EARPLUG TRANSITION PHASE AS AN INDICATOR OF SEXUAL MATURITY IN FEMALE ANTARCTIC MINKE WHALES*

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ABSTRACT

The transition phase in the earplug of the minke whale (*Balaenoptera acutorostrata*) was examined on its meaning as an indicator of the sexual maturity by use of earplug materials of 360 females caught in the Antarctic Areas III and IV in 1971/72–1981/82 Seasons.

It was confirmed from seven kinds of examinations that the transition phase can be regarded as an indicator of the sexual maturity of the minke whale. However, few whales form the transition phase in sexually immature stage, when they grow near the body length or age at sexual maturity. The transition phase becomes to be identified fully by the time of accumulation of 4–5 growth layers after its formation. Ten to fifteen percent of sexually mature whales do not form identifiable transition phase in earplugs for their life.

Annual ovulation rate was estimated from age at capture, age at transition phase and number of ovarian corpora to change from 1.9 in the early stage of sexual maturity to 0.9 in the oldest stage of life in recent years.

INTRODUCTION

Growth layers of the earplug have been used as the best age character of baleen whales since the discovery of the layers by Purves (1955). Ichihara (1966) suggested for the fin whale that the age when width of growth layers suddenly declines might indicate the age at sexual maturity. Lockyer (1972) confirmed this through the comparison of growth layers and biological data of the Southern Hemisphere fin whales, and named the phase where the growth layer width changes abruptly as 'transition phase'.

Masaki (1973) found the presence of the transition phase in earplugs of the Antarctic minke whale as already reported on other *Balaenoptera* whale species. Masaki (1979) further studied the age at sexual maturity of the Antarctic minke whale, and indicated that the age at sexual maturity suggested by the transition phase agreed well with the age obtained from the data of

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reproductive tract. Kato (1983) used the transition phase to estimate the yearly change in the age at sexual maturity of the Antarctic minke whale, and compared the results obtained from other independent methods. Best (1982) confirmed the correlation between sexual maturity and presence of transition phase in earplugs of minke whales off Durban, and he also studied yearly change in age at sexual maturity by use of the transition phase.

Although these authors indicated the usefulness of transition phase as a mark of the sexual maturity of the Southern Hemisphere minke whale, it has been understood that there are some need to examine further on this matter through the discussion in the Scientific Committee of the International Whaling Commission in the beginning of 1980s (Anon., 1983). This paper will examine if the transition phase in the earplug can be used as an indicator of the sexual maturity of the Antarctic minke whale. As the materials only females were used, because the sexual maturity can be more easily identified.

Mr Hidehiro Kato of the Whales Research Institute provided me with earplug materials and biological data for this study. I would like to express my sincere thanks to him for his endeavor to select these materials. I am largely indebted to Dr Toshio Kasuya of the Far Seas Fisheries Research Laboratory who kindly criticized my manuscript and made many suggestions.

MATERIALS AND METHODS

The materials used in this study were earplugs of 360 female minke whales caught by Japanese whaling expeditions in the Antarctic Areas III (0–70°E) and IV (70–130°E) in 1971/72–1981/82 Seasons and stored in the Far Seas Fisheries Laboratory. Mr H. Kato selected these materials under the principle agreed by the Scientific Committee for use in the Minke Whale Ageing Workshop which was held in Cambridge in April 1983 (Anon., 1984). The selecting procedure of these earplugs was described in detail by Kato (1984). In this case stratified sampling of two readability classes and nine corpora count classes (18 strata) was adopted: 20 samples were allocated to each stratum. The earplugs were read by myself for total number of growth layers (age at capture) and the number of growth layers before the transition phase (age at transition phase). Each half-sectioned earplug was put in water and read for these two kinds of layers under a binocular dissecting microscope for three times without referring to any biological information of the whale, and finally decided the best numbers of these layers on each whale as the average.

