SKELETON DEVELOPMENT
IN
CATOSTOMUS COMMERSONII

THE SKELETON

AND ITS

DEVELOPMENT IN CATOSTOMUS COMMERSONII, (L.).

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INTRODUCTION:

The following paper covers the results so far obtained in the study of the ossification of the skeleton of the common small-scaled sucker (Catostomus commersonii, Leseur).

Up to the present, very little work has been carried out on the skeleton of this fish, other than of a taxonomic nature, and accordingly, it has been found advisable to include descriptions of the adult skeleton, and also to record observations from a dissection of several adult fish.

With regard to the skull, it was not found possible to describe its ossifications clearly without an accurate knowledge of the chondrocranium, and the first part of the paper is given over to a description of the chondrocranium as it was found in two stages, which were reconstructed. The details of the cartilaginous precursors of the rest of the skeleton (branchial apparatus, girdles, etc.) are sufficiently clear in the transparent preparations.

In covering such a wide field, as the entire skeleton of one fish, it is not possible, at the same time, to enter into theoretical considerations, without making the paper too long and cumbersome.

MATERIAL AND METHODS:

The observations recorded were made on a series of larval suckers (Catostomus commersonii), comprising part of a collection of larval stages of the fish of the southern part of the Province of Quebec, made during the summers of 1930, 1931, and 1932.

The fish were taken at different times from two locations, a single haul from each giving a short series. The later stages were completed by fish from various other locations. In 1930, a single haul gave a series of from 1.2 to 1.7 cms.; in 1931, a second series of from 2.0 to 2.5 cms., and later in the season, a specimen of 5.1 cms. (Circ.1½ yrs.). In 1932, an earlier series of from 1.0 to 1.4 cms. was taken.

Serial section of 1.0 - 1.4 and 1.8 cms., and alizarin preparations of specimens 1.0 - 1.2 - 1.3 - 1.5 - 1.6 - 1.7 - 2.0 - 2.4 - 2.5 - 2.9 and 5.1 cms., were made. In addition, in order to check the stability of various skeletal features, Alizarin preparations of twenty specimens, ranging in length from 2.2 to 3.5 cms., were made.

According to Batson (1), the specificity of certain dyes for bone has been known for a long time. He records two early observations on the vital staining of bone as the result of animals feeding upon madder. The earliest is that of Laevinius Lemnius in 1581. His findings were re-discovered by Belchier (-) in 1735. Subsequent to this, the subject was virtually untouched until recently, when it was found that the active staining substances were principally Alizarin, and to a lesser extent Purpurin.

With the introduction, by Spalteholtz and Schultze, of methods for preparing transparencies, a new field was opened to anatomists. Prior to these techniques, the greater part of embryological studies, and the study of the osteology of small forms, had been carried on mainly by means of gross dissection, maceration, and drying, or else by means of cross-sections and reconstructions.

The new techniques enabled the making of direct observations upon various parts as a whole and without loss of immediate relations. The principal difficulty lay in the fact that the majority of structures in a specimen so treated were of a very close refractive index and as such, it was difficult to make them out clearly. Naturally, it was far easier to examine bone and bone growth, and so this became the principal use for the technique. But even in this case, there remained difficulty, especially in the observation of early centres of ossification, and the practice of employing stains specific for bone was introduced.

The earliest attempt at staining in this connection seems to have been by Schultze who employed Potassium Dichromate in his fixatives. This is washed out of the tissues and, when the specimen was treated with Potassium Hydroxide, the bones became stained a brown color. Bardeen was also early in advocating the use of Alum-cochineal, which stained both the bone and cartilage.

Later, Alizarin became employed generally, having been introduced again by Spalteholtz (—). Batson, (1), made a study of various salts of Alizarin and also of several other stains, arriving at the conclusion that the presence of the anthraquinone group was not essential for the staining of bone.

It would appear that Dawson, (4), was the first to introduce the combination of Alizarin staining and the Schultze method of clearing, though many workers had been using this stain with the Spalteholz method and also with Lundvall's technique. Dawson's method, however, employed Mall's modification of Schultze and not the original technique.

This combination of stain and clearing techniques is that which the author has been employing, and, with care, it has given generally excellent results, even though applied to a wide range of objects, from young fish larvae 1 cm., long, up to mammal embryos 3½" long. Preparations of an adult smelt, (O.mordax), 5" long have been made with success. Also it has been possible to prepare newts, both larvae and adults, and a frog.

The process consists in converting the tissues into their metaproteins by the controlled use of Potassium Hydroxide, and infiltrating the translucent tissues so produced with glycerine in order to obtain a high refractive index, and so increase the degree of transparency.

It may be readily understood, as was found by Strong, (17), that any fat present will tend to saponify owing to the presence of the KOH, and as such, it will not become transparent. Strong, working with large mammal and bird embryos, was able to overcome this difficulty by simply dissecting away such fat from the specimen during the time that he was treating it. Dawson, (4), has introduced the treatment of the specimen before clearing with a wash of acetone, and so removing the fat quite readily. Since Dawson was working with material preserved in alcohol, it was quite logical for him to remove the acetone wash by alcohol washes.

In the case of formalin material it did not seem necessary to run specimens up to strong alcohol in order to remove the acetone; but, practically, it was found that good results were only to be obtained by doing this.

Even when this treatment was carried out, it was found that occasionally there remains a substance which will not clear.

Miller (16) has noted this in mammalian embryos, and similar patches were found in chick embryos by the writer. In the latter case these were located in the neck, alongside of the vertebrae, and along the ventral wall of the stomach.

The Dawson process falls into three stages:

1.- Clearing by KOH
2.- Staining
3.- Infiltration with glycerine

Clearing by Potassium Hydroxide is carried on in two definite steps. Firstly, before staining, the specimen is placed in a solution of KOH in water, and left there until the tissues have undergone the action of the alkali and reached such a point that they will not take up the stain; and secondly, after staining, the specimen is placed in a mixture of KOH, glycerine and water, (Mall's solution), both to complete the clearing and to form the first stage in the glycerine series.

The conditions under which the process is carried out may be varied to a great extent, depending upon the type of preservative, the delicacy of the specimen, and the amount of time available. Depending upon the strength of the KOH solutions employed, the length of time during which they are allowed to act, and also with the frequency with which the solutions are changed, so may the clearing process be speeded up and the best results be still obtained. The majority of writers, (Schultze, Mall and Strong), recommend strengths of KOH from 1% to 3% for the clearing of material preserved in alcohol, and Mall recommends a strength of 10% for formalin preserved material. It has been found best to stay within this range, solutions in excess of this usually producing maceration too easily. It is obvious that the greatest speed is produced by leaving the specimen in the stronger solution as long as is safe, since clearing will proceed very slowly in Mall's; but the danger in this is that the process may go so far that maceration will set in, and once this has started a good preparation cannot be obtained. The case is the same where it is attempted to clear alcoholic specimens in 10% KOH. On the other hand, when the specimen is small and delicate, e.g., fish larvae, it is best to reduce the time in this stronger solution to one of hours only. All that is required is to leave the specimen until the tissues have undergone sufficient change not to take up the stain.

Obviously, it is almost impossible to give any criteria by which the length of time in this solution can be determined. In the case of large objects, it has been found sufficient to leave them until any pigmentation has commenced to turn brown and fade; but in the case of small material, this is far too long, and it has been generally found sufficient to leave them only until they show a slight degree of transparency, about similar to that produced by clearing in Xylol. Mammalian embryos, and other forms in which some part is smaller than the rest, present their own difficulties in that the wrist and hands will proceed far more rapidly than the rest, and in such cases, it is necessary to control this stage with respect to such regions.

After the preceding treatment, the specimens are moved into the staining solution. Batson, (1), employed a staining solution of about 1:2000, and used this prior to clearing. However, he was employing the Spalteholtz method. He found that such a solution almost invariably ~~also~~ stained the tissues other than bone, and had to decolorize in acid solutions. Tönig's method was similar to this. Dawson recommends the use of 1:10,000 parts of stain in 1% KOH, and leaving the specimens in this solution until the bones were sufficiently stained. Apparently, he found that the bone would continue taking up the stain from weak solutions until eventually they were brilliantly colored.

I have been unable to obtain such results, and have found it far better to employ a stronger solution (1:2,000). Such a strength does not seem particularly liable to stain the tissues, and will give very brilliant results with only a short period of time. Subsequent to staining, the specimen is moved into Mall's solution. This is made up of water 79 parts; glycerine 20 parts, and KOH 1 part (by weight); and the specimen should be left in this until no further change takes place. All traces of pigment should have disappeared, the bones stand out clearly, and only the outlines of the viscera be visible. Large specimens, especially mammal embryos, will not attain this degree of clearness.

Both Mall (11), and Strong (17), advise transferring the specimen back into solutions of KOH from 3% to 5% in order to speed up this step; but the danger of maceration setting in at this stage is great; and also, the removal of glycerine from the tissues gives rise to the possibility of the specimen falling to pieces from its own weight. When it appears that Mall's solution does not seem to be taking any further effect, the final stage of running up to 100% glycerine may be undertaken. The glycerine both completes the clearing process, by introducing a medium of high refractive index into the tissues, and also, by its high viscosity, affords a support to the specimen. It has proven satisfactory to transfer specimens from Mall's into 50%, then 75%, 90% and finally into 100% glycerine by easy stages. 100% glycerine acts as the final mount~~ant~~, and in this the specimen has regained sufficient strength to allow of its being freely handled, dissected, if desired, and ~~it~~ may even be lifted clear of the glycerine without danger.

Observations may also be made upon the insertions of various muscles in transparent preparations. Even in a good preparation with the light cut down to a suitable degree, it is possible to make out much of the nature of simple cartilaginous structures; and with a still lesser degree of light, it is possible to observe the insertion of various ligaments into some of the bones.

Occasionally, usually with the smallest specimens, for some unknown reason, after several months, at least three, certain changes take place in some of the specimens and the muscles become apparent. In such cases, the specimen is generally ruined as a transparency; but, when used in conjunction with a good preparation, much information regarding the relation of muscle to various bones can be obtained.

In one case, where two specimens of the same size were taken through the treatment together, in the same receptacle, one of these specimens exhibited this change in a very short time, while the other, identical with it in all ways, both having been fixed together, and kept together all the time, has not yet altered although the two were prepared about a year ago.

There are several points to which special attention must be called:

1.- In all cases it is best to employ large quantities of solutions, and to make frequent changes. This applies especially in the earlier stages. Here, a dense fluid collects on the bottom of the vessel, and if this is not cleared away it will rapidly cause the specimen to become brown. For the same reason it is best to use fresh KOH each time, and also to turn the specimens over frequently. It is often best to change solutions twice daily. With careful observance of this it has not been necessary to employ any bleaching agent such as Mall (11) advises.

2.- While the objects are being cleared, they become extremely delicate, and if carelessly handled will fall to pieces under their own weight. This condition gradually becomes worse until the infiltration with glycerine is commenced. In some cases it is necessary to employ a cradle of glass-wool.

3.- Mammal embryos need to be skinned and eviscerated. Skinning can be best performed after the specimen has been stained, and then there is less danger of destroying any of the bones.

4.- Attention can again be called to the danger of maceration setting in. The onset is so rapid, and the course so extremely short, that specimens can be lost in a day. It is best guarded against by making the duration of the first stage in KOH as short as possible, and relying upon Mall's to do the greater part of the clearing.

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THE CHONDROCRANIUM:-

Serial sections of three larval stages, 1.0 cms., 1.4 cms., and 1.8 cms., were prepared at 10µ. The two earlier stages were stained with picronigrosin; the later, with Ehrlich's haematoxylin, and eosin. From these, four reconstructions of the chondrocrania of the two early stages were prepared, a lateral and a dorsal view of each, by the graphic method. This was done primarily to obtain a better working knowledge of the regional formations of the chondrocranium, than could be obtained from the transparent preparations.

An attempt is also made to point out the similarity between the development of the chondrocranium and the bony skull.

General Description:-

The two stages selected for reconstruction are significant in that they represent two important phases in the history of the chondrocranium, the earlier stage being one of formation; the later, of disintegration.

The floor is typically teleostean, being composed of fused trabeculae, (Tr^{ab}_{tr}; Fig.2), (trabecula communis), before the hypophysis, and paired parachordalia, (Par), behind it. The posterior end of the trabecula communis is split and the halves diverge about the basicranial fenestra, and so form the anterior and antero-lateral walls of the fenestra merging almost indistinguishably behind into the parachordals, which complete the posterior portion of the wall. The anterior end of the trabecula communis is broadened and forms the ethmoidal plate. The parachordals, on either side of the notochord, extend laterally to form the floor of the otic region, (Fig. 5).

The ethmoidal plate, (Eth.p. Fig.2), bears a dorsal, median ridge, (Mesethmoid, Mes. Fig. 10), and four lateral extensions, (paired ethmoid cornua, (Eth.c.), in front, and paired ectethmoid processes, (Ecteth.), behind). (Fig.2).

The otic capsules, (aud.c), are attached ventrally to the ventro-lateral extensions of the parachordals, (Fig.5), and extend dorsally, enclosing the ear, to meet over the brain and so form part of the roof of the chondrocranium, (tectum synoticum), (t.s., Fig.4). Posteriorly, they are fused with the postvagal, (pila occipitalis, (P.i. occ)), cartilages. These latter also meet over the brain and form the tectum posterius, (t.p. Fig.2). The anterior edges of the otic capsules are continuous with the reduced sphenoidal regions, (alisphenoid, post-orbital cartilages, (Fig.1 Post-orb.)). From the dorsal surface of this cartilage, two bars, ~~(Supraorbitals S.O.)~~, proceed forwards, looping over the eyes, and joined anteriorly with the posterior portion of the dorsal extensions of the ethmoidal plate, (Fig.3). Immediately behind the level of the pineal body, the two bars are joined, over the brain, by the epiphysial bar, (eph.b. Fig.1).

STAGE 1, (Figs. 1 and 2).

Ethmoid Plate:-

The anterior end of the trabecula communis is broadened out laterally to form the ethmoid plate, and supports the olfactory organs and the olfactory lobes. The ventral surface exhibits the anterior continuation of the ventral groove of the trabecula communis. The groove flattens out before reaching the anterior edge of the plate, (Fig.9), so that the ventral surface of the plate is slightly concave posteriorly, and flattens out gradually forwards. Two lateral extensions, the ectethmoids, extend outwards from the plate below the olfactory organs, and curve slightly upwards at their distal ends, (Fig.1). Prae-ethmoidal cornua are not yet developed; and the palato-pterygo-quadrate bar is not attached to the ethmoidal plate, but extends forwards below its lateral border, (Fig.9). The olfactory lobe extends just beyond the level of the ectethmoidal processes; and only a very short olfactory tract is present. Anterior to the olfactory bulb, there is a slight elevation of the mid-dorsal line of the plate. This is the mesethmoidal ridge, (mes, Figs.1 & 5), and is only slightly developed. The olfactory tract, (NI, Fig.2), is short, and passes directly into the olfactory organ. There is no cartilaginous olfactory foramen.

Trabeculae: (tr.⁶).

The trabeculae cranii are fused to form the trabecula communis, the condition found in the typical tropybasic chondrocranium common to the majority of the teleosts. Posteriorly, the two trabeculae are separated, and pass around the hypophysial fenestra, as previously described. Fusion of the two is complete at the level of emergence of the optic nerve from the brain. In the fused region, each trabecula is roughly elliptical in cross-section, each ellipse lying with its major axis in an oblique, dorso-ventral plane, so that the dorsal pole is more medial than the ventral. Fusion of the two trabeculae takes place along the contiguous margins, and the trabecula communis comes to be concave on the dorsal, and convex on the ventral, surfaces. As previously mentioned, this ventral groove is carried forwards onto the ventral surface of the floor of the ethmoid plate where it flattens out and terminates.

Parachordalia:- (Para.).

In this stage the parachordals do not entirely envelop the cranial end of the notochord, and a solid basal plate is not yet formed. Anteriorly, they are fused almost indistinguishably with the trabeculae, a slight, though sudden, change in size and in direction of the bars, forming the wall of the basicranial fenestra, may be taken as distinguishing the two portions of the basis cranii from each other.

Morphologically, the parachordals are divisible into two regions, (Swinnerton), an anterior mesotic region, principally concerned in the support of the ear, and auditory capsule; and an occipital, (post-vagal), region.

The post-vagal portion of the parachordals is applied to the side of the notochord, almost enveloping it anteriorly; but, posteriorly, tapering off against the dorso-lateral surfaces. Dorsally, the post-vagal region is confluent with the occipital region of the chondrocranium, (pila occipitalis). The anterior portion of the post-vagal parachordal is invaded by the saccular portion of the ear, forming the cartilaginuous recessus sacculi, (Rec.Sac., Figs. 1 & 5). The invasion has not proceeded far, in this stage. The emergence of N.x marks the anterior limit of this region, and also hinders the fusion of this portion of the parachordal with the auditory capsule.

The mesotic region is given over to the support of the auditory capsule. In this stage the fusion is not complete; and a large anterior basicapsular, and a smaller posterior basicapsular, fenestrae are present, (Ant.b. and Post.b. Fen., Figs. 1 & 2). The two fenestrae are separated by the large basicapsular commissure, (Mes.com., Fig.1), which is formed by the growth laterally of the ventro-lateral surfaces of the parachordals, the ventral growth of the auditory capsule, and the fusion of the two, (Fig.5). A stronger, anterior basicapsular commissure, (Ant.Com., Figs. 1 & 2), is also present, closing off the anterior end of the anterior basicapsular fenestra. A small growth of cartilage has taken place ventrally from the posterior edge of the otic capsule, in front of the emerging vagus nerve. This is also fused with the parachordal, and may be considered as a posterior basicapsular commissure. The anterior basicapsular fenestra is present below the ampulla of the anterior, vertical semi-circular canal, (Fig.6); the posterior, in the region of the utriculus of the ear.

Anterior to the mesotic basicapsular commissure, the parachordals become increasingly oval in section, and increasingly massive. Beyond the anterior end of the notochord, their section changes to a blunt-wedge-shape, the apex down, and obliquely inwards. The flat end of this wedge becomes extended dorsally and outwards to fuse with the anterior end of the auditory capsule, and form the anterior basicapsular commissure, (Ant.com.). This is the region of the greatest development of cartilage supporting the auditory capsule. In between the parachordals, anterior to the end of the notochord, is the posterior basicranial fenestra, (Post. Fen., Fig.2), distinguishable from the anterior, (hypophysial, (Ant.fen.)), in that it is filled with acrochordal tissue, (Figs. 6 & 7). The parachordals in front of the anterior commissure, rapidly assume an oval section, become more and more divergent, and then merge into the trabeculae.

The anterior region of the parachordals is considered as that part anterior to the anterior basicapsular commissure, (Swinnerton). A strong ridge, marking the anterior boundary of the ear, is present and extends up along the medial surface of the anterior basicapsular commissure. Immediately anterior to this ridge, the external rectus muscle crosses the parachordal.

<u>Auditory Capsule</u>: (Aud.caps., Figs.1 & 2), and its relations to the canals.

The auditory capsule is composed of a wall moulded about the lateral parts of the ear, and fused incompletely below with the parachordals. A shelf projects below the external horizontal semi-circular canal. There are three connections with the parachordals as mentioned above; a strong but narrow anterior commissure; a weaker, more extensive, mesotic commissure; and a small and weak posterior commissure.

The mesotic commissure is the most extensive of the three, and is connected with the greater part of the lateral wall, serving to protect the utriculus, (Fig.2). In form, it is a thin, cartilaginous plate. The anterior commissure is much thicker in section, though not very extensive, and is continuous with the anterior portion of the capsule. Its thickness appears to have been developed in connection with the articulation of the dorsal end of the hyomandibular cartilage with the under surface of the postorbital cartilage, (Fig.7), which is firmly fused with the anterior end of the capsule.

The posterior commissure is represented only by a small growth of cartilage from the ventral edge of the capsule between the foramina of the glossopharyngeal and the vagus.

The glossopharyngeal foramen has been formed by the growth of the ventral edge of the capsule,(Fig.2). Posteriorly, the wall is fused with the occipital arch, so forming the anterior, posterior walls and the roof of the foramen of the vagus. The floor of this latter foramen is formed by the dorsal surface of the recessus sacculi,(parachordal),(Fig.5).

The posterior and anterior portions of the capsule are moulded about the lateral surfaces of the anterior and posterior vertical canals, respectively. The posterior end of the wall is continued dorsally and ends in a flat plate forming an incomplete roof to the brain cavity, anterior to the tectum posterius, (Fig.5).

Running along the greater part of the wall of the capsule, medial to the external horizontal canal, there is a heavy ridge of cartilage, roughly rectangular in section and placed at an oblique to the horizontal plane,(Fig.6). The lateral angle of this ridge is continued below the external horizontal canal as a shelf, with its edge turned dorsally about the lateral surface of the canal, so that the canal is almost entirely closed in,(Fig.1). This plate is fused with the wall of the capsule both in front and behind. The dorsal edge of the rectangular cartilage is extended as the dorsal portion of the wall, and along with the ventral angle forms the wall of the capsule. The medial edge serves as a support for the two vertical canals. The anterior vertical canal passes along the medial, dorsal surface of this cartilage, which gradually extends more medially to form a small shelf. Anteriorly, in returning to the utriculus, the canal passes down between the plate and the wall of the capsule; and the plate is continued forwards, unattached at the anterior end, and lying medial to the canal.

The condition for the posterior vertical canal is very similar. The canal runs for a very short distance along the medial surface of the rectangular cartilage, and then loops over it; the cartilage becoming reduced to a small rod. The posterior continuation of this rod expands dorsally to form a vertical plate which is fused to the wall and appends from it, (Fig. 5). Posteriorly, the plate soon loses its attachment to the wall and continues back as a short, freely ending, rod of cartilage.

<u>Post-vagal region:</u> (Occipital), (Pil.occ.).

In this stage the occipital arch, (pila occipitalis), is complete, and each half meets in the mid-line above the medulla oblongata, so forming the tectum posterius, (t.p., Fig.2), which is the only portion of the roof formed; the tectum synoticum not having yet developed. The anterior portion of the pila occipitalis is fused with the posterior portion of the auditory capsule; and so forms the roof and posterior wall of the vagus foramen, (Fig.2).

The commencement of the backward growth of the tectum posterius has already taken place, and it ~~already~~ extends nearly as far back as the posterior end of the parachordal. N. spinalis I emerges over the postvagal portion of the parachordal posterior to the pila occipitalis, (N.Sp.I., Fig.1).

<u>Sphenoidal region:</u> (Post-orbital), (Post-orb.).

The anterior end of the auditory capsules are continued forwards into the sphenoidal, (post-orbital), cartilages. These are heavy, solid bars of cartilage, roughly, a right-angled triangle in section, with the apex dorsal and the right-angle at the ventral lateral corner, so that the lateral surface of the cartilage is vertical, (Fig.7). Anteriorly, the dorsal surface of the sphenoidal region tapers off and is continuous as the supra-orbital bars, (Fig.1).

From the median, ventral surface, a cartilaginous process (the prootic cartilage (Pro Com.) passes obliquely down and medially towards the parachordal. This bar separates the emerging roots of the trigeminal and facial nerves. In this stage it fails to meet with the parachordal.

Along the middle line of the ventral face is articulated the hyomandibular cartilage, its dorsal end fitting into a slight groove (Hy. Fig. 7). A fine canal piercing the body of the sphenoidal cartilage obliquely from the lateral to the medial surfaces, appears to indicate that this cartilage has been developed from an anteriorly projected portion of the face of the auditory capsule; and that the supra-orbital cartilages have been developed from the dorsal surface of this structure, and have, only later, become fused onto the antero-dorsal aspect of the otic capsules. The canal contains the otic branch of N. VII.

The hyomandibular muscles have their origin along the lateral, and medial, ventral angles of the sphenotic cartilage.

Supra-orbital bars:- (S.O. Fig.1)

The supra-orbital bars are present as anterior continuations dorsally of the anterior (post-orbital) cartilage of the auditory capsules in the form of vertical plates of cartilage. In proceeding forwards, these plates rapidly decrease in height, from the bottom up, until they assume a circular section, when they become twisted to extend out laterally in the horizontal plane, and assume an elliptical section. In the region of the epiphysis, they are converted into plates concave on their upper, convex on their lower, surfaces, and extend suddenly medially to meet the epiphysial bar (Fig.2). Anterior to this, there is a growth downwards of the medial edge (Fig.8); and still more anterior the bars become again rounded in section, and pass into an area of rapid chondrification.

The bars follow very closely the lateral outline of the brain, and lay in close relationship to it (Fig.2), at the same time bounding, though more remotely, the dorso-medial aspect of the eye.

<u>Epiphysial Bar</u>: (Ep.b.) (Fig.2).

The epiphysial bar is only poorly developed, and is represented by a small, irregular strip of cartilage connecting the supra-orbital bars over the brain with which it is in very close relationship being moulded to its outline, so that the bar itself is curved convexly. The bar is also curved in the horizontal plane, its junctions with the supra-orbital bars being more anterior than the center section. The anterior edge is concave, and closely applied to the posterior surface of the pineal body (Fig.1).

<u>Anterior myodome:</u> (Ant.myo.) and the oblique muscles.

Both an anterior and a posterior myodome are present in <u>Catostomus</u>. The anterior myodome in the adult (Fig.11) is present in the form of a canal running forwards from the anterior end of the orbit, dorsal to the parasphenoid. Laterally, the canal is expanded by excavations in the medial surface of the ventral portion of the prefrontals (ectethmoids); and two bony plates, medially projected, from this bone above the groove from each side, meet in the mid-line to form the anterior portion of the roof. The posterior portion of the roof is formed by an anteriorly projected plate, from the orbitosphenoid, below the brain, meeting with the posterior edge of the plates previously described. The oblique eye-muscles enter this canal, passing obliquely forwards to the mid-line, and take their origins from the dorsal surface of the expanded end of the parasphenoid, and from the walls of the canal. Several areas ~~([illegible])~~ where the bones do not meet are present. These are all completed by connective tissue membranes. A small blood-vessel (opthalmic artery?) penetrates between the two muscles on each side.

In the earlier stage, which was reconstructed, the condition is very similar (Fig.2). As the trabecula communis passes forwards, slightly anterior to the middle of the eye, the membrane forming the floor of the cranial cavity, becomes detached from it, and a canal is formed between the two, which extends as far forwards as the exit of the olfactory nerves from the cranial cavity where it is obliterated. The anterior portion of this canal is the anterior myodome, and is quite short. The superior oblique muscle seems to take its origin from the membraneous roof of the canal (the floor of the cranial cavity). The inferior oblique takes its origin from the dorsal surface of trabecula communis. Both origins are in the form of a flat, broad sheet continuous across the mid-line, and pass simply backwards and outwards to become inserted into the eye-ball above and below its equator.

Posterior myodome and recti muscles: (Fig.2).

The posterior myodome, developed in relation to the origin of the recti muscles, is a canal continued backwards below the brain-case to terminate blindly in the body of the basiocoipital. In the adult it may be readily divided into an anterior and a posterior portion. The posterior portion is extended into the body of the basiocoipital, below the cavum sinus impar, and its roof, walls, and floor are formed by this bone. The anterior portion has its roof formed by horizontal plates, projected medially from the prootic and meeting in the mid-line. These plates also form the floor of the cranial cavity for this region. The walls are formed by ventral extensions of the prootics, as vertical plates, and by the lateral edges of the parasphenoid, with which they meet. The floor is formed by the parasphenoid.

Immediately anterior to the middle of the horizontal plates of the prootic, there is a vertical elevation in the mid-line of the parasphenoid (Fig.11). This is connected dorsally with the prootics by processes which extend posteriorly and laterally from its posterior, dorsal edge, meeting with anterior continuations of the horizontal plates of the prootics which are extending forwards to meet with the alisphenoids.

This vertical pillar marks the posterior division of the two canals by bone. Behind this, the canals of either side are divided only by a vertical sheet of connective tissue, which reaches from the floor to the roof of the canal and extends its entire length.

The relations of the muscles to the canal are relatively simple. Only the external and the internal recti muscles are continued into the canal; the former extending its entire length, the latter taking origin on the parasphenoid, just posterior to the anterior edge of the prootic. The external rectus muscle has its origin on the basioccipital. Both of these muscles are contained in a connective tissue sheath, in which they can move freely. The sheath of the external rectus muscle also extends about the muscle down to the foot of the myodome, and passes laterally to that of the internal rectus. The inferior rectus muscle arises from the connective tissue between the top of the vertical pillar of the parasphenoid, and from the alisphenoid. There is also a second origin, the muscle arising from a part of the sheath of the internal rectus. The superior rectus has a very similar origin, in that it arises from the lateral edge of the parasphenoid, just anterior to the vertical pillar, and also from the dorsal surface of part of the sheath about the external rectus. The two latter muscles, in passing to their insertions, cross each other between the external and internal recti.

The commencement of this condition is found in the first specimen reconstructed (Fig.2), the superior and inferior recti muscles taking their origin from the floor of the chondrocranium, actually from the posterior ends of the trabecula communis, where the trabeculae are divided about the anterior basicranial fenestra. The external and internal recti muscles are already in relation to a definitely formed myodome.

The posterior myodome is well-formed, though its walls and roof are still mostly membraneous. The roof is formed solely by the membrane forming the floor of the cranial cavity; its floor, partly by the ossifying parasphenoid, mostly by connective tissue; and the lateral wall, by the prefacial commissure, and the emerging roots of Nns.v and vii (Fig.7). Posterior to this, the canal runs between the two anterior parachordals, and passes into the heavy acrochordal tissue of the interparachordal (posterior basicranial fenestra) space. M.rectus externus continues back along the floor of the space so formed, passes dorsally over the ventral tip of the prefacial (prootic) commissure, and the emerging roots of Nns.v and vii, into the canal, where it runs back between the hypophysis and the anterior parachordals, crossing over the latter just anterior to the mesotic ridge, and so comes to run along their medial surface, where the muscle flattens out into the horizontal plane to extend to the mid-line as a flat band traversing the posterior basicranial fenestra through the acrochordal tissue to the muscles' origin in the acrochordal tissue about, and just anterior to the tip of the notochord (Fig.2).

M.rectus internus has its origin nearer to the anterior end of the myodome, arising from the membraneous roof of the canal, and runs directly forwards to cross over the dorsal surface of the divergent, posterior end of the trabecula communis of its side, and then continues forwards immediately lateral to the trabecula communis. The emerging N.ii loops over this muscle, and appears to restrain it to the medial position (Fig.8). Immediately anterior to the optic nerve, the muscle is bent directly outwards and inserted into the eye-ball (Fig.2).

STAGE II - illustrated by Figs. 3 and 4.

The principal changes from the previous stage has been the completion of many regions, and the commencement of disintegration of the trabeculae and the parachordals.

A considerable amount of ossification, especially along the base of the skull has taken place.

Ethmoid Plate (Eth.p.).

The ethmoidal region has become completed; the ethmoidal plate having expanded underneath the olfactory organ, by a filling in of the angle between the ectethmoidal processes, and the lateral border of the anterior portion of the plate. So that now there is almost a complete shelf of cartilage below each olfactory organ, which is relatively much smaller than before (cf. Figs. 1 and 3). From each of the antero-lateral corners, a large ball-like cartilage has developed (ethmoid, pre-ethmoid cornua (eth.c.f.)) and the anterior end of the palato-pterygo-quadrate cartilage now articulates with them. The anterior portion of the brain has "retired" from the greater part of the dorsal surface of the ethmoid, and a large mesethmoidal elevation has been formed (Fig.10). This is present in the form of a vertical plate raised along the mid-line of the ethmoid plate, with the sides concave, and the dorsal surface rounded. Posteriorly, the dorsal surface is elongated by two bars of cartilage, which roof over the top of the olfactory foramen and meet with similar cartilaginous rods, the anterior ends of the supra-orbital bars, and the dorsal ends of the planum antorbitale. From the posterior surface of the ectethmoids, a bar passes outwards, upwards and slightly backwards to meet with the end of the supra-orbital bar of that side. The foramen closed off by the latter bar (Pl.ant. Fig.3), and the one from the mesethmoid, is the olfactory foramen, a portion of which is also present on the floor (solum nasi) of the ethmoid plate. The ventral groove, is still present on the ventral surface of the floor of the ethmoid plate.

