

**Study on the Brains of the Deep Sea Fishes, *Cylothone microdon*,
Gonostoma ritiogi and *Coryphaenoides acrolepis***

BY

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INTRODUCTION

Although the knowledge on deep sea fishes has been greatly advanced in recent years, studies on their brains are lagging far behind among the research works of deep sea fishes.

Since the comprehensive study of Shanklin in 1935 on the diencephalon and mesencephalon in the three deep sea fishes which belong to the order Iniomi, almost no literature has been published, in so far as we are aware of.

Even before the Shanklin's there had been a very few investigators who paid attention on these brains, for instance, Gierse (1904), Trojan (1906), Dammerman (1910), and Charlton (1932).

Environment where deep sea fishes live is remarkably different from that of normal sea fishes, especially in conditions such as pressure, darkness, food and so forth. Among those fishes, some may swim up and down between some thousands meters depth.

From the point of comparative neurology in disclosing relationship between brain structure and ecology, on which we are working, it is not without interest to find how the brains of deep sea fishes are constructed as they can be adaptable to conditions on their life.

Fortunately, one of the authors (H. T.) was presented the three deep sea fishes from Professor T.S. Rass in Oceanographical Institute, U.S.S.R. Academy of Sciences. Hence we studied on the brains of these fishes under the purpose above mentioned and the result of the observation is reported herewith.

MATERIALS AND METHOD

All the deep sea fishes employed for the present investigation were caught by the U. S. S. R. Expedition Boat 'Vitjaz' during 1952 to 1954. They were adult form. Their specific names and the characteristic features are as follows;

- 1) *Cylothone microdon* (fig. 1). Sampling depth, 2000-0 m., St. No. 1599.

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It belongs to the sub-family *Gonostomatidae*, and is the smallest among the fishes investigated. The body length is about 5 cm. It possesses luminous organs arranged strigously on the lateral side of the body. The mouth is quite large with teeth. The eyes are exceedingly small.

2) *Gonostoma ritiogi* (fig. 2). Sampling depth, 5550-0 m., St. No. 3206.

It belongs to the sub-family *Gonostomatidae* as well as *Cyclothone*. The body length is about 9.5 cm. Although it possesses luminous organs on the lateral side of the body and a large mouth as in *Cyclothone*, the eyes are not small differing from those of *Cyclothone* and fluorescent.

3) *Coryphaenoides acrolepis* (fig. 3). Sampling depth, 8000-0 m., St. No. 2216.

It belongs to the family *Coryphaenoididae* and is known as the synonym *Macrurus*. It was the biggest among the fishes studied, being about 61.5 cm. The fluorescent eyes are very large. It possesses a pair of short barbels on the lower jaws.



Fig. 1. *Cyclothone uicrodon*, Natural size.

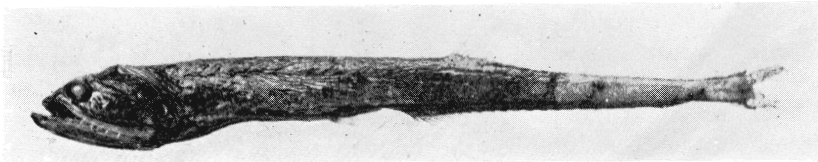


Fig. 2. *Gonostoma ritiogi*, Natural size.

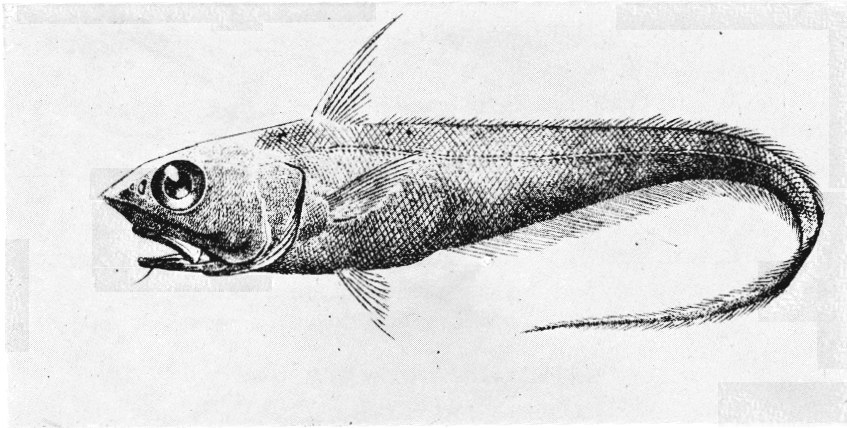


Fig. 3. *Coryphaenoides acrolepis*. $\times \frac{1}{3}$. (The photograph was presented by Prof. Rass).

Although the preservation of materials was not in an excellent condition, the brains of the above three species were imbedded in celloidin, cut serially in the transverse plane and stained by Pal-Weigert method. In addition, the

brains of *Cyclothone* and *Gonostoma*, were stained by Mayer's hematoxylin and eosin in paraffin sections.

RESULTS OF OBSERVATIONS

EXTERNAL FORMS OF THE BRAINS

1. TELEENCEPHALON

In *Cyclothone* and *Gonostoma* the olfactory bulbs are close together with the olfactory lobes (figs. 4 and 5), but in *Coryphaenoides* (fig. 6) the bulbs are not directly in contact with the olfactory lobes being connected with the longer olfactory tracts. The olfactory lobes are relatively well-developed in all three of these fishes. In *Coryphaenoides*, each olfactory lobe exhibits an ovoidal shape. The paired lobes over which several fissures run are divided

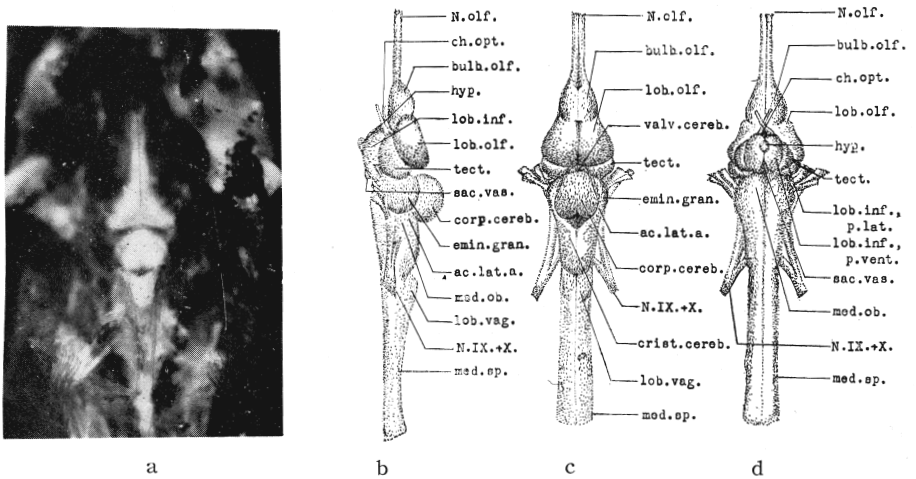


Fig. 4. Brain of *Cyclothone microdon*. a, dorsal view. $\times 15$. b, lateral view. $\times 20$. c, dorsal view. $\times 20$. d, ventral view. $\times 20$.

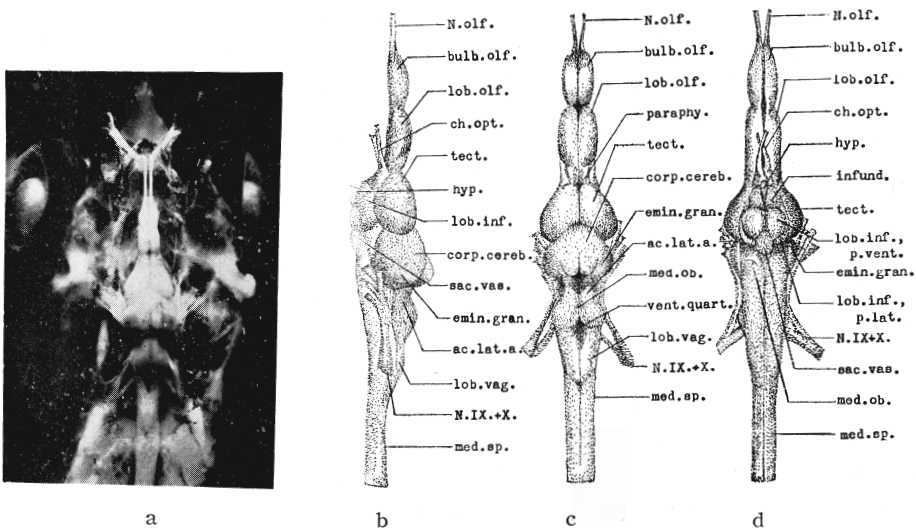


Fig. 5. Brain of *Gonostoma ritiogi*. a, dorsal view. $\times 20$. b, lateral view. $\times 30$. c, dorsal view. $\times 30$. d, ventral view. $\times 30$.

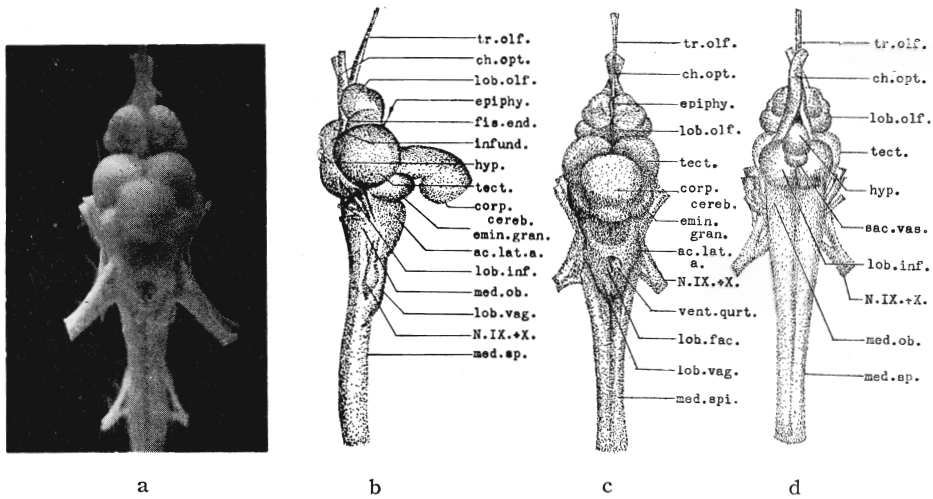


Fig. 6. Brain of *Coryphaenoides acrolepis*. a, dorsal view. $\times 2$. b, lateral view. $\times 2$. c, dorsal view. $\times 2$. d, ventral view. $\times 2$.

superficially into the various tubercles. The most prominent among those fissures is the sulcus ypsiliformis. On the other hand, in *Cyclothone* and *Gonostoma*, there are not found any distinct fissures on the paired lobes. In *Cyclothone*, each olfactory lobe exhibits a pear-like shape, and is much larger than the olfactory bulb. In *Gonostoma*, both the lobe and the bulb are elongated in lengthwise and the difference between them in size is not remarkable.

