

The Vertebral Column of the Anura.

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WHILE looking through the first volume of *Current Science* at random the other day, I came across a note by Mookerjee¹ and an article by Ramaswami,² which have especially interested me. Both these authors appear to have started their investigations on the vertebral column of some frogs by a perusal of Nicholls' note³ in *Nature* (1914) about the vertebræ of the genus *Bufo*, and to have assumed that no further papers existed on this subject criticising the older, more prevalent view of such authors as Boulenger (1897),⁴ Gadow (1901)⁵ and others. As a matter of fact, however, Beddard⁶ in 1907 pointed out "the procœlous excavation of the vertebral centra" in *Megalophrys nasuta*, contrary to what Boulenger had believed, and Boulenger⁷ himself in 1908 confirmed Beddard's finding and added, "but at the same time I find the vertebræ to be procœlous also in some specimens of *M. montana*, the type of the genus, and of *M. longipes*, of which species other specimens showed them to be opisthocœlous. It is therefore clear that the character, however important it may appear at first, is worthless even as a specific character in these Batrachians." In this connection, perhaps the most important work is a detailed article⁸ by Nicholls in the *Proceedings of the Linnean Society of London* (1915-16), and unfortunately both Mookerjee and Ramaswami have overlooked it. Nicholls examined "practically the entire collection of Anuran skeletons in the British Museum," in all "over four hundred vertebral columns of some fifty genera of Anura"; and it is almost certain that a reference to his paper might have saved Mookerjee all the labour of preparing his note, and Ramaswami

some unnecessary duplication of work.⁹ A comparison of all the three articles shows that Mookerjee's observations on the eight vertebra of *Rhacophorus maximus* has been completely anticipated by Nicholls,¹⁰ who seems to feel the inadvisability of admitting this genus into the family *Ranidae*. He says:

"A more puzzling exception is met with in the genus *Rhacophorus*, and there can be, I think, in this case, no question of abnormality or individual variation.

"The genus is one in which Boulenger has merged the genus *Polypedates*, and it is represented, in the British Museum collection of skeletons, by nine specimens. Of these, four, belonging to the species *R. maculatus*, *R. cruciger*, *R. macrotis*, and *R. robustus*, were diplasiocœlous.¹¹ The remaining specimens, *R. maximus*, *R. madagascariensis*, *R. schlegelii*, and *R. reinwardtii*, were uniformly procœlous.¹² . . .

"Such a condition is apparently inexplicable in view of the fact that the *Rhacophori* are generally accepted as true *Ranidae*. It is, however, of peculiar interest in view of the fact that the *Rhacophori* have not always been regarded as *Ranidae*. Originally they were placed with the *Hylidae* (which are of course procœlous), to which they bear a most remarkable resemblance which is, at the present time, attributed merely to convergence. How close is this resemblance may be judged from a fact

⁹ I must admit, however, that Mookerjee and Ramaswami's work has a confirmatory value, and that Ramaswami has added materially to our knowledge in this respect.

¹⁰ Nicholls, Geo. E., *op. cit.*, 1915-16, 89-90.

¹¹ The term "Diplasiocœlous" was suggested to Nicholls by Boulenger, and was proposed by Nicholls to designate "those vertebral columns, hitherto described as procœlous, which have only the first seven vertebral centra hollow in front, the eighth hollow upon both faces and the ninth doubly convex." The term is really good and should be employed more widely than it has so far been done.

¹² The term "procœlous" has been loosely used by most authors to designate even such a vertebral column as is found in *Rana*. Strictly speaking, it should be employed only to those cases where all the vertebræ have their centra concave anteriorly. This term has been used only in its correct sense in the present article, and it is hoped that other authors also will use it in its strict meaning so as to avoid needless confusion.

¹ Mookerjee, H. K., *Curr. Sci.*, 1932, 1, 165.

² Ramaswami, L. S., *Curr. Sci.*, 1933, 1, 306.

³ Nicholls, Geo. E., *Nature*, 1914, 94, 420.

⁴ Boulenger, G. A., "The Tailless Batrachia of Europe," 1897, p. 38.

⁵ Gadow, H., "Amphibia and Reptiles," *Camb. Nat. Hist.*, 1901, 20 (reprinted in 1923).

⁶ Beddard, Frank E., *Proc. Zool. Soc.*, London, 1907, 1, 328.

⁷ Boulenger, G. A., *Proc. Zool. Soc.*, London, 1908, 1, 407.