Trabeculae (Tr.).

The trabeculae are practically the same as described before. The principal change is the disintegration of their connection with the parachordals, and they now present posteriorly two relatively shorter, split ends.

The superior and inferior recti muscles remain attached to their posterior ends. The ventral poles of the anterior elliptical portions are much further developed ventrally.

Parachordalia: (Para).

Ossification of the parachordals has already commenced. Posteriorly, the sacculus has invaded, and expanded, the ventral part of the parachordal to form the large recessus sacculi (Fig.3). A more dorsal portion of the parachordal remains untouched by the sacculus, and tapers off posteriorly along the dorso-lateral surface of the notochord (P.para. Fig.3).

The cartilage, applied against the lateral aspect of the notochord, and forming the medial wall of the recessus, is replaced by bone. This has also taken place to some extent in the roof, and median portion of the floor; and, in the region of the foramen N. ix only the lateral wall remains unossified. Anterior to the ductus transversus, which joins the two sacculi over the notochord, a feature of the Plectospondyli, in the region of the glossopharyngeal foramen, the parachordals are unossified, meet over the top of the notochord, and rapidly become massive, increasing in size as the notochord diminishes, until they come to form the strong cartilaginuous, basal plate (Bas.p. Fig.4), laterally continuous with the auditory capsules. The middle region of this plate (pronotochordal plate) forms the roof over the myodome (interparachordal space). The walls of this space are formed by two ventrally directed ridges, on the under-surface of the basal plate, which represent the original parachordals. The floor is formed by the parasphenoid. The branchial skeleton articulates with the ventral edge of these ridges. The pronotochordal plate becomes free from the parachordals and is continuous forwards a short distance between them, to terminate behind the pituitary fossa (Fig.4). Anterior to this, the parachordals extend forwards a short distance to end abruptly after having diverged slightly about the posterior portion of the hypophysial fossa.

The fusion with the auditory capsules is practically complete, and the anterior and posterior basicapsular fenestrae are almost obliterated. The posterior basicapsular fenestra is represented only by the foramina of the glossopharyngeal and vagus nerves which are separated by a strip of cartilage; the anterior, only by a small space where the anterior cardinal vein is pressed closely against the wall of the cartilage about the lower portion of the ear (hidden in Figs. 3 and 4 by the overhang of the articular facet for the opercular bone). No distinction can be made between the mesotic and the posterior basicapsular commissures. The anterior commissure is recognisable by the traces of the mesotic ridge, which is very small, and restricted to the dorsal surface of the parachordal (Fig.4).

<u>Auditory capsule:</u> (Aud.caps.) and relations of cartilages to canals.

Chondrification of the auditory capsules is completed. Ventrally they are completely fused with the parachordals; dorsally, the two capsules meet over the top of the brain and form a relatively extensive roof (tectum synoticum) (Fig.4). The relation of the canals and the cartilages surrounding them is very similar to the condition described in the earlier stage.

The external horizontal canal runs in a completed tunnel of cartilage open to the cranial cavity only at its anterior and posterior ends ~~only~~. This tunnel has been completed by the growth of cartilage up the sides of the canal from the upturned edge of the shelf described in the previous stage, and its fusion with the wall dorsally. The roof is also formed over the posterior vertical canal. The outer surface indicates the moulding of the cartilage about the canals (Fig.3).

The anterior and the posterior basicapsular fenestrae are obliterated, as mentioned, by the downward growth of the ventral portion of the wall, and its fusion with the parachordals. The only remnants of the posterior fenestra are found in the foramina of the glossopharyngeal and vagus nerves.

The mesotic ridge, which in the earlier stage followed the anterior basicapsular commissure, is very small in this stage, and principally confined to the dorsal surface of the parachordal (Fig.4). The mesotic, and posterior commissures are continuous and protect the lateral aspect of the ear by a thin sheet of cartilage.

At the level of foramen N.x. the lateral ~~region~~ wall of the capsule is thickened and slightly ossified in the region of the origin of the levator branchiae muscles (cf. Fig.5). Anteriorly, this thickening is continuous with a vertical plate of cartilage suspended from the inner side of the capsule medial to the posterior portion of the posterior vertical semi-circular canal, which pierces it further forwards as it comes to the lateral position. The plate immediately decreases in size beyond this point, until it is only a small ridge of cartilage on the inner side of the capsule. Prior to piercing this plate, the posterior vertical canal runs a short distance along the medial surface of the ridge just described.

Anteriorly, at the level of the return of the anterior portion of the external horizontal canal to the cranial cavity, the ridge expands ventrally to project slightly below the anterior vertical canal, and soon broadens medially to form a short shelf supporting the curve of the external horiz canal. The canal pierces the anterior end of the shelf which is continued forwards only by a short, small rod of cartilage on the medial side of the canal, unconnected anteriorly.

<u>Post-orbital cartilages</u>: (Post-orb.).

The condition of the post-orbital cartilages is very similar to that in the earlier stage.

The principal feature in the growth to this stage, has been the development of the prootic commissure into a flat plate separating the foramina of the facial, and the trigeminal nerves (Fig.3). The anterior cardinal vein passes medially to this commissure, entering onto the median surface of the cartilage by a notch formed in the angle between the top of the commissure and the cartilage forming the roof over the facial foramen.

There is no indication of any completion of this bar by its fusion with the parachordal.

Supra-orbital Cartilages: (S.O.) and epiphysial bar.

The anterior end of the supra-orbital bars, on either side, has chondrified as far forwards as the posterior end of the ethmoidal plate and is continuous with the posterior edge of the dorsal surface of the mesethmoid, having fused with a backward extension of the dorsal portion of that cartilage above the olfactory foramen, and also with the dorsal end of the upturned lateral portion of the ectethmoid.

The ventral plate, developed along the ventral surface of the supra-orbital bar to only a slight extent in the earlier stage, is now relatively much larger, and extends down a short distance below the dorsal margin of the eye. (Fig.3).

The epiphysial bar is still a curved bar, with the convex surface dorsal; but is relatively much larger. The pineal body having "retired" from the intimate position it held previously with the front of the bar, it has now been possible for ~~this~~ the latter to straighten out, and even to develop somewhat forward from the level of the fusion of the bar with the supra-orbitals. The posterior border is convexly curved.

Post-vagal region: (Pil. occ.).

The condition of the pila occipitalis is similar to that found in the earlier stage. Fusion with the posterior edge of the auditory capsule is more complete and is continuous onto the dorsal surface of the chondrocranium, so that the tectum posterius, and the tectum synoticum form a single unit (Fig.4). The tectum posterius is now extended back to the neural arch of the vertebral complex.

Myodome: and related structures.

The form of the anterior myodome is very similar to the condition found in the earlier specimen. The principal change has been in connection with the growth of the mesethmoid cartilage. The anterior end of the canal now runs beneath the posterior end of the mesethmoid cartilage, which is separated from the ethmoid plate for a short distance, and overhangs the canal. The roof over the anterior end is also formed by posterior extensions of the planum orbitale, from its ventral edge (Fig.4). Between the blind end of the canal, and the region of origin of the muscles, there is a mass of connective tissue, bearing the same relation to the canal and the muscles as the acrochordal tissue in the posterior canal.

The chondrification of the walls, and roof of the posterior myodome, mark the major change between this stage and the preceding one. The roof is formed by the basal plate, and its anterior continuation in the form of a tongue. The walls are composed of the ventral ridges (parachordals) of this plate, and their anterior continuations, the parachordals about the hypophysial fenestra. The ossification of the parasphenoid forms the floor. Otherwise, the condition is similar to the earlier stage, though the canal is much longer.

ADULT SKULL:

The adult skull of Catostomus has not been completely described.

In general features, the neurocranium closely resembles that of a typical Cyprinid. The floor is formed by the basioccipital, parasphenoid, and vomer; the roof, by the supraoccipital, parietals, frontals and mesethmoid; the walls, by the epiotics, exoccipitals, prootics, pterotics, sphenotics, orbitosphenoid, alisphenoids, and the ectethmoids (Fig.11).

Of the bones forming the base of the skull the parasphenoid is the largest, extending from near the posterior extremity of the skull, forwards to articulate with the posterior, ventral portion of the mesethmoid. Posteriorly, it overlaps the anterior end of the basioccipital; anteriorly, it lays between the vomer and the ventral surface of the ectethmoids. Dorsally, it articulates with the prootic, orbito-sphenoid, and ectethmoid. Its anterior end interdigitates with the posterior end of the mesethmoid. The shape of the bone grades from a strongly, V-shaped bone posteriorly, to a flat, elongate plate in front, the transition occurring at the level of the front end of the prootic, where there are two lateral projections, one on either side, with which the pharyngobranchials articulate. In the mid-line, at this same level, there is a short, dorsal elevation on the parasphenoid, extending to the level of the base of the cranial cavity. The dorsal end of this elevation is slightly expanded and is connected to the anterior edge of the prootics by small bars of bone. Similar bridges join it to the alisphenoid. This elevation marks the anterior end of the posterior myodome, and the level at which the membrane, extending around the brain in earlier stages, is attached to the base of the neurocranium. The expanded foot of the orbitosphenoid rests on the dorsal surface of the anterior, flat plate of the parasphenoid, anterior to this elevation.

The basioccipital (Basi-occ.), is relatively complex. Posteriorly, it presents the usual facet for the articulation of the first vertebra.

Ventrally, it is continuous as two vertical, flat, triangular plates of bone, suspended by their apices on either side of the mid-line. The ventral edges of these plates are bent laterally, and curl up dorsally, to form a large, curved triangular bony plate (Mastic.), which is highly fenestrated. The posterior angle of this plate is continued back almost to the level of the anterior face of the transverse bony septum formed by the vertebral complex. The dorsal angle is connected, secondarily, to the basioccipital, just below the line of its articulation with the exoccipital, by a delicate bony bridge. This fenestrated, bony plate supports a horny pad against which the pharyngeal teeth act. The dorsal surface of the basioccipital is slightly excavated to form the floor of the cavum sinus impar (C.S.i. Fig.28). The body of the bone is itself excavated and serves as the posterior portion of the posterior myodome. Anteriorly, the basioccipital interdigitates with the parasphenoid; the dorso-lateral surfaces articulate with the exoccipitals, and to a very small extent with the prootic.

The vomer (Vo.), forming the anterior portion of the floor, is a triangular bone, with the apex situated anteriorly. The mid-line is convex, and the parasphenoid and posterior portion of the ventral part of the mesethmoid are contained in a groove formed on its dorsal surface. The base of the triangle is extended posteriorly in the mid-line. The lateral angles articulate with the ectethmoids. The anterior end, apex of the triangle, bears a lateral cup-like extension (Vo.cr.) on either side into which are fitted two balls of cartilage with which the palatine cartilage articulates. The dorsal surface, above this apex, is extended upwards by a plate of bone, which fits around the ventral projection of the anterior end of the mesethmoid, completing the outline of the anterior end of the skull.

The exoccipital (Exocc.), is a large, four-sided plate forming the most posterior portion of the wall of the neurocranium, and, in the absence of an opisthotic, is applied to the posterior and postero-lateral aspects of the ear.

The posterior portion forms the lateral border of the foramen magnum, and is continued dorsally, to form its dorsal border, by a narrow plate of bone which, on meeting its fellow, is turned posteriorly and continued back, forming an incomplete roof (Ex.br.) ~~of~~ over the spinal canal, to meet the anterior edge of the expanded foot of the neural plate. This formation almost excludes the supraoccipital from the dorsal margin of the foramen magnum.

The lateral surface of the exoccipital is pierced by the foramen N.x. Foramen N.ix is located between the prootic and the exoccipital. On the medial aspect, below the foramen N.x, a plate extends towards the mid-line, where it meets its fellow to form the roof over the cavum sinus impar. The plate does not extend beyond the anterior end of this canal, and the dorsal and ventral portions of the ear are connected through the gap between the anterior end of this plate, and the similar plates of the prootic. (Fig.13).

Posteriorly, the medial surface is slightly gouged to form the floor of the recess containing the posterior vertical canal.

Dorsally, the exoccipital articulates with the pterotic, epiotic, and the supraoccipital.

The prootic (Proot.), a five-sided plate of bone, forms the anterior portion of the lateral wall about the ear.

On its medial surface, it is grooved for the reception of the anterior vertical, and external horizontal canals, forming the floor of their recesses. A vertical plate, extending slightly into the cranial cavity, represents the anterior limit of the otic cavity.

A plate extended medially from the lower portion of each prootic forms the roof over the posterior myodome (Fig.13).

Slightly posterior to the anterior edge is the foramen N.vii. A weak bony bridge closes this off from Foramen N.v, which is present between the alisphenoid and the prootic, which meet above it and form the top and sides of the foramen.

The floor is formed by an anterior continuation of the medial plate which meets the alisphenoid.

In addition, the prootic articulates ventrally with the parasphenoid, and basioccipital; posteriorly, with the exoccipital; dorsally, with the pterotic and sphenotic.

The pterotic and epiotic form the postero-dorsal angle of the neurocranium, both extending onto the roof and the wall.

The latter (Epiot.), is a flat bone, circular in outline, with the usual processes for the articulation of the post-temporal. Present on the posterior aspect of the skull above the exoccipital, the epiotic roofs over the top of the curve of the posterior vertical canal, and articulates with the exoccipital, supraoccipital, parietal and sphenotic.

The pterotic (Pter.) is typical in having the large, posteriorly directed process, and in forming the posterior portion of the fossa in which the hyomandibular articulates. The medial surface, along with that of the sphenotic, is hollowed to receive the external horizontal canal.

A ridge, elevated on the dorsal surface of the pterotic, articulates with the lateral edge of a portion of the parietal which is lifted above the surface of the skull. The other, posterior edge of this plate of the parietal articulates with the dorsal edge of the epiotic, the latter also extended above the surface of the skull. The structure so produced forms a large, deep canal, the pterotic forming the floor and anterior wall; the epiotic, the posterior wall; and the parietal, the roof. M.levator arcus palatini posterius takes origin in this canal.

A small bone is present on the posterior angle of the skull, connecting the ventral surface of the pterotic process to the exoccipital. This bone could not be homologised with any element in the typical chondrocranium. It is not in relation with the ear, being shut off from the otic cavity by the exoccipital.

The sphenotic (Sphen.) is simple, forming the antero-dorsal portion of the wall about the ear. The medial surface is recessed for the anterior vertical, and portion of the external horizontal canals. The anterior portion of the fossa for the articulation of the hyomandibular is formed by this bone. By extending as two plates, it also forms the posterior portion of the roof of the orbit. The sphenotic articulates with the pterotic, frontal, alisphenoid and prootic.

The orbitosphenoid and alisphenoid form the wall of the neurocranium in the orbital region.

The alisphenoid (Alis.), is a simple plate of bone, filling in the region of the wall of the skull between the orbitosphenoid and prootic. Dorsally, it articulates with the frontal, and the sphenotic; and to a very slight extent with the prootic above and below the foramen N.v. The lateral surface is highly fluted.

The orbitosphenoid (Orbito.) is V-shaped in cross-section, with the foot expanded and resting on the parasphenoid. Each arm of the V is a plate, reaching dorsally, on either side of the cranial cavity, to articulate with the frontals above; the alisphenoid behind; and the ectethmoid in front. The ventral confluence of the two plates in the formation of the foot of the V, lifts the floor of the cranial cavity away from the parasphenoid.

The ectethmoids (Ect.) form the anterior portion of the wall of the neurocranium. Each is a curved plate of bone, with an expanded medial end articulating with the mesethmoid, frontal, and orbitosphenoid, above the anterior myodome; and the vomer, parasphenoid and mesethoid, below. N.i emerges through a space left between the anterior surface of the ectethmoid and the posterior surface of the mesethmoid. The dorsal portion forms the anterior section of the roof over the eye; the ventral, the solum nasi.

The mesethmoid (Meseth.) an unpaired bone, closes the cranial cavity anteriorly. It may be divided into a vertical and a horizontal portion. The vertical portion is expanded ventrally, articulating with the vomer, parasphenoid and ectethmoid. Dorsally, it is continued as the horizontal plate forming the roof over the olfactory organ.

The roof of the neurocranium is formed by the small supraoccipital, and parietals; the large frontals, extending laterally to form the middle of the roof over the eye; and to a small extent by the horizontal plate of the mesethmoid. A small fontanelle is present, extending from the anterior edge of the supraoccipital, forwards to the level of the middle of the eye, where it is closed by the meeting of the anterior portion of the frontals in the midline.

Ossification of the chondrocranium may be divided into three stages; the first, that involving bone formation on the base; the second, the formation of centers in correlation with the articulation of various elements to the chondrocranium; and finally, the third, the appearance of centers apparently forming in connection with the maintenance of the form of the head. In these respects, the course of development of the skull closely follows that of the chondrocranium, though earlier stages of the latter are needed to establish a completely identical course for both.

The actual details of bone formation will not be dealt with, having been thoroughly studied, in the closely similar Amiurus, by Kindred and Mc.-Murrich. The following description is concerned only with the order and regions of appearance of bone.

Ossification of the base of the chondrocranium commences with the appearance of two centers, the basioccipital and the parasphenoid.

The former first appears in the formation of a ring of bone about the anterior end of the notochord. Later, this center expands, invading the region of the floor of the auditory capsule.

The parasphenoid appears as a weak development of bone in the subtrabecular groove reaching from the level of the ectethmoidal processes back to end as the floor of the basicranial fenestra. The formation of the lateral process for the articulation of the branchial skeleton coincides with the second stage.

The secondary centers are more numerous, appearing most markedly in the postorbital and the anterior regions in connection with the articulation of the hyomandibular (Fig.12).

The centers of the sphenotic and pterotic develop on the side of the chondrocranium; the former appearing along the anterior face of the post-orbital, and the ventral face of the root of the supraorbital cartilages, also extending slightly over their other surfaces; the latter develops on the surface of the portion of the auditory capsule surrounding the external horizontal canal.

In addition, ossification of the prootic commences principally on the anterior basicapsular commissure, also extending back over the antero-ventral portion of the capsule.

A second area, the posterior end of the chondrocranium, shows the formation of secondary centers in the development of the large exoccipital center. This appears principally about the postero-lateral portion of the wall about the ear, and also extends up the pila occipitalis onto the tectum.

Anteriorly, the center of ossification of the vomer becomes established below the ethmoidal plate in the anterior continuation of the subtrabecular groove (Fig.10. Vo.), in a similar fashion to the parasphenoid.

A mesethmoid center forms on the anterior face of the mesethmoidal cartilage, correlated with the development of the suspension of the premaxilla.

The epiotic and ectethmoids, which develop relatively late, belong in the second group (Fig.15).

The appearance of the third type of center is correlated in time with the expansion of the second centers over the surface of the chondrocranium (Fig.14).

The first of these to appear is the frontal (Fig.12), followed closely by the parietal and supraoccipital, soon leading to the formation of a bony roof over the cranial cavity (Fig.15).

The alisphenoid and orbitosphenoid belong to this last group.

The similarity between the formation of the chondrocranium and the bony skull has been pointed out. A comparison of Figs. 1 and 12 shows a remarkable similarity in the distribution of cartilage and of bone. The presence of bone in the occipital region, about the ventral and ventro-lateral aspects of the ear; in the postorbital region; and along the supraorbital bar, as well as the presence of bone along the floor of the neurocranium, closely resembles the distribution of cartilage in the early chondrocranium.

The second chondrocranium reconstructed compares in a similar fashion with the stage of the skull shown in Fig.14; the two representing further advanced conditions of the previous stages. Various modifications are introduced in the later skull through the adoption of specific features by the developing larva, e.g., the mesethmoid bone and vomer do not correlate very closely with the mesethmoid or ethmoid cartilages.

This similarity is also found in the ossification of the hyoid and branchial arch skeleton, where the cerato-element is the first to chondrify, and also to ossify (V.i., Figs. 16 and 17).

The Splanchnocranium and its Development:

The hyomandibular (Hyom.) is a rod-like bone extending from the dorso-lateral edge of the otic region ventrally and curving slightly anteriorly, to articulate with the symplectic and quadrate bones. The dorsal end is enlarged and bears three tubercles; the two most anterior articulate with the sphenotic, and the pterotics; the third, forms the facet with which the opercular bone articulates. A plate, partially closing the anterior end of the branchial chamber, extends medially from the anterior edge of the more dorsal portion of the bar. This plate is articulated with the metapterygoid by its ventral edge.

The separate symplectic bone (Sympl.) is roughly triangular in outline, the apex pointing down and forwards, and is situated in an elongate, V-shaped cut in the postero-dorsal portion of the quadrate. The dorsal edge, base, is in contact with the ventral end of the hyomandibular, and also with the metapterygoid. The posterior and anterior edges are firmly attached to the quadrate.

The quadrate (Quad.), the most ventral of the three bones attaching the mandible to the auditory region of the skull, has the typical form. The posterior edge continues up behind the symplectic to meet the foot of the hyomandibular. The dorsal surface posteriorly articulates with the metapterygoid; the anterior portion articulates with the pterygoid. A thin plate of bone (Ptery.) extends the anterior edge forwards.

The metapterygoid (Metapt.) is an extensive, vertical plate of bone; the dorsal portion bent medially to form the posterior portion of the incomplete bony floor of the orbit from which the large m.adductor mandibulae takes origin. The posterior edge is deeply grooved and is connected to the hyomandibular.

The pterygoid (Mesopt.) resembles the metapterygoid and forms the anterior portion of the orbital floor. It articulates posteriorly with the metapterygoid; ventrally with the anterior portion of the dorsal edge of the quadrate; and anteriorly, with the posterior extension of the palatine bone.

The latter bone is highly modified in connection with the peculiar form of the mouth. When viewed laterally, several prominent processes are seen; an antero-lateral, from which a ligament reaches forwards to the dorsal end of the maxilla; an antero-medial, which articulates with the vomerine cornu; and a large posterior process, articulating with the mesopterygoid and the pterygoid.

In the early larva (Fig.16), the hyomandibular, symplectic, palatine, pterygoid and quadrate bones are all represented in cartilage.

The hyomandibular cartilage (Hyom.cart.), appears to be continuous with the symplectic (Sympl.), the whole forming a rod, the ventral end of which is strongly bent anteriorly, and lays along the medial surface of the heavy quadrate cartilage. Dorsally, the bar is thickened to end as a broad, articular head, bearing three large tubercles, the anterior two (Ant.hyom.) for the articulation with the chondrocranium; the posterior, for the articulation of the opercular bone. The foramen N.VII is quite obvious. The articulation of the lateral end of the hyoid bar (interhyal ?), enables a distinction to be made between the hyomandibular and symplectic regions.

The palato-pterygo-quadrate bar extemds from the level of the posterior edge of the hyomandibular forward to articulate with Meckel's cartilage, as a broad, heavy plate of cartilage. Beyond this, it is continued by a slender process (Pal.cart.).

The lower jaw is formed by the typical Meckel's cartilage (Meck. cart.) in the form of a heavy, triangular plate, articulating by a groove in the base with the quadrate region of the palato-pterygo-quadrate cartilage. Anteriorly, the apex curves towards the mid-line, and is joined to its fellow by a ligament.

The centers of the ossification of this portion of the skeleton are well established in the second preparation, (Fig.17).

On the hyomandibular, an extensive formation of bone has resulted in the dorsal end of the cartilaginous rod, below the articular tubercles, becoming enveloped by bone. Bone from this center extends, partly over the facet with which the operculum articulates; and also, into the connective tissue which up to now has served as the origin of the m. adductor mandibulae, to form the medial plate of bone. The lower end of the rod, (Symplectic, Sympl.) also shows a distinct center. The quadrate cartilage has a development of bone in the "neck", behind the articular facet, also extending along the ventral and,anterior edges.

A small "metapterygoid" center is present on the dorsal edge of the palato-quadrate plate, remote from the more anterior pterygoid center.

The dentary (Dent.) is well established, enveloping much of the anterior portion of Meckel's cartilage. Posteriorly, the latter is also encased by the development of bone forming the articular. A distinct angular cartilage, already showing signs of ossification, is present and attached by a ligament to the anterior end of the interopercular.

The third stage selected (Fig.18) shows a very marked advance over the previous, the most interesting feature appearing in the formation of the hyomandibular bone separating the cartilage and the still cartilaginous articular facets.

The hyomandibular, interhyal and symplectic all converge to meet by cartilaginous tips. The symplectic is already situated in a deep groove in the quadrate.

The quadrate, metapterygoid and pterygoid are all well ossified. The latter two extend medially below the eye. The membraneous anterior plate (Ptery.) of the quadrate is rapidly ossifying.

The palatine cartilage has become ossified and shows the extreme modifications found in the adult. The articular facets are still cartilaginous.

The dentary is enlarged and shows much of the adult form. Posteriorly, it fuses with the articular. Meckel's cartilage also shows a fragmentation into two parts, articular and distal portions, similar to that found in the hyomandibular. In this case the two parts of the cartilage are separated by the formation of the articular bone.

The skeleton of the hyoid arch is typical. Laterally, each end is connected with the hyomandibular by a small interhyal bone, which also articulates by its medial end with the lateral end of the vertically flattened epihyal. The medial end of the latter, in turn, articulates with the ceratohyal. The other extremity of the ceratohyal is V-shaped, and in contact with the anterior and posterior portions of the hypohyal elements. The latter, present as two separate bones, articulates medially with the basihyal, and with the ventral urohyal.

The whole bar, in the adult, forms a strong, inflexible unit, movable only at the lateral and medial ends, and, in this respect, shows a marked variation from the subsequent gill-bearing arches.

~~As previously mentioned,~~ The branchiostegals articulate with the epi-, and cerato- hyal elements.

In the earliest preparation (Fig. 16), the arch is simple, being represented only by two cartilaginous bars: a small, poorly defined, lateral element (interhyal); and a longer, stronger bar, representing the undifferentiated epi-, cerato-, and hypo- hyal segments. The latter bar serves as the origin of the m.genio-hyoideus, and may be recognized accordingly as the fused epihyals (lateral) and the ceratohyal (medial) portions. The remaining medial end of the bar represents the hypohyal.

The interhyal is in contact with the junction of the hyomandibular and symplectic cartilages.

The basihyal is continuous posteriorly with the basibranchial, and is already expanded anteriorly.

Ossification first appears, about the time that the opercular bones commence to form, by the development of a ring of bone enveloping the ceratohyal portion of the bar; and, to a smaller extent, in the region of the anterior surface of the anterior portion of the hypohyal element.

(Fig.18), Slightly later, all the opercular bones being well established, ossification appears about the epihyal portion of the bar and the posterior portion of the hypohyal.

It is not until quite late that the interhyal cartilage becomes enveloped by bone; and even in the adult, a large portion of this element remains cartilaginous.

The urohyal develops in membrane directly to its adult form; the ossification of the anterior, articular facets occurs relatively late.

The condition of the skeleton of the branchial arches in the adult is similar to that of the late larva (Fig.20).

Four typical arches are present. A fifth arch is rudimentary and bears the pharyngeal teeth (Phy.dent).

Each typical arch has the usual segments, viz. pharyngo- (dorsal), epi-, cerato-, and hypo- (ventral), branchial elements. The pharyngobranchials are modified in the articulation of the arches to the base of the skull. The first and fourth are cartilaginous; the second and third weakly ossified. The first pharyngobranchial is small and joins the dorsal region of the arches to the lateral process of the parasphenoid. The second and third pharyngobranchials are rectangular and are pierced by nerve foramina (Fig.20). The second is situated between the enlarged dorsal end of the first epibranchial and the anterior face of the third pharyngobranchial. Its distal edge articulates with the medial end of the epibranchial of its arch. The third pharyngobranchial possesses a long anterior edge in contact with the posterior edge of the second. The shorter, distal and posterior, edges articulate with the epibranchial, and the fourth pharyngobranchial respectively. The latter cartilage is roughly triangular in shape, and a portion of the anterior side makes contact with the third pharyngobranchial. The base articulates with the epibranchial of the same arch.

A small cartilage situated on the posterior edge of the base of the fourth pharyngobranchial may represent a vestigial portion of the fifth arch.

The epibranchial of the first arch differs from the others in having the medial end expanded. This expanded end takes over, at least in part, the function of a pharyngobranchial. The epibranchials of the second, third, and fourth arches are similar. The second is larger than the other two.

Each of the epibranchials when viewed from in front shows a double curve. On the dorsal portion of this curve is a small, dorsal process for the insertion of the levator muscle of the arch.

The ceratobranchials of all four arches are similar in form, each being the largest bone in its arch.

The hypobranchials exhibit a gradation in size. The hypobranchial of the first arch is the longest, and is ossified; that of the second, intermediate between the first and third. The latter is very small and unossified. The hypobranchial of the fourth arch resembles that of the third.

The medial ends of the hypobranchials articulate with the basibranchial. The latter is mostly cartilaginous in the adult, having only two small ossifications, an anterior, between the articulation of the hypobranchials of the first and second arches; and a posterior, between the second and third.

The fifth arch is articulated ventrally with the posterior end of the basibranchial. Dorsally, it is connected to the ventral end of the fourth epibranchial by a rod of cartilage.

In the youngest specimen (Fig. 16) the branchial arches are very complete, only the ceratobranchials (Cerato.br), and the hypobranchial (Hyp.br) of the first arch being present. The lateral end of the ceratobranchials is in a state of rapid chondrification. The medial end of the second appears to be fragmenting to form the hypobranchial.

The basibranchial (basi.br) is unsegmented and continuous with the posterior end of the basihyal.

The rudimentary fifth arch is present. Ossification has commenced, enveloping the cartilaginous rod of the arch with bone; several teeth are formed.

Subsequent development leads to the addition of the dorsal elements and differentiation of the ventral (Fig.19).

The epibranchial and the pharyngobranchial cartilages are formed, and already exhibit rudiments of the adult form.

The first and last pharyngobranchials are present only in cartilage; the third has begun to ossify. The second is most peculiar in still being only procartilage.

Ossification of the epibranchials has commenced on all. Each bears to some extent the dorsal projection, over which bone is beginning to spread from the epibranchial center. The medial ends of the fourth epibranchial are elongated posteriorly by cartilaginous processes.

Hypobranchial cartilages have appeared between the medial ends of the three anterior ceratobranchials and the basibranchial. Ossification has commenced about the mid-region of the anterior two hypobranchials.

The basibranchial is separated from the basihyal, and shows two centers of ossification as found in the adult. The portion of the basibranchial, posterior to the articulation of the fifth arch, is distinct from the anterior portion.

The fifth arch is strongly ossified and bears many teeth, each set in a small cup. The typical flatness of the teeth is just developing. The cartilaginous rod, about which the bone is formed, is still present.

Later development rapidly leads to the condition found in the late larva (Fig.20), and in the adult.

The four common opercular bones, the operculum, preoperculum, sub-operculum, and interoperculum are present, as well as the branchiostegals. These bones serve to support the flap forming the flexible wall of the branchial chamber(Fig.18).

