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Contributions to the Knowledge of Richthofenia in the Permian of West Texas

By EMIL BÖSE

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ILLUSTRATIONS.

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By EMIL BÖSE

PREFACE

During recent years Dr. J. A. Udden has made some geological studies in the Paleozoic area south and north of Marathon, Brewster County, and has paid special attention to the development of the Guadalupian in the Glass Mountains. He was able to collect a great number of fossils in those beds, and this fauna contains many specimens of Richthofenia. Later on, in September to October, 1915, Dr. Udden entrusted to me the detailed study of a cross-section through the Glass Mountains, a task which I performed with the assistance of Mr. W. F. Bowman. On this trip I made another collection of well preserved specimens of Richthofenia.

Several years ago, in 1904, Dr. Udden had collected a fauna in what was then thought to be the Pennsylvanian, near the Shafter mine, Presidio County. This collection had been turned over to the University of Chicago but it has been loaned to me for further study. The collection also contained several Richthofenia, which had not been mentioned in the lists published in 1904; Richthofenia being practically unknown in this country at that time.

The state of preservation of the specimens found in the Glass Mountains allowed me to prepare a number of them in such a manner that they show a great many details which had been known but imperfectly in American Richthofenias.

The material thus brought together showed so many points of interest that I decided to publish my observations on Richthofenia separately, although the rest of the fauna contains a great number of other very interesting genera and species, especially of cephalopoda.

It remains to express my sincerest thanks to the different gentlemen who have helped me in my work; in the first place to Dr. J. A. Udden, who, with the greatest liberality, put at my disposal his different collections and his numerous and important

field notes and who also enabled me to obtain the necessary literature. To Dr. Stuart Weller of Chicago I am indebted for the loan of the Shafter mine collections, and to Mr. W. F. Bowman for his untiring and efficient help in collecting fossils and constructing the corresponding cross-sections which will be published at a later date. Under great obligations I also find myself to Prof. F. L. Whitney of the University of Texas for his kindness in devoting much of his time to making the splendid photographs which were used in the compilation of the plates accompanying this paper.

HISTORICAL SKETCH

The first specimens of the genus Richthofenia have been described in America in the year 1859 by Shumard[1] under the name of *Crania permiana*. These specimens came from a white limestone in the Guadalupe Mountains of Texas. They were not figured, but the description makes it most probable that the species belonged to the Richthofenia later rediscovered by G. H. Girty in the same mountain range.

Shortly afterwards, in the year 1862, specimens of the same genus were described from a very distant region, the Salt Range of India, by de Koninck,[2] under the name of *Anomia Lawrenciana*. While Shumard had recognized at once that these peculiar shells belonged to the brachiopods, de Koninck had mistaken them for lamellibranchs, although he noticed the similarity of their hollow spines to those of Productus.

For nearly twenty years Richthofenia does not seem to have been mentioned from anywhere. Then E. Kayser[3] found in a collection of fossils from Lo Ping in China, made by F. v. Richthofen, two specimens of a shell which he compared and identified with the *Anomia Lawrenciana* de Koninck. Hhe showed that these fossils had near relations to the brachiopods, especially to Productus and Crania, and created for them the new genus *Richthofenia*.

In 1882 Waagen[4] published his first observations about the Richthofenias from the Salt Range in India. Founding his views on these Kayser[5] changed his opinion and placed Richthofenia among the corals, and considered it similar to the Cystiphyllidae of the older Paleozoic.

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[1]B. F. Shumard, Notice of fossils from the Permian strata of Texas and New Mexico, obtained by the U. S Expedition under Capt. John Pope, for boring artesian wells along the 32nd parallel, with descriptions of new species from these strata and the Coal Measures of that region. Trans. Acad. Sci., St. Louis, Vol. I, (1860), pg. 395.

[2]L. De Koninck, Descriptions of some fossils from India discovered by Dr. A. Fleming . . . Quart Jour. Geol. Soc. London, Vol. 79, 1863 (1862), pg. 6, pl. IV, figs. 7, 8, 9.

L. de Koninck et Th. Davidson, Mémoire sur les fossiles paléozoiques dans l'Inde, 1863, p. 18, pl. 3, figs. 7, 8, 9.

[3]E. Kayser, Zeitschr. d. deutsch geol. Ges., XXXIII. 1881, p. 351.

[4]W. Waagen, N. Jahrb. f. Min. etc., 1882, I. p. 115.

[5]E. Kayser, Oberkarbonische Fauna von Lo-Ping. In F. von Richthofen, China. Ergebnisse eigener Reisen und darauf gegründeter Studien. Vol. IV, Berlin, 1883, p. 195, pl. 24, fig. 4, 5.

Kayser had possibly been influenced by the opinion expressed by Lindström[1] who had stated that in his opinion Richtofenia probably was a coral.

In 1883 Waagen[2] published his first complete description of our genus and in 1885 he[3] repeated and completed these in his final work on the Productus-limestone of the Salt Range. There he compared Richthofenia with corals, Rudistae and brachiopods, and finally decided that it belonged to the latter ones, having intimate relations to the Productidae and Craniidae. In consideration of the unique features of Richthofenia, Waagen created for this genus a new family *Richthofenidae* and a new sub-order, the *Coralliopsida.* While Kayser had identified the Chinese specimens of Richthofenia with the Indian *R. Lawrenciana,* Waagen considered it a different species and gave it the name of *Richthofenia sinensis.*

Waagen's opinion about the form of the interior in Richthofenia was in great part obtained by the study of cross-sections through the lower valve. Evidently these interpretations of the inner structure by W. Waagen have in part been the cause of Oehlert's[4] expressing the opinion, in the year 1887, that Kayser, in his interpretation of 1883, was not right, and that Richthofenia represented a tetracoral of the operculate type.

In 1894 James Hall and John M. Clarke[5] in their great work on the Palaeozoic brachiopods of New York, reproduced the opinion of W. Waagen and seemingly accepted his interpretation as the most probable.

In the same year of 1894 the first notice about specimens of Richthofenia found not in the Asiatic localities, but at a new locality in Europe, was published by G. G. Gemmellaro.[6] This author had found Richthofenia in the lower Permian of Palazzo

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[1]G. Lindström, Obersilurische Korallen von Tshau-Tien. In F. von Richthofen, China, etc. Vol. IV, p. 74.

[2]W. Waagen, Records geol. Surv. of India, Vol. 16, Pt. I, p. 12, pls. I, II.

[3]W. Waagen, Salt Range fossils, I. Productus limestone fossils IV (fasc. 5) Brachiopoda. Mem. Geol. Surv. India, Palaeontologia Indica, Ser. XIII, Calcutta, 1885, pp. 729-743, pl. 82, 82A, 83.

[4]D. P. Oehlert, Brachiopodes. In P. Fischer, Manuel de Conchyliologie. Appendice, pg. 1334, 1887.

[5]James Hall and John M. Clarke, Natural History of the State of New York. Palaeontology, Vol. VIII. An Introduction to the study of the genera of Palaeozoic Brachiopoda, part II, p. 315.

[6]G. G. Gemmellaro, Le Richthofenie provenienti dal calcare con Fusulina della valle del fiume Sosio nella provincia di Palermo. Bull. d. Soc. di Sc. Nat. di Palermo, No. 1, 1894.

Adriano near Palermo, in Sicily. He sustained the idea that these curious fossils belonged to the operculate Tetracoralli.

From the first time that he had an opportunity to study the descriptions of W. Waagen and material from India, and later from Sicily, K. A. v. Zittel had regarded the Richthofenia as belonging to the brachiopoda. He[1] expressed this opinion in the first edition of his "Grundzüge."

In 1896 Gemmellaro[2] mentioned Richthofenia in a second paper. Influenced by Zittel, he had changed his opinion and now considered that although Richthofenia was not a typical brachiopod, it had nearer relations to these than to the Tetracoralli. Gemmellaro made some new and important observations about the structure of the inner shell and the form of the apparatus which supports the muscles, but unfortunately, did not illustrate his observations by figures.

In the year 1900 Schellwien[3] studied several specimens of Richthofenia from Sicily and showed that they certainly belonged to the brachiopoda, that an exterior covering of the whole real shell could be observed not only in Richthofenia, but also in his new genus of brachiopoda, *Tegulifera.*

Since that time Richthofenia has been generally considered as a genus belonging to the brachiopoda, although the value of the suborder of Coralliopsida sometimes has been doubted.

In 1901 *Richthofenia sinensis* was mentioned again by Fliegel[4] in his revision of the fauna of Lo Ping, but nothing added to the descriptions of Kayser and Waagen.

In the year 1903 Girty[5] announced his important discovery of several species of Richthofenia in the Permian of western Texas. This was only a provisional note; in the final report, those different species were united, and identified with *Crania permiana* Shumard.

According to Tschernyschew[6] *Richthofenia Lawrenciana* has

[1]K. A. v. Zittel, Grundzüge der Palaeontologie, 1895.
[2]G. G. Gemmellaro, Sopra due nuovi generi di Brachiopodi provenienti dai calcari con Fusulina della provincia di Palermo. Giorn. di Sc. Nat. ed econ. di Palermo, Vol. 21, 1896, pp. 3 and 4, Note.
[3]E. Schellwien, Die Fauna der Trogkofelschichten in den karnischen Alpen und den Karawanken. I. Die Brachiopoden. Abh. d. K. K. geol. Reichsanstalt, Wien, Vol 16, 1900, pp. 26-33, fig. 1-4.
[4]G. Fliegel, Ueber obercarbonische Faunen aus Ost- und Südasien, Palaeontographica, Vol. 48, 1901, page 131.
[5]G. H. Girty, Upper Permian in western Texas. Amer. Jour. Sci. 4th ser., Vol. 14, 1902, pp. 365, 368.
[6]Th. Tschernyschew, Die obercarbonischen Brachiopoden des Ural und des Timan. Mém. du Com. Géol., Vol., XVI, No. 2, 1902, p. 731.

been found in a limestone of the valley of the Sutschan in the region of Ussuri bay, but very little is known about the age of these rocks. They correspond probably to the middle Productus limestone and possibly the base of the upper Productus limestone.

In 1903 Schellwien[1] described and figured a Richthofenia found by K. Futterer in the Permian gray limestone on the northern slope of the Semenow mountains in northeast Tibet. Only one broken specimen was found and therefore nothing new about the structure of the shell could be added, but the author deduces that it corresponds entirely to that of the Sicilian Richthofenias.

In 1903 Diener[2] described and figured from the Central Himalayas an incomplete specimen which probably belongs to Richthofenia.

In 1905 Schellwien[3] for the first time made known the existence of Richthofenia in the upper Permian Bellerophon limestone of the Alps.

In 1908 Girty[4] published his rediscovery of *Richthofenia permiana* in the Permian limestones of the Trans-Pecos region of Texas. Shumard at his time had given only a very short and incomplete description without any figures, and nobody could imagine that his *Crania permiana* was generically identical with the peculiar Richthofenia from India. The material collected by Girty does not seem to have been well enough preserved to enable him to interpret Waagen's observations about the interior structure of the genus, but Girty recognized that the Texan specimens did not show those septa that the Indian forms were supposed to have. We shall discuss this point later on in connection with the description of the Texan species.

In the same year Girty[5] described a new species under the name of *Tegulifera armata* from the Pennsylvanian of LaSalle,

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[1]G. Schellwien, Palaeozoische und triadische Fossilien aus Ostasien. In K. Futterer, Durch Asien, Vol. III, 1902-1903, p. 148, pl. 4, figs. 1, 1a, 1b.

[2]C. Diener, Permian fossils of the Central Himalayas. Palaeontologia Indica, ser., XV Himalayan fossils, Vol. I, pt. 5, pg. 45, pl. II, fig. 17, Calcutta, 1903.

[3]G. Schellwien, Bericht über eine von F. Kossmat und ihm im alpinen Bellerophonkalk aufgefundene neue Fauna. Zeitschr. d. deutsch. geol. Ges., Vol. 57, 1905, p. 358.

[4]G. H. Girty, The Guadalupian fauna. U. S. Geol. Surv., Prof. Paper No. 58, 1908, p. 283, pl. 14, fig. 27; pl. 20, fig. 23; pl. 22, fig. 6; pl. 24, fig. 10; pl. 31, fig. 1-3.

[5]G. H. Girty, On some new and old species of carboniferous fossils. Proc. U. S. Nat. Mus., Vol. 36, 1908, p. 294, pl. 20.

Illinois. I have very little doubt that this species belongs in reality to Richthofenia and that it is nearly related to our *Richthofenia Uddeni n. sp.* We shall discuss this relationship later on in our chapter on the stratigraphical value of Richthofenia and in our description of R. Uddeni.

In 1910 C. Diener[1] described and figured the Richthofenia found in the upper Permian Bellerophon limestone of the Alps mentioned already by Schellwien in 1905. Diener shows that the species is very similar to *R. Lawrenciana* de Koninck, but seems to differ through the great height and slenderness of the pseudo-deltidium.

In 1911 Fr. Frech[2] published his revision of the fauna of Lo Ping which he considers as Permian. Frech explains his opinion about the palaeontological position of Richthofenia, but does not add anything to the description given by Waagen. He unites *R. Lawrenciana* and *R. sinensis,* taking the latter as a juvenile form.

In 1914 the Sicilian species of Richthofenia were described and figured for the first time by G. Di-Stefano.[3] This paper represents the greatest progress in the interpretation of the different parts of Richthofenia since the time of Waagen. Di-Stefano shows the real position of the muscles, demonstrates what organs take the place of Waagen's vertical septa in the Sicilian form, and explains satisfactorily the relations between the three different shells of the ventral valve.