2. DIENCEPHALON

In *Coryphaenoides* the saccus dorsalis is visible, but in *Cyclothone* and *Gonostoma* it is not observed macroscopically owing to its smallness. In all three of these fishes, the infundibulum is not eminently protruded in the ventral side of the brain. The hypophysis, saccus vasculosus and lobi inferiores are well-developed in all of them, particularly in *Coryphaenoides*. The optic chiasma is seen in usual place, but the optic tracts are exceedingly slender in *Cyclothone*, very small in *Gonostoma* and relatively large in *Coryphaenoides*. Although in all species the chiasma is the simple crossing, it is with the right nerve uppermost in *Cyclothone*, while in *Gonostoma* and *Coryphaenoides* it is the left nerve uppermost which is typical for teleosts (Herrick, 1899).

3. MESENCEPHALON

In the three species the optic tectum differs in its shape respectively. As is shown in figs. 4 to 6, the optic tectum in *Coryphaenoides* is well-developed, while in *Gonostoma*, in a lesser extent and in *Cyclothone*, exceedingly poor so that it is almost covered by the forebrain.

4. CELEBELLUM

In *Coryphaenoides* the cerebellum is well-developed. It consists of the valvula cerebelli which comes deeply into the ventricle underneath the optic tectum and of the large corpus cerebelli which extends caudo-dorsally. In the ventro-lateral border of the corpus cerebelli is found an enlarged eminentia granularis on both sides. In *Cyclothone* and *Gonostoma*, the cerebellum is not so well-developed as in *Coryphaenoides*, but the eminentia granularis is very well-developed. In *Gonostoma* there is a large fissure along the midline of the

corpus cerebelli on the surface of the caudal portion, but in *Cyclothone* it is hardly visible.

5. MEDULLA OBLONGATA

In dorsal view, all of the fishes examined show no distinct difference from the common teleost type. However, the acoustic tubercle bulges dorsally in a shape of bank on both sides, but such bulging is not so clear in the vagal and facial lobes.

INTERNAL STRUCTURE OF THE BRAINS

1. TELEENCEPHALON

The internal structure of the cerebrum in the three species examined possesses remarkable features in arrangement of the cells and the fiber tracts respectively.

As pointed out already, the olfactory bulb is not in direct contact with the olfactory lobe in *Coryphaenoides*, different from that of *Cyclothone* and *Gonostoma*. In *Coryphaenoides*, tractus olfactorius enters into the olfactory lobe forming the two fiber bundles, tractus olfactorius medianus and tractus olfactorius lateralis, which terminate in respective olfactory centers as seen in many teleostean types. In *Gonostoma* and *Cyclothone*, however, it is very difficult to indicate the fiber bundle which corresponds to the tractus olfactorius lateralis. In these fishes, there are few cell groups which are identified as nucleus medianus, nucleus olfactorius lateralis (Sheldon, 1912, Tuge, 1929). Particularly, in *Cyclothone*, there is no cell group that corresponds to the palaeostriatum (fig. 7a). In *Gonostoma*, there are few cells scattered in the area regarded as the palaeostriatum in the teleostean brain (fig. 7b). It is very

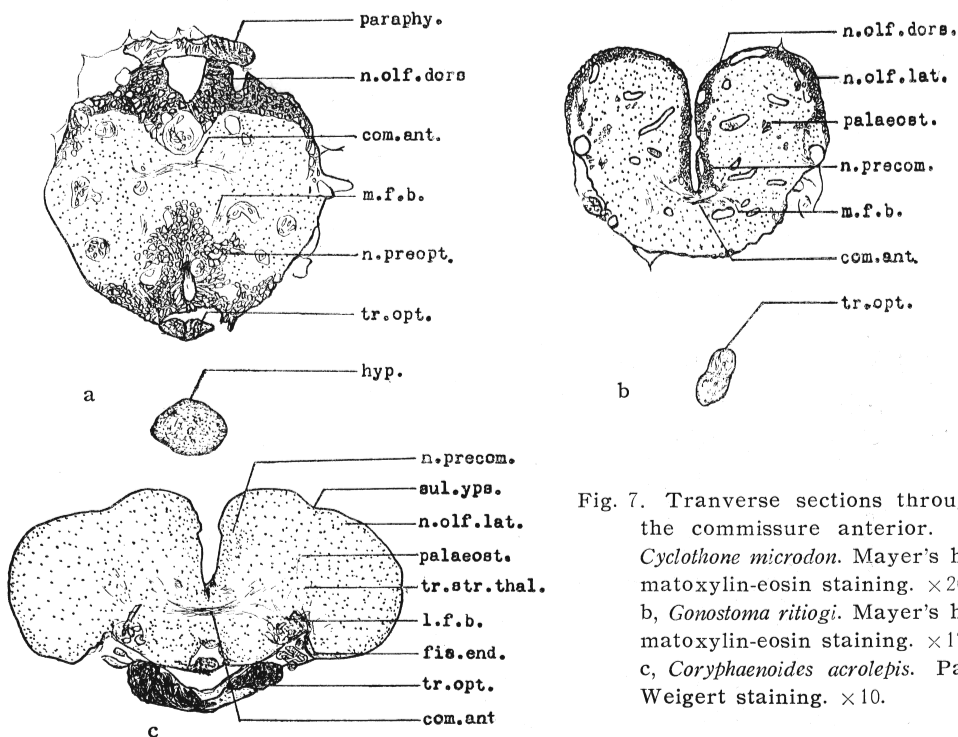


Fig. 7. Transverse sections through the commissure anterior. a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. $\times 200$. b, *Gonostoma ritiogi*. Mayer's hematoxylin-eosin staining. $\times 170$. c, *Coryphaenoides acrolepis*. Pal-Weigert staining. $\times 10$.

interesting to notice here that the nerve cells in the olfactory lobe in *Cyclothone* look like immatured nerve cells. In *Cyclothone*, for example, the size of the nerve cell in the nucleus medianus measures 5-6 μ in average. The number of the nerve cells in the olfactory lobe is exceedingly few as compared with that of other teleostean brains.

In all three of these fishes, the anterior commissure is situated in the usual position. In *Cyclothone*, the commissure is consisted of a small number of fibers which originate mostly from the nucleus medianus and nucleus pre-commissuralis, while in *Gonostoma* a few fibers possibly originating from the poorly developed palaeostriatum constitute a part of the commissure.

In *Coryphaenoides*, the internal structure of the olfactory lobe does not differ from these typical for teleostean brains. Palaeostriatal region is relatively well-developed (fig. 7c). Accordingly, the degree of the development of the forebrain bundles seems to be in accordance with the difference mentioned above. Substantially, in *Cyclothone* and *Gonostoma*, it is possible to trace the medial forebrain bundle downwards to the hypothalamus, but impossible to do so for the lateral forebrain bundle which is very poorly developed (fig. 7a, b). In *Coryphaenoides* (fig. 7c), on the other hand, the lateral forebrain bundle as well as the medial is so well-developed that one can follow further caudally to the diencephalic regions as will be stated later.

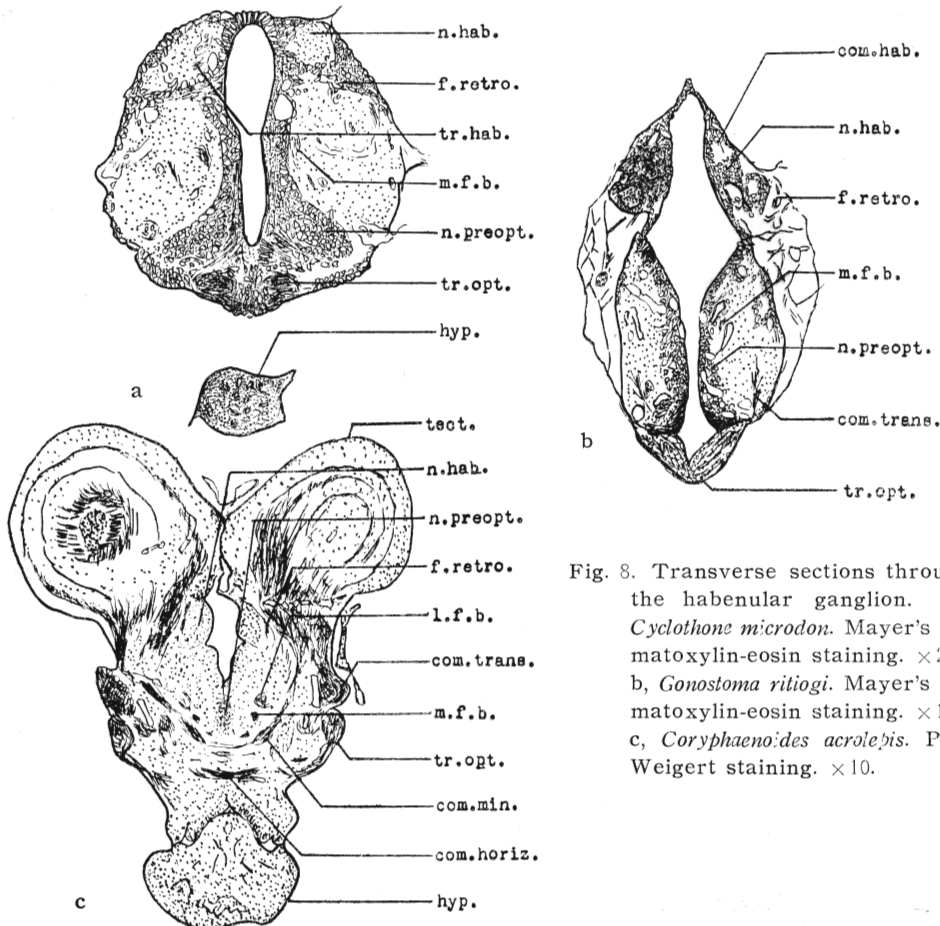


Fig. 8. Transverse sections through the habenular ganglion. a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. $\times 200$. b, *Gonostoma ritiogi*. Mayer's hematoxylin-eosin staining. $\times 170$. c, *Coryphaenoides acrolepis*. Pal-Weigert staining. $\times 10$.

