

THE SINIAN SYSTEM.

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I. INTRODUCTION

The Name *Sinian System* ("Sinische Formationenreihe") was first employed in a stratigraphic sense by Ferdinand von Richthofen whose geographic and geologic explorations in China must for all time form the starting point of all subsequent studies of this character. We turn to the second volume of von Richthofen's monumental work, "China, Ergebnisse eigener Reisen und darauf gegründeter Studien" (Berlin 1882) for the first comprehensive discussion of the stratigraphy and structure of China, this volume covering northern China, including a part of the province of Fengtien or southern Manchuria. He begins with the description of the geological observations made in the latter province from May to July 1869, though he had explored parts of the province of Shantung in the earlier months of that year.

II. THE SINIAN OF VON RICHTHOFEN IN MANCHURIA.

The peninsula of Liaotung (Liau-Tung) from which we have the first description of the formations included in the Sinian System, lies between the Gulf of Liaotung and Korea Bay, and terminates on the southwest in the peninsula of Kia-Tung (Kwantung) the "Regents Sword" of von Richthofen's maps, on which are situated the important cities of Dairen and Port Arthur. The district with which we are chiefly concerned, lies to the north of this terminal land tongue, forming the westerly portion of the main peninsula. Here the formations which cover the old gneiss, are chiefly the Sinian, which von Richthofen divides into Lower, Middle, and Upper Sinian, the last two being represented by a single color on his map (1885). On the map he classifies the entire series as Cambrian. Besides these Sinian rocks, he records the presence, in a small area, of "Kohlenkalk", a formation widely developed in North China, and known to be of Ordovician age. He further observed a small development of productive Coal-Measures.

We find on page 73 of volume II of von Richthofen's work the first characterization of the *Sinian System* under the heading "*Untersinische Sandsteine (Yungning-Sandstein)*". This formation is described as a prevailing red, and deep purple, cross-bedded friable sandstone, with occasional conglomerates, the whole series having a very gentle dip to the north.

Regarding the age of these beds v. Richthofen concludes:—"dass sie zweifellos von *Cambrischem* Alter sind und den tiefsten Theil einer langen, dieser Epoche angehörenden Schichtenfolge bilden, die in China ungemein entwickelt ist, und von welcher im weiteren Verlauf der Betrachtung unter dem Namen der *Sinischen Formationsreihe* vielfach die Rede sein wird". The name *Yungning Sandstone* was applied to this series from the ruined city of Yungning-Kien, near the coast, and its thickness was estimated to be at least 2000 feet. It is apparently, throughout, a continental formation. Blackwelder studied this sandstone in 1903[§] and came to the conclusion that it probably represented a local phase of the basal Cambrian which in Shantung and Shansi had been called the *Manto* formation and which carries the *Redlichia* fauna of late Lower or early Middle Cambrian age. The possibility of a Pre-Cambrian age is however not denied.

Overlying these sandstones are siliceous limestones, platy limestones, shales, and some sandstones, which underlie the city of Fouchou, (復州) and which v. Richthofen correlated with similar beds in Shantung to which he had given the name *Tungwōnn series* (see below). These beds underlie the oölitic and brecciated limestones of the Upper Cambrian. The thickness of these beds appears to be considerably over a thousand feet. This is the Fouchou series of Blackwelder, who found no fossils in it, but from another locality apparently in this formation, Iddings collected Middle Cambrian fossils, which were described by Walcott^{§§}. Von Richthofen placed this series in his Middle Sinian, his Upper Sinian which comprises the Upper Cambrian of Shantung, being wanting here.

Overlying this series, and probably separated from it by a disconformity, is a limestone called by von Richthofen "*Kohlenkalk*," and identified by him with a similar limestone previously found in Shantung, which he also regarded as *Kohlenkalk*, but which is now known to be of Ordovician age. He records a thickness for this limestone of 1200 feet, and found it overlain by sandstones, shales and coal-bearing beds with some crinoidal limestones, the whole being referable to the Coal Measures. The *Kohlenkalk* of von Richthofen is the Ordovician limestone, but it is not known which division

§ Willis, Research in China, vol. I. p. 89 and 95, 1907.

§§ Research in China vol. II.

is represented here. Farther northeast, however, in the Tai-tsze valley (S. E. of Mukden) this limestone carries *Actinoceras richthofeni* Frech, a characteristic late Middle Ordovician fossil, found in the Machiakou limestone of that age in Chihli and Shantung (see below).

It will thus be seen that in his very first characterization and detailed description of the *Sinian System*, von Richthofen restricted the term to the Cambrian and older strata, that is to the entire series of unmetamorphosed older sediments which overlies unconformably the metamorphic schists, gneisses and other rocks of the basal complex. Furthermore, he definitely excluded from this series the Ordovician limestone, which he recognized as forming a distinct series, although he erroneously identified it as Carboniferous limestone (Mississippian) because of its lack of fossils, and because of the fact, that it appeared to underlie the coal-bearing series conformably (in reality there is a disconformity and great hiatus). In the basal portion of the coal-bearing series, fossiliferous limestones are found in some sections.

This has been the attitude of von Richthofen towards these formation throughout his studies of the rocks of north China, with one or two unimportant exceptions, as we shall see in the sequel.

Von Richthofen again crossed the Sinian strata in his journey eastward to the shores of Korea bay. He records about 6000 feet of strata underlying the Kohlenkalk (Ordovician limestone, about 1500 feet). "Im liegenden des letzteren (des Kohlenkalks) beginnt mit discordanter Lagerung die Reihe der *Cambrischen* Schichten in regelmässiger Folge von oben nach unten" (p. 79). The section of this series, which he gives on p. 80, shows no discordance between the "Kohlenkalk" (Ordovician) and the "Cambrian" or Sinian, and the relationship is probably a disconformable one, as it is known to be farther south in Chihli province.

The upper beds of the Sinian series of this section are described by v. Richthofen as red, gray, and green, as well as white and yellow, somewhat micaceous clay-slates and non-slaty shales (argillutites). Thin-bedded sandstones occur at several levels, and there are at least three limestone horizons. The limestones are oolitic (globulitic), and contain the Cambrian fauna, this type of formation being widespread in north China, and characteristic of the Middle Cambrian series. Some of these globulites reach the size of bullets, or

even that of a hen's egg. This horizon appears to be analogous to the Lungmön limestone of Honan-fu. Below them are the platy limestones of the Tungwön (Fouchou) series, and still lower, irregular (concretionary?) limestones. Below these lie the Lower Sinian sandstones and conglomerates, which rest in turn upon the crystalline gneiss.

In the Sai-ma-ki basin in eastern Manchuria (about lat. 41° N., long. $124^{\circ} 45'$ E) a small section of von Richthofen's Upper Sinian limestones is exposed, these beds being disconformably succeeded by Carboniferous sandstones. In the highest members of the Upper Sinian limestones (5 & 6 of v. Richthofen's section p. 94) was found a part of the Middle Cambrian fauna described by Dames and Kayser in Vol. IV. Below these trilobite- and brachiopod-bearing beds, lie non-crystalline marl-shales and calcareous shales with the species of *Lingulella*, figured and described by Kayser. Below this, lie globulitic and other limestones, all representative of Middle Cambrian horizons. The base is not exposed, but the series rests apparently with an unconformity upon older (pre-Sinian) quartzites, on which formation Carboniferous beds rest direct, though unconformably, elsewhere in this locality.

About 80 li north of the Sai-ma-ki, in the valley of the Tang-ho at Hsiangmo, the Lower Sinian beds are exposed in horizontal strata, lying upon and abutting against vertical quartzites and schists. These Lower Sinian beds are green and red shales, with a thickness of at least 2000 feet. Both north and southward, they pass beneath Upper Sinian limestones, which on the south are characterized by the Middle Cambrian faunas found in the corresponding beds at Sai-ma-ki. On the north, however, higher limestones are exposed, for in the valley of the Taitze-ho at Hsiau-sörr, about 100 li north of Sai-ma-ki, is the type locality for *Actinoceras richthofeni*, the characteristic fossil of the late Middle Ordovician limestones of north China—i. e. the Actinoceras or Machiakou limestone. These beds appear to lie disconformably upon the Middle Cambrian of this region, for beds of the lithic character of the latter series, i. e. globulitic limestones and "Wu-mkalk", are found only a short distance below.

This is one of the few occurrences of Ordovician limestone, which were included by von Richthofen in his Upper Sinian series. Their age was recognized by von Richthofen as Ordovician (Untersilur), and their inclusion

in the Sinian series was apparently due to the fact, that he found that "aus etwas tieferen Schichten aber kommen Bruchstücke von Kalken herab, welche ungemein charakteristisch und der Sinischen Formation eigentümlich sind". These are the oölitic limestones (globulitische Kalke) and intraformational (edgewise) conglomerates (*Wurmkalke*) above referred to, and typically developed in the Cambrian series.

Whatever the true relationship of the Ordovician to the Cambrian beds is in this section, the fact, that von Richthofen thought that the Cambrian was only a short distance below (instead of several thousand feet as elsewhere in north China), and the further fact, that these Ordovician beds are succeeded by Carboniferous coal-bearing beds, which at Sai-ma-ki, 100 li to the south lie directly upon the Middle Cambrian, were justification enough at that time, for the inclusion of these fossiliferous Ordovician beds in the Sinian. This however does not justify the inclusion of the great mass of Ordovician strata in this system, for these von Richthofen systematically excluded therefrom, wherever they are fully developed. It does not alter this fact that von Richthofen believed these limestones to be of Mississippian age, whereas we know that their upper portion is of the same age as the fossiliferous beds of Hsiau-sörr, which at that locality were classed with the Sinian.

Von Richthofen's position is made quite clear by the fact, that less than 75 li down the valley of the Taitze-ho, from Hsiau-sörr, he met with a more typical development of the Ordovician limestones, which he estimated at 1000 feet. He described these limestones as quite distinct, lithologically, from the Sinian limestones, excluded them from that series, and, as usual, referred them to the "Kohlenkalk". His comment on this section on the right bank of the Taitze-ho is illuminating. He says: (p. 102) "In diesem Profil ist Alles von früher her bekannt, mit Ausnahme des Kalksteins ⁵,[‡] dessen Alter sich aber leicht festsetzen lassen wird, wen ein Reisender Zeit hat, dem Suchen nach Versteinerungen in demselben grössere Aufmerksamkeit zu widmen." In the profile given by him on the preceding page, he calls this limestone Kohlenkalk, and so marks it upon his map. He again finds this "Kohlenkalk" or "Bergkalk" (Mountain limestone) north of Pönn-hsi-hu,

[‡] Italics are mine.

35 li farther west, in the valley of the Taitze-ho, where it also rests upon Upper Sinian (Cambrian) limestone, and is succeeded by productive Coal Measures.

