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THE BOUNDARY BETWEEN THE LOWER AND UPPER CARBONIFEROUS IN JAPAN

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ABSTRACT. A review of the stratigraphy and faunas of the Carboniferous rocks of Japan indicates that two systems, Mississippian and Pennsylvanian, are justified, and that the boundary lies between the Onimaru Series and the Nagaiwa Series. The uppermost Mississippian is the zone of *Neokoninckophyllum* and the base of the Pennsylvanian includes the Sabukura Stage which immediately underlies the zone of *Profusulinella*. In most areas in Japan the Pennsylvanian section does not extend above the zone of *Fusulina* and is overlain unconformably by early Permian formations carrying the *Pseudoschwagerina* fauna, but in the Fukuji district the Pennsylvanian System runs up through about 50 meters of the zone of *Triticites*.

The Mississippian System in Japan consists largely of dark slates with large amounts of tuffaceous material. The Pennsylvanian, on the contrary, is largely calcareous.

STRATIGRAPHY AT TYPE AREAS

Fossiliferous Carboniferous deposits have been detected in all the Japanese Islands except Hokkaido (the northernmost main island), but the areas of outcrop are generally small and most of them still await detailed investigations.

Before discussing the boundary between the Lower and Upper Carboniferous in Japan, it is proposed first to describe briefly the major divisions, the lithologic nature, and the fossil contents of those deposits in their type areas, beginning with the Kitakami Mountains, northeastern Honshu.

Kitakami District

The Carboniferous in the Kitakami district is divisible on a lithologic basis into two major parts. The lower half consists mainly of pyroclastic sediments and slates, while the upper half is chiefly limestone; each of these divisions has in turn been divided into series or stages, as presented below in ascending order.

Hikoroichi Series.—This series unconformably overlies the Tobigamori Series, presumedly Upper Devonian in age, and also overlaps still older formations. It is more than 750 meters in thickness and consists chiefly of gray or black slates, alternations of green tuffs and slates, and less numerous limestones. The lowest member is a conglomerate about 10 meters in thickness. The succession of these rocks is schematically given in figure 1. This series is divisible on a faunal basis into two stages: the lower is named the Ikawa stage after the type locality, while the upper is called Ohmata.

Ikawa Stage.—Three important fossil-bearing beds commonly termed as A_0, A_1, and A_2, are found in the middle portion of this stage. The beds consist mostly of impure limestone or calcareous slate intercalated by reddish tuffs. Fossils from A_0 follow: *Actinocrinus higuchisawaensis* Minato, *A. ohmoriensis* Minato, *Amphoracrinus* sp., *Leptaena analoga* (Phillips), *L. convexa* Weller, *Schellwienella izirii* Minato, *Schellwienella* sp., *Productella* cf. *caperata* (Sowerby), *Kitakamithyris tyoanjiensis* (Minato), *K. hikoroichiensis* (Minato), *K. semicircularis* Minato, *Brachythyris kitakamiensis* Minato, *Brachy-*

thyris sp., *Actinoconchus planosulcata* (Phillips), *Delthyris* aff. *clarksvillensis* (Winchel), *Schizophoria* sp., *Spirifer* cf. *loganii* Hall, *Spiriferina paratransversa* Minato, *S. octoplicata* Sowerby, *Spirifer ultratransversa* Minato, *S. ohmoriensis* Minato, *S. kozuboensis* Minato, *Cliothyridina royssii* (L'Evillé), *Planoproductus? gigantoides* Minato, *Amygdalophyllum* sp., *Lithostrotionella* sp., *Conularia tyoanjiensis* Sugiyama, *Litophaga* sp., *Palaeophyllipsia japonicum* Sugiyama and Okano, *Phillipsia ohmoriensis* Okubo.

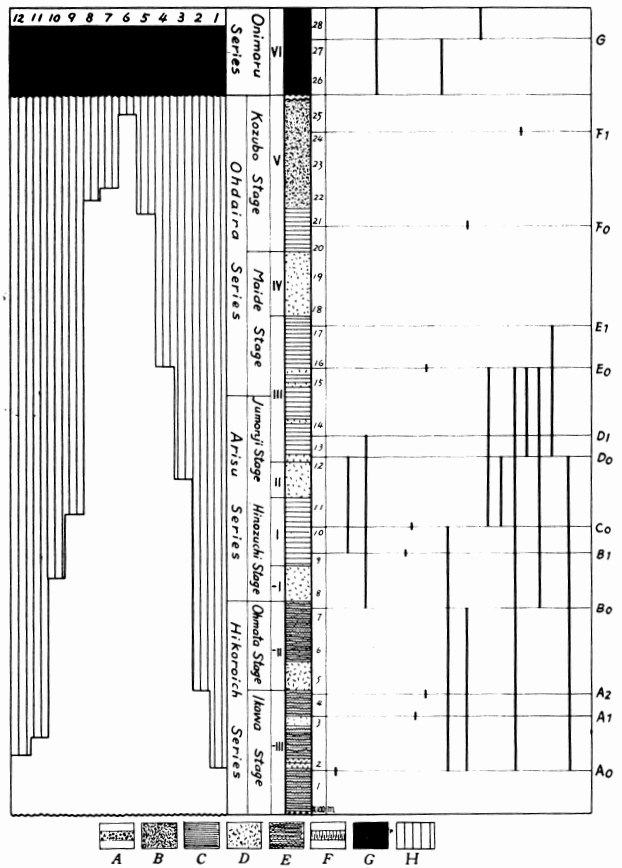


Fig. 1. Columnar geological section of the Lower Carboniferous deposits in the Kitakami Mountains. Roman numerals indicate major lithologic divisions; arabic numerals give thickness above base in hundreds of meters; letters with numeral subscripts are important fossil-bearing layers. A. Conglomerate facies; B. Sandstone facies; C. Shale facies; D. Tuff facies; E. Slate, sandstone, and tuff in alternation; F. Impure limestone; G. Limestone facies; H. Stratigraphical hiatus.

Fossil-bearing bed A_1 lies above A_0; between these two there is a formation about 200 meters in thickness. A_2 is found in a horizon higher by about 70 meters than A_1. These two beds are also very fossiliferous, but their fossils have been little investigated in detail.

