CRITERION FOR DETERMINING AGE OF FIN WHALE WITH REFERENCE TO EAR PLUG AND BALEEN PLATE

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INTRODUCTION

The age determination is an important problem for the fisheries science as well as for the development of whale biology. In the fisheries science it is a basic study contributing to the human management for natural resources through the stock assessment. In order to estimate the age of the fin whale (*Balaenoptera physalus*), various methods have been developed since the early in this century and they are represented by the regular accumulation of corpora in ovaries (Wheeler, 1930., Laws, 1961), the periodical occurrence of baleen plate ridges (Ruud, 1940), the colouration of crystalline lens (Nishiwaki, 1950a) and the ear plug laminae accumulated in the external auditory meatus of the baleen whale (Purves, 1955). Among these age material, the ear plug laminae which is accumulated throughout the life of whale in both sexes is the most valuable. The report by Purves who found the ear plug an important age indicator for the first time has fascinated me but simultaneously induced me to have some doubts on the formation mechanism of ear plug.

My study in a series began in 1959 from the examination on structure which is essential for interpreting the ear plug proper. The alternation of the dark and the bright layer in the ear plug indicates the complicated aspects in most cases. The alternation of layers was counted only by the naked eye and there was no objective measuring method. In order to examine the biological meaning of two different layers, the photometric apparatus* recording the laminae had to be devised in 1963. In 1964, the prenatal development of ear plug and its feature in the structure was examined in relation to its formation in the adult whale.

It is necessary to estimate the annual increment rate of laminae to determine the age of whale by means of the ear plug. Since Purves' report, many scientists have estimated the annual increment rate of laminae, assuming factors effecting on the alternation of the ear plug layers. These works, in relation to the ages of the fin whale and the humpback whale (*Megaptera novaeangliae*), have resulted from the comparison of the ear plug with the other age indicator, particularly from the interrelation between the annual ridge on the baleen plate and the ear plug laminae for the young whale (Laws & Purves, 1956) and between the annual increment of corpora in female ovaries and the ear plug laminae (Laws, 1961). With regard to this point, no work concerning the ear plug proper has been reported and only the elapsed time from fire to recovery in the marking experiment checked the increment rate of laminae in a year (Dawbin, 1959., Chittleborough, 1960.,

* Grant-aided by the developmental research in the ministry of education in Japan.

Ohsumi, 1962). There are many instances of recaptured fin whales which were marked in the unknown age at fire, in the Antarctic and the North Pacific. All previous papers are grounded on the estimation that the increment of laminae is annually regular throughout the life of whale. It means that the alternation of two different layers does correspond to the calendar time.

My question on the regular formation of lamina arised from plotting the thickness of each lamina according to the Walford graphic method (1946). This examination was carried out in the ear plugs of male fin whales captured in the 1957/58 season in the Antarctic, because the occurrence of layers in the male is clearer than that in the female. In the present study, I propose my opinion that the annual increment rate of laminae is slightly different in the growing stages of the fin whale and hence that the ear plug is rather a relative age indicator representing the physiological time related to the life history of whale.

It was necessary to examine the structure of baleen plate in relation to the age determination and new findings are given for it as well as a new devised method to study it. The material of this study was brought by the Japanese expeditions in the Antarctic and supplemented by the North Pacific expedition. The biological examination in October and November in 1964 at South Georgia in addition to 4 months period from December to March on board the pelagic whaling factories enabled me to cover 6 months periods in the Antarctic. The material from fin whales in the breeding season probably is indispensable to examine the biological meaning of the ear plug layer, but no Japanese Whaling Company operated for the catch of the fin whale at the land station in the winter season.

The future experiment of either the time-marking to the ear plug or the marking for the calf accompanied by the cow will confirm the proposed annual increment rate of ear plug laminae in this paper.

PHOTOMETRIC APPARATUS RECORDING EAR PLUG LAMINAE

The idea recording the alternation of layers in the ear plug of baleen whale was presented and the first trial to take successful records was made through construction of the simple apparatus (Ichihara, 1963).

The primary purposes to develop the photometric apparatus exists in not only taking the objective record for the dark and the bright layer in the bisected ear plug, but also grasping the biological significance of the occurring each layer through the record. In order to attain the latter purpose, the biological research for the individual possessing ear plug should be combined with the photometric records. This biological meaning will be discussed later in this paper. To answer the former purpose, the apparatus in the first step was improved in detail, although the principle of recording is almost the same. The main improvement is in the points that the automatic recording was developed to some degree and the the compensated recording became possible in addition to take the natural colour change on the surface of bisected ear plug. In Fig. 1, the schematic diagram of the recording apparatus is given and the photograph for the set of photometric apparatus is indicated in Fig. 2. The same notation (A, B) is used both in the upper diagram indicating the optical mechanism and in the lower diagram showing the electrical mechanism in a set. The bisected ear plug submerged in 10% formalin solution is illuminated by a 8 mm cine-lamp and the glass vessel containing the plug is

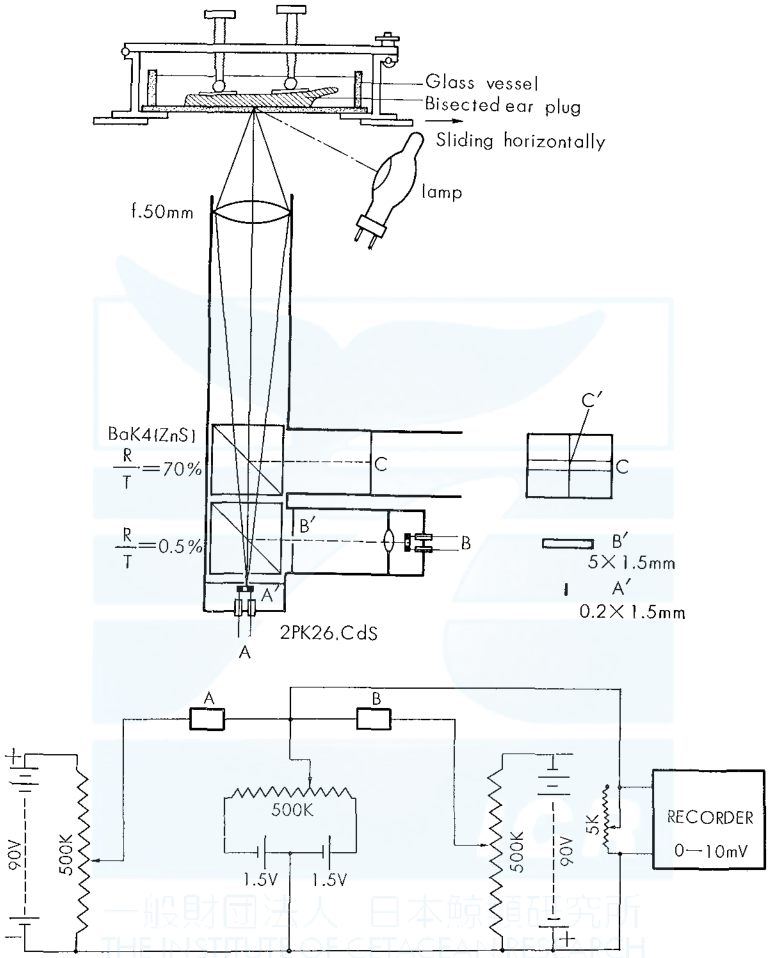

Fig. 1. Schematic diagram indicating mechanism of the photometric recording apparatus for the ear-plug laminae. Optical mechanism is shown in the upper and electronic mechanism in the lower. See notations in the text.

moved horizontally in a constant speed by a 8 mm-cine motor. As two prisms composed of BaK_4 (ZnS) are included in a tube, the refleced light on the surface of the ear plug is divided into two components in the first prism where the ratio of reflection to transmission (R/T) is 70 percent. Through the view finder (C), we can observe the movement of ear plug. At the next prism, the value of R/T is

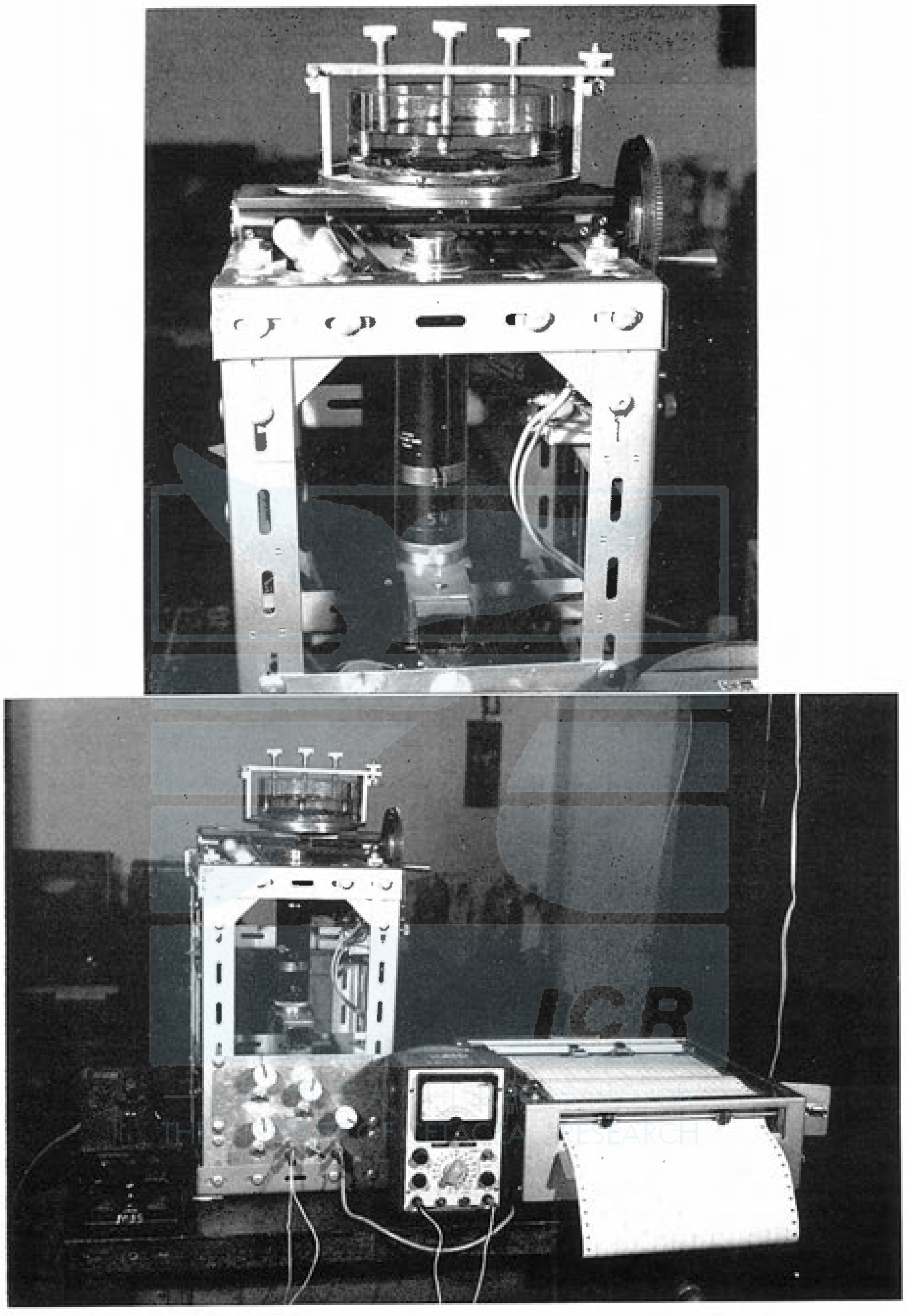

Fig. 2. Photographs indicating a set of photometric apparatus recording the ear-plug laminae.

0.5 percent and most of light reaches to CdS (2PK26) on A through A' slit (0.2 × 1.5 mm). The light which reaches to CdS on B through B' slit (5.0 × 1.5 mm) is used for compensating the original photometric record. The pen writing recorder

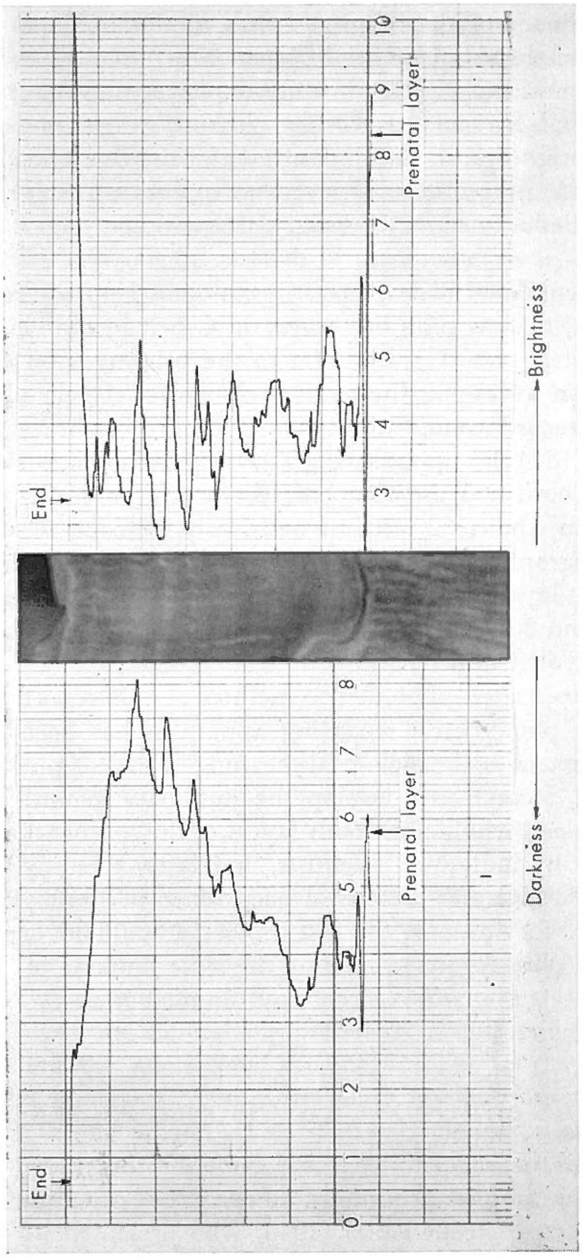

Fig. 3. Photometric record for a ear plug from a young fin whale, 62 feet long female in the North Pacific. 18.8 mm core in length shows 7 laminae already formed and the 8th lamina under formation. The record by compensated method is indicated in the upper and the ordinary record in the lower. The photograph of bisected ear plug is indicated in the middle.

is able to follow the change of current till 0.2 second. Under this condition, we can control voluntarily the rotation of 8 mm cine motor and the movement of recording paper, and hence several kinds of record is obtainable for a single specimen.

When B is switched off, the photometric record depends on the light reaching to A and only the ear plug image on C' line in the view finder is recorded. In this case, the record reflects the natural colouration on the bisected ear plug and indicates the general change of the brightness as a mountain slope as well as the alternation from the dark layer to the bright layer (See the lower in Fig. 3). The alternation of the dark and bright layer in the ear plug is important as an age indicator of baleen whales. By such a recording method, we can not exaggerate the change of alternating brightness in the limited area of the recording paper. Considering this point, furthermore, it is desirable to undurate the record around a standard level. This desire is closely related to obtain the record satisfying the human eye-sense.

The compensation method is developed by the kind help of Prof. M. Hirata. When B is switched on, the ear plug brightness on C belt in the view finder is included in the photometric record in addition to the brightness on C' line. This method has an effect on averaging the general change of the ear plug brightness. It is possible to take a record around the standard level of brightness, with gradual sliding of the specimen (See the upper in Fig. 3). Fig. 3 indicates the comparison between the original record and the compensated record for the ear plug from the North Pacific female fin whale, 62 feet in length. By the contrast of two kinds of records with the photograph of ear plug, the significance will be clarified. In this ear plug, the 8th bright layer is now under formation. In the original record (the lower figure), the 7th and 8th bright layers are not recorded clearer, compared with the compensated record (the upper figure).

I applied the compensated photometric method to this report instead of the original method. The photometric recording apparatus has been developed for three projects, firstly to examine the biological meaning of the ear plug layer through the accurate recording, secondly to develop the automatic counting for the ear plug laminae of the baleen whale and tooth layers of the sperm whale in order to avoid subjective counts by individual scientists, and lastly to study the racial difference of population through the pattern of occurrence in the layer. As a long time had been expended for attaining the first project, I could not expand my study in other two projects. With regard to reading the scale laminae of fish, Kuroki *et al.* (1965) devised a semi automatic recorder and applied it to the scale of chum salmon in the North Pacific.

PHOTOGRAPHIC METHOD FOR SECTIONED BALEEN STRIP

Since the baleen plate is an important age indicator for the young baleen whale, its structure should be examined accurately. Few paper concerning structure of the plate has been reported except Ruud (1940) who presented its significance in detail. Although he indicated photographs of longitudinally sectioned plate in order to examine the thickness of two components; the cortical layer and the medullary layer, these photographs for a fin whale plate were divided into three parts.

By the normal photographic method, it is difficult to examine the general structure of the long plate, because the thickness of plate is much thinner compared with the length of plate. If the devised photographic method to enlarge the width and shorten the length in a long strip is developed, it is very convenient to study the structure of plate. Prof. Hirata developed the special photographic method to attain this object in 1959. By his courtesy, I applied this method to the baleen plate from the very young fin whales killed in the North Pacific and the Antarctic. The mechanism is indicated in the diagram of Fig. 4, and the devised structure of camera is of importance to understand the mechanism.

A slit of 5 μ in width is placed just before the film plan in a 35 mm camera. The winding lever is exchanged by a gear which contacts with another gear in smaller diametre. At the tip of stem of the smaller gear, there is a pulley which a piano wire winds. A piano wire is stretched by a lead as indicated in Fig. 4.

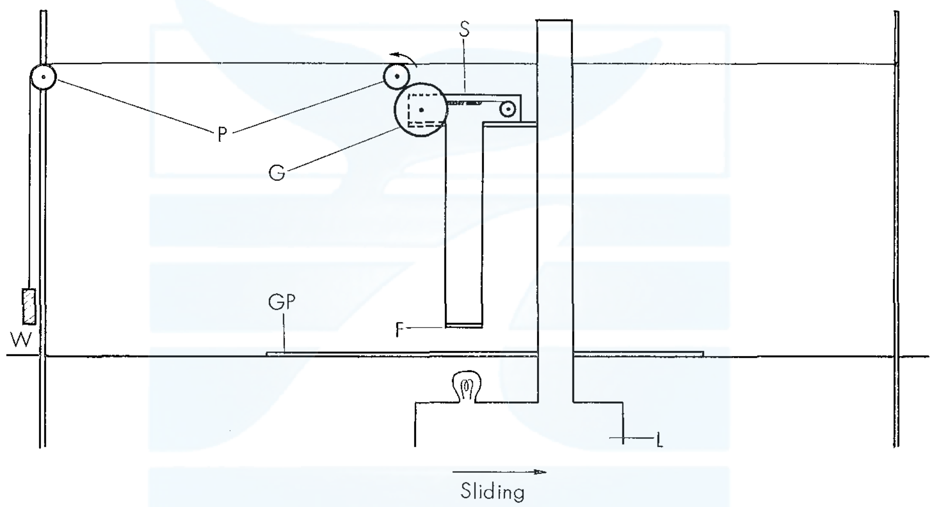

Fig. 4. Diagram indicating the mechanism of photographic apparatus recording the baleen strip. F: filter, L: lathe, G: gear, GP: glass plate, S: slit, P: pulley, W: weight.

A support of a copy apparatus which is equipped with the camera shifts in a constant speed with an old lathe operated by a motor. The film is wound in a slower speed than the movement of camera. The long strip in the thickness of 0.2–0.3 mm was taken off by a plane along the outside curvature of the longest baleen plate of the fin whale. This strip was placed on the glass plate and illuminated from underside. Photographs of the devised apparatus is shown in Fig. 5 in which the left figure indicates the general view and the right the enlarged part of camera.

Fig. 6 is a photograph for the long strip of the baleen plate from the immature fin whale, 60 feet long female, killed in the Antarctic. In the longitudinal section of the baleen plate, the length of about 64 cm is shorten and the thickness of about 4 mm is enlarged. The horizontal scale has cm unit and the vertical scale does mm unit. In the left side, there appear clearly the end of cortical layer as well as the end of tube in the medullary layer and so the right side indicates the tip of baleen plate. In this figure, the anterior part of plate is indicated at the upper border and the posterior part at the lower border. It seems that there are many inflections in the longitudinal direction of plate and large 8 inflections are remarkable. Near the tip of plate, the length from inflection to inflection is shorter than near the base of plate. The border line between the cortical layer and the medullary layer is

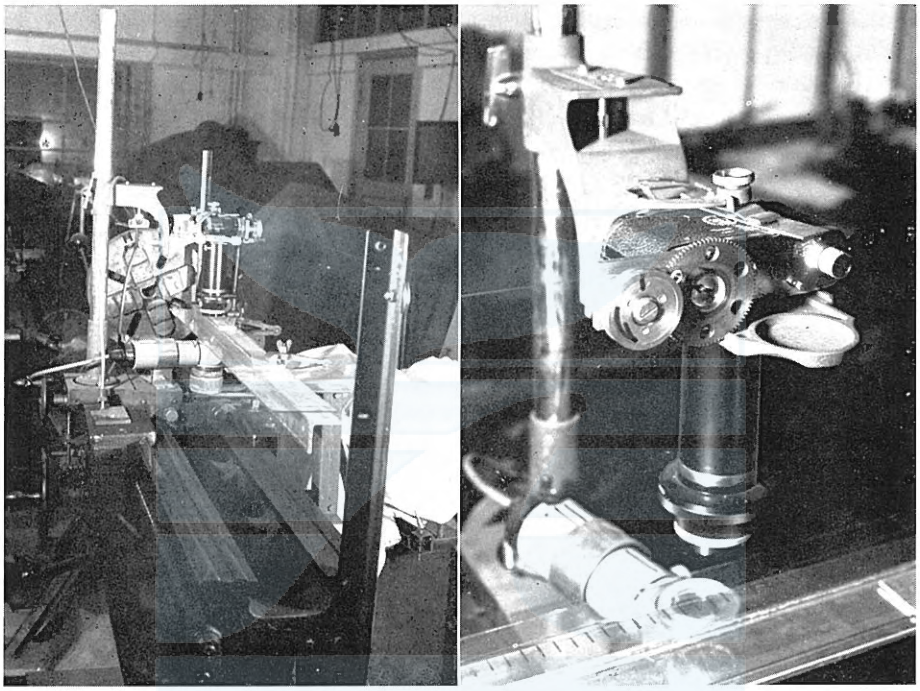

Fig. 5. Photographs of the apparatus taking a continuous picture of sectioned baleen strip. Left: The general view of the apparatus. Right: The part of the reconstructed camera.

Fig. 6. Photograph of a longitudinally sectioned baleen strip. The proximal end of plate is indicated in the left and the distal end in the right. The horizontal scale in cm unit and the vertical scale in mm unit. This strip was obtained from a longest baleen plate of a 60 feet long fin whale in the Antarctic.

clearly discriminated in the photograph. It is recognizable that the thickness of plate varies from tip to base in the cortical layer as well as in the medualllry layer and that the changing thickness in the anterior cortical layer does not correspond to that in the posterior layer. This suggests that the growth of the anterior layer is independent of that of the posterior layer.

STRUCTURE OF BALEEN PLATE

Eshricht and Reinhardt (1866), Tullberg (1883) and recently Utrecht revealed the structure of the baleen plate from the adult fin whale. The each baleen plate consists of an inner, medullary layer (horny layer) built up of horny tubes arranged in

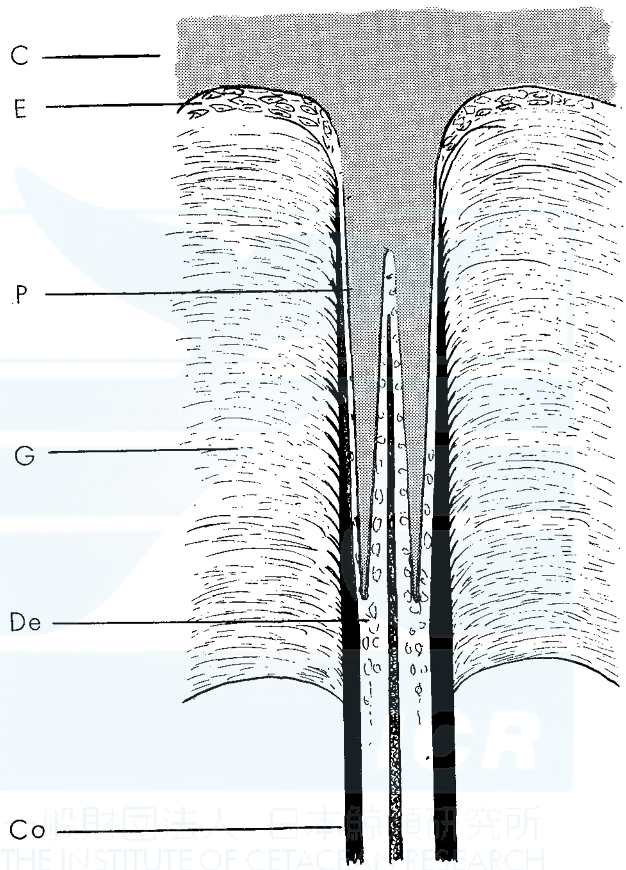

Fig. 7. Diagrammatic sketch indicating the base of baleen plate, modified from the original (Utrecht, 1958)
C: Connective tissue of palate. E: Epithelium. P: Papillae covered with epithelium. G: Gum. De: Dead epithelial cells in the hollow part of horn tube. Co: Cortical layer.

a flat sheaf. The medullary layer is covered by the outer layer, cortical layer which is pushed out by the continuous cornification of the gum cell. A diagrammatic sketch of the structure of the baleen plate was drawn by W. L. van Utrecht and included in the paper by Slijper (1958). In Fig. 7 I indicate a diagrammatic sketch, modified slightly from the original, to confirm the structure of the baleen plate and to help the understanding for my interpretation.

