THE MUSCULATURE OF CHITON.

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INTRODUCTION.

THE study of the musculature of Chiton was begun at the suggestion of Professor Lang at Zürich, and to him and to Dr. Karl Fiedler I am greatly indebted for advice and assistance during the first part of the work : the study was completed under the direction of Professor Morgan, of Bryn Mawr College, who has furnished me with material in addition to that originally procured by Professor Lang, and has greatly aided me by his kind interest and assistance. I am glad to have this opportunity to acknowledge Professor McMurrich's kindness in looking over the manuscript.

The anatomy of Chiton has been carefully worked out by Haller; he has described in detail the digestive tract, the circulatory system, the nervous system, the nephridia, the reproductive system, and also the muscles of the walls of the internal organs. The chief muscles of Chiton are those of the shell, of the foot, of the mantle, and of the radula. The muscles of the shell, foot, and mantle are attached to the shells, and it is therefore important to bear in mind the arrangement of the shells.

On the dorsal side of Chiton are seen the exposed surfaces of eight distinct shells encircled collectively by the mantle. Shells III to VII inclusive (reckoning from anterior to posterior) are plates arched over the back of the animal (Fig. 1, V); the anterior portion of shell II, which is longer antero-posteriorly than any of the other shells except the terminal ones, is curved over the anterior end of the body, while shells I and VIII (Fig. 1, I and VIII) cover the curved ends of the body to the edge of the mantle where it passes around the ends of the animal. The lower layer of each shell (except I) is continued anteriorly on either side under the shell next in front

of it, as an "apophysis," so that the shells deeply overlap at the sides like scales. (Fig. 1, *ap*). When the animal is extended, each shell covers the apophysis of the next posterior shell and also a portion of the outer layer of the same shell posterior to the apophysis. When the animal is contracted, only the apophyses are covered, and the shells, therefore, do not overlap in the middle line. The edges of the shells that are bordered by the mantle (*i.e.*, the anterior edge of the first, the posterior edge of the last shell, and the lateral edges of the intervening shells) are notched and firmly inserted in the muscular tissue, and a small ridge of the mantle folds over their extreme edges (*cf.* Figs. 4, 5, 7, 8, *etc.*). This general description applies to the various species which I have seen;[1] the principal variations in detail are in the degree of curvature of the shells over the back and ends of the animal, and in the thickness of the shell.

The muscles have been worked out chiefly in transverse and sagittal sections of C. olivaceus (found at Naples), though horizontal sections and dissection of the same species have aided in confirming the results; dissections of C. viridis, Spengler, a species from Jamaica that very closely resembles C. olivaceus, were of still greater assistance, as the animals are larger. An individual of this species is represented in Fig. 2 (the specimen was about 5 cm. in length after preservation in alcohol). All the figures of sections are taken from preparations of C. olivaceus.

After writing the description of the muscles, an opportunity occurred for making observations on living Chitons from Woods Holl, probably C. apiculatus.

The animal, never rapid in its movements, is capable of assuming the greatest variety of positions, notwithstanding its dorsal plate armor. It crawls slowly by means of the foot, and can travel through the arc of a comparatively small circle. When disturbed, it attaches itself firmly to the surface on which it crawls. If the animal is removed, it rolls itself together until the ventral surface of the anterior and posterior ends of the body

[1] C. pellis serpentis, C. olivaceus, C. granulatus, C. cajetanus, C. viridis, Spengler.

are flattened against each other, or even overlap, in which case the natural position seems to be with the posterior end curled under the anterior; if the anterior edge of the mantle folds under the posterior, the animal may several times open and close, the posterior edge getting more and more nearly under the anterior at each attempt, until finally the posterior edge is entirely folded under, and the animal remains quiet. It lies thus rolled together for some time on the bottom of the dish or on the stone; in trying to recover its footing, it is able to arch the ventral surface of the foot, thus making its dorsal side bearing the shells concave, to such an extent that the ventral surface of both anterior and posterior edges of the mantle is turned under, and rests on the stone or other surface on which the animal has been lying; this position is not retained very long at a time, but is repeatedly assumed after intervals of rest in the contracted state. Such attempts to regain the normal position do not appear to be successful unless by its exertions the animal may happen to move to a part of the stone where it can lay hold of some irregularity of the surface. The Chiton, when on its back, can twist itself into most contorted shapes, and may finally attach itself to a stone if the stone lies near by.

Muscles of the Shells.

Changes in the relative positions of the shells are brought about by muscles immediately ventral to the shells, which can be removed in somewhat imperfectly preserved specimens. The muscles are then seen exposed on the dorsal surface (Fig. 2).

They are: (1) A median dorsal longitudinal muscle (Figs. 2, 3, also 4, 5, 10, *md*), whose fibres pass for the most part from the anterior edge of each shell, between the apophyses, to the ventral surface of the anterior part of the next anterior shell, though some fibres are continuous under the junctions of the shells; this muscle is thickest on either side of the middle line, except at the point of the posterior attachment (*cf.* Fig. 4, *md* with Fig. 5, *md*).

(2) A pair of oblique dorsal muscles (Figs. 2, 3, 4, 5, 6, *od*) attached with the median dorsal muscle to the anterior edges of shells VIII–II, inclusive. These muscles run obliquely forward, at first along the edges of the apophyses of the shell to whose median anterior edge they are attached, and anteriorly they are attached to the next anterior shell (under which they have taken their course) on the line where its apophyses begin (Figs. 2, 3, *od*); *e.g.*, one of these muscles is attached to the anterior edge of V, runs obliquely forward under IV, and is attached to the ventral surface of IV where its apophyses begin. Both the median and oblique dorsal muscles are wanting under VIII, as no shell posterior to it occurs. Under II, the median dorsal muscle is comparatively narrow and thick (Fig. 10, *md*), for it is crowded toward the median line by a group of muscles (*dr*) extending from II to the radula; under the more anterior part of the shell, the fibres diminish in number, so that the anterior limit of the muscle is at the beginning of the curvature of the shell over the end of the body (*cf.* Fig. 3 and description of the shells). The anterior attachment to the shell of each of the oblique dorsal muscles under II is not continuous, but the fibres are attached in groups that alternate with the attachments of groups of fibres of pedal muscles (v. *infra*, see Fig. 3): this is also true to some extent of the corresponding muscles under the other shells. Under shell I are two pairs of muscles that pass anteriorly (and also ventrally, following the shape of the shell) from the anterior edge of II; the muscles of the median pair diverge but slightly from their attachment to II, and represent the median dorsal muscle (Fig. 3, *md*); the more lateral pair (Fig. 3, *od*) corresponds to the oblique dorsal muscles of the other shells, but each muscle of the pair is divided very near to its attachment to II into two main strands; the outer fibres of the outside strands end at the shell with alternating groups of fibres of a dorso-ventral muscle (*cf.* Fig. 3).

(3) At the lateral edges of the shells, longitudinal muscles (Figs. 2, 3, *ll*, and also *ll* of cross-sections) on either side which pass from the ventral surface of one shell to the dorsal surface of the apophysis of the next posterior shell. As in the

case of the median dorsal muscle, some fibres are continuous under the overlapping edges of the shells.

(4) Between the shells where they overlap, a thin cushion of muscles covering dorsally the apophysis, and having therefore the same outline. The arrangement of muscles forming this cushion is complicated: at the antero-lateral edge of the apophysis are oblique fibres (Figs. 4, 6, c_1) lying in the transverse plane, which pass from the ventral shell (apophysis) obliquely toward the median line, to be attached to the dorsal shell. Further relations of these fibres to a large muscle in the mantle will be described in connection with the muscles of that organ. The fibres of this border of muscles at the edge of the apophysis are gradually replaced by fibres in the sagittal plane (Figs. 4, 6, c_2), which are attached anteriorly to the ventral shell and pass to a more posterior attachment to the dorsal shell. Between the ventral shell and the posterior ends of these fibres is a region occupied by a set of fibres in the horizontal plane (Figs. 4, 6, c_3) that are also attached by their anterior ends to the ventral shell and pass laterally and posteriorly to be attached by their posterior ends to the dorsal shell.