SUMMARY OF VON RICHTHOFEN'S VIEWS OF THE SINIAN OF LIAUTUNG.

There can thus be no doubt whatever, what von Richthofen included in the Sinian System in Liaotung, Manchuria, and what he excluded therefrom. His Upper Sinian comprised the typical Middle Cambrian limestones, recognized by him as of Cambrian age. His Lower Sinian includes the red and green sandstones, shales etc., which underlie these with apparent conformity. These he also called Cambrian on his map-sheets, and they may represent a part of that system, or may be older. There is no doubt whatever, that he included in his Sinian system the entire series of unaltered sediments from the Middle Cambrian *downwards*, and that he excluded the Ordovician limestones (his Kohlenkalk) therefrom, as lithologically wholly distinct from the Sinian limestones. Only in a little-understood section, that of Hsiau-sōn, does he include some fossiliferous beds of the Ordovician in the Sinian, because subsequent identification showed the fossils to be of Ordovician and not of Mississippian age. His own summary of this series of formations from the base of the Sinian upwards is given on pages 108-111 of vol. II, and as it is the first general summary given by him, I include it here in translation as nearly verbal as possible.

"In regular succession they [the Sinian Strata] rest one upon another. Everywhere they show a marked stratification [reiche Gliederung] which is nearly uniform in the higher parts, but shows much variability in the lower parts, because of the inequalities of the sea-bottom on which the sediments were deposited, this being covered with reefs [of older quartzites etc.] so that in some regions the series extends farther down [in the depressions between the reefs] than in others. In a certain niveau, high in the series, we found a petrographic horizon marked with rare distinctness, the *globulitic limestones*, and this furnishes at the same time a palaeontological datum-plane [einen paläontologischen Anhalt]. According to a preliminary communication of Mr. Dames, the trilobite fauna of Sai-ma-ki and the Tai-tze valley, consists chiefly of the genera, *Dikellocephalus* and *Canocephalus*, and

approaches closely the faunas of the *Potsdam sandstone* of New York, Wisconsin, Iowa, and Minnesota especially the region of the Upper Missouri, to such an extent that a similarity of age can not be doubted. In the *40th Parallel Survey* the same fauna was found by Hall in the White Pine and Eureka mining districts. It appears that the Chinese fauna resembles more nearly the American *Potsdam* than the Swedish Cambrian fauna; with the Bohemian primordial fauna it has nothing in common.

"It might not be practicable to apply the name "Cambrian" unqualifiedly for the designation of the system of formations in question. For until a further paleontological subdivision is possible, we must refer to it an extraordinarily extensive series of strata which, because of stratigraphic parallelism, forms a great circumscribed unit [ein grosses geschlossenes Ganzes bildet]; and of which there is at present no possibility to demonstrate, that its beginning and its end coincide with the boundaries within which the name Cambrian is applied in Europe and America. It is much more probable that the Chinese formation, in which the strata with the primordial fauna form a readily determinable, but volumetrically subordinate horizon [räumlich untergeordneten Horizont] extend much farther downwards, and therefore cover a much longer [time] period, while upwards, they might extend without noticeable interruption into the Lower Silurian [Ordovician] [während sie nach oben ohne merkliche Unterbrechung bis in das Untersilur hineinreichen dürfte]?"

"Dominant as this formation is in the mountain structure of Liaotung [Liautung] its thickness is much inferior to that which it reaches in other regions. In the progress of our further study, we shall learn to recognize it as the most important stratigraphic series of China^{§§§} and shall more especially find its lower members enormously developed in certain regions ["und besonders in ihren tieferen Gliedern in manchen Gegenden massenhaft entwickelt finden"].

§ Potsdam is here used in the old sense, essentially equivalent to Cambrian.

§§ I would call attention to this wording of von Richthofen, which implies extreme conservatism in respect to the upward extension of the Sinian series—for his words mean that possibly the series may extend into the Ordovician, but that this is not the normal state.

§§§ Italics are mine.

"A subdivision is possible in each separate region. However, even though we constantly attempt to compare the characteristics of the several divisions of one region with those of an adjoining one, we find the differences in stratigraphic development so great, especially when comparing pelagic and littoral facies of sediments, that a comprehensive subdivision into a series of stages, applicable to the whole of China, is as yet not possible. As Sinian system or formations [Sinische Formationsreihe] is designated in general a succession of sediments which is characterized by uniform bedding [concordant superposition] and sharp delimitation against the older series; whose thickness can be estimated at from twelve to twenty thousand feet; and which consists of the greatest variety of shales, sandstones and limestones with sandstones generally predominating in the lower, and limestones in the upper part. In the discussion of the structure of Shantung, it will be possible to present certain primary points for comparisons. Here I will only consider briefly the development which we have observed in Liautung. The great movements, which gave the country the fundamental structural lines which it has preserved to the present day, had long ago come to an end in Liautung when the deposition of the Sinian formations began; for the lower strata of the latter have suffered no greater disturbance than the upper. But it is not improbable, that two [igneous] series, connected with the after-effects of the eruption of the Korea granite, opened the new period. These are the rocks which appear in association with porphyrite in Li-kwan-tshun (Li-kuan-tsun 李官村), and the low ridge between Hsiau-yang-ho and Ta-yang-ho. The relationships to the porphyrite which has furnished a part of the sedimentary material, as well as interpenetrated the completed sediments, are similar to those of the tuffs, in south Tyrol, to the augite porphyry. If we omit the consideration of these somewhat problematic formations, to which belong also the reef quartzites on the Fu-tshou-ho, we find the sedimentary series to begin with:

"(1) *Deep red, friable quartz sandstones*, which never appear otherwise than in direct superposition upon the crystalline strata or the granite. We met these at various points of the west and south coast, where they form a low undulating land surface of moderate fertility, and designated them as *Yungning Sandstone*.

"(2) *Indurated quartzitic sandstones and quartz-pebble conglomerates* alternating with softer argillo-arenaceous strata, partly of light color and partly red. We had to leave it undecided, whether they really formed the superposed series of the strata of (1), or whether they were merely formed from these through greater induration at a higher angle of inclination. They produce massive land-forms with sheer fracture walls, but generally bear on their summits more subdued surfaces. Several of the islands of Society Bay are to be classed here. With this ends the lower series, which in Liautung is probably at least 2000 feet thick. With slightly, or not all altered position, there follows upon this:

"*The limestone-bearing division of the Sinian Series.* Unfortunately I am not in a position to give a detailed description of these interesting and extensively developed formations. This is due to the low angle of dip of the strata, and to the rapidity of my journey. Where slightly inclined strata cover many miles of the line of traverse, which moreover, alternately approaches to, and recedes from the section along the valley sides, (these being often interrupted by broad lateral valleys), much time is required for their careful study. Steep declivities, which here and there give a convenient exposure, generally disclose only a fraction of the series to be examined. Besides this, one usually recognizes the completeness of the profile only when the end of the same is reached, and no time remains for the necessary attention to details. I must therefore confine myself to a presentation of the principal horizons. But to future investigators I would earnestly recommend a week's stay among the Sinian terraine, along the *Taitze-ho*, and careful systematic collecting, from successive strata, of the inexhaustibly rich series of petrefactions. The most obvious horizons are the following:

"(a) Concretionary [Krummschalige], shattered siliceous limestones, [silico-calciliths] the cracks as well as the stratification surfaces filled with a talcose shaly substance. With this occur wavy limestones [Wellenkalke]* and scarred limestones [Narbenkalke].

"(b) Platey, flat-surfaced clearly resounding silico-calciliths [Kieselkalke]. This is the zone of the Tungwönn strata (See pp. 74, 80).

* These may be the *Collenia*-bearing beds of the Nankou division see below.

"(b) First zone of globulitic [coarsly oölitic] limestones.

"(d) Scarry limestones of Sai-ma-ki, similar to the Virgloria limestones of the northern Alps, with greenish coating on the stratification planes. They alternate with thin-bedded calcilutites [Kalkschiefer] which contain *Lingula*.

"(e) Upper zone of globulitic limestones [calcisphaerites].

"(f) A succession of limestones, nearly 1000 feet thick, and of varying constitution, among which globulitic limestones [calcisphaerites] and intraformational [edgewise] conglomerates [Wurmalk] are especially characteristic.

"Group (c) to (f) form the Lungmünn limestone stage. The previously-noted primordial [Middle Cambrian] fauna characterizes it.

"All these several formation members are separated from one another by red and green marl-shales and sandstones. These latter rock types also alternate frequently with the individual limestone layers. The totality of the formation comprises certainly not less than 5000 feet.

"6. Greenstone dikes which cut the formations described.

"7. Carboniferous limestone (Kohlenkalk)[‡] grayish-white upon the outer surfaces, gray and liver-brown within. Although I did not find any recognizable fossils in this rock in Liautung, its age, besides being shown by interbedding of the upper limestone layers with strata of the productive coal-measures, is certified to by petrographic characters which are peculiar to the Carboniferous limestone [Kohlenkalk] of north China throughout. This is a certain cloudy appearance on the fracture surface, caused by an alternation of dark and light brown coloration. In extensive development, the Carboniferous [Ordovician] limestone occurs along my route of travel only near Wu-hö-shui (Wu-hu.shui 五湖水) and Pönn-hsi-hu (Pen-Ki-hu 本溪湖). Its almost parallel bedding with the Sinian limestones is noteworthy. We shall find this throughout the whole of north China where the Upper Silurian [Silurian] and Devonian are everywhere absent.

"8. The productive Coal Measures.

"9. Porphyry eruptions of Pönn-hsi-hu and associated:

[‡] New known to be of Ordovician age.

"10. Porphyry conglomerate, porphyry tuff, and red sandstone of Pöun-hsi-hu. This closes the succession of the older formations. Of much more recent age are the succeeding:

"11. Basalt eruptions....."

"12. Recent formations....."

In Liao Hsi-or, western Fengtien von Richthofen again met with isolated exposures of the Sinian sandy shales, resting upon the crystallines, but he gave only a very cursory description of these beds. His next recorded more detailed observations are near Shan-hai-kwan in northern Chihli, and these are followed by his observations in Shantung, which however antedate those of Liautung, with which his description opens. We shall next consider the Sinian of Chihli province as described by von Richthofen, and follow it by the corresponding deposits of Shantung, Shansi and the other provinces.