The gum composed of non-cornified epidermal cells undergoes constant cell division by which worn off material is continually replenished from the basal layer. Two descriptions are cited here with regard to the formation mechanism of the cortical layer and the horny layer, because such two parts are necessary to understand the baleen plate as an age indicator of the fin whale.

' Because of this cell division and the consequent outward migration of cells, tensions are set up in a specific spot close to the wall of the baleen. These tensions cause cornification of the gum cells. The resulting cornified layer is pushed out with the tubules and the gum, and emerges as the cortical layer of the tubules. The gum itself contributes no further material to the baleen, new material being added exclusively by the cell covering the walls of the baleen where they face the gum. The cells of this intercalated layer shift outward with the horn tubules and the cells of the gum, and gradually become cornified. Hence the thickness of the cortical layer is determined by the thickness of this special intercalated layer——. Difference in thickness may be produced in these regions ' (Slijper, 1958). In the skin or epidermis external to the papillae the horny tubes are formed and it is the free ends of these which make the baleen fringe (Burne's cetacean dissection, 1952). These two descriptions suggest us that two parts of each baleen plate derive from the different phases of the epithelium of the upper jaw.

Examining the longitudinal and transverse sections of the baleen plate from the full grown fin whale, Ruud (1940) concluded that one medullary tissue is formed gradually from one papilla and probably keep the same thickness from the young to the old. This finding supports his method for the age determination from the baleen plate. Tomilin (1945) reported independently the significance of baleen plate as an age indicator. The proposal that the variation of the thickness in the baleen plate must be due to variations of the thickness of the cortical layer was accepted also by Nishiwaki (1950b) who examined the age of the blue and the fin whale in the Antarctic by the same method as Ruud.

Considering the structure of the baleen plate, I had some doubts on this proposal supported by the previous workers. The horny layer is formed gradually onwards by the movement of the keratinized cell in the epidermis of the projected papillae. If the speed of keratinization is constant and no physiological factors accelerates or reduces the keratinized degeneration of the epidermal cell, the thick ness of the horny layer seems to be constant. But it is generally difficult to accept these conditions in the animal tissue.

As indicated in Fig. 8, the part of the outer margin of the baleen plate was planed down on the glass plate as a long strip from 0.2 mm to 0.3 mm thickness. It demands a kind of technical skill to obtain the perfect material along the outer curvature of the plate. After the smooth long strip was obtained successfully, the remains was used for recording the baleen sculpture.

Taking the photograph of the long strip through the same method already described, I measured the total thickness of the plate, the thickness of the cortical layer and the horny layer respectively from the tip to the end of the horny tube in the baleen plate. The measurements are made by the 10x shadowgraph. Fig. 9 indicates the measurements for three parts and the photograph of the long strip for this baleen plate. Both in parts of the tip and of 30–40 cm from the tip, the measurements was impossible, because of the vague border mainly based on the thick section. In an example of Fig. 9, the horny layer fluctuates between 1.0 mm and 2.2 mm thickness, indicating three or more peaks, whereas the thickness of the cortical layer increases from the tip to the base of the plate, varying from 0.4 mm to 2.3 mm.

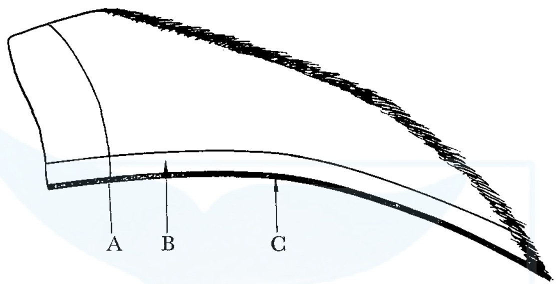

Fig. 8. Outline of a longest baleen plate of fin whale.
A: Gum line.
B: Portion used for recording sculpture.
C: Portion used for the photographic method.

Nevertheless the total thickness is expressed as a sum of both thickness in the cortical and the honry layer, its fluctuation is mainly affected by the varying thickness of the honry layer. Four arrows in Fig. 9 indicate positions of discrepancy in the thickness between the horny and the cortical layer. In spite of the lower value in the cortical layer, the higher value or the peak is given in the horny layer at the position indicated by arrows. At the first arrow, the total thickness is comparatively thinner but does not indicate the trough in its fluctuation. This figure shows that the fluctuation of the thickness is out of phase between the cortical and the horny layer.

The photograph of this specimen indicates that the growing direction of the baleen plate is not uniform but has several changes. At the points shown by arrows, there are remarkable inflections in the growth direction of the plate. In the photograph, the anterior surface of the plate is taken in the lower side. I found the inflection point of the plate correspond to the increasing part or the peak in the fluctuating thickness of the horny layer, in the examined specimens. This fact suggests that the active keratinization of the epidermal cell on the remarkably projected papillae determines the growth direction of the baleen plate. During the active formation, the growth of plate become rapid in thickness as well as in length. The inflections result from the alternation of the active and resting formation. Such inflections often exist in the accumulated layer of keratinized cells. In the course of the histological study on the ear plug of baleen whales, I have pointed that the inflection of the longitudinal bright layer is affected by the

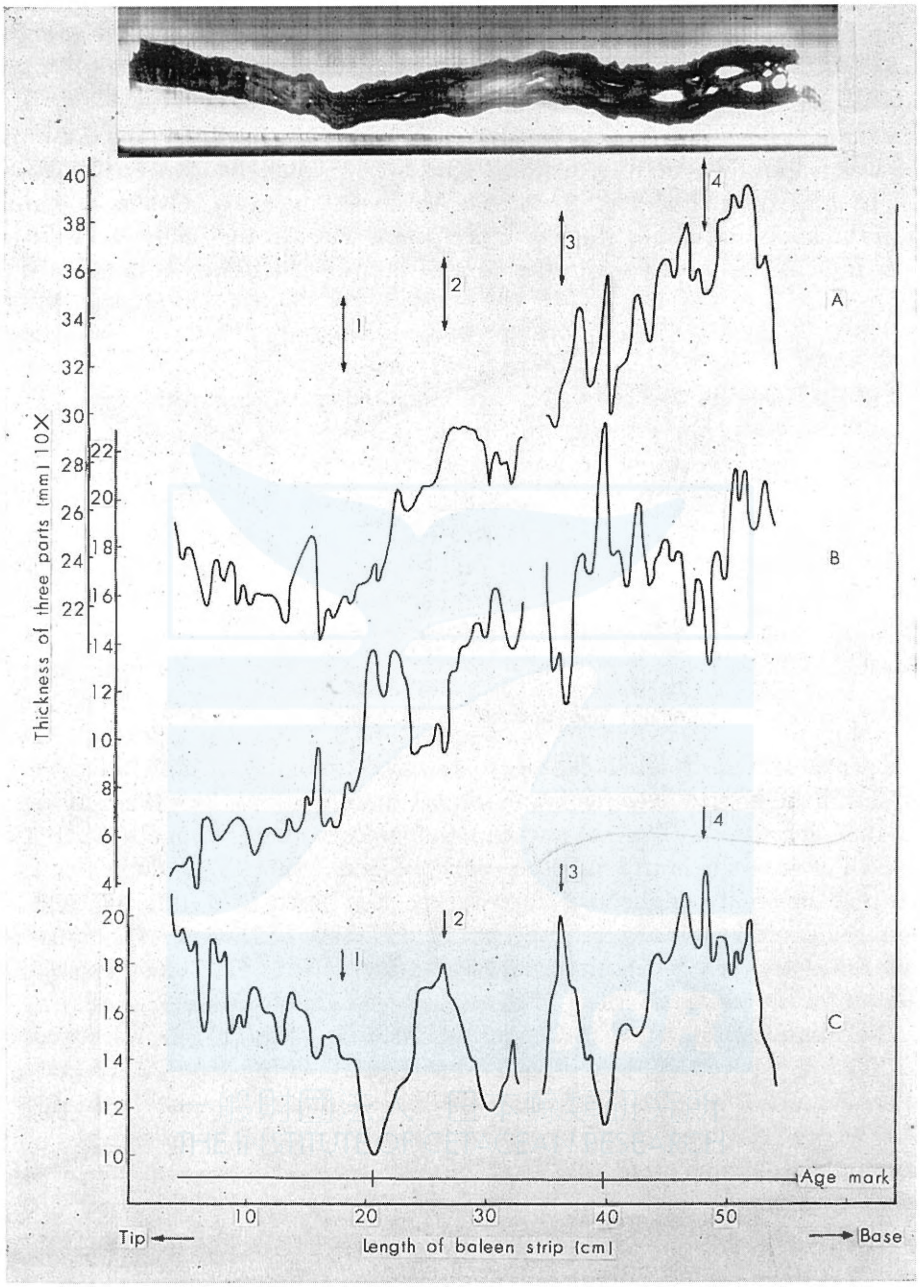

Fig. 9. Fluctuation of thickness for three parts of a baleen plate from a 60 feet long female fin whale in the Antarctic.

A: Total layer thickness. B: Cortical layer thickness. C: Horny layer thickness.

physical force during the accumulation of keratinized cell in the glove-finger epidermis (Ichihara, 1959). Numbers of varying vectors are related to the age unit of the baleen plate.

As indicated in Fig. 9, the age mark in the trace of the baleen sculpture lies in the position between two inflection points of the photographic section. In the baleen plate from the grown fin whale, an age unit generally includes two or four changes of vectors in the longitudinal growth of the baleen plate.

Ruud (1940) has also described that the medullary tissue varies little in the thickness longitudinally in the plate and that there remain the possibility of new papillae gradually formed. It should be noted that the thickness of the medullary tissue varies much than Ruud reported.

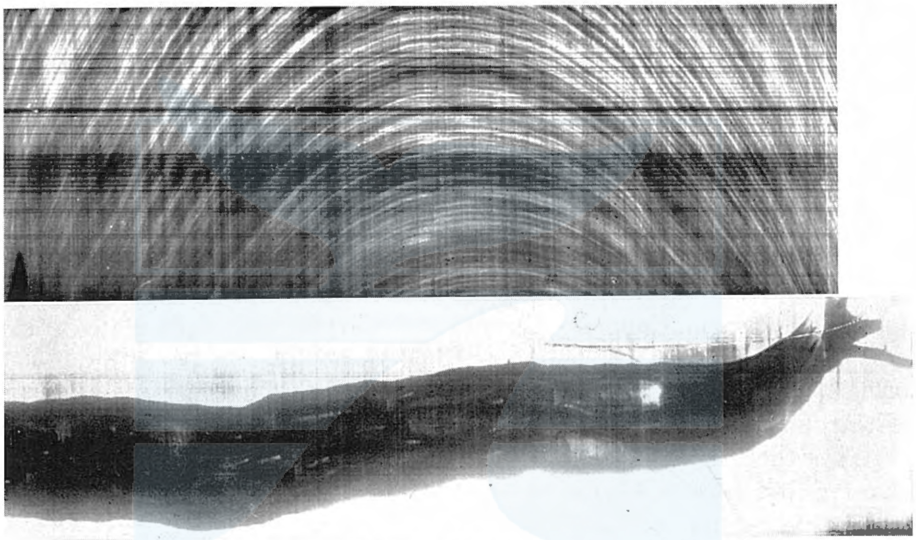

Fig. 10. Comparison between the longitudinal sculpture on the surface of a baleen plate and the changing vectors in the longitudinal section of the same plate. This photograph was obtained from a longest baleen plate of a 54 feet fin whale in the Antarctic.

Yablokov and Andreyeva (1965) found the ring-like structure in the walls of large and small tubules composing the medullary layer. They state that there is possibly a positive relation between the tubule stratification and the age of the baleen whale, however, the great variation in the thickness of the medullary tissue throws doubt upon the increasing stratification with the advancing age of the whale.

Each horny tube running longitudinally is embossed on the surface of the plate. Its embossment runs as parallel lines at a glance, but there are several periodical inflections in detail on a plate. In Fig. 10, the photograph of the surface structure in the plate is compared with the photograph of the longitudinal section.

The surface structure of the plate is taken in photograph by the devised method already mentioned. The inflection of running lines occurs simultaneously on the growing plate, that is, these inflections appears at the same position on the plate.

The fact that these inflections are coincident with the inflections in the longitudinal section of the plate, indicates that the baleen plate bends periodically not only from the anterior to the posterior but from the left to the right direction. All these bend ings are influenced by the periodic growth in the thickness of the medullary tissue of the plate.

GROWTH OF BALEEN PLATE AND ITS VALIDITY AS AN AGE INDICATOR

In this chapter, I present a historical review for previous works concerning the growth of baleen plate and its validity as an age indicator. Mackintosh and Wheeler (1929) states that the first rudiments of the two blocks of baleen plate are found after the blue whale foetus reaches a length of 2 metre or more and then two plain strips of a soft whitish material appear, one on each side of the upper jaw. They state, furthermore, that at the 2.5 to 3 metres, minute transverse ridges appear on these strips and later develop into whalebone plates. They refer to the prenatal development of the baleen plate in the fin whale, reporting that the development of the baleen plate in the blue whale foetus applies equally to its development in the fin whale foetus. Ohsumi (1960) found the first rudiments of the baleen plates at the length of 1.75 metre in the antarctic fin whale foetus. These foetal lengths corresponds to the 7th pregnancy months for both species, according to the reasonable foetal growth curves indicated by Laws (1959). The initial baleen plate develops in the latter half of foetal stage, and after birth its length and width grow with the increasing length of whale as the filter organ of the swallowed zoo-planktons.

There are two stages in the development of the baleen plate in the postnatal growth. For the antarctic fin whale, Mackintosh and Wheeler (1929) have pointed out that the first growth of the lengths in plates is followed by the sudden spurt in the early life.

The baleen plate is exposed in the month of the baleen whale, and rubbed by the entrance and exit of the water and food during feeding. If the influence of these continuous frictions to the thickness of the plate is intensive, besides, it is different at the locality of the plate, the traces of the surface sculpture in the plate will be disturbed in the periodicity. In the fin whale, Ruud (1940) describes that the surface sculpture of the plate appears to be unaffected by wear from the base up to very near to the tip.

Ruud (1945, p. 35) indicated the tracing records for the baleen plate sculptures from 8 calves taken in the coast of Norway. All of these young fin whales were accompanied by cows and hence they are in the sucking or the weaning stages. The characteristics of these tracing records lies both in the presence of the prenatal plate and in the uniform thickness of the plate from the birth to killing. In addition to these valuable records, many traces are shown by him for fin whales from the young to the old age. It is important that the great similarity is found in these traces from fin whales of the same growing stage. In the personal communications, Mr. G. C. Pike indicated me very valuable records of baleen plates from young fin whales captured in the North Pacific. The clear similarity in tracing pattern is found for these 17 records from British Columbia fin whales. Taking notice the similar tracing pattern for baleen plates, Chittleborough (1959) determined ages of Australian humpback whales. He indicated typical records of baleen plate sculptures from a 1-year old individual to 6 year and more old individuals. Finding the similar pattern or the periodicity in the fluctuating thickness of the plate, Ruud proposed the theory of the age determination by means of the baleen sculpture in the baleen whale. He estimated that the different levels in the thickness of the plate are associated with annual alternations of a storing metabolism in the cold water and a consumptive metabolism in warm waters and that every period would then represent a year in the whale life. Nishiwaki (1951) has estimated that the inter val zone between the successive two main ridges on the baleen plate corresponds to the annual growth of the plate, by the statistical treatment of the baleen length formed in the antarctic feeding period. These indirect estimations concerning the annual formation were checked by the marking experiments. Dawbin (1959) and Chittleborough (1960) reported the validity of such estimations, examining the baleen plate sculpture of young humpback whales which were recaptured off New Zealand and Australia. These whales were marked at the known age in the early life.

PERIOD OF SUCKLING

Determining the age of very young whale by sculpture records needs the accurate knowledge about the periods of lactation and weaning. Scouting catcher ships were often dispatched to various localities in the Antarctic to observe distributions and the movements of fin whales. In the Japanese expeditions I requested experienced captains of these ships to take records of calves accompanied by fin whale cows. Besides, in the voyages for the whale marking under the International Cooperation, body lengths of calves were estimated from the ships. A pair of cow and calf is discriminated from the other fin whales in the following swimming habits. The thin cow accompanying the calf always rises to the surface of water at every spout of the calf even if she does not respirate at that time. All scouting ships took records, confirming this habit during the chase of fin whales. In the 1964/65 season in the Antarctic, 40 voyages were tried to examine the distribution of the fin whale. Monthly frequencies of these cruises are shown in Table 1.

The peak of the frequency in the scouting voyage was in February among the examined period from October 23 and March 24. Ten ships which worked for the whale observation in a total of 817 days covered the area of 30°S–65°S and of 90°E–0–170°E in the Antarctic. In such vast areas, only 63 pairs of fin whales were observed mainly in Area III (0°–70°E). Table 2 shows the latitudinal localities of swimming cows accompanying calves during the observation by ships.

Except two pairs in January, most of pairs were observed far north than 60°S. The mode of basic numbers is in the range of 45°–50°S in December and in the range of 50°–55°S from January to February. From a few records in November and March, there is no definite finding. However, Table 2 shows a trend that cows and calves remain in warmer sea far north than the antarctic convergence in the early of the summer and enter gradually in the southern waters with advance of month. The low frequency of the observed sucklings is mainly based on the recent depletion of the stock in the antarctic fin whale. The recent overfishing to the mature stock of the fin whale has reduced numbers of new born calves.

Simultaneously, it is impossible to neglect the ecological feature of sucklings. Discussion on this point will be made later. The occurrence of the pair is indicated in a broken line curve in Fig. 11 as the monthly percentage frequency.

TABLE 1. FREQUENCY OF THE 1964/65 RESEARCH VOYAGE BY MONTH FOR OBSERVING FIN WHALE COWS AND CALVES IN THE ANTARCTIC

Month	Frequency of voyage
October	2
November	5
December	6
January	9
February	12
March	6

TABLE 2. LATITUDINAL DISTRIBUTION OF OBSERVED 63 PAIRS COMPOSED OF COWS AND CALVES IN THE ANTARCTIC FIN WHALE.

Range of latitude	October	November	December	January	February	March	Total
40–45°S	—	1	5	—	—	—	6
45–50°S	—	—	13	2	1	—	16
50–55°S	—	1	9	12	4	1	27
55–60°S	—	2	—	6	3	1	12
60–65°S	—	—	—	—	—	—	—
65–70°S	—	—	—	2	—	—	2
Total	—	4	27	22	8	2	63

The mode of this curve is in the middle of December and the mean is in the third week of December. The shape of the curve for the antarctic fin whale has a slightly positive skewness indicating a resemblance to the shape of the curve of calving frequencies indicated by Mackintosh & Wheeler (1929) and Laws (1961). The occurrence of the lactating female which was examined by biologists on board the recent Japanese expeditions in the Antarctic, is shown in a full line curve in Fig. 11.

Since the catch of the fin whale is prohibited after April 8 in the Antarctic by the International Whaling Convention, the mean month for the occurrence of the lactating fin whales is not accurately determined by this figure. From the analogous shape between two distributions, it is estimated that the peak influx of the lactating female is in the middle of February and the mean occurrence is in the end of February. If the extrapolation for the decline of the curve is permitted, this figure suggests that there may be the occurrence of the lactating female until the coming May and June.

In the past pelagic antarctic whaling, generally speaking, there were records that fin whales were captured near to the ice-pack line. Before the depletion of the whale stock became remarkable, fin whales distributed widely in the area where *Euphausia superba* raises as the main food. After the 1959/60 season, the pelagic whaling ground has inclined towards the northern part than in the past. This tendency has been remarkable from year to year and the recent catch of fin whales has taken place far north than the antarctic convergence. Numbers of fin whales captured by the Japanese expeditions from the 1959/60 season to the 1961/62 season are shown in Table 3, in which the captured locality is summarized by 5 degree of latitude and by the whaling area. In the 1959/60 season, 69.2 percentage of the total was captured from 55°S to 60°S, 50.1 percentage in the 1960/61 season from 55°S to 60°S and 51.8 percentage in the 1961/62 season from 50°S to 55°S.

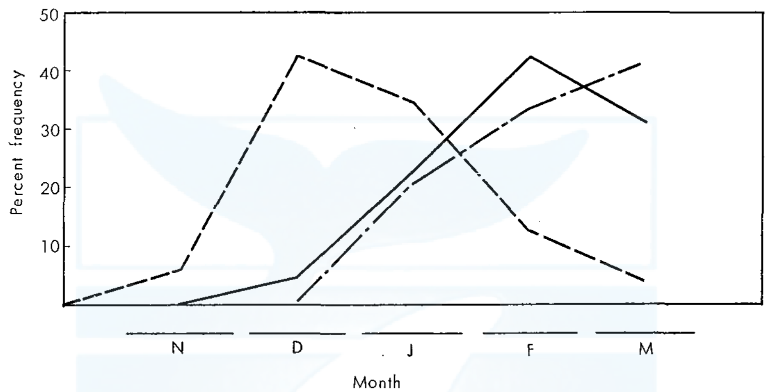

Fig. 11. Occurrence of cows accompanied by calves and of lactating females in the Antarctic fin whales.
- - - - -: Observed cows and calves. ———: Examined full lactating females.
— - —: End of lactating stage.

According to the International Whaling Statistics, the Japanese whaling fleets took 33.7 percentage of the total pelagic catch for fin whales in the 1959/60 season, 32.5 percentage in the 1960/61 season and 44.8 percentage in the 1961/62 season. In spite of the recent bias of locality in the whaling ground, much food composed primarily of *Euphausia superba* has been found from the examined fin whale, in particular far south than the antarctic convergence. Because of the extreme concentration of the whaling ground, it was rare to observe fin whales even in more southern areas near the ice pack where patches of krills were often observed in the sea. One of resonable causes which account for the recent bias of the whaling locality seems to be the extreme depletion of the fin whale stock in the An tarctic. There is no remarkable difference in the antarctic sea condition between the past and the recent days (Mackintosh, 1946., Nasu, 1966). Most of fin whales entering to the Antarctic remains recently the feeding area near the antarctic convergence (about 50°S) through the summer season and do not migrate so far south. This habit is neither observed nor reported in days when fin whales were abundant. On the basis of the figures for the period 1927–35 for South Georgia and 1945–47 for the pelagic catch, Laws (1961) reports that the month of occurrence of the lactating female is slightly different between two whaling localities. The mean month of the catch for the lactating female is in January for the South Georgia waters and in February for the pelagic whaling grounds.

