An AUSTRALIAN SAUROPTERYGIAN *(CIMOLIO-SAURUS)*, CONVERTED INTO PRECIOUS OPAL.

By R. Etheridge, Junr., Curator.

(Plates v., vi., vii.)

I was recently favoured by Messrs. Tweedie and Wollaston, Merchants, of Adelaide, through the good offices of Mr. H. Y. L. Brown, Government Geologist for South Australia, with a large quantity of opalised material from White Cliffs, representing the broken-up skeleton of a Plesiosaur, but unfortunately wanting the skull. There are numerous vertebræ in various states of completeness, innumerable portions of ribs, a few teeth, phalanges, and other bones that will be subsequently referred to. These have now become the property of the Trustees of the Australian Museum.

I.—Precious Opal as an Agent of Replacement.

The replacement of the calcareous matter in fossils by Precious Opal appears to be a fact but little commented on by Authors.

The search for opal in the Upper Cretaceous at the White Cliffs Opal-field on Momba Holding, about sixty-five miles north-north-west of Wilcannia, in Co. Yungnulgra, has been signalised by the discovery of many beautiful examples of the entire conversion of the shelly envelopes of Pelecypoda and Gasteropoda, the internal shells of Belemnites, and Reptilian remains, into Precious Opal by a process of replacement.

Many of these are in the Collection of the Geological Survey of N.S. Wales, others have been lent to the same, and through the courtesy of Mr. E. F. Pittman, Government Geologist, I have been permitted to examine them.

The process of "silicification," as it is called, or the replacement of matter in fossil organic remains, by silica, in one or other of its varieties, is too well-known to require more than the briefest notice.

Silicification is said to be *primary* when organisms have undergone a slow process of alteration in water holding silica in solution, each particle of tissue, as it decayed, being replaced by the mineral in question, the minute structure of the body thus acted on being so preserved. "By far the commonest mode of replacement is that whereby an originally calcareous skeleton is replaced by silica. This process of 'silicification'—of the replacement of *lime* by *silica*—is not only an extremely common one, but it is also a readily intelligible one ; since carbonate of lime is an easily, and flint a hardly soluble substance. It is thus easy to understand that originally calcareous fossils, such as the shells of Mollusca, or the skeletons of Corals, should have in many cases suffered this change, long after their burial in the rock, their carbonate of lime being dissolved away, particle by particle, and replaced by precipitated silica, as they were subjected to percolation by heated or alkaline waters holding silica in solution."* On the other hand, if the minute structure of the fossils has been injuriously affected during this process, or destroyed, notwithstanding the preservation of the outward form, the silicification is said to be *secondary*, having taken place at a period long posterior to the entombment of the organic remains. "In the first stage of the process," adds Prof. H. A. Nicholson, from whom I am quoting, "the outer layer of the fossil very commonly becomes converted into, or covered by, small circular deposits of silica, having the form of a central boss surrounded by one or more concentric rings ('orbicular silica,' or 'Beekite markings'). If the process goes on the whole of the fossil may ultimately become converted into flint."

A *third* form of silicification may, I believe, exist—the conversion of the original calcareous matter into the form of chalcedony, so excellently seen in the shells (*Physa*, etc.) of the Lower Intertrapean chert beds of the Deccan Tertiary Trap Series at Nagpur, in India, or the chalcedonic Permo-Carboniferous Brachiopoda of Point Puer, Port Arthur, Tasmania.

The mode of occurrence of the Opal at White Cliffs has already been so fully described by Mr. W. Anderson and Mr. J. B. Jaquet that it need only be briefly referred to. It is met with in beds of kaolin and conglomerate forming a portion of the Desert Sandstone, but the former author also says in the "vitreous-looking" Desert Sandstone itself. Four separate conditions of occurrence are detailed† by Mr. Jaquet, viz. :—

1. In thin horizontal veins, between the bedding planes of the kaolin.
2. As irregular nodules scattered through the kaolin.
3. As Wood Opal.
4. As opaline shells, etc.

We are at present concerned only with the two last.

The Wood Opal is usually of an opaque milk-white or horn-yellow colour, and is simply hydrous silica, although the woody structure is still visible and in some instances well preserved, but in other

* Nicholson, Man. Palæontology, 3rd edition, i., 1889, p. 7.

