The external morphology of the Mormon cricket (Anabrus simplex Haldeman) with special reference to exoskeletal factors involved in the penetration of sodium arsenate dust

by Leo W Tannenbaum

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the degree of Master of Science in Entomology
Montana State University

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THE EXTERNAL MORPHOLOGY OF THE MORMON CRICKET (*Anabrus simplex* Haldeman) WITH SPECIAL REFERENCE TO EXOSKELETAL FACTORS INVOLVED IN THE PENETRATION OF SODIUM ARSENITE DUST

By

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ABSTRACT

The external morphology of the Mormon cricket was studied in its entirety in order that exoskeletal factors involved in sodium arsenite penetration might be better understood. Of special interest were thorax modifications. The mesothoracic spiracle is unusual because it consists of two separate openings leading into individual tracheas. Twenty-three figures of the insect's anatomy are here included.

After trying some thirty plastics and paraffins a paraffin melting at 38-40°C. was used to localize sodium arsenite penetration. A simple test for cricket normalcy was devised. It was noted that crickets go through definite stages in their ability to react to simple stimuli after the sodium arsenite applications have begun to penetrate. Nine lots of the Mormon cricket were dusted on different parts of the body to determine if preferential penetration exists. Applications to membranous areas which are not too smooth resulted in earlier reactions and slightly earlier 50% mortality points. Wide portions of sclerotized areas were not far enough behind in this respect to be significant. It was concluded that other factors besides degree of sclerotization, such as position in respect to major organs, were of great importance and would modify the results. Analysis indicated that time of death and amount of penetration of sodium arsenite are not closely related.

INTRODUCTION

The Mormon cricket, Anabrus simplex (Hald.), is an important pest of several agricultural and range crops in Montana and certain other Western states. Control in recent years has consisted, for the most part, in the use of sodium arsenite as a dust. This insecticide has been of general use throughout those states infested. Although it is known to be a powerful poison little is known either of its method of penetration or of the exoskeletal factors involved. Since penetration does take place through the exoskeleton, the outer parts of the insect influence it and may well be factors regulating the efficiency of control. This paper has a twofold purpose: (1) a study of the external morphology of the Mormon cricket so that the exoskeletal areas may be better understood, and (2) experimental determination of the barrier the major exoskeletal areas offer to penetration of sodium arsenite dust.

To carry out the first purpose a complete study of the external morphology was made. To carry out the second purpose, experiments were conducted to determine or gather information on the following points: (1) the possible existence of parts of the cricket more susceptible to penetration than other parts, and (2) the relation of amount of penetration to the time necessary for fifty per cent mortality.

The author is greatly indebted for suggestions and criticism to Dr. H. B. Mills under whom this study was conducted. Mr. Ellsworth Hastings has taken a kind interest in chemical aspects of the work, and Dr. G. C. Crampton, of the Massachusetts State College, has offered valued criticism in its morphological aspects. Mr. D. J. Pletsch has been most helpful in matters dealing with illustrations. All these kind services are greatly appreciated by the author.

Section I

EXTERNAL MORPHOLOGY

No complete morphological study of a decticine Orthopteran is available in the literature. Snodgrass (1909), in discussing the thoracic sclerites of the various Orders, illustrated three views of the mesothorax of *Anabrus simplex*. The same author (1937) in considering the male genitalia of Orthopteroid insects discussed the male terminalia of this species. Insects in related groups have been treated in greater detail. Crampton (1930) made a detailed study of the head of *Stenopelmatus*. The same author in a series of papers (1915-1938) paid special attention to the phylogenetic relationships of the Grylloblattidae and other Orthopteroids, and studied in a comparative fashion the head, mouthparts, and thoracic sclerites in Orthoptera and related orders. Walker in a series of papers (1919-1933) dealt with subjects in the same general manner. Of especial interest to this study are this author's papers (1919b, 1922) on the terminal structures of Orthopteroid insects. Yuasa (1920) studied the anatomy of the head and mouthparts of Orthoptera. Gurney (1936) made a complete study of *Ceuthophilus* and its phylogenetic position.

HEAD

The head of *Anabrus* is similar in many respects to the heads of *Stenopelmatus* and *Ceuthophilus*. The marked, broad dorsal roundness and the smoothness of *Stenopelmatus* are lacking. These differences may be related to the differences in habit since *Anabrus* does not burrow as does *Stenopelmatus*. In its more general characteristics the head of *Anabrus* is more like that of *Ceuthophilus* since antennae and eyes are more centrally as well as more dorsally located. These characteristics may be taken for evidence that Anabrus has departed further from the more primitive type than has Stenopelmatus.

Head capsule: When seen from in front as shown in fig. 1, the head capsule of Anabrus is oblong-ovoid in shape. The coronal suture cs which represents the stem of the Y-shaped epicranial suture is plainly but not strongly demarked. It extends centrally terminating at a point near the distal end of a prominent raised process, the fastigium, fas. The latter is homologous with the process occurring in Licodia, Paranabrus, Ceuthophilus and other genera. Frontal sutures, which represent the arms of the Y-shaped epicranial suture, are not present in Anabrus. Immediately below the fastigium, fas, and almost at right angles to the line of the coronal suture, cs, are suture-like folds caused by the close proximity of antennal sockets and fastigium, fas.