The body lengths were measured in 0.1 m unit on board of the whaling factory ships. The numbers of corpora lutea and corpora albicantia in the ovaries were counted in the Far Seas Fisheries Research Laboratory or by biologists on board of factory ships. These data have been stored in the Far Seas Fisheries Research Laboratory, and used to determine the sexual maturity of the materials. The sexual maturity was determined by the presence of corpus luteum or albicans in the ovaries. Among them a female having one or two

TABLE 1. APPEARANCE OF TRANSITION PHASE ACCOMPANIED WITH SEXUAL MATURITY AND AGE AT CAPTURE OF THE ANTARCTIC MINKE WHALES

Age	Immature			Mature			Total		
	−	+	Total	−	+	Total	−	+	Total
3	4	–	4	–	–	–	4	–	4
4	5	–	5	–	–	–	5	–	5
5	9	–	9	3	–	3	12	–	12
6	7	–	7	2	1	3	9	1	10
7	4	–	4	3	2	5	7	2	9
8	6	–	6	2	1	3	8	1	9
9	2	–	2	4	3	7	6	3	9
10	–	1	1	5	9	14	5	10	15
11	1	–	1	4	11	15	5	11	16
12	–	–	–	2	14	16	2	14	16
13	–	–	–	2	10	12	2	10	12
14	–	–	–	3	17	20	3	17	20
15	–	–	–	1	15	16	1	15	16
16	–	–	–	1	13	14	1	13	14
17	–	–	–	1	17	18	1	17	18
18	–	–	–	–	14	14	–	14	14
19	–	–	–	1	10	11	1	10	11
20	–	–	–	3	8	11	3	8	11
21	–	–	–	–	10	10	–	10	10
22	–	–	–	–	11	11	–	11	11
23	–	–	–	4	10	14	4	10	14
24	–	–	–	–	9	9	–	9	9
25	–	–	–	3	9	12	3	9	12
26±	–	–	–	7	69	76	7	69	76
Unknown	–	1	1	1	4	5	1	5	6
Total	38	2	40	52	267	319	90	269	359

Remarks: −: Transition phase not appeared, +: Transition phase appeared.

ovarian corpora was recognized as a whale just after the attainment of sexual maturity, and used as an indicator of a stage of attainment of sexual maturity.

RESULTS

Transition phase and sexual maturity

Among 360 females used in this study, an earplug of a whale had an abnormal pattern of growth layers, and it was impossible to read age at capture or at transition phase. This whale was omitted from the later analysis. Earplugs of other 6 whales were incomplete missing either germinal or neonatal layer, and their age at capture was not estimated, although some of their transition

TABLE 2. APPEARANCE OF TRANSITION PHASE ACCOMPANIED WITH ACCUMULATION OF CORPORA LUTEA AND ALBICANTIA IN THE OVARIES OF THE ANTARCTIC MINKE WHALES

Number of corpora	−	+	Total
0	38	2	40
1	9	2	11
2	7	10	17
3	2	7	9
4	1	8	9
5	5	13	18
6	1	12	13
7	–	11	11
8	1	19	20
9	2	7	9
10	3	10	13
11	–	21	21
12	–	7	7
13	–	10	10
14	1	15	16
15	4	12	16
16	3	15	18
17	1	9	10
18	1	11	12
19	4	12	16
20	2	13	15
21±	5	43	48
Total	90	269	359

Remarks: −: Transition phase not appeared,
+: Transition phase appeared.

phase could be identified (Table 1).

As shown in Tables 1, 2 and 3, 40 whales were sexually immature. Among them two (5.0 %) had transition phase, and others (38 whales, 95.0 %) did not. This indicates that most of the immature whales have no transition phase in the earplugs, but few immature whales have already formed it.

These tables also show that 267 whales (83.7 %) have transition phase among 319 sexually mature females, but it is not detected on remaining 52 whales (16.3 %). Some of the latter may have transition phase actually, but the post-transition phase could not be thick enough to be identified, because transition phase has just formed on the individuals which were soon after the attainment at sexual maturity. In addition to it, there are old whales of which transition phase was not detected at all.

