XXIII. *On the Microscopic Structure of the Scales and Dermal Teeth of some Ganoid and Placoid Fish. By* W. C. Williamson, *Esq. Communicated by Dr.* Lankester, *F.R.S.*

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At an early period after the invention of the microscope, the structure of the scales of fish attracted the notice of observers. At that time, little was known respecting the important group to which M. Agassiz has since applied the term "Ganoid;" their attention was consequently directed to the other subdivisions, and especially to the "Cycloid" forms; the object aimed at being to account for the concentric circles on the surface of the scale, which had been noticed by Barellus in 1656*. Hooke touches upon them in his 'Micographia,' published in 1667. Five years later, the accurate Leeuwenhoek submitted them to a careful examination, and concluded, according to M. Mandl, "Qu'il se forme chaque année, une nouvelle écaille au dessous de l'ancienne, qui la déborde, de sort que l'on aperçoit sur l'écaille le bord de l'ancienne écaille, et qu'on peut ainsi en comptant dans une section transversale le nombre des couches, déterminer l'âge du poisson et le nombre d'écailles accessoires, qui forment l'écaille entière†."

During a century subsequent to this discovery, but little new light appears to have been thrown upon the subject; and though Mandl, in the memoir just quoted, cites the names of Reaumur, Roberg, Petit, Schæffer, Baster, Ledermuller and Brousonnet, as having directed their attention to it, they appear to have left it pretty much where they found it.

During the present century, Heusinger, Kuntzmann, Ehrenberg, Agassiz, Mandl and Owen have in succession investigated the matter, but the labours of the three last alone require a more special notice.

At an early period in the progress of the colossal labours of M. Agassiz, he was struck with the vast importance of studying the scales of fish, and, as is well known, ultimately made their variations the basis of his classification. In the fourth chapter of his large work, headed "Dermatologie et en particulier des écailles des poissons‡," he enters very elaborately into the structure of the skin and scales, with the relationship of the one to the other; and he especially seeks to illustrate, what was then a new topic, the structure of the scales of many of his "Ganoid" fish, pointing out their enamelled (*émaillé*) surface, the large development of a dentine-like substance in the

* Petrus. Observationum Microscopicarum Centuria.

† Annales des Sciences Naturelles, vol. ii. p. 338.

‡ Poissons Fossiles, vol. i. p. 61.

upper part of many of them, as well as the existence of a true osseous tissue with lacunæ, and even Haversian canals in the lower portions of some scales. The usual existence of a structure more or less laminated, is accurately noticed; and he especially points out the close and striking resemblance between some of these organisms and the teeth of fishes; one general result of his observations being a conviction that these scales were formed by the gradual and successive deposition of layers of osseous tissue, a practical revival of the opinion first promulgated by LEEUWENHOEK, nearly two centuries ago. These views were opposed by M. MANDL, in a memoir* in which he endeavoured to account for the structure of cycloid scales especially in a totally different way. This publication elicited from M. AGASSIZ an effective reply, in which he gives the following valuable summary of his views :—" J'envisage l'écaille du poisson comme une sécrétion épidermoidale, absolument analogue à celle des ongles et autres de même nature, qui s'observent chez les animaux supérieures. Comme les ongles, elles se composent de lamelles très fines d'une substance cornée, superposées dans l'ordre de leur formation. L'organe sécréteur est la poche épidermoidale dans laquelle elles sont enfoncées par leurs bords antérieurs. La portion de l'écaille recouverte par le feuillet supérieur de cette poche est plus ou moins considérable; le feuillet inférieur, au contraire, recouvre presque toute la face interne de l'écaille, excepté dans quelques cténoides, où la face inférieure des dentelures est libre. Les lamelles nouvellement formées, sont plus molles, mais de même composition que les plus anciennes. La poche grandit à mesure que l'écaille dévelope, de sorte que les lames, nouvellement déposées, sont toujours plus grandes que les anciennes. Les stries concentriques de la poche sont dues à cette circonstance, en ce sens que le bord de chaque nouvelle lame occasionne par le pression qu'il exerce sur la poche un pli, ou plutôt une impression très légère qui correspond naturellement au bord de cette lame. Les lignes concentriques des écailles sont le reflet des bords des lamelles superposées. Aussi sont elles plus nombreuses chez les poissons âgés que chez les jeunes†."

In the body of his large work‡, M. AGASSIZ introduces descriptions of the microscopic structure of some ganoid scales, especially of those of the recent *Lepidosteus osseus* and *Polypterus*, as well as of the *Lepidotus gigas* and *L. unguiculatus*: and in the volume on the fossil fish of the old red sandstone, he gives the result of some very careful examinations of the scales belonging to many of the interesting genera from that group of deposits.

Professor OWEN has slightly touched upon the subject in his recently published lectures§, where he observes, " In the *Lepidosteus*, the scales defend the body in close-set oblique rows; are thick, completely ossified, and with an exterior hard, shining, enamel-like layer, having the microscopic structure of the hard dentine of sharks' teeth; the subjacent osseous part exhibits the radiated corpuscles. I described

* Annales des Sciences Naturelles, vol. ii. † Ibid. vol. xiv. p. 108. ‡ Poissons Fossiles.

§ Lectures on the Comparative Anatomy and Physiology of the Vertebrate Animals, 1846, p. 140.

the organic structure of the so-called ganoid scale-bones in 1840, both in recent and extinct fishes, showing that it militated against the theory of the development by successive deposition of layers being applied, at least to ganoid scales." A reference is made to the 'Odontography,' p. 15, where I find the following foot-note:—"A very close analogy exists between the dermal bony tubercles and spines of the cartilaginous fishes and their teeth. The system of minute parallel tubes, with their branches and anastomoses in the thick scales of the extinct *Lepidotus*, is as complicated as in many teeth, and equally militates against the theory of transudation of layers being applied, at least to ganoid scales." The new facts brought forward by Professor OWEN are some observations on the opercular and other bones of the Carp and Gold-fish, from which he concludes that the opercular bones are not modified dermal scales; the remaining illustrations had already been developed by M. AGASSIZ, both in his descriptions and by his drawings*.

The last writer who has alluded to the subject is Mr. E. QUEKETT. His observations however† are confined principally to the forms of the lacunæ found in the scales of *Lepidosteus osseus* and *Callichthys*. Such was the state of this subject when I entered upon a further series of observations. The difficulty which I had experienced in identifying what I had seen of the structure and development of human bone, with the descriptions given by MULLER, TOMES, TODD, BOWMAN and others, led me to take up the examination of these forms of osseous tissue, in the hope that they would throw some additional light on the question. The wide difference also which existed between the views of OWEN and AGASSIZ as to their mode of growth, rendered a further inquiry into the development of the scales necessary. I hope and believe that the facts about to be brought forward will at least be found sufficiently conclusive to settle the question; by showing that, whilst the scales are formed, as originally stated by M. AGASSIZ, by the apposition of successive layers, these layers are not generated by any process of secretion, but by the calcification of an organized basis, resembling that of bones and teeth, as asserted by Professor OWEN.

Though M. AGASSIZ has already investigated the structure of the scales of *Lepidosteus osseus* and *Polypterus niloticus*‡, the importance of an accurate knowledge of these recent types of the Sauroid group of fish, in contributing to the illustration of the fossil species, led me again to subject the scales of *Lepidosteus osseus* to a careful examination: whilst the result has been confirmatory of most of the observations of M. AGASSIZ, it has also revealed one or two points which have escaped his eye, but which are of importance.

Plate XL. fig. 1 represents a vertico-longitudinal section of a scale of *Lepidosteus osseus*. From *a* to *b* represents the anterior portion of the scale, which, when *in situ*, is imbedded in the skin, and covered by the posterior overlapping margin of the antecedent scale. *c* represents the posterior margin. The whole structure is composed of

* Poissons Fossiles, vol. i. p. 73 tab. H.; vol. ii. tab. G.

† Transactions of the Microscopical Society of London, vol. ii. part 2.

‡ Vol. ii. part 2, p. 5 *et seq.*

exceedingly thin lamellæ*, which are folded back upon themselves at the edges of the scale, the lowermost ones overlapping those which rested upon them, and covering them over to a considerable extent. This is especially the case at the anterior portion of the scale, but also exists to a considerable extent at the lateral margins, or those which are parallel to the mesial line. Fig. 2 represents the section of the half of a scale taken at right angles to this line, and where along the whole of the upper margin we see this duplicature of the lamellæ towards the centre of the scale. It is also seen to a slight extent along its anterior border.

Between these parallel lamellæ are multitudes of lacunæ with radiating canaliculi. These lacunæ M. AGASSIZ designates by the almost exploded term of "bone-corpuscles." They appear to be cavities between two contiguous lamellæ, in the plane of which the canaliculi are spread out, but without appearing to perforate either of them. I have not attempted to represent them in the Plate, as they would have rendered its details confused and indefinite.

Along the upper margin of the section, especially at certain points, as at fig. 2 *a*, the terminations of several of these lamellæ combine to form a tooth-like projection, each of which corresponds with more clearly marked divisions existing in the section of the scale, and which I have distinguished as constituting the *Laminæ*; were not these surmounted by ganoin†, they would have formed elevated ridges on the surface of the scale.

Arranged nearly at right angles to the lamellæ, are a number of narrow tubes, figs. 1 *f* and 2 *b*. These penetrate from the exterior to the interior of the scale, and have usually a diameter of about $\frac{1}{8000}$th of an inch. They are of nearly uniform width, somewhat undulating, and though usually simple, sometimes divide into two or three branches. A few of them terminate in the inferior and middle lamellæ of the scale, but in the central and anterior regions, they are generally prolonged until reaching within a short distance from the upper surface. At the anterior part, and towards the lateral margins, they terminate in the region where the successive lamellæ turn back upon themselves, figs. 1 *c* and 2 *c*. Thus the scale is divided into two portions; a superior one, in which all these tubes, preserving their rectangular position in relation to the lamellæ through which they pass, enter from the upper surface, and an inferior and far more extensively developed one, which is wholly supplied from below. At their termination these tubes generally divide into two or three short branches. They were seen by M. AGASSIZ, but on some points our observations differ. He says

* I have employed the terms lamellæ and laminæ throughout the memoir to represent two distinct appearances. The former I have applied to the ultimate thin layers into which the use of high magnifying powers enables us to subdivide the thickness of the scale. By the latter I have distinguished certain more conspicuous subdivisions, each consisting of numerous lamellæ, and each of which is thought by M. AGASSIZ to be the result of one year's growth.

† I have preferred employing the term Ganoin, to represent the hyaline substance covering over many of these scales, in preference to that of Enamel. It is different in its character from the prismatic structure covering the dentine of the teeth of mammals, and the employment of one term to designate both leads to error.

that "ces tubes vont mourir à la limite de la substance osseuse, et jamais on ne les voit entrer dans la couche émaillée." Sometimes however they do penetrate the layers of ganoin, as at fig. 2 *d*, where the tubes perforate several of its laminæ, having evidently once passed through them to open upon the external surface of the scale, and having only been closed up by the subsequent addition of new laminæ of ganoin. In the *Lepidosteus* their branching extremity always terminates in the structure *below* the ganoin and never in it.

M. Agassiz thinks that these tubes have not served as channels for the conveyance of nutriment to the interior of the scale, but as depôts of calcareous matter. "Je serais plutôt disposé à croire que ces tubes ont une destination analogue aux corpuscules osseux et des tubes dentaires, savoir, de servir de dépôts de matière calcaire." With this conclusion I cannot agree; the tubes appear to me to be open canals in the hard tissue of the scale. Besides which, most modern physiologists entertain a different view, both of the lacunæ of bone and the dental tubes of teeth, to that held by the Swiss philosopher.

The real nature and use of these tubes is a point about which I am dubious. In *Lepidosteus osseus* we only see their partial development, but in some of the fossil species, hereafter to be described, we shall find them assuming a new aspect.

In addition to these, there exists an extensive development of a second set of tubes (fig. 2 *e*), which are still more minute, but which also radiate from the outer surface to the inner portions of the scale. They penetrate the lamellæ in a much more oblique direction, crossing the larger tubes at an acute angle, verging as they do so, from the outer border, towards the centre of the scale. They do not ascend directly, but in the manner of a succession of steps, having a constant tendency to be spread out for a short space between the lamellæ, and then obliquely penetrating those above them, they repeat the same process. They are very much branched. This system of tubes appears to have escaped the notice of M. Agassiz, and I have not seen any reference to their existence in *Lepidosteus* by subsequent writers. We shall find, as we proceed, that in one form or another there are very few ganoid scales in which they are not extensively developed, and as we shall often have to refer to them, I should propose to distinguish them by applying to them the term *Lepidine*. Though not the homologues of dentine, they appear to fulfill a similar function in the scales to that which the dentine tubes do in the teeth, though they are often limited in their distribution to particular portions of the true scale tissue, which is not the case with dentine. I suspect that they have much more to do with the general nutrition of the scale, than the more parallel and larger tubes previously described: we shall afterwards find that the latter only exist in a few groups of fish, and that in them the ultimate distribution of these tubes is mainly restricted to particular regions of the scale. But the lepidine tubes are very different. I have seen few scales in which I could not demonstrate their existence, generally crowded together in vast numbers, and giving off numerous minute branches as they proceed, to each succeeding lamella, even when their distribution is confined, as we shall occasionally find it to be, to particular portions of the scale; they always penetrate every one of the lamellæ, and thus communicate with each parallel layer of lacunæ, through the canaliculi of which the necessary lateral communication can be carried on*.

There is in addition, a third set of still larger, though less numerous canals, which pass completely through the scale, fig. 1 *g*. These are supposed by M. AGASSIZ to convey the blood through the scale in order to supply the epidermal layer by which it is covered. Existing, as we shall subsequently see, in nearly all the fossil species, they obviously play an important part in the economy of the scale, by keeping up a free communication between its upper and lower surfaces. They are not confined to, or even chiefly found in, the anterior portion of the scale, which, when *in situ*, is embraced by the thick duplicature of the skin, but in that part of it which is free, and which has beyond doubt been covered over with a thin secreting membrane like a periosteum, and which has received some of its supply of blood through these open canals, by means of anastomosing blood-vessels, ascending from the integument below. About the posterior two-thirds of each scale is covered over with a layer of ganoin. In some parts this is so thin as to be scarcely visible, figs. 1 *h* and 2 *f*, whilst in others it is developed into irregular tubercles, fig. 2 *g*. From the latter representation, we see the way in which these tubercles of ganoin arę formed. They are, in fact, prolongations of the upturned edges of the bony lamellæ, running towards the centre of the scale, but only covering small portions of the surface, instead of uniformly extending over the whole, as we shall afterwards find to be the case in *Lepidotus* and other fossil forms. We see from this, that each lamella of the ganoin was formed contemporaneously with that of the bone from which it springs; each lamina, shown in the drawing, consists of a number of more minute lamellæ, as has been already observed in reference to the osseous portions. With the exception of the tubes, of which the orifices have been already alluded to as perforating its laminæ, I have not been able to detect any other microscopic structure than these lamellæ in the ganoin.

I subjected some of these scales to the decalcifying action of dilute hydrochloric acid, and obtained a dense flexible tissue, preserving all the original contour of the scale. In this were still exhibited the three sets of canals or tubes, and the lacunæ with their canaliculi. The traces of the lepidine tubes were to be seen so crowded together as apparently to compose almost the entire tissue of the scale. Sections taken at right angles to these tubes exhibited very similar appearances to what are seen in a corresponding section of the decalcified tooth of a Cachalot, or any other

* These tubes appear to correspond with those to which Prof. OWEN has applied the term "plasmatic." But as he includes under this title all those commonly known as canaliculi, radiating from the lacunæ, which are obviously distinct in their nature, I think it will serve the purpose of rendering our descriptions more clear, if we employ a new term to distinguish those which I have designated "lepidine" tubes. See the Lectures on the Comparative Anatomy and Physiology of the Vertebrate Animals, by Prof. OWEN, part 1, p. 28. This eminent anatomist appears to have noticed them in the scale of the Sturgeon.

analogous form of dentine. But what I more especially sought for I obtained, in the comparative ease with which vertical sections could be torn into fragments along the lines of the original lamellæ, in the same way that Dr. SHARPEY has demonstrated in the case of human bone*. This result left no doubt on my mind as to the applicability of the views of LEEUWENHOEK and AGASSIZ to the scales of *Lepidosteus osseus*, being thoroughly convinced that their formation was accomplished by the successive organization of separate lamellæ, though this organization was not confined, as imagined by LEEUWENHOEK, to the inferior surface.

