III. *On the Structure and Development of Vascular Dentine.*

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[Plates 3–5.]

The minute structure and the development of that variety of dentine which is met with in most mammalian teeth, and which goes by the name of hard or unvascular dentine, have been repeatedly and very carefully worked out, and our knowledge of their intimate nature is quite on a par with our knowledge of that of the tissues of other parts of the body. But the intimate structure of those interesting and, from a morphological point of view, important varieties of dentine, known as vaso-dentine and osteo-dentine, is but very imperfectly known; in point of fact, whilst the arrangement of the tubes and channels which permeate their substance has been satisfactorily described by many observers, so far as it can be studied in sections of dried teeth, next to nothing is with any certainty known as to the contents of these channels, nor as to the manner in which they were formed.

In this paper I propose to give the results of a series of observations upon the development of vascular dentine, and the relation which it, in its completed condition, bears to the dental pulp; and I hope to be able to place the nomenclature and classification of the varieties of dentine upon a more satisfactory basis, by bringing them into accordance with the facts elicited by a study of development, which at present they are not.

So far as I can ascertain, although several observers had at an earlier period described the tissue which we know as vaso-dentine, Retzius was the first whose descriptions were accurate, and how accurate they were is attested by the fact that, so far as they go (he having described the hard tissues only), there is now, forty years later, little or nothing to be altered in them. But although Retzius recognized and very carefully described the tissues in question, he did not give to them any distinctive name, and Professor Owen, following in the footsteps of Retzius, introduced the convenient terms vaso-dentine and osteo-dentine, and hence ('Odontography,' p. xvii.) claims to have been the first to characterise vascular-dentine "as a component of tooth, 'distinct from ivory, enamel, cement, and true bone, and as easily recognisable,'" so that Continental writers often speak of the "vaso-dentine" and "osteo-dentine" of Owen. But it should not be forgotten that Retzius, though he did not give a distinctive name, described these varieties of dentine in the clearest terms. For example, he says, "this form of dental bone presents the most evident similarity to proper bone. There are found in it medullary tubes (canals of the pulp) and medullary fibres (fibres of the pulp), round which groups of concentric layers have been formed; from these the minute tubes radiate, which in the different layers are as it were pieced together, and in these layers concentric rows or rings of cells are again found, just as in bones." And again, when describing the teeth of the Pike, he says of the large tubes that in a few recent teeth "they contained a blood-red substance, and may hence be regarded as divisions of a cavity of the pulp." (NASMYTH 'On the Teeth,' p. 105.)

As Professor OWEN'S definitions and descriptions of vaso-dentine and osteo-dentine are generally accepted and followed, it is necessary to gather from his writings extracts which will show what precise meaning he attaches to the terms, and indeed little exception could be taken to his grouping of the varieties of dental tissue, were it not that his classification is not based upon, and indeed sometimes conflicts with, the evidence derived from a study of their development.

Vascular-dentine is described by Professor OWEN ('Odontography,' p. xvii.) thus: "The prolongation or persistence of cylindrical canals of the pulp cavity in the dentinal tissue, which is the essential character of vascular dentine, manifests itself under a variety of forms. In mammals and reptiles these canals, which I have termed 'medullary' from their close analogy with the so-called canals of bone, are straight and more or less parallel with each other; they bifurcate, though rarely, and when they anastomose, as in the Megatherium, it is by a loop at or near to the periphery of the vascular dentine. In the teeth of fishes, in which the distinction between the dentinal and osseous tissues is gradually effaced, the medullary canals of the vascular dentine, though in some instances straight and parallel and sparingly divided or united, yet are generally more or less bent, frequently and successively branched, and the subdivisions blended together in so many parts of the tooth as to form a rich reticulation. The calcigerous tubes sent off into the interspaces of the network partake of the irregular character of the canals from which they spring, and fill the meshes with a moss-like plexus.

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"If the first described modification of vascular dentine which forms the chief part of the teeth of the Sloth and Megatherium be regarded as a fourth dental tissue (*i.e.*, enamel, cement, dentine, and this), this second modification of vascular dentine from its close resemblance to bone might be reckoned as a fifth; in proportion, however, as it resembles bone, so, likewise, it approaches to the structure of cement."

At a subsequent page Professor OWEN further subdivides vascular dentine into three varieties. The first in which all the medullary canals are parallel, each having its own distinct system of dentinal tubes, as in *Pristis* or *Myliobates;* the second in which the anastomoses between the medullary tubes are more numerous, and the boundaries between the component denticles less distinct, as in *Cestracion;* and the third in which the dentine is permeated by a network of medullary canals, of which the interspaces are occupied by the calcigerous tubes and cells. The canals ramify and anastomose abundantly, as in Lamna, and in the Percoid, Lucioid, and Gadoid families.

In his 'Anatomy of Vertebrates' (vol. i. p. 361), he says: "The simplest modification of dentine is that in which capillary tracts of the primitive vascular pulp remain uncalcified, and permanently carry red blood into the substance of the tissue.

"These so-called 'medullary' or 'vascular' canals present various dispositions in the dentine which they modify, and which is called 'vaso-dentine.'

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"A third kind of dentine is where the cellular basis is arranged in concentric layers around the vascular canals, and contains 'radiated cells,' like those of osseous tissue; it is called 'osteo-dentine.' The transition from dentine to vaso-dentine, and from this to osteo-dentine, is gradual, and the resemblance of osteo-dentine to true bone is very close."

HERTWIG (Ueber Bau und Entwickelung der Placoidschuppen und der Zähne der Selachia. Jenaische Zeitschrift, 1874), in describing the dentine of Shark's teeth speaks of the frequent absence of a definite pulp-cavity, its place being taken by a canal system containing cells and blood-vessels. He notes the absence of a definite odontoblast layer upon the formative pulps of either teeth or scales (which are practically speaking the same in these respects), but says that the cells which do lie upon the surface, though not forming a very sharply defined layer, play the part of odontoblasts. He also compares their method of calcification to that of osteoblasts, and notes the occurrence of similar cells in the larger canals far within the formed dentine.

His description of the dentine met with in these scales and teeth, as well as of their development, would bring the tissue so formed within the restricted meaning which I have proposed in the following pages for the term osteo-dentine, a result at which I had myself arrived.

The foregoing extracts, few though they are, embody most of the facts of importance which I can find upon record; and what little mention is there made of the relation of vascular dentine to the formative pulp and of the contents of its larger tubes, appears not to have been grounded upon observation so much as upon *à priori* deductions.

As I shall endeavour to show, the study of their development must lead to the discrimination of at least three varieties of vascular dentine, but since the terms vaso-dentine and osteo-dentine are in common use, it will be far more convenient to retain them instead of introducing new terms, merely limiting and rendering exact their application, which is at present as vague as it well can be. For the third variety also a name already in use may be found which will describe its nature with sufficient accuracy.

The teeth of the common Hake throw so much light upon the question to be discussed that I will commence by a description of their minute structure. They are conical, slightly recurved, and very sharply pointed, being furnished with a sort of spear-point of enamel (see *a*, fig. 1, Plate 3), as are the teeth of all the Gadidæ which I have been able to procure.* They are arranged in a *double* † row round the margins of the mouth, the outer row being firmly anchylosed, and the inner row set upon an elastic hinge, which allows them to bend inwards towards the mouth, like the hinged teeth of the *Lophius piscatorius* (see page 41 of this paper); the teeth situate near to the front of the mouth of a Hake which weighed 11 lbs. (in poor condition) are $\frac{1}{3}$ of an inch in length. The teeth are hence rather conspicuous, and they are made more so in a freshly-caught fish by their bright red colour; the dentine is very transparent, and the pulp is richly vascular, so that the red blood is seen through the exterior of the tooth, in the tubes of the dentine of which it, as will be presently seen, actually circulates.

When viewed with a low magnifying power the axial pulp-chamber is usually seen to be of large size relatively to the whole tooth, and the dentine to be permeated through the greater part of its thickness by a system of canals which spring from the pulp cavity (see fig. 1).

These canals are of almost uniform diameter in the different parts of their course, measuring from $\frac{1}{2000}$ to $\frac{1}{2500}$ of an inch in diameter; they are arranged with great regularity, radiating outwards from the pulp cavity, and terminating by anastomosing with neighbouring tubes, forming squarish-ended loops towards the surface of the dentine. Owing to this flattening of the ends of the loops and to the tubes all stopping short at the same distance from the surface, an outer layer of dentine into which no such tubes penetrate is sharply marked off (*d* in fig. 1).

No fine dentinal tubes are given off from these canals, which do, however, here and there give off quite short prolongations of smaller calibre; these are not, either from their size or frequency of occurrence, of much importance.

