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ON TWO LITTLE-KNOWN SPECIES OF THE EARTHWORM GENUS *DIPLOCARDIA*¹

G. E. Gates²

Few zoologists realize how little is known about the earthworms of North America. An erroneous assumption that their distributions in the United States are adequately characterized certainly seems to have been involved in some recent zoogeographical discussions.

During the last 16 or so years, Professor D Elden Beck of the Department of Zoology and Entomology, Brigham Young University, Provo, Utah, has been collecting earthworms on his travels through various states from Maine to California. Those collections eventually will provide information about some of the many areas with unknown faunas. A series from a single site provides the basis for much of this first report on the "Beck" material.

That series is of interest for two reasons: (1) It provides the first record of an earthworm from the state of New Mexico. (2) The species is native, not exotic as is each of the three hitherto reported from the adjacent state of Arizona.

A single specimen of the same species from Wisconsin, under different circumstances, could have been of equal interest. However, it is noteworthy that only two megadrile taxa had been reported from Wisconsin hitherto. *Alltolobophora turgida* Eisen, 1874, recorded by Ude in 1885, could have been any one or more of three different species. Another, *Sparganophilus eiseni* Smith, 1885, was recorded by Hague from the state as long ago as 1923.

No single species was added to the short list of Arizona earthworms since 1900. Fortunately, Professor Beck has interested Professor T. W. Barrett of Arizona State University, Tempe, in adding to our limited knowledge of the area. As a result of Professor Barrett's early collecting, it is now possible, for the first time, to record a North American native from Arizona.

Diplocardia verrucosa Ude

1895. *Diplocardia verrucosa* Ude, Zoologischer Anzeiger, 18:339. (Type locality, Omaha, Nebraska. Types in the Zool. Mus., Hamburg, Germany.)

1. From research financed by the National Science Foundation.
2. University of Maine, Orono.

1962. *Diplocardia verrucosa* Murchie, Ohio Journal of Science, 62:185. (Two subspecies recognized after examination of a "syntype" and other specimens.)

HABITAT.—New Mexico (Hidalgo County). Rodeo, six inches below the surface in sticky, black, gumbo-like soil under a rank growth of Russian thistle, February 27, 1966, 1 (+ 16 mostly juvenile and 10 fragments?)—0-30. D E. Beck.

Wisconsin (Dane County). Between Arena and Mazomanie, damp, willow, swamp loam. September 22, 1963, 0-0-1. Christina Hobby.

EXTERNAL CHARACTERISTICS.—Size, 80 by 4 mm. (Wisconsin), to 107 by 3 mm. (New Mexico, but softened). Undisturbed specimens in the soil, according to Professor Beck, reached a length of six inches. Segments, 118 (Wisconsin). Color, white, clitellum yellowish brown. Prostomium, epilobous; tongue narrowing to a point, or open, with a transverse furrow slightly behind anterior margin of the peristomium. Secondary annulation, one presetal and one postsetal secondary furrow present per segment beginning with v or vi. Setae, small, retracted; follicles not visible in coelomic cavities, AB ca. = CD , little difference in sizes of BC and AA or $BC < AA$ (Wisconsin), DD ca. = $\frac{1}{2} C$, $a, b/xix$, xxi penial, $a, b/xviii$ lacking. Nephropores, inconspicuous whenever distinguishable at or slightly above D and so in a single rank on each side of the body. First dorsal pore, at 9/10 (1 specimen), 10/11 (9, including Wisconsin), ?11/12 (2), 11/12 (3).