2. DIENCEPHALON

1) Nucleus habenulae

In *Cyclothone* and *Gonostoma*, the nucleus habenulae is relatively well-developed (fig. 8a). As observed in other deep sea fishes by Shanklin (1935), and Gierse (1904), asymmetry of the nucleus habenulae on both sides is found also in our materials. In both specimens the right habenular nucleus is larger than the left one, as they found in *Cyclothone* and *Bathypterois* (fig. 8a, b). In *Coryphaenoides*, nucleus habenulae is not markedly large (fig. 8c). Especially, in *Cyclothone*, the cells of the habenular ganglion are large and compact around the periphery. The habenular commissure is present in the usual place in these fishes, but it is not well-developed in *Cyclothone*. In *Cyclothone* and *Gonostoma* the fasciculus retroflexus is identified in such a way that it originates from the nucleus habenulae and proceeds caudally to the hypothalamus. But we did not follow it down to the nucleus interpeduncularis. There are a few fibers which originate from the nucleus habenulae mingling with the fasciculus retroflexus and penetrate into the thalamic and hypothalamic areas, but their connections in detail have not been ascertained.

2) Nucleus preopticus

The nucleus preopticus occupies a very large area in *Cyclothone* and *Gonostoma* (fig. 8a, b). But, in *Cyclothone*, it is not easy to distinguish the pars magnocellularis from the pars parvocellularis. In *Gonostoma*, the difference between both parts is fairly distinct. In *Coryphaenoides* the pars magnocellularis which is occupied with large cells, is clearly visible. In all of these fishes, a number of fibers of the medial forebrain bundle terminate into the nucleus preopticus.

3) Corpus geniculatum lateralis

It is very well-developed in *Cyclothone* and *Gonostoma* as has been shown in *Bathypterois* by Shanklin (1935). The fact that the corpus geniculatum lateralis is well-developed in *Cyclothone* (fig. 9a), though it possesses very atrophied eyes, may indicate that it receives many fibers other than optic fibers. In *Coryphaenoides* it is not so conspicuous and situated at the usual place. Accordingly, it requires further study to decide whether or not the nucleus which was identified as the corpus geniculatum lateralis in *Cyclothone* and *Gonostoma* as well as in *Bathypterois* by Shanklin (1935) is homologous with that of higher forms.

In connection with this, Charlton (1933) who studied on the brain of blind cave fishes suggests that this nucleus may be a correlation rather than a relay center for the optic path-way, because it is present in those fishes though somewhat atrophied.

4) Nucleus pretectalis

We were not able to identify this nucleus either in *Cyclothone* or *Gonostoma*. However, in *Coryphaenoides* it is very well-developed in a position caudal of the corpus geniculatum lateralis (fig. 9c).

Charlton (1933) in blind fishes, however, mentions that the nucleus is large and formed of large cells scattered here and there.

5) Lobus inferior

The lobi inferiores are well-developed in all three of deep sea fishes (fig. 9a, b, c), but the type of this structure is quite different between *Coryphaenoides* and the small ones, *Gonostoma* and *Cyclothone*. The lobi inferiores of *Coryphaenoides* are a type similar to the other common fish so that no detailed

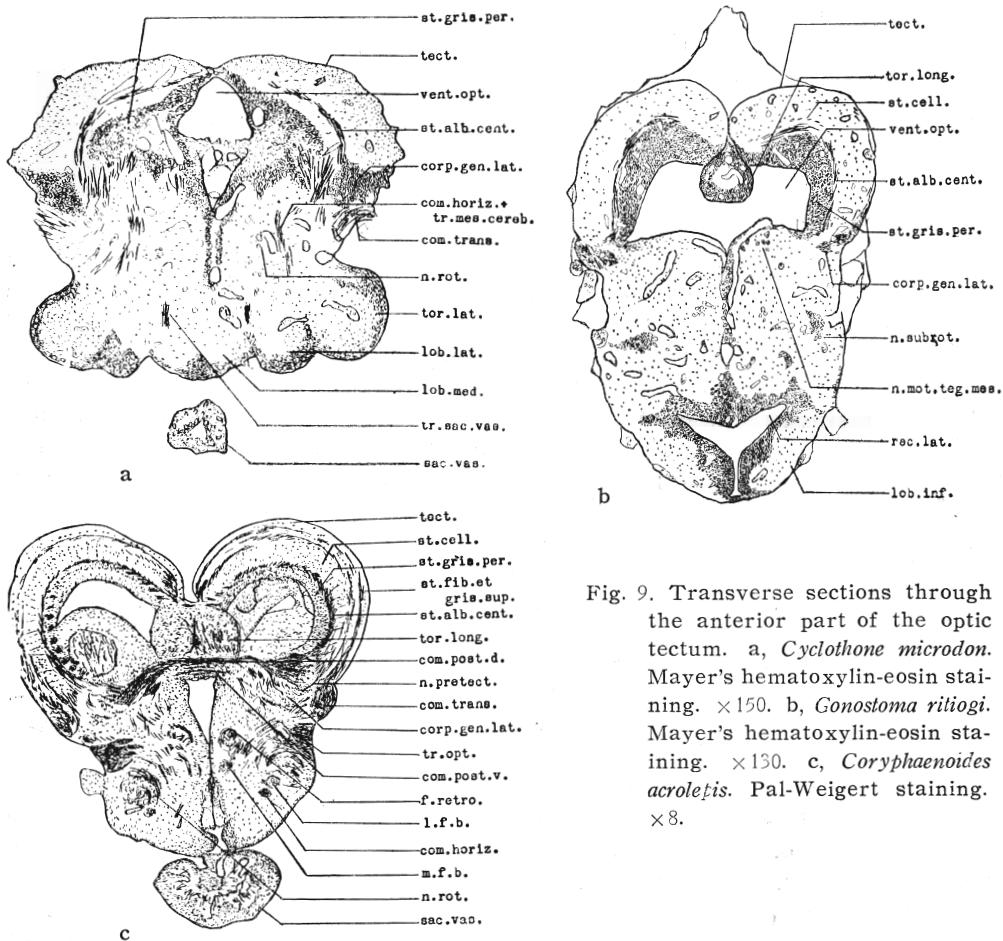


Fig. 9. Transverse sections through the anterior part of the optic tectum. a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. $\times 150$. b, *Gonostoma ritiogi*. Mayer's hematoxylin-eosin staining. $\times 130$. c, *Coryphaenoides acrolepis*. Pal-Weigert staining. $\times 8$.

description would be needed.

In *Cyclothone* and *Ccnostema*, as stated by Shanklin (1935) in deep sea fishes, the lobi inferiores are divided into the three typical parts; lobus medius, lobi laterales, and tori laterales. But in *Cyclothone* the tori laterales show a higher degree of development than the lobi laterales. Within the tori laterales, though well-developed in size, only few cells are scattered except the nucleus rotundic components.

In *Gonostoma*, on the contrary, the tori laterales is smaller than the lobi laterales. In *Coryphaenoides*, the part to be identified as the tori laterales is almost lacking.

Notwithstanding that the nucleus rotundic components are poorly developed in these fishes, the fact that the lobus inferior reaches a high degree of development suggests that it may play an important role not only in visceral function but also in static function. This will be supported by the fact that in these fishes the acoustico-lateral system, including the cerebellum and the saccus vasculosus, are well-developed.

6) Nucleus rotundic components

Although in many fishes, nucleus rotundic components constitute a large

characteristic structure in the hypothalamic region being divided into the rotundus proper, prerotundus and subrotundus, these are very poorly developed in *Cylothone* (fig. 9a) and *Gonostoma* (fig. 9a, fig. 10a). In *Cylothone*, the prerotundus begins to appear in the peripheral portion of the lobus inferior contiguous to the thalamic region and extends medially. The nucleus rotundus proper is enormously small and is continuous with the nucleus prerotundus in its dorsocaudal portion. No cell group which corresponds to the nucleus subrotundus is observed. Principally these findings hold good in *Gonostoma*. Even in *Coryphaenoides* the nucleus rotundus and nucleus prerotundus are not well-developed, but the nucleus epirotundus of Shanklin (1935) is pretty well-developed (fig. 9c, fig. 10b). At any rate it may be worthy to note that in the deep sea fishes under consideration the nucleus rotundic components are not well differentiated. In so far as we know, *Gadus* is an example which shows badly developed structure of the nucleus rotundus. Above observation in the deep sea fishes coincides with that of Shanklin (1935), but his nucleus subrotundus

