XLI.—*On the Existence of an Osseous Structure in the Vertebral Column of Cartilaginous Fishes.* By JAMES STARK, M.D., F.R.S.E.

(Read 18th March 1844.)

IN the course of an investigation into the structure and composition of the solid frame-work of vertebrated animals, I remarked, in the vertebral column of cartilaginous fishes, an important peculiarity of structure, which seems to have almost entirely escaped the notice of writers on ichthyology and on comparative anatomy.

Fishes have been divided into two great sub-classes, according as their skeleton consisted of bone or of cartilage;—the first sub-class being denominated Osseous, the latter Cartilaginous or Chondropterygious fishes. The writers on ichthyology and on comparative anatomy, up to the year 1817, appear to have remarked nothing more regarding the skeletons of the chondropterygious fishes, than that their hard parts were composed of cartilage. But in the year 1817, the “*Regne Animal*” of the celebrated Baron CUVIER was published, and in it occurred the following particulars, relative to the cartilaginous skeleton of those animals—particulars not noticed in the first edition of the “*Leçons d’Anatomie Comparée*.” “Their skeletons,” says CUVIER, “remain essentially cartilaginous; and, in general, no osseous fibres are formed in them. The calcareous matter is deposited in little grains, and not in threads or filaments.* . . . It even happens that articulations which are moveable in other fishes are not at all present in them. For instance, a part of the vertebræ of certain Rays, and all the vertebral column of the Lampreys, are united into a single mass, and are only distinguished by annular markings.” In speaking of the family of the Cyclostomes, he adds: “The bodies of the vertebræ are united into a single tendinous cord, filled internally with a mucilaginous substance, and clothed exteriorly with cartilaginous rings, scarcely distinguishable from one another. The annular part, which is a little more solid than the rest, is not, however, cartilaginous in all its thickness.”

BLUMENBACH, whose work on comparative anatomy was translated into the English language, the first edition by LAWRENCE, and the second by COULSON in 1827, and CARUS, in his *Introduction to the Comparative Anatomy of Animals*, translated into English, and published in 1827, take no notice of these peculiari-

* CUVIER, *Regne Animal*, 1st Edition. Paris, 1817. vol. ii., p. 114.

ties of the cartilaginous skeletons of chondropterygious fishes—simply styling it cartilage. Nor is any farther information given by MECKEL. He, however, notices the consolidation of the cartilaginous vertebræ of the Rays, at that portion corresponding to the cervical vertebræ.

In 1828, Baron CUVIER commenced the publication of his great work on Fishes. The first volume contains the general remarks on the structure of these animals; and the peculiarities of the skeleton of cartilaginous fishes is summed up in these words: “Their hard parts consist internally of a homogeneous and semitransparent cartilage, which is only covered over at its surface in the Ray and Shark tribes, with a layer of small opaque calcareous grains, closely applied to each other. But in the Lampreys, even this envelope is wanting; and, finally, in the Ammocetes this part remains absolutely membranous.”* Baron CUVIER, however, shewed that there occur a few exceptions to this general rule; as, for instance, in the Sturgeon, about whose head and shoulder true bones occur.

In 1834, MÜLLER,† in a paper on the Comparative Anatomy of the Myoxinoideæ—a family of chondropterygious fishes, endeavoured to shew that four kinds of cartilage occur in cartilaginous fishes. The *first*, or hyaline cartilage, is nearly transparent, and abounds in the Sturgeon and Chimæræ. The *second*, or tubercular cartilage, occurs in the Ray and Shark tribes. The *third*, or cellular cartilage, is met with in the Bdellostoma. And the *fourth*, or ossified cartilage, forms the harder parts of the Sharks and Rays. Subsequent writers do not seem to have been aware of MÜLLER’S researches, as I have not seen them alluded to by any one.