On each side of the coronal suture cs are the regions known as parietals par. The areas above and behind the compound eye e are the temples or tempora te. The regions below and behind the eyes are the cheeks or genae ge. Above the compound eyes e and extending toward the postoccipital suture pos of fig. 2 is a suture here considered to be temporal suture tes. Because there are no frontal sutures the frons f may be considered to be the area below and between the antennae extending down to the frontoclypeal suture fcs. Beneath the gena ge and separated from it by the epistomal suture es is the subgena or basimandibulare bm. The latter is separated from the mandible md by the basimandibular membrane bmm. In the Mormon cricket each epistomal suture es extends mesad meeting its fellow on the other side. The portions of the epistomal sutures es between the frons f and the clypeus c comprise the frontoclypeal suture fcs. In Anabrus coincident with the sutures labelled es are the frontal pits fp, the roots of invaginations forming the pretentorium pt of fig. 5. Anterior to the frontoclypeal suture fcs is the clypeus c.

If the head capsule be viewed from the rear as in fig. 2 the postgenal suture pgs may be seen to separate the genae ge from the postgenae pge. The postgenal suture pgs leads upward from the subgena bm and is lost or discontinued in the occiput. In Anabrus it meets two thickened or buttressed areas. The lower one labelled bu is an easily seen thickened area between the postgenal ridge pgs and the postocciptal suture pos. Slightly above this area and running through the terminus of the postgenal suture pgs is the temporal suture tes.

Eyes: The compound eyes e are not very large but are relatively larger than the eyes of Stenopelmatus and Ceuthophilus. This may be in line with the suggestion of Crampton (1930) that there seems to be a marked correlation of insects having both small eyes and long sensitive antennae in insects with hiding habits. Anabrus with less marked hiding habits than the two above mentioned genera has larger eyes and relatively shorter antennae than Ceuthophilus.

The ocelli in Anabrus are vestigial and may be non-functional. The median ocellus is present as a light spot below the fastigium fas. The lateral ocelli are present as similar spots at about the widest point of the fastigium as shown in fig. 1.

Occipital region: The postoccipital suture pos of fig. 2 separates the postgena pge from the postocciput po. The postocciput po bears a pair of processes, the occipital condyles occ upon which the lateral cervical plates are articulated. The occipital condyles in Anabrus are small sclerites which are folded on their long axes. They are separated from the postocciput merely by grooves. Posterior to the submentum sm and the postocciput po is the membrane of the cervix. If this membrane be removed a posterior view would be had of the posterior tentorial arms poc and the occipital foramen ocf of which an anterior view is had in fig. 5.

Tentorium: The tentorium is the endoskeletal portion of the head capsule. It is very similar to the type seen in the more generalized Orthopteroid insects. The tentorium is formed by invaginations of the head capsule. If the labrum, clypeus, and the anterior portion of the head capsule be removed from a 10% KOH preparation the parts of the tentorium may be seen as in fig. 5. The anterior arms or pretentorium pt extend backward from the frontal pits fp of fig 1 as invaginations. The dorsal arms or supratentorium st are of a thin and tendonous nature and rise anterior to the body of the tentorium or eutentorium eu. Immediately anterior to the body of the tentorium eu is the neural foramen nf. Through the neural foramen pass commissures connecting the brain and the suboesophageal ganglion. Extending forward from the gular pits gp seen in fig. 2 as invaginations are the posterior arms of the tentorium or parocciput poc. The posterior arch p is also a result of the invagination. The body of the tentorium eu may be considered as a fusion of anterior and posterior tentorial arms. In fig. 5 also, may be seen an ental view of the rear portion of the head capsule. Besides the added strength given to this portion by a thick parocciput poc there is further buttressing bu above the parocciput. The postgenal process pp is also thickened in that area within the dotted line in the figure. In the postgenal process pp is the postgenal acetabulum pga a socket for the hypocondyle h of the mandible seen in fig. 4. Along the lower edge of the postgenal process is a thickened marginal area, the parastomium pst.

HEAD APPENDAGES

Antennae: About the base of the antenna is a ring, the antennale an of fig. 3. In Stenopelmatus and Ceuthophilus the antennale bears a median projection for pivotal purposes, the antennifer. In Anabrus the antennifer is lacking. The basiscape of Stenopelmatus and other insects is also lacking in Anabrus. However, there is a small "inpushed" tendon-connection (in the membrane immediately anterior to the first antennal segment) which helps in moving the antennae. The antennae are long and thread-like, in most cases slightly longer than the body. The number of antennal segments is variable,in some specimens reaching more than one hundred and forty. The first antennal segment or scape sc is broad and flattened. Basally it has projections which aid in pivoting the antennae. The segment next to the scape, the pedicel pd, is more cylindrical and is followed by the postpedicel ppd. The postpedicel and all other segments distal to it are known collectively as the flagellum. Flagellar segments may be divided into the short segments or brachymeres, and long segments or dolichomeres. In Anabrus long brachymeres lb, short brachymere sb, and slender dolichomeres sd, may be easily distinguished. Intermediate types are also present.

