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Comparative morphology of the Osteocranium in three species of the genus with a note on its utility in Taxonomy (Ariidae : Siluriformes)

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COMPARATIVE MORPHOLOGY OF THE OSTEOCRANIUM IN THREE SPECIES OF THE GENUS *ARIUS* WITH A NOTE ON ITS UTILITY IN TAXONOMY
(ARIIDAE : SILURIFORMES)

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INTRODUCTION

It is a well known assertion that for any phylogenetic interpretation, especially of the vertebrate phyla, the organisation of the basic structural pattern and anatomical features are the essential base. From Agassiz's time (1857) the internal skeletal structure and the associated modifications as reflected in the external morphology have been utilized for classifying the families and the genera of fishes. One of the reasons for depending upon the basic skeletal structure, perhaps lies in the consistency of various bones in the particular taxa. Absence or presence of major bone elements, extent of fusion of different bones and also the nature of their interdigitations have all been used as indicators of the taxonomic status of various taxa.

The fishes belonging to the family Ariidae have attracted the attention of several workers from an osteological viewpoint (Bhimachar, 1933 ; Shelden, 1937 ; Berg, 1947 ; Bamford, 1948 ; Berrill, 1950 ; Karandikar and Masurekar, 1954 ; Tolentino and Clement, 1958 ; Srinivasachar, 1958 ; Hubbs and Miller, 1960 ; Tilak, 1965 ; Alexander, 1966 ; McAllister, 1968 ; Lenous, 1968). Tilak (1965) published a comparative morphology of the osteocranium and the Weberian apparatus of 14 species of the family Ariidae (=Tachysuridae). Still further information is required so as to have a comprehensive account of the comparative morphology of the osteocranium in various species of the genus *Arius*.

The osteocranium of three species of the genus *Arius, A. arius* (Hamilton), *A. caelatus* Valenciennes and *A. thalassinus* (Riippell) have been described. These species belong to three different species complexes comprising more than two related species whose specific

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identity is in a state of confusion (Dhanze and Jayaram, 1982).

Material and methods :

The material presented in this paper is based on the collection of fresh specimens made by the authors of *A. arius*, *A. caelatus* and *A. thalassinus* from the eastern coast of India, mainly at Portonovo and Mandapam in Tamil Nadu and Hooghly estuary in West Bengal. Twenty skulls of each species belonging to different size groups (90—450 mm in SL) and sex were prepared by slightly modified "Trypsin and KOH maceration methods" as proposed by Taylor (1967).

Two skulls of each species were disarticulated by further maceration in 2% ammonia solution in hot water in order to study the exact shape of each bone and the nature of its articulation. Finally, all the articulated and disarticulated skeletons were bleached in a 50% solution of commercial hydrogen peroxide and dried in sunlight.

Small specimens (below 150 mm SL), after the completion of maceration, were washed in tap water and stained with alizarin red to study the disposition of various bones *in situ*. The alizarin transparencies were cleared in series of glycerine solution and finally preserved in 100% glycerine. All the observations pertaining to articulation of different bones were made with a stereo-binocular microscope and the drawings were made or produced with the aid of a camera lucida. The bones of circumorbital series, illustrated in the dorsal aspect of the skulls are diagramatic representations. The nomenclature adopted here is mainly after Harrington (1955), Patterson (1957) and Howes (1983) or otherwise discussed under the description of respective bones where some other name is considered more appropriate.

Observations :

In all the three species of the genus Arius *(A. arius, A. caelatus, A. thalassinus)* the skull or the osteocranium (=syncranium, Gregory, 1933) is a well ossified, compact and massive structure. When viewed from its dorsal aspect, it is more or less wedge shaped, with certain projections in various directions such as the supraoccipital process, epioccipital lamellae, supracleithrum and lateral ethmoid's anterior process. Dorsally most of the bones are well ossified ; the fronto-occipital surface is granulated and destitute of skin, the region is covered by only a thin epidermis. The sutural connections in this region are dovetailed to such an extent that sometimes, in large specimens it is difficult to locate the sutures without disarticulation.

The cranial cavity does not extend anteriorly beyond the orbitosphenoid thus the skull is not platybasic (Bhimachar, 1933) unlike other siluroids (Tilak, 1965). The skull is longer than its width which is at maximum at otic region. For the sake of descriptive study of each bone and the enumeration of specific osteological features, the osteocranium is divided into the neurocranium and the branchiocranium, after Gregory (1933). Further subdivisions of these two regions follows Harrington (1955).

1. NEUROCRANIUM

Based on the functional morphology, the neurocranium of fishes may be said to comprise four distinct regions : olfactory, orbital, otic and basicranial regions. In the three species considered here the basic gross contour of the neurocranium is interspecifically variable, besides the individual variations in different bones constituting it. Seen from its dorso-ventral aspect, the cranium is deeply constricted in the orbital region in *A. arius* and *A. caelatus,* whereas in *A. thalassinus* no such constriction is seen since the lateral margins run almost parallel to each other (pl. 1, figs. I-III). In *A. arius* and *A. caelatus* the supraoccipital process is broader at its base than it is long and the temporal fenestrae are present whilst in *A. thalassinus* the supraoccipital process (SOCP) is longer than its width and the temporal fenestrae (TEO) are absent. The roof of the cranial cavity is incomplete inasmuch as the different bones are separated by three median longitudinal fontanels, *viz :* an anterior (AF), median (MF), and posterior (PF). The shape of the median fontanel is interspecifically variable, being cylindrical in *A. arius* ; conical in *A. caelatus* and dumbell shaped in *A. thalassinus.* The lateral fenestrae (LF) are uniformely present in all the three species, are enclosed by the posterior process of the lateral ethmoids (PLETH) and the anterior processes of the frontals. It is worth mentioning here that these fenestrae are taxonomically important and can be used to distinguish the species of the genus *Arius* (see p. 8). The anterior process of the lateral ethmoid is backwardly directed in *A. arius* and *A. thalassinus* while outwardly in *A. caelatus*. The posterior process of the same bone is narrow and slender in *A. arius* and *A. caelatus* while broad and flat in *A. thalassinus*. (pl. 1, figs. I-III).

It is worth noting that in the above cited species specific osteological features such as the general contour of the neurocranium and the shape of lateral ethmoid are also reflected to some extent in the external morphology of these fishes. Further, detailed variations in different bones are dealt with as below :

1.1. OLFACTORY REGION : This region comprises of endochondral bones : paired lateral ethmoids (LETH) and median, unpaired ethmoid (ETH) ; dermal bones : paired nasals (N) and median, unpaired vomer (VO).

1.1.1. *Ethmoid* (ETH) : The ethmoid (=supraethmoid of Tilak, 1965) is a long median bone situated between the olfactory capsules and forming the anterior most part of the neurocranium. Its tip bears a medial notch, and two horn-like cornua extend laterally over the premaxillaries. Posterodorsally the bone is bifurcated and thus forms the anterolateral boundary of the anterior fontanel (AF) ; the two processes of the bone ultimately suture with the dorsal protuberance of the orbitosphenoid (ORSP) and the frontals (FR). Laterally, on either side, the ethmoid articulates with each lateral ethmoid (LETH), and ventrally with the vomer (VO) and the parasphenoid (PSP). Both the postero-dorsal and postero-ventral articular surfaces split up into a number of osseous spicules, which provide a firm interdigitation with the corresponding spicules of respectively the frontals and the parasphenoid. Among the three species studied, there is little variation with respect to the shape and disposition of the ethmoid. If at all, such differences are in the relative size of the various projections of the bone such as antero-lateral cornua being relatively longer in *A. caelatus* as compared to *A. arius* and *A. thalassinus* and the posterior projections being broader in *A. thalassinus* and *A. caelatus* than in *A. arius*. However, such variations are gradual and associated with the extent of ossification of the bone (pl. 1, figs. I-III ; pls. 4-6, fig. 1).

1.1.2. *Lateral ethmoids* (LETH) : The paired lateral ethmoids (=ectethmoids of Tilak, 1965) are complex endochondral and perichondral bones situated on either side of the ethmoid (ETH) with which bone are sutured. Each bone comprises a broad, round, basal head and two lateral projections which enclose the olfactory foramen in continuation with the orbitosphenoid (ORSP) posteriorly for the passage of olfactory nerve. Antero-laterally the bones possess engraved surface to which the lachrymals (LA) attach ligamentously. The disposition of the anterior projections are interspecifically variable. In *A. arius* and *A. thalassinus* the projections are inclined backward at an angle less than 60° to the midline whereas in *A. caelatus* they form an angle more than 90°. In all the three species each bone articulates posterodorsally with the frontals (FR) via two facets (Tilak, 1965). No suture is formed at the inner facet, the ånterior projection of the corresponding frontal merely overlaps the lateral ethmoid. The outer facet is sutured with the corresponding frontal's cornua, resulting in the formation of the lateral fenestrae (LF) (see p. 8). It may be noted that these fenestrae are absent in some other species of the genus *Arius* such as in *A. sagor* (Bhimachar, 1933 ; Tilak, 1967) and *A. dussumieri*. Moreover, the shape and size of the posterior processes of the lateral ethmoid differ inter-specifically amongst those species studied. In *A. arius* and *A. caelatus* each process is narrow and slender whereas in *A. thalassinus* it is broad and flat. Antero-ventrally each bone articulates with the lateral extensions of respectively the vomer and the orbitosphenoid and is slightly overlain by the anterior projections of the parasphenoid (PSP). The ventral aspect of each lateral ethmoid is completely covered by toothed 'dermopalatine' (ectopterygoid of Tilak, 1965), the shape of which varies considerably inter-specifically and is discussed elsewhere in this paper (see p. 18). From the foregoing account it is evident that the lateral ethmoids are taxonomically important bones whose morphology is useful for distinguishing the species of the genus *Arius* (pl. 1, figs. I-III, pls. 4, 6, fig. 4).

1.1.3. *Nasals* (NA) : These are the paired lamellar, tubular bones embeded in the connective tissue on either side of the ethmoid

(ETH). In all the three species they extend from the antero lateral cornua of the ethmoid to the anterior projection of the frontals on the dorsal side of the neurocranium. The morphology of the nasals varies little amongst the three species. However, some intraspecific variation associated with growth are noted, (pl. 1, figs. I-III ; pls. 4-6 fig. 3).

1.1.4. *Vomer* (VO) : The vomer (=pre-vomer of Tilak, 1965) is a small median, unpaired 'T' shaped bone situated on the mid ventral surface of the ethmoid (ETH). Its lateral extensions articulate with the antero-ventral aspect of the lateral ethmoid on either side while the long, tapered posterior shaft articulates with the ventro-mesial surface of the ethmoid and anterior projections of the parasphenoid (PSP). In all the three species the lateral extensions of the vomer are covered by the toothed 'dermopalatine' (pl. 2, figs. I-III ; pls. 4-6, fig. 5).

1.2. ORBITAL REGION : This region is composed of cartilage bones : median orbitosphenoid (ORSP), paired pterosphenoids (PTSP) ; dermal roofing bones (all paired) : laehrymals (LA), suborbitals 2-3 and frontals (FR).

1.2.1. *Orbitosphenoid* (ORSP) : It is a large median bone dorsoventrally sandwitched between the frontals and the parasphenoid. The antero-lateral wing-like extensions articulate with the ethmoid mesially, and the lateral ethmoid antero-laterally. At the junction of the ethmoid (ETH) and frontals, it protrudes dorsally and forms the fontanel bridge that separates the anterior fontanel (AF) from the median fontanel. The anterior extension of the cranial cavity is restricted by the dorsal protubrance of the orbitosphenoid which is a characteristic feature of the species of the family Ariidae. The orbitosphenoid encloses the olfactory foramina in continuation with the lateral ethmoid (LETH) anteriorly. Posteriorly, it forms the anterior, ventro-lateral walls of the cranial cavity and also contributes to the optic foramina on either side in conjunction with the lateral extensions of the parasphenoid, the pterosphenoids (PTSP), and the frontals (FR). Although the three species studied do not differ strikingly in respect of the morphology of the orbitosphenoid, it may be mentioned here that in some other species such as *A. dussumieri*, the shape and disposition of this bone is quite different and distinct when compared with the rest of the species of the family Ariidae (to be dealt with elsewhere) (pl. 2, figs. I-III ; pls. 4-6, fig. 8).