I may observe, that on decalcification, the lacunæ and tubuli did not disappear, as is stated by M. AGASSIZ, though they became somewhat less distinct, as they do in human bone under similar circumstances. This latter example has been already explained by Dr. SHARPEY†; and his explanation is probably applicable to these bony scales: consequently the circumstance of the lacunæ and tubuli becoming somewhat less conspicuous after decalcification, does not militate against the idea of their being cavities.

Did any doubt exist however on this point, the long streams of air-bubbles which issue out of them on mounting a section in Canada balsam would settle the question.

Employing this scale of *Lepidosteus* as a valuable, and I believe the only recent, type of its class, we will proceed to examine those of some of the numerous fossil genera which have been constructed upon the same general plan. These are especially the widely-diffused genera of *Lepidotus*, *Seminotus*, *Dapidius*, *Tetragonolepis*, *Pholidotus* and *Ptycholepis*.

Lepidotus.—The scales of two species of this genus have already been examined by M. AGASSIZ with reference to their microscopic structure, *L. unguiculatus* and *L. gigas*. Of the former, he merely notices the superimposed arrangement of the lamellæ‡. Of the latter he says, " Lorsque l'émail est enlevé, on aperçoit à la surface de la partie osseuse les bords des lames d'accroissement dont se composent les écailles, et de distance en distance des lignes plus marquées, indiquant des interruptions dans l'accroissement; elles sont causées par l'usure des bords des dernières lames qui ont précédé un nouveau développement. Je me suis assuré par l'examen des poissons vivans que ces interruptions étaient périodiques et annuelles§."

The most beautiful scale belonging to the genus which has come under my notice, is that of the *L. semiserratus*, from the Whitby lias, two representations of which are given in figs. 3 and 4. The general form of the scale is rhomboidal, having one of its free margins furnished with large teeth, two other sides of the rhomboid having been imbedded in the soft integument, and overlaid by the margins of the adjoining scales.

On making a vertical section of the scale (fig. 3) in the direction of the lateral line, we find it to consist of well-marked parallel laminæ, varying from $\frac{1}{240}$th to $\frac{1}{400}$th of an inch in thickness, which, as in *Lepidosteus*, though in a less degree, are turned

* Dr. QUAIN's Anatomy, 5th edition, by Dr. SHARPEY and Mr. QUAIN, p. cxlii. † *Ut supra*.

‡ Poissons Fossiles, vol. ii. p. 253. § Ibid. vol. ii. part 1, p. 237.

upwards at an acute angle round the margin of the scale—especially on the two sides that are fixed in the soft integument—from one of which the section represented in the sketch (fig. 3) was made. These laminæ are composed of a multitude of still more minute lamellæ. They are perforated by a number of narrow parallel tubes $\frac{1}{5600}$th of an inch in diameter, the greater proportion of which ascend direct from the inferior surface to the region immediately under the ganoin, fig. 3 *a*; but in the anterior margin of the scale these tubes abandon the vertical and assume the horizontal one, or even descend obliquely (fig. 3 *b*), but always run at right angles to the plane of the laminæ through which they pass. In the latter case, instead of terminating, like the vertical ones, immediately under the ganoin, they do so at the angles which the various lamellæ make, when assuming the upward direction; many of them even appearing to take their rise from the under surface of the ganoin, as at fig. 3 *c*; but in the latter case the tube was originally in the position of fig. 3 *d*, its orifice having been subsequently covered over by the formation of newer lamellæ of bone and ganoin.

At the two free margins of the scale which overlap the concealed borders of those behind them, the tubes ascend from the lower surface, as shown at fig. 5 *b* (which represents a similarly constructed scale of *Seminotus rhombifer*). On reaching the ganoin these tubes become branched; their ramifications spreading out in a very thin layer, which covers the outer surface of each of the ridge-like projections which form the upper boundary of the vertical osseous laminæ. This layer consists of a substance alike distinct from the ganoin above and the true bony tissue below, and to which I propose to give the name of Kosmine (from *κόσμειν, to adorn*). It is much more dense in its structure than the true bone containing no lacunæ (though these, as the case in the example before us, are often seen through it), but is always furnished with some arrangement or other of minute branching tubuli. This kosmine, which has hitherto been confounded with the ganoin, under the common name of "enamel," occurs so frequently as to constitute an important feature in many ganoid and other scales, and consequently requires to be distinguished from the transparent and almost structureless tissue to which I have limited the application of the term *ganoin* throughout this memoir.

The exquisitely beautiful appearance produced by this distribution of the tubes in the scale under consideration, is shown in fig. 4 *a*, which represents the upper surface of that portion of the scale as seen through the transparent ganoin. The sharp tooth-like ridges presented in the vertical section, fig. 3 *c*, are here more highly magnified, and form parallel spaces, fig. 4 *a*, before reaching which, the tubes usually divide into two or three branches, which afterwards give off beautiful arborescent ramifications, reminding us of leafless trees in winter. These communicate freely with one another, by means of anastomosing loops, in the arches of which some of the small lateral twigs dilate into crescentic cavities, fig. 4 *b*. The branches of each tube are usually limited, in their distribution, to the one lamina to which it is destined, but sometimes, after thus giving off a group of branches, the main trunks pass on to supply the next lamina which lies on the inner side.

This distribution of tubes on the extremity of each lamina, shows that the more strongly-marked lines of division which separate them, in contradistinction to those merely dividing the lamellæ, are not due to "l'usure des bords des dernières lames qui ont précédé un nouveau développement," but to some internal physiological cause, which, whatever it has been, may have operated annually, as is supposed by M. AGASSIZ.

In the central and earliest formed lamellæ, these tubes terminate as at fig. 3 *b*, *c* and *d*, by subdividing into two or three small branches, but do not exhibit any extensive ramifications. The same is also the case with the tubes of the two opposite margins which terminate in the interior of the scale.

We also find in this scale a development of lepidine tubes; they are not diffused throughout its whole extent, as in *Lepidosteus*, but appear to be chiefly confined to the margins; and even there, only exist in those portions of the lamellæ which assume the oblique and vertical directions. These latter are copiously perforated by them, fig. 3 *f*, but the horizontal portions exhibit few, if any, traces of their existence.

Between each of the contiguous lamellæ is distributed a layer of lacunæ which exhibit the same features as those of the *Lepidosteus* already described. In the parallel spaces of fig. 4 we only see the edges of the lacunæ and their canaliculi following the plane of the ascending lamellæ.

On the upper surface of the scale is found a thick deposit of ganoin, the formation of which, the section represented in fig. 3 enables us to comprehend. At *g*, like the subjacent part of the scale, it consists of parallel laminæ, each of which, under a high magnifier, is seen to be again separated into still more minute lamellæ. At *h*, we find that each of the laminæ is merely a prolongation of a corresponding one in the osseous portion, only having the character of ganoin instead of bone, and separated from it by the thin film of kosmine already described. To some extent we found the same condition to exist in *Lepidosteus*, only the kosmine was wanting, and what was there seen to be a partial and unequal distribution, producing irregular superficial tubercles, here extends uniformly over the whole scale, showing that, in *Lepidotus* at least, each new growth has completely surrounded all that had been previously formed, enclosing it as a nut does its kernel; only the upper portion was ganoin, whilst the lower one was true bone.

We also find in the large opercular bone of the same *Lepidotus* a still further resemblance to the scales of *Lepidosteus*, in the existence of similar large canals communicating between its upper and lower surfaces. I have observed sections of these to exhibit concentric laminæ surrounding the canals, showing that the membrane which lined them was also a secreting tissue, depositing calcareous matter, and was doubtless a prolongation of the periosteum already spoken of. These concentric lamellæ do not all exhibit complete circles, those forming the canal alone doing so; on one side of, and external to the latter, we often observe a number of half-circles, as if it had for a long time been merely a groove at the margin of the scale. In other respects, the bony lamellæ of the operculum exhibit the same appearances as those of the true scales, and prove that it has been formed by a similar deposition of laminæ. This close resemblance between the minute structure of the scales and opercular bones of *Lepidotus* seems to support the view once entertained by Prof. OWEN, but since abandoned by him, that the opercular bone is merely a modified scale, and consequently belongs not to the endo- but to the exo-skeleton.

Lepidotus Mantelli and *L. fimbriatus* have scales of a similar structure to those of *L. semiserratus*, only the latter appears to want the beautiful ramifications of the kosmine. The central tubes which ascend from below all terminate in short branches like those seen in the centre of the last-described scale. The ganoin of *L. Mantelli* is filled with minute brown granular points; but whether these are parts of its original structure, or whether it is merely an effect of fossilization, I am undecided. I suspect the former to be the case. Similar, but still more minute, granules exist in great abundance in the ganoin of *L. fimbriatus*.

Seminotus.—Fig. 9 represents a vertical section of *Seminotus rhombifer*, taken parallel to the mesial line of the fish. It exhibits an excellent illustration of the general contour of this class of fossil scales: *a* is the anterior extremity, which is imbedded in the soft skin, its oblique margin being overlapped by the scale in front of it: *b* is the opposite edge, adapted for resting on the anterior bevelled portion of the adjoining scale. We have the same arrangement of laminæ, lamellæ, lacunæ, canals and lepidine tubes as in *Lepidotus*, only we want the arborescent ramifications of the kosmine tubes. The ganoin exhibits the laminated structure found in the other scales.

Pholidotus.—In *Pholidotus Leachii* we have a close resemblance to the scale of *Seminotus rhombifer*, only the edges of the upturned laminæ, as seen in a vertical section, exhibit less of a tooth-like arrangement; and amongst the lower laminæ of each scale is developed a large central lenticular cavity, produced by the divergence of some of the last-formed layers. I have not yet discovered any traces of an opening into this cavity, though there most probably is one. The parallel tubes take their rise from it as from the bases of ordinary scales, ascending towards the ganoin.

Ptycholepis Bollensis.—In the structure of the small thick scale of this curious species, we find a resemblance to that of *Lepidotus semiserratus*. The parallel ascending canals terminate in a similar thin layer of kosmine, which exhibits three or four parallel rows of anastomosing loops, giving off minute branching tubuli. The ganoin, which is unusually thick, exhibits precisely the same laminated structure as that of the *Lepidotus*.

Beryx.—The scales of a new species of this genus, from the Chalk of Sussex, belong to the same group. We find the large canals, like those of the *Lepidosteus*, communicating between the two surfaces of the scale—the parallel ascending tubes, which, as in *Lepidotus semiserratus*, terminate in a considerable development of kosmine, the elevated ridges of which project into the ganoin. The anastomosing loops of the kosmine are in every way larger and stronger than in any species hitherto described, the numerous branches and twigs which they give off from their elongated arches exhibiting the appearance of *chevaux-de-frise*.

Dapidius.—In *Dapidius orbis*, the lamellæ of the scale are exceedingly distinct and beautifully parallel, but the division of them into laminæ is less obvious. We have the large canals communicating between the two surfaces, causing the puncta on the exterior of the scale, and the parallel tubes as in the *Lepidosteus*. The lepidine tubes are very extensively developed, especially at the anterior margin of the scale. The ganoin is remarkably thin, and in some examples scarcely visible.

In *Dapidius granulosus*, the substance of the scale has the same structure as that of *D. orbis*, but its surface is studded over with scattered raised points, one of which, as seen through the superficial ganoin, is represented in fig. 5. Each one forms an elevated point, the posterior portion of which (*a*) exhibits a defined convex edge. It is covered with a layer of ganoin, which is but slightly developed over the intervening layer of the scale. This is seen in fig. 6 *a*, which represents a vertical section of one of these tubercles, made in the direction of the dotted line, fig. 5 *c c*. Under each of these exists a small cavity, figs. 5 *b* and 6 *b*, which opens externally, by means of three or four small canals, fig. 5 *d*, the orifices of which are placed behind the tubercle. Above this cavity we have a development of kosmine, the tubes of which chiefly arise from the anterior side of the cavity, 6 *e*, 6 *c*. Thus we find that each of these tubercles consists of a local development of kosmine and ganoin upon the upper laminæ of the scale, fig. 6 *d*, these latter being constructed on the ordinary type seen in so many of the lepidoid scales. To this limitation in the distribution of the kosmine and ganoin we shall have to refer again, as it constitutes one of the earliest forms, in which the tendency existing in many fish to the development of dermal teeth-like structures, manifests itself.

Palæoniscus.—This genus, of which I have investigated two species, the *P. comptus* from the magnesian limestone of Durham, and the *P. Beaumonti* from Autun, is allied in many respects to the group already noticed. In the arrangement of the laminæ and lamellæ, the scales of the above species exhibit the general aspect of the Lepidoids already described, but they materially differ in the distribution of their system of internal canals.

On making a vertical section of the scale of *P. comptus*, parallel with the mesial line, we see none of the long parallel tubes traversing the laminæ at right angles, which form so conspicuous a feature in the scales hitherto described. In other respects, the laminæ, fig. 7 *e*, both in their horizontal and upturned portions, as well as the lacunæ and their canaliculi, agree with those of *Lepidotus* and its allies.

On looking through the ganoin, when the lower portion of the scale has been ground away to render it more transparent, we find a beautiful arrangement of tubes or canals running immediately under and in the plane of the ganoin, forming, by their branches, a development of kosmine. The main channels (7 *a*) are slightly undulated, and send off to each lamina small lateral twigs (7 *b*), which, anastomosing with similar ones from adjoining tubes, form a series of loops, the arborescent terminal ramuli of which supply the parallel lines of the kosmine with nutriment.

The subjacent laminæ may be ground so thin as to exhibit no trace of either lacunæ or any other kind of cavity or perforation whatever, appearing merely as a structureless calcareous layer separating two layers of lacunæ and their parallel planes of canaliculi. There appears to be no way in which these horizontal laminæ could receive their nutriment except through the lepidine tubes. The latter abound at each extremity of the section, where the laminæ leave the horizontal to assume the upward direction: through the branches of these tubes the nutrient fluid might reach each layer of lacunæ, and, by means of their canaliculi, be distributed laterally to every portion of the scale. The lacunæ are somewhat larger than in *Lepidotus semiserratus*. I have found, that, however various may have been the dimensions of the scales under examination, there is but little difference in the size of their lacunæ. The centre of each scale of *P. Comptoni* (7 *c*) merely exhibits a layer of these lacunæ, and corresponding ones, following the plane of the upturned laminæ, are seen edgeways through the kosmine, 7 *d*.

M. Agassiz describes the enamel (*émail*) of *Palæoniscus* as being nearly opake. It is, however, not more so than in any other genus.

The scale of *P. Beaumonti* resembles that of *P. comptus* in its general features, but differs in points of detail. The large tubes or canals supplying the kosmine chiefly enter at the sides of the scale, Plate XLI. fig. 8 *a*. They do not terminate at the central rhomboid in the fine filamentous loops which characterise *P. comptus*, but some of the large tubes traverse this central portion, and communicate with corresponding ones entering from the other sides of the scale, 8 *b*. Along the upturned edge of each of the laminæ, and parallel with it, are large transverse inosculating branches, 8 *d*, which, by connecting the main trunks together, form a network, from which are given off a vast number of minute branching filaments; these are distributed to the thick layer of kosmine. On one side these anastomosing branches are very long, their extent being occasionally equal to the entire diameter of the scale, 8 *e*, owing to the entire absence, in this portion, of the large trunks which enter laterally. The very few which are visible, instead of being parallel with the ganoin, seem somewhat to ascend from below, 8 *f*. The same is the case with some of the main trunks at the angles of the scale, 8 *c*.

Its anterior and posterior margins are freely supplied with lepidine tubes.

No pencil can adequately depict the beauty of the filamentous branches of the anastomosing canals in the kosmine of this interesting scale. Though differing in some of its details from that of *P. comptus*, the two evidently belong to one common type, which is distinct from any previously described. So far as the nutrition of the kosmine is concerned, the horizontal canals evidently fulfill the functions of the parallel vertical ones amongst the *Lepidoti*; they do not appear to contribute any branches to the osseous lamellæ, which, as in the case of the *P. comptus*, must be nourished through the lepidine tubes.

Gyrodus.—The scale of a species of *Gyrodus* from Kellheim exhibited the appearance represented in fig. 9*. It is a modified form of the type found in the *Lepidosteus*, presenting similar laminæ, lamellæ, parallel tubes, and lepidine. The anterior portion of the scale, 9* *a*, which is very much thickened, exhibits well-marked concentric lamellæ, which become curiously inflected towards the centre of the scale. Owing to these inflections, the posterior portion, which rests on the thickened extremity of the one behind it, suddenly becomes very thin, fig. 9* *b*, but still preserving its laminated structure, and divisible into two parts; a lower one, in which the large tubes ascend from below, fig. 9* *c*, and an upper one, in which they enter from above, fig. 9* *d*. These tubes are much less numerous and less regularly arranged than in the majority of the preceding scales; those especially which come from above exhibiting less parallelism. The anterior extremity of the section, which when *in situ* has been deeply imbedded in the soft integument, is abundantly supplied with lepidine tubes, fig. 9* *e*; those from the upper surface inclining downwards, and those from the lower margin running upwards in the direction of the centre of the scale.