Clypeus and labrum: In many insects the clypeus may be divided by differences such as coloring into a posterior postclypeus and an anterior anteclypeus. This division is apparent only faintly in Anabrus. If the labrum la and clypeus c are inspected from an inner or buccal view as in fig.7 the epipharynx may be seen. The greater part of the epipharynx is covered by fine sensory hairs. Two main divisions may be distinguished, an anterior preepipharynx pre and a posterior postepipharynx poe. These two areas correspond to the labrum and clypeus respectively. The epipharyngeal area has several small sclerites. The tormae to are a pair of small sclerites situated near the labro-clypeal lateral angles, and thus delimit the labrum and clypeus. Between the labrum and clypeus and extending transversely between the tormae is a small sclerite, the intertorma it.

Mandible: Beneath the basimandibular membranes bmm of fig. 1 are the paired jaws or mandibles md. The mandible is roughly pyramidal in shape and the space within it is filled with tissue. The base is triangular and there are three faces. In fig. 4, a posterior view of the dextral mandible, the rear face may be seen. The apex of the roughly pyramidal mandible is the tearing area or gnathapex ga. The grinding portion, or mola m is proximad of the gnathapex. A brustia or brush br is present on the biting edge near the base. The base of the mandible has two articulatory points. The posterior articulatory point, the gnathocondyle or hypocondyle h of fig. 4.fits into the postgenal acetabulum pga of the postgenal process pp shown in fig. 5. Anterior articulation for the mandible is afforded by means of the ginglymus gi. The ginglymus (shown in figs. 1 and 4) fits into a groove in the side of the clypeus. To the extensor prominence ep (on the outer edge of the mandible near the hypocondyle h) is joined the extensor tendon et which helps open the mandible. Near the median ridge of the mandible, at its base, is the tendon sclerite or gnathite gn to which is attached a large flexor tendon ft. In Anabrus both the gnathite gn and flexor tendon ft are slightly modified from their homologs in Ceuthophilus and Stenopelmatus. The gnathite gn is not readily distinguishable as a separate sclerite and is fused with the flexor tendon ft. The flexor tendon is very large since it is in closing the jaws during chewing that strength is most needed. At its base it extends more than half the distance to the gnathocondyle h. Extending inwardly, the flexor tendon ft is composed of one large posterior portion closely apposed to the base of three additional narrow branches. The endognath eg is an internal shelf at the base of the mandible.

Maxilla: In fig. 2 there may be seen a posterior view of the sinistral maxilla. The labium and hypopharyngeal regions are connected to the maxilla by means of the basimaxillary membrane b. The basal segment or cardo of the maxilla is divided by the cardinal suture or cardosuture cds into a basal basicardo bc, and a distal disticardo dc. Distal to the cardo are the stipes s and the parastipes ps which are separated by the parastipital suture pss. When the posterior side of the cardo and stipes are viewed entally as in fig. 6 an internal ridge, the endocardo ec corresponds to the cardosuture cds, and another internal ridge, the endostipes est corresponds to the external parastipital suture pss of fig. 2. The internal ridges offer additional support to the maxilla and afford places of attachment for muscles. The endostipes est affords attachment for the flexor muscles of the maxilla. The disticardo dc is enlarged by an extruding bulge which supplies space for muscles. A process not seen externally (unless the maxilla is pulled out) the cardoprocess cp offers attachment to the cardotendon ctn. The extensor muscles act in conjunction with the latter to open the maxilla by pulling it away, laterally, from the mesal part of the head. The condyle acting in this operation is the articulatory process of the basicardo d which pivots externally on a process of the paroccipput poc. In *Anabrus* a division of the stipes into basal and distal regions is not perceptible. A small region the palpifer pf is clearly seen. It bears the five-segmented maxillary palpus mp. The fifth segment of the maxillary palpus bears a rather large sensitive area at its tip. The stipes s bears distally an outer galea and an inner lacinia l. The galea is divided distinctly into a basigalea bg and a distigalea dg. In *Anabrus* the basigalea is not much wider than the distigalea at their juncture and the latter is blunt, not slender and graceful. In fig. 9, an anterior or mesal view of part of the maxilla, five sensory areas may be seen on the galea. A large area at the tip of the distigalea is obvious; basad of this and indicated by fine lines are four less easily distinguished sensory areas the function of which is obscure. At the distal end of the lacinia l are two tooth-like projections the laciniadentes ld. A third process the lacinula lii is joined to the lacinia by means of a socket which can be better seen from the anterior view. The lacinia bears a fringe of setae on its mesal border. In *Anabrus* there is present also, on the anterior face of the lacinia, a process with probable sensory function which is similar in appearance to those on the galea.