TABLE 3. APPEARANCE OF TRANSITION PHASE ACCOMPANIED WITH SEXUAL MATURITY AND BODY LENGTH OF THE ANTARCTIC MINKE WHALES

Body length	Immature			Mature			Total		
(m)	−	+	Total	−	+	Total	−	+	Total
6.9– 7.0	1	–	1	–	–	–	1	–	1
7.1– 7.2	2	1	3	–	–	–	2	1	3
7.3– 7.4	5	–	5	–	1	1	5	1	6
7.5– 7.6	4	–	4	–	1	1	4	1	5
7.7– 7.8	8	–	8	–	3	3	8	3	11
7.9– 8.0	2	–	2	2	6	8	4	6	10
8.1– 8.2	5	–	5	8	8	16	13	8	21
8.3– 8.4	3	–	3	7	32	39	10	32	42
8.5– 8.6	5	1	6	4	38	42	9	39	48
8.7– 8.8	3	–	3	16	54	70	19	54	73
8.9– 9.0	–	–	–	3	48	51	3	54	57
9.1– 9.2	–	–	–	3	32	35	3	32	35
9.3– 9.4	–	–	–	6	25	31	6	25	31
9.5– 9.6	–	–	–	–	14	14	–	14	14
9.7– 9.8	–	–	–	2	3	5	2	3	5
9.9–10.0	–	–	–	–	2	2	–	2	2
10.1–10.2	–	–	–	1	1	2	1	1	2
Total	38	2	40	52	267	319	90	269	359

Remarks: −: Transition phase not appeared, +: Transition phase appeared.

TABLE 4. COMPARISON OF PRESENCE OF TRANSITION PHASE AMONG SOME REPORTS

Sexual maturity classification	Lockyer (1972) Fin whale Females		Best (1982) Minke whale Both sexes		Present paper Minke whale Females	
	Sample size	%	Sample size	%	Sample size	%
Immature	27	0.0	21	4.8	40	5.0
Pubertal*	47	19.2	12	16.7	28	42.9
Other mature	177	96.5	94	83.0	291	87.6

Remarks:
*: One to two corpora in ovaries or both mature and immature tubules in testes.

Correlation between ovarian corpora number and transition phase

Table 4 shows that the proportion of whales having transition phase is 42.9 % in early stage of mature females (one or two ovarian corpora), which is lower than that of older mature whales (87.6 %). This suggests that there will be some correlation between ovarian corpora number (or time after maturation) and proportion of individuals having transition phase.