Spermathecal pores, transverse slits (New Mexico), small, but obviously larger than the other genital apertures, superficial, at or close to A , just behind intersegmental furrows 7/8 and 8/9. Centered around each spermathecal pore (New Mexico) is a small circular area of slight tumescence. Female pores, paired, anteromedian to a , in some New Mexico specimens within a single small field lacking clitellar coloration. Seminal grooves, broad and shallow, nearly straight, in AB between eq/xix and eq/xxi . Male pores, each on a tiny spheroidal protuberance from bottom of seminal groove, at or immediately behind probable level of 19/20. Two follicle apertures are present at each end of a seminal groove, sometimes definitely not within the grooves. The body wall seems to be slightly thickened ventrally in xix - xxi , but aside from the grooves there is no specially characterized male field (New Mexico). The ventral region between grooves of the Wisconsin worm is slightly tumescent and after staining seemed to contain three pairs of slight circular tumescences. Clitellum, saddle-shaped (all), extending down to B (Wisconsin), nearly to mV (all New Mexico), reaching into $xiii$ and xix (Wisconsin), in xii - xix (1), $xiii$ - xix (28), $xiii$ - xx (1), lacking ventrally in xix or xix - xx .

Genital markings, lacking (all New Mexico specimens). Each marking of the Wisconsin worm has a circular area of translucence surrounded by a broad rim of slight epidermal tumescence so

shaped that the marking has a circular to shortly and transversely elliptical shape. Markings, usually paired but not median when single, usually in the region of *AB* or centered there. Locations, only approximate because of invisibility of intersegmental furrows in some areas. 8/9, postsetal in ix, x. (in x on left side only and centered at *A*), 10/11 just lateral to *B*, presetal in xviii, xix, postsetal in xxi, xxii, xxiii, perhaps also in xxiv but there tumescence slight and no translucence is recognizable.

INTERNAL ANATOMY.—Septa, 4/5 membranous, 5/6 muscular and translucent, 6/7-8/9 (Wisconsin) thickly muscular, thickness of 9/10-12/13 decreasing posteriorly, 6/7-12/13 (New Mexico) slightly muscularized. The usual subpharyngeal and subesophageal horizontal mesenteries are present. Pigment, none visible in sections through the body wall. A special mid-dorsal, longitudinal muscle band is present from the region of 10/11 to the hind end. Pharyngeal glands, confined to region in front of 4/5.

Gizzards, rather weak, in v-vi (11). Calciferous glands and lamellae, lacking. Esophagus (Wisconsin) not especially wide in any segment, with a ventral typhlosole and numerous, low, closely crowded nonlamelliform vertical ridges in x-xiii. Intestinal origin, doubtfully in xvi (Wisconsin and 2, New Mexico), in xviii (8, New Mexico). Such variation seemed unusual. After determining intestinal origin in the eight specimens, the other two New Mexico worms were reexamined. An esophageal valve was unrecognizable. The gut in xvi-xvii certainly was grossly distended by the ingesta. Condition does not permit determination of the nature of the tissues in the region in question. Typhlosole, beginning in the region of xx-xxi, relatively fairly high, simply lamelliform, ending abruptly in the 87th segment (Wisconsin).

Dorsal blood vessel, single from the periproct to region of iii where it passes under the brain and bifurcates (Wisconsin). The branches shortly attenuate to invisibility. Ventral trunk, complete. Supra-esophageal trunk, at least in part empty and extent not determinable. Extra-esophageal trunks, median to hearts, close to or on the gut in vii-xiii. Posterior lateroparietal trunks, no trace recognized though probably present. Subneural trunk, unrecognizable throughout and probably lacking. Hearts, of vii-ix (perhaps also of x) lateral, of xi-xii probably latero-esophageal. Last pair of hearts, in xii (11). A large, looped vessel from the dorsal trunk passes down to the ventral parietes on each side of the body and just in front of each septum in the intestinal region. A short, transparent thread sometimes seems to connect such a segmental vessel to the ventral trunk.

Nephridia, present from ii, without recognizable vesicles, small, simple, investing peritoneal cells not distended, funnels about at *A*, ducts passing into parietes at *D* gap in the musculature.