TABLE 3. LOCALITIES OF THE FIN WHALE CATCH BY THE JAPANESE EXPEDITIONS FROM THE 1959/60 SEASON TO THE 1961/62 SEASON IN THE ANTARCTIC

1959/60 season

Latitude	Area II	Area III	Area IV	Area V	Area VI	Total	%
45°–50° s	—	1	11	47	—	59	0.7
50°–55°	—	—	27	154	—	181	2.0
55°–60°	—	—	5913	238	—	6151	69.2
60°–65°	—	601	526	674	195	1996	22.4
65°–70°	—	195	—	190	123	508	5.7
70°–75°	—	—	—	—	2	2	0.0
Total	—	797	6477	1303	320	8897	
%		9.0	72.8	14.6	3.6		100.0

1960/61 season

Latitude	Area II	Area III	Area IV	Area V	Area VI	Total	%
40°–45° s	—	86	—	—	—	86	1.0
45°–50°	—	1096	259	—	—	1355	15.2
50°–55°	—	954	276	—	—	1230	13.8
55°–60°	—	2395	1493	—	574	4462	50.1
60°–65°	—	231	16	236	1282	1765	19.8
65°–70°	—	—	—	—	5	5	0.1
Total	—	4762	2044	236	1861	8903	
%		53.4	23.0	2.7	20.9		100.0

1961/62 season

Latitude	Area II	Area III	Area IV	Area V	Area VI	Total	%
45°–50° s	—	940	69	—	—	1009	8.5
50°–55°	226	5269	643	—	—	6138	51.8
55°–60°	—	1956	2052	—	—	4008	33.8
60°–65°	—	547	—	—	—	547	4.6
65°–70°	—	153	—	—	—	153	1.3
Total	226	8865	2764	—	—	11855	
%	1.9	74.8	23.3				100.0

Remark: Area II (60°W–0°), Area III (0°–70°E), Area IV (70°E–130°E), Area V (130°E–170°W), Area VI (170°W–120°W)

He suggested that the influx of lactating females to the whaling grounds might begin when sea surface temperatures rose above about 0°C and that it occurred about 5–6 weeks earlier in the South Georgia waters than in the pelagic whaling ground. The locality of the pelagic whaling ground in the 1945/47 season which Laws reported, could be estimated to be near 62°S from his descriptions. As mentioned above, the recent Japanese catch of fin whales has taken place mainly the same latitude or in the slightly southern area in the South Georgia (about 54°S, 37°W) waters (See Table 3), however, the peak influx of lactating females occurs in February in my data. From the 1959/60 to the 1964/65 season, the monthly percent frequency of lactating females is almost constant in the Japanese expeditions. If cows accompanying calves were killed at random from January to March, the shape of the full line should be different from that indicated in Fig. 11 and show the peak in December. In this meaning, it seems to me that Laws emphasized extremely the incidence of the lactating females in the South Grorgia catch for estimation of weaning date. The shape of frequency distribution curve of the lactating whale in the South Georgia waters is different from that of the calving curve. The earlier influx of lactating females in the South Georgia waters may be dependent on the habit in subpopulations of fin whales which both the recovery of the whale mark (Brown, 1954) and the examination on the blood type (Fujino, 1964) revealed. My data for the lactating females primarily come from area III (0°–70°E).

Both from the field observation on calves accompanied by cows and the frequency of the lactating females in the pelagic whaling, I conclude fin whales wean calves in the end of January when 50 percentage of weaning occurs in the sucking calf of the fin whale. Since the mean calving date for fin whales in the southern hemisphere is determined in the end of May (Laws, 1959), the period of suckling is about 8 months for the antarctic fin whale. Mackintosh & Wheeler (1929) suggested that the lactation period was about 6–7 months for the antarctic fin whales and estimated that the average length of the calf at weaning was probably about 12 metres, on the basis of an apparent increase in the rate of growth of the baleen plates at weaning and on the sizes of the largest sucking calves and the smallest independent calves. Ash (1956) also estimated the weaning date using the blubber thickness of the lactating female fin whale. The average blubber ratio (blubber thickness in cm/length of whale in feet) of five lactating females given by Ash is 0.279. If these lactating female are very near to weaning, the fatness curve for non-pregnant female is extrapolated backwards in time to a value of 0.279. In the non-pregnant female, this value correspond to the third week of December. Laws (1961) also confirmed the period of lactation that was proposed by Mackintosh and Wheeler. In these previous papers, the period of lactation is slightly underestimated. Fig. 11 indicates that the peak occurrences in pairs of cows and calves is in the third week of December, 7 months from the calving date.

The Japanese catcher ships engaged in the whale marking under the International Cooperation estimated the body length of cow and calf from the deck. From the 1954/55 season to the 1964/65 season, body lengths of 18 fin cows and calves were estimated by experienced gunners and captains in the Antarctic. Table 4 shows estimated lengths for cows and calves from November to January. Numbers of observed calves listed in this table are excluded from Table 2 and hence not used for estimating the occurrence of cows and calves. Because the data on the marking voyages do not include all records of observed cows and calves. The mean length for the fin whale calf is estimated as 44 feet in December and 45 feet for three months period.

In order to check whether the estimation is correct or not, I utilized the result of marking experiments. At the whale marking, lengths of all swimming whales have been estimated by gunners and captains from the ship. If the hit mark is recovered during the same whaling season, the estimated length would be checked at the flensing. I pick these whales up from the marking records reserved at the Whales Research Institute. From the 1956/57 to 1962/63 season, the numbers of fin whales in this case amounted to 46 and no case from the 1963/64 to 1964/65

TABLE 4. ESTIMATED LENGTH OF FIN WHALE COW AND CALF, BY RESEARCH SHIP IN THE ANTARCTIC.

November		December		January		Total
Cow	Calf	Cow	Calf	Cow	Calf	Calf
67	45	71	30	68	40	30×1
67	45	68	35			35×1
69	47	60	40			40×3
?	54	65	40			45×6
		65	45			47×2
		?	45			50×4
		67	45			54×1
		72	45			
		65	47			
		67	50			
		68	50			
		70	50			
		70	50			

season. Estimated lengths from the catcher ships are plotted against the measured lengths on the floating factories in Fig. 12. When the estimation is correct, the estimated value should be given on a line of 45°. Fig. 12 indicates, however, that there is a bias for the estimation. Over 63 feet in length, the length of the swimming whale is underestimated, whereas it is overestimated for the whale under 63 feet. This tendency may be a characteristics for the Japanese estimation. Kawakami (1956) presented a note on this problem for the fin, sei and sperm whales in the North Pacific, but the conclusive tendency was not examined on account of a few material. Although it is resonable that the young whale grows faster than the old whale between the marking and the recovery, the human bias overestimated the length of the young at the sea. This bias may come from the size limit, 57 feet in length, imposed on the fin whale and reflect the human desire in the whale catch, but the principal reason for underestimating of large whales probably lies in the relative shortness of tail region. With the growing body length of balaenopteriid whale, the percentage of tail region to total length gradually decreases. This trend of estimation is applied for the suckling but the extrapolation in Fig. 12 is not appropriate.

It is safe to say that the length of the fin whale suckling also is overestimated on the sea and a calf of 54 feet in length (Table 4) is too large. The actual length of the calf in December seems to be under 44 feet (13.4 metres) in length.

Mackintosh and Wheeler (1929) stated that in the growth of the baleen plate of the fin whale no spurt took place after the calf had reached much more than 13.0 metre and that one might expect it occurred between 12.0 metre (39 feet) and 13.0 metre (43 feet). According to their Fig. 96 it is reasonable to think the rapid growth of the baleen plate occurs at 43 feet in the length of the calf. Because the growth curve of the baleen plate is discontinuous at 43 feet of the whale length.

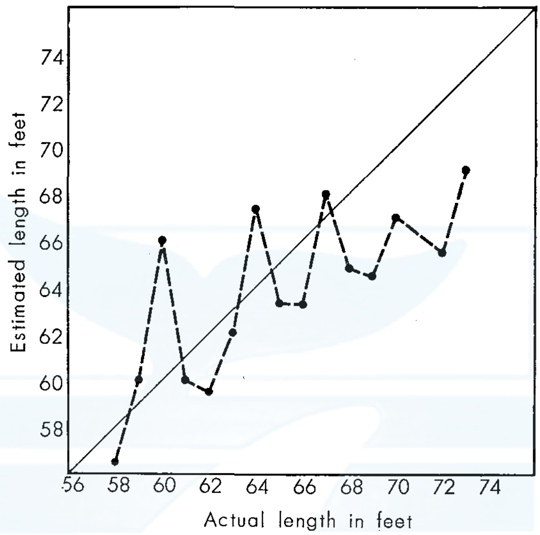

Fig. 12. Bias in the estimated length for the antarctic fin whale, checked from the recapture of marked whales in the same whaling season.

Measuring the longest plates from very young fin whales captured off the norwegian coast, Ruud (1945) testified that the growth curve of the plate, estimated by Mackintosh and Wheeler was valid. The rapid growth of the plate at 43 feet of the whale length suggests the shift from sucking milk to swallowing krill in the feeding habit. The growth of the plate is followed by the elongation of fringes which consist of the exposed horny tubes in the medullary tissue of the plate. There is a important relation between the feeding habit of the baleen whale and the size of the fringe in the plate (Tomilin, 1954). Besides this finding, Nemoto (1959) pointed out that the young fin whale has finer and shorter fringe than the old.

As in the case of the terrestrial mammal, there is also a weaning period for the fin whale. In this period, the fin whale calf will suck milk from the cow as well as feed on the plankton. It is difficult to determine the accurate period of weaning. It is possible, however, to assume that a short period in the end of sucking stage is occupied by such a weaning period. Tavorga and Essapian (1957) observed such a weaning period in *Tursiops truncatus* kept in the aquarium. In the fin whale, the weaning period is estimated to be not so long as in the bottle-nosed dolphin because of limited distributions in food. On the basis of 27 females in the recent Japanese expeditions, the frequency in the end of lactating stage is illustrated in the chain-line curve of Fig. 11. Laws (1961) reported that the thickness of mammary gland decreased under 17 cm in the end of lactation in the antarctic fin whale and Chittleborough (1958) noted in the Australian humpback whale that after lactation has ended, when involution of the gland is well marked, there may be liquid in the lacteal ducts, which is usually a whitish or turbid yellowish thin fluid. From examined lactating females, I picked up individuals satisfying two findings by Laws and Chittleborough. My small samples show that the peak frequency occurs in March and suggests that the fin whale calf becomes independent of the cow in the antarctic summer.

In conclusion, it is estimated that the sucking period including the weaning period is about 8 months from late-May to late-January for the antarctic fin whale and that around the antarctic convergence the calf is weaned from the cow at 43 feet in length.

Accurate estimation is indispensable to determining the formation period of the dark and bright layer in the ear plug.

RELATIONSHIP BETWEEN RECORD OF BALEEN SCULPTURE AND PHOTOMETRIC RECORD OF EAR PLUG

The tip of the growing baleen plate is gradually worn off by the friction with the lower jaw. This is the fatal defect for the age determination by means of the baleen plate. Strictly speaking, only the age of very young whales, of which baleen plates possess the neonatal marks on their tips, is determined by this method. The conspicuous convergence of the horny tubes is present from the gum towards the tip on the baleen plate from the sucking calf. It is important for the age determination by the baleen plate to decide whether or not the neonatal mark remains until any age.

It is essential to obtain very young baleen plate in order to examine the formation of ear plug laminae in the early life. 22 baleen plates were collected from fin whales during several years. One of these longests plates comes from a stranded young fin whale in the Okhotsk Sea. It is estimated that this male strayed apart from its mother in the weaning stage, judged from the body length of 42 feet. 21 baleen plates come from the antarctic whaling and include those from the weanlings misshot by the gunner of the catcher ship. Perfect ear plugs were collected from 20 fin whales and the photometric recording was applied to them. In individual from which imperfect ear plug is taken, only baleen sculpture was recorded and compared with others. Table 5 lists these samples and biological data.

The estimated lengths of Nos. 3. 4 and 6 seem to be too high, compared with the growth curve of the baleen plate, the broken line, given by Mackintosh & Wheeler (See Fig. 13). The length of the longest baleen plates from each whale is plotted in Fig. 13 where the open circle indicates the plate with neonatal mark on its tip and

TABLE 5. LIST OF EXAMINED YOUNG FIN WHALES

Sample No.	Locality	Date killed	Body length in feet	Sex	Diatom infectien	State of ovaries	Diametre of largest follicle (mm)	Weight of Testes (kg)
1	Okhotsk Sea	Aug. 11	42	Male	None			not measured
2	Antarctic	Mar. 16	48	Female	,,	Immature		
3	,,	Feb. 12	49*	Male	,,			0.2, 0.2
4	,,	Feb. 11	50*	Male	,,			0.4, 0.3
5	,,	Mar. 27	57	Female	,,	Immature		
6	,,	Feb. 26	55*	Female	,,	Immature		
7	,,	Jan. 8	54	Male	,,			0.4, 0.4
8	,,	Feb. 10	57	Male	,,			0.2, —
9	,,	Feb. 17	57	Female	,,	Immature		
10	,,	Dec. 28	57	Female	Incipent	Immature		
11	,,	Feb. 11	57	Female	None	Immature		
12	,,	Feb. 5	57	Female	,,	Immature	5	
13	,,	Jan. 3	57	Male	,,			0.4, 0.4
14	,,	Mar. 6	57	Male	,,			0.5, 0.5
15	,,	Feb. 7	58	Male	,,			0.3, 0.4
16	,,	Dec. 28	58	Male	Incipent			1.0, 1.0
17	,,	Jan. 14	58	Female	None	Immature		
18	,,	Mar. 7	58	Male	,,			0.9, 0.8
19	,,	Dec. 15	60	Female	,,	Immature		
20	,,	Jan. 13	60	Female	,,	Immature	8	
21	,,	Jan. 10	61	Female	Incipent	Immature	7	
22	,,	Jan. 3	74	Female	Incipent	Mature 24 corpora albicantia	20	

* Estimated length

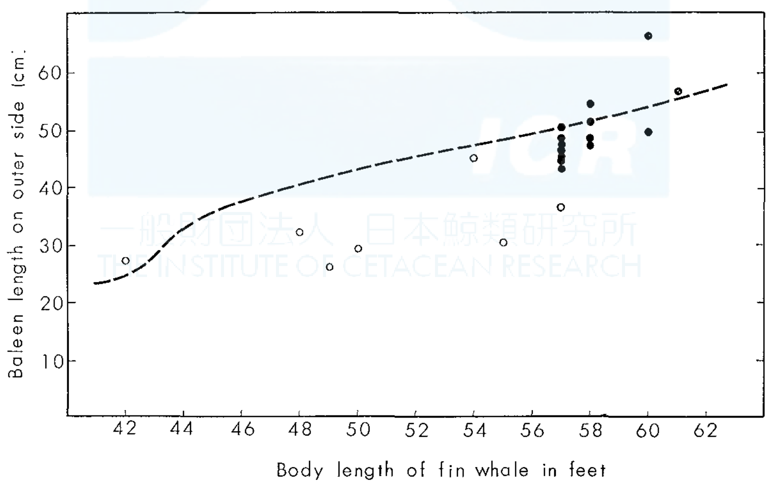

Fig. 13. Growth of baleen plate in the young antarctic fin whale. A 42 feet long male from the North Pacific is included. Broken line is cited from Mackintosh and Wheeler (1929). Open circle: plates with neonatal mark.

the closed circle shows the plate of which the neonatal mark is worn off. Most of my samples distributes along the broken line and the neonatal mark remains only in the baleen plate under 45.0 cm in length along its outer side. No whale over 57 feet, the size limit imposed on fin whales captured by the antarctic whaling, has baleen plates indicating the neonatal mark. Fig. 14 shows frontal views of the

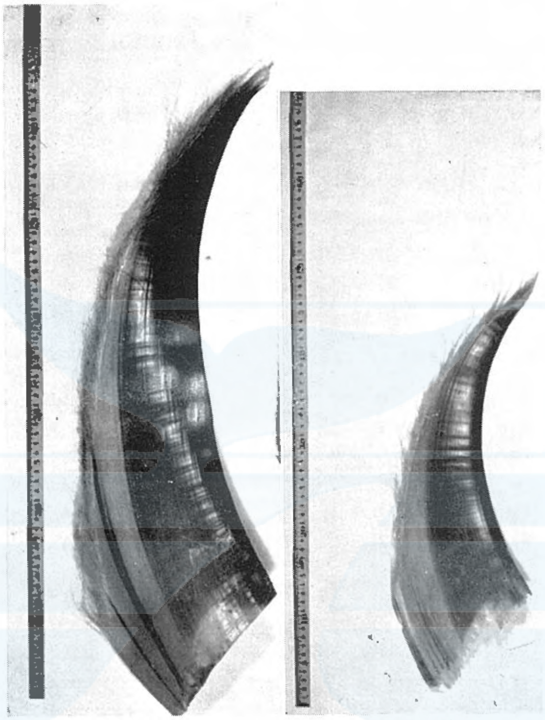

Fig. 14. Longest baleen plates from two fin whales. Sample No. 17 in the left and sample No. 6 in the right. Gum line is remarkably projected in the right plate. Scale unit is cm.

longest plates from Nos. 6 and 17 whale. The shape of gum lines is different between two specimens; the gum line of the plate possessing the neonatal mark is more protrudent than that of 58 feet fin whale.

The photometric records were taken on longitudinally bisected ear plugs collected from Nos. 2, 3, 4, 5 and 7 whales. Since the baleen plates of these whales have the neonatal marks, it is possible to contrast the photometric records for ear plugs with the sculpture records for baleen plates. Observing the view finder of the photometric apparatus, we can check both the prenatal point and the proximal point of plug-core on the recording paper. The bright prenatal layer exists always in the distal end of the core in the ear plugs (Ichihara, 1964) and the last formation of ear plug is seen above the epidermis of the glove-finger. In the careful collection, the epidermis of the glove-finger remains on the proximal end of the ear plug and looks like white layer.

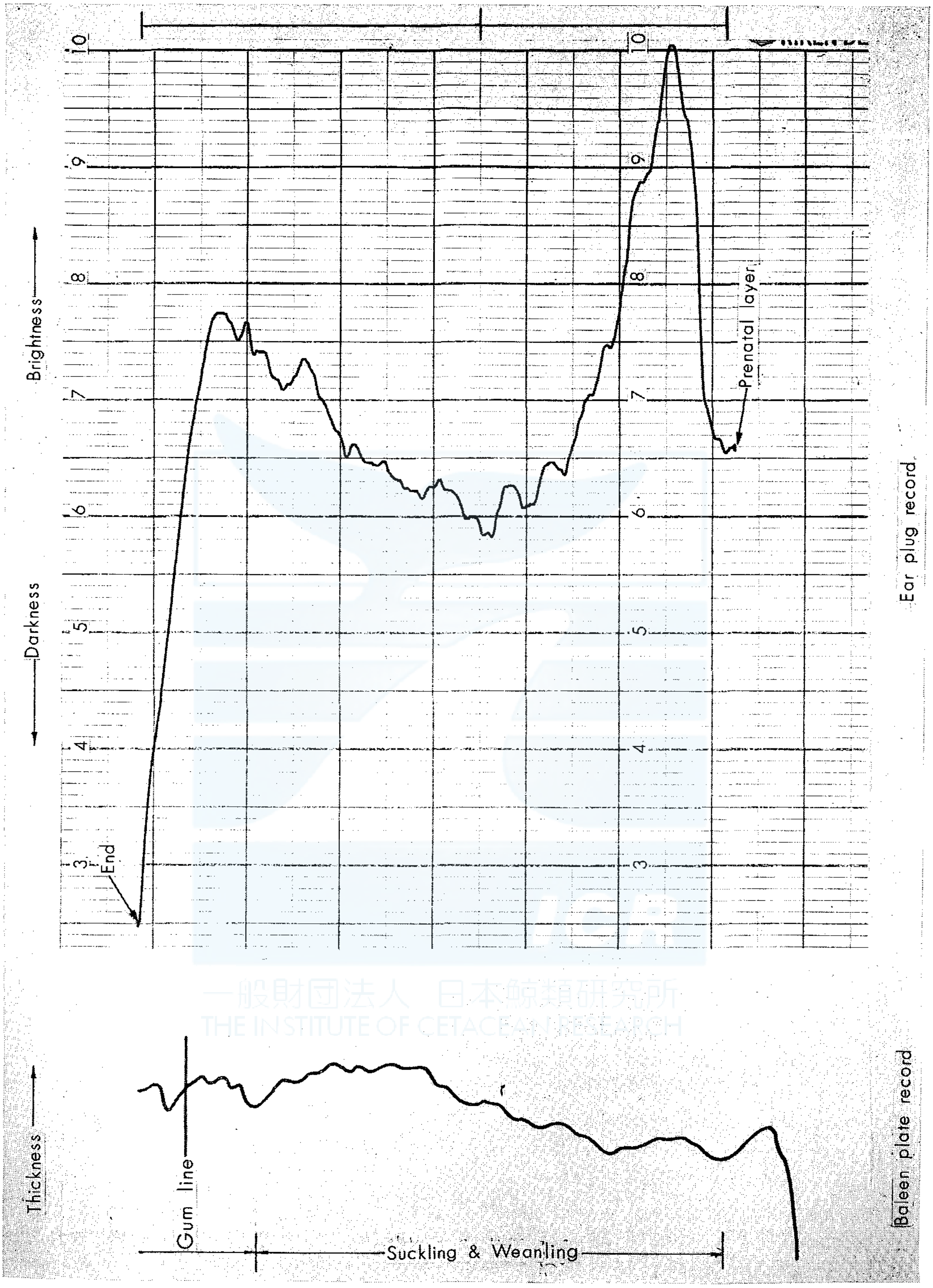

Fig. 15. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 2 fin whale. Core length of the ear plug is 8.4 mm and the length along the outer side of the baleen plate is 32.0 cm. Counts for both age characters are indicated.

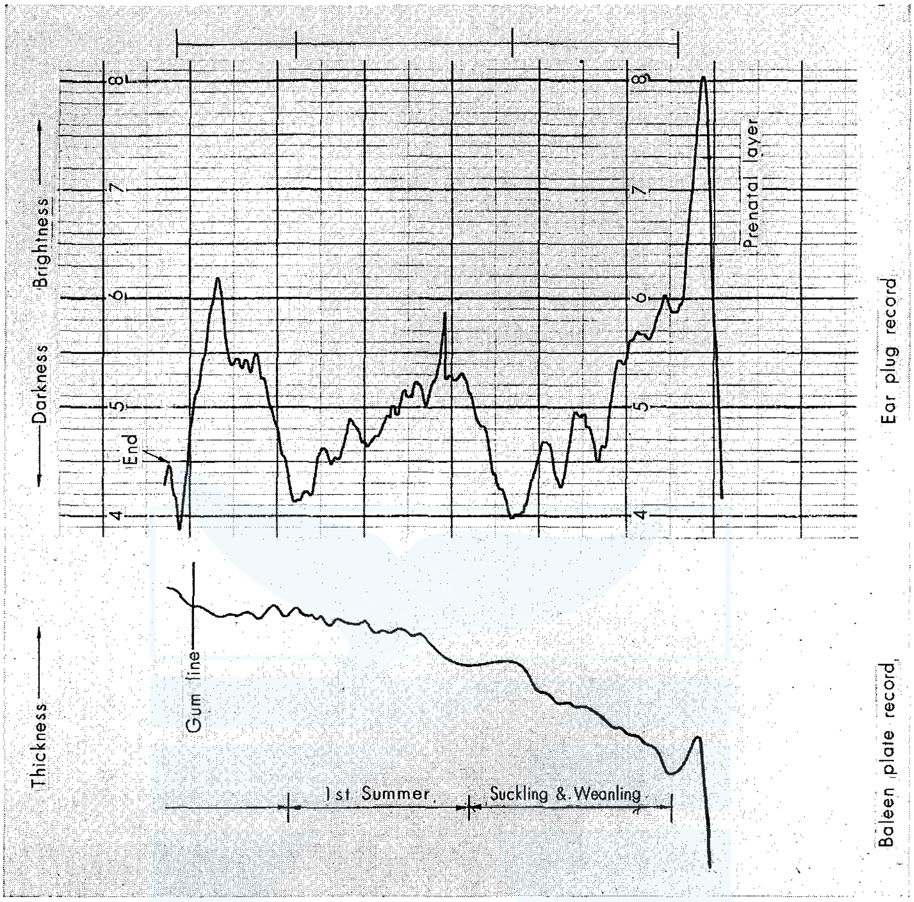

Fig. 16. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 3 fin whale. Core length of the ear plug is 8.4 mm and the length along the outer side of the baleen plate is 26.0 cm. Counts for both age characters are indicated.