The sudden inflection of the laminæ produces the appearance of the thick transverse rib, extending over the breadth, which is the longer axis, of the scale.

Aspidorhynchus.—In the large scale of *Aspidorhynchus acutirostris*, from the lithographic stone of Solenhofen, we find a somewhat analogous structure to the last, only without the contracted inflections of the laminæ. The bulk of the scale consists of an arrangement of lamellæ, perforated by beautifully defined and regular parallel tubes, the interlamellar spaces being occupied by layers of magnificently developed lacunæ with their branching canaliculi. These last are more beautiful than in any species of fish which I have examined. The upper surface of the scale exhibits a series of large and nearly parallel ridges and furrows: a vertical section (fig. 10 *a*) shows these ridges to be formed by an undulatory arrangement of the upturned lamellæ, which here take the place occupied by the ganoin amongst the *Lepidoti*. These undulating lamellæ are perforated from above by a series of tubes, fig. 10 *b*, which, like those coming from below, fig. 10 *c*, terminate in a kind of neutral line between the upper and lower portions, which is about one-third of the thickness of the scale below its upper surface.

If there is any ganoin upon the scale, it is so thin as to be invisible. Its place is occupied by these wavy lamellæ; and not only do the latter occupy its position, but they produce those superficial irregularities, which in *Lepidosteus* are due to the distribution of the ganoin: they have obviously been produced by the superior portion of the periosteal membrane corresponding to that which forms the ganoin in the other scales.

Acipenser.—Sections of the scale of the common Sturgeon present a structure somewhat similar to that existing in the *Aspidorhynchus*, only the numerous ascending parallel tubes are wholly wanting, and the process of involution of the upper portions of the lamellæ has been carried to a much greater extent, leading to the production of true Haversian canals.

When one of the large lozenge-shaped scales is examined, its upper surface is found to be rough and thorny. This is owing to the existence of what at first sight would appear to be a deposition of something resembling ganoin upon the true bony tissue: this hard substance, which covers the free portion of each scale, has a tendency to be arranged in the form of radiating ridges, extending from the centre to near the circumference of the scale, excepting on the anterior portion, which, having supported the opposite margin of the preceding scale, is quite smooth, as is also the inferior surface. In the central portion of the upper surface the radii are less regular than towards the posterior edge of the scale, being more cribriform in their aspect, from the existence of numerous irregular pits and deep depressions which exist in it. A smooth elevated ridge crosses the centre parallel with the lateral line; this covers over a very large canal, the superficial opening of which is in the smooth anterior portion of the scale, which has been covered over by the upper fold of the integument: its opposite extremity is at the under surface of the scale, near its posterior border. The canal has obviously transmitted blood-vessels, and probably nervous twigs also, keeping up a free communication between the two portions of the integument. Several smaller but analogous canals communicate between the upper and lower surfaces, each of them verging towards the centre as it ascends.

The lower surface is very smooth and translucent, exhibiting a series of concentric lines, like those in the interior of a bivalve shell, and which at first glance might lead to the idea that the enlargement of the scale had been accomplished, as in the shell, principally by the addition of new matter to its edges. Such, however, is not the case. These concentric lines are in reality only the points at which the successive laminæ constituting the inferior portion of the scale turn upwards and inwards at a very acute angle, as seen in the section, fig. 11 *a*: these lines of course represent what were from time to time the external boundaries of the scale, which were enclosed by successive new growths.

As we have seen to be the case in *Aspidorhynchus*, soon after leaving the horizontal condition, the upturned laminæ present a strong tendency to undulate, but even to a much greater degree. Near the margins of the scale, these undulations only produce alternating grooves and ridges on the surface. This appears to be the portion figured by M. Agassiz*; whose representation, however, gives a very imperfect idea of its true structure. But as the section approaches the centre of the scale, we find that

* Poissons Fossiles, vol. ii. Tab. H. fig. 22.

by the deposition of new layers, these grooves are covered over and converted into true Haversian canals. As we should expect to be the result of this mode of growth, none of the laminæ forming these canals exhibit complete circles; the involutions of the lower layers are met by corresponding ones in the upper laminæ; and by the juxtaposition of their respective salient points, the canal is rendered complete. Thus in fig. 11, the depressions *b* are quite ready to be covered over in the same way as the completed canals *c*, and doubtless, in time, the addition of new laminæ would have so closed them in. The whole of the scale is abundantly supplied with lacunæ and their stellate canaliculi, though in the inferior horizontal portions of the lamellæ these are not so beautifully distinct as in those surrounding the Haversian canals. The latter portions are also freely supplied with minute branching lepidine tubes, which descend from above, and, with the exception of the large canals already described, appear to be the only tubes the scale contains*. This beautiful illustration of the way in which Haversian canals may be formed is one of great value to the physiologist; because, from the size and distinctness of the laminæ, and the ease with which their direction can be traced, they leave no possible room for doubt on the subject. We thus derive, from this comparatively remote source, strong corroborative evidence of the accuracy of Professor SHARPEY's views respecting the origin and mode of formation of the analogous structures in human bones.

Platysomus.—Constructed on the same principle as those already noticed, but exhibiting a very curious modification of it, is the scale of *Platysomus parvulus*, from the upper coal-measures of Leeds and Manchester.

The exposed part of the upper surface of this scale is covered with deep grooves and intervening ridges, running nearly parallel with its long axis, which, as in *Gyrodus*, really represents its breadth, and is at right angles to the direction of the lateral line of the fish.

On making a section of the scale in the opposite direction to that taken by these ridges, we find it to consist of two portions, an upper and a lower one. The latter, figs. 12 *a* and 13 *a*, though apparently of a dense homogeneous structure, exhibits, on a careful examination, clear evidence that it consists of a series of minute lamellæ, though these do not appear to be aggregated into any more conspicuous laminæ. In the upper portion, we find that each elevated ridge consists of a series of concentric arches, fig. 12 *b*, having intervening crescentic spaces, 12 *c*, and exhibiting traces of the existence of canals, connecting one set of arches with another. On making a section in the opposite direction, along the line of one of these elevated ridges, fig. 13, this structure is more fully explained; and each individual ridge shown to be formed by a series of arching plates, 13 *b*, which arise from the compact portion of the scale, 13 *a*, and after successively overlapping each other, losing themselves at the upper surface of the scale. In fig. 14, which represents a horizontal section, taken in the

* These were noticed by Prof. OWEN, and recognized as belonging to his "plasmatic series." See Lectures on the Vertebrate Animals, part 1, p. 31.

plane of the line 12 *e*,*f*, the same letters are employed to mark the corresponding portions of the two sections: thus, whilst the portion 14 *e* dips rather deeply into the lower part of the scale, the oppposite one, 14 *f*, cuts across the bases of the arches 14 *b* shortly after taking their rise from the body of the scale. We see that they do not spring up at right angles to the axis of the ridge, but obliquely; the section of this portion of each intervening cavity, 14 *c*, being somewhat pyriform. Each lamina is about $\frac{1}{1600}$th of an inch in thickness. Between these and the body of the scale is a series of anastomosing canals, 14 *d*, which connect the isolated cavities together, opening into them by small oval orifices, 14 *h*. Traces of the corresponding canals are seen in 12 *d* and 13 *d*, whilst their orifices are likewise shown in 12 *h* and 13 *h*.

In the lower part of this section, 14 *e*, we find numerous laminæ cut through somewhat obliquely, 14 *g*. These are also seen in the two vertical sections.

Singular as is the construction of this scale, a very careful investigation of it has satisfied me that it is formed on the type of those previously described. The pointed extremity of the section, fig. 13, represents the anterior margin of the scale, which has been covered with the fold of soft integument and by the free edge of the antecedent scale; the curious arched plates, 13 *b*, are in reality formed by the upturned portions of the lamellæ, and probably correspond with the laminæ of the other scales; each of them, whilst enclosing those previously existing, has not been deposited in immediate contact with it, but intervening spaces have been left; whilst between each of these cavities there exist connecting channels admitting of a free vascular intercommunication. The cavities and the canals together appear to be the representatives of the true Haversian canals; the large cavities bearing the same relation to the connecting passages, probably, that the large cancelli of Mammalian bones do to the Haversian canals which open into them. Each of the arched plates contains numerous lacunæ, with peculiarly long trailing canaliculi, especially at the surface of the scale. No appreciable layer of ganoin covers these arches.

The modifications of the Lepidostean type of scale found in *Aspidorhynchus* and *Acipenser*, conduct us to some of the most complicated and beautiful structures that I have yet seen amongst the ganoid fish, occurring in the genera *Megalichthys*, *Diplopterus*, and *Holoptychius*; but notwithstanding all their complications, it is not difficult to trace the same principle of growth which we have thus far seen to apply in every case.

Megalichthys.—The matured scales of this genus exhibit on their exposed surfaces a layer of bright shining ganoin, which is densely covered with minute puncta. These were noticed by M. AGASSIZ, who says, respecting them, "Ce sont des petits points creux, extrêmement rapprochés, et dont les intervalles en relief forment un réseau de mailles*." On making a vertical section of a scale of *Megalichthys Hibbertii* from the upper coal-measures of Lancashire, fig. 15, I found that each of these puncta constituted the orifice of a vertical trumpet-shaped cavity, 15 *a*, very narrow superiorly, but expanding and becoming triangular or quadrangular inferiorly. This is well shown

* Poissons Fossiles, vol. ii. part. 2, p. 154.

in Plate XLII. fig. 16, which represents a horizontal section of the upper surface of the same scale, as seen when looking downward through the transparent ganoin. The inferior portion has been more freely ground away at the light-coloured extremity *h*, than at the opposite one, where the section retains some of the deeper osseous layers; consequently these vertical cavities are here cut across at their narrowest part and exhibit a circular contour, 16 *a*, but in the middle portion, we find that the section has passed through these cavities lower down, where they assume a triangular or quadrangular form, 16 *b*. In their upper and middle part, we not unfrequently see them to be surrounded by concentric rings, reminding us of the rudimentary Haversian canals in the opercular bone of *Lepidotus semiserratus*. After descending a little distance, these cavities give off three, four, or five narrow horizontal tubes, which communicate with contiguous cavities, 15 *c*; thus combining to form a horizontal network which lies a little below the superficial ganoin. Neither these cavities nor the tubes into which they thus subdivide give off any minute branches. They are obviously but the channels of communication which lead to more important tissues. After giving off the tubes, the cavity becomes suddenly constricted, and, descending a little further, connects itself with a second and more irregular network of larger canals, 15 *d* and 16 *d*, constituting the uppermost of the Haversian canals. The meshes of the network of tubes 15 *c*, 16 *c*, constitute a series of cup-shaped areolar spaces, 15 *e* and 16 *e**; into each of which the second layer of canals sends up an ascending branch, or cul-de-sac, like the stump of a pollard willow, 15 *f*, 16 *f*. This gives off a multitude of ramifying tubuli, the main branches of which ascend, and distribute their terminal ramifications immediately under the ganoin. Their distribution is very well seen in the horizontal section 16, in the thicker extremity of which the branches are still connected with the cul-de-sac from which they spring, 16 *f*, whilst at the opposite end we have only the branches or their terminal twigs remaining, 16 *h*, the cul-de-sac being wholly ground away. The inferior portion of each areola is supplied with exceedingly minute recurved tubuli, which spring from the same point as the larger ascending branches.

In each of these areolar systems, four or five of the branches, instead of subdividing until they become wholly lost, retain their original calibre, and connect themselves laterally with corresponding branches from adjoining areolæ, forming a third network (16 *g*, 17 *b*) which is still nearer the ganoin than the other two, and which gives off numerous minute horizontal and ascending twigs.

After thus giving rise to these three well-marked systems of reticulations, distributed in the plane of the surface of the scale, the trumpet-shaped cavities continue their downward course, when they become lost in an irregular network of Haversian canals, 15 *b*, which generally terminate inferiorly, in others of a much larger size,

* In the large scales of *M. Hibbertii*, each of these areolæ have an average diameter of $\frac{1}{110}$th of an inch. In the smaller species from Leeds, fig. 17, they average about $\frac{1}{160}$th of an inch.

15 *g*; and which usually exhibit a tendency to run parallel with the long axis of the scale.

In fig. 15 these are cut transversely, but in fig. 17, which represents a vertical section of a smaller species of *Megalichthys* from the coal-measures near Leeds, the large canal is divided longitudinally, 17 *g*. In this latter species, the ramifications of the Haversian canals are much less extensively developed than in *M. Hibbertii*. The same is the case with an analogous scale from the old red sandstone of Cromarty.

With the exception of the thin superficial layer of ganoin, 15 *h*, all that portion of the scale which lies above the plane of the network of narrow tubes, 15 *c*, consists of a beautiful and largely developed form of kosmine; the remaining channels are Haversian canals, penetrating true osseous tissues. The two structures merge in each other through the ascending cul-de-sacs.

Below this system of Haversian canals, we find a large development of exceedingly thin parallel laminæ, the majority of which extend completely across the scale, fig. 15 *i* and 18 *a*, each having an average thickness of about $\frac{1}{1500}$th of an inch. Their number and regular parallelism are alike the greatest towards the central and anterior portions of the scale. As we approach the posterior margin, each one becomes thicker, less uniformly parallel, and more disposed to curve upwards, mingling with those forming, by their involutions, the Haversian canals.

Inferior to these parallel laminæ, which divide the scale horizontally into two portions, we find a second distribution of Haversian canals, fig. 15 *k* and 18 *b*. They are especially developed along the centre and across the anterior extremity of the scale, where they form a projecting ridge. I have not found any example in which these canals penetrate the parallel laminæ towards the centre of the structure to any considerable extent; but as we approach the anterior margin, where the laminæ lose much of their parallelism, a free communication is established between the upper and lower portion by means of large anastomosing canals. Along the inferior surface the outline is exceeding irregular, in consequence of the existence of the numerous open orifices of these canals, and where, as at fig. 15 *l*, incipient canals are in process of formation, like those already described in the scale of the Sturgeon. On the upper surface of the anterior portion of each scale, also, where from the juxtaposition of the upper fold of the soft integument no ganoin was needed, and consequently it did not exist, we find precisely the same structure, which is one reminding us most strongly of the aspect presented by the section of a human fœtal bone. Through these open canals, blood-vessels have had free access to every part of the scale. Fig. 15 is taken from near the lateral portion of a scale, where the extension of the inferior system of Haversian canals is limited, but fig. 18 is from a section which cuts across the central ridge already described, and where the degree of their development is well shown. In this specimen the ganoin has been accidentally removed.

With the exception of the ganoin and kosmine, all the various modifications of laminæ in this scale abound in lacunæ. The bony matter surrounding the Haversian canals is deposited in concentric lamellæ, between which are numerous lacunæ with their stellate canaliculi of various forms, usually of the common ichthyal type; but sometimes, especially in the lamellæ nearest to the canals, showing a disposition to become elongated in the direction parallel to the axis of the latter. In the horizontal laminæ, already described, fig. 15 *i*, we find a very curious form of lacuna. They are very much elongated, being about $\frac{1}{200}$th of an inch in length, and sometimes almost linear, giving off numerous rectangular canaliculi. Not unfrequently these spring from the lacuna diagonally; those on different sides verging to the opposite extremities of the lacuna, as is seen in fig. 19 *b*, which sketch represents the appearance of these lacunæ as seen under a magnifier of 300 diameters linear. Those of each layer exhibit a considerable tendency to parallelism of arrangement, but owing to the extreme thinness of the laminæ, the lacunæ belonging to two or three layers may be seen at once, even under a magnifying power of 300, as shown in fig. 19: and it is a curious fact, that those constituting one layer exhibit a very considerable tendency to run in the direction of the canaliculi of an adjoining layer. In fig. 19, *a*, *b* and *c* represent individual lacunæ belonging to three of these parallel series. In addition to the above, each lacuna gives off small vertical canaliculi, which penetrate the lamellæ, and thus connect the different layers together, fig. 15 *i*. These structures become highly interesting when viewed in connection with Mr. QUEKETT's instructive attempts to identify the bones of the four classes of the Vertebrata by means of the variations of their microscopic structure*. In that memoir Mr. QUEKETT considers that this elongated form of lacuna is characteristic of the Reptilia; and there is certainly a very striking resemblance between his representation of those of the Pterodactyle†, the accuracy of which, my own specimens of the latter confirm, and my fig. 19. We thus find that some of the elementary tissues of this fish, which on its first discovery was so readily mistaken for a reptile, exhibit a most striking resemblance to the reptilian type: I shall have to show, by and by, that the same form of lacuna exists in the genera *Diplopterus* and *Holoptychius*; consequently the fusiform lacuna can no longer be regarded as typical of the Reptilia, as was imagined by Mr. QUEKETT, though it is unquestionably the form most commonly found in that class of Vertebrata, as the quadrate one is chiefly characteristic of fish: great caution however requires to be exhibited ere we decide a disputed question on this evidence *alone*. I find but little difference between the majority of the lacunæ of the small *Platysomus parvulus*, already described, the scales of which are about the $\frac{1}{18}$th of an inch in length, and those from the gigantic femur of an Iguanodon, in the possession of Dr. MANTELL, which, when perfect, he informs me has not been less than 27 inches in circumference at the shaft. A legitimate inference from these

* Transactions of the Microscopical Society of London, vol. ii. part 2. p. 46.