The Stratigraphical Value of Richthofenia

Theoretically the age of a formation or of a horizon should be determined by the consideration of the whole fauna contained in it. Practice has shown that only certain forms are of real stratigraphic value, because they change so quickly in character that the vertical range of the species or group of species or subgenus is so small that it does not exceed a zone, a

[1]C. Diener, Die Brachiopodenfauna des Bellerophonkalkes von Schaschar und Schönbrunn, p. 299, pl. 15, fig. 12, 13. In F. Kossmat und C. Diener, Die Bellerophonkalke von Oberkrain und ihre Brachiopodenfauna. Jahrb. d. K. K. geol. Reichsanstalt in Wien, Vol. 60, 1910.

[2]Fr Frech, Die Dyas, pg. 134, 135. In F. v. Richthofen, China. Ergebnisse eigener Reisen und darauf gegründeter Studien. Vol. V, 1911.

Another publication of Frech's, which apparently contains a more complete longitudinal section, has been inaccessible to me; it appeared in Zeitschr. f. Rassen und Gesellschaftshygiene 1909, p. 21, fig. 6.

[3]G. Di-Stefano, Le Richthofenia dei calcari con Fusulina di Palazzo Adriano nella valle del fiume Sosio. Palaeontographia Italica, vol. 20, 1914, p. 1-27, pl. 1-3.

horizon, or a formation. In older times this circumstance has led to the creation of the so-called index-fossils (Leitfossilien). These have lost greatly their stratigraphical value on account of the extension of our knowledge in different parts of the earth, and also because modern palaeontology has split up the former species and has made much finer distinctions, so that actually the species retains is stratigraphical value more or less locally and the place of the index-fossil has been occupied by the "group of species" or sometimes the subgenus.

Not every class, order, or suborder is of equal stratigraphical value. Practice has shown that while the greater part of an order does not contain species or subgenera restricted to certain zones or horizons, with perhaps the exception of one or two families which represent a kind of "monstrous" development, but which are excellent for stratigraphical purposes on account of the short vertical range of the genera, subgenera, or groups of species; for example, the Chamidae and Rudistae among the lamellibranchs, the Fusulininae, Nummulitinae and Cycloclypeinae, among the Foraminifera.

There are classes among the invertebrates which are far more valuable for stratigraphic purposes than the lamellibranches or the foraminifera. For the Mesozioc the cephalopoda have proved to be by far the most propitious animals for finer zonal distinctions. The cephalopods, and among them especially ammonites, seem to have changed so rapidly that each group of forms, generally speaking, lived during an extremely short period before changing its character. Only this peculiarity has made possible the distinguishing of very small zones in the Jurassic and Cretaceous of Germany, France, Switzerland, etc. At the same time, these ammonites seem to have spread rapidly over very large portions of the oceans of that time, so that the form of the species changed very little over great distances. This would explain why we find the same groups of ammonite species all over the world during the Triassic, Jurassic, and Cretaceous; always in the same zones and the same succession. Striking examples of this are the stratigraphical zones of the Jurassic and Cretaceous in South America and Mexico and the Triassic in California.

Also in the Palaezoic the ammonoid forms, the "Goniatites"

have proved to be the best and safest index-fossils, especially if this term does not simply refer to the species but to the group of species. But ammonoids are much less frequent in the Palaezoic than in the Mesozoic, and the "Goniatites" are generally of a much simpler form than the ammonites of the Mesozoic, and a finer specific distinction may be often found impossible. Fortunately there seems to be a change in the youngest Palaeozoic, the Permian. The ammonoids seem to get commoner and to develop greater differences not so much in ornamentation as in the sutures. Several localities are known, where ammonoids are by no means very rare, for example, in Sicily, in the Artinsk of Russia, and in the southern part of the Trans-Pecos region in Texas. It should therefore be possible to obtain a better subdivision of the Permian by means of cephalopod zones. This would be of great importance also for the drawing of the limit between the Pennsylvanian and the Permian.

The greater part of the Carboniferous and Permian faunas is without doubt composed of brachiopods and it is only natural that these have been given the preference for the subdivision of them. Even Ch. Schuchert[1] in his excellent study about the relations between the Russian, Indian and American Carboniferous and Permian, says that "this class of fossils (brachiopoda) can be relied on for detailed correlation of stratigraphic horizons over widely separated regions, and further on account of their persistence and wide distribution, they are among the best evidence for facial affinity." The apparent failure to obtain a finer subdivision and correlation based on the brachiopoda, Schuchert seems to explain through a too great specific latitude given to the Carboniferous and Permian brachiopods by many palaeontologists. Schuchert to a certain degree follows Waagen in this, apparently; who advocated the finest divisions in Palaeontology without regard to the class where they belong. He thinks that theoretically the forms of a group of species must be different in each different zone so that by a sufficiently exact observation we should be able to distinguish those zones if we only make our distinctions between the different species exact enough. Waagen probably established this theory on account

[1]Ch. Schuchert, The Russian Carboniferous and Permian compared with those of India and America. Amer. Jour. of Sci., 4th ser., Vol. 22 (172), 1906, p. 157.

of the results he obtained in the study of Jurassic ammonites. He may even have inherited it from his master, A. Oppel; but he did not consider that not in every class the species changes its character as quickly as in the ammonites. Gröber[1] justly remarks that even if Waagen's theory is right, and if the forms in two different horizons are such that really have undergone changes, we often are not able to distinguish them because those changes have caused no difference in the skeleton or the shell.

It seems that the Carboniferous and Permian brachiopoda changed in part very slowly so that the representatives of the same group often not only are found throughout the whole Pennsylvanian, but also in the Permian. Schuchert is certainly right that in many cases the species have been given too great specific latitude and that often it will be possible to make finer palaeontological distinctions which will permit us to distinguish stratigraphical zones based on brachiopod species, but I doubt that it will be possible to use brachiopods for the correlation of widely separated regions. Diener[2] has given us an excellent example of the unreliability of brachiopods for the determination of age. He shows that the brachiopod fauna of the Indian Productus limestone has as many affinities to the fauna of the upper Carboniferous of Russia as to that of the Upper Permian, the Bellerophon limestone, of the Alps. On the one hand the similarity of the upper Carboniferous brachiopoda of the Ural and Timan with those of the Productus limestone is so strong that Tschernyschew[3] tried to correlate the greater part of the Indian Productus limestone with the upper Carboniferous. On the contrary, Diener shows that the fauna of the undoubtedly upper Permian Bellerophon limestone has a great similarity to that of the Productus limestone of India, and that in general the Brachiopods contain a number of ancient types which even show intimate relations with forms of the lower Carboniferous. Diener's conclusion is that the anthracolitic brachiopods are not very reliable for determination of age. This possibly goes a little too far, but certain it is that anthracolitic brachiopods

[1]P. Gröber, Carbon und Carbonfossilien des nördlichen und zentralen Tian-Schan. Abh. d. K. bayer. Ak. d. Wien, II Kl., Vol. 24, München, 1909, p. 342.
[2]C. Diener, Die Brachiopodenfauna des Bellerophonkalkes von Schaschar und Schönbrunn, loc. cit., pg. 304, et. seq.
[3]Th. Tschernyschew, Die obercarbonischen Brachiopoden des Ural und des Timan.—Mém. du Comité Géologique, Vol. 16, No. 2, 1902, p. 728.

have not by far the value often attributed to them, and Waagen's finer limitation of species has not prevented him from at first taking the Productus limestone of India to be Carboniferous; an opinion based on the brachiopods. Later he determined their age as Permo-carboniferous to Permian, and at last Noetling declared them to be Permian. Noetling[1] says that, based on the study of the brachiopod fauna, the Productus limestone little by little has been removed from the lower Carboniferous to the upper Permian. But that if instead of the brachiopods the cephalopods had been studied first, they would have been declared Triassic, because at that time the occurrence of real ammonites in the Permian was unknown.

While these opinions about the relative value of anthracolitic brachiopods for the determination of age are certainly right in general, we have to make an exception for several groups which develop at the end of the Palaezoic era.

Several authors, such as Schellwien[2] and Noetling[3], have indicated that near the end of the Palaeozoic time, a great number of aberrant forms of brachiopoda developed; especially characteristic are the following genera: *Tegulifera, Richthofenia, Keyserlingina, Oldhamina, Lyttonia, Proboscidella.* Such aberrant forms which probably represent phenomena of degeneration, generally have a short life, which of course gives them a great stratigraphical value. Several of these genera are known more or less locally but others like Lyttonia have a vast distribution. Noetling, who has made a special study of this genus, and Frech cite it from the following localities: Permian of the Salt Range (Virgal and Chideru group), Himalaya (Productus shale), Lo-Ping (Prov. Kiang-si), Kwan-yin-chao near Ki-Kiang-hsien (Prov. Sz'-tshwan), Tung-tze-hsien northeast of Tsun-i-fu (Prov. Kweitschou) in China (Middle Dyas, according to Fr. Frech); in Rikuzen, Japan, in beds that, according to Yabe, correspond to the middle Productus limestone (Virgal group); in the Permian of Sicily and in the Permian of West Texas. Thus

[1]Fr. Noetling Beiträge zur Geologie der Salt Range; insbesondere der permischen und triassischen Ablagerungen. N. Jahrb. f. Min. Beilagebd. XIV, p. 401

[2]E. Schellwien. Die Fauna der Trogkofelschichten in den karnischen Alpen und den Karawanken. I Die Brachiopoden. Abh. d. K. K. geol. Reichsanstalt, Bd. 16, Wien, 1900, p. 27.

[3]F. Noetling Untersuchungen über die Familie Lyttoniidae Waag. emend. Noetling. Palaeontographica Bd. 51, 1904, p. 153.

it seems that Lyttonia is really restricted to the Permian, at least it has never been found in the Pennsylvanian until now.

We shall now try to show in which beds Richthofenia has been discovered up to the present time.

Waagen says that he found *Richthofenia Lawrenciana* in the Amb beds directly above the Lavender clays; that is to say, in his lower Productus limestone, or Upper Speckled Sandstone. Noetling[1] found the fossil also in the Amb beds, but 135 feet above the Lavender clay, and he says[2] that he doubts very much the exactness of Waagen's[3] section at Amb, because he himself has not been able to find a similar section near Amb.

The Amb beds were considered by Waagen in his latest views as Permo-carboniferous, by Noetling as Palaeodyas (Rotliegendes).

According to Waagen the principal Richthofenia bed is the middle Productus limestone or Virgal group. According to Waagen as well as Noetling, this represents a part of the Permian. In the upper Productus limestone, Richthofenia is rarely found. The Upper Productus limestone or Chideru group represents, according to Waagen and Noetling, the Zechstein, or part of it.

Diener described Richthofenia (?) sp. from the Chitichun No. 1 beds. In his first work about this fauna, he had stated that it represented the Permo-carboniferous or Artinsk stage, but later on, convinced by his studies of larger collections and by proofs with respect to the age of the middle Productus limestone given by F. Noetling, Diener showed that the Chitichun No. 1 fauna in reality belongs to the upper Permian, and also that there is only one horizon represented at that locality.

Richthofenia has also been described from China. It was found at Lo-Ping and the fauna of this place has formerly been considered by E. Kayser as upper Carboniferous, in which opinion he was followed by Fliegel. But both considered the fauna as the equivalent of the lower Productus limestone, which by Noetling, Diener and others is considered as belonging to the Permian; and by Waagen as Artinsk (Permo-carboniferous).

[1]Noetling, Beitr. a. Geol. d. Saltrange, loc. cit., pg. 428.
[2]Noetling, loc. cit., p. 434.
[3]W. Waagen, Salt Range fossils, Vol. IV, pt. 1, Geological results, p. 159.

Frech considers these rocks as middle Dyas, or upper Palaedyas, to lower Neo-Dyas.

We know very little about the rocks of the Ussuri region which contain Richthofenia. They certainly are not older than the Artinsk; they may even correspond to the middle Permian (Saxonian or Rothliegendes).

Very little is known, also, about the Tibetan locality (Semenow mountains) where Richthofenia has been found. According to Schellwien the few brachiopods are of Permian character and he considers the age of the faunula as lower Permian.

More important than most of the Asiatic localities are the European, where Richthofenia has been found. This genus is very common at Palazzo Adriano in the valley of the Sosio river near Palermo. It is represented by two species—*R. communis* Gemm., and *R. sicula* Gemm. The fauna is very rich in cephalopods and this should make a determination of its age relatively easy; but the difficulty is that this fauna is almost unique and that there is nearly no other to compare with; at least, none which contains a similar number of cephalopods. Very different opinions have been expressed about it. While Karpinsky, Tschernyschew, Gortani and Jakowlew take it to be the equivalent of the upper part of the Artinsk (which is not characterized by cephalopods), Waagen places it above the Artinsk and considers it to represent the Rothliegendes and Weissliegendes of the Permian. Diener considers it as middle Permian, and Noetling as Permo-carboniferous. Everybody seems to concord in the opinion that the Sosio beds are not contemporaneous with the Artinsk cephalopod-bearing beds, but somewhat younger. The only question is how much so. The occurrence of Arcestidae of such a complicate suture line as Waagenoceras and Hyattoceras make it probable that these beds belong at least to the upper part of the Permo-carboniferous.

The other European locality where Richthofenia has been found belongs to the Bellerophon limestone of the Alps, and there is not the slightest doubt that these represent the highest part of the Permian. The Bellerophon limestone everywhere is covered by the Werfen beds, the lowest part of the Triassic (Buntsandstein), and rests on the Gröden sandstone, equally a representative of the Permian.