† Ann. Rep. Dept. Mines and Argic. N.S.W., 1892 [1893], p. 141.

specimens hardly any structure at all is to be observed, beyond the outward form of stem or branch, as the case may be. Not infrequently radial cracks are filled with Precious Opal, when the play of colour is very fine.

The Animal Remains occur under the following conditions :—

1. As external or internal casts in kaolin, without opalization of any kind.

2. Entirely converted into hydrous silica or Common Opal, white and opaque, but occasionally with traces of the coloured variety scattered through.

3. Wholly or partially converted into translucent-glassy to vitreous semi-opaque Precious Opal, displaying a fine range of colour.

The colours visible by reflected light are principally blue, red, green, and yellow, with their various shades and combinations, not the least pleasing being an ever-varying degree of red and blue-tinted purple.

When the fossils are in the form of kaolin casts, specific identification, with a very few exceptions, is almost unattainable. Those in which opalisation, however, has taken place, are always determinable, more or less, and the substitution of the original carbonate of lime has been very thoroughly carried out. Fragments of these opalised remains, chiefly shells, are freely scattered throughout some hand-specimens of the opaline kaolinised conglomerate, from the bed B of Mr. Jaquet's section.* The kaolin casts are either white or tinged with iron-oxide, arising from the highly ferruginous clays that Mr. Jaquet says the kaolin passes into.

The opalised fossils comprise Crinoid remains, the shells of Pelecypoda and Gasteropoda, portions of Belemnite guards, and Sauropterygian bones. The preservation of some of these fossils is excellent, although all are not alike in this respect, and the extent to which the opalisation has at times been carried is remarkable. In some Pelecypoda, the external growth laminæ, and intermediate sculpture striæ are fully preserved, whilst the shell substance is completely changed, and by transmitted light the valves of many are almost transparent. On the fractured edges of one of these bivalves the glassy opal is quite translucent by reflected light. When such valves are met with in apposition, the interiors are often found to be filled with soft kaolin, and no better examples of the complete change that has taken place can be examined.

The replacement of the fibrous calcite of the Belemnite guard, when viewed in cross-section, presents a far less translucent, and

*Ann. Rep. Dept. Mines and Agric. N.S.W., 1892 [1893], p. 141.

much more opaque and vitreous-looking appearance than that seen in the other Mollusca. In one small guard in particular, now before me, remains of the radiating fibres and concentric layers of calcite are visible round the periphery, gradually fading off into a dark blue and purple vitreous-looking opal.

Pre-eminent for its beauty is a bivalve, obligingly lent to the Geological Survey of N. S. Wales for examination by Mr. H. Newman, jeweller, of Melbourne. This is without exception one of the most beautiful conditions of fossilisation I ever beheld—perfectly clear of the matrix, with the valves in apposition, and save for a slight crushing about the centre of one of them, quite perfect, wholly converted into Precious Opal, and with a play of colour quite equal to the fragments in quartzite shortly to be referred to. The shell substance is almost glassy transparent. It is probably identical with the shell already referred to, with the translucent fractured edges, from the collection of Mr. G. de V. Gipps, also lent to the Geological Survey.

Mr. J. E. Carne informs me that the Survey Collection contained, previous to the Garden Palace fire, an Ammonite, wholly converted into Precious Opal, six inches in diameter! This came from White Cliffs, and was probably one of the first fossils ever obtained there.

By no means the least interesting specimen found in this field, previous to Messrs. Tweedie and Wollaston's reptile, is the half, split longitudinally, of a Sauropterygian vertebra, with the osseous matter converted in the first instance into the common white and opaque opal, and the canals and lacunæ remaining open and filled with a little ferruginous powder. The roughened edges of the fractured surfaces are then tipped, and the cavities to some extent lined with Precious Opal. This is also from the cabinet of Mr. J. de V. Gipps.