I have endeavored by comparing measurements of several specimens killed in a contracted state with those of animals killed while extended, to determine the functions of the various shell muscles, but have been unable to obtain any satisfactory results because of the small size of the animals and the variations in the proportions of different individuals. The following account is a suggestion of the possible mechanism of the shells, based on observations on the positions of the muscles. When the animal is contracted or extended, the relative lengths of the lines on the parts covered by the shells must be very much like those of the finger when bent or straight: the median dorsal line is longest when the finger is bent, and at the same time the median ventral line is shortest, while some line between the two remains constant in length, whatever the position of the finger, *i.e.*, the line, probably, along which there are the fewest wrinkles of the skin. If the finger were covered by strips of paper shaped like the shells of

Chiton, and projecting at the sides under one another, we should have a rude representation of the condition of the shells. The median dorsal muscle I regard as probably an extensor, for the median dorsal line is obviously increased in length when the animal is contracted, and conversely diminished when the animal is extended. The muscle is attached from anterior to anterior edge of the shells, so that it is impossible that the muscle by its contraction should draw two shells at an angle to each other and itself form the third side of the triangle, as might occur if the muscle went from the anterior edge of one shell to the posterior edge of the next posterior shell (from the tip of the finger to the second joint). It seems probable that the oblique dorsal muscles likewise function as extensors. The lateral longitudinal muscles, on the other hand, are on a line that is diminished when the animal is contracted, for the maximum overlapping of the lateral edges of the shells occurs at that time; these muscles, then, are to be regarded as contractors.

It is reasonable to suppose that these last two muscles, and also the muscles of the cushion, are used in motions that involve the two sides of the animal in different ways, and it is possible that this is the chief function of the oblique dorsal.

The muscles of the cushion in the sagittal and horizontal planes (c_2 and c_3) probably serve to readjust the shells at the extension of the animal. The median dorsal tends to draw the anterior shell over the posterior, and does not control the posterior edge of the shell. The sagittal muscles (c_2) of the cushion, acting on either side of the median line, and the horizontal muscles (c_3) controlling the shells more laterally where they are curved, tend, by virtue of their oblique position, to draw the posterior shell from under the anterior, and at the same time to draw the surfaces of the shells together; or, in other words, these muscles lie in the direction of the resultant of a force parallel with the surfaces of the shells, and of a force perpendicular to the shells. The muscles in the transverse plane at the antero-lateral edge of the cushion, perhaps serve to draw the antero-lateral edge of the apophysis nearer to the dorsal shell on contraction of the animal, a motion

opposed to the action of the sagittal and horizontal cushion muscles (which draw the posterior part of the dorsal shell nearer to the ventral) in the extension of the animal.

Muscles of the Foot.

The muscles to the foot are attached to the ventral surface of the shells, on either side, between the body cavity and the mantle, whence they pass in various directions into the foot and are dispersed through the whole organ; some of the fibres cross the middle line, and the body cavity is bounded by muscle fibres below and at the sides (Figs. 4, 5).

Corresponding with the regularity in the relations of the shells, the muscles that occur under one shell are exactly repeated under each of the others, except where the regularity is interrupted by other organs. For any cross-section of shell IV, with the underlying muscles, there is an exactly corresponding section of shells V and VI. The same order of muscles is easily recognized under III and also under VII, where, however, the connections between the auricles and the branchial veins, and the efferent ducts of the nephridia and reproductive organs introduce modifications; I and VIII are different, owing to their terminal positions, and the buccal muscles under II (and also under I) disguise to some extent the usual order, although, even in these cases, muscles corresponding to those under the other shells occur.

Shell VI.

I shall first describe the muscles under a typical shell — for example under VI — and shall limit the description to the muscles of one side of the animal (the bilateral symmetry being perfect).

The muscles are divided into two groups, which, near the shell, are separated from each other (*cf.* under V, Figs. 6, 2, right side). Owing, however, to the diverse directions in which the fibres run, the muscles form at a lower level a compact mass from end to end of the animal, completely occupying the foot and the narrow space between the mantle chamber and body cavity.

The anterior group of muscles is attached to the shell in the region where it emerges from under the shell next anterior to it (Fig. 3, *aga ; cf.* also Figs. 2, 6); the posterior group to the region anterior to the underlying edge of the apophysis of the next posterior shell (Fig. 3, *pga ;* Figs. 2, 6). Nephridial branches occupy, as a rule, the spaces immediately ventral to the shell and alternate with the groups of muscular attachments.

In each group, at the shell, are three muscles that correspond in the two groups, although the exact relations of the muscles to one another are not identical. The muscle nearest the median line at the shell will be called (because of its distribution) the "latero-pedal," the most lateral muscle, the "medio-pedal," and the muscle between, the "antero-oblique."

The inner fibres of the latero-pedal (Figs. 4, lp_1, 5, lp_2) are attached to the shell over the body cavity (so that they form the roof of the lateral part of the cavity), curve out, and then pass ventrally into the foot ; the remaining fibres of the muscle are, on the whole, dorso-ventral. After leaving the shell, some of the fibres diverge anteriorly and posteriorly (Figs. 2, 6, lp_1, lp_2) until those of consecutive anterior and posterior groups meet ; the muscle is distributed to that part of the foot which lies outside the pedal nerve, including the portion spread out under the mantle chamber (Figs. 4, 5). The posterior fibres of the latero-pedal of the anterior group, and the most lateral fibres of the oblique dorsal muscle, overlap near the shell. (Fig. 4 is taken from a section anterior to this region ; but *cf.* Fig. 3, *od* and *aga.*)

The medio-pedal muscles (Figs. 4, mp_1, 5, mp_2) are attached to the shell over the mantle chamber, and pass obliquely inward until they cross the path of the latero-pedal fibres (Fig. 6, mp_1, mp_2), and continue the boundary of the body cavity ; some fibres are distributed to the part of the foot inside the pedal nerve, and others cross the median line, and end in the opposite half of the foot. The fibres of the medio-pedal of the anterior group do not diverge anteriorly and posteriorly from their attachments to the shell like those of the latero-pedal muscles, but the muscle has a broader attachment antero-

posteriorly than the latero-pedal of the same group, extending beyond it anteriorly, and for some distance posteriorly (Fig. 13, III–VI, lp_1, mp_1 ; *cf.* also Fig. 2, lp_1, mp_1 of IV).

The fibres of the medio-pedal of the posterior group, like the latero-pedal fibres, diverge from the shell, and where these two muscles and the antero-oblique occur side by side, it is difficult to draw sharp lines of division between them, as may be seen in cross-section (Fig. 5, lp_2, mp_2). The medio-pedal muscle, however, as a whole, is relatively more posterior than the latero-pedal (Fig. 13, III–VI, lp_2, mp_2 ; also Fig. 2, lp_2, mp_2 of IV).

In the floor of the body cavity are occasional fibres that stretch horizontally across, and disappear among the fibres of the medio-pedal muscle on either side (Fig. 5).

The antero-oblique of the anterior group (Figs. 2, 4, 6, ao_1) runs obliquely forward from its attachment between the latero- and medio-pedal muscles, and the anterior and posterior limits of its attachment to the shell are relatively a little posterior to those of the latero-pedal (Fig. 13, III–VI, ao_1, lp_1). The attachments of the antero-oblique fibres of the posterior group begin anteriorly outside of the attachment of the latero-pedal muscle (Fig. 13, III–VI, ao_2, lp_2), and more posteriorly are mingled with the fibres of the latero- and medio-pedal muscles (Fig. 5, ao_2) ; the fibres run very obliquely forward, overtake those of the antero-oblique muscle of the anterior group (Fig. 4, ao_1, ao'_2 ; *cf.* also Fig. 2, ao_1, ao_2 of V), and pass ventral to them into the foot.

In the anterior group, still another muscle, the "postero-oblique" (Figs. 2, 4, 6, *po*), is attached to the shell immediately inside the attachment of the medio-pedal muscle, although it does not extend posteriorly so far as the medio-pedal and its attachment reaches relatively more anteriorly (Fig. 13, III–VI, *po*); this muscle runs obliquely backward inside the medio-pedal of this group (Fig. 4, *po*), but outside the medio-pedal of the posterior group (Fig. 5, *po'*).

There are, then, two groups of muscles to the foot under the typical shell, each composed of three muscles having a similar distribution in the two groups, but differing in the

relative anterior and posterior limits of their attachments ; in the anterior group a fourth muscle occurs not represented in the posterior group. Fibres in the thick part of the foot that in cross-section appear to be the cut ends of longitudinal muscles, are in reality the continued fibres of the oblique muscles, and arise in part, also, from a horizontal muscle from VIII and an oblique muscle from I and II that extend a long distance into the foot. Both will be described among the muscles of the shells to which they belong. Longitudinal fibres which are independent of all these muscles occur in the most ventral part of the foot and in its lateral edge ; and, in the network of muscles in the ventral part of the foot, are additional diagonal and horizontal fibres in the transverse plane (see cross-sections). This general description applies to the three shells, IV, V, and VI.

Shell III.

The arrangement under shell III is scarcely modified. The antero-oblique muscles, in this more anterior part of the body, are reduced in extent, and the fibres are perhaps more perpendicular in direction ; on this account the antero-oblique fibres of the posterior group are in cross-section less distinguishable than in the typical case from those of the latero- and medio-pedal muscles. The postero-oblique muscle, on the other hand, is large and conspicuous ; the corresponding muscle of II is also large, and still prominent at its lower level under III.