But the point of greatest interest about the teeth of the Hake is the nature of the contents of these larger tubes. *Each tube contains a capillary blood-vessel*, and *nothing else;* the thin wall of the capillary being in actual contact with the hard dentine of the completed tooth, and no other soft tissue being interposed. In fact, the tubes in the dentine are just the size of the capillaries of the pulp, and red blood is circulating through the capillaries enclosed in the dentine when the tooth is in use, just as it might be circulating in the capillaries of the pulp prior to its calcification. Thus blood is brought close to the surface of the dentine, and this, with the abundance of the tubes, it is that gives to the tooth of the living or freshly-killed Hake its brilliantly red colour.

* Namely, the Cod (*Gadus morrhua*), Haddock (*G. æglefinus*), Whiting (*Merlangus vulgaris*), Coalfish (*M. carbonarius*), Pollack (*M. pollachius*), Hake (*Merlucius vulgaris*), and Ling (*Lota molva*).

† They are often, owing to a fact respecting their attachment to be presently described, supposed to form a single row only.

This is well seen in fig. 2, which is a section of dentine cut with a sharp knife from the tooth of a Hake within a couple of hours of its capture. From the edge of the dentine there hang out (at *cp*) torn capillary vessels, from the ends of several of which hundreds of blood corpuscles were slowly flowing out as I was making my drawing. The section was also sufficiently thin to allow of the blood corpuscles contained in the capillaries within the dentine to be distinguished through its substance, as is seen in the figure.

This dentine may therefore be most appropriately called VASO-DENTINE, and no better name could be found by which to designate it; but I confess myself unable to see what useful purpose can be served by the rich vascularity of the dentine; it would seem improbable that the dentine should need nutriment, for the teeth of the Hake, like those of most fish, are obviously frequently shed off and renewed, and there are five or six teeth in preparation for every one that is in place and at work. And this rich plexus of capillaries is the less intelligible as the intervening dentine is of unusually dense and impermeable structure, and, one would think, was as little in need of vascular supply as anything which remains in continuity with a living organism could well be.

In the clear external layers of dentine a very faint striation perpendicular to the surface can be made out, but I have entirely failed to make out the existence of any thing like tubes in it, whether by the use of powers as high as a $\frac{1}{32}$nd objective, or by the endeavour to get coloured fluids to penetrate them. I am pretty well satisfied that no tubes exist, but that the indistinct striation is simply a result of the manner in which the tissue was developed, as will be presently described.

In addition to the markings just alluded to, there is a faint striation of the whole dentine in line, roughly speaking, parallel with its surface. Like the striation of the peripheral dentine, these lines probably do not represent any tube system; but may be due to successive depositions of calcified material on the interior of that already formed, and mark lines of growth.

A tooth which has been decalcified shows sometimes a tendency to split up along these lines, but although I have used a variety of processes and examined very fine sections taken in many planes, I cannot make out the existence of actual tubes in the interspaces of the large capillary canals. But the vascular canals are so close together that there is comparatively little interstitial tissue, and the nature of the dentine matrix may be more advantageously studied in the teeth of other Gadidæ, such as the Cod, in which the vascular loops are not quite so close to one another, and in describing the teeth of that genus I shall recur to this matter.

The pulp of the tooth of a Hake is, like its dentine, remarkable for its vascularity; at first sight it appears to consist of nothing whatever besides blood-vessels and odontoblast cells, the latter being upon the surface. More minute examination reveals the existence of a very delicate connective tissue binding it all together, but the great bulk of it really does consist of blood-vessels.

If the pulp be withdrawn from a tooth, and slightly teased out, capillaries filled with blood and clothed upon their surfaces with odontoblast cells may be abundantly found; the odontoblast cells are apparently seated directly upon the capillary, no connective tissue nor other cells intervening (see fig. 7); by the calcification of these odontoblasts the capillary vessel would obviously become closely embraced by hard dentine.

And this is a strong argument in favour of what is known as the "conversion theory" of the development of dentine; supposing these odontoblasts to be calcified and themselves converted into dentine, there is no difficulty in seeing how the capillary comes to be enclosed in a tube of dentine having the same calibre as itself. But if the odontoblast cells "secrete" the dentine, as maintained by HERTZ and others, how is the process to be completed when there is no longer room for an entire odontoblast or the half of an odontoblast between the rigid wall of already formed dentine and the capillary? One can hardly conceive a secreting cell going on shedding out from its end its secretion when it has been reduced to, say one-tenth, of its length; and unless one is prepared to accept such a conception, this observation of the structure of a Hake's tooth-pulp becomes fatal to any "secretion" hypothesis of the formation of dentine.

There is not much difficulty in procuring sections which show the relations of the pulp and the dentine *in situ*, if the teeth and their contents be hardened and decalcified in chromic acid; I have found immersion in $\frac{1}{3}$ per cent. solution for ten days to be effectual in decalcifying them sufficiently to enable sections to be cut with a razor, and much longer treatment with the acid decidedly injures the pulp tissues. A transverse section prepared in this way is represented in fig. 4; in cutting the sections the pulps have been to a slight extent dragged away from the dentine, but this is rather an advantage than not, as it renders the figures clearer than they would otherwise be.

In fig. 4 several capillaries (*cp*) are seen stretching across from the pulp and entering the substance of the dentine, each one fringed with its layer of odontoblast cells; in the axial portion of the pulp are seen the cut ends of the numerous blood-vessels which make up so large a part of its bulk. In fig. 9 the distribution of the odontoblast cells is also seen; they clothe the whole surface of the pulp, and where there is a capillary at the surface they clothe it, so that when they calcify the capillary becomes solidly embedded in dentine.

The capillary plexus does not extend quite to the surface of the original formative pulp, so that the outermost layers of the dentine are formed from the continuous sheathing of odontoblasts which invests the pulp, and hence contain none of the larger capillary canals. A portion of the thin decalcified dentine cap taken from a tooth-sac in which calcification had only just commenced is shown in fig. 6. It will be seen that the rods, so to speak, of dentine formed from the several odontoblast cells have not entirely coalesced, and show a tendency to separate from one another;

this explains the appearance of faint striation in the outer layer of dentine, in which nevertheless no tubes nor real interspaces exist.

Some isolated odontoblast cells are shown more highly magnified in fig. 5; the constrictions in their middles are due to the shrinkage caused by absolute alcohol, the end next to the dentine (*q*) being apparently too rigid to shrink, and the presence of the oval nucleus preventing shrinkage at the opposite extremity; examined in serum they are of uniform diameter.

The odontoblasts of the Hake measure about $\frac{1}{800}$th of an inch in length and $\frac{1}{6000}$th of an inch in diameter; they are, after calcification has once commenced, furnished with a variable number of fine processes at the end next to the dentine, which project for a little way into it; but they do not remain permanently uncalcified, like the dentinal fibres of Mammalia. The opposite end of the cell tapers off into a fine process, but I have never detected lateral processes connecting them with their neighbours. The nucleus is oval, very distinct in some of the cells, but sometimes indistinguishable; I have been unable to discover under what conditions this is the case. I have described the structure of the tooth of the Hake at some length, because I am not acquainted with any description of it in the pages of writers on odontology, nor with any other tooth which so clearly exemplifies the true nature of this kind of vaso-dentine. But before proceeding to remark upon the teeth of certain other Gadidæ, I will quote RETZIUS' description of the dentine of the Ling.

As quoted by NASMYTH ('On the Teeth, 1839,' p. 107,) RETZIUS thus described the dental tissues of the Ling:—"Along the wall of the cavity of the pulp, which ran longitudinally, and was in part tubiform, the main tubes opened with short trunks of from $\frac{1}{50}$ to $\frac{1}{70}'''$ p.m. ($\frac{1}{550}$th of an inch, about) in thickness, which ran towards the apex and in an outward direction, and gave off branches on both sides, between which there were considerable intervals; these branches formed, with others of the contiguous tubes, large loop-shaped anastomoses, and their outer extremities entered also into closed anastomoses, *almost like the more minute blood-vessels in the villi of the abdominal canal.*"

"The more minute lateral branches of the tubes of the dental bone in the Ling were not easily discovered; they appeared to be less regular, and generally ran in a direction transverse to the tubes from which they rose, or parallel to the axis of the tooth."

From the passage which I have italicised, it will be obvious that RETZIUS suspected the true nature of the contents of the larger canals which permeate the tooth of the Ling, and Professor OWEN's name of vaso-dentine would imply the same interpretation, but the latter's more detailed description does not confirm the supposition that he believed the tubes to be occupied by capillaries and capillaries alone.

Thus he writes of the dentine of the Gadidæ:—"Processes of the pulp are conveyed by medullary canals which diverge from all parts of the main central cavity into the substance of the dentine; these are about $\frac{1}{600}$th of an inch in diameter at their origin, but they quickly divide, and their branches form anastomoses with those of the neighbouring tubes; the loops thus formed by the smaller terminal branches constitute a well-defined boundary between the coarse central and the fine external dentine.

