# OSSIFICATION PATTERN OF THE VERTEBRAL EPIPHYSES IN THE SOUTHERN MINKE WHALE

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ABSTRACT

The pattern of fusion of the vertebral epiphyses to the centrum in the southern minke whale was examined using materials collected during the 1978/79 and 1979/80 Antarctic whaling expeditions. The fusion of the vertebral epiphysis to the centrum proceeds from the center of epiphysis to the peripheral on each vertebra regardless of the position on the vertebral column. On a vertebral column, epiphyseal fusion starts at anterior cervical then at posterior caudal vertebra, and is completed on the middle or posterior dorsal vertebrae. The fusion is completed on the entire vertebral column at ages of 23–36 years (males) or 28–36 years (females), and it has little correlation with the body length.

## INTRODUCTION

The southern minke whale (*Balaenoptera acutorostrata* Lacépède, 1804) is the only species which is currently exploited by the pelagic whaling in the Antarctic. Because of its importance in the stock management and study of the antarctic ecosystem, various studies attempted to clarify historical changes in their growth. For example, the decline of age at sexual maturity with time prior to the full exploitation started in 1971/72 has been suggested (Masaki, 1979; Best, 1982; Kato, 1983, 1987), which was thought to have resulted from the decline of possible competitative whale stocks such as blue (*B. musculus* (Linnaeus, 1758)) and fin whale (*B. physalus* (Linnaeus, 1758)).

Recently Kato (1987) compared growth curves between year classes of the southern minke whale and found the recent year-classes grew faster than the earlier ones. He analysed and suggested a possible change in the body length at the attainment of physical maturity with year-class. Although the examination of epiphyseal fusion to centrum is essential for the identification of physical maturity of whales, our information has been very fragmental on age, body length and progression of such change on the vertebral column. Kato (1987) analysed some of these aspects of southern minke whales using only the middle dorsal vertebrae, but he didn't present technical bases that this vertebral part can be used as a mark of the physical maturity. This study presents such basic information missing from the study of Kato (1987).

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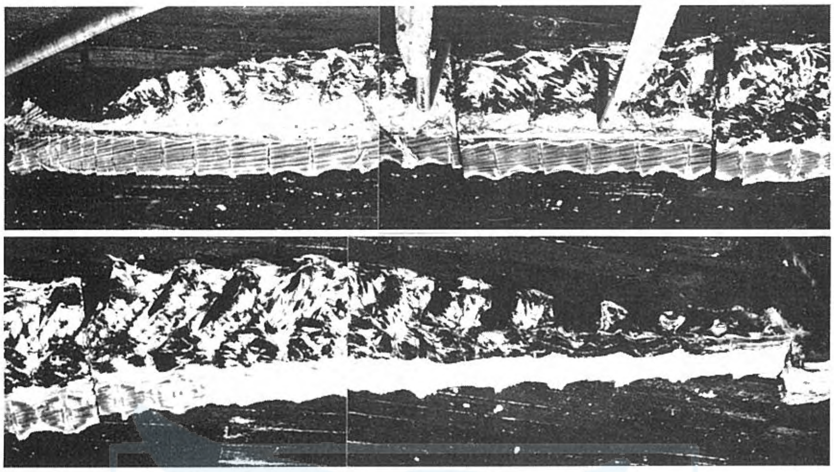

Fig. 1. Vertebral column of the southern minke whale bisected on the deck of *Nisshin-maru* No. 3 for the present study.

## MATERIAL AND METHOD

Materials were collected from 45 males and 51 females caught by 1978/79 and 1979/80 Antarctic whaling expeditions of the *Nisshin-maru No. 3* to the south of 60° S and between 0° to 130°E (Areas III and IV). Age was determined counting growth layers in earplug and assuming annual deposition of the layer (Best, 1982; Kato and Best, unpublished). The layers were counted with stereoscopic microscope (6~10×) by myself. Female maturity was determined by examining ovaries, most of which were done by myself and some by Drs S. Ohsumi (Far Seas Fish. Res. Lab.) and Y. Masaki (South-East Regional Fish. Res. Lab.). Male maturity was not analysed in the present study.