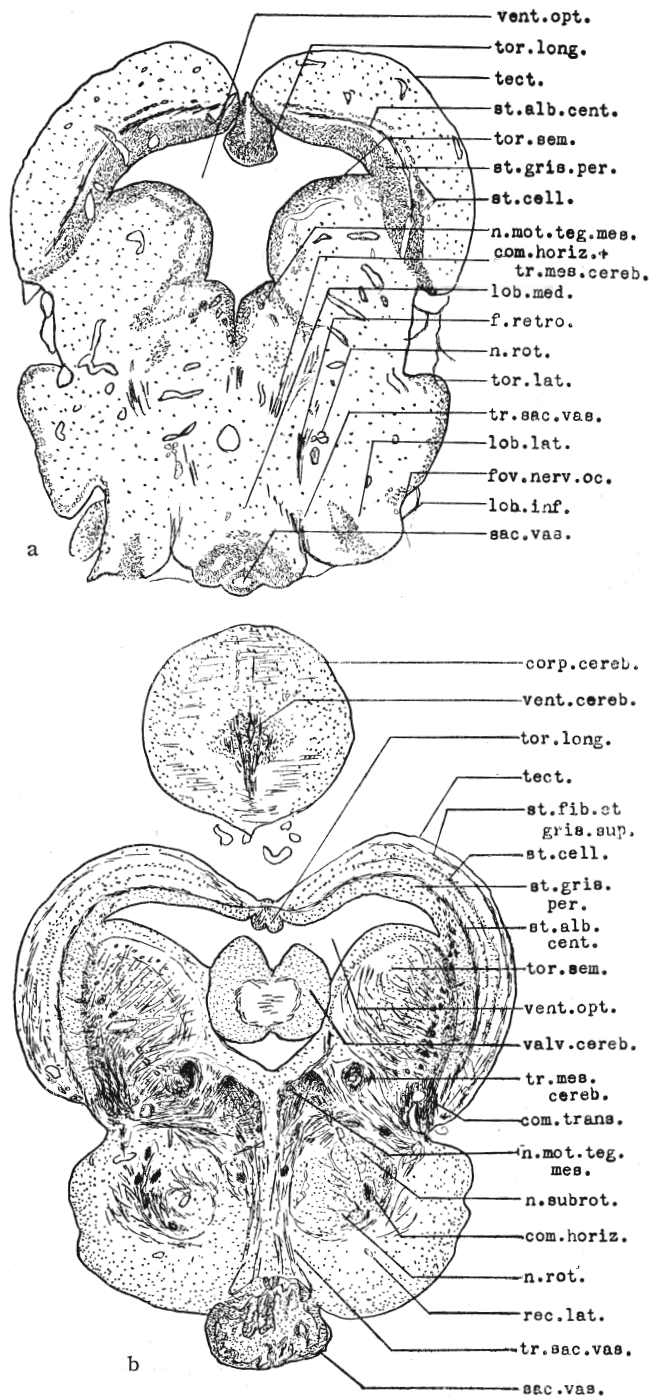


Fig. 10. Transverse sections through a level of approximately middle part of the optic tectum. a, *Gonostoma ritiogi*. Mayer's hematoxylin-eosin staining. $\times 170$. b, *Coryphaenoides acrolepis*. Pal-Weigert staining. $\times 10$.

(see Shanklin, fig. 16) seems to indicate our nucleus prerotundus.

7) Hypophysis

In all of the deep sea fish it is very well-developed. The hypophysis in *Cyclothone* is rostrally elongated and ovoidal in the caudal part (fig. 7a, fig. 8a), in *Gonostoma* ovoidal as a whole. In *Coryphaenoides* it is egg-shaped and its caudal part covers the ventral side of the saccus vasculosus (fig. 8c, fig. 9c). Charlton (1933) in blind fishes states that the hypophysis is small. Accordingly, the fact that the hypophysis is large in deep sea fishes would show that it relates with the ecology of deep sea life.

8) Saccus vasculosus

Morphologically, it is well-developed in *Cyclothone* (fig. 9a), poorly developed in *Gonostoma* (fig. 10a, fig. 12b), and very well developed in *Coryphaenoides* (fig. 10b). In the latter, the tractus sacci vasculosi is easily recognized. This tract which is composed of unmyelinated fibers comes out from the ventral part of the thalamus and penetrates into the succus vasculosus after decussation (fig. 10b). But in *Cyclothone* and *Gonostoma* this tract was not possible to be identified.

Dammerman (1910) claimed that the saccus vasculosus is an organ for the sense of depth according to his observation on the deep sea fishes. Our observation could not substantiate his opinion as well as that of Shanklin (1935), because we found such a case as in *Gonostoma*. It is interesting that Charlton (1933) observed a well-developed saccus vasculosus in blind fishes. According to a recent study of van de Kamer and Verhagen (1954), this organ seems to be of a secretory function.

9) Optic tract

The optic tracts in *Cyclothone* are enormously slender (fig. 7a), and in *Gonostoma* are rather small, but in *Coryphaenoides*, they are of usual size. In all three of these fishes they enter into the brain after having formed the chiasma exterocerebrally. They descend dorso-laterally in the thalamic region together with the commissura transversa and end mostly into the tectum. In our preparations, the termination of the tract was not possible to detect in detail in *Cyclothone* and *Gonostoma*, but in *Coryphaenoides* a part of the tract penetrates into the corpus geniculatum lateralis.

10) Diencephalic commissures

a. Commissura transversa

In *Cyclothone* and *Gonostoma* the commissura transversa is very large. After decussating at the base of the hypothalamus, it runs dorso-laterally along the periphery of the latter, passes through the corpus geniculatum lateralis and the most of the commissural fibers enter into the torus semicircularis. Possibly a small number of the commissural fibers penetrate into the tectum. In *Coryphaenoides* also the commissura transversa is relatively large. Most of the fibers end into the torus semicircularis, but a part of the commissure connects the tecti on both sides. The fact that the commissura transversa is well-developed in these deep sea fish coincides with that observed in the torus semicircularis. It agrees very well with the observation of Shanklin (1935), who found that it is conspicuously developed corresponding to the hypertrophied torus semicircularis.

b. Commissura horizontalis

In all three of these fishes, it is relatively well-developed. After having penetrated into the nucleus rotundic components, it terminates into the dorsal part of the thalamic region (fig. 8c, fig. 9a, fig. 9c, fig. 10b, fig. 11a, fig. 11b).

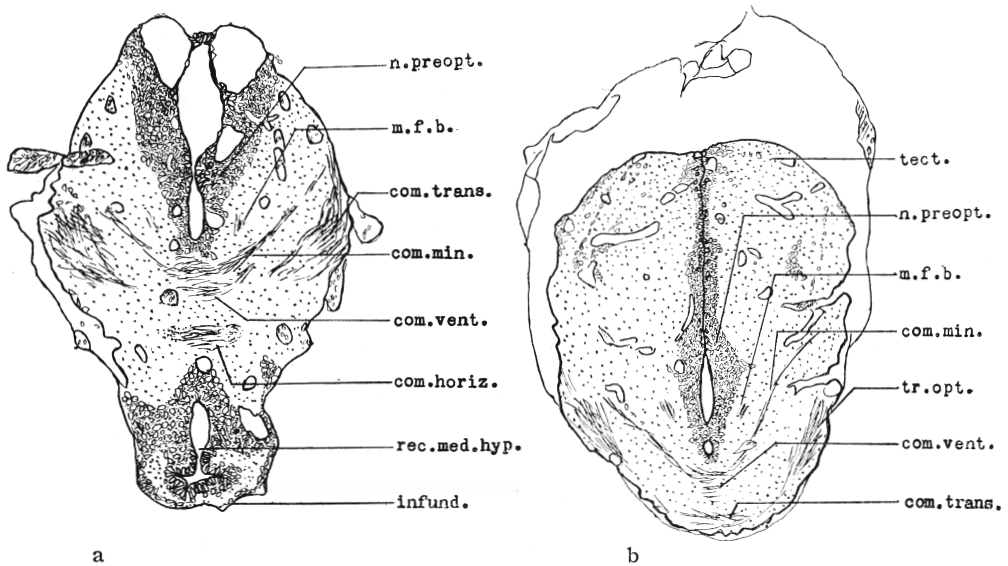


Fig. 11. Transverse sections through the caudal end of the diencephalon.
 a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. $\times 200$.
 b, *Gonostoma riliogi*. Mayer's hematoxylin-eosin staining. $\times 170$.

Accordingly, it is not necessary to add to the description made in usual teleostean brains.

c. Commissura minor

In *Cyclothone* and *Gonostoma*, it is very well-developed. After decussating it runs abruptly obliquely toward dorsal and almost all of its fibers end into the corpus geniculatum lateralis (fig. 11a, b). It is also found in *Coryphaenoides* as seen in the common teleosts (fig. 8c). However, it is worth while to notice that in such deep sea fishes of small size the commissura minor is especially large.

Contrary to this, Shanklin (1935) holds an opinion that it is a tectal commissure, because "it is especially well-developed in fish with a large optic tectum (i.e., *Diaphus*) and it is poorly developed in fish with a small optic tectum (i.e., *Bathypterois*)." (p. 393). However, according to his illustration of the commissura minor in *Bathypterois* (fig. 14), it does not seem to be small when compared with that found in common teleosts.

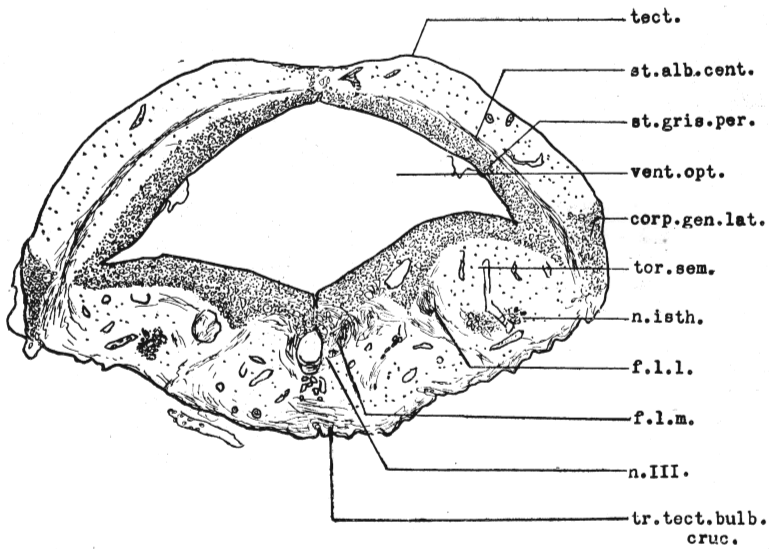
d. Commissure posterior

In *Cyclothone* and *Gonostoma* this commissure is not well-developed, while in *Coryphaenoides* it shows a normal development (fig. 9c). Accordingly, it is supposed that this commissure mostly relates to the optic function. The nucleus of the commissure posterior in *Coryphaenoides* is comparatively large, but in *Cyclothone* and *Gonostoma* it is not so clear as to be identified.