Some polished hand specimens of a highly fossiliferous chocolate-brown quartzite were presented by an unknown donor to the Geological Survey Collection, the whole of the organic remains being converted into Precious Opal, and the interstices between the component constituents of the rock likewise similarly filled as a secondary infiltration, probably replacing the calcite particles of the deposit. Beyond the fact that these specimens come from White Cliffs, I am not in possession of information as to the stratigraphical position of this quartzite, but possibly it may be derived from the water-worn vitreous boulders mentioned by Mr. Jaquet as occurring in the clay and conglomerate beds. The organic remains are those of Mollusca, with traces of Corals and stem-joints of Crinoids, showing such a marvellous kaleidoscopic play of colours that words are quite lacking to render the general appearance of the specimens appreciable.

There is a univalve in these hand specimens after the Euomphaloid type, and in consequence of the direction in which the latter have been cut, the sections are almost invariably across the whorls. It is a small shell, the largest not measuring more than three-eighths of an inch in diameter, biconcave, and the inner whorls barely distinguishable. From the difference in outline exhibited by the cross-section and the body whorls, I should say two, if not three species are present. The next commonest section is probably that of a Brachiopod, very geniculate in outline, the sections passing from the umbo to the front margin of either valve. One section in particular catches the eye from the comparatively large process, projecting from underneath the incurved umbo. This may be either a fulcrum supporting some of the internal shelly plates of a Brachiopod, or a spoon-shaped cartilage process of a Pelecypod, but I am inclined to the first opinion. Several small circular bodies, hollow in the centre, about three-eighths of an inch in diameter, and with median central vacuities, are scattered at random through the rock. There is no definite structure observable in these, but the size and general appearance closely resemble that of the stem joints of many Crinoids.

I am strongly of opinion that these highly opalised chocolate-coloured quartzites are of Devonian age, being portions of travelled blocks, in all probability coming from Mr. Jaquet's bed C.

The whole of the specimens now under discussion, were submitted to a careful examination by Dr. Thomas Cooksey, Mineralogist to the Australian Museum, and myself. Dr. Cooksey is of opinion* that in the chocolate quartzite the carbonate of lime of the fossils has been in the first instance converted into crystalline calcite, and the latter then replaced by secondary silicification in the form of Precious Opal. The traces of the cleavage planes and twinning of the calcite crystals are still preserved in the opal, the former in a great measure serving to produce that play of colour which gives to the opal its beauty and value. A few instances of a similar process are certainly visible in the opalised shells from the kaolin deposit, but in the majority of these there appears to have been simply a secondary replacement by hydrous silica of the ordinary carbonate of lime of the Molluscan and other tests.

There is no trace amongst these fossils of the Beekite stage of silicification. The occurence of this mineral in connection with "Fossil Organic Remains" in N.S.Wales is by no means an uncommon one, and has already been noted by the Writer.† Such occurrences, however, are confined to some of our Silurian and Permo-Carboniferous fossils.

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* Rec. Aust. Mus., ii., 7, 1896, p. 111.

† *Ibid*, ii., 5, 1893, p. 74.

II.—The Reptile Remains.

To return to Messrs. Tweedie and Wollaston's reptile, *Cimoliosaurus leucoscopelus*, the remains that can be satisfactorily determined from the mass of opalised material are as follows :—

17 Cervical vertebræ, usually fragmentary.
2 Humeri.
4 Teeth.
Rib fragments (numerous).
Phalanges (numerous).

The absence of the skull practically bases systematic determination on the vertebræ and teeth, hence the following facts in the first place lead to the conclusion that it is a Sauropterygian :—(1) the vertebræ are amphicœlus ; (2) the single costal facets of the cervical vertebræ are entirely on the centra ; (3) each rib articulates to a single vertebra ; (4) the epiphyses of the humeri are enlarged ; (5) the teeth have more or less curved and sharp crowns with fluted enamel.

In the second place the form of the cervical vertebræ, and the absence of a foramen in the humeri indicate the Plesiosauridæ as the family to which these remains should be referred ; whilst within this family the complete anchylosis of the neural arches and cervical ribs to the centra, single costal facets on the cervical vertebræ, and the slender and non-carinated teeth point out *Cimoliosaurus*, Leidy, as the natural resting place of this reptile from White Cliffs Opal-field.