For the present study the vertebral columns of animals which were randomly selected from the catch were cut into three or four segments with an electric chain saw (valid length = 2.5m) after stripping off the muscles, then they were bisected along the axis with the same saw (Fig. 1). Using the method I was able to examine small caudal vertebrae burried between the tail flukes. The cut surface was observed by naked eyes and classified into four stages after Laws (1961) (Fig. 2):

*UTC*; unfused, thick cartilage present
*UFC*; unfused, thin cartilage present
*FJV*; fused, join visible
*FJI*; fused, join invisible

The stage of *UTC, UFC, FJV* and *FJI* are equivalent to those of *N, n, a* and *A* of Ohsumi, Nishiwaki and Hibiya (1958) respectively.

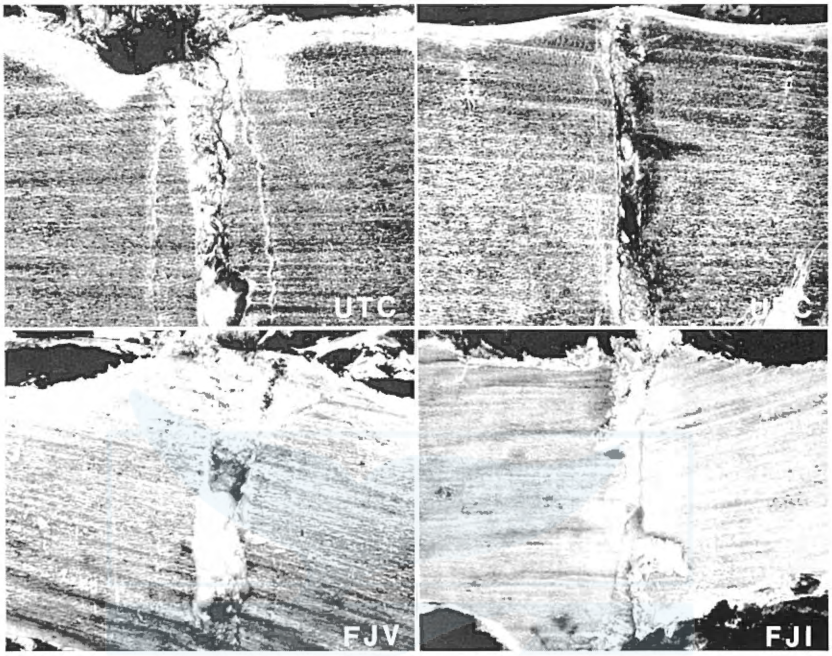


Fig. 2 Typical examples of the epiphyseal fusion stages used in the present study. *UFT*, unfused with thick cartilage; *UTC*, unfused with thin cartilage; *FJV*, fused with join visible; *FJI*, fused without visible join.

The epiphyseal fusion was examined on both center and ventral margin of the posterior epiphysis. Such observation was initially made on all the vertebrae of the sampled animals and recorded on the factory ship. However results on the 12 selected vertebrae are used in the following analyses. These vertebrae are:

1st, 4th and 7th cervical vertebrae;
2nd, 6th and 10th dorsal vertebrae;
2nd, 6th and 10th lumber vertebrae;
3rd, 10th and 17th caudal vertebrae.

Physically mature individuals were defined as those where epiphyseal fusion was completed on the above 12 vertebrae (stage *FJI*). All the other stage were defined as physically immature.

## RESULT

Firstly I compared epiphyseal fusion between center and ventral margin of the same epiphysis. The result is grouped for the three vertebral segments of cervical, dorsal, lumber and caudal vertebrae and shown in Table 1. Majority

TABLE 1. COMPARISON OF EPIPHYSEAL FUSION STAGES* BETWEEN THE CENTER AND PERIPHERAL OF A EPIPHYSIS.