Ohmata Stage.—An important fossil-bearing bed B_0 lies some 300 meters above A_2. From B_0 the following species have been found: *Derbya depressa* Demanet var. *transversa* Minato, *Leptaena analoga* (Phillips), *Spirifer ultratransversa* Minato, *S. ohmoriensis* Minato, *Syringothyris* sp., *Schizophoria* sp., *Kitakamithyris* sp.

Arisu Series.—This series lies conformably on the Hikoroichi Series. It is about 700 meters in thickness, consists of tuffs and slates, and is divisible into two stages: the lower part, the Hinozuchi Stage, and the upper, the Jumonji Stage. The succession and boundary between these two stages are also diagrammatically given in figure 1. The former view (Minato and others, 1953) in respect to the boundary line between the Hinozuchi and Jumonji stages is now slightly modified.

Hinozuchi Stage.—It is about 300 meters in thickness. The very important fossil beds B_1 and C_0 are found in the middle portion of this stage. Fossils from B_1 are: *Actinoconchus lamellosa* (L'Evillé), *Schumardella* cf. *missouriensis* (Schumard), *Brachythyris* sp., *Productus* sp. *a*, *Syringothyris* sp., *Actinocrinus higuchisawaensis* Minato, *Planoproductus? gigantoides* Minato, besides Fenenstellids. From C_0: *Camarotoechia* sp., *Brachythyris* aff. *pinguis* (Sowerby), *Productus* sp. *b*, *Fusella nipponotrigonalis* Minato, *Amplexus* sp. *a*, *Phillipsia ohmoriensis* Okubo and *Spiriferina octoplicata* Sowerby.

Jumonji Stage.—The thickness is nearly 400 meters; fossils are rather numerous, especially in beds D_0 and D_1, and are found in the middle portion of this stage. From D_0: *Schizophoria resupinata* (Martin), *Fusella nipponotrigonalis* Minato, *Amplexus* sp. *b*, *Fusella nipponotrigonalis* var. *minor* Minato, *Syringothyris transversa* Minato, *S. kitakamiensis* Minato, *Plicatosyrinx singulare* Minato, *P.? kumanoi* Minato, *Spirifer kozuboensis* Minato, *Kitakamithyris semicircularis* Minato, *Orthotetes keokuk* (Hall), *Pustula* cf. *tenuipustulata* Thomas, *Platycrinus asiatica* Minato. From D_1: *Derbya depressa* var. *transversa* Minato. *Schizophoria resupinata* (Martin) and *Productus* sp. *b*.

Ohdaira Series.—Very thick, but less prolific in fossils, consisting also of thick tuffs, slates, and alternations of tuffs and slates, besides very thin lenticular limestones; divisible also into two stages, the lower, the Maide Stage, and the upper, the Kozubo Stage.

Maide Stage.—This stage is some 500 meters in thickness; two important fossil-bearing beds E_0 and E_1 are found in the lower part. Fossils from E_0 are: *Amplexus nipponensis* Oishi and Minato, *A.* sp. *a* and *b*, *Syringopora* sp., *Brachythyrina nagaoi* Minato, *Productus* sp. *b*, *Cliothyridina royssii* (L'Evillé), *Spiriferina octoplicata* Sowerby, *Syringothyris transversa* Minato, *S.* sp., *Fusella nipponotrigonalis* var. *minor* Minato and *Brachythyris* aff. *pinguis* (Sowerby). From E_1, also *Brachythyris* aff. *pinguis* (Sowerby).

Kozubo Stage.—This stage, about 500 meters thick, consists mainly of tuffs and slate in alternation, especially in its lower part, while the upper part is chiefly composed of fine-grained sandstones intercalated by very thin cherts. From the two fossil layers, F_0 and F_1, the following fossils have been found: from F_0, *Sugiyamaella carbonarium* Yabe and Minato, *Productus* sp., *Chonetes* sp. and *Spirifer* sp. *c*; from F_1, *Spirifer* sp. *d*.

An abrupt change in lithologic facies is observable at the very base of the overlying Onimaru Series. The Carboniferous deposits above the Kozubo Stage are mostly composed of limestone, calcareous slates, carbonaceous slates and less numerous pyroclastic rocks, showing a marked contrast to the foregoing formations which are characterized by the prevalence of pyroclastic sediments. The calcareous upper formations are more than 1000 meters in thickness, and are divisible into two series, the Onimaru and the Nagaiwa respectively.

Onimaru Series.—This series unconformably overlaps the underlying Ohdaira and Arisu Series, and even most of the Hikoroichi Series which are locally lacking through erosion which happened prior to the transgression of the Onimaru Epoch. This series, about 350 meters thick, consists mainly of limestones, while black carbonaceous slates and alternations of slate and limestone follow this. So far as the present writer is now aware, no pyroclastic sediments have ever been detected in this series. It is divisible into two stages, the Hotokezaka Stage below, and the Hiishi Stage above.

Hotokezaka Stage.—The following fossils are known: *Caninia juddi* Thomson var. *ozawai* Minato, *Pseudocaninia* sp., *Siphonodendron pseudomartini* (Yabe and Hayasaka), *S. densitabulata* (Yabe and Hayasaka), *S. martini* (Edwards and Haime), *S. pauciradiale* (M'Coy), *S. inugasirayamaensis* Minato, *Lithostrotion hinozuchiense* Minato, *Dorlodotia?* sp., *Diphyphyllum flexuosum* Yabe and Hayasaka, *Dibunophyllum bristolense* Garwood and Goodyear, *D. inugasirayamaensis* Minato, *D. asiaticum* Minato, *Rhodophyllum yokoyamai* Minato, *R. sugiyamai* Minato, *Carcinophyllum onukii* Minato, *Setamainella* (?=*Aulophyllum*) *hayasakai* Minato, *Yuanophyllum yabei* (Nagao and Minato), *Kueichouphyllum yabei* Minato, *K. kesenense* Minato, *K. yahagiense* Minato, *Syringopora reticulata* Goldfuss, *Kueichoupora setamaiensis* Minato, and *Gigantoproductus* sp.