Seminal vesicles, medium-sized, acinous, in ix and xii; the anterior pair sometimes with several fairly large lobes, the posterior

pair sometimes with more but smaller lobes. Sperm ducts, without epididymis, coming into contact in xiii, at least through xviii not united, in xix just lateral to prostatic ducts, not traceable to the male pores. Prostates, large, in some or all of xiii-xxiv, once reaching into xxviii, to 15 mm. long and 0.5 mm. thick. Prostatic ducts, only a little thicker than the slender penisetal follicles, without muscular sheen, 2+ mm. long (Wisconsin), 1+ mm. long (New Mexico). Diagonal muscles in region of the male field (New Mexico) are few and weak. Penisetal follicles, shorter than the prostatic ducts, do protrude slightly into coelomic cavities.

Spermathecae, small to medium sized, ampullae empty and strongly contracted (Wisconsin), large and reaching to the dorsal parietes (New Mexico). Ducts, slender and shorter than the ampullae. Diverticulum, approximately discoidal, vertically placed, with a row of seminal chambers somewhat like the teeth of a comb, opening into the duct just below the ampulla. As so described, the diverticulum looks much the same as in various other species of *Diplocardia*. However, in present specimens of *verrucosa*, as well as in various congeners, individual organs often deviate more or less widely from the norm described above. Thus, the seminal chambers may not be in a row but arranged in an arborescent pattern. The organ may be more or less deeply bi-, tri-, or quadri-lobed or otherwise. One lobe may be much larger than the others and without iridescence. The bottom of each of several New Mexico ampullae was occupied by a flat and markedly iridescent disc. That material is continuous with the contents of diverticular seminal chambers. Obviously the seminal chambers did not have space enough to hold all of the seminal fluid.

Follicles of *a* and *b* setae of viii-x are just visible in the parietes and probably do not contain specially enlarged and modified (copulatory) setae.

Ovaries, fan-shaped, each with several egg-strings, which are short (New Mexico) or long (Wisconsin). Ovisacs, small, in xiv (Wisconsin).

REPRODUCTION.—Iridescence on male funnels is brilliant and indicative of massive production and aggregation of sperm. Iridescence also is obvious in spermathecal diverticula, proving that copulation had been completed. Accordingly, and in absence of any definite evidence to the contrary, reproduction can be assumed to be amphimictic.

INGESTA.—Very fine-grained, black (Wisconsin) or red (New Mexico) earth in which few plant fragments were recognizable. The species appears to be geophagous.

PARASITES.—Coelomic cavities of posteriormost segments (Wisconsin) were filled with spheroidal cysts. Nematodes and other foreign organisms were not seen.

SYSTEMATICS.—The two subspecies are distinguished from each other by situation of ventral boundary of the clitellum, location of spermathecal pores, shape of seminal grooves, and patterns of genital-marking location. The Wisconsin worm has genital markings as do both subspecies, is more like the Oklahoma subspecies, *recta*, as regards clitellar boundaries and spermathecal pore locations. New Mexico worms also have the *recta* location of spermathecal pores but a *verrucosa* clitellar boundary and are distinguished from both subspecies by absence of genital markings as well as by a more posterior intestinal origin.

REMARKS.—One fourth of the area of Wisconsin is a major part of some 15,000 square miles that until recently was called the Driftless Area. The name indicated a belief that the region had not been glaciated during the Quaternary. A much better chance of survival would seem to have been provided earthworms by such an area than by the possibly bare, mountain-peak nunataks on which living organisms sometimes are thought to have survived through Ice Age millennia. Collections eventually procured for the author from the Driftless Area contained only one specimen of a native American species. Any importance that individual might have had was dissipated by geologists who found that all of Wisconsin had been covered by ice. Although the glaciation of the region in question is described as light, earthworms are unlikely to have survived therein.

D. verrucosa is, of course, endemic somewhere in America—though just where still is to be determined. No information is available as to self-migration rate of any diplocardia. There is, however, no good reason for believing sufficient time has been available for migration to Wisconsin from well below the southern limit of the ice sheet. Presence in Wisconsin then is due to transportation and probably by man since the first European settlement. Elsewhere *D. verrucosa* has been recorded from Lake St. Marys, Ohio (a single specimen), central Illinois (where Harman, 1960, found it in 16 counties), Omaha (Nebraska), and two counties in Oklahoma. The Ohio site, as also all Illinois sites, is within the glaciated area. Introduction to Ohio and to Nebraska is anticipated. Unfortunately, our knowledge of Illinois earthworms dates only from 1885, but even so, introduction to central Illinois does not seem impossible or even improbable. Certainly there seems to be no reason at present for suspecting introduction by man to the two Oklahoma counties.