| Vertebral segment | fusion at epiphyseal center | fusion at epiphyseal peripheral* | | | |
|---|---|---|---|---|---|
| | | *UTC* | *UFC* | *FJV* | *FJI* |
| Cervical | *UTC* | 25 | – | – | – |
| | *UFC* | 4 | 70 | – | – |
| | *FJV* | – | 5 | 118 | – |
| | *FJI* | – | – | 1 | 415 |
| Dorsal | *UTC* | 436 | – | – | – |
| | *UFC* | 6 | 169 | – | – |
| | *FJV* | – | 85 | 123 | – |
| | *FJI* | – | – | 59 | 107 |
| Lumber | *UTC* | 402 | – | – | – |
| | *UFC* | 28 | 128 | – | – |
| | *FJV* | – | 59 | 123 | – |
| | *FJI* | – | – | 98 | 260 |
| Caudal | *UTC* | 269 | – | – | – |
| | *UFC* | 53 | 116 | – | – |
| | *FJV* | 4 | 46 | 140 | – |
| | *FJI* | – | – | 184 | 811 |

* *UTC*, unfused with thick cartilage; *UFC*, unfused with thin cartilage; *FJV*, fused with join visible; *FJI*, fused with join invisible.

of the vertebrae showed the equal stage of fusion between the center and peripheral (ventral). Such vertebrae comprised 85.5% of the total data sets (4,344) or 77% of 2,751 vertebrae excluding those with fully fused epiphyses. However, 14.5% of them showed more advanced stage of fusion at the epiphyseal center and none of them showed the opposite case. Agreement of the two observations was lower on the posterior vertebral column; 95.5% in cervical vertebrae, 82.9% in dorsal vertebrae, 77.5% in lumbar vertebrae, and 64.7% in caudal vertebrae (excluding observations on vertebrae with fully fused epiphyses).

It is important to note that if the two observations disagreed the fusion near the peripheral of epiphysis was always less advanced. This indicates that the fusion of the vertebral epiphysis proceeds from its center to the peripheral, and that the progress is slower on the posterior vertebrae. Epiphyseal fusion completes at the marginal of each epiphysis. In the following analyses, I used only the status of epiphyseal fusion at the peripheral part.

Table 2 shows the progress of epiphyseal fusion with increasing body length. The fusion begins at the anterior cervical vertebrae in both sexes, and cervical epiphyses were completely fused to the centrum even on the smallest male sample (22ft in body length). Epiphyseal fusion on the posterior caudal vertebrae starts at a body length of about 27ft for both sexes. After then, the fusion proceeds with increase of body length towards the middle vertebral column. However, there are considerable individual variations in the stage of the epiphyseal fusion among the individuals of the same body length and sex. For example, some individuals almost completed fusion while others had only started the process on the dorsal and lumber vertebrae at the body length classes between 27ft and 29ft in males, and between 28ft and 31ft in females. However the ossification is usually advanced on older individuals of the body length classes above.

Then, the individual data were rearranged according to their age to produce Table 3 (individuals without sufficient age information were excluded). It was confirmed again that the fusion of epiphyses begins firstly at the anterior cervical at about age two years, and subsequently at the posterior caudal at about age 10 years in both sexes. The fusion proceeds with age from the both ends toward the middle region of the vertebral column and have been completed at the middle or posterior parts of the dorsal region. The youngest physically mature animals appeared at 23 years and 28 years in males and females respectively, while the oldest physically immature animals were 36 years in both sexes. However, the differences between sexes may not be significant.

## DISCUSSION

Although histological technique will be desirable for the observation of epiphyseal fusion as by Wheeler (1930), it was not applicable in the present study. I cannot deny, therefore, misclassification of some stages of fusion, especially between later stage of *UFC* (unfused, thin cartilage present) and beginning of *FJV* (fused, join visible). However, as shown in Fig. 2, the presence or the absence of cartilage on the joining line can be easily recognized without histological section if observed carefully. Thus I consider the present method is adequate for the present study.

Mackintosh and Wheeler (1921) had preliminarily examined the physical maturity status of blue and fin whales by the epiphyseal fusion on some parts of the vertebral column, based on the suggestion given by an earlier work (Flower, 1864). Wheeler (1930) examined further the nature of the ossification pattern on column in southern fin whale, and found in female that the epiphyseal fusion starts from both ends of the column and is completed at the anterior dorsal vertebrae. Later Ohsumi *et al.* (1958) confirmed similar pattern of ossification in the North Pacific fin whale using a larger sample size and detailed observation.