Hiishi Stage.—In this stage are found not infrequently species which show a long geological range extending from the Hotokezaka Stage to the Hiishi Stage, for instance: *Caninia juddi* var. *ozawai* Minato, *Siphonodendron pseudomartini* (Yabe and Hayasaka), *S. martini* (Edwards and Haime), *S. pauciradiale* (M'Coy), *Dibunophyllum bristolense* Garwood and Goodyear, *Kueichouphyllum yabei* Minato, *Gigantoproductus* sp. Besides them, however, such newly arising forms are to be found as *Palaeosmilia kitakamiensis* Minato, *Amygdalophyllum kitakamiensis* Yabe and Minato, *Pseudodorlodotia kakimii* Minato, *Stylidophyllum japonicum* (Yabe and Hayasaka), *Hexaphyllia japonica* Yabe and Sugiyama, *Heterophyllia kitakamiensis* Yabe and Sugiyama, *Millerella* sp., *Saccamminopsis carteri* (Brady), *Eostaffella parva* (Möller) and *Parastaffella struvii* (Möller). Of these, the presence of *Millerella, Parastaffella* and *Eostaffella* in the Hiishi Stage is quite worthy of note, because their first appearance is regarded to be in a rather limited horizon in foreign standard. Moreover, a coral, *Dibunophyllum bipartitum konicki* (Edwards and Haime) is also one of the important elements of the Hiishi fauna, although this species shows a comparatively long geological range extending as far upward as the lower part of the Nagaiwa Series.

Nagaiwa Series.—The stratigraphic relation between the preceding and the Nagaiwa Series was not clearly known until a short time ago, although dis-

covery of an unconformity had long been expected. However, this unconformity became quite evident through our recent field work. This series, about 750 meters thick, also consists chiefly of limestones, intercalated by several thin tuffaceous layers, except for the basal part, about 20 meters in thickness, which is composed of sandstones and conglomerates in alternation.

A green tuffaceous layer with limestone lenticules is found at a horizon situated about 200 meters above the base of this series. That layer is characterized by the first appearance of *Profusulinella* and *Pseudostaffella* in association with numerous corals such as *Chaetetes*, *Thysanophyllum*, *Lithostrotionella* and *Sciophyllum*. This layer has been regarded as a good key bed (so-called Horizon H_0), being widely traceable throughout the south Kitakami district. Hence it may be quite convenient to divide the Nagaiwa Series into two divisions, taking the base of this characteristic layer as a boundary line. Thus the lower half of the Nagaiwa Series is termed the Sabukura Stage, while the upper is the Yomogibata Stage.

Sabukura Stage.—This stage, about 250 meters thick, consists chiefly of limestones, subordinate slates and tuffs, though the basal part is composed of thin conglomerates and sandstones. The nature of the limestones of this stage and also of the following Yomogibata Stage seems to be somewhat different from that of the Onimaru Series, the Nagaiwa limestone is mostly white in color and massive, while the Onimaru is black in color and usually shows clear stratification.

No remarkable guide fossils have thus far been found in this stage. It is rather characterized by the sudden disappearance of the Onimaru type of corals, except for *Dibunophyllum bipartitum konincki* (Edwards and Haime) and such foraminifera as *Millerella*. These two forms begin to appear for the first time in the upper half of the Onimaru Series as already stated, and certainly existed also in the Sabukura Stage, although the latter is not specifically determined yet. *Chaetetes nagaiwaensis* Minato, *Thysanophyllum aseptatum* Dobrolyubova, and *Sciophyllum japonicum* Minato and Saito appear especially in the uppermost part of this series, though the first-named coral shows a long geological range to the top of the Yomogibata Stage and the last two extend at least to the base of that stage.

Yomogibata Stage.—This stage, about 500 meters thick, also consists chiefly of limestones, and subordinate thin tuffaceous layers. It is especially characterized by the presence of such fusulinid remains as *Profusulinella*, *Pseudostaffella*, *Ozawainella* and *Eoschubertella* besides *Millerella*.

The stratigraphic distribution of these fusulinid genera together with coral species, shown in figure 2, are based mainly on the data gathered by Yamada (1958), and also by Minato and others (1958a). At the present moment, the actual upper limit of this stage is unknown to the writer, because the Yomogibata Stage is unconformably covered elsewhere in the Kitakami district by the Lower Permian Sakamotosawa Series with the *Pseudoschwagerina* fauna. The maximum thickness of the Yomogibata Stage is now estimated to be at least 500 meters, so far as can be measured at its type locality.

As described in the foregoing, the Carboniferous deposits younger than the *Profusulinella* zone are wholly lacking in the Kitakami district.

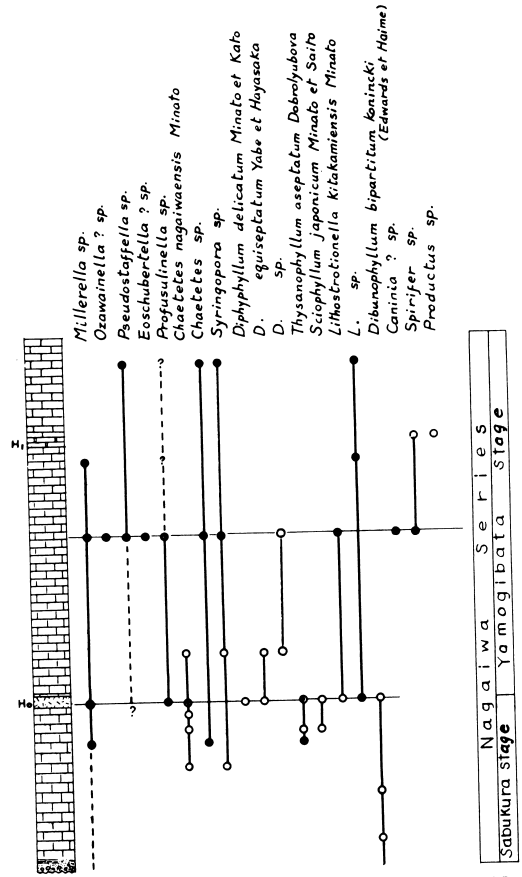


Fig. 2. Stratigraphical distribution of certain fossils of the Nagaiwa Series.