The other distributional discontinuity may at first seem suggestive of human introduction to New Mexico. However, the paucity of information about the earthworms of an area extending from central Texas to the Pacific Ocean at present contraindicates any such conclusion. Also, very much more needs to be learned about distributions within the diplocardian refugium. Texas straight east to the Atlantic Ocean.

Diplocardia texensis Smith

1924. *Diplocardia keyesi texensis* Smith, Proceedings, United States National Museum, 66(12):2. (Type locality, Chillicothe, Texas. Types, 2, both sectioned, in the U. S. Natl. Mus.)
1965. *Diplocardia* sp., Bhatti, Proceedings, Pennsylvania Academy of Science, 39:8.

HABITAT.—Arizona (Gila County). Watershed F at 3 Bar Watershed, at ca. 3,800 feet, upper six inches of soil underneath a *Turbinella* oak bush, March 31, 1966, 5-0-0-2. T. W. Barrett per D E. Beck. Sierra Ancha Exp. Forest, moist, dark, clay loam (soil sample #107) from thicket of walnut and oak trees, about one mile from waterfall at head of Workman Creek, at 7,450 feet, November 22, 1966. 0-1-0. Floyd Stockton per T. W. Barrett.

Pennsylvania (Delaware County). Swarthmore, bank of Crum Creek, November, 1962, 0-1-1, H. K. Bhatti.

Texas (Lubbock County). Lubbock, flower bed, August 16, 1955, 0-0-2. J. E. Sublette per W. J. Harman.

(Victoria County), 0-1-0, (U.S. Natl. Mus. No. 57489). Victoria, 5 miles southeast of town, prairie region, October 7, 1941, 0-2-13. J. D. Mitchell. (U.S. Natl. Mus. No. 57463).

EXTERNAL CHARACTERISTICS.—Size. 44-100 by 2.0-2.5 mm. Segments, 74, 83, 100 (posterior amputees?). 121 (Swarthmore), 122 (+?), 129, 130, 131 (2 specimens), 132, 134, 135, 136, 142, 147, 156 (Lubbock). Color, white. Secondary annulation, usually pronounced behind male field except in last 8-20 segments, a pre- and postsetal secondary furrow per segment, the posterior secondary annulus usually with a well-marked tertiary furrow and other tertiary furrows may be present. Such annulation makes counting of segments very difficult especially as setae often are unrecognizable externally and dorsal pores are not distinguishable. Body, with a nearly circular cross section posteriorly. Prostomium, epilobous, tongue closed (Swarthmore and 5 Arizona), open (17). Setae, present from ii where none are lacking, $AB =$ or slightly $< CD$, BC much $< AA$, DD ca. $= \frac{1}{2} C$, posteriorly BC may become so much smaller as to be only slightly larger than AB , a, b follicles of viii, ix, xviii-xx confined to parietes and in them setae usually seem to be lacking. Nephropores, when detectable, about at D in iii-vi or vii (several), posteriorly at or well above D but without regular alternation in level, and accordingly in a rather irregular single rank on each side of the body. First dorsal pore, at 7/8? (1 specimen). ?8/9 (4), 8/9 (1), ??9/10 (1), ?9/10 (1), 9/10 (3), ??10/11 (2), ?10/11 (1), 10/11 (2), ???11/12 (1), ??11/12 (1).