In the first volume of the second edition of CUVIER’S “Leçons d’Anatomie Comparée,” published by Dumeril in 1835, the following interesting remarks are made relative to the skeletons of chondropterygious fishes:

“The earthy molecules of these (cartilaginous) fishes are deposited in many different ways, but never form threads, nor take the stony hardness of some of the bones of the mammalia. In most of the bones of the Rays and Sharks there is found at the surface a layer of closely applied grains, while the centre remains pure cartilage. These grains are seen uniformly everywhere. There are no radiations nor centres of ossification, consequently, no sutures on the cranium or jaws. In the thick bones, as the bodies of the vertebræ and certain jaws, there is also a granular layer on the surface; but the interior of the cartilage is often penetrated by phosphates, either in lamellæ forming cellulosities, or in plates differently but regularly disposed. In certain larger Squali (the maximus, for example), there are cylindrical plates, quite concentric, all separated by layers of a tender carti-

* CUVIER, Hist. Nat. des Poissons. Paris, 1828, vol. i., p. 294.

† Abhandlungen der Königlichen Academie der Wissenschaften zu Berlin. Aus dem Jahr, 1834. Berlin, 1836.

lage, all pierced by holes, as if riddled; in a word, with admirable regularity. Sometimes, the total appearance seems homogeneous, though less hard in the interior than at the surface.”*

Dr GRANT, in his “*Outlines of Comparative Anatomy*,” published first in the *Lancet* in 1833 and 1834, and afterwards as a separate treatise, adds but little to CUVIER’S above description. In pointing out the progress of ossification, as we advance higher in the scale of animated beings, he remarks, “you can easily perceive this consolidation of the laminae in this Shark, and in several other specimens of this animal that are before you, and still better in the Sturgeon; indeed, in the Sturgeon you have a beautiful illustration of this fact, that while the bodies of the vertebrae remain perfectly united, transparent, soft, and cartilaginous, the laminae and spinous processes, and the transverse processes themselves, have become white, opaque, and ossified, and have received a larger quantity of the earthy matters we have enumerated, than the bodies themselves.”†

The only other work on comparative anatomy, which has of late years appeared in this country, is the very excellent one of JONES, entitled, “*A General Outline of the Animal Kingdom*,” and published in 1841. Relative to the vertebrae of fishes he has the following remarks:—

“Even in tracing the modifications observable in the construction of the vertebral column, we have a beautiful illustration of the progressive advances of ossification, in this central portion of the osseous system. The spine of the Lamprey, although at first sight apparently entirely soft and cartilaginous, presents already, in the arches which compose the spinal canal, and in the soft cord that represents the bodies of the vertebrae, slight indications of an incipient division into distinct pieces; rings of ossific matter are distinguishable, encircling at intervals the soft spinal cartilage upon which they perceptibly encroach, so that on making a longitudinal section of the cord, it offers an appearance sketched in the adjoining figure (Fig. 220, A). In a more advanced form of a fish’s skeleton, as, for example, in the Sturgeon, these ossified rings are found to have enlarged considerably, and penetrate still more deeply into the cartilaginous mass (Fig. 220, B). As the bony rings thus developed approximate the centre, it becomes more and more evident that they represent the bodies of so many vertebrae.”‡

Fig. 220.

Further on he says: “The skeletons of the cartilaginous fishes (*Chondropterygii*) will require a distinct notice, inasmuch as they present very remarkable

* CUVIER, *Leçons d'Anatomie Comparée*, by DUMERIL. Paris, 1835, vol. i., pp. 127-28.

† GRANT, in *Lancet* for December 1833, p. 540.

‡ JONES, *General Outline of the Animal Kingdom*. London, 1841, p. 490.

peculiarities of no inconsiderable interest. In the Sharks, Skates, and other genera belonging to this important division of the great class we are now considering, the interior of the bones remains permanently cartilaginous; but the skeleton is in some regions encrusted, as it were, with osseous granules. No centres of ossification, from which radiating fibres of bony matter progressively extend themselves, as is the case in the osseous fishes, are ever developed.”*

Such, then, is the amount of information relative to the vertebral column of the cartilaginous fishes, contained in works known to me. The beautiful descriptions of Sir EVERARD HOME, of the intervertebral apparatus of the Sharks and rays, have been omitted to be noticed, as it is of the bones alone I purpose to make any mention in this communication.

