horizontal distribution. A form belonging to this genus has been met with deep within the Arenig formation; and its most recent species marks the highest known zone of the Bala rocks.

In the Llandeilo rocks of Wales forms of *Dicellograptus* are common; but the genus does not appear to attain its maximum until we reach the higher zones of the Glenkiln shales. In the succeeding Lower Hartfell beds examples occur in countless multitudes on several horizons, but the species are fewer. In the highest Birkhill only two species are known.

The most conspicuous species is *D. sextans*, Hall, which marks the Upper Llandeilo and Glenkiln shales in Wales and Scotland and their equivalents in Scandinavia and in North America. *D. complanatus*, Lapw., and *D. anceps* are the characteristic fossils of the Upper Hartfell beds, as *Dicellograptus Forchhammeri*, Geinitz, is of the Lower Hartfell.

Dicranograptus.—The genus *Dicranograptus* (which is, morphologically, merely a *Dicellograptus* whose branches are conjoined proximally for a portion of their length) is as yet unknown in the Upper Arenig. Its oldest known species is of Llandeilo age. It attains its specific maximum in the Glenkiln zones, only two British species surviving into the Lower Hartfell. In the Upper Caradoc subdivision the genus is as yet unknown.

The most conspicuous species is *D. ramosus*, Hall, an Upper Llandeilo and Glenkiln fossil in Britain. Like its associate *Cænograptus gracilis*, Hall, its horizontal distribution appears to have been almost world-wide.

[To be continued.]

VI.—On the Internal Structure of the Brain of *Limulus polyphemus*. By A. S. PACKARD, Jun.

SEVERAL years ago I attempted to study the brain of the horse-shoe crab (*Limulus polyphemus*), and had it sliced into a large number of sections. Owing to interruptions these sections, made from unstained alcoholic specimens, were not examined. During the past winter I have been able, with the aid of Mr. N. N. Mason of Providence, to take up the study afresh. Mr. Mason has kindly made sections, both transverse and horizontal, stained with osmic acid,—also sections of the brain and supracæsophageal ganglion of the

lobster, stained with picrocarmine, for comparison. The following results, then, are based on over two hundred sections of the supracæsophageal ganglion of *Limulus*, but more especially on two brains, which were cut by Mr. Mason each into over fifty sections, from $\frac{1}{1000}$ to $\frac{1}{500}$ of an inch in thickness. The examination of a few sections of the lobster's brain enabled me to comprehend more readily the recent papers of Dietl, Newton, and Krieger on the brain of the Decapodous Crustacea and of the Insecta, and thus gives me a standard of comparison by which to study the topography and histology of the brain of *Limulus*.

General Anatomy of the Brain.—The singular relations of the central nervous system of the adult *Limulus* have been fully described and beautifully illustrated by A. Milne-Edwards; and Dr. Dohrn and myself have described its general anatomy in the larval stage. The central nervous system of *Limulus* consists of an œsophageal collar, mostly made up of six pairs of ganglia, from which nerves are distributed to the six pairs of foot-jaws (gnathopods), while the ring is closed or completed in front by the brain, or what corresponds to the supracæsophageal ganglion of normal Crustacea and insects. In these Arthropoda the brain is situated in the upper part of the head, in a plane parallel to but quite removed from that of the rest of the ganglionic chain; in *Limulus*, however, the brain is situated directly in front of and on the same plane with the rest of the central nervous system. Milne-Edwards states that the œsophageal ring, as well as the posterior part of the nervous system, is enveloped by an arterial coat. He also states that the brain and nerves are enveloped in a similar arterial coat; but this we have failed to find. The brain is protected by a thick membrane ("perineurium" of Krieger) formed of fibrous connective tissue; and the nerves are protected by a continuation of this membrane, as several longitudinal sections of these nerves have taught us. The brain in a *Limulus* 10 inches long, exclusive of the caudal spine, is about 5 or 6 millims. in diameter; it is flattened slightly above, and on the upperside has a shallow median furrow, indicating that it is a double ganglion. Three pairs of nerves and a median unpaired one (the ocellar) arise from the upper third of the anterior face of the brain. The two optic nerves are the largest ones, arising one on each side of the median furrow, so that the fifth to fifteenth sections made by the microtome pass through them. Next below (from above downwards) is the origin of the ocellar nerve, which, as described by A. Milne-Edwards, is single, arising from the median line; on each side, and in nearly the same plane,

arise two tegumental nerves ; and directly below a second pair of larger nerves (fronto-inferior tegumental) descend vertically. No nerves arise from the lower half or two thirds of the brain, which is smooth and rounded with no median furrow underneath. It will thus be seen that, as stated by A. Milne-Edwards, there are no antennal nerves, such as exist, as a rule, in Arthropods, except Arachnida. This we have proved, in the same manner as Milne-Edwards, by laying open the arterial coat or modified neurilem, which reaches to the posterior end of the brain, and seeing that the fibres of the nerves sent to the first pair of legs originate quite independently of the brain itself.

Internal Structure and Histology of the Brain.—Transverse sections of the brain throw but little light on the topography, as the nerve-fibres extend horizontally, the nerves being sent out horizontally and from the anterior end only of the brain ; hence the examination of nearly two hundred sections threw little light on the topography, and considerable time was spent in a vain and baffling attempt at understanding the geography of this ganglion.

The study of the brain, in sections mounted in consecutive order, finally enabled me to arrive at a tolerably complete idea of the relations of parts ; so that I could mentally construct a model of the brain of *Limulus*, and compare it with the normal Arthropod brain.