Fig. 1B shows this correlation using data in Table 2. The proportion of

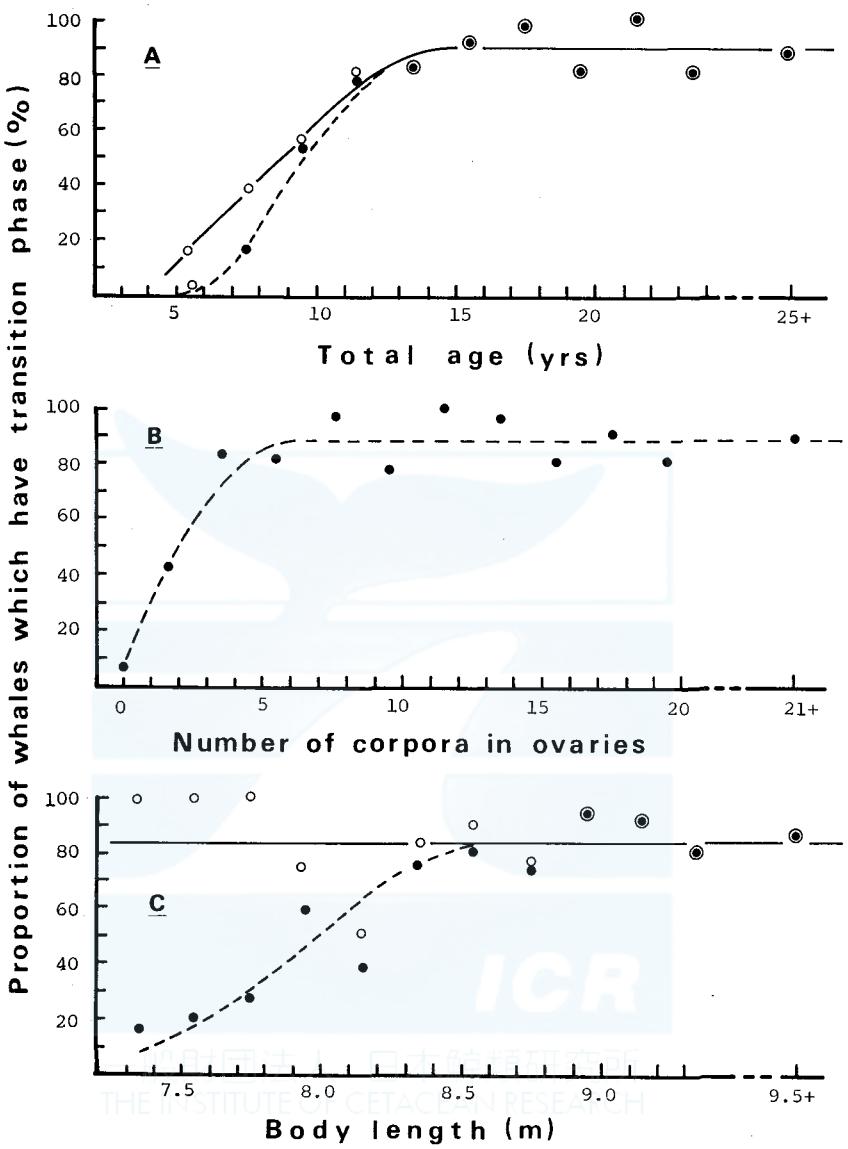

Fig. 1. Proportions of whales which have transition phase in earplug to total whales in each growth stage. A: Based on total ages, B: Based on corpora number in ovaries, C: Based on body length. Open circle and solid line: Sexually mature whales, Closed circle and broken line: Total whales.

individuals which have transition phase in earplug increases rapidly till accumulation of 4 or 5 corpora, then it becomes constant at a level of 87.9 % individuals with five corpora. This indicates that the transition phase is difficult to be identified at the beginning of its formation, although it is formed around

the attainment of sexual maturity, but it can be detected fully after the stage of 4 or 5 corpora number, if it is formed in an individual.

Correlation between age at capture and transition phase

Table 1 shows frequency distributions of ages at capture of 359 females used in the present analysis. Ages of sexually immature whales are distributed in the range of 3 to 11 years. Two immature whales have transition phase. One of them is 10 years old. The age of another whale is unknown, because germinal layer was missing from the earplug. This whale is estimated to be at least 14 years old from remaining part of the earplug. These two whales indicate that the transition phase may be formed in some whales after a certain age when most whales attain at sexual maturity, even if the whale remains in the immature stage.

At the ages of 6–9 years, all the 19 immature whales had no transition phase, but seven individuals in 18 mature females had it. This means that the correlation of transition phase with age is lower than that with sexual maturity. Although sexually mature whales were found from 5 years of age, sexually mature whales with transition phase appeared from 6 years of age. This is reasoned by that the transition phase is difficult to identify at the beginning of its formation.

Fig. 1A shows age related change in proportion of whales with transition phase in earplugs. The proportion increases from the age of 5–6 years to 13–15 years, and then it becomes stable at a level of 89.8 % over 14 years as in the case of corpora numbers mentioned above. The increase in the proportion with the age (5 to 14 years) will be related with the increase in the proportion of sexually mature whales as well as the increase of detectability of transition phase. The proportion is higher than that calculated including immature whales. This means that the formation of transition phase is related more with the sexual maturity than the age. However, even in the sexually mature whales the proportion of whales having transition phase increases with age the same as in the case of ovarian corpora.

Ages of full identification of transition phase

Due to the definition of the earplug transition phase, it is reasonable to consider that the detection of transition phase becomes easier after several growth layers have been accumulated after the phase.

Fig. 2 shows a frequency distribution of times after transition phase (age at capture minus age at transition phase). The recognized shortest time after transition phase is one year which is represented by only three whales, but the highest frequency is at 5 years. This indicates that the presence of transition phase can be rarely recognized when one growth layer is accumulated after the phase, but most usually recognized after the deposition of 2 to 5 layers. The transition phase can be fully identified, if it exists, when more than 4 layers are accumulated after its formation.