Labium: The labium may be seen in fig. 2. The glossae gl and the paraglossae pgl are attached to the glossiger gg. The portion of the labium immediately basad of the glossiger gg is the labial stipites li. In *Anabrus* demarcation of the glossiger gg from the paraglossae pgl and glossa gl is more easily distinguished on the posterior than on the anterior face of the labium. On the anterior face as shown in fig. 8, the line of division is not perceptible. A basal area the basiglossa bgl may be seen basad of the glossa gl. Sutural division between the labial stipets li and glossiger gg may be seen as in fig. 2.

The palpiger pg is lateral of the sclerites li and bears the three-segmented labial palpus lp. Crampton (1930) has discussed the theories on homologies of labial and maxillary parts mentioned above. The labial stipites li and the mentum mn are separated by a membranous area. The mentum mn is distinct in *Anabrus*. It has a notched appearance distally. To the mentum are attached internally muscles which move the labium. In *Anabrus* latero-basal to the mentum are the anterior arms of the submentum asm (anterior arms of postmentum of Snodgrass) which extend back to the main body of the submentum sm. The large membranous area between the anerior submental arms and between the mentum and submentum is the submental membrane. It has two degrees of membranization. The portion between the anterior arms behind the dotted line shown in fig. 2 is slightly darker and harder than that portion immediately anterior to it. In insects of this rather primitive hypopnathous type the gular region is generally considered to be the rear portion of the plate labelled sm, or alternatively, that it has not yet developed as in the more advanced prognathous type. The gular pits gp are situated near the base of the plate labelled sm. They are the openings to invaginations which form the posterior arms of the tentorium poc of fig. 5.

There is no postgular plate as there is in Stenopelmatus.

Hypopharynx: The hypopharynx hp of fig. 10 is a fleshy tongue-like structure found in the median ventral part of the head between the labrum and labium. It is very much like the hypopharynx of Stenopelmatus. In fig. 10 the hypopharynx hp is seen to be composed of several parts. The distilingua dl is the region at the free end. It is sclerotized for the most part but portions are very thin as shown in fig. 10. The basal region of the hypopharynx is composed of a dorsal dorsolingua or surlingua sl immediately anterior to the mouth and a ventral membranous basilingua bl. The salivary duct opens into the basal basilingua above the labium. In Anabrus on the side walls of the distilingua dl a pair of plates afford attachment for the hypopharyngeal retractor muscles. A slender sclerite the lingualora ll is in the basal portion of the hypopharynx as is also the postlingua pl.

CERVIX

The cervix is the membranous neck region immediately behind the head and immediately anterior to the prothorax. In *Anabrus* the cervical area is much larger than it appears since normally it is partially concealed beneath the anterior border of the pronotum. In figs. 13 and 18 the cervix is shown to have three pairs of plates. The large lateral sclerite *lc* of fig. 13 is the laterocervicale. It is one of a pair, its fellow being on the other side. The anterior end of the laterocervicale *lc* articulates with the occipital condyle *occ* of fig. 2. Ventrad of these as seen in fig. 18 are the ventral cervical sclerites *vc*. Dorsad of the lateral cervicales are a pair of small dorsal cervical sclerites *dcs* connected so closely mesally as to suggest that they are a single central sclerite.

THORAX

The thorax of the Decticinae has been little investigated. Snodgrass (1909) drew three views of the mesothorax of Anabrus. Most notable in the anatomy of Anabrus is that elongation of the pronotum has been accompanied not only by prothoracic modification but also by modification of the pterothorax as well. In Anabrus the tegmina have been so shortened that in the male they reach only to the middle of the first abdominal tergite and in the female they are even shorter. The wings in both sexes are represented only by membranous pouches. The thoracic spiracular apparatus offers an interesting modification which may be seen in certain other insects of the subfamily.

PROTHORAX

Pronotum: The pronotum pn of fig. 13 extends back from the membrane of the cervix to a point above the middle of the metathorax. It is free dorsally from a point anterior to the mesothoracic tergum. The pronotum pn covers the episternum eps_1 and the epimeron epm_1 so that they are only partially visible. In this study specimens of Anabrus simplex examined from Montana and eastern Idaho, the pronotum was found to be very smooth and carinae and sulci were only very faintly indicated. Gurney (1939) stated that carinae are rare in the genus except in Anabrus longipes but suggested the possibility of longipes being a subspecies of simplex. As in other Orthopteroids, Anabrus has no prothoracic spiracle.

Propleuron: The first portion of the propleuron is a narrow border-like sclerite, the prepectus ppc, which extends ventrally and continuously through the sternal area. The dorsal terminus of the prepectus ppc is coincident with that point at which the episternum eps_1 is overgrown by the pronotum pn. The episternum eps_1 is closely united with the pronotum. If the pronotum is removed the episternum is seen to be almost triangular in shape and to extend almost to the dorsum. At its base the episternum is continuous with the precoxale $prcx_1$. The pleural ridge plr is a mesal inflexion of the episternum extending along its posterior edge. At its lower portion the pleural ridge is represented externally by a suture, the pleural suture pls which separates the episternum eps_1 from the epimeron epm_1. In the generalized thoracic segment the pleural ridge bears an internal arm or apophysis which is closely associated with the ventral apophysis (furca). The pleural apophysis is absent in the prothorax of Anabrus. Unlike most Orthopteroids the epimeron epm_1 of Anabrus is a short sclerite. The major portion of the epimeron has been lost and as may be seen in fig. 13 only enough of the epimeron exists for the pronotum to overlap. The shortness of the epimeron is a useful adaptation since it allows for more flexible movement of the pronotum. At the basal extremity of the external portion of the episternum in Anabrus there is a small sclerite upon which the trochantin tn_1 pivots. The small sclerite is very probably a portion of the primitive coxopleurite, part of which has fused with the anopleurite to form the pleuron and part of which has remained a free sclerite, the trochantin tn_1.