"In this latter the calcigerous tubes, which are about $\frac{1}{15000}$th of an inch in diameter, proceed as usual, parallel to each other and parallel to the axis of the tooth at its apex, but transversely to that axis at its sides" ('Odontography,' p. 163).

The tooth of the Cod differs in some particulars from that of the Hake, so that it may be worth while for me to briefly describe its structure.

Cod (*G. morrhua*).—The teeth are not so slender as those of the Hake, and they are more solid, the pulp being smaller relatively to the size of the completed tooth. Just as has been described in the case of the Hake, the dentine of the Cod is permeated by a system of canals about $\frac{1}{2500}$ in diameter, which form loops and anastomoses with one another, just as do the capillaries of the pulp prior to the commencement of calcification around them. These tubes contain, in the fresh condition, capillary vessels in which blood circulates; in fact the only difference between the dentine of the Cod and that of the Hake lies in the arrangement of the capillary channels, which are less abundant in the dentine of the Cod, and form loops with rounded instead of with flattened ends, so that the boundary of that external layer of dentine which is not permeated by the tubes is less sharply pronounced. In a longitudinal section there is faint striation running in the long axis of the tooth or rather parallel with its surface; this is to be seen in all parts of the tooth, but the striation is most pronounced near to the base.

Under a high power this appears (in longitudinal sections) like parallel tubes, about $\frac{1}{30000}$th of an inch in diameter, but they do not start either from the pulp cavity or from the vascular canals, and there is an exactly similar appearance in the bone which supports the tooth (*c* in fig. 25).

No coloured solution can be induced to enter them, even by boiling the thinnest sections in it, or by placing the sections immersed in the fluid under the receiver of an air-pump and exhausting the air as completely as possible. Nothing can be seen of tubes in transverse sections, and their direction is parallel to the long axis of the tooth, so that, if these striæ are tubes, they are at right angles to the ordinary course of dentinal tubes, and at right angles to the long axes of the formative odontoblast cells.

But the most conclusive evidence as to their not being the representatives of the dentinal tubes of other creatures is derived from an examination of the teeth of some members of another family, viz., the Pleuronectidæ. In this family the teeth are composed of vaso-dentine of the same type as that possessed by the Gadidæ, with this difference, that at their apices the dentine is poor in vascular canals, but is permeated by an abundance of true dentinal tubes. Passing downwards from the enamel-tipped apices of the teeth the vascular canals become more and more abundant, and the dentinal tubes become fewer and fewer, irregular in course, and finally one third of the way down altogether cease (see fig. 10*). But the lower portion of the dentine which is devoid of dentinal tubes presents the longitudinal striation, and is, in fact, precisely like the dentine of the Gadidæ. And at the point where the dentinal tubes are few in number (*t* in fig. 10*), the longitudinal striation is traversed by transverse dentinal tubes, thus proving by the co-existence of the two that they are due to different and independent causes.

I cannot therefore confirm the opinion of RETZIUS and Professor OWEN, that the whole tooth substance of the Gadidæ is permeated by a minute tube system: on the contrary, I believe it to be quite solid.

But although it is solid the matrix of the dentine is not quite homogeneous; in transverse section very faint striæ radiate outwards from the pulp cavity, and the spaces between the striæ (the distinctness of which has been intentionally slightly exaggerated in fig. 7) are mapped into a finely reticulate pattern.

Under a higher magnifying power this pattern is found to present the appearance shown in fig. 3, and as this appearance is found alike in transverse, longitudinal, and oblique sections, it is probable that it is due to calcification first taking place in such manner as to form isolated globules (as indeed happens to a greater or less extent in all varieties of dentine), and to these globules failing to completely coalesce but becoming modified in form by mutual apposition.

That that is the true interpretation of the nature of the pattern is indicated by the occasional occurrence of globules which have not been thus distorted, but retain their spherical form, and also by the appearance of fine reticulation in the dentine of the teeth of allied fish, such as the Pleuronectidæ.

The pulp is less rich in blood-vessels and far more rich in connective tissue than that of the Hake; otherwise, it does not call for any special description. On its surface the odontoblast cells form a very distinct layer about $\frac{1}{500}$ of an inch in thickness, and capillary vessels may be seen running out from the pulp through the odontoblast layer into the dentine (see fig. 9). But I have never seen capillaries clothed with odontoblasts like that of the Hake represented in fig. 7, though this may be due to my never having examined a Cod-fish so freshly caught as was the Hake from which fig. 7 and fig. 2 were drawn.

The dentine in the Haddock, Whiting, Coalfish (*Gadus carbonarius*), Pollack, and Ling, does not differ in essential particulars from that of the Cod. The frequency, size, and the form of the capillary loops vary, so that anyone well familiarised with their respective appearances might probably succeed in identifying them, but the differences are in minor points, and the structure of the matrix is similar in all.

In all of them we have the same essential features, the penetration of actual hard dentine by capillary vessels, and the absence of true dentinal tubes.

But although I have not found the dentinal tubes in any of the Gadidæ which I have examined, and although their absence is the rule in this modification of dentine, no mention of this peculiarity can be made in a definition of vaso-dentine, as in the teeth of Pleuronectidæ, which are obviously of the same type of structure, the dentinal tubes exist near to the tip of the tooth, as seen in fig. 10.*

And although, as a rule, the outermost portion of the dentine is dense, and is not permeated by the vascular canals, this dense external layer is not found in all such teeth. For instance the teeth of *Ostracion* (fig. 10) are composed of this vaso-dentine, but the vessels extend right up to the surface of the dentine, and the thick and strongly coloured enamel which clothes their teeth takes the place of the dense dentine of the surface. The transition between vaso-dentine of the type just described, and the ordinary hard dentine of Mammalia teeth is tolerably gradual. Thus in the Pleuronectidæ (fig. 10*) we have a tooth the apex of which is composed of hard unvascular dentine with true dentinal tubes, whilst its lower two-thirds have abundant vascular capillary canals, but no dentinal tube. In *Serrasalmo* (fig. 11 and 11*) we have a tooth the upper half of which consists of ordinary (at least for the present purpose ordinary) fine tubed dentine, and in it the dentinal tubes permeate the dentine of the base as well as that of the upper portion of the tooth.

But near to the base of the tooth there are a few capillary canals; by the suppression of these we should get ordinary unvascular dentine. The interpolation of capillary tracts in dentine is not unknown amongst Mammalia; thus it is found in the Megatherium, in the Tapir, and in the Manatee, though whether red blood really does circulate through them in the completed tooth is not definitely ascertained. From this variety of dentine, most appropriately called Vaso-dentine, the relationship of which to unvascular dentine has been shown, we pass to the consideration of a very distinct variety, which although hitherto universally known as vaso-dentine, has in reality very little relationship to that tissue.

Of the teeth of the Pike, RETZIUS (as quoted by NASMYTH, 'On the Teeth,' 1839, p. 104) says, "The dental bone itself in the Pike is properly divided into an internal kernel provided with large tubes, and into an external thinner part, which latter forms the covering of the first, and contains minute and parallel tubes. The large main tubes which occupy the internal more imperfect part of the dental bone, are in their widest part about $\frac{1}{85}$ p.m. ($\frac{1}{900}$ of an inch) in diameter. They run almost parallel with each other, and with the axis of the tooth, and form with each other numerous larger and smaller anastomoses.

"Near the base of the firmly fixed teeth, the larger transverse anastomoses are so near to each other that the interstices are scarcely as wide as the diameter of the large tubes. In some few recent teeth these tubes contained here and there a blood-red substance, and may hence be regarded as divisions of a cavity of the pulp.

"Here, too, those (larger tubes) which are near to the apex run almost parallel with the axis of the tooth; but those which are nearest the root transversely to it, and so on. They divide at their commencement into bundles of larger and smaller branches, which enter into numerous reticular anastomoses with each other, but which most externally give off very beautiful, close, parallel, generally straight tubes of about from $\frac{1}{1500}$ to $\frac{1}{2000}$ p.m. ($\frac{1}{23000}$) of an inch in breadth;" amongst the latter RETZIUS could discover neither branches, anastomoses, nor cells.

"This most external stratum of dental bone gives to the transverse sections of the tooth of a Pike a peculiar and pretty appearance, and resembles, slightly magnified, a layer of enamel.

"This minutely tubular external portion of the dental substance is of the purest white, and is also much harder and more compact than the interior of the dental bone. To judge by the hardness of the surface in dried teeth, RETZIUS would have concluded that it was invested with an extremely thin layer of enamel; but he could not detect any with the microscope, although accurate authors have asserted that it is present on teeth of the Shark."

Professor OWEN adds nothing to RETZIUS' description—there is, in fact, little to be added, as it is both accurate and comprehensive. But as I wish to emphasize the points of difference between this and the vaso-dentine just described, I will add a few words to it.