Shell VII.

Under VII the genital duct crosses to its external opening into the mantle chamber beyond the gill, anterior to the attachment of the medio-pedal of the anterior group, but ventral to the anterior part of the attachment of the postero-oblique. Thus the attachment of the medio-pedal is interrupted, and the medio-pedal does not extend anteriorly beyond the latero-pedal (Fig. 13, VII). Posterior to the anterior group of muscles the auricle extends to the branchial vein and the nephridial duct to its external opening into the mantle cham-

ber, and the attachments of the muscles are accordingly equally limited posteriorly; the branchial artery sends a branch toward the body cavity in the same region (Fig. 13, VII, attachments of the anterior group).

The nephridial duct and extended auricle cut off also the anterior portion of the attachment of the latero-pedal and antero-oblique muscles of the posterior group, until the anterior limits of these attachments are relatively posterior to the anterior limit of the medio-pedal (Fig. 13, VII, posterior group). The postero- and two antero-oblique muscles thread their way between the various ducts and blood vessels as strands rather than bands of muscles, as under the other shells.

Thus under VII not only is the space between the muscular attachments occupied by organs other than the nephridial branches, but the attachments even of the muscles to the shells are reduced, and the oblique muscles are compressed into small spaces between the ducts and vessels; notwithstanding these modifications, however, muscles corresponding to all of those under the typical shell can be clearly recognized, and have a perfectly typical distribution.

Shell VIII.

Under VIII the postero-oblique muscle is merely a small group of fibres, not entirely wanting, as I at first supposed. The antero-oblique fibres, on the other hand, are especially prominent. There is no sharp division of the muscles into two groups, but the latero- and medio-pedal fibres form almost continuous muscles from the anterior to the posterior limits of their attachments: both muscles begin on the ventral surface of the most anterior portion of the apophysis, a point which is relatively in front of the usual attachment even of the medio-pedal, under the other shells[1] (Fig. 13, VIII). Toward the posterior part of shell VIII the muscles of the opposite sides gradually approach (corresponding to the narrowing of the

[1] In a preceding account, a sufficiently anterior limit was not attributed to these muscles. It should also be noted that in the diagram, Fig. 2 of the account referred to, the median dorsal muscle of shell II is extended too far anteriorly (*Jenaische Zeitsch. f. Naturwiss.* xxviii, Bd. N.F. xxi).

shell) and are limited posteriorly by a muscle of the mantle around the end of the body. An anterior antero-oblique muscle is well defined. At the level of the narrowest part of the foot, within the latero-pedal muscle and hence bounding the body cavity, is a powerful horizontal longitudinal muscle that is attached to the shell (Fig. 13, VIII, *hl*) as it forms the dorsal curvature of the end of the body, and extends anteriorly into the foot : its attachment to the shell reaches the median line, and thus the muscle meets its fellow of the opposite side of the body, over the union of the branchio-visceral nerves. At a higher level than the horizontal muscle, fibres are attached to the shell among and outside the fibres of the latero-pedal muscle (Fig. 13, VIII, *ao*) and pass anteriorly and slightly obliquely into the foot, taking the place of the antero-oblique muscle in the posterior part of the shell.

Shell II.

Under II a condition the reverse of that under VIII, at the opposite end of the body, is found among the oblique muscles, since the postero-oblique is very prominent and antero-oblique fibres are wanting ; the antero-oblique were seen to have diminished already under III, where the muscle of that direction in the anterior group is so reduced as to be no longer recognizable as a distinct muscle when the fibres have passed anteriorly under II.

The attachments of the fibres of the oblique dorsal shell muscle are in groups among the latero-pedal fibres of the anterior group, and some of the oblique dorsal fibres reach so far laterally as to interrupt the posterior part of the attachment of the postero-oblique (*cf.* Fig. 3 and Fig. 13, II).

Some of the attachments of the muscles of the anterior group are interrupted also by muscles to the buccal mass, and the relations of their anterior limits altered : a large radula muscle (perhaps the "sphincter oris" of Haller), attached far out in the mantle to II (Figs. 10, 9, *or*, 3, *ora*), passes obliquely forward to the buccal mass ("oblique radula muscle"). Immediately ventral to this muscle where it has reached the

region of the attachment of the latero-pedal, another buccal muscle ("lateral protractor") passes across from the mantle to the buccal mass (Fig. 3, *lpra*, Figs. 9, 11, *lpr*). The anterior limit of the attachment to the shell of the medio-pedal fibres is relatively posterior to that of the latero-pedal fibres (Fig. 13, II), for the oblique radula muscle, approaching the anterior group from the lateral edge of the shell, cuts off the attachments of the outer muscles of the group obliquely, and, with the lateral protractor muscles, passes anterior to the latero-pedal fibres to reach the buccal mass (Fig. 9, *or*). Under the posterior part of II (or most anterior edge of the apophysis of III), medio-pedal fibres that bound the body cavity are interrupted, on a line with the narrowest part of the foot, by a thick muscle to the buccal mass ("posterior lateral" Figs. 10, 12, *pl*).

In front of the region of the anterior group, the buccal musculature occupies the large space over the posteriorly slanting fibres (Fig. 9, *o*) of an oblique muscle from I and II. The anterior group of fibres (here including the latero- and medio-pedal with the postero-oblique, but not the usual antero-oblique) occupies under II a relatively posterior position (*cf.* Fig. 3), *i.e.*, it lies much nearer to the posterior group, and farther from the anterior edge of the apophysis than under the other shells. The foot proper ends, and the "head-fold" takes its place in front of the region of the anterior group, so that this group is in a position to supply the foot itself.

The head-fold is joined to the body of the animal in the same way as the foot, spreading out under the mantle chamber; anteriorly it is parallel with the edge of the mantle, and the portion spread under the mantle chamber is continued posteriorly as a lobe on either side, dorsal to the foot; the projecting edge of the foot is rounded anteriorly, ventral to the head-fold (*cf.* Fig. 9, where the head-fold and the underlying anterior edge of the foot are met in cross-section), and in the center of the head-fold lies the mouth, bordered by a thick circular lip. The muscles, therefore, under the anterior half of II and under I have to do with the head-fold and lips, and not with the foot proper; one exception to this, however, is to be noticed.

Shells I and II.

Corresponding in distribution with the horizontal longitudinal muscle (attached to shell VIII) of the posterior end of the body is an oblique muscle from I (Fig. 7, o_1), attached immediately anterior to the edge of the apophysis of II; this muscle and another dorsal to it, attached to the most anterior part of the apophysis of II (perhaps to be regarded as another section of the same muscle), pass together obliquely into the foot itself. Although oblique in direction, the muscle does not correspond with the postero-oblique muscles of the other shells, but, like the horizontal muscle under VIII, is different from anything to be found elsewhere in the animal; the muscles appear to have corresponding functions at the opposite ends of the body. The oblique muscle under I is attached outside the attachments of certain "dorso-ventral" fibres that appear to correspond to latero-pedal fibres of the other shells; to this extent, it resembles postero-oblique muscles, but unlike them, it passes into the foot between and not outside of the groups of "dorso-ventral" fibres (Fig. 7, o_1 and *dv*). Furthermore, the oblique muscle is attached to so posterior a part of the shell, that it must belong to a posterior rather than to an anterior group of muscles, and it will be remembered that a postero-oblique muscle is found under the other shells with the anterior group only. Finally, if, as seems probable, this muscle is completed by the oblique muscle attached to II, it differs from all the other muscles of the body, in being attached partly under one shell, partly under another. An oblique muscle passing backwards in the posterior group under the other shells would interfere with the apophysis in the movements of the shells, while the relative positions of the first and second shells appear to be less variable than those of the others; under all the shells, except I, a space occurs anterior to the edge of the apophysis.

Shell I.

