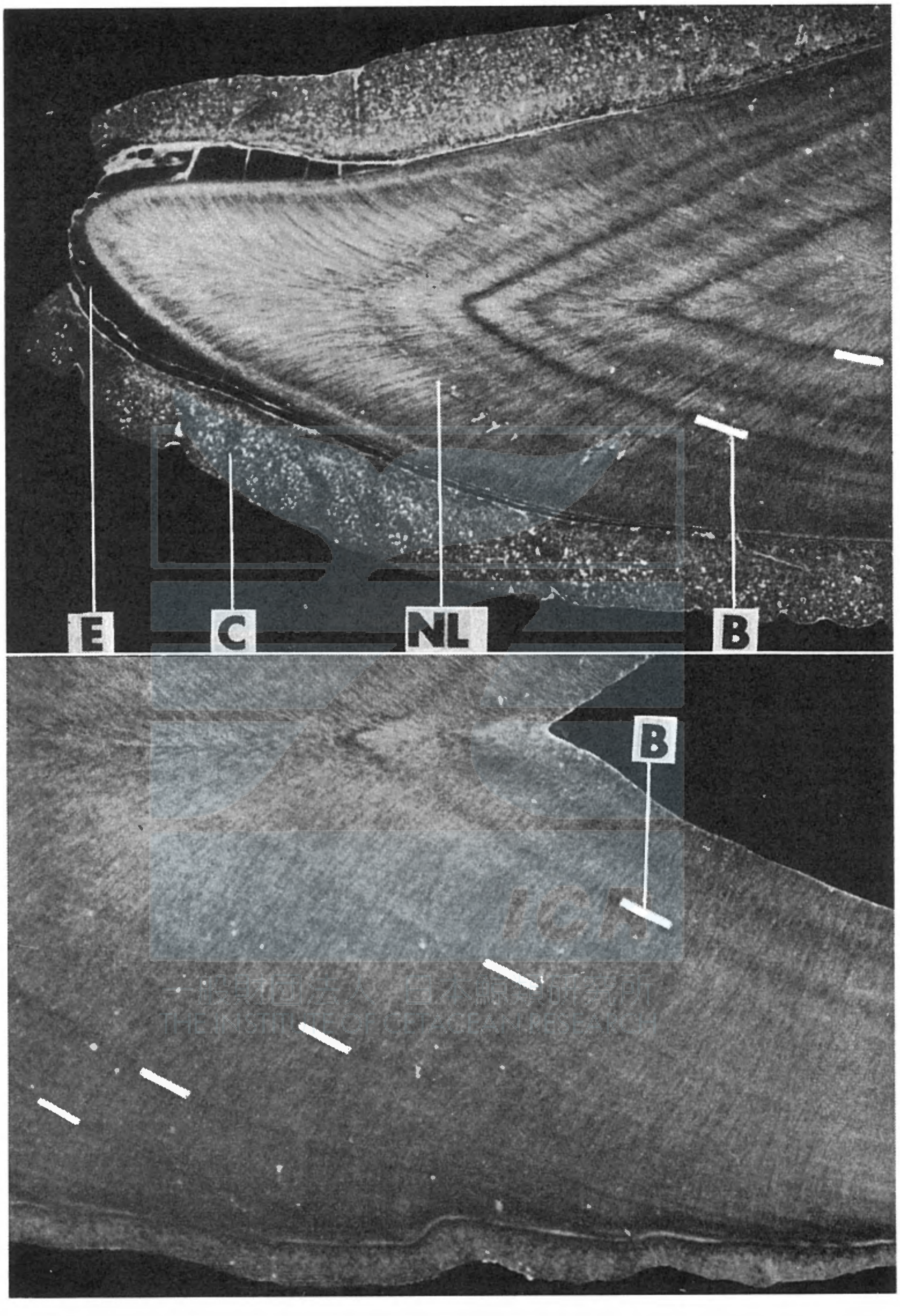
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