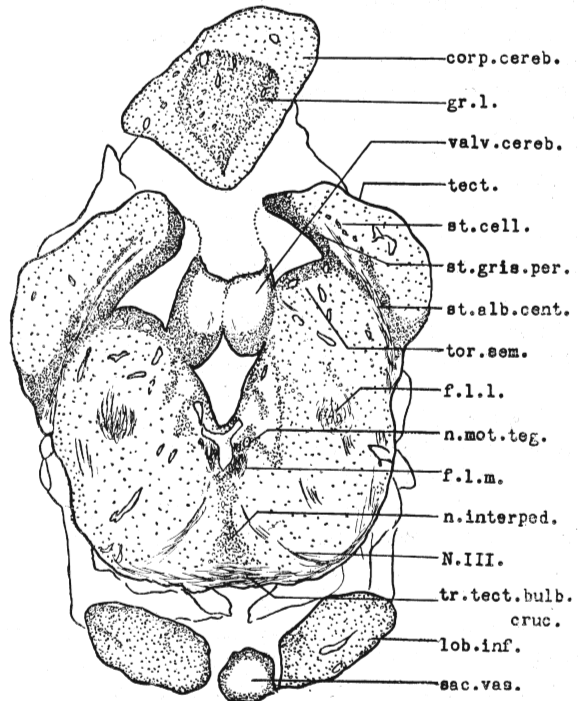
3. MESENCEPHALON

1) Tectum opticum

In the three deep sea fishes the structure of the tectum opticum differs each other. In *Cyclothone* which possesses atrophied eyes the tectum is the smallest. As shown in fig. 9a and fig. 12a, in this fish, the superficial layer is thickest among the tectum, but there are only very few cells scattered in this layer. In this layer also the fibers run very scarcely. In the deeper part of this layer there is a thin stratum consisted of fibers, internally of whose layer



a



b

Fig. 12. Transverse sections through the caudal part of the optic tectum.

a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. ×200.

b, *Gonostoma ritiogi*. Mayer's hematoxylin-eosin staining. ×170.

there is a thin ependymal layer which faces to the midbrain ventricle. Among the thick cell layers there are only few optic fibers penetrating.

The structure of the tectum in *Gonostoma* (fig. 10a, fig. 12b) is principally similar to that of *Cyclothone* excepting that in the superficial layer the fibers are a little more stratified than in *Cyclothone* and there exists one celled layer, though not clear, between the fiber stratum and the superficial layer. In *Coryphaenoides*, the tectum (fig. 9c, fig. 10b) is not different from that of the usual teleosts. Although the structural pattern of the tectum in *Cyclothone* and *Gonostoma* is alike to that of *Bathypterois* (Shanklin, 1935), it is much more inferior than in the latter in its development. Furthermore, the optic tectum in *Cyclothone* seems to be a little more poorly differentiated than that of the blind cave fishes examined by Charlton (1933). As will be stated later, it is a characteristic feature that the tectum in *Cyclothone* and *Gonostoma* is very small, while the torus semicircularis is enormously large. In this connection, however, it must be noted that Marshall (1955) remarks that the eye in *Cyclothone microdon* is sensitive in the darker reaches of the ocean twilight (p. 224).

2) Torus longitudinalis

In *Cyclothone* the torus longitudinalis is completely lacking (fig. 9a, fig. 12a). In *Gonostoma* it is relatively well-developed but does not exhibit a paired structure (fig. 9b, fig. 10a). The periphery of its structure is formed by the cells and the inside is of synaptic layer. In *Coryphaenoides* also it is large (fig. 9c, fig. 10b). In the rostral part it is unpaired but in the caudal it becomes paired. It is in contact with the tegmental area at the level of the posterior commissure (fig. 9c).

Shanklin (1935) in *Bathypterois* and Gierse (1904) in *Cyclothone* describe that the torus longitudinalis is lacking. In the blind fish, however, Charlton (1933) points out the presence of the torus. These facts suggest that the torus longitudinalis is related not only to the optic function, but also to other unknown function.

3) Torus semicircularis

In all three of these fishes the torus semicircularis is enormously well-developed. In *Cyclothone* (fig. 12a) and *Gonostoma* (fig. 10a, fig. 12b), the cellular layer of the torus is contiguous with that of the tectum in its rostral part (fig. 12a). In its caudal part the tori on the both sides extend laterally of the cerebellum (fig. 13a, b). Due to the greatest development of the torus, the fasciculus longitudinalis lateralis becomes very large. Although in *Coryphaenoides* the torus semicircularis develops very well as stated above (fig. 10b), the caudal part of the torus does not extend so laterally toward the cerebellum as is in *Cyclothone* and *Gonostoma*.

Our finding concerning the torus semicircularis agrees fully with that of Shanklin (1935). Accordingly, that the torus semicircularis is highly developed in deep sea fishes should be an established fact.

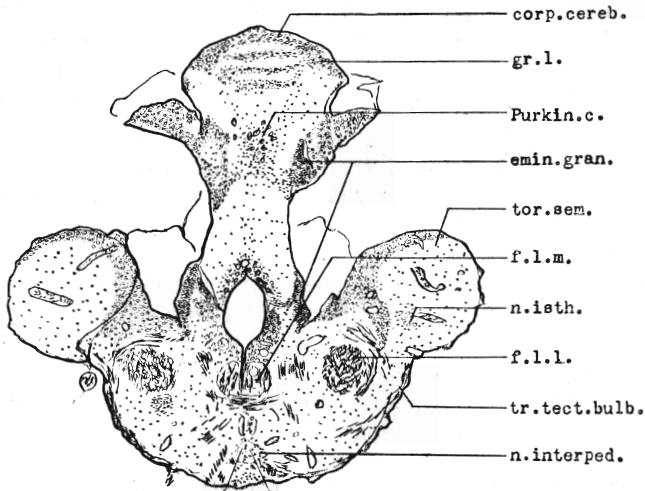
4) Nucleus interpeduncularis

In all three of the deep sea fishes the nucleus interpeduncularis exhibits a distinct structure in the usual place. In *Cyclothone* it occupies a relatively extensive area, but there are not many nerve cells within it (fig. 13a). In *Gonostoma* it shows a highest degree of development within which many cells are scattered (fig. 13b). In *Coryphaenoides* it is of a normal development.

4. CEREBELLUM

The cerebellum both in *Cyclothone* and *Gonostoma* is quite large. The inner

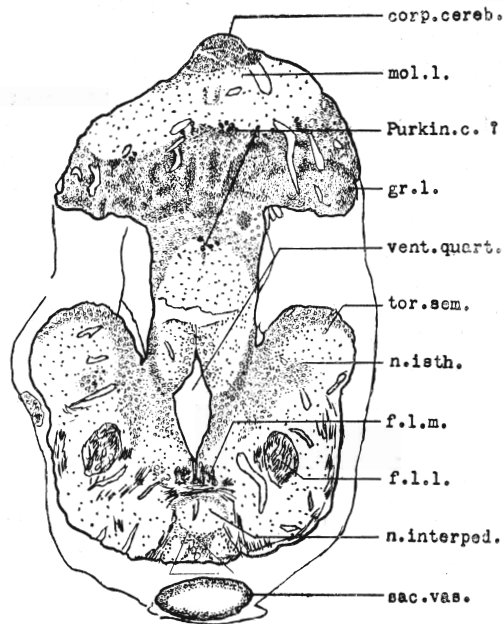
structure of the cerebellum is very different from those of common teleosts. The corpus cerebelli is composed of small cells in which they aggregate densely. It appears to correspond to the so-called granular layer of the cerebellum (fig. 13a, b, fig. 14a, b). The lateral protuberance of the cerebellum forming an auricle is also made up of many small cells. It may correspond to the eminentia granularis. Internally of the small cell group of the eminentia granularis there are irregularly scattered large cells which may be equivalent



a

Fig. 13. Transverse sections through the cephalic part of the corpus cerebelli.

- a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. $\times 200$.
 b, *Gonostoma riliogi*. Mayer's hematoxylin-eosin staining. $\times 170$.



b

to the Purkinje cells. However, in the surface of the granular layer there are no large cells at all. In the caudal portion of the eminentia granularis the lateral line nerve is penetrating.

In *Cyclothone* the part corresponding to the valvula cerebelli is hardly detectable, but in *Gonostoma* it is relatively well-developed. Shanklin (1935) illustrated in his figures a somewhat well-developed valvula cerebelli in the deep sea fishes, that is, *Diaphs*, *Bathypterois* and *Saurida*. In *Coryphaenoides* the valvula cerebelli and corpus cerebelli are both well-developed. The corpus cerebelli extend dorso-caudally as seen in fig. 15 and fig. 16. The internal structure is not so different as in the common teleosts.

5. MEDULLA OBLONGATA

Since the medulla oblongata in the three deep sea fishes studied does not in principle differ from those in the common teleosts, only important findings will be described as follows:

1) Somatic sensory system

Although a part of the sensory V nerve ends in a somatic sensory area in the medulla oblongata, in *Coryphaenoides* this area is very well-developed and the

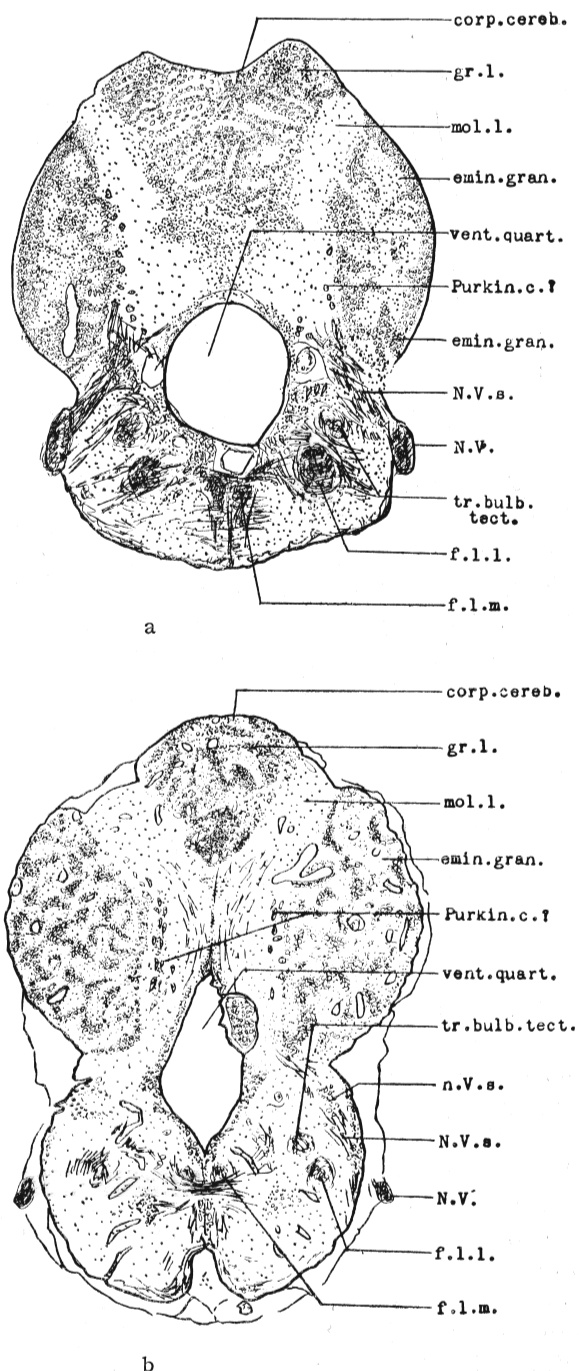


Fig. 14. Transverse sections through the middle part of the corpus cerebelli. a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. $\times 200$. b, *Gonostoma ritiogi*. Mayer's hematoxylin-eosin staining. $\times 170$.