To understand the distribution of the muscles under I, it is necessary to bear in mind that ventral to it the radula, with its enormous supply of muscles, occupies the cavity of the head region; that large bundles of buccal muscles pass from the shell; that the mouth and lips occupy a portion of the ventral surface; and that the œsophageal ring (giving off the branchio-visceral and pedal branches) occurs in this region; also, that the head cavity gradually diminishes in width, toward its anterior end, and that the line on which the muscles are attached is not straight, but curved, *i.e.*, parallel to the anterior edge of the mantle or shell (*cf.* Fig. 3). To the posterior part of I is attached a "dorso-ventral" muscle immediately anterior to II; portions of its fibres pass either side of the œsophageal ring and of the oblique muscle to the foot (Fig. 7, *dv*), and are distributed to the lateral portions of the head-fold and in part to the lips, corresponding to the latero-pedal fibres of the posterior group of the other shells. Slightly anterior to these, is another group of "dorso-ventral" fibres, that passes entirely outside the œsophageal ring: these fibres may be referred to the latero-pedal fibres of the anterior group, although no sharp division exists between them and the more posterior fibres. The more anterior dorso-ventral fibres are attached to the shell with fibres of the oblique dorsal muscle (*cf.* Fig. 3), just as the latero-pedal of the anterior group under the other shells is connected with the anterior attachment of the most lateral oblique dorsal fibres. I have called these groups of fibres the dorso-ventral muscles, as a matter of convenience, although their direction is rather oblique than dorso-ventral; the muscles in the region of the buccal mass are crowded to a relatively more lateral attachment to the shell than is the case with the corresponding muscles under other shells. Fibres that can be roughly compared to the medio-pedal muscles ("horizontal fibres," Fig. 7, *h*) are attached to the lateral portion of the shell, far out in the mantle, the fibres lying almost in the horizontal plane; this position is possible in the region of the body in which the fibres occur, for the gills, with their nerve

and blood supply, are absent, and the mantle chamber is low. There is no division of fibres of this description into anterior and posterior groups, but the fibres are found more or less interruptedly under a large part of shell I, and posteriorly even under the anterior part of shell II (Fig. 9, *h*).

More anteriorly, where the shell becomes considerably narrower, are two additional sets of dorso-ventral muscles (Fig. 3, *dv'a*, *dv''a*, which, with the dorso-ventral muscles already described, may be regarded as parts of one system, making a condition similar to that under VIII; under I, the system is divided into three parts by two large groups of horizontal muscles to the radula, that are attached to the anterior part of the shell and cross between the groups of dorso-ventral fibres to the buccal mass (*cf.* Fig. 3 and Fig. 13, I). The most anterior dorso-ventral muscle (*cf.* Fig. 3, *dv'a*) is separated from the corresponding muscle of the other side, by an oblique median muscle to the anterior lip (Figs. 3, *omla*, 8, *oml*); and a small horizontal muscle (Fig. 8, *hml*) attached more anteriorly to I, runs in the median line, also to the anterior lip.

The lips are furnished with other conspicuous muscles. (1) Circular muscles (Figs. 7, 8, *cl*), most of which form an incomplete ring around the mouth. Anteriorly where the ring is not closed the fibres pass on either side of the oblique median lip muscle and are there lost; some of the circular muscles, however, cross posterior to the mouth and pass horizontally into the foot, and a few circular fibres are found in the anterior lip.

(2) Longitudinally directed fibres (Fig. 8, *rp*) that originate in the foot and spread like fingers in the posterior lip between the circular fibres.

(3) Shorter and less prominent, spreading fibres in the anterior lip (Fig. 8, *ra*).

MUSCLES OF THE MANTLE.

The mantle is armed on the dorsal surface with calcareous spicules; ventrally it is smooth and forms the boundary of the mantle chamber, in which lie the gills, and which receives the

external openings of the reproductive and excretory organs; it is protective and is used also as a water course in respiration and during the discharge of eggs and spermatozoa, as described by Metcalf.[1] "During the ordinary respiration of the Chitons, at one anterior point, and at a posterior point on the opposite side, a small tube is formed by the arching up of the mantle edge, the bottom of the tube being formed by whatever surface the mollusc is resting upon. A constant stream of water passes into the anterior tube, through the mantle chamber and out of the posterior tube. During the discharge of the sexual products, instead of one there are two posterior tubes, one on each side, in the region of the orifice of the oviduct or of the vas deferens as the case may be. The eggs, or spermatozoa, are carried out of the mantle chamber through these tubes by the ordinary respiratory current. At other times during ovulation, the whole posterior part of the mantle of the female would be raised from the floor of the aquarium and the eggs allowed to pass out freely through the wide space thus formed."

The most prominent muscle, the "interior mantle muscle" (Figs. 4, 5, 7, *etc.*, *im*), passes from the ventral surface of the shells where the mantle joins the body, and occupies the part of the mantle that borders immediately upon the mantle chamber; the muscle is found in every part of the mantle, around the entire body. To the median shells it is attached almost continuously along a line over the highest part of the mantle chamber (Fig. 3, *ima*, Fig. 4, *im*), and immediately anterior to the apophysis of each shell, the fibres reach farther in under the shell than in any other regions, so that they meet and even cross the most lateral of the medio-pedal fibres of the posterior group (*cf.* Fig. 3). As the apophysis broadens posteriorly, the fibres become continuous with those at the antero-lateral edge of the cushion of muscles dorsal to the apophysis (Fig. 10, *im* and c_1). Still more posteriorly the fibres assume their attachment to the ventral surface of the apophysis, the dorsal shell being no longer accessible because of the greater

[1] Contributions to the Embryology of Chiton. Studies from the Biological Laboratory of Johns Hopkins University, vol. V, No. 4.

width of the apophysis. For a short interval under the new shell (apophysis) the attachment of the fibres is interrupted, and in the space, blood passes to the mantle (Fig. 3). Fig. 4 shows a section immediately posterior to this interruption, where all the fibres have not resumed their attachment. The attachment is continued posteriorly along the region of the attachment of the anterior group of pedal muscles (*cf.* Fig. 3), and posterior to this a second interruption occurs where a well-defined branch of the branchial vein, and also nerves, pass to the mantle: these spaces interrupt only the attachments of the fibres, while ventral to the spaces there is no break in the continuity of the muscle. The attachment of the interior mantle muscle to the shell is continuous around the anterior edge of I (Fig. 3, *ima*, Fig. 8, *im*) and likewise around the posterior edge of VIII. Under II, the attachment is interrupted by the lateral protractor of the buccal mass (Fig. 3, *lpra*), while the oblique radula muscle passes through the space that regularly occurs for the blood and nerve supply. Under I two pairs of groups of horizontal muscles pass from the anterior part of the shell through the interior mantle muscle to the buccal cartilages.

The mantle is further supplied by bundles of fibres that radiate from the extreme edge of the shell into the fold that covers its insertion and into the interior part of the mantle (Figs. 4, 5, *etc.*), by fibres that occur in the directions parallel to the lateral (or dorsal) and to the ventral surfaces of the mantle, and by a network of fibres in the ventral portions of the mantle. Muscle fibres occur between the branchial vein and artery, and the branchio-visceral nerve, and in the lamella of the gills.

SUMMARY.

Under IV, V, VI, are: (1) Muscles of the shell: — a median dorsal and a pair of oblique dorsal muscles, attached to the anterior part of each shell and extending forward under the next anterior shell to be attached to it anteriorly; a series of longitudinal muscles connecting the ventral and dorsal surfaces of consecutive shells at their sides; a muscular cushion

between each shell and the apophysis of the shell next posterior, composed of oblique fibres in the sagittal plane, and, under the posterior part of these, oblique fibres in the horizontal plane, both directed so that the more anterior attachment is that to the ventral shell; and also oblique fibres in the transverse plane at the antero-lateral edge of the apophysis, continuous with the fibres of a large mantle muscle where the apophysis is of sufficient width to reach the mantle. (2) Two groups of muscles to the foot, separated from each other near the shell by a space occupied by nephridial branches; each group consists of an inner latero-pedal, a middle antero-oblique, and an outer medio-pedal muscle that crosses the latero-pedal, and continues ventrally the boundary of the body cavity (each with a distribution denoted by its name); a postero-oblique muscle occurs in the anterior group, and fibres in the ventral part of the foot, not united into defined muscles, complete the supply to the foot. (3) In the mantle, a muscle from the part of the ventral surface of the shells that is immediately dorsal to the mantle chamber, interrupted at the shell for a short distance anterior to the region of the anterior group of pedal muscles, and interrupted again more extensively anterior to the region of the posterior group; fibres from the extreme edges of the shell to the mantle, and scattered fibres of various directions in the ventral part of the mantle. The deviations from the typical arrangement under the other shells will be noted.

Shell III.

The antero-oblique muscles are reduced and the postero-oblique is enlarged.

Shell VII.

Under VII the arrangement of the muscles is modified by the efferent ducts of the internal organs, and by the blood vessels that here occur. The attachment of the medio-pedal of the anterior group is limited anteriorly and posteriorly, that of the postero-oblique is limited posteriorly and the attachment of the antero-oblique is slightly cut off posteriorly: the ante-

rior portion of the attachment of the antero-oblique and of the latero-pedal of the posterior group is interrupted.

Shell VIII.

The peculiar shape of VIII and its terminal position necessarily lead to differences in the muscular arrangement; the median and oblique dorsal muscles do not occur, there is no underlying apophysis and, therefore, no cushion of muscles ventral to VIII, and no lateral longitudinal muscle extending posteriorly; there is no division into anterior and posterior groups of the latero- and medio-pedal muscles; the antero-oblique muscles are very large, the postero-oblique almost wanting. An additional horizontal longitudinal muscle either side of the median line at the level of the narrowest part of the foot is present, and above this level, among the latero-pedal fibres and outside of them, are attached to the shell oblique fibres (representing the posterior antero-oblique muscle). The usual mantle muscles occur in every part of the mantle around this shell.