The present study compared ossification pattern with absolute age by earplug growth layer counts, though both Wheeler (1930) and Ohsumi *et al.* (1958) used number of ovulation, and confirmed, for the southern minke whales, similar pattern of the ossification of the vertebral column to that in fin

TABLE 2. RELATIONSHIP BETWEEN EPIPHYSEAL FUSION STAGES AND BODY LENGTH

MALE

| BL (ft) | Position on vertebral column* C | D | L | Ca |
|---|---|---|---|---|
| | 1 4 7 | 2 6 10 | 2 6 10 | 3 10 17 |
| 22 | ● – – | – – – | – – – | – – – |
| 24 | ▲ ▲ ▲ | – – – | – – – | – – – |
| 25 | ▲ △ △ | – – – | – – – | – – – |
| | ● △ △ | – – – | – – – | – – – |
| | ● ▲ △ | – – – | – – – | – – – |
| 26 | ▲ ▲ △ | △ – – | – △ △ | △ ▲ △ |
| | ● ● △ | △ – – | – – – | – △ △ |
| | ● ● △ | △ – – | – – – | △ △ △ |
| 27 | ● △ △ | – – – | – – – | – – – |
| | ● ● △ | – – – | – △ ▲ | △ ● ● |
| | ● ● ● | ▲ – – | – – – | △ ▲ ● |
| | ● ● ● | △ – – | – – △ | △ ▲ ● |
| | ● ● ▲ | ▲ – – | – – ▲ | ● ● ● |
| | ● ● ● | ▲ ▲ △ | △ ● ● | ● ● ● |
| | ● ● ▲ | ▲ ▲ ▲ | ▲ ● ● | ● ● ● |
| | ● ● ● | ● ▲ ▲ | ▲ ▲ ● | ● ● ● |
| | ● ● ● | ● ● ▲ | ▲ ● ● | ● ▲ ● |
| 28 | ● ● ▲ | △ – – | – – – | – △ – |
| | ● ● △ | – – – | – – – | – ▲ ▲ |
| | ● ▲ △ | – – – | – – △ | △ ▲ ● |
| | ● ▲ △ | △ – △ | – – △ | ● ● ● |
| | ● ● △ | △ – – | – – ▲ | ● ● ● |
| | ● ▲ ▲ | – – – | – △ ▲ | ▲ ● ● |
| | ● ● ● | ▲ △ △ | △ ▲ ▲ | ● ● ● |
| | ● ● ● | △ △ △ | ▲ ▲ ▲ | ● ● ● |
| | ● ▲ ▲ | ▲ △ ▲ | ▲ ▲ ● | ● ● ● |
| 29 | ● △ △ | – – – | – – – | – △ – |
| | ● ▲ △ | – – – | – – – | ● ● – |
| | ● ▲ △ | △ – – | – – ▲ | ▲ ● ● |
| | ● ● △ | △ △ △ | △ ▲ ● | ● ● ● |
| | ● ● ● | ▲ △ △ | ▲ ▲ ● | ● ● ● |
| | ● ● ▲ | ▲ △ ▲ | ▲ ▲ ● | ● ● ● |
| | ● ● ▲ | ▲ ▲ ▲ | ● ● ● | ● ● ▲ |
| | ● ● ● | ▲ ▲ ▲ | ▲ ● ● | ● ● ● |
| | ● ● ● | ● ▲ ▲ | ▲ ● ● | ● ● ● |
| | ● ● ● | ● ▲ ▲ | ▲ ● ● | ● ● ● |
| 30 | ● ● ● | ▲ △ – | △ ▲ ▲ | ▲ ● ● |
| | ● ● ▲ | ▲ △ ▲ | ▲ ▲ ● | ● ● ● |
| | ● ● ● | ● ● ● | ● ● ● | ▲ ● ● |
| | ● ● ● | ● ● ● | ● ● ● | ● ● ● |
| | ● ● ● | ● ● ● | ● ● ● | ● ● ● |
| 32 | ● ● ● | ▲ △ △ | △ △ ▲ | ● ● ● |