These contrasts of records between two age charactors are illustrated from Fig. 15 to Fig. 19, in which age counts for such charactors are also indicated. The count for laminations in the ear plug is made between successive two maximum dark points, because the first dark layer is formed just after birth according to my previous study. There are no clear alternation of dark and bright layers in the photometric records for Nos. 5 and 7 whales. Ear plugs from these two whales indicates the complicated formation of keratinized and fatty degeneration in epidermal cells of the glove-finger. Even for Nos. 5 and 7 photometric records, however, it is easy to count the alternation of dark and bright layer, if we turn the positions of these figures. This is a practical method to interpret the photometric record. Two or three adjacent layers should be counted as one lamina, as in the case of the naked eye count. In many case of young ear plugs, the vague laminae are often

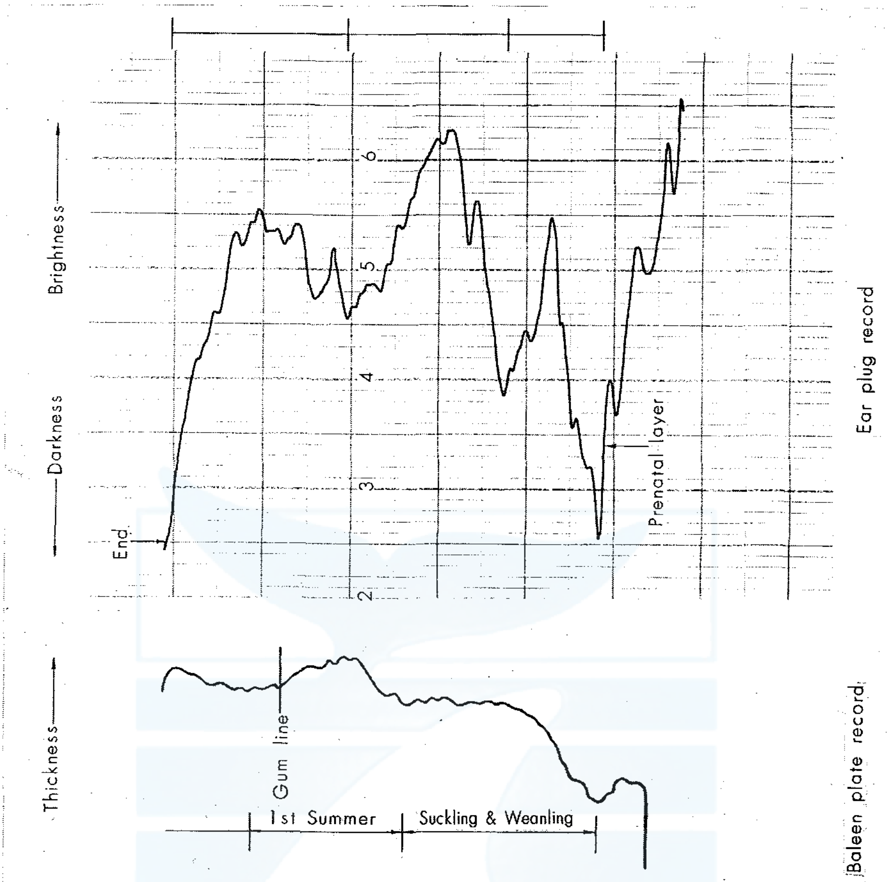

Fig. 17. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 4 fin whale. Core length of the ear plug is 4.3 mm and the length along the outer side of the baleen plate is 29.7 cm. Counts for both age characters are indicated.

present and becomes an obstacle to standardize the naked eye count. Since the sensibility of the photometric apparatus records accurately the vague occurrence of colour, it is possible to check the position of vague laminae. Strictly speaking, each lamina length to be counted as one lamination includes three undulations in the record for No. 5 whale and the situation is more complicated in the record for No. 7 whale than in other records. How to interpret a unit in the photometric record is a way to standardize counting for the alternation of laminae. Since Purves (1955) found the validity of ear plug laminae as an excellent age indicator, many scientists have reported the relation between other age materials and the number of laminae in the ear plug. In these previous reports, the basis of counting is dependent on the naked eye. Even for the young ear plug indicating the occurrence of vague laminae, this simple method has been applied for and whether or not the counting is agreeable has been reported. On the basis of the experienced counting for many

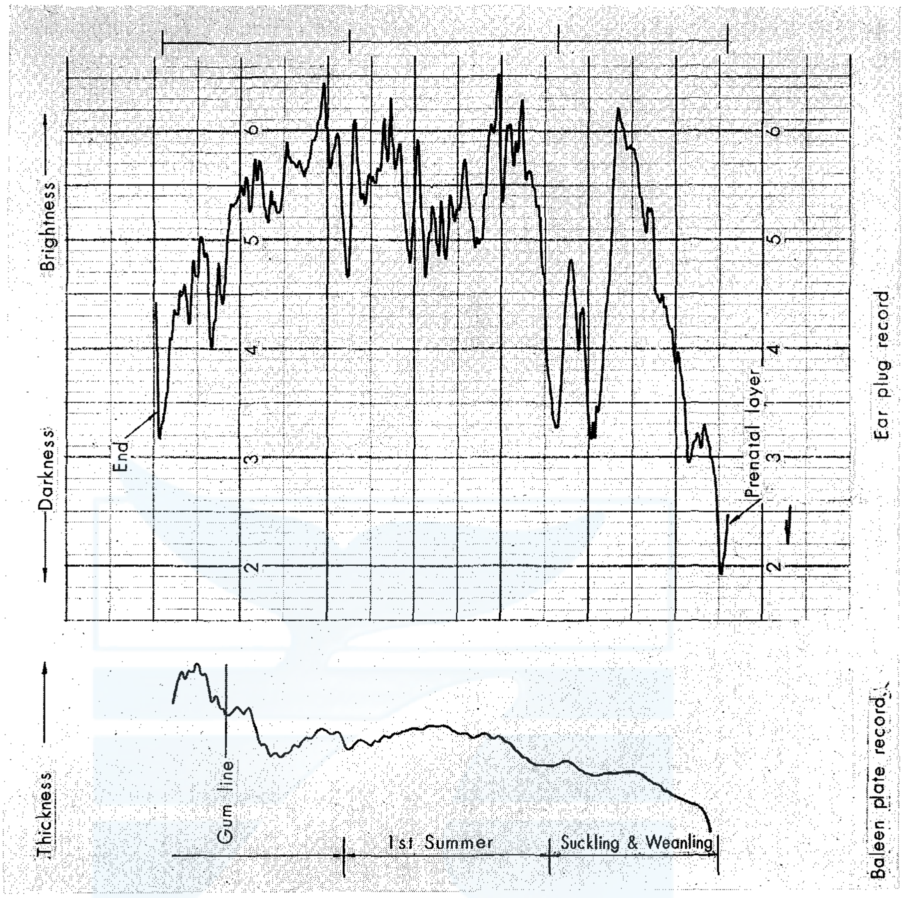

Fig. 18. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 5 fin whale. Core length of the ear plug is 18.2 mm and the length along the outer side of the baleen plate is 45.2 cm. Counts for both age charactors are indicated.

ear plugs collected from the Antarctic and the North Pacific fin whale, I compared the photometric records with the count by the naked eye, particularly for the young ear plug. Counting by two methods is made independently and checked each other. The comparison between two kinds of counting has not been clear until the compensation method of the photometric recording is devised. The all records on Figs. 15–19 are written by this devised method, through which every gradual change of colour on the bisected ear plug can be reproduced.

The traces on the sculpture of baleen plates was made through the improved apparatus by courtesy of Mr. Pike. The end of the record indicates the end of horny tubes in the plate existing in the more proximal portion than the gum line. From the sucking stage to the weaning stage, the trace is very smooth showing a characteristics in the early life of the whale. After weaning, the thickness of the plate

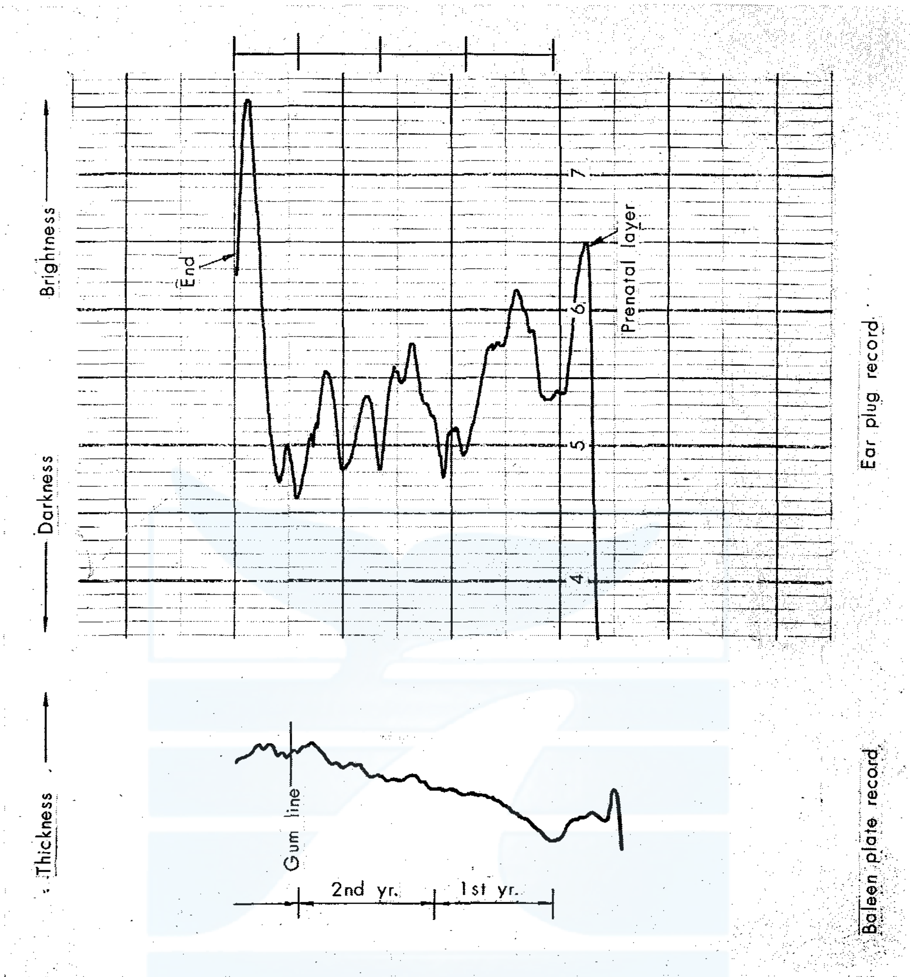

Fig. 19. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 7 fin whale . Core length of the ear plug is 4.6 mm and the length along the outer side of the baleen plate is 36.0 cm. Counts for both age characters are indicated.

undulates at fixed distance. Here, the count is made according to Mr. Pike's suggestion and written in Fig. 15–19. Two kinds of records deriving from different materials are contrasted by the way that both the neonatal mark and the end of records corresponds with each other. The photographs of bisected ear plugs from 5 very young fin whales are shown in Fig. 20. In the plates, there are comparisons between the photometric records and the baleen sculptures from 8 antarctic fin whales. The longest baleen plates from Nos. 10, 11, 12, 13, 14, 17, 18 and 19 whales have no neonatal mark and hence it is impossible to compare two kinds of records in the way applied for whales in the early life. When two undulating records are observed carefully, however, analogous patterns are found in the phase. If we arrange end

Fig. 20. Photographs of ear plugs from very young fin whales. Sample Nos. 2, 4 and 7 from the left of the upper. Sample Nos. 3 and 5 from the left of the lower.

points and suitable trough between two records, it is possible to find a correspondence between rhythmical waves deriving from different material. This interesting fact that at first was noticed in No. 13 records is applied for the other records and indicated in the plates. It is either difficult or nonsense to examine fine waves in two records, because not only the recording mechanism is different between the photometric method for the ear plug and the method measuring the thickness of the plate, but also records is more sensitive in the former than in the latter. The fact that the undulating similarity is found in the case arranging both the end of horny tube and the end of the ear plug, supports the finding that the thickness of horny layer is primarily related to age determined by the baleen plate. As metnitioned already, the fluctuating thickness of the horny layer affects the total thickness of the baleen plate. If the waving thickness of the cortical layer effects on the determined age, it is necessary to try to trace the plate till the end of cortical layer which is divided into two parts at the proximal end. (See Figs. 6 and 9). This try is impossible through the apparatus recording the thickness of plate and unnecessary for the age determination.

There is a slight discrepancy of phase between two records, since the last layer of ear plug is composed of the fresh keratinized or fatty degenerated cells deriving from the glove-finger epidermis and hence it shows the extraordinary thickness in comparison with the other layer formed in the past. Measuring the thickness of each lamina in the fin whale ear plug, Purves (1955, Tex-Fig. 2) reported such a extreme thickness in the last layer. Considering this resonable finding in the formation of the ear plug, the width of the photometric record for the last layer should be shorten. When this revision is applied for No. 11 record in the plates, we can interpret the discrepancy of phase at the end of two records. When this revision is applied for other records in the plates, the importance of the honry tube end is closed up in determining age through the baleen sculpture.

In the early life of the whale, particularly in the suckling and weanling stages, there is no clear similarity between two undulating records. It is difficult from re-

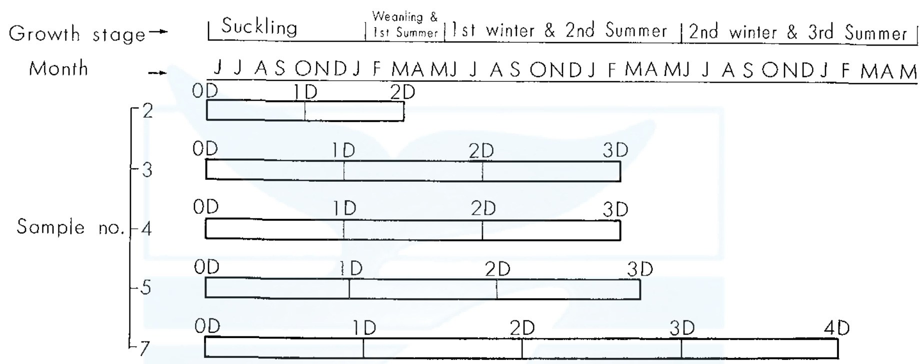

Fig. 21. Relationship between the growth of early life in the fin whale and the occurrence of dark layer in the ear plug. D: Peak of the dark layer formation.

cords to discriminate and evaluate the smooth trace corresponding to the first lamination in the ear plug, however, the following estimation is helpful to do so.

In Fig. 21, the birth months for Nos. 2, 3, 4, 5 and 7 whales are arranged in the end of May. On the basis of both the age determined by the baleen plate sculpture and the captured month, the time when the last dark layer is formed is written. The peak of the dark layer formation is only given in the figure. Assuming that the formation of laminae in the ear plug is regular, the time when dark layers were formed in the past can be put down. Therefore, 0D indicates the birth time and 1D, 2D, 3D and 4D do the occurrence of the each dark layer after birth. According to this schematic figure, the 1st dark layer occurs from the end of October to the end of January for five specimens. As a mean, the peak formation of the 1st dark layer exists in the period from the end of December to the early of January. This means that the first lamina after birth is formed in the suckling stage. Laws and Purves (1956), examining ear plugs from very young fin whales taken in the coast of Norway, reported that the first lamination after birth was regarded as the combined nursing and first free feeding period in the life of whale, representing a total period of approximately one year. Although they do not give any comment on the formation of ear plug whether or not the dark layer is made just after birth, the estimation of one year is too long for the initial formation of laminae.

Besides it is estimated from Fig. 21 that the peak formation of the bright layer is present in different months except May and June, in the young stage of whale after weaning. This problem, probably concerning the feeding habit of the young fin whale, will be discussed later in this paper.

TABLE 6. COMPARISON BETWEEN THE AGE DETERMINED BY BALEEN PLATE SCULPTURE AND THE NUMBER OF EAR PLUG LAMINAE. DATA OBTAINED FROM 5 FIN WHALES FROM THE ANTARCTIC.

Sample No.	Age determined by baleen plate record (A)	Number of laminae in ear plug (B)	Period of one lamina formation (A/B)	Annual accumulation rate of ear plug laminae
	month		month	
2	10	2	5.0	2.4
3	21	3	7.0	1.7
4	21	3	7.0	1.7
5	22	3	7.3	1.6
7	32	4	8.0	1.5
Total	106	15	7.1	mean 1.7

TABLE 7. CORRESPONDENCE OF THE NUMBER OF LAMINAE IN THE EAR PLUG TO THE AGE DETERMINED BY THE BALEEN PLATE RECORD. DATA OBTAINED FROM 8 FIN WHALES FROM THE ANTARCTIC. (SEE PLATES.)

Sample No.	Number of lamine in ear plug	Age determined by baleen plate record	Correspondence		Annual accumulation rate of ear plug laminae (A/B)
			Number of laminae (A)	Number of age mark on baleen plate (B)	
19	3.0	3+	3	3	1.0
11	3.5	2+	2	2	1.0
18	3.5	3+	3	3	1.0
12	4.5	2+	3	2	1.5
17	4.5	2+	3	2	1.5
13	5.5	3+	2	2	1.0
10	6.5	2+	4	2	2.0
14	8.0	2+	2	1	2.0
					mean 1.4

The presence of the 1st bright layer during the sucking stage suggests a positive relation between the growth of whale body and the nutritious level. It is reasonable to think that the growth ratio of body in the fin whale decreases for a time after birth and at the weaning period, and that this trend is related to the change of food, as in the case of other mammals. Considering that the calf adapts itself to the mother's milk and shows the rapid growth in the early stage of suckling, the slope in the photometric record is interpreted. Generally speaking, the rising slope is steep while the falling slope is gentle in the first lamina of the photometric records (See Fig. 15–19). Accordingly, the peak occurrence of bright layer is not present in the middle between the neonal mark and the 1st trough of the compensated undulating record.

Through two kinds of records, it is possible to estimate the period of one lamina formation and annual accumulation rate of ear plug laminae. According to the growth stage, examined young whales are divided into two groups. Specimens in Table 6 has the neonatal mark on the tip of baleen plate while the neonatal mark is worn off in the blaeen plate of the specimens in Table 7. Although the ageing basis lies in the baleen sculpture in this examination, the method of estimation is slightly different between two groups. In Table 6, the age determined by the baleen sculpture is shown as the month age. In the early life of whale, the annual accumulation rate of ear plug laminae is larger than in the older whale. As a mean the ratio for the first group is 1.7 and 1.4 for the second group.

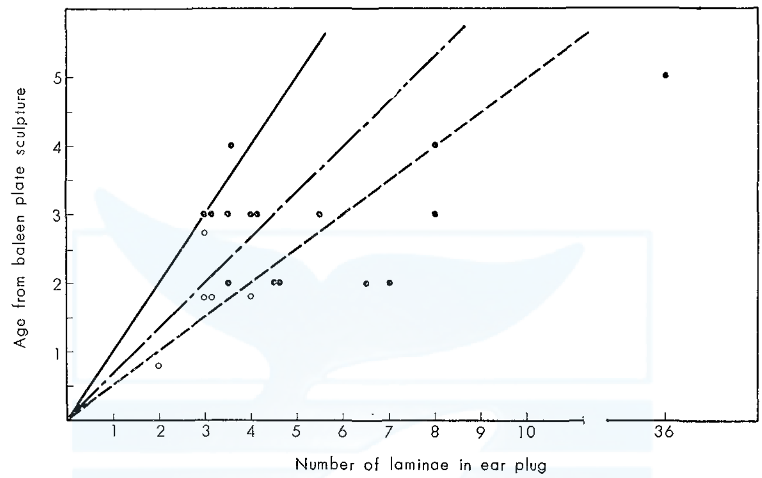

Fig. 22. Relation between the number of laminae in the ear plug and the age determined by baleen plate from 20 antarctic fin whales. Open circle: The prenatal mark remains on the tip of baleen plate. Closed circle: The tip of baleen plate was already worn and hence the age of whale exceeds the dotted position. Solid line: annual formation of laminae. Broken line: bianual formation of laminae. Chain line: 1.5 laminae formation per year.

The rate for the second group is estimated on the basis of the corresponding unit in two kinds of records. Since the ageing unit is entered respectively for the two kinds of records in the plates, it is easy to select the correspondence from them. This examination shows no rule that one laminae in the ear plug corresponds to one ridge on the baleen plate or two laminae do to one ridge. In particular, the value of the annual accumulation distributes widely for the first group.

The comparison between the age determined by the baleen plate and numbers of laminae in the ear plug is indicated for examined all specimens in Fig. 22. Open circles in the figure show the first group and closed circles include the second group. The tip of baleen plate begins to be worn off in the early life of the whale and there is no neonatal mark for the baleen over three ages.

When the same kind of figure is drawn by the data given by Laws and Purves (1956, Table 1), the distribution of each dot is agreeable with my finding. They have concluded that the laminae formation is biannual, although each dot distributes around both solid line (annual formation) and the broken line (biannual formation). Nishiwaki (1957) supported the biannual formation of laminae, comparing the baleen plate with ear plug laminae from the antarctic fin whale. On the other hand, Ohsumi (1964) emphasized extremely the correspondence of one lamina to one ridge of the plate, examing the North Pacific and the antarctic fin whales. I disagree with the regular formation of laminae throughout the life of whale. Open circles in Fig. 22 distribute along both the broken line and the solid line. Discrepancy from the conclusion by Laws and Purves, is derived from the interpretation of ageing by the baleen plate. There are controversies on the question when the tip of baleen plate begins to wear off. Utrecht (in Slijper, 1958) examined that the age determination was only reliable up to an age of four years and Nishiwaki (1957) also supported this finding. From the sculpture records in this paper, I disagree with Ruud's estimation that six to seven years will be represented on the baleen plate. The age estimated by him and colleague is only on the low side.

FORMATION TIME AND PERIOD OF EAR PLUG LAMINAE

It is essential to know when the alternation of the dark and bright layer occurs in the plug core, in order to examine whether or not the occurrence of layer is regular with advance of the whale age. I raised this problem as an approaching method to examine the increment rate of laminae. (Ichihara, 1959). It is impossible to determine the formation time and period of layers in the ear plug by means of the observation by the naked eye or the microscopic examination on the unstained material, because the last lamina under formation is very soft tissue indicating no clear border and its accumulated length is longer than that of the previous lamina. In the otolis and scale of fishes, the ratio of the length of the last ring under formation against the length of the previous ring is useful for the estimation of annual increment of ring. These age material belongs to the hard tissue as well as the tooth of the aquatic mammals. Ohsumi et al. (1963) estimated the annual accumulation rate of dentinal growth layer in the tooth of the sperm whale, adopting the same method, but it should be noted that there were a great variation among length of already formed layer. Sergeant (1962) presented the same method for estimating the annual increment of teeth layer in the Newfoundland pilot whale. For the careful examination, I developed the following method for the ear plug. Ear plugs collected from the flensed whale were preserved in 10% formalin solution and sent to our Institute. After the bisected specimens were presented to the counting by the naked eye, the proximal part of the ear plug-core was cut off as a small block. After then this block was longitudinally sliced in the frozen section in the thickness from 10 to 15 μ. These specimens were collected by myself in the 1961/62 whaling season in the Antarctic and hence they could be preserved as perfectly as possible. For the present purpose, the preservation of the proximal end in the ear plug was essential. Sectioned tissues from 857 fin whale were stained by SUDAN III and partly by Haematoxylin and Eosin. The fatty degenerated cell layer was stained by SUDAN III and the keratinized cell layer by Eosin. As the histological structure of the ear plug has been clarified in my paper (1959), I don't repeat it here. At first, I used Haematoxylin-Eosin together with SUDAN III for the continuous sections from the

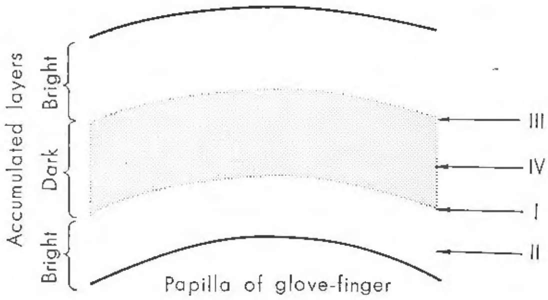

Fig. 23. Diagram indicating the progressive stages in degeneration of the epidermal cells at the base of ear plug. Each stage was determined at the most proximal end of ear plug.