In the course of investigations into the structure of the skeletons of the vertebrated animals, I procured the vertebral column, and some of the other solid parts of the Common Skate (*Raia batis*), Thornback Ray (*R. clavata*), Starry Ray (*R. radiata*), and Sharp-nosed Ray (*R. oxyrhynchus*), for the purpose of submitting them to a chemical examination. The bones or cartilages were carefully cleaned of all fleshy and other matters, dried till they ceased to lose weight, and were then burned. As I had been prepared to expect, the calcareous granular particles which were seen very distinctly on the surface of the cartilages, were procured in the state of a loose granular powder; but I was not a little surprised to find that each vertebra yielded, at the same time, a solid osseous nucleus, very analogous in form, and somewhat resembling in structure, the bony vertebræ of the osseous fishes.

A careful examination of the vertebral column of these animals satisfied me, that this internal nucleus consisted not of agglutinated calcareous particles, resembling those scattered over the surface of the cartilaginous skeleton, but of true bone, having the same general structure as the vertebræ of osseous fishes, being, like them, composed of concentric rings, or laminæ of osseous matter. In these fishes, however, this osseous nucleus was highly condensed, so as to cause it to resemble ivory itself; and in consequence of this condensation, the fibrous structure could not be distinctly seen in it.

It further appeared, that the essential part of each vertebra was composed of this truly osseous substance, and that the whole of the external cartilaginous covering, with its interspersed calcareous grains, could be removed without interfering with the integrity of the vertebral column, in so far as the union of the one vertebra to the other was concerned. In fact, it was by means of this osseous portion, that solidity and strength were given to the whole vertebral column; and it was to this osseous portion, and to it alone, that the intervertebral ligamentary apparatus, so well described by Sir EVERARD HOME, was attached.

* JONES, p. 505.

In the Rays, then, the vertebral column, far from being solely formed of cartilage, consists essentially of true bone, surrounded, it is true, by cartilaginous matter, and having all its processes formed of cartilage, with its attendant covering of calcareous granules, but still consisting essentially of the very same structure as the vertebræ of osseous fishes.

Each vertebra consists internally of two cup-shaped osseous pieces united by their narrow bases, or of two truncated cones united by their truncated apices, so that each vertebral bone resembles a wooden egg-cup, or an hour-glass. Towards the extremity of the tail of the Rays, these hour-glass-shaped vertebræ are nearly simple; or the point of union between the two cups—that part which forms the body of the vertebra—is swollen out into a bulging ring, as at fig. 1, *a*. In some Rays this form of vertebra is often alternated with the simple double cup-shaped one. The bodies of all these vertebræ are perforated by an aperture so minute as scarcely to admit the point of the finest needle. (Fig. 1.)

As the body of the animal is approached, these double cups receive strengthening pillars or plates of osseous matter, first on two opposite sides (Fig. 2), and soon on four sides (Fig. 3), so as perfectly to support the enlarged size of the vertebræ in all violent motions of the animal. These solid strengthening pillars or plates are placed perpendicularly to the outer surface of the vertebræ, and are always strongest and broadest on the upper or dorsal surface, and on the lower or abdominal surface, and fill up more or less of the angular space between the two cups of each vertebra (Fig. 3). The upper or dorsal plate is generally single, and, in all the larger vertebræ, extends forward to the edge of the cup of the articular surface of the vertebra (Fig. 3, *b*). The plate on the anterior or abdominal surface of the vertebra is either double in the larger bones (Fig. 4, *a*), or consists of a broad, somewhat grooved, plate in the centre, opening out into two plates or supporting bases, as it reaches the edge of the vertebral cup (Fig. 5, *a*). In all the larger vertebræ, the anterior plate or plates extend forwards to the outer margin of the cup-shaped articular surfaces of the vertebræ, and thus fill up the whole angular space. It is otherwise, however, with the lateral columns. They rarely fill up the whole angular space left by the union of the articular cups of each vertebra, but only about a third or half of that space (Figs. 4 and 5, *b b b*). In the upper dorsal vertebræ, however, these lateral pillars are often double, and advance forwards to the edge of the articulating cups. The central aperture which pierces the body of the largest vertebra, is not larger than that of the smallest vertebra—scarcely admitting the point of the finest needle.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Now, it is worthy of remark that these strengthening pillars represent exactly the analogous supporting columns of the vertebral cups of the osseous fishes. Indeed, deprive the vertebræ of many of the osseous fishes of their spinous processes (those of the Haddock for example), and it will appear evident to every one that these supporting columns are not only of equal number, but subserve the same useful purposes, in both classes of fishes.