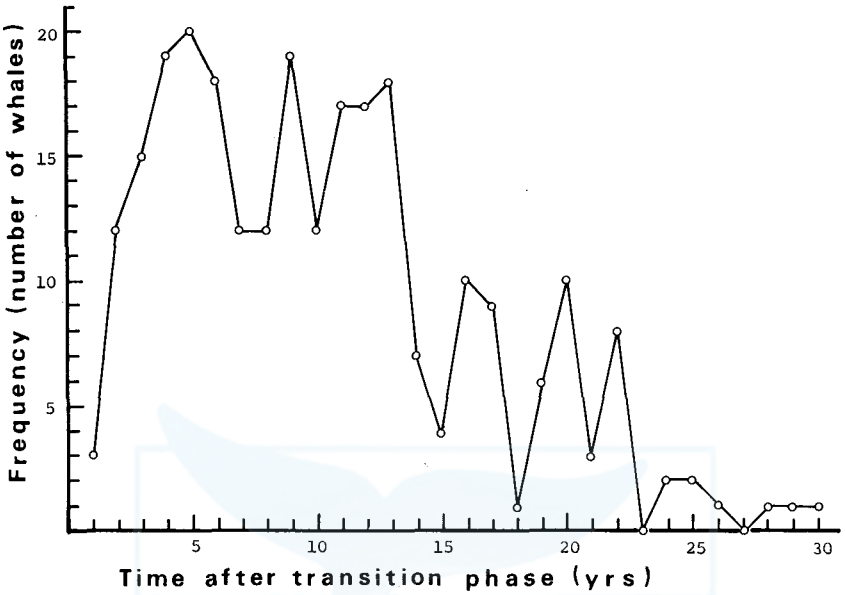

Fig. 2. Frequency distribution of ages after transition phase in earplugs of the female Antarctic minke whales.

Correlation between body length and presence of transition phase

Table 3 shows frequency distributions of body lengths of the present material. Whales without identifiable transition phase are found in all size classes. Fig. 1C shows the relationship between body length and proportion of whales having transition phase. In the length range of 7.4 to 8.6 m, the proportion increases with increasing body length. Above 8.7 m of body length the proportion is constant at the average of 84.5 %.

Fig. 1C also shows the proportion of whales with transition phase calculated using only sexually mature whales. Although the sample size is small (11 whales) for whales below 8.0 m, it is considered that there is no correlation between the proportion and body length, suggesting that the formation of transition phase is not directly related with the body length.

Comparison of age of whales just after sexual maturity and age at transition phase

Table 5 shows distribution of age at capture of whales with one and two corpora in ovaries. The range of the ages is from 5 to 15 years with average of 9.4 years. Among 28 whales which have one or two ovarian corpora, 12 whales are identified with the transition phase in earplugs, and the distribution of ages at transition phase of these whales is also shown in Table 5. The ages ranged from 4 to 10 years with an average of 7.7 years. This figure is less than the average of ages at capture of these 12 females, because these whales have passed some time after the attainment of sexual maturity before the capture

TABLE 5. AGE DISTRIBUTIONS OF THE ANTARCTIC MINKE WHALES IN SEVERAL CASES

Age	Total ages		Ages at transition phase			
(yrs.)	*	**	≤ 13 yrs	≤ 15 yrs	Total yrs.	**
3	–	–	–	–	–	–
4	–	–	–	2	3	1
5	2	3	2	3	4	1
6	1	2	10	11	21	1
7	1	4	11	13	23	3
8	1	2	8	14	34	–
9	2	3	16	27	53	4
10	2	4	3	9	44	2
11	–	4	–	2	25	–
12	1	1	–	1	21	–
13	1	2	–	–	16	–
14	–	2	–	–	12	–
15	–	1	–	–	3	–
16	–	–	–	–	5	–
17	–	–	–	–	1	–
18	–	–	–	–	2	–
19	–	–	–	–	1	–
Total	11	28	50	82	268	12
Average	8.55	9.39	7.70	8.04	9.73	7.67
S.D.	2.54	2.85	1.36	1.61	2.65	1.89

Remarks: *: One corpus in ovaries, **: One or two corpora in ovaries.

but the age at transition phase can be closer to the age at the attainment of sexual maturity. However, the deviation between the two is 1.7 years.