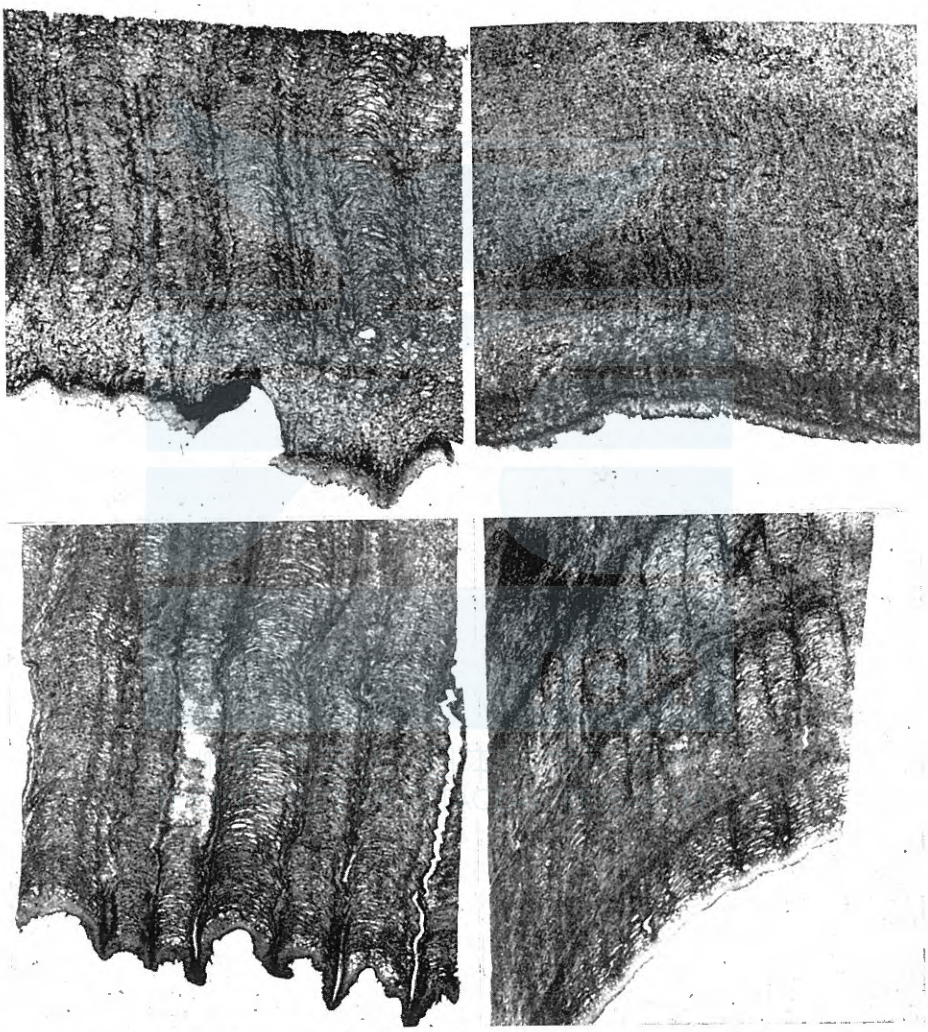

Fig. 24. Progressive stages in the ear-plug base of the fin whale. Each photograph indicates the frozen section stained by SUDAN III. Black parts show bright layers and the most proximal part do the glove-finger epidermis. From the upper left to the right: I and and II stages. From the lower left to the right: III and IV stages.

same ear plug. As the result, however, only SUDAN III staining, was enough to examine the state of base of the ear plug. As the aim of this examination principally lies in observing the degenerated cell above the basal layer of the glove-finger epidermis, I classified the progressive degenerations into several stages and examined what kind of stages the present degeneration corresponded to. Fig. 23 is a diagram showing kinds of stages to be determined and Fig. 24 indicates the photograph of the ear plug base stained by SUDAN III.

Discrimination of each stage needs the presence of the epidermis of the glove-finger from which the tissue of the plug-core is derived. Confirming the presence of the epidermis at the base of the stained ear plug, I selected 464 specimens (54.1%) from 857 samples. The shadowgraph of 20x or 50x was used for this examination.

Four stages from I to IV are divided into further four stages by the help of the following idea. The peak occurrence of the bright layer, stained by SUDAN III is in stage II while that of the dark layer is in stage IV. Observation on cells under degeneration at the germinal layer supports this finding. The germinal

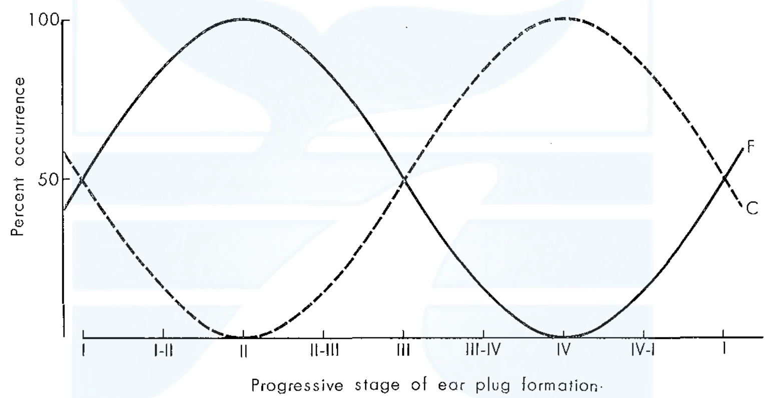

Fig. 25. Occurrence of the fatty degenerated cells (F) and the keratinized cells (C) at each stages in the germinal layer of the glove-finger epidermis.

layer is fully occupied by the fatty degenerated cells in stage II, on the other hand, by the keratinized cells in stage IV. Two kinds of degenerated cells occurs at 50 percentage level in both stages I and III, judging from the shadowgraphic observation. It is permissible to draw Fig. 25 on the basis of such a histological examination.

In addition to 464 specimens from the pelagic whaling, 35 specimens from the South Georgia whaling also were examined in the same way. The material from the Japanese pelagic whaling were collected from Dec. 12 to the end of March in Area III (0°–70°E), therefore, they covered about 4 month by periods in the antarctic summer. The material from South Georgia were taken from the sexually immature fin whales captured between Oct. 1 and Dec. 8 in 1964. Although the size of South Georgia sample is scarce, the aggregated material amounts to 176 ear plugs from the sexually immature whales captured during 6 monthly periods from October to March. A slight anxiety remains for the sampling from the different races existing in the population of the antarctic fin whale (Brown, 1954, 1962), however, it is permissible if the material from the pelagic whaling is examined with reference to the material from South Georgia.

By the light penetrating the material through the shadowgraph apparatus, the proximal end of all meterial was classified into 8 stages.

Table 8 shows the monthly percentage frequencies at each stage, for the ear plug from 141 immature fin whales taken by the pelagic whaling. In tabulation,

TABLE 8. PERCENTAGE FREQUENCIES BY MONTH OF DEGENERATING STAGES IN THE BASE OF EAR PLUG. SEXUALLY IMMATURE MALE AND FEMALE FIN WHALES FROM THE ANTARCTIC.

Stage	Dec.	Jan.	Feb.	Mar.
III	0			
III-IV	8.1	0		
IV	5.4	8.6		
IV-I	21.6	8.6	0	0
I	8.1	2.9	3.4	15.0
I-II	13.5	14.3	6.9	17.5
II	13.5	22.9	24.2	17.5
II-III	21.7	22.9	3.4	10.0
III	8.1	20.1	6.9	12.5
III-IV	0	0	20.7	0
IV			13.8	22.5
IV-I			20.7	5.0
I			0	0
Total	100.0	100.0	100.0	100.0
Size of sample	37	35	29	40

TABLE 9. PERCENTAGE FREQUENCY BY MONTH OF DEGENERATING STAGES IN THE BASE OF EAR PLUG. SEXUALLY MATURE MALE AND FEMALE FIN WHALES FROM THE ANTARCTIC

	Male				Female			
Stage	Dec.	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.
III								
III-IV	0	0			0	0		
IV	5.3	2.7	0		7.4	6.8	0	0
IV-I	21.1	2.7	5.1	0	14.8	9.1	11.3	14.3
I	10.5	18.9	20.5	8.7	18.5	15.9	16.1	12.2
I-II	26.2	16.2	10.3	17.4	18.5	20.5	17.7	8.2
II	10.5	29.8	20.5	21.8	18.5	31.8	27.4	26.5
II-III	15.8	18.9	20.5	13.1	22.3	9.1	9.7	20.4
III	5.3	10.8	12.9	6.5	0	6.8	9.7	8.2
III-IV	5.3	0	5.1	4.3		0	4.8	2.0
IV	0		5.1	15.2			3.2	8.2
IV-I			0	13.0			0	0
I				0				
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Size of Sample	19	37	39	46	27	44	62	49

the gradual advance of stage with the passage of time was taken into account. For the mature whale as well as for the immature whale, the similar tabulation is practised in Table 9, based on 141 males and 182 females taken by the pelagic whaling.

From the basic figures in these tables, Figs. 26, 27 & 28 are presented. The black portion in these figures indicates the occurrence of the dark layer under formation and the white portion does that of the bright layer under formation in the proximal end of the ear plug. There is the characteristic bimodal peak for the immature

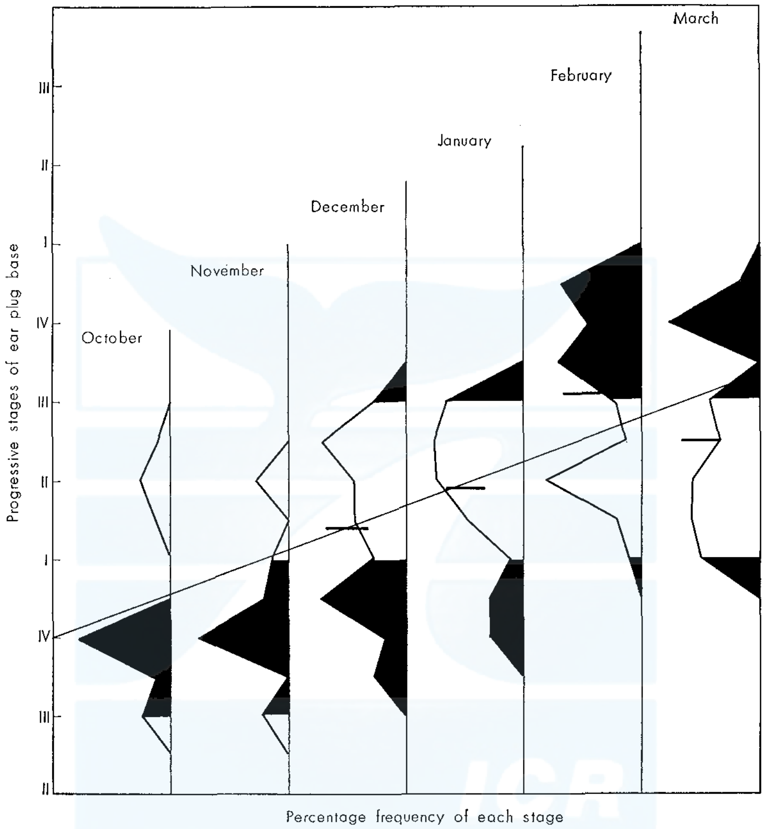

Fig. 26. Monthly degenerating stages of epidermal cells in the ear plug base. Male and female whales of sexual immaturity from the Antarctic.

group, while there is the unimodal peak rather than otherwise for the mature group. The frequent occurrence of the dark layer in the South Georgia specimens supports such a feature in the immature group. In the early summer of the Antarctic, the occurrence of the dark layer is predominant but the bright layer is frequently present during December and January and the dark layer is frequent in February again.

The samples from March do not fall in this progressive trend from October to February. It is presumable that the catch of March belongs to the different population of the fin whale from the population captured from December to February. Examining the blood type frequency of the antarctic fin whale, Fujino (1964) has reported that whales of the Atlantic population disperse eastwards to area III (0°–70°E) and that whales of the West Indian population migrate west-

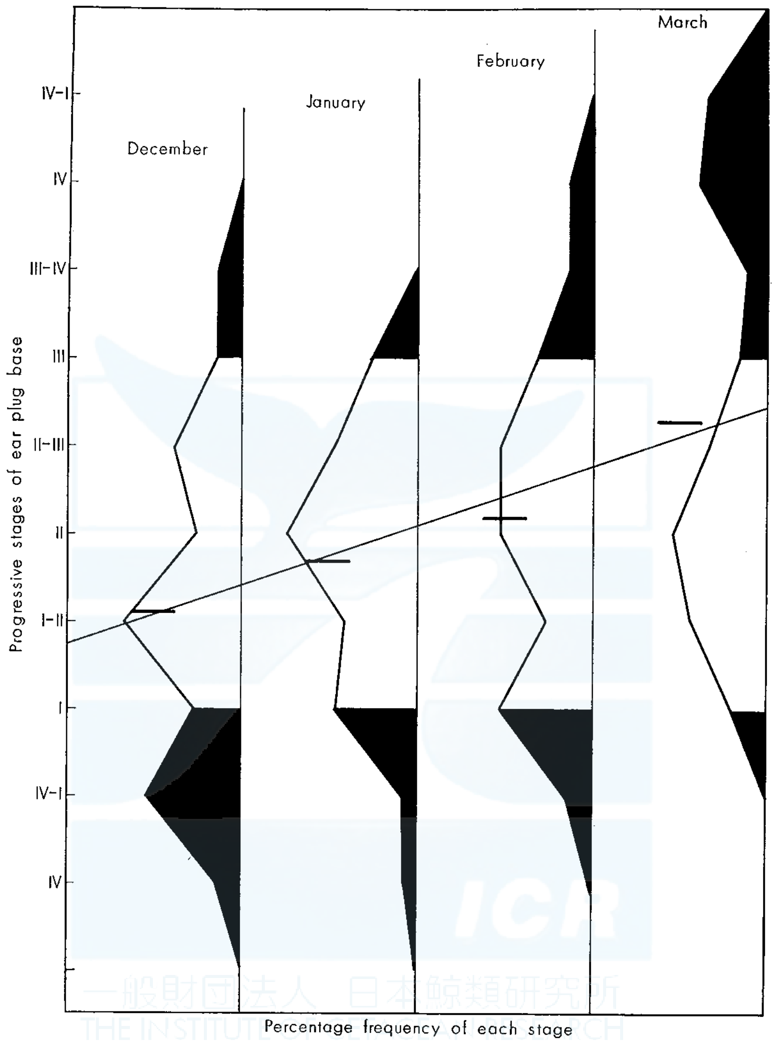

Fig. 27. Monthly degenerating stages of epidermal cells in the ear plug base. Male fin whales of sexual maturity from the Antarctic.

wards to the east-half of Area II (0°–60°W). I collected the blood samples from the fin whales captured by our fleet from the opening of the whaling to the end of February but failed to take samples in March because of lack in sampling bottle. Dr. Fujino informed me in the personal communication that whales examined by me from December to February belongs to the West Indian population. The captured fin whale in March in the west-half of Area III shows different thickness of blubber from that of December-February whale. The blood samples from the other Japanese fleet operating in the same time and locality shows that March whale belongs to the Atlantic population.

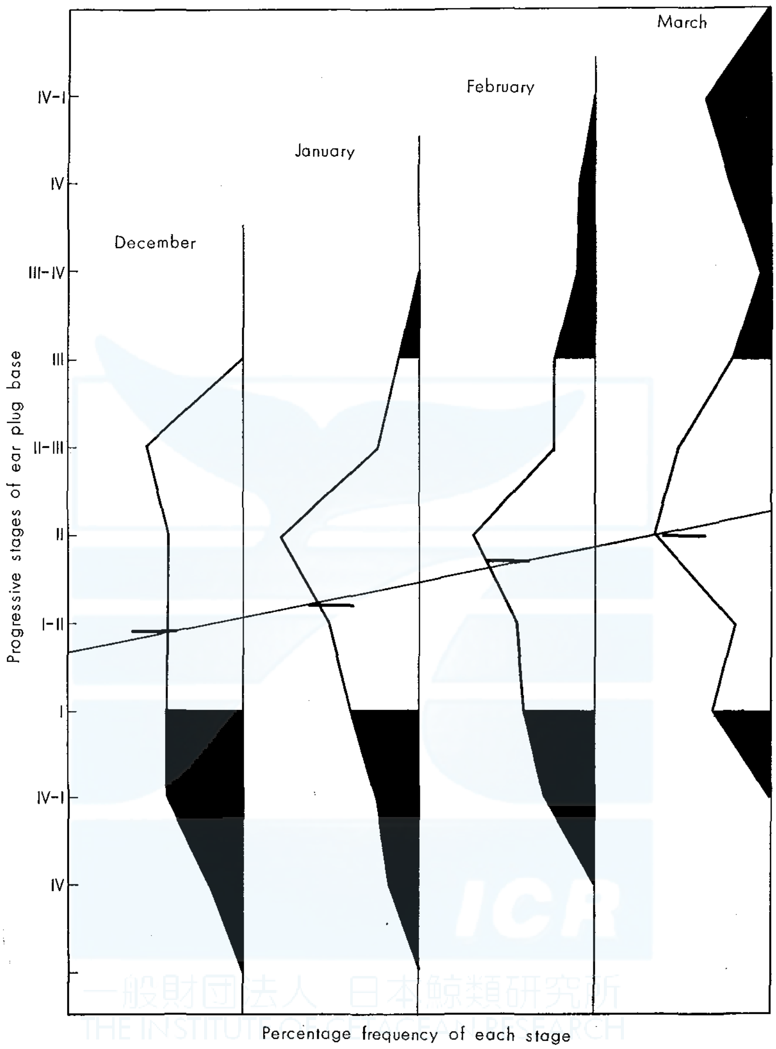

Fig. 28. Monthly degenerating stages of epidermal cells in the ear plug base. Females of sexual maturity from the Antarctic.

Mean stages for each month are indicated in Figs. 26, 27 & 28 and the mean growth of stage also is shown in the straight line. Although it is estimated that the growth ratio of layers is not constant but sigmoid with advance of time, it is approximated by the straight line.

In the mature group, there is the predominant occurrence of the bright layer from December to March and the growth of layers is slower than that in the immature group. From the growth ratio indicated in figures, the formation period of the bright layer is estimated for each group. The bright layer is formed during stage I—III with the peak of stage II. The formation period is 4.0 months for the immature group, 5.3 months for the mature male and 7.8 months for the mature female. The mean formation period is 6.0 months for the mature group including both sexes as shown in Table 10. These values are obtained by drawing the graph for each group.

The same graphic method is applied for 5 age group; under 10, 11–20, 21–30, 31–40 and over 41 in the number of laminae of the ear plugs. Counting laminae by the naked eye and by the photometric record was made before sectioning. Grouping by 10 laminae is helpful to examine the change of the formation periods with the increasing age of whale. Fin whales attain the sexual maturity at about 10 laminae in the ear plug and the physical maturity at 40–45 laminae in the ear plug (Nishiwaki, Ichihara & Ohsumi, 1958., Ohsumi, 1964).

TABLE 10. FORMATION PERIOD AND TIME OF THE BRIGHT LAYER IN THE EAR PLUG OF THE ANTARCTIC FIN WHALE.

	Advancing whale age	Formation period of bright layer (Months)	Month of peak occurrence of bright layer
Number of ear plug laminae	<10	4.0	Middle January
	11–20	6.0	Early February
	21–30	5.3	Early February
	31–40	7.5	Early March
	>41	6.4	Middle March
Sexual class	Immature male and female	4.0	Middle January
	Mature male	5.3	Late January
	Mature female	7.8	Middle March
	All mature	6.0	Middle February

The formation period of the bright layer is estimated to be 4.0, 6.0, 5.3, 7.5 and 6.4 months for respective age group and there is no increasing trend in the age group over 10 laminae. The mean occurrence of stage II indicating the maximum fatty degeneration is from January to March and it slightly advances with the increase of the whale age.

Fig. 26 indicates the shift of degenerated stages with advance of month. The lower mode of the dark layer gradually changes to the mode of the bright layer with the passage of month. On the contrary, another mode of the bright layer shifts to the mode of the dark layer. It is interesting that two different layers occurs for the immature group during 6 months. For the mature group, the bright layer occurs mainly in the antarctic summer. Taking into consideration that the bright layer is formed during 6 months and its pattern of occurrence is almost constant every year, the dark layer is formed during another 6 months for the mature group. From this fact, it is reasonable to think that the formation of lamina is annual for the mature fin whale. As there is a slight difference in the peak occurrence of the bright layer with the increasing age of the whale, the periodic formation is indicated in the diagram of Fig. 29. This diagram suggests that the bright layer is related to the feeding migration while the dark layer is related to the breeding migration of the fin whale.

For the immature group, the occurrence of two layers is irregular compared with the mature group. Whether or not the bimodal distribution is maintained during a year, is not concluded here because of lack in samples for the unexamined months. The graphic method suggests that the mean formation period of a lamina is 8 months and hence the annual increment is 1.5 lamination. This result is compatible with my findings obtained from the relation between the records of baleen plate and the photometric records of ear plugs. Both records has been already given to immature whales.

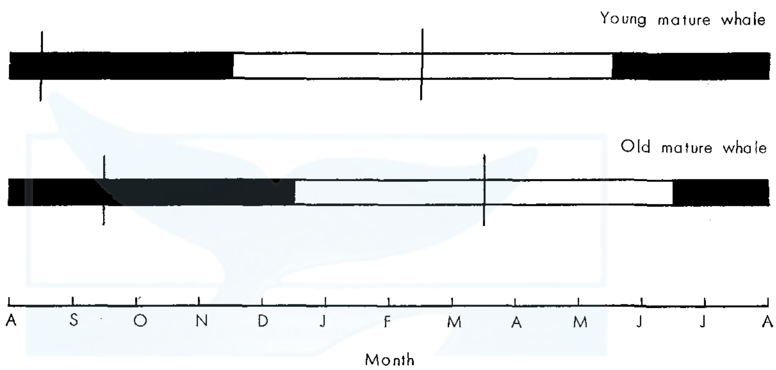

Fig. 29. Diagrammatic occurrence of bright and dark layers in the ear plug from the sexually mature fin whales in the Antarctic. Old mature whales include animals over 41 laminations.
White portion (fatty degenerated layer). Black portion (keratinized layer).

The relationship of the bright layer to the feeding stimulus will be discussed later in this paper. As a migratory rule of fin whale, older whales arrive earlier in the feeding area than younger whales (Wheeler, 1930., Laws 1961). Although there is a reverse trend in the peak occurrence of bright layer, it seems that the internal stimuli for the occurrence of bright layer is different among age groups and that the reaction of epidermal cell is more sensitive in the young whale than in the old whale.

MITOTIC ACTIVITY IN RELATION TO INCREMENT OF LAMINAE

Tissue cells generally reproduce by mitotic division and the epidermal cell belongs to the same category. It is pointed that the rapidly proliferating epidermis, as in psoriasis and other skin diseases, usually shows neumerous mitosis. Pinkus (1954, p. 586–589) stated on the reproduction by the mitotic division in the human epidermis as follows.

A fully keratinized human epidermal cell is a thin flake with a diametre of from 25 to 30 μ. A basal cell is a cuboidal or columnar body, with a diametre of

5–6 μ. Accordingly, the area of 625–900 μ^2 covered by one horny cell on the surface is occupied by 25 basal cells, each having a basal area of 25–36 μ^2. This figure does not take into account that the rate ridges and papillae increase the basal area of the epidermis several times over what it would be if the cells were arranged in one plane. As the upper surface of the epidermis is more nearly plane, the ratio of basal cells over keratin cells is increased considerably. If the duration of mitosis is 1 hour, then it follows that $1/(25\times24)$ or 1 out of every 600 basal cells, has to be found in mitosis at any given time (mitotic index or number of dividing cells per thousand cells is 1.67) in order to replace one horny flake per day under the most unfavorable theoretical circumstances. This theoretical value agrees well with actual observation in adequately preserved material. The actual observation was made by Thuringer (1928) and etc. Sutton (1938) found the renewal time of the stratum corneum, using silver nitrate and observing the disappearance of the stain. Von Volkmann (1950) found the renwal time of the human skin, pricking India ink into the epidermis and watching the gradual disappearance of the ink.

It is impossible to practise the direct experiment on the whale epidermis and to observe the duration of mitosis. However, Pinkus' theory can be applied for estimating the mitotic activity of the glove-finger epidermis, if the size of examined cell can be measured. I reported that the size of keratinized cells is larger than that of the fatty degenerated cells (Ichihara, 1959). The difference of size appears above the germinal layer in which the cell division is observed. The keratinized cell, stained densely by Eosin, is the fusiform and on the other hand the fatty degenerated cell, stained well by SUDAN III is the round form. A mass of fatty degernated cell constitutes the concentric bright layer as well as the longitudinal bright layer in the ear plug. Three kinds of layers are derived from the degenera tion of cells in the basal layer of the glove-finger epidermis. As the cell division is active in the glove-finger epidermis, the degenerated cell is remarkably accumulated outwards and continues to form the core of ear plug from the latter half of foetal stage. In the fin whale, the accumulation of keratinized cells begins at the $6^1/_2$ foetal months and it is followed by the fatty degeneration which arises at 8th foetal months and continues to progress until birh (Ichihara, 1964).

In the stained germinal layer of the glove-finger epidermis, sizes of cells were measured by the ocular micrometre and shown in Table 11. For the measurements, cells which are appeared to be cut the centre approximately were chosen. The size of keratinized cell is given as a mean of the major and minor axis, because of the elliptic or fusiform cell. Fujita (1947) examined the effect of the embedding method to the measurement of the cell size and pointed that the size of renal corpuscle was slightly larger for the celloidin section than for the frozen section. Although the present foetal samples are obtained as the celloidin section and the postnatal samples are given as the frozen section, it does not seem that the measurements effects intensively to the final results, because the diametre of epidermal cell is extremetry small compared with the size of renal corpuscle examined by Fujita.