In the Rays, every space between the supporting columns is filled up by cartilaginous matter, so as to cause the body of each vertebra to assume the form of a short cylinder; and it is this cartilaginous envelope which has hitherto prevented the above described osseous structure from being recognised.

In almost all the vertebræ, however, there is an additional means used to strengthen the osseous cups, and prevent them from being fractured in violent motions of the animal. It is well known that cartilaginous, like other fishes, possess only a limited power of flexing the spinal column in a perpendicular direction. The generally square or triangular form of the cartilaginous envelopes of the vertebræ, but especially their large interlocked processes, effectually prevent much power of flexion in a perpendicular direction. Lateral motion, however, is freely allowed; and as we have seen that the lateral osseous supporting columns do not strengthen above half the diameter of the cups of the vertebræ, had no other means been used, there might have been some chance of the vertebræ giving way in this direction, during violent motions of the animal. This, however, is guarded against by a most beautiful arrangement.

From the lateral edges of the cup-shaped bodies arise from two to six or more processes of true bone, which, however, after extending a very little way to meet those from the opposite cup of the same vertebra, are continued as a chain of calcareous granular particles, resembling those forming the calcareous encrustations of the skeleton (Fig. 6, *a*). Between these are frequently remarked lines of square calcareous granules running in the same direction—viz., from the outer margin of the upper cup to that of the lower cup of the same vertebra. This arrangement, consequently, forms a series of supporting pillars, partly osseous and unyielding, partly composed of yielding jointed particles. As these jointed lateral supports are attached to the margin of the cups, while the lateral solid columns above described do not extend over more than from a third to a half of the outer surface of the cup, a free space intervenes between these two kinds of support,—a space filled up in the recent vertebra with cartilaginous matter. (Fig. 7.)

This apparatus seems beautifully adapted to the purpose of allowing a great amount of lateral motion without endangering the rupture of the vertebræ. The shortness of the internal solid osseous

Fig. 6.

Fig. 7.

column permits a small amount of flexibility in the body of each vertebra; and the jointed external lateral supports, while they prevent that flexion being carried too far, in consequence of the square particles of calcareous matter supporting each other, tend, by their partly cartilaginous nature, to restraighen the vertebræ.

As already remarked, the above described osseous structure was found present in the vertebral column of the Common Skate, Thornback Ray, Long-nosed Ray, and Starry Ray; so that I have no doubt it is present in all this order of cartilaginous fishes. As might be expected, the minute disposition of these parts varies a little in each species, yet not so much as to deviate in any material point from the above description.

Before leaving the Rays it may be as well to point out the mode in which these osseous portions of the vertebræ are united to the cartilaginous tube which occupies the place of the cervical vertebræ (if we may so speak) in these animals. All writers, as above noticed, simply describe this portion of the spine as a cartilaginous tube. But it is instructive to remark, that this cartilaginous tube, at its lowest part, contains the solid osseous bodies of several vertebræ, united to each other by the same regular intervertebral ligamentary apparatus, as the free vertebræ. These osseous portions, however, as they approach the head, gradually diminish in size, and at last terminate in a minute cup, which is regularly articulated to the lower vertebra, but superiorly gives place to the cartilaginous mass which supplies the place of vertebræ in the upper part of the spine. (Fig. 8.)

Fig. 8.

Being anxious to ascertain whether another great family of cartilaginous fishes contained osseous nuclei in their vertebral column, I procured a few species of Dog-fish, animals belonging to the family of Squalidæ or Sharks, as this family had been characterised by Baron CUVIER as one of those whose skeletons contained no true bone, but consisted of cartilage, soft within, and with an interspersion of calcareous granules on the surface only.

The internal nucleus of the vertebræ of these animals was found to consist of a truly osseous basis, of much the same general form as that of the Rays. Each vertebra consisted essentially of two cup-shaped bodies, or hollow truncated cones, united by their truncated apices, and resembled wooden egg-cups still more closely than the vertebræ of the Rays. (Fig. 9, *a*). When perfectly cleaned, it was seen that the cup on the one extremity of the vertebra communicated by a large rounded aperture with that on the opposite extremity, as had been remarked in 1809 by Sir EVERARD HOME, when describing the intervertebral structure of the *Squalus maximus*, or Basking Shark. The aperture is smaller in the more minute vertebræ, and of larger diameter in the larger vertebræ.