Shell II.

The region under I and part of II is anterior to the foot proper, and on the ventral surface, in the place of the foot, is the head-fold (with the mouth and circular lip).

Under II, the median dorsal muscle is crowded into a small space in the median line, and its fibres do not reach the anterior portion of the shell; the fibres of the oblique dorsal muscles are broken up into groups at their anterior ends. The anterior group of pedal muscles is posterior to its usual position, and in this group, the anterior portion of the attachment of the medio-pedal and of the postero-oblique are cut off by the oblique radula muscle, joined by the lateral protractor. Antero-oblique muscles are not found anterior to III. The interior mantle muscle is interrupted for a short distance by the lateral protractor.

Shell I.

Under I the median dorsal muscle is separated into two diverging parts, each oblique dorsal likewise into two. The lateral longitudinal passes from I posteriorly to II, but is not extended anteriorly from I, because of the terminal position of the shell; an oblique muscle from the posterior part of the shell passes with a parallel oblique muscle from II into the foot. A system of dorso-ventral fibres in the head-fold is separated by horizontal buccal muscles into two small anterior groups, and a posterior group in which can be recognized representatives of the latero-pedal muscles of the anterior and posterior groups of other shells. The muscles of the two sides gradually approach as the anterior end of the body becomes narrower; fibres corresponding to the medio-pedal muscles of other shells are attached to a lateral region of the shell in the mantle. The interior mantle muscle is interrupted by two pairs of horizontal buccal muscles, and its attachment partially interrupted by a median muscle to the lip.

In the anterior lip is also a median horizontal muscle attached to I; circular muscles occur about the mouth, and longitudinal muscles from before and behind radiate into the lips.

Muscles of the Radula.

To the description of the other muscles of Chiton may be added a very brief sketch of the muscles of the radula, and of their general direction and places of attachment.

The relations of the radula to the mouth and other organs are best seen in longitudinal sections (*cf.* Fig. 8); the mouth opens into the pharynx, which leads dorsally into the œsophagus (Fig. 8, *oe*); ventral to the œsophagus, the radula sheath opens into the pharynx (at *r*, Fig. 8), and fits around the radula or lingual ribbon, the radula and sheath being extended posteriorly for a long distance, ventral to the œsophagus. On either side of the radula are the so-called "cartilages," long hollow vesicles with thick cartilaginous walls which serve for the attachment of muscles; anteriorly, the radula sheath is

extended laterally on either side, dorsal to the cartilages (*cf.* Figs. 7, 9, 11, *rs*); a pair of glands opens into the œsophagus at a point posterior to these lateral projections (see Fig. 10, *gl*).

The names used for the muscles in the following description indicate in most cases the position and directions of the muscles rather than their function, as that is not understood; the plan is that adopted by Geddes, and in cases where the muscles in Chiton appear to correspond with those in the forms described by him, I have used the same lettering.

The muscles pass from the radula sheath to the cartilage (*ms*1 and *ms*2 of figures); from the shells to the cartilage (*pr*, *cr*, and *lpr* of figures), or to the radula sheath (*or* and *dr* of figures); from the muscular head-fold or foot to the cartilage (*vpr*, *al*, *pl* of figures); and in one case from one cartilage to the other (*vtr*).

The muscles from the radula sheath to the cartilage are of two kinds: broad, flat muscles from the lateral extension of the radula sheath (Figs. 7, 9, *ms*1) running posteriorly to the outside of the cartilage (Fig. 9, *ms*1), and thread-like muscles (approximately circular in cross-section, Figs. 11, 12, *ms*2), running from the part of the radula sheath that immediately surrounds the radula (Fig. 9, *ms*2), posteriorly, to be attached to the inner and dorsal surface of the cartilage (*ms*2, posterior to Fig. 10); these thread-like muscles are attached to the cartilage more posteriorly than the broad muscles, and so cover them dorsally posterior to the lateral projection of the radula sheath (Fig. 11, *ms*2).

The horizontal muscles ("protractors") that are attached in two groups on either side to the anterior part of shell I, and pass between the groups of dorso-ventral fibres (as described in the account of the muscles to the head-fold under I), unite posteriorly into one group, and then pass to the outside of the cartilage, to be attached to it posterior to the attachment of the broad muscles (*ms*1) of the sheath (*cf.* Figs. 7, 9, 10, 11, *pr*). A pair of muscles (Fig. 11, *cr*), attached to I at a point almost as anterior as the attachments of the protractors, cross in the middle line, and pass with the protractors to the cartilages (Fig. 9, *cr*), but are attached to the cartilage anterior to the broad sheath muscles (*ms*1).

The lateral protractor muscles from shell II are attached to the outside of the cartilage, posterior to the attachment of the longitudinal protractors from I (Fig. 11, *lpr*).

The oblique radula muscle from II, that crosses the pedal muscles with the lateral protractor, is attached to the lateral projection of the radula sheath (Figs. 9, 11, *or*).

A group of dorsal muscles (Figs. 10, 11, *dr*) on either side passes obliquely forward from shell II (anterior to the opening of the gland into the œsophagus), to be attached to the portion of the radula sheath that is immediately posterior to the region where the thread-like muscles of the sheath (ms_2) are attached to it. It is these muscles that have been described as compressing the median dorsal shell muscle under II.

Immediately ventral to the attachment to the shell of these oblique muscles from II, are muscles from the floor of the body cavity, in the median line, that pass posteriorly and laterally (Figs. 10, 12, *vpr*), to be attached to the cartilage posterior to the attachment of the thread-like muscles (ms_2) from the radula sheath.

The lateral portion of each cartilage is bound to the muscular head-fold by a large muscle on either side of the posterior limit of the mouth (Figs. 9, 12, *al*). A similar muscle occurs more posteriorly under the edge of the apophysis of III, running from the muscular mass that bounds the body cavity laterally, to the lateral portion of the buccal muscles and cartilage (Figs. 10, 12, *pl*).

The anterior portions of the cartilages of the opposite sides are joined to one another ventrally by a thick transverse muscle (Figs. 7, 9, 12, *vtr*). Finally, on the dorsal side of the buccal mass is a Y-shaped muscle (Fig. 11, and in cross-section, Figs. 7, 9, 10, *y*) attached to the radula sheath.

Historical.

The earliest account which I have found of the musculature of Chiton is the description by Poli in his work on the "Mollusca of the Sicilies," published in 1791. His first figure represents the animal from the ventral side after the removal

of the internal organs, somewhat as in Fig. 3. The oblique dorsal muscles he describes; the pedal muscles have apparently not been cut away close to their attachments, and Poli therefore finds a series of "pyramidal muscles." These are evidently the internal fibres of the latero-pedal muscles seen from the ventral side, for, by comparing cross-sections with Fig. 3, it will be seen that, if in Fig. 3 the latero-pedal muscles had been cut off only to within some distance from their attachment, instead of close to the shell, the fibres of consecutive muscles, as they diverge anteriorly and posteriorly from the shell, would have formed groups pointed toward the median line and spread laterally to meet one another at a level nearer the observer, thus forming pyramids; and there is a pair of pyramidal muscles (the latero-pedal of the anterior and posterior groups) corresponding to each oblique dorsal muscle. Poli describes, outside the pyramids, a circular muscle around the body which is difficult to identify with any one muscle observed, but seems rather to correspond to the muscular tissue of the mantle near the shells. The pyramids, he says, go from the circular muscle to the separate shells and bind them firmly; the shells are still more securely bound by "girding muscles" (apparently the muscles of the cushion) and by the serrations at the edges of the shell; each of these girding muscles, also proceeding from the circular muscle, is attached at its edge to a shell; and the serrations of the shell are deeply imbedded in alveoli, in the circular muscle, as Poli shows in a figure of the dorsal side without the shells. Poli concludes his description of the muscles by showing in a part of the same figure (where the dorsal muscles are cut in the median line and turned back) the "transverse muscles" of the foot that are united together in little bundles.

Middendorff, writing in 1847, gives a very brief account of some of the muscles of Chiton (Cryptochiton) Stelleri; he says the muscles in the body-wall (seen on opening the animal on the dorsal side) are continuations of a flat, muscular sheet, which he calls the "Bauchmuskel"; this muscle bounds ventrally the body cavity, and is the innermost layer of the usual organ of locomotion among the Gastropods, that is, the foot.

Middendorff describes the muscles as running parallel to one another till they reach the sides of the animal, and as then separating into groups, leaving spaces filled with a spongy substance (anterior and posterior groups of pedal muscles with nephridia between). Three parts of the "Bauchmuskel" under each shell partially bound these spaces, and appear to correspond (1) to what I have called the inner fibres of the anterior group, at the attachment to the shell (Poli's pyramidal muscle); (2) perhaps, to the inner fibres of the posterior group, and (3) to the oblique dorsal-shell muscle; he adds that a longitudinal muscle runs along either side of the dorsal artery, being, therefore, the median dorsal-shell muscle.