† Tab. 8. fig. 2, *ut supra*.

facts is, that Mr. QUEKETT's objection to the arrangement of the Lepidosiren amongst fishes, as proposed by Professor OWEN, derived from the form of its lacunæ, is not a valid one.

On viewing the variety and complication in the arrangement of the elementary tissues combining to form the scale of *Megalichthys*, it is difficult to resist the conclusion that it must have been constructed on a very different plan to that followed in the genera previously described. I am satisfied however that such has not been the case to any material extent. We have seen that the results arising from the successive organization of lamellæ have gradually increased in complexity as we ascended from *Lepidotus* and *Seminotus* to *Gyrodus*, *Platysomus*, *Aspidorhynchus* and *Acipenser*. This complexity appears to have reached its climax in *Megalichthys*, at least so far as refers to the fish that I have had an opportunity of examining. At the same time there are some points of detail which differ from those which I have observed in the genera already noticed, and consequently I would express myself with legitimate caution on the point.

I believe, however, that some of the parallel laminæ, fig. 15 *i* and 18 *a*, have been formed the first: whilst additional layers were being organized, inferiorly, by intra-membranous ossification through the agency of the lower portion of the secreting sac, these laminæ being parallel to their predecessors, the corresponding and coeval portions, being secreted by the upper wall of the sac, were much undulated, their various inflexions laying the foundation of the Haversian canals. After this process has continued for some time, and a considerable amount of thickness been given to the scale, the new lamellæ added to its inferior surface, instead of retaining their parallelism with those already formed, have begun to assume an undulatory arrangement, in the same way that *all* the superior ones, corresponding to the upturned lamellæ of the Sturgeon, had done from the commencement. This inflexion of the newly-added lamellæ did not take place to an equal extent over the entire inferior surface of the scale, but was chiefly confined to the centre and to one extremity; the remaining portions, and especially that occupying the anterior margin, retaining their tendency to horizontal parallelism.

The osseous framework of the scale being thus completed, new processes have come into operation. Prolongations from the periosteal membrane have lined the Haversian canals, and these have deposited new and internal lamellæ—at once thickening their walls and diminishing their diameter—a process, of which we have hitherto met with no trace in the scales of any of the fish described, excepting in the opercular bone of *Lepidotus*.

At some period *prior to* this partial filling up of the Haversian canals, a deposition of kosmine has taken place on the surface of the scale, but of which, also, in the first instance, only the framework has been formed. The careful preparation and examination of numerous sections has enabled me, I trust satisfactorily, to remove much of the obscurity that has hitherto rested upon this portion of the subject.

Each areola has, in the first instance, temporarily presented a similar appearance as is permanently exhibited by some species of *Diplopterus* and *Holoptychius*. The most superficial portion has been separated from the textures below by a large horizontal cavity, into which the numerous extensions of the Haversian canals destined to form the cul-de-sacs have opened. This superficial chamber has only been traversed by the hollow pillars of kosmine surrounding the descending trumpet-shaped cavities. The framework of the kosmine has been penetrated by a multitude of exceedingly minute tubuli, opening into the diffused chamber. As new internal organizations of bone have filled up the Haversian canals, prolongations from the osseous lamellæ have also contributed to fill up this open space, by thickening the walls of the hollow pillars and their narrow tubular canals, as well as the uppermost layer which supports the ganoin. The increase of these depositions has led, after a time, to the closing up of the channels communicating between contiguous areolæ, a small aperture only being left permanently open, constituting the network of narrow tubes, fig. 16 *g*. The concentric walls of the hollow pillars, fig. 16 *a*, thus becoming confluent, the central cavity of each areola has been isolated; and further organizations have narrowed its dimensions, until nothing remained of each originally large space but the permanent cul-de-sac, into which the minute tubes, gradually uniting to form the larger branches penetrating each succeeding lamella, have ultimately opened.

This process has gone on with the increasing age of the fish, until in some instances the cul-de-sac is nearly obliterated, leaving only a narrow vertical tube or stem, supporting the arborescent arrangement of tubuli. In some of my sections these lamellæ are beautifully distinct, the innermost ones following the outline of the cul-de-sac, and the outer ones that of the trumpet-shaped cavities around which they were deposited. This arrangement is represented in the areolæ of fig. 15. We should infer that in young fish the cul-de-sacs of the kosmine and the Haversian canals of the bone would be very large in proportion to the solid tissues of the scale, and I can even believe it possible that scales of a very young individual might easily be mistaken for those of a *Diplopterus*. I possess sections of the latter which exhibit precisely this condition. The Haversian canals appear as very large cancellated cavities, and the structure of the kosmine also resembles the early state of *Megalichthys* as just described.

There appears to be a period in the history of the scale when its kosmine ceases materially to increase in its superficial diameter. This extension seems to have reached its limit when the deep grooves which mark the boundary of the kosmine on two sides of the scale are formed. Further additions of bony substance continue to be made inferiorly, as well as to the upper surface of the two margins, which, being imbedded in the soft integument, need neither ganoin nor kosmine; these being the portions where the development of the two latter is arrested by the groove. Whether or not any additions continue to be made to the other two margins which overlap the contiguous scales behind and beneath, I have not been able to satisfy myself.

One question arises to which I am unable to give a decisive answer. May there not have been in this scale of *Megalichthys*, a central nucleus of cartilage in the midst of the Haversian canals, in which the first deposition of calcareous matter may have taken place, and upon which the horizontal lamellæ have been subsequently added by the ordinary process of intramembranous ossification? This is just possible, though we have no evidence of its truth; whilst the scale of a *Holoptychius*, shortly to be described, and presenting a closely allied structure, is opposed to the supposition, and supports the idea, that the scale of *Megalichthys*, complicated as it is, has been wholly formed by the successive organization and inflexion of layers of membrane in which the granules of calcareous matter have been subsequently diffused.

Diplopterus.—M. AGASSIZ has already examined some species from the old red sandstone. He remarks, "Les écailles présentent une fine granulation provenant d'une quantité de petits trous qui s'ouvrent de passage pour les nombreux petits vaisseaux sanguins qui traversaient l'écaille pour se rendre dans l'épiderme. Examinées au microscope, les écailles présentent une épaisse couche d'émail, au dessous de laquelle se trouve un tissu osseux montrant des réseaux fort élégants, qui ne diffèrent de ceux de Polyptère que par leur développement considérable. Les trous et les canaux médullaires l'emportent de beaucoup sur les piliers intermédiaires*."

Fig. 20 represents a horizontal section of a very thin scale belonging to an undescribed species from the coal-field near Leeds. The original specimen was about half an inch in length, and, as in *Megalichthys*, was covered with shining ganoin, which was perforated by innumerable minute apertures, the orifices of canals. The section was made at a slightly inclined angle to the plane of the scale, so that whilst the extremity *a* cuts obliquely through the superficial ganoin and its subjacent kosmine, the opposite end *b*, especially to the right-hand of the figure, dips more deeply into the bony tissue of the scale. Though I have not been able to procure a second example of this scale, in order to make a vertical section, there is no difficulty in reading off its beautiful structure, and comparing it with the vertical sections of *Megalichthys* and *Holoptychius*. It corresponds exactly with what has already been described as the immature condition of the former, and closely resembles that presented by one species of the latter.

c is the superficial layer of the kosmine supporting an exceedingly thin film of ganoin; the dark portion *d* is the horizontal cavity, traversed by the hollow pillars of kosmine, *e*, which surround the trumpet-shaped descending cavities: these commence by small apertures in the superficial layer, *f*; at *e* they gradually enlarge, becoming angular at *g*, and at *h* giving off the minute connecting tubes *i*, which correspond with those of the *Megalichthys*, fig. 15 *c*. Below this the descending cavities become lost in the ramifications of the Haversian canals *l*, as at *k*. The small tubes *i* divide the kosmine into areolar spaces, and into the centre of each there arises an offshoot from the Haversian canals, *m*, opening superiorly into the horizontal cavity *d*,

* Poissons de Vieux Grès Rouge, p. 54.

which separates the upper layer of the kosmine from the tissues below. As we have already seen to be the case with *Megalichthys*, neither the descending cavities *e*, *g*, nor the small tubes *i* into which they subdivide, give off any minute tubuli, but their walls are wholly supplied either from the superficial space *d*, or from the cavity in the centre of each areola, *m*. The latter especially give off branching kosmine tubuli of considerable size and great beauty. In the former the tubuli are very small, with the exception of those which ascend to the superficial layer *c*, which are thicker and more branched. In the hollow pillars, *e*, these tubes are uniformly parallel, radiating inwards. As in *Megalichthys*, all the tissues in the plane of and above the small inosculating tubes *i*, consist of kosmine, excepting the thin superficial layer of ganoin.

The tissues surrounding the Haversian canals, which are rather large, are osseous, presenting the same appearances as those of *Megalichthys*. The inferior laminæ of the scale also are horizontal and parallel, presenting the characteristic fusiform or linear lacunæ represented by fig. 19.

A vertical section of another scale already alluded to, also from Leeds, slightly differs from the last. The upper layer of the kosmine is thicker, and from the vertical cavities entering it but a small distance before giving off the inosculating tubes, 20 *i*, it would be impossible by any horizontal section to exhibit the elegant rings seen in 20 *e*. The Haversian canals are more like the large cancelli in the diploe of bone, and the branches which they send up into the kosmine are equally large; illustrating the description given of the development of the scale of *Megalichthys*.

Holoptychius.—The structure of some scales from the old red sandstone, belonging to this genus, has been already described by M. Agassiz*. His results, however, differ in many material points from those obtained by my own observations upon scales belonging to the same genus from the upper coal-measures of Lancashire, where at least two, if not more, species exist, which have hitherto been confounded under the name of *H. sauroides*.

These scales vary from being nearly orbicular to being so elongated, that their larger diameter becomes three or four times greater than the opposite one. In all cases one extremity is more pointed than the other, the latter being not unfrequently cordate. Their inferior surface is usually the only one seen, the upper one being adherent to the matrix. Fig. 21 represents the usual aspect of the latter, and fig. 22 of the former, amongst the larger scales of *H. sauroides*. Both surfaces exhibit the concentric lines noticed by M. Agassiz as "répétant les contours de l'écaille." These are the most beautifully regular and definite on the upper surface, especially at its anterior extremity, 21 *a*, but towards the pointed end, *b*, they give place to others of a larger size, but which are less numerous as well as less regular in their distribution. When the scale was *in situ*, the latter occupied the exposed portion, the remainder being covered over by the pointed extremities of the two scales in front of it; these con-

* Poissons de Vieux Grès Rouge, p. 70, tab. 24, fig. 10.

centric ridges are traversed at the two extremities, but especially at the posterior one, *b*, by minute radiating lines; at the two sides of the scale they are not visible. On the inferior surface the concentric lines extend over two-thirds of the scale, fig. 22, but they are less regularly definite and uniform in their thickness than on the opposite side. We find none of the radiating lines which M. AGASSIZ noticed in the corresponding portion of the scales from the old red sandstone, but its acuminated extremity, 22 *a*, corresponding to 21 *a*, exhibits a number of large puncta, 22 *c*, which are the orifices of ascending canals. On making a vertical section of one of these scales, I found few traces of either kosmine or ganoin; it consisted of numerous lamellæ, the lower ones resembling those seen in the corresponding portion of Megalichthys. These are shown in fig. 23 *a*, which represents a vertical section of a large scale, taken in the direction of the dotted line *c* in fig. 22. These lamellæ are furnished with lacunæ and canaliculi like those of *Megalichthys* and *Diplopterus*, fig. 19. The upper portion of the scale consists of the upturned lamellæ, which by their inflexions form the ridges which ornament its external surface, 23 *b*. In the section represented in the Plate, these ridges are less striking and prominent than ordinary; generally, instead of the section presenting a gently undulating outline, these ridges are irregular and even overhang the furrows which separate them, but still consist of the inflected extremities of the lamellæ, as do also the fine radiating lines of fig. 21.

Under these ridges, at the anterior part of the scale, we find a series of concentric canals, connected together by short anastomosing branches. They do not follow any very uniform direction in their distribution, varying considerably in the details of their arrangement, always however showing a tendency to be regulated by the direction of the lamellæ themselves, they having evidently been formed on the principle seen in the scale of the Sturgeon: thus in the section fig. 23, we find that many of the branches of these canals exhibit a curvilinear arrangement, 23 *c*, their direction corresponding with that of the lamellæ. From these Haversian canals are given off numerous vertical branches, especially at the acuminated extremity of the scale. Those which ascend, open in the grooves separating the concentric ridges, fig. 23 *d*, whilst the orifices of the descending ones produce the puncta seen at fig. 22 *c*. These vertical canals have not been formed by inflexions of the lamellæ, but by the leaving out of the apposite portions of each succeeding lamella as it was organized; consequently they merely pass through the latter nearly at right angles to their plane.

The whole texture of the scale is crowded with various modifications of lacunæ, from the fusiform ones already described to those of the ordinary ichthyal type; and though many of their canaliculi traverse the lamellæ, they are chiefly developed parallel with these layers, and follow their direction.

In the species examined by M. AGASSIZ, that philosopher found a structure very similar to the one just described; he applies the term enameled (*émaillée*) to the layers constituting the external ornaments of the scale, at the same time however observing, that they are "qu'une substance osseuse plus épaisse, dans laquelles les couches sont effacées, et les corpuscules plus grandes." M. AGASSIZ also notices radiating lines crossing the concentric ones, but he describes them as "formées par de petits canellures très fines et à peine en relief, dans lesquels se fixaient probablement les fibres de la peau." In *H. sauroides,* as we have seen, the inferior surface exhibits none of these lines; and in the upper layers the lamellæ are not effaced, though the structure is dense. I have not unfrequently observed, in some of the projecting ridges, a slight disposition towards the development of kosmine tubes, as if nature was making her earliest efforts at converting the true osseous lamellæ into kosmine.

The preceding description, which applies to the majority of the scales of Holoptychius which I have examined, reveals to us many points of remarkable identity between them and those of *Megalichthys* and *Diplopterus*, indicating a much closer affinity between these three genera than has hitherto been recognised. The examination of one oblong scale belonging to an undoubted species of *Holoptychius* from the upper coal shales of Lancashire, establishes this affinity still more strongly. Its inferior surface exhibited the same appearance as *H. sauroides*; smooth concentric lines existing at its rounded extremity, whilst the acuminated one was studded with large puncta. But on making a vertical section, a striking difference presented itself in the superior surface, which, being adherent to its matrix, could not previously be seen. The rounded extremity exhibited the structure seen in the corresponding part of *H. sauroides*. The inferior layers of the opposite extremity also correspond, fig. 24 *a*. The puncta open into ascending canals, which perforate the laminæ, 24 *b*, and communicate superiorly with a system of canals or cavities, 24 *d*, analogous to those of the *Diplopterus*, fig. 20 *d*, to the appearance that would be presented by a vertical section of which this form of *Holoptychius* forms an excellent illustration. Above and around this superficial cavity, 24 *d*, is a development of kosmine, which is penetrated from above by trumpet-shaped cavities, 24 *e*, and which give off small connecting tubes, 24 *f*, transverse sections of which, coming from the more distant cavities not cut across by the section, are seen at *g*. These trumpet-shaped cavities are not quite so gracefully formed as in *Megalichthys*, but in other respects they are very similar. After giving off these tubes, the cavities spread out continuously in every direction over the osseous tissue, and send up into each areola formed by the network of tubes, an expansion, 24 *h*, analogous to the cul-de-sacs of *Megalichthys*, but which, instead of being isolated as in that genus, in the mature state of this *Holoptychius* all open into one another, as seen at the extremity of the scale, *d*; the only connecting portions between what may be regarded as the roof and the floor of this space being the hollow pillars surrounding the cavities, *e*. As in *Diplopterus*, the whole of the kosmine receives its minute tubuli from this large superficial space, from which they radiate in every direction.