FEMALE

| BL (ft) | Position on vertebral column C | D | L | Ca | No. Ovulations |
|---|---|---|---|---|---|
| | 1 4 7 | 2 6 10 | 2 6 10 | 3 10 17 | |
| 24 | ▲ △ – | – – – | – – – | – △ △ | 0 |
| 25 | ● △ – | – – – | – – – | – △ △ | – |
| | ● △ – | – – – | – – – | – △ △ | 0 |
| | ● ● △ | △ – – | – – – | – – △ | 0 |
| 26 | ● ▲ △ | – – – | – – – | – – △ | 0 |
| | ● ● ● | ▲ – △ | △ △ ▲ | ● ● ● | 20 |
| 27 | ▲ △ △ | – – – | – – – | – – △ | 0 |
| 28 | △ △ △ | – – – | – – △ | △ △ ▲ | 0 |
| | ▲ ▲ △ | – – – | – – – | △ ▲ – | 1 |
| | – ▲ △ | – – – | – – – | ▲ ▲ ● | 9 |
| | ▲ ▲ △ | – – – | – – △ | ▲ ▲ ▲ | 12 |
| | ● ▲ △ | △ – – | △ △ ▲ | ▲ ● ● | 5 |
| | ● ● ● | ● ● ▲ | ▲ ● ● | ● ● ● | 23 |
| | ● ● ● | ● ▲ ● | ● ● ● | ● ● ● | 16 |
| 29 | ● ▲ △ | – – – | – – △ | △ ▲ ▲ | 7 |
| | ● △ – | – – – | – – △ | ▲ ▲ ▲ | 2+ |
| | ▲ ▲ ▲ | △ △ △ | △ △ ▲ | ▲ ▲ ● | 23 |
| | ● ● ▲ | ▲ △ △ | △ △ △ | ▲ ▲ ● | 12 |
| | ● ● ● | ▲ △ △ | ▲ △ ▲ | ● ● ● | 21 |
| | ● ● ▲ | ▲ △ ▲ | ▲ ▲ ● | ● ● ● | 18 |
| | ● ● ● | ▲ △ ▲ | ▲ ● ● | ● ● ● | 17 |
| | ● ● ▲ | ▲ ▲ ▲ | ▲ ▲ ● | ● ▲ △ | 17 |
| 30 | ▲ △ – | – – – | – – – | – ▲ △ | 17 |
| | ● – – | – – – | – – – | – ▲ △ | 6 |
| | ● ▲ △ | △ – – | – – – | – ▲ ● | 4 |
| | ● ● ▲ | ▲ – – | – – – | – ▲ ● | 4+ |
| | ● ● ▲ | △ – – | – – – | ▲ △ △ | 9 |
| | ● ● ● | △ △ – | – △ △ | ● ● ● | 10 |
| | ● ● ▲ | △ – – | △ △ ● | ● ● ● | 28 |
| | ● ▲ ▲ | △ △ △ | ▲ ▲ ● | ● ● ● | 19 |
| | ● ● ▲ | ▲ △ △ | ▲ ▲ ● | ● ● ● | 13 |
| | ● ● ● | ▲ △ △ | ▲ ▲ ● | ● ● ● | 19 |
| | ● ● ● | ● ▲ ▲ | ● ● ● | ● ● ● | 26 |
| | ● ● ● | ● ● ▲ | ▲ ● ● | ● ● ● | 30 |
| | ● ● ● | ● ● ● | ● ● ● | ● ● ● | 28 |
| | ● ● ● | ● ● ● | ● ● ● | ● ● ● | 36 |
| | ● ● ● | ● ● ● | ● ● ● | ● ● ● | 29 |
| 30 | ● ▲ – | – – – | – – – | – ▲ △ | 9 |
| | ● ▲ ▲ | △ – – | – △ △ | △ ● ● | 10 |
| | ● ● △ | – – – | – △ △ | ● ● ● | 13 |
| | ● ● ● | ▲ – – | △ ▲ ● | ● ● ● | 22 |
| | ● ● ● | ● – – | △ ▲ ● | ● ● ● | 24 |
| | ● ● ▲ | △ △ ▲ | ▲ ▲ ● | ● ● ● | 14 |
| | ● ● ▲ | ▲ ▲ ▲ | ▲ ● ● | ● ● ● | 28 |
| | ● ● ● | ● ▲ ● | ● ● ● | ● ● ● | 30 |
| | ● ● ● | ● ● ● | ● ● ● | ● ● ● | – |
| | ● ● ● | ● ● ● | ● ● ● | ● ● ● | 28 |
| | ● ● ● | ● ● ● | ● ● ● | ● ● ● | 21 |
| | ● ● ● | ● ● ● | ● ● ● | ● ● ● | 33 |