1.2.2. *Pterosphenoids* (PTSP) : The pterosphenoids (alisphenoid of Bhimachar, 1933 ; pleurosphenoids of Joseph, 1960) are irregularly curved bones, broad at the distal end and tapering proximally. Dorsally, each bone articulates with the corresponding frontal (FR) and sphenotic (SPH) and ventrally with the lateral extensions of the parasphenoid (LEPSP). Anteriorly they contact the orbitosphenoid (ORSP). Each bone contributes to the formation of the cranial cavity on either side. The inner surface of the pterosphenoid is concave and smooth while its outer surface is irregular. At its anterior extremity each pterosphenoid forms the posterodorsal boundaries of the optic foramen and posterodorsally contributes to the trigeminofacial foramen. Postero-ventrally the bones articulate with the prootics (PRO). (pl. 2, figs. I-III). The shape and disposition of the pterosphenoids are more or less constant in the three species studied (pls. 4-6, fig. 9).

1.2.3. *Lachrymals* (LAC) : Each lachrymal is a curved bone situated antero-lateral to the nasal capsule. The distal end of each bone articulates with the respective lateral ethmoid. The proximal end of the bone is notched in *A. caelatus* and *A. thalassinus,* but blunt in *A. arius*. The homology and synonyms of the lachrymal have been discussed by Tilak (1965). It should not be confused with the 'antorbital' (Weitzman, 1962) and 'adnasal' of earlier workers since it bears an infraorbital sensory canal in continuation with the infraorbital series. The shape of this bone as noted above, varies interspecifically in *Arius* species (pl. 1, figs. I-III).

1.2.4. *Infraorbitals* (SO$_{1,2,3}$,) : The infraorbitals are paired dermal bones forming the antero-ventral, ventral and posterior boundaries of the orbits on either side. These are three large, stout and curved elements. The first infraorbitals (SO$_1$) articulates anteriorly with the distal end of the lachrymal and the anterior projection of the lateral ethmoid. The second infraorbital (SO$_2$) lies between the first and the third (SO$_3$) infraorbital which is attached ligamentously with the frontal and the sphenotic. These bones carry the suborbital or infraorbital sensory canal. There seems to be little differences in the morphology and disposition of these bones within the three species studied here (pl. 1, figs. I-III).

1.2.5. *Frontals* (FR) : These are two long flat dermal bones forming the largest part of the roof of the cranial cavity. In all the three species studied each frontal is bifurcated into an inner and outer projection. The inner prolongation of each frontal is the longer and further splits into fine spicules which interdigitate with the corresponding posterior projections of the ethmoid (ETH). This prolongation encloses the dorsal sensory canal which ultimately continues on to the respective nasal (NA). The outer prolongation is shorter than the inner one and is sutured with the posterior process of each lateral ethmoid, thus enclosing the lateral fenestra (LF) of either side.

Along the mid-dorsal line the two frontals are separated by the median fontanel (MF) and the posterior fontanel (PF). The median fontanel is bounded by the dorsal protuberance of the orbitosphenoid anteriorly and the fontanel bridge (the inner extensions of each frontals are fused) posteriorly. The shape of this fontanel differs interspecifically, being cylindrical in *A. arius*, conical in *A. caelatus* and dumbbell-shaped in *A. thalassinus*. However, the relative size of this fontanel like that of other fontanel may vary intraspecifically, associated with the process of the ossification, and obviously with the age of the individual specimen. The posterior fontanel is very small and its posterior border is formed by the fusion of the frontals in *A. caelatus* and *A. thalassinus* while in *A. arius* the two frontals do remain separated and independently suture with the supraoccipital thus in this species the posterior boundary of the fontanel is formed by the supraoccipital. Posterolaterally each frontal articulates with the sphenotic (SPH) and overlaps the orbitosphenoid (ORSP) and the pterosphenoid mesially. The dorsal surfaces of both frontals are granulated except for the anterior projections which are smooth and ridged.

Earlier workers have reported only two fontanels along the midline of the skull of the ariids (Bhimachar, 1933 ; Tilak 1965). However, it may be noted that there are three distinct fontanels in most of the species of the genus *Arius*. The first (anterior fontanel, AF) being enclosed by the ethmoid and separated from the second (median fontanel, MF) by a dorsal protuberance of the orbitosphenoid (ORSP) thus severing its direct connection with the cranial cavity. The two other fontanels (median and posterior) are situated in the frontal region and represent the dorsal openings of the cranial cavity. Perhaps, this may be a characteristic feature of the fishes belonging to the family Ariidae since in most of the siluroids, either only one or two fontanels have been reported (Bhimachar, 1933 ; Nawar, 1954 ; Joseph, 1960 ; Mahajan, 1966 ; saxena and Moitra, 1963 ; Tilak, 1963 ; Jayaram, 1971) (pl. 1, figs. I-III ; pls. 4-6, fig. 7).

1.3. OTIC REGION : This region comprises the complex (endochondral and dermal origin) bones (all paired) : sphenotics (SPH), pterotics (PTR) ; cartilage bones : paired prootics (PRO), epioccipitals (EP), exoccipitals (EXOC) and unpaired median supraoccipital (SOC) ; dermal bones : paired posttemporals (ST), and supracleithrum (PT).

1.3.1. *Sphenotics* (SPH) : The sphenotics are complex paired bones, Each sphenotic is composed of the dorsal perichondral portion which is flat, dentated and sensory canal bearing, The ventromesial portion of the bone is ridged and endochondral and completely fused with the dorsal portion. In view of this complexity, it would not be proper to use the prefix 'auto' or 'dermo' in the species of Ariidae as advocated by Harrington (1955) in cyprinid fishes, since the terms indicate respectively either chondral or dermal ossification of the bones (De Beer, 1937). Each sphenotic articulates antero-mesially with the pterotic (PTR) and posteromesially with the supraoccipital (SOC). The dorsolateral sensory canal opens at the antero-lateral acute angle of this bone, the point where it is attached to the infraorbital$_3$ (SO$_3$). The shape of this bone varies interspecifically in the three species studied here. Viewed from its dorsal aspect it is pear shaped in *A. arius* and *A. caelatus* but somewhat rectangular in *A. thalassinus*. On its ventral side it articulates with the orbitosphenoid (ORSP) anteriorly, the prootic (PRO) mesially and the pterotic posteriorly. The ventro-lateral ridged surface of each sphenotic forms a well developed and grooved facet in conjunction with the pterotic (PTR) for the articulation of the hyomandibula (pls. 1,2, figs. I-III ; pls. 4-6, fig. 10).

1.3.2. *Pterotics* (PTR) : These are also paired complex bones having both dermal and chondral elements like the sphenotics. There has been considerable confusion regarding the nomenclature of this bone. Sagemehl (1891) called this bone 'squamosal' and Mc Murrich (1884) named it as pterotic. Kindred (1919) and Bhimachar (1933) considered it a compound bone derived from the dermal and the chondrocranial elements, thus named as 'squamosopterotic' But Westoll (1937) and others (as quoted by Harrington, 1955) have shown that the true squamosal is absent from the Actinopterygian skull. Harrington (1955) observed two different elements of this complex in the cyprinoids and named independently as dermopterotic and autopterotic. However, in the species of the genus *Arius,* studied by us the dermal and the chondral elements are completely fused together thus the name pterotic is more appropriate thereby avoiding the prefix 'auto' and 'dermo'.

In the three species *A. arius, A. caelatus* and *A. thalassinus,* each pterotic is roughly pentagonal in shape and forms the postero-lateral boundary of the auditory capsule. Dorsally each bone is granulated and lodges the dorsolateral sensory canal. It articulates with the sphenotic (SPH) anteriorly, the supraoccipital mesially, the supracleithrum (PT) and the posttemporal (ST) posteriorly.

In *A. arius* and *A. caelatus* the pterotic forms the anterior boundary of the temporal fenestra (TFO) while in *A. thalassinus* there is no such opening in this region. However, a small depression without dorsal granulations is uniformly present at the junction of the pterotics, the posttemporals and the supraoccipital in *A. thalassinus.* These features separate this species distinctly from the former two. The ventral margin of each pterotic articulates with the sphenotic (SPH) ; anteriorly, the epioccipital (EP , the posttemporal (ST), the supracleithrum posteriorly ; the prootic mesially ; and the exoccipital posteromesially. They also take part in the formation of articular facets for the articulation of the hyomandibulars in conjunction with the sphenotics anterolaterally (pls. 1,2, figs. I-III ; pls. 4-6, fig. 13).

1.3.3. *Prootics* (PRO) : These are large flat irregularly angular bones forming the antero-lateral wall and the major part of the floor of the auditory capsule. Anteriorly each bone forms the posterior border of the trigeminal foramen and articulates with the pterosphenoid (PTSP). Each prootic meets its fellow of the opposite side in the mid-ventral line above the parasphenoid and extends up to the junction of the basioccipital (BOC), thus also forming the base of the cranial cavity. But when viewed from the ventral aspect of the skull the two bones are separated by the parasphenoid (PSP) and the basioccipital (BOC) with which each bone articulates antero-mesially and postero-mesially respectively. Dorso-laterally, the anterior half of each bone articulates with the sphenotic (SPH) and posterior half with the pterotic (PTR) and posteriorly with the corresponding exoccipital (EXOC). There are no interspecific variations in respect of this bone in the three species under investigation (pl. 2, figs. I-III, pls. 4-6, fig. 12).

1.3.4. *Exoccipitals* (EXOC) : These are irregularly shaped bones situated laterally on either side of the foramen magnum. Each exoccipital meets its fellow of the other side along the ventromedian line above the cavum sinus imparis thereby forming its roof and the ventral and lateral boundaries of the foramen magnum. Posteriorly, the bone is pushed inwards vertically giving rise to an internal ridge which, in continuation with a small portion of a ridge in the supraoccipital, forms the posterior boundary of the otic recess. When views ventro-posteriorly the whole structure is bowl-shaped, with the anterior margin articulating with the prootic (PRO) and the pterotic (PTR), mesially with the basioccipital (BOC) and the trans-scapular ligament (=inferior limb) of the supracleithrum. Postero-dorsally each exoccipital articulates with the posttemporal (ST), epioccipital (EP) and the downwardly directed mesial ridge of the supraoccipital (SOC). Posteriorly, there is a backwardly directed, curved lateral ridge on each bone which may, extend to the epioccipital lamellae in the larger specimens. At the base of this ridge there are two foramina for the exit of the vagus nerve and the branchial branch of the glossopharyngeal nerve. Antero-ventrally towards the ventral median line there is another foramen for the exit of the palatine branch of the glossopharyngeal nerve. The shape and disposition of the exoccipitals are more or less constant in the three species (pl. 2, fig. I-III ; pls. 4-6, fig. 15).

1.3.5. *Epioccipitals* (EP) : The homologies of the epioccipitals (=Epiotics of Tilak, 1965) have been discussed by Patterson (1975). These are paired cartilage bone situated at the postero-dorsal angles of the skull, on either side of the supraoccipital process. Dorsally each epioccipital articulates with the Supraoccipital (SOC), the posttemporal (ST) and the Supracleithrum (PT) and ventrally with the exoccipital (EXOC) and the pterotic (PTR). It encloses thc posterior semicircular canal dorsally and a small foramen opens posteriorly at the base of its lamella. The posterior, downwardly directed broad epioccipital lamellae interdigitate firmly with the parapophysis of the fourth vertebra, a characteristic feature of ariid fishes (except *Galeichthys*, Regan, 1911). These lamellae are notched at the free distal end. The disposition of this bone varies interspecifically particularly with respect to the dorsal aspect and the contour of the skull. Among the three species studied only in *A. arius* the bone is seen dorsally at the junction of posttemporal and supraoccipital, whereas in the other two species it is overlapped by the above mentioned bones (pl. 1, fig. I-III ; pls. 4-6, fig. 19).