Dentine of the Pike.—Both in its structure and in its development this differs markedly from the form of vaso-dentine first described; in fact it is a misnomer to call it vaso-dentine at all. The dentine is divisible for descriptive purposes into two portions: an outer which is permeated by numerous fine tubes perpendicular to the surface, like the tubes of ordinary unvascular dentine, and an inner which is of much coarser structure and is permeated by large irregular spaces having a general longitudinal direction (see fig. 13).

The tubes of the outer layer are parallel and end apparently short of the surfaces; they are about $\frac{1}{20000}$ in diameter.

They spring, through the intervention of short branches of intermediate size, from the larger spaces of the coarse core of the tooth (see fig. 14). These latter form longitudinal canals of varying diameter and irregular form; they give off from their sides and ends branches which abruptly subdivide and become small; at the point where these merge into the fine dentinal tubes of the exterior they lose their tubular form and are dilated into irregular spaces of small size, like small bone lacunæ or the interglobular spaces of the granular layer of human dentine. From these spaces originate the dentinal tubes (see fig. 14).

There is thus a strongly marked difference between the dentine of the Pike and that of the Gadidæ, even when the structure of the hard tissues of the tooth alone is considered, but the distinction between the two varieties becomes yet more marked when the relation of the soft parts to the dentine is also taken into account.

For the larger longitudinal canals of the Pike's tooth do not, except as a matter of accident, contain capillary blood-vessels; that is to say, the dentine as it is formed is not deposited round capillaries, so as to enclose them within itself, and hence very few of the channels do contain capillaries; when they do, the capillary only forms a part and not the whole contents of the tube. In the fresh condition the channels of the dentine contain a firm cellular tissue, not unlike that which forms the bulk of most tooth pulps, but it is exceptional for it to be rich in vessels.

The nature of the contents of the channels will be best understood by following out their development.

Of the development of the Pike's tooth Professor OWEN ('Odontography,' p. 133) tells us "that the formation of a tooth is an act of conversion of the substance, and not of cells upon a formative surface of the pulp, is clearly illustrated in the Pike. The cone-shaped cap which the half-developed tooth forms upon the remaining matrix can only be removed by overcoming a certain resistance, and this resistance is seen to be due to the processes of the pulp which extend into the medullary canals of the tooth; the broken ends of these processes give an irregular surface to the exposed pulp, and their continuation into the tooth may be seen by sawing the latter across. This connection between the substance of the tooth and of the pulp is still better seen in a finely injected specimen; the mechanical relation between the tooth and the pulp is then seen to be of precisely the same kind as those between an ordinary osseous nucleus and the cartilaginous matrix in which it is developed; it is in the course or direction of development that the chief difference exists; in the tooth it is centripetal, in the bony epiphysis centrifugal, but the mode of development is the same."

An early dentinal pulp from the jaws of a Pike does not present any special peculiarity; it is a conical mass of richly cellular tissue, the surface of which is covered as by an epithelium, with a layer of larger elongated cells, which do not form so distinct and sharply defined a layer as the odontoblasts of most dentinal pulps. By the calcification of these the exterior layer of fine tubed dentine is formed in the ordinary way, and presents no peculiarities worth description. But no sooner is the thickness of this outer layer (*f* in figs. 13 and 14) completed, than the nature of the process of calcification becomes profoundly changed; the remainder of the dentine is not formed by the calcification of the more or less defined layer of cells corresponding to the "membrana eboris," but by an extension of calcification through the mass of the pulp in a manner to be presently described. The surface of the pulp in immediate contact with the dentine already formed is no longer clothed with a continuous layer of odontoblasts, but the cells which are near to the surface become aggregated into masses, between which there appears an almost structureless transparent tissue, which then forms trabeculæ shooting from the dentine into the substance of the pulp between the cellular aggregations. Calcification follows very close on the heels of the formation of this tissue, and a longitudinal section of a pulp at this stage (see fig. 15) shows the extent to which the whole mass of the pulp becomes penetrated by these calcifying processes. Their course as they run down into the pulp is not at all determined by the position of the capillaries, in which the pulp is not rich; on the contrary, they extend in almost straight lines from the dentine already formed down into the pulp, and subsequently become connected with one another by cross branches. The canals of the completed tooth are the spaces left out by and included between these tracts of calcification; the contents of the canals are the masses of pulp so enclosed.

If the calcifying dentine of one of the Gadidæ be compared with this of the Pike, it will be seen that the internal surface of the former to which additions are being made is smooth and of even outline (see fig. 4 and fig. 9), whereas the internal surface of the latter is extended out into a large number of greatly elongated processes. This is well seen in the transverse section represented in fig. 16*. In fig. 16 the ends of one or two of the processes to which additions are being made are represented. The growing surfaces are found to be covered with a layer of nearly spherical cells, like the osteoblasts by which bone is built up; but there are no elongated cells, such as are ordinarily called odontoblasts, to be found. In fact, viewing the tooth of the Pike from the point of the minute development of its constituent parts, it might not inaptly be described as consisting of a core of porous bone coated over with a thin skin of dentine, and, had not the name osteo-dentine been somewhat loosely applied to other tissues than this, no more fitting term by which to designate it could have been found. The teeth of those PLAGIOSTOMI which have been examined by HERTWIG and by myself are developed in a manner precisely similar, as might be expected from their structure.

Thus far I have sought to distinguish from amongst the tissues hitherto indiscriminately classed as vaso-dentine two strongly marked varieties.

(1.) A dentine formed wholly by calcification of a layer of special odontoblast cells, and permeated by a system of canals formed around and enclosing capillary blood-vessels.

To this variety I would apply, and to it strictly limit, the application of the term VASO-DENTINE.

(2.) A dentine formed at its surface only by a cellular layer, its interior being formed by the extension of calcifying trabeculæ through the substance of the pulp. It also is permeated by larger channels, but these bear no relation to capillary blood-vessels.

To this variety I would limit the application of the term OSTEO-DENTINE.

There is at least one other way in which the structure of dentine may become complicated, and in which it may come to contain a system of channels larger than dentinal tubes. The formative pulps of the two varieties of dentine to which I limit the terms vaso-dentine and osteo-dentine are simple cones, but the surfaces of the pulps themselves may be complicated by various folds and inflections, so that by their calcification a complicated looking tissue results.

As an example of this I have figured the transverse section of a tooth of *Lepidosteus osseus*, which I was so fortunate as to procure in chromic acid solution (fig. 12).

In this the complication of the tissues is due to complication in form of the formative pulps; the whole of the dentine is formed by the calcification of odontoblasts, thus contrasting with that of the Pike, which is formed from a *simple* pulp by an irregular calcification running through its substance, and which is only in very small part formed from odontoblast cells.

Dentine which has been formed from a convoluted pulp may attain to great complexity of structure, as happens in the *Labyrinthodon*, or the sub-division of the formative pulp may result in the production of a tooth which might be regarded as an aggregation of denticles, as happens in the *Myliobates*.

But although in this way considerable variety is arrived at, and the tissues bear a more or less close resemblance to osteo-dentine, yet there is one character which will generally serve to distinguish these from it.

Each of the larger canals in the completed tissue forms an axis from which dentinal tubes radiate with some degree of regularity, these dentinal tubes having resulted from the calcification of the layer of odontoblasts with which each subdivison of the formative pulp was clothed ; whereas, in osteo-dentine, like that of the Pike, no such distinct and regular systems of dentinal tubes radiate from the larger canals.

The true character of dentine derived from a convoluted pulp is not badly expressed by the term PLICI-DENTINE, already applied by Professor OWEN to some examples of this structure, and it would embrace dentine of every degree of complexity, from that of such teeth as those of the *Lepidosteus*, which are simple in their apices and not very greatly complicated at their bases, to such as those of the *Labyrinthodon*.

An exceedingly instructive modification of dentine structure is to be found in the teeth of the Sparidæ, of which I have examined *Sargus ovis*, *Chrysophrys* ——(?), and *Pagellus*.

The manner in which their teeth are supported is very curious ; if a longitudinal section of a front tooth and the bone beneath it of *Sargus* or of *Chrysophrys* be very carefully made (the tooth is easily broken off at the level of the bone, and the section can only be made by a skilled hand with a lapidary's wheel), it will appear to the naked eye as though the tooth were furnished with a long root, half as long again as its crown, implanted in a socket of bone to which it is anchylosed ; whilst at its upper part this "root," if such it can be called, is sharply defined, at its lower end or apex it merges into the surrounding and subjacent bone.