The two cup-shaped bodies of which each vertebra is composed, are, on their outer margin, not perfectly circular, but of an irregular, somewhat hexagonal, form, and consist of a truly osseous structure, differing little, excepting in increased density, from the vertebral bones of osseous fishes. The osseous matter is, as in osseous fishes, deposited in concentric rings. The mode in which these cups are strengthened differs, however, as might be expected, from that observed in the Rays. The motions of this family of fishes are more quick and varied than those of the rays; and no class, perhaps (Eels alone excepted), possesses a greater amount of flexibility in their spinal column than the Squalidæ or Sharks.

The double cup-shaped vertebræ, then, are not supported by pillars or plates which fill up the angle formed by the sloping sides of each cup, as it is in the Rays, but the supporting plates are wholly external, and consist of six flat plates of osseous matter, stretching from the outer edge of the one cup to the outer edge of the other of the same vertebra. (Fig. 9, *b*). The breadth of each plate corresponds to that of the hexagonal side of the cup which it supports. The anterior or abdominal side being much the narrowest, possesses the narrowest supporting plate; but this plate is in general grooved. The other plates are of nearly equal breadth, and almost touch each other by their margins. In the recent animal, however, the margins are prolonged into cartilaginous processes, covered with calcareous particles, and form the various vertebral laminae, processes and canals, remarked on the spinal column. The free space between the osseous cups and the supporting plates is filled up with tough cartilage—a cartilage removeable by boiling. (To exhibit this, a section is represented at Fig. 9, *c*.)

Fig. 9.

Notwithstanding the somewhat hexagonal form of the external margin of the cups of each vertebra, the articular surfaces, or rather the internal cavity, of the cup is nearly circular.

The same general structure was found present in the *Spinax Acanthias*, the Picked Dog-fish, in the *Scyllium Canicula*, the Spotted Dog-fish, the *Scyllium Catulus*, the Common Dog-fish, and the *Galeus vulgaris*, the Common Tope. It is reasonable, therefore, to infer, that the same structure will be found present in all the allied species.

In the other genera of the great family of Squalidæ or Sharks, the osseous portion of the vertebral column presents various modifications of structure. In the *Selache maximus*, or Basking Shark, the vertebræ are of much larger dimensions, in proportion to the size of the animal, than in the genera above alluded to. This is easily accounted for when the structure of these vertebræ is examined. The osseous matter is not, as in the dog-fish, deposited as a central nucleus of stony hardness, but is deposited in concentric plates, each of which is separated from the adjoining one by a layer of cartilage. From the centre to the circumference of the vertebræ, therefore, there is presented alternate layers

of bone and cartilage. These osseous plates are all beautifully cribriform, and, by their numerous apertures, allow a free communication between the adjoining layers of cartilage. The plates of bone, however, do not appear to send processes from one osseous plate to the other: each forms an independent plate or layer encircling the layers within it. The adjoining figure represents a section of this vertebra,—A A representing the section of the two cup-shaped articular surfaces, B B the concentric layers of osseous matter. The internal layers are more condensed than the external ones. It ought to be mentioned, that the osseous plates are partially interrupted on four sides.

Fig. 10.

With this structure no additional means are required for giving support to the vertebræ in violent motions of the animal, and none else are found present.

In the *Carcharias vulgaris*, or White Shark, each vertebra is composed of two very flat slightly hollowed discs, formed of concentric layers of osseous matter. These discs are supported on four sides by very broad supports, which extend from the outer margin to the centre of the discs. The lateral supports are by much the broadest; in fact, each supports about a third of the circumference of the vertebral cups. These supporting columns are formed of plates of spongy osseous matter, which extend from the circumference to the centre of the vertebræ, and, in this respect, differ essentially from those of the *Selache maximus*, which have a concentric arrangement. A central aperture perforating the body of the vertebra is barely perceptible.