Haller marks on one of his figures what he refers to as a longitudinal muscle in the narrow part of the foot, but which I interpret as the fibres of the oblique muscles.

Lang briefly mentions: (1) longitudinal muscles over the foot on either side (the oblique muscles apparently cut transversely in cross-section, as Haller also figures them); (2) muscles in the dorso-ventral direction from the sides of the shell into the foot (latero- and medio-pedal); and (3) the muscles passing in various directions in the foot. The dorso-ventral muscles he regards as the representatives of the shell muscle of Fissurellidae, *etc.*, and of the spindle muscle of the other Gastropods; he further describes the crossing of the medio-pedal muscles of opposite sides.

The buccal muscles of Cryptochiton were described in detail by Middendorff (1847), and Schiff in 1858 gave a short account of the muscles of the radula in Chiton piceus; Schiff refers to Middendorf's paper, but leaves his reader to compare the muscles described in the two accounts. Both authors have described the position of the cartilages and radula, the transverse muscles between the cartilages, muscles surrounding the cartilages, and other muscles attached to the radula sheath, to the cartilages, and to the shells and body-wall. Middendorff's figures are not altogether clear, and neither of the authors has studied the muscles in section, so that it is sometimes difficult to understand the exact position of the muscle attachments; in some cases, I have found a different attachment from that

described by Schiff for muscles that otherwise appear to correspond in position with those figured by him. For these reasons I shall not attempt to compare, muscle by muscle, the two descriptions with the present account. The description by Schiff appears to represent more nearly than Middendorff's the condition in the forms that I have studied.

Both Middendorff and Schiff speak of muscles that are attached by both ends to the same cartilage, but I have been unable to find such muscles, and presume from comparison of the drawings, that the muscles from the radula sheath to the cartilage (*ms*$_1$ or *ms*$_2$) are those referred to. The muscles of these groups appear to be attached anteriorly to the cartilage, when seen from the dorsal side; but the lateral projection of the radula sheath, dorsal to the cartilage, produces this effect, and in dissections, as well as in sections, the anterior attachments are seen to be on the sheath.

Both authors have discussed at some length the functions of the muscles, and Middendorff briefly describes some of the muscles of the head region.

GERMANTOWN, October, 1894.

BIBLIOGRAPHY.

1. J. BLUMRICH. Das Integument der Chitonen. *Zeitschr. für wiss. Zool.* Heft 3, Bd. lii, 1891.
2. PATRICK GEDDES. On the Mechanism of the Odontophore in certain Molluscs. *Trans. Zoöl. Society London.* Vol. x, Pt. ii, 1879.
3. B. HALLER. Die Organisation der Chitonen der Adria. *Arbeiten aus dem Zool. Inst. in Wien.* I Theil, Bd. iv, 1882. II Theil, Bd. v, 1884.
4. LANG. Lehrbuch der vergleichenden Anatomie.
5. MIDDENDORFF. Beiträge zu einer Malacozoologia Russica. *Mém. de l'Acad. de St.-Pétersbourg.* Tom. vi, p. 101.
6. J. POLI. Testacea utriusque Siciliae eorumque Historia et Anatome. Parma, 1791.
7. SCHIFF. Beiträge zur Anatomie von Chiton piceus. *Zeitschr. für wiss. Zool.* Bd. ix, 1858.

REFERENCE LETTERS.

I Shell I.
II Shell II.[1]
Etc.
II ap apophysis of shell II, *etc.*
A anterior.
aga region of attachment of the anterior group of pedal muscles under IV.
al anterior lateral muscle of the buccal mass.
ao antero-oblique muscle.
ao_1 antero-oblique muscle of the anterior group.
ao_2 antero-oblique muscle of the posterior group.
ao'_1 or ao'_2 antero-oblique muscle (at a low level) of the group next posterior to the group in the section represented.
ap apophysis.
ba branchial artery.
bv branchial vein.
bvn branchio-visceral nerve.
bc body cavity.
bm a portion of the buccal mass protruded through the mouth.
C buccal cartilage.
c cushion of muscles between the shells.
c_1 oblique muscles of the cushion in the transverse plane.
c_2 oblique muscles of the cushion in the sagittal plane.
c_3 oblique muscles of the cushion in the horizontal plane.
cl circular muscles in the lip.
cr crossed muscle of the buccal mass.
cra region of attachment of this muscle.
dpr dorsal protractors of the buccal mass.
dpra region of attachment of these muscles.
dv "dorso-ventral" muscles under I, corresponding to the latero-pedal muscles under the other shells.
dva region of attachment of these muscles.
dv'a region of attachment of the inner group of additional dorso-ventral muscles.
dv''a region of attachment of the outer group of additional dorso-ventral muscles.
gl gland opening into the œsophagus.
F foot.
h horizontal fibres in the transverse plane under I.
HF head-fold of the foot.
hml horizontal median fibres to the anterior lip.
hl horizontal longitudinal muscle from VIII to the foot.
im interior mantle muscle.
ima region of attachment of this muscle.
L lips.
ll lateral longitudinal muscle of the shells.
lp latero-pedal muscle.
lp_1 latero-pedal muscle of the anterior group.
lp_2 latero-pedal muscle of the posterior group.
lpr lateral protractor of the buccal mass.
lpra region of attachment of this muscle.
M mantle.
mc mantle chamber.
md median dorsal muscle of the shells.
mp medio-pedal muscle.
mp_1 medio-pedal muscle of the anterior group.
mp_2 medio-pedal muscle of the posterior group.
ms_1 broad muscles of the radula sheath.

[1] The numerals II and III have been reversed in Fig. 10.

ms$_2$ thread-like muscles of the radula sheath.
o oblique muscle from I and II to the foot.
o$_1$ portion of this muscle from I.
od oblique dorsal muscle of the shells.
oe œsophagus.
oer œsophageal nerve-ring.
oml oblique median muscle to the anterior lip.
omla region of attachment of this muscle.
or oblique radula muscle.
ora region of attachment of this muscle.
P posterior.
pga region of attachment of the posterior groups of pedal muscles under IV.
pl posterior lateral muscle of the buccal mass.
pn pedal nerve.
po postero-oblique muscle.
po' postero-oblique muscle (at a low level) of the group or shell next anterior to the group in the section represented.
pr horizontal protractor muscles of the buccal mass.
pra region of attachment of these muscles.
r radula surrounded by the radula sheath.
r' radula exposed where the radula sheath and œsophagus communicate.
ra radiate muscles to the anterior lip.
rp radiate muscles to the posterior lip.
rs lateral projection of the radula sheath dorsal to the cartilage.
vpr ventral protractors of the buccal mass.
vtr ventral transverse muscles of the cartilages.
y y-shaped muscle of the radula.

EXPLANATION OF PLATE XXXI.

FIG. 1. Outline of shells I, V, and VIII, dorsal surface.

FIG. 2. Chiton viridis, Spengler. Dorsal view after removal of the shells. The shell muscles in the region of shells III (in part), IV, and V have been cut on the right side along the interior limit of the attachment of the pedal muscles, and turned back on the left side; the viscera removed, showing the pedal muscles *in situ* on the right side. The pedal muscles under shells IV and V on the left, are in part dissected near their attachments to the shell, and turned back to show the relations of the muscles to one another. The muscular cushion, dorsal to the right apophysis of V, has been partly removed, to show more clearly the region of attachment of the anterior group of pedal muscles under that shell.

FIG. 3. Diagram of the anterior end of Chiton viridis, Spengler (shells I, II, III, IV, apophyses of V), seen from the ventral side after removal of the viscera and of the pedal and mantle muscles, showing the muscles of the shells and regions of the attachments of the muscles of the foot and mantle and of buccal muscles.

FIG. 11. Diagram of the muscles of the buccal mass (C. viridis, Spengler) as seen from the dorsal side. The dotted lines represent the position of the radula at a lower level, beneath the radula sheath, which, in this region, is extended laterally, dorsal to the cartilages.

FIG. 12. Diagram of the muscles of the buccal mass (C. viridis, Spengler) as seen from the ventral side.

FIG. 13. Diagram showing approximately the relations among the attachments of the pedal muscles to the shells.