Akiyoshi District

In the Akiyoshi district in southwest Honshu, the Carboniferous deposits have been investigated more in detail by Ozawa (1925), Sugiyama (1939), Hanzawa (1941), Kawano (1953) and especially by Toriyama (1954). Kato and Hasegawa of Hokkaido University are now carrying out a stratigraphical survey in the same area at the writer's request. Preliminary results of their field work will be here briefly reported in combination with some of the writer's own palaeontological data. based on their collections of fossils.

The Carboniferous of Akiyoshi district is divisible into the following three subdivisions in descending order:

Clisaxophyllum ofukuense zone

Clisaxophyllum awa zone { *Styldiophyllum* sp. subzone / *Nagatophyllum satoi* subzone }

Nagatophyllum satoi subzone.—Made up largely of impure and in part oolitic limestones, the basal part is usually intercalated by purplish or rarely greenish

tuffs: it is more than 40 meters in total thickness. Fossils are: *Meniscophyllum longiseptata* Minato, *Akiyosiphyllum stylophorum* Yabe and Sugiyama, *Lonsdaleoides enormis* (Ozawa), *L. toriyamai* Minato, *Clisaxophyllum awa* Minato, *Nagatophyllum satoi* Ozawa, *Amygdalophyllum naosoidea* Minato, *A? gracile* (Hayasaka), *Polycoelia japonica* Ozawa and *Chaetetes* sp.

Stylidophyllum sp. subzone.—This consists of massive grayish limestones with subordinate intercalations of öolitic limestones. No sharp lithologic boundary can be found between this subzone and the preceding. Entire thickness is at least more than 150 meters. Fossils are: *Clisaxophyllum awa* Minato, *Amygdalophyllum naosoidea* Minato, *A.? gracile* (Hayasaka), *Lonsdaleoides toriyamai* Minato, *Taisyakuphyllum rostfer* Minato, *Stylidophyllum* sp. (=so-called *Lonsdaleia floriformis crassiconus* of Ozawa, non Smith), and *Chaetetes* sp.

Kato and Hasegawa are now of the belief that the upper half of their *Stylidophyllum* sp. subzone is stratigraphically almost equivalent to the so-called *Profusulinella beppensis* zone of Toriyama (1954). From this zone Toriyama once listed the following fusulinids: *Profusulinella beppensis* Toriyama, *P. rhomboides* (Lee and Chen), *Akiyoshiella ozawai* Toriyama besides *Staffella akagoensis* Toriyama, and *Eoschubertella obscura* (Lee and Chen).

The *Clisaxophyllum ofukuensis* zone is lithologically much like the immediately lower formation of the *Stylidophyllum* sp. subzone, but the lower limit of this zone is easily known from the first appearance of *Fusulinella*, although no stratigraphical break has ever been detected between those two formations. The upper limit of this zone is also not easily recognizable from the lithologic facies; however, the overlying limestone is characterized by more advanced forms of fusulinids of Permian age such as *Pseudoschwagerina* and *Pseudofusulina*.

It is far from doubtful that the *Clisaxophyllum ofukuense* zone completely coincides with the *Fusulinella bocki* zone of Ozawa or the *Fusulinella biconica* zone of Toriyama, both from stratigraphical and palaeontological evidences. Fossils are: *Taisyakuphyllum rostfer* Minato, *Clisaxophyllum ofukuense* (Ozawa), *Lonsdaleiastraea nipponica* Minato, *Stylidophyllum* sp., (=so-called *Lonsdaleia floriformis crassiconus* of Ozawa, non Smith), and *Chaetetes* sp. Also Toriyama reported the occurrence of the following fusulinids from this formation: *Fusulinella biconica* (Hayasaka), *F. itoi* Ozawa, *F.* cf. *bocki* Moeller, *F.* cf. *pseudobocki* (Lee and Chen), *F. subspherica* Toriyama, besides *Fusulina akiyoshiensis* Toriyama and *Fusiella* cfr. *typica* Lee and Chen.

Fukuji District

Carboniferous deposits developed in a narrow area at Fukuji, Gifu Prefecture, have been investigated by Kamei (1952), Igo (1956, 1957) and Minato and Kato (1957b). Igo especially contributed much to establish numerous faunal zones in these deposits, ranging from the *Millerella* to the *Triticites* zone. According to him, the Carboniferous in the Fukuji district is represented by deposits which are comparatively thin, chiefly made up of limestones, without any stratigraphical breaks between the respective faunal zones. The faunal zones are as follows in ascending order:

Zone of Millerella, made up chiefly of limestones, is divisible into three parts: (1) *Millerella kanmerai* subzone, about 30 meters. Fossils are: *Millerella kanmerai* Igo, *M. komatui* Igo, *M. discoidea* Igo, besides several corals as *Siphonodendron*, *Palaeosmilia*, *Rhodophyllum*, *Dibunophyllum*, *Kueichouphyllum*, *Hexaphyllia* and *Syringopora*. (2) Limestones without fossils, about 20 meters in thickness. (3) *Millerella bigemmicula* subzone. Also limestones; about 5 meters in thickness. Fossils are: *Millerella bigemmicula* Igo, *M.* cfr. *marblensis* Thompson, *Nankinella* cf. *plummeri* Thompson, *Pseudostaffella kanumai* Igo, *Pseudostaffella kanumai* var. *pauciseptata* Igo, *Paramillerella ampla* (Thompson).

Zone of Profusulinella.—Consists chiefly of limestones and red shales. About 70 meters in thickness. Fossils are: *Millerella* cfr. *marblensis* Thompson, *M.* sp., *Paramillerella ampla* (Thompson), *Pseudostaffella* sp., *Profusulinella fukujiensis* Igo.

Zone of Fusulinella.—Made up of öolitic limestones and red shales about 140 meters in thickness. Divisible into two subzones.

Zone of Fusulina.—Composed of öolitic limestones and limestones about 70 meters. Divisible into two subzones.

Zone of Triticites.—About 50 meters thick, mainly limestones, red shales, and öolitic limestones. Fossils are: *Quasifusulina longissima* (Moeller), *Triticites exsculptus* Igo, *T. exsculptus* var. *naviforme* Igo, *T. hidensis* Igo.