III. THE SINIAN OF VON RICHTHOFEN IN CHIHLI PROVINCE.

SHAN-HAI-KWAN REGION

Von Richthofen studied in some detail the formations of the coal basin of Shih-mun-chai or Chih-män-chai, (Shi-mönn-tsai of von Richthofen). This region has become more fully known to us through studies carried on by members of the Geological Survey[§] and the more recent studies of Dr. F. F. Mathieu¹ whose palæontological collections were submitted to me for description²

The Palæozoic Coal-Measure series is here disconformably underlain by more than 500 meters of shales, limestones, red-beds, and some igneous members, which carry several fossil horizons both near the top and near the bottom. From these it is recognized that the entire series belongs to the lower Ordovician, the fauna being very similar to that of the Beekmantownian of eastern North America. Because of the presence in this series of several oölitic horizons, and some intra-formational conglomerates, and because of its very different aspect from the limestones of the later Ordovician, which is

§ L. F. Yih and C. C. Liu, Report on Liu-Kiang Coal Field of Lin-Yü-Hsien, Chihli. Bulletin I, Geological Survey of China, English Summary p. 6 (map).

¹ Bulletin IV, Geological Survey of China (map).

² Palæontologia Sinica, Series B. Vol. I, fascicle I.

most wide-spread in north China, and which von Richthofen referred to the Carboniferous (Mississippian), the limestone and shales of Chih-men-chai were identified by that investigator with the Upper Sinian of Liautung. As von Ritchehofen found no fossils in this series, this correlation by lithic resemblance, was most natural, but this erroneous identification (of Lower Ordovician as Middle Cambrian strata) can hardly furnish a basis for the inclusion of the Ordovician as a whole in the Sinian system, any more than his erroneous inclusion of the great mass of Ordovician limestone in the Carboniferous series, can furnish a basis for uniting them with the Coal Measures into a stratigraphic system. This is not altered by the fact that in a brief resume of the Sinian on p. 123 he says "Besonders typisch ist die Formations bei *Shi-mönn-tsai* (Chih-men-chai) entwickelt", for this refers solely to the lithologic resemblance of these Lower Ordovician beds to the Middle Cambrian strata of Liautung and Shantung.

THE PEKING REGION.

This is described by von Richthofen in Chapter VII of the second volume, following the discussion of Shantung. His first recorded geological observations in this district are in the Kaiping Coal Basin of eastern Chihli (p. 285) a region which has been repeatedly studied by the geologists of the Geological Survey of China.* He begins with a brief reference to the enclosing mass of more or less quartzitic sandstones, which he refers to as probably the same Sinian sandstones found by him in the vicinity of Ning-yuen-tshou (Ning-yuan-chou 寧遠州) and which we now recognize as belonging to the Pre-Cambrian sediments of this region, the Sinian in the sense advocated in the sequel. The Cambrian beds of this region are mostly concealed, though in the northern rim of the basin a few exposures of them are found, between the Ordovician limestones (Kohlenkalk of von Richthofen) and the Sinian sandstones and limestones.¹ The productive coal series of this region (chiefly of Permian age) is disconformably preceded by from 700 to 800 meters of Ordovician limestone, the upper beds of which have furnished late Middle Ordovician fossils (equivalent to the Black River horizon of North America),

* Investigations carried on here by myself and assistants of the Survey will be reported upon at a future time.

1 The faunas which we collected here are now being studied by Mr. Y.C. Sun.

while the lowest members have furnished a few fossils which indicate Lower Ordovician (Beekmantownian) age. These rest disconformably upon the eroded surface of the Upper Cambrian of this region.

The entire series of limestones was referred by von Richthofen to the Mississippian under the name *Kohlenskalk*. He describes this limestone as different from all limestones which he had previously described from west of Mukden (i.e. Cambrian limestones of Shantung etc.) and he especially notes, that the globulitic oölitic limestones and other characteristic rock types of the Sinian System are wanting (p. 287).

We come now to von Richthofen's description of the mountain districts which enclose the "Bay of Peking" on the east, north and west. He begins with the discussion of the *Poshan*; the "corner-monument" of the Peking plain, visible from the enclosing walls of the city (p. 290). Already in approaching it from the east, he found more or less metamorphic Sinian limestones with oölitic and giant globulites, with concentric globules 3 to 4 inches in diameter (*calcisphaerites*), these rocks forming the range of the *Nian-ting-shan*. But these globulitic limestones are less frequent than in the more northern region,* and red beds are infrequent. This series is in reality of pre-Cambrian age (Sinian in the revised sense of this article).

To the southwest and west of Peking, in the complex of the *Hsi-shan* or Western Hills of Peking, large areas of Ordovician limestones are exposed, but the Cambrian and older sedimentary series are shown only in the northwestern and northern portion of the region. Von Richthofen traversed part of this area, and in his summary he says of this younger (Ordovician) formation (p. 299). "In this thick and variable system is found not a single one of the widely distributed and very characteristic rocks of the Sinian limestones, which in some cases form the substratum of the productive Coal-Measures. Cherty segregations are found, it is true, in the form of nodules and thin intercalations, but they are not characteristic, pure limestones remaining dominant". He gives further details of lithic character, noting the occurrence of dolomites in the upper part, and compares the series with the corresponding rocks of *kaiping*, *Liautung* and *Shantung*, all of which

* See reference to *Collenia* beds below.

† See Memoir A:1 Geological Survey of China.

he refers to the Carboniferous limestones (Kohlenkalk). The thickness of the formation has recently been estimated as roughly 750 meters[§] which is approximately its thickness in the Kaiping basin, though v. Richthofen considers the thickness in the latter region to be much less.

Here we see again that von Richthofen definitely excluded the great limestone series now known to be of Ordovician age, from his Sinian system, and that its subsequent inclusion in it was not in accord with the definitely expressed opinions of the author of that system.

The Ordovician limestones in the Western Hills are succeeded disconformably by the Yang-Chia-T'un coal series of late Carboniferous or Permo-Carboniferous age, followed by Permo-Triassic (?) sandstones, and Jurassic coal-bearing strata.^{§§}

The Hsi-shan (Western Hills) complex is an erosion remnant of Cambro-Ordovician and younger strata, which rests upon a great mass of Pre-Cambrian sediments and older metamorphic and igneous rocks. The mountains formed of this older series of rocks surround the plain of Peking on the east, north, and west, and their crest is for some distance followed by an inner branch of the Great Wall of China. The slightly, or not at all metamorphosed sediments of these ranges, constitute the typical Lower Sinian series of von Richthofen, the Upper Sinian being formed by the Cambrian strata which overlie them on the northern border of the Hsi-shan, and in a few other localities, and which in the northern region are disconformably succeeded by the Carboniferous formations, the Ordovician limestones not appearing there,^{§§§} though they come in farther to the west.

The main range, to which in general the name *Nankou Range* has been applied, was crossed by von Richthofen between Chei-tang and Fan-shan-pu. Along this line, the Ordovician beds lie below the Carboniferous series, and are followed downwards in the section by Cambrian limestones. The two groups were not differentiated by von Richthofen, who classed them together as Cambrian, no fossils having been seen by him in the upper part.

§ L. F. Yih, *Memoir Geological Survey of China*, Series A vol. I p.9, 1920.

§§ Yih—*loc. cit.*

§§§ See section B-B in Mr. Yih's memoir.

Below this upper series, the thickness of which is given by von Richthofen as 2000 feet, lie the Middle Cambrian globulitic (oölitic) limestones with trilobites, and below these the red shales and intercalated limestones of the Mant'o series of late Lower Cambrian age, the lowest division of the Cambrian recognized in north China.

Below these Cambrian beds, and concordant with them, though probably separated from them by a disconformity, are the black shales and sandstones known as the *Hsiamaling series* of Pre-Cambrian age, and 500 feet or more in thickness. Below these lies the great series of siliceous limestones which forms the most prominent member of the formations composing this range and to which von Richthofen applied the name *Nankou limestone*, from the excellent exposures at Nankou pass, farther to the east. At that point, these limestones are, however, extensively cut by igneous intrusions.

These siliceous limestones of the Nankou series, von Richthofen classed as Lower Sinian; the Hsia-ma-ling shales and sandstones, the Mant'o shales, and the Middle and Upper Cambrian limestones, he grouped together as Upper Sinian. Comparing the series with that found in Liautung and Shantung, he finds a close correspondance in the upper (Cambrian) series of the several districts, while the lower shows marked diversity, consisting largely of siliceous limestones in the Peking district, but of clastic material in the Manchurian region. He recognizes the fact that these represent different facies of the Lower Sinian. To the latter he assigns a minimum thickness of 8000 feet, and to the Upper Sinian one of about 4600 feet, which is, however, probably excessive.*

* Considerable work has been done on these deposits by members of the Geological Survey, and officers and advanced students in the Department of Geology in the Peking National University. The first fossils from these deposits were found by Dr. J. G. Andersson in the Hung-Ho canyon through these ranges. Other specimens, described below as *Collenia sinensis* were found by us in the Nankou limestone of Nankou pass, during a reconnaissance trip in that region under the auspices of the Third Asiatic Expedition in charge of Prof. F. K. Morris. More recently my students in the Paleontological and Stratigraphical section of the fourth year class of the Department of Geology in Peking National University, have made detailed sections of these limestones in Nankou pass, and secured numerous specimens of *Collenia* of several species. These will be noted more at length below. The limestones of the pass, though tilted and even overthrust by post Jurassic deformations and cut by igneous rocks are practically unmetamorphosed. Chert is common in certain of these bedded layers, but the heavier-bedded strata are quite pure, and it is in these that the fossils are found. I have noted these spheroidal masses of *Collenia* at a number of horizons in the series.

IV. THE SINIAN OF VON RICHTHOFEN IN SHANSI PROVINCE.

Von Richthofen entered the northern Shansi region from Mongolia. In the Ta-tshing-shan south of Hsi-ying-tze in inner Mongolia, he found quartzites and black shales resting upon gneiss and granite. These he regarded as forming the lowest member of the Lower Sinian. These beds are moderately folded and are unconformably (?) succeeded by the steeper dipping Lower Jurassic coal-bearing series.* North of this at the mission station of Hsi-ying-tze he found Lower Sinian limestones (Nankou limestones?) dipping northward, and apparently brought up by a fault so that they appear to overlie the Jurassic beds. The contact-line is concealed by loess deposits (See section v. R. II p. 353). This is one of the few sections in which there seems to be a distinct unconformity between the Jurassic and the older (Sinian) series. The possibility of a fault contact between the Jurassic beds and the Lower Sinian quartzites in this section must, however, not be overlooked.

The western border of the Loess plain, which extends southward from Tatungfu in north Shansi, has the appearance of a fault-line-scarp, with a continuous and almost straight southwest trend. In one part the old gneisses are brought up to form the edge of the scarp, and upon these rest unconformably the Cambrian limestones, preceded by red shales, the whole having a thickness of about 1000 feet. For the greater part of the distance, however, the Cambrian limestones form the oldest rock exposed. These beds are called by von Richthofen Upper Sinian, and he recognizes the absence here of the Lower Sinian, which is so prominently developed on the southwest and of which he found an outlier in the Hsi-ying-tze region (Mongolia) to the north.