The cervical vertebræ are much elongated between their dorsal and ventral extremities. They vary in size, as usual, according to their position in the whole series, but the measurements of three of the more perfect and typical are as follows :—

	1.	2.	3.
Length of centrum body...	1 in.	$1\frac{1}{16}$	1 in.
Height „ „	$1\frac{2}{8}$	$1\frac{7}{16}$	$1\frac{7}{16}$
Breadth „ „	$1\frac{1}{2}$	$1\frac{11}{16}$	$1\frac{13}{16}$
Height, including neural spine	$3\frac{1}{2}$	...	...
Breadth of cup...	$\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{5}{16}$
Fore and aft extent of neural spine at about the middle	$\frac{5}{8}$	...	...
Fore and aft extent of the neural arch below the zygopophyses	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{10}{16}$
Fore and aft extent of costal surface ...	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{5}{8}$
Height of neural canal	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{1}{2}$
Breadth „ „	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{5}{8}$

The measurements are in inches and parts of inches.

The centra in these vertebræ are decidedly short, more proportionately so than in *Cimoliosaurus cantabridgiensis*, Lydk.,* and in this respect approach nearer to those of *C. valdensis*, Lydk.,† and *C. eurymerus*, Phill.‡ There is not the slightest appearance of any rugosity round the edges of the terminal faces of the centra as in *Plesiosaurus rugosus*, Owen,§ from the Lias, but they are prominent and outwardly bevelled as in *C. cantabridgiensis*; nor is there any sinuous profile with overhang of the upper border, and prominence of the lower border of the centra as in the genus *Polyptychodon*. The sides of the centra can hardly be described as concave, although the ventral surfaces are fairly so on either side the hæmal carina. The anterior and posterior articular surfaces vary in contour from circular to subquadrate, the transverse diameter being always the greater, with a well marked although not thick border, surrounding a wide and fairly deep concavity or cup. There are no mammillæ, or any trace of a pit in the vertebræ examined. The venous or hæmal foramina are situated in definite depressions, well marked and deep, and in the best preserved vertebra No. 1, (Pl. v., Fig. 4) three-sixteenths of an inch apart, this being the transverse measurement of the hæmal carina. The latter expands fore and aft in buttress formation into the anterior and posterior peripheries of the terminal faces, producing on the whole an hour-glass shaped figure, as in *C. constrictus*, Owen. The single costal facets are rarely seen in consequence of the thorough union that has taken place between the head of the ribs and the costal surface itself. In one, however (No. 2), where the head of the rib appears to have broken out, the pit or scar seems to be circular. The fore and aft borders of the neurapophyses are vertically concave, the fore much more so than the hind, and transversely are more angular than convex, particularly posteriorly. The neuro-central suture is almost totally obliterated. Zygopophysial ridges, the prominent lateral oblique ridges extending from the pre-zygopophyses to the posterior borders of the pedicle, can hardly be said to exist. The pre-zygopophyses are rather high, and in the only vertebra in which they are sufficiently preserved No. 1, (Pl. v., Fig. 5), do not project forward beyond the vertical line of the terminal face of the centrum, not even as much as in *C. valdensis*, Lydk., and *C. limnophilus*, Koken.|| The zygopophysial articular surfaces approach the oval in form, and are very obliquely inclined, much more so than in either the last-named species, *C. cantabridgiensis*, or *C. eurymerus*. The post-zygopophyses are not preserved in the most perfect vertebra of the

* Cat. Foss. Reptilia and Amphibia Brit. Mus., pt. ii., 1889, p. 183, f. 60.

† *Ibid*, p. 188, f. 61.

‡ Lydekker, *ibid*, p. 206, f. 67.

§ Mon. Foss. Reptilia Liassic Formations, pt. i., 1865, p. 35.

|| Leydkker, *loc. cit.*, p. 225, f. 69.

collection, but broken off short at the point of their enlargement from the neural spine. The latter extends one and three-quarters of an inch from the roof of the neural canal upwards, and is five-eights of an inch in fore and aft measurement immediately above the zygopophyses, linear oval in section, and very sharp along the anterior and posterior edges; anteriorly this sharp edge is continued downwards over the neurapophysial surface as a similar ridge to between the prezygopophyses, and is but shallowly excavated, much less than in *C. cantabridgiensis*, nor anything as much inclined as in *C. valdensis*, or the extreme condition of the spine in *C. eurymerus*, but seems to approach nearest to that of *C. limnophilus*. The neural canal is large and subquadrate, proportionately larger in fact than appears to be general in this genus, even more so than in *C. limnophilus*.