In a young specimen of the *Pristis antiquorum*, or Saw-fish, an animal belonging to the same family as the Sharks, I found the internal portion of each vertebra composed of a solid osseous portion, which, however, differed in its specific characters from that of the other cartilaginous fishes. Each vertebra was composed of two flat, but strong, somewhat rounded, cup-shaped bodies, so flat, however, as to resemble two discs united by a narrow neck. In fact, the vertebral column almost exactly resembled a continued series of the joints of some of the Crinoideæ. I could not detect any aperture piercing the body of the vertebra, so as to allow the flat cup-shaped articular surface of the one side to communicate with that of the other. As the specimen was a young one, and had but few of the vertebræ remaining, the rest having been removed for the purpose of stuffing it, I am unable to give further particulars regarding them, or of the mode by which they are strengthened; but, from their form, great strength, and solidity, I do not think it likely that they receive any strengthening pillars. Figure 11 represents the general form of the osseous portion of the vertebræ of the Saw-fish—viz., two rings or discs separated by a neck, and hollowed into shallow cups on each articular surface.

Fig. 11.

In the *Chimæra*, which belongs to a family closely allied to the Sharks, the

vertebræ are extremely solid, and bear a very close resemblance to those of the saw-fish. Each vertebra is formed of two flat shallow saucer-shaped discs of bone, united to each other by four very broad osseous pillars which extend from the margins of the cups to the centre of the vertebra. The margins of the cups project somewhat beyond those broad supports which form the body of the vertebra. These strengthened portions are on the abdominal and dorsal, and two lateral surfaces: the intermediate portions, however, are hollowed out, and form square cavities filled with cartilaginous matter, which extend nearly to the centre of the vertebra. (Fig. 12 represents one of the dorsal vertebræ.

A the anterior or abdominal supporting plate; B the lateral hollow; C the flat articular surface.) The examination of the articular surface shews that, in these vertebræ, the osseous matter of the cups is deposited in concentric layers, as in all the other cartilaginous fishes; but not having had an opportunity of making a section of the bone, I am unable to speak of the peculiar disposition of the supporting plates which form the body of the vertebra.

Fig. 12.

Two other orders of fishes are arranged under the chondropterygious subclass, viz., the *Cyclostomi* and *Sturiones*. These two orders, however, differ in many essential points from those cartilaginous fishes the structure of whose vertebræ we have been considering: For, while the *Plagiastomi*, which include all the Sharks and Rays, possess, generally speaking, an organization of a higher order than that of the osseous fishes, the *Sturiones*, but especially the *Cyclostomi*, possess an organization of an inferior order,—an organization which renders them in some measure the connecting link between the more highly organized Mollusca and the Fishes.

This circumstance is accordingly not only seen in their digestive, generative, and nervous development, but extends, in a remarkable degree, to what ought to constitute their internal skeleton. In the *Sturiones*, or Sturgeons, the spinal column is formed of a continuous purely cartilaginous tube, divided at intervals into regular pieces, but with no osseous matter whatever in that part which ought to constitute the bodies of the vertebræ. Mr JONES, therefore, must have made some mistake in the passage above quoted, in instancing the spinal column of the Sturgeon as one in which osseous matter is encroaching on the cartilaginous matter of the bodies of the vertebræ; while Dr GRANT and CUVIER are strictly correct in describing the vertebral column of the Sturgeon as consisting of soft transparent cartilage, having earthy salts only deposited on the laminæ.

It is to be recollected that the Sturgeon is one of those animals in which the external skeleton is very strongly developed; and the different rows of osseous plates or shields are so placed as mutually to support one another, and thus keep the body extended, even although no osseous structure is developed in the spinal column.

I have not had an opportunity, as yet, of examining minutely the vertebral column of the Lamprey, Pride, or Hake, the fishes which belong to the order *Cyclostomi*; but I have every reason to believe, that CUVIER and Dr GRANT are correct in describing that column as consisting of a simple cartilaginous tube.

As doubts may arise in the minds of some as to whether the osseous structure, which is above described, be really bone, or is simply condensed cartilage, impregnated with earthy matter, I submitted it to a chemical examination, and found it to yield in every case the same amount of earthy and of animal matter as the most solid bones of osseous fishes.