Along the entire border or the fault-block which bounds the Tatungfu plain on the west, the Cambrian beds are succeeded by Liassic coal-bearing strata and according to von Richthofen's sections (See especially fig. 76 p. 358) there is a distinct unconformity. This may, however, be apparent, as the dip of the strata changes rapidly from steep inclination on the east

* There is probably no real unconformity here, but a disconformity the difference in dip being only apparent.

(82° west of Tatungfu) to 45° on the west of the Cambrian outcrop, while the Liassic strata rapidly diminish in dip until they are nearly horizontal. Certainly here as in the section farther north, further examination is required before the unconformity between the Palaeozoic and the Mesozoic can be considered as established. Probably the relationship is throughout a disconformable one, as is usual in north China.

The direct superposition of the Cambrian (Upper Sinian) limestones upon the gneiss was again observed by von Richthofen in the long but relatively narrow Man-tou-shan range which separates the plain of Tatungfu from that of the Huto on the south. The nearly horizontal Cambrian beds form isolated erosion remnants in the higher parts of the range.

Southeast of the Man-tou-shan, and roughly parallel to it lies the complex of the Wutaishan, the two being separated by the broad loess-covered valley of the Hu-to-ho. This region has been studied in some detail by Willis and Blackwelder. Here the old Arenæan gneisses (the Tai-shan complex of Willis and Blackwelder, apparently the same series which forms the Man-tou-shan on the north) is unconformably overlain by the metamorphic Wutai series of schists of Algonkian age. Upon these, in some sections of the northwestern portion of the range, lie horizontal Cambrian beds (Upper Sinian of v. Richthofen). The southern and southeastern spurs of the range are, however, formed by the Lower Sinian formations as shown on von Richthofen's map, though in his journey he had no opportunity to examine these strata in detail. They were, however, carefully studied by Willis and Blackwelder, who named this series the *Huto Series*, from the Hu-to-ho where it crosses the southwestern spur of the Wutaishan. (Map sheet B-I Atlas of Research in China.)

Willis and Blackwelder divided their *Huto system* into the *Tou'tsun* slates at the base and the *Tungyü* limestone at the top. The former have a thickness of not less than 3,500 feet, and may reach 5,000 feet. They comprise gray and purplish phyllites, with some dolomitic and siliceous limestones, and red and gray quartzites near the base.

The *Tungyü* limestone has a thickness of probably 3,000 feet, and is massive, gray and cherty. Farther east on the western border of the Great Plain in west Chihli province, the entire series is represented by limestone

with an abundance of chert. This, the *Tayang Limestone* of Willis and Blackwelder is the southwestward extension, approximately along the strike, of the Nankou Limestone of the ridge north of Peking. According to Willis and Blackwelder[§] "The formation is exceedingly uniform in lithologic character, the greater or less proportion of chert and the occasional occurrence of white quartzite being the chief variations. A notable characteristic is found in curved and minutely contorted laminae of flint, the contortion of which appears to be independent of local deformation of strata. Similar bands have been noticed in the Siyeh limestone of the Belt formation, Montana.^{§§} They are noted by Loezy as occurring in the Nanshan sandstone of Tibet.⁽¹⁾ Similar forms described by Stose in Cambrian limestones of the Appalachian Valley, are classed as *Cryptozoon proliferum* Hall.⁽²⁾ Whether the peculiar structures are in some cases mechanical or organic is not known but they have a long range". These are probably the *Collenia* masses found in the limestone at Nankou ranges. They have not been seen in the Cambrian or Ordovician limestones of China, nor have the oolitic and conglomeritic (edgewise) phases of the Cambrian been found in the Tayang or Nankou limestone.

The Tayang limestone, which may reach a thickness of 6000 feet, has usually a thin stratum of slate or phyllite at the base and was found to rest with marked unconformity upon the Taishan complex (Archæan). The limestone is disconformably succeeded by Cambrian strata, which begin with a heavy bed of residual chert pebbles, derived from the pre-Cambrian limestones, and followed by quartzite and black argillite conformable with the succeeding Cambro-Ordovician series and in all probability a part of it.

The limestone outcrops may be traced southwestward along the western border of the Great Plain in the Föng-ling-shan and Hsi-ping-shan. Von Richthofen described a section through the latter ridge at Huo-lu-hsien where it is succeeded by the Cambrian, followed in turn by the Ordovician. The Cambrian and underlying limestones were mapped by v. Richthofen as Upper Sinian and the Ordovician as Kohlenkalk. The limestone at Tayang he mapped as metamorphic Sinian; followed by Kohlenkalk.

§ B. Willis Research in China Vol. II pp. 8, 9.

§§ Willis B., Bull. G. S. A. Vol. XIII, p. 305, 1902.

(1) Reise des Grafen Széchenyi in Ostasien Vol. I p. 553.

(2) Journal of Geology Vol. XIV pp. 210-517, 1906.

These limestones and the Nankou limestone farther northeast, appear to lie essentially along the axis of the ancient geosyncline in which these strata were deposited. As we go northwestward, we find, in the Wutai-shan, a great reduction in the limestones of the series which are restricted to the upper division, while in the lower they are replaced by clastic material, evidently derived from the western border of the geosyncline. Finally with the Cambrian marine transgression these pre-Cambrian beds are overlapped and we find to the northwest of the geosyncline, that the Cambrian rests directly upon the older metamorphic rocks. This geosyncline extended northeastward into Liautung, Manchuria. Its southeastern border is seen in the Shantung region next to be described.

V. THE SINIAN OF VON RICHTHOFEN IN SHANTUNG PROVINCE.

In west Shantung v. Richthofen mapped Lower, Middle and Upper Sinian, but the Ordovician (his Kohlenkalk) he recognized only in the Poshan region. Willis and Blackwelder on the other hand, who studied and mapped two small areas in west Shantung in detail, found a number of irregular erosion remnants of the Ordovician limestone which they named *Tsinan limestone*.

The beds classified by von Richthofen as Sinian in Shantung were first met with by him north of I-chou-fu, along the Tung-wön-ho. Here the series, repeated several times by faulting, begins with thin-bedded argillocalcareous rocks, 300 feet thick, which rest upon gneiss, and are succeeded upwards by 400 feet of reddish sandstones, and 150 feet of red micaceous shales followed by limestones, 200 feet, and red shales, 120 feet, totalling 1170 feet. These beds were mapped as Lower Sinian, but in the text they were distinctly referred to the Middle Sinian (p. 225). They probably represent in part, the Manto series of Willis and Blackwelder. Above the regular succession are other beds of similar character, which may be a repetition of this series, and the section is terminated by fossiliferous Middle and Upper Cambrian limestones. These von Richthofen referred to the Upper Sinian under the name *Lungmönns beds*.

In the Sin-t'ai Coal Basin (Kohlenbecken von Hsin-tai-hsien) Willis and Blackwelder found 575 feet of Manto shale overlying the Archæan rocks (Taishan complex) and followed in turn by 800 feet of Middle and Upper

Cambrian limestone, upon which in turn rest the Ordovician beds. Von Richthofen mapped the northern part of the district as Sinian but did not recognize the occurrence of Ordovician strata (Kohlenkalk). From his text it would appear that he examined only the coal-measures of this basin.

What von Richthofen regarded as the most typical section of the Sinian in Shantung, was obtained in the valley of the Yü-fu-ho near Tchanghsia (Ch'ang-hia) within the district subsequently mapped in detail by Willis and Blackwelder under the name Ch'anghia district. The base of the series on the west or left side of the valley is much higher than that on the right. Von Richthofen attributed this to a fault followed by the valley, but Willis thinks it is due rather to flexures in the strata.

Resting upon the gneiss are 525 feet of red sandy shales and gray shaly limestones, marls, shales etc. which were classed by von Richthofen as the upper part of the Middle Sinian. "Here are absent not only the Yungning sandstones, but the whole lower part of the Tongwönn series", which constitute his typical Middle Sinian (p. 226). These are the Manto shales of Willis and Blackwelder, and they are followed by the Middle Cambrian (Ch'anghia) limestones with oolites and the overlying (Kushan) shale series. The Upper Cambrian (Ch'anmitien) limestones are not preserved in this section and thus the Upper Sinian of von Richthofen in this, his most typical Shantung section, comprises only Middle Cambrian. This division, according to Willis and Blackwelder, has a thickness of 550 feet, while the Ch'anmitien limestone is given as 600 feet. Regarding the relationship of these beds to others, von Richthofen says "The series here mentioned becomes more complete up the valley [southward] in its lower, and down the valley in its upper portion." (p. 197)

In western Shantung, von Richthofen met with the Ordovician limestones only in the Poshan Coal Basin, of which they form the southeastern rim. This is indeed the first time in his travels in North China that he met with this formation, his journeys in Shantung having preceded those in Liautung, Chihli and Shansi. After describing its uniform character, he says "In der ganzen Schichtfolge fand ich keine Versteinerungen" (p. 203) and he considers that a further negative character, by which it could be distinguished from the Sinian limestones, was the absence of chert. These limestones,

of which only about 600 feet is exposed, and which close with cavernous dolomites, are followed with apparent conformity by varicolored clays which fill the cavities of the dolomite.[§] These clays are followed by sandstones and marls, in which, 300 feet above the limestone, occur intercalated limestone beds, from which were obtained the fossils described by Frech as of late Lower Carboniferous age. It was because of the apparent conformity of these fossiliferous limestones with the great limestone series, that von Richthofen thought the latter represented the Carboniferous limestone of Europe and designated it "Kohlenkalk". This is the Tsinan limestone of Willis and Blackwelder who found exposures of it in the vicinity of Tsinan-fu, and classed it as Upper Sinian, despite the fact that von Richthofen expressly excluded it from the Sinian wherever he identified it in north China. In its upper portion have since been found several species of *Actinoceras* and other early Upper Ordovician (Black River) fossils.^{§§} "Warscheinlich" says von Richthofen, in speaking of these limestones, "würde man unter diesen die Sinischen Kalke antreffen" (p. 204).

Von Richthofen gives, on p. 206, a section across the crest of the Yuen-shan, westward of Poshan-hsien, in which he finds the higher Sinian (in his sense) resting unconformably upon the gneiss complex of the Taishan range. It begins with the limestones, shales and red beds, now included in the Manto shales series of late Lower or early Middle Cambrian age, followed by Middle and Upper Cambrian limestones. The entire Lower Sinian formation (the Sinian in the restricted sense of this article) is here wanting, being overlapped by the Cambrian strata. The Upper Sinian (Cambrian) limestones are succeeded by higher beds which von Richthofen did not examine.