In Texas, Richthofenia occurs in both subdivisions of the "Guadalupian" in the Delaware Mountain beds as well as in the Capitan limestone. Girty[1] seems to correlate these tentatively with the Russian Artinsk and Permian and perhaps with the Sosio limestone, but it appears that the character of part of the fauna makes him doubt about this result. Girty apparently gives a little too much importance to the carboniferous character of his brachiopods. We have seen that many brachiopods of the Bellerophon limestone indicate a decidedly carboniferous age, like *Productus striatus, semireticulatus, inflatus;* and these fossils do not occur there at all rarely, but in a very great number of specimens. Diener says that he himself never would have supposed that this fauna could be Permian if he had not known its stratigraphical position. Girty seems to accept Tschernyschew's view about the age of the Indian Productus limestone, but Tschernyschew also judged principally by the brachiopods, while the studies of Noetling and Diener show that the Productus limestone is certainly much younger than the Russian Gshelian and probably than the Artinsk, at least in part. Unfortunately, there were only a few ammonoid forms among the fauna described by Girty, but these show a decided relation to those of the Sosio limestone, which is considered by everyone as being younger than the cephalopod-bearing Artinsk. One of the most important types, Waagenoceras, occurs as low as the Delaware Mountain beds. We probably may suppose with safety that the Delaware Mountain beds correspond to some part of the Sosio limestone; that is to say, to a fauna younger than the cephalopod beds of the Artinsk.

Girty has described Richthofenia also from the Glass Mountains near Marathon. In this region, Dr. J. A. Udden has made extensive studies and collections, and I myself have lately made a cross-section through that region. The upper part of the strata which probably correspond to the Capitan limestone show very few fossils, but the Delaware Mountain beds are rather rich, and also the beds below them which do not seem to be exposed in the Guadalupe Mountains. The uppermost bed in which I have been able to find Richthofenia is a mass of limestone in the Dela-

[1] G. H. Girty, the Guadalupian Fauna, p. 40-50.
Idem, The Guadalupian fauna, and new stratigraphic evidence. Ann. N. Y. Acad. of Sci., Vol. 19, 1909, pp. 136, 137.

ware Mountain formation which is characterized by a large Medlicottia n. sp., entirely different from M. Copei White; in the same beds we find frequently Waagenoceras sp. nov., a globular form different from any other known. *Lyttonia americana* is not rare, and I have also found *Oldhamina* sp. nov. *Richthofenia permiana* is extremely frequent in these beds, while I have been able to find only one specimen of R. Uddeni n. sp., which has been collected in these beds. Below these beds I have found principally R. Uddeni n. sp. although *R. permiana* occurs there also. These beds are characterized by the occurrence of Waagenoceras n. sp., which in its entire form is somewhat similar to *W. Cumminsi* var. *Guadalupensis* Girty; and by another Waagenoceras n. sp. of very large dimensions and somewhat similar to, but by no means identical with, *Waagenoceras Hilli* P. Smith. Together with these occurs a large Productus of the *P. sino-indicus* Frech group, and a *Camarophoria* related to *C. mutabilis* Tschernyschew. There are still lower beds containing *Popanoceras* aff. *Parkeri* Karp. (non Heilprin), *Agathiceras* cfr. *uralicum* Karp, and *Thalassoceras* aff. *Gemmellaroi* Karp., etc., where Richthofenia has been found and also where Lyttonia still occurs, while the lowest beds with *Schistoceras* contain a common Pennsylvanian fauna without either Richthofenia or Lyttonia.

The upper beds which contain Richthofenia probably may be correlated with some part of the Sosio limestone and so would represent the upper part of the Permo-carboniferous or a horizon a little higher, while those immediately below them, which contain Thalassoceras aff. Gemmellaroi, Popanoceras aff. Parkeri Karp. (non Heilprin), Agathiceras cfr. uralicum Karp., with some probability may be considered as the equivalent of the cephalopod-bearing Artinsk of Russia, or lower Permo-carboniferous. Richthofenia Uddeni n. sp. has been found by Dr. Udden also near the Shafter mine, Presidio County. One specimen was taken from the so-called Transition beds, and two from the Cibolo limestone above the Transition beds. [1]Udden subdivides the Paleozoic rocks of that region in three different groups (from below to above): Cieneguita beds, Alta beds and Cibolo beds. Richthofenia was found in the Cibolo beds. These were subdivided from below

[1]J. A. Udden, the Geology of the Shafter silver mine district, Presidio County, Texas. Bull. Univ. Texas, No. 24, Austin, 1904.

to above in: Transition beds, Lower Brecciated Zone, Zone of Sponge Spicules, Thin-bedded limestone, Yellow limestone. Richthofenia was found in the lower zone, the Transition beds and somewhat above these. The Transition beds contain a number of specimens of large Spirifer which appears to belong to the groups of *Sp. Musakheylensis* Dav., *Sp. Marcoui* Waag., and *Sp. Ravana* Dien., and a number of other brachiopods, among which there is a number of small Productus, part of which seem to belong to the group of *Pr. gratiosus*, further *Plagioglypta canna* White, *Conularia* similar to *C. crustula* White, but more slender; and several gastropods. This zone, which is about 100 feet thick, is covered by the lower brecciated zone, which contains a very well preserved small Waagenoceras, determined by Perrin Smith as *Waagenoceras Cumminsi* White, var. *Guadalupensis* Girty. This is probably a provisional determination. The two forms do not seem to be identical; the suture line is certainly altogether different from that one published by Girty (pl. 29, fig. 24 and 25a) and the whole form is a little different, the height of the cross-section being greater than in the Guadalupian species. Above these beds we find the zone of Sponge Spicules. I have seen no fossils from this group. It is covered by the thin-bedded zone, which contains large Productus of the *Pr. sino-indicus* Frech group, a Spirifer somewhat similar to *Sp. nitiensis* Dien., several other brachiopods and a small ammonite determined by Perrin Smith as *Dalmatites Uddeni* n. sp. ms. The rest of the series is made up by a considerable mass of yellow limestone (650 ft.).

There is no doubt that this series belongs to the Permian. The Waagenoceras in the lower part indicates a position above the cephalopod-bearing Artinsk and the Dalmatites in the higher part—a relatively high position in the Permian. We may say that the whole series represents the upper Palaeodyas and perhaps part of the Neodyas in the sense of Frech (Lethaea geognostica). Unfortunately there is no fossil-bearing bed immediately below the Cibolo beds, but a mass of 3,500 feet of barren sandstones and shales below which exists a series of conglomerates, limestones, shales, etc., which contain a number of brachiopods of carboniferous character like *Pugnax* cfr. *uta* Marc., *Squamularia* cfr. *perplexa* McCh., *Composita* cfr. *mexicana*

Hall, *Comp.* cfr. *subtilita* Hall, *Dielasma* n. sp., and an *Euconospira* cfr. *turbiniformis* McCh. These beds, called the Cieneguita beds, may belong to the Carboniferous, but an exact determination of the age will have to be left to later studies.

If we consider the results obtained on the foregoing pages, we must come to the conclusion that the genus Richthofenia occurs with the greatest frequency at the end of the Palaeodyas and the beginning of the Neodyas; that it is found also possibly in lower strata (Amb group), the lower part of Palaeodyas and often in the higher division of the Neodyas (Bellerophon limestone; Upper Productus limestone). Nowhere has it been found in the Upper Carboniferous.

Thus Richthofenia is a genus of certain stratigraphical importance, and characteristic for the whole Dyas.

In the first part of this paper we have mentioned that Girty[1] described a *Tegulifera armata* from the Pennsylvanian of La-Salle, Illinois, and that this species is probably a Richthofenia. Girty himself says that his type suggests the genus Richthofenia, but he does not indicate which characters distinguish his form from that genus, but only mentions what are the principal differences between Tegulifera and Richthofenia. Comparing Girty's description and figures with our R. Uddeni we find a great similarity. Girty mentions the existence of a shelf in the ventral valve at the level of the dorsal one. In his fig. 7 and 8, the upper ends of the longitudinal ridges (at both sides of the area in Richthofenia) seem to be well visible; it is therefore most probable that an area and pseudodeltidium existed between them. The hinge line shown in fig. 7 is exactly like that in our Richthofenias. In Tegulifera the form of the hinge is entirely different and much more triangular (compare pl. 6, figs. 1b, 2b, 4, 4a, in Schellwien, Fauna der Trogkofelschichten, l. c.). The rim with its spines is, in Girty's form, exactly like that in R. Uddeni. The spines, which in some cases seem to bifurcate also in the Illinois form, are developed especially on the anterior side of the rim, while on the posterior side, blade-like laminae develop. The exterior aspect of the Illinois type is very similar to some of our smaller specimens of R. Uddeni with a truncate

[1] G. H. Girty, On some new and old species of carboniferous fossils. Proc. U. S. Nat. Mus., Vol. 34, p. 294, pl. 20.

apex. According to Girty, a difference exists in the nature of the spines on the surface. In the Illinois form, there are only a few small spines not mounted on spine bases, while in our Trans-Pecos species the spines are strong and generally expand at their base, so that when broken off there remains a wart or spine base.

It is, of course, impossible to show by the study of the somewhat imperfect figures only with certainty that T. armata Girty in reality belongs to Richthofenia, but even under these unfavorable conditions there is very little room for doubt. The species has certainly nothing to do with Tegulifera as described by Schellwien or with the more than doubtful *Teg.(?) uralica* Tschern.

If the Illinois type should prove to be a real Richthofenia it would be of a certain stratigraphical importance. The specimens have been found at LaSalle, but unfortunately, nothing is indicated with respect to the exact horizon. We know that at LaSalle the highest strata of the Pennsylvanian occur and the question would be, if those beds which contain Richthofenia still belong to the Pennsylvanian or if they represent the base of the Permian—the Artinsk. In the former case, this would be the first Richthofenia known to occur in the real upper Carboniferous. This question can be solved only in the field. Although Girty unfortunately does not indicate how many specimens he had, from his figures it seems that there exists at least a small number; it can be hoped, therefore, that more material may be found at the same locality and that it may be shown in which horizon they occur.

The Character of the American Species of Richthofenia and the Systematic Position of the Genus

Most of our knowledge of the nature of Richthofenia is based on the studies made by Waagen. Additional observations were made by Schellwien and Gemmellaro, while at last Di-Stefano was able to correct a number of errors committed by the earlier writers and to give us the right interpretation of a number of interior features of the shell. In the following general description of the shell we shall be guided principally by our own American material, but at the same time note what different observations have been made in Richthofenia of other localities.

The External Shape

Richthofenia is a shell composed of two valves, and has generally a somewhat irregular conical form. It often resembles a straight cone but in other cases the cone is curved towards some side (not always the same one!) and so resembles to a certain degree a cornucopia. This is especially the case in R. Uddeni n. sp., where the apex of the ventral valve was not attached to some foreign object. There the apex is decidedly bent over toward one side and rather sharply pointed.

The cross-section of the shell is generally oval in the right and left direction; that is to say. the postero-anterior diameter is shorter than the one at right angles to it. In some cases the cross-section is nearly circular. The height of the entire shell seldom is more than 4.5 to 5 cm. The Sicilian species are much larger. The relation of height to the two diameters of the shell varies a good deal; actual measurements will be given in the descriptions of the different species. The upper rim of the shell is generally thickened and on the anterior side armed with thick and sharp spines which point obliquely upward and toward the posterior side of the shell. In R. Uddeni the rim of the shell extends sometimes shelf-like towards the right or left hand; sometimes it also expands on the posterior side. The rim is generally much thicker on the anterior side than on the posterior.

The dorsal valve is deep in the interior of the ventral one, so that when it is closed a calyx-like cavity shows above it, formed by the walls of the ventral valve which are covered here also with a number of thin spines arranged so that they do not disturb the opening of the dorsal shell. The details of this will be shown in the description of the ventral valve.

Many of the specimens collected are broken off at the apex, which may mean that they were attached with that part to some foreign object, but quite a number is complete and show that they were attached sidewise to other specimens of Richthofenia; there are also several which do not show that they were attached anywhere. Very frequently Richthofenia seems to have lived in a kind of colony. There are several groups in my collection which show specimens of different age attached sidewise to each other by anchoring spines, with the apex turned more or less

to a certain point, so that the different specimens seem to radiate from this point.

The Ventral Valve

The form of the ventral valve is the one of the whole shell as described in the anterior paragraph.

As Waagen has shown the ventral valve consists of three different layers: the external, the medial, and the internal one. The real ventral valve is the internal one. It shows the area and the pseudodeltidium, but is entirely covered by the external shell and fastened and connected to it by the medial layer. *The external layer* or cover shell, as we might well call it, is relatively thin, is lamellous and covered by thin spines curved downward (considering the shell in its natural position with the apex on the ground). These spines are hollow, and where they are broken off a perforation in the shell remains. Generally the spines are not preserved but the perforations are always visible. In some cases it could be shown that these perforations communicate with the interior through all the three layers; this is always the case in the upper part of the shell, i. e., in that above the dorsal valve. The surface of the external shell is rugose in consequence of the thick and somewhat irregular growth lines which do not always form a perfect horizontal circle around the shell but sometimes bend downward in a certain part, thus corresponding to the distortion of the shell. As Girty truly remarks, this external shell without ribs, but with strong growth lines and covered with hollow spines, recalls to a certain degree the shell of some groups of Productus. If the specimen is not attached to some foreign body with its lower part, it ends in a sharply pointed and curved apex. At the upper rim of the valve the external shell seems to be pressed closely to the internal, the spines on the rim belonging to the internal shell.