The osseous portion of the vertebræ of the Skate and Thornback Ray yielded 69.1 per cent. of earthy, and 30.9 of animal matters; while the common cartilaginous skeleton of the same animals yielded only 35.0 per cent. of earthy, and 65.0 per cent. of animal matters. In the various species of Dog-fish or *Squalidæ* examined, the proportions of earthy and of animal matters were found to be within a fraction of those of the Rays, being, in the perfectly cleaned osseous portion of the vertebræ, 68.9 per cent. of earthy, and 31.1 per cent. of animal matters. In the osseous laminae of the vertebræ of the *Squalis maximus* or Basking Shark, I found 71.5 per cent. of earthy matters, and 28.5 per cent. of animal matters. These proportions are almost the very same as those which I have found to be present in the perfectly cleaned bones of osseous fishes. The earthy matters were chiefly composed of phosphate of lime; carbonate of lime was also present, but in very small quantity.

CHEVREUL and MÜLLER are the only writers known to me who have published analyses of the hard parts of cartilaginous fishes. CHEVREUL appears to have undertaken the analyses for Baron CUVIER, and in 100 parts of the vertebra of the Basking Shark (*Squalus maximus*), he found of azotized matter and of oil 64.85, sulphate of soda 18.59, chloride of sodium 13.62, subcarbonate of soda 2.00, phosphate of lime, &c., only 0.94. M. CHEVREUL thought that all these soluble salts did not exist in a solid state in the cartilage, but were held in solution by the large quantity of water which recent cartilage contains,—a quantity amounting to no less than 90 per cent. of the weight of recent cartilage.

It is quite apparent from this analysis, that M. CHEVREUL had only analysed a portion of the enveloping cartilage of the vertebræ, and none of the truly osseous structure which constitutes the essential basis of these bodies. The circumstance of meeting with no phosphates proves this point:—it does more; it proves he had not even included in his analysis any appreciable amount of the concentric osseous plates of the vertebræ.

MÜLLER, on the other hand, analysed each of the varieties of cartilage which he found present in cartilaginous fishes. In what he calls tubercular cartilage, he found a small proportion of earthy matter, which chiefly consisted of the phosphate of lime. In what he terms the ossified cartilage, he found in one case

41.55 per cent. of earthy matter, and in another 42.068 per cent. of earthy matter. These earthy matters consisted chiefly of phosphate of lime, with a small proportion of carbonate of lime, sulphate of lime, muriate of soda, &c.

It is evident from this analysis, that MÜLLER had not discovered the existence of the osseous structure which I describe, but had analysed the whole vertebræ, laminæ and all, considering it all to be what he terms ossified cartilage. He had, in fact, made no distinction between the osseous nucleus and its enveloping cartilage, with its covering of calcareous granules. When I analysed the vertebra in the same way, that is to say, with its cartilaginous laminæ and enveloping cartilages, I got, in one instance, in the Skate 53.3 per cent. of earthy matter, and 46.7 of animal matter, and in the Thornback Ray 54.2 of earthy, and 45.8 of animal matters. But this gives no information as to the real amount of earthy or animal matters in any part of the structure, seeing that the osseous base of the vertebra contains a very different amount from the enveloping cartilage; and seeing, also, that the proportions will vary according to the relatively greater or lesser size of the cartilaginous laminæ and enveloping cartilage.

The essential portion, then, of the vertebræ of cartilaginous fishes is true bone, which has the same composition, and the same concentric laminar arrangement, as the bones of osseous fishes. This fact appears to be of no small importance in enabling us to arrive at more just conclusions regarding the position which cartilaginous fishes ought to occupy in the scale of animated beings. Possessing, as all the *Plagiostomi* do, in so far as their nervous, generative, and digestive, systems are concerned, an organization superior to that of most fishes, it always appeared an anomaly that they should, by their imperfect skeletons, approach so much nearer the mollusca than other fishes. The discovery, however, of a perfect osseous structure in their vertebral column,—that column which is the distinguishing mark of their belonging to the higher classes of animated beings,—at once serves to explain the supposed anomaly, by shewing it resulted from an imperfect knowledge of their true anatomical structure.