The operculum (Operc.), is an extensive, thin plate of bone supporting the greater part of the flap, and extends between the posterior border of the dorsal end of the hyomandibular and the anterior face of the cleithrum. It is roughly triangular; articulating by a facet on the apex with a tubercle on the posterior border of the hyomandibular. The apex bears a distinct process (Lat.pro.), which passes forwards laterally to the hyomandibular and into which the ligament of m.dilator operculi is inserted. The dorsal edge of the triangle is concave; the base, convex. The anterior border, which is vertical, is strengthened, being thickened into a ridge.

The preoperculum (Preop.), is an elongate, thin plate of bone, the ventral portion sharply bent forwards, filling an angle left between the front edge of the operculum, and the posterior border of the hyomandibular to which it is firmly bound. It is continued anterior to the foot of the latter, passing laterally to it and extending forwards, partly below the symplectic and the quadrate which it incompletely covers, almost to the level of the articular facet of the latter.

The interoperculum (Interop.) completes the remaining portion of the angle between the anterior border of the operculum and the branchiostegals. Anteriorly, it continues forwards below the symplectic and the quadrate, medial and ventral to the foot of the preoperculum, almost to the articular facet of the quadrate. The anterior end is connected to the angular bone of the jaw by a strong ligament.

The suboperculum (Sub.op.), also an elongate, thin plate of bone completes the area of the lateral wall of the branchial chamber between the ventral edge of the operculum, and the branchiostegals. In form, it closely resembles a large branchiostegal; but differs in that its anterior end is related to the interoperculum.

The branchiostegals (Br.) complete the ventral portion of the wall. Only three are present. The first articulates with the epihyal; the second and third, with the ceratohyal. The articular end of the third is rod-like and strongly bent inwards; the outer surface of this curved portion being in contact with the posterior border of the ceratohyal.

The operculum is the first of these bones to ossify, appearing in an early stage as a bony cup fitting over the posterior tubercle of the hyomandibular cartilage (Fig.16), and continued back into the developing opercular membrane as a short plate of bone.

No intermediate stage was found between the above and the condition illustrated in Fig.17.

In the latter, the opercular plate has become expanded considerably, and shows signs of very rapid ossification. The preopercular, interopercular, and subopercular bones are present and show similar signs of extremely rapid formation. The first branchiostegal is well formed; the second less so; and the third in the early stages of bone formation.

Subsequent development is slower and uniform.

The formation of these bones gives the impression that a sudden burst of ossification has taken place.

The mechanism of the jaws has been described by Edwards (6); and the external features, during the translocation of the jaws from the terminal position to the ventral, by Stewart (19).

The changes in the skeleton during this movement are illustrated by Figs. 17 and 18.

In Fig. 17, the premaxilla (Pm.x), is present as two irregular splinters of bone lying one on either side of the mid-line, along the edge of the mouth. These represent the ventral portions of the adult premaxilla. The maxilla (Mx.), also appears as an irregular body. The insertion of the m.adductor mandibulae(Lig.add.mnd.), into the latter marks it as being the anterior edge of the adult maxilla. A short, median, articular rod is present.

Subsequent differentiation of the palatine cartilage, and the formation of the rostral cartilages (Rost.cart.), carry the jaws away from the anterior end of the neurocranium. The down-growth of the lips is coincident with the ventral growth of the premaxillae. The maxillae rapidly assume the adult form.

In the strong ligament joining the premaxillae to the anterior border of the skull, a bony rod (Med.rod), develops.

Vertebral Column:

As in all Plectospondylous fish, there are three distinct regions in the vertebral column of Catostomus.

The most anterior of these, the "vertebral complex" represents the fixation of the immediately post-occipital vertebrae to the back of the skull, forming a stable unit enabling the function of the Weberian ossicles in isolation from the general body movements (Fig. 11). Behind this is the typical abdominal region, without a completed haemal arch, and with the basiventrals unfused to the centra (Fig. 30); and posterior to this again, the caudal portion of the column, with the completed haemal arch (Fig. 26), terminating in the peculiarly modified last vertebra, supporting the tail fin (Fig.34).

Between the two latter regions, there is a transition in form of the vertebral attachments. From the typical abdominal vertebra, with its distinctly separate basi-ventral (basal stump (Basiv, Fig.30)), bearing the head of the rib, there is a sudden change to vertebrae with the basal stumps fused to the centra (about vert. 23), and extending further laterally, carrying the head of the rib out with the tip.

With the termination of the abdominal cavity posteriorly, the basiventrals are able to meet in the mid-line, forming the haemal arch, and are continued ventrally, by ossification of the haemal spine, in the median, ventral longitudinal septum (Fig.23). A gradient in size and shape of the articular elements extends the full length of the vertebral column. The zygapophyses of the vertebrae immediately posterior to the vertebral complex are relatively immense in size, especially in the case of the anterior zygapophyses (Fig. 11). Proceeding posteriorly, there is a rapid decrease in size, until in the caudal vertebrae the zygapophyses are greatly reduced (compare Figs. 11 and 34).

This may be translated into terms of mobility of the regions of the body ~~[illegible]~~, when it is seen that the vertebrae of the anterior abdominal region, immediately posterior to the vertebral complex, also exhibit a tendency towards the immobility shown in the complex itself.

The anterior four vertebrae are, as stated above, highly modified in correlation with the presence of the Weberian ossicles, to form the "vertebral complex". The following description is of these bones in the adult (Fig. 11).

The first centrum (Vert.1) is highly compacted, and is present in the form of a thick plate of bone sandwiched between the articular facet of the basioccipital (Basi-occ.), and the second centrum ~~(Vert.2)~~.

The latter has lost its individuality, and is fused with the third centrum, the two together, forming a large, strongly constricted body, similar in appearance to a typical, constricted centrum. The fourth centrum (Vert.4) is also large, and highly constricted, and, excepting for its size is quite typical. The fifth centrum is the first rib-bearing centrum.

The only appendage of the first centrum is the scaphium (Stapes (Scaph.)), a scoop-shaped bone, circular in outline, with its concave face medial, articulating with the dorso-lateral surface of the centrum by a short process from its ventral edge. This is considered as being the modified neural arch of this centrum (Wright, etc.). The lateral portion of the posterior border of the first centrum is slightly indented, the transverse process of the second centrum articulating with the first in this notch.

The fused second and third vertebrae support the intercalarium (incus (Interc)), considered as being the modified neural arch of the second centrum; and the tripus (malleus (Trip.)), the transverse process of the third centrum. The second centrum also possesses a large transverse process, (Basiv.1), which extends into the lateral, longitudinal septum from the anterior edge of the body of the fused centra. The base of this transverse bar articulates with the dorsal edge of the anterior plate of the ventral appendage of the fourth vertebra. The intercalarium is present in the form of a slender, slightly curved rod, articulating medially with the dorso-lateral surface of the anterior border of the large body formed by the fusion of the second and third centra.

The tripus articulates with this large centrum immediately posterior to the base of the transverse bar. This element, forming the posterior bone of the Weberian chain, is triangular in shape, with the two sides concave, the base convex, and the posterior angle extended backwards to come into contact with the anterior end of the air-bladder. It articulates by its apex with the centrum.

Dorsally, the second and third centra retain their neural arches (Neuv.), each arch being an extensive bone fused with the dorso-lateral aspect of the centrum, and extending its full length. The dorsal edge of each of these arches is fused with the expanded foot of the neural plate, which roofs over this portion of the spinal canal. A lateral projection of each of these bones roofs over the canal containing the Weberian ossicles anteriorly, and posteriorly respectively.

The elements of the fourth vertebra are somewhat simpler. A similar dorsal arch is present, without the formation of the lateral plate, the plate laying close to the body of the centrum and fused with the dorsal portion of the ventral appendage of this centrum. The dorsal end of this arch supports the posterior end of the roof over the vertebral canal.

The ventral appendage (Pro.4) of the fourth vertebra is highly developed. It consists of a strong bone directed laterally, passing over the top of the space about the tripus, and turning ventrally to pass down the medial surface of the abdominal wall. Medially, from the upper half of this bone, a plate extends into the mid-line, where it over-laps its fellow. The dorsal portion of the plate slopes forwards below the tripus, and articulates with the base of the transverse process of the second centrum. So this appendage comes to form the incomplete roof, wall, and floor of the foramen through which the posterior end of the tripus passes. The medial wall of this foramen is formed by a small, thin, flat bone, a ventral continuation of the base of the basiventral, medial to the tripus. This latter bone is fused distally with the angle of the median, vertical plate, where it bends forwards. The distal end of the vertical bone is also expanded and interdigitates with its fellow.

As mentioned above, the roof over the spinal cord is formed by the expanded foot of a strong vertical plate of bone (Neuv. pl.), supported by the dorsal elements of the third and fourth vertebrae.

This plate is continuous anteriorly with a second bone, similar to the expanded foot of the former, but lacking the vertical plate. This anterior bone is attached to the front edge of the foot of the neural plate and by a weak bridge to the first centrum. The anterior border is notched, and the posterior extensions of the dorsal edge of the exoccipitals pass into this notch.

The first appearance of bone in the ossification of the vertebral column is the formation of a series of narrow rings about the anterior end of the notochord, posterior to the region later forming the basioccipital where an elongated ring of bone forms at the same time on the notochord, leaving only the tip free. More rings are formed rapidly behind these, until the entire length of the notochord is ringed. Each ring is separated from its neighbours by an intervertebral space (Int.a. Fig.21), at first relatively wide.

Even before this process of the ringing of the notochord is completed, ossification of the neural arches of the anterior vertebrae has begun. (Compare Figs. 21 and 27). Following the course of ossification in a typical vertebra, (the 33rd and 34th), possessing completed haemal and neural arches in the adult, it is found that after their first appearance each ring begins to expand slowly, enveloping more of the notochord, and the intervertebral space becomes correspondingly diminished. At about the same time that this encroachment on the notochord commences to slow down, ossification of the arches sets in (Fig. 22).

The neural (Neur.) and haemal (Haem.) arches are at first represented only by two pairs of short pegs of cartilage, situated on the dorsolateral, and ventro-lateral surfaces of the notochord, anterior to the spinal nerve. These, the basi-dorsal and basi-ventral elements, become ossified and are represented in the adult. The basi-dorsal and basi-ventral cartilages come to be present on the anterior edge of the osseous rings, and soon begin to ossify (Fig.22).

At first, their growth is simply dorsal and ventral respectively; but, with the onset of ossification, they commence to slope backwards (Fig.23) and their tips curve in towards the median line (Fig. 24). The base of each is at first circular in section. Soon afterwards, a development of bone, in the form of a vertical plate, from the anterior edge of the base of the dorsal elements converts the base into a thin plate from the anterior edge of which the anterior zygapophysis is formed (Fig. 25). These become opposed to the posterior zygapophyses of the immediately anterior centrum, previously developed from simple, vertical plates of bone the posterior edge of which growing backwards comes into closer relationship with the adjacent anterior zygapophysis. Growth of the two brings them into contact. Later, excepting in the case of the more anterior abdominal vertebrae, there is a slowing down of the rate of growth of the zygapophyses, and a corresponding decrease in their relative size in the adult skeleton (cf. Figs. 25 and 26).

Shortly before this, constriction of the centra has commenced, and in dorsal and lateral views, there is shown a bulging of the tissue of the intervertebral space (Figs. 23 and 24).

Further development is relatively simple. The rings appear to continue their encroachment on the intervertebral spaces until the latter become quite narrow. At the same time, strong constriction of the middle region of the vertebra begins and there is a gradual adoption of the typical hour-glass shape. (Fig.25). The tips of the haemal and neural arches come together in the mid-line, and the arches are continued ventrally and dorsally respectively, in the ventral and dorsal median longitudinal septa by ossification of the haemal and neural spines (Haem. sp. and Neur. sp. Fig. 25). In the abdominal region, the ventral arch is not closed. The basiventrals become ossified as lateral projections of the centra, and bear at their distal ends the heads of the ribs which have ossified before (Figs. 27 and 28), as cups of bone enveloping the distal end of the cartilage.

The ribs (Pleur. Fig.29) ossify in the medial portion of the connective tissue septa between the muscles. Ossification of the basi-ventral to form the basal stump (costiferous pedicle), takes place subsequent to ossification of the rib (Basiv. Fig.30). No cartilaginous precursor of the rib was found.

In the anterior region, the basal stump, as mentioned before is not fused to the centra, and is small. Posteriorly, the fusion of the stump to the centrum takes place early, and the extension of the stump, carrying out the head of the rib, occurs simply in the connective tissue in which the rib ossifies.

In a very early larval stage, it was possible to distinguish twelve very faint rings of bone on the notochord behind the future basioccipital region. Of these, the first four already showed a distinct size differentiation. The first ring, the smallest, being only half the size of any of the others; the second, was slightly larger, but not as long as any of the more posterior ones; the third, and fourth, were of almost equal size and about half as large again as the subsequent rings.

No intermediate condition was found between the above and the following stage where the complex is well established.

In the latter (Figs. 27 and 28), the first centrum (Vert.1) is smaller than the rest, and the ventral surface being shorter than the dorsal, the posterior face is sloping. No trace of a basiventral element is present; but dorsally, the very large, concave scaphium articulates by a small ventral process with a small cartilaginous tubercle (Art. cart. Fig.27), situated on the dorso-lateral surface of the centrum.

The second centrum (Vert.2) is slightly larger, and, having the bottom surface longer than the dorsal, the anterior face slopes in the opposite direction to that of the posterior face of the first centrum to which it is opposed.

A basiventral process (Trans. pro. 2 - Fig.28), is present and ossified as an elongate, flat plate extending into the lateral transverse septum. A short ventral process is already formed from the ventral surface of the proximal end of the process (Vent. pro.2 - Fig.28). The intercalarium articulates with a small cartilaginous tubercle on the dorso-lateral surface of the centrum, and extends laterally as a small, irregular rod of bone.

The third centrum differs from the preceding in that both articular facets are vertical. A neural arch (basidorsal) is ossified on the dorso-lateral surface, firmly attached to the centrum, and extended dorsally to contact with the base of the heavy cartilaginous, neural plate. The basiventral is present in cartilage, and articulates with the apex of the tripus. A slight constriction of the centrum has already taken place (Vert.3 - Fig.28). The tripus has assumed its typical form.

The fourth centrum is similar to the third, the articular facets are both vertical; and it has a neural arch (Neur.4). The basiventral element is firmly attached to the body of the centrum, and is already highly modified. Laterally, it extends as a rod of bone, over the tripus, terminating shortly afterwards. Attached to its lateral end there is a bone (Pro.4 - Fig.27), rapidly ossifying in membrane and comparable to a pleural rib passing forwards and downwards about the lateral surface of the anterior end of the air-bladder. A process (Med. pro. 4 - Fig.28) is also formed from the ventral surface of the proximal end of the basi-ventral. This latter bone extends directly ventrally, passing medial to the posterior end of the tripus, along the middle of the anterior face of the air bladder.

The roof over this portion of the vertebral canal is formed by a large mass of cartilage situated in the median,dorsal, longitudinal septum. (Neur. cart. - Fig.28). The base of this cartilage is confluent with the dorsal ends of the neural arches of the third and fourth vertebrae.

Seven centers of ossification are established, with an eighth developing later. Four of these, represent the expansion of bone from the bases of the neural arches, up the arches themselves and onto the base of the cartilage (Fig.28). The remaining three, are divided into two lateral centers, one on either side of the anterior end of the neural cartilage; and the third, a large median center developed over the dorsal surface of the posterior portion of the cartilage. The latter also extends dorsally into the septum by the formation of a median, vertical plate (later the neural plate).

In the above stage, the three ossicles are connected by a strong ligament (Lig. Fig.27), running from the anterior tip of the tripus to the lateral end of the intercalarium. From the latter, it extends to the lateral surface of the scaphium. The relations of these three elements are already the same as in the adult; the shape alters only slightly; but the relative size changes immensely. (Compare Figs. 28 and 11).

By applying pressure to the dorsal surface of the head, above the posterior fontanelle, in these preparations, it is possible to cause movement of the chain of ossicles. This is illustrated in Fig.27, where the right-hand ossicles are drawn in the normal position; the left-hand, in the position they assume when pressure is applied.

Further ossification of this region proceeds rapidly; especially in connection with the development of the basiventral elements. The lateral process of the second centrum expands further sideways, increasing simply in size. The ventral process, suspended from its base, extends down and slightly posteriorly in the form of a rod of bone with its distal end expanded. The latter comes into relation with the anterior surface of the anterior projection of the pleural rib of the fourth vertebra (Fig.29). The dorsal element, the intercalarium, does not change, excepting for the ossification of the basidorsal cartilage supporting it.

The pleural rib of the fourth vertebra becomes greatly enlarged, growing ventrally, and expanding medially towards the mid-line, so forming the large plate across the anterior end of the air-bladder. The two plates so formed, later meet in the mid-line, as described, and overlap. The medianly suspended rod from the proximal end of the basiventral becomes fused to this plate by its distal end and completes the bony circle about the tripus. The anterior surface of the bone is extended forwards by the formation of a plate, which articulates, and later fuses with, (Fig.30) the posterior surface of the distal portion of the ventral projection of the base of the transverse process of the second vertebra. There is a striking change in relative size of this latter rod between the condition in the larva and in the adult (Figs. 30 and 11).

The neural arches of the third and fourth centra become expanded by the formation of anterior and posterior plates. A lateral plate is also formed from the base of each, roofing over the canal containing the elements of the Weberian chain.

The neural plate increases in size. The two antero-lateral centers become expanded towards the mid-line, where their edges meet, forming a bridge of bone above the backwardly directed process of the dorsal surface of the ex-occipitals. The last center of ossification to develop, forms in the mid-line, between the anterior and the median ossifications. The partial fixation of the vertebrae immediately posterior to the complex, is brought about by the formation of large anterior and posterior zygapophyses. The latter develop normally; but the former are ossified in definite ligaments (Fig.29). The ligament joins the posterior edge of the neural plate to the anterior edge of the more proximal portion of the arch of the fifth vertebra; or in the case of more posterior arches, from the ~~tip~~ posterior surface of the immediately anterior spine to the proximal portion of the next posterior (Fig.29). So that it would seem that the large anterior zygapophyses are not strictly comparable to those of the more posterior vertebrae.

Median and paired fins:

In the early larval fish, median fins of local extent are not present; but are represented by an embryonic structure, the median fin-fold.

The median fin-fold commences mid-way along the back, and passes posteriorly around the end of the notochord, onto the ventral surface, running the whole way along the median, longitudinal line. On the ventral surface, it does not extend anterior to the anus; and is to be distinguished from the remnant of the yolk-sac, which is very similar to it in appearance, and structure, even being supported by horny rays. With later development, there commences a growth of local areas of the fin-fold, defining the adult, median fins.

The condition, on hatching, of the paired fins is quite different. The pectoral fins are formed, and are relatively immense, being used in the maintenance of balance; the pelvics are not indicated.

An essential feature of the morphology of the fin-folds, in connection with the formation of their skeleton, is that they represent out-pushings of the skin, and contain mesoblastic tissue. On the outer surface of this layer of mesoblastic tissue are formed the bony structures supporting the fin-membrane itself. The cartilaginous structures supporting the fin are formed inside this layer of connective tissue. In the early stage, throughout the greater part of the median fin-fold itself, there is a formation of delicate, horny fibres, which support it (actinotrichi). Coincident with the development of local areas of the fin-fold, there is a slight increase in size of these actinotrichi; but as the fin grows the actinotrichi do not develop rapidly in length, and are carried out with the growing edge of the fin (Fig.32). Their function of supporting the fin is then taken over by a new structure, the lepidotrichi.

The lepidotrichi (bony fin-rays) are paired similar structures, each developing on the surface of the connective tissue, as mentioned. Distally, the two opposed lepidotrichi become closely approximated; proximally, the feet by which each is articulated with the supporting skeleton of the fin are separated and each articulates with the side of a radial. In form, each lepidotrich is an elongated plate of bone, composed of many segments, each segment being rectangular with its long axis in the axis of the ray; and curved so that it presents a concave medial and a convex lateral face. Distally, the greater number of the rays, with exceptions as pointed out later, are branched, and are so enabled to spread over the greater increase in area found in the distal portion of the fins. Although the two lepidotrichi composing a ray are so closely approximated distally, nevertheless, each retains its individuality throughout its length, and may be readily separated from its fellow.

The rays of a region show a close correlation in length with the distance from the base to the edge of the fin along the axis described by the ray. The greater the latter, the greater the former, and the converse. This is also shown, at least in the stages prepared, in the length of the individual segments of a ray. If of two rays, one is the longer; then all its segments are longer, though the difference in length is often very minute. The most proximal, the foot-bearing, segment is the longest in a ray; and illustrates the same length differentiation.

This feature of rays, and their segments, has been developed during their growth. Growth of a ray proceeds closely with the growth of the fin, and is carried on, both by addition of more segments slightly longer than the more proximal, and also by a uniform growth of the segments already laid down.

Distal branching is brought about by the establishment of two plates per segment, in place of the one ordinarily formed; not by the division of existing plates.

Caudal Fin: (Figs. 31 ~~and~~ to 34).

The embryonic formation of the caudal region results in a structure in which the posterior end of the notochord, continued back in a straight line, supports, by actinotrichi, the posterior portion of the median fin-fold, which passes around it from the dorsal to the ventral surfaces. (Fig.31). Owing to the presence of the air-bladder, and the development of the head (Kyle, 12) the balance of the early larva is upset, and the head sinks. This places a new strain on the muscles of the back, as they endeavour to maintain the head in an erect posture. This strain, transmitted along the back, finally affects the posterior end of the notochord, resulting in its dorsal flexure (Fig.31). With this there is a consequent decrease in size of the epichordal lobe; the hypochordal lobe becoming the principal fin-membrane of the tail. It is in this latter region that lepidotrichi first appear.

The last vertebra of the vertebral column is highly modified in the support of the hypurals (Fig.34). It may be divided into two portions; an anterior, similar in form to the anterior half of a centrum and bearing a typical neural arch, with anterior zygopophyses but no spine, the latter being represented by a radial bone, connected to the dorsal ends of the arch by a ligament; and a posterior portion in the form of two elongated, thin plates of bone, laying along the sides of the old terminal portion of the notochord. The former portion supports mainly the hypurals of the lower, ~~lobe~~ and the latter, the hypurals of the dorsal, lobes of the hypochordal portion of the fin (Fig.33).

The primary ossifications of this region, appear in the formation of two ridges along the lateral aspect of the dorsal surface of the notochord (Uro. Fig.32). On the ventral surface, slightly later, ossification of the regions of articulation of the heads of the hypural cartilages takes place.

These two centres are soon joined by the formation of a ring of bone around the body of the notochord itself (Last.cent. Fig.32), extending back as far as the articulation of the head of the fifth hypural.

Occasionally, it is found to arise in two parts; the one, anterior, supporting the sixth, seventh and eighth hypurals; the other, the fifth. In this case, the two rings are joined only by the dorsal, longitudinal ridges.

From the anterior ends of the dorsal ridges, shortly after their ossification, the neural arch of the hemi-centrum (last vertebra) is formed, and soon develops the small, anterior zygapophysis, later to be lost.

The neural spines of the last two, sometimes three, vertebrae (Mod.neur.sp.) differ in their formation from the neural spines of the rest of the vertebral column being developed as cartilage bones. This is considered (Goodrich (7)), as being the result of the fusion of the radials of this region with the neural spine.

Two very common anomalous conditions are shown in Figs. 32 and 33. The condition shown in Fig.33 is the presence of three pairs of neural arches on the last hemicentrum. The most anterior is in very close relationship to the "spine" ossifying in cartilage above it. The second and third processes are remote from the single cartilage (Rad.) above them.

There is no corresponding anomaly on the ventral surface, and this can only be taken as a demonstration of the diversity of the formation of the neural arches, commonly found elsewhere in the vertebral column, and not as an indication of the inclusion of another vertebra into the last hemicentrum.

The total number of vertebrae in this case was the typical 46.

The second anomaly (Fig.32), is interesting in that there is the formation of a neural arch and spine without a corresponding formation of a centrum, or a haemal arch.

In the adult (Fig.34), there are eight bones (hypurals) supporting, and connecting, the rays of the caudal fin between the two major rays (v.i.), of the hypochordal lobe to the axial skeleton. The most posterior, morphologically of these is the smallest, and is splint-like, lying just below the posterior end of the urostyle.

Along with the second, third, and fourth hypurals, the first does not articulate with the last bone. In form the second, third and fourth illustrate a gradient from the splint-like first to the elongate, plate-like form of the fifth. This last is firmly attached to the last centrum, in the angle formed by the urostyle and the sixth hypural. The sixth, seventh and eighth are all flat and elongate, tending to be triangular in outline. The sixth is fused with the posterior end of the hemicentrum, as mentioned. The seventh and eighth are fused together at their proximal ends and attached to the ventral surface of the body of the last centrum.

A prominent, lateral wing is present on either side of the base of the eighth hypural. From the anterior face of the seventh and eighth hypurals, thin plates extend into the adjacent tissues.

The rest of the rays, i.e., the rudimentary rays, are supported by modified neural and haemal spines, mentioned before as being pre-formed in cartilage.

The hypural bones are formed by the ossification of seven, flat plates of cartilage (Hyp.cart. Fig.32). No cartilaginous precursor for the first could be found.

The hypural cartilages are laid down in a series, commencing with the more anterior. (Fig.31). The anterior three, those supporting the ventral division of the tail, are laid down in the early stages of the dorsal flexion of the notochord. The rest do not form till sometime later. The lack of a cartilaginous precursor for the first hypural may simply represent an abbreviation in development, similar to many of the membrane bones of the skull, Norman ('7).

At its first appearance, each cartilage is rod-shaped, later developing a knob-like, proximal end. Excepting for the first and second, which are irregular, the distal end grows rapidly and soon flattens to a vertical plate.

The proximal end expands into a large, flat articular surface in contact with the notochord. Immediately distal to the articular head, there is a constriction, circular in section (the neck). The cartilaginous seventh and eighth hypurals become proximally fused and firmly attached to the ventral surface of the last centrum. The sixth also becomes strongly attached to the last centrum, and so forms an angle with the urostyle in which the fifth becomes attached (Fig.33). The remaining cartilages show a slighter degree of relationship to the urostyle as they are posterior in position, so that of this group only the fourth is in any degree closely related to the urostyle.

Ossification of the hypurals takes place about the same time as it begins in the lepidotrichi and the centrum.

Bone first appears in the neck region of the more anterior hypurals, and spreads rapidly distally, leaving the growing distal edge free. Ossification of the articular foot occurs slowly, but is completed before that of the distal end. Fusion of the sixth to the last centrum does not take place until late.

The prominent lateral wing of the eighth hypural is formed by ossification of the proximal end of the hypural cartilage, which is attached to the centrum by two small rods of cartilage (basiventrals), one on either side, formed shortly after the hypural cartilage has chondrified between the latter and the notochord, and so does not form in the fashion of a typical haemal arch.

The first appearance of lepidotrichi is in the form of paired, long, flat, thin plates of bone (Fig.32), extending out towards the periphery of the fin, where they come into contact with the actinotrichi.

Growth of these rays is by the addition of further segments, and also by the growth of the previously formed segments.

Almost with the first appearance of rays, the hypochordal lobe takes on the typical homocercal lobation; and the rays may be distinguished as those supporting the ventral and the dorsal lobes of the hypochordal fin, and an intermediate, the central region. The rays of the central region, from their inception, grow slower than those of the two other regions, although appearing at the same time.

Two rays (Maj. ray), one at the border of each lobe, become much larger than the rest, and are also distinguished by a failure to branch. The one, in the dorsal portion of the fin, is relatively constant in its direct articulation with the urostyle; the other, not so constant, may articulate with the haemal spine of the last typical vertebra, or with the last hypural. Each of these rays is longer than any other and also thicker in section. Between the two, there is a gradient in size and the shape of the articular feet grading to the opposite condition, found in the rays of the center portion of the fin. The feet of the major rays differ from those of the more central in that they are longer and more slender, and also lack prominent lateral tubercles developed for the insertion of the fascia in which the myomeric muscles terminate.

Dorsal fin (Figs. 35 ~~and~~ to 38).

The dorsal and anal fins become distinct from the longitudinal fin-fold at about the same time; the former arising slightly before the latter, and developing much faster, its component parts become differentiated earlier.

The typical radial of the dorsal fin of the adult is composed of three parts: a proximal (Pro.seg. Fig.38), dagger-shaped portion extending down between the neural spines in the dorsal longitudinal septum; a shorter, rod-like, medial segment (Med.seg.) articulating with the distal end of the former; and a distal, globular segment, with a posterior process articulating with the medial process of the ray.

In the early larva (Fig.35), these elements are represented by two chondrifications; the more proximal corresponding to the proximal plus the medial segments (Prox.cart.), in the form of a vertical, slightly curved rod extending from the level of the base of the immediately anterior ray ventrally, back to the level of the foot of its own ray dorsally; and a distal segment corresponding to the distal segment in the adult, in the form of a ball of cartilage, which does not chondrify until slightly later than the proximal, and then forming as a ball ~~of cartilage~~ between the feet of the ray it later supports.

Ossification of the radial commences about the lower three-quarters of the proximal cartilage, as a ring, leaving the proximal tip free. A second center of ossification involves the remaining quarter, and is distinct from the first ring. The dorsal tip is also left free (Fig.37). These two centers do not fuse, and a fragmentation of the radial cartilage takes place forming the two more proximal segments of the radial.

Ossification of the distal segment differs in that two centers develop, one on either side of the dorsal surface. From each of these two centres, a rod of bone is formed, extending back dorsally to the medial process of the foot of the ray (Fig.37).

Later development is principally in the formation of bony plates on the anterior and posterior surfaces of each radial. These plates form first on the anterior radials (Fig.37), from the upper end of the ossifying proximal segment. The later growth of these plates gives the typical dagger-shape to the proximal segment.

The anterior two radials (Figs. 36 and 38) are peculiar in not possessing median segments. The first supports the rudimentary rays and the first segmented ray (Maj.ray). (Fig.36). The anterior plate of this radial is relatively immense, serving as the origin for the large, anterior erector muscle, the posterior plate is not developed. In the adult, the three anterior radials are firmly fused distally.

The first lepidotrichi appear in the middle of the future fin (Fig.35) and with later growth, extra rays become developed both before and after those first formed.

In the larva, the fin extends between the eighteenth and the twenty-fourth vertebrae; in the late larval stage, which is nearly the same as the adult, the fin extends between the fourteenth and the twenty-fourth, and a total of fifteen or sixteen lepidotrichi are formed (Fig.37).

Of these lepidotrichi, the first three, though sometimes only two, rays are rudimentary and unsegmented. These rays are firmly fastened to the first segmented ray, which is notable in not being branched. The subsequent rays are normal, excepting for the last two, which are complete rays differing from the rest only in that both articulate with the distal element of the last radial.

When first laid down (Fig.35) each ray possesses a distinct foot in the form of an expansion of the proximal segment. The feet articulate with the distal segment of the radial. The form of the foot, as the length of the ray itself, exhibits a gradient from the heavy, large, triangular plate forming the foot of the first segmented ray to the small expansion of the last. The feet of the rudimentary (unsegmented rays), also exhibit a definite form.

Each foot bears in some degree, three processes; a median, extending medially below the ossified posterior extension of the distal segment of the radial of the immediately anterior fin ray (Med.pro., Fig.38), and serving as an axis about which the ray rotates during erection and depression; an anterior (Ant.pro.) in the form of a tubercle, extended slightly laterally from the anterior end of the foot and serving for the insertion of the erector muscle of the ray; and a posterior (Post.pro.), an extension of the posterior angle of the triangular foot to form a process into which the depressor muscle is inserted (Figs. 36 and 38). In addition, there is also a ligament running from the anterior process back to the anterior edge of the dorsal surface of the ossification on the immediately posterior distal element (Lig., Fig.38). This latter apparently serves to prevent over-action on the part of the erector muscle.