⁸ Nicholls, Geo. E., *Proc. Linnean Soc.*, London, 1915-16, Session 128, 80-92.

recently brought to light by Stejneger¹³ (1907). This author has pointed out that the specimen originally figured by Schlegel and regarded as the type of *Polypedates* (*Rhacophorus*) *schlegelii* is actually a mere variety of *Hyla arborea* (*H. arborea japonica*). This view, he remarks (1907, p. 77), has been confirmed by an examination of the original specimen in the Leiden Museum. He figures this variety of *Hyla* as possessing the tongue typical of the Hylidæ but as having a foot which, so Mr. Boulenger informs me, is absolutely characteristic of *Rhacophorus*."

One should like to point out, however, that even if the genus *Rhacophorus* is shifted from the family Ranidæ to one of the families (*viz.*, *Bufo*nidæ, *Hylidæ* and *Cystignathidæ*) forming the tribe *Procæla* of Nicholls, the difficulty is hardly solved, as this genus includes both procœlous and diplasiocœlous forms and a suitable explanation would then be required of the presence of the Ranid type of the vertebral column in some species of this genus.

Ramaswami's observations¹⁴ fully confirm Nicholls' on the vertebræ of *Rhacophorus*, and also add *R. eques* to the diplasiocœlous, and *R. dubius* and *R. microtympanum*, to the procœlous forms. This latter author also feels the position of *Rhacophorus* as problematic and says: "Possibly an examination of other species of this genus may reveal a similar divergence and if it be so, then we have clearly included in this genus *Rhacophorus*, two groups which, so far as the character of the 8th and 9th vertebræ is concerned, will have to be dissociated. Whatever may be the nature of these vertebræ the transverse process of the 9th vertebra is typically Ranid in the forms examined by me, and this fact should not be lost sight of in the investigation of the other species of *Rhacophorus*."

Apparently in view of these studies, three questions arise bearing on the taxonomic status of the genus *Rhacophorus*, and we hope that later workers who have access to the necessary material, will throw some light on them. *First*, how far can we justifiably include within the same genus species so much differing from each other in the nature of their vertebral centra; *secondly*, is it really advisable to include this

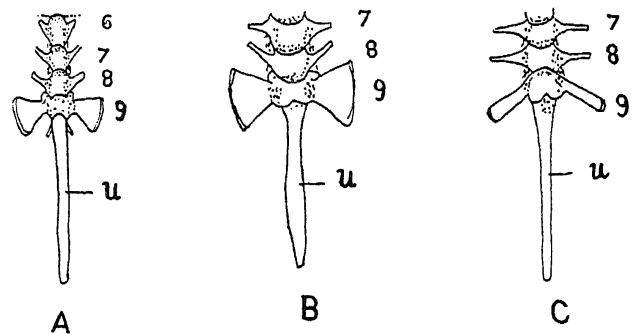


Fig. 1.

Ventral View of the hinder part of the Vertebral Columns of (A) *Discoglossus pictus*, (B) *Bufo andersonii*, and (C) *Rana tigrinal*, to show the opisthocœlous, procœlous, and diplasiocœlous condition (After Nicholls).

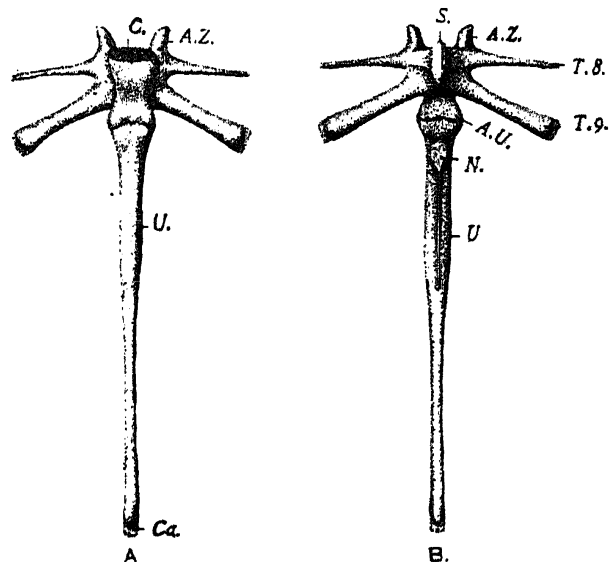


Fig. 2.

The fused 8th and 9th vertebræ and the Urostyle of normal *Rana curtipipes*.

A. Ventral View. B. Dorsal View.
A. U., Articulation of the last vertebra with the urostyle; *A. Z.*, Anterior Zygapophysis; *C.*, Procœlous centrum; *Ca.*, cartilage; *N.*, Bony nodule on the urostyle; *S.*, Neural spine; *T. 8.* Transverse process of the 8th vertebra; *T. 9.* Transverse process of the 9th vertebra; *U.*, Urostyle.

genus (or, at any rate, the strictly procœlous forms of it) in the family *Ranidæ*; and *thirdly*, how far are other features of organization in the procœlous forms of this genus allied to such families as *Bufo*nidæ, *Hylidæ* and *Cystignathidæ*, which are all grouped together as *Procæla* by Nicholls? It is not unlikely that the presence of both procœlous and diplasiocœlous forms in the same genus be due to a state of *plasticity* (as opposed to fixity of structure) on account of a recent state of evolution, and that the genus may help to bridge over the gap between the tribes *Procæla* and *Diplasiocœla* of Nicholls to some extent.