The medial layer, called by Waagen the cystiferous layer, is generally thicker than the two other ones. It is formed by a network of cells which are constituted in the lower part of the apex region by nearly hemispherical cysts (pl. 3, fig. 4), while on the side of the animal chamber these cells are more irregular, their bottoms being directed obliquely towards above and towards the outside (pl. 3, fig. 7). They are subdivided by ir-

regular partitions which in most of the cases are only bifurcations of the principal partitions. The form of these cells varies extremely from round to elliptical and polygonal. As Waagen has shown already, this layer of cysts is pierced by radial, conical pointed tubes, which begin with their broad end at the outside of the layer and ascend towards the inner portion; but not all of them reach the innermost part with their sharp end; most of them stop half way. Others begin in the middle of the cystiferous layer and reach its inner limit. The cystose layer is irregular in thickness. It is thickest in the region of the apex, is much thinner at the side of the animal chamber, gets very thin in the part above where the dorsal valve is located, and thickens again in the rim of the ventral valve, where the cells have again a nearly hemispherical shape, being very narrow and much longer than high.

The internal layer, which, as Waagen says, is the really essential shell of Richthofenia, is formed by porous lamellae covered with small papillae. The interior side of this layer below the dorsal valve shows a number of hollow spines which are directed from below to above, the opening showing at the upper side of them. These spines are not free, but pressed against the side of the interior layer and partly imbedded in it, as was stated already by Girty. In the room above the dorsal valve we see the internal layer covered with a great number of spines all very different in sizes and arrangement, which will be described in our paragraph on the character of the internal shell. The internal layer is a little thicker than the external one, but not much.

Character of the Internal Shell

After having described the composition of the different layers which form the ventral valve, we shall now discuss the form and details of the essential part of it, the inner shell. Waagen says correctly that the medial and external layers are probably due to an exuberant growth of the shell. It would have been very difficult to describe the real form of the ventral valve and especially the details of its interior if we had not first made clear that the two outer layers only serve to obscure the outline of the essential shell.

The internal shell has a somewhat irregular conical form, much shorter, of course, than the external shell. In the outer surface of the Italian specimens, longitudinal stripes and ribs are observed, which are also visible in some of ours. When the outer and middle layer are removed on the posterior part of the internal shell an area and a pseudodeltidium are clearly visible (pl. 2, fig. 14; pl. 3, fig 1.). The area consists of two elongated, flat, triangular parts, the surface of which is smooth with the exception of lines of growth and sometimes a fine vertical striation. The pseudodeltidium is triangular, rather convex, and of variable length. Area and pseudodeltidium reach down to the apex of the internal shell. While they can be made visible from outside by removing the calcareous external and medial shell, they very frequently are shown in the interior of silicified shells. Opposite and near the pseudodeltidium, Waagen had observed three vertical septa, the middle one straight and never curved, while the lateral ones are convex on their outer and concave on their inner side. Girty was not able to find these three septa, and doubted that they could have been developed. Girty's specimen, probably, as most of my own, showed only the area and pseudodeltidium from the inner side. But Waagen's observation was certainly right. In the Sicilian specimens exist in front of area and pseudododeltidium, two narrow tubes which certainly contained the muscles; they are divided by a medial septum. These tubes were first observed by Gemmellaro and well described and figured by Di-Stefano, who calls them the myophore tubes. Di-Stefano explains that where these tubes were partly destroyed they would take the aspect of the three septa described by Waagen; that is to say, the lateral parts of the tubes would appear as internally concave septa, while the middle septum would be entirely straight. This explanation may be entirely right, but it is quite possible that in the Asiatic species of Richthofenia, three septa were developed in front of the area and pseudodeltidium, while the Sicilian species possess two myophore tubes. We shall see later on that the form found near Palermo differs also in other respects from the Asiatic and the American representatives of Richthofenia.

I have not been able to observe such an apparatus in any of the many R. permiana prepared by me. Only in one of my

specimens from the Medlicottia zone we observe two very thin tubes apparently divided by a median septum. These two tubes cover the space in front of the pseudodeltidium between the two parts of the area. I am by no means sure that these two tubes really represent the myophore apparatus of the Sicilian form. They may even be accidental formations of fossilization. The specimen is silicified and does not allow much preparation with the needle. If the myophore apparatus described by Di-Stefano or the septa figured by Waagen ever existed in R. permiana, they must have been so delicate that they were always destroyed; at least, not a trace of them can be observed in the material from the Glass Mountains. That the existence of the myophore tubes is not very probable is shown by the specimen which contains the two tubular openings described above. As we shall see later on, the shell is projected at either side of the area, forming a kind of a vertical, very pronounced ridge on both sides. In one of these ridges we observe two hollow spines entirely free from the wall in their upper end and projecting a little towards the center of the shell. These spines could not exist if the myophore tubes had had the position described by Di-Stefano, because the upper end of them would interfere with the tubes.

Altogether different are the conditions in R. Uddeni. There we see (pl. 3, fig. 2) in front of the pseudodeltidium a strong, knife-like septum which nearly reaches to the hinge line. It is curved a little to the left at its base, and is apparently destroyed in part. There possibly existed the two myophore tubes. The curve at the base of the septum might indicate the rest of the left hand tube. A remnant of the median septum can still be observed in another specimen (pl. 3, fig. 3). In front of the pseudodeltidium and exactly in the position of the septum in the specimen mentioned we observe a sharp conical elevation with the remains of a thinner partition in the posterior part of it; clearly a remnant of the median septum as described in the other specimen; but the upper part is entirely destroyed.

Opposite the pseudodeltidium in the anterior side of the animal chamber we often observe a rounded and low ridge on the bottom, which divides the room in two parts, causing a shallow trough on both sides of it. This ridge which was described and

figured by Waagen (loc. cit., pl. 83, pp. 7 and 8) and mentioned by Girty (loc. cit., p. 285, pl. 31, fig. 1, 2) as well as by Di-Stefano (loc. cit., p. 7) seems to exist in all the specimens which could be cleaned entirely. In several specimens of Richthofenia permiana the interior side of which could be entirely laid free, we see a deep pit between this ridge and the pseudodeltidium, a pit which goes deep down toward the apex of the internal shell, but without reaching it (pl. 1, fig. 6). I have not been able to determine if this pit is natural or if it is the place where the septa existed. This pit is visible also in other less well preserved specimens. The form of the bottom of the animal chamber is quite variable. Where the anterior part is very much thickened, the base of the ridge is nearly horizontal; where that part is very little thickened, the ridge ascends strongly and nearly forms an elevation on the anterior wall of the living chamber.

The animal chamber also varies in other respects. Its height often occupies two-thirds or even less of the inner shell; in other cases it occupies nearly four-fifths or even nine-tenths of the inner shell. These variations are not due to the age of the animal. We find them in shells of the same height, and living together in the same group. These differences of height exist in R. permiana as well as in R. Uddeni. In general, the animal chamber of the American specimens is much deeper than in the Asiatic forms, if Waagen's figures (loc. cit., p. 738, fig. 24) really represent the average of the longitudinal sections. Also the Sicilian specimens seem to have a smaller animal chamber than ours, but this depends entirely on the thickness of the medial layer in the region of the apex, which, as Girty has stated already, is much less in the American specimens than in those from India.

The transverse section of the animal chamber is more or less circular or elliptical with the exception of its posterior part. There we see that a nearly rectangular part of the outline protrudes towards the area and pseudodeltidium. Looking at an opened shell we see that the area and pseudodeltidium do not lie in the same plane as the inner wall of the animal chamber, but are sunk into it and that at each side of the area exists a longitudinal ridge rounded at is edge, which accompanies the

area down to its lower end. These two ridges have been called "dental callosities" by Girty, because they resemble the supports of the dental pit in some brachiopoda (f. e., in Rhynchonellina and some Rhynchonella), but this expression is entirely improper because there can be no dental callosity where no teeth exist. These ridges had certainly the object to strengthen the shell at its weakest point near the area, and the space between them, as we shall see further on, had to receive the protruding end of the dorsal valve. A longitudinal section through one of these ridges (pl. 1, fig. 16) shows that these are not produced by the thickening of the inner shell but by a curvature of the inner shell itself, a bending in which the external shell does not partake so that the hollow space thus formed had to be filled out by a thickening of the medial layer. Both ridges end above in a cup-like concavity very similar to the dental pits in other brachiopods. In this concavity we see generally one larger perforation, the end of a tube which passes through the shell in a nearly vertical direction and which communicates with one of the hollow spines on the outside of the external layer (pl. 1, fig. 14). The concave end of the ridges is covered with a great number of small spines directed upward. From the concave end of the ridges a shelf-like extension ascends slightly, thinning out quickly.

A little below the upper rim of the ridges we observe a narrow shelf-like band nearly all around the interior wall of the inner shell. It begins at the posterior side of the shell, immediately at the side of the area. It does not exist on the area itself, but on both ridges, and from there ascends slightly toward the anterior side of the shell, where it reaches its highest point. This rim, ring or shelf is visible in every well preserved individual (pl. 1, fig. 11, 16, 17; pl. 3, fig. 2), and served as a rest or support of the dorsal shell when this was closed. This ledge was observed by Waagen (l. c., p. 739); below it exists a number of impressions parallel to it; these Waagen took to be a pallial impression. These impressions are visible also in the American specimens (pl. 3, fig. 1). Generally there are two ring-like depressions below the upper ledge, separated from each other by a broad elevated band, and below the lower of the impres-

sions we generally observe a thin elevated ledge parallel to the upper one.

The upper ledge or shelf which supports the dorsal valve when closed, is not a thickening of the internal shell, but is produced by a fold around this. On the outer side of the inner shell it consequently shows in the form of a ring-like groove. I suppose that this groove on the outside of the inner shell is what Di-Stefano calls the "aulacoterma." Di-Stefano thinks that this aulacoterma, his false valve, the vesicular internal tissue, the calyx and the dorsal valve belong to what he calls the dorsal apparatus. Of all these organs, only the aulacoterma and the dorsal valve exist in the American specimens, and in these the aulacoterma is nothing but a ring-like fold in the internal shell. We shall discuss this matter in detail a little later.

Above the animal chamber which ends at the described shelf, the inner shell continues up to the rim. This part is sometimes nearly as high as the animal chamber, sometimes much lower. When the dorsal shell is closed this upper part of the ventral shell resembles a calyx or cup with a more or less flat bottom. The inner surface of this part of the shell is entirely different from that of the animal chamber, while in this latter one we only observe some perforations and hollow spines partly imbedded in the wall, we see here the whole inner surface covered with thin spines. We can distinguish two different kinds of spines, large and small ones. The small ones cover the whole surface of the inner walls, but are better developed on the posterior side than on the anterior. When the spines are broken off the walls of the shell appear to be covered with small papillae. Near the ledge or shelf above the animal chamber, the small spines are strongly directed upward; a little higher they form a right angle with the surface of the shell, or even are pointed downward. That is the case where this position cannot disturb the movement of the dorsal valve. The large spines are mostly found on the anterior wall and are all pointing upward so as not to disturb the movement of the dorsal valve. Near the ledge no large spines exist; a little above the ledge the spines are much smaller than near the rim; they grow slowly in size from the ledge to the rim. On the posterior side we find large spines only in the upper part near the rim, all pointing upward (compare text, fig. 1). When the

room above the animal chamber is very shallow, large spines only show on the rim. All the spines on the internal side above the animal chamber seem to be solid, and none of them connects through the medial and external layer with the outside. Be-

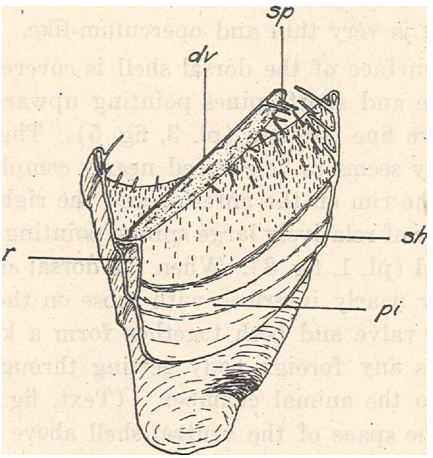

Fig. 1

Figure showing a schematic longitudinal cut through Richthofenia permiana; showing the interlocking of spines of ventral and dorsal valve, the latter being open. *dv*, dorsal valve; *sp*, spines on lower side of dorsal valve; *sh*, shelf in ventral valve supporting the closed dorsal valve; *pi*, pallial impression; *r*, longitudinal ridge at the side of the area of the ventral valve.

tween these spines we find a number of perforations in the wall which connect directly with the hollow spines on the external layer.

The rim of the shell is defended by thick strong spines on its anterior side, spines that enter deeply with their base in the medial cystiferous layer; at the rim itself they resemble strong teeth in R. permiana (pl. 1, figs. 11, 17), while in R. Uddeni they form a defense work of long, thick and often bifurcating spines, pointing obliquely toward the center of the shell and slightly upward (pl. 2, figs. 1, 3, 4, 5, 6, 7, 13). The posterior part of the rim is formed by several lamellae directed obliquely outward and upward (pl. 1, fig. 11, 17; pl. 2, fig. 5). These blade-like lamellae belong in part to the inner and in part to the external layer. In R. Uddeni we often observe the shell protrude shelf-like toward one side (pl. 2, figs. 1, 2, 5).

The Dorsal Valve

The dorsal valve is much more simple than the ventral one. It is circular or elliptical, small, flat or slightly concave. It is composed of two layers, an outer and an inner one; no medial layer exists; it is very thin and operculum-like.

The upper surface of the dorsal shell is covered with a great number of fine and short spines pointing upward, which when broken off leave fine papillae (pl. 3, fig. 5). The lower surface on the contrary seems to be covered nearly completely with real papillae, but the rim on the anterior and the right and left side shows a number of relatively large spines, pointing downward and a little forward (pl. 1, fig. 3). When the dorsal shell opens wide these evidently nearly interlock with those on the anterior wall of the ventral valve and both together form a kind of defense which prevents any foreign body getting through between the two valves into the animal chamber. (Text, fig. 1.) In those shells where the space of the ventral shell above the dorsal one is very narrow the spines on the rim of this latter one must have nearly touched the spines on the anterior rim of the ventral valve. This probably was the case in R. Uddeni, but unfortunately no dorsal shell of this species has been found until now.