The writer is not certain about the conclusive remark made by Igo (1957) regarding the stratigraphy of the above faunal zones, especially on the stratigraphical relation of the respective faunal zones and their correlations. Despite Igo's conviction, the present writer is now inclined to believe that there are at least a few stratigraphical breaks which have been overlooked.

Also it is proposed to make a brief comment on the correlation of the so-called zone of *Millerella* established by Igo, in later pages.

Kakisako District

In Kyushu, Carboniferous deposits are typically developed in the mountainous area of the southern part of the island, especially in the Kakisako-Kuriki district, Kumamoto Prefecture. Thanks to the efforts of Yabe and Sugiyama (1939) and Kanmera (1952a, b, 1954), the stratigraphical sequence of the formations has been clarified to some extent. Following is a brief description of a typical section of Carboniferous in this area, based mainly on the data presented by Kanmera. The rocks in ascending order are:

Kakisako formation. Divisible into two members. The Lower Kakisako member is mostly composed of dark gray to black shales with some lenticular beds of sandstones, limestones, cherts and conglomerates. Thickness about 300 to 350 meters. The limestones occupying the middle part of this member yield the following fossils: *Dibunophyllum* cf. *kankouense* Yü, *Kueichouphyllum latifossulatum* Kanmera, which closely resembles *K. yabei* Minato, *Diphyphyllum platiforme* Yü var. *kakisakoense* Kanmera, *Siphonodendron* sp., *Hexaphyllia* sp., *Millerella japonica* Kanmera, *M. gigantea* Kanmera, *Saccamminopsis carteri* (Brady).

The upper Kakisako member is about 200 to 250 meters in thickness, and is composed mainly of slates and pyroclastic sediments intercalated by basaltic lavas. No fossils.

Zone of *Fusulinella* (Unnamed formation). Mostly consists of limestones. Fossils are: *Fusulinella bocki* Moeller and *Fusulinella biconica* Hayasaka.

Kuriki Series.—About 250 meters in thickness. Limestones. Fossils are: *Nankinella* sp., *Staffella pseudospheroidea* Doutkevitsch, *Fusulinella gracilis* Kanmera, *Wedekindellina prolifica* Kanmera, *Fusulina higoensis* Kanmera, *Fusulina ohtanii* Kanmera, *F. kurikiensis* Kanmera.

Hikawa Series.—About 120 meters in thickness. Consists mostly of limestones. Fossils are: *Staffella* sp., *Schubertella* sp., *Quasifusulina longissima* (Moeller), *Triticites matsumotoi* Kanmera, *T. yayamadakensis* Kanmera.

The Hikawa Series unconformably covers the Kuriki Series, and the Kuriki Series is also unconformably covered by the limestone formation with *Pseudoschwagerina* fauna, in which Kanmera reported the presence of such fusulinids as *Pseudoschwagerina* aff. *moungthensis* (Deprat), *P. minatoi* Kanmera, *Paraschwagerina shimodakensis* Kanmera, *Triticites parvula* (Schellwien), *T. subobsoleta* (Ozawa), *T. montipara* (Moeller), *Schwagerina krotowi* (Schellwien) and *Pseudofusulina* cf. *vulgaris* var. *fusiformis* Schellwien.

CORRELATION

Correlation of the Japanese Carboniferous.—To sum up the description presented above, the Onimaru Series and its equivalents together with the formations ranging from the *Profusulinella* as far as the *Triticites* zone mainly consist of calcareous deposits, while the lower formations earlier than the Onimaru Series are mainly detrital and tuffaceous. This is also true of other districts in Japan besides the typical areas described above; at least it is quite evident that the formations ranging from the *Millerella* to the *Triticites* zone are largely represented by limestones elsewhere in Japan (see fig. 3).

At the present moment fossiliferous deposits equivalent in stratigraphical position with those of the Hikroichi, Arisu, and Ohdaira Series have been not detected in Japan outside of the Kitakami district. There is one exception in the North Abukuma Mountains, where Sato recently found Lower Carboniferous deposits with fossils showing similar aspects to those of the Hikoroichi Series. These deposits, according to oral information from Sato, consist of rocks showing similar lithological facies to that of the Hikoroichi Series.

Further, there are widely distributed metamorphic complexes in Japan; for instance, the Sambawaga-Mikabu metamorphic complexes developed along the central axis of southwest Japan, and the so-called green metamorphic rock series of northeast Honshu. The original rocks of those metamorphic complexes are now believed to have largely consisted of pyroclastic sediments, which remind us strongly of the Hikoroichi, Arisu, and Ohdaira Series in the Kitakami district. Accordingly it is by no means deniable that at least some part of those metamorphic complexes may be originally stratigraphically equivalent to the Carboniferous deposits with less numerous calcareous sediments now under consideration, although no guide fossils have ever been detected from those complexes.