This section also explains what has been already said respecting the growth of the kosmine in *Megalichthys*. Its permanent structure in *Holoptychius* presents the condition which has obviously existed in the young state of the scale in that genus. On comparing figs. 15 and 24 together, and bearing in mind the concentric lines in the kosmine of the former, this identity will be obvious at a glance; and it will be seen how the addition of successive lamellæ to such a framework as fig. 24 exhibits, would lead to all the results which we find in *Megalichthys*, and also establishes the close connection that exists between the two genera, as well as between them and *Diplopterus*; instead of one being found amongst the Cœlacanths, and the other two amongst the Sauroids, this resemblance, connected with the close analogy existing between their teeth and such fragments of bone as have been met with, requires that they should in future be classed side by side.

No doubt can exist that in these species of *Holoptychius*, the bony lamellæ have been deposited on the same plan that we have found to prevail throughout all the forms of scale which I have examined. This is especially seen in fig. 23. The existence of the Haversian canals can be distinctly traced, either to the inflexions of these lamellæ, or to the leaving out of portions of them, as in the case of the vertical branches.

Bearing in mind the close affinity just noticed, between the genus under consideration and *Megalichthys*, we can scarcely suppose it probable that their scales have been constructed on two widely different physiological plans. That of *Holoptychius* appears to be intermediate, as to the complexity of its structure, between those of *Acipenser* and *Megalichthys*; consequently we can scarcely resist the conclusion, to which the study of the latter fish alone has led me to incline, that complicated as its scales are, they have been formed, *ab initio*, on the same plan of intramembranous ossification as all the rest.

Judging from the descriptions given by M. Agassiz, it appears evident that a recent example of a scale somewhat similar to the type found in *Holoptychius*, occurs in the *Polypterus* of the Nile. Though in his description M. Agassiz does not notice anything analogous to the forms of kosmine described in the last genera, yet in the horizontal network of canals, and their vertical branches communicating with both the upper and lower surfaces, we have an analogy too evident to be overlooked; and one which attracted the attention of the Swiss philosopher, whilst examining some of the *Diplopteri* from the old red sandstone. It is highly interesting to find, that, though we have so small a number of ganoid fish still existing, when compared with the multitudes which crowded the ancient seas of our globe, we have, in the Bony Pike, the Sturgeon and the Polypterus, living representatives of the most conspicuous types of scale-structure found amongst their fossil allies.

Macropoma.—This anomalous genus has long been a source of perplexity to ichthyologists. *Macropoma Mantelli*, first discovered in the Sussex chalk by the distinguished geologist whose name it bears, was first arranged by M. Agassiz amongst the sauroid subdivision of the ganoid fish. He afterwards removed it to the Cœlacanths, and still more recently he has proposed to unite it with the genus *Undina* of Munster and some others, of which he designed to form a new group*. On

* Poissons Fossiles de Vieux Grès Rouge, p. 61.

examining a portion of the opercular scale of this fish, I found it to be studded over with tubercles, fig. 25 *a*, like those in a piece of shagreen. On grinding away the under surface, so as to render the upper part transparent, there appeared beneath each tubercle a large lenticular cavity, fig. 25 *b*, which, as we shall subsequently show, is homologous with the pulp-cavity of the dermal teeth of placoid fish. From each cavity is given off a number of small tubular canals, fig. 25 *c*, which radiate outwards and upwards, and communicate with the external surface of the scale. The posterior portion of each tubercle, 25 *d*, is more prominent than its opposite extremity, evincing a disposition to become pointed and grooved on its surface. The tissue surrounding the bases of these tubercles is studded with numerous lacunæ and a few scattered points, 25 *e*, constituting the orifices of canals which come up from below. On making a vertical section of the specimen, fig. 26, I found that the tubercle surmounting each cavity, fig. 26 *a*, was composed of kosmine with exceedingly fine branched tubes, 26 *b*, radiating from the cavity, 26 *c*, and covered over with and merging in a layer of transparent ganoin, 26 *d*, which on its posterior margin exhibited the irregular superficial grooves already noticed. The kosmine consisted of a number of very dense but still distinct lamellæ, arranged in concentric lines, which, superiorly, followed the curved outline of the tooth, and inferiorly, that of the roof of the subjacent cavity. Beneath each tubercle is this lenticular pulp-cavity, figs. 25 *b*, 26 *b*, the radiating prolongations of which, 25 *c*, 26 *e*, proceeding upwards and outwards, form channels of communication with the external surface, reminding us of those existing in connection with similar tubercles on the scale of *Dapidius granulosus*.

The textures which give support to these tooth-like appendages, consist of a series of osseous laminæ, fig. 26 *f*, which are again subdivided into numerous minute lamellæ. Amongst the inferior laminæ are a number of very large cavities, which run into each other by means of narrow connecting passages, forming the homologues of Haversian canals, fig. 26 *g*. They send up narrow vertical branches to the external surface, which generally open at the small apertures, 25 *e*, but occasionally unite with one of the canals radiating from the lenticular pulp-cavities, fig. 26 *h*.

The lowermost osseous laminæ are not so thick, individually, as the upper ones, but they are more regularly uniform in size, as well as more parallel with the inferior surface, and with one another.

Between the lamellæ is a copious distribution of lacunæ, many of the canaliculi of which radiate vertically as well as horizontally, perforating the lamellæ, and thus establishing a communication between contiguous layers of lacunæ.

The specimens which I have had the opportunity of examining exhibited no trace of upturned lamellæ in any part of their course, though their inflexions appear to have formed the large Haversian cavities, fig. 26 *g*. It is possible, however, that they may do so at the margin of the operculum, a portion which I have had no opportunity of investigating, and which requires further attention.

In addition to the canaliculi of the lacunæ, we also find a considerable supply of what appear to be lepidine tubes, ascending from the inferior surface to the uppermost layers of the structure, fig. 26 *k*.

The general aspect of the exterior of the body of *Macropoma Mantelli*, is that of an ordinary scaled fish. This is especially shown in a fine specimen, formerly in the collection of Dr. MANTELL, and now in the British Museum; originally figured by that gentleman in his work on the Fossils of the South Downs, and afterwards by M. AGASSIZ*. Specimens exhibiting the exterior of the fish are very rare, since, owing to the roughness of the outer surface of the scales, they are usually adherent to the matrix, the inner portion being exposed; or, what is even more frequently the case, each scale has split horizontally, and only exhibits its internal tissues.

According to the enlarged figures of M. AGASSIZ†, the anterior part of the upper surface of each scale is marked with concentric lines, which he regards as lines of growth; whilst the posterior or visible portion is crowded with elongated tubercles, or pointed cylinders; those on the centre of each scale being the largest. On making a very careful examination of the surface of these scales, I found that the tubercles, the "cylindres pointus" of AGASSIZ, were dermal teeth, corresponding with those already described as existing on the opercular scale; instead however of being nearly orbicular as in that example, they are all more or less elongated, whilst some of them, and especially four or five large ones ranged along the middle of many of the scales, stand up in bold relief, appearing like well-defined pointed teeth, equal in their degree of development to any which I have seen in the skins of recent Placoids. The pulp-cavity is similarly elongated, still however giving off the radiating canals at its base. These latter frequently communicate between one cavity and another.

Each of the teeth is irregularly grooved on its external surface, and these grooves, being prolonged in irregularly parallel lines on the broad thin expansions into which the bases of the teeth spread out, give to them somewhat the appearance of concentric striæ. In none of those which I have seen have I been able to discover the regularly concentric arrangement shown in the figures of M. AGASSIZ. Plate XLIII. fig. 27 represents a vertical section of the greater part of a scale in which the tubercles are very small, but in which the lower tissues appear to be complete; 27 *f* is the posterior extremity of one scale resting upon the anterior margin, 27 *g* of another; a small portion of the posterior extremity of the latter is still wanting.

The textures exhibited in this section are divisible into two portions, an upper and a lower one. The former, fig. 27 *a*, is of a dense structure, and appears mainly to consist of the expanded bases of the tooth-like tubercles in which some few lacunæ are developed. In this the tubercles are implanted, 27 *b*, each of which corresponds in its general structure with those already described from the opercular scale, fig. 26 *a*, only in this instance they are more depressed, and the pulp-cavity is larger in proportion to the size of the tubercle. The concentric lamellæ of the kosmine are also seen completely to surround the pulp-cavity, being continuously developed to some extent be-

* Poissons Fossiles, vol. ii. tab. 65 *b*.

† *Ut supra*, tab. 65 *b*.

low as well as above it. Similar canals communicate between the pulp-cavity and the upper surface, fig. 27 *d*. Beneath this superficial tissue we find another structure, composed of numerous thin parallel lamellæ, which gradually ascend as they proceed from the anterior towards the posterior margin of the scale, fig. 27 *e*; and upon the outcropping edges of which, to employ a geological illustration, the more superficial layer rests in unconformed stratification. No true lacunæ appear to enter into the structure of these lamellæ, but between them are layers of small irregular tubes, which anastomose freely with one another; those found on opposite sides of each lamella, like the fusiform lacunæ of *Megalichthys*, usually running in different directions, so as to give to the horizontal section the aspect of network. These do not appear to be modified lacunæ, but seem more analogous to lepidine tubes. They give off numerous branches, which pass through the lamellæ, keeping up a communication between contiguous layers.

Fig. 28 is a section of one of the rows of large teeth from the centre of the scale. In this specimen, from which the lower laminæ have been accidentally detached, as is usually the case, the tubercles are developed into the form of regular pointed dermal teeth, each having a pulp-cavity, fig. 28 *a*, from which spring small branching tubes, 28 *b*, like those seen in the dermal teeth of ordinary Placoids. Each one exhibits a laminated structure like that seen in the true teeth of reptiles, the lamellæ being arranged as a succession of cones, having evidently been formed by the addition of new internal layers organized around the soft pulp. In fact, it is only one of the laminated tubercles of the operculum, fig. 26 *a*, drawn out vertically; the lenticular space, fig. 26 *c*, being also elongated in the form of a true pulp-cavity, whilst, in consequence of this modification of the external contour, the lamellæ have assumed the appearance of a succession of cones inclosing each other. At the base of each tooth we still find the radiating canals, fig. 28 *d*, communicating with the exterior of the scale, as in those of the operculum.

Fig. 28 *e* represents the externally grooved appearance of each tooth, the section not having passed completely through its centre.

The most extraordinary feature in the anatomy of this singular fish yet remains to be described. In its interior there is invariably found a long hollow fusiform viscus, which has generally been regarded as a stomach. M. Agassiz, who entertained this opinion, says, "Il ressemble à un cylindre squammeux, et cet aspect est évidemment le résultat des changemens survenus dans les différentes membranes qui en composaient les parois."

On mounting prepared sections of this "membrane," I found that it consisted of true laminated bony tissue. When a vertical section was made through its entire thickness parallel to the long axis of the viscus, it presented the appearance represented in fig. 30. It chiefly consists of horizontal lamellæ, fig. 30 *a*, between which are developed large lacunæ, fig. 30 *b*, identical with those found in the bones of its endo-skeleton. These lacunæ not only distribute their large canaliculi in the plane of the lamellæ, but shorter vertical twigs penetrate the lamellæ, and thus keep up a communication between the inner and outer surfaces of the viscus.

Some of the external lamellæ lose their exact parallelism with those below, and one in particular assumes an undulatory arrangement, fig. 30 *c*, in the folds of which, alternately above and below, are placed large irregularly-shaped lacunæ, fig. 30 *d*, the distorted prolongations from which are obviously modified canaliculi. This curious structure is covered over with other more dense and apparently structureless lamellæ, which fill up the inequalities and restore the parallelism of the surface with the lower lamellæ, constituting the exterior of the viscus.

On examining a horizontal preparation of a fragment of the same viscus, we see that the undulations of the lamella, fig. 30 *c*, produce the appearance exhibited by fig. 29. Numerous parallel lines enclose corresponding spaces, about the $\frac{1}{1200}$th of an inch in width, which circumscribe the viscus at right angles to its longer diameter. The lacunæ, fig. 29 *a*, which are arranged in corresponding rows, are alternately above and below the lamella, their irregularly projecting canaliculi, 29 *b*, giving them the aspect of Hebrew or Arabic characters. On making a horizontal section amongst the lower lamellæ, 30 *a*, we find that the numerous lacunæ are of the common ichthyal type, only they are more than usually crowded together, as well as anastomose more freely through their spider-like lacunæ. No canals of any kind pass through the tissue. These facts of course do away with all probability of this anomalous viscus having been a stomach; according to Dr. MANTELL, to whom we are indebted for the discovery of this singular creature, the broad anterior extremity of the cylinder is always open, and situated opposite the posterior margin of the opercular bone, whilst its caudal termination is as invariably closed.

I am disposed to believe that it has been an organ fulfilling the functions of an air-bladder. Its osseous structure would render it capable of resisting a considerable amount of pressure, and if its patulous extremity has been closed up by an elastic membranous appendage, capable of acting as a valve, this would enable the creature to regulate its buoyancy by increasing or diminishing the compression of the contained air, and thus facilitate its movements in either shallow water or at great depths. Except in cases of diseased ossification, the existence of an internal thoracic or abdominal viscus, having hard parietes of true bone, is an anomaly, which, as far as I am aware, has hitherto presented no parallel in nature.

The structure of the scale of *Macropoma*, as now described, is wholly different from that presented by any of the ganoid fish noticed in the preceding pages. It bears a much closer resemblance in its leading points to the dermal appendages found amongst the group of true Placoids, between which and the Ganoids the *Macropoma* appears to form an inosculating link. In order to illustrate this opinion, I have accompanied the memoir by figures of portions of the dermal appendages of one or two Placoids, which will enable us better to comprehend the structure and affinities of this singular creature.

Fig. 31 represents a thin horizontal section of the shagreen or skin of the Dog-fish. It consists, as is well known, of a number of small dermal teeth, implanted in a more or less linear manner in a soft skin, figs. 31 *a*, 32 *a*. Each tooth contains a pulp-cavity, fig. 31 *b*, from which radiate several large canals. One of these descends vertically, as seen in fig. 32 *b*, which represents a vertical section of an individual tooth. The remainder, varying in number from one to three or four, proceed in a horizontal direction towards the posterior portion of the tooth, figs. 31 *c*, 32 *c*, where they appear to communicate with the most superficial layers of the integument, if not with the external surface itself, being apparently the analogues of the radiating canals in the tubercles and teeth of *Macropoma*, figs. 25 *c*, 26 *e*, 27 *d* and 28 *d*.

From each pulp-cavity is also given off numerous branching tubes like those seen in the dentine of the teeth of sharks. They only differ from those in the corresponding dermal teeth of *Macropoma* in being larger and less crowded together.

The superficial portion of each of these appendages, which is not imbedded in the soft cutaneous tissues, is covered over with a very thin layer of glossy ganoin, but between which and the tubular structure there is no distinct line of demarcation.

If we compare these vertical and horizontal sections of the dermal teeth of the Dog-fish, figs. 31 and 32, with the corresponding representations of the operculum and scale of *Macropoma*, figs. 25, 26 and 28, we cannot fail to be struck with their identity in every respect. The only real difference appears to be, that, whilst in the Dog-fish the teeth are isolated, being implanted in a soft integument, in the *Macropoma* they are fixed upon a calcareous basis. In the case of the operculum, this basis consists of a true osseous structure; and in the scales, though the true bony matter has dwindled down into the thin superficial film surrounding the bases of the teeth, its place is supplied by a thin laminated tissue which is its equivalent, as a solid foundation on which numerous teeth are aggregated, and which is probably but the homologue of the thin laminæ of which the stellate bases of the dermal teeth of many Placoids are composed.

If these are true analogies and not mere resemblances, they afford us an interesting illustration of the successive steps in the development of the hard cutaneous covering seen in the ganoid fish: but before endeavouring to trace this development, I would direct attention to an additional link in the chain supplied by the fossil shagreen of the *Hybodus reticulatus*, from the lias of Lyme Regis; a vertical section of which is represented in fig. 33.

We here find another modification of the dermal teeth, fig. 33 *a*, with large pulp-cavities, 33 *b*, and canals opening laterally as well as vertically, 33 *c*, communicating with the soft tissues in which the teeth have been originally implanted. From these pulp-cavities, also radiate branching tubes resembling those of dentine. So far, there is no material difference between these and the dermal teeth of the Dog-fish; but beneath them, and imbedded in the soft tissues of the true skin, we find a vast number of small, irregular calcareous nodules, 33 *d*, each of which consists of a series of concentrically arranged lamellæ. They contain neither lacunæ nor visible tubes, but frequently exhibit small brown points, which however may merely be some effect of their subsequent mineralization. Though not composed of true bone, these are surely to be regarded as a rudimentary attempt at the extension, amongst the Placoids, of that calcareous exo-skeleton which has received so complete a development in the ganoid fish.

We may now for a moment retrace our steps and endeavour to mark some of the successive stages in the development of this portion of the exo-skeleton.