| | | | | | |
|---|---|---|---|---|---|
| 32 | ●●● | ●●● | ●●● | ●●● | 41 |
| 33 | ●●● | ●●● | ●●● | ●●● | 32 |
| 34 | ●●● | ●●● | ●●● | ●●● | – |

* Symbols used are; C, crevical; D, dorsal; and Ca, caudal vertebrae. Hyphen indicates stage unfused with thick cartilage (*UTC*), open circle unfused thin cartilage (*UFC*), closed triangle fused join visible (*FJV*), closed circle fused join invisible (*FJI*).

TABLE 3. RELATIONSHIP BETWEEN EPIPHYSEAL FUSION STAGES AND AGE.

MALE

| Age | BL (ft) | C 1 4 7 | D 2 6 10 | L 2 6 10 | Ca 3 10 17 |
|---|---|---|---|---|---|
| 2 | 25 | ●△△ | – – – | – – – | – – – |
| | 25 | ●▲△ | – – – | – – – | –△△ |
| 4 | 26 | ●●△ | △– – | – – – | –△△ |
| 5 | 29 | ●△△ | – – – | – – – | –△△ |
| 7 | 26 | ●●△ | △– – | – – – | △△△ |
| 8 | 28 | ●●△ | – – – | – – – | –▲▲ |
| 9 | 26 | ▲▲△ | △– – | –△△ | △▲△ |
| | 29 | ●●● | ▲△△ | △▲▲ | ●●● |
| 12 | 29 | ●▲△ | – – – | – – – | ●●– |
| | 28 | ●●△ | △– – | – –▲ | ●●● |
| 14 | 27 | ●●● | △– – | – – – | △▲● |
| | 27 | ●●● | ▲– – | – – – | △▲● |
| 16 | 28 | ●●● | △△△ | ▲▲▲ | ●●● |
| 17 | 30 | ●●▲ | ▲△▲ | ▲▲● | ●●● |
| 19 | 29 | ●▲△ | △– – | – –▲ | ▲●△ |
| | 28 | ●▲▲ | ▲△▲ | ▲▲● | ●●● |
| | 29 | ●●▲ | ▲▲▲ | ●●● | ●●▲ |
| 21 | 32 | ●●● | ▲△△ | △△▲ | ●●● |
| 23 | 30 | ●●● | ▲△– | △▲▲ | ▲●● |
| | 30 | ●●● | ●●● | ●●● | ●●● |
| 26 | 27 | ●●● | ▲▲△ | ▲●● | ●●▲ |
| 29 | 29 | ●●● | ▲▲▲ | ▲●● | ●●● |
| 30 | 30 | ●●● | ●●● | ●●● | ●●● |
| 36 | 27 | ●●● | ●▲▲ | ▲▲● | ●●● |