While in the Sicilian specimens the border of the dorsal valve is finely indented, it seems to be entirely rounded in ours. On the anterior side we see a tongue-like, nearly rectangular projection which fits in between the area and the cup-like ends of the two vertical ridges on both sides of the area of the ventral shell (pl. 3, fig. 5). In the middle of the posterior side of this projection we see a very small rounded cardinal process, which covers the space included by the pseudodeltidium of the ventral shell. This process does not show on our fig. 5, of plate 3, because it is covered by the rim of the ventral valve, but it shows very well on our fig. 6, plate 3. There we see that the hinge line has exactly the length of the area and that when the shell opens the hinge line of the dorsal valve rests on the two parts of the area of the ventral valve. We also see that the cardinal process enters and swings in the space formed by the pseudodeltidium between the two parts of the area. None of our specimens shows the area of the dorsal shell; it must be exceedingly narrow. On

the lower side of the cardinal process we see two small parallel ridges limited and separated by three deep, pit-like grooves. These two apophyses certainly formed the point of attachment for the divaricators.

If the two myophore tubes with their separating septum really existed in our specimens, that septum would enter in the groove between the two apophyses of the cardinal process, while these would enter into the two myophore tubes. In the same figure 6 of pl. 3 we see also the beginning of one of the small curved elevations on the side of the dorsal valve which, in more complete specimens, limits the dendritic impressions of the adductors. These impressions are very well visible in our fig. 17, pl. II. They have an elliptical form, the surface of which is covered with somewhat irregular radiating elevated lines which start from a median elevated crest. These impressions are entirely similar to the common scars of the adductors in Productus, as they are shown for example in pl. XVIIa, fig. 21 (Productus punctatus Mart.) and in pl. XIX, fig. 22 (Prod. semireticulatus) of Hall and Clarke's work on the Palaeontology of New York. On the level surface between the two scars we see a groove with an antero-posterior direction which divides them.

These impressions of the adductors are different from those of the Sicilian Richthofenias as described by Di-Stefano and figured in his pl. II, fig. 23, and pl. III, figs. 5 and 7. The impressions of the Italian form are less elliptical, nearer together at their posterior part, and the dendritic elevated lines do not start from a ventral elevated ridge but from some point near the anterior end of the scar. Also the position of the impressions is a little different; in the Sicilian species they begin near the cardinal process, while in our specimen they are quite distant from it.

We cannot compare the impressions of the adductors on the Indian species because Waagen has not observed them very distinctly. His figures 1c and 14 show only some indented lines which may be much coarser than in our own species. He also mentions a median septum between the two impressions which certainly does not exist in our specimen.

On the exterior side of each of these scars of the adductors, we observe in our specimen a slightly elevated ridge which

follows their outline more or less parallel. Presumably these constitute the beginning of the two ridges described by Di-Stefano (l. c., p. 11), which, according to him farther on, turn toward the interior with the tendency toward a spiral form. Di-Stefano sees in them crests limiting the so-called reniform impressions as they are found in Productella and Strophalosia. These elevated lines can then be considered as brachial ridges. We have not been able to observe the ends of these ridges possibly because that part of the dorsal valve is not represented in any of our specimens.

In the Sicilian as well as in the Indian specimens a thin and low median septum on the anterior half of the lower side of the dorsal valve has been noted. In the specimens of R. permiana no such median septum seems to exist on the lower side of the dorsal valve. In our collection is one very well preserved fragment which shows the lower side of the dorsal valve and it is entirely covered by papillae and near the rim by teeth-like spines; not the slightest trace of a septum being visible. If such septum ever existed it must have been much shorter than in the European and Asiatic species.

Differences Between the American, Asiatic and European Forms

We have already indicated some points in which our specimens differ from the European and the Asiatic forms. Our ventral valve is exactly alike that of R. Lawrenciana from India with the only exception that the cystiferous layer in the apex region is much thinner in our specimens than in the Indian ones, and that we cannot observe the three median septa illustrated by Waagen (loc. cit., pl. 83, fig. 1a, 1b)[1] although they may have existed and only have been destroyed by fossilization. Another difference may be found in the form of the rim, but it is very possible that also on the rim of the Indian ventral valve spines existed, although they may not have been preserved in the specimens found until now.

Our dorsal valve is likewise absolutely similar in its character to that of the Indian species with the exception of the medial sep-

[1]Di-Stefano, l c., p. 7, thinks that these two illustrations represent the external exfoliated part of the dorsal valve. The figures really look very strange, but possibly the drawing is not very good. The question naturally can only be settled by an inspection of the original.

tum which does not seem to exist in our specimens. The row of curved spines on the lower side and parallel to the margin of the valve has been observed also by Waagen (loc. cit., 737).

Evidently there is not a very great difference between the two groups of American and Asiatic Richthofenias, but we shall see that both distinguish themselves very much from the Sicilian species. The animal chamber of the ventral valve is not very different from that of the other species; the principal difference is to be found in the presence of the two myophore tubes in the Sicilian species instead of the three septa in the Indian form and the single septum or none at all in the American forms. Entirely different are the conditions of the ventral valve above the shelf which serves as a rest for the dorsal valve. Instead of being of an open cup-like form, we find it closed by a mass of net-like tissue far above the dorsal valve.

Still more peculiar is the structure of the dorsal valve. As far as can be judged from the figures of Di-Stefano, this valve seldom is found closed, and instead of being a thin, opercular valve, it is composed of a thin opercular valve (corresponding in every respect to that of the Indian shell) and a false valve pressed against the wall of the ventral valve, partially connected with the dorsal valve by an internal reticular tissue. Above this we see the whole space of the ventral valve filled out by a vesicular tissue which forms often even a calyx-like depression in the upper part of the ventral valve. It seems that water and food could get to the animal chamber only by passing through the vesicular calyx.

This astonishing arrangement is different from anything that is known in the Asiatic and American Richthofenia. I have studied a number of complete or nearly complete specimens belonging to R. permiana and R. Uddeni and it is entirely impossible that such an arrangement should ever have existed in them, if it was not destroyed before fossilization, but even supposing this, it would be remarkable that only those tissues and the false valve should have been destroyed without leaving even a vestige. I should rather suppose that these organs never were developed in the American Richthofenia.

The question arises if the Sicilian species should be distinguished from Richthofenia subgenerically or if those strange

features developed above the dorsal valve could be explained simply as originated by a still more exuberant growth than in the Asiatic and American forms; but it seems to me absolutely impossible to solve this problem without comparing, first, material from the different localities. One might be inclined to see in all these features only an exuberant growth of shell material. In favor of this speaks even the presence of spines called "lacinie" by Di-Stefano and which might be the spines we find on the rim of our shells; if these were covered by some vesicular matter they would nearly present the aspect produced by the "lacinie" in pl. 2, fig. 7 of Di-Stefano's paper; but in the Sicilian those "lacinie" or flaps or teeth do not exist only on the anterior side. They are even stronger on the posterior part where they appear on the edge of the false valve.

Systematic Position of Richthofenia

Waagen (loc. cit., p. 732) has shown that Richthofenia has certain relationship with the Productidae. Schellwien (loc. cit., p. 26-33) lays stress on the similarity between R. and Scacchinella, leaving the question open, if these belong to the Productidae or the Strophomenidae. Girty (loc. cit., p. 281) thinks that R. permiana has a distinct relationship with Productus, through Strophalosia and Aulosteges. He says: "The general character of the sculpture—spiniferous without ribs, but with strong growth lines—immediately recalls certain Producti; the high area and pseudodeltidium are found in Aulosteges, while the little ridge which stands opposite to the area on the inside of the Richthofenia finds, in some cases at least, an apparently analagous structure in Strophalosia." Schuchert[1] places Richthofenia near his Strophalosiinae of the family of the Productidae but in an independent family—Richthofenidae of the super family Strophomenacea. In this family Schubert unites Tegulifera Schellw. Richthofenia Kays, and Gemmellaroia Cossm. (Megarhynchus Gemm. non Lap.)

Di-Stefano (loc. cit., p. 14-16) emphasizes the near relationship to Tegulifera, Proboscidella and Scacchinella, on account of the existence of external layers which cover the real shell, the

[1]Schuchert, in Zittel-Eastman, Text Book of Paleontology, 2nd ed., London, 1913, p. 391.

cystiferous character of the middle layer and the abundance of internal transverse septa. On account of the remarkable development of the dorsal apparatus in the Sicilian Richthofenia, Di-Stefano defends the validity of Waagen's suborder "Coralliopsida," a suborder which has not been recognized by other authors. Di-Stefano even wants to make the Coralliopsida an order.

Di-Stefano sees the nearest relationship with Richthofenia in the Productidae and less in the Strophomenidae, because the former ones are deprived of teeth. The nearest genera according to him seem to be Productus, Strophalosia and Aulosteges, because these have a perforated external layer while the internal parts of the valve are covered with papillae, a triangular area divided by the cardinal process of the dorsal valve, and another one much lengthened and divided by the pseudodeltidium of the ventral valve, a median septum on the inferior side of the dorsal valve which also shows the cardinal process and the dendritical impressions of the adductors. Di-Stefano does not believe that Scacchinella and Gemmellaroia (=Megarhynchus Gemm. non. Lap.) can be considered as belonging to the family of the Richthofenidae, although the external form of their shell is very similar, but the internal characters are very different.

Frech (loc. cit., p. 134) thinks that as Gemmellaro already remarked, Richthofenia, Gemmellaroia and the somewhat less closely related Scacchinella, form a continuous group, and that for the two first genera the name Coralliopsida may be retained as a family name. Frech sees no principal differences in the series Strophalosia-Aulosteges-Gemmellaroia-Richthofenia.

There does not exist any doubt about the near relationship between the Productidae and Richthofenia. To the reasons cited by other authors we might add a negative character—the lack of a solid brachial apparatus. A still greater similarity seems to exist between Strophalosia and Richthofenia, especially with respect to the development of the area in the ventral valve. Aulosteges resembles Richthofenia still more on account of the high area and pseudodeltidium. If we take into consideration only the internal shell of Richthofenia, we find that this has a great similarity with Gemmellaroia Cossm. (=Megarhynchus Gemm. non Lap.); the greatest difference is found in the im-

pressions of the adductor which are not dendritical in Gemmellaroia. I would not give too much importance to the covering or epidermical outer and middle layers, which certainly constitute only a feature of exuberant growth of the shell substance. This cover is also found to a certain degree in Tegulifera, but the inner shell of this genus is so different that we certainly cannot collocate both genera in the same family. If any genus besides Richthofenia could be united with it in the family "Richthofenidae" it should be Gemmellaroia. Scacchinella seems to be far less related to Richthofenia; Schuchert may possibly be right when he puts it near Derbya, Meekella and Geyerella. Tegulifera certainly has a great similarity to Richthofenia if we only consider the external aspect, but as Schellwien already remarked, the inner shell is entirely different and certainly belongs to the Productidae. In my opinion Tegulifera should not be put in the Richthofenidae family.

We get thus the result that Richthofenia belongs to a family distinct from the Productidae, and that in this family, the Richthofenidae, the genus Gemmellaroia Cossm. may be included. The suborder Coralliopsida should be discarded, because it is founded on a character of secondary value, the form of the outer shell which only results from an exuberant growth of shell material. Because if we recognize Corralliopsida we would have to include in it Tegulifera also, but this genus clearly belongs to a family of entirely different relationships. Tegulifera belongs to the Productidae while Richthofenia does not, although it is connected with this family through Aulosteges and Strophalosia.

DESCRIPTION OF THE AMERICAN SPECIES

Richthofenia permiana (*Shum.*) *Girty*

Pl. 1, fig. 1-16; pl. 2, fig. 8, 15; pl. 3, fig. 1, 4, 5, 6, 7.

1859 *Crania permiana*	Shumard,	Notice of fossils from the Permian strata of Texas and New Mexico, etc. Trans. Ac. Sci. St. Louis, Vol. I, (1860), p. 395.
1908 *Richthofenia*—	Girty	The Guadalupian Fauna. U. S. Geol. Surv. Prof. Paper 58, p. 283, pl. 14, fig. 27; pl. 20, fig. 23; pl. 22, fig. 6; pl. 24, fig. 10; pl. 31, fig. 1-3.

Girty has reproduced the definition of Shumard for his Crania permiana, and there really seems to be very little doubt that

that species actually belongs to Richthofenia. Shumard described the outer form very well, observed that below an outer cover an area and pseudodeltidium was hidden and noticed the existence of a nearly flat dorsal valve. The interior characters remained unknown to him. Girty unfortunately had not very well preserved material which made it impossible for him to give an entirely complete description.

In our discussion of the characters of American Richthofenidae we have described all the principal points of the external form and the internal structure of the shell. It will thus be unnnecessary to repeat all those details here, which are common to both our species. We shall principally emphasize the characters which distinguish our species from the other known forms.

The Shape of the Shell

Richthofenia permiana consists of two valves. The larger or ventral valve is of an irregular conical form sometimes almost resembling a cornucopia, while in other specimens it is a nearly perfect cone, although the rim is mostly not forming a right angle with the longitudinal axis of the valve, but slanting upward from the posterior to the anterior side. The shell resembles a cone which has been cut off obliquely at its base. The outer part of the ventral valve is covered with a great number of strong hollow spines, generally curved from above downward, especially if the valve is altogether free; and where it is not, on those sides that are not near a foreign body. When the individuals grow in groups or colonies, the spines are often not well developed on one to even three sides, where the shell is pressed against others, while in the parts that are left free, strong spines are developed, and those often form a right angle with the surface of the valve. Our species has therefore real anchoring spines like the Productidae. Very frequently a specimen seems to have been attached to a foreign body by its apex; then the apex is not developed in a point as is the case when the indivdual is attached to other bodies by its spines.