Prosternum: Posterior to the prepectus ppc of fig. 18 is the basisternum bs. The furcal pits fup are the outward evidences of sternal apophyses which form the furca fu_1. The furcal pits fup are inwardly connected by a ridge or sternacosta of which the outward evidence is, in Anabrus, a groove the sternacostal suture stcs. The sternacostal suture divides the eusternum into two parts. The anterior part is the basisternum bs; the posterior portion is the sternellum or furcasternum fs. The furca is useful for support of the prothorax and for muscle connection. Posterior to the furcasternum fs_1 and separated from the latter by a narrow membranous area is the spinasternum ss, which in Anabrus is a very narrow transverse sclerite. The spinasternum ss bears the spinal pit spp an outward evidence of an internal apodeme, the spina spi. The spina in Anabrus is roughly hammer-like in shape.

PTEROTHORAX

Mesonotum: In fig. 14 the dorsum of the male pterothorax is shown. Immediately behind the intersegmental membrane is the acrotergite atg_2 of the mesothorax. The antecostal suture acs divides the acrotergite atg_2 from the prescutum psc. Internally the suture is represented by an apophysis or prephragma ph. The prephragma ph of fig. 14 is shown as in the male. In the female the prephragma ph is shorter. The scutum sct is the area immediately behind the prescutum psc. In Anabrus the scutum is marked sparingly with setae. The slightly raised area behind the scutum sct is the scutellum scl. Extending posteriad from the antecostal suture to opposite the rear tip of the scutellum and running along the side of the processes mentioned above are the maxillary sclerites by means of which the tegmen is articulated. These sclerites will be discussed under "articulation of the wings". In the male Anabrus the posterior part of the mesonotum is folded under immediately behind the scutellum scl and then refolded to form the postscutellum pscl. The first fold, visible as the posterior sclerite of the eunotum is the posttergite ptg. In the female cricket the postscutellum is absent.

The spiracles sp are considered part of the tergum throughout the body. Anabrus presents a special modification of the mesothoracic spiracle sp_2 of fig. 13 which is not evident in Stenopelmatus or Ceuthophilus. In the membrane between the propleuron and mesopleuron of fig. 13 there may be seen a "biforous" spiracle. The mesothoracic spiracle of Anabrus consists of two openings each of which leads to a trachea. The larger (posterior) opening is unusual for an Orthopteroid in that it is guarded by numerous tiny satae. This large opening gives immediate entrance to a large air-sac type of trachea. The smaller, anterior opening is guarded by two small sclerites. The posterior sclerite appears to be part of the peritremal sclerite of the posterior opening. The smaller opening gives immediate entrance to a small trachea. The tracheae of both entrances do not lead into a common chamber and apparently are in no way connected. Although this is not a respiratory study a brief note on the tracheae involved will not be out of place. The large air-sac type of trachea is connected transversely with its fellow on the other side of the thorax by means of a very narrow trachea. From the body of the sac a large trachea leads directly to the front leg. The large trachea is about one-third the diameter of the leg itself and extends down the leg past the auditory apparatus aa of fig. 12. The smaller (anterior) trachea extends cephalad. It bears several branches at the head. Midway between the head branches and the orifice this trachea gives off a branch sharply in a ventral direction. This branch divides several times also; one of the subsidiary branches descends to the front leg and another to the long ventral tracheal chain.

Metanotum: The metanotum of Anabrus is somewhat like the mesonotum. The acrotergite atg_3 is followed by the prescutum psc_3. The prephragma ph_3 is much smaller than in the mesonotum. The scutum sct is anterior to the scutellum scl. In Anabrus both sexes lack the metathoracic postscutellum or postnotum. To the dorsolateral area, to which is articulated the wing in the mesothorax, is attached a membranous wing pouch w_3.