¹³ Stejneger L., *Smithsonian Inst. Bull. U. S. Nat. Mus.* 1907, No. 58, Washington.

¹⁴ Ramaswami, L. S., *op. cit.*, 1933, 306.

Nicholls found that in his tribe *Diplasiocæla*, the species *Atelopus oxyrhynchus*, *A. ignescens* and *Rhombophryne testudo* belonging to the family *Engystomatidæ*,¹⁵ as well as some species of *Rhacophorus* (*Ranidæ*), show the procœlous condition. To the procœlous types of *Ranidæ* examined by him, one can now add the following further species investigated by Ramaswami:

Ixalus chalahodes, *I. sylvaticus*, *I. nasutus*, *I. oxyrhynchus*, *Micrixalus saxicola*, *Nannobatrachus kempholensis* (n. sp., Rao).

Thus in our present state of knowledge, only the species of *Rana*¹⁶ (except *R. curtipes*,¹⁷ which has the eighth and ninth vertebræ fused together to form a synsacrum) and of *Nyctibatrachus*,¹⁸ as well as the diplasiocœlous *Rhacophori* have a typically "ranid" type of vertebral column, Ramaswami's work having deducted three more genera from this group, and thus having further limited the strictly-defined "Diplasiocœla" of Nicholls. So the "ranid" type of vertebral centra does not seem to be prevalent even in the family *Ranidæ*, and it is necessary for every species to be carefully examined for this feature before a sound generalisation can be achieved. Our present knowledge of the vertebral column of Anura may be summed up as follows:

I. *Alossa*: vertebræ opisthocœlous.

II. *Phaneroglossa*:

(1) *Discoglossidæ* (Tribe *Opisthocœla* of Nicholls): vertebræ opisthocœlous; no exceptions recorded so far.

(2) *Pelobatidæ*: (Tribe *Anomocœla* of Nicholls): vertebræ procœlous. Exceptions are *Asterophrys*¹⁹ and some species of *Megalophrys*

¹⁵ Nicholls examined only three specimens of this family belonging respectively to the three species *Atelopus oxyrhynchus*, *A. ignescens* and *Rhombophryne testudo*. Obviously, it is necessary to examine more specimens of each of these species, as well as of others, to put his conclusions on a firmer footing.

¹⁶ Nicholls examined 160 specimens belonging to 33 species of this genus, while Ramaswami examined only 19 species. In all, if we allow for the species examined by both these authors, we find 50 species of *Rana* investigated for this feature. All but one of these conform to the diplasiocœlous type, the only normal exception being *R. curtipes*.

¹⁷ Investigated by Ramaswami (1933).

¹⁸ Only three species were examined by Ramaswami and they were *N. major*, *N. pygmaeus*, *N. sanctipalustris*. All conformed to the diplasiocœlous group.

¹⁹ Sedgwick, A., *A Student's Text-book of Zoology*, 1905, 2, 310. With reference to the family *Pelobatidæ*, he says, "vertebræ procœlous except in *Asterophrys* and *Megalophrys* where they are opisthocœlous."

phrys,²⁰ which have opisthocœlous vertebræ.

(3) *Bufo**nidæ* Grouped together as

(4) *Hylidæ* *Procœla* by Nicholls.

(5) *Cystignathidæ* Vertebræ uniformly procœlous. No exceptions yet recorded.

(6) *Engystomatidæ* (Included by Nicholls in the Tribe *Diplasiocœla*): sacral vertebra biconvex, eighth vertebra biconcave, the first seven vertebræ procœlous. Exceptions are *Rhombophryne testudo*, *Atelopus oxyrhynchus* and *A. ignescens*.²¹ Many genera, however, have yet to be examined.

(7) *Ranidæ* (included by Nicholls in the Tribe *Diplasiocœla*): The forms having the diplasiocœlous vertebral column, as far as is definitely known, are species of *Rana* (except *R. curtipes*) and *Nyctibatrachus major*, *N. pygmaeus*, *N. sanctipalustris*, *Rhacophorus maculatus*, *R. eques*, *R. cruciger*, *R. macrotis*, *R. robustus*. The strictly procœlous forms are *Ixalus chalahodes*, *I. sylvaticus*, *I. nasutus*, *I. oxyrhynchus*, *Micrixalus saxicola*, *Nannobatrachus kempholensis*, *Rhacophorus marinus*, *R. madagascariensis*, *R. schlegelii* and *R. reinwardtii*. Many genera and species remain yet to be examined.