It has already been incidentally mentioned that the tooth readily breaks off at the level of the surface of bone, easily parting from its implanted portion ; if a section such as that described be rubbed down and examined microscopically, it will be found that there is a rather abrupt change of structure at the point alluded to. The outstanding portion or crown of the tooth (*d* in fig. 23 and 24, Plate 3) is composed of hard fine-tubed dentine coated with enamel ; the implanted portion (*d′* in same figures) of vascular dentine. The pulp cavities of the two segments of the tooth are continuous and of the same diameter, and so are the walls of dentine (in fig. 17, the pulp cavity of the implanted portion is not shown, because the section is oblique, and does not pass truly along the long axis of the tooth). In tracing the development of the teeth, I find (in the case of *Sargus*, the only one which I have been able to procure fresh, or preserved from the first in chromic acid) that the exserted and implanted portions of the teeth are alike developed from the same dentinal pulp (see *k* in fig. 23), and, what is somewhat remarkable, I cannot detect any difference in structure between that upper portion of pulp which is engaged in forming hard dentine, and that lower portion which is building up vaso-dentine, save only that this latter part is more richly vascular. Why the pulp should at a particular point cease to form "hard" dentine, I cannot see; possibly had I been successful in making an injection, which I attempted, but failed in effecting, the distribution of the vessels might have explained it.

In the implanted portion, near to the point where the change takes place (see figs. 19 and 20), the pulp is furnished with odontoblasts, and the dentine formed is the vaso-dentine with a few true dentinal tubes, the large channels being the spaces left for and occupied by capillaries. Lower down no dentinal tubes occur, and the dentine presents the appearance represented in fig. 21, whilst in a fully completed tooth we find near to the end of the root the shell of vaso-dentine (*d'* in fig. 18) becoming thinner and thinner, whilst instead of its surrounding a central pulp chamber, this latter is blocked up by a coarsely reticulated calcified tissue (see also base of the left hand tooth in fig. 23). It is hard to say where the tooth ends, for the vaso-dentine thins out to nothing, and the coarse bone of the axial portion merges into that which surrounds and underlies the tooth, and serves to secure it by anchylosis to the walls of its socket (*c* in fig. 23 and 19). In the development of these teeth we have therefore a single dentinal pulp which at its apical part forms true or hard dentine; at a certain point it changes somewhat abruptly, and forms vaso-dentine, and then by more insensible gradations its axial parts, and finally its whole base, change their manner of calcification, and become converted into an osteo-dentine which blends insensibly with that coarse bone which is being formed outside the limits of the tooth pulp. No other tooth with the development of which I am acquainted shows with the same clearness as the tooth of *Sargus*, the relation of these several tissues to one another and to bone.

It appears to me exceedingly undesirable to multiply names, so in the place of doing so, I would suggest merely rendering more precise and more limited the meaning attached to the terms VASO-DENTINE, OSTEO-DENTINE, and PLICI-DENTINE, to the latter of which, however, a more extended application than it has hitherto had must be given.

To summarise the result of the foregoing observations, we should distinguish four varieties of dentine, to be thus described :—

I. HARD UNVASCULAR DENTINE; a tissue wholly developed from the odontoblast layer of the dentinal pulp, and permeated by a system of dentinal tubes radiating from a central pulp chamber. Example; Human Tooth. This passes through gradational forms, such as that met with in the Serrasalmo (fig. 11*) and the Flounder (fig. 10*), into typical

II. VASO-DENTINE; a tissue without true dentinal tubes, although it is wholly formed from the odontoblast layer of a simple pulp. It is abundantly permeated by tubes of larger calibre formed by the enclosure of, and containing, capillary blood-vessels. Example: Tooth of Hake.

Hard unvascular dentine derived from the calcification of a pulp of simple form, passes through gradational forms in which the bone of the tooth is fluted as in *Lepidosteus* (fig. 12) into

III. PLICI-DENTINE; a tissue with true dentinal tubes, which is derived from the calcification of a pulp, the odontoblast-carrying surface of which has been rendered complicated by infoldings of its surface. Example: Tooth of *Labyrinthodon.*

And lastly, we have typical

IV. OSTEO-DENTINE; a tissue devoid of true dentinal tubes (save in the form of a layer of hard dentine upon its surface) and derived from a calcification shooting through the whole substance of the formative pulp, so that it is not derived from a specialized odontoblast layer at all. The larger tubes do not contain capillaries, and its only complete distinction from bone lies in the fact of its development in a dentinal pulp, but not in the manner of that development. It is so closely akin to bone that the tooth of a Pike might be not inaptly described as a conical core of bone, furnished with a thin skin of hard dentine.

In the foregoing definition of osteo-dentine it may be noticed that no mention is made of the two characters by which Professor OWEN sought to distinguish that tissue, viz. the arrangement of the matrix in concentric rings around the vascular canals, and the presence of lacunæ similar to those of bone. These characters have been intentionally omitted for several reasons; the one, that there are many teeth the dentine of which I would, both from its development and its structure when perfected, class as osteo-dentine, in which neither of these characters is to be found, as, for example, the teeth of the Pike; another, that a concentric arrangement of the matrix around the canals is to be met with in vaso-dentine sometimes, and that lacunæ, or at all events spaces very similar in character, occur in dentine that no one would class as osteo-dentine; whilst lacunæ are absent both from bones and teeth in many fish whose teeth must, if my classification by developmental characters be adopted, be considered as consisting of osteo-dentine.

But although these are adequate grounds for leaving them out of the definition, it may save misapprehension to add that a laminated arrangement of matrix, and spaces similar to bone lacunæ, are, as might be expected, more commonly met with in the osteo-dentine than in any of the other forms of dentine.

When I commenced the examination of the teeth of Gadidæ, my object was not so much to investigate the nature of vaso-dentine, as to endeavour to ascertain how far minute structure was constant within the limits of a well-defined group. Unfortunately I have not as yet obtained materials sufficient to enable me to carry out my original purpose, to which I hope at a future time to recur, but I may here briefly indicate one or two of the facts which I have ascertained which bear on this question.

So far as I have been able to ascertain by an examination of the teeth of such Gadidæ as I could procure, true vaso-dentine, tipped with a spear-point of enamel, constitutes the teeth of all of the family. In the Pleuronectidæ we find the same thing, viz. true vaso-dentine tipped with a point of enamel, but the teeth (fig. 10*) at their apices hardly differ from unvascular dentine, while their bases are typical vaso-dentine. This structure, the true dentinal tubes being in greater or less abundance at the apex, exists in the teeth of the Pleuronectidæ commonly used as food. On the whole we might conclude that, so far as minute structure goes, the teeth within the limits of these two families are of one type. A similar agreement in minute structure is met with in *Sargus*, *Dentex*, *Pagellus*, and *Chrysophrys*. But one type of minute structure does not run throughout larger groups, such as Orders, thus for example, amongst PHYSOSTOMI the Eels have hard unvascular dentine : some Siluroids have true vaso-dentine ; *Serrasalmo* has hard dentine, at its base merging into vaso-dentine (fig. 11*), and the Pike has osteo-dentine.

And great divergence in minute structure may be found within an Order which comprises far fewer genera than the PHYSOSTOMI.

Thus amongst PLECTOGNATHI, *Ostracion* (fig. 10*) has a tooth composed of vaso-dentine quite devoid of dentinal tubes, while *Balistes* has teeth composed of hard unvascular dentine ; the teeth of *Gymnodonts* also are built up of unvascular dentine.

The subject is, however, too large a one for discussion in this paper, and the exceeding small number of fishes' teeth examined as compared with the vast number of genera and species comprised in the class, may well make a writer diffident in expressing any opinion as to the relation between minute structure of the teeth and general affinity.

Note on some Peculiarities in the Attachment of Teeth in the Gadidæ.

In the course of investigating the development of vaso-dentine in the teeth of the Hake, I became acquainted with some facts as to their attachment, which are in themselves so interesting that, although not quite relevant to the subject matter of the rest of my paper, I venture to append a short note describing them. That the predatory angler (*Lophius piscatorius*) was furnished with large teeth set upon an elastic hinge, so that they may be bent inwards towards the gullet, and when relieved from pressure at once spring up again, has long been known.

But I had not met with any mention of the teeth of the Hake, or indeed of any other fish, except Anableps and Pœcilia, being similarly attached to the bone which carries them.

Round the margins of the mouth, both in the upper and lower jaws, the teeth, which are sharply pointed and slightly recurved, are arranged in a *double* row. The outer row are strongly anchylosed to the bone ; the inner row are attached by an elastic hinge upon the inner sides of their bases, and are free on the outer side. They admit therefore of being bent inwards into the mouth, but they cannot be displaced outwards, and so soon as pressure is removed from them, they spring back into the upright position.

In the *Lophius* the outer row of (anchylosed) teeth in the lower jaw are insignificant in size as compared with the large hinged teeth, but in the Hake the disparity is not so great. The inner row in the latter fish are however much longer than the outer row and stand higher, and it is easy to see the benefit which a fish of its voracious habits, feeding amidst shoals of herrings, would derive from the mobility and elasticity of its longer teeth. In the dashes which it makes at its prey, if the latter were struck by fixed immovable teeth, either the herring would be thrown out of the way or the teeth broken; but with the elastic hinge with which they are furnished they would give way, the herring enter the mouth of the Hake, and the teeth resume their upright position.