Although the size of sample is scarce for the prenatal stage, the mean diametre of cell indicates the same value in both the fatty degeneration and the keratinization. In the postnatal stage, the size of sample is enough and composed of various ages. The mean diametre of keratinized cell is 49.3 μ while that of the fatty degenerated cell is 28.5 μ. The mean cell diametre of the basal layer is slightly larger in the postnatal life than in the prenatal life. From the square of the mean diametre,

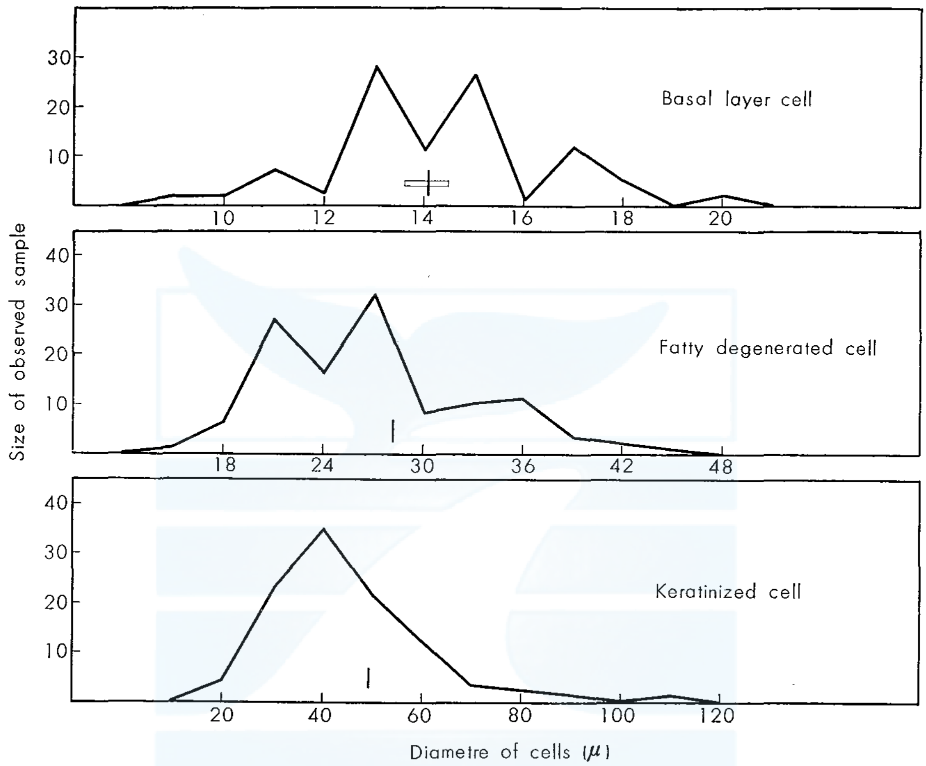

Fig. 30. Comparison of the cell size to examine the relative mitotic speed in the epidermis of the glove-finger. The cell sizes of the basal layer, under fatty degeneration and under keratitinization were measured. Mean sizes are indicated for three kinds of cell and two standard errors for the basal layer cell.

the ratio of the area occupied by three kinds of cells is calculated and given in Table 11. According to Pinkus' theory, the mitosis is more active in the prenatal epidermis than in the postnatal epidermis. In the epidermis after birth, the cell division is very active for the period of the fatty degeneration and there is three times proliferation than for the period of keratinization. The difference in the activity between two kinds of layers is very important to interpret the formation of ear plug.

The size distribution of the cell diametre is indicated in Fig. 30 for the postnatal sample. While it is a normal distribution for the basal layer cell, it is positively skewed for the degenerated cell. For the keratinized cell, the skewness of the size distribution is more intensive than for the fatty degenerated cell. The mean diametre and two standard errors are indicated for the distribution of basal cell.

The skewness is related the age composition of sample. Fig. 31 indicates the relation between the cell size of glove-finger epidermis and the increasing age of the fin whale. As counting laminae already has been made for the examined specimens, it is possible to check the change of cell size with advance of the whale age.

TABLE 11. COMPARISON AMONG CELL SIZES OF THE GLOVE-FINGER EPIDERMIS, FROM THE FOETUS TO THE ADULT IN THE ANTARCTIC FIN WHALE

A) Prenatal life

Classification of cell	Sample size	Mean diametre of cell (μ)	Ratio of cell area
Basal layer	12	11.8	1
Fatty degeneration	24	19.5	3
Keratinization	17	19.5	3

B) Postnatal life

Classification of cell	Sample size	Mean diametre of cell (μ)	Ratio of cell area
Basal layer	100	14.1	1
Fatty degeneration	117	28.5	4
Keratinization	102	49.3	12

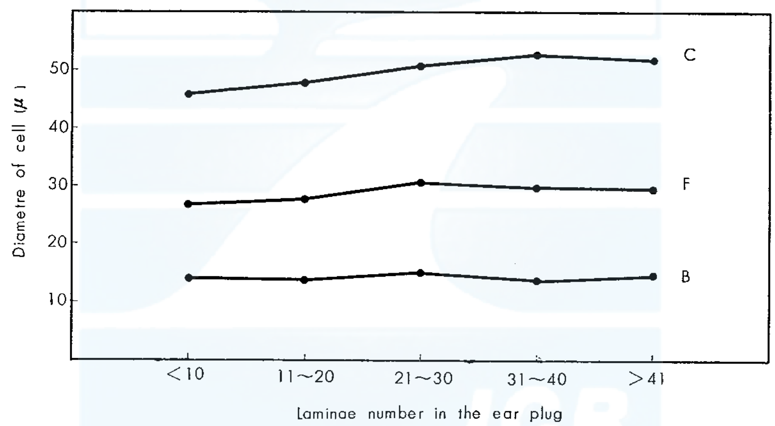

Fig. 31. Relation between the cell size of glove-finger epidermis and the advancing age of the fin whale.
C: Keratinized cell, F: Fatty degenerated cell, B: Basal layer cell of the epidermis.

Samples are grouped at each 10 laminae and the mean diametre of cell is plotted for each age group. The diametre of the basal cell (14.1 μ) is constant in spite of the advancing age, on the other hand, there is a trend that the diametre of the degenerated cell increases with the passage of the whale life. Compared with the fatty degenerated cell, the increasing tendency is remarkable in the keratinized cell. If the intensive catch is taxed at random on the population of the fin whale, most of catch is occupied by the young fin whale. About 50 percentage of the sample consists of individuals under 20 laminations. The measured size of cells is arranged for each age group and tablulated in Table 12.

If a constant mitotic activity is maintained for the degeneration of the same quality and hence the duration of the mitosis is constant in such degeneration throughout the life of whale, the relative growth of layer at a constant period is estimated. Of course, the mitotic activity of the keratinization differs from that of the fatty degeneration, therefore, it is necessary to assume two kinds of mitotic activities. In the final stage of the fatty degeneration, granules of lipoids in the cytoplasm overflow to destroy the original form of cell. Accumulated soft granules of lipoid is apt to be effected by the outward pressure which the newly proliferating cell gives. It is reasonable to examine seperately the different degeneration; the bright layer and the dark layer in the ear plug.

TABLE 12. THE CELL SIZE (μ) OF THE GLOVE-FINGER EPIDERMIS IN SEVERAL AGE GROUPS AFTER BIRTH

Classification of cell	Latter-half of foetal stage	Range of lamination number in ear plug after birth				
		1–10	11–20	21–30	31–40	41–
Basal layer (B)	11.8	14.1	14.1	14.1	14.1	14.1
Keratinized cell (C)	19.5	45.7	47.7	50.6	52.8	51.8
Fatty degenerated cell (F)	19.5	26.9	27.1	30.2	29.6	29.3

TABLE 13. THE RELATIVE ACCUMULATION SPEED OF TWO LAYERS IN THE EAR PLUG. THE VALUE IS GIVEN BY THE THEORETICAL BASIS.

	Latter-half of foetal stage	Range of lamination number in ear plug after birth				
		1–10	11–20	21–30	31–40	41–
B2/C	7.14	4.35	4.17	3.93	3.77	3.84
B2/F	7.14	7.39	7.34	6.58	6.71	6.79

When the diametre of the basal cell is B and the diametre of the keratinized cell is C, the ratio of the area occupied by the keratinized cell against the area by the basal cell is B^2/C^2. This relative mitotic activity is obtained from the value for each age group of Table 12. As B is constant throughout the life of whale, the relative mitotic activity decreases with the increasing age of whale. Under the present condition, the accumulated length of horny flake is proportional to B^2/C^2. On the other hand, the accumulated length is proportional to the size of one horny flake (C). Accordingly, the next formula is obtainable.

$$L = k\, B^2/C^2 \cdot C \cdot t$$

where L is the accumulated length of the horny flake during t time and k is a coefficient. When t is constant, L is expressed by the value of B^2/C as indicated in Table 13.

By the same method, the accumulated length of fatty layer is obtained in Table 13. These values seem to indicate the relative speed of accumulation. When the speed of the latter half of foetal stage is 100, several speeds for each age group are given and compared with each other. These relative speeds of accumulation are plotted in the semilogarithmic scale of Fig. 32. Individuals of the range from 1 to 10 laminae represents the sexually immature whale and individuals over 41 laminae represent the physically mature whale.

For the fatty degeneration, the value distributes around the standard level of the latter half of foetal stage and there is no remarkable change with advance of the whale age. Compared with older age over 31 laminations, the accumulation during a constant period is more speedy in the younger age under 20 laminations.

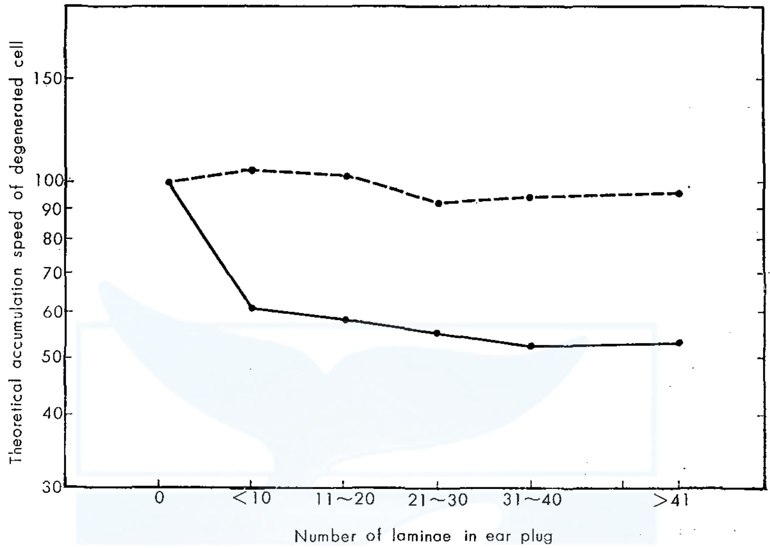

Fig. 32. The relative speed of accumulation of two layers in the fin whale ear plug.
Dotted line for the fatty degenerated (bright) layer.
Solid line for the keratinized (dark) layer.

For the keratinization, the value has a decreasing trendency with the increasing age of whale. In detail, it is represented by three steps; the immature group under 10 laminae, the young mature group from 21 to 40 laminae and the old mature group over 41 laminae indicating physically mature individuals. As the sample size for the last group is scarce, the definite findings is not obtained. It is safte to say, however, that in a constant period the keratinized layer is more rapidly accumulated for the immature group than for the mature group, and hence that the accumulation rate is different between age groups. It should be regarded that the fatty degeneration is not taken into account in this examination. There is a constant decreasing trend for the young mature group and the value again rises slightly for the old mature group. Examing the formation period of dark layer in the previous chapter, I concluded that it takes 6 months as a mean for the mature group. A constant rate of decreasing for the young mature group in Fig. 32 supports this conclusion. On the other hand, the steep slope of the immature group can not be explained by the constant accumulation rate from birth to young mature class. The slight increase of the accumulation rate after physical maturity which results from the theoretical base is discrepant from my examination in the previous chapter. According to the previous chapter, the formation period of dark layer is estimated to be 6 months and constant for the all mature group. Fig. 32, however, suggests the possible change of the accumulation rate in the old mature group. It is necessary to check this discrepancy on the basis of large samples in the future. Through the theory of the mitotic activity in the epidermal cell, I examined the accumulation rate of separate two components in the ear plug. The structure of the ear plug is not so simple as considered here but the pursuit for the mitotic activity supports the findings that the annual increment rate of laminae is not always constant throughout the life of the whale and it is closely related to the growing stage of the fin whale.

FACTORS AFFECTING THE FORMATION OF EAR PLUG LAMINAE

In the ear plug the alternation of two different layers is gradual, and the occurrence of the bright layer and the dark layer is comparatively periodical for the sexually mature whale. The gradual alternation was examined by the photometric record and applied for examining the formation period of the ear plug layer. In the previous paper (Ichihara, 1959), I have briefly concluded that the degeneration of the epidermal cells in glove-finger arises in response to many factors related to the metabolism of whale body and that the effect of hormone and enzyme on the epidermis are regarded primarily. Examining the foetal ear plug which has an alternation of the dark and bright layer, I presented my opinion that it is the most reasonable to accept the endocrinal stimulus through the blood supply from the maternal body. Reexamining these hypotheses to some degree, the factors affecting the formation of ear plug layer is discussed. The final conclusion should be examined by the tissue culture or the direct experiment to the tissue of the glove-finger. Since my material is lacking in the specimens in the major breeding season of the fin whale that exists in other months than the season of the antarctic whaling, the endocrinological examination is difficult. If there is any analogous epidermis in other animals, approaching ideas would be applied for the ear plug. I have looked for the analogous epidermis but can never find tissues like glove-finger epidermis which raises the fatty degeneration in some periods and keratinization in other periods. In this meaning, the glove-finger of the baleen whale has an unique tissue.

By classifying the degenerating stages of the epidermis in the maternal glove-finger, the relation of the ear plug layer between the mother and foetus is examined. I had already pointed that the keratinization in the epidermal cells of the glove-finger appears at the 61/2 foetal month of the fin whale and that the fatty degeneration occurs after the 8th foetal months. The ear plugs of mother whales, having the large foetuses over the 6th months from fertilization are classified from I to IV stage and compared with the ear plugs from the foetuses. The reasonable growth curve of the fin whale foetus, indicated by Laws (1959) is applied to determine the foetal month of my sample. Fig. 33 shows the occurrence of the progressive stage of the maternal ear plug, grouping into two classes. In the upper of figure the percentage frequency at each stage is indicated for the mother of the 6th and 7th pregnancy months and for that from 8th to 10th pregnancy months in the lower. As there is no difference in the distribution of stage between two classes, it is concluded that the formation of the foetal layers is independent of that of the maternal layers and probably related to the growth of foetus.

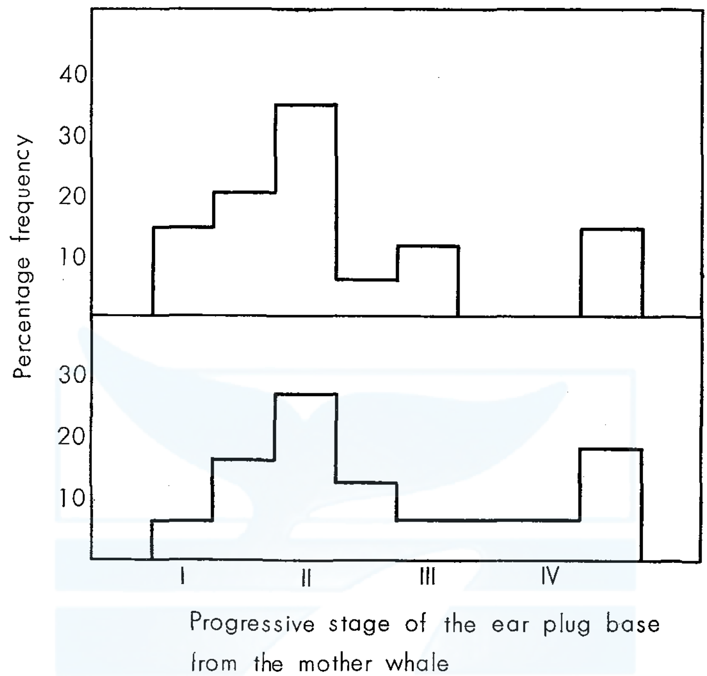

Fig. 33. Occurrence of the progressive stage of the ear plug base in the mother fin whale gestating the large foetus.
Upper: for the whale in 6th and 7th months of pregnancy.
Lower: for the whale from 8th to 10th months of pregnancy.

Ohsumi (1960) examined the relative growth of the external parts of the antarctic fin whale foetus and classified it into 4 stages; 10–30, 30–115, 115–300 and 300–650 cm of the length. According to Laws' growth curve for the fin whale foetus, 115 cm in the foetal length corresponds to the $6^1/_2$ pregnancy month and 300 cm to the end of the 9th pregnancy months. The latter half of Laws' growth curve well fits for straight lines on the semilogarithmic scale but the foetal growth ratio from the 8th pregnancy months to birth is more rapid than under the 8th month. These two findings suggest that the fatty degeneration of the foetal epidermis is related to the growth of foetus although there is no difference in the size of degenerated cells between the keratinization and the fatty degeneration (See Table 12). No difference of the cell size seems to indicate a delicate relationship between the keratinization and the fatty degeneration in the epidermal cell of the glove-finger. In the adult whale, the keratinized cell has a three times area than the fatty degenerated cell. The fatty degeneration, therefore, seems to be a transformed cornification of the epidermal cell. On the basis of the histological examination I previously showed that the longitudinal bright layer exists always between two projected papillae of the corium in the glove-finger and that no presence of such a longitudinal layer in the foetal stage besides its vague presence in the juvenile whale. The longitudinal layer is clear with the projection of papillae which occurs with advance of the whale age. The pressure of proliferating epidermal cells from the side of projected papillae inhibits the developing size of degenerated cell, inducing the fatty degeneration. Such a physical force as well as the internal physiological stimuli are essential to interpret the structure of ear plug.

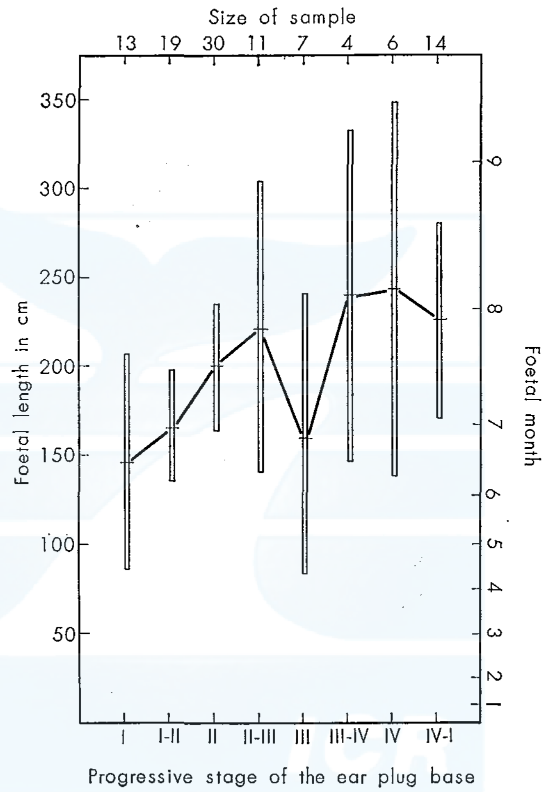

Fig. 34. Relationship of the foetal length against the progressive stage of the ear plug base of the mother whale. Mean length and two standard errors are indicated for the fin whale from the Antarctic.

In Fig. 34, the mean length of foetuses and two standard errors are indicated for each stage of maternal ear plugs. This figure is drawn on the basis of 104 pregnant females. There is a trend that the foetal length increases with the progress of ear plug stage in the mother. Stages from I to II composed of comparatively large sample is present after the 4th foetal months. It is estimated that 77% of the antarctic fin whale foetuses are conceived in the 5 monthly period between April and August and the mean date of conception is the early in June (Laws, 1961). It will be estimated that stage I indicating the alternetion from the dark layer to the bright layer in the pregnant female arises in the periods except the major breeding season. Stages I-III represent the bright layer and stages III-IV do the dark layer in the ear plug.

In the experimental work, administration of estrogens has a profound effect on the life-processes of epithelial tissues in both sexes. In squamous stratified epithelium, there is enhanced proliferation, keratinization, and desquamation. In the skin proper, the increased epithelial proliferation, cornification, and desquamation in response to estrogen were observed in the rhesus monkey (Zuckermann, 1940) on the nape of the neck, over the crown of the head, and to a lesser degree, over the upper part of the nose, in addition to the perigenital areas.

Vitamin A as well as estrogen affects the germinative cells of the epithelium and modifies keratinization indirectly. Vitamin A, essentially, inhibits the differentiation of stratified squamous epithelium (Moritz, 1943) and therefore becomes an " antikeratinizing " factor (Harris, Irmes and Griffith, 1932). The reverse " keratinizing effect " of Vitamin A deficiency was reviewed by Wolbach and Bessey (1942). To the contrary, excess of vitamin A hinders the normal development of stratified epithelium. The keratinization is an intrinsic feature of the life-cycle of epidermal cells.

Depressed mitotic activity in the epidermis may cause a decrease in the rate of cell loss. Bullough and Ebling (1952) reported that in adult male mice, maintained on calorically inadequate diets over a 4 week period, epidermal mitotic activity was depressed to 25 per cent of normal without noticeable atrophy resulting.

These experiments for other animals is helpful to interpret the keratinization and the fatty degeneration in the glove-finger epidermis of the baleen whale. The mitosis is very active in the latter degeneration. Fisher, Kon and Thompson (1952, 1962) examined the content Vitamin A in marine crustacea and reported that the free-swimming euphausiids contains high concentrations of preformed vitamin A in addition to large quantities of astaxanthin. The eyes of the euphausiids containes over 90 percentage of their total Vitamin A. *Euphausia superba* is the main food of the fin whale migrating to the antarctic region (Marr, 1962). The Japanese factory ship that I was on board in the 1961/62 season extracted Vitamin A from the whale liver. The mean value of Vitamin A content was about 8×10^4 IU/kg/BWU in the fin whale migrating to Area III. Vitamin A content of the whale liver depends on the physiological conditions of the whale body and indicates low values for the lactating whale and the immature whales, however, it is reasonable to think in general that the content of vitamin A increases with advance of feeding in the Antarctic area and decreases in the major breeding season in the low latitude area. The Union whaling Co. at Durban informed me no data on Vitamin A content in the liver of the fin whale captured in the coast of South Africa.

Mackintosh (1942) and Laws (1961) summarized many direct and indirect evidences on the seasonal migration of fin whales. These indicate the bulk of the population spends the winter months in lower latitudes and the summer in the

Antarctic. Brown (1957) has reported that 'not all rorquals go south for the southern summer and it may be that more than was thought either miss the southern migration altogether, or get out of step with the main migration movements.' According to Ash (1955, 1956), the blubber thickness and oil production increase with advance of season, when the population comes into the antarctic waters. In relation to the feeding activity, I examined the blubber thickness of the fin whale cap-

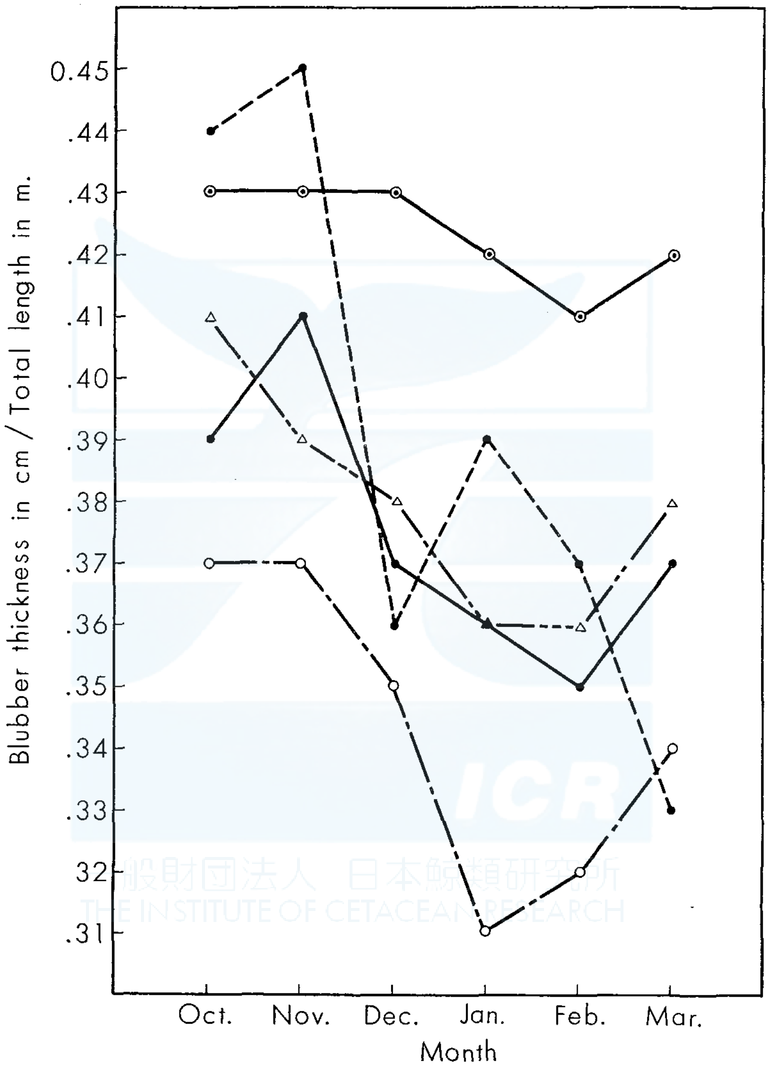

Fig. 35. Fluctuation of the bblubber thickness of the antarctic fin whale with advancement of month. From South Georgia whaling in October and November, and from the pelagic whaling from January to March.
⊙——⊙: Pregnant female. – – – –: Resting female. ——-——: Lactating female.
————: Sexually mature male. ——- - ——: Sexually immature whale.

tured in the 1961/62 season. In Fig. 35, the blubber ratio of the fin whale (average blubber thickness in cm/length of whale in metre) is plotted by month from October to March. The blubber ratios in October and November come from the South Georgia whaling in 1964. Except the resting female, there are similar tendencies for groups of the pregnant whale, the lactating whale, the sexually mature whale and the sexually immature whale. In this respect, there is no difference with Ash (1956), and Ohno and Fujino (1952). The blubber ratio, however, does not indicate increasing trend with advancing season that Ash (1955) pointed out for two consecutive season (1953/54 and 1954/55), and on the contrary there is a decreasing trend in my samples.