1.3.6. *Supraoccipital* (SOC) : This is a median cartilage bone, which is exceptionally large and forms the roof of the cranial cavity behind the frontals (FR). Anteriorly it articulates with the frontals and laterally with the sphenotics (SPH), the pterotics (PTR), the posttemporal (ST) and the epioccipitals (EP). Behind the occipital region the bone extends backwardly as the supraoccipital process (SOCP) which is notched in all the three species, although the relative size of this process varies interspecifically. In *A. arius* and *A. caelatus*, it is broader at its base than long while in *A. thalassinus* it is longer than broad. In *A. arius* the supraoccipital also forms the posterior boundary of the posterior fontanel (PF) whereas in the other two species it is excluded from the posterior fontanel by the fusion of the two frontals. The bone is uniformely granulated at its dorsal surface axcept for a small portion at the junction of the sphenotic, pterotic and posttemporal in *A. thalassinus*. On the mid-ventral surface of the bone, a thick downwardly directed mass of cartilage forms the postero-dorsal lamellar portion of the exoccipitals (EXOC), which excludes this bone from the foramen magnum. At the base of the cartilaginous portion in the centre, there are two pairs of prominent foramina, one above the other, for the exit of the auditory nerves. The shape and relative size of the supraoccipital seems to be species specific in distinguishing the species of the genus *Arius* (pl. 1, figs. I-III, pls. 4-6, 17).

1.3.7 *Posttemporals* (ST) : The homologies of posttemporals (=extra scapular of Fink & Fink, 1981—Supratemporal of Tilak, 1965) have been discussed by Lundberg (1975). They are paired flat dermal bones situated on either side of the posterolateral, dorsal surface of the neurocranium. Each articulates suturally with the pterotic (PTR) anteriorly, the supraoccipitals (SCO) mesially, the epioccipital (EP) posteriorly and the supracleithrum laterally. In all the three species the dorsal surface of the bone is uniformly granulated and carries the dorsolateral sensory canals. It also takes part in the formation of the posterior boundary of the temporal fenestra in *A. arius* and *A. caelatus* but in *A. thalassinus* there is no such opening in this region (pl. 1, figs. I-III ; pls. 4-6, fig. 18).

1.3.8. *Supracleithrum* (PT) : The nomenclatural status and the homologies of the uppermost element of the shoulder girdle the supracleithrum (=posttemporal of Tilak, 1965) have been clarified by Lundberg (1975) and further discussed by Fink and Fink (1981) and Howes (1983). These are paired dermal bones situated at the posterolateral corner of the neurocranium and firmly attached to the latter by two limbs. The dorsal limb is somewhat conical, the broader end of this limb is notched in *A. arius* and *A. caelatus* and each process articulates with the pterotic (PTR) and the posttemporal forming the posterolateral boundary of the temporal fenestra (TFO). While in *A. thalassinus*, the fenestra is lacking. The ventral or inferior limb (=trans-scapular) (IPT) of the supracleithrum is smooth and articulates with the articular facet formed by the basioccipital (BOC) and the exoccipital (EXOC). At the junction of the two limbs, there is a wide groove for the articulation of dorsal process of the cleithrum which is ligamentously attached with it (pl. 1, figs. I-III ; pls. 4-6, fig. 16).

1.4. BASICRANIAL REGION : This region comprises the cartilage bone, an unpaired basioccipital (BOC) ; and a dermal bone, the unpaired parasphenoid (PSP).

1.4.1. *Basioccipital* (BOC) : It is a midventral cartilage bone forming the ventro-posterior extremity of the neurocranium. It is quite massive in the posterior region and articulates dorsally with the exoccipitals (EXOC). Posteriorly it is fused with the ventral half of the first vertebra and articulates suturally with the complex vertebra. Anterior to this the bone is expanded into two lateral processes which in conjunction with the exoccipitals form the articular facet for the articulation of the trans-scapular of the respective supracleithrum. Anteriorly the bone is narrow and fractured into fine spicules for the firm interdigitation with the parasphenoid (PSP) ; laterally it articulates with the respective prootic (PRO). The upper surface of this bone bears a vertical ridge, having a deep concavity posteriorly and spatulated anteriorly along the midline, forming the floor of the recessus sacculi on either side. The shape, disposition and configuration of this bone is uniform in the three species studied (pl. 2, figs. I-III ; pls. 4-6, fig. 14).

1.4.2. *Parasphenoid* (PSP) : It is a median, ventral, and the longest, dermal bone which forms the base of the neurocranium. At its anterior end, it overlaps and is closely applied to the hind tapered process of the vomer (VO). It is overlapped dorsally by the lateral ethmoids (LETH) and the orbitosphenoid (ORSP). The parasphenoid articulates anteriorly with the ventral surface of the ethmoid (ETH) by means of fine splint like processes and dorse-mesially with the posterior portion of the orbitospenoid. At its centre the bone expands into two lateral expansions on either side which take part in the formation of optic foramina and articulate with the corresponding pterosphenoids (PTSP) and the anterior end of the prootics (PRO). The shape of these latera expansions vary inter-specifically among the most species of the genus *Arius* (see pl. 2, figs. I-III). Posteriorly, the bone tapers and forms a fine dentate suture with the anterior end of the basioccipital (BOC). Postero-laterally it articulates with the prootics (PRO), of either side which overlap the parasphenoid dorso-mesially (pl. 2, figs. I-III ; pls. 4-6, fig. 11).

2. BRANCHIOCRANIUM

The branchiocranium includes the oromandibular region, the hyoid region and the branchial basket (Gregory, 1933). The branchial basket will be described elsewhere.

2.1. OROMANDIBULAR REGION : This region comprises carilage bones : paired autopalatines (PL), metapterygoids (MPT), quadrates (Q) ; dermal bones : paired premaxillaries (PMX), maxillaries (MX), entopterygoids (ENPT), ectopterygoids (ECPT), dermopalatines (DPL), dentaries (D) and anguloarticulars (A).

2.1.1. *Autopalatines* (PL) : The autopalatine (=palatine of Bhimachar, 1933 ; as quoted by Tialk, 1965) is a paired cartilage bone representing the anteriormost element of the pterygoquadrate bar, though the bone has lost its sutural connection with the latter in the three species studied, as in other siluroids. It is a long rod like bone articulating with the lateral surface of the lateral ethmoid and maxilla anteriorly and the metapterygoid at its posterior end. It has undergone a slight modification from the normal structure, being thin in the middle and thicker at its two ends which are cartilaginous. It runs parallel to the longitudinal axis of the skull on either side and forms an acute angle with the corresponding maxillaries at its anterior end. Posteriorly it overlaps the rudimentary ectopterygoid, a notable feature of this bone in the three species *A. arius, A. caelatus* and *A. thalassinus* (pl. 3, figs. I, IV, VII).

2,1.2. *Metapterygoids* (MPT) : These are fairly large irregular, flat, cartilage bones of the suspensorium. Each metapterygoid forms a strut anteriorly for the articulation of the autopalatine (PL), the entopterygoid (ENPT) and the ectopterygoid (ECPT). Posteriorly and ventrally each bone splits up into fine splints for the firm interdigitation with the hyomandibular and the quadrate respectively. The homology of the siluroid palate-quadrate elements is still debatable (Howes, 1983, see p. 17). The metapterygoids have apparently shifted anteriorly to fill the space vacated by the reduction of the entopterygoids and the ectopterygoids in all the three species of the genus *Arius* (pl. 3, figs. I, IV, VII).

2.1.3. *Quadrates* (Q) : These are the triangular cartilage bones situated anterior to the preoperculars and below the hyomandibulars. The lower angle of each bone is thick and has an articular facet for the anguloarticulars ; antero-dorsally it articulates with the metapterygoid, postero-dorsally with the hyomandibula via a cartilage, and posteriorly with the preopercular and the interopercular. The shape, disposition and configuration is constant among the three species studied (pl. 3, fig. I, IV, VII).

2.1.4. *Premaxillaries* (PMX) : These are two dermal bones roughly rectangular in shape, and firmly attached to the ventral surface of the anterior cornua of the ethmoid (ETH). The outer end of each premaxilla is notched and on its ventral surface villiform teeth occur in all the three species *(A. arius, A. caelatus, A. thalassinus).* The two bones meet each other at the symphysis and dorso-laterally are attached by ligament to their respective autopalatine and the maxilla. The skull is said to be akinetic in these species since the upper jaw is immovably fixed to the neurocranium. The relative size of the premaxillaries varies interspecifically among the three species. In *A. arius,* the bone is comparatively shorter than *A. caelatus* and *A. thalassinus* (pl. 2, figs. I-III ; pls. 4-6, figs. 2).

2.1.5. *Maxillaries* (MX) : These are exceptionally reduced dermal bones just apposed to the base of each maxillarly barbel. Each bone is a small rod-like structure with a broad end which is attached with the anterior end of the autopalatine, the premaxillary and the lateral ethmoid by ligaments. The other end of the bone is pointed and gives support to the respective maxillary barbel. This is uniformly patterned in all the three species (pl. 1, figs. I-III).

2.1.6. *Entopterygoid* (ENPT) : There has been much confusion regarding the nomenclature of this bone. Starks (1926) named it as mesopterygoid in the siluroids. Gregory (1933) adopted the name endopterygoid in all the fishes where the bone is present. Harrington (1955) called this element an endopterygoid in cyprinid fishes. Gosline (1975) attempted to clarify the nomenclatural ambiguity in respect of this bone and stated, "the mesopterygoid (=endopterygoid) is frequently absent in catfishes. When present it is a toothless bone with a strong antero-medial ligamentous attachment to the lower surface of the skull just behind or beside the vomer. The catfish mesopterygoid (=endopterygoid) may extend laterally to below the posterior part of the autopalatine. When present, it is joined to the metapterygoid behind it either directly or by ligament. Regan (1911) has usually, though by no means always, identified the mesopterygoid correctly, for example, he calls the mesopterygoid of pimelodids a pterygoid. The bone named ectopterygoid in the most of Tilak's catfish papers is the mesopterygoid of the present paper ; however, the endopterygoid of his 1961 work and figures 2, 7, 9 and 18 of his (1964 a) paper is the mesopterygoid of this one" Howes (1983), discussed the homology of the entopterygoid. However, the present observations reveal that the entopterygoid (ENPT) is distinctly present in all the three species *(A. arius, A. caelatus, A. thalassinus)* though in reduced form as noted by Tilak (1965). Each entopterygoid is a fan shaped structure, narrow and thick at its anterior end which have ligamentous connection with the lateral ethmoid. Posteriorly it is flat, thin and adjoins the autopalatine and metapterygoid junction. There is no interspecific variation in respect of the shape and disposition of this bone in the three species studied (pl. 3, figs. I, IV, VII).

2.1.7. *Ectopterygoids* (ECPT) : These are considerably reduced cone shaped bony ossicles embedded in the muscular fibers on the lower surface of the posterior end of the autopalatines (PL). Posteriorly each bone is attached to the strut of metapterygoid (MPT) just under-neath the connection of autopalatine (PL). The bone is exceptionally small ; in a specimen of 900 mm, it is only 5 mm long though well ossified and distinct. But in smaller specimens (below 200 mm SL) the bone is rudimentary, transparent and the ossicles are only discernible in alizarin stained skulls. Perhaps this may be the reason that many earlier workers either did not notice this element and misidentified some other bone as the ectopterygoid. Regan (1911) observed a small bone adherent to the lower surface of the posterior part of the autopalatine in the ariid catfish *(Aelurichthys),* Kindred (1919) also noticed the same condition in the chondrocranium of a 10 mm *Amiurus.* Howes (1983) discussed the homology of this bone.

Starks (1926) correctly pointed out the shape, disposition and the relationship of the ectopterygoids in ariids. But Bhimachar (1933) and Tilak (1965) identified, in error, the teeth bearing plates on the palate (=dermopalatine of Starks, 1926) as ectopterygoids without realising there true nature, Gosline (1975) however, doubted the existence of a true ectopterygoid in catfishes. But since the bone is very distinct in the large specimens of all the three species *(A. arius, A. caelatus, A. thalassinus)*, although rudimentary in smaller specimens, the name ectopterygoid seems to be more appropriate in view of its disposition and the relationship with the other bones (pl. 3, figs. I, IV, VII).