In the common Thornback, *Raia clavata*, Cuv., a long central row of dermal teeth extends from the head to near the extremity of the tail. They exhibit the tubular structure found in this class of objects, but contain very little calcareous matter; they are scarcely more solid in their structure than the cartilaginous column which they surmount. The skin of the same fish is studded over with still more minute teeth, but which contain much more earthy matter: we have however no trace of true bone. Each dermal tooth consists of a succession of conical lamellæ placed one upon another; the apex, which rises above the cuticle, resembles that of the Dog-fish in structure; inferiorly, these lamellæ expand into a stellate base, in which portion they are much less consolidated, considerable spaces occasionally existing between individual layers after they have been artificially dried. The pulp-cavity is quite open inferiorly, there being no extension of the lamellæ across its base, and consequently no necessity for the horizontal canals, which are wanting. In the shagreen of the Dog-fish we have an advance upon this structure. The lower tissues are more consolidated, and present an extension of the lamellæ across the base, closing in the pulp-cavity as already described, and being only perforated by the narrow canals, fig. 32 *d*. In *Hybodus reticulatus* we find dermal teeth of a similar type to those of the Dog-fish, but we have a further development of calcareous granules in the subjacent skin, but no true bone. In *Macropoma* we advance still further. In each scale we find a laminated texture, probably analogous in its nature to the expanded bases of the teeth in the shagreen of the Thornback: upon this texture, the teeth, no longer isolated, are aggregated; whilst on the surface of the scale thus formed, we find, for the first time, a thin film of true bone. In the operculum of *Macropoma*, the sub-structure upon which the dermal teeth are implanted exhibits all the essential characters of true bone, its laminated structures preparing us for the ganoid fish, where not only the operculum but also the other scales are of an osseous nature. Amongst these we still find scattered dermal teeth, studding the scales of *Dapidius granulosus*, presenting the same external contour, internal pulp-cavity, branching tubuli and canals communicating with the exterior as in the preceding forms.

These successive steps, conducting us from the dermal appendages of the Placoids to the ganoid scales, indicate a series of analogies which can scarcely be questioned. But I should even venture to go still further; I can trace no real difference between the tubercles of the scale of *Dapidius granulosus*, and what I have called the kosmine, in *Lepidotus* and its allies. The latter appears to me to be only a more extended development of the former. In the beautiful form in which this kosmine exists on the scales of *Megalichthys, Diplopterus* and *Holoptychius*, we have nothing more, apparently, than the confluent aggregation and superficial depression of a number of placoid teeth, surmounting a highly developed bony scale. Compare for a moment the horizontal section of the shagreen of the Dog-fish, fig. 31, with the horizontal section of the *Diplopterus*, fig. 20. The dermal teeth of the former are represented by the areolæ of the latter; the pulp-cavity and branching tubes of the true dermal tooth, fig. 31 *b*, have their homologues in the ascending central cavities and branching tubes of the areolæ of the *Diplopterus*, fig. 20 *m*. In the same way the ascending cul-de-sac in each areola of the *Megalichthys* appears to correspond with the pulp-cavity, whilst the arborescent tubuli which it gives off represent the dentine-like tubes of the shagreen. The chief difference appears to consist in the fact, that in the Ganoid, the areolæ, being closely aggregated upon a bony basis, have coalesced, and been flattened, superiorly, to an uniform level; whilst in the Placoid, each areola forms an isolated conical tooth, implanted in the soft integument. The different degrees to which the same structure may be either flattened, or drawn out and become acuminate, is seen in the various parts of the exo-skeleton of *Macropoma*, showing that the process is a very trivial one, involving no typical change*.

* Since the above remarks were penned, I have found a still more beautiful illustration of this homology. When the smooth shining membrane covering the snout of the Saw-fish is examined under the microscope, it is found to consist of a thin soft skin, in which are implanted numerous flattened dermal teeth, each resembling, in its form, the small studs commonly worn as breast-ornaments. They are packed closely together, with only a few minute intervening spaces. This closely aggregate arrangement, combined with their depressed form, causes the whole to present a smooth, shining surface, nearly resembling that of a ganoid scale. Fig. 34 represents a vertical section of some of these teeth with the subjacent tissues; 34 *a* is the upper portion of the osseous (?) structure of the snout; *b*, the soft integument; *c*, individual teeth; *d*, the pulp-cavity; *e*, canals radiating from the latter, from four to eight existing in each tooth, and arranged as in *Macropoma*, fig. 25; *f*, descending canal, communicating between the pulp-cavity and the subjacent soft integument; *g*, dentine-like (kosmine) tubes; *h*, open spaces surrounding each tooth, and appearing, when viewed vertically by transmitted light, like a network of canals, reminding us most forcibly of the similar appearance surrounding each areola in *Megalichthys*, fig. 16. Where three or four of the teeth meet there is usually a minute space not filled up, opening into this network, which latter is formed by the horizontal constriction of the teeth, as seen in 34 *i*, which represents the exterior of an individual which the section has not divided.

On comparing this section with the vertical one of *Megalichthys*, fig. 15, the homologies of the various parts are still more striking than in the example of the Dog-fish. Each tooth in the Saw-fish represents one superficial areola of the *Megalichthys*. The small superficial intervals between the teeth appear to be the homologues of the descending trumpet-shaped cavities, 15 *a*; these communicate between the exterior and the interdental spaces, 34 *h*, which apparently correspond with the network of small tubes in *Megalichthys*, 15 *c* and 16 *c*, as already observed. The pulp-cavity, 34 *d*, takes the place of the cul-de-sac, 15 *f*, a communication being maintained between the interdental spaces and these pulp-cavities, by means of the radiating canals, 34 *e*. And, as

This supposed analogy is, in some degree, supported by the resemblance in the process by which the areolæ of *Megalichthys* and the dermal teeth of the Placoids are developed and increased. In both examples it is by the addition of new internal layers around the central cavity. The same is the case in the tubercles and teeth of *Macropoma*. These facts (if correctly interpreted, and I believe them to be so) confirm the necessity of my proposed restriction of the terms ganoin, enamel (*émail*), &c. Two perfectly distinct structures have hitherto been comprehended in the expression "enamel," as hitherto applied to the scales of fish, viz. the superficial, transparent, hyaline tissue, which usually gives glossiness to the surface of the scale, and a subjacent one, which I propose to distinguish by the name of kosmine*. In some genera, such as *Megalichthys*, this latter structure is gradually blended with the former, the line of demarcation not being visible; whilst in others, such as *Lepidotus*, *Palæoniscus* etc., it is perfectly distinct from it, blending rather with the subjacent osseous tissue. These two appear to be as distinct as bone and dentine. The ganoin exhibits no visible trace of structure beyond its arrangement in the form of laminæ, and the occasional existence of minute coloured granular points. When separated from the tissue upon which it rests, it evinces a marked disposition to crack and splinter in every direction. The kosmine, on the other hand, in a fossil state at least, is usually coloured, and always exhibits some arrangement of minute branching tubes, resembling those of dentine; and as, in some species of fish, Prof. OWEN has pointed out the direct passage of Haversian canals into the pulp-cavities and dentinal tubes of the true teeth, so in the kosmine do we find a direct extension of the similar canals into the corresponding tubular structures of the surface of the scale.

I have seen no instance in which this kosmine has been present without a covering of ganoin, whilst the latter may frequently be present without any subjacent kosmine. I am further led to conclude, that, whatever name be ultimately employed to represent what I have designated kosmine, it must also be applied to those dentine-like tissues, which, in the form of dermal teeth, ornament the skins of so many Placoids.

If then I am correct on these points, we must come to the conclusion, that, whilst the scales of many of the so-called "Ganoid" fish, such as the Sturgeon, and other similar forms, exhibit few or no traces of either ganoin or kosmine, many of the "Placoids" exhibit such an extensive development of both, as finds few parallels amongst the Ganoids; so that, not only have we several connecting links merging the two groups in one another, more of which links doubtless remain to be discovered, but the distinction of "Ganoid," as the term has hitherto been applied, ceases to be a physiological one.

in *Megalichthys* each cul-de-sac communicates with the subjacent tissues through the medium of the Haversian canals, so in the Saw-fish the descending canal, 34*f*, communicates with the soft integument, *b*, which alone separates it from the curious cancellated structure, *a*, representing the bony (?) part of the snout. It is obvious that we only require the upper and lower disc-like expansions of contiguous teeth to become confluent, to give us a structure closely resembling that which covers the bony scales of *Megalichthys*.

* See page 442.

Another conclusion to be drawn from the foregoing observations, is the corroboration of a portion of the views of M. Agassiz in reference to the mode of growth which has obtained amongst the scales of "ganoid fish," viz. that it has been accomplished by the addition of new lamellæ applied to their exterior*: but these growths have not been confined to the lower surface; in some, as in *Lepidosteus*, *Acipenser*, and *Holoptychius*, they have partially covered the upper one also; whilst in others, as in *Lepidotus*, *Aspidorhynchus*, &c., the concentric circle has been made complete, superiorly, either by the addition of continuous layers of true bone or of ganoin. In either of the latter cases the newly-formed lamellæ have completely enclosed the older growths; consequently, though agreeing with M. Agassiz in the main, I can scarcely conclude, as he does, that "l'organe sécréteur est la poche épidermoidale dans laquelle elles sont enfoncées par leurs bords antérieurs." It is evident that each scale must have been completely and permanently surrounded by a kind of periosteum, closely embracing its entire circumference, and prolongations from which have entered many of the Haversian canals in such genera as *Megalichthys*, in the opercular bone of *Lepidotus*, and in *Macropoma Mantelli*. Though corresponding prolongations may have also entered the smaller parallel tubes of the *Lepidostei* and *Lepidoti*, we have no evidence that these latter prolongations possessed any secreting power, since no parallel lamellæ line their vertical walls; and in the same way, those portions which have lined the *vertical* Haversian canals of *Holoptychius* and the trumpet-shaped cavities of *Megalichthys*, do not appear to have secreted any solid tissues. This membrane has doubtless derived its supplies of blood from the soft integument, which has not only been in contact with the whole base of the scale, but also with the superior surface of its anterior and often lateral margin.

We also obtain from the history of these scales, some important evidence illustrating the process of bone-growth amongst the Mammalia. Most anatomists are aware that some new and highly interesting views have been advanced by Prof. Sharpey, who has shown that, in the case of each human bone, but a comparatively small portion of it had originated from the deposition of calcareous matter amongst the cells of true cartilage; all its subsequent increase in thickness or diameter proceeding from the calcification of the inner layer of the periosteum, whose fibres are always found to be in intimate connection with the osseous surface. According to this view, the Haversian canals have not necessarily originated in any previous arrangement of the cartilage cells, but mainly resulted from the inflexions of the intermembranous growths of bony lamellæ, formed in the substance of the periosteum without the intervention of any temporary cartilaginous structure: and as an additional sequence, it becomes probable that the lacunæ and their canaliculi had resulted neither from a modification of the cartilage cell, as is believed by Schwann and Henle, nor of its nucleus, the view entertained by Mr. Tomes†; but rather that they are little vacuities

* See page 437.

† See Todd and Bowman's Physiological Anatomy, p. 119.

that have been left out, during the deposition of the membranous lamellæ and their subsequent impregnation with calcareous matter *.

The appearances presented by the scales described in the preceding pages, go far to confirm these views. I have not been able to detect the slightest trace of cartilage cells in either the recent scales of the Sturgeon and Lepidosteus, or in the dermal teeth and plates of any of the Placoid fish. The decalcified scales of the Sturgeon and Lepidosteus, show that the lime is deposited in a granular form, in the minute interstices of membranous lamellæ, and that, consequently, the origin of the magnificent lacunæ with their largely developed canaliculi, must be explained without having recourse to the intervention of cartilage cells, either in producing the cavity or influencing its position in the bone.

In the same way, the gradual progression to be observed as we pass from the simple laminated scale of *Seminotus* and *Lepidotus*, to the complicated development of Haversian canals existing in *Acipenser*, *Holoptychius* and *Megalichthys*, illustrate how the periosteal laminæ thickening the exterior of the shaft of a mammalian bone, may have been twisted and inflected; their undulations producing, first, grooves on its surface, and subsequently canals, from the arching over of the grooves so formed, by the corresponding but inversed inflexions of the more newly-formed lamellæ: whilst in some cases, as in *Megalichthys*, we find, what is less evident in the Sturgeon, that after these canals have been thus constructed, additional and more completely concentric lamellæ have been deposited within each canal, at once diminishing its diameter and thickening its walls.

We also obtain an additional illustration of what the study of comparative anatomy so frequently reveals, viz. the unequal degree in which the various portions of an organized structure are developed, in reference to the homological type of each. Thus, whilst in *Lepidosteus osseus* we have one of the simplest forms of the laminated scale, associated with vertebræ exhibiting the ball-and-socket-joint of the Ophidians, and teeth approximating to a Saurian form, in *Megalichthys* and *Holoptychius* we have scales mainly consisting of a complicated arrangement of Haversian canals, and abounding in long fusiform lacunæ, of the true reptilian type; whilst the vertebræ of *Holoptychius*, certainly, and I believe of *Megalichthys* also, present the double concave articulation ordinarily found in fishes and enaliosaurs.

The further carrying out of this investigation into the microscopic structure of the scales of fish, will afford an important means of distinguishing different fossil species, and also, when prudently employed, of establishing their affinities and alliances; but at the same time I would venture to caution the palæontologist against expecting too much from it. In many cases it will enable us to decide that two imperfect fragments belong to distinct species, and also to form a pretty correct judgment as to the general nature of each; but in numerous other instances, even very different genera

* Dr. QUAIN's Anatomy, 5th edition, by Dr. SHARPEY and Mr. QUAIN, part 2, p. cxxxii. *et seq.*

of fish may present but a small and inappreciable amount of difference in the microscopic structure of their scales: thus, for example, a longitudinal section of the scale of a *Gyrodus* exhibits a much closer *apparent* analogy to that of an *Aspidorhynchus* than to that of the more closely allied genus *Platysomus*; though a close typical resemblance assimilates it to the latter. The uncertainty of this result is also increased by the various effects produced by the mineralization of the fossil scale. I have examined scales from some specimens of *Lepidotus semiserratus*, in which I had the greatest difficulty in detecting traces either of the beautiful arborescent tubuli or of the lacunæ shown in fig. 4, they having been almost, though not altogether, obliterated by the process of fossilization, teaching a lesson of caution, which the student will do well to remember. But notwithstanding these difficulties, the value of the inquiry, as furnishing us with an instrument which will facilitate the identification of affinities, is considerable, provided it is not made the *sole* standard of classification, but employed in conjunction with an equally minute examination of every other portion of the animal organism.

It now only remains for me to acknowledge the great kindness with which Sir Philip M. De Grey Egerton, Bart., M.P., Dr. Mantell, Mr. Binney, Mr. John Edward Gray and Mr. Searles Wood, have afforded me every assistance in their power, by supplying me with many important specimens for examination which my own cabinet did not contain. To each of these gentlemen my warmest thanks are due for their most valuable cooperation.

APPENDIX.

Since the preceding memoir was placed at the disposal of the Royal Society, the continued kindness of Sir Philip Egerton has enabled me to examine specimens of the curious premaxillary bones of the *Cœlorhynchus*, obtained both from the London clay and from the tertiary beds of North America. They exhibit a form of kosmine which is alike new and interesting. I learn from Sir Philip Egerton that the rostral appendage of this fish is made up of two semi-cylindrical bones (see fig. 35 *a a*) inclosing a canal, which is double towards the base, but which becomes coalescent as it approaches the apex, of which latter portion, fig. 35 represents a transverse section. These bones are marked externally with longitudinal grooves and corresponding ridges, the latter being the external margins of a series of long cuneiform plates, which radiate from the centre to the circumference.

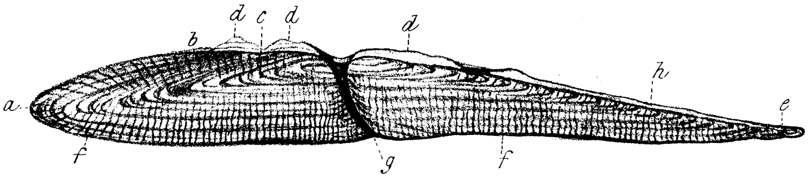
Fig. 36 exhibits a profile representation of three of these plates, showing their internal structure. Each plate is separated from its neighbour by a thin vertical network of small canals, fig. 36 *a*, which open, externally, along the narrow groove, fig. 36 *b*, separating the convex ridges. In the transverse section, the divided orifices of the canals constituting this network are visible, fig. 36 *c*, along the vertical line of demarcation between the segments. From each side of this line, vast numbers of minute kosmine tubes are seen arching downwards and inwards towards the centre of the plate, fig. 36 *d*. Similar tubes also descend from the convex upper surface of each plate, 36 *e*. From the top to the bottom of the segment are also seen numerous arched lines of growth, which run parallel to the upper surface; these are best represented in the segment, fig. 36 *f*, in which I have omitted the kosmine tubes, in order to exhibit the lamellæ with more clearness. Running longitudinally through the centre of each plate are several narrow, depressed, semilunar canals, fig. 36 *g*, arranged at nearly equal distances from one another, and into each of which many of the kosmine tubes, coming both from above and from below, appear to open.