With regard to the nature of the vertebral centra as a useful feature in taxonomy and classification, Ramaswami says, "Judging by the inconstancy and arbitrary nature of the centra in these forms, I think that the character of such variable structures as the vertebra may not prove a very useful criterion in the classification of these forms." Such a view is supported by Boulenger²² (1882, 1908), Gadow²³ (1901) and some

²⁰ Sedgwick's remark about this genus (see footnote 19) is to be modified in the light of Beddard, Boulenger and Nicholl's work.

²¹ Only one specimen of each of these species was examined, and hence the necessity of confirmation by examination of more examples. All the three specimens examined had procœlous vertebræ.

²² Boulenger, G. A., "Catalogue of the Batrachia *Salientia s. Ecaudata* in the collection of the British Museum" (1882) and "A revision of the Oriental Pelobatid Batrachians (Genus *Megalophrys*)" (*Proc. Zool. Soc.*, 1908).

²³ Gadow, H., "Amphibia and Reptiles", *Camb. Nat. Hist.*, 1901, 8. He says: "The systematic value of this pro- or opisthocœlous character has been much exaggerated" (p. 19), and further, "it is not difficult to imagine that in the Anura the production of Pro or and opisthocœlous vertebræ depends simply upon the centra articulating knobs happening to fuse either with the hind or the front end of the vertebræ." (p. 20.)

subsequent authors; while Nicholls²⁴ (1915-16) believes implicitly in the value of this character, and thinks that "the difficulty experienced in attempting to draw hard and fast lines between the different families suggests that our classification is, in the main, a natural one and does not represent merely a convenient key." Amongst the authors who laid stress on the nature of the vertebral centra as a valuable feature in amphibian classification, mention might be made of Cope²⁵ (1866), Lataste²⁶ (1879) and Blanchard²⁷ (1885).

In the end, I should like to express my deep sense of gratitude to Dr. S. C. Sarkar

both for kindly presenting me his valuable collection of reference papers on this as well as on other subjects and for giving me much encouragement. Without the help of friends like him, my work would hardly be possible.

POSTSCRIPT.

After having written the foregoing article, I have been reminded of Whitehouse and Grove's explanation²⁸ of the biconvexity of the ninth vertebra in the frog. These authors feel that such a vertebra provides a much stronger base than a procœlous one could have done, and that it thereby fulfils the extra demand made upon its strength by the movement of the pelvic girdle. This view appears to be in contradiction to Gadow's notions²⁹ and to lose a great deal of its weight on account of the presence of a great many exceptions in the Anura.

²⁴ Nicholls, *op. cit.*, 1915-16, p. 91.

²⁵ Cope, E. D., *Jour. Acad. Sci., Philad.*, 1866, 6.

²⁶ Lataste, F., *Actes Soc. Linn.*, Bordeaux, 1879, 33.

²⁷ Blanchard, R., *Bull. Soc. Zool., France*, 1885.

²⁸ Whitehouse, R. H., and Grove, A. J., *Dissection of the Frog*. Univ. Tutorial Press Ltd., London, 1933, pp. 28-29.

²⁹ See footnote 23 above.

The Dead Sea: A Store-House of Chemicals.

IN a paper read before the Institute of Chemical Engineers, on March 6th, Mr. M. A. Novomeysky, read a paper on "the growth of the potash industry in the Dead Sea region" (*Chem. Age*, 1936, 34, 235). The separation of a potash salt of the grade required by the markets (80-99 per cent. KCl) from the waters of the Dead Sea by solar evaporation, is an achievement involving numerous chemical engineering problems of the first magnitude. Results of experiments led to the conclusion that to produce a high-grade carnallite with a low content of sodium chloride the process of evaporation of the mother-liquor after the separation of the common salt, should be conducted in two or even three stages. In February

1930, the Palestine Potash Ltd., began constructional work with a view to extracting salts on a commercial scale. In 1931, a bromine plant was added. The present output is 25,000 to 30,000 tons of potash and 1,000 to 1,200 tons of bromine. A carnallite with the composition of 22.23 per cent. KCl and 8.96 per cent. NaCl decomposed after its first treatment with water into a sylvinite with 50.38 per cent. KCl and 20.75 per cent. NaCl and this after the first spraying with water yielded a product containing 78.1 per cent. dry KCl. With one or more sprayings, or treatment with brine saturated with KCl, the product can be brought up to a purity of 99 per cent. KCl.