2.1.8. *Dermopalatines* (DPL) : These are the tooth bearing, paired, dermal plates embedded in the dermal tissue on the palate. The basic contour, disposition and the number of these bones and also the nature of teeth vary interspecifically while the size and arrangement of teeth (spars or crowded) may vary intraspecifically with growth.

In *A. arius* there are two semi-oval dermopalatines, tooth-plates bearing globular teeth. Each bone extend from the anterior portion of the parasphenoid, the entopterygoid and partially cover the autopalatine and the metapterygoid. In *A. caelatus* there are also two dermopalatines which differ from those of *A. arius* in the nature of teeth which are villiform, the shape and the disposition of the bones. Each bone is triangular in shape and bears villiform teeth. It covers the lateral ethmoid and the lateral extensions of the vomer, and posterior narrow angle partially covers the orbitosphenoid. In *A. thalassinus* there are three pairs of tooth plates all bearing villiform teeth. The anterior inner one is smallest, round and situated on the vomer on either side of the midline, lateral to this there is another plate more or less rectangular in shape and covers the ventral portion of the lateral ethmoid on either side. Posteriorly a triangular plate covers the entire orbitosphenoid and extend up to the anterior end of the metapterygoid. In juvenile and young specimens each plate is separated by some inter space between them but in older specimens the three plates on either side get fused with each other to give an appearance of a single triangular teeth patch on the palate.

It is apparently clear that these bones exhibit species specificity in respect of their basic contour, number and disposition. But there has been considerable confusion regarding the nomenclature of these elements in the past, as evident from the literature ; thus some attempt of clarification is considered necessary.

Starks (1926) first demonstrated that the tooth bearing plate on the palate of ariid fishes are not the homologues of the pterygoid elements and thus named them as dermopalatines. Bhimachar (1933) identified these elements as ectopterygoids in siluroids, a view followed by Tilak (1965) from his studies of the species of the genus *Arius*. However, Tilak (*(op. cit.)* named some of the elements as 'additional toothed plate (ATP)', and vomerine toothed plate (VOTP), besides recognising the ectopterygoid (ECTPT) (p 152, fig. 2).

Bamford (1948) has shown that two tooth bearing plates on the palate in *Galeichthys* are dermopalatines. Gosline (1975) also doubted the nomenclature adopted by various workers for these bones and remarked "often in catfishes there is a tooth bearing plate on the oral surface of the ligamentous tissue mentioned above. Such plates have frequently been identified as ectopterygoids, but the identification seems questionable."

Thus in view of the above mentioned nomenclatural controversies, it would seem that the name dermopalatine is more appropriate for the independently ossified dermal plates on the palate which bear teeth.

These bones have taxonomic potential in distinguishing species of the genus *Arius* since their shape and number are easily discernible in the intact specimens (pl. 2, figs. I-III, pls. 4-6, fig. 6).

2.1.9. *Dentaries* (D) : These are the longest dermal bones in the mandibular arch. Each bone is broad posteriorly and gradually tapered anteriorly. Each slightly curves mesially to meet its fellow of the opposite side to which it is joined syndesmotically. There is a narrow band of villiform teeth on the antero-dorsal aspect of each dentary. At its posterior end it is lunate with a long postero-ventral projection which articulates with the angular. On the posterior portion of the inner surface there is a conical groove which lodges Meckel's cartilage and on the antero-ventral surface there are a series of sensory canal openings (pl. 3, figs. I, IV, VII).

2.1.10. *Anguloarticulars* (A) : These are also dermal elongated bones of the mandibular series (=articulars of Bhimachar, 1933 and Tilak 1965). Each anguloarticular is thin and broad anteriorly where it articulates with the dentary and is grooved for Meckel's cartilage on its inner surface. Just dorsal to Meckel's cartilage there is another endochondral ossification known as the *Coronomeckelien* (=sesamoid articular of Haines, 1937; splenial of Tilak, 1965). Posteriorly the anguloarticulars are thick and solid and articulate with the quadrates (Q). At this junction a very small and thin element of the retroaticular (=the conventional angular) is present on the lateral surface. The shape and disposition of the anguloarticulars are more or less constant in all the three species studied (pl. 3, figs. I, IV, VII).

2.2. HYOID REGION : This region comprises cartilage bones : paired hyomandibulars (HM), interhyals (IH) posterohyals (EH), anterohyals (CH), dorsal hyals (UH), ventral hyals (LH) ; dormal bones : paired operculars (OP), preoperculars (POP), interoperculars (IOP), branchiostegals (BS), Unpaired urohyal (URH).

2.2.1. *Hyomandibulars* (HM) : These are large roughly rectangular thin flat bones which connect the pterygoquadrate bar with the neurocranium. Dorsally, each bone is thick and arched which articulates with the facet formed by the sphenotic and the pterotic. In *A. caelatus* and *A. thalassinus* the antero-dorsal surface forms an elongated strut which articulates with the pterosphenoid, while in *A. arius* there is no such structure but the entire antero-dorsal surface is connected with the pterosphenoid. Postero-dorsally there is another strut uniformly present in all the three species, which forms the site of ligamentous attachment for the opercular ventrally, and the pterotic dorsally. Anteriorly, each hyomandibula articulates suturally with the respective metapterygoid, ventrally with the quadrate through a cartilage and poster-oventrally with the preopercular and the opercular. The relative size of the cartilage between hyomandibula and the quadrate varies specifically ; in *A. caelatus* it is comparatively larger than that of *A. arius* and *A. thalassinus*. The inner surface of the bone is smooth while the outer is ridged to facilitate the insertion of the adductor muscles. On its postero-mesial margin it forms the border of a foramen in conjunction with the preopercular for the passage of the main ramus hyomandibularis facilis nerve. The relative disposition of this foramen is a species-specific feature (pl. 3, figs. I, IV, VII).

2.2.2. *Interhyals* (IH) : These are exceptionally small rod-like bones attached ligamentously in between the posterohyal (EH), the quadrate (Q) and the interopercular (IOP). They are uniformly present in all the three species studied (pl. 3, figs. III, VI, IX).

2.2.3. *Posterohyal* (EH) : Posterohyals (=epihyals of Tilak, 1965) are elongate, flattened, triangular bones situated between the anterohyals (CH) and the interhyals (IH). The posterior end of each bone is pointed and has ligamentous attachment with the interopercular (IOP), preopercular (POP), and the quadrate (Q). Anteriorly each posterohyal is broad and adjoins the anterohyals. Between the two bones there is a distinct layer of cartilage on the inner half while the outer half interdigitates firmly by means of fine splints arising from both the bones. The mesial and outer surface are smooth and a low ridge on the ventral surface gives attachment to the last two branchiostegals which the last but one is at the junction of the posterohyal and the anterohyal. The number of branchiostegals on this bone may vary inter-specifically (Tilak, 1965), however, in the present three species (*A. arius, A. caelatus* and *A thalassinus*) we did not record any such variation (pl. 3, figs. III, VI, IX).

2.2.4. *Anterohyals* (CH) : Anterohyals (=ceratohyals of Tilak, 1965) are elongate thick bones situated between the posterohyals (EH) and the ventral hyals (LH). Each anterohyal is twice the length of the posterohyal and is narrow-waisted. The posterior end is broad, flat and articulates with the anterohyal partially through cartilage and partially by firm suture. The anterior end is thick with a spongy articular facet for the articulation of the dorsal hyal and the ventral hyal. The inner ventral edge of the bone has a low ridge in continuation with that of posterohyal for the attachment of branchiostegals which varies interspecifically. In *A. arius* there are four, in *A. caelatus* five and in *A. thalassinus* three branchiostegals attached to this bone (pl. 3, figs. III, VI, IX).

2.2.5. *Dorsal hyals* (UH) : Each dorsal hyal (=upper hypohyal) is a small, thin, roughly triangular bone situated in between the first hypobranchial and the ventral hyal. It is separated from its fellow of the other side by a cartilage A distinct layer of cartilage is also present at the junction of this bone and the first hypobranchial. It articulates at one end with the anterohyal (CH) and at the other end with the ventral hyal (LH) mainly by suture as well as through cartilage. There is a distinct foramen at the mesial junction of the dorsal and the lower ventral hyals in all the three species (pl. 3, figs. III, IV, IX).

2.2.6. *Ventral hyals* LH) : Ventral hyals (=lower hypohyals) are thick and irregular and are the anterior-most bones of the hyoid region Anteriorly each element is united firmly with its fellow of the other side by a thin cartilage. The posterior end is thicker and forms the articular surface for the articulation of anterohyal. A thin layer of cartilage is distinct in all the three species at the lower mesial junction of the bone and the anterohyal. Each ventral hyal unites dorsally with the dorsal hyal and mesially with the median urohyal (URH) (pl. 3, figs. III, VI, IX).

2.2.7. *Urohyal* (URH) : It is a median dermal bone situated in between the ventral hyals and beneath the basibranchial and the hypobranchials. Anteriorly the bone is narrow, thick and irregular in shape while posteriorly expand abruptly into two lateral and a median thin projections giving it the appearance of a trident. Dorso-medially it bears vertical thin cleft which terminates at the point of median projection. The bone articulates with the ventral hyals, the basibranchial and the first hypobranchial anteriorly while posteriorly it is attached with the pectoral girdle by means of ligaments and muscles. The basic contour and disposition of this bone do not exhibit any significant interspecific variation among the present three species, however, the bone is notched at its anterior end in *A. caelatus* and *A. thalassinus,* while in *A. arius* only young specimens (below 150 mm SL) bear a narrow slit at the anterior end of thc bone ; in older specimens there is no such notch as in the preceeding two species (pl. 3, figs, II, V, VIII).

2.2.8. *Branchiostegals* (RS) : These are the paired dermal, slender or flat curved rays attached proximally to the anterohyals and the posterohyals. The size of the branchiostegal rays increases from anterior to posterior and the first branchiostegal is only about one third the length of the last one. Each ray is compressed laterally and is connected with each other by means of the *hyohyoidei adductores* muscular elements. The number of branchiostegals have been used as a species specific feature. In *A. arius,* there are 6 rays, (2 on the posterohyals and 4 on the anterohyals). In *A. caelatus* normally there are 7 rays (2 on the posterohyals and 5 on the anterohyals) but of the 20 specimens skeltonized, in a single specimen we have noted only six rays. Whereas in *A. thalassinus* there are five branchiostegals only (2 on the posterohyals and 3 on the anterohyals). It may be mentioned here that earlier ichthyologists (Day, 1877, 1889 ; Misra, 1976) have reported a constant number of these rays, viz. 6 in all the species of the genus *Arius*. However, it was McAllister (1968) who pointed out for the first time the interspecific variability of the branchiostegals in these fishes (pl. 3, figs. III, VI, IX).

2.2.9. *Preoperculars* (POP) : These are thin crescent dermal bones lying posterior to the hyomandibulars (HM) and the quadrates (Q) and anterior to the interoperculars (IOP) and the operculars (OP). Each preopercular has a thick posterior convex edge which is irregularly ridged. Its proximal end interdigitates firmly with the quadrate while its distal end covers the posterior groove of the hyomandibular and extends up to the posterodorsal knob of the latter bone. Anteriorly the concave surface of the preopercular articulates with the hyomandibula and its posterior convex surface is ligamentously attached to opercular. In conjunction with the hyomandibula it forms the foramen for the exit of the ramus mandibularis facialis and is itself traversed by the lateral line sensory canal at its anterior end (pl. 3, figs. I, IV, VII).

2.2.10. *Operculars* (OP) : These are roughly triangular-shaped dermal bones situated posterior to the preoperculars. The apex of each opercular is thick and adjoins the articular process of the hyomandibular anterodorsally. The posteroventral margin of this bone is concave in *A. arius* and *A. thalassinus* while straight in *A. caelatus.* Tilak (1965) also used this character for distinguishing the species of the genus *Arius*. Ventrally each opercular fits into the concavity of the interopercular and along the entire length of the anterior border it is connected to the preopercular by ligament (pl. 3, figs. I, IV, VII).