Fig. 37 represents a *horizontal* section of two similar plates; at 37 *a* we again see the orifices of the network of canals. Owing to the arched direction assumed by the kosmine tubes, this section divides them nearly at right angles at the central part of each plate, whilst it is almost parallel with their plane at each margin; hence, at 37 *b*, these tubes are seen very distinctly, whilst at 37 *c* rows of minute dots alone mark the position of their divided orifices. The latter do not always run in lines exactly parallel to the plane of the marginal canals, but they exhibit a strong tendency to do so. Fig. 37 *d* shows the direction taken by one of the semilunar canals, fig. 36 *g*.

It is very easy to trace the process of growth in this interesting structure, in which each plate or segment represents a tooth turned inside out. The first deposition of calcareous matter has been made in the form of a thin cylinder surrounding the central cavity, fig. 35 *b*. New lamellæ, perforated with minute apertures, have been formed upon this basis; the apertures in each lamella being arranged in exact juxtaposition with those of the contiguous lamellæ. The minute tubes thus formed have *at first* all opened at the external surface, but it will be readily seen, that, after the addition of many new lamellæ, owing to their arched arrangement, the tubes of adjoining plates would meet at the line of junction, fig. 36 *c*, and thus each segment would contribute to block up those of its neighbour, preventing them from receiving their proper supply of nutritious fluids. To obviate this difficulty, however, the network of minute canals, fig. 36 *a* and *c*, has been left open between contiguous segments. The orifices of the kosmine tubes open into these canals, and maintain a free communication with the surface through the row of small orifices seen in each superficial sulcus, fig. 36 *b*. Thus the nutrition of the tissues in the interior of each segment continues to be provided for. The use of the longitudinal canals, figs. 36 *g* and 37 *d*, is uncertain. They have probably contained some form of pulpy matter. No trace of true bone is seen in the entire structure, which consists wholly of kosmine. In this it bears a resemblance to the rays and dorsal appendages of the placoid fish. The kosmine breaks with a translucent and shining fracture.

It is difficult to conceive of any arrangement by means of which a stronger fabric could have been produced, than is exhibited in this cylindrical combination of long radiating plates. The true nature of the appendage itself, as well as that of the fish to which it belongs, is yet uncertain; but if it has been a weapon of defence, like the

Fig. 1.



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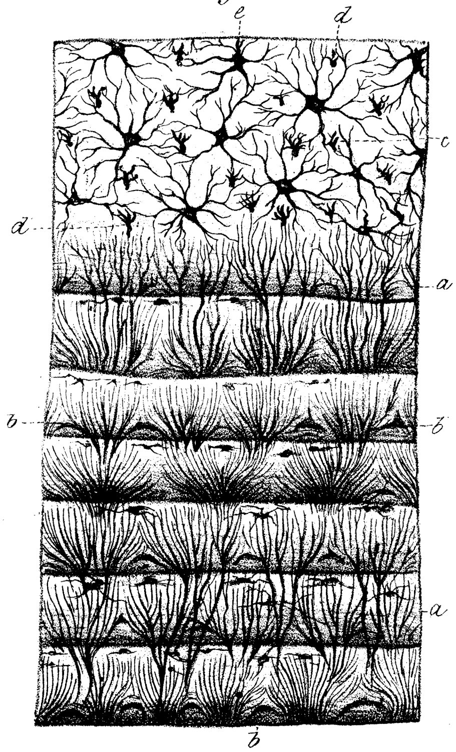

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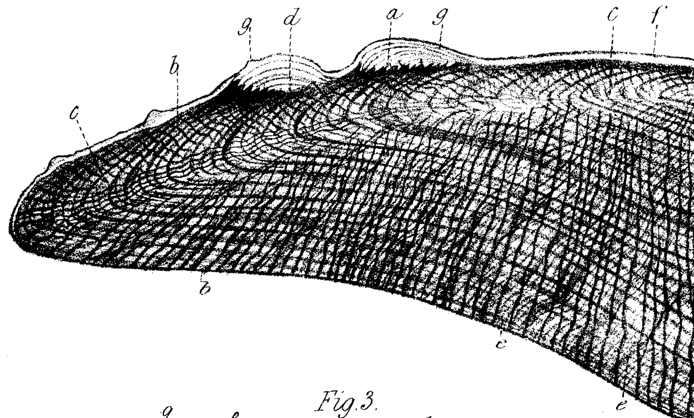

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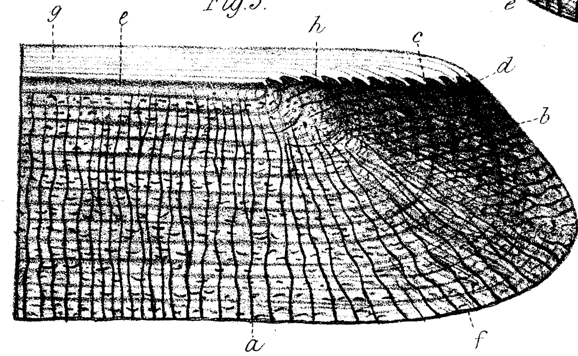

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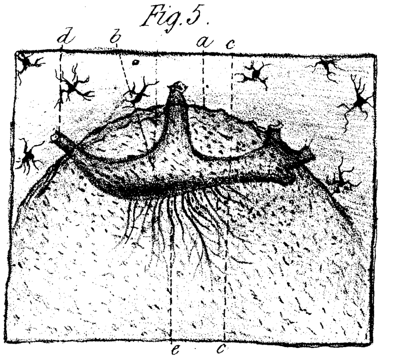

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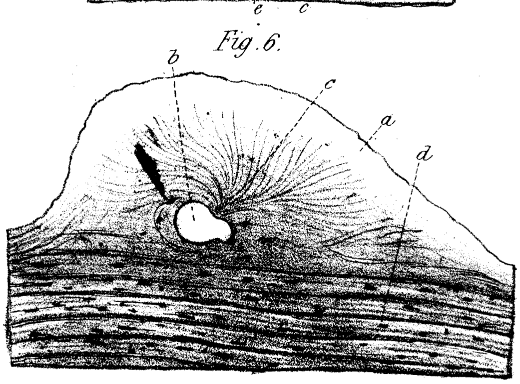

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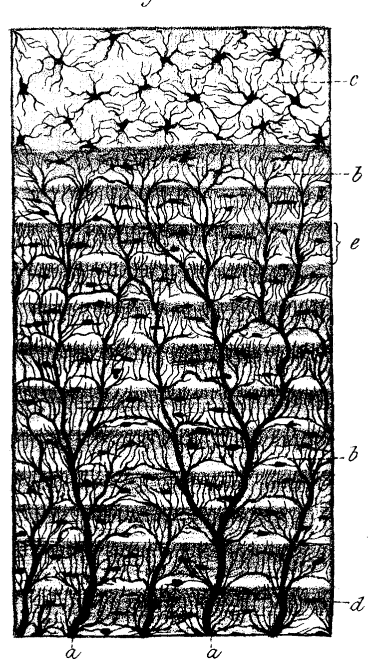

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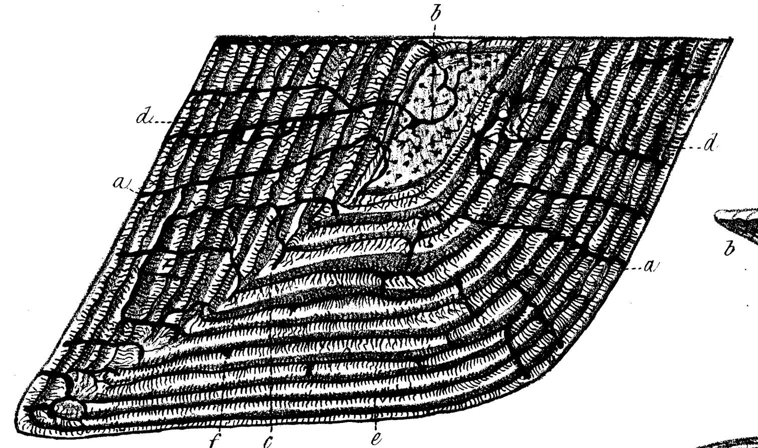

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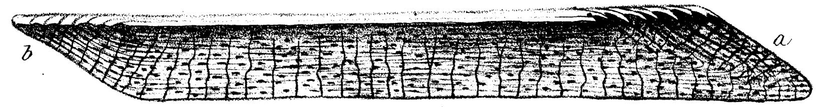
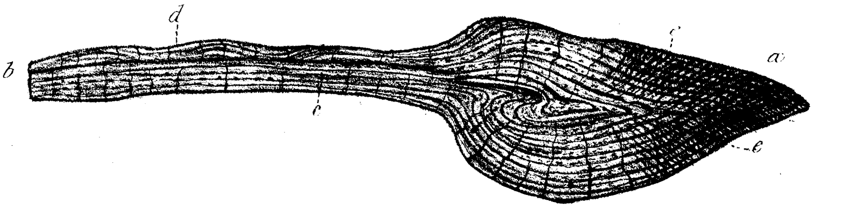


Fig. 9*



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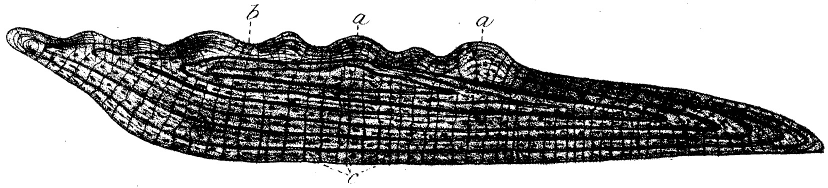

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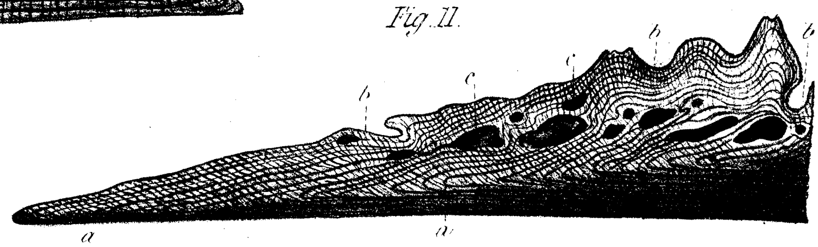

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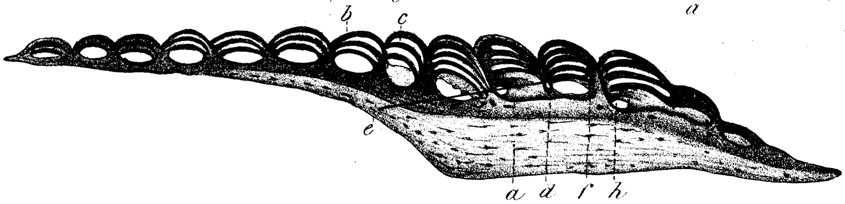

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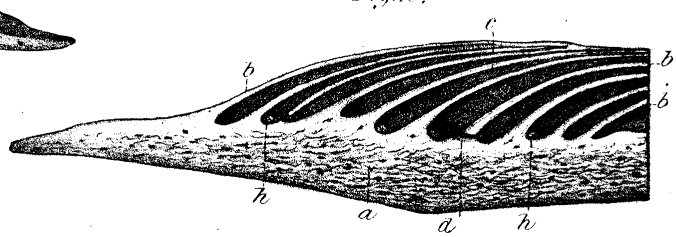


Fig. 15.

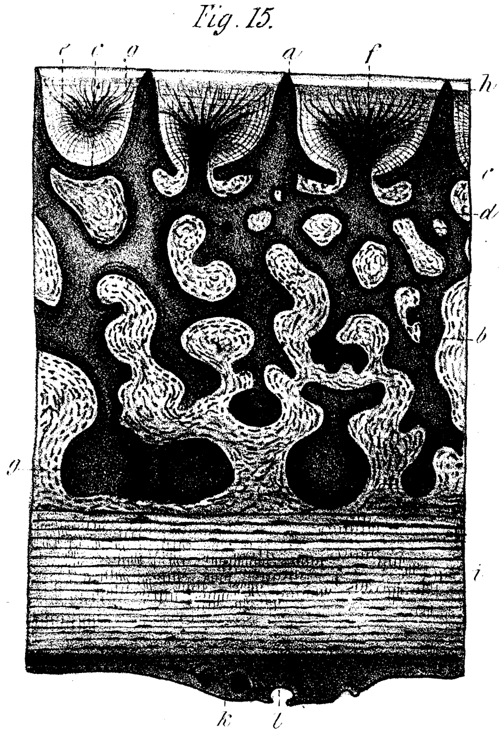
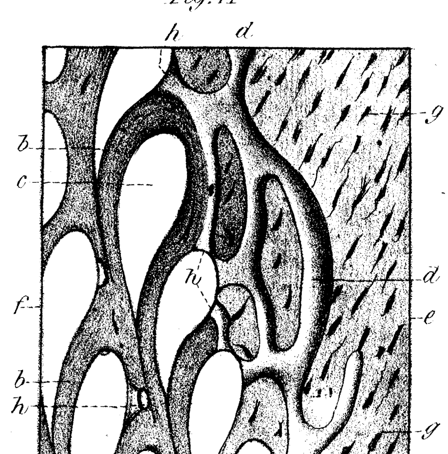


Fig. 14.



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snout of the recent Sword-fish, the creature must have proved, in no small degree, formidable to its congeners.

In all its details, the structure corroborates the conclusion arrived at in the preceding memoir, and shows not only a process of growth by the addition of lamellæ, similar to that already described, but also indicates further, that whatever may be the direction and distribution either of kosmine or lepidine tubes, the additions to the structure which they permeate are always made to the surface on which their largest apertures open; whether that surface be found in an internal cavity, as in *Megalichthys* and *Diplopterus*, or whether it is in their exterior, as in *Cœlorhynchus*.

Description of the Plates.

PLATE XL.

Fig. 1. Vertical section of a scale of *Lepidosteus osseus*, parallel with the lateral line of the fish. Magnified 8 diameters.

Fig. 2. Vertical section of the half of a similar scale, made at right angles to the lateral line. Magnified 14 diameters.

Fig. 3. Vertical section of the anterior border of a scale of *Lepidotus semiserratus*, parallel with the lateral line. Magnified 25 diameters.

Fig. 4. Horizontal section of the upper surface of part of the same scale. Magnified 112 diameters.

Fig. 5. Horizontal section of a tubercle from the surface of a scale of *Dapidius granulosus*.

Fig. 6. Vertical section of the same.

Fig. 7. Horizontal section of part of the surface of *Palæoniscus comptus*. Magnified 90 diameters.

PLATE XLI.

Fig. 8. Horizontal section of part of the surface of *Palæoniscus Beaumontii*.

Fig. 9. Vertical section of a scale of *Seminotus rhombifer*, made parallel to the lateral line.

Fig. 9*. Vertical section of a scale of a *Gyrodus* from Kellheim, parallel to the lateral line.

Fig. 10. Vertical section of *Aspidorhynchus acutirostris*, parallel to the lateral line. Magnified 16 diameters.

Fig. 11. Vertical section of part of a scale of *Acipenser Sturio*, parallel with the lateral line of the fish, and midway between the centre and the lower angle of the lozenge-shaped scale. Magnified 7 diameters.

Fig. 12. Vertical section of a scale of *Platysomus parvulus*, parallel with the lateral line. Magnified 80 diameters.

Fig. 13. Vertical section of the upper half of the same scale, made at right angles to the lateral line. Magnified 100 diameters.

Fig. 14. Horizontal section of part of the same scale, made in the direction of the line, fig. 12 *ef*.

Fig. 15. Vertical section of part of a scale of *Megalichthys Hibbertii*. Magnified 80 diameters.

PLATE XLII.

Fig. 16. Horizontal section of part of the surface of the scale of *Megalichthys Hibbertii*. Magnified 60 diameters.

Fig. 17. Vertical section of part of a scale of a small species of *Megalichthys*. Magnified 110 diameters.

Fig. 18. Vertical section of the lower part of a scale of *Megalichthys Hibbertii*, made at right angles to the lateral line. Magnified 10 diameters.

Fig. 19. Horizontal section of the laminæ, fig. 15 *i*, *Megalichthys Hibbertii*. Magnified 300 diameters.