Mesopleuron: Snodgrass (1909) drew figures of the internal and external mesopleuron of Anabrus simplex. This author points out the existence of a preepisternum homologous to that seen in Gryllus, Dissosteira, and Melanoplus. The sclerite in question is separated from what Snodgrass (1909) called episternum by a suture which runs almost the full length of the episternum. Gurney (1936) noted the existence of "a lengthwise suture" on mesopleuron and metapleuron in Ceuthophilus. These sutures would appear to be homologous to those similarly placed in Anabrus. In this paper, the preepisternum will be considered merely as part of the episternum, and that the episternum eps_2 is separated from the epimeron epm_2 by the pleural suture. The pleural suture pls is represented internally by a pleural ridge which extends down from the wing process wp_2 of fig. 13 to the pleural coxal process. The pleural ridge of the mesopleuron branches near its upper extremity and comes forward to support the episternum. The anterior portion of the episternum is divided transversely by a suture. At the base of the tegmen are two paraptera. The one anterior to the wing process wp_2 is the basalare ba_2, that posterior to the wing process $\underline{wp_2}$ is the subalare $\underline{sa_2}$. Both are aids in wing manipulation and are used for muscle attachment. The pleural apophysis pla is an invagination forming an internal arm continuous with the pleural ridge. The pleural arm is closely associated at its distal end with the furca. The precoxale $\underline{prcx_2}$ of the mesothoracic pleuron is basally contiguous with the base of the anterior episternum (preepisternum of Snodgrass). It should be noted in fig. 13 that the precoxale of the mesothorax is considerably shorter than the one present on the propleuron.

Metapleuron: The metapleuron is very much like the mesopleuron. Perhaps the most striking difference is the modification attendant to the atrophy of the wings. In *Anabrus* neither sex is able to fly. The anterior and posterior lateral edges of the episternum $\underline{eps_3}$ have fused with the metanotum mtn of fig. 13. The wing process $\underline{wp_3}$ has not only fused with the notum but also has fused with the subalare $\underline{sa_3}$. The basalare $\underline{ba_3}$ is closer to the episternum $\underline{eps_3}$ (being separated from the latter only by a suture) than the corresponding parts of the mesothorax. The suture which divides the episternum $\underline{eps_3}$ into two parts does not run through the full length of the latter. There is no precoxal bridge in the metapleuron.

Mesosternum: As shown in fig. 18 the mesothoracic basisternum of *Anabrus* is divided into two parts, the anterior basisternum $\underline{abs_2}$ and the posterior basisternum $\underline{pbs_2}$. The anterior basisternum $\underline{abs_2}$ is composed of two roughly quadrate sclerites which are projected well below the level of surrounding membrane. Two broad spines project below the basal portion of the posterior basisternum $\underline{pbs_2}$. Immediately posterior to the spine-bearing process there is a median triangular impression in the sternum.

The triangular area bears the roots of three apophyseal processes which form the furca $\underline{fu}_2$. This sclerite is the double sclerite furcasternum plus spinasternum $\underline{fss}_2$. Internally furca and spina are joined. The distal ends of the furca $\underline{fu}_2$ are closely associated with the distal ends of the pleural apophyses pla of fig. 13. The spina of the mesosternum bears one median and two pairs of lateral projections.

Metasternum: The metasternum of Anabrus is divided into an anterior basisternum $\underline{abs}_3$ and a posterior basisternum $\underline{pbs}_3$. The anterior basisternum $\underline{abs}_3$ is a single prominent sclerite. The posterior basisternum $\underline{pbs}_3$ is marked by the presence of two prominent broad spines. The furcasternum $\underline{fs}_3$ is united with the posterior basisternum $\underline{pbs}_3$. As in other Orthopteroids except Grylloblatta the spina is lacking in the metasternum.

Articulation of the wings: The tegmina are articulated by means of axillary sclerites. In fig. 14 their disposition and number may be seen as well as the disposition of other pteralia in the male thorax. The tegula tg is a small hairy scale-like lobe at the anterior base of the tegmen. Between the tegula tg and articulated with the Costa is the humeral plate hup. The first axillary sclerite lax in Anabrus is supported by an anterior notal process which is bent under the main body of the notum so that a good portion of the axillary is hidden beneath the notum also. The anterior end of the first axillary lax articulates with the complex of costal, subcostal, and radial veins which have anastamosed at the base. The second axillary 2ax is hinged mesally to the first axillary and the vein complex mentioned above is flexibly attached to its outer side.

The second axillary 2ax may also be seen on the ventral side of the tegmen in fig. 13 where it articulated with the mesothoracic wing process wp_2. The third axillary 3ax, because of the centralization and merging of most of the important longitudinal veins of the tegmen represents in *Anabrus* a fusion of the third axillary and the two median plates which are usually basad of the Media, Cubitus, and first Anal vein. The remaining tegmen articulation represents an interesting intermediate stage. It is generally considered that the fourth axillary is a strongly sclerotized portion of the posterior notal process which has become separated from the latter. The posterior apex of the third axillary articulates with the fourth axillary when it is present and with the posterior notal process when the fourth axillary is not present. In *Anabrus* an intermediate condition exists. The sclerite labelled 4ax in fig. 14 is separated from the main part of the posterior notum by a thinly sclerotized area which is not, strictly speaking, membranous. The sclerite labelled 4ax may therefore be considered to be a part of the posterior notal process. Since it is more highly sclerotized than the rest of the posterior notal process and is fused with the posterior apex of the first axillary 1ax it is here considered to be an axillary 4ax. The fourth axillary sclerite 4ax articulates with the third axillary sclerite 3 ax.