A similar succession was found by von Richthofen farther east in Shantung, so that for this entire region it would appear that the Pre-Cambrian members of his Sinian (Sinian in the restricted sense of this article) are absent. Shantung must therefore be regarded as forming the eastern border of the geosyncline in which these strata were deposited, for it is not very likely that pre-Cambrian erosion would have removed them over the entire

§ A characteristic feature of the disconformity at this horizon over wide districts in north China.

§§ See Grabau A. W. Ordovician Fossils from North China. *Palaeontologia Sinica*, Series B, Vol. I. Fascicle I. Geol. Survey of China, 1922.

area, had they been present, though a certain amount of erosion of these older rocks undoubtedly occurred before the transgression of the Cambrian sea.

In north-eastern Shantung, however, at Tong-tschou-fu (Tenschowfu) he found that the gneisses and schists were overlain by massive reddish quartzites, at least 400 feet thick, followed by coarse quartz breccias, about 200 feet thick, upon which lies a great thickness of red sandstones, the whole being capped by basalt which lies on various members of the series (See von Richthofen's section p. 218). The whole series of which about 1000 feet is exposed, suggested to von Richthofen the basal Sinian series of Liantung. The age of these beds is in doubt. They may belong to a pre-Cambrian horizon, or they may represent a marginal continental phase of Cambrian or younger strata.

VI. GENERAL SUMMARY OF THE SINIAN AS UNDERSTOOD BY VON RICHTHOFEN.

"Nothing" says von Richthofen (p.22) "is more characteristic for the geology of China, than the long succession of sediments which we have previously designated by this name [Sinian]. Already in Liantung it has shown itself in strong contrast with everything which lay beneath it, as the product of a long period of sedimentation uninterrupted by marked disturbances, while not only the material but also the depth of the sea in which these sediments were found, was variable.[‡] Without noteworthy modification in uniformity, stratum follows upon stratum. In the lower part in that region, the sediments were purely arenaceous, in the upper division they were nearly pure limestones, in the intermediate portion of variable character, consisting principally in an alternation of limestones and sandy or clayey beds. Considering the limestones by themselves we find a gradual change from strongly siliceous [cherty] to pure [calcareous] modifications, while when we consider only the intercalated strata a change from sandy to clayey facies occurs. At a definite horizon, *which belongs to the upper part of the formation*,* dark limestones appear which are definitely characterized by an inclusion of closely crowded globulitic grains [oölites] and in which the primordial fauna appears; and from this point upwards, we find this [fauna] more or less well represented in the limestones.

[‡] The great mass of these strata is now considered to be of continental rather than marine origin.

* Italics are mine.

"The *globulitic limestones*, in which traces of trilobites are seldom wanting, are petrographically the most noteworthy members of the entire series in northern China. Their appearance is so peculiar that one can without question always recognize the formation by them. From the most distant localities one can obtain hand specimens the similarity of which renders them indistinguishable. Whether we regard the origin of the globulites as organic or not we are at least justified in assuming that such remarkable and widespread deposit, which appears only in a single geological period, also belongs, throughout, essentially to the same horizon. This assumption is strengthened by the fact, that the rock type which we have designated *Wurmalk* [intra-formational, or edgewise conglomerate] and which likewise is of persistent peculiarity, occurs everywhere at a somewhat higher level than the globulitic limestones. It thus appears to represent a second [distinct] horizon.

"If in the absence of a detailed palæontological zoning for the different regions, we accept these globulitic limestones, or rather their first appearance, as marking a definite horizon, we can in a measure determine what follows and what precedes them in the different regions. It then appears, on a comprehensive survey, that the upper parts are nearly everywhere, in north China, of essentially uniform character, while the lower are extremely diverse. In some sections the globulitic limestones lie directly upon the gneiss, in others, several hundred feet of sediments intervene between them and the formation subjacent to the Sinian, while in still other regions they are separated from pre-Sinian formations by strata several thousand feet in thickness. This is explained by the inequality of the sea-bottom upon which the sedimentation took place."

From the detailed discussion, and the quotations given in the preceding pages, which cover practically the entire field in which von Richthofen noted the presence of Sinian strata in north China, it appears beyond question that that investigator understood by the term Sinian the Cambrian and older unmetamorphosed formations of north China and that he systematically and consistently excluded the great series of Ordovician limestones, which wherever preserved, form such a prominent member of the Palæozoic in the Chinese provinces of Shantung, Chibli, and Shansi, and in Liautung, Manchuria.

These he invariably, though mistakenly, designated Carboniferous or Mountain limestone (Kohlenkalk or Bergkalk) and he again and again dwells upon the petrographic differences of these limestones from those of the Upper Sinian (Cambrian) limestones. In his map sheets von Richthofen always bracketed the several divisions of the Sinian under the term Cambrian, but in his discussion he recognized that the series extended below the base of the recognized Cambrian. We know now that the greater part of the strata included by von Richthofen in the Sinian, are of pre-Cambrian age, and that a disconformity and hiatus of unknown magnitude separates them from the Cambrian series. Moreover, we now recognize that these pre-Cambrian beds are of continental origin, while the Cambrian strata are purely marine, with the exception of the basal Manto group, which represents continental sediments of pre-marine Cambrian time, more or less reworked by the transgressing late Lower Cambrian sea.

The only noteworthy inclusion of Ordovician strata in the Sinian by von Richthofen, was in the region west of Shan-hai-quan, in the Shieh-men-chai coal basin. These strata are however lithologically more like the Cambrian series than they are like the great mass of the Ordovician limestones, and on this account von Richthofen mistook them for Cambrian strata. They have since furnished Lower Ordovician (Beekmantown) fossils and in this section the great bulk of the higher Ordovician beds (the *Actinoceras* limestone series) is absent, Carboniferous beds resting directly and disconformably upon the Lower Ordovician strata. This inclusion of Ordovician strata, which he mistook for Cambrian beds, can of course furnish no basis for the inclusion of the limestones which von Richthofen consistently excluded from this system.

The third volume of von Richthofen's great work appeared in 1912 after his death, and in it we find the last definite statement of the author's position on this question. In a foot note on p. 148, he quotes his original definition (given on pages 108 of vol. II and reproduced in translation on p. 50 of this paper). He then goes on to say: "It is herein^s positively stated that the Sinian Formation comprises the Cambrian, but further it is added,

^s i. e. in this definition.

that with probability it extends higher up and lower down. This supposition has been verified in both directions. I have to thank Mr. Bailey Willis for the proof, that the division into Upper Sinian and Lower Sinian proposed by me really exists, that the latter belongs wholly to the upper part of the Algonkian, the former, however, separated from it by an unconformity[‡] belongs to the Cambrian and unnoticeably passes upward into the stage which at that time (1882^{§§}) was referred to the Lower Silurian, and is now designated Ordovician, as appeared already from one of my own discoveries''^{§§§}

This was written in 1905, the last year of his life^{§§§§} and after the discussion, with Bailey Willis, of the results of the Carnegie Expedition, this discussion, as Willis tells us, occurring in March 1905. It must therefore be regarded as the final expression of von Richthofen's views with reference to the limits of the Sinian system. He was willing to include the Ordovician with the Cambrian in his Upper Sinian but Lower Sinian he was determined to retain for the great series of conformable sediments below the Cambrian.

In the descriptions of the formations of southeastern China in the third part of vol. III von Richthofen frequently used the term Sinian for the oldest sediments met with. The manuscript of this section, we are told by the editor, Dr. Ernst Tiessen, was the least advanced of all those left by von Richthofen, no work having been done on it after 1898, and perhaps not after 1893. It is therefore, not a final expression of von Richthofen's view, and his inclusion in the Sinian of rocks now known to be of various ages, can not affect the question before us. In the determination of the Sinian, as understood by von Richthofen, the last section of Vol. III must be left out of consideration.

VII. THE SINIAN AS USED BY BAILEY WILLIS.

In their monumental work, in which are recorded the observations and conclusions of their studies of the geology of parts of China, made in 1903-04 under the auspices of the Carnegie Institution, Bailey Willis and Elliot Blackwelder, deliberately applied a different meaning to the term

[‡] Disconformity, in present day usage.

^{§§} According to the determination of Em. Kayser (remark by E. Tiessen).

^{§§§} This refers to the discovery of "*Orthoceras*" (*Actinoceras richthofeni*) at Hsiuu-Sörr in Liautung (vol. II p. 99) already noted in this paper.

^{§§§§} Ferdinand, Freiherr von Richthofen died on October 6, 1905.

Sinian, from that employed by von Richthofen. Recognizing the pre-Cambrian age of the greater part of the series thus designated by von Richthofen, they excluded this from the Sinian of their definition, while at the same time they included as an upper member the great Ordovician limestone series, which von Richthofen so consistently excluded from his system. Thus the Sinian system in the Willis-Blackwelder sense comprises the Cambrian and Ordovician formations of north China.

Willis states his position in the following sentences[§] :

"The name and its application. Sinian was first applied by Pumpelly to the prevailing structural axes of eastern Asia, which trend north-east and southwest. It was adopted by von Richthofen to designate a series of conformable strata which exhibit folds having the Sinian direction. They are characterized in part by Cambrian fossils, but were believed by him to extend downward below the base of the Cambrian and at the top to include part of the Ordovician.^{§§} The term is here used to designate the Cambrian and Ordovician strata to which he applied it^{§§§} but those limestones which underlie the lowest fossiliferous Cambrian are excluded, after conference and agreement with von Richthofen himself."

One might be pardoned for doubting whether the venerable geologist to whom we owe so much of our knowledge of Chinese geology, would have been persuaded to assent to this exclusion of the principal part of his Sinian system, had the significance of such assent been fully clear to him at the time. For it must be evident that if Sinian is used as synonymous with Cambro-Ordovician in China, the term is doomed to inevitable relegation to the limbo of outworn and forgotten temporary formation names, useful for a time in expressing the incompleteness of our knowledge, but of no further value when systematic study is once under way. Chinese geology has progressed beyond

§ Research in China, Vol. II, Systematic Geology, by Bailey Willis Washington, July 1907, p. 35 et seq.

§§ We have seen that the inclusion of Ordovician strata was due chiefly to misapprehension as to their age, or, where he recognized their Ordovician age, as in the case of the Hsiau Sörr section, because he believed them to be distinct from the great mass of Ordovician strata, which to him were representative of the Carboniferous limestone.

§§§ This is misleading, as Willis includes the great mass of Ordovician strata which von Richthofen excluded from his Sinian system.

this preliminary stage and we have no longer any doubt regarding the limitations of the Cambrian and Ordovician in north China, and where the exact line of separation of these formation has not yet been ascertained, because of cursory and superficial examination, the well-known term Cambro-Ordovician fully covers all the needs of temporary nomenclature, and expresses the facts so far as known. Moreover it is now known that the Cambrian and Ordovician are separated, in some parts at least, by a marked disconformity and a hiatus of still undetermined magnitude. Again there is accumulating evidence that the Ordovician itself may be divided by a hiatus, as it is in Europe and North America.