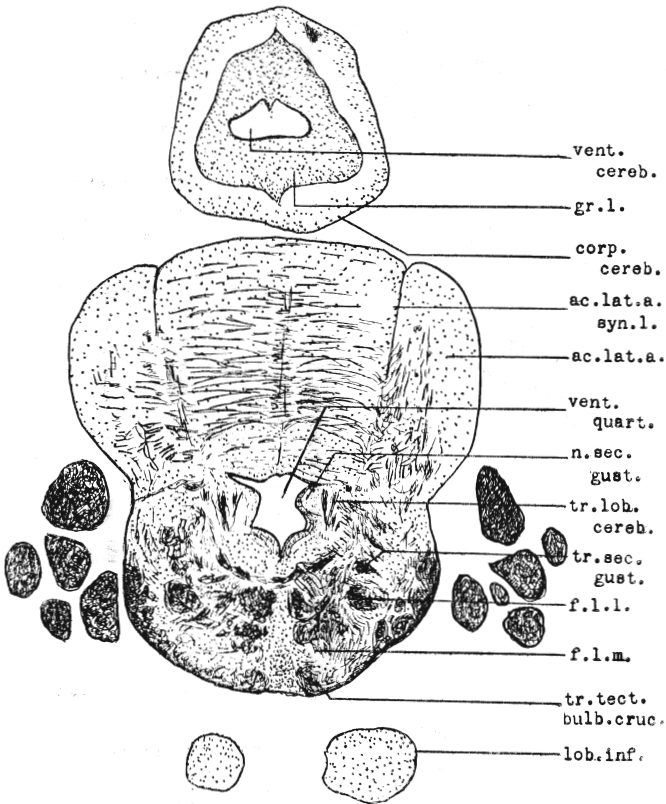


Fig. 15. Transverse section through the caudal end of the cerebellum. *Coryphaenoides acrolepis*. Pal-Weigert staining. $\times 10$.

Among the somatic sensory system, the acoustico-lateralis system is highly developed in the three deep sea fishes examined. Main roots belonging to this system, VIII nerve and lateral nerve, after their entrance into the brain, run rostrally and end at the acoustico-lateralis area and the eminentia granularis of the cerebellum.

Considering them in proportion with the

tractus V spinalis is also large (fig. 15).

The somatic sensory area of the Vth nerve in *Coryphaenoides* begins to appear at the caudal end of the tuberculum acusticum and extends dorsally forming the Vth sensory lobe which is connected with the acoustico-lateralis area.

As shown in figs. 17 a and b, in *Cyclothone* and *Gonostoma* the Vth sensory area is so typical that it is composed of a large number of cells. Especially in the former it is conspicuous. In these specimens, the Vth sensory area is intimately related with the synaptic layer of the acoustico-lateralis area.

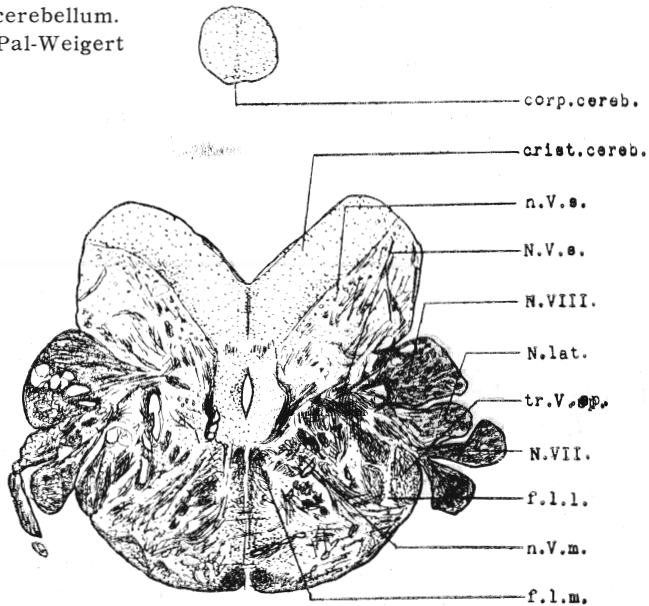


Fig. 16. Transverse section through the region of the entrance of the VIII nerve. *Coryphaenoides acrolepis*. pal-weight staining. $\times 10$.

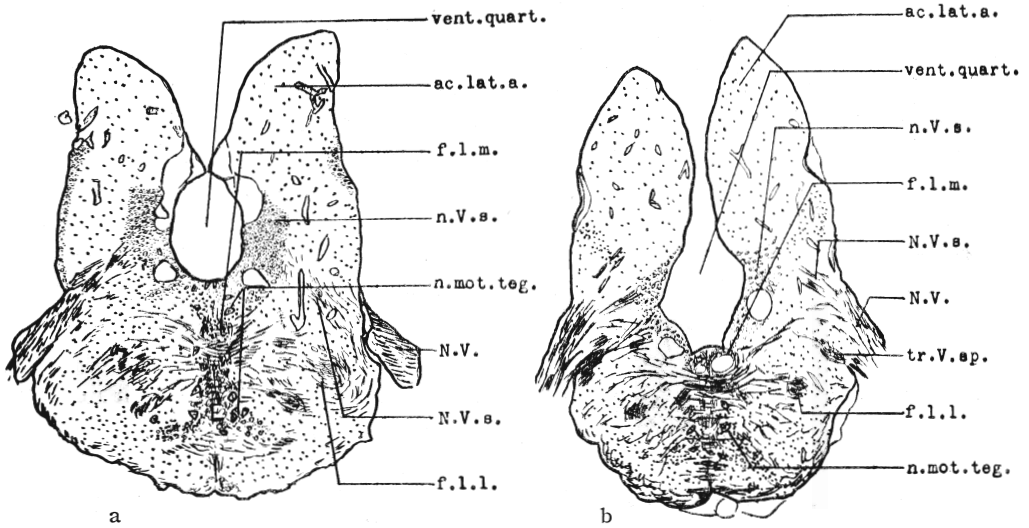


Fig. 17. Transverse sections through the anterior region of the acoustico-lateralis area. a, Mayer's hematoxylin-eosin staining. $\times 200$. b, *Gonostoma ritiogi*. Mayer's hematoxylin-eosin staining. $\times 170$.

size of the brain, *Cyclothone* is the largest in development of the eminentia granularis and the acoustico-lateralis area, and the next is *Gonostoma* and finally *Coryphaenoides*.

2) Visceral sensory system

As the sensory areas belonging to this system in the medulla, we consider

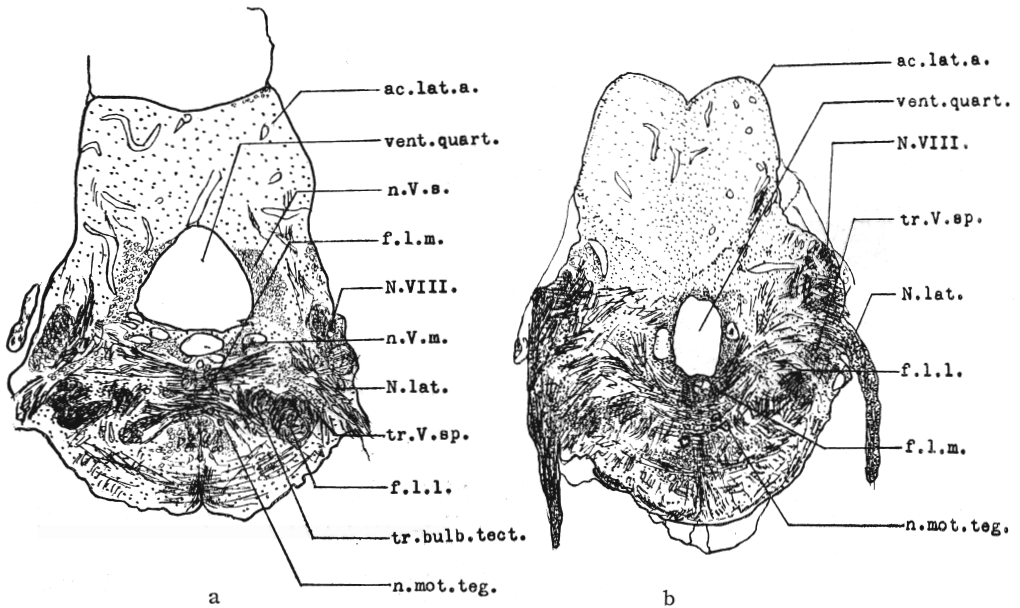


Fig. 18. Transverse sections through the acoustico-lateralis area several sections caudal to fig. 17. a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. $\times 200$. b, *Gonostoma ritiogi*. Mayer's hematoxyline-eosin staining. $\times 170$.