This discrepancy between the past and the recent examination on the blubber thickness has appeared since the 1959/60 season and probably depends on the difference of the whaling locality. In the recent antarctic expedition, the pelagic whaling has been practised far north than the past. The recent catch is intensive to the population trying to enter the feeding area and hence to that before storing the thick blubber.

When the staying period of the whale in the feeding area is reflected by the increase of the blubber thickness, the descrepancy is understandable. The rise of the blubber ratio in March probably depends on the catch for the other population than that from December to February. Attention should be paid to the occurrence of the bright layer (fatty degenerated layer) in the ear plug in spite of the decreasing thickness in blubber.

Mackintosh and Brown (1956) estimated the seasonal rise and fall of the population of large baleen whales in the ice-free antarctic waters. According to Fig. 29, the formation period of the bright layer in the mature fin whale agrees well with the rising period of the population which they estimated. It means that the occurrence of the bright layer in the ear plug is closely related the southern migration of antarctic fin whales and on the other hand the dark layer is related the northern migration.

Based on these discussions, the occurrence of the bright layer can not be interpreted without taking into account the critical point of the Vitamin A supply through food. In respect of the layer formation in the ear plug, it is also assumed that the growth hormone contributes to the bright layer and estrogen to the dark layer. This assumption will be applied for the whales migrating with seasonal regularity. Presenting the growth curve of newly mature females, Laws (1961) stated that the growth ratio was larger for the feeding season than for the paring and the parturition season in the antarctic fin whale. Finally, it is concluded that the promotion of mitotic activity in the glove-finger epidermis closely related to the growth of the fin whale. The keratinization as an intrinsic feature of the epidermal cell is influenced by the active mitosis and transformed to the fatty degeneration. For the immature whale as well as for the foetus and the adult whale, this idea will be applied. In order to interpret the alternation of two layers in the ear plug, it is essential to examine patters of the feeding activity.

ANNUAL INCREMENT RATE OF LAMINAE AND AGE DETERMINATION OF FIN WHALE

At first I review here the previous representative papers concerning this problem and the foundation in previous estimation on the annual increment rate of laminae.

Purves (1955) who found the ear plug existing in the external auditory meatus of the Mysticeti an important age material, estimated the relation between the growth of the skull width and the formation of ear plug. His statement is as follows. ' The characteristically great lateral growth of the posterior region of the skull is apparently almost wholly associated with the lateral extension of the zygomatic process of the squamosal, the paraoccipital process and the mastoid process of the tympano-periotic and during the lateral extension of these bones which are concerned in the formation of the bony external meatus, the wax plug would tend to drawn away from its contact with the glove-finger'. Laws & Purves (1956), noting such a relationship, states ' that the dark layer found in the fin whale plug marks an abrupt interruption which implies almost complete cessation in the growth of the entire skull and presumably in that of the skeleton and such an interruption, therefore, would have occurred during the migratory period when the excessive physiological demands of active swimming are coincident with complete absence of food.' Purves and Mountford (1959) and Ichihara (1959) independently deny this relationship between the growth of skull and the formation of ear plug and state that the increasing length of core should be positivly based on the internal progressing metabolism of whale body. On the annual formation of laminae, Purves and Mountford, examining the approximate numbers of laminae formed between the sexual and physical maturity, pointed out the validity of biannual formation. This estimation results from how many accumulation rate of laminae is consistent with other informations on the age determination given by the previous scientists. They state in conclusion that the rate is either one or two per year and that the latter is more consistent with all the previously accumulated knowledge of the natural history of fin whales. Comparing the ridge number of young baleen plate with the lamination number, Laws and Purves (1956) estimated the biannual formation of lamine for fin whales captured in the North Atlantic. Nishiwaki (1957) supported the biannual formation in examining the relation between the baleen ridge and the laminae in the ear plug for the young antarctic fin whale. In order of published years, Dawbin (1959) and Chittleborough (1960) obtained the direct knowledge on the accumulation rate of ear plug laminae and on the annual occurrence of baleen ridge, based on the recapture of young humpback whales which had been marked at known age. From these evidences they supported the biannual formation in the laminae of the ear plug; Dawbin indicated 5 distinct and two indistinct laminations for a estimated three years old humpback male and Chittleborough showed 12 laminations for a humpback male, estimated 6 years old. For the recaptured whale, Dawbin presented the trace of baleen sculpture indicating three years intervals. Although humpback whales were not calves accompanied by cows when they were marked, these evidence should be appreciated. The ear plug of the humpback whale indicate the same formation mechanism of that of the fin whale.

Laws (1961) gave an explanation on the assumed biannual formation of ear plug lamination and estimated that the biannual hormonal cycle, regulated by changes in day lengths associated with the long migration of the fin whale might be responsible. He states that during the southward or the northward migration, there is always a rise in the amounts of circulating oestrogens, associated with oestrus, and this is responsible for the formation of a keratinous layer in the epithelium of the glove-finger. The basis of his hypothesis results from the consistency of the biannual formation of laminae with the figure of 1.4 for the anual increment of corpora in the female ovaries. In his study on the sexual cycle for the antarctic fin whale, he obtained the figure of 1.4. Compared with the other assumptions hormonal stimuli is acceptable to interpret the formation of keratinized layer in the ear plug, however, Laws did not refer to the formation of fatty degenerated layer. His statement (p. 468) should be noticed that this hypothesis explains lamina formation in adults satisfactorily, but little is known of the migrations of immature fin whales and the early laminations are the most difficult to interpret.

Many direct knowledges on the increment rate have been obtained from the recoveries of the whale marks by the Japanese whaling. In the International Cooperation of the whale marking, prewar marks which the former Discovery Committee, the present National Institute of Oceanography in England, developed have been recovered by the Japanese expeditions since the 1954/55 whaling season. Many ear plugs have been collected from the recaptured fin whale by the method reported by Omura (1963). Examined biological materials including ear plugs and ovaries were summarized for recaptured fin whales until the 1960/61 season (Ohsumi, 1962) and for the 1961/62 season (Omura and Ohsumi, 1964). 10 ear plugs to which counting laminae was made by staffs of our Institute, came from fin whales marked in the prewar days. These direct evidence showed that about one lamina annually was laid down in the ear plug, although the accurate estimation is impossible because of unknown ages of whales at fire. Examination on the recovered whales which were marked at unknown ages is an approaching method with accuracy to estimate the increment of laminae. Ohsumi (1964) evaluated which is valid, the annual formation or the biannual formation of ear-plug laminae, applying the artificial models to the population of whale, and then took the annual formation as a better estimation. This method is significant for the practical assessment but the model should be revised by the development of biology.

These reviews clarify that there is a discrepancy in estimating the increment rate of laminae. Whether the annual increase of lamination is one or two, the basis of above estimations is present in assuming the regular formation of ear plug layer. This assumption means that the ear plug of an age character is the absolute one and hence that the occurrence of laminae indicates the calendar time. Before this as sumption is correct, it is the most important to check whether or not the physiological rhythm of the whale body arises with the calendar time.

Reviewing the various papers on the age determination of aquatic mamals, but presenting no data, Slijper, Utrecht and Naaktgeboren (1964) state as follows. ' The periodicity in baleen plates, teeth and ear plugs may be an indication that periodical changes in food supply are pricipal cause of the periodicity in these organs and that cyclic sexual events are superimposed on it.' With regard to accumulation of ear plugs and baleen plates for blue, fin and humpback whales, they think that no lamination will appear or at least an irregularity in the process of formation of these laminations will appear, when an animal stays in warm waters during the summer.

From the photometric record, it is possible to measure accurately the distance between two dark layer. I plotted the accumulated thickness at each layer for many ear plugs from the Antarctic and the North Pacific fin whale. Fig. 36 indicates the representative two patterns for the growth of core length. One growth, the left figure, follows the exponential curve and the other, the right figure, has two growth stages after weaning. Although the occurrence of layer is more irregular for the female whale than the male whale, two patterns exist for both sexes. In the ear plug represented by the left figure, the growth is regular and in the ear plug following the growth of the right figure the growth rate is different between the immature stage and the mature stage.

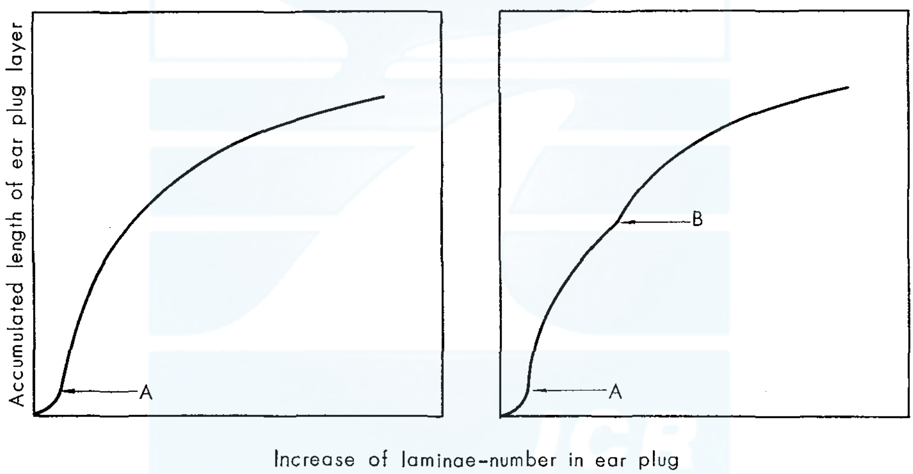

Fig. 36. Schematic growth of the fin whale ear-plug core with the increment of lamination. Inflection A point occurs at 1 lamina indicating weaning. Inflection B point occurs at about 10 laminae indicating sexual maturity.

Inflection point A appears at 1 lamina indicating weaning and point B at about 10 laminae showing the sexual maturity. When these growth curves are plotted in the Walford graphic method (1946), the clear difference is obtained. A foundation of assumption on the regular occurrence of ear plug layer lies in the exponential growth indicated by Purves (1955, Text-fig. 2). His figure for the fin whale ear plug, however, belongs to a pattern shown in the right of Fig. 36 and A point is at 1 lamina and B point is at 12 laminae.

On the occurrence of ear plug layer in the fin whale, my interpretation in conclusion is summarized as follows.

I Prenatal life

The dark layer begins at the $6^1/_2$ pregnancy months and the bright layer arises after the 8th pregnancy months. (The gestation period is the 11 3/4 month for the fin whale according to Laws (1959)).

II Postnatal life

The first lamina (an alternation of the dark and the bright layer) is formed during suckling (during 8 months after birth)

For the immature stage, the occurrence is a little complicated and three cases are considerable.

1. Annual formation of laminae
2. Complex of the annual and biannual formation of laminae
3. Biannual formation of laminae

As a mean, the figure of 1.5 for the annual increment is appropriate for the sexually immature stage in both sexes. After the sexual maturity, the regularity of annual formation is maintained, but after the physical maturity there is a possibility which such a regularity is disturbed and the increment rate become increase again annually. I can not here comment on the figure for the increment rate in the very old whale after the physical maturity. Such a possibility resulted from the examination on the mitotic activity in the glove-finger epidermis. In the ear plug indicating large numbers of laminae, for example in a sample (100 laminae) shown by Nishiwaki, Ichihara and Ohsumi (1958), the distance of neighbouring laminae is remarkably reduced and does not indicate the regular decrease, however, it seems that an assumption on the annual formation rate for very old fin whales has no intensive effect on the practice of the stock assessment for the fin whale. There are gradual shifts in the incremrnt rate of laminae at the sexual maturity and the physical maturity.

My proposal suggests that the laminae of ear plugs indicates the relative indicator of age for the fin whales, probably for other baleen whales. In this respect, my conclusion disagrees with the previous opinions on the ear plug, but the conflict among the previous estimations is disolved to some degree through my interpretation. Ecological studies for young fin whales is not so advanced as humpback whales reported by Dawbin (1956), because there is few chance to observe the fin whale as an oceanic species compared with the many chances for the humpback whale as a coastal species. With regard to the occurrence of fin whales off Durban in South Africa, Bannister and Gambell (1965) presented valuable informations. Fin whales off South Africa is closely related to the population of the Antarctic Area III (0°–70°E) from which material of my study comes, according to the movement of marked whale (Rayner, 1940). Examing the sexual state of captured fin whale, they pointed that the sexually immature group of fin whales has the peak influx in June during the 1954–57 seasons and in August during the 1960–63 seasons, while the mature group in July through the 1954–63 seasons. For the presence of a number of immature whale in both sexes, they state it is impossible to say whether these are simply young whales that have got out of step with the main migrations for some reason, or whether a large proportion than has been previously suspected do not migrate south until young whales are older, and they described further that a higher proportion of young fin whales than of adults are apparently feeding off the Natal coast but this evidence is mostly from whales observed the end of the season.

In the antarctic area, the percentage of immature whales in the catch generally increases towards the end of the season (Mackintosh, 1942) and the Japanese pelagic catch also supports this tendency. However, the examination on the South Georgia fin whales during the 1925–31 seasons shows evidence that the influx of immature whale is bimodal for both sexes; one smaller mode (24.1–25.4%) is present in October and the other (46.0–50.0%) in March according to Mackintosh.

From the mark recovery, Brown (1954) suggests that fin whales are shown to return from their migrations year after year to somewhere near the marked place and that the dispersal may take place among the younger whales rather than among older whales.

These evidences shows that in general the migratory habit and hence the feeding habit is irregular in the immature group than the mature group. These also support my opinion on the rather irregular occurrence of bright layer in the immature whale. It is interesting to find that the peak of baleen plate records agrees with the peak of the photometric record for the ear plug. Some of young fin whales presumably feed in spring and autumn even in the antarctic area. The indirect evidence that the bloom of diatom occurs twice in spring and autumn of the temperate zone

TABLE 14. EAR PLUG LAMINAE AT THE SEXUAL MATURITY OF THE FIN WHALE.

Author	Year	Male	Female	Locality
Laws and Purves	1956	8–12	—	North Atlantic
Nishiwaki	1957	—	10	Antarctic
Nishiwaki, Ichihara and Ohsumi	1958	11	11	Antarctic & North Pacific
Purves and Mountford	1959	9	10–12	Antarctic
Laws	1961	—	10	Antarctic
Ohsumi	1964	9.4	10.7	Antarctic

and once in summer of the high latitude zone presumably suggests that some of young fin whale feed irregularly both in the temperate zone and in the Antarctic.

The age of fin whale will be determined more accurately from the proposed annual increment rate of ear plug laminae. Previous opinions concerning the accumulated laminations until the sexual maturity of fin whale are summarized in Table 14.

In the point of the large size of sample, I support Ohsumi's figure for the Antarctic fin whale. According to my examination, the same figure is given to the population of the fin whale inhabiting Area III (0°–70°E) in the Antarctic. Individuals having testis over 2.5 kg are diagnosed as the mature male and individuals indicating the first ovulation as the mature female. Accordingly, the mean age of maturity is 6 years for the male and 7 years for the female. This interpretation for the antarctic fin whale is applied for the North Pacific fin whale because of the same formation mechanism in ear plugs between two localities. The figure presented by Nishiwaki, Ichihara and Ohsumi (1958) is slightly higer for the North Pacific male.

According to the growth curve, the maximum length is reached at 40–45 earplug laminae for both sexes in the Antarctic and the North Pacific fin whale. When the maximum leghth is considered to correspond to the length of physical maturity, the physical maturity is attained within 40 years from birth for both sexes. As far as some doubts remain for the increment rate of laminae after the physical maturity, the rigid longevity of the fin whale is not determined here. Judged from the countable maximum laminae in the ear plug; 101 laminae in the male and 100 laminae in the female in the Japanese material, however, it is concluded that the fin whale has a longer life span than that estimated by previous scientists. Table 15 shows the body length at the sexual maturity of the fin whales. When the maturity percentage in each length is plotted, these figures are obtained at 50 percent level of maturity. From the examination on reproductive organs by Japanese biologists from the 1955/56 to the 1962/63 seasons in the antarctic pelagic whaling, I summarize them in each Area. The length at the sexual maturity of the North Pacific fin whale results from the examination from the 1956 to the 1964 season in the Japanese pelagic whaling.

TABLE 15. THE BODY LENGTH IN FEET AT THE SEXUAL MATURITY OF FIN WHALES, DETERMINED BY THE EXAMINATIOH ON REPRODUCTIVE ORGANS OF CAPTURED WHALE BY THE JAPANESE PELAGIC WHALING. PARENTHESES SHOW THE SIZE OF SAMPLE.

North Pacific

Male	57.5	(6018)
Female	60.2	(5513)

Antarctic

	Area I 60°W–120°W	Area III 0°–70°E	Area IV 70°E–130°E	Area V 130°E–170°W	Area VI 120°W–170°W
Male	61.0 (1408)	62.6 (627)	61.7 (609)	62.8 (887)	61.5 (5887)
Female	64.7 (1289)	65.6 (1454)	65.6 (1665)	65.6 (1124)	64.5 (5116)

Mackintosh (1942) reported that the antarctic fin whale reaches the sexual maturity at 63.0 feet in the male (473 sample sizes) and 65.3 feet in the female (770 sample sizes) on the basis of biological examination from the 1927/28 to 1940/41 season in the antarctic whaling. Although his criterion for the mature male is different from mine, his results are very near to my findings except for Area I (60°W-120°W) and Area VI (120°W-170°W). In the Pacific sector, the fin whale of both sexes attains to the sexual maturity in smaller length than in other sectors. 61.7 feet of the male in Area IV (70°E-130°E) seems to be too small because of the scarcity in the sample size. Based on the large sample size, the North Pacific fin whale attains to the maturity at 57.5 feet in the male and at 60.2 feet in the female.

During my field work in the Grytviken Station at South Georgia, No. 1294, a prewar mark of the Discovery Committee was recovered after 29 years and 9 months from fire. Two perfect ear plugs were collected from the female fin whale of 74 feet in length and showed 40 laminations. Both ovaries were lost because the belly of this whale was cut.

Record at fire;

53°48′S, 40°56′W, 16 January, 1935.

Record at recovery

56 43′S, 39 24′W, 17 October, 1964.

SUMMARY

Age determination is very important for the fisheries biology of whales and many studies on this project have been carried out during the past 40 years. Compared with other age charactors, the accumulated laminae in the ear plug which has been recently found is the most believable as the ageing method for baleen whales. This paper results from my continuous study in a series on the biology of fin whale ear-plug from the foetus to the very old whale and includes comments on the previous papers related to the age determination by means of the ear plug layer. In the course of this study, the structure of the baleen plate which is another valuable age indicator for the young fin whale had to be examined again by the devised photographic apparatus. The photometric apparatus recording the alternation of ear plug layer was devised as a method researching for the biological meaning of each layer. The race of fin whale population was considered particularly in estimating the aunual increment rate of laminae. The results of this study are summarized as follows.

1. The improved photometric recording apparatus for the ear plug layer was accomplished. Main improved points exist in the development of compensation method for recording, and in the semi-automatic mechanism. By this apparatus, the alternation of the dark layer (keratinized cell layer) and the bright layer (fatty degenerated cell layer) in the ear plug was accurately recorded in the undulating brightness on a standard level.

2. Photographic method for the long strip of baleen plate was devised and the structure of the longitudinally sectioned baleen plate was examined by this method. The unique mechanism exists in the photographic method to shorten the long baleen plate and simultaneously enlarge the thickness of thin plate.

3. The baleen plate has several inflections in its longitudinally growing direction. These inflections result from the different growth rate of plate between the active and the quiescent formation of the medullary layer, and the numbers of inflections are closely related to the age determined by the baleen sculpture. The increasing medullary layers in thickness correspond to these inflection points in their positions. The change of thickness in the medullary layers has an intensive effect on the periodical change of thickness in the baleen plate and supports the previous finding that the baleen ridge is a valuable ageing charactor for the young fin whale. The varying thickness of the cortical layer is not so significant for the age determination as that of the medullary layer.

4. It is impossible to determine the age of fin whale over 4 years by means of the baleen ridge count because the neonatal mark of plate begins to wear off at 3 years from birth.

5. Except the suckling stage, the sculpture record of baleen plate corresponds to the photometric records for the ear plug. In typical records the increasing thickness of plate corresponds to the occurrence of bright layer in the ear plug.

6. It is estimated that the period of suckling is about 8 months for the antarctic fin whale and the calf weans at about 43 feet in the length in the end of January.

7. Ear plugs are derived from the glove-finger epidermis. The keratinization of the foetal glove-finger epidermis arises from the $6^1/_2$ pregnancy months and the fatty degeneration occurs after the 8th pregnancy months in the fin whale. The occurrence of bright layer in the foetal ear plug is closely related the increasing growth rate of foetus proper and independent of the occurrence of bright layer in the maternal ear plug. All degenerated cells of the glove-finger epidermis remain in the external auditory meatus throughout the life of whale from the $6^1/_2$ foetal months. This is an indication that the ear plug is the most valuable ageing material for the fin whale of both sexes.

8. The next dark layer to the foetal layers indicated the neonatal mark in the ear plug. It is estimated that the first lamina (an alternation of the dark and the bright layer) is formed during the suckling stage of the fin whale.

9. Previous hypotheses for the formation of ear plug layer were commented. The laminae of ear plug does not infer an absolute age indicator for the fin whale but a relative age indicator.

10. Factors affecting the formation of ear plug layer after birth were examined in relation to the life history of fin whale. In the glove-finger epidermal cell contributing to the formation of ear plug, the fatty degeneration shows three times mitotic activity than the keratinization. It is assummed that Vitamin A, rapid food supply and growth hormone induce the formation of bright layer and that on the other hand Vitamin A deficiency, starvation and estrogen do the formation of the dark layer. The relation between these factors and the epidermal mitosis was discussed.

11. The formation time and period of the ear plug layer after birth were examined by an application of SUDAN III staining method to the base of ear plug. During the examined 6 monthly period in the Antarctic, both dark and bright layers occur in the sexually immature whale but the occurrence of bright layer is predominant in the mature whale. The bright layer in the sexually mature whale is formed during the period of feeding migration and the dark layer during that of breeding migration.

12. The ear plug of young whale shows the irregular occurrence of layers. The annual increment rate of layer is 1.5 lamination for the sexually immature fin whale of both sexes. It was checked by three kinds of approaching method. From the sexual maturity to the physical maturity, one lamina is annually laid down. After the physical maturity, the increment rate probably increases again but the rigid conclusion is not given in this respect.

13. The age at the maturity of the fin whale was estimated on the basis of the aunual increment rate of ear plug layer. The male fin whale attains to the sexual maturity at 6 years after birth and the female at 7 years. This finding is applied for both the Antarctic and the North Pacific fin whale. Both sexes reach to the physical maturity until 40 years after birth.

14. On the basis of large samples, the length of the sexual maturity was estimated for the fin whale. For the North Pacific population, it is 57.5 feet for the male and 60.2 feet for the female. In the east Pacific sector in the Antarctic, it is shorter by about one foot than the other area and 61.3 feet for the male and 64.6 feet for the female.