It is further interesting to note that, although the more posterior rudimentary ray has a foot similar to that described (Fig.36), the erector muscle is inserted upon the anterior face of the ray itself.

<u>Anal fin</u>: (Fig.39)

The similarity of the osteology of the two median fins is remarkable.

The anal fin does not become differentiated from the median fin-fold until about five rays are developed in the dorsal fin, when the region of the median fin-fold between the vertebrae thirty-fourth and thirty-eighth commences growing rapidly, and chondrifications of the radial cartilages commence. This region develops immediately behind the anus, and as usual is only supported at first by actinotrichi. By the time that six radials have been formed, the osseous rays begin to develop. These first develop in the middle region of the future fin, at about the same time that the distal segments of the anterior radials commence to chondrify as small balls of cartilage situated between the feet of each developing ray.

With the development of one more radial, the adult number of seven is attained; and with the formation of lepidotrichi anterior and posterior to those laid down at first, the adult number of ten rays is arrived at. Of these rays, the last two share the greatly enlarged distal segment of the last radial. The first segmented ray shares the enlarged distal element of the second radial, which appears to be either fused with, or in very close relation to that of the first radial, with the two unsegmented rays.

By the time that the rays are present in their full number, the feet form three processes similar to those developed on the feet of the rays of the dorsal fin, which bear the same relations to the distal ends of the radials as in the dorsal. The depressor and erector muscles are similar in form, origin and insertion to the muscles found in the dorsal.

In the adult, the two anterior radials are fused distally.

From the posterior surface of the medial, and proximal segments of the last radial, a bony plate extends backwards into the septum (Ter.pl. Fig.39). Bridges (3) considered this to be the remnants of the radial which should have developed in the support of the last fin-ray. No cartilage corresponding to this plate was formed. A similar plate is attached to the last radial in the dorsal fin. Chondrification of the radials is similar in both fins. Ossification of the medial, or of the distal segments of the radials of the anal fin was not found in the series; but, in the late larval stage, the median segments are strongly ossified. The distal segment is not ossified even in this late stage. (Fig.39).

The first three radials do not possess a median segment.

In the last stage prepared, it is evident that the dorsal fin is much further advanced with regard to its ossification than the anal fin.

From the above description of the anterior rays and radials of the dorsal and anal fins of Catostomus, it would appear that they are highly developed, for the erection of the fin.

With this in mind, the simple experiment of separating the rays of the dorsal and anal fins to the base was performed on a specimen of N. cornutis, the medial fins of which are similar in essentials to those of the Catostomus.

At first, the anterior rays were separated from the rest of the rays of the fin, by careful division of the fin-membrane behind the major ray, in both the dorsal and the anal fins. Erection of the fin was very little impaired, though the anterior rays were brought more into the erect line, than were the rest. Later, it was possible to observe that the erect position of the posterior portion of the fin was not maintained; the fin would be erected to a maximum, and then slowly fall back into a semi-erect position. At the same time, the anterior rays would be erected fully and maintain that position.

Later, the anterior (rudimentary and major) rays were completely cut away. No further effect upon the erection of the fin was observed.

After several days, the fish carried the dorsal fin in the semi-erect position nearly all the time. The effect on the anal fin was not nearly so marked.

<u>Pectoral girdle and fin</u>: (Figs 40 - 43)

The pectoral girdle is divisible into two components; a primary girdle, formed by the ossification of a cartilaginous precursor; and a secondary girdle, formed in membrane.

In the adult, the primary girdle is composed of three bones (Fig.42), the dorsal scapula (scap.), in the form of a slightly curved, rectangular plate of bone, pierced by the readily recognizable "scapular foramen" (Scap.For.); the large, ventral coracoid (Cor.), a strongly curved plate of bone, articulating with the ventral border of the scapula; and a thin, curved, elongated plate of bone, the mesocoracoid (mesoc.), articulating ventrally with a tubercle formed by an elevation on both the scapula and the coracoid where they are in contact, and dorsally, with the scapula alone. The curved mesocoracoid loops over the m. adductor profundus.

The medial surface of the primary girdle articulates in a groove along the posterior aspect of the coracoid of the secondary girdle.

The radials articulate with the lateral edge of the primary girdle, by special "glenoid" facets. The most lateral facet serving for the articulation of the enlarged, first ray of the dorsal set, is located entirely on the scapula. The more medial facet is situated on the combined edge of the scapula and the coracoid, at the point of their contact.

The secondary girdle is composed of a series of three bones, the two most dorsal being in contact with the skull. The third, the cleithrum, is by far the largest, and supports the primary girdle.

The cleithrum (Cl. Fig.43), the most ventral element, extends from behind the skull downwards behind the branchial chamber, forming the posterior wall and the posterior portion of the floor of this chamber. This formation is brought about by the presence of two plates. The one plate (Ant.pl.), lays below the posterior end of the chamber; the other extends laterally to form the posterior border. The primary girdle articulates in the groove formed by the junction of the posterior and the anterior plates.

The supra-cleithrum (Sup.cl.), the second element of this girdle, is situated at the dorsal end of the cleithrum, and articulates with it. Dorsally, it articulates with the post-temporal, and also the pterotic process. In form it is a rod of bone with a deeply grooved posterior surface. The dorsal end of the cleithrum rests in this groove.

The post-temporal (Post.t.), usually a Y-shaped bone, is present in Catostomus, only as a small, curved splinter of bone, extending between the dorsal end of the supra-cleithrum, and the epiotic process of the skull.

A fourth element, the post-cleithrum (Post.cl.), is also assigned to this secondary girdle. It is present as an elongated rod of bone extending back in the septa above the base of the fin. Anteriorly, it articulates with the posterior plate of the cleithrum, by an expanded foot.

Ossification of the primary pectoral girdle does not commence until relatively late, bone first appearing in connection with it at about the time that the post-temporal of the secondary girdle begins to ossify.

The primary girdle is, however, early represented by a definite cartilaginous formation. In the youngest specimen (Fig.40), it is present in the form of a Y-shaped cartilage, articulated by the tip of one limb (Scap. cart.), with the posterior surface of the dorsal portion of the cleithrum, and by the tip of the tail-piece (Cor.cart.), with the posterior surface of the transverse foot. The third limb extends posteriorly below the base of the fin.

The surface of the angle between the tail-piece and the dorsal limb is not in contact with the cleithrum. A large fenestra is present at the junction of the three limbs. The base of the fin lays along the full extent of the dorsally directed limb.

Subsequent growth leads to the filling in of the space between the cleithrum and the anterior, vertical surface of the structure just described (Fig.41). This growth also results in the formation of the scapular foramen. The angle between the two limbs is slowly filled, until the whole assumes a somewhat triangular shape.

The formation of a heavy, extensive plate of pro-cartilage (Procart. rad.), along the posterior surface of this triangular cartilage, carries the base of the fin back, away from the dorsal limb of the girdle. (Fig. 41).

Fragmentation of this latter "plate" begins, soon after it has become established, at the ventral border and proceeds medially. The fragmentation is produced by the formation in the plate of large, elongate fenestrae. The cartilage on either side of each aperture remains as the radial.

On the medial aspect of the coracoid, and scapular cartilages, two small, cartilaginous tubercles develop. These later become joined by a curved bar of cartilage (mesocoracoid bar). Shortly afterwards, ossification of this bar commences at the end in contact with the scapula, and extends rapidly over the bar, until the full length is ossified. This occurs before ossification of the scapula, or of the coracoid, is completed. (Fig.43).

Ossification of the scapula, and of the coracoid begins at the same time at the posterior surface~~s (in contact with the radials)~~.

The ventral tubercles supporting the mesocoracoid, becomes ossified by extensions from both centres (Fig.42).

As in their formation from the cartilaginous plate, the lateral radials become ossified first; and ossification of the medial ones does not take place till much later (Fig.43).

The first ossification in the secondary girdle is that of the cleithrum notable in being the first ossification in the pectoral girdle, and one of the first two ossifications found in the development of the skeleton.

In the youngest specimen, the cleithrum is represented by a vertical rod of bone formed in the first myoseptum (Myos. Fig.40)* behind the occipital region of the skull. The ventral end of this bar is bent sharply in and downwards to approach its fellow below the pericardial cavity. At the same time, the ventral portion curves slightly forwards. Ossification in this early stage is present only in the region of the base of the fin.

The form of the bar soon becomes altered by the extension of several plates of bone into the surrounding connective tissues (Fig.41). From the posterior surface of the ventral half of the vertical portion of the bar, a plate of bone (Post.pl.), extends back in the vertical plane. From the anterior surface of the lower portion of the cleithrum, and from the anterior surface of the foot, a plate is formed extending below the posterior portion of the branchial chamber (Ant.pl.). The resulting formation appears as though a rotation of the bar had taken place.

Further development of the cleithrum involves mainly a continued growth of these plates, and their extension into the connective tissues, so forming the origin for the many muscles of this region. A posterior expansion of the ventral plate forms and roofs over the primary girdle.

Slightly later than the plates commence forming on the various surfaces of the cleithrum, the ossification of the second element begins. The supra-cleithrum (Sup.cl.), first appearing as a slender, flat rod of bone, extending between the posterior aspect of the auditory capsule backwards to cross the lateral surface of the cleithrum (Fig.41), later develops two plates, one extending ventrally, and the other, medially, forming an angle into which the dorsal end of the cleithrum later slips.

The dorsal end of the supra-cleithrum is at first in contact with the posterior edge of the auditory capsule. Later, with the development of the pterotic, the dorsal part becomes closely applied to the pterotic process, and in doing so becomes strongly curved.

The post-temporal is the last to ossify, appearing as a short, flat, elongated bone reaching from the epiotic process to the medial surface of the supra-cleithrum.

The peculiar post-cleithrum ossifies in membrane just above the base of the fin, and first forms, slightly after the time that the commencement of plate formation on the cleithrum occurs, in the form of an elongated strip of bone, not yet connected anteriorly. The formation of the foot is a later development, occurring shortly afterwards (Fig.43).

The rays of the pectoral fins differ in the nature of their articulation from the condition found in the median fins. In place of two similar sets of lepidotrichi, one on either side of the radials, there are two distinct types, a "posterior" and an "anterior" set.

The feet of the lepidotrichi of the posterior set are much the simpler, and terminate in distinct, strongly curved hooks, which bend into the base of the fin. The outer curve of the hook articulates with the end of the radial. There is also a flat, medial projection laying along the base of the fin from each foot.

The foot of the first ray articulates directly with the edge of the scapula, in a special glenoid facet. In addition, this lepidotrich is highly developed, and for greater part of its length extends around onto the dorsal edge of the fin. (Fig. 43).

The feet of the anterior set differ from that of the other set in that they are bent, not into the base of the fin, but along the surface. Each lepidotrich bears a large plate extending from the anterior edge of at least the proximal segment, into the fin over to the medial surface of the opposite lepidotrich. Rays first appear along the dorsal edge of the fin at the time that the post-temporal commences to ossify.

A very small ball of cartilage, a vestigial radial, lays between the feet of the first ray. Some time after ossification of the ray has taken place, this becomes fused onto the medial surface of the foot of the first lepidotrich of the posterior set, and forms the facet with which this ray is articulated to the scapula. The details of the fin musculature were not definable.

Pelvic fin:

The form of the adult pelvic girdle is relatively simple (Fig.47). It is composed of two similar bones, one on either side of the mid-line, only connected by the meeting of the medial ends of the transverse posterior portion (Pelv.b.).

Each half (basipterygium) of the girdle may be divided into two parts; the first, an anteriorly directed rod of bone (Pelv.pro.), extending from the lateral end of the transverse portion forwards and slightly medially; the second, a transverse, heavy bar of bone (Pelvic bar, pelv.b.), extending to the mid-line. The former does not meet its fellow; the latter, meets the medial end of the similar bar on the other side. The obtuse angle, formed between the bar and the process, is filled by a bony plate (med.pl.), which fragments distally and is continued forwards in the form of two fluted, plate-like processes.

These three units serve for the origin of the adductor, and abductor muscles of the fin.

The posterior border of the transverse bar is irregular, bearing several large tubercles distally, developed in connection with the articulation of the radials. On its dorsal surface, there is also a slight tubercle (Dors.tub.). The latter elevation serves for the insertion of a strong ligament which stretches across the dorsal surface of, and connects the two halves of the girdle holding them together.

Articulating with the posterior edge of the transverse bar, as mentioned above, are the radials (distal pterygiophores). Only three radials are present, the lateral two of a simple, somewhat ovoidal shape; and a third, a ball with the posterior surface elongated in the form of a rod.

The pelvic girdle first appears in the form of an elongate rod (Pelvic.cart. Fig.44) of cartilage on each side of the mid-line, situated at the base of each of the pelvic fin-buds. The anterior end of the rod is approximated to the mid-line; but slopes gently away from it as it proceeds posteriorly. The posterior end of this rod becomes expanded, and the broad, posterior face of this expansion is rapidly carried back to form a broad, flat plate, the posterior edge of which comes to support the early lepidotrichi. The actinotrichi of the early larval fin are supported by the lateral border of the pelvic process (Fig.44).

Rapid growth medially of the broad hinder end of the cartilaginous rod soon leads to the formation of a transverse bar (Pelv.b. Fig.45), and the developing lepidotrichi become restricted in their articulation to the posterior edge of this bar.

Ossification of the girdle commences slightly later than that of the lepidotrichi, and develops rapidly over the greater extent of the pelvic cartilage, leaving, however, the tips and outer edge of the angle of the bar free. (Fig.45). In addition, there is a rapid formation of bone in membrane, which forms a large plate (Med.pl. Fig.45) filling in to some extent the obtuse angle between the transverse bar and the pelvic process. This plate extends forwards rapidly and soon becomes divided into several smaller, thinner plates, the medial edges of which become coarsely serrated and meet, interdigitating with the similar formation of the other side (Fig.46). The three processes so formed (Pelv.pro., Pelv.b and Med.pl.) serve as the origin for the adductor and the abductor muscles of the fin.

The free, cartilaginous, medial ends of the transverse bars grow towards the mid-line, and at the same time become expanded posteriorly (Fig.46). The anterior portion of this expanded, medial end later serves as the articular surface in contact with the medial end of its fellow; the posterior portion of the expanded end becomes flattened, and plate-like, with the medial border serrated. The latter part serves for the insertion of the infracarinales muscle.

The lateral angle, formed by the medial development of the posterior portion of each bar, remains free from ossification for some time, and develops several tubercles. Ossification of this region commences with the formation of bone about the bases of the tubercles, and the slow covering of them, and of the outer edge of the angle, only as a somewhat later development. The median plate later becomes fluted by the extension of the plates into the connective tissue about each of the muscles. The long anterior rod becomes solidly ossified, and forms the pelvic process from the surface of which the long, and the short abductor muscles take origin.

Three radials form along the posterior edge of the transverse bar which is sculptured to receive them. The more lateral two (Radel.Rad.2 - Fig.41), are represented by simple, ovoidal cartilages, which lay between the feet of the lateral seven fin-rays. These two radials ossify very slowly, no signs of their ossification being found in any of the stages prepared; but in the adult, they are represented by two small bones, in similar relation to the feet of the fin-rays as in the larva.

The most medial, the third, radial (Rad.3), is to be distinguished from the preceding ones, both on account of the fact that it is the first to ossify and on account of its shape.

This radial first appears in the form of a ball of cartilage, from the posterior surface of which there extends, along the median edge of the fin, an elongation, in the form of a bar of cartilage (Fig.45). Ossification of this bar of cartilage soon commences (Fig.46), and is the only sign of ossification of the radialia found in the prepared specimens. The bone is later extended by the formation of several plates of bone along its sides.

The relations of this process of the third radial to the rays is similar to those of the "ilium" to the lateral surface, both extending along an edge of the fin.

The relations of the radials in the pelvic fin of the adult is similar to the condition found in the earlier stages.

A small, curved, somewhat rod-shaped bone, slightly heavier at the distal, than at the proximal, end, is present at the base of the lateral border of each fin. This bone (Ilium, Fig.45), is distinct from the fin-rays in not being paired in either fin. The proximal end of the bone generally extends into the myoseptum of the rib attached to the sixteenth vertebra; but is not attached, nor in contact with, the end of the rib. As the bone extends medially to the base of the fin, it is strongly bent, so that the distal portion comes to lay along the lateral border of the first ray (Fig.45). The bone lays quite superficially in the body wall, the medial portion passing laterally and posteriorly to the posterior end of the abductor longus muscle.

Ossification of the ilium is in membrane, and commences slightly later than the chondrification of the radials. The rays of the pelvic fin develop in the typical fashion.

In the adult, the rays show two distinct types, closely similar to those found in the pectoral fins. The two sets may be conveniently called "dorsal" and "ventral".

The foot of a laterally situated ray of the ventral set is strongly bent towards the mid-line of the body. At the angle so formed, a weak process is given off which extends into the base of the fin, articulating along the posterior border of the radial.. The border of the medially directed process is developed into a strong ridge into which the m. abductor brevis is inserted.

The feet of the rays forming the dorsal surface (dorsal set) do not exhibit such an acute angle of flexion; the foot is slightly longer; and the internally directed process is stronger, and articulates in the same way as the ventral set.

A gradient in size and form of the feet is exhibited in both sets, the maximum development being found in the feet of the more lateral rays. The feet of the inner, more medial rays are poorly developed in comparison to the condition of the lateral rays. In the ventral set, the median process is only present in the more lateral three or four rays. No absolute proof that the more lateral rays were the first to develop was found; but (Fig.44) in the case illustrated it would appear that this was so.

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Several microphotographs are included at the end of the figures. These were prepared by Mr. P. J. Croft, Secretary of the Montreal Camera Club, in the pursuit of his hobby. He has kindly consented to their inclusion in this thesis.

I am further indebted to Mr. Croft for the time and labour he has expended on the preparation of the photographs of the figures.

The first microphotograph is of the head of an early larva, 1.4 cms. stage, and shows clearly the distribution of bone in a skull of this size. Cf. Figs. 12, 17 and 19.

The second, and third show the skull and vertebral complex of a 2.0 cms. stage. The skull is shown in a focus slightly below the surface. Cf. Figs. 14, 15, 18, and 20. The third shows very clearly the relation of the modified rib of the fourth centrum to the anterior end of the air-bladder. Cf. Fig. 30.

S U M M A R Y:

1.- Two stages in the development of the chondrocranium of Catostomus commersonii are figured and described.

2.- A description of the skull and its centers of ossification is given.

3.- A close similarity is found between the formation of the chondrocranium and of the skull.

4.- The cartilaginous and bony splanchnocrania and the development of the latter are described.

5.- Ossification of the cartilaginous visceral arches is found to resemble their formation in cartilage. Both processes exhibit a serial development, differentiation commencing anteriorly.

6.- The vertebral column and Weberian apparatus and the ossifications of the two are given. The latter is typical in its formation from the elements of the anterior vertebrae.

Ossification of the vertebral column and subsequent differentiation commences anteriorly and spreads backwards.

7.- The skeleton and its ossification are described for the caudal fin. A serial development of the hypurals is found in both their chondrification and ossification, the anterior hypurals forming first.

8.- The skeletons of the anal and dorsal fin are typical. A detailed description is given of the nature of the feet of the rays and their articulation with the radial elements, and is found similar in both fins.

9.- The development of ossification in the radials does not follow the sequence of their chondrification.

10.- The skeleton of the paired fins and its ossification are described. A close similarity is found between the feet of the rays of both.

11.- Three radials are present in the skeleton of the pelvic fin.

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EXPLANATION OF FIGURES

The first four figures are reconstructions of the chondrocranium prepared by the graphic method. Many of the other figures were made from dissections.

In all figures, excepting the first eleven, stippling has been employed only to indicate the presence of bone. In the first four, it is used as shading.

All sketches of the transparent preparations were made in outline with a camera-lucida, and filled in under a binocular microscope.

Fig. I - Graphic reconstruction of the lateral aspect of the chondrocranium of a 1.0 cm. larva of C. commersonii. X 100.

Fig. 2 - Reconstruction of the dorsal view of the same stage. X 100.

Fig. 3 - Graphic reconstruction of the lateral view of the chondrocranium of a 1.4 cm. Stage. X 50.

Fig.4 - Reconstruction of the dorsal view of the same specimen as Fig.3. X 50.

Fig. 5 - Transverse section through the region of the posterior end of the auditory capsule of the 1.0 cm. stage. X 40.

Fig. 6 - Transverse section through the region of the anterior end of the auditory capsule of the same stage as Fig.5. X 40.

Fig. 7 - Transverse section through the post-orbital region of the same stage as Fig.5. X 40.

Fig. 8 - Transverse section through the middle of the orbital region of the same stage as Fig.5. X 40.

Fig. 9 - Section through the anterior end of the ethmoid plate of the same stage as Fig.5. X 40.

Fig.10 - Transverse section through the anterior end of the ethmoid plate of the 1.4 cm. larva. X 30.

Fig.11 - Lateral view of the adult skull, and anterior portion of the vertebral column. X $1\frac{1}{2}$.

Fig.12 - Lateral view of ossifying skull of early (1.4 cms.) larva. Surface view. X 30.

Fig. 13 - Formation of floor in otic region of a 1.4 cms. larva, dissected and viewed dorsally. The for. n. IX is incorrectly labeled. X 30.

Fig. 14 - Lateral view of the skull of a late (3.5 cms.) larva. X 15 surface view.

Fig. 15 - Roof of same stage as Fig.14, dissected and flattened X 15.

Fig. 16 - Splanchnocranium of a 1.1 cms. larva, dissected out and viewed dorsally. Flattened preparation. X 40.

Fig. 17 - Suspensorium, opercular apparatus, and hyoid arch of an early (1.4 cms.) larva. Dissected, flattened and drawn from the medial surface. X 25.

Fig. 18 - Suspensorium, opercular apparatus, and hyoid arch of a 3.4 cms. stage. Dissected and flattened, Medial view. X 12.

Fig. 19 - Visceral arches of 1.4 cms. larva. Dissected, flattened, and viewed dorsally. X 25.

Fig. 20 - Visceral arches of a 3.5 cms. stage. Dissected, flattened, and viewed dorsally. X 10.

Fig. 21 - Lateral view of the thirty-third and thirty-fourth vertebrae of a 1.4 cm. larva. X 45.

Fig. 22 - Lateral view of the same vertebrae in a 1.4 cm. slightly more advanced larva. X 45.

Fig. 23 - Lateral view of the same vertebrae in a 1.6 cm. larva. X 20.

Fig. 24 - Dorsal view of the same vertebrae shown in Fig. 23. X 20.

Fig. 25 - Lateral view of the thirty-third and thirty-fourth vertebrae in a 2.0 cms. specimen. X 20.

Fig. 26 - Lateral view of the thirty-third and thirty-fourth vertebrae of the adult, showing the relative size of the various elements. X 2.

Fig. 27 - Dorsal view of the anterior vertebrae of an early 1.4 cm. larva. X 60.

Fig. 28 - Lateral view of the same region shown in Fig.27. X 60.

Fig. 29 - Lateral view of the same region in a 1.6 cm. larva. X 60.

Fig. 30 - Lateral view of the anterior region of the vertebral column in a late larval stage (2.0 cms.). X 18.

Fig. 31 - Lateral view of the elements of the caudal fin of a 1.1 cms. larva. X 45.

Fig. 32 - Lateral view of the caudal fin of a slightly later stage 1.4 cms. X 45.

Fig. 33 - Lateral view of the caudal fin of a 2.0 cms. specimen. X 20.

Fig. 34 - The terminal vertebrae supporting the caudal fin of the adult. X $1\frac{1}{2}$.

Fig. 35 - Lateral view of the early dorsal fin found in a 1.6 cms. larva. X 25.

Fig. 36 - The anterior radials and rays of the late larval, 5.1 cms., specimen. X 10.

Fig. 37 - The dorsal fin of a 2.5 cm. larva. X 18.

Fig. 38 - The radial and eighth ray of the dorsal fin of the 5.1 cms., specimen. X 20.

Fig. 39 - Anal fin of the late larval stage (5.1 cms.). X 12.

Fig. 40 - Lateral view of the pectoral fin and girdle of a 1.1 cms. larva. X 90.

Fig. 41 - Lateral view of the pectoral girdle and fin of a slightly later larva (1.4 cms.). X 45.

Fig. 42 - Postero-dorsal view of the primary girdle of the adult. X $1\frac{1}{2}$.

Fig. 43 - Pectoral girdle and fin of the late larval stage (3.5 cms.) viewed from above. X 25.

Fig. 44 - Ventral view of the early pelvic girdle and fin in a 1.7 cms. larva. X 45.

Fig. 45 - Dorsal view of the pelvic fin and girdle of a 2.0 cms. larva. The dorsal lepidotrichi of the left fin have been removed to expose the radial cartilages. X 45.

Fig. 46 - Dorsal view of the pelvic girdle and fin of a 3.5 cms. larva. The lepidotrichi forming the dorsal set of the left fin have been removed. X 25.

Fig. 47 - Dorsal view of the pelvic bone (basipterygium) of the adult. X 1.

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INDEX TO FIGS. 1 - 10:

Ant.b.fen., anterior basicapsular fenestra; A.c.v., anterior vena cava; Ant.com., anterior basicapsular ~~fenestra~~ commissure; Ant.fen., anterior basicranial fenestra; Ant.myo., anterior myodome; Ant.vert., anterior vertical semicircular canal; Aud.caps., auditory capsule; Bas.p., basal plate; Cer., cerebellum; Dien., diencephalon; Ect.eth., ectethmoid process; Eph.b., epiphysial bar; Eth.cr., ethmoid cornu; Eth.p., ethmoidal plate; Ext.horiz., external horizontal semicircular canal; Ext.rect., m. external rectus; F.b., fore-brain; Inf. rect., m. inferior rectus; Int.rect., internal rectus muscle; I.ob., internal oblique muscle; Lat.wall., lateral wall about the external horizontal canal; Lev.br., levator branchiae muscle; Med.p., cartilage plate medial to the external horizontal canal; Mes., mesethmoid elevation; Mes.com., mesotic commissure; Mes.r., mesotic ridge; M.o. medulla; N.l——N.X; cranial nerves; N.sp.l, first post-vagal nerve; Ntc., notochord; O.l., olfactory lobe; Olf.for., olfactory foramen; Olf.org., olfactory organ; Op.l., optic lobes; Pal.b., palatine cartilage; Para., parachordal; Pil.occ., pila occipitalis; Pin.b., pineal body; Pit., pituitary body; Pl.ant., planum antorbitale; Post.b.fen., posterior basicapsular fenestra; Post.fen., posterior basicranial fenestra; Post.orb., postorbital cartilage; Post.vert., posterior vertical canal; P.para., posterior portion of posterior parachordal; Pro.com., prootic commissure; Rec.sac., recessus sacculi; S.nas., solum nasi; S.o., supraorbital cartilage; t.p., tectum posterius; Trab., trabecula communis; Trab.groove, trabecula groove; t.s., tectum synoticum; Ut., utriculus.

INDEX TO FIGS. 11 - 20:

Add.mnd., m.adductor mandibulae; Alis., alisphenoid; Ang., angular; Ant.b.fen., anterior basicapsular fenestra; Ant.Zyg., anterior zygapophysis; Art.hyom., articular end of hyomandibular; Artic., articular; Art.mx., articular portion of maxilla; Basi.br. (B.br.) basibranchial; Basihy., basihyal; Basi-occ. basioccipital; Basiv., basiventral; Br., branchiostegal ray; Br.pro., branchial articulation; Cerato-br., ceratobranchial; Cerato-hy., ceratohyal; Dent., dentary; Dors.pro., dorsal process of epi-hyal; Ect., ectethmoid; Epi.br., epibranchial; Epi.hy., epihyal; Epiot.(Epi.) epiotic; Ex.br., exoccipital bridge; Ex.occ., exoccipital; F.n.v.vii, etc.(For.n.vii) foramen N.v etc.; Front., frontal; Hyom., hyomandibular; Hyp.br. hypobranchial; Hypohy., hypohyal; Int.car., foramen internal carotid artery; Intero., intercalarium; Interhy., interhyal; Interop., interopercular; Lat.pro., lateral process of operculum; Lig.ad.mnd., ligament of adductor mandibulae muscle; Lig.dil.operc., ligament m.dilator operculi; Mastic., masticatory process of basioccipital; Meck.cart., Meckel's cartilage; Medi.oss., median ossification; Med.pl., median plate of hyomandibular; Med.rod, ossification of ligament supporting the premaxilla; Meseth., mesethmoid; Metapt., metapterygoid; Mx., maxilla; Neur., neural arch; Neur.pl., median plate in dorsal septum; Operc., operculum; Orbito., orbitosphenoid; Pal., palatine; Para.(Paras.) parasphenoid; Par., parietal; Paras.r., median elevation on parasphenoid; Phary.br. pharyngobranchial; Phy.dent., Pharyngeal teeth; P.mx., premaxilla; Post.b.fen., posterior basicranial fenestra; Post.zyg., posterior zygapophysis; Preop., preoperculum; Proot., (pro.) prootic; Pro.com., prootic commissure; Pro.4, process of fourth centrum; Pro.cart., procartilaginous pharyngobranchial; Pter., (Ptery.) pterygoid; Pt.q.b., palato-pterygo-quadrate bar; Quad., quadrate; Rec.sac., recessus sacculi

Rost.cart., rostral cartilage; Scap., scaphium; Sphen., sphenotic; Sup.occ., supraoccipital; Sub-op., subopercular; Sympl., sympletic; Trip., tripus; Vert.1 - 4, vertebral centra 1-4; Vo., vomer; Vo.cr., vomerine cornu.

INDEX TO FIGS. 21 - 30:

A.B., air-bladder; Ant.cart., basidorsal, centrum 2; Ant.lat.oss. (neur.pl.1), anterior lateral ossification of neural cartilage; Ant.med.oss. anterior median ossification of the neural cartilage; Ant.pl.pro.4, anterior continuation of the ventral process of the fourth centrum; Ant.zyg., anterior zygapophysis; Basid., basidorsal; basiocc., basioccipital; Basiv., basiventral (B.v.); Cent., centrum; Cr.cav., cranial cavity; C.s.i., cavum sinus impar; Dors.bent., dorsal longitudinal septum; Dors.lig., dorsal longitudinal ligament; Exocc., exoccipital; Exocc.pl., median plate of exoccipital roofing the c.s.i.; Haem., haemal arch; Haem.sp., haemal spine; Int.a. intervertebral space; Interc., intercalarium; Inter.cart., "interspinous cartilage"; Lig., ligament connecting the Weberian ossicles; Lig.zyg., ligament preceding the ant.zyg. of the anterior vertebrae; Mastic., masticatory process; Med.oss., median ossification of neural cartilage; Med.pro.4, median ventral process of the fourth centrum; Neur., neural arch (3,4,etc.); Neur.cart., neural cartilaginous roof; Neur.pl., dorsal plate of neural cartilage; Neur.sp., neural spine; Pleur., pleural rib; Post.zyg., posterior zygapophysis; Pro.2, (Trans.pro.2), (and 4), basiventral elements of centra 2 and 4; Rec.sac., recessus sacculi; Rib.vert.5, pleural rib, fifth centrum; Sac., sacculus; Scaph., scaphium; Tect.syn., tectum synoticum; Trip., tripus; Vent. pro.2, ventral process second vertebra; Vert.1,2, etc., centra of first, second vertebrae, etc.