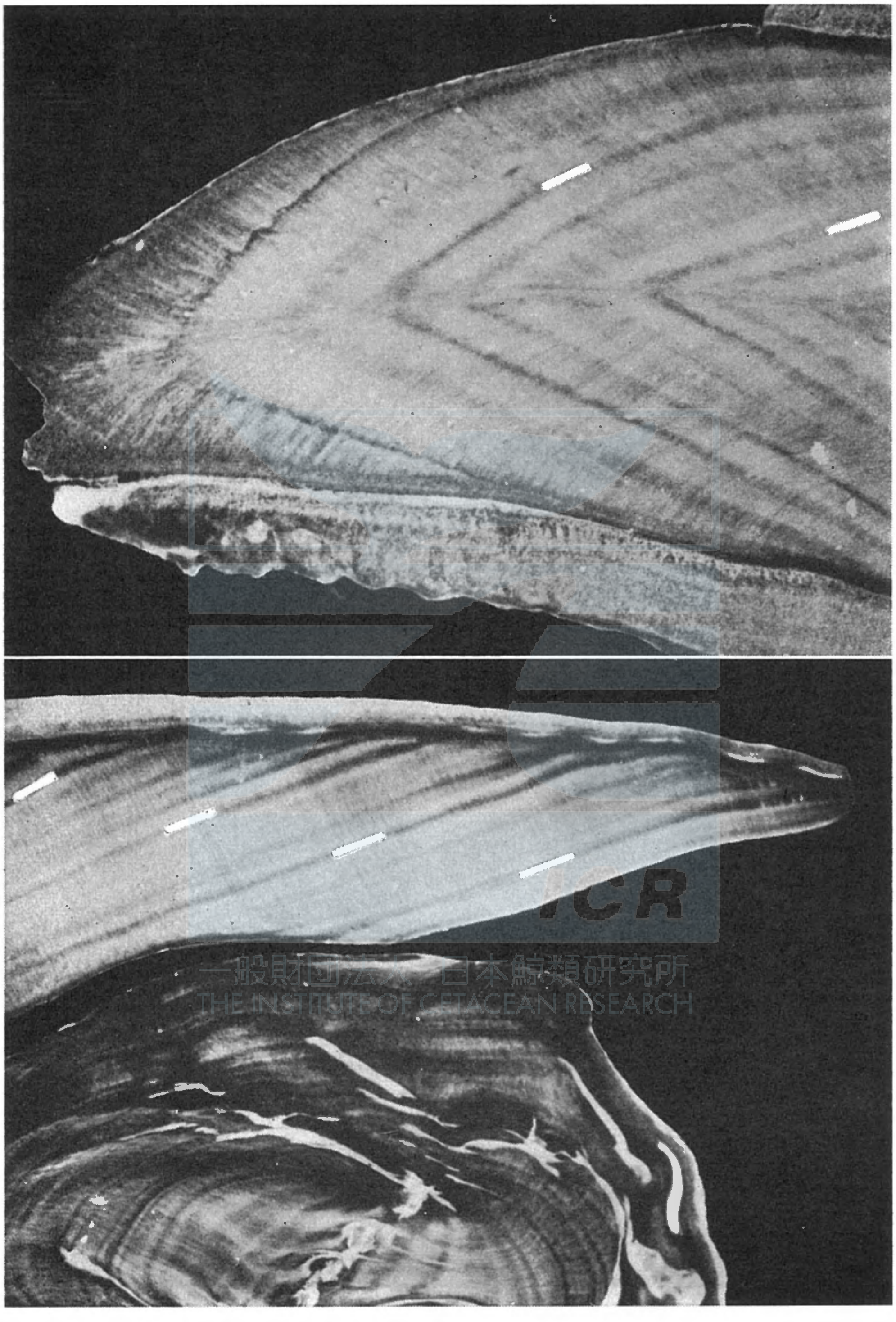

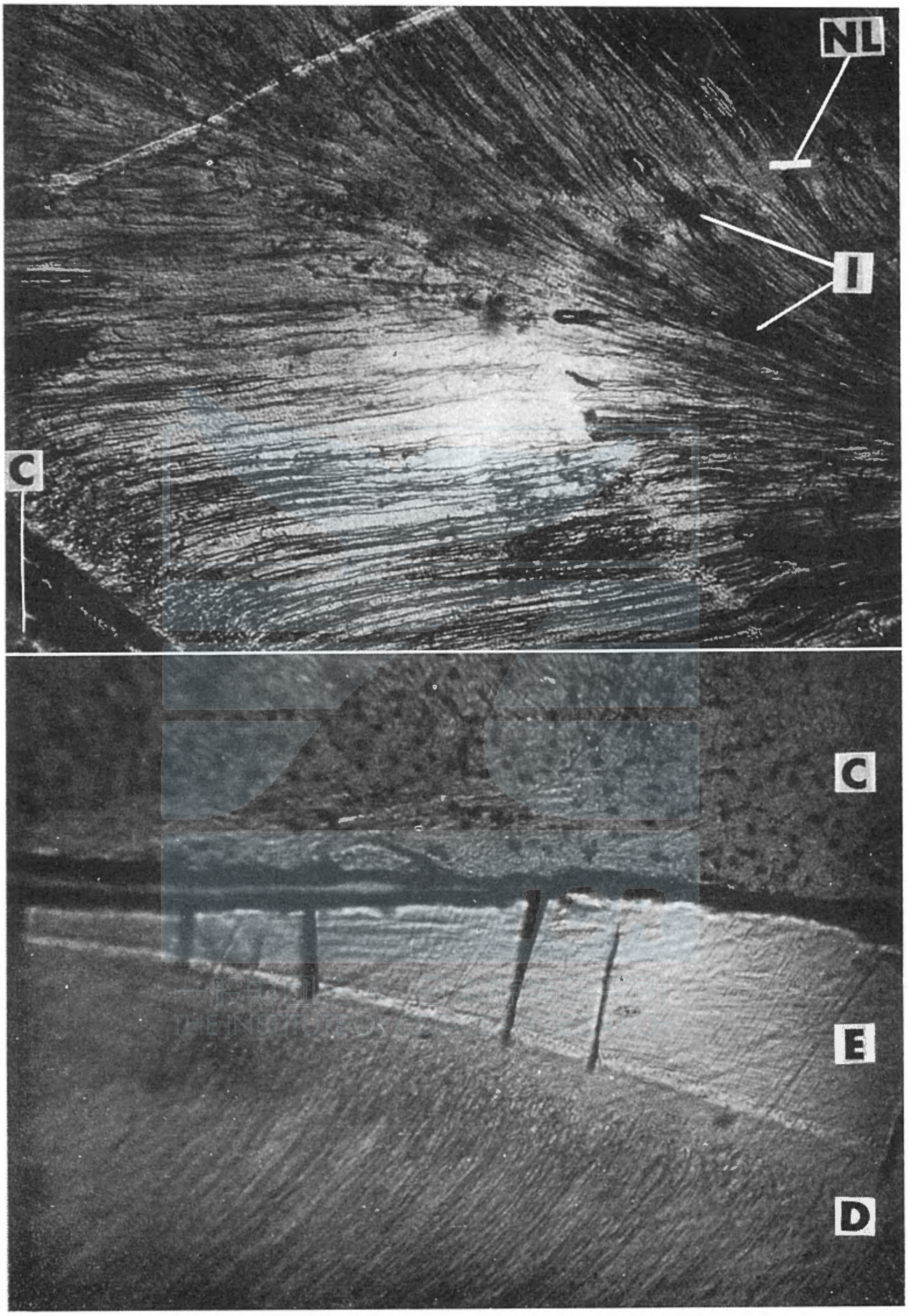
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