In the female *Anabrus* the tegmen is more reduced and shows an even more strongly fused group of axillaries. All are apparently present in a less sclerotized state than in the male.

Wings: It can be seen in figs. 22 and 23 the tegmina of the sexes differ. The tegmen of the male is larger. In this sex the Costa, Subcosta, and Radius are present together as large ridge with the several veins composing sub-ridges. Very little other venation is recognizable because the tegmen is so atrophied. The male Anabrus stridulates by means of the tegmina. As in many other stridulatory insects the left tegmen folds over the right. Both tegmina bear a file-like vein on the ventral surface. Stridulation is accomplished when the tegmina are vibrated, the file on the ventral surface of the left tegmen being scraped on the veins near the posterodorsal margin of the right tegmen. The right tegmen is less highly sclerotized than the left. The median cell in the right tegmen is almost hyaline. The female tegmina are shorter and thicker than those of the male. They cannot be folded over each other. All that remains of the venation in this sex is the presence of four longitudinal ridges in a homologous position to the ridges on the male tegmen. The female has no means of stridulation. All that remains of the wings in both sexes is a membranous pouch w_3 of figs. 13 and 14.

LEGS

Although the legs could have been considered in the discussion of the pleural areas, they are here discussed together for convenience and ease of comparison. The prothoracic leg may be seen in lateral view in fig. 12 and its basal articulation may be seen in figs. 13 and 18. In fig. 13 the coxa cx_1 is seen to have two means of articulation. The first is the pleural coxal process (a projection of the pleuron); the second is the trochantin tn_1. The coxa cx of fig. 12 is rather broad. It bears a basal border the basicoxite bcx which is set off from the main distal portion of the coxa by a suture (the basicostal suture). The basicoxite bcx in the foreleg of *Anabrus* bears one small fronto-lateral process and two mesal knob-like processes which are probably sensory in nature. The more lateral striated process may be seen in fig. 12. The mesal knob-like processes bear tiny setae and may be seen in fig. 13 where the coxa cx_1 has been pushed rearward for purposes of illustration. The coxa bears one very large spine and numerous small setae. The main body of the coxa bears a small invagination (indicated by the dark pit in fig. 12) which is used for muscle connection. The coxa articulates with the trochanter tr by means of two fulcral points k, k which are seen best in fig. 13. Near the fulcral points the coxa is strengthened by internal ridges which are represented externally by sutures which cut off small sclerites from the main coxal walls. The coxa and trochanter are connected loosely by membrane. The trochanter tr and femur fe are joined firmly. Both bear tiny setae. The femur fe of fig. 12 is ridged and flat beneath. The mesal ridge of the femur bears several spines. Both lateral and mesal ridges usually bear a pair of small apical spines. The tibia ti is quadrate-cylindrical in cross section and of uniform thickness. The under side is somewhat flattened. The tibia ti bears a variable number of spurs. The usual arrangement is six ventral pairs, a laterodorsal row of five, and two or three on the mediodorsal surface. Near the base of the tibia ti of fig. 12 there may be seen a slit labelled aa. This slit is matched on the mesal side by another slit. The two together comprise the auditory apparatus. Below the auditory apparatus aa there is a pair of small impressions one of which may be seen in fig. 12. The impressions are deeper than faint tibial grooves which lead into them. The tarsus tar is four-segmented. The four segments are loosely joined and in fig. 12 have been pulled apart to show their articulation to better advantage. The first tarsal segment is the longest and broadest; the fourth is almost as long and is the most slender. The third tarsal segment is distinctly bilobed. Fig. 11 is a ventral view of the pretarsus of the foreleg. The pretarsus is attached to the fourth tarsal segment ta_4. The unguitractor plate utr when pulled by the tendon ten moves the unguis.

Mesothoracic leg: As in the foreleg the coxa cx_2 of figs. 13 and 16 articulates on a pleural coxal process and on the trochantin tn_2. Like the first trochantin, the trochantin tn_2 is rather boot-like in shape. Its basal end articulates with the pleuron at the terminus of the suture which divides the episternum eps_2 into two parts, and thus is closely associated with the posterior end of the precoxale $prcx_2$. The membrane between the base of the coxa and the trochantin is marked by a narrow line-like sclerotization which delimits the inner attachment of the basicoxite bcx and is indicated in fig. 13 by a light dotted line. The basicoxite bcx bears knob-like processes as in the foreleg. The pleural articular socket pas of fig. 16 articulates with the pleuron and divides the basicoxite into two parts. The posterior portion of the basicoxite is the meron mer. The trochanter tr articulates loosely with the coxa at two points. The trochanter has an internal basicosta (represented by an external suture) which gives it a marginal sclerite. This proximal sclerite bears a small setae-bearing process similar to the areas present on the basicoxite. The trochanter tr and femur fe are joined firmly. The femur is grooved beneath and bears a variable number of spines. The tibia ti is shaped very much like the tibia of the foreleg and bears a variable number of spurs. The four-segmented tarsus tar is attached to the tibia and bears the claws or ungues ung.