The histological elements of the brain of *Limulus* are four in number :—1. Large ganglion-cells, filled densely with granules, and with a well-defined nucleus similarly filled and with a granular nucleolus. These cells may be crowded, or loose, with the granules fewer in number, and with loose thick cell-walls ; they terminate in large fibres which subdivide. 2. Similar cells, but smaller, with less protoplasm, and like those in the lobster's brain. 3. Nerve-fibres ; these, like the large-sized ganglion-cells from which they originate, are stained tawny yellowish brown with osmic acid. These fibres are large, coarse, their granular contents very homogeneous ; and they closely resemble the nerve-fibres distributed to the compound and simple eyes. Certain fibres near the origin of the optic nerves are distinctly nucleated at intervals. 4. Rounded masses, consisting wholly of nuclei, enclosed in a network of fibres, which stain dark brown with osmic acid ; these bodies form the larger part of the substance of the brain. While staining dark brown with osmic acid, in unstained alcoholic sections these masses are dark or greyish, the substance or fibres enclosing them being whitish by transmitted light. The brain is enveloped by a thick perineurium, formed

of a fibrous tissue and some (probably) elastic tissue, which occasionally penetrates into the brain-substance between the white rounded fungoid masses, forming the meshwork surrounding them. The general topography of the brain of *Limulus* is on a simple plan compared with that of Decapodous Crustacea and insects. The brain is mostly composed of large, irregular, rounded masses or balls of granules, with a thick fungoid or ruffle-like periphery, formed by a layer of secondary, smaller, rounded, granular masses. The centre of the primary masses is stained paler brown by osmic acid. These bodies are often seen in section rounded, but more often are irregular, not closed, spheroids; these dark bodies extend through the brain like ruffles. The lower half or two thirds of the entire brain is apparently filled with these nucleogenous bodies, as we may provisionally designate them. In the upper third of the brain, whence the nerves originate, the larger ganglionic cells and the nerve-fibres appear, and preserve a definite topographical relation to the entire brain. The nucleogenous bodies are confined at the top to each side of the brain; the central and hinder regions are filled with the large ganglionic cells, mixed with numerous much smaller ones; and the mass of nerve-fibres which spring from them becomes larger from the upper third to the top of the brain, where the optic fibres originate. Opposite the beginning of the optic nerves these large nerve-fibres are seen directed towards the origin of the nerves, as if they were the roots, as they undoubtedly are. In the section passing through the ocellar nerve and the tegumentary nerves on each side, the nucleogenous bodies are situated in the front of the brain; but they disappear from the front higher up at the origin of the optic nerves, and occupy a much more restricted area on the sides of the brain. Thus the tract of nerve-fibres on either side of the brain is irregularly wedge-shaped, the apex situated near the centre of each hemisphere, and the base spreading out on the top, thus crowding to the outer walls the nucleogenous bodies.

It would thus appear as if the lower half of the brain were in an indifferent state*, and the dynamic part confined to the upper third, the region giving origin to the nerves of sensation.

* This area, made up of granules and nuclei, seems really to be connective tissue, and to represent the connective tissue in which the ganglia of the embryo of the young larva are imbedded. There seems no reason why the brain should not be partly formed from connective tissue as much as the remaining ganglia, as we have seen them to be in different sections of different ganglia, all or nearly all except the supracæsophageal one.

The asymmetry of the brain is remarkable: the large ganglionic cells are most abundant in the centre behind the middle, and from there to the posterior side of the brain a median line is slightly indicated by the arrangement of the nucleogenous bodies. The tract composed of large nerve-fibres with scattered ganglionic cells on the left side is very much more extensive than on the right.

Comparison with the Brain of other Arthropods.—So wholly unlike, in its form, in the want of antennal nerves, and in internal structure, is the supracæsophageal ganglion or “brain” of *Limulus* to that of insects and the higher Crustacea, that it is very difficult to find any points of comparison.

Histologically, judging by my specimens of the brain of the lobster which are stained with carmine, the brain of *Limulus* agrees with that of other Arthropods in having similar large ganglion-cells; the smaller ganglion-cells, so abundant in the brains of insects and crustacea, are wanting in *Limulus*. There are in *Limulus* no “ballen-substanz” masses homologous with those of the other Arthropods.

Topographically the internal structure of the brain of *Limulus* is arranged on a wholly different type from that of any other Arthropodous type known—so much so that it seems useless to attempt to homologize the different regions in the two types of brain. The plan is simple in *Limulus*, much more complex in Arthropods, especially in the brain of the crawfish as worked out by Krieger, as in the Decapodous brain there arise two pairs of antennal nerves besides the optic pair; and in external form the two types of brain are entirely unlike. The symmetry of the brain of the crawfish, as of the lobster and insects, is marked throughout, each hemisphere exactly repeating in its internal topography the structure of the opposite side; that of *Limulus* is obscure and imperfect.

VII.—On a new *Species of Chiton lately found on the British Coasts*. By J. GWYN JEFFREYS, LL.D., F.R.S.

*Chiton scabridus**.

BODY thin, semitransparent, of a blood-red colour: *mantle* dirty white: *mouth* small: *foot* lanceolate, only one third the width of the body, tapering rather gradually to a fine point; the sole is marked lengthwise by six red lines, which are

* Rough.

Packard, A. S. 1880. "VI.—On the internal structure of the brain of *Limulus polyphemus*." *The Annals and magazine of natural history; zoology, botany, and geology* 6, 29–33. <https://doi.org/10.1080/00222938009458891>.

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