That von Richthofen's consent to the restriction and upward extension of the meaning of his systemic term was not given because of his conversion to the views of the Carnegie geologists, is fully shown by the fact, that after this consultation he deliberately reexpressed his views in the footnote already quoted (in translation, p. 68) and once more defined the Lower Sinian as including the unaltered sediments below the Cambrian (accepting Bailey Willis' reference of this part to the Algonkian). The Upper Sinian he begins with the Cambrian and accepts its extension into the Ordovician. Thus it would appear that the assent which he gave to the change proposed by Willis was, on reflection, withdrawn, this withdrawal being couched in the courteous form of a restatement of his adhesion to his original definition. This of course Dr. Willis did not know, because the third volume of "China" in which this footnote occurs, appeared 5 years after the publication of the results of the Carnegie Expedition. Had he known it, I have no doubt, he would have restricted the term Sinian in the only way consistent with von Richthofen's views, namely to the Lower Sinian.

Willis stresses the fact, that there is usually an unconformity at the base of the red Manto shales. What he means is that there is usually a *disconformity*,* for in the best known sections the strata are parallel, though Willis gives a columnar section about 4 miles south of Tung-yü, Shansi (vol. I, p. 139 fig. 33) in which he represents an unconformity and he describes these formations as having different inclinations. Hence he says "We are

* A term of subsequent introduction.

Sinian, from that employed by von Richthofen. Recognizing the pre-Cambrian age of the greater part of the series thus designated by von Richthofen, they excluded this from the Sinian of their definition, while at the same time they included as an upper member the great Ordovician limestone series, which von Richthofen so consistently excluded from his system. Thus the Sinian system in the Willis-Blackwelder sense comprises the Cambrian and Ordovician formations of north China.

Willis states his position in the following sentences[§] :

"The name and its application. Sinian was first applied by Pumpelly to the prevailing structural axes of eastern Asia, which trend northeast and southwest. It was adopted by von Richthofen to designate a series of conformable strata which exhibit folds having the Sinian direction. They are characterized in part by Cambrian fossils, but were believed by him to extend downward below the base of the Cambrian and at the top to include part of the Ordovician.^{§§} The term is here used to designate the Cambrian and Ordovician strata to which he applied it^{§§§} but those limestones which underlie the lowest fossiliferous Cambrian are excluded, after conference and agreement with von Richthofen himself."

One might be pardoned for doubting whether the venerable geologist to whom we owe so much of our knowledge of Chinese geology, would have been persuaded to assent to this exclusion of the principal part of his Sinian system, had the significance of such assent been fully clear to him at the time. For it must be evident that if Sinian is used as synonymous with Cambro-Ordovician in China, the term is doomed to inevitable relegation to the limbo of outworn and forgotten temporary formation names, useful for a time in expressing the incompleteness of our knowledge, but of no further value when systematic study is once under way. Chinese geology has progressed beyond

[§] Research in China, Vol. II. Systematic Geology, by Bailey Willis. Washington, July 1907, p. 35 et seq.

^{§§} We have seen that the inclusion of Ordovician strata was due chiefly to misapprehension as to their age, or, where he recognized their Ordovician age, as in the case of the Hsiau Sörr section, because he believed them to be distinct from the great mass of Ordovician strata, which to him were representative of the Carboniferous limestone.

^{§§§} This is misleading, as Willis includes the great mass of Ordovician strata which von Richthofen excluded from his Sinian system.

this preliminary stage and we have no longer any doubt regarding the limitations of the Cambrian and Ordovician in north China, and where the exact line of separation of these formation has not yet been ascertained, because of cursory and superficial examination, the well-known term Cambro-Ordovician fully covers all the needs of temporary nomenclature, and expresses the facts so far as known. Moreover it is now known that the Cambrian and Ordovician are separated, in some parts at least, by a marked disconformity and a hiatus of still undetermined magnitude. Again there is accumulating evidence that the Ordovician itself may be divided by a hiatus, as it is in Europe and North America.

That von Richthofen's consent to the restriction and upward extension of the meaning of his systemic term was not given because of his conversion to the views of the Carnegie geologists, is fully shown by the fact, that after this consultation he deliberately reexpressed his views in the footnote already quoted (in translation, p. 68) and once more defined the Lower Sinian as including the unaltered sediments below the Cambrian (accepting Bailey Willis' reference of this part to the Algonkian). The Upper Sinian he begins with the Cambrian and accepts its extension into the Ordovician. Thus it would appear that the assent which he gave to the change proposed by Willis was, on reflection, withdrawn, this withdrawal being couched in the courteous form of a restatement of his adhesion to his original definition. This of course Dr. Willis did not know, because the third volume of "China" in which this footnote occurs, appeared 5 years after the publication of the results of the Carnegie Expedition. Had he known it, I have no doubt, he would have restricted the term Sinian in the only way consistent with von Richthofen's views, namely to the Lower Sinian.

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* A term of subsequent introduction.

In its earliest publication, (Bulletin I, Memoir I) the Survey has followed Willis in applying the term Sinian to the Cambro-Ordovician rocks, but this was due to the fact that the merits of the case had not yet been thoroughly considered. The usage of this term in those publications was preliminary and subject to modification with the definite formulation of the Survey policy. In future the term will be restricted as here outlined.

In thus restricting a term formerly more widely applied, the Survey has excellent precedent in the classical example of the restriction of the term Silurian, as proposed by Murchison, to his Upper Silurian, and the separation of his Lower Silurian under the distinctive systemic name of Ordovician. No one has thought it necessary to include in the revised term Silurian the Devonian of Great Britain, even though there is a marked lithic similarity between the Upper Silurian and the lower Old Red in some regions and there may locally be some question as to the exact position of the dividing line. It is true, Barrande extended the term Silurian to cover all the fossiliferous older Palaeozoics of Bohemia, from the Middle Cambrian to the Middle Devonian, but in this he has not been upheld. Again the attempt of some European geologists to use the term in the Murchisonian sense and divide the larger group into the Ordovician and Gotlandian, has not met with general favor. If this were adopted, the term Silurian would eventually go into discard to the obvious great injustice towards Murchison, and the loss of a good and well-known systemic term. If modification of older systemic terms becomes necessary, the policy of restriction is the only safe one, certainly an extension of the term to cover systems which already have a well-known and definite designation is bound to meet with disaster. Such policy of restriction of systemic terms has been adopted by Ulrich and Schuchert in their redefinition of the Palaeozoic systems, though it remains to be determined whether the restrictions they have advocated, and the separation of new systems, is desirable. The separation of the old Lower Carboniferous as Mississippian, and of the old Lower Cretaceous as Comanchean, are other examples of restriction which are being gradually adopted by many stratigraphers.

A more limited example of restriction is found in the old term Helderbergian, which originally included all the limestones of the Helderberg mountains, from the Manlius limestone to the Onondaga. The Manlius

limestone is now classed as uppermost Silurian, the term Helderbergian is restricted to the remaining portion of the old Lower Helderberg, *i.e.* the Lower Devonian limestones of eastern North America, while the Onondaga limestone, the original Upper Helderberg, is no longer designated by that name.

In the discussion of this subject among Survey geologists and others it has been argued that the application of the term Sinian to a geological system—comparable in value to Cambrian, Ordovician, Silurian, etc., meets with the objection that it is derived from too large an area, *i.e.* the whole of China, whereas the other systemic names are derived from more limited regions (Cambrian, Devonian, Mississippian, Jurassic) or from names of tribes which formerly occupied a limited region. This can not be urged as a very strong objection to a good name, especially when it is realized that this system is one of the most wide-spread in China. Moreover we have already adopted a name in stratigraphic literature derived from a country of similar extent. This is the term Canadian, which is applied to one of the subdivision of the Ordovician system, and which Ulrich has proposed to separate as a distinct system from the Ordovician. Thus this objection falls to the ground, in the face of a well established precedent.

The fact that the Survey decides not to follow Willis and Blackwelder, in future in the use of the term Sinian, does not in any way imply that it undervalues the work of these workers in Chinese geology. The place of the Carnegie geologists, in the history of Chinese geology is established, and their work will remain with that of von Richthofen and Loczy, the point of departure for all future researches.

X. FOSSILS OF THE SINIAN ROCKS OF CHINA.

Up to the present time nothing has been obtained from the rocks of the Sinian system which can with positiveness be referred to known animal types. There are however structures which are without much doubt referable to calcareous algae of the type found in the limestones of the Belt terrane of Montana. These have been observed at various localities.

In the Ta-yang limestone Willis found ".....curved and minutely contorted laminae of flint, the contortion of which appears to be independent

of local deformation of the strata". He remarks: Similar bands have been noticed in the Siyeh limestone of the Belt formation, Montana. They are noted by Loczy as occurring in the Nan-shan sandstone of Tibet. Similar forms, described by Stose in Cambrian limestones of the Appalachian valley, are classed as *Cryptozoon proliferum* Hall. Whether the peculiar structures are in some cases mechanical or organic is not known, but they have a long range from late Proterozoic [Sinian] to Ordovician. They have not, however, been seen in the Sinian [Sinian in the Bailey Willis sense, i.e. Cambro-Ordovician]".⁴

The first undoubted examples of these structures obtained from the Nankou limestone, were collected by Dr. J. G. Andersson in the canyon of the Hueng-Ho in Wan-P'ing-Hsue southern Chihli.

Subsequently during a reconnaissance journey made through the Nankou pass and the Kalgan region by the author as the guest of the Third Asiatic Expedition, in company with Messrs. Morris, Barbour, Pope, and Sun we discovered these forms plentifully represented in the massive limestone in the quarries opened in these rocks, as well as on loose weathered limestone masses in several portions of the gorge. All these forms apparently belong to the same species which is provisionally referred to the genus *Collenia* under the name *Collenia sinensis*, sp. nov. During November 1922, the fourth year students in stratigraphic geology and palaeontology at the National University, Peking, made a detailed survey of the Nankou pass region under the direction of Prof. J. S. Lee. During this survey, they not only located the horizon of *C. sinensis* in the limestone series but also discovered two other species, each characteristic of a distinct horizon. These are *Collenia cylindrica*, and *Collenia angulata*, the former occurring below, the latter above the horizon of *C. sinensis*.

It has not yet been possible to prepare thin sections for detailed study and the present diagnosis of these forms is based solely on their macroscopic characters; which are, however, sufficiently distinct to permit ready separation. The generic reference in all cases is provisional and its exact determination must await detailed study in the future.