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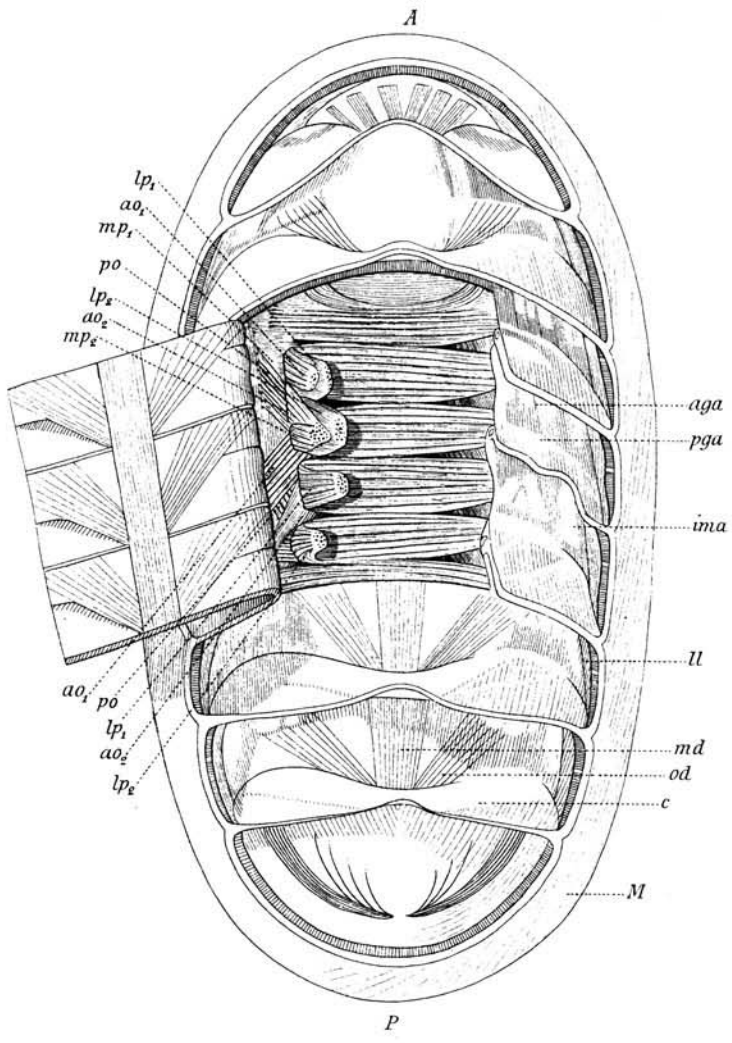

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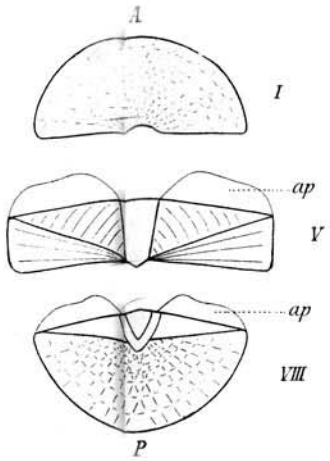

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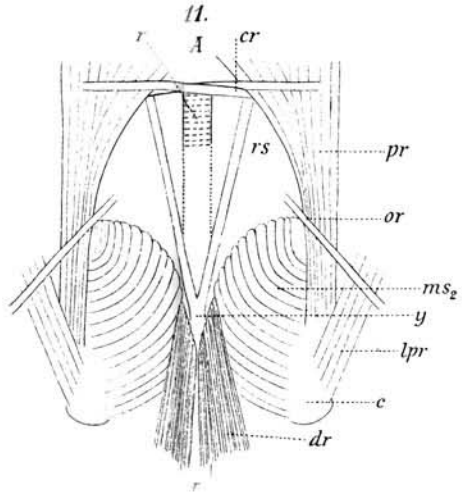

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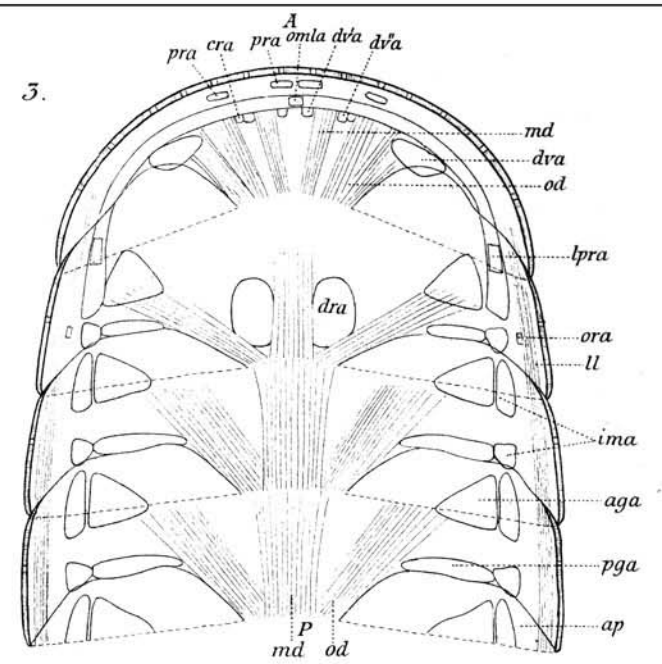

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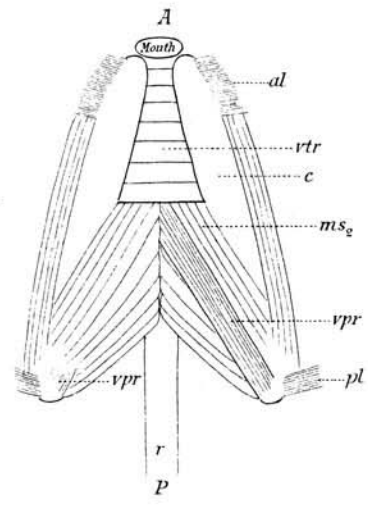

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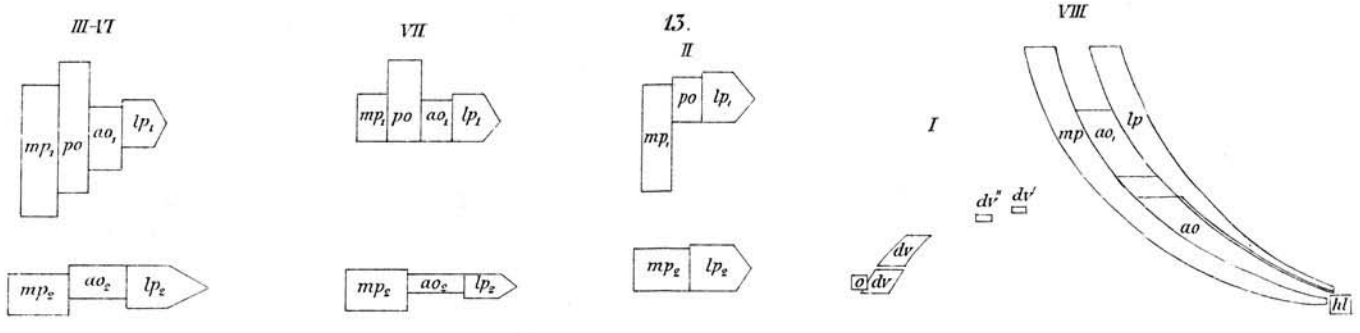

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EXPLANATION OF PLATE XXXII.