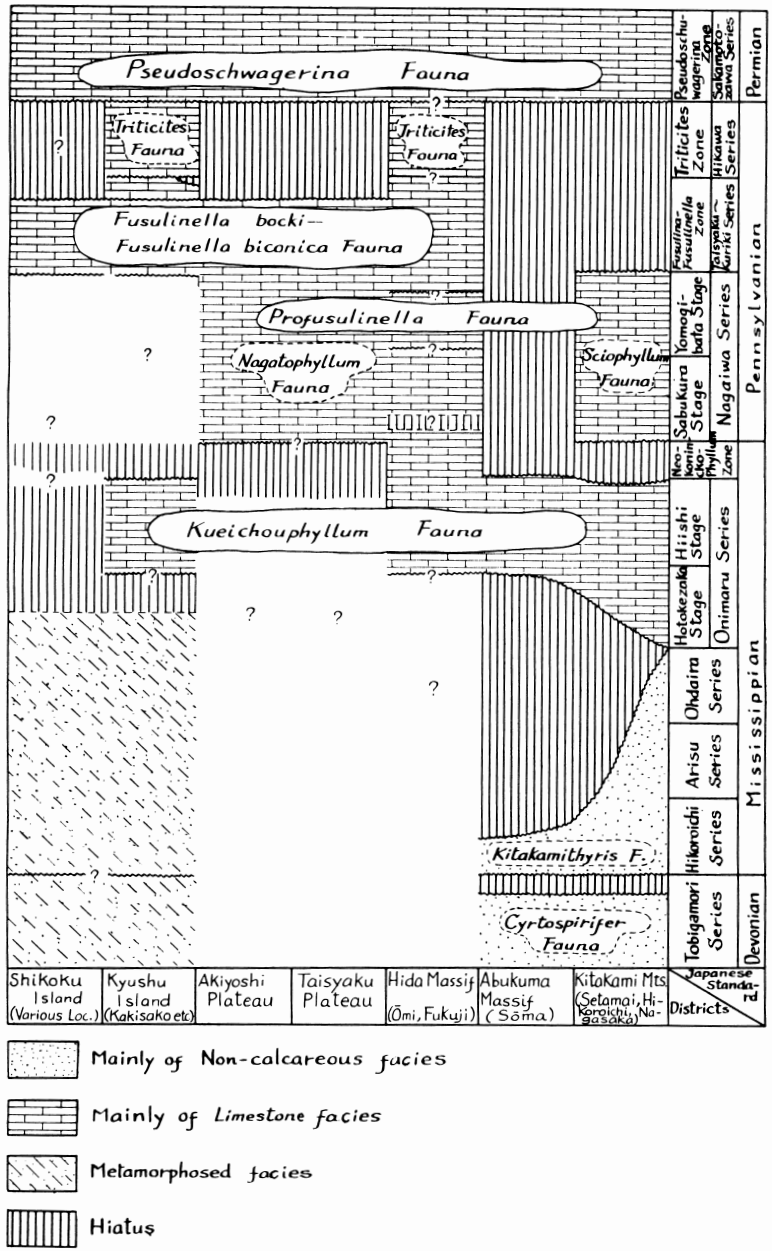


Fig. 3. Distribution of facies and faunas in the Carboniferous deposits of Japan.

If such be true, the marked lithologic contrast observable between the two divisions of the Japanese Carboniferous should be a convenient criterion

for separating them into two systems or subsystems, putting aside any problem of their international correlation for the present.

It is, however, by no means reasonable to establish a boundary between the Upper and Lower Carboniferous in such a manner; therefore, to supply further data, the correlations of the faunas and faunal zones will be briefly stated below.

First of all, the faunal zone with *Dibunophyllum*, *Kueichouphyllum*, *Siphonodendron* and *Gigantoproductus* in association with *Hexaphyllia*, *Millerella* and *Saccamminopsis*, viz., the so-called Hiishi fauna, corresponding to the upper half of the Onimaru Series, is widely traceable throughout Japan as in the Kitakami, Abukuma, Hida and Kyushu districts, although the presence of the lower half of the Onimaru Series has yet been ascertained only in the Kitakami district.

The Onimaru faunas, both lower and upper, are dominantly of North European genera together with south Chinese and less numerous Australian elements. *Dibunophyllum*, *Rhodophyllum*, *Siphonodendron*, *Lithostrotion*, *Diphyphyllum*, *Aulophyllum* (=? *Setamainella*), *Palaeosmilia*, *Dorlodotia*, besides *Hexaphyllia* and *Heterophyllia* are common in both Japan and Europe. These associations of coral genera together with such a brachiopod as *Gigantoproductus* show the approximate equivalence of the Onimaru Series to the *Dibunophyllum* zone of the Upper Viséan in Europe. *Yuanophyllum*, *Kueichoupora*, *Kueichouphyllum* together with such species as *Dibunophyllum asiaticum* Minato, *Dibunophyllum kankouense* Yü and *Diphyphyllum platiforme* Yü are found in both the Onimaru Series and the *Yuanophyllum* zone of south China. *Amygdalophyllum*, found in the Japanese Onimaru Series, may be considered to be an element of the Australian Lower Carboniferous fauna.

The Hiishi fauna representing the upper half of the Onimaru Series is especially characterized by the presence of such coral genera as *Hexaphyllia*, *Heterophyllia*, *Palaeosmilia*, *Amygdalophyllum*, *Pseudodorlodotia*, and *Stylidophyllum*, besides *Kueichouphyllum*, *Siphonodendron*, *Dibunophyllum* and also foraminiferal remains, *Millerella*, *Saccamminopsis*, *Parastaffella*, and *Eostaffella* together with the brachiopod *Gigantoproductus*. Based on the association of those genera above enumerated and especially on the presence of *Millerella* and *Stylidophyllum japonicum* (Yabe and Hayasaka), the Hiishi fauna may possibly be correlated with the uppermost Viséan in Europe and also with the Upper Chesterian in the United States. *Millerella* is common both in the Hiishi Stage and Upper Chesterian, while *Stylidophyllum japonicum* (Yabe and Hayasaka) is nearly like *Stylidophyllum floriformis* Martin, the good guide fossil of the uppermost Viséan in Europe.

Furthermore, Hanzawa reported the presence of such foraminifera as *Endothyra parva* Moeller and *Ozawainella struvi* Moeller (Yabe and Sugiyama, 1939) in the Onimaru Series, especially in the upper part, corresponding presumedly with the Hiishi Stage. This is quite worthy of note, because they are, according to Malaghova (1956), *Eostaffella parva* (Moeller) and *Parastaffella struvi* (Moeller) respectively; the former is a good guide fossil of the formation ranging from Venev to Protova, while the latter is found at Protova.

Next, the *Profusulinella* zone has also been firmly established in the Taisyaku district, Hiroshima Prefecture (Yokoyama, 1957), in addition to the Akiyoshi, Fukuji and Kitakami districts. The base of this zone in Japan may be presumed correlative with the base of the Atokanian in the United States, and the Bashkirian in the Soviet Union. As far as the literature available to the writer indicates, *Profusulinella* is now believed to appear first in the lowest Atokanian and also in the lower part, though not the lowest, of the Bashkirian, being almost equivalent with the Kayalian in stratigraphical position.

The zone of *Fusulinella* or the zone of *Fusulinella-Fusulina* has been more widely known in Japan than the *Profusulinella* zone, although these faunal zones seem to involve many difficulties in correlation.

The so-called zone of *Triticites* is lacking in such areas as the Kitakami, Abukuma, Taisyaku and Akiyoshi districts in Japan, but it has been certainly established in the Fukuji and Kakisako districts as stated before.