2.2.11. *Interoperculars* (IOP : These thin roughly triangular dermal bones with a convex ventral edge and concave posterodorsal edge. Anteriorly each bone articulates with the interopercular and is ligamentously attached to the posterior end of the anguloarticular. Posterodorsally the concavity appears to be species specific since in *A. arius* and *A. caelatus* it is lunate while in *A. thalassinus* it is angular with a narrow posterodorsal processes. On its anteromesial surface the interopercular provides attachment to the posterohyals and the interhyals (pl. 3, figs. I, IV, VII).

DISCUSSION :

The general plan of the osteocranium configuration in three species of the genus *Arius (A. arius, A. caelatus, A. thalassinus)* agrees with the basic siluroid cranial pattern (Regan, 1911 ; Goodrich, 1930 ; Gregory, 1933 ; Bhimachar, 1933 ; Nawar, 1954 ; Joseph, 1960 ; Tilak, 1963, 1965 ; Alexander, 1966). It reveals many features which have been considered as common to catfishes such as, well ossified depressed and massive skull ; firm interdigitation and loss of bones in the neurocranium such as absence of intercalar, parietal, symplectic, subopercular, sphenotic spine, interorbital septum, basisphenoid, myodome and the temporal fossa ; presence of dorsal median longitudinal fontanels, incorporation of parasphenoid in the floor of the brain case. The suspensorium is methyostylic (De Beer, 1937) occupying a more dorsal position close to the neurocranium with a reduced entopterygoid, rudimentary ectopterygoid and edentulous and reduced maxillaries.

However, the comparative cranial osteology of *A. arius, A. caelatus* and *A. thalassinus* presents a great deal of interspecific variations that can be correlated to their taxonomic status. The skull is not platybasic, unlike other siluroids (Tilak, 1965), since the cranial cavity does not extended anteriorly into the ethmoidal region because of the dorsal protubrance of the orbitosphenoid resulting in the formation of an anterior fontanel. As such there are three dorsal median fontanels instead of two as reported by earlier workers (Bhimachar, 1933 ; Tilak *op. cit*.) The shape of the median fontanel varies interspecifically ; in *A. arius* it is cylindrical, in *A. caelatus* conical and in *A. thalassinus* dumbbell shaped.

The dorsal aspect of the neurocranium exhibits a number of interspecific differences in the three species such as the presence of temporal fenestrae (TFO) in *A arius* and *A. caelatus* while they are absent in *A. thalassinus ;* the width of the base of the occipital process is greater than its length in the former two species but in the latter it is longer than broad. The lateral borders of the neurocranium are constricted orbitally or converge anteriorly in *A. arius* and *A caelatus* whereas in *A. thalassinus* they are straight. The lateral fenestrae at the ethmo-frontal junction, though uniformly present in all the three species studied, are absent in *A. sagor* (Bhimachar, 1933 ; Tilak, 1965) and *A. dussumieri.*

In the olfactory region the lateral ethmoid (LETH) is a good taxonomic character since the configuration and disposition of this bone varies inter-specifically among the different species of the genus *Arius.* The posterior process of the lateral ethmoid articulates by two facets posteriorly with the frontal in all the three species and in most other species of the genus *Arius* except *A. sagor* and *A. dussumieri* where it articulates only by one facet. The presence of cartilage at the ventromesial base of each lateral ethmoid is considered as an advanced feature among the siluroids (Bhimachar, 1933). However, the retention of cartilage is neotenic and is considered to be a primitive feature in the species of *Arius.*

Other specialised features common in the three species in this region include the presence of dermal tooth bearing plates attached to the ventral aspect of vomer and lateral ethmoid which have been identified either as 'ectopterygoid', or 'vomerine' or 'additional toothed' plate by earlier workers (Bhimachar, 1933 ; Tilak, 1965). In fact these tooth bearing plates are the dermopalatine (Starks. 1926 ; Berg, 1947 ; Bamford, 1948 ; Alexander, 1965) and not the derivatives or homologues of either the vomer or ectopterygoid. They develop independently by the ossification of the tissue on the palate. However, their disposition, basic contour and number are species specific and the morphology of the teeth on these plates may distinguish the species of the genus *Arius.* In *A. arius* there are two semioval dermopalatine with globbular teeth, each bone extends from the anterior extremity of the lateral ethmoid to the lateral extension of the parasphenoid covering the lateral process of the vomer, the ethmoid, lateral ethmoid, the orbitosphenoid, anterior portion of the parasphenoid, the ectopterygoid and partially the autopalatine and the metapterygoid. In *A. caelatus* although there are also two dermopalatines, the nature of teeth, shape and disposition are characteristic features which distinguish this species from the proceeding one. Each bone is triangular, bearing villiform teeth situated at the anterior P. 34 MS since it is the well-developed orbitosphenoid which prevents the anterior extension of the cranial cavity into the ethmoidal region and thus the skull in ariids is not platybasic (Tilak, 1965).

The otic region shows remarkable species-specific features in respect of the comparative osteology of the three species. The term 'complex bone' used in the present study is applied to some of the bones of otic region indicating that the bone has been derived both from dermal as well as cartilage elements, for instance the sphenotics and the pterotics. Both the bones bear lateral sensory canals and are granulated at their dorsal aspect. The shape of the sphenotic seems to be species specific which is pear-shaped in *A. arius* and *A. caelatus* while somewhat rectangular in *A. thalassinus*. The temporal fenestra is bordered by the pterotic, the supracleithrum and the posttemporal in the former two species, whilst fenestra is lacking in the latter. The supraoccipital process also differs specifically, in *A. arius* and *A. caelatus* it is broader at its base than long while In *A. thalassinus* it is longer than broad. The supraoccipital also takes part in the formation of the posterior fontanel in *A. arius* while in the other two species it is excluded from the posterior fotannel by the fusion of the two frontals. The disposition of the epioccipital may be helpful in separating the species since in *A. arius* it appears on the posterodorsal aspect of the neurocranium at the junction of the posttemporal and the supraoccipital while in other two species the epioccipital remains underneath the above mentioned two bones.

The basicranial region consists of only two cartilage bones : the basioccipital and the parasphenoid. The shape of extremity of the palate covering only the lateral ethmoid, the vomer and slight anterior portion of the orbitosphenoid. In *A. thalassinus* there are three pairs of dermopalatine, each pair bears villiform teeth and extend from the lateral ethmoid backwardly up to the anterior end of the metapterygoid. In view of the present investigation it is apparently clear that the dermopalatines do not exhibit any relationship with the rudimentary ectopterygoid which is adhered to the postero-ventral end of autopalatine, thus the phrase "ectopterygoid teeth" should be avoided, however, sometime a portion of these plates may get fused with the vomer with the age (Eigenmann and Eigenmann, 1890) under such circumstances the regional designation of these plates may also creates nomenclatural confusion. Thus to avoid the nomenclatural ambiguity and to attain stability in naming the tooth bearing plates on the palate, it would be proper to use the name dermopalatine at least in all the ariid catfishes irrespective of their disposition on the palate.

The bones of the orbital region do not present much significant interspecific differences among the present three species. However, it would be pertinent to mention here that the shape and disposition of the orbitosphenoid in *A. dussumieri* is quite distinct from the rest of *Arius* species. The frontals may also be of taxonomic importance since in *A. dussumieri* and *A. sagor* they do not form the lateral fenestra in conjunction with the lateral ethmoid unlike that of other species of the genus *Arius*. The presence of a well-developed orbitosphenoid which forms the interorbital septum is considered by Bhimachar (1933) as an archaic feature. On the other hand he contended that the platybasic nature of skull in the siluroid is a primitive character, the statement seems to be somewhat contradictory the lateral extensions of the parasphenoid may perhaps be useful in distinguishing the species of *Arius* The presence of basisphenoid in the Ostariophysi is the subject of much controversy kindred (1919) and De Beer (1937) have reported it in *Amiurus*. According to Sagemehl (1884) and Berg (1947) it is lacking in Ostariophysi. Bhimachar (1933) has reported this bone (as suprasphenoid) in all the catfishes he studied, and stated that in *Arius* (=*Tachysurus*) species it is fused with the parasphenoid. The present study, however, shows no indication of its presence or being fused with the parasphenoid in the three species studied.

The oromandibular region of these three species is of taxonomic interest. The skull in all the species is akinetic, as the premaxillaries are firmly attached to the ventral aspect of the ethmoid. The relative size of these bones varies inter-specifically, in *A. arius* the bone is comparatively shorter than that of *A. caelatus* and *A. thallassinus*. Generally in teleosts the suspensorium is attached with the neurocranium at two points, by the autopalatine anteriorly and the hyomandibular posteriorly. But due to specialized nature of the skull in *Arius* species, as in other siluroids, the autopalatine has lost sutural articulation with the pterygo-quadrate bar, though ligamentously attached at its posterior end with the metapterygoid and anteriorly with the lateral ethmoid. Therefore, the autopalatine has effectively ceased to be a part of the suspensorium (Alexander, 1966). A notable feature of the oromandibular region in the three species is the presence of all the three pterygoid elements (metapterygoid, mesopterygoid and the ectopterygoid) as noted by Tilak (1965). But he has erroneously interpreted the homology and the relationships of these bones and stated "In the present study of the members of the family tachysuridae, the three pterygoid bones i.e. the metapterygoid, the ectopterygoid and the endopterygoid, have been observed in their usual position. The endopterygoid (the mesopterygoid of Regan, 1911 and Gregory, 1933) lies dorsal and medial to the ectopterygoid. The relationship of the ectopterygoid and endopterygoid in Tachysuridae are as in Characidae (Harrington, 1955 ; Weitzman, 1962) except that the two bones lie closely applied in the latter while in the former they lie away from each other because of their reduced size". It may be mentioned that Harrington (1955) did not describe the osteology of Characidae but the cyprinid fish, *Notropis bifrenatus* where the ectopterygoid and endopterygoid are both in contact with the quadrate (pp. 273, 75 ; figs. 2, 3) whereas in ariid catfishes there is no connection between the above mentioned bones and the quadrate. The true ectopterygoid element which is adhered to the posterior ventral end of autopalatine in the form of rudimentary ossicles in *A. arius*, *A. caelatus* and *A. thalassinus*, although considerably reduced is always present and its relationships with the other bones of the branchiocranium are the same as reported by Regan (1911) in the ariid catfish *(Aelurichthys)* and Kindred (1919) in *Amiurus*. The dermopalatine (ectopterygoid of Bhimachar, 1933 ; Tilak, 1965) is not the derivative of any pterygoid elements (Starks, 1926 ; Berg, 1947 ; Bamford, 1948 and Alexander, 1965) but the independent ossification on the palate. The metapterygoid is large and flat, its disposition in the present species agrees with the general plan of siluroids, more particularly it resembles that of the ariid *Galeichthys felis* (Merriman, 1940). There is a distinct strip of cartilage between the hyomandibular and the quadrate as in other siluroids (Bhimachar, 1933 : Tilak, 1961, 1965). This cartilage has been considered as a remnant of the sympletic by McMurrich (1884), Kindred (1919) and Bhimachar (1933) although Joseph (1960) did not agree with this view and suggested that this is not a symplectic cartilage, since a similar cartilage persists in the same position in other teleosts which possess a well-developed symplectic, for example in *Otolithus ruber* (Dharmarajan, 1936). However, regardless of its homology, the cartilage is persistent in all the three species examined and varies inter-specifically in respect of its size which is reletively broader in *A. caelatus* than in *A. arius* and *A. thalassinus* when compared in the skulls of same size.