The ribs are so reduced by fracture that it is almost impossible to afford precise details about them, but the majority appear to have been irregularly oval in cross-section, flattened on the sides. The costal articulations on the centra are invariably single.

A small portion of bone is figured (Pl. vii., Fig. 2) under the belief that it may be the expanded distal end of a short or cervical rib, forming one of the "hatchet bones." Notwithstanding its incompleteness, I believe this to be the nature of the specimen. The body is angular on the inner or hæmal surface, and flattened on the outer; the anterior extension is shorter than the posterior, itself abbreviated and thick. In Pl. vii., Fig. 4, is probably represented the distal end of one of the trunk ribs, broken at the apex.

Several interesting fragments are present, similar to Pl. vi., Fig. 5. I labour under the impression that these may be the expanded distal ends of the diapophyses of the dorsal vertebræ. They possess a distinct oblique convex articular facet, bounded by a slightly elevated ridge. Such portions of the shafts as remain are compressed between dorsal and ventral, and are angular transversely, *i.e.*, fore and aft. Pl. vii., Fig. 3, is another diapophysis, possibly one of the anterior with a portion of the sides of the neural arch remaining attached. It will be seen that the articular surface is much longer and more oblique in the former specimen. These diapophyses seem to have some points in common with those of *Mauisaurus haastii*, Hector,* although much shorter, still this may be only the result of position in the series. At the same time it is strange that not a distinguishable fragment of a dorsal vertebra, other than these processes, has occurred with the remains of this interesting reptile.

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* Trans. N. Zealand Inst. vi., 1874, p. 347.

Amongst the numerous fragments of ribs are several that seem to be the proximal ends of trunk ribs (Pl. vii., Figs. 5 and 6), but if so the terminal faces are cupped for the reception of the convex heads of the diapophyses already described. None are absolutely perfect, but the figures given will explain their appearance and characters almost better than words. However, the head of the rib is in each case expanded and terminally hollowed into an oval rather deep depression or cup of variable size. This appears to be similar to the structure described by Hector in *Lieodon haumuriensis.**

The proximal ends of both humeri (Pl. vii., Fig. 1) are present in the collection, and very remarkable bones they are, allied in many respects to those of *Mauisaurus haastii*, Hector.† One is three inches long, the other three and a quarter inches approximately. They are heavy and much thickened bones, the proximal articular surface hemispheric, with a sharp angular periphery and a diameter of about one and three-quarter inches. The trochanterian process is much thickened, and protuberant, and separated from the articular surface by a well marked although incomplete bicipital groove, overhung by sharp margins. The transverse diameter of the humeri is one and a half inches. The distal sloping surfaces of the bones are much roughened and pitted for muscular attachment. To one side of the trochanterian process in each is what Dr. Hector calls in *Mauisaurus* a bold rugose tuberosity "to receive the attachment of the bicipital tendon."‡ The plantar surfaces would appear to be somewhat concave.

These humeri seem to possess some important points of departure from the ordinary Plesiosaurian humerus, but are closely allied in form and character to those of *Mauisaurus*, at the same time showing sufficient differences of a distinguishing nature. For instance we see the very marked trochanterian process well separated from the articular surface, or head of the bone, by the bicipital groove, although not circumscribed by it, as such appears to be the case in *M. hastii.* We further see an equally large, although less hemispheric articular surface, and an equally strong if not stronger protuberance for the bicipital tendon, whilst the latter is somewhat differently placed to what it is in the New Zealand reptile.

Two short, transversely elongated bones are distinguishable that may be one or other of the paddle-bones, possibly the "intermedium." (Pl. vi., Fig. 6). The terminal faces are roughly facetted.

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* Trans. N.Z. Inst., vi., 1874, p. 352.

† *Ibid*, p. 347.

‡ *Loc. cit.*, p. 348.

Phalanges are numerous throughout these remains, but I am not in a position to differentiate between them. (Pl. v., Figs. 6 and 7; Pl. vii., Figs. 7 - 9).