INDEX TO FIGS. 31 - 34:

Act., actinotrichi; Ant.pl., anterior plate; Haem., haemal arch; Hyp. cart., hypural cartilages; Last.cent., terminal "centrum"; Haem.sp., haemal spine; Lat.wing, lateral process; Maj.ray., major unbranched ray; Neur., neural arch; Nto., notochord; Rad., "radial"; Rud.ray., rudimentary ray; Uro., urostyle.

INDEX TO FIGS. 35 - 39

Act., actinotrichi; Ant.pl., anterior plate; Ant.pro., anterior process; Dep.m., depressor muscle; Dist.seg., distal segment of radial; Erect.m., erector muscle; Lep., lepidotrichi; Lig., ligament; Maj.ray., major, unbranched ray; Med.pro., median process; Med.oss., ossifying median segment; Med.seg., median segment of radial; Post.pl., posterior plate; Post.pro., posterior process of foot of ray; Prox.cart., proximal cartilage of radial; Prox.oss., proximal ossification of radial; Rad., radial; Rud.ray., rudimentary ray.

INDEX TO FIGS. 40 - 47:

Act., actinotrichi; Ant.pl., anterior plate; Art., articular portion of transverse bar; Cl., cleithrum; Cor., coracoid; Cor.cart., coracoid cartilage; Dors.lep., dorsal set of lepidotrichi; Dors.tub., dorsal tubercle; Exocc., exoccipital; Foot., transverse portion of cleithrum; Glen.f., glenoid fossa; Lat.pl., lateral plate; Lep., lepidotrichi; Maj.ray., major, unbranched ray; Med.pl., median plate; Mesoc., mesocoracoid; Mesoc. for., mesocoracoid foramen; Myos., myoseptum; Ntc., notochord; Otic reg., auditory capsule; Pelv.b., pelvic bar; Pelv.cart., pelvic cartilage; Pelv. pro., pelvic process; Post.cle., post-cleithrum; Post.lep., posterior set of lepidotrichi; Post.occ.myo., first post-occipital myotome; Post.pl., posterior plate; Post.t., post-temporal; Pro.cart.rad., procartilaginous radial plate; Rad.1, Rad.2, etc., radials; Rec.sac., recessus sacculi; Scap., scapula; Scap. for., scapular foramen; Sup.cl., supracleithrum; t.s. tectum synoticum; Vent.lep., ventral set of lepidotrichi.

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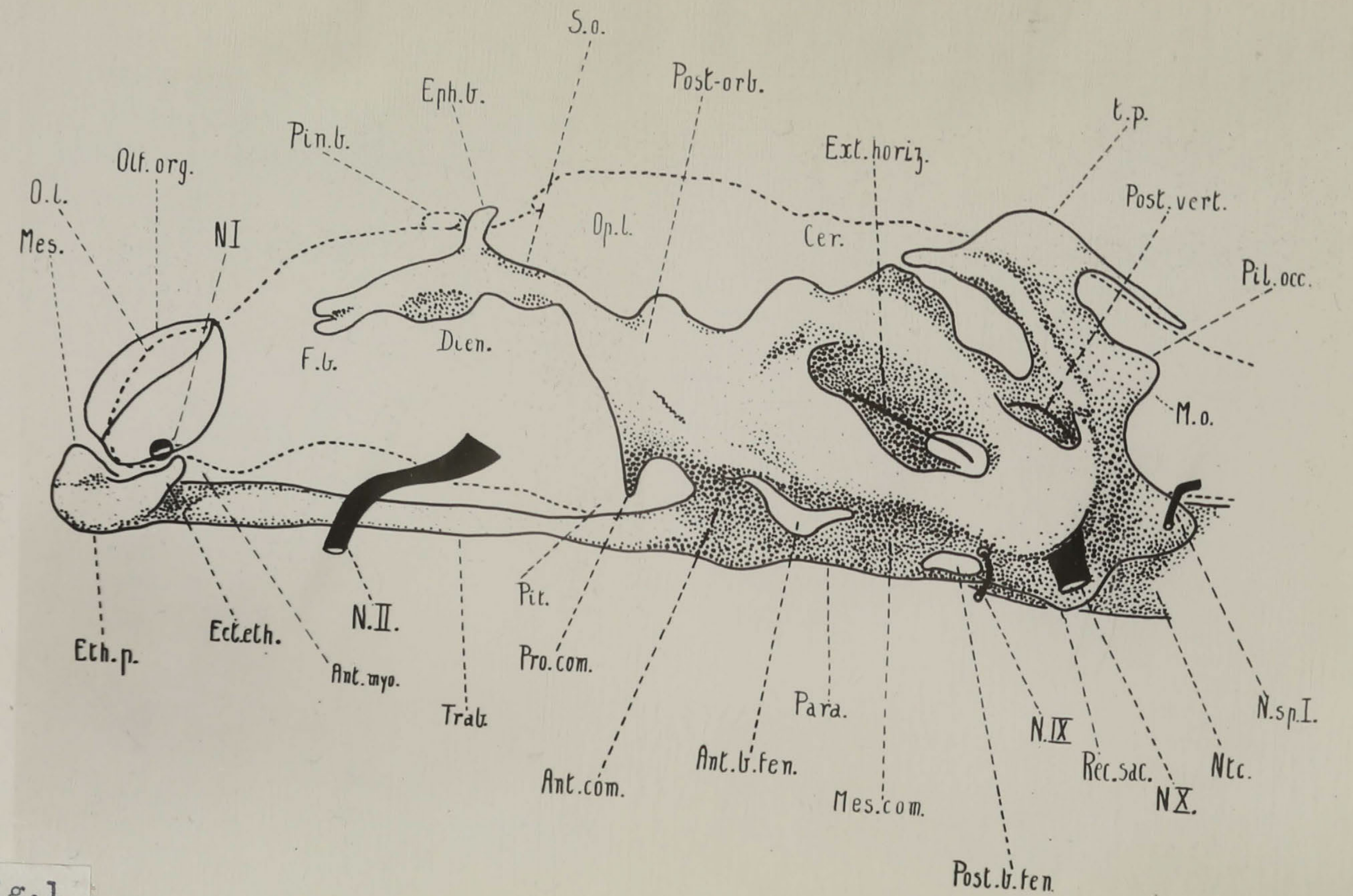
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Fig.1

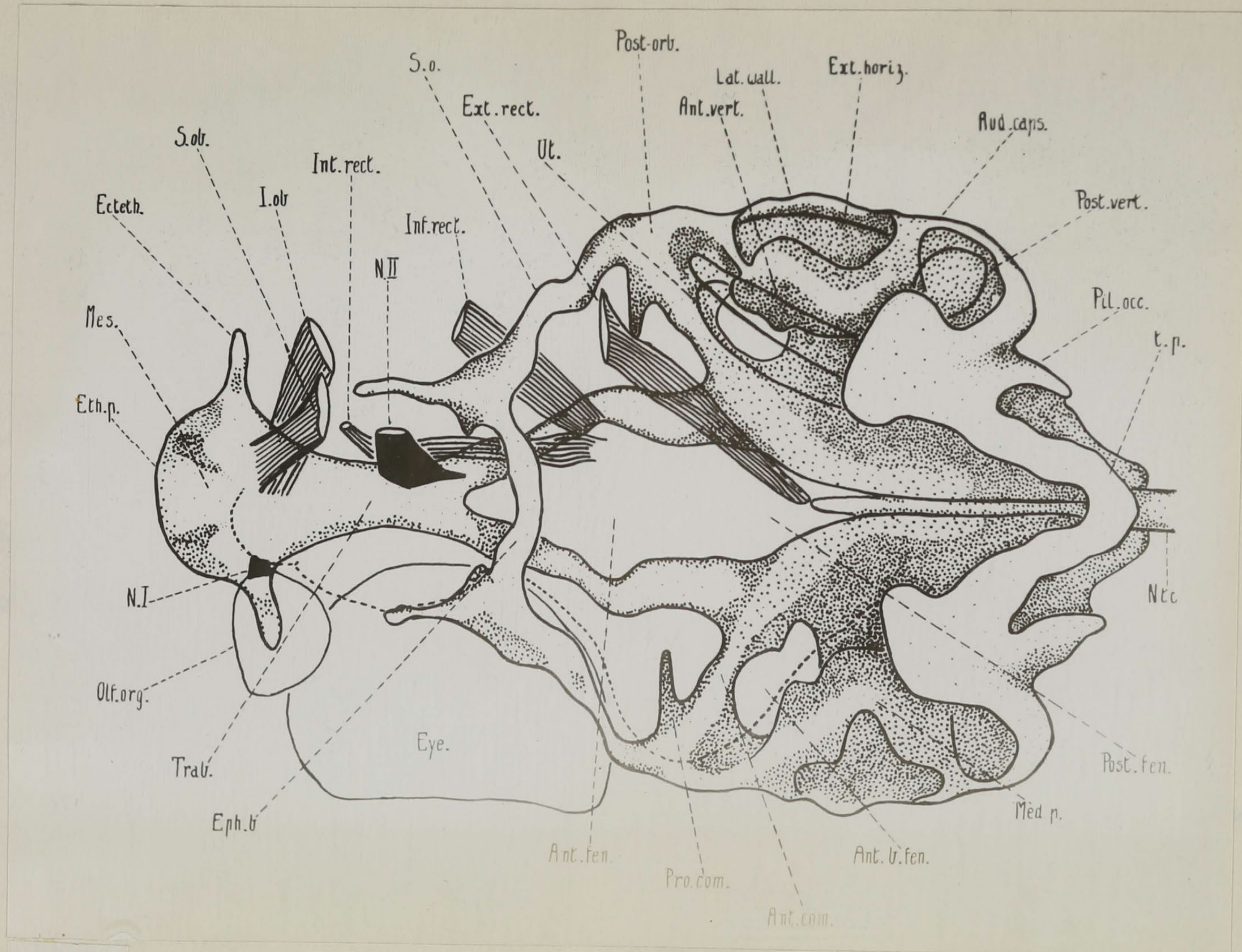
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Fig. 2

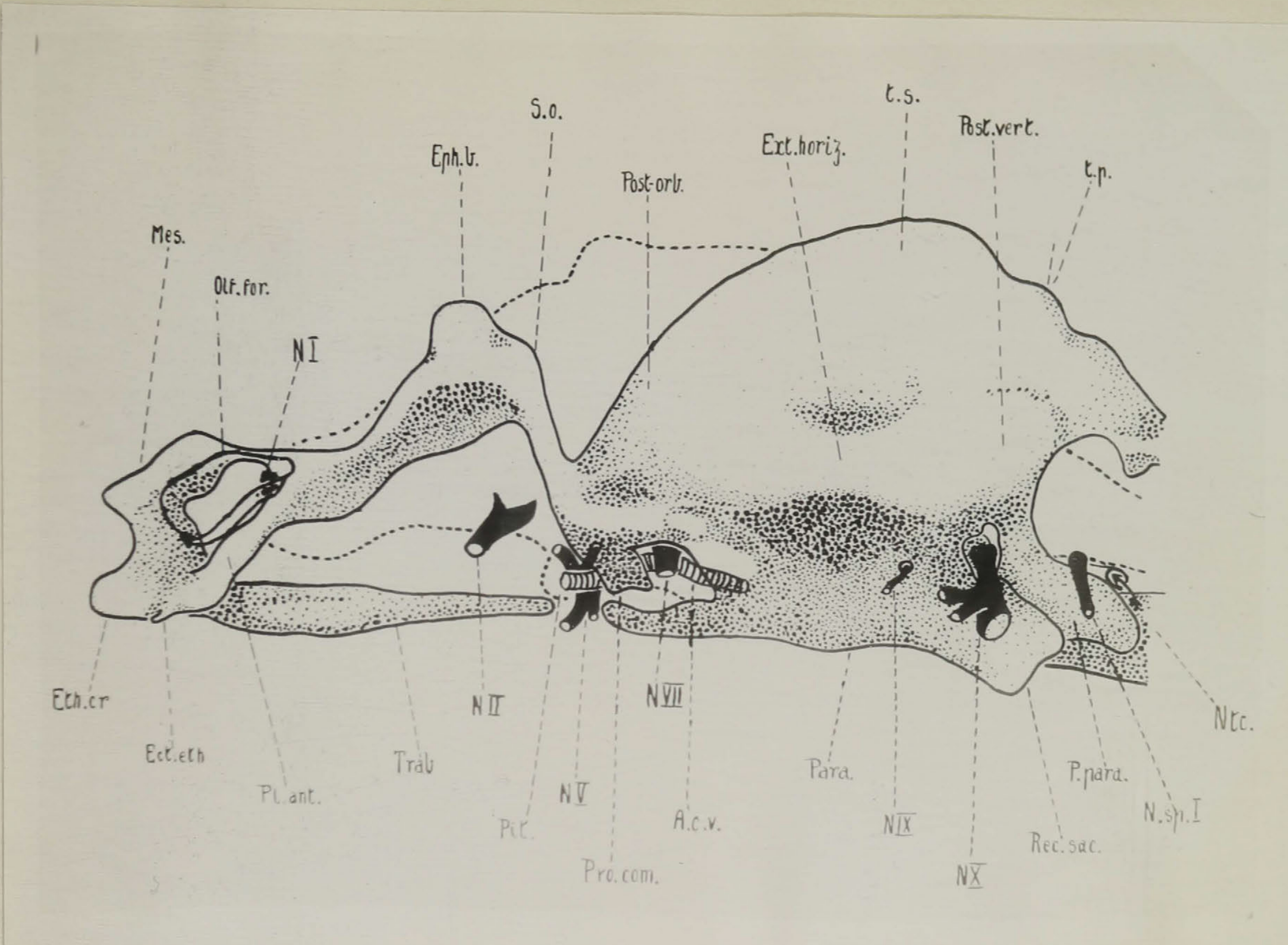

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Fig.3

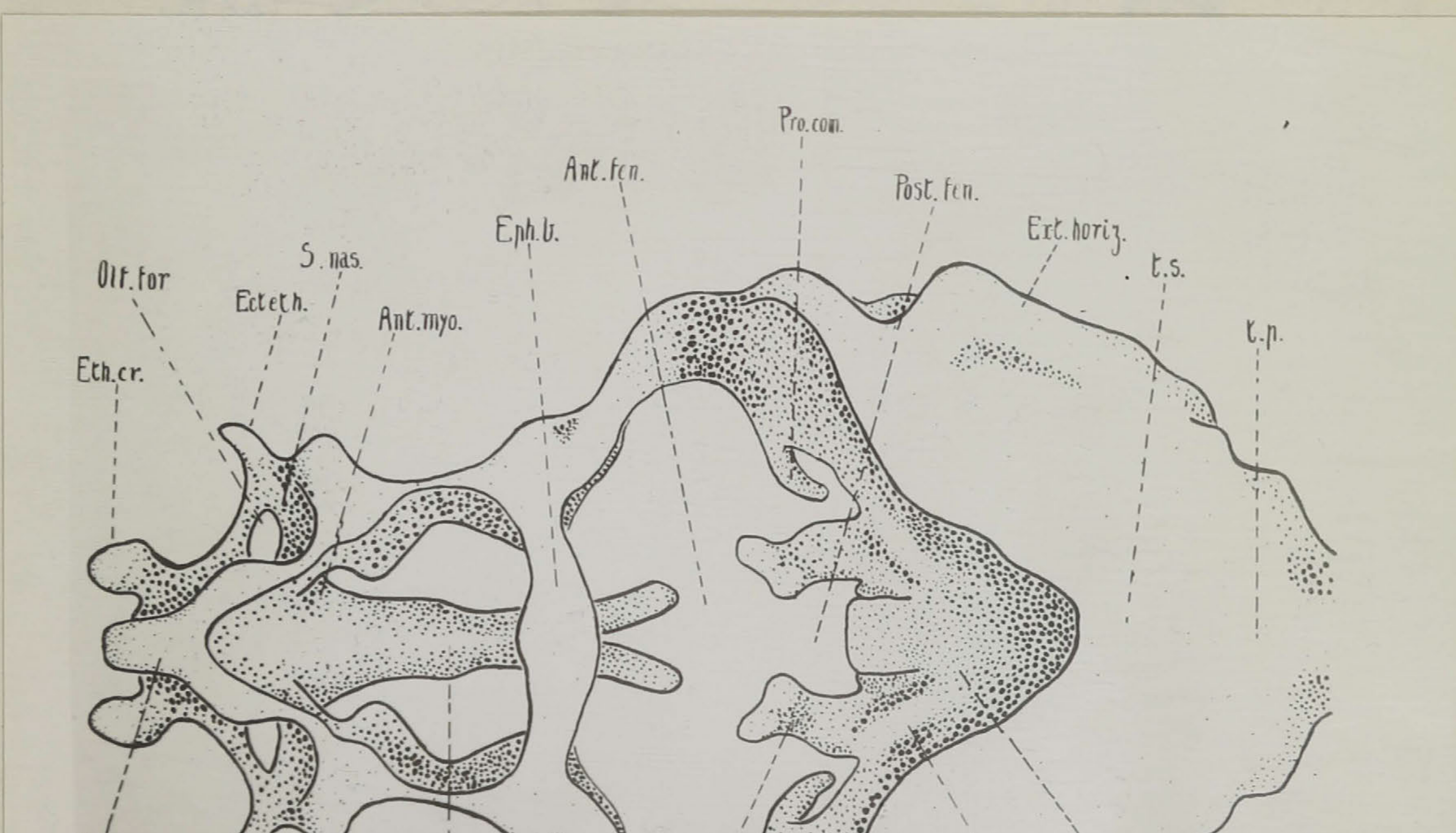

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Fig.4

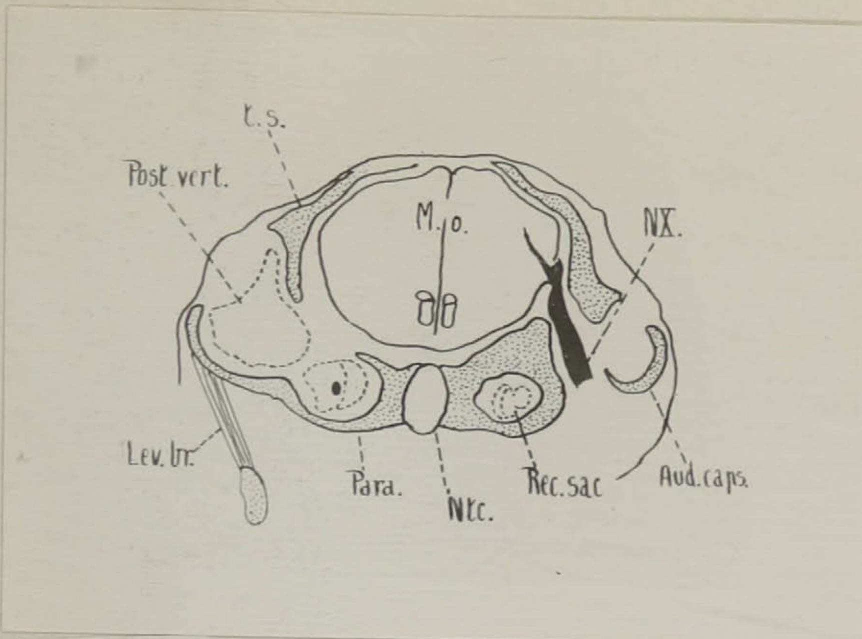


Fig.5

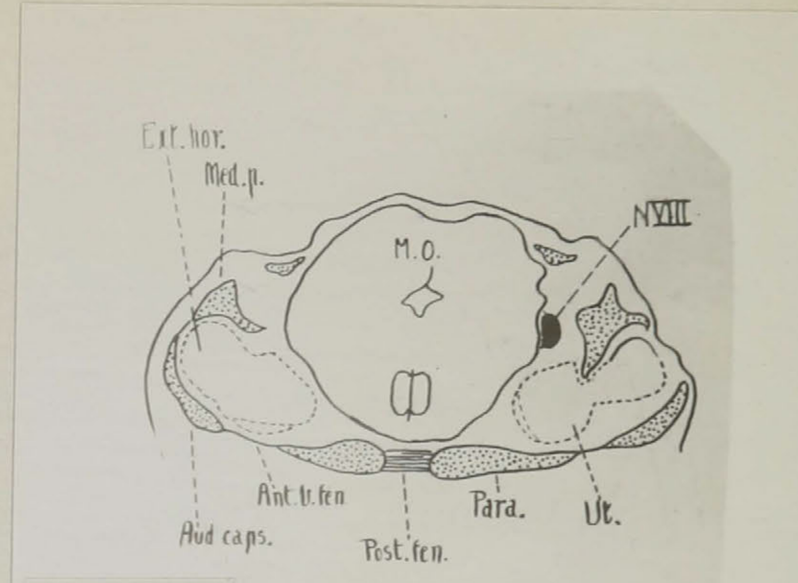


Fig.6

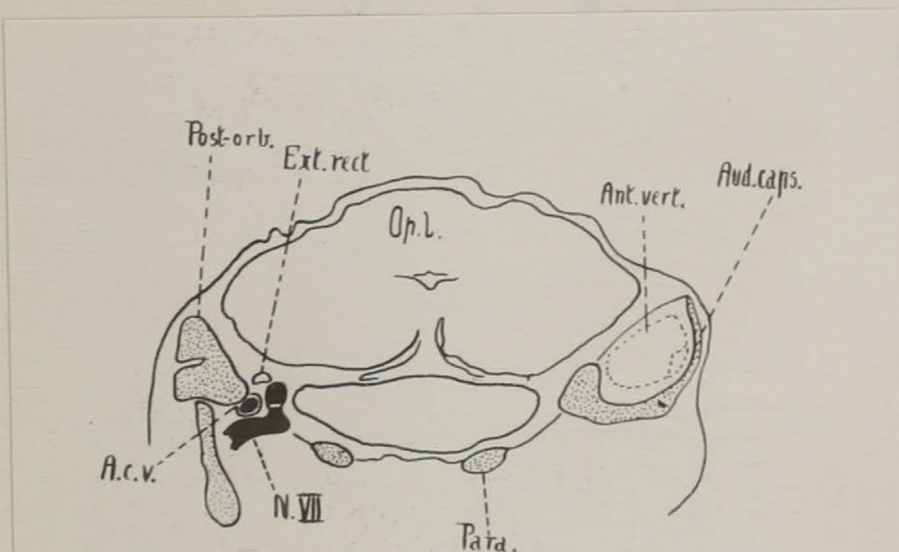


Fig.7

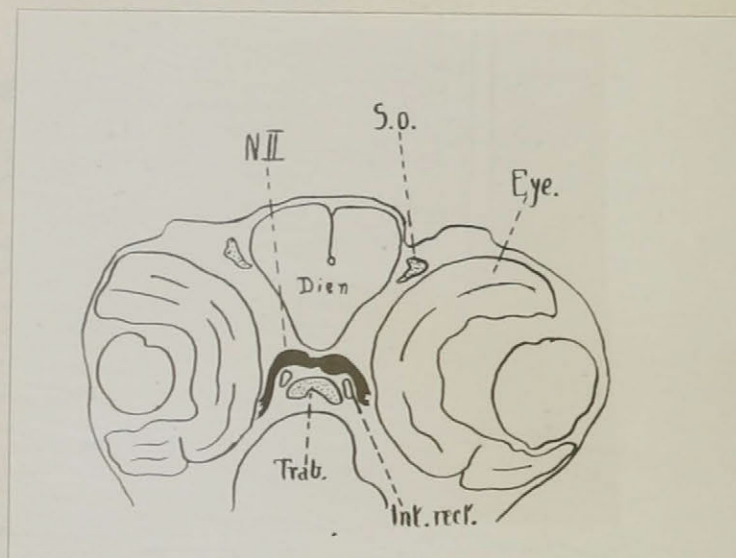


Fig.8

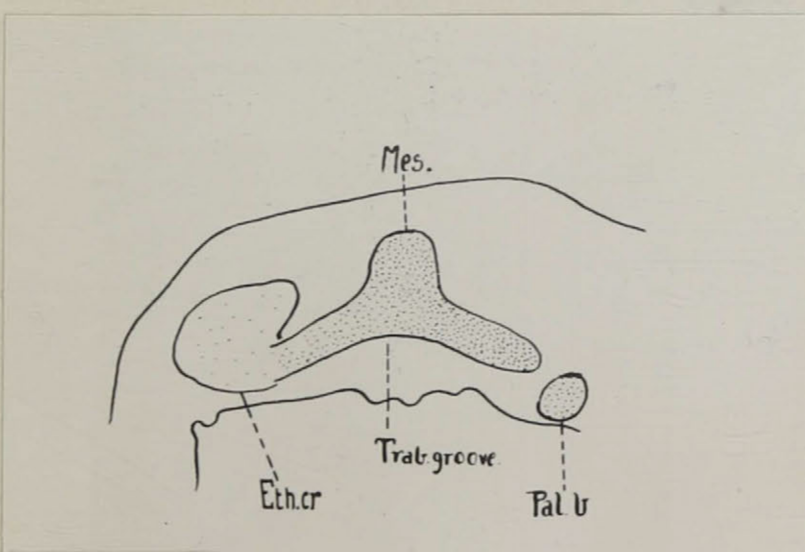


Fig.9

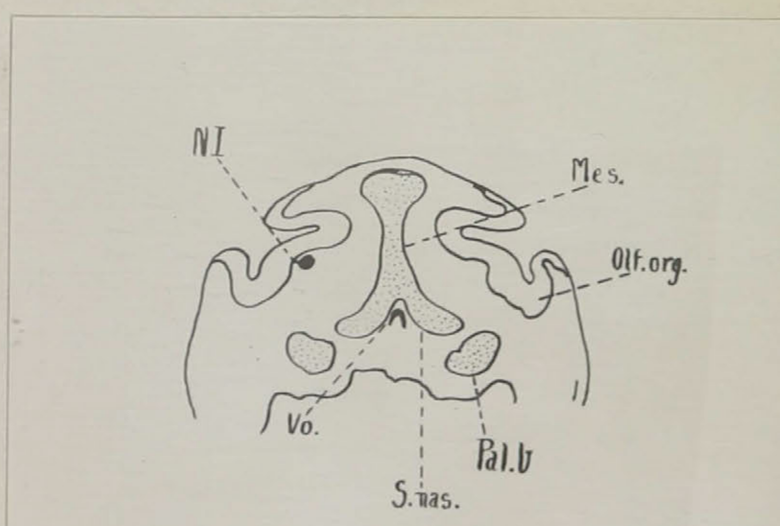


Fig.10

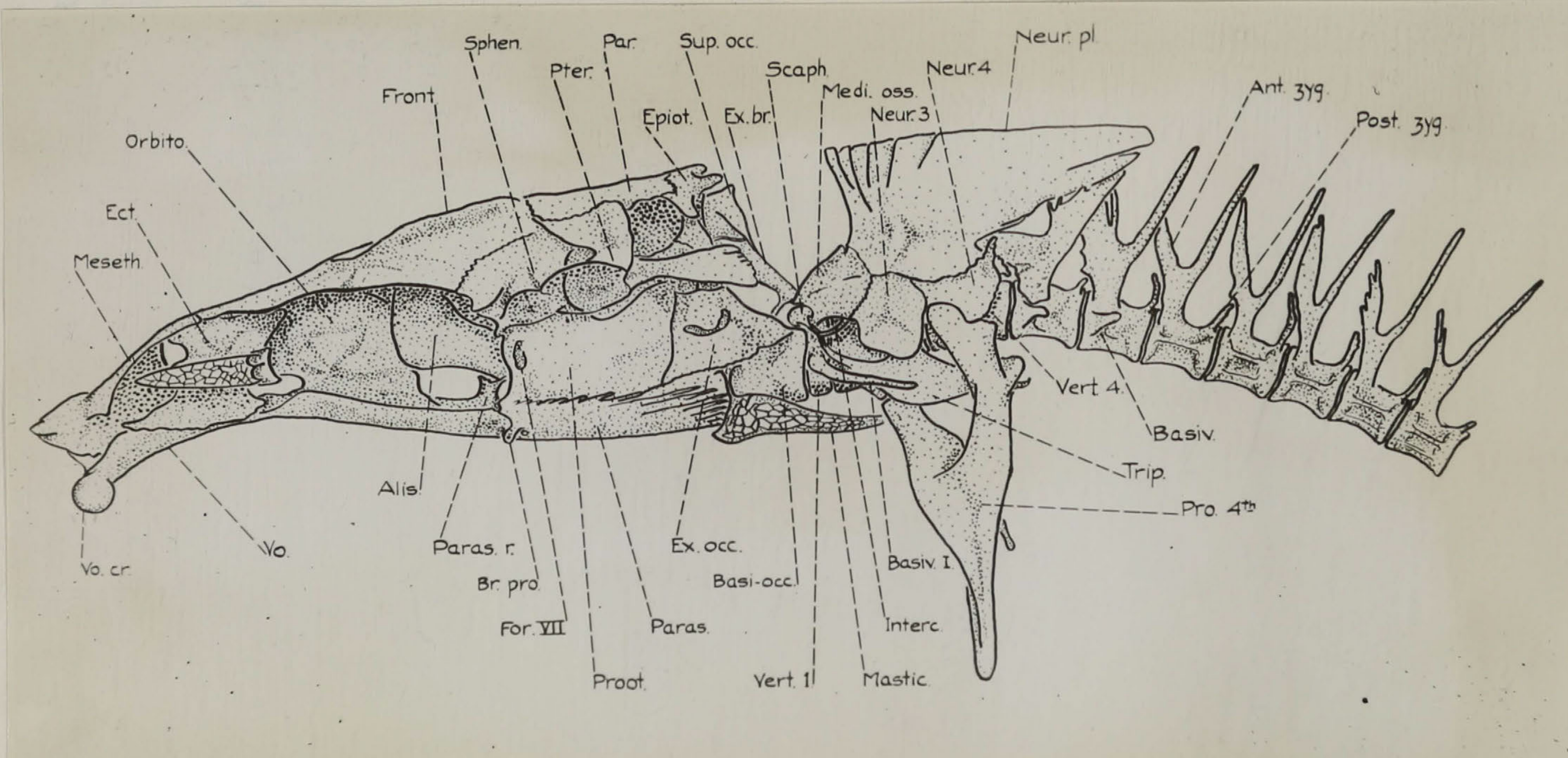

Sphen.
Par.
Sup. occ.
Neur. pl
Pter.
Scaph.
Neur.4
Front
Medi. oss.
Epiot.
Ex. br.
Neur. 3
Ant. 3yg
Post. 3yg
Orbito.
Ect.
Meseth.
Vert 4.
Basiv.
Trip.
Pro. 4th
Alis.
Paras. r.
Vo.
Ex. occ.
Basiv. I.
Vo. cr.
Br. pro.
Basi-occ.
For. VII
Paras.
Interc.
Proot.
Vert. 1
Mastic.