In the hyoid region the hyomandibula is the chief cartilage bone providing suspensory support to the pterygo-quadrate bar and thus the suspensorium is *Methyostylic* (De Beer, 1937). The configuration of the head of this bone exhibits species-specific differences since in *A. caelatus* and *A. thalassinus* there is a prominent antero-dorsal strurt which articulates with the pterosphenoid while in *A. arius* there is no such structure but the entire antero-dorsal surface is attached ligamentously with the pterosphenoid. The disposition of the foramen formed by the hyomandibular is also of specific nature. Other dermal bones of this region which vary inter-specifically are the paired branchiostegal rays and the median unpaired urohyal. It may be noted that most of the earlier ichthyologists (Day, 1877, 1889 ; Misra, 1976) contended that the counts of branchiostegals do not vary inter-specifically in the species of the genus *Arius*. However, the present investigations confirm Tilak's (1965) view, regarding the interspecific variability with respect to branchiostegal ray numbers in the 14 species of *Arius*.

Based on the comparative morphology of the osteocranium of *A. arius, A. caelatus* and *A. thalassinus* the most distinguishing features of the above mentioned three species are as fallows :

1. The gross contour of the skull varies inter-specifically among the three species *(A. arius, A. caelatus, A. thalassinus)*.

2. The skull in all the three species in quite massive and the bones are well ossified articulating with each other by firm sutures.

3. The cranial cavity does not extend anteriorly into the ethmoid region thus the skull is not platybasic. There are three median fontanels in the roof of the skull. The shape of these fontanels varies inter-specifically (pl. 1, figs. I-III).

4. The shape, relative size and the configuration of the lateral ethmoids vary inter-specifically among the three species studied (pls. 4-6. fig. 4).

5. The dermopalatines are present on the palate in all the three species. These tooth-bearing bones are of much taxonomic utility since their morphology is species-specific (pl. 2, figs. I-III, pls. 4-6, fig. 6).

6. A well-developed median orbitosphenoid which replace the interorbital septum and having a dorsal protubrance which prevents the anterior extension of cranial cavity into the ethmoidal region contrary to that of other siluroid fishes (pls. 4-6, fig. 8).

7. The lateral fenestrae in the ethmo-frontal region, although uniformly present in all the three species studied is absent in some other species of the genus *Arius (A. sagor* and *A. dussumieri)* (pl. 1, figs. I-III).

8. The skull is akinetic since the premaxillaries are firmly attached to the ventral aspect of the ethmoid in all the three species, however, the relative size of these bones vary inter-specifically (pl. 2, figs I-III ; pls. 4-6, fig. 2).

9. All the three elements of the pterygoid i e. metapterygoid, entopterygoid (=endopterygoid) and ectopterygoid are present but the latter two are exceptionally reduced (pl. 3, fings. I, IV, VII).

10. The number of branchiostegal rays vary inter-specifically since there are 6 rays in *A. arius,* 7 in *A. caelatus* and 5 in *A. thalassinus* (pl. 3, figs. III, VI, IX).

11 As stated earlier the three species of the genus *Arius* (*A. arius, A. caelatus* and *A. thalassinus*) belong to three different species complexes namely *maculatus, caelatus* and *thalassinus* respectively (Dhanze and Jayaram, 1982). Each species complex comprises more than two related species and some of these species may prove later either to be synonymous or subspecific. Thus it is expected that the comparative cranial morphology of the three species studied will serve as the basis for further comparison with the allied species of each respective complex in order to ascertain the taxonomic identity of doubtful taxa at species level.

SUMMARY

Three species of the genus *Arius* (*Arius arius, A. caelatus* and *A. thalassinus*) belonging to three different species complexes were critically examined for their osteological attributes mainly to crosscheck whether the external morphological differences can be correlated to their internal skeleton. The study has conclusively proved that the three species are distinct in respect of their cranial osteology thereby justifying their separate taxonomic status. As a result the osteological features as revealed by the comparative study of the osteocranium of the three species have proved to be of classificatory significance at species level. In particular, the shape, configuration, disposition and relative size of certain bones such as the lateral ethmoid, dermopalatine, frontal, supraoccipital, epioccipital, sphenotic, orbitosphenoid, parasphenoid, hyomandibula and branchiostegal rays exhibit species specificity. Besides these features, the shape and the extent of the dorsal midline frontals, presence or absence of lateral fenestrae in the ethmo-frontal region and temporal fonestrae have also been found helpful in distinguishing the species of the genus *Arius*.

A provisional clarification regarding the nomenclatural status of various bones and the possibility of their being utilized as taxonomic characters have also been provided. It has been demonstrated that the bone identified by earlier workers as an 'ectopterygoid' in ariids is a dermopalatine, which is invariably toothed and can be used potentially to distinguish the species of the genus *Arius*. The true ectopterygoid although present in all the three species studied is exceptionally reduced in the form of ossicles. Likewise. contrary to earlier assumptions that there are only two fontanels in the dorsal midline of the skull, there are clearly three fontanels at least in the neurocranium of the three species studied. The number of branchiostegal rays has also been found to vary inter-specifically, unlike the observations of earlier workers that they are of a constant number amongst *Arius* species.

The disarticulated elements of the neurocranium of three species studied depict notable interspecific differences in respect of the comparative size, configuration and disposition of various bones inasmuch as the specimens used for disarticulation were of the same size (pls. 4-6 ; tab. 1).

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Abbreviations :

A=Anguloarticular, AF=Anterior fontanel, BH=Basihyal, BOC=Basioccipital, BS=Branchiostegals, CH=Anterohyal, D=Dentary, DPLT=Dermopalatine patch of teeth, ECPT=Ectopterygoid, EH=Posterohyal, ENPT=Entopterygoid, EP=Epioccipital, EPL=Epioccipital lamelle, ETH=Ethmoid, EXOC=Exoccipital, FR=Frontal, HM=Hyomandibular, IH=Interhyal, IOP=Interopercular, IPT=Transscapular ligament, LAC=Lachrymal, LEPSP=Lateral process of parasphenoid, LETH=Lateral ethmoid, LF=Lateral fenestra, LH=Ventral hyal, MF=Median fontanel, MPT=Metapterygoid, MX=Maxilla, NA=Nasal, OP=Opercular, ORSP=Orbitosphenoid, PF=Posterior fontanel, PL=Autopalatine, PLETH=Posterior process of lateral ethmoid, PMX=Premaxilla, POP=Preopercular, PRO=Prootic, PSP=Parasphenoid, PT=Supracleithrum, PTR=Pterotic, PTSP=Pterosphenoid, Q=Quadrate, SO=Infraorbitals, SOC=Supraoccipital, SOCP=Supraoccipital process, SPH=Sphenotic, ST=Posttemporal, TFO=Temporal fossa, UH=Dorsal hyal, URH=Urohyal, VO=Vomer.

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TABLE—1

Showing the interspecific diffences in various disarticulated bones of the three species.

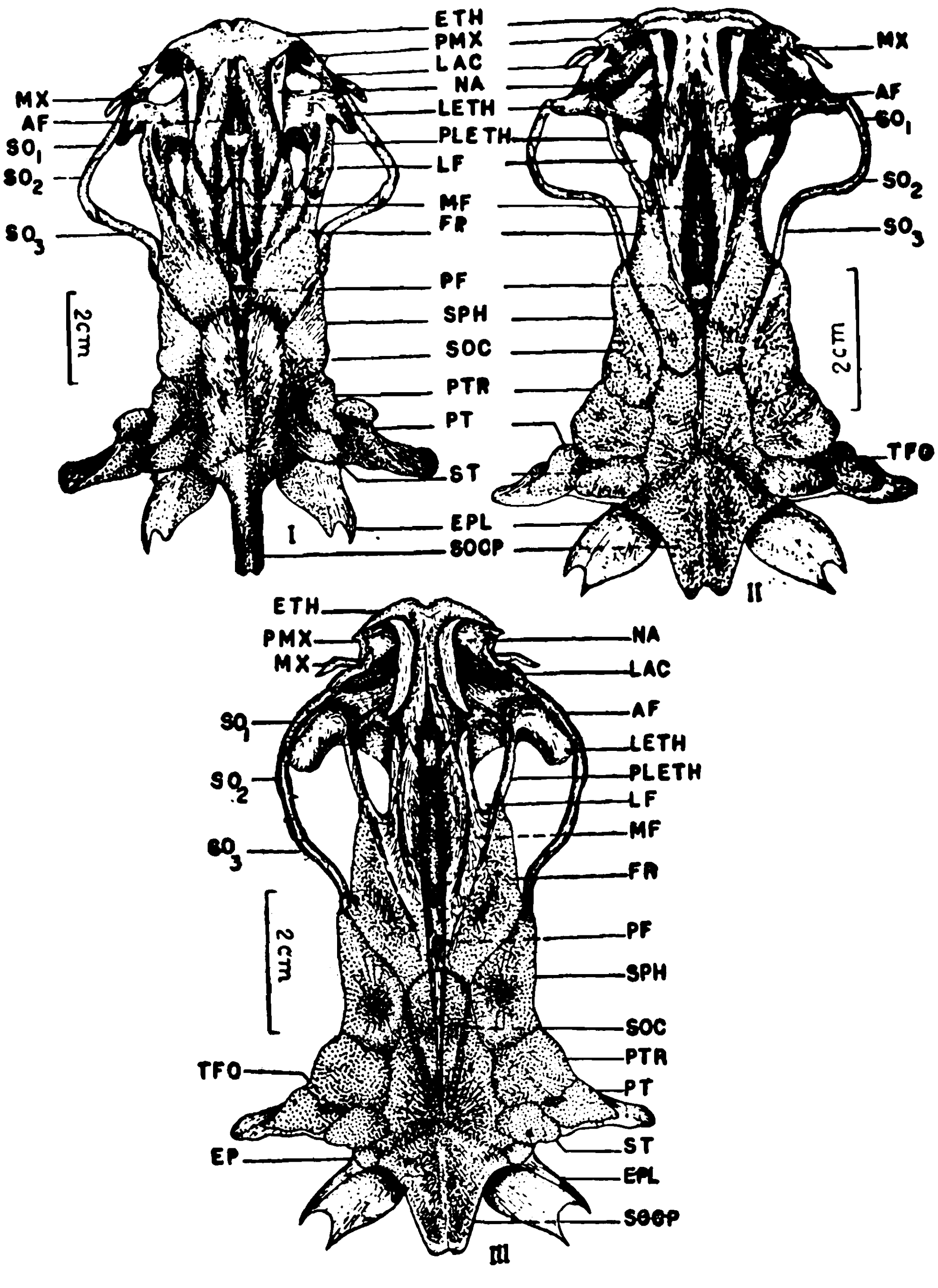
Name of Bones	*A. arius*	*A. caelatus*	*A. thalassinus*
1. Ethmoid	Narrow and notched at tip.	Broad and truncated anteriorly.	Broad and notched at tip.
2. Premaxillary	Comparatively small slightly longer than broad.	Comparatively long.	Comparatively long.
3. Nasal	Slender	Long, thin and arched.	Broad and arched.
4. Lateral ethmoid	Anterior lateral process narrow and incline backwardly at an angle of 60°. Posterior process-narrow and slender.	Anterior lateral process tapering, directing outwardly at an angle of 90°. Posterior process-comparatively thicker.	Anteor lateral process broa and incline backwdy at an angle of 60° Posterior process:broad and fla.
5. Vomer	T—shaped.	T—shaped.	T—shaped.
6. Dermopalatine	One pair, semiovoid.	One pair, triangular.	Three pair, anterior two pairs are rectangular or round and posteror pair triangular.
7. Frontal	Comparatively narrow, deeply bifurcated anteriorly and rounded posteriorly.	Moderately broad, notched anteriorly and truncated posteriorly.	Broad with four projetions anteriorly and pointed posteriorly.
8. Orbitosphenoid	Rectangular and longer than broad.	Anteriorly broad.	More or less similar to *A. caelatus*.
9. Pterosphenoid	Triangular, slightly notched posteriorly.	Triradiate.	Triangular, slightly nothed posteriorly.