those of VII, IX and X sensory roots. In *Coryphaenoides*, in spite of possessing the barbels, the facial area appears not to be so prominently well-developed. The VII sensory root is not so large. At about the caudal end of the V sensory lobe, the VIII sensory root enters the medulla. It descends caudally so far as the facial areas make their appearance on both sides of the IV ventricle. The facial areas on both sides do not come into contact with each other. Near the caudal end of the facial area the relatively large vagal lobes on both sides appear dorso-laterally of the facial areas. The vagal lobe receives rootlets of the IX and X sensory nerves as usual. The so-called secondary gustatory tract which emerges from the vagal and facial areas ascends rostrally to end at the nucleus secondary gustatory, being in close contact with the fasciculus longitudinalis lateralis. In this connection, an additional remark will be made that the tertiary gustatory tract which departs

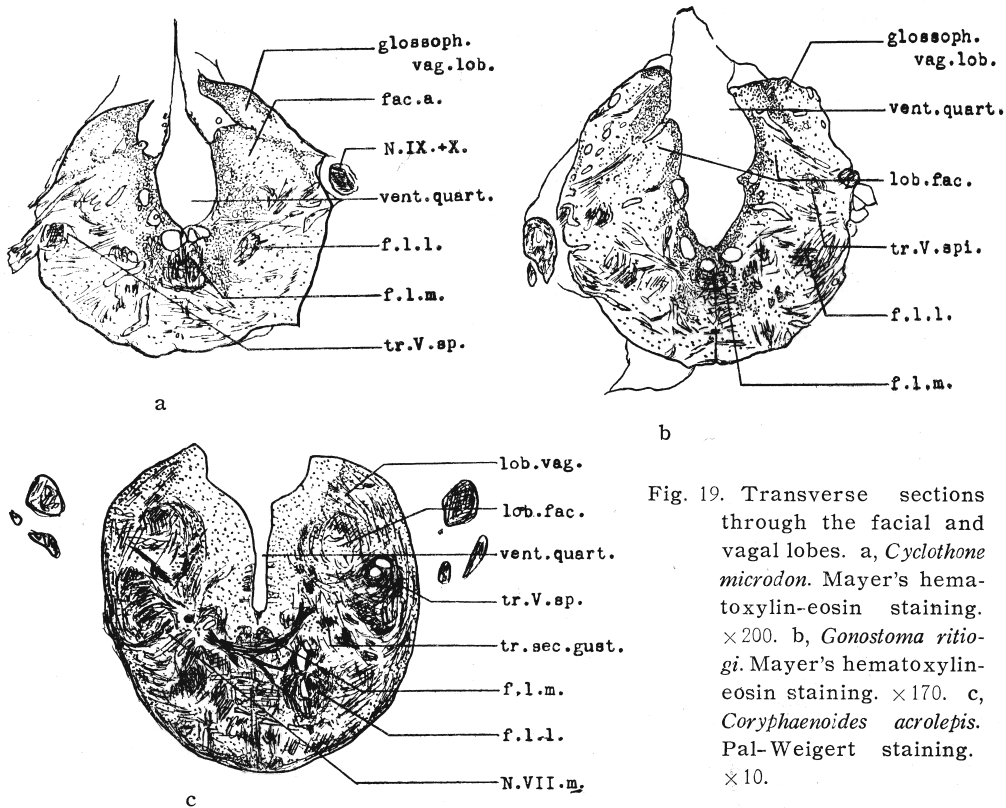


Fig. 19. Transverse sections through the facial and vagal lobes. a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. $\times 200$. b, *Gonostoma ritio-gi*. Mayer's hematoxylin-eosin staining. $\times 170$. c, *Coryphaenoides acrolepis*. Pal-Weigert staining. $\times 10$.

from the nucleus secondary gustatory is traceable to the inferior lobe. In this fish, it may be said that the gustatory system mentioned above exhibits morphologically a normal development.

The facial area in *Cyclothone* and *Gonostoma* is present as is in *Coryphaenoides*, but it is very small. The vagal lobe is not well-developed too. In our preparations, it was impossible to identify the secondary gustatory tract and its nucleus very clearly.

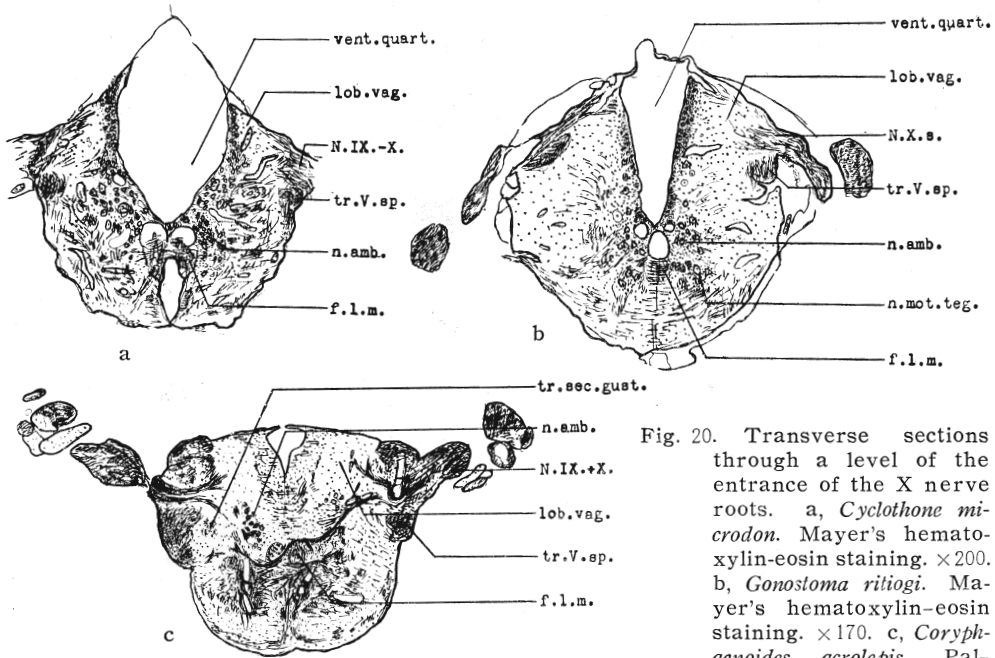


Fig. 20. Transverse sections through a level of the entrance of the X nerve roots. a, *Cyclothone microdon*. Mayer's hematoxylin-eosin staining. $\times 200$. b, *Gonostoma ritiogi*. Mayer's hematoxylin-eosin staining. $\times 170$. c, *Coryphaenoides acrolepis*. Pal-Weigert staining. $\times 10$.

3) Visceral motor system

Almost all of the fibers of the motor elements of the V roots in the three deep sea fishes end at the Vth motor nucleus which is situated at the dorso-lateral position of the fasciculus longitudinalis medialis and is composed of large cells.

In *Coryphaenoides* and *Gonostoma* this nucleus is under normal development, but in *Cyclothone* is considerably poor in development.

The motor nucleus of VII root in the three deep sea fishes is situated at a latero-ventral position of the fasciculus longitudinalis medialis. In *Cyclothone* and *Gonostoma* it is relatively well-developed, but in *Coryphaenoides* is not unusual.

Nucleus ambiguus in *Cyclothone* and *Gonostoma* is very well-developed in the same position as seen in the common teleosts. In *Coryphaenoides* it is normally developed.

4) Somatic motor system

There is very few to be added here about the somatic motor system as compared with that typical for the common teleosts. Except those in *Coryphaenoides*, all of the nerves of the eye muscles are exceedingly small and their nuclei are so poorly developed that one cannot indicate them, especially in *Cyclothone* in which IV and VI nerves are lacking. Charlton (1933) in blind cave fishes finds that the III, IV, and VI nerves and their nuclei are absent.

In this connection, observation upon the fasciculus longitudinalis medialis will be noted briefly. In *Cyclothone* and *Gonostoma* this fasciculus begins to be formed in the mesencephalic tegmentum in a usual way. Being consisted mostly of those fibers coming from the tectum, cerebellum, acoustico-lateralis area, and other bulbar correlation centers, it is relatively large. However,

the nucleus of this fasciculus was not identified in those fishes.

In *Coryphaenoides* this fasciculus is well differentiated and its nucleus is identified. The giant axonal fiber of the Mauthner cell is found to locate in a dorsal portion of this fasciculus in this fish, but in *Cyclothone* and *Gonostoma* it is not possible to detect it in our preparations.

Concerning the large cells of the so-called reticular formation or the motor tegmental nuclei the following will be noted. Although in *Coryphaenoides* there is no need to add excepting that the structure in question is much more highly developed than in the common teleosts. In *Cyclothone* and *Gonostoma*, there are a larger number of large cells scattered throughout the mesencephalic tegmentum and the bulbar region. These large cells belong to the Müller cells in type. They are mostly distributed in the more dorsal portion and around the fasciculus longitudinalis medialis, but rarely in the ventral portion. In these fishes, this system is hardly divided into several nuclei as is made in other teleosts brain (refer to Tuge, 1932).

SUMMARY

General features concerning the three deep sea fishes studied may be pointed out as follows: *Coryphaenoides* has a large eye, a moderately well-developed acoustico-lateralis system. *Gonostoma* has a small eye, a well-developed olfactory organ and a very well-developed acoustico-lateralis system. *Cyclothone* has an atrophied eye, a well-developed olfactory organ and a very well-developed acoustico-lateralis system.

In *Cyclothone*, the palaeostriatal area in the forebrain is lacking, but in *Gonostoma* there is found only a precursor of such structure. In *Coryphaenoides*, it shows the features similar to that in common teleosts. Therefore, the lateral forebrain bundle is very developed in *Cyclothone* and *Gonostoma*, but moderately well-developed in *Coryphaenoides*.

In *Cyclothone* and *Gonostoma*, the habenular nucleus is very well-developed as well as the nucleus preopticus. Also, the fact that the nucleus geniculatum lateralis is well-developed in spite of an atrophied or small eyes suggests that it is not related exclusively to the optic system. The above structures are moderately differentiated in *Coryphaenoides*. However, rotundic nuclei components, especially nucleus rotundus proper, are exceedingly reduced in all of these deep sea fishes, despite that they have relatively large lobi inferiores.