However, not only are they movable, but they are in several ways modified so as to adapt them to this unusual condition. In fig. 26, Plate 4, one of these teeth is shown in a section transverse to the jaw; at the inner side its base is prolonged far below the outer side, and terminates in a thin edge, the elastic ligament being attached to this edge and to the outer surface of the tooth for some distance up its side, embracing rather less than half the periphery of the tooth.

The ligament is composed chiefly of waved fibres of elastic tissue, and returns the tooth to its upright position instantly when the pressure by which it was bent down is taken off. It is attached to a rugged surface of bone below, its surface of attachment upon the bone being much larger than that upon the tooth, so that it is somewhat fan-shaped, and it is perforated to give passage to the nutrient vessels of the pulp.

The tooth, as will be evident from an inspection of fig. 26, is sufficiently firm under a vertical pressure to make it serviceable as a piercing instrument, whilst it at once yields to an inward pressure.

The opposite or outer side of the base of the tooth is quite free, and in no way bound down to the bone beneath it, and instead of terminating in a thin edge, it is much thickened (see *d'* in fig. 26), especially on its internal aspect, so that it encroaches upon the pulp cavity of the tooth.

This thickened strengthened portion of the base of the tooth is received upon a sort of buttress of bone, which is built up to receive it, and the tooth abuts directly upon the bone, nothing in the way of a cushion being interposed. An inspection of the figure (fig. 26) will show at a glance that it would be impossible, without tearing or greatly stretching the ligaments, to bend the tooth outwards, whilst there is nothing beyond the elasticity of the ligament to prevent its bending inwards towards the mouth.

I had always wondered what became of the pulps of the movable teeth of the *Lophius* when its teeth were bent down, and had imagined it to be probable that the vascular formative pulps had withered or undergone some form of degeneration prior to the teeth coming into use. But in the Hake, at all events, such is not the case ; these movable teeth, capable of being, without injury, bent down to an angle of 60° with their normal position, are furnished with richly vascular pulps to the last.

The blood-vessels (v) enter the pulp through a perforation in the ligament (see fig. 27) at a point which undergoes little or no change of position when the tooth is moved, and the pulps have no connection with the parts subjacent, except in the immediate neighbourhood of the ligaments ; and no blood-vessels enter it from below, as is usually the case in other tooth pulps.

When the tooth is bent down the pulp is therefore carried with it, and is lifted up from the bone beneath it, but no strain is put upon any part of it.

From the foregoing description it will be seen that the hinged teeth of the Hake have attained to an high degree of specialisation, and have in this matter of attachment attained to a close similarity with the teeth of *Lophius*, to which in structure they do not bear the smallest resemblance. Moreover the *Lophius* is an acanthopterous fish and the Hake one of the Gadidæ (PHYSOSTOMI), so that they are sufficiently remote from one another. And as it was remarkable that one member of the family of Gadidæ should alone possess a structure believed to be very uncommon, I sought in other members of the family for any similar arrangement, and though I did not find it, I found what is of more interest, namely, what may be regarded as transitional steps towards its attainment.

Professor OWEN ('Odontography,' p. 162) says, "All the teeth are less firmly attached to the bones in the Gadoids than in other osseous fish with laniariform teeth. In the Cod-fish the gelatinous conical pulp after having formed the body of the tooth, is continued in an uncalcified state, but condensed into ligamentous firmness, from the base of the tooth to the alveolar margin of the jaw ; ossification then proceeds from the jaw along the ligaments towards the base of the tooth, which, however, rarely becomes anchylosed to the ossified ligaments. The teeth therefore of the Cod are generally detached in macerating the head, and the broad alveolar margin of the dentigerous bones is then covered by the ossified dental ligaments in the form of truncated cylinders of various sizes, the largest being the most external in the intermaxillary and the reverse in the premandibular bones."

It is thus well known that the teeth of the common Cod are not firmly anchylosed to the bone, so that they are often lost when the skull is macerated, being held in place by ligamentous fibres only. But it is not generally known, nor had I myself any suspicion until after examining the teeth of the Hake, that they (the teeth of the Cod) are normally possessed of a slight degree of mobility, and that they have sufficient resiliency to at once resume the upright position. Like the teeth of the Hake, they can be bent inwards towards the mouth, though only a very little way, and they cannot be bent outwards at all.

This is effected by the arrangement of bony support and ligament shown in fig. 25 ;

the inner side of the tooth extends to a lower level than the outer side, and is firmly bound down by dense ligamentous fibres (2 in fig. 25) to the bone beneath it.

On the opposite side, however, it is of different form; the dentine terminates in a sort of shoulder (2′ in fig. 25), which abuts upon a surface of bone shaped so as to fit it; to this it is bound down by a band of ligamentous fibres, but in such a manner as to allow of a certain small degree of motion, the extent of which will readily be appreciated by an inspection of fig. 25.

Thus in the Cod the outer side of the tooth, which was altogether free in the Hake, is so attached as to allow of slight mobility only. In other members of the family, *e.g.* the Haddock and the Coalfish (*Gadus carbonarius*), the base of the tooth is furnished with a similar sort of shoulder round its whole circumference, and by this it is fitted upon and into a short supporting cylinder of bone (see fig. 24).

This arrangement of course allows of practically no mobility whatever, and the Haddock, the Cod, and the Hake thus present three very instructive steps in the production of a highly specialised organ. The degree to which the little shoulder of dentine is fitted within the osseous cylinder beneath it varies much in different genera and species, but an attachment of this kind, completed by a few slight ligamentous fibres binding the parts together, may be taken to be the rule in Gadidæ and Pleuronectidæ.*

Description of Figures.

a. Enamel.
b. Vascular dentine.
c. Bone of jaw.
c′. "Bone of attachment."
c″. Specialised buttress of bone of attachment.
d. Hard dentine.
d′. Modified vascular dentine.
e. Formative cells of enamel-organ.
f. Finely tubular dentine in osteo-dentine tooth.
g. Large canals of osteo-dentine.
h. Calcifying trabeculæ—osteo-dentine.
i. Osteoblast cells.
k. Cellular tissue external to developing tooth (fig. 23 only).

* Since the foregoing paper has been in the hands of the Royal Society, I have found that the teeth in certain parts of the mouth of the common Pike are hinged; a description of the mechanism by which they are attached, which is very remarkable, will be found in the 'Quarterly Journal of Microscopical Science,' January, 1878.

l. Elastic ligament which attaches the Hake's and Cod's teeth.
o. Odontoblasts.
p. Formative dental pulp.
p′. Empty pulp chamber.
cp. Capillary blood vessels.
v. Artery entering pulp.

The lettering is the same in all the figures.

PLATE 3.

Fig. 1. Anchylosed tooth, consisting of vaso-dentine tipped with enamel. Longitudinal section. *Merlucius vulgaris* (Hake).

Fig. 2. Fragment of fresh Vaso-dentine from a Hake just caught, × 100. Capillary blood-vessels hang out from the edge of the dentine, and blood corpuscles are pouring out in abundance from one of the vessels.

Fig 3. Portion of dentine of Hake between the vascular canals, × 600. Longitudinal section. The matrix is not homogeneous, but looks as though made up of coalesced globules rendered somewhat angular by mutual apposition.

Fig. 4. Sections of dentine and surface of the pulp, the latter slightly dragged away from the former, × 100. Hake.

Fig. 5. Three isolated odontoblast cells, × 500. Hake.

Fig. 6. Surface of pulp, with thin layer of newly formed dentine, which tends to split up into rods, each one corresponding with an odontoblast cell, × 70. Hake.

Fig. 7. A capillary vessel with adherent odontoblast, × 100. Hake, taken from surface of pulp.

Fig. 8. Young tooth-sac, × 50. Hake. The largest enamel cells correspond in position to the future enamel cap.

Fig. 9. Section of base of tooth and of the pulp. Cod (*Gadus morrhua*).

PLATE 4.

Fig. 10. Tooth consisting of vaso-dentine, the place of the ordinary external layer of hard dentine being supplied by a layer of thick enamel, × 50. *Ostracion.*

Fig. 10.* Tooth of vaso-dentine with an apex of hard dentine, × 40. Flounder (*Pleuronectes flesus*).

Fig. 10.** Tooth of hard dentine with base of vaso-dentine. *Serrasalmo.*

Fig. 11. Fine tubed dentine, with capillary canals interspersed in it, × 90. *Serrasalmos.*

Fig. 12. Transverse section of hardened and decalcified tooth and tooth-pulp, near to the base of the tooth, × 60. *Lepidosteus oxyrrhinus.* The radiating processes of pulp, each coated with odontoblasts, surround a central coarse meshed connective tissue framework (*p*).