In this table frequency distributions of ages at transition phase are shown for 82 whales of age at capture of 15 years (upper limit of ages at capture of whales with one and two ovarian corpora in Table 5) and younger. The average of the ages at transition phase in this case is 8.0 years with range of 4 to 12 years. This is almost the same as that (7.7 years) of the same kind of ages in the case of whales with one and two ovarian corpora, and 1.4 years less than the average age at capture of females with one and two ovarian corpora.

Comparison of estimated and read total ages

Lockyer (1972) examined the meaning of transition phase of fin whales by comparison of total earplug growth layers with ages of the animal at capture calculated using age at transition phase, number of ovarian corpora and average annual ovulation rate of the stock. The same method is applied in this study.

The age of a female at capture is calculated from following equation:

$$t_e = t_t + (c/r) \quad \ldots\ldots \quad (1)$$

Where, t_e is calculated age at capture, t_t is age at transition phase, c is ovarian corpora number and r is annual ovulation rate. The data of t_t and c are available from the carcass. The problem is the value of annual ovulation rate. According

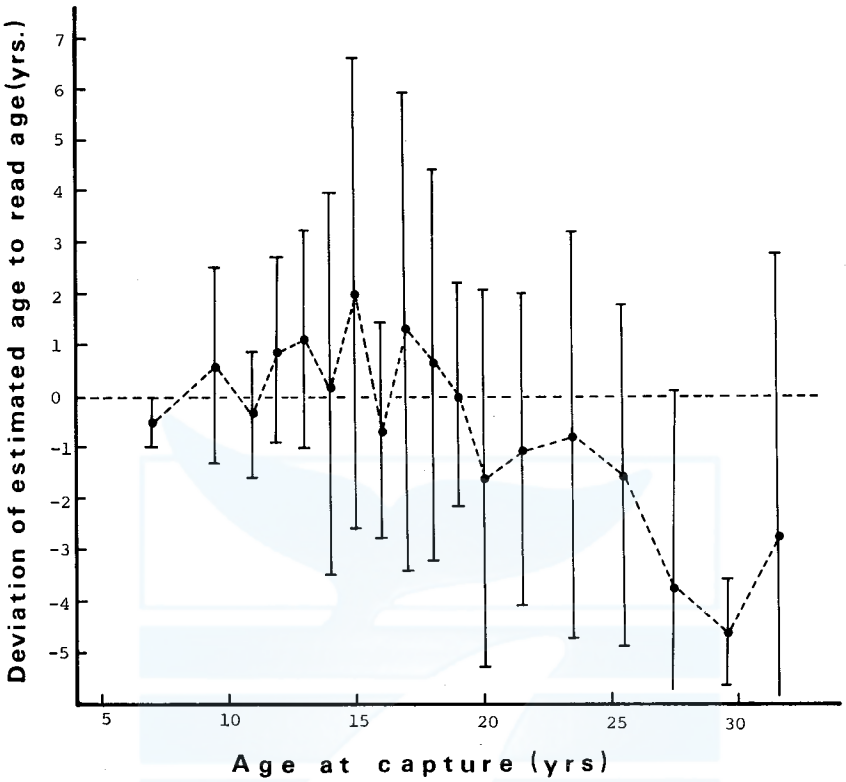

Fig. 3. Comparison between estimated and read total ages for the Antarctic minke whale. Closed circle: Average deviation of estimated age to read age, Range: Standard deviation.

to Masaki (1979), individual variation of annual ovulation rate ranges from 0.835 to 1.401 in the Antarctic minke whale. Best (1982) estimates the mean ovulation rate of minke whales off Durban at 0.811. Kato (1983) reports that the ovulation rate of the Antarctic minke whale increased from 0.77 (1952–54) to 1.25 (1967–69). Recently Kato (1985) showed a figure of 1.17 as the annual ovulation rate, although he indicated the rate declines with age.