In fact, the *Plagiostomi* ought to constitute a separate sub-class of fishes; and, in a descending scale of organization, be placed at the head of the fishes, as they manifestly form the connecting link between the Fishes and Reptiles.* While the *Sturiones* and *Cyclostomi* ought to constitute another and distinct sub-class, to which the term *Cartilaginous* might still be retained, and be placed after the Osseous fishes in the descending scale of natural classification, forming, as they undoubtedly do, the connecting link between the higher organised mollusca, and the lower organised fishes.

* Even the intervertebral ligamentary apparatus in the *Plagiostomi* makes a very close approach to the same structure in the *Amphibia*. In many of the species, especially in those whose vertebral cups are flat, it consists of concentric rings of fibro-cartilaginous matter, with softer albuminous or albumino-cartilaginous matter between them.

But, though these facts be interesting to the student of zoology, it is, perhaps, to the geologist to whom they will prove of most value. It is a known fact in geology, that though the dorsal spines, teeth, and palates, of Sharks and other cartilaginous fishes, have been met with in great abundance in various strata, few or no remains of their skeletons have been discovered; and Dr GRANT,* and other writers on comparative anatomy, state, that there is no likelihood of such remains being ever found, on account of the destructible nature of the cartilage, of which they suppose the skeleton is alone formed. It is true that M. AGASSIZ, in his great work on Fossil Fishes, has given five figures of three nearly complete impressions of cartilaginous fishes,—viz., of one allied to the Dog-fish—one allied to the Saw-fish,—and one allied to the Skate. In these impressions, the forms of the vertebral column, as well as of the fins and scales, have been preserved; but still, with these exceptions, it is from the scales, teeth, palates, or dorsal spines alone, that all the species of cartilaginous fishes are known. The vertebræ, in fact, have not been recognised when met with in a separate state. It is interesting, however, to remark, that in those impressions of entire fossil cartilaginous fishes, figured by M. AGASSIZ, the form of the osseous vertebræ may at once be recognised, so as, from their character alone, to determine to what order the fish belonged. Thus, in the two plates representing the *Spinacorhynchus polyspondylus* (Plates 42 and 43 of Vol. III.), any one who previously examines the vertebræ of the Saw-fish, laid on the table, could at once say that the animal figured by M. AGASSIZ must belong to that division of cartilaginous fishes. The same is true of the other impressions of cartilaginous fishes figured in that work.

One circumstance may be noticed as shewing the probable importance of recognising in the fossil state these osseous portions of the vertebral column. When the teeth or dorsal spines of cartilaginous fishes are found imbedded in the strata, the size of the animal to which they belonged can only be judged of by comparing these remains with the analogous structures of recent species. In this way, however, wrong inferences may occasionally be drawn. Thus, in contact with one of the dorsal spines of a Shark figured by M. AGASSIZ, which, from its size, he thinks had belonged to a very large species (the *Spinax major*), a few vertebral remains occur. From their character, they evidently belong to the same animal to which the dorsal spine belonged; but they prove that, far from the animal having been of gigantic dimensions, it could not have exceeded two feet in length—so much have the weapons of defence of the antediluvian races exceeded those of our day.

Not being sufficiently conversant with this branch of geology, I applied to one or two known geologists, and through them to the great Oxford authority,

* GRANT, Lectures in Lancet, Jan. 1834, p. 576.

to ascertain whether the vertebræ of cartilaginous fishes were known to occur in a fossil state,—whether they had themselves seen any,—or, if recognised, what they were taken for. In answer, it was stated, that the vertebræ of cartilaginous fishes were unknown in a fossil state, nor were they ever expected to be met with on account of the destructible nature of the cartilaginous matter of which they were supposed to be alone composed. Dr HIBBERT WARE added, that M. AGASSIZ had several times expressed to him the same sentiment. Both Dr HIBBERT WARE and Mr TREVELYAN, however, think they have seen in the chalk, and in the new tertiary strata, bodies like what I have shewn constitute the essential portion of the spinal column of cartilaginous fishes. This, along with the circumstance of the exact figures of the osseous portions of the vertebræ being preserved in the impressions of the cartilaginous fishes figured by M. AGASSIZ, shews that, when the attention of geologists is drawn to the subject, they will probably meet with them in the same strata as those in which the teeth and spines occur.

Specimens of the structures above described were laid on the table.