Fig. 13. Tooth consisting of osteo-dentine, × 35. Common Pike, *Esox lucius.* A thin layer of fine tubed dentine (*d*) surrounds a central core of large channeled bony tissue.

Fig. 14. One of the larger canals of a Pike's tooth near to the surface, showing their connexion with the fine tubed layer (*f*) external to them, × 120.

Fig. 15. Section of developing tooth and dentine pulp of a Pike, × 30. From the first formed layer of hard dentine (*d*), run down trabeculæ (*h*) of rapidly calcifying tissue, which permeate the whole thickness of the pulp. No odontoblasts exist during this process.

Fig. 16. Trabeculæ from same specimen, × 200. Cells like osteoblasts (*i*) clothe their surfaces.

Fig. 16* and 16**. Transverse sections, somewhat diagrammatic, of a developing tooth of a Pike 16*) and of a Hake (16**). These show the even contour of the pulp forming vaso-dentine and the irregular contour of that forming osteo-dentine.

Fig. 17. Base of extruded (*d*) and upper part of implanted portion (*d'*) of tooth. Longitudinal section, × 50. *Chrysophrys.* The section not being true to the long axis of the tooth, the implanted portion appears solid, which it is not, having a central pulp cavity continuous with that of the upper part. At the junction of what might be termed crown and root the structure abruptly changes, fine tubed dentine above giving place to a tissue permeated by large channels (*d'*).

Fig. 18. Base of implanted portion of tooth, transverse section, × 30. *Chrysophrys.* The vascular dentine of the exterior is in the interior replaced by a very coarsely reticulated calcified mass (*d''*).

PLATE 5.

Figs. 19 and 20. Transverse section of teeth of *Chrysophrys* just at the junction of the implanted portion with that above the gum. The transition from the one type of structure to the other is abrupt.

Fig. 21. Portions of the vascular dentine more highly magnified. *Chrysophrys,* × 200.

Fig. 22. Dentine close to the point of transition, from fine tubed to vascular dentine. *Chrysophrys,* × 70.

Fig. 23. Developing teeth of *Sargus ovis.* On the left is a tooth just moving into place, on the right is a younger one.

Fig. 24. Tooth of a Haddock (*Gadus æglefinus*) with its supporting bone, showing its manner of attachment.

Fig. 25. Tooth of Cod (*Gadus morrhua*), a tooth of vaso-dentine attached to the supporting bone by ligaments (*l* and *l′*), which admit of slight mobility in one direction.

Fig. 26. Section of a hinged tooth of a Hake, with its pulp and supporting bone. It is attached to the bone on the left side by a ligament (*l*) ; on the right side its base is quite free, and thickened where, in its motions, it impinges upon the buttress of bone (*c″*) built up to receive it.

Fig. 27. Section of a hinged tooth of a Hake, showing the entrance of its vessels through a perforation in the ligament, an arrangement by which stretching of the vessels is avoided when the tooth is bent down.

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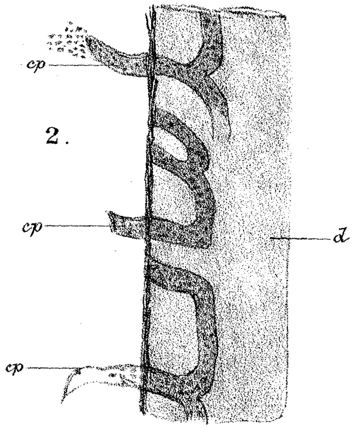

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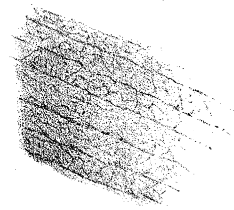

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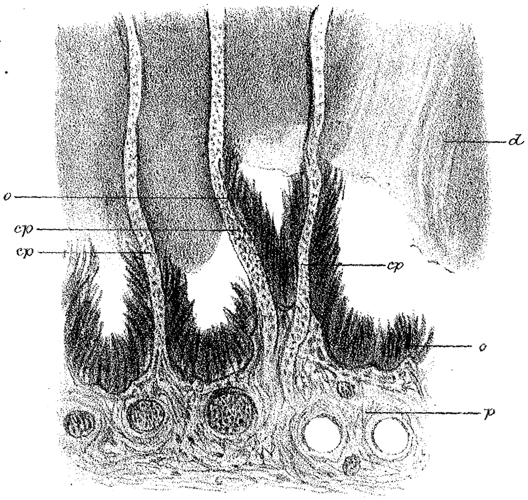

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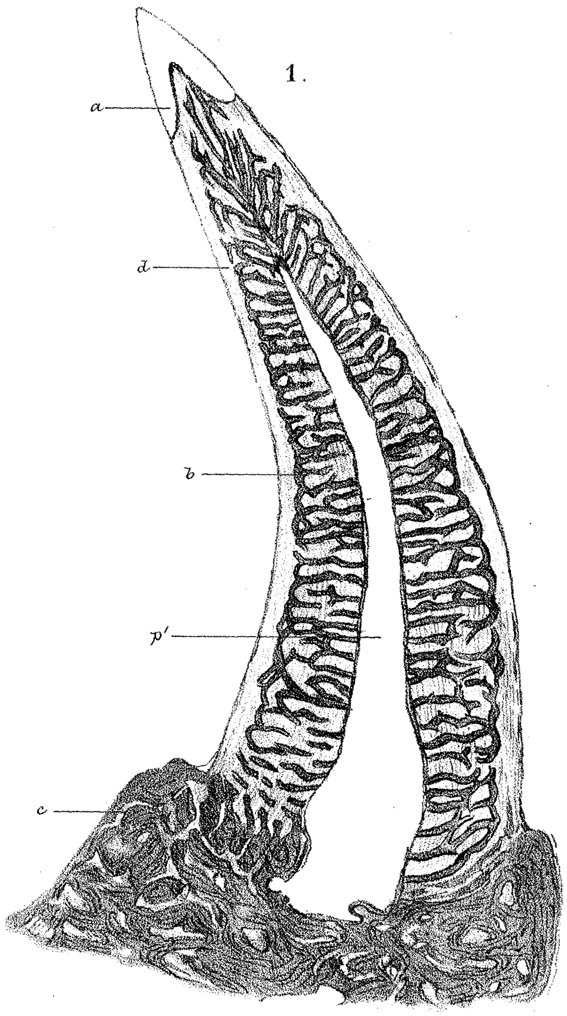

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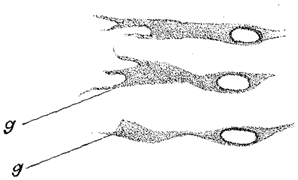

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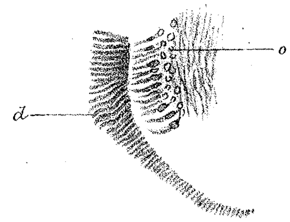

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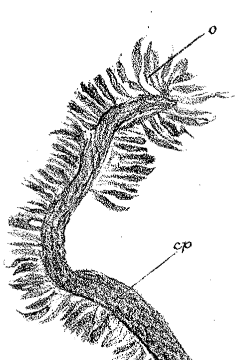

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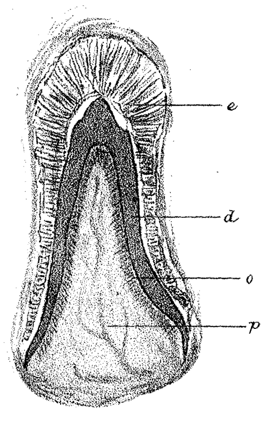

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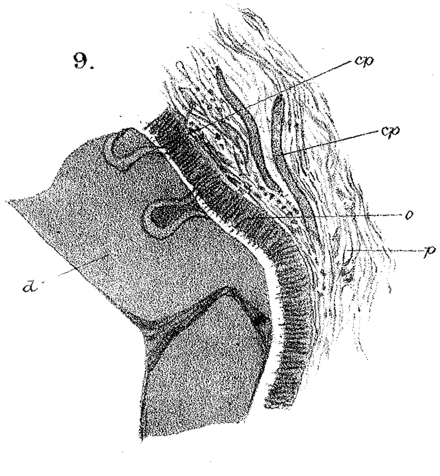