If the age at capture thus calculated is close to the total growth layers of the same individual, the counted age at transition phase is proved to be close to the age at sexual maturity under the condition that the annual ovulation rate is true. A series of simulations was carried out using various values of ovulation rate to obtain the best match between total earplug age and the calculated age at capture. The best match was obtained assuming an annual ovulation rate of 1.4 as shown in Fig. 3. In this case average deviation between these two kinds of ages was around zero till the earplug age at 19 years, although there are large individual variations. This examination suggests that the age at transition phase can be regarded as the age at sexual maturity and

the annual ovulation rate of the Antarctic minke whale is 1.4 for individuals below 19 years, which is larger than those ever estimated. The average deviation changes gradually to lower figures in the ages older than 19 years. This phenomenon means that the annual ovulation rate is not constant throughout all ages, and the ovulation rate of older age or earlier born generations had been smaller than 1.4. When an annual ovulation rate is assumed to be 1.0 for the age class of 26–28, the deviation of calculated and counted ages at capture becomes to be close to zero.

DISCUSSION

Presence of immature whales which have transition phase

Two sexually immature females were found among the present materials to have transition phase. There is a possibility of miss-collection or miss-preparation of earplug of one of the whale (No. W-293), because this whale was 7.1 m long (most individuals of this size are sexually immature as shown in Table 3), its age at capture was 14+ with the age at transition phase of 6 years. However, another one is difficult to assume such a possibility, for it is 8.5 m long and 10 years old at capture. Both of these figures leave for the female possibility of being sexually immature. As shown in Table 5, Best (1982) already reported immature minke whales having transition phase. Therefore, it can be concluded that some females will form transition phase in earplug while they are sexually immature, when they attain at certain age and body length. On this connection, Lockyer (1972) and Kato (1985) examined the growth of skull in relation to mechanism of the formation of transition phase in earplugs of the fin and minke whales, respectively.

However, as examined in this study, the sexual maturity seems to correlate in many individuals with the formation of the transition phase, even if they are very small or very young.

Identification of transition phase

All the sexually mature female minke whales do not have always transition phase in earplugs. There are two cases of the absence of transition phase in sexually mature stage. One comes from the difficulty of identifying it soon after its formation. The low proportion of whales with transition phase in females just after the attainment of sexual maturity reflects this (Table 4). The transition phase becomes identifiable after the accumulation of 4–5 growth layers of post-transition phase as examined in this study.

Another is the case where transition phase cannot be recognized for life due to the gradual change of the layer width. These whales comprise 17 % (Best, 1982), or 12.4 % (this study) of adult females. The corresponding figure is only 3.5 % in fin whales (Lockyer, 1972). The frequency will be different between whale species.

Use of transition phase for estimation of ovulation rate

Using several methods, it was confirmed in this study that the formation of transition phase approximately coincides with the attainment of sexual maturity of the Antarctic minke whale. Then, the time after sexual maturity can be estimated from age at capture and age at transition phase. On the other hand, the data on ovarian corpora numbers are available for each whale independently. Then, the mean ovulation rate of each whale is estimated from these data as follows:

$$r = c/(t_a - t_t) \quad \ldots\ldots (2)$$

Where, t_a is earplug age at capture, and other symbols are the same as those of the equation 1.

Fig. 4 shows that the mean annual ovulation rate declines with increasing age at capture. Although the lower limits of the standard deviation are almost constant (0.75 corpora annually) through the age, the upper limits of the standard deviation decrease largely with age. Thus, the standard deviation decreases with age at capture. The mean annual ovulation rate decreases from 1.9 at the beginning of sexual maturity to 0.9 in the oldest ages. The declining trend of ovulation rate has been reported for the minke whale by Masaki (1979), Best (1982) and Kato (1985). The apparent decline of ovulation rate will reflect two causes. One is the true age dependent change, where the ovulation rate decreases with age even under constant environment. The second cause will be the year factor. The change in the environment of the Antarctic minke whale could have been continuously increased the annual ovulation rate of females especially of young females and decreased the age at sexual maturity. Both factors may affect this whale population, and obtained this apparent result, but it is difficult to separate these two factors from the result. Kato, Shimadzu and Kirishima (1985) tried to introduce the change in age at sexual maturity and pattern of change in ovulation rate with age to explain the apparent relationship between the age after maturation and ovarian corpora number.