Spermathecal pores, sometimes obviously larger than other genital apertures, superficial, each within a very small protuberance, at or close to A and slightly or immediately behind 7/8, 8/9. Female pores, anteromedian and much closer to a than to each other, within a distinctly delimited transverse area (occasionally dumbbell shaped) that covers the anterior half of xiv in AA (14),

a female field unrecognizable in the other worms. Prostatic pores, at ends of seminal grooves and hence at eq/xx and eq/xxii, in *AB*. Male pores, each on a very small tubercle in a seminal groove and at or just behind level of 20/21, perhaps about at eq/xxi of one Texas worm. Seminal grooves, nearly straight, deep and wide. A postequatorial and preequatorial furrow in xxii, between the *A* meridians, of the Swarthmore specimen, at first appear to be median continuations of 20/21 and 21/22, with the seminal grooves seemingly confined to xxi. Intersegmental furrows are, however, obliterated across the male field. The latter is not distinctly demarcated, nor is it depressed, but it is distinguished by a greater epidermal opacity that extends well into *BC* between 19/20 and 22/23. Genital markings, lacking (all).

Clitellum, reddish brown reaching just below *A* (Swarthmore), to just below *C* in xxi, to *mBC* in xx, in other segments to well below *A* or nearly to *mV*, from eq/xiv to 16/17 (1),) or annular in xiv (1), xiv-xv (1), dorsal pores occluded, setae retained, intersegmental furrows obliterated (Swarthmore) or faintly indicated dorsally and gradually becoming more obvious ventrally (some Texas), in xii-xx (Swarthmore, 1 Arizona), xiv-xix (12), xiii/n-xix (1), xiii-xx (2), xii-xxi (Lubbock).

INTERNAL ANATOMY.—Septa, 4/5 membranous, 5/6 slightly thickened, 6/7-10/11 increasing a little thicker, 11/12 muscular and opaque or translucent, 12/13 slightly muscular and translucent. Insertions on parietes laterally of 6/7-10/11 are posterior to levels of corresponding intersegmental furrows. Special longitudinal muscle band at *mD*, too indistinct to be helpful in determination of function of pore-like markings. Gaps in longitudinal musculature show that *AB* obviously < *CD*. Pigment, unrecognizable in sections of body wall.

Gizzards, two, in v-vi (14). Calciferous glands and lamellae lacking. Esophagus usually of nearly uniform width throughout, very slightly widened in xii-xiii, xii-xiv, viii, or xiv and then thin-walled, or even much widened in xviii (2). The inner wall may have at *mV* a well-marked and blood-gorged ridge lateral to which there are low and rounded, red or white, nonlamelliform, vertical or longitudinal ridges, or ridges may be replaced by villiform protuberances. Intestinal origin, in xix (12). A widening of the gut in xviii of two worms is believed not to be intestinal but condition did not permit certainty. Typhlosole, first recognizable in region of xxi-xxiii, low but thickened lamelliform, height gradually decreasing posteriorly, unrecognizable behind 50th (1), 80th (1), 63rd (147), or 74th (of 142), segments. The lamella in a posterior amputee of 83 segments was rudimentary behind the 44th and was unrecognizable behind the 63rd.

Dorsal trunk, single throughout (5), complete, bifurcating under brain, the branches uniting (1) to become the ventral trunk which also is complete. Supra-esophageal, single, adherent to gut reaching

into ix and xii. Extra-esophageals, median to hearts, on gut from ix or x through most of xiii. Posterior lateroparietal trunks recognized only from xxi or xx, turning up to join the extra-esophageals on the anterior face of 12/13. Subneural trunk, no trace recognized in any dissected specimen, probably lacking. Hearts, in v not traceable all the way to ventral trunk, in vi-ix lateral, in x-xii probably latero-esophageal though no blood is present in filaments passing to dorsal trunk, last pair in xii (14). Segmental commissures, behind clitellum are covered by a layer of chloragogue that often is thicker than the vessel itself.

Nephridia, small, simple, seemingly avesculate, on parietes in *AD* or from *mBC* to somewhat lateral to *D*, ducts passing into parietes about at *D* (or? entrance often not recognizable because of condition).