The transverse section of the shell is generally elliptical, the postero-anterior axis being the shorter one; less frequently the section is nearly circular.

The surface of the shell shows strong growth lines and is rugose, as described in the general definition of American Richthofenia. The spines generally are broken off and in their place are seen numerous perforations.

The shell is in general very slender, even in very juvenile specimens; only very young individuals of a diameter of 3 mm. and less show a more cup-like form (pl. 1, fig. 11), but they evidently develop rapidly in length, specimens with a diameter of 8 mm. show already a very long and slender form.

The dorsal valve is sunk more or less deeply into the ventral valve and has an opercular appearance; it is thin and generally concave, its shape imitates the cross-section of the ventral valve.

The ventral valve is composed of three layers: the external, the medial and the internal (pl. 3, fig. 7) as described above in the general definition. The medial layer in this species is thickest in the region of the apex; i. e., around the apex of the inner layer and below it; but even there it is not thicker than a few millimeters even in large shells (pl. 3, fig. 4). It thickens also considerably on the rim of the valve, especially on the anterior side. The outside of the valve is covered with spines generally bent downwards as described above. Where the spines are broken off a perforation remains. In the portion of the valve which lies above the dorsal valve these perforations pass from the outside into the interior.

The posterior side of the inner shell shows a long and slender area composed of two triangular parts, reaching from the hinge line to the apex. The area is covered by strong horizontal growth lines. The two parts of the area are united by a long convex pseudodeltidium (pl. 2, fig. 15; pl. 3, fig. 1).

The animal chamber is of varying length, sometimes occupying about two-thirds or less of the ventral shell, sometimes about four-fifths or even more. At both sides of the area we observe a longitudinal ridge formed by a fold of the shell (pl. 3, fig. 1). These ridges are concave at their upper end and generally show a perforation in the pit which connects with one of the hollow spines on the outside by means of a nearly perpendicular tube (pl. 1, fig. 14). On account of the presence of these ridges, the area and the pseudodeltidium, the cross-section of the interior

is not subcircular or elliptical as the outside, but shows a nearly rectangular projection on the posterior side.

In one specimen the room between the two parts of the area in front of the pseudodeltidium seems to be occupied by two tubes separated by a septum, but it cannot be ascertained if this is accidental or if really the two myophore tubes observed by Di-Stefano exist in this species. In all the other specimens the area and pseudodeltidium are in direct connection with the animal chamber. At the bottom of this chamber we find a deep pit in front of the area and pseudodeltidium (pl. 1, fig. 6); the rest of the bottom is much higher and shows a rounded ridge with an antero-posterior direction (pl. 1, fig. 6). On both sides of it are shallow troughs. The walls of the animal chamber show a number of hollow spines generally imbedded in the wall, directed from below to above with the opening at the upper end (pl. 1, fig. 7); in a few cases short free spines not imbedded in the wall are observed.

The upper end of the animal chamber is indicated by a shelf in the interior going from the area all around the inner wall and slanting a little upward from the posterior to the anterior side. This shelf is produced by a fold of the inner shell, so that on its outside a deep groove corresponds to the shelf, as described in the general definition of American Richthofenias (pl. 1, fig. 16).

That part of the inner wall which lies above this shelf shows a great number of papillae and finer and thicker spines pointing upward and toward the interior of the valve; the size of the spines grows toward the rim (pl. 1, fig. 16).

At the rim the shell thickens considerably and develops a number of thick and strong short spines at the anterior side. These spines are pointed at about 45 degrees toward the interior and upward; their base often prolongs in folds on the rim and a little downward (pl. 1, fig. 11, 17; pl. 2, fig. 8). On the posterior part of the rim the thickening of the shell produces some low laminae or leaves on the anterior side of the rim (pl. 1, fig. 11, 17).

The dorsal valve is opercular, thin, and flat or slightly concave (pl. 1, fig. 2; pl. 3, fig. 5). It is composed of laminae and shows an inner and an outer layer, but no medial cystiferous

one seems to exist. The lower or inner side of the valve is covered with papillae and shows a zone of strong spines near the rim, but not on it. This zone exists on the anterior part as well as on the right and left side. The spines are directed downward and a little outward (pl. 1, fig. 3, compare also text, fig. 1). The upper or outer side is covered with papillae and a great number of finer spines (pl. 1, fig. 2; pl. 3, fig. 5).

While the greater part of the valve is subcircular or elliptical, it shows a broad subrectangular projection on the posterior part, which protrudes between the two longitudinal ridges toward the area and pseudodeltidium of the ventral valve (pl. 1, fig. 2; pl. 3, fig. 5). On the posterior side of this projection we notice a short and straight hinge line interrupted in the middle by a short semi-circular cardinal process which occupies the room in front of the pseudodeltidium of the ventral valve (pl. 3, fig. 6). On the lower side of this cardinal process we observe two subparallel short ridges or myophore apophyses the point of attachment of the divaricator. A little before these apophyses we see in one specimen the beginning of dendritic impressions of the adductor. In another specimen (pl. 2, fig. 17), the scars of the adductor are almost completely preserved; they consist of two nearly elliptical impressions, the longer axis of which has an antero-posterior direction. Their surface is covered with somewhat irregular radiating elevated lines which start from a median elevated crest lying in the middle of the impression in the direction of the longer axis. As already remarked in the general definition of American Richthofenias, these scars are entirely similar to those of Productus. On the exterior side of each of those muscle impressions we observe a slightly elevated ridge which accompanies the outline of the scars; these ridges presumably correspond to those observed by Di-Stefano in the Sicilian Richthofenias and which may be considered as brachial ridges. The two muscular impressions are divided by a groove.

No median septum is developed on the anterior or central part of the lower side.

Dimensions

Ventral valve.

	Height in mm.	Antero-posterior diameter of the rim, in mm.	Right to left diameter of the rim, in mm.	Breadth of area at hinge line mm.
I	* 38.2	22.3	22.2	5.2
II	* 36.7	20.7	20.6	?
III	**36.1	15.2	22.5	5.1
IV	* 17.5	15.2	18.0	4.1

	Breadth of pseudo-deltidium at hinge line, in mm.	Height of anterior side of ventral shell, from rim to shelf, in mm.	Height of posterior side of ventral shell from rim to hinge line, in mm.
I	1.6	6.0	?
II	?	±6.1	6.1
III	1.6	9.4	9.4
IV	?	4.8	±4.8

Dorsal valve.

	***Antero-posterior diameter, in mm.	Right to left diameter, in mm.	Breadth of projection (right-left), in mm.	Length of projection (antero-posterior), in mm.
A	14.1	15.0	5.2	2.5
B	13.0	15.4	±5.0	±2.5

*Apex incomplete **Rim incomplete ***Projection included.

Relation to Other Species

In its outer form our species is somewhat similar to R. Lawrenciana de Kon., although it is a little more slender; but the American species is easily distinguished from the Indian by the thinner medial layer, especially below the animal chamber, by the non-existence of the three septa in the ventral valve, and because a median septum is lacking in the dorsal valve. It seems also that the rim of the asiatic species is not armed with spines, which should be visible on the specimen illustrated by Waagen in his pl. 83, fig. 7.

All these differences should make it advisable to distinguish the American forms at least subgenerically from the Asiatic species, but such a division of the genus can only be accomplished by someone who has material from all the different localities at his disposition.

Somewhat similar to our species in its outer form seems to be

also Richthofenia aff. Lawrenciana Diener from the Bellerophon limestone of Schaschar in the Carnian Alps, but the area seems to be narrower and the pseudodeltidium broader than in our species. The Alpine form is too incompletely known for any detailed comparison. Di-Stefano identified the Alpine species with his R. communis Gemm., but this proceeding does not seem advisable considering how little we know about Diener's species and how much the species of Richthofenia resemble each other exteriorly, even when the interior is entirely different.

The Sicilian species cannot very well be compared with R. permiana, on account of their development of the false valve, the calyx, the dorsal tissue, etc. In its exterior form, R. sicula is more similar to our species than R. communis, the latter one being extremely slender and very irregular in outline, especially in the lower part of the ventral valve. In both species the pseudodeltidium seems to be relatively broader than in ours. Girty doubted that the Sicilian species had spines on the outer surface, but Gemmellaro already remarked in his original note that R. communis had a smaller number of spines than R. sicula.

The differences between R. permiana and R. Uddeni will be discussed in the description of this latter species.

Occurrence

Richthofenia permiana has been found by Shumard and by Girty in different places of the Guadalupe Mountains, both in the Delaware Mountain beds and in the Capitan limestone. In the Glass Mountains it occurs principally in the zone of Medlicottia sp. nov., in the lower part of the Delaware Mountain beds, but also lower down, in the zone of Waagenoceras n. sp. (similar in form to W. Hilli P. Smith). It is frequent in the Gilliam Canyon, on the mountains immediately north of Leonard Mountain, in the mountains west of Iron Mountain, at Hess Tank, Word's ranch, and other places. Dr. J. A. Udden has found it also in the Altuda Mountains and Mr. Chas. L. Baker found it in the Mt. Ord range, south of the Southern Pacific between Marathon and Alpine.

Number of specimens examined: more than fifty.

Age: Permian.

Richthofenia Uddeni nov. sp.

Pl. 2, figs. 1-7, 9-14, 16; pl. 3, figs. 2 and 3.

While most of our material from the Glass Mauntains belongs to R. permiana, we have found a small number of specimens which are decidedly distinct of that species; they generally seem to occur in a somewhat lower horizon although one at least has been found also together with R. permiana.

R. Uddeni has more the shape of a very short cornucopia than that of a cone. In most of the specimens the well preserved apex is pointed and curved towards the posterior or obliquely to the right hand side; in some instances the apex is broken off, but it could not be distinguished if the specimen had been attached by it to a foreign body. The rim forms about a right angle with the longitudinal axis of the shell and seemingly does not slant much upward toward the anterior side.

The outside of the shell is covered by a great number of long, hollow spines, curved downward, which sometimes serve as anchoring spines that connect one specimen with another.

The transverse section is subrectangular but rounded at the edges, the antero-posterior diameter always seems to be longer than the one from right to left.

The surface of the shell is rugose and shows strong lines of growth. The form of the shell is stout, in young as well as in mature individuals. It never attains very large dimensions.

The dorsal valve is unknown but must have had its place deep in the interior of the ventral one, as is shown by the position of the shelf in this latter one. Its shape must have been more rounded and elliptical than the outer cross-section of the ventral valve.

The ventral valve is composed of three layers as all the other Richthofenia, the outer, the medial, or cystiferous, and the internal layer. The medial layer is thickest in the region of the apex and on the anterior and posterior side of the rim.

The external layer is covered with very numerous and long hollow spines as described above. Where these are broken off they leave round perforations. Owing to the kind of preservation of our material, it has not been possible to observe if these perforations on the part above the shelf are connected with openings on the interior side.

The posterior side of the inner shell shows a long and slender area composed of two triangular parts, reaching from the hinge line to the apex. The two parts of the area are united by a long convex pseudodeltidium.

The animal chamber occupies about half or a little more of the internal shell. At both sides of the area strong, rounded, longitudinal ridges are present, which at their upper end are concave; these ridges get thinner and less distinct towards the bottom of the animal chamber. While the greater part of the cross section of the interior is elliptical, these ridges together with the area and pseudodeltidium cause a nearly quadrangular projection of this line on the posterior side. The walls of these ridges show a distinct vertical striation.

The walls of the animal chamber show several perforations but no hollow spines imbedded in the wall.

In front of the pseudodeltidium we see a strong septum like a knife-blade rise out of the bottom of the animal chamber up to nearly the height of the hinge line (pl. 3, fig. 2, 3). This septum is not quite completely preserved, but it does not seem to have been in connection with the pseudodeltidium. At the base the septum is not entirely straight, but a little curved toward the left. The base of it continues in the form of a very low ridge through the bottom of the anterior side of the animal chamber, causing a very shallow trough to the right and left of it. In front of the area we see two small pits caused by the lateral extension of the base of the septum (pl. 3, fig. 2).

The upper end of the animal chamber is characterized by a relatively strong shelf or ring-like ridge going all around the inner wall of the internal shell and ending on both sides of the area on the longitudinal ridges mentioned above (pl. 3, fig. 2). This shelf is formed by a nearly horizontal fold in the inner shell and probably would show as a groove on the outside of it if the internal shell could be separated from the medial layer. The shelf slants very slightly upward toward the anterior side, and shows several (five) vertical, rounded incisions near the middle of the anterior side.

Above the shelf we observe on the inner wall of the ventral valve numerous papillae and near the rim of the posterior side the rests of spines. Owing to the silification of the shell the

finer details are not very well preserved in this part. On the anterior side we observe immediately above the shelf the base of a great number of thick spines which develop on the rim. These spines are very long, slender, but strong, and very frequently bifurcate at their upper end. They point toward the inside and upward at an angle of approximately 45 degrees. These spines resemble to a certain degree triangular blades and are altogether unlike the hollow spines on the outside with their circular cross-section (pl. 2, fig. 1, 3, 4, 5, 6, 7, 9, 13; pl. 3, fig. 2, 3).

On the posterior side the thickened rim divides into two or more thin laminae which sometimes curve and bend over a little toward the interior of the shell (pl. 2, fig. 1, 2, 3, 5; pl. 3, fig. 3).