Fig. 20. Oblique horizontal section of the upper part of a *Diplopterus*. Magnified 27 diameters.

Fig. 21. Upper surface of a large scale of *Holoptychius sauroides*, natural size.

Fig. 22. Inferior surface of the same scale.

Fig. 23. Vertical section of a scale of *Holoptychius sauroides*, taken in the direction of the dotted line, fig. 22 *c*. Magnified 30 diameters.

Fig. 24. Vertical section of part of the scale of a species of *Holoptychius*, made nearly in the direction of the line, fig. 22 *c*, only verging more towards the centre of the scale. Magnified 30 diameters.

Fig. 25. Horizontal section of the surface of the opercular bone of *Macropoma Mantelli*. Magnified 25 diameters.

Fig. 26. Vertical section of part of the same opercular bone, taken parallel to the lateral line of the fish. Magnified 70 diameters.

PLATE XLIII.

Fig. 27. Vertical section of parts of two scales of *Macropoma Mantelli*, made parallel to the mesial line. Magnified 25 diameters.

Fig. 28. Vertical section of a row of large dermal teeth, from the centre of a scale of *Macropoma Mantelli*. Magnified 18 diameters.

Fig. 29. Horizontal section of the surface of the internal osseous viscus of *Macropoma Mantelli*. Magnified 350 diameters.

Fig. 30. Vertical section of the parietes of the same viscus, taken in the direction of its long axis, and parallel to the mesial line. Magnified 350 diameters.

Fig. 16.

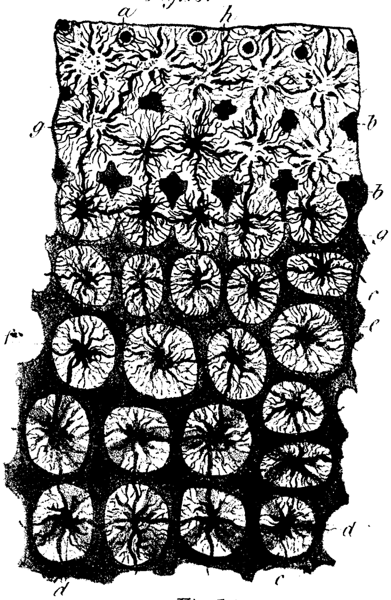


Fig. 17.

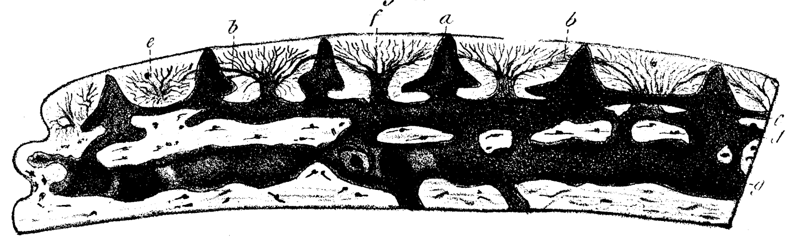
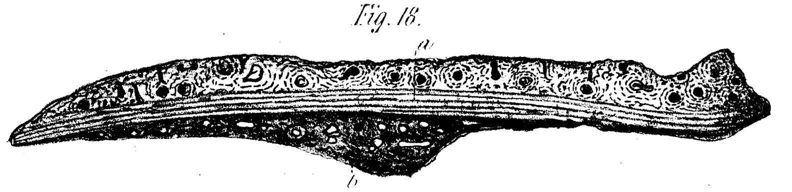


Fig. 21.

Fig. 18.



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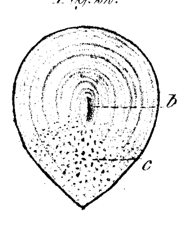

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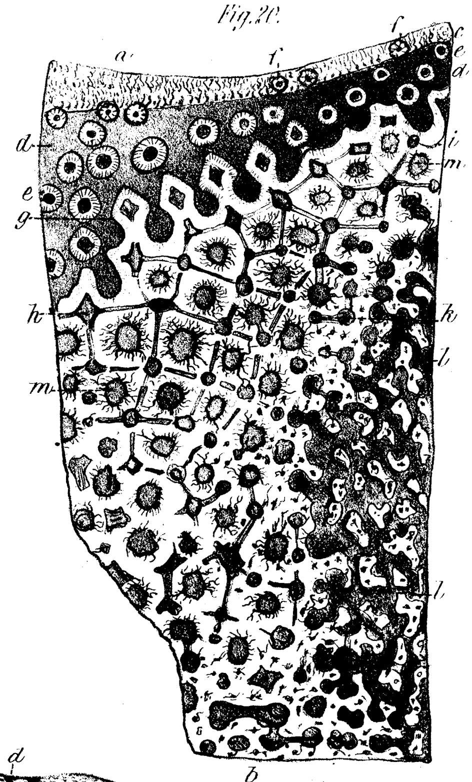

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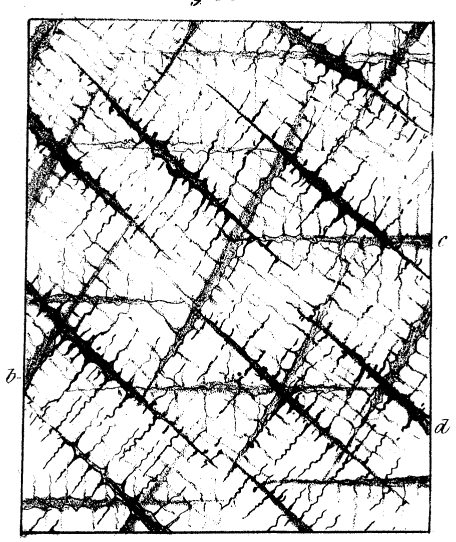

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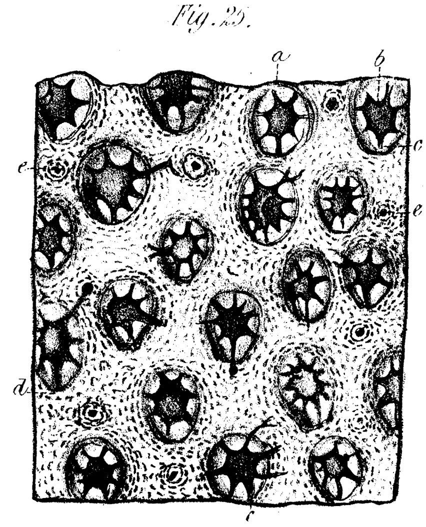

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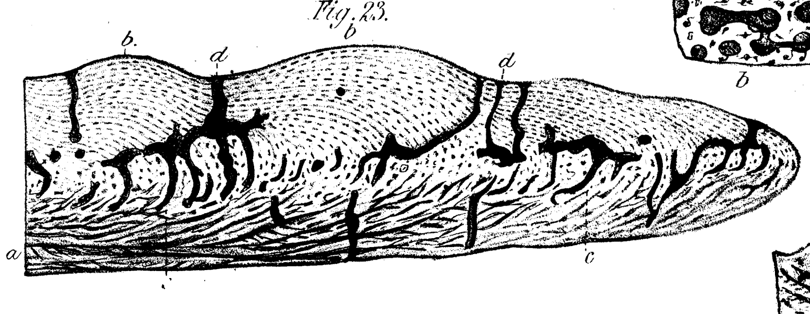

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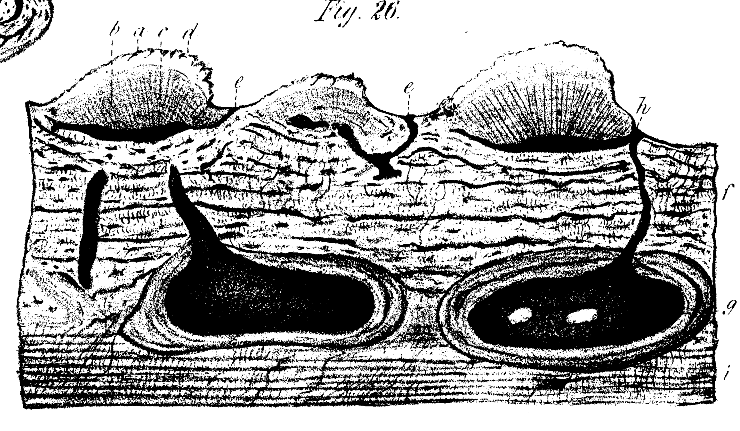

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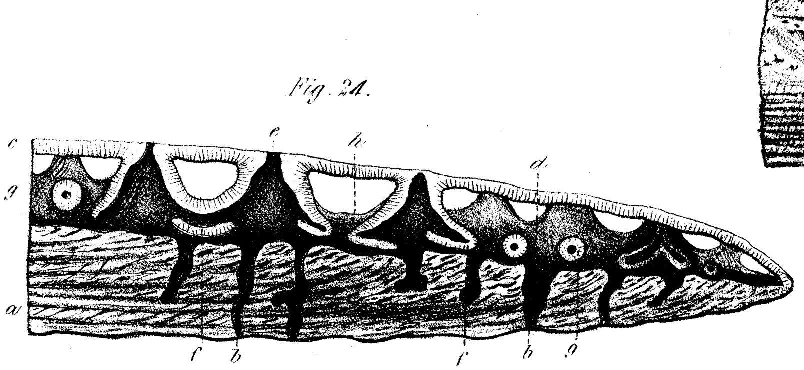
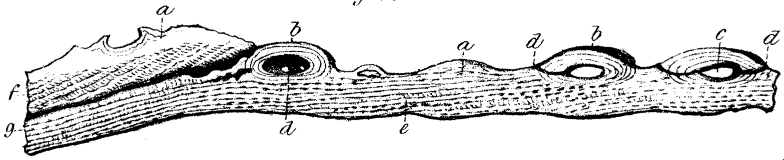


W.C.W. del.

Fig. 27.



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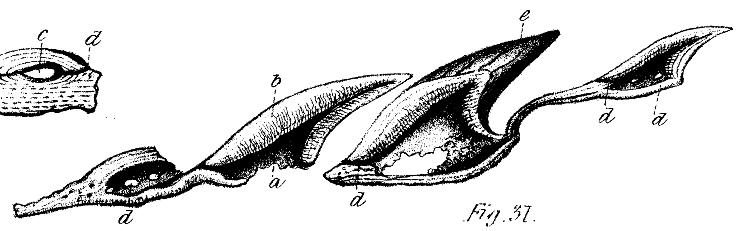

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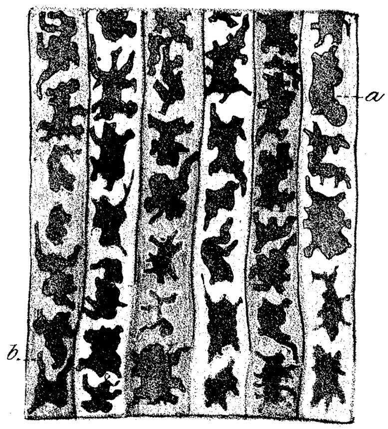

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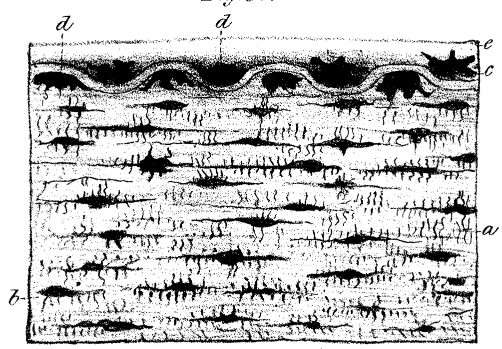


Fig. 31.

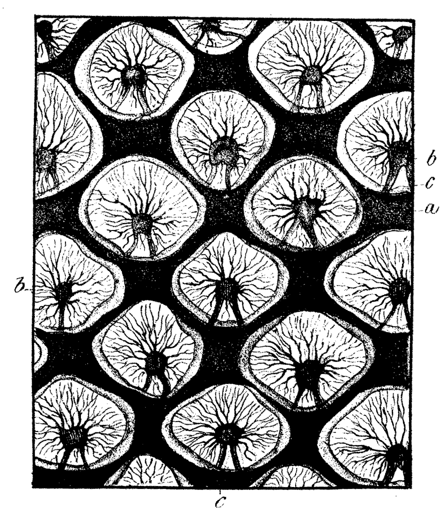
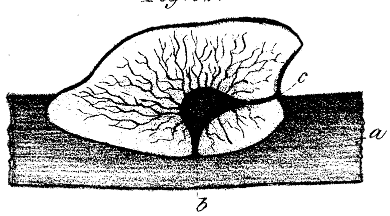


Fig. 32.



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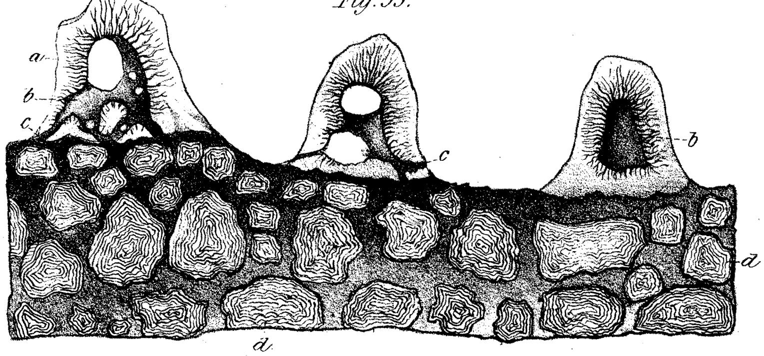

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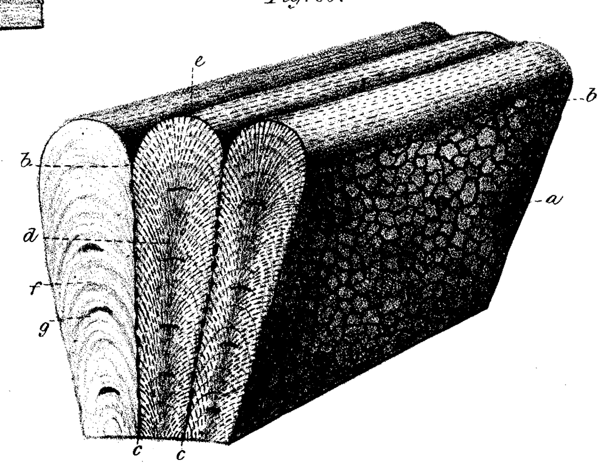

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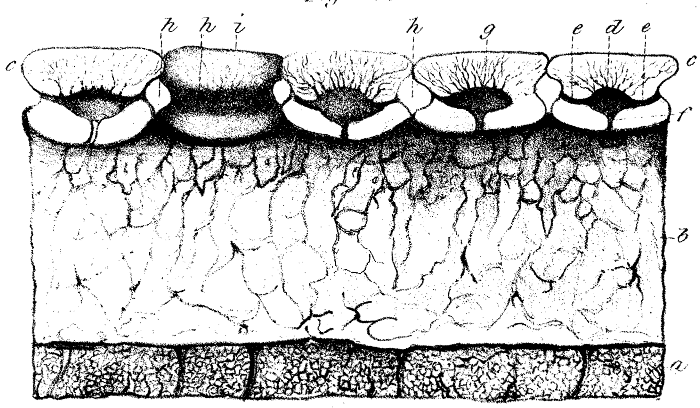

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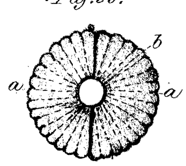
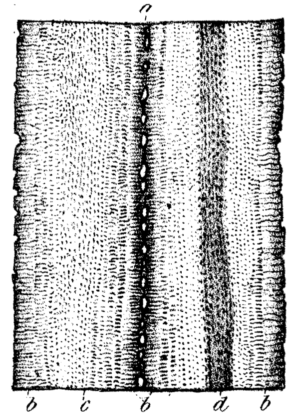


Fig. 37.



W. C. W. del.

J. Basire lith.

Fig. 31. Horizontal section of the shagreen of the common Dog-fish, the bases and apices of the dermal teeth being alike ground away. The faint ring surrounding each areola is produced by the form of the tooth; the upper section having divided it at a narrower point than the lower one, thus shows a portion of the surface of each.

Fig. 32. Vertical section of one of the dermal teeth of fig. 31.

Fig. 33. Vertical section of the fossil shagreen of the *Hybodus reticulatus*.

Fig. 34. Vertical section of the surface of the snout of the common Saw-fish (*Pristis*). Magnified 65 diameters.

Fig. 35. Vertical section of the premaxillary bones of a *Cœlorhynchus*. Natural size.

Fig. 36. Profile view of part of the same organism. Magnified 6 diameters.

Fig. 37. Horizontal section of portions of two segments of the same. Magnified 9 diameters.