Metathoracic leg: A lateral view of the hind leg may be seen in fig. 15. The hind leg is very large and is not drawn to the scale of the other legs for this reason. The coxa cx is marked by a suture on its posteroventral side. Posteroventral views of this and the other two coxae may be seen in fig. 18. In most respects the coxa is very much like that of the mesothoracic leg. The trochanter tr is very small and when not pulled out as in fig. 15 can hardly be seen. The trochanter is joined firmly to the femur fe. At the base of the femur a basicostal suture separates a marginal sclerite from the remainder of this leg segment. The femur bears a variable number of spines. The tibia ti bears numerous spines and spurs. The pulvillus of the first tarsal segment is divided to form plantulae pln.

ABDOMEN

The abdomen of Anabrus is essentially similar to those of other Tettigoniidae. Walker (1919) discussed female terminal abdominal structures of Orthopteroids in a manner which affords easy comparison with homologous structures in the Mormon cricket. Snodgrass (1937) stated that Anabrus and other Decticinae exhibit some important phallic modification.

Abdominal segments: The abdomen of Anabrus is rather cylindrical in shape. As shown in fig. 19 there are ten abdominal tergites t_{1-10}, and nine sternites s_{1-9} in the male. The female as shown in fig. 20 has ten abdominal tergites and eight sternites. In both sexes the membranes between the tergites are almost as wide as the tergites themselves. Normally most of this membrane is hidden in the telescoping of the abdominal segments. The sternum, however, does not reveal a similar equality of sclerite and membrane. Therefore, if the abdomen of Anabrus were drawn out fully it would appear quite like a semi-circle. The sternites are very small and the membranous pleural area very large. The membranous pleural area is composed of dorsal, pleural, and ventral membrane. The tergites and sternites are distinct.

Spiracles: There are eight pairs of abdominal spiracles sp in Anabrus. All are located in the membrane. An abdominal spiracle consists of two small sclerites which guard the opening to the trachea.

TERMINAL STRUCTURES OF MALE

Tergites: Starting with the eighth tergite t_8 of fig. 19 the tergites are smaller than those preceding it. Except for a tiny median dorsal area the anterior border of the tenth tergite t_{10} is almost entirely hidden from external view both by the posterior edge of the ninth tergite and by membrane. The tenth tergite t_{10} presents a secondary modification. The median portion is of a membranous nature as shown in figs. 19 and 21.

Sternites: The ninth sternite s_9 of figs. 19 and 21 is larger than the other sternites. This sternite is the subgenital plate. It is divided transversely by a suture. The posterior portion of the ninth sternite bears styli sty. In primitive insects such as *Grylloblatta* the styli sty are borne by coxites. The ninth sternite in *Anabrus* is considered, therefore, to bear united ninth coxites. Gurney (1936) pointed out that styli are not present in Ceuthophilus but are present in *Rhaphidophora*, *Neoconocephalus*, and *Scudderia*.

Cercus: The male cercus is broad unsegmented, hooked apically and with a tooth directed mesally. Cowan (1929) used the cercus to identify the instars of *Anabrus simplex*. Gurney (1939) pointed out that the size and angle at which the tooth projects from the main body of the cercus may be used to separate *A. simplex* and *longipes* from *cerciata* since in the latter the inner tooth is large and projects at right angles.

Anal sclerites: About the anal opening a of fig. 21 are three sclerites. The supra-anal plate sap is often called the epiproct by systematists and was so called by Snodgrass (1937). However, the former term was applied to the tenth tergite by Crampton (1929, 1931) as Gurney (1936) pointed out. On each side of the anal opening a and below the supra-anal plate sap are the paraprocts ppt which are well defined sclerites in Anabrus.

Penis: Snodgrass (1937) discussed the penis of *Anabrus simplex.* The tettigonioid type of phallic structure bears in a modified form the three pairs of phallic lobes usually present in the Orthoptera. The lateral phallic lobe lpl may be seen in fig. 19. Beneath the lateral phallic lobe the posterior edge of the ventral phallic lobe vl may be seen. The dorsal phallic lobe is hidden internally and cannot be seen in fig. 19. It divides the phallic cavity in two acting as the floor of the upper cavity. The ventral phallic lobe is the floor of a ventral cavity or spermatophore sac. The sclerotic arms of the phallus rest upon the top of the dorsal phallic lobe.,

TERMINAL STRUCTURE OF FEMALE

General features: The most marked differences from the abdominal sclerites of the male are seen starting at the eighth segment. The eighth and ninth tergites t_8 and t_9 of fig. 20 differ in shape from the homologous male tergites. The tenth tergite t_{10} is rather similar to the tenth tergite of the male. There are only eight complete abdominal sternites in the female. The valvifer vf is a part of the ninth abdominal sternite. The eighth abdominal sternite s_8 articulates with the lower edge of the eighth tergite t_8. The cercus ce of fig. 20 is slender and not broad and hook-like as that of the male shown in fig. 19. The supra-anal plate sap and paraprocts ppt are similar to those of the male.

Ventral valves: The valves of the adult female *Anabrus* fit together tightly to form a sword-like ovipositor which is as long as the