⁴ Research in China Vol. II p. 9

PROVISIONAL DIAGNOSIS OF SPECIES.

COLLENIA SINENSIS Grabau (sp. nov.)

Spheroidal masses of somewhat variable regularity of form and structure, composed of concentric layers of calcium and magnesium carbonate with the general aspect of a Cryptozoon, and attaining a diameter of a foot or over, in the larger specimens.

The concentric laminae are slightly undulating, this undulation being subregular, so as to give the upper surfaces of the lamina the appearance of being covered with broad low subregularly placed pustules, and the lower surface a correspondingly pitted appearance.

On the weathered sections the laminae appear to be fine and rather regular. In some sections there may be five layers to the millimeter, in others apparently only three. Again in a specimen from the Hueng-Ho gorge, layers of dark dolomite, about 0.5 mm. thick, are separated by layers of white dolomite 0.2 mm. or less in thickness. Massive specimens from the Nankou pass show a marked alternation of black and white layers or strata, all apparently of dolomite. The black strata are mostly about 1 mm. thick, and the white layers from 2.5 to 3mm. In still others the relative thickness of the black and white layers is reversed. These are probably variations due to conditions of preservation or subsequent alteration. These thicker layers or strata are in turn composed of finer laminae, these being often visible even on fracture surfaces. More rarely, in the specimens so far obtained, is there an alternation of dolomitic and cherty layers, each from one to two millimeters thick, and arranged in a regular concentric manner. It is possible that closer study will reveal differences in microscopic detail, associated with these apparent differences, and thus compel us to divide this group into several species.

The form is common in the massive beds of the Nankou pass, and in the canyon of the Hueng-ho. At present it is definitely known from only one horizon, but the fact that blocks of limestone with this fossil are plentifully scattered through the valley, suggest that it may have a greater vertical distribution than is now recognized.

COLLENIA CYLINDRICA Grabau (sp. nov.)

This species differs from the preceding largely in the manner of growth, which is, however, strikingly distinct. In general, this method of

growth may be said to be stalagmitic, the individual masses growing by a cap-like addition at the top, while the circumference increases comparatively to only a slight degree. The specimens are commonly silicified, and in consequence weather out in relief upon the surface of the limestone. They then appear as cylindrical masses projecting at right angles to the stratification planes. Some of them have been found to be a foot or more in length, but the average is much less. The diameter of an average specimen is about 10 cm. but larger and smaller masses occur. The macroscopic structure is essentially as in the preceding species, strata of light-colored (white) material (mostly silica) with a thickness of two to two and a half millimeters are separated by layers of black (chert) ranging in thickness from a mere line, to half a millimeter or more.

This species is common at a horizon below that in which occurs *C. sinensis*. It has so far only been obtained from the Nankou pass region where it was collected by students in geology, in the National University, Peking.

COLLENIA ANGULATA Grabau (sp. nov.)

This species too, is based upon the general form of the calcareous mass, which serves readily to distinguish it. No complete specimen has been obtained, but the fragments indicate that it has in general the form of a giant nummuloid with rather strongly compressed margins, where the layers meet at an acute angle. Indeed, one might be tempted to compare a section of this species with that of a gigantic *Nummulites* so far as the general appearance is concerned.

This structure is not regular, however, for one or both sides may rise in the form of a rounded dome as in some species of *Orbitoides*. This may be very abrupt, so that the outer surface is strongly concave above and below and the compressed periphery appears like a projecting median flange. The structure shown on fractured or polished surfaces is, as in the other species, an alternation of black and white layers, the former from 1 to 2 mm, and the latter from 1.5 to 3 mm, in thickness. The concentric layers in this form seem to be less regular than in the others, changing in thickness in an undulating manner.

This species is less common than the others. It occurs in the highest horizon in which these bodies have so far been found in the Nankou limestone at Nankou Pass.

XI. THE SINIAN SYSTEM IN OTHER PARTS OF THE WORLD.

If the Sinian represents a distinct system in the stratigraphic sequence, formed during a distinct time period, the Sinian, we would expect it to have representative deposits in other parts of the world. True, the lack of fossils or the non-marine character of those that are found, would make determination of exact equivalency difficult, if not impossible. But the unique position of the strata of this system, between the known Cambrian at the top, and the more or less strongly metamorphosed Algonkian below, would form at least one very distinctive basis for correlation. Next, the fact that the Sinian strata are as a rule but little or not at all metamorphosed (in the usual sense of that word) and that they have seldom suffered strong disturbance before the deposition upon them of the Cambrian and higher strata, furnishes another serviceable basis for correlation. Finally the fact that they are generally separated from the Cambrian strata by a disconformity, or a moderate unconformity, while their relationship to the underlying Algonkian rocks is a pronouncedly unconformable one, also serves the purpose of correlation. Any one of these criteria, by itself, would of course be of little value in correlation, but if all three occur together, the evidence of time relationship would seem to be as strong as can be obtained in the absence of distinctive organic remains. In seeking therefor formations of Sinian age in other parts of the world we will keep these three criteria of correlation in mind.

A. THE SINIAN SYSTEM IN NORTH AMERICA.

Belt Terrane of Montana etc. That the Belt Terrane of the north-western United States represents a group of formations of essentially the same age equivalent as the Sinian formation of China has generally been recognized. Bailey Willis says in his description of the Hu-to formation of rocks of Shansi: "The nearest relations of the Hu-t'o system are with the Belt terrane of Montana, and it is probable that pre-Cambrian fossils such as have been found in the Belt may eventually be discovered in the Hu-t'o[§]

[§] Research in China Vol. II p. 7. Such fossils have since been found in equivalent deposits elsewhere in China.

To this Walcott adds the remarks "In the above quoted paragraph Doctor Willis unconsciously gives a strong argument for the non-marine origin of the rocks of the Hut'o system, when he says that the presence of a rich fauna in the Sinian [Cambrian] seas distinguished that period from the preceding (Hu-t'o) time. It was the absence of marine life and the character of the sediments that led me to conclude that there were no marine deposits on the north American continent (nor probably on any of the continents) representing the Lipalian interval, or the interval between the fossiliferous Cambrian formations and the period of the development of the early pre-Cambrian marine life along the shores of the continents"[§]

The Huto, like the Belt, is regarded by both these authors as a non-marine formation, but the Nankou limestone was regarded by Willis as probably marine. He says: "The greater part of the Nan-kou system in this northeast-southwest trend is siliceous limestone, which from its extent and unusual thickness, is obviously a marine deposit." To this I would remark that the marine character of this formation has not been proved, and in the absence of undoubted marine fossils is extremely unlikely; moreover it must be remembered, that the Belt terrane contains a large development of limestone, which is unhesitatingly referred to a fresh-water origin by Walcott. Such is most likely the origin of the Nankou and other limestones of the Chinese Sinian, as is indeed indicated by the fossils found.

The Belt series which has an aggregate thickness of 37,000 feet, is disconformably succeeded by marine Middle Cambrian formations, and rests with a pronounced unconformity upon the older rocks. These are in all cases highly metamorphosed, while the Belt series is no more altered than are the succeeding Cambrian strata. According to all the available criteria for correlation then, the Belt terrane should be referred to the Sinian System.

The Uinta Quartzite Series. This series of strata lies within the same ancient geosyncline in which the Belt terrane was deposited, but to the south of it, being chiefly confined to Utah, where it forms the core of the Uinta Mountains. It represents a great alluvial fan of sand and pebbles with

[§] *Ibid.*, Vol. III pp. 20-30.

some shales, which apparently was formed chiefly by rivers flowing westward from a highland, which lay where now are the Front Ranges of the Rocky Mountains. Its thickness reaches 14,000 feet, and it rests with a profound unconformity upon the metamorphic old rocks (Archaean). The series is no more metamorphosed than are the succeeding Cambrian rocks which are separated from it by a disconformity. Being a purely elastic continental formation it is probably unfossiliferous throughout. According to all available criteria then, the Uinta quartzite belongs to the Sinian System.

The Grand Canyon series. Still farther south, in the same geosyncline, another deposit is met with below the Upper Cambrian Tonto sandstone. This is the series shown in the walls of the Grand Canyon of the Colorado in northern Arizona. This series, which in the lower part consists of red sandstones, and of dolomites, with basaltic layers both at the base and at the top, (*Unkar formation*) and in the upper part of sandy shales and limestone (*Chuar formation*) rests with a violent unconformity upon the older rocks, and is separated by a second very moderate angular unconformity, but a pronounced erosion hiatus, from the upper Cambrian sandstones. Because of the slight tilting of the strata and the profound erosion, most of which probably was accomplished during early Cambrian time, the late Cambrian Tonto sandstone rests upon various members of the series and in places upon the old gneiss. In spite of the great erosion, there still remain some 12,000 feet of these strata. So far as the few organic remains which have been found permit us to judge, the series is of continental origin.

In spite of the fact that there is here a true unconformity between the Cambrian and the older series, the Grand Canyon series is referred to the Sinian system, for it has all the other characters which indicate that stratigraphic position. The moderate tilting of the strata bears no comparison to the profound folding and metamorphism of the older rocks upon the eroded surfaces of which they rest. Nor does the extensive erosion of these rocks indicate a longer time interval between their deposition and the beginning of Cambrian time than is shown elsewhere between the Sinian system and the Cambrian, because much of this erosion went on, without doubt, during Cambrian time.

The Keweenaw Series. This is found in the Lake Superior region, where it is especially well exposed on the Keweenaw peninsula of Michigan. It underlies the Upper Cambrian (St. Croix) sandstone disconformably and consists of conglomerates, coarse, red and white sandstones with interbedded conglomerates, and shales, with some thin beds of limestone. The sandstones are often feldspathic, indicating relatively dry climate during their formation. This is also indicated by the red color of the shales and the abundant mud-cracks which occur in them. Interbedded with the sediments are vast sheets of basic lavas (basalts, melaphyres etc.) and some rhyolitic rocks. Some of the conglomerates are derived from these contemporaneous lavas. The silver ore and native copper of the region is largely found in the igneous rocks. The formation which is of great thickness is of continental origin and has so far furnished no fossils. Considering all the known characteristics there seems little doubt that the Keweenaw is referable to the Sinian system.*

The Avalon Series. This is known from the Avalon peninsula of eastern New Foundland and consists of an extensive series of quartzites, slates, and other rocks, only slightly metamorphosed, and carrying in some cases indistinct organic remains. The formations have been moderately arched and truncated by erosion, and upon the eroded edges of the older rocks lie the marine Lower Cambrian strata of the region.

These formations may be older than those previously described, and their reference to the Sinian System is more doubtful. The greater age is indicated by the fact that arching and extensive erosion of the strata preceded the transgression of the Lower Cambrian sea, and by the fact that the strata are slightly metamorphosed. On the other hand they may represent an earlier member of the Sinian System.