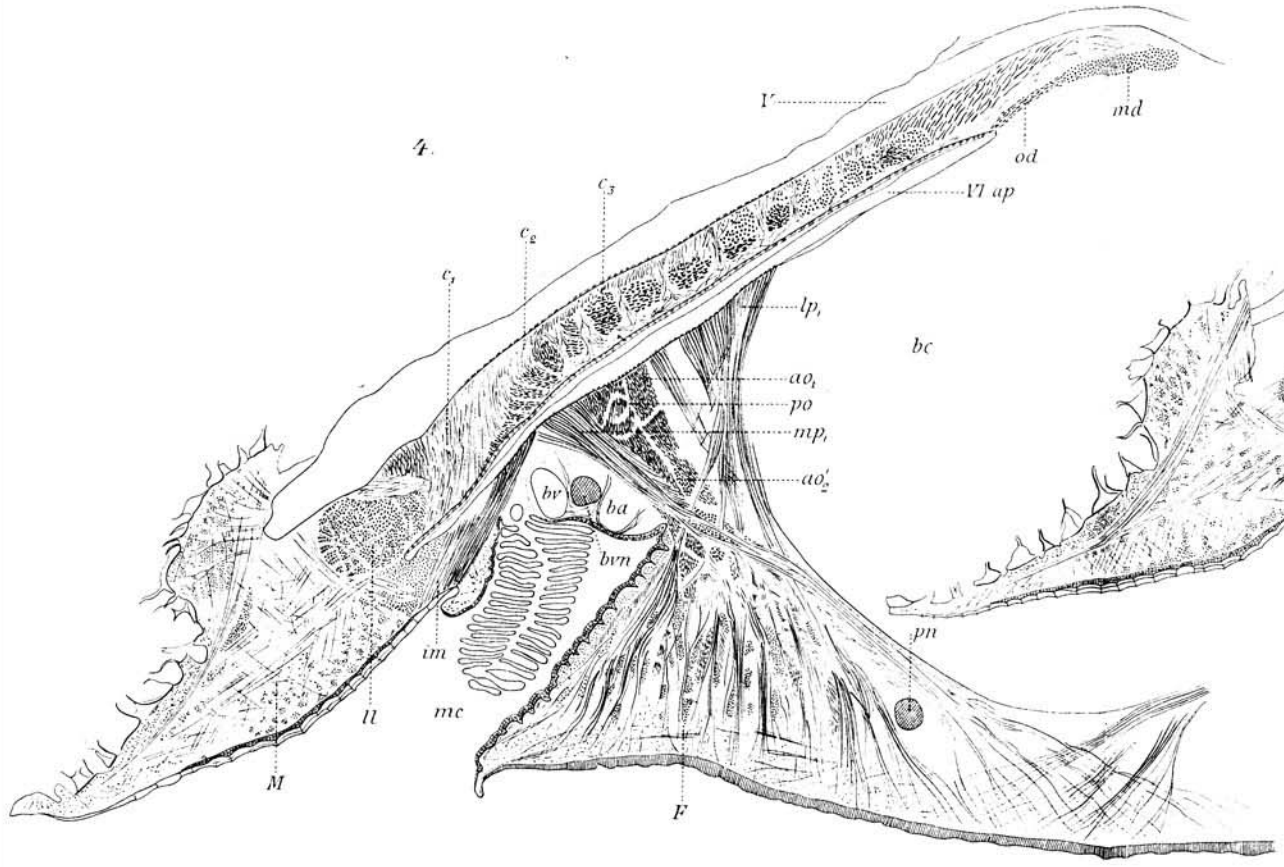
The figures of sections are drawn from preparations of C. olivaceus.

FIG. 4. Cross-section through the anterior group of pedal muscles on one side under VI. Interior mantle muscle (*im*) is cut immediately posterior to the region where a break occurs for blood supply to the mantle. Camera drawing, × 28.

FIG. 5. Cross-section through the posterior group of pedal muscles on one side under VI. Interior mantle muscle (*im*) is cut immediately anterior to the region where the main blood supply passes to the mantle. Camera drawing, × 28.

FIG. 6. Sagittal section through the attachments of the latero-pedal muscles of the anterior and posterior groups under shell V; showing also the posterior group under IV and the anterior group under VI. Camera drawing, × 28.

FIG. 7. Cross-section through one side of the posterior region under I. Camera drawing, × 28.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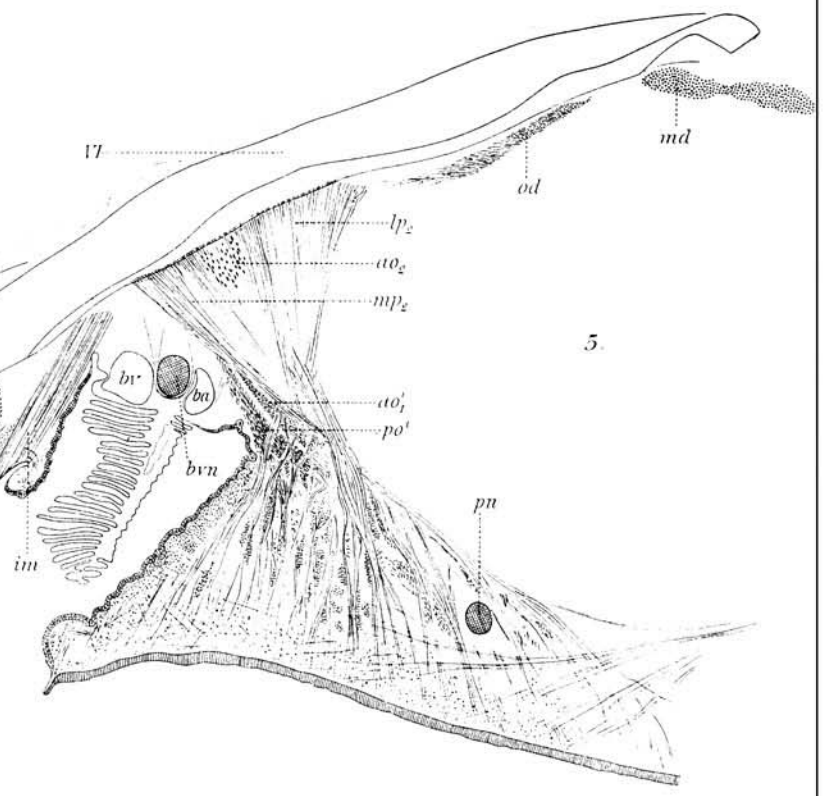
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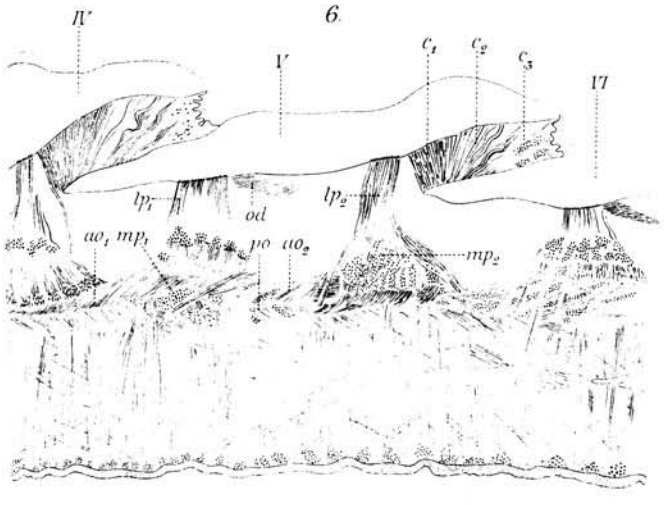
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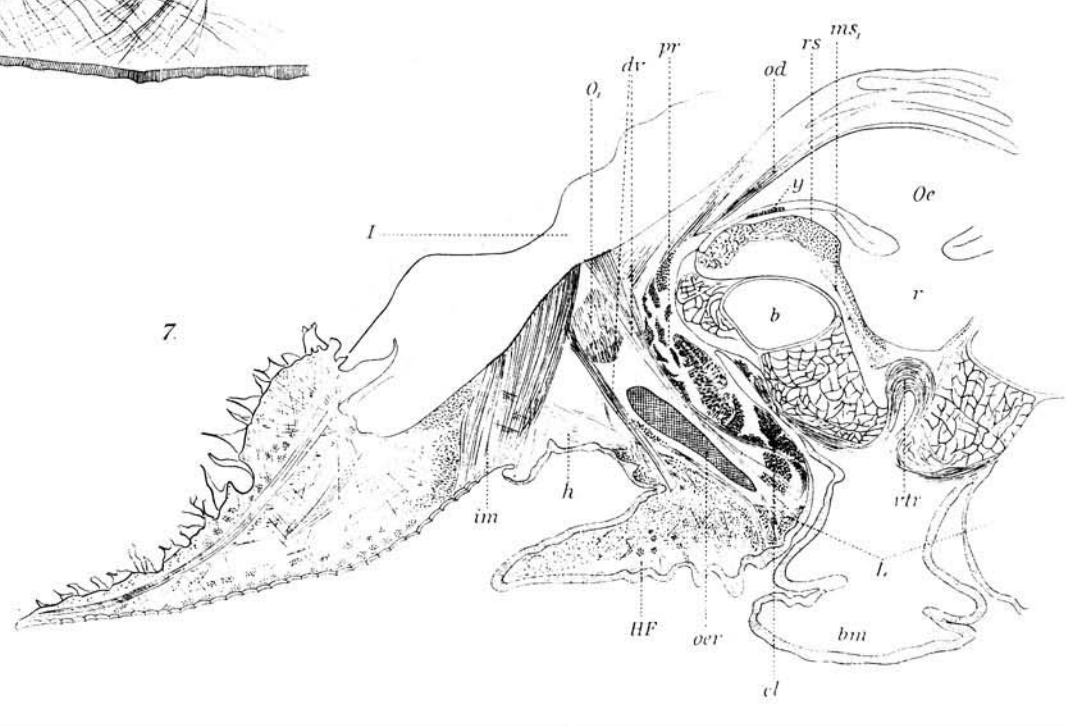
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EXPLANATION OF PLATE XXXIII.

FIG. 8. Median sagittal section under I. Camera drawing, × 28.

FIG. 9. Cross-section through buccal mass on one side under II. Camera drawing, × 28.

FIG. 10. Cross-section through buccal mass on one side more posterior than Fig. 9. Camera drawing, × 28.

PLATE XXXIII MISSING