The dorsal valve of this species is unknown.[1]

Dimensions.

Ventral valve.	Height (without spines on the rim) in mm.	Antero-posterior diameter of rim in mm.	Right to left diameter of rim in mm.	Breadth of hinge line in mm.	Brdth. of pseudodeltidium at hinge line in mm.	Height of ventral valve from rim to shelf	
						Anteriorly in mm.	Posteriorly in mm.
I	19.8	20.6	*32.4	5.2	1.5	?	10.1
II	14.2	18.1	23.2	3.5	1.0	4.1	6.7
III	14.3	15.8	23.3				
IV	** 9.0	13.8	18.3				

*24.2 without the shelflike extension on the righthand side.
**Apex broken.

Relations to Other Species

There are quite a number of differences between Richthofenia Uddeni and Richthofenia permiana. The former has a strong median septum in the ventral valve, while the second one has none at all. Other differences are: the stout form, the strong and peculiar spines on the rim, the cup-like shape of the ventral valve, the subrectangular cross-section, the comparatively broad hinge line and the great number of spines on the outside of R. Uddeni. The differences in the shape of the ventral valve are

[1]On a recent trip I found a Richthofenia similar to or identical with R. Uddeni, a little above the strata with Agathiceras cfr. uralicum, which shows a strong median septum on the lower side of the dorsal valve, and also the two elliptical scars of the adductor.

especially striking when individuals of about the same size are compared; only very small specimens of R. permiana (with a diameter of 3-4 mm. on the rim) resemble a little R. Uddeni, but those are always nearly circular in their cross-section, while that of the latter one is more or less subrectangular. Specimens of an antero-posterior diameter of 7 to 8 mm. are already easily distinguished from each other even from the outside.

There is a certain similarity between our species and Tegulifera armata Girty[1] which we believe to be a Richthofenia. This species has also a very stout and short form and shows a rim covered by long spines, but there are also considerable differences. T. armata is in general a much smaller form; it has frequently two or three rows of spines on the rim, which is never the case in our specimens. The hinge line of the Illinois type is much shorter than that of our species; it develops spines on the shelf which supports the dorsal valve, and this has never been observed in any of our specimens. The spines on the outer surface are few and small, and according to Girty, are not mounted on spine bases. None of Girty's specimens shows the apex, but I would not give much importance to this character. The general outline of the Illinois specimen is somewhat different from ours, being more elliptical in the cross-section instead of rectangular.

It may be accidental, but at every locality rich in Richthofenias there seem to be developed a long and slender form and a broad and stout one. In the Asiatic localities, these two forms are R. Lawrenciana and R. sinensis; in Sicily they are R. communis and R. sicula; in the American, R. permiana and R. Uddeni.

Our species resembles to a certain degree R. sinensis Waagen on account of its broad and stout cup-like form, but the Asiatic species is somewhat higher than ours (the upper part is missing in the specimens figured by Waagen, loc. cit., pl. 82a, fig. 4) and the cross-section is more rounded; the interior features of R. sinensis are unknown. Frech (in Richthofen, China, V, p. 135) is of the opinion that R. sinensis is only a juvenile form of R. Lawrenciana. As he has seen material from the different localities he is probably in a better position to judge about this

[1]G. H. Girty, On some new and old species of Carboniferous fossils.—Proc. U. S. Nat. Mus., Vol. 34, 1908, p. 294, pl. 20.

question than I am, but certainly the specimen figured by Waagen has a general form different from those figured as R. Lawrenciana. Unfortunately, a detailed comparison between our species and that from Asia is impossible on account of our fragmentary knowledge of the latter one.

The Sicilian R. sicula is much stouter than R. communis but differs from our species entirely. It has the complicated dorsal apparatus and the myophore tubes of R. communis which certainly does not exist in our species. R. Uddeni is also much stouter and lower than R. sicula.

Occurrence[1]

R. Uddeni is apparently much rarer than R. permiana. It seems to occur in the Glass Mountains mostly in the zone of Waagenoceras sp. nov. (similar to W. Hilli in its general aspect). I found several specimens in this zone on Leonard Mountain. Dr. Udden collected one excellent specimen in strata probably corresponding to our zone of Medlicottia sp. nov., near Word's ranch, in the same region. Another specimen was found by him in the drift in some other locality of the Glass Mountains. R. Uddeni does not seem to occur in the zone of Medlicottia sp. of Gilliam Canyon, and of the mountain immediately north of Leonard Mountain; at least, neither Dr. Udden nor I found a single specimen in those localities although pretty extensive collections were made. The species was also found by Mr. C. L. Baker in the Permian of the Mount Ord range.

Little doubt exists that R. Uddeni also occurs in the Permian of the Shafter region, Presidio County. The collections made near Shafter contain three specimens of a very low Richthofenia of a subrectangular cross-section. Unfortunately the interior of them could not be prepared and on account of the small number of specimens I did not think it advisable to grind one of them down to the septum. In their outer form they cor-

[1]On a recent trip to the Marathon basin Mr. Ch. L. Baker and the author discovered a number of Richthofenias immediately above the strata with Agathiceras cfr. uralicum Karp; they resemble somewhat R. Uddeni but represent possibly a new species similar to R. armata. We also found several specimens of R. permiana in the strata beneath the zone of Waagenoceras n. sp. (similar to W. Hilli) and several specimens of R. Uddeni in the lower part of the Medlicottia zone. This material could not be described in the present paper because text and plates had alerady been printed.

respond entirely to R. Uddeni, and differ from R. permiana considerably. The rim is not preserved in any of them.

***Number** of specimens examined:* nine.

Age: Permian.

Addendum to page 9

In 1913 Erich Haarmann[1] described a locality in Mexico (Hacienda de las Delicias State of Coahuila) where he had found Permian fossils, which later on have been studied by Wilhelm Haack.[2] Although this author published his results in 1915, I had no opportunity to see this paper until after my manuscript on Richthofenia had been printed.

Haack (loc. cit., p. 491, pl. 38, figs. 6a and b) describes a fragmentary fossil which he takes to belong to Richthofenia permiana Shumard. The figures published by Haack do not give a very clear idea of the object but if it really beongs to Richthofenia it would seem to be more like R. Uddeni n. sp. than like R. permiana.

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[1]Erich Haarmann, Geologische Streifzüge in Coahuila. Zeitschr. d. deutsch. geol. Ges., 1913, Monatsberichte, p. 18-47.

[2]W. Haack, Ueber eine marine Permfauna aus Nordmexico nebst Bermerkungen über Devon daselbst. Zeitschr. d. deutsch. geol. Ges., Vol. 66, 1914 (1915).

PLATE I.

(All the figures on this plate are in natural size.)

Fig. 1-3. *Richthofenia permiana* Shumard sp.—From the zone of Medlicottia sp., of the mountain due north of Leonard Mountain, Glass Mountains.

Fig. 1. From the anterior side.

Fig. 2. The same, from above, complete dorsal valve visible, and spines near rim of anterior side of ventral valve.

Fig. 3. The same, from the right hand side. *sp*, spines near the rim on the lower side of dorsal valve.

Fig. 4-6. *Richthofenia permiana* Shumard sp.—From the same locality.

Fig. 4. Very slender specimen seen from the posterior side.

Fig. 5. The same, seen from the left hand side; rim not preserved.

Fig. 6. From above. *dv*, part of the opened dorsal valve; p, deep pit in front of the area and pseudodeltidium; *r*, ridge on the anterior part of the bottom of the animal chamber.

Fig. 7. *Richthofenia permiana* Shumard sp.—From the zone of Medlicottia sp. near the junction of Road and Gilliam Canyon, Glass Mountains.

Fragment showing the anchoring spines, the inner walls of the animal chamber with the imbedded spines opened towards above, and the teeth-like spines near the rim. *rr*, upper end of the longitudinal ridges at both sides of the area.

Fig. 8-10. *Richthofenia permiana* Shumard sp.—From the zone of Medlicottia sp. near the junction of Road and Gilliam Canyon, Glass Mountains.

Fig. 8. Very stout specimen seen from the anterior side, rim not preserved.

Fig. 9. The same, seen from the right hand side. *dv*, dorsal valve open; the spines on its lower side are lost in the shadow.

Fig. 10. The same, from above. h, hingeline; dv, dorsal valve open; its anterior rim is not completely preserved.

Fig. 11, 12, 17. *Richthofenia permiana* Shumard sp.—From the zone of Medlicottia sp. of the mountain north of Leonard Mountain, Glass Mountains.

Fig. 11. A group or colony of specimens composed of individuals of different age, shown from above. *j*, very young individuals; *sp*, anchoring spines; *t* strong teeth-like spines on the thickened anterior rim; *h*, hingeline; *a*, adolescent specimens; *sh*, shelf on which the dorsal shell rests, when closed; *rr*, upper end of the longitudinal ridges on both sides of the area of the ventral valve; *l*, laminae on the posterior side of the rim.

Fig. 12. The same, seen from below to show how the animals radiate from a certain point.

Fig. 17. The same, from one side. *t*, teeth-like spines on the anterior side of the rim; *l*, laminae developed on the posterior side of the rim; *sh*, shelf on which rests the closed dorsal valve; *rr*, longitudinal ridges on both sides of the area in the ventral valve; *aa*, area; *ps*, pseudodeltidium.

Fig. 13-15. *Richthofenia permiana* Shumard sp.—From the zone of Medlicottia sp. on the mountain north of Leonard Mountain, Glass Mountains.

Fig. 13. Young and stout individual seen from the posterior side, showing the spines on the anterior side near the rim; this latter one is very little thickened.

Fig. 14. The same, seen from above. *rr*, cuplike upper part of the longitudinal ridges at both sides of the area in the ventral valve; the perforations visible in the middle of these upper ends connect with spines on the outside. The animal chamber is filled with siliceous matter.

Fig. 15. The same, seen from the anterior side.

Fig. 16. *Richthofenia permiana* Shumard sp.—From the zone of Medlicottia sp. near the junction of Road and Gilliam Canyon, Glass Mountains.

Stout but not quite adult specimen cut open on the right hand side. *r*, longitudinal ridge cut open; *ml*, medial layer; *el*, external layer; *t*, teeth-like spines near the rim.

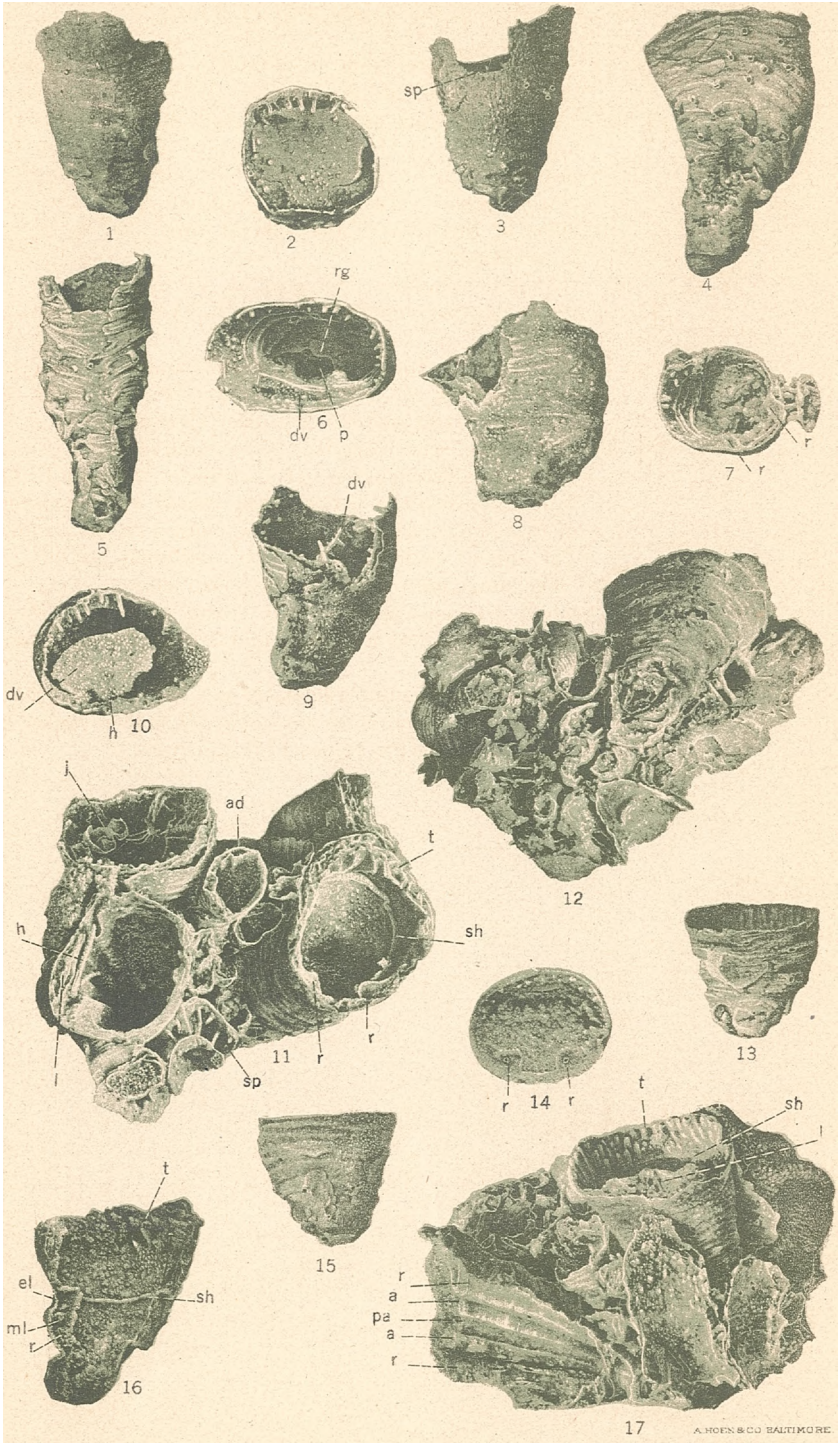
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PLATE II.