B. THE SINIAN SYSTEM IN EUROPE.

The Torridon Sandstone. In the northwestern part of Scotland, the Lewisian gneiss of Archaean age is unconformably succeeded by an enormous thickness of elastic strata, which consist in large measure of arkoses and con-

* Both Lawson and Lane include the Keweenaw in the basal Palaeozoic, the former also including the Animikian in that system. (Lawson, A. C. University of California Publications, Bulletin of the Department of Geology vol. X, no. 1. pp 1-19, Apr. 27, 1918. Lane A.C. American Journal of Science, vol XLIII, Jan. 1917. table opp p. 48.

glomerates, and of red sandstones and shales, all of continental origin. These form the *Torridon sandstone* of the British geologists, and they represent a still almost unmetamorphosed elastic series, which is but little disturbed, though locally it suffered much erosion. Upon it lie Lower Cambrian (*Olenellus*) beds, with which they form only a slight angle of discordance. All their characteristics point to a late pre-Cambrian age and they are unhesitatingly referred to the Sinian System.

The Jotnian and Jatulian series. In Finland the youngest pre-Cambrian strata which underlie the Cambrian disconformably, consist of but slightly altered quartzites and ripple-marked sandstones, conglomerates and clay slates, (Jotnian series) cut by intrusives, and having a thickness of about 2000 meters. These appear to be referable to the Sinian system. Underlying these is an older series, the *Jatulian*, of similar thickness, which was slightly folded, and suffered erosion before the deposition of the Jotnian series. This includes clay-shales and bituminous shales with a bed of anthracite coal two meters thick, and in addition comprises dolomites, quartzites and conglomerates with intrusives. Some of the sediments are characterized by ripple-marks and mud-cracks. These rocks are little altered, and sometimes still nearly horizontal. They rest with a violent unconformity upon the metamorphic *Kalevian* series of early Algonkian age.

The Jatulian may be referable to the early Sinian, or it may be of pre-Sinian age, the latter being more likely, but the Jotnian seems to be of Sinian age.

The Biri limestone of Norway and associated rocks may also be of Sinian age, though they may also represent a younger horizon.[‡]

C. OTHER SINIAN DEPOSITS

The Nantou Tillite. Returning to China we may suggest that the Nantou tillite of the Yangtze region most probably belongs to the Sinian system. If so it represents the only known glacial deposit of the Sinian period, though it is not impossible that the silimar ancient glacial deposit of Australia also belongs here. The Glacial tillites of Canada may also belong to the earliest Sinian, though it is perhaps most likely that they are pre-Sinian.

[‡] See A. W. Grabau Bull. Geol. Soc. America Vol. 27 pp. 570-572 1916.

XII. SYSTEMIC AFFINITIES OF THE SINIAN SYSTEM.

The formations here included in the Sinian system have almost always been placed in the Algonkian or late Proterozoic division of the rocks of the earth's crust. The well-established usage of beginning the Palaeozoic group of systems with the Cambrian, brought with it the reference of all pre-Cambrian rocks to a pre-Palaeozoic division of the earth's history. There have, however, been students of these rocks to whom their general character and the nature of their organic remains have suggested a much nearer relation to the Palaeozoic than to the preceding rock series, and some of these, notably Lawson (1916) and Lane (1917) have placed a number of them in the Palaeozoic.

When compared with the older Algonkian rocks in the same region, they present a contrast so pronounced, that the conviction, that these two can not belong to the same great time division of the earth's history, is irresistably forced upon us. Thus the rocks of the Wutai system, probably the true Algonkian series of northern China, are biotite and chlorite schists, gneisses and marbles, with garnets, staurolites, and other minerals, the whole mass being intensely folded and subjected to thrusts, with the production of isoclinal structure. The period of disturbance, here represented, was one of the master periods of deformation which effected our earth. Bailey Willis says of it: "This period of orogeny was for the provinces affected equally as important, apparently, as the intense orogenic disturbances which mark the Permo-Mesozoic period in central Asia, and the western United States. It was very possibly an incident of a period of diastrophic activity such as closed the Palaeozoic".⁹ and again: "After the Wutai sediments had been deposited they were folded, depressed by folding or subsidence to a notable depth, intruded by large igneous masses, and deformed under great pressure, so that their original structure was replaced by schistosity, and their constituents were recrystallized. The Hu-t'o rocks suffered none of these changes. They were deposited only after the schists had been exposed by uplift and deep erosion. Obviously an interval of the first magnitude intervened."¹⁰

⁹ Loc. cit. Vol. II p. 30.

¹⁰ Loc. cit. p. 7-

Not so in the case of the Sinian deposits, in the sense in which that term is here used. Though separated by a disconformity, or locally an unconformity, from the Cambrian, this is no more pronounced than are local unconformities within the Palaeozoic, such as that between the Hudson River (Ordovician) and Shawangunk or younger Silurian beds in New York and Pennsylvania, that between the Cambro-Ordovician Shinarump shales and the late Ordovician of western England, that between the Siluro-Ordovician and the old Red Sandstone at Siccar Point in Scotland, or that between the Ordovician and the Mountain Limestone (Dinantian) in the Pennine range of north England—to cite only a few well-known examples. Bailey Willis describes the relation of the Cambrian and Huto-Nankou strata in the following words:

"The last event of the Proterozoic [Sinian] (pre-Sinian) [pre-Cambrian] era was a movement which is recorded in folding of the latest pre-Cambrian sediments: although possibly a local phenomenon of the littoral zone, so far as yet known, it occasions a decided unconformity of structure in the Wu-tai district and is represented by an erosion interval, [disconformity] even where there is no known discordance of dip with the Sinian [Cambrian]. It is consequently regarded as an interval of sufficient importance to distinguish the Hu-t'o or Nan-kou system [Sinian system] of the Proterozoic [early Palaeozoic era] from the Sinian [Cambro-Ordovician] system of the Palaeozoic era."[§] Again he says: "The movement [at the end of the Huto-period] did not compare in intensity with that which closed the Wut'ai period; and even though it should ultimately be found to have affected an extensive belt, we can not assign to the epoch of deformation and consequent erosion a duration at all equivalent to that of mid-Proterozoic diastrophism".^{§§}

Another point that has some significance in the classification of these rocks, is their development within the same geosyncline in which the Cambrian and younger Palaeozoic beds were laid down. Thus the distribution of the Sinian of northern China falls within the region in which Cambrian strata are developed, though these overlap the borders of the Sinian deposits both to the northwest and the southeast. True, there was erosion of the Sinian strata

[§] *Loc. cit.* pp. 30-31 The emendations in square brackets are added by me.

^{§§} *Loc. cit.* p. 29.

before the deposition of the Cambrian, probably in early Cambrian time, but there is no evidence that this was profound enough to remove the Sinian from extensive areas in which it was deposited. The Wutai system too is found chiefly within this same area but the Wutai rocks are known to have suffered extensive erosion after folding, and their former extent can only be conjectured. The reason for their preservation within the area of the Sinian-Cambro-Ordovician geosyncline may be found in the early formation of this geosyncline and the consequent depression of a part of the Wutai system below the level of erosion.

The well-known occurrence of the pre-Cambrian rocks of western North America, here included in the Sinian system, within the geosyncline in which the later Palaeozoic strata were deposited, though not everywhere in the same part of this geosyncline, further shows that they belong to the time period in which the physical conditions characteristic of the Palaeozoic, were established.

It must be evident, that the classifying of the Sinian system (in our sense) in one division with the Wutai system, from which it differs in all its lithic and structural characters, and its unmetamorphosed condition, and from which moreover it is separated by a break of the first magnitude, and the separation of it from the older Palaeozoic rocks, with which it is for the most part conformable, though separated by an erosion break, or locally by a minor unconformity (such as is repeatedly found in the Palaeozoic), and with the strata of which it has moreover the closest lithic affinities, can be due only to deference for the accepted view that the Palaeozoic begins with the Cambrian, and that all pre-Cambrian rock are *ipso-facto* pre-Palaeozoic. If these strata carried marine fossils of Palaeozoic types, though distinct from the Cambrian, no one would hesitate to class them in a new pre-Cambrian system within the Palaeozoic. The absence of such fossils is explained by the continental origin of these rocks, including the limestones. Yet no one would be willing to assert, that this is a sufficient reason for excluding them from the Palaeozoic, because we recognize that they are continental representatives of a group of rocks deposited in the oceans of that time, and which we have not yet found, and may never discover. Moreover, the fossils that have been found in

rocks which clearly belong to this system in China as well as in other parts of the world, are of undoubted Palæozoic affinities. This is true of the eurypterid *Bellina danai* found in the Belt series of Montana, for this class of Merostomes is known to be otherwise confined to the Palæozoic. The calcareous algæ of the Nankou limestone as of the limestones of the Belt formation furthermore have their nearest affinities with the Cryptozoons of the Ordovician, and the same is true of other organisms.[‡]

If we consider the fact that the trilobites, undoubtedly the most characteristic organisms of the Palæozoic, were already highly developed in Cambrian time, where indeed they approached very closely to the acme of their development, we must allow that a long time period preceded the Cambrian in which this development took place. But if rocks with older types of trilobites than the Cambrian were found, we should still class them as Palæozoic, from which it appears that the Cambrian can not be *ipso facto* regarded as the beginning of the Palæozoic. Indeed from a purely biological point of view, we should probably not be far wrong in classing it nearer the middle than the beginning of the Palæozoic. There would thus seem to be ample room for the inclusion of Pre-Cambrian systems in the Palæozoic, if the rocks of these systems, and their fossils, if found, show Palæozoic affinities.

Nor are we without precedent for such a downward extension of a great division of the earth's crust, if precedent were deemed desirable. The Palæocene, now very generally accepted as an older system in the Tertiary or Cenozoic series, which formerly was regarded as beginning with the Eocene, is a case in point. But even if we lacked such a precedent, the overwhelming evidence in favor of the Palæozoic affinities of the rocks of the Sinian system, should determine us to remove this system from the Algonkian or Proterozoic, and include it in the Palæozoic.

The revised base of the Palæozoic then would be as follows:

‡ I recall having been shown several years ago by the late Professor A. Rothpletz, some crustacean remains, probably phyllocarid, which he collected in the rocks of the Grand Cañon series in Arizona. Professor Rothpletz pronounced these as unmistakably of Palæozoic types, and in this pronouncement I fully concurred.

Palæozoic	{	Permian	}	or	{	Permian
		to				to
	{	Devonian	}	{	Devonian	
		Silurian or Siluric				
		Ordovician or Ordovician				
		Cambrian or Cambrian				
{	Sinian or Sinic	}				