The present analysis suggests that the annual ovulation rate of the Antarctic minke whale changes from 1.9 in the beginning of sexual maturity to 0.9 in the oldest stage in recent years. As examined in previous section, another kind of examination indicates that the mean annual ovulation rate keeps a value of 1.4 till 19 years of age. Kato *et al.* (1985) show a graph of change in ovulation rate with age of the same whale species that it changes from 1.6 at the beginning of maturity to 0.2 in 40 years of age. On the other hand, Best (1982) has a doubt on the possibility of the existence of ovulation rate of 1.56 and over per conception, because a failure rate will be very high in such a case, if the true pregnancy rate is about 78 %. However, we cannot explain the actual phenomena unless we consider the values of the ovulation rate which was estimated in the present study.

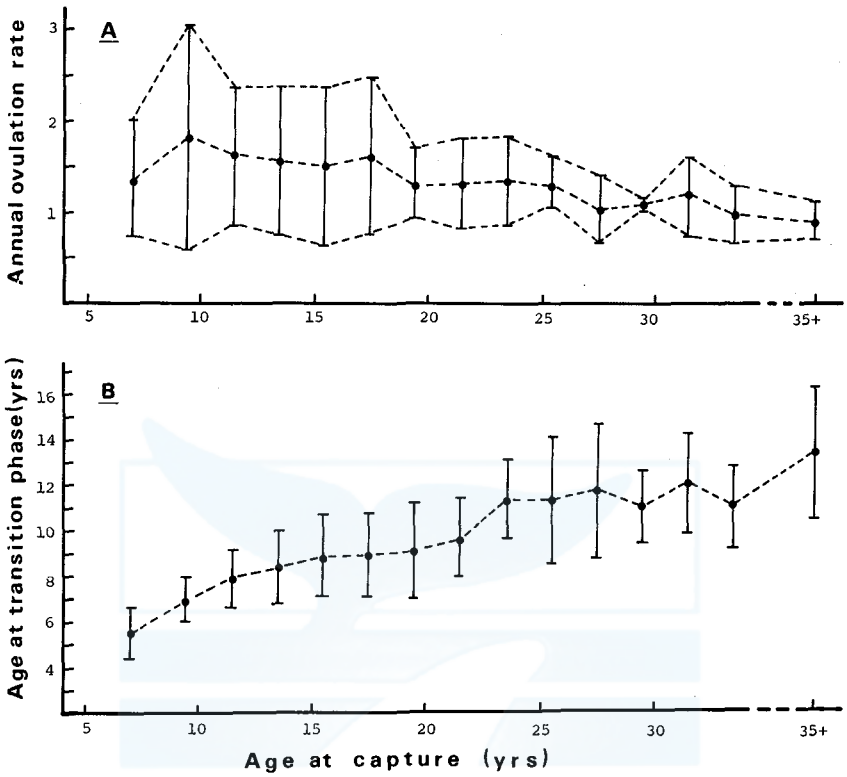

Fig. 4. Estimation of trends in annual ovulation rate and age at sexual maturity under the condition that the transition phase is a mark of the sexual maturity. A: Relation between total age and annual ovulation rate, B: Relation between total age and age at transition phase. Closed circle: Average, Range: One standard deviation.

Transition phase to estimate yearly change in age at sexual maturity

Fig. 4B shows mean and standard deviation of age at transition phase calculated in accordance with age at capture. The mean age at transition phase clearly increases with increase of age at capture. The average age at transition phase in whales of 35 years or over at capture is 13.5 years, but it is 7 years or less in whales captured before 10 years of age. Although this study did not deal with the data based on the year class as examined by Masaki (1979), Best (1982) and Kato (1983), similar values and trend as these papers were observed in this way.

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