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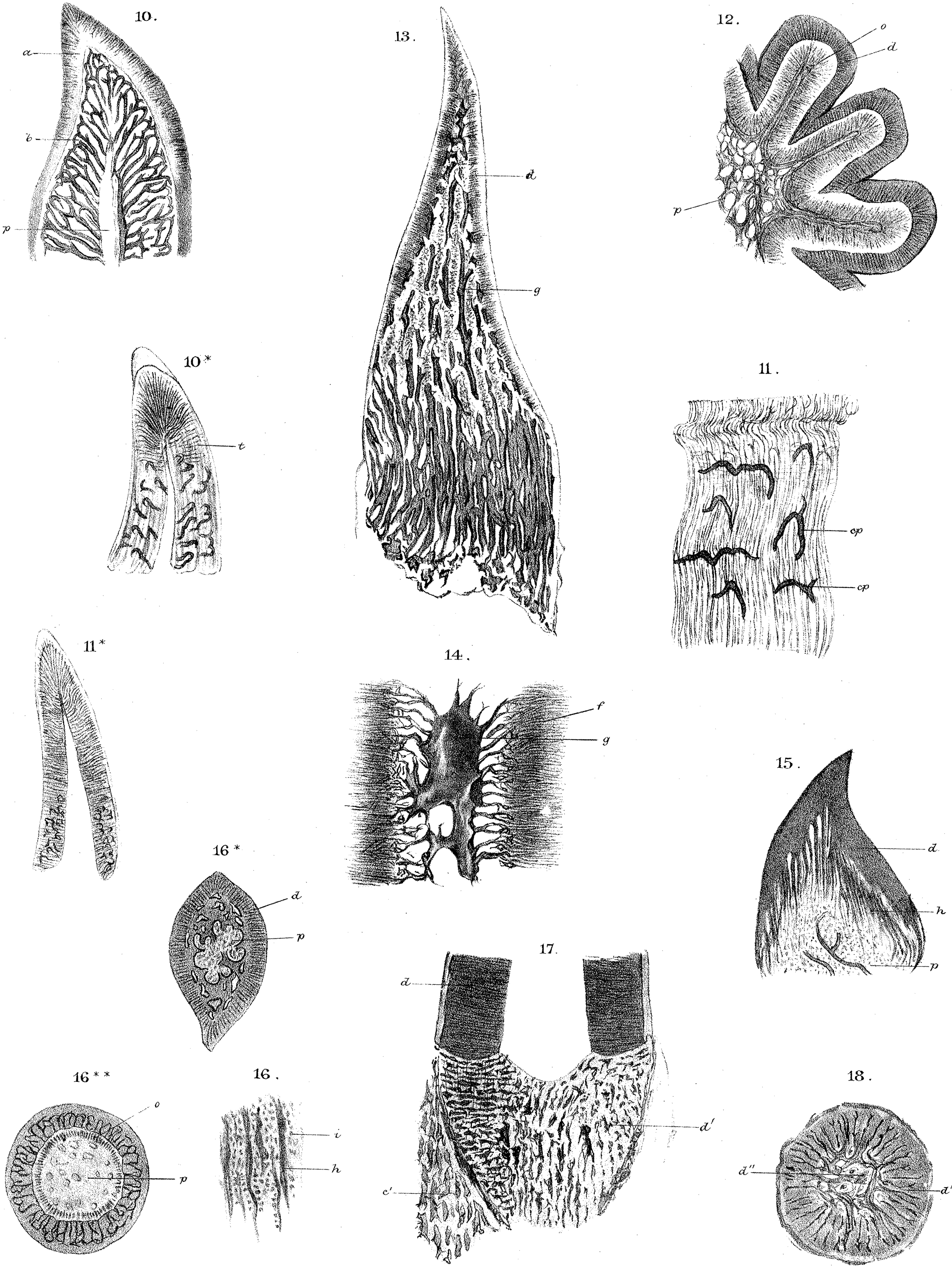
W. West & Co. lith.



C. S. Tomes del^t.

W. West & C^o. lith.

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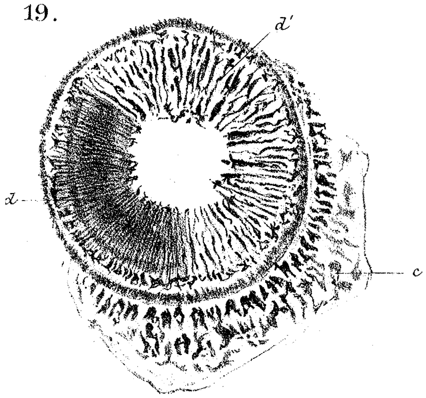

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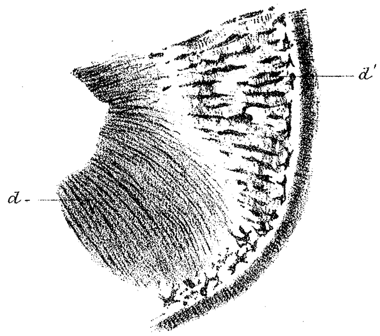

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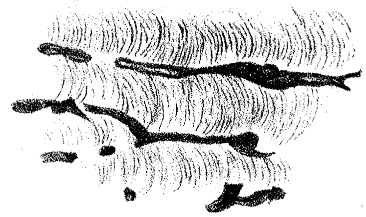

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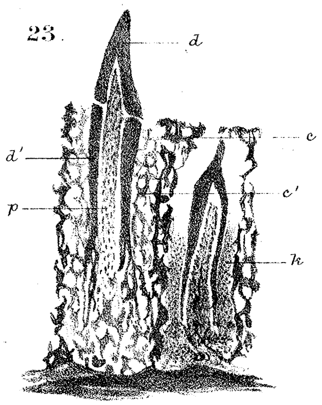

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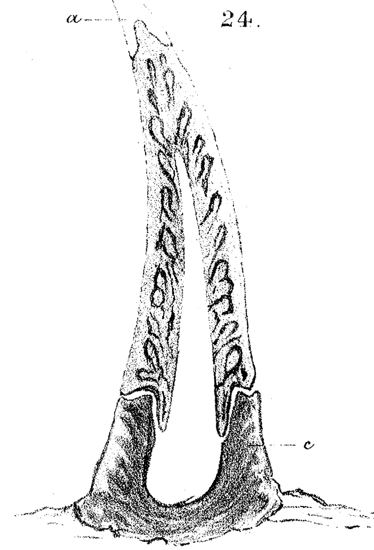

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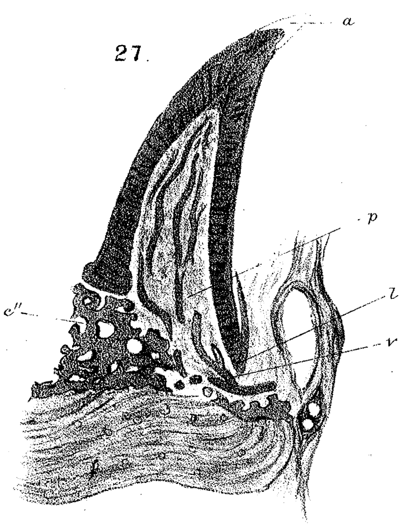

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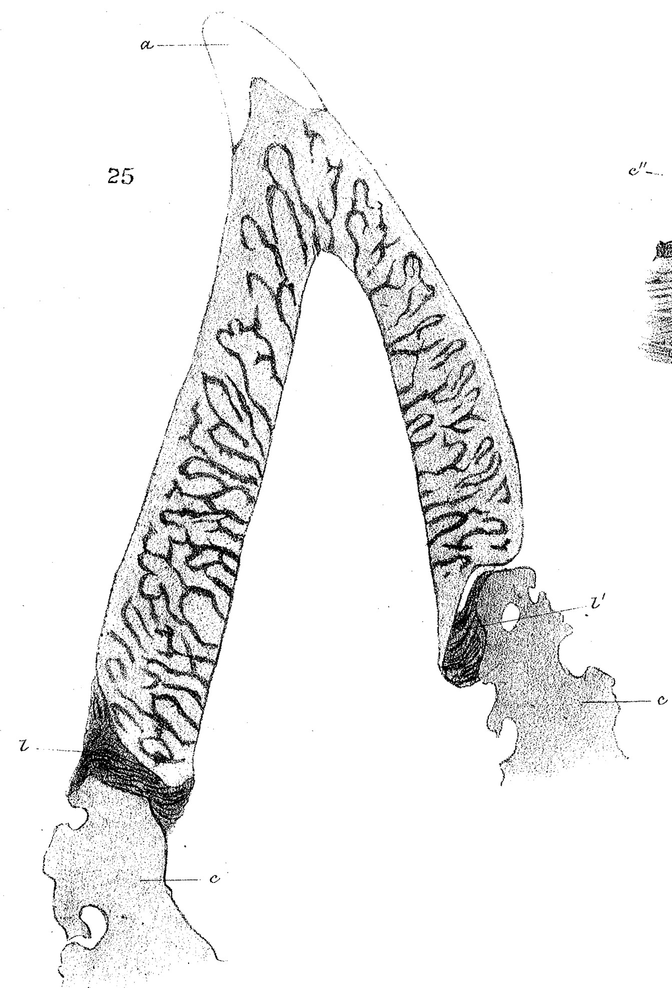

26.