It is next proposed to discuss in ascending order the faunal zones found in the lower division of the Carboniferous showing less numerous calcareous facies in Japan. As has been already described in detail, there are numerous fossil-bearing beds of stratigraphical importance in the formations ranging from the Hikoroichi through Arisu to the Ohdaira Series.

There are to be found species on the one hand, which have quite a short geological range restricted only to one such horizon as A_o, B_o, B_1, D_o, and E_o respectively; while, on the other, there are also species which show a long geological range extending from A_o to B_o, B_1, C_o, D_o or even E_o. Gradual changes which happened in the faunal assemblages are easily traceable through the long ages from the Hikoroichi to the lower half of the Ohdaira. *Leptaena analoga* Phillips is especially characteristic of the Hikoroichi Series, being found both in A_o and B_o, while the same species is believed to have a geological range extending from the *Cleistopora* to *Syringothyris* zone (Km to C_1) in England, from the *Cleistopora* to *Zaphrentis* zone (K to Z) in Belgium and also throughout the Kinderhookian in the United States.

Cliothyridina royssii (L'Evillé) shows a geological range in Japan from the A_o bed of the Ikawa Stage up to E_o of the Maide Stage. This species is also believed to have been especially flourishing in the age between the *Cleistopora* to *Zaphrentis* zone (K and Z) in England, although its true range has been ascertained to be still longer than the mentioned period, because it has been known even in the Km as the lowest horizon on one side, while also in C_2 as the highest horizon in Europe. *Schizophoria resupinata* Martin has been detected only from the Jumonji Stage (D_o to D_1) in Japan up to the present, while it is also commonly found in the formations ranging from the *Zaphrentis* zone to the *Syringothyris* zone Z_2 to C_1 in western Europe.

Actinoconchus lamellosa (L'Evillé) shows a geological range extending from B_1 to D_o in Japan, while this species is believed to be a good guide fossil usually for K_2 in England. *Spiriferina octoplicata* Sowerby is also a species showing a long geological range. It has been found not only in the Lower Carboniferous but also in the later Devonian both in Europe and Japan. In

the Kitakami district, this species was collected in the Tobigamori and Hikoroichi Series, and in the Jumonji and Maide stages.

Spirifer kozuboensis Minato, having been found in A_0 of the Ikawa Stage and D_0 of the Jumonji Stage, may be considered to belong to the same category of such spiriferids as *Spirifer tornacensis* De Kon., and *Spirifer marionensis* Shumard. All of them have shells showing similar outer configuration and plicae, besides similar cardinal areas which are almost parallel to their very extremities, resulting in the appearance of a very narrow parallelogram.

The genus *Kitakamithyris* of the subfamily Reticulariinae Waagen, 1883, was not known outside Japan until a short time ago, but its presence in the Mississippian in the Penn-York embayment of the United States was found lately by F. D. Holland (personal communication). This genus is quite distinctive in having shells decorated by biramous spine bases and in having dental plates and a median septum in the ventral valve instead of wholly lacking any apical platets in the dorsal valve. Therefore it is evident that this genus is quite closely related to *Torynifer*, found in the Mississippian of the United States, except in the absence of a median plate in the dorsal valve of the former. In Japan there are to be found three species belonging to *Kitakamithyris*, two of which, *Kitakamithyris tyoanjiensis* (Minato) and *Kitakamithyris hikoroichiensis* (Minato) are found restricted to horizon A_0; the other one, *Kitakamithyris semicircularis* Minato shows a rather long range extending from A_0 to D_0.

However, this genus, according to Holland, was found in a formation, presumedly the earliest Mississippian in age. The present writer believes that this genus may play an important role in the correlation of the Japanese Lower Carboniferous and the Mississippian.

Further, a well-known crinoid genus *Actinocrinus* (or *Actinocrinites*) is usually regarded as a leading form to characterize especially the lower half of the Avonian and Dinantian as well as the Mississippian. This genus is also found in both A_0 and B_0 of the Hikoroichi Series in Japan.

To sum up, it is by no means deniable that the Japanese Hikoroichi Series may correlate approximately with the Lower Mississippian or the lower part of the Avonian as well as the Dinantian. The writer is now inclined to regard the formation between A_0 and B_0 of the Hikoroichi Series to be certainly equivalent with the formations ranging from k_1 to k_2, the *Cleistopora* zone in England.

Next, the Jumonji Stage has intermediate faunal assemblages between the underlying and the immediately covering formations, although it also contains several fossils characterizing only this stage.

For instance, in the Jumonji Stage such comparatively older elements as *Spirifer kozuboensis* Minato, *Cliothyridina royssii* (L'Evillé), and *Spiriferina octoplicata* Sowerby are also found. All of them begin to appear in the A_0 bed of the Hikoroichi Series or still older beds, as already noted. Further, *Platycrinus asiatica* Minato, a crinoidal species, may also possibly belong to the same category, although it has never been found elsewhere than in the Jumonji Stage in Japan, because this species is similar to *Platycrinus guttifer*

Schmidt, which was described by Schmidt (1930) from the Etroeungtian near Düsseldorf in Germany.

There are also to be found such younger elements in the Jumonji Stage as *Syringothyris transversa* Minato, *Amplexus* sp. *b*, *Brachythyris* aff. *pinguis* (Sowerby), and *Fusella nipponotrigonalis* var. *minor* Minato; all of those species appear first in the D_0 bed and range to E_0 or E_1 beds of the Maide Stage.

The Jumonji Stage is, however, also rich in other fossils besides the long-ranged species above enumerated; especially *Syringothyris kitakamiensis* Minato, *S. jumonjiensis* Minato, *S. transversa* Minato, and *Fusella nipponotrigonalis* Minato in this series. *Syringothyris jumonjiensis* Minato is somewhat like *Syringothyris cuspidata* var. *exoleta* North, while *Fusella nipponotrigonalis* Minato may be most like *Spirifer triangularis* Martin among fusiform spiriferids. These two foreign species are good horizon indicators of the *Syringothyris* zone (C) of the Avonian in England. *Brachythris pinguis* (Sowerby) is known in the same zones (C_1 and C_2) in England, and the Japanese species referable to it is also found in beds D_0 and E_0 in the Jumonji and the lower half of the Maide Stage.