Commissure transversa is rather large in these deep sea fishes. This coincides with that the torus semicircularis is enormously well-developed, particularly in *Cyclothone* and *Gonostoma*. The commissura minor is also well-developed in *Cyclothone* and *Gonostoma*.

In all of the deep sea fishes the hypophysis is very large. The saccus vasculosus is very well-developed in *Cyclothone* and *Coryphaenoides*, but rather poorly developed in *Gonostoma*.

The development of the optic tectum is very poor in *Cyclothone* and *Gonostoma*, revealing a similarity to that of the blind cave fishes. In *Coryphaenoides*, on the contrary, it is well arranged in its cellular and fibrous layers as in common fishes.

In *Cyclothone* the torus longitudinalis is completely absent differing from the other deep sea fishes studied.

Nucleus interpeduncularis is very well-developed in *Cyclothone* and *Gonostoma*.

The cerebellum in *Coryphaenoides* is quite large, possessing a part of the protruded valvula cerebelli, and its internal structure is not different from common teleosts. But, the structure of the cerebellum is peculiar in *Cyclothone* and *Gonostoma*. The granular cell layer of the corpus cerebelli is so enormously developed that it extends to the surface of the latter and is connected with the large area of the eminentia granularis. Large cells are very irregularly scattered within the molecular layer. These cells may be homologous with the Purkinje cells.

In the three deep sea fishes, the acoustico-lateralis area is conspicuously well-developed, as well as the sensory Vth nucleus. Development of these structures in the medulla may characterize the unusual behavior of the deep sea fishes.

The visceral sensory areas are not well-developed as compared with common teleost. In spite that *Coryphaenoides* possesses a pair of barbels, the facial area is not so large as in other teleosts with barbels. The secondary gustatory nucleus is not distinctly differentiated in *Cyclothone* and *Gonostoma*, but it is normally developed in *Coryphaenoides*, from which nucleus the tertiary gustatory tract is traceable toward the hypothalamus.

Nothing new has been found in the medulla of the deep sea fishes except what was described above in comparison with the common teleostean brain.

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ABBREVIATIONS

<i>ac. lat. a.</i>	acoustico-lateralis area
<i>bulb. olf.</i>	bulbus olfactorius
<i>ch. opt.</i>	chiasma opticum
<i>com. ant.</i>	commissura anterior

<i>com. hav.</i>	commissura habenularum
<i>com. horiz.</i>	commissura horizontalis
<i>com. min.</i>	commissura minor
<i>com. post. d.</i>	commissura posterior pars dorsalis
<i>com. post. v.</i>	commissura posterior pars ventralis
<i>com. trans.</i>	commissura transversa
<i>com. vent.</i>	commissura ventralis
<i>corp. cereb.</i>	corpus cerebelli
<i>corp. gen. lat.</i>	corpus geniculatum lateralis
<i>em n. gran.</i>	eminentia granularis
<i>epiphy.</i>	epiphysis
<i>fac. a.</i>	facial area
<i>f. l. l.</i>	fasciculus longitudinalis lateralis
<i>f. l. m.</i>	fasciculus longitudinalis medialis
<i>f. retro.</i>	fasciculus retroflexus
<i>fis. end.</i>	fissura endorhinalis
<i>fov. nerv. oc.</i>	fovea nervi oculomotorii
<i>glossoph. vag. lob.</i>	glossopharyngo-vagal lobe
<i>gr. l.</i>	granular layer
<i>hyp.</i>	hypophysis
<i>infund.</i>	infundibulum
<i>lob. fac.</i>	lobus facialis
<i>lob. inf.</i>	lobus inferior
<i>lob. lat.</i>	lobus lateralis
<i>lob. med.</i>	lobus medialis
<i>lob. olf.</i>	lobus olfactorius
<i>lov. vag.</i>	lobus vagi
<i>l. f. b.</i>	lateral forebrain bundle
<i>m. f. b.</i>	medial forebrain bundle
<i>med. ob.</i>	medulla oblongata
<i>med. sp.</i>	medulla spinalis
<i>mol. l.</i>	molecular layer
<i>N. III.</i>	nerve III
<i>N. V.</i>	nerve V
<i>N. V. m.</i>	nerve V motor
<i>N. V. s.</i>	nerve V sensory
<i>N. VII.</i>	nerve VII
<i>N. VIII.</i>	nerve VIII
<i>N. IX.+X.</i>	nerve IX + nerve X
<i>N. olf.</i>	nerve olfactorius
<i>N. lat.</i>	nerve lateralis
<i>n. V. m.</i>	nucleus V motor
<i>n. V. s.</i>	nucleus V sensory
<i>n. amb.</i>	nucleus ambiguus
<i>n. hav.</i>	nucleus habenularis
<i>n. isth.</i>	nucleus isthmi
<i>n. interped.</i>	nucleus interpeduncularis
<i>n. mot. leg.</i>	nucleus motorius tegmenti
<i>n. olf. dor.</i>	nucleus olfactorius dorsalis
<i>n. olf. lat.</i>	nucleus olfactorius lateralis
<i>n. precom.</i>	nucleus precommissuralis
<i>n. prelect.</i>	nucleus pretectalis
<i>n. rot.</i>	nucleus rotundus
<i>n. sec. gust.</i>	nucleus of secondary ascending gustatory tract
<i>n. subrot.</i>	nucleus subrotundus
<i>palaeost.</i>	palaeostriatum
<i>paraphy.</i>	paraphysis
<i>Purkin. c.</i>	Purkinje cell
<i>rec. lat.</i>	recessus lateralis
<i>rec. med. hyp.</i>	recessus medialis hypothalami
<i>sac. vas.</i>	saccus vasculosus

<i>st. alb. cent.</i>	stratum album centrale
<i>st. cell.</i>	stratum cellulare
<i>st. fib. et gris. sup.</i>	stratum fibrosum et griseum superficialc
<i>st. gris. per.</i>	stratum griseum periventriculare
<i>sul. yps.</i>	sulcus ypsiliformis
<i>tect.</i>	tectum
<i>tor. lat.</i>	torus lateralis
<i>tor. long.</i>	torus longitudinalis
<i>tr. V. sp.</i>	tractus V-spinalis
<i>tr. bulb. tect.</i>	tractus bulbo-tectalis
<i>tr. hab.</i>	tractus habenularum
<i>tr. mes. cereb.</i>	tractus mesencephalo-cerebellaris
<i>tr. olf.</i>	tractus olfactorius
<i>tr. opt.</i>	tractus opticus
<i>tr. sac. vas.</i>	tractus sacci vasculosi.
<i>tr. sec. gust.</i>	tractus secondary gustatory
<i>tr. str. thal.</i>	tractus strio-thalamicus
<i>tr. tect. bulb.</i>	tractus tecto-bulbalis
<i>tr. tect. bulb. cruc.</i>	tractus tecto-bulbalis cruciatus
<i>valv. cereb.</i>	valvula cerebelli
<i>vent. cerev.</i>	ventriculus cerebelli
<i>vent. opt.</i>	ventriculus opticus
<i>vent. quart.</i>	ventriculus quartus

深海魚 (*Cyclothone microdon*, *Gonostoma ritiogi*, *Coryphaenoides acrolepis*) の腦の研究

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摘 要

深海魚の腦に関する研究は極めて少いが、深海魚の生態を知る上において、これらの腦の構造を解明することは非常に有意義である。ソ連調査船ビジャス号によって捕獲された下記深海魚3種の腦の外部並びに内部構造の検索を行った。(1) *Cyclothone microdon*; (2) *Gonostoma ritiogi*; (3) *Coryphaenoides acrolepis*.

Coryphaenoides は大きな眼、中程度に発達した嗅覚器、よく発達した聴側線系を具え、*Gonostoma* は小さい眼、よく発達した嗅覚器と非常によく発達した聴側線系をもち、*Cyclothone* は退化した眼、よく発達した嗅覚器、非常によく発達した聴側線系をもっている。

Cyclothone では、大脳のパラエストリウムに相当する領域は欠如し、*Gonostoma* では未発達のパラエストリウムが見られる。従つて、両者では lateral forebrain bundle は極めて未発達である。*Coryphaenoides* ではパラエストリウムは一般の硬骨魚程度に発達している。

Cyclothone と *Gonostoma* の nucl. habenularis はよく発達している。また、眼の発達が悪いにも拘らず、外側膝状核はよく発達している。*Coryphaenoides* では、以上の核は普通程度の発達である。しかし、nucl. rotundus 並びにそれに関連する核群は、深海魚において極めて発達が悪い。lobus inferiores は比較的大きい。

Commissura transversa は深海魚では比較的良好に発達しているが、これは torus semicircularis の異常な発達と一致している。*Cyclothone* と *Gonostoma* では、commissure minor はよく発達している。

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これらすべての深海魚で脳下垂体は非常に大きく、また *Coryphaenoides* と *Cyclothone* では血脈囊もよく発達しているが *Gonostoma* では発達がよくない。

Cyclothone と *Gonostoma* の視葉の内部構造は極めて単純で、洞穴に棲む盲目魚のそれに似ている。しかし、*Coryphaenoides* では、視葉の層的構造は通常の硬骨魚に等しい。

Torus longitudinalis は、*Cyclothone* では欠如しているが、他の2種では存在する。*Cyclothone* と *Gonostoma* では、nucl. interpeduncularis が非常によく発達している。

Coryphaenoides の小脳は大きい、内部構造は普通の硬骨魚と異なる。しかし、*Cyclothone* と *Gonostoma* の小脳は特殊であり、Purkinje 細胞と見做される大細胞が存在するが、それらは極めて不規則に散在している。

すべての深海魚で、聴側線領域は極度に発達している。また、感覚性第五脳神経核は著しく発達している。これらは延髄における深海魚の特長を示すものと考えられる。

深海魚では、延髄中の臓器的感覚領域は一般硬骨魚に比し発達が劣っている。*Coryphaenoides* は、1対のヒゲをもつにも拘らず、顔面葉はよく発達してない。第2次味覚中枢は、*Coryphaenoides* では中程度であるが、*Cyclothone* と *Gonostoma* では、未発達である。*Coryphaenoides* では、第3次味覚路が視丘下部に走行することも確認された。深海魚の延髄においては、上述の点以外には他の一般硬骨魚と異なる特長を見出しえなかつた。