Fig.11

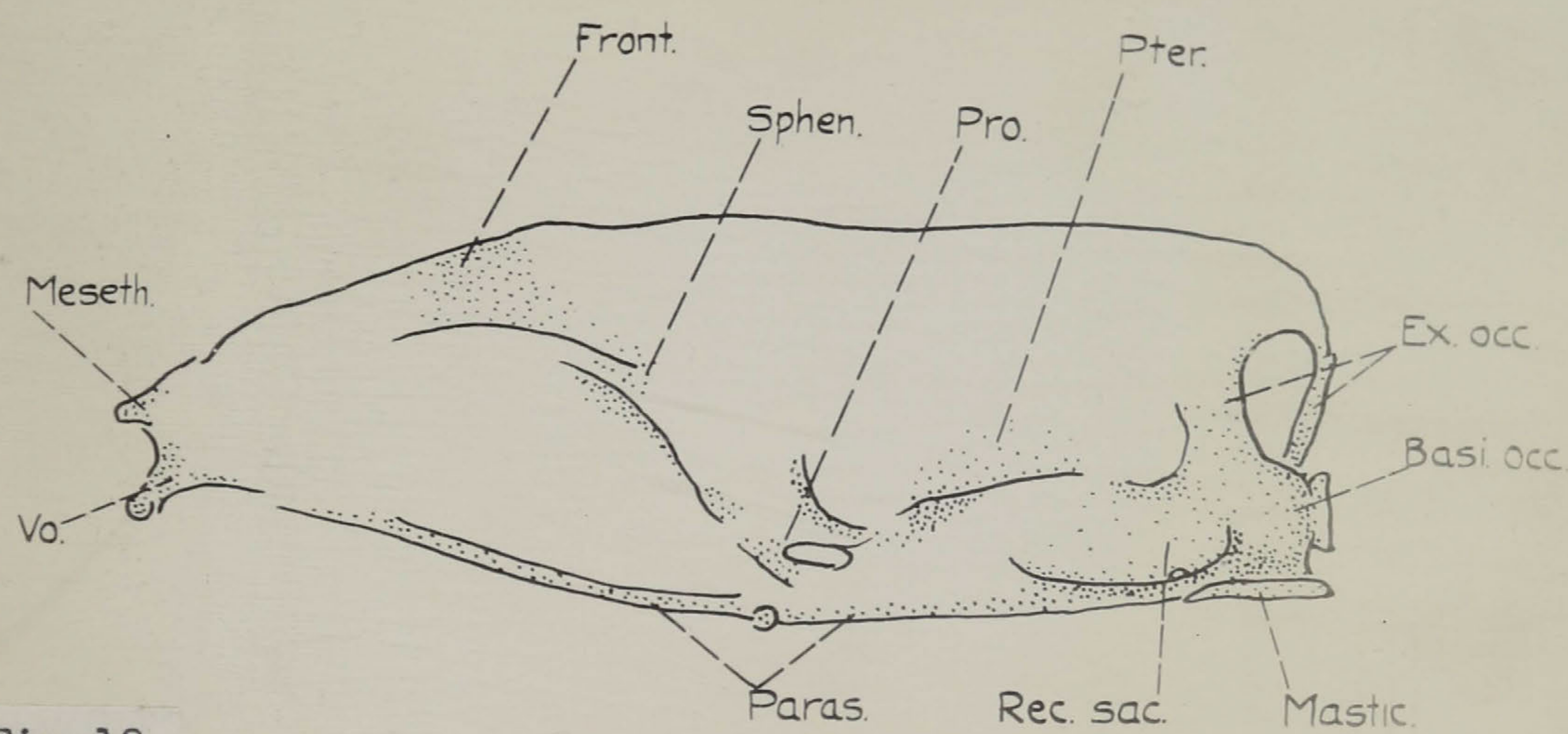

Front.
Sphen.
Pro.
Pter.
Meseth.
Ex. occ.
Basi. occ.
Vo.
Paras.
Rec. sac.
Mastic.

Fig.12

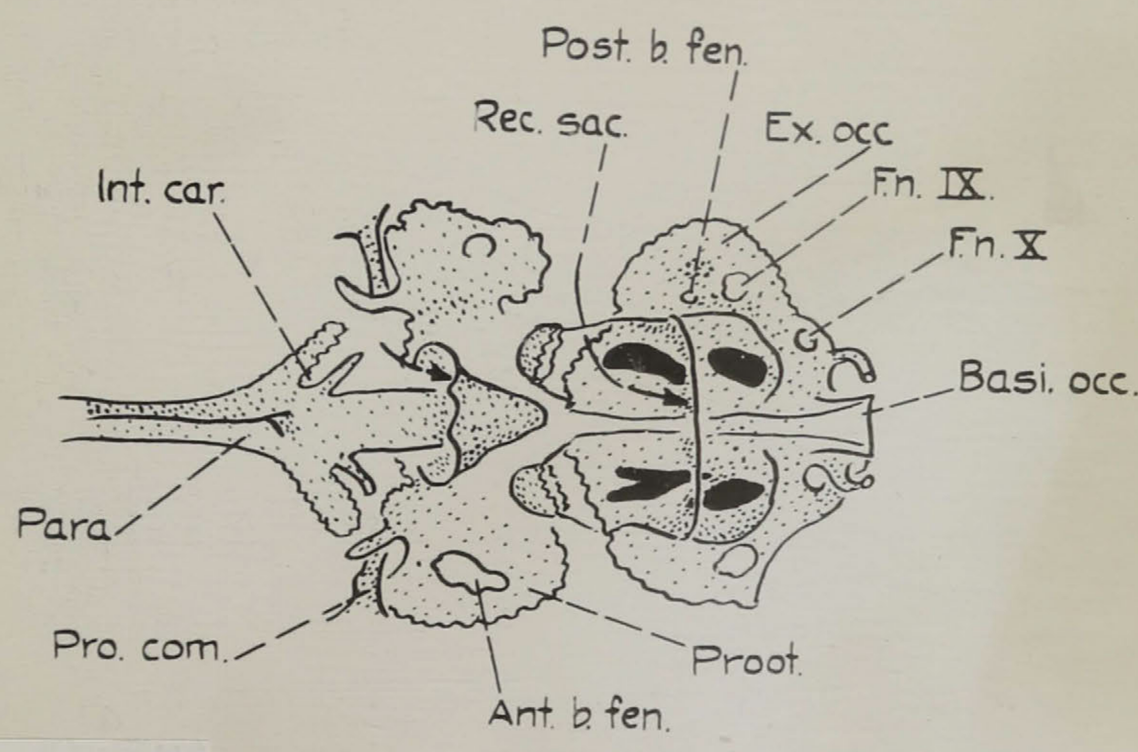

Post. b. fen.
Rec. sac.
Ex. occ
Int. car.
F.n. IX.
F.n. X
Basi. occ.
Para
Pro. com.
Proot.
Ant. b. fen.

Fig.13

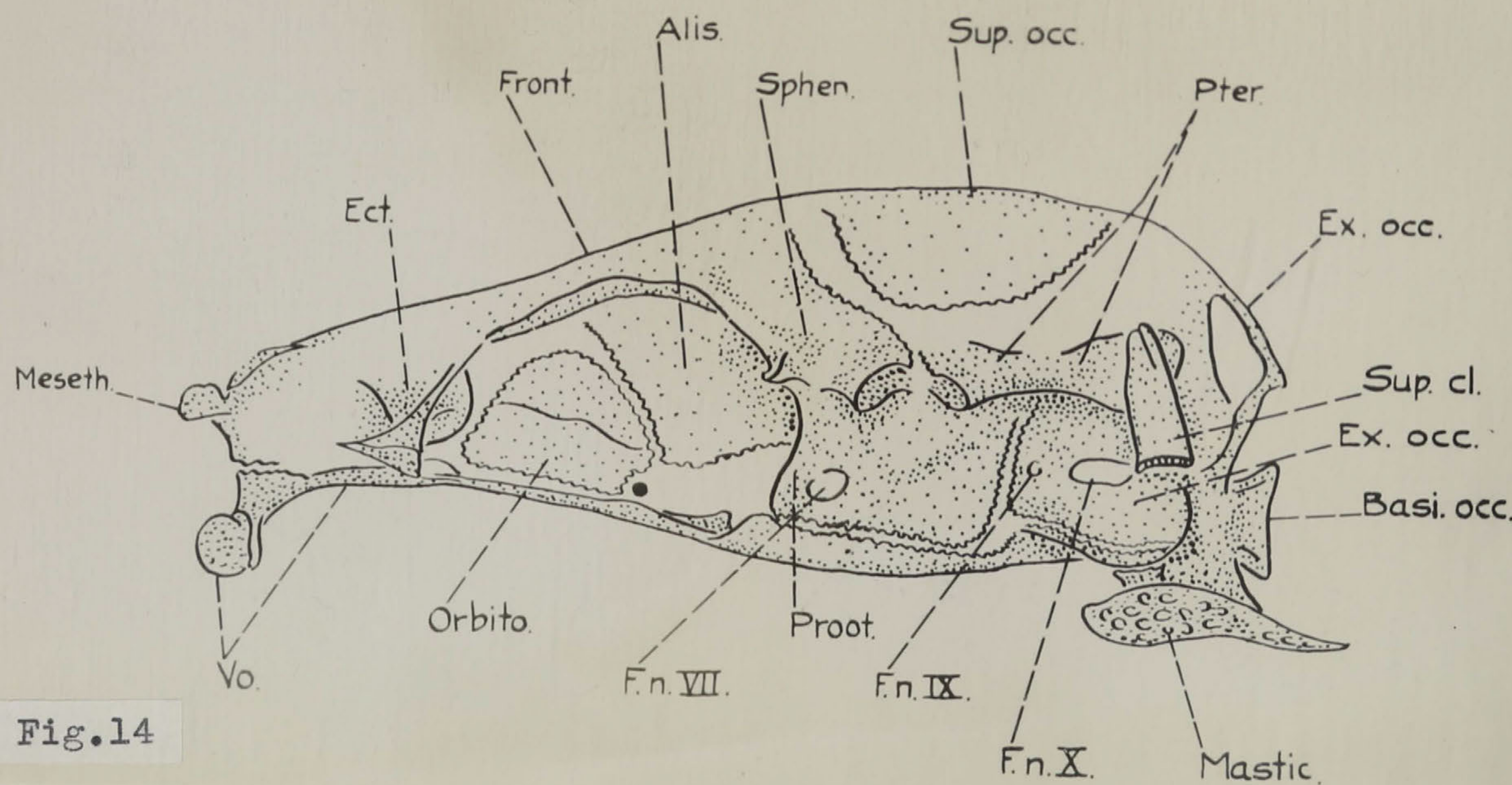

Alis.
Sup. occ.
Front.
Sphen.
Pter.
Ect.
Ex. occ.
Meseth.
Sup. cl.
Ex. occ.
Basi. occ.
Orbito.
Proot.
Vo.
F.n. VII.
F.n. IX.
F.n. X.
Mastic.

Fig.14

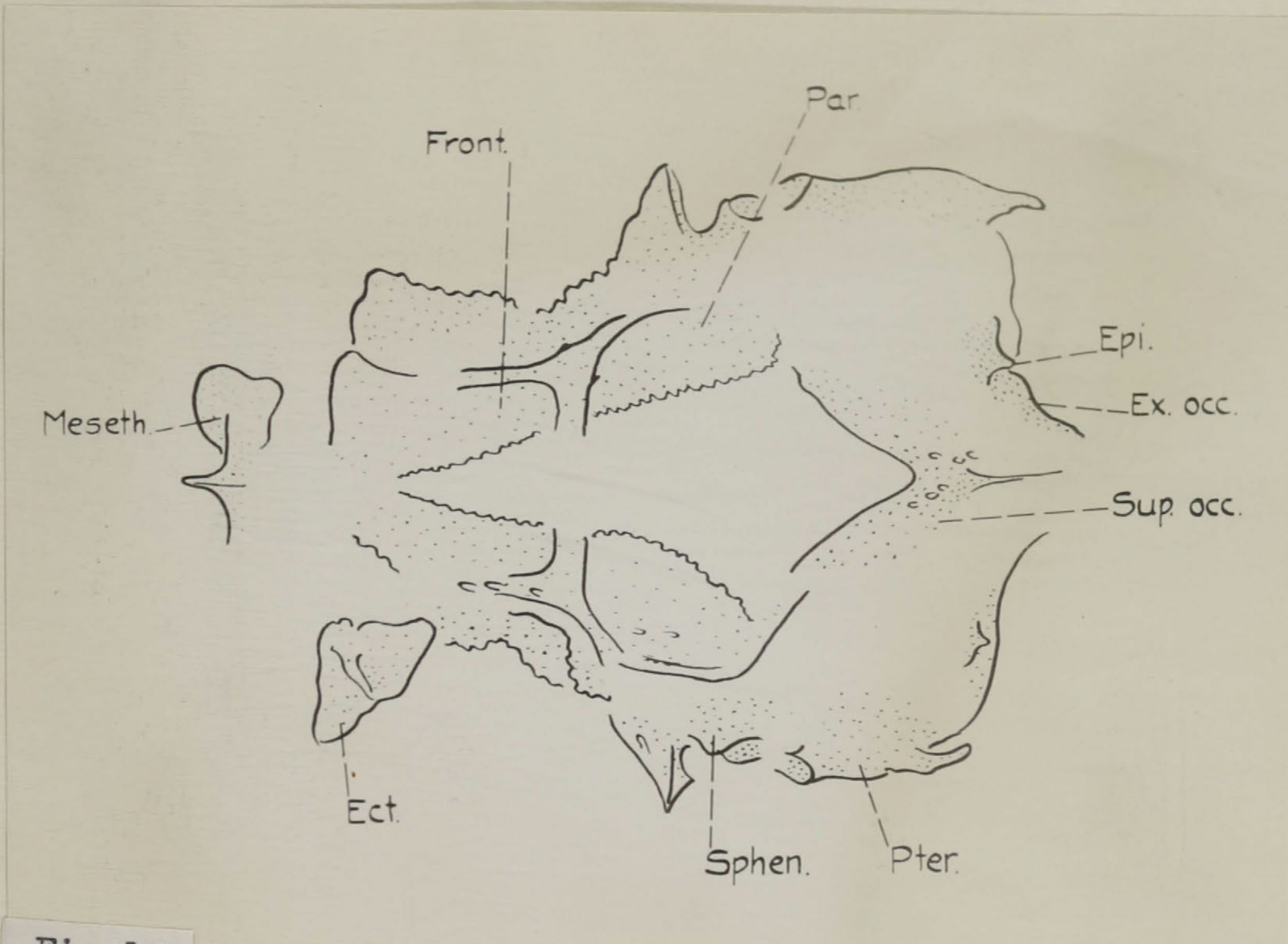

Par.
Front.
Epi.
Meseth.
Ex. occ.
Sup. occ.
Ect.
Sphen.
Pter.

Fig.15

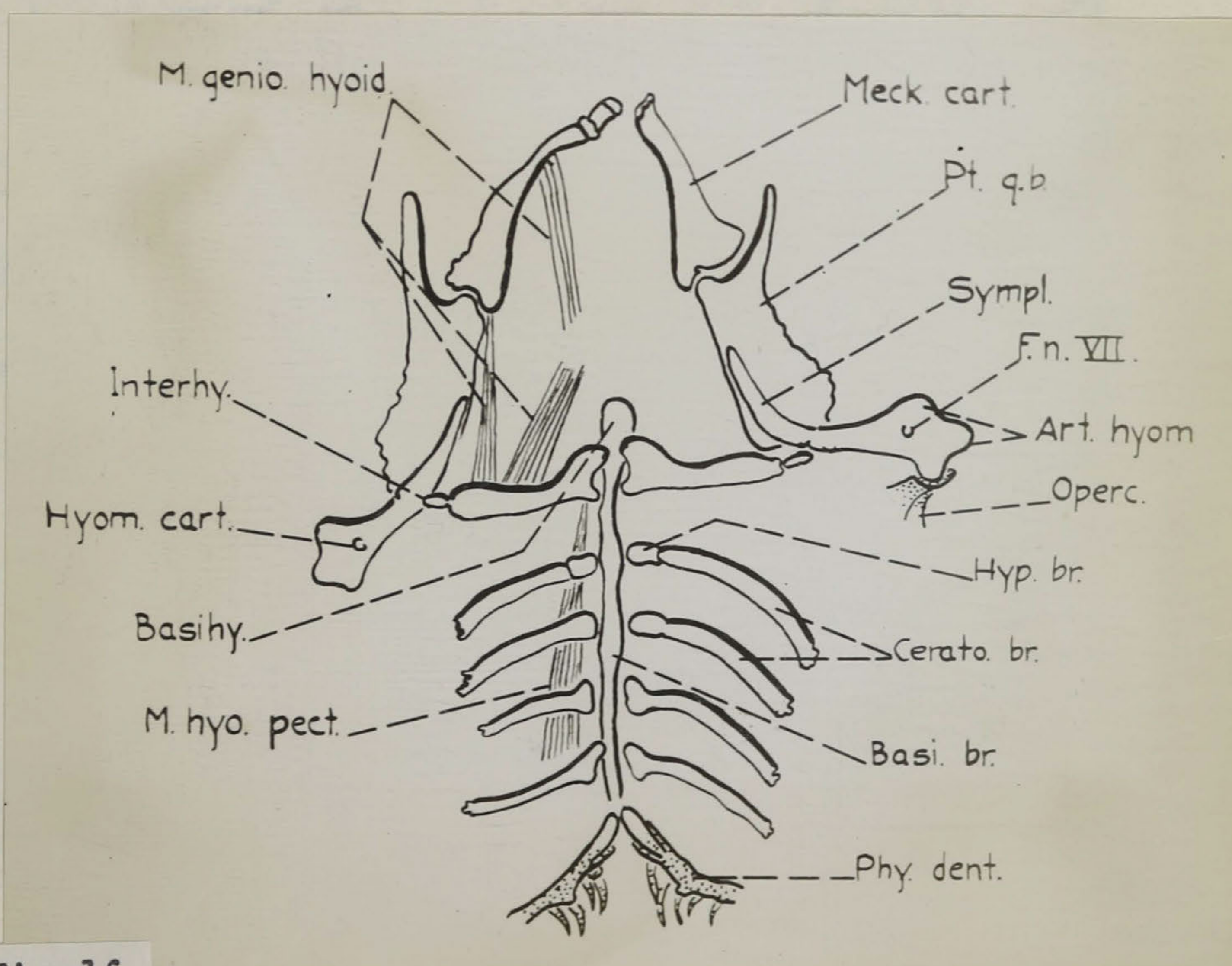

M. genio. hyoid.
Meck. cart.
Pt. q.b.
Sympl.
F. n. VII.
Interhy.
Art. hyom
Operc.
Hyom. cart.
Hyp. br.
Basihy.
Cerato. br.
M. hyo. pect.
Basi. br.
Phy. dent.

Fig.16

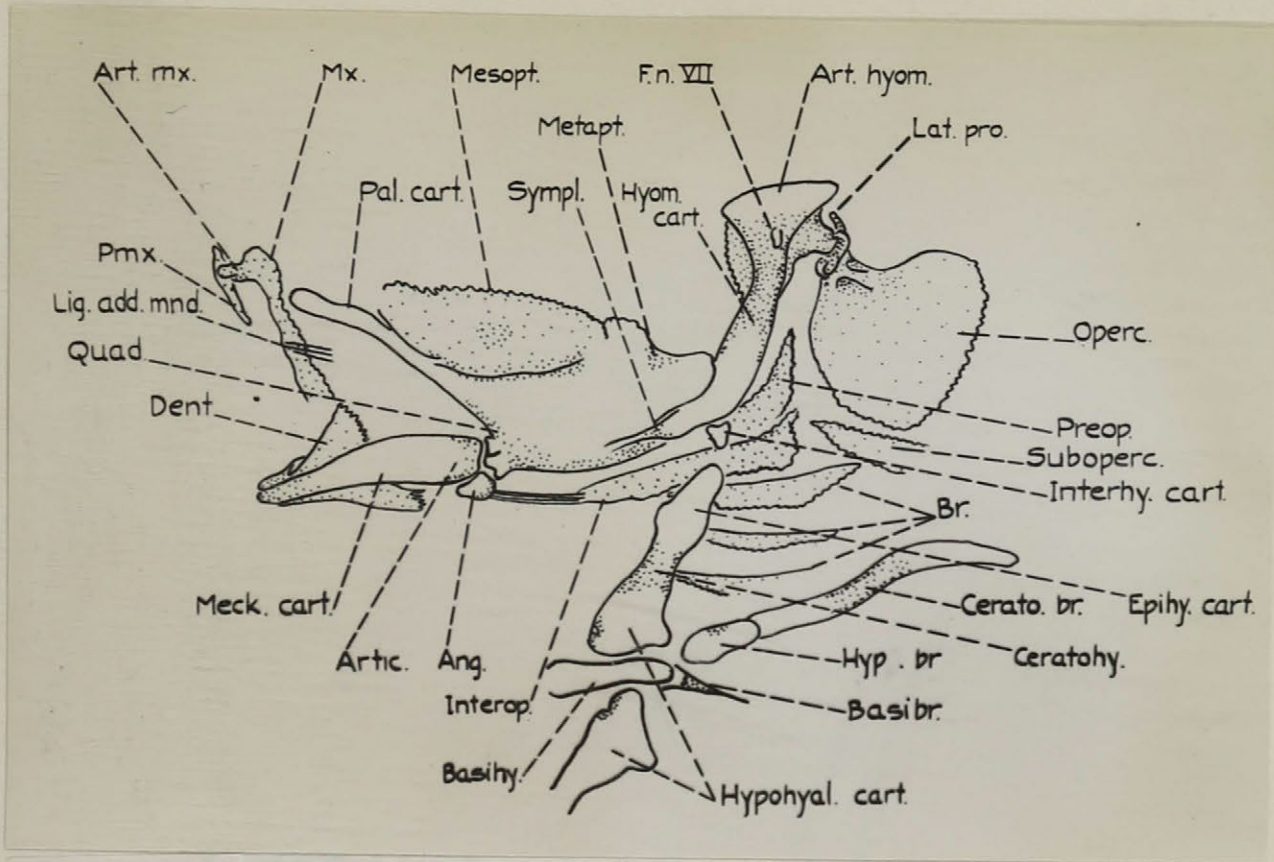

Art. mx.
Mx.
Mesopt.
F.n. VII
Art. hyom.
Metapt.
Lat. pro.
Pal. cart.
Sympl.
Hyom. cart.
Pmx.
Lig. add. mnd.
Quad.
Operc.
Dent.
Preop.
Suboperc.
Interhy. cart.
Br.
Meck. cart.
Cerato. br.
Epihy. cart.
Artic.
Ang.
Hyp. br
Ceratohy.
Interop.
Basibr.
Basihy.
Hypohyal. cart.

Fig.17

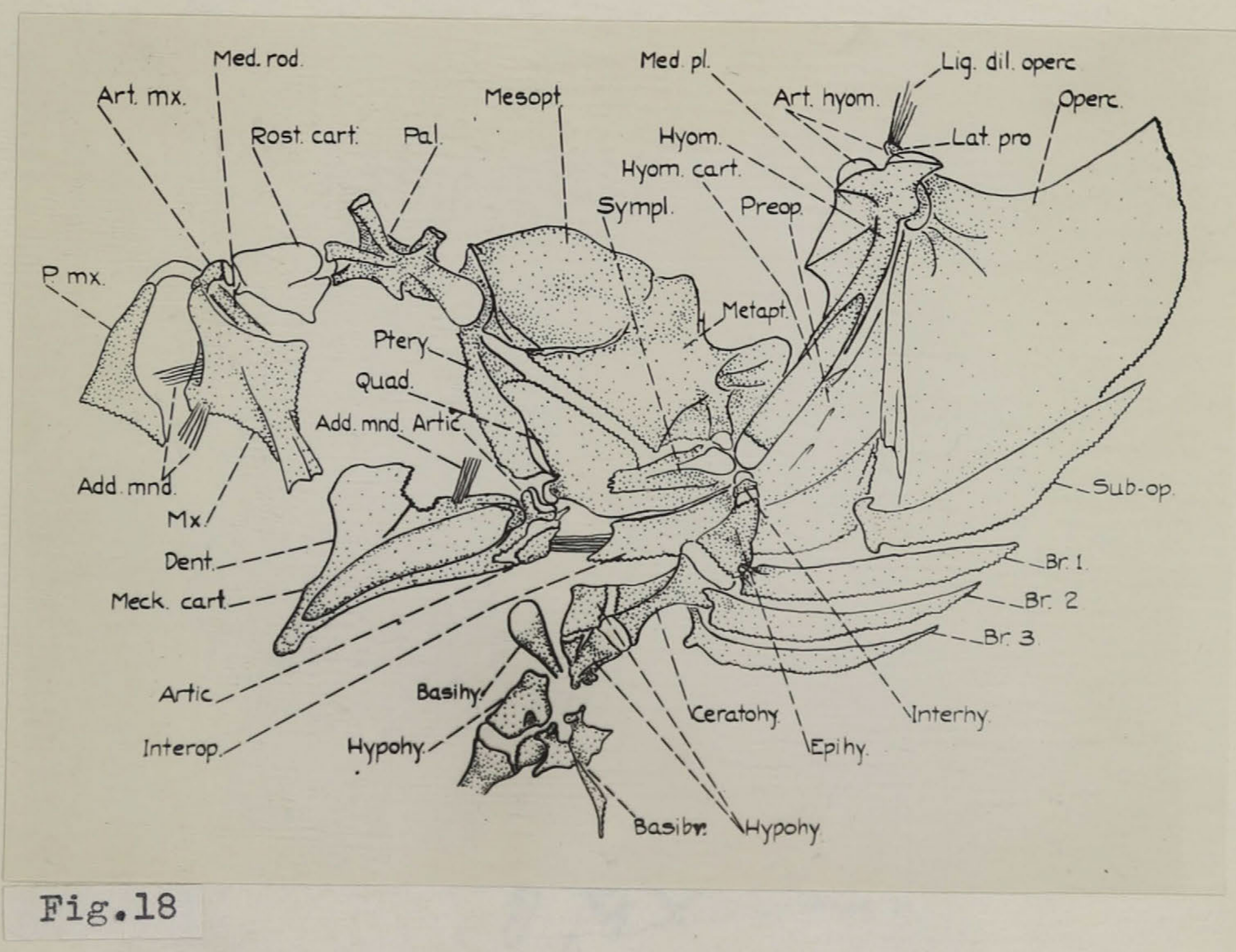
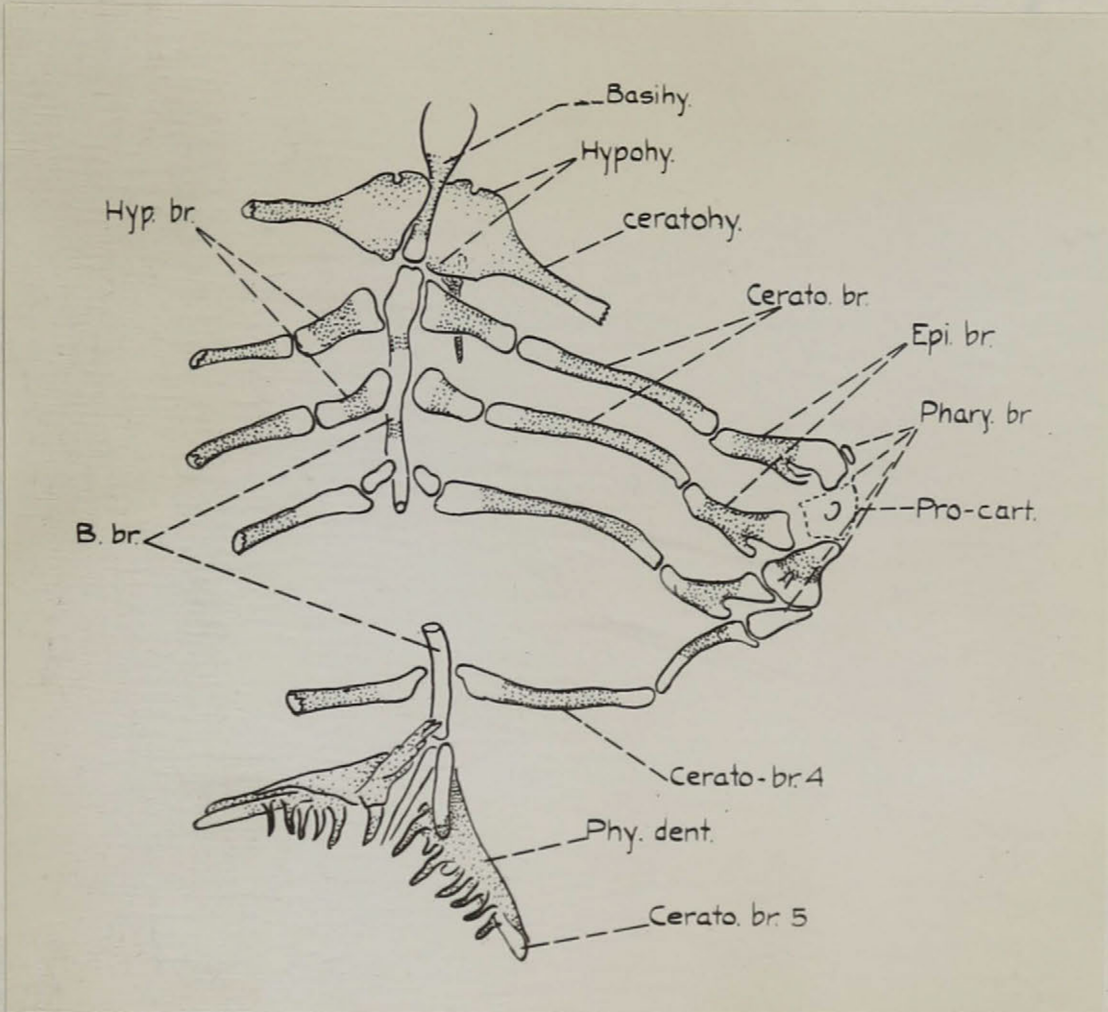
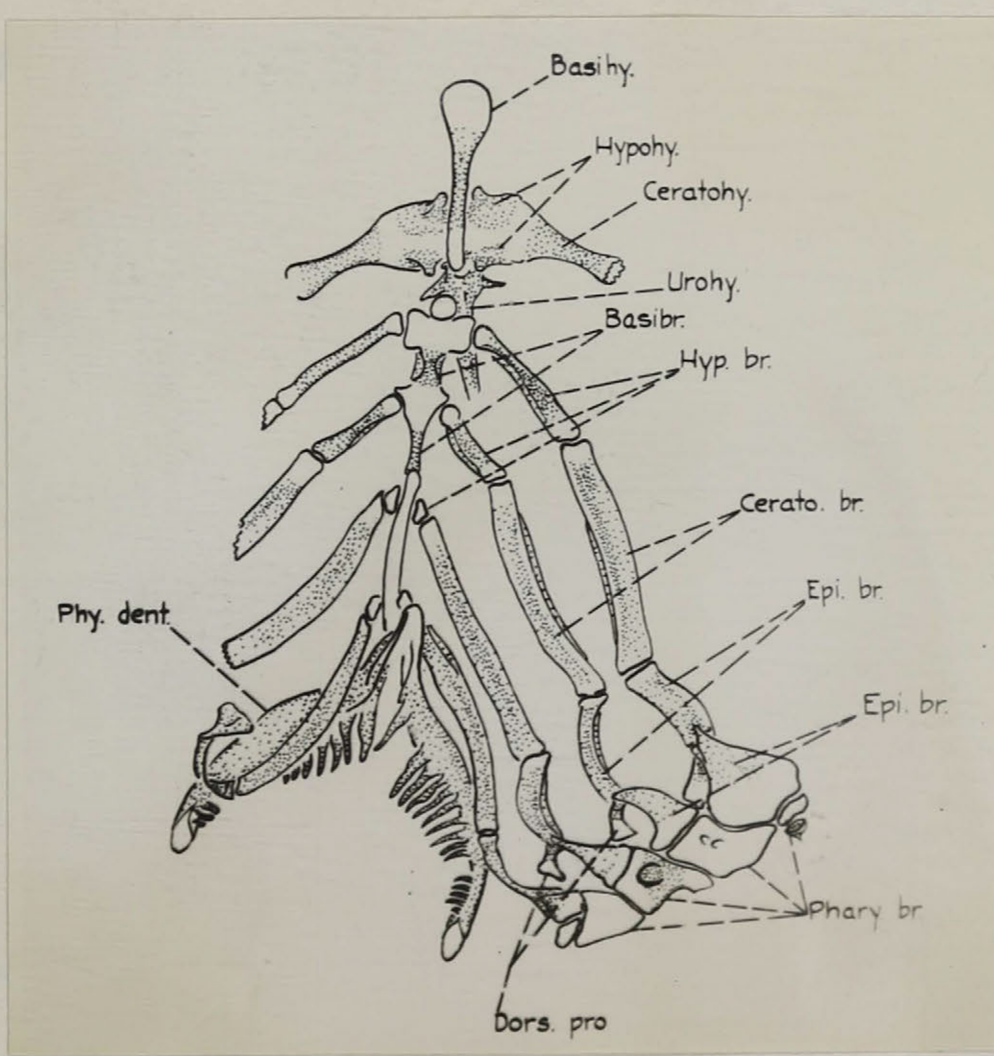

Med. rod.
Med. pl.
Lig. dil. operc.
Art. mx.
Mesopt.
Art. hyom.
Operc.
Rost. cart.
Pal.
Hyom.
Lat. pro.
Hyom. cart.
Sympl.
Preop.
P. mx.
Metapt.
Ptery.
Quad.
Add. mnd. Artic.
Add. mnd.
Sub-op.
Mx.
Dent.
Br. 1
Meck. cart.
Br. 2
Br. 3
Artic.
Basihy.
Ceratohy.
Interhy.
Interop.
Hypohy.
Epihy.
Basibr.
Hypohy.