(All the figures on this plate are in natural size with the exception of Figure 17.)

Fig. 1-3, 5, 6. *Richthofenia Uddeni*, n. sp.—From rolled block in the Glass Mountains, exact horizon unknown, probably from rocks below zone of Medlicottia sp.

Fig. 1. Typical specimen seen from the anterior side, showing the strong bifurcating spines on the rim, the long hanging hollow spines on the external layer and the shelf-like lateral extension.

Fig. 2. The same, seen from the apex.

Fig. 3. The same, seen from the posterior side, showing the bifurcating spines on the anterior rim, the lateral shelf-like extension, the numerous long spines on the external layer, and the pointed apex.

Fig. 5. The same, from above, showing the strong bifurcating spines on the anterior rim, the shelf-like lateral extension on the right hand side, and the blade-like laminae on the posterior side.

Fig. 6. The same, from the right hand side, showing the bifurcating spines on the anterior side, the blade-like laminae on the posterior side, the long hanging spines on the external layer and the pointed and curved apex.

Fig. 4, 7, 9, 13. *Richthofenia Uddeni* n. sp.—From Word's ranch, Glass Mountains. Zone of Medlicottia sp.

Fig. 4. A typical specimen seen from the right hand side showing the strong bifurcating spines on the anterior rim, the blade-like laminae on the posterior rim, and the curved and pointed apex.

Fig. 7. The same, from the posterior side, showing the bifurcating spines on the anterior rim, the two blade-like laminae on the posterior side, the hanging hollow spines on the external layer in part anchoring the specimen to another Richthofenia, and the curved and pointed apex.

Fig. 9. The same, from the anterior side, showing the apex pointed and turned obliquely. The teeth-like spines are not completely visible, on account of the position of the shell.

Fig. 13. The same, from above; for explanation compare with pl. III, fig. 2.

Fig. 8. *Richthofenia permiana* Shumard sp.—From the zone of Medlicottia sp. on mountain north of Leonard Mountain, Glass Mountains.

Same specimen as figured in pl. I, fig. 11, 12, 17, seen from above. *rr*, longitudinal ridges on both sides of the area; *aa*. area; *ps*, pseudodeltidium; *tu*, tubular openings?; *t*, teeth-like

spines on the anterior rim; *ml*, vescicular structure of the medial layer showing on the anterior rim.

Fig. 10, 11, 14. *Richthofenia Uddeni* n. sp.—From the Transition beds of the Cibolo limestone, six miles N. N. W. of Shafter, Presidio County.

Fig. 10. Seen from the anterior side.

Fig. 11. The same, from the left hand side, showing the curved and pointed apex.

Fig. 12. The same, from the apex.

Fig. 12, 16. *Richthofenia Uddeni* n. sp.—From the rocks above the Transition beds of the Cibolo limestone, five miles N. W. of Shafter, Presidio County.

Fig. 12. Seen from the anterior side.

Fig. 16. The same, seen from the left hand side.

Fig. 15. *Richthofenia permiana* Shumard sp.—From 1⅓ mile N. N. E. of Hess Tank; probably from the zone of Medlicottia sp. or a little higher.

Part of the external and medial layer has been taken off so that area and pseudodeltidium are shown in the right position, while in all the rest of the figures these parts of the shell can only be seen from the inside. *aa*, area; *ps*, pseudodeltidium.

Fig. 17. *Richthofenia permiana* Shumard sp.—From junction of Road and Gilliam Canyons. Zone of Medlicottia sp. *mm* muscle scars of the adductors on the dorsal valve; *hh* hinge line; *cp* cardinal process of dorsal valve; *aa* area of ventral valve; *ps* pseudodeltidium of ventral valve. (Magnified about four times.)

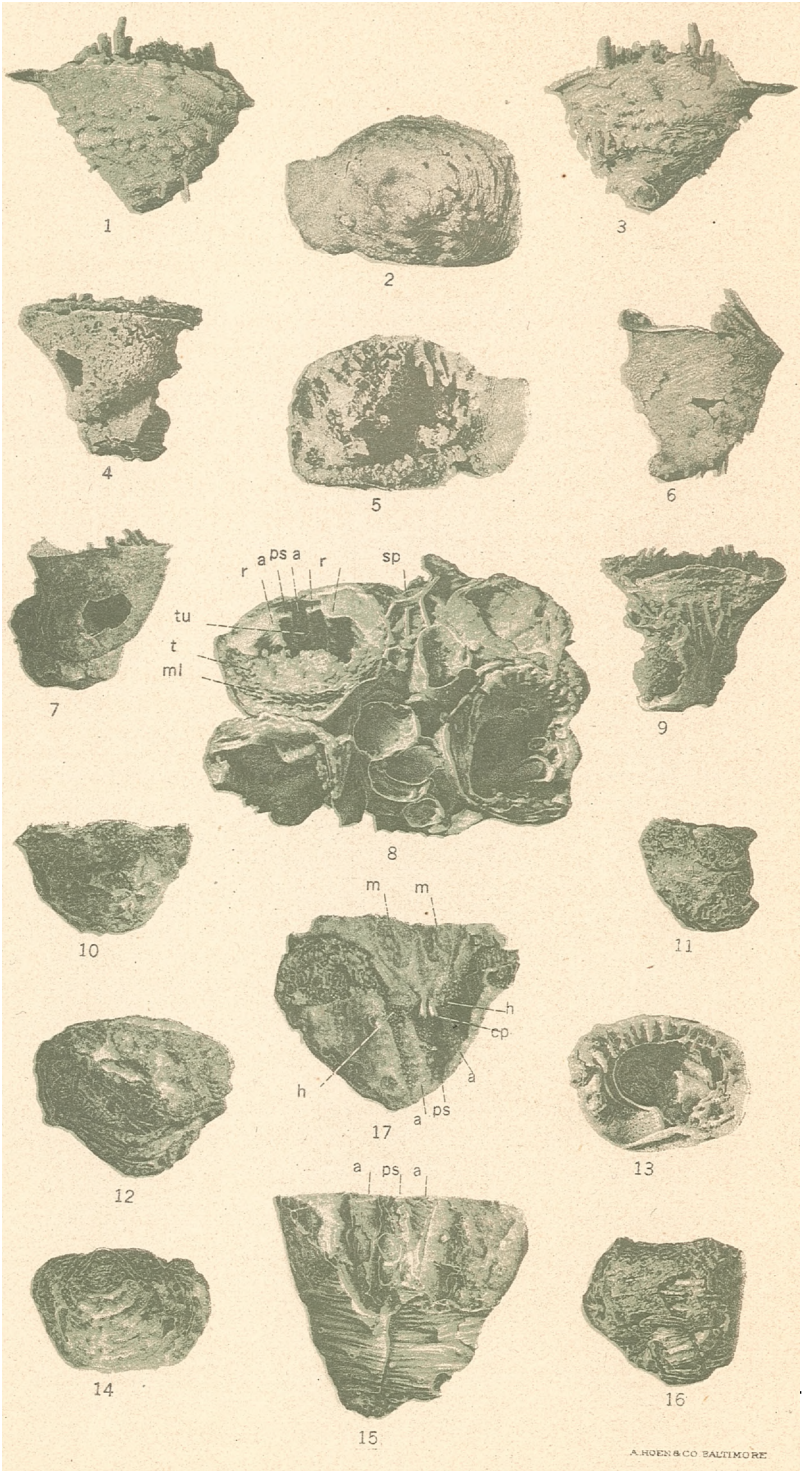
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PLATE III.

(All the figures on this plate are magnified 2:1, with the exception of Figure 6.)

Fig. 1. *Richthofenia permiana* Shum.—From the zone of Medlicottia sp. on mountain north of Leonard Mountain, Glass Mountains. *rr*, longitudinal ridges at both sides of the area; *aa*, area; *ps*, pseudodeltidium; *pi*, pallial impressions(?)

Fig. 2. *Richthofenia Uddeni* n. sp.—From Word's ranch, Glass Mountains. Zone of Medlicottia sp.

t, teeth-like bifurcating spines on the anterior rim; *rr*, upper end of the longitudinal ridge at each side of the area in the ventral shell; *ms*, median septum; *l*, blade-like laminae on the posterior rim.

Fig. 3. *Richthofenia Uddeni* n. sp.—From rolled block in the Glass Mountains.

ms, median septum; *l*, blade-like laminae on the posterior rim; *t*, teeth-like bifurcating spines on the anterior rim.

Fig. 4. *Richthofenia permiana* Shumard sp.—From zone of Medlicottia sp. on mountain north of Leonard Mountain, Glass Mountains.

v, vesicular structure of the middle layer around the apex of the inner shell.

Fig. 5. *Richthofenia permiana* Shumard sp.—From zone of Medlicottia sp. on mountain north of Leonard Mountain, Glass Mountains.

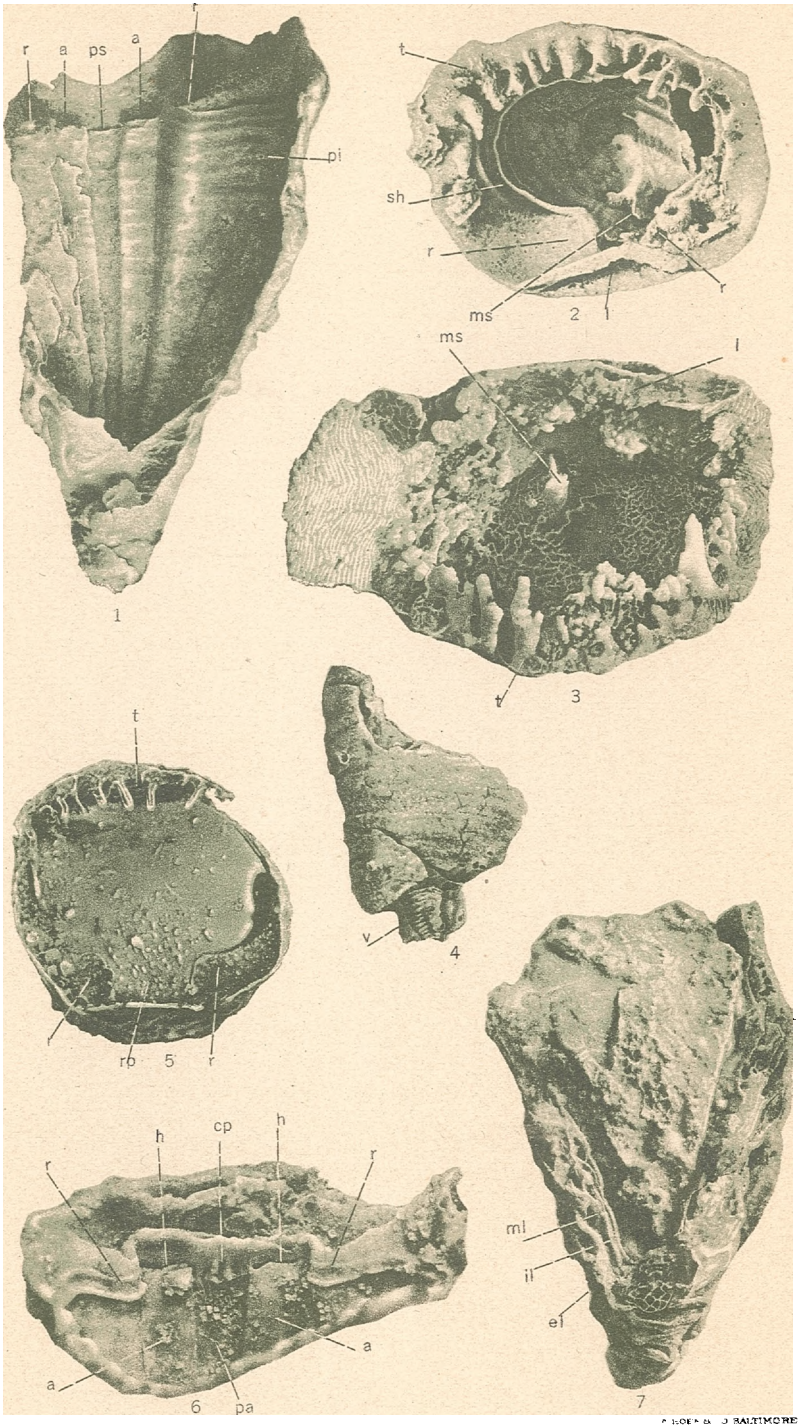
Closed dorsal valve with its spines on the posterior side. *t*, spines near the rim of the ventral valve; *rr*, upper end of the longitudinal ridges at both sides of the area of the ventral valve; *rp*, rectangular projection of the dorsal valve.

Fig. 6. *Richthofenia permiana* Shumard sp.—From the zone of Medlicottia sp. on mountain north of Leonard Mountain, Glass Mountains.

Hinge line and cardinal process of the dorsal valve, magnified about four times. *hh*, hinge line; *cp*, cardinal process of the dorsal valve with its two parallel apophyses; *rr*, upper portion of the longitudinal ridges at both sides of the area in the ventral valve; *aa*, area of the ventral valve; *ps*, pseudodeltidium of the ventral valve.

Fig. 7. *Richthofenia permiana* Shumard sp.—From 1⅓ mile N. N. E. of Hess Tank, Glass Mountains.

Natural section through the three layers of the shell. *el*, external layer; *ml*, vesicular medial layer; *il*, internal layer.



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