Tab. 1 Contd...2

Name of Bones	*A. arius*	*A. caelatus*	*A. thalassinus*
10. Sphenotic	Rectangular with acute antero-lateral angle.	Pear shaped	Rectangular with acute antero-lateral angle.
11. Parasphenoid	Comparatively narrow.	Broad.	Broad.
12. Prootic	Irregularly angular.	Irregularly angular.	Irregularly angular.
13. Pterotic	Pentagonal in shape.	Pentagonal in shape.	Pentagonal in shape.
14. Basioccipital	Cone shaped.	Cone shaped.	Cone shaped.
15. Exoccipital	Bowl shaped.	Bowl shaped.	Bowl shaped.
16. Supracleithrum	Notched at the junction of upper limb and the trans scapular and shallow.	Notched, broad and deep.	Nothed, narrow and deep.
17. Supraoccipital	Notched anteriorly, supraoccipital process as long as broad at its base.	Truncated with a slight median projection, occipital process broader than long at its base.	Truncated anteriorly, occipital process longer than broad at its base.
18. Posttemporal	Rectangular with an acute antero-lateral angle.	Oval shaped.	Oval shaped.
19. Epioccipital	Appears dorsally at the junction of posttemporal and supraoccipital, posteriorly the epioccipital lamellae slightly notched.	Remains underneath the posttemporal and supraoccipital, posteriorly the epioccipital lamellae deeply notched.	Remains underneath the posttemporal and supraoccipital, posteriorly the epioccipital lamellae lunate.

FIGURES

PLATE I



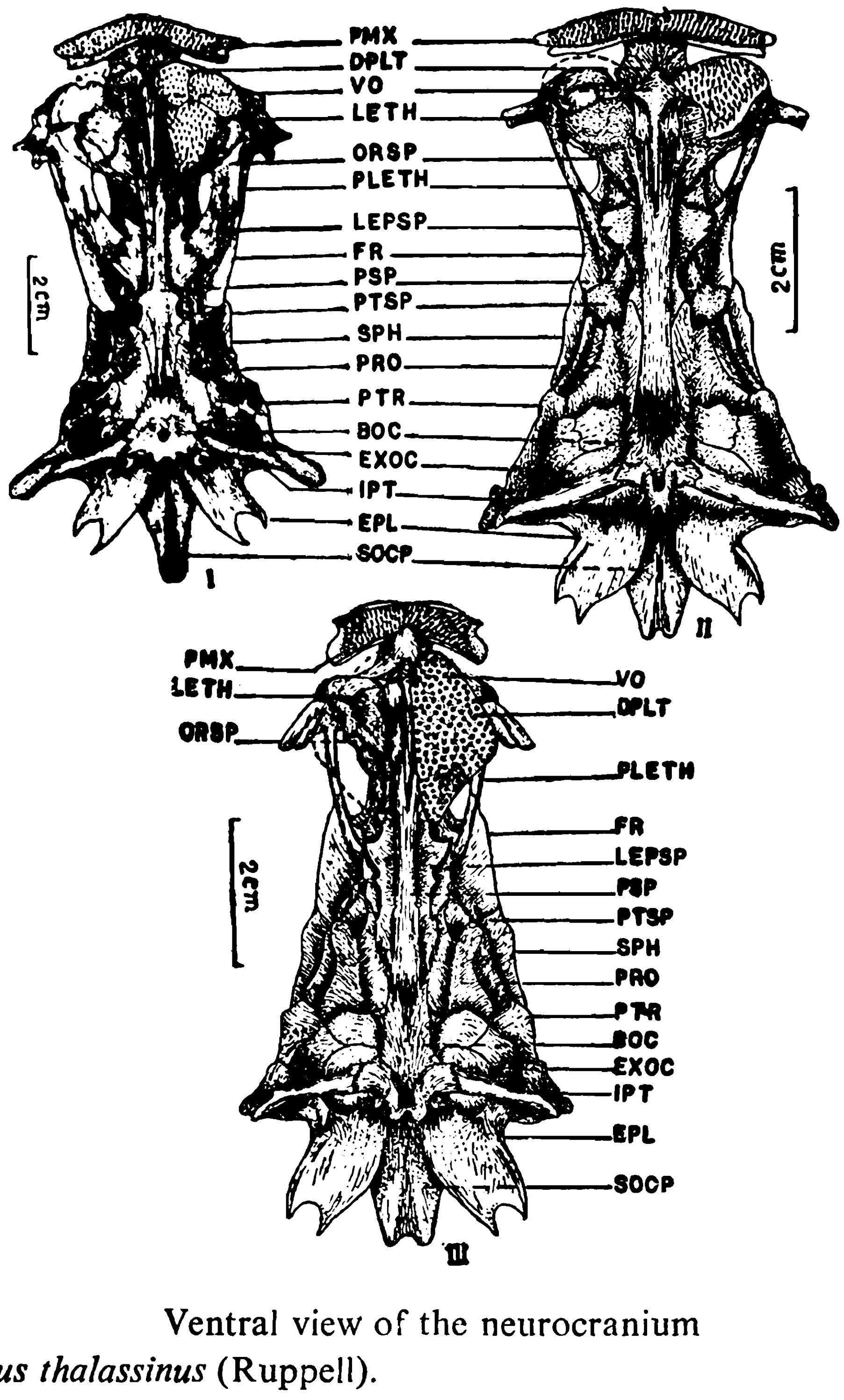
Dorsal view of the neurocranium

I. *Arius thalassinus* (Ruppell).

II. *Arius caelatus* Valenciennes.

III. *Arius arius* (Hamilton).

PLATE 2



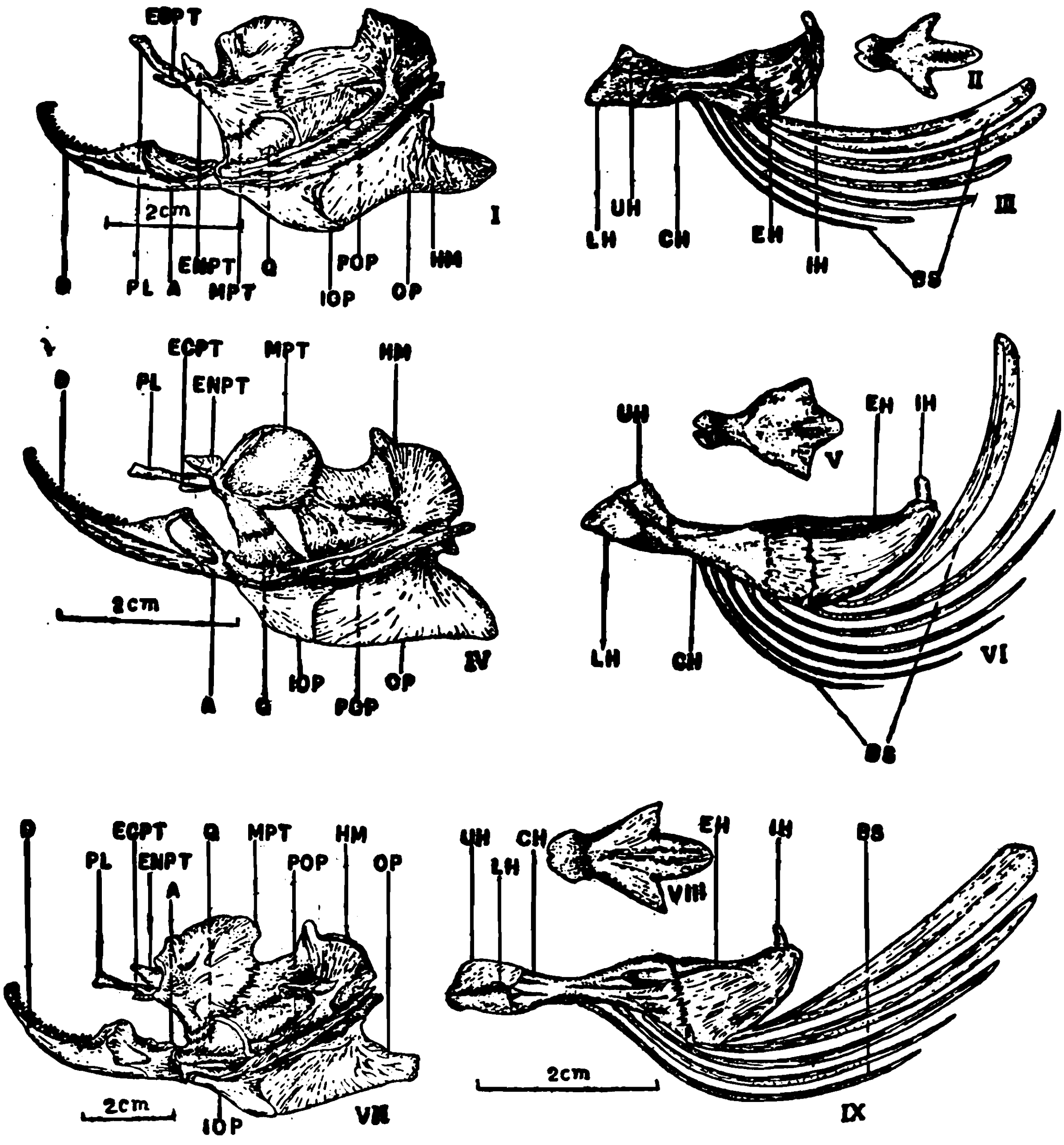
Ventral view of the neurocranium

I. *Arius thalassinus* (Ruppell).

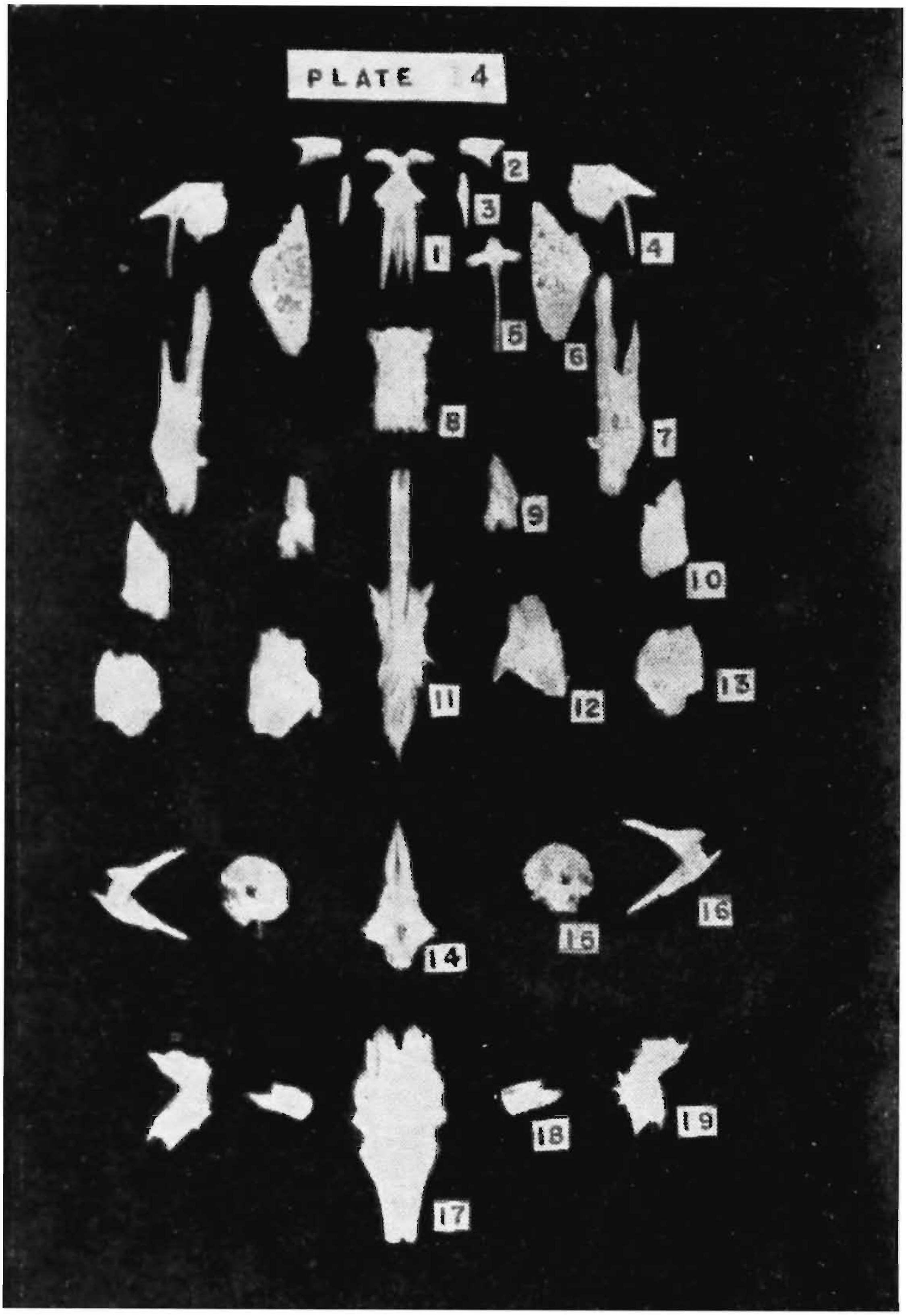
II. *Arius caelatus* Valenciennes.