FEMALE

| Age | BL (ft) | C 1 4 7 | D 2 6 10 | L 2 6 10 | Ca 3 10 17 |
|---|---|---|---|---|---|
| 4 | 25 | ●△– | – – – | – – – | – – – |
| 5 | 27 | ▲△△ | – – – | – – – | – – – |
| 7 | 30 | ●●▲ | ▲– – | – – – | –△● |
| 10 | 28 | ▲▲△ | – – – | – – – | △▲– |
| 11 | 31 | ●▲– | – – – | – – – | –▲△ |
| | 30 | ●▲△ | △– – | – – – | –▲● |
| 13 | 30 | ●●– | – – – | – – – | –▲△ |
| 14 | 31 | ●▲▲ | △– – | –△△ | △●● |
| 15 | 30 | ▲△– | – – – | – – – | –▲△ |
| | 28 | ●▲△ | △– – | △△▲ | ▲●● |
| 16 | 29 | ●△– | – – – | – –△ | ▲▲● |
| | 28 | ▲▲△ | – – – | – –△ | ▲▲▲ |
| 17 | 28 | –▲△ | – – – | – – – | ▲▲● |
| 18 | 30 | ●●● | ▲△△ | ▲●● | ●●● |
| 19 | 31 | ●●△ | – – – | –▲● | ●●● |
| 21 | 29 | ●▲△ | – – – | – –△ | △▲△ |
| | 30 | ●●▲ | △– – | – – – | ▲△△ |
| | 28 | ●●● | ●▲● | ●●● | ●●● |
| 22 | 31 | ●●▲ | △△▲ | ▲▲● | ●●● |
| 24 | 30 | ●●● | △△△ | △△△ | ●●● |
| | 29 | ●●▲ | ▲△△ | △△△ | ▲▲● |
| 25 | 29 | ●●● | ▲△▲ | ▲●● | ●●● |
| | 30 | ●●● | ●●▲ | ▲●● | ●●● |
| 26 | 29 | ●●● | ▲△△ | ▲△▲ | ●●● |
| 28 | 31 | ●●● | ▲– – | △▲● | ●●● |
| | 30 | ●▲▲ | △△△ | ▲▲● | ●●● |
| | 30 | ●●● | ●●● | ●●● | ●●● |
| 29 | 34 | ●●● | ●●● | ●●● | ●●● |
| 30 | 26 | ●●● | ▲–△ | △△● | ●●● |
| 31 | 31 | ●●● | ●●● | ●●● | ●●● |
| 32 | 30 | ●●▲ | ▲▲▲ | ▲▲● | ●▲– |
| 34 | 30 | ●●● | ●●● | ●●● | ●●● |
| 35 | 28 | ●●● | ●●▲ | ▲●● | ●●● |
| 36 | 30 | ●●● | ●▲▲ | ●●● | ●●● |
| 38 | 30 | ●●● | ●●● | ●●● | ●●● |
| 41 | 31 | ●●● | ●●● | ●●● | ●●● |
| 42 | 33 | ●●● | ●●● | ●●● | ●●● |

* Position on vertebral column. For symbols see Table 2.

whale above. Some differences exist, however, between fin and minke whale; in the fin whale the epiphyseal fusion firstly commences at posterior parts of caudal vertebrae while it firstly starts at the anterior of the cervical in minke whales; the fusion is completed among the anterior dorsal vertebrae for fin whale rather than the posterior dorsal as in minke whale.

As stated by Wheeler (1930) and Mackintosh (1942) the completion of epiphyseal fusion bears relation to number of ovulation and little to the body length. It was considered, in fin whale, that the ossification was completed at 13–16 ovulations (Wheeler, 1930; Peters, 1939; Nishiwaki and Oye, 1939; Brinkman, 1948; Ohsumi, *et al.*, 1958); based on the evidence of ossification at the particular vertebrae. By converting these values of ovulation to absolute age by average annual ovulation rate reported (0.67-0.71; Laws, 1961; Lockyer, 1971; Gambell, 1973) and assuming average age at sexual maturity in the 1930–1950s to be age 11-12 years (from studies by Lockyer (1984) and Ohsumi (1986)), the values can be roughly calculated to be age 28-36 years. These ages for fin whale is similar to those in the present study for minke whale (age 23-26 years), though the maximum life span for the former is about twofold to the latter (Ohsumi, 1979).

However, it is still not clear whether completion of epiphyseal fusion of individual depend on time after sexual maturation or absolute age. Moreover, another aspect should be considered; the relationship between the physical maturity and changes in density. For example, Kato (1987) found that density dependent changes in growth parameters such as age at sexual maturity and growth rate and suggested increase in body length at physical maturity with density in the southern minke whale stocks. These aspects are desired to be examined further in the future study.

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