Fig.18



Basihy.
Hypohy.
Hyp. br.
ceratohy.
Cerato. br.
Epi. br.
Phary. br
Pro-cart.
B. br.
Cerato-br. 4
Phy. dent.
Cerato. br. 5

Fig.19



Basihy.
Hypohy.
Ceratohy.
Urohy.
Basibr.
Hyp. br.
Cerato. br.
Phy. dent.
Epi. br.
Epi. br.
Phary. br
Dors. pro

Fig.20

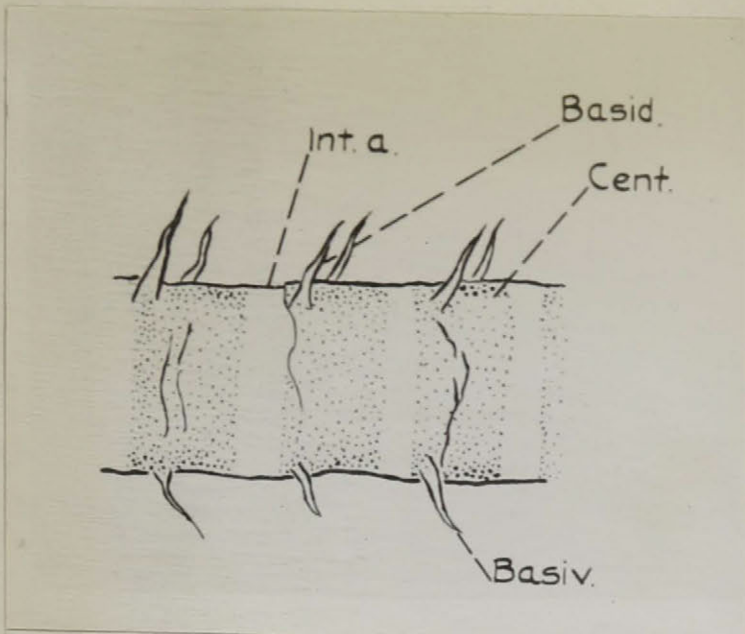


Fig.21

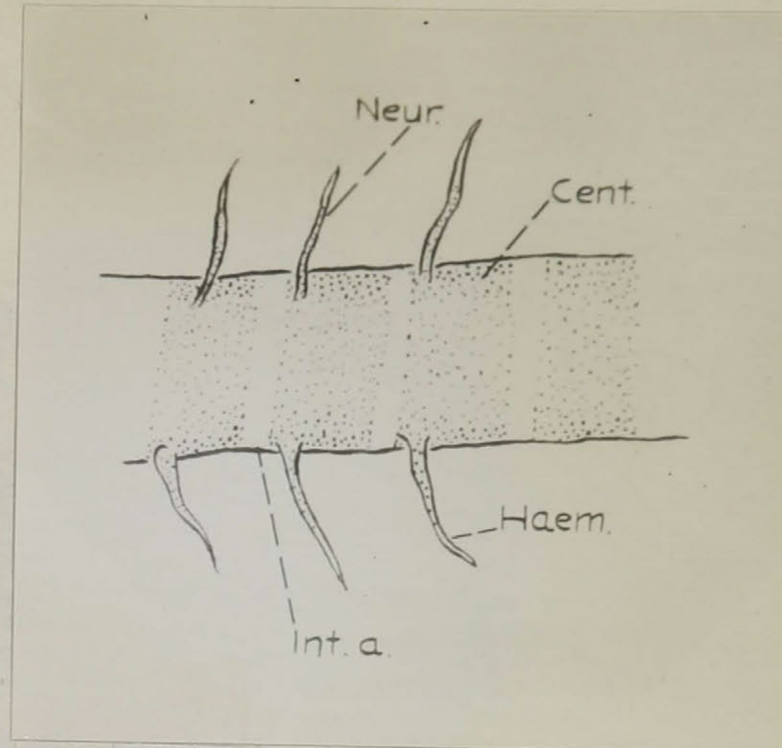


Fig.22

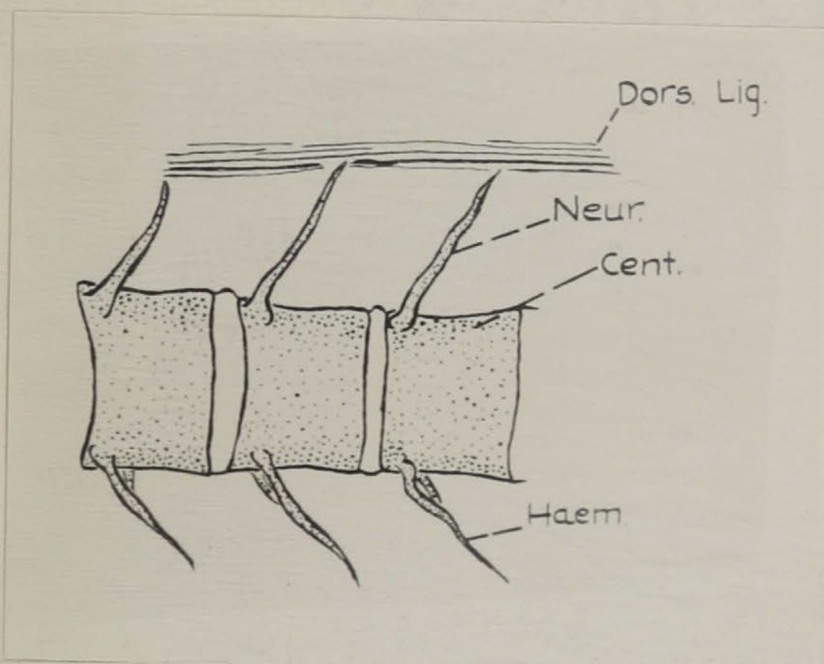


Fig.23

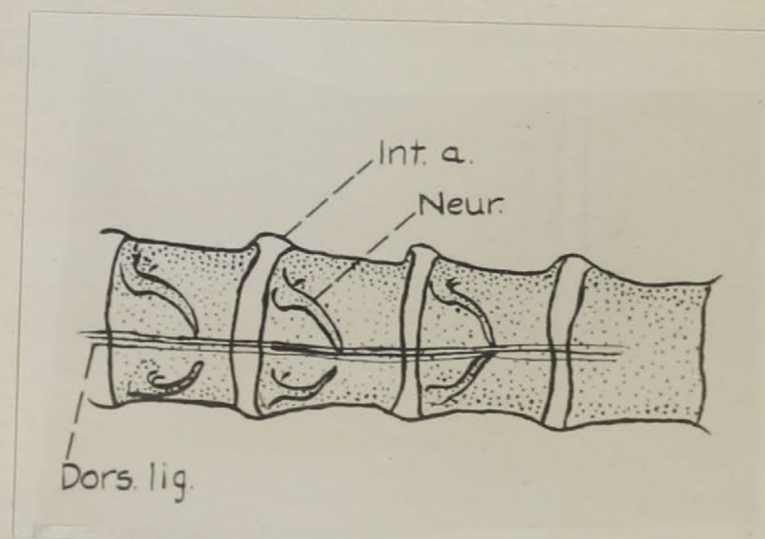


Fig.24

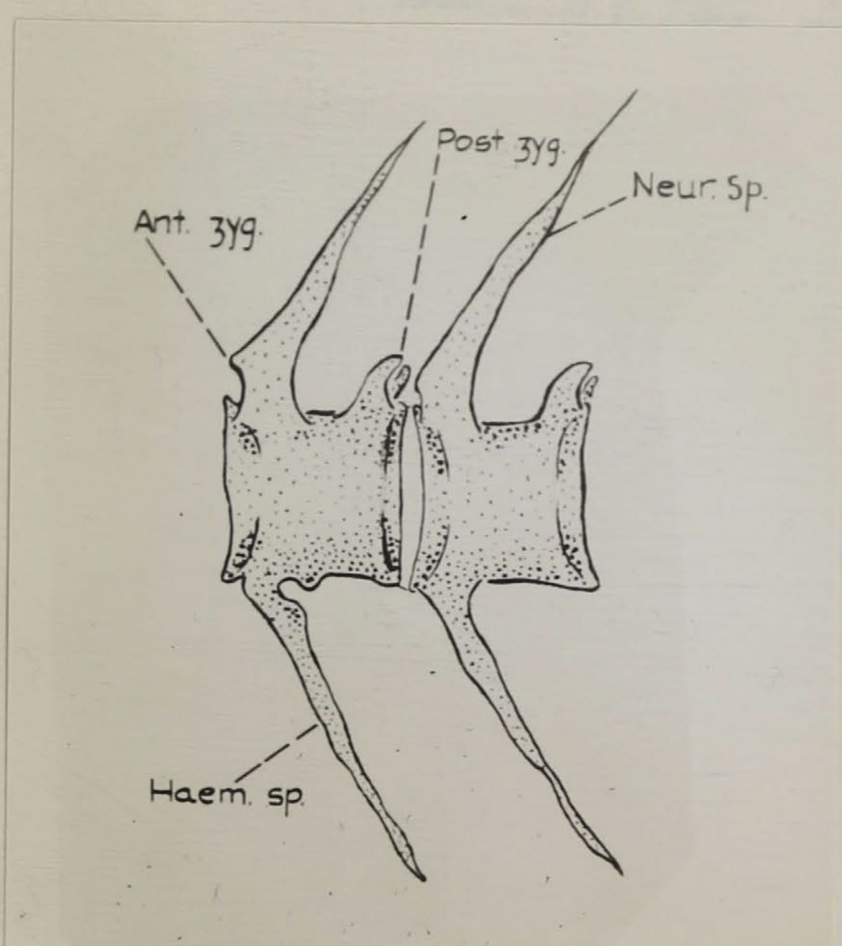


Fig.25

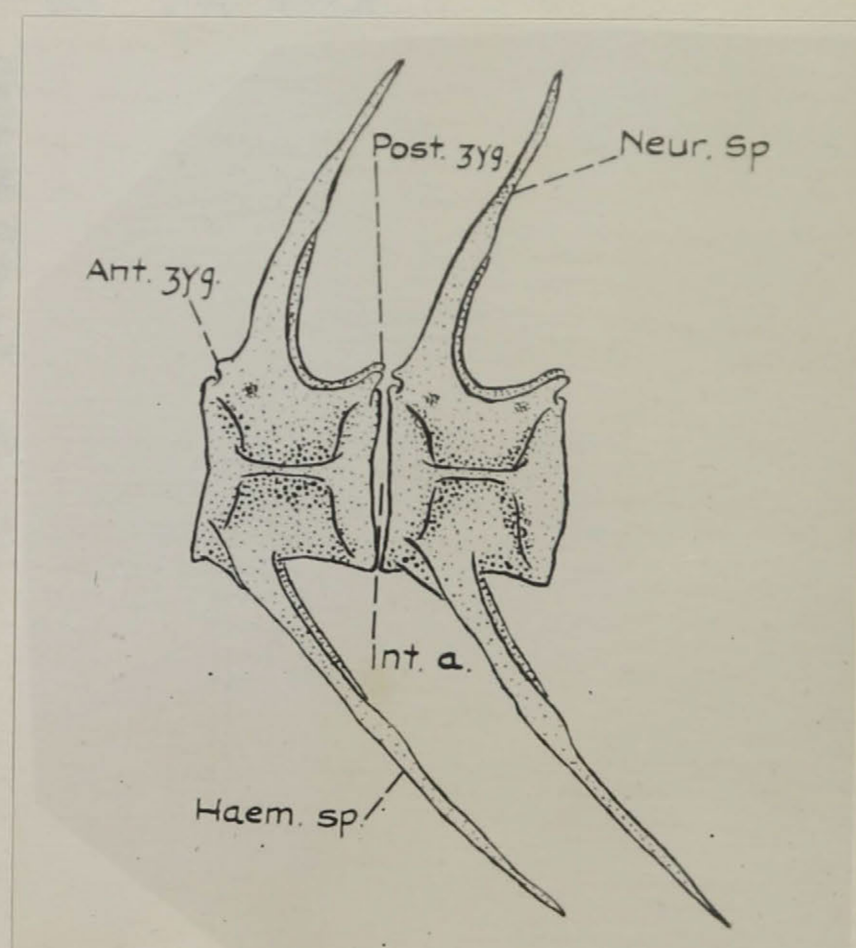


Fig.26

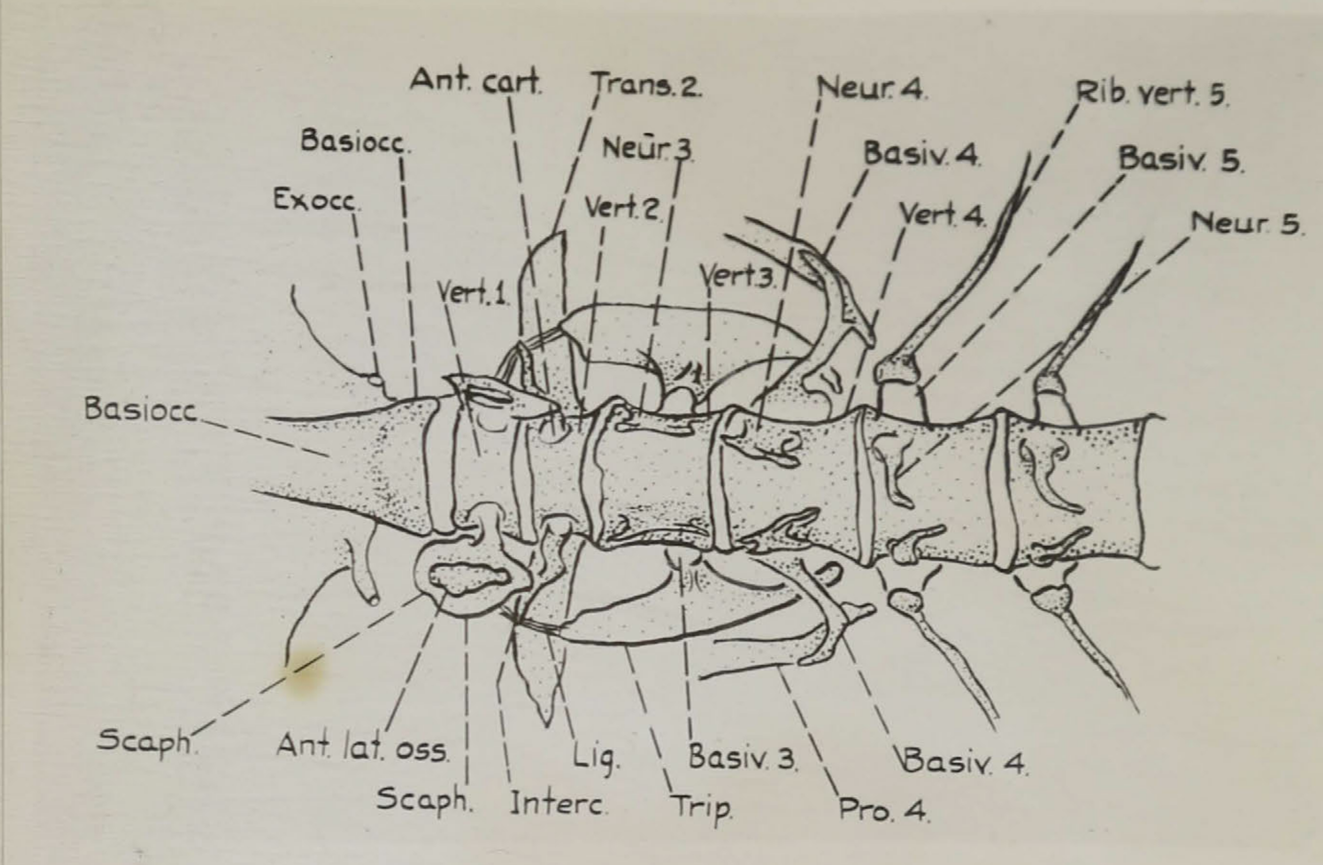

Ant. cart.
Trans. 2.
Neur. 4.
Rib. vert. 5.
Basiocc.
Neur. 3.
Basiv. 4.
Basiv. 5.
Exocc.
Vert. 2.
Vert. 4.
Neur. 5.
Vert. 1.
Vert. 3.
Basiocc.
Scaph.
Ant. lat. oss.
Scaph.
Interc.
Lig.
Trip.
Basiv. 3.
Pro. 4.
Basiv. 4.

Fig.27

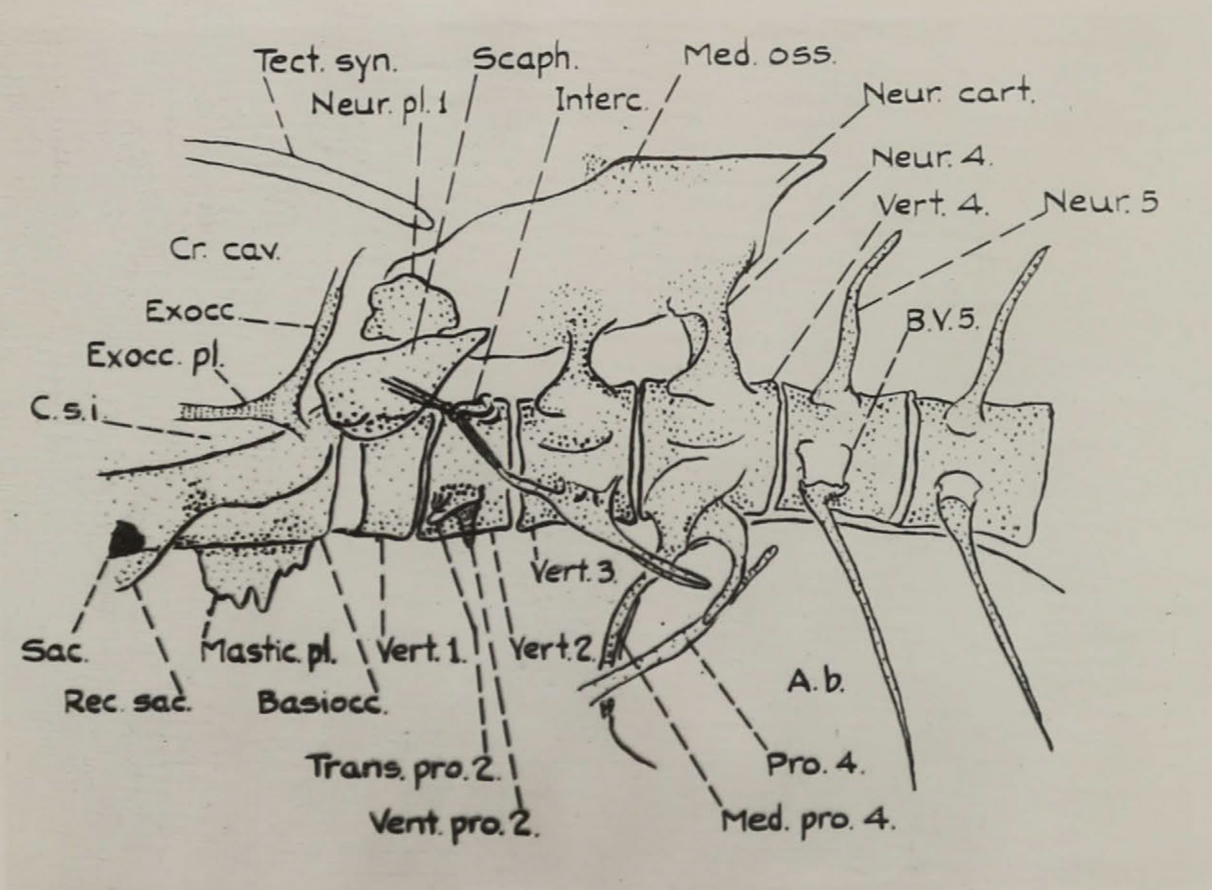

Tect. syn.
Scaph.
Med. oss.
Neur. pl. 1
Interc.
Neur. cart.
Neur. 4.
Vert. 4.
Neur. 5
Cr. cav.
Exocc.
Exocc. pl.
B.V. 5.
C.s.i.
Vert. 3.
Sac.
Mastic. pl.
Vert. 1.
Vert. 2.
A.b.
Rec. sac.
Basiocc.
Trans. pro. 2.
Pro. 4.
Vent. pro. 2.
Med. pro. 4.

Fig.28

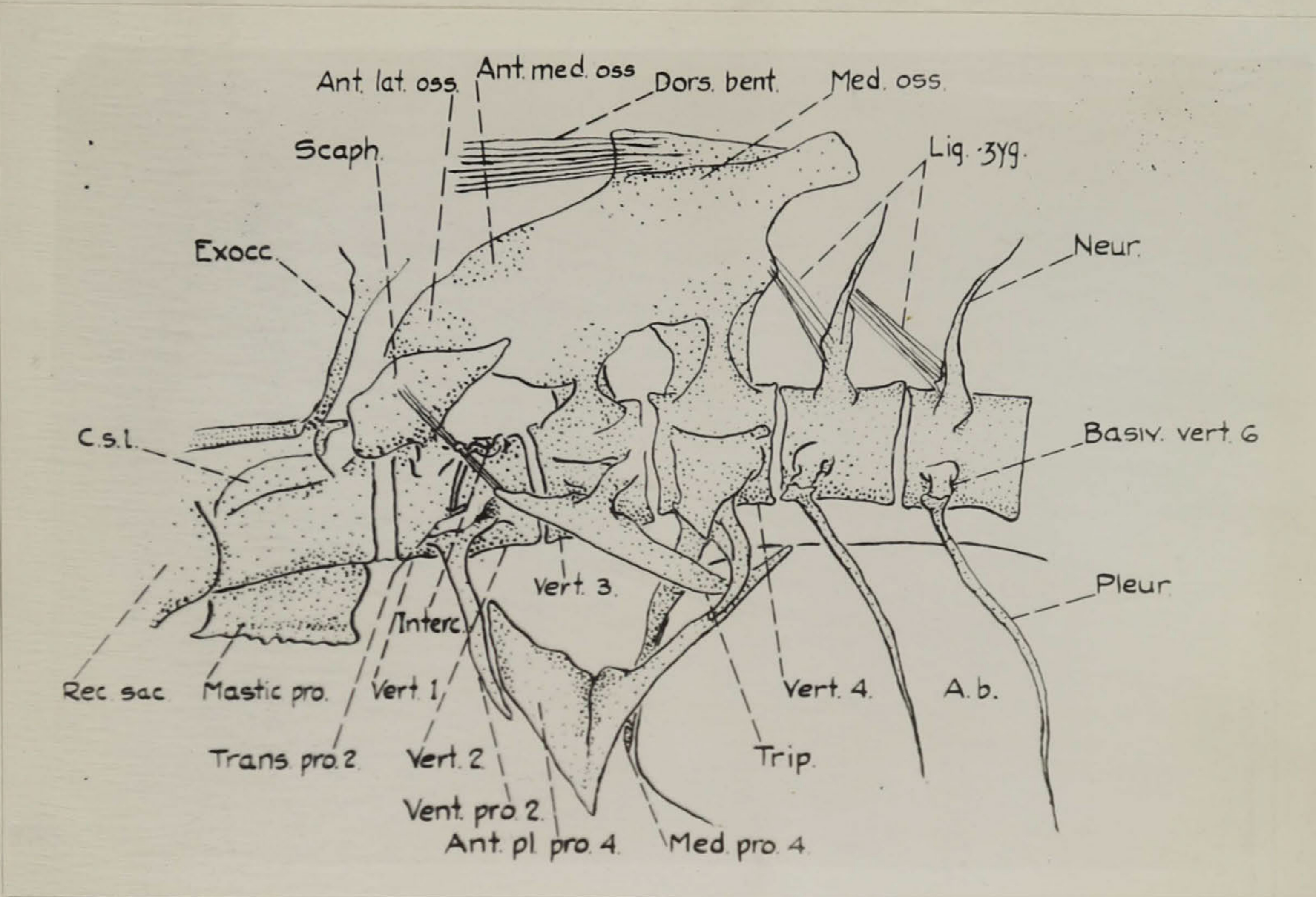

Ant. lat. oss.
Ant. med. oss
Dors. bent.
Med. oss.
Scaph.
Lig. 3yg.
Exocc.
Neur.
C.s.l.
Basiv. vert. 6
Vert. 3.
Pleur.
Interc.
Rec. sac
Mastic pro.
Vert. 1
Vert. 4.
A. b.
Trans. pro. 2
Vert. 2
Trip.
Vent. pro. 2.
Ant. pl. pro. 4.
Med. pro. 4

Fig. 29

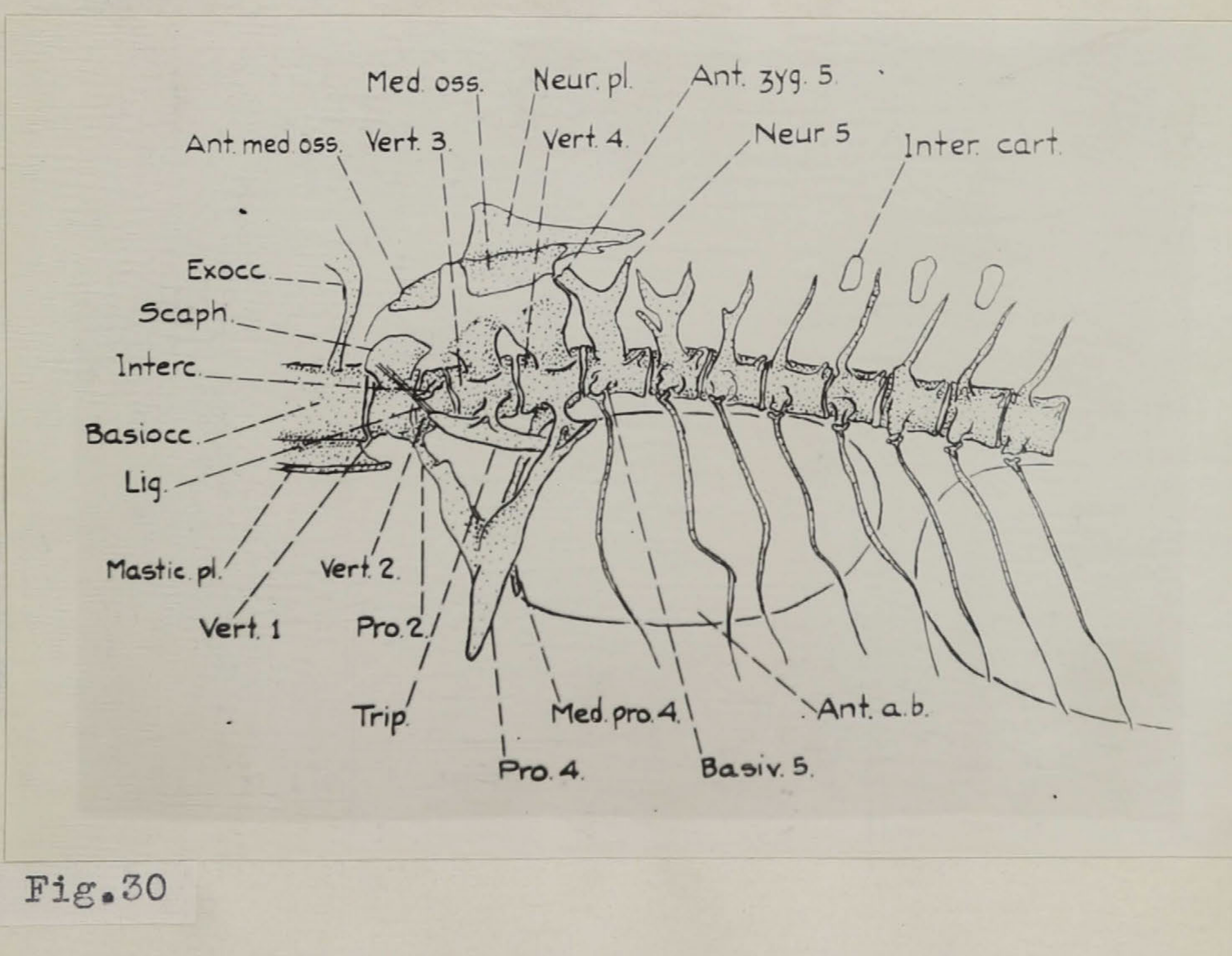

Med. oss.
Neur. pl.
Ant. 3yg. 5
Neur 5
Ant. med. oss.
Vert. 3.
Vert. 4.
Inter. cart.
Exocc.
Scaph.
Interc.
Basiocc.
Lig.
Mastic. pl.
Vert. 2.
Vert. 1
Pro. 2.
Trip.
Med. pro. 4.
Ant. a. b.
Pro. 4.
Basiv. 5.