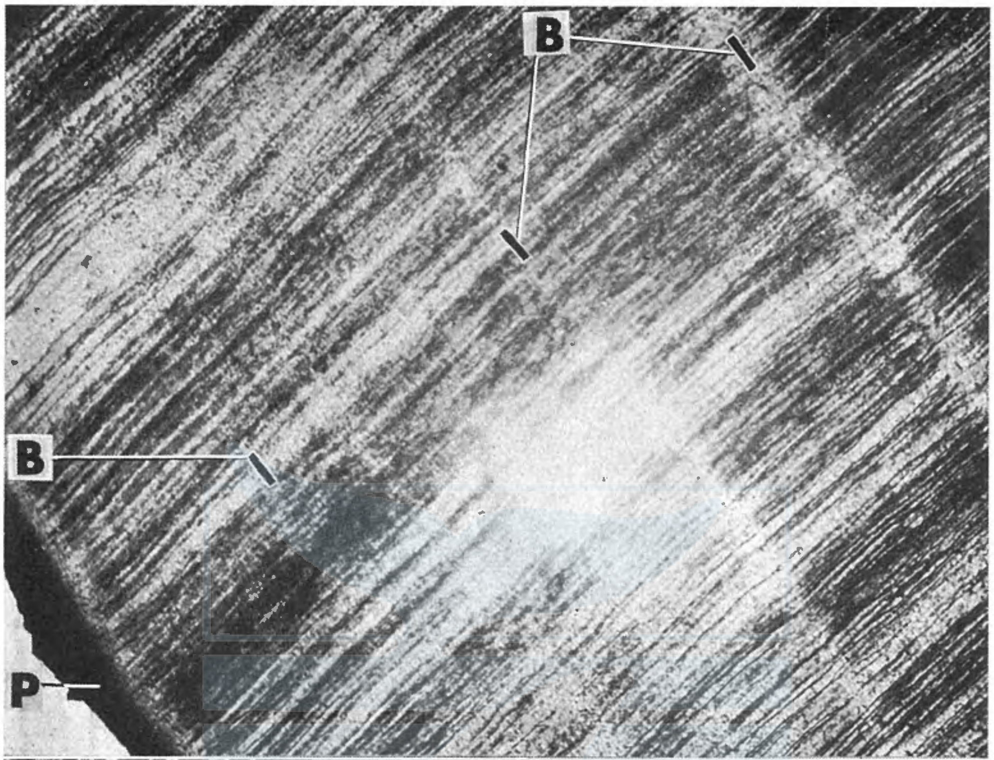
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