15. The accurate knowledge for the ecology of young and very old fin whales is necessary for the future development of whale biology.

ACKNOWLEDGEMENTS

I am indebted to Dr. Hideo Omura, Director of the Whales Research Institute for his kind support throughout this serial work. My grateful acknowledgements are due to Prof. Dr. Moriso Hirata, Department of Physics, Faculty of Science, University of Tokyo, who accomplished the photometric apparatus recording the ear plug laminae and devised the photographic method for the long strip of the baleen plate, and permitted me to describe its mechanism in this paper. Miss Toyoko Asami assisted me in the patient work taking the records of ear plugs. Without their thorough helps and suggestions, this work was not completed.

Sincere thanks are due to Mr. Gordon C. Pike, Biological Station at Nanaimo, Fisheries Research Board of Canada who kindly took the sculpture records of baleen plates from young fin whales by his improved apparatus and wrote age marks in these records which are presented in this paper.

Records of baleen plates left by Dr. Masaharu Nishiwaki and Dr. Kazuo Fujino, the former members of the Whales Research Institute, gave me very valuable suggestions. Mr. Sidney G. Brown, the National Institute of Oceanography in England, who informed me the fire date of the prewar mark. Mr. Toshio Kasuya helped me in collection of very young baleen plates. My thanks are due to their kind helps.

Many whaling inspectors of the Japanese Governments and staff of the Japanese Whaling Companies collaborated me in field works. Mr. John Dye and Mr. Martin Toop, whaling inspectors and biologists of the government of The Falkland Island Dependencies also actively cooperated in the biological examination at the South Georgia whaling. Finally, my acknowledgements are due to them.

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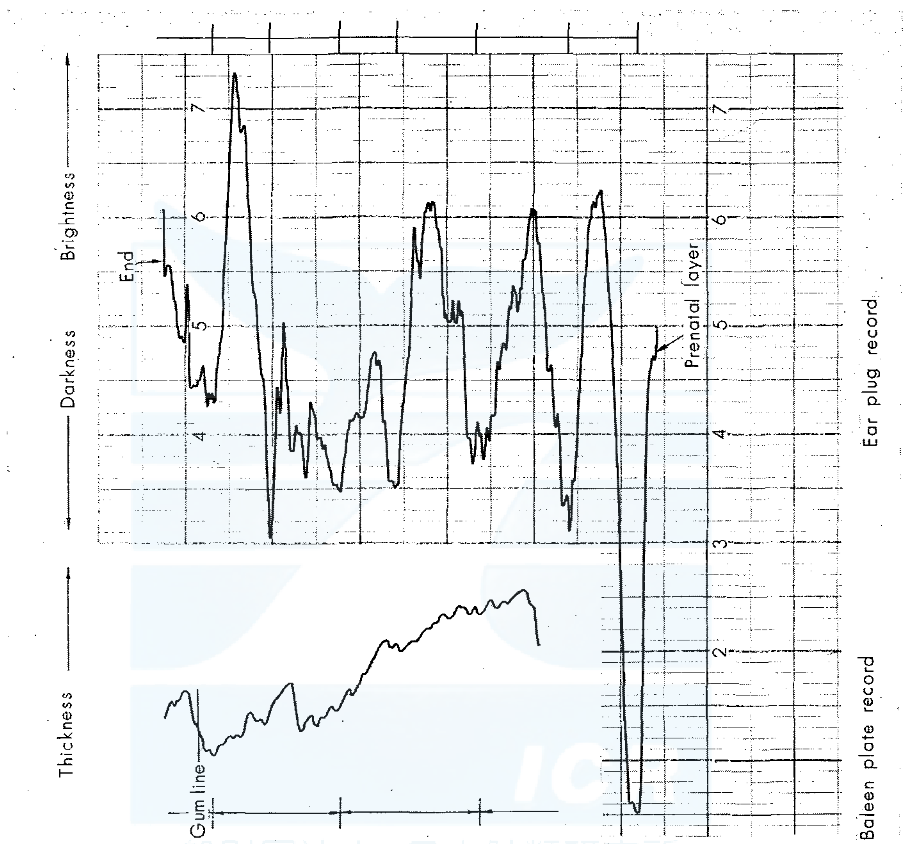
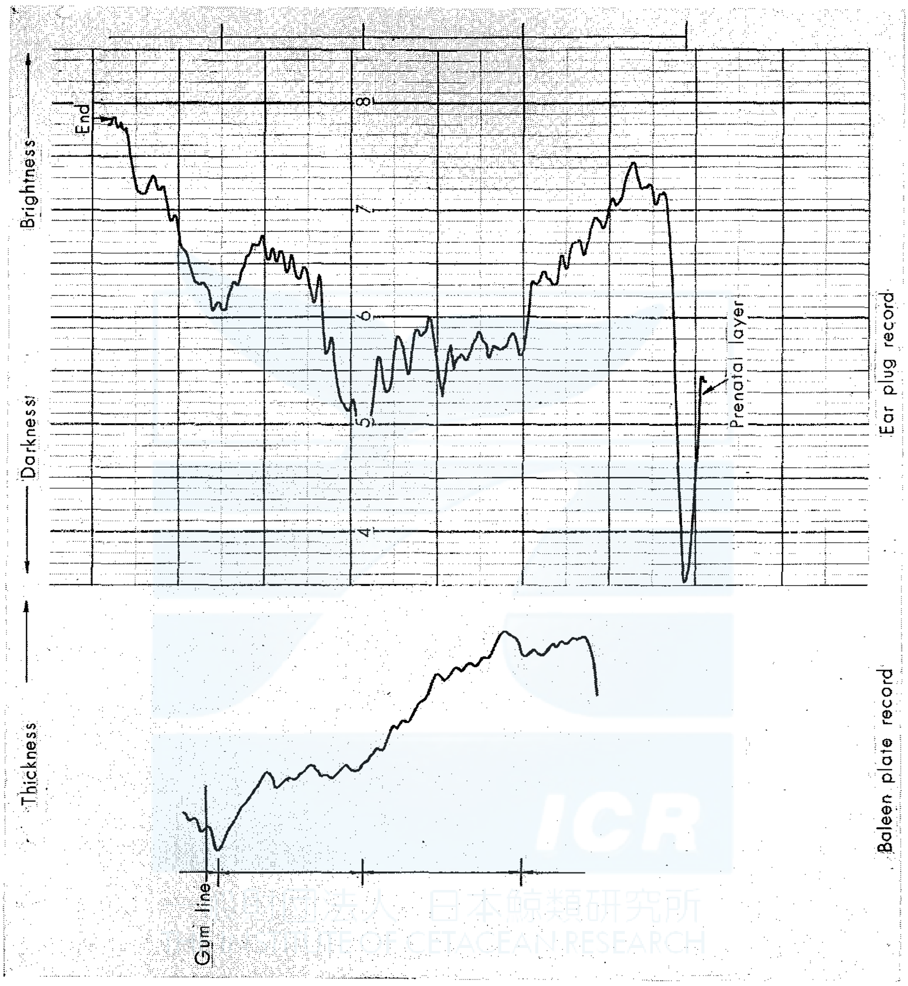
EXPLANATION OF PLATES I—VIII

Comparisons between the sculpture records of baleen plates and the photometric records of ear plug layers in 8 young fin whales from the Antarctic.

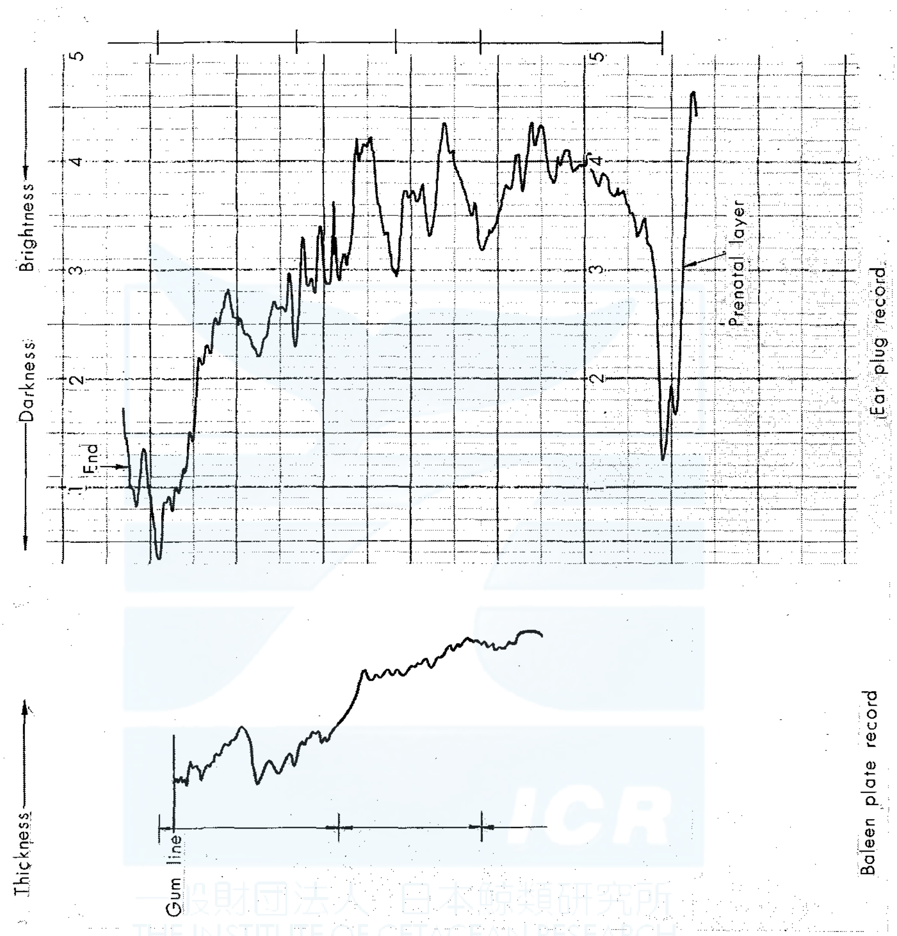
The age mark for baleen plate is given in the lower and the border of each lamina in the ear plug in the upper. All ear plugs have prenatal layers but tips of baleen plates have been already worn off. These figures show that the photometric record is very sensitive. When the photometric records are reversed, the dark layers are emphasized.



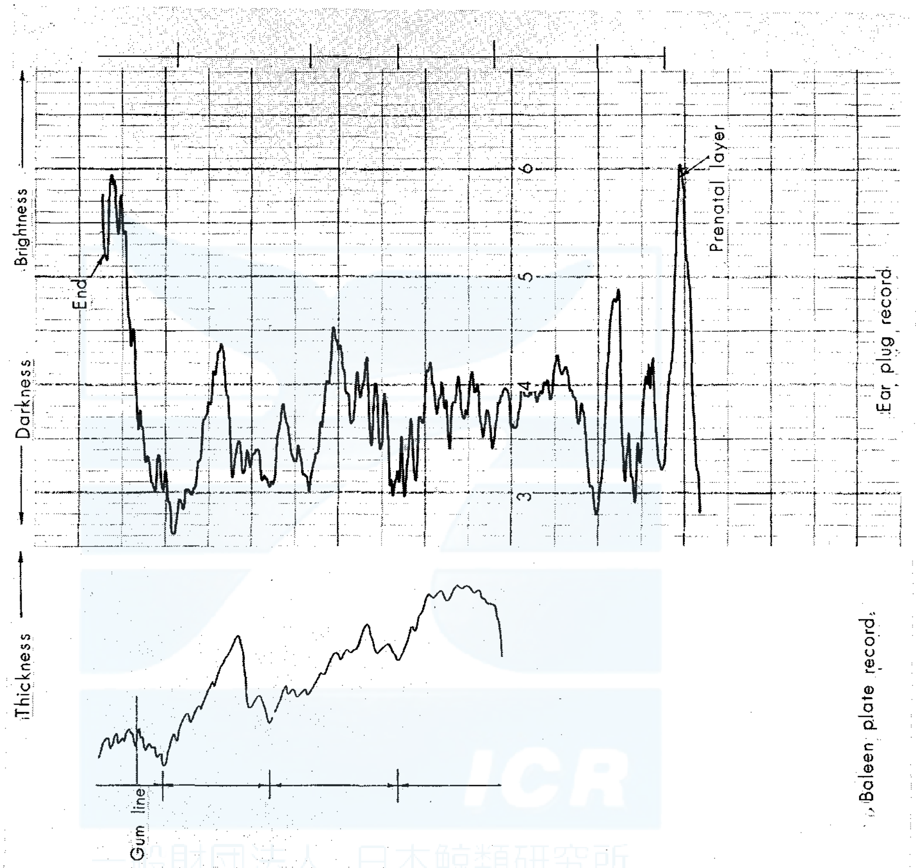
Records for No. 10 fin whale. Unit of horizontal scale is 1.40 mm



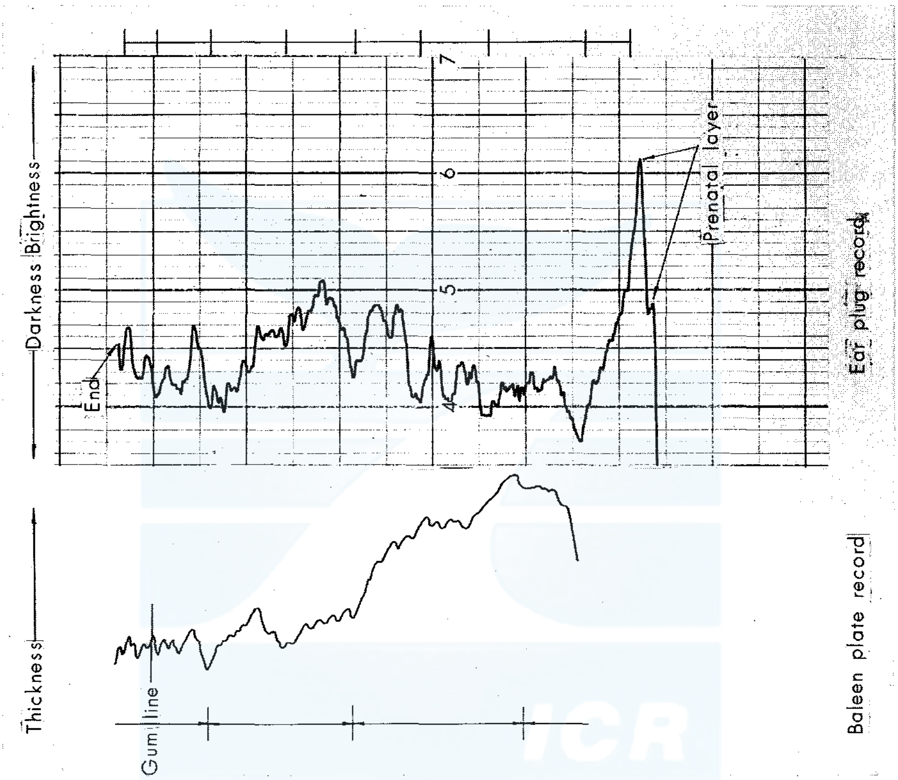
Records for No. 11 fin whale. Unit of horizontal scale is 0.70 mm.



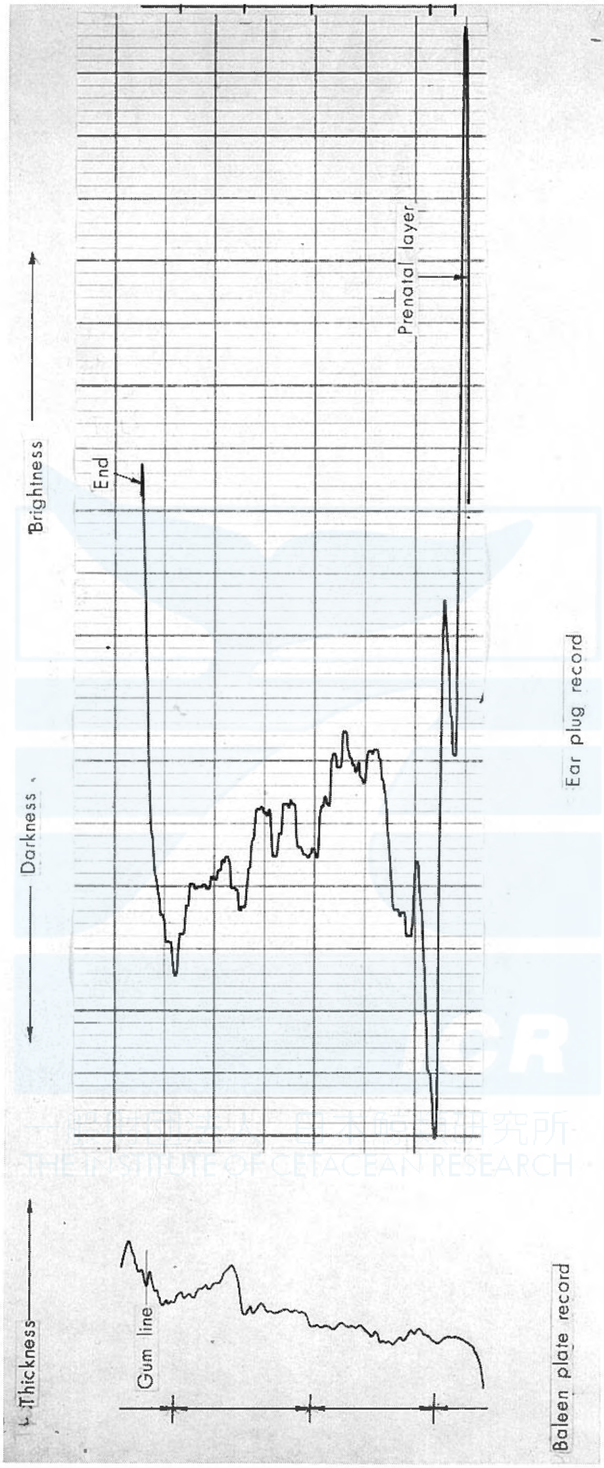
Records for No. 12 fin whale. Unit of horizontal scale is 0.70 mm.



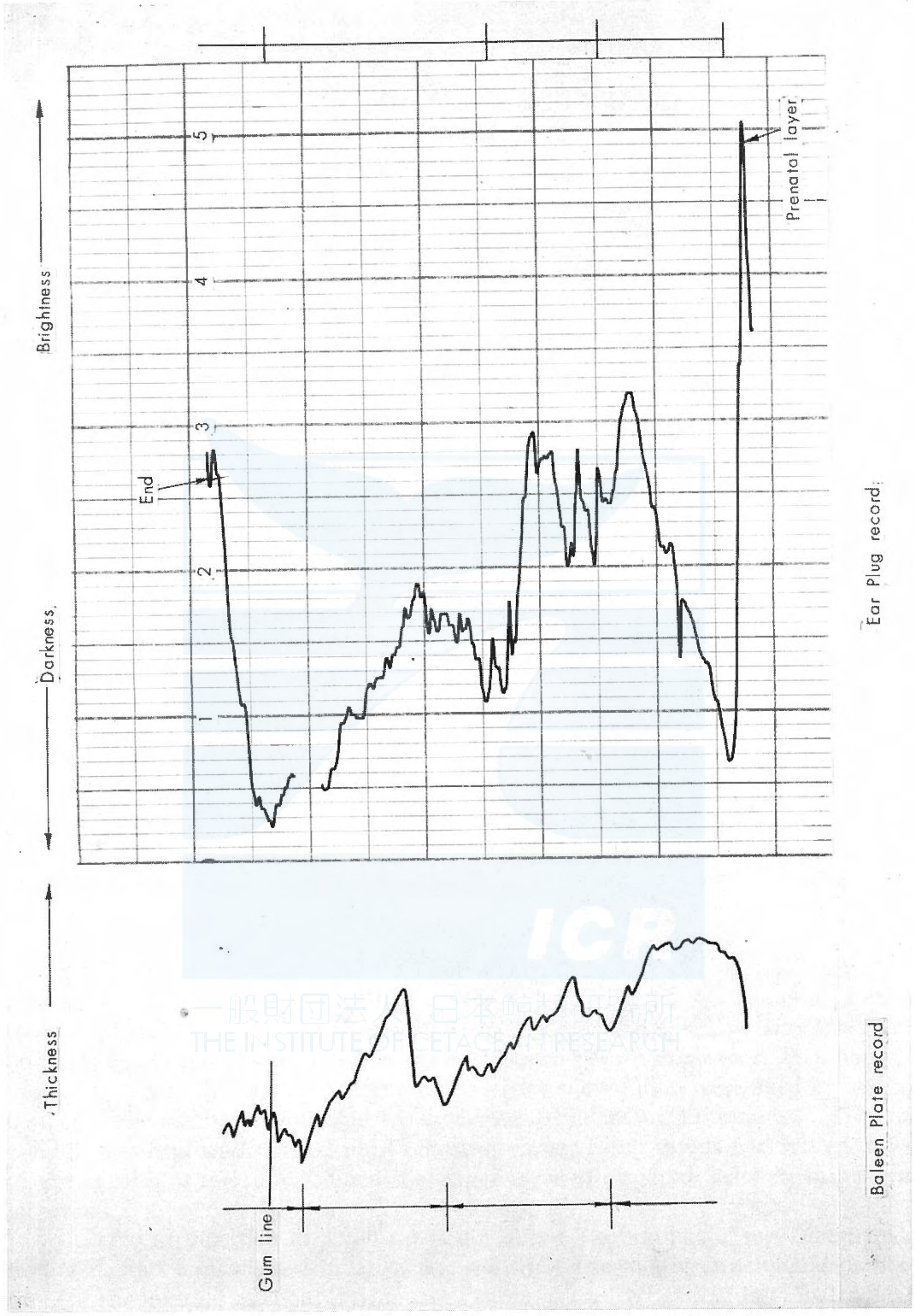
Records for No. 13 fin whale. Unit horizontal scale is 1.40 mm.



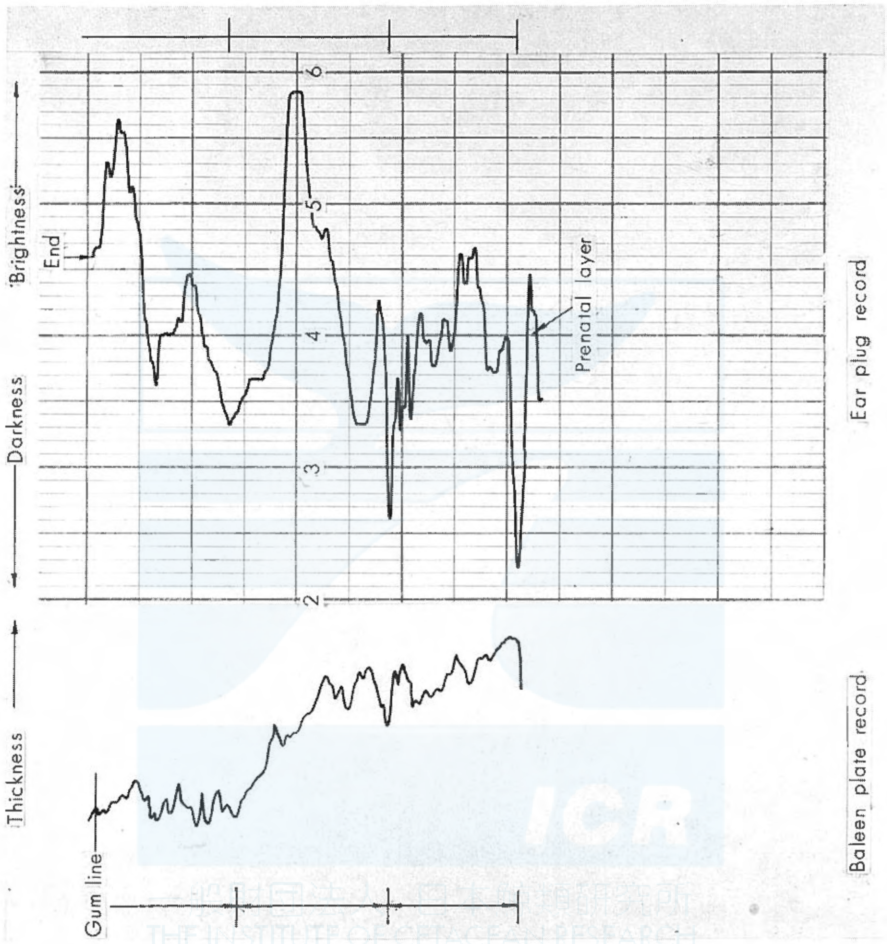
Records for No. 14 fin whale. Unit of horizontal scale is 1.40 mm.



Records for No. 17 fin whale. Unit of horizontal scale is 2.81 mm.



Records for No. 18 fin whale. Unit of horizontal scale, is 1.40 mm.



Records for No. 19 fin whale. Unit of horizontal scale is 1.40 mm.