Seminal vesicles, acinous, nearly filling coelomic cavities (Swarthmore) but larger in xii. Vesicles of ix were not found in several Texas specimens and must have been rather small unless disintegration was involved. Sperm ducts, slender, those of a side uniting in xx shortly before disappearing into the parietes of xxi. Prostates, 5-9 mm. long (Swarthmore and some Texas), *ca.* 2 mm. long and laterally directed in own segments (Lubbock), or in a U-shaped loop in own segment, or variously twisted or extended, in one worm reaching back into xxviii. Ducts, slender, without muscular sheen, 1-2 mm. long, sinuous or in one or two shortly U-shaped loops, passing into body wall at *B* gap. Diagonal muscles, although a number are present in xx-xxii, appear to be weak, no depression or elevation of male field was recognizable. Follicles of ventral setae may protrude slightly into coelomic cavities of xx and xxii but often seem to have no shafts. When present, setae are straight or nearly so, unornamented or with several fine teeth scattered near the tip.

Spermathecae, small, medium-sized, or reaching to or slightly above level of dorsal face of gut. Ducts, shorter than, as long as, or somewhat longer than the ampullae, narrowest within the parietes and gradually widening entally but without becoming markedly thickened. Diverticulum, as usual attached by a mesentery to the posterior face of the septum in front, along lateral face of duct entally, rather sausage-shaped, sessile (no stalk), opening into duct directly through a single aperture in a middle portion, with 2-5 seminal chambers indicated by the nearly discrete balls of sperm. Copulatory setae were not recognized in ventral follicles of viii-ix.

Ovaries, fan-shaped, with several short or long (and then with as many as 20 ova) egg strings. One egg string of a Texas specimen passes well down into the oviduct of its own side. Oviducts, narrowed behind 13/14. (Ovisacs, recorded by Smith, were not recognized.)

REPRODUCTION.—Spermatozoal iridescence is brilliant on male funnels of dissected clitellate specimens with ovarian ova in discrete egg strings. Iridescence in spermathecae was confined to the diverti-

cult, and as usual in worms of many other species, was not recognizable in the main axis. Iridescence was lacking in Texas individuals with ovaries still not separated into discrete egg strings even though clitella seemed to be well developed. Copulatory transfer of sperm having been demonstrated by the spermathecal iridescence, reproducing yellowish or reddish fragments.

DISTRIBUTION.—A self-acquired range from Pennsylvania to Arizona would be very much larger than that of any other diplocardia. Such is not to be expected of a species that seems, in several ways, to be highly specialized. Absence of records for *texensis* between the Delaware and Mississippi Rivers is of no significance at present because of the paucity of information about earthworms of that area.

Several diplocardias probably have been carried around the United States by man who may have been responsible for presence of *texensis* in the vicinity of Philadelphia as well perhaps as also in Arizona.

SYSTEMATICS.—Relationships suggested by the male terminalia are with *Diplocardia keyesi* Eisen, 1896, known only from descriptions of a single sectioned worm from Baja, California. Differences from worms herein referred to *texensis* now seem too great to be attributable to individual or even to intraspecific geographic variation. An intestinal origin in xv, in *Diplocardia*, certainly seems to be primitive. Origin in xix, recorded for each of thirteen specimens of *texensis*, now seems to represent greatest esophageal elongation in the genus. However, much more information about variation in each of the two taxa is needed.

PARASITES.—Two small nematodes were found in coelomic cavities of a Texas worm.

REMARKS.—Intestinal contents show the worms are geophagous. Soil particles were mostly quartz grains along with bits of mica and black mineral particles of similar size (Pennsylvania) or (Lubbock worms) rounded quartz grains with occasional black bits and numerous yellowish or reddish fragments.

Unusual thickness of the clitellum of one Texas worm is not associated with presence of mature sperm but with spermathecae and ovaries that seemingly are juvenile. The clitellar tumescence may then sometimes be a preservation artifact rather than an indicator of height of breeding activity.

Usually seminal grooves or diplocardias are recognizable before the epidermis of clitellar segments begins to become tumescent and also after that condition has completely disappeared. As types were said to be clitellate, supposed absence of seminal grooves needs an explanation, especially as there seems to be no reason to suspect that parthenogenesis (which would allow their elimination) is involved.

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