The shape of all, however, is particularly "hour-glass" like, more so than in the majority of Plesiosaurian paddles, and most of them are short, stout, and strong, with well marked articular surfaces. As the smallest seen are much constricted, longer, and have articular surfaces, the digits, like those in *Mauisaurus*, "must have been enormously prolonged to produce such attenuation."*

The only evidence of a skull consists of four teeth (Pl. vii., Figs. 10 and 11). They are small, slender, acutely conical, and curved, nearly circular in section from midway upwards, but possessing a rather more oval section below. The enamel is delicately fluted, but the teeth are not in the slightest degree carinate, as in *Pliosaurus* and *Thaumatosaurus*. None are quite perfect, but the most so, although not the largest, measures thirteen-sixteenths of an inch long by three-sixteenths in diameter at about the centre. The largest fragment, on the other hand, has a diameter of two-eighths of an inch.

The genus *Cimoliosaurus* is divided by Lydekker into two sections, the Cœlospondyline and Typical Groups. In the former the centra are excavated fore and aft, regularly amphicœlus in fact, but in the latter they are nearly flat. It follows from this that *C. leuoscopelus* belongs to the Cœlospondyli. *Mauisaurus*, Hector, with which the White Cliffs reptile agrees in more than one point, belongs to the Cœlospondyli, and had it not been so, as well as the marked difference in the vertebræ, I should have been much inclined to consider *C. leucoscopelus* as closely allied to Hector's fossil.

An epitome of our scanty knowledge of the Australian Sauropterygii will be found in the "Geology and Palæontology of Queensland."† Two species at least, perhaps three, are believed to exist, and possibly both the former are referable to *Cimoliosaurus*. They are *Plesiosaurus macrospondylus*, McCoy, and *P. sutherlandi*, McCoy. It is to be regretted that my friend, Mr. R. Lydekker, in the British Museum "Catalogue of Fossil Reptilia and Amphibia,"‡ relied on a second-hand reference to these forms, for although they have never been adequately described, still, I think they deserve a better fate than mere relegation to the limbo of MS. names.

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* *Loc. cit.*, p. 349.

† Jack and Etheridge, Junr., 1890, pp. 508-9.

‡ Pt. 2, 1889, p. 247.

As regards *P. sutherlandi*, I have endeavoured to supply further details than those given by Sir F. McCoy from an examination of the type specimens, kindly placed at my disposal by him, supplemented by additional material from Queensland.* I believe *C. leuoscopelus* to be distinct from both these forms. The flattened articular portions of the centra in *P. sutherlandi*, and the "more flattened than concave" centres of the cervical vertebræ appear to separate this species. In *P. macrospondylus* the edges of the articular surfaces of the centra are rugose, and thereby wholly differ from those of our form.

Of the New Zealand species, *C. australis*, Owen (+ *P. crassicostatus*, Owen),† possesses cervical vertebræ with flattened centra terminations, a distinct median pit in each, four hæmal foramina, and the neural arches and ribs persistently independent of the centra. The difference between this and the corresponding structure in *C. leuoscopelus* is manifest. In *C. hoodii*, Owen,‡ the hæmal surface of the cervicals is broad and flat, and there is no special transverse oblong depressions in the middle of the articular surfaces of the centra.

The cervical vertebræ of *P. holmesi*. Hector,§ have flat terminal faces, and a humerus referred to this species, has the articular head divided by a bicipital notch, not a groove as in the present case.

P. traversi, Hector,|| and *P. mackayi*, Hector,** are less known forms; the first is said to possess quadrate vertebral centra. Lastly, the absence of cervical vertebræ in the type specimens of *C. caudalis*, Hutton,†† renders a comparison difficult.

* Etheridge, Junr., Ann. Rep. Dept. Mines N.S.W., 1887 [1888], p. 167, t. 1, f. 1-4.

† Geol. Mag., vii., 1870, p. 51, t. 3, f. 4-5.

‡ *Ibid.*, f. 1-3; Hector, Trans. N. Zealand Inst., vi., 1874, p. 343.

§ Hector, *loc. cit.*, p. 344.

|| *Ibid.*, p. 344.

** *Ibid.*, p. 345.

†† *Ibid.*, xxvi., 1894, p. 354.