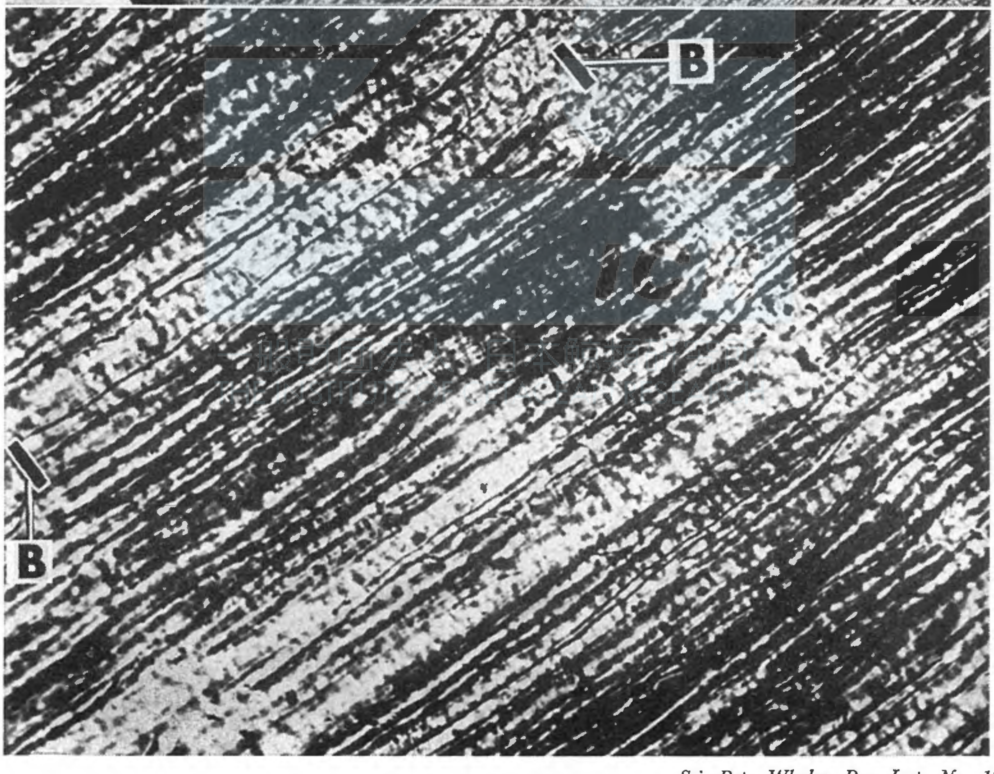
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