Fig. 30

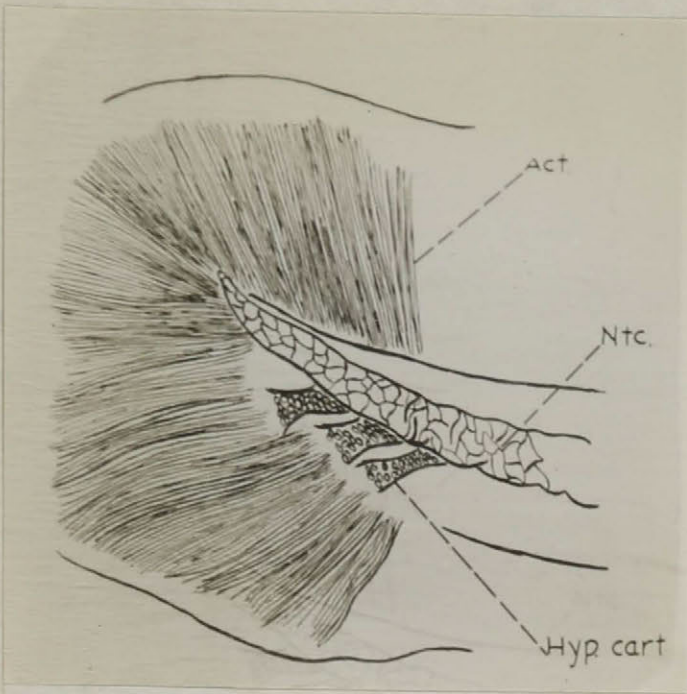


Fig.31

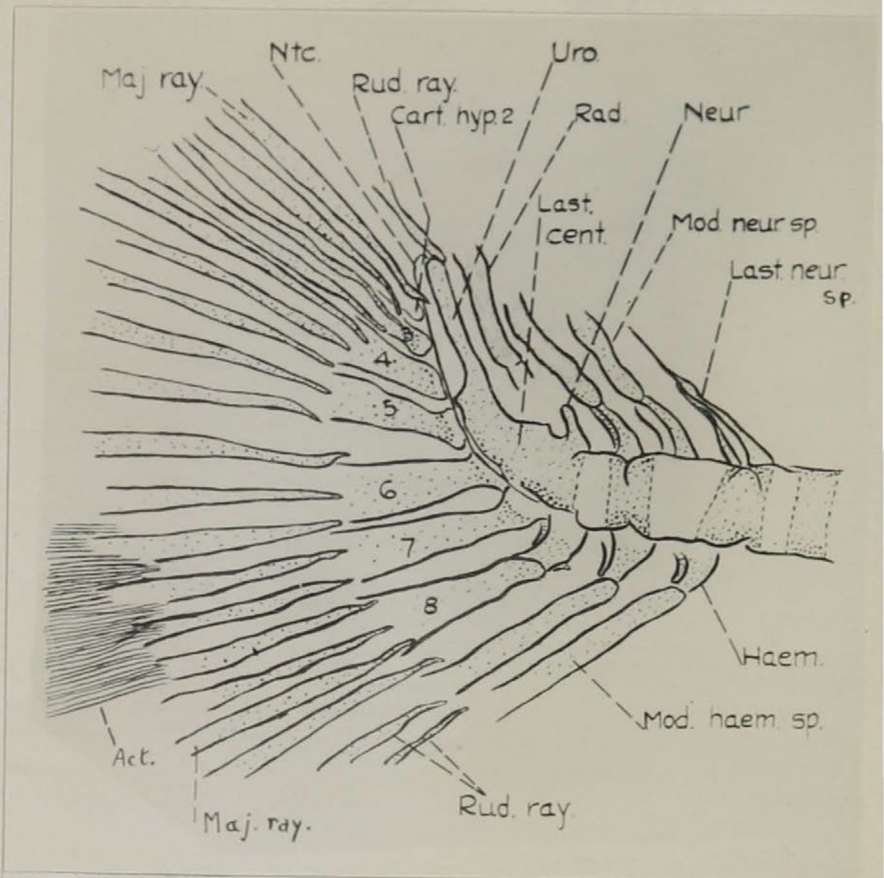


Fig.32

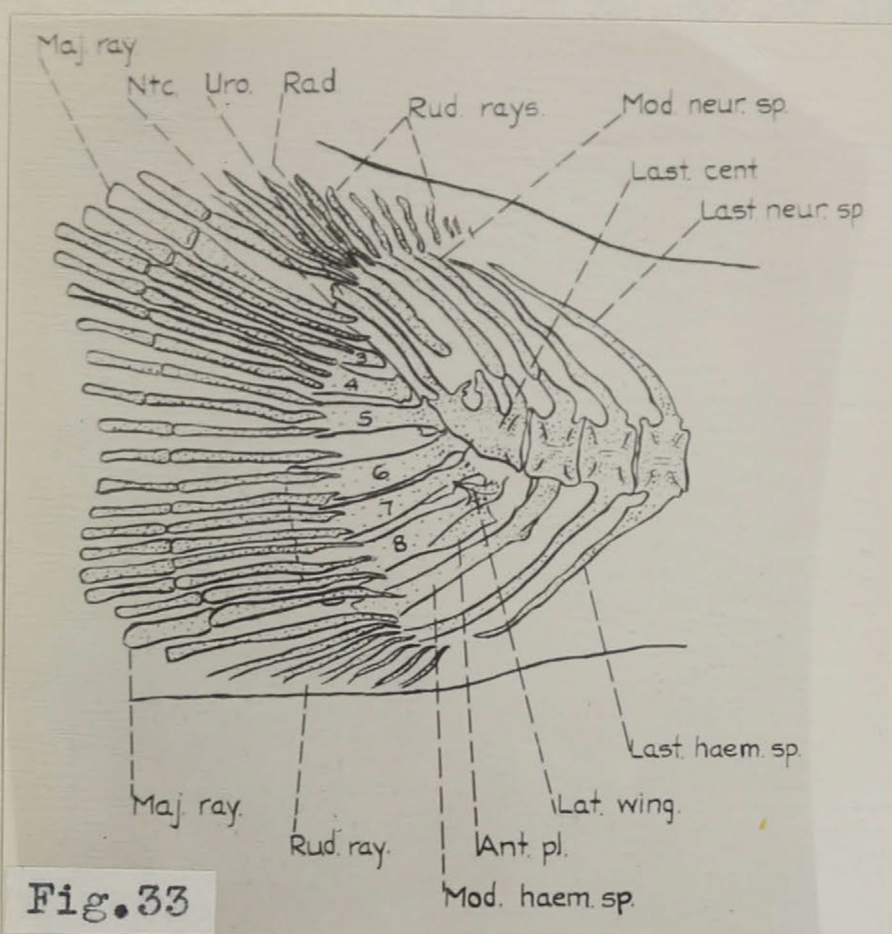


Fig.33

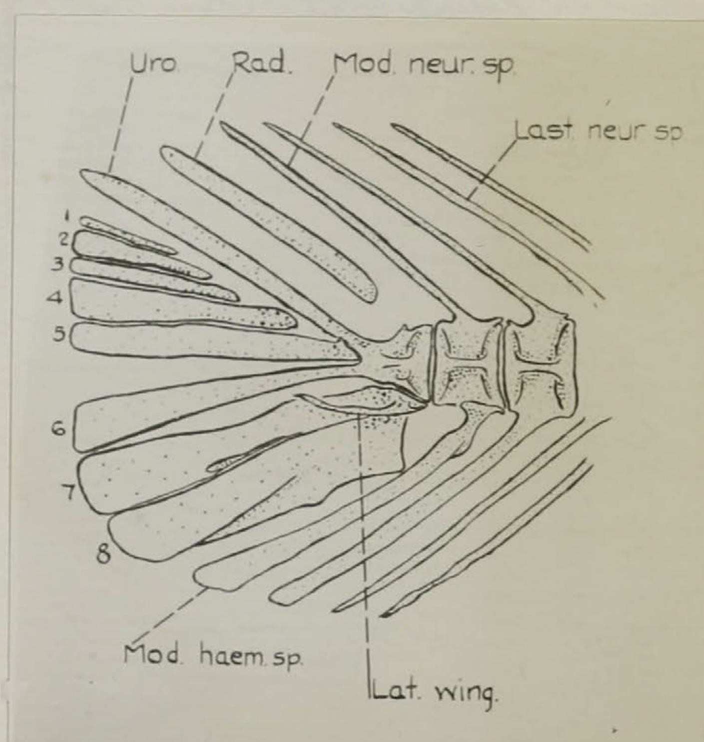


Fig.34

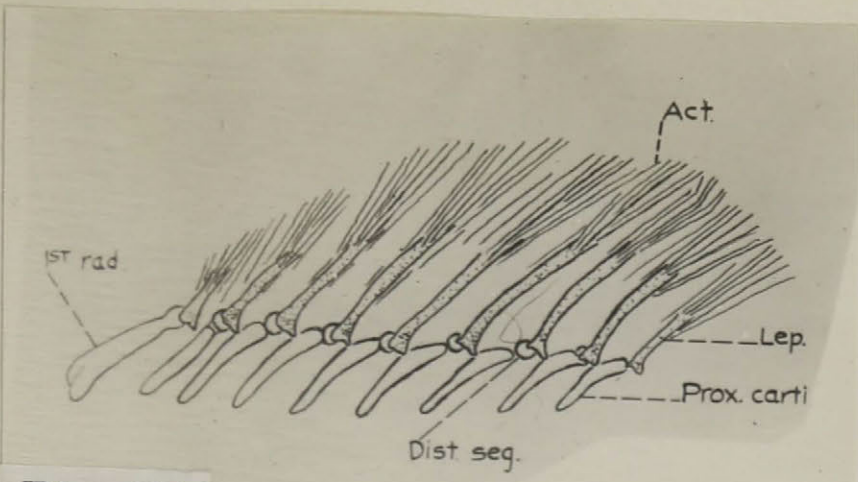


Fig.35

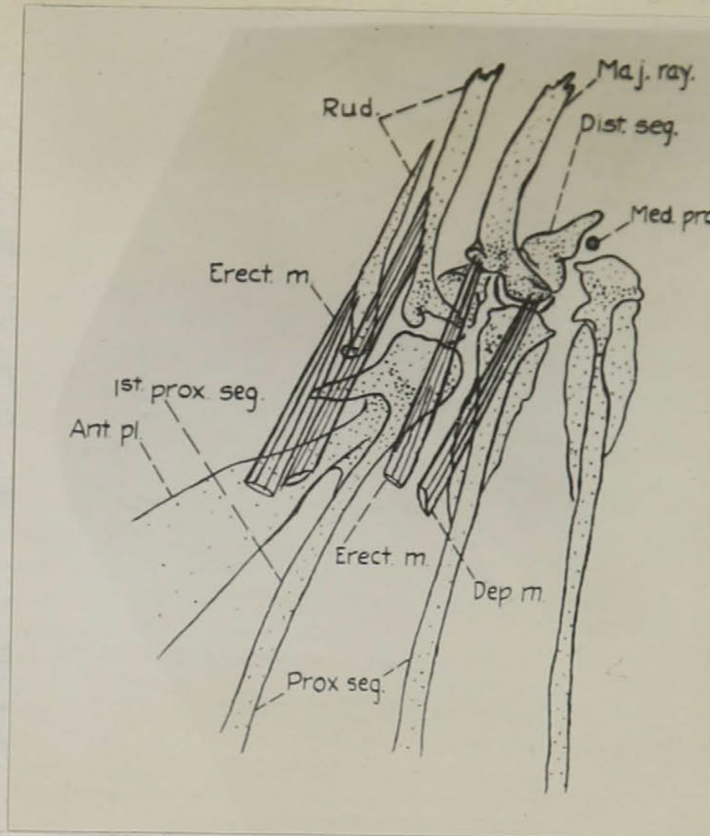


Fig.36

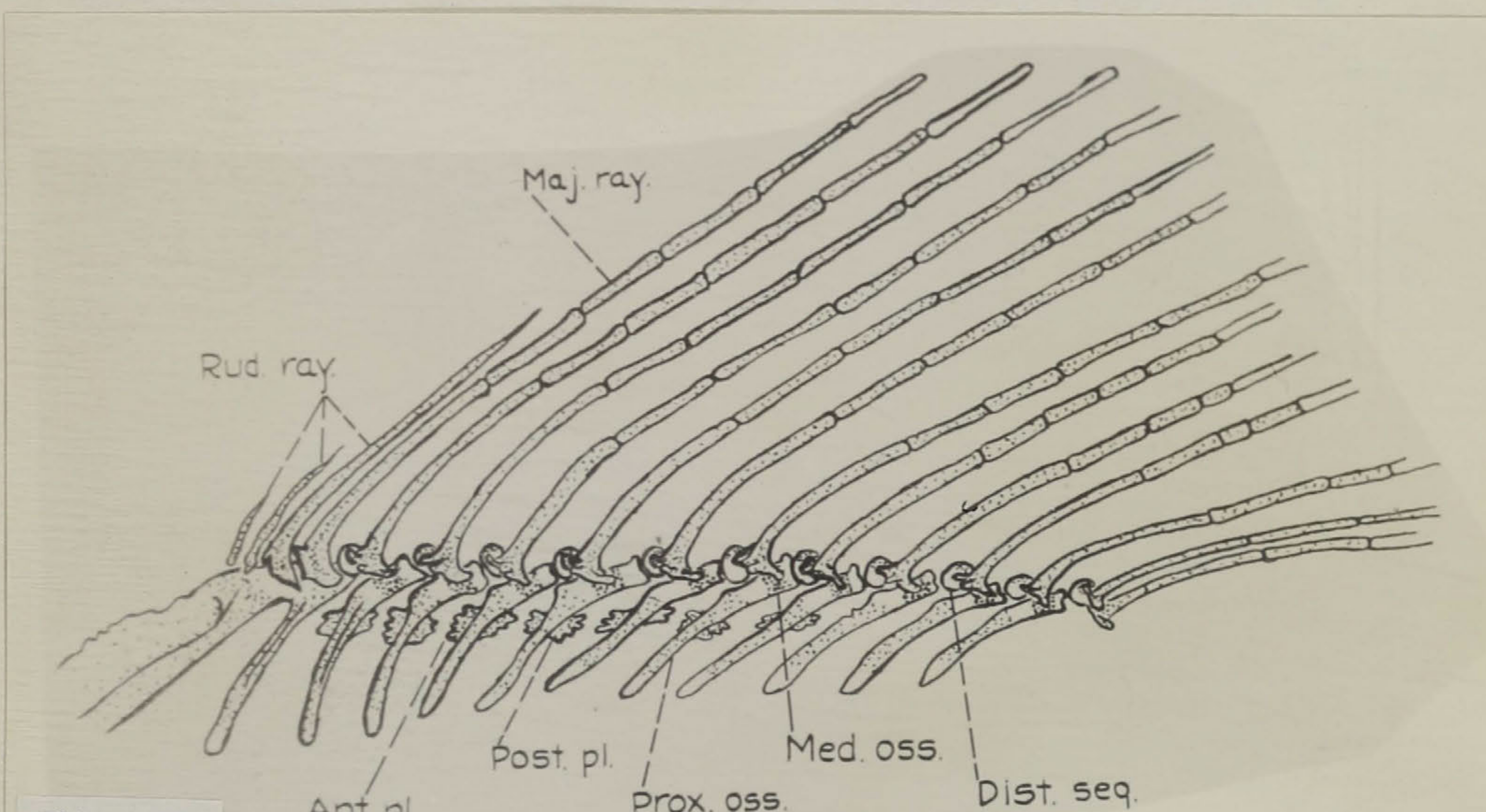


Fig.37

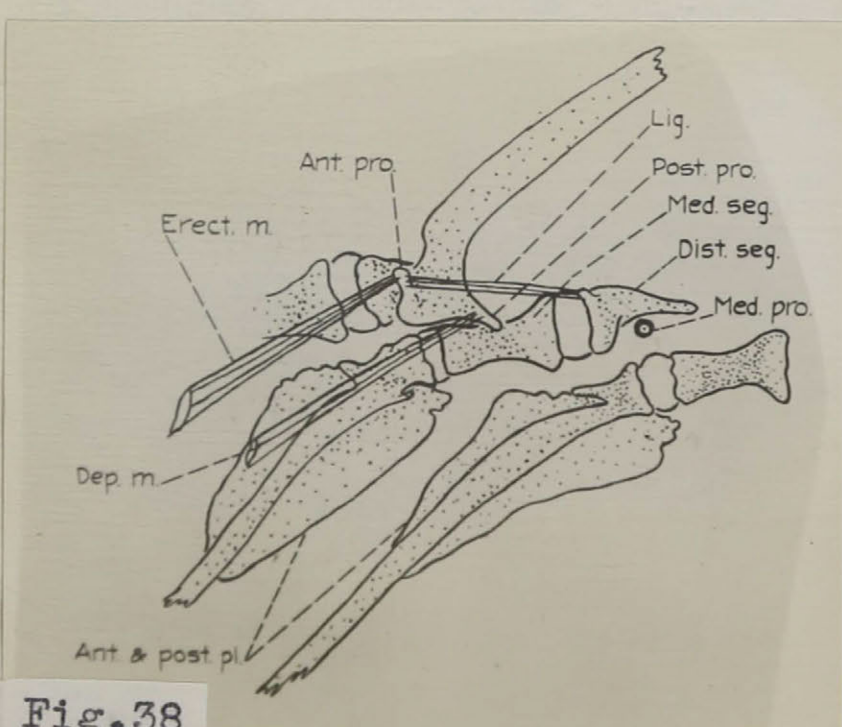


Fig.38

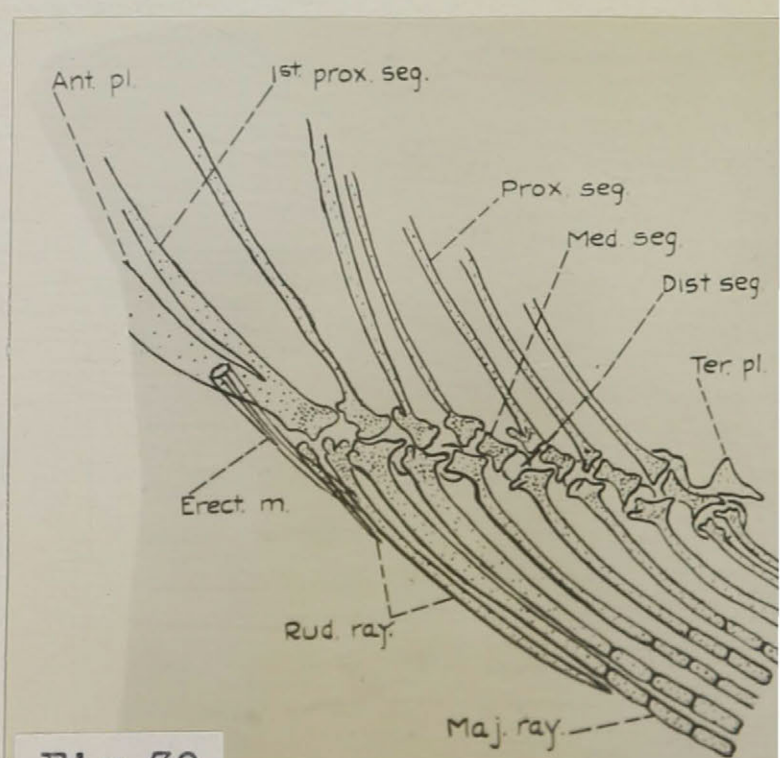


Fig.39

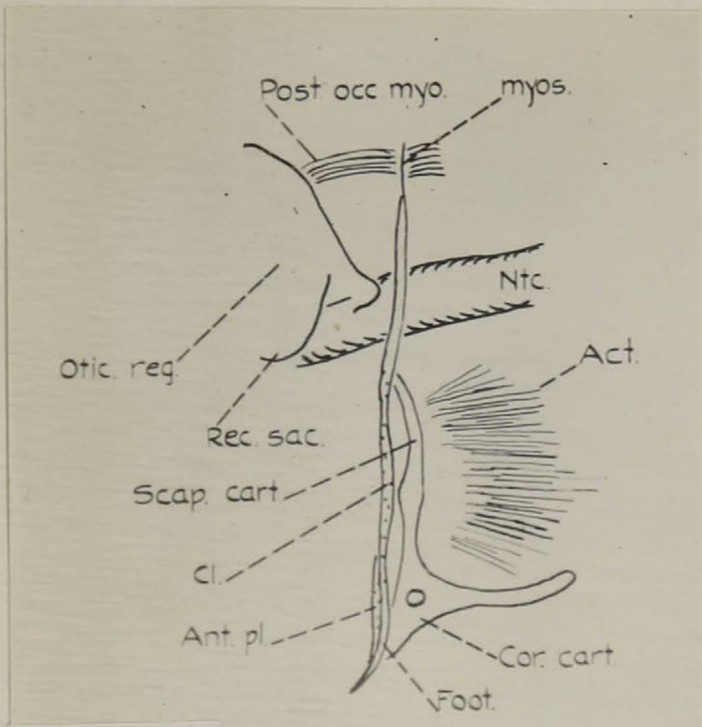


Fig. 40

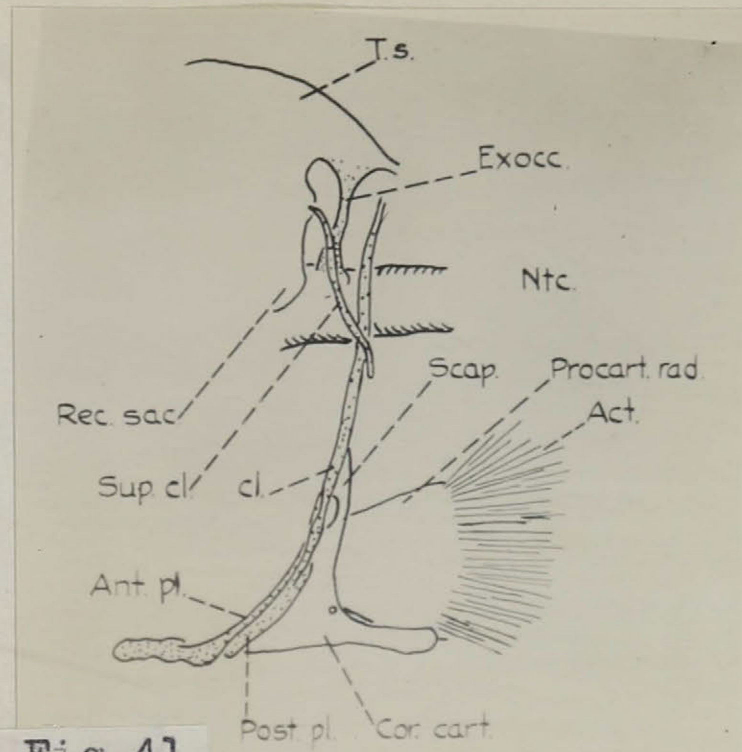


Fig. 41

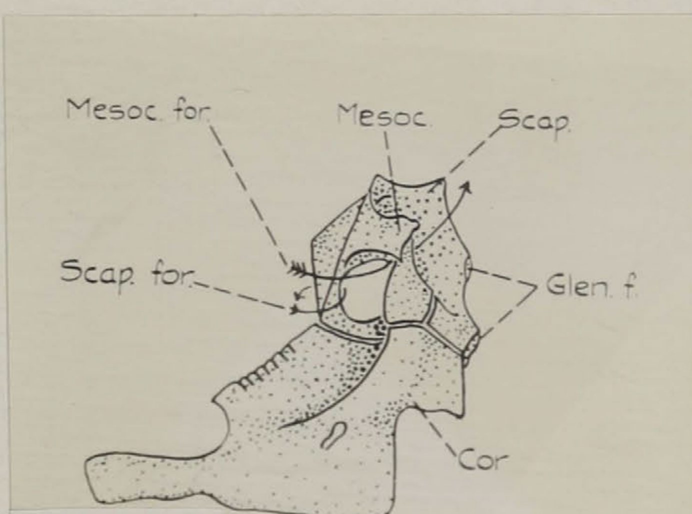


Fig. 42

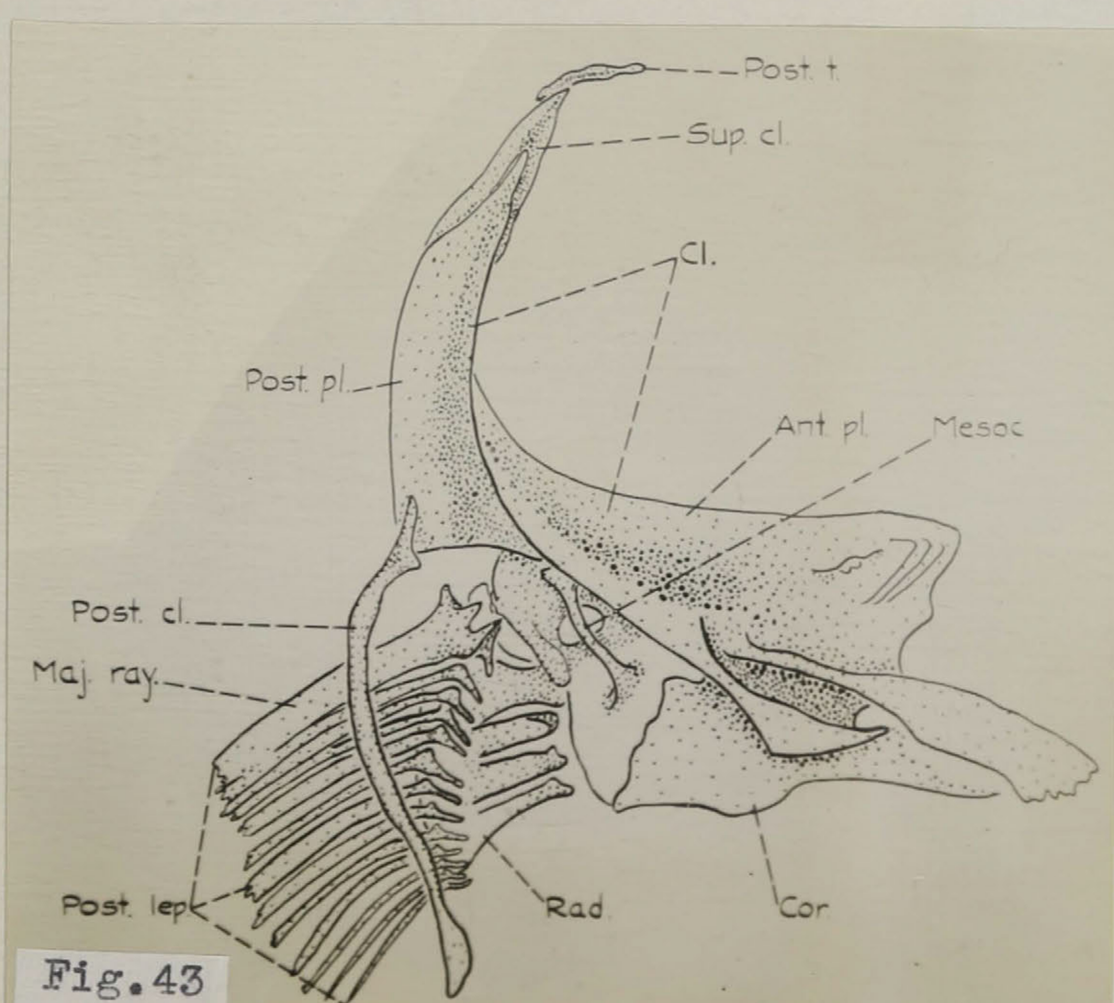


Fig. 43

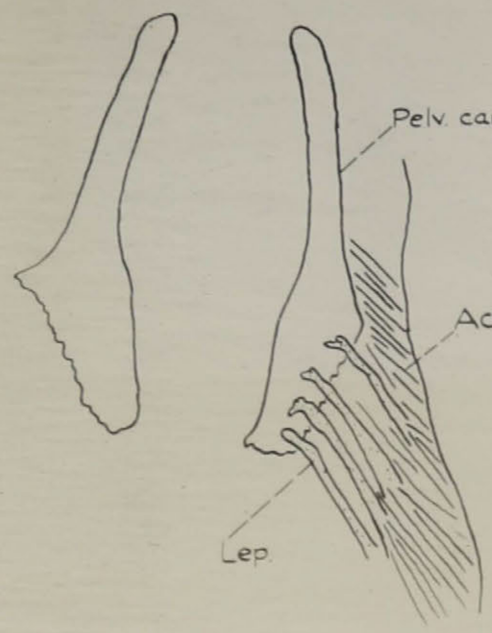


Fig.44

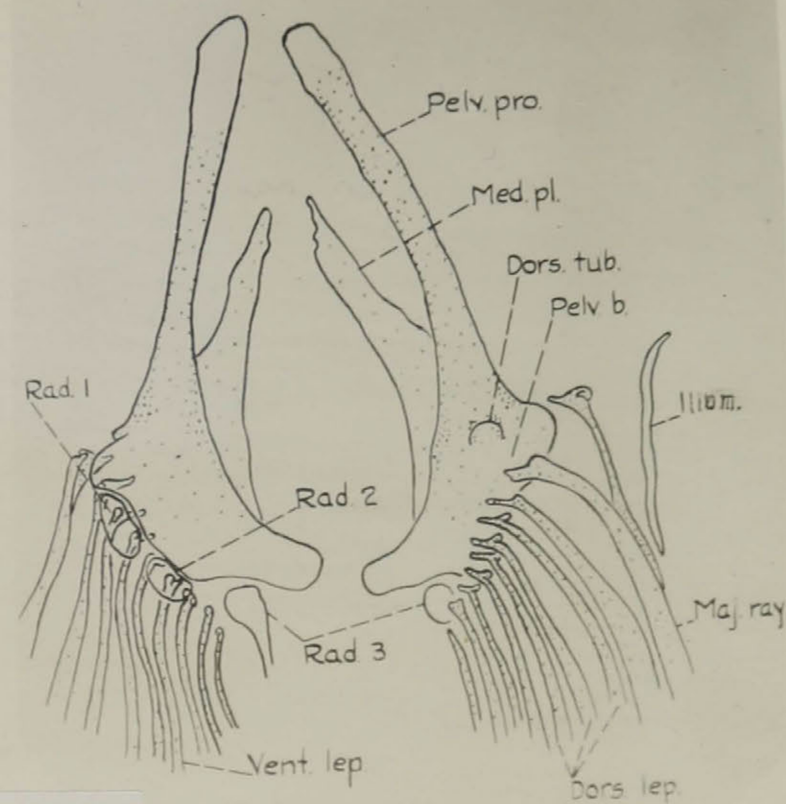


Fig.45

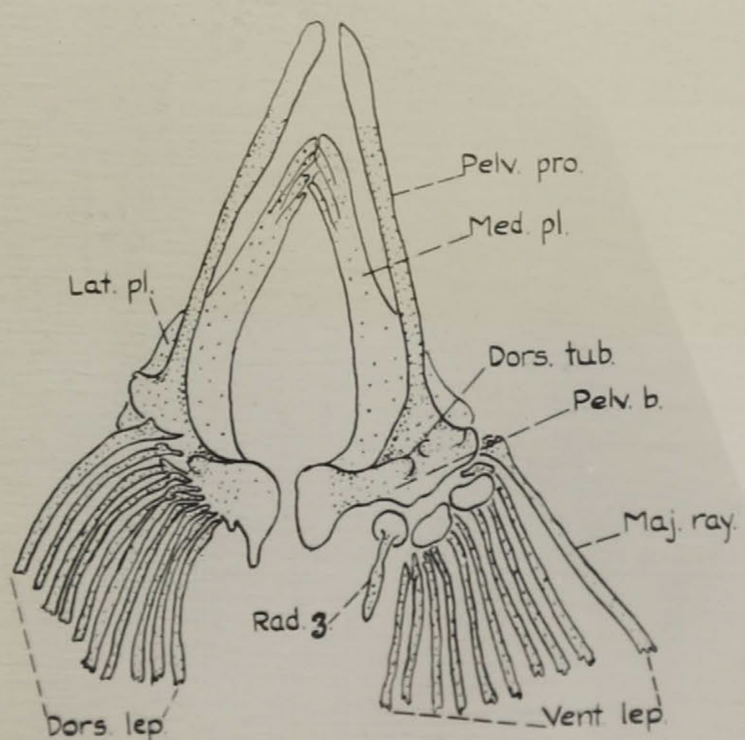


Fig.46

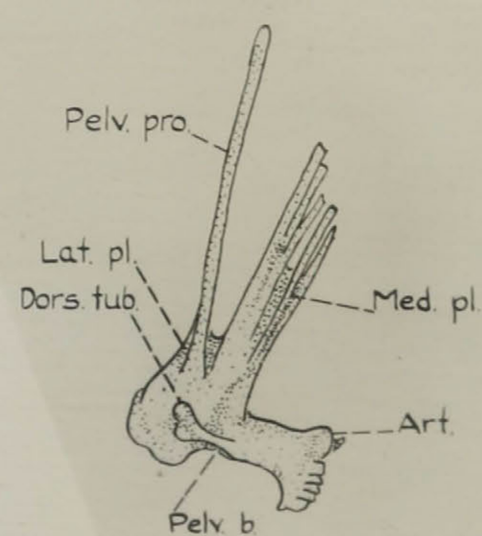


Fig.47

1.

11.

111.