III. *Arius arius* (Hamilton).

PLATE 3

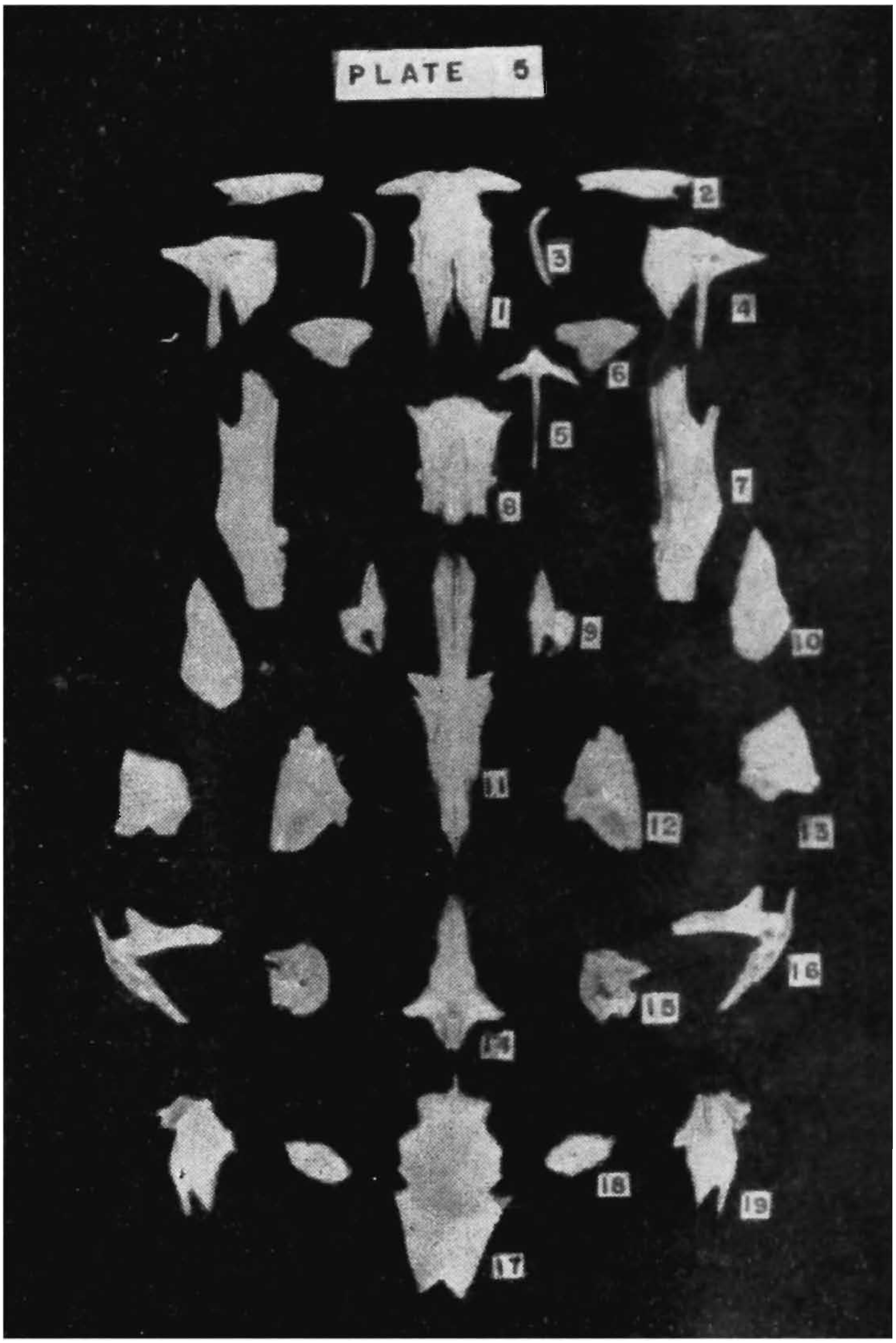


I. Suspensorial bones of *Arius arius* (Hamilton) (Lateral view).
II. Urohyal of *A. arius* (Ventral view).
III. Hyoid arch and branchiostegal rays of *A. arius* (Lateral view).
IV Suspensorial bones of *Arius caelatus* Valenciennes (Lateral view).
V Urohyal of *A. caelatus* (Ventral view).
VI. Hyoid arch and branchiostegal rays of *A caelatus* (Lateral view).
VII. Suspensorial bones of *Arius thalassinus* (Ruppell) (Lateral view).
VIII. Urohyal of *A. thalassinus* (Ventral view).
IX. Hyoid arch and branchiostegal rays of *A. thalassinus* (Lateral view).



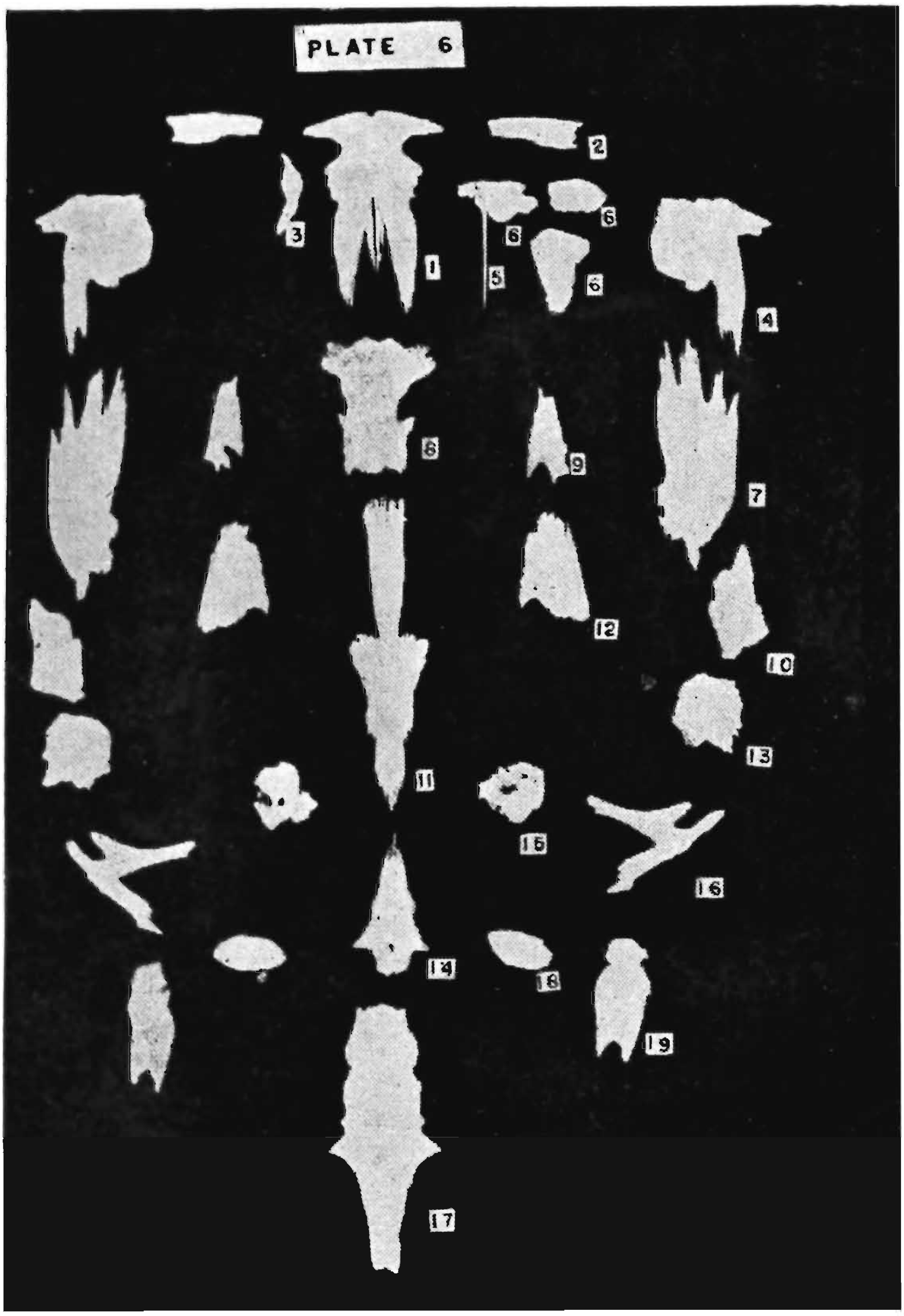
Disarticulated bones of the neurocranium of *Arius arius* (Hamilton)

1 Ethmoid (dorsal aspect).
2. Premaxilla (ventral aspect).
3. Nasal (dorsal aspect).
4. Lateral ethmoid (dorsal aspect).
5. Vomer (ventral aspect).
6. Dermopalatine (ventral aspect).
7. Frontal (dorsal aspect).
8. Orbitosphenoid (dorsal aspect).
9. Pterosphenoid (ventral aspect).
10. Sphenotic (dorsal aspect).
11. Parasphenoid (ventral aspect).
12. Prootic (ventro-lateral aspect).
13. Pterotic (dorsal aspect).
14. Basioccipital (ventral aspect).
15. Exoccipital (postero-dorsal aspecct).
16. Supracleithrum (anterior aspect).
17. Supraoccipital (dorsal aspect).
18. Posttemporal (dorsal aspect).
19. Epioccipital (dorsal aspect).



Disarticulated bones of the neurocranium of *Arins caelatus* Valenciennes.

1. Ethmoid (dorsal aspect).
2. Premaxilla (ventral aspect).
3. Nasal (dorsal aspect).
4. Lateral ethmoid (dorsal aspect).
5. Vomer (ventral aspect).
6. Dermopalatine (ventral aspect).
7. Frontal (dorsal aspect).
8. Orbitosphenoid (dorsal aspect).
9. Pterosphenoid (ventral aspect).
10. Sphenotic (dorsal aspect).
11. Parasphenoid (ventral aspect).
12. Prootic (ventro-lateral aspect).
13. Pterotic (dorsal aspect).
14. Basioccipital (ventral aspect).
15. Exoccipital (postero-dorsal aspect).
16. Supracleithrum (anterior aspect).
17. Supraoccipital (dorsal aspect).
18. Posttemporal (dorsal aspect).
19. Epioccipital (dorsal aspect).



Disarticulated bones of the neurocranium of *Arius thalassinus* (Ruppell)

1. Ethmoid (dorsal aspect).
2. Premaxilla (ventral aspect).
3. Nasal (dorsal aspect).
4. Lateral ethmoid (dorsal aspect).
5. Vomer (ventral aspect).
6. Dermopalatine (ventral aspect).
7. Frontal (dorsal aspect).
8. Orbitosphenoid (dorsal aspect).
9. Pterosphenoid (ventral aspect).
10. Sphenotic (dorsal aspect).
11. Parasphenoid (ventral aspect).
12. Prootic (ventro-lateral aspect).
13. Pterotic (dorsal aspect).
14. Basioccipital (ventral aspect).
15. Exoccipital (postero-dorsal aspect).
16. Supracleithrum (anterior aspect).
17. Supraoccipital (dorsal aspect).
18. Posttemporal (dorsal aspect).
19. Epioccipital (dorsal aspect).