The present writer would place particular stress on the fact that *Syringothyris* is most abundantly found in the Jumonji Stage in respect to both individuals and species, although one unnamed species shows a still longer range extending from B_0 to E_0 in the Kitakami district. Such being the case, the writer holds the view that the Jumonji Stage is probably equivalent to the *Syringothyris* zone in England which is also known to be especially rich in *Syringothyris*, and further to have a fauna intermediate as a whole between that of the Tournaisian and Viséan.

If such be true, the Hinozuchi Stage, the lower half of the Arisu Series comprising important fossil-bearing beds B_1, and C_0, and the uppermost part of the Hikoroichi Series, represented by B_0, may be correlated with the *Zaphrentis* zone of England, because the formations noted above are situated immediately below the Jumonji Stage characterized by *Syringothyris* and are above the formations with a fauna showing the Kinderhookian or the lower Avonian as well as Dinantian aspect.

From the Kozubo Stage, the upper half of the Ohdaira Series, no good guide fossils except *Sugiyamaella carbonarium* Yabe and Minato, an endemic form of coral, have ever been found up to the present. But this stage is stratigraphically situated below the Onimaru Series characterized by the *Kueichouphyllum-Dibunophyllum* fauna, and is also far higher than the Jumonji Stage which is correlated with the *Syringothyris* zone, so it seems highly probable that the Kozubo Stage is almost equivalent to the Lower Viséan.

Next, the Sabukura Stage has comparatively few fossils; *Dibunophyllum bipartitum konincki* (Edwards and Haime) is found throughout, and such corals as *Chaetetes nagaiwaensis* Minato, *Thysanophyllum aseptatum* Dobrolyubova, *Sciophyllum japonicum* Minato and Saito *and Lithostrotionella kitakamiensis* Minato are found especially in the upper part of this stage. Except for the species above enumerated, no noteworthy species have been detected from this stage.

Dibunophyllum bipartitum konincki (Edward and Haime) begins to appear first in the later half of the Onimaru Age and seems to have survived until the earliest Yomogibata Age, while the other corals show a geological range extending at least up to the lower part of the Yomogibata Stage, which is characterized by the presence of such fusulinids as *Profusulinella, Eoschubertella, Ozawainella* and *Pseudostaffella.*

Of the Sabukura fauna, *Dibunophyllum bipartitum konincki* (Edwards and Haime) has been believed to range from the Upper Viséan to the Lower Namurian in Europe; *Thysanophyllum aseptatum* Dobrolyubova was described by Dobrolyubova from the Carboniferous of the Ural Mountains; *Lithostrotionella kitakamiensis* Minato is somewhat allied to *L. stylaxis* (Trad.) described also by Dobrolyubova (1936) from the Middle Carboniferous of the Moscow Basin; *Chaetetes nagaiwaensis* Minato is believed by Japanese geologists to be conspecific with an undescribed chaetoid coral found in the Penchi Series of South Manchuria. The genus *Sciophyllum* is a coral known only from the Yukon-Alaska boundary except for the Kitakami district in Japan. The age of the formation in the Yukon-Alaska boundary is now believed, according to Harker and McLaren (1950), to be not certain, although they once suggested it to be Mississippian.

Such being the case, the Sabukura fauna, though not numerous in species, seems to show a somewhat intermediate nature between that of the Lower and the Upper Carboniferous (*s.l.*); it must be noted however, that most corals except *Dibunophyllum bipartitum konincki* (Edwards and Haime) are wholly lacking in the Sabukura fauna. So the difference between the Sabukura and the Onimaru fauna should be regarded as being great as far as the corals are concerned. The writer is now of the opinion that the time break indicated by the presence of unconformity between the Onimaru and the Nagaiwa Series is far greater than formerly believed by some geologists in Japan. Further, the writer is now of the opinion that the Sabukura fauna should be regarded as being more closely related to that of the Yomogibata Stage, the *Profusulinella* zone, than with the Onimaru fauna.

Now the upper limit of the geological age of the Sabukura Stage is firmly settled because the lowest part of the Yomogibata Stage, immediately covering the Sabukura Stage, is characterized by the first appearance of *Profusulinella.* Also, the lower limit of the geological age of the Sabukura Stage is determined to some extent, because the underlying Hiishi Stage, the upper half of the Onimaru Series, is apparently equivalent to the Upper Chesterian or the uppermost Viséan as already stated. Therefore, it may be by no means unreasonable to assume the Sabukura Stage to be lowest Pennsylvanian or the lowest Upper Carboniferous (*s.l.*) in age.

Even though one holds the view that the correlation between the Sabukura Stage and the foreign standard section of the Carboniferous is by no means certain at the present moment, especially on account of the lack of any good guide fossils in the Sabukura Stage, the writer cannot help believing that the boundary line between the Lower and Upper (*s.l.*) Carboniferous would be

best drawn at the base of the Nagaiwa Series, at least as far as the type area of the Kitakami district is concerned.

Meanwhile, the formations which are probably in sub-equal stratigraphical position with the Sabukura Stage in the Kitakami district are widely traceable throughout southwest and central Honshu Island. The fauna of the latter formations, however, shows quite a different aspect to that of the Sabukura Stage, especially regarding the association of the coral species.

As already stated, the formations called the *Nagatophyllum satoi* subzone, together with the lower half of the *Stylidophyllum* sp. subzone, are situated with certainty immediately below the *Profusulinella beppensis* zone of Toriyama at the type area of the Akiyoshi district. Those formations with similar fauna are, furthermore, widely traceable in the Taisyaku district, Hiroshima Prefecture (Yokoyama, 1957), the Ibuki district, Kyoto Prefecture (Seki, 1939), and as far as the Omi district in the Niigata Prefecture (Hayasaka, 1924).

The fossils of stratigraphical importance in those formations and their geological distributions are shown in table 1 which suggests that a gradual change may have occurred among the corals during the *Nagatophyllum satoi* and the *Clisaxophyllum ofukuense* zones. This is quite like the change observable in the coral fauna of the Sabukura and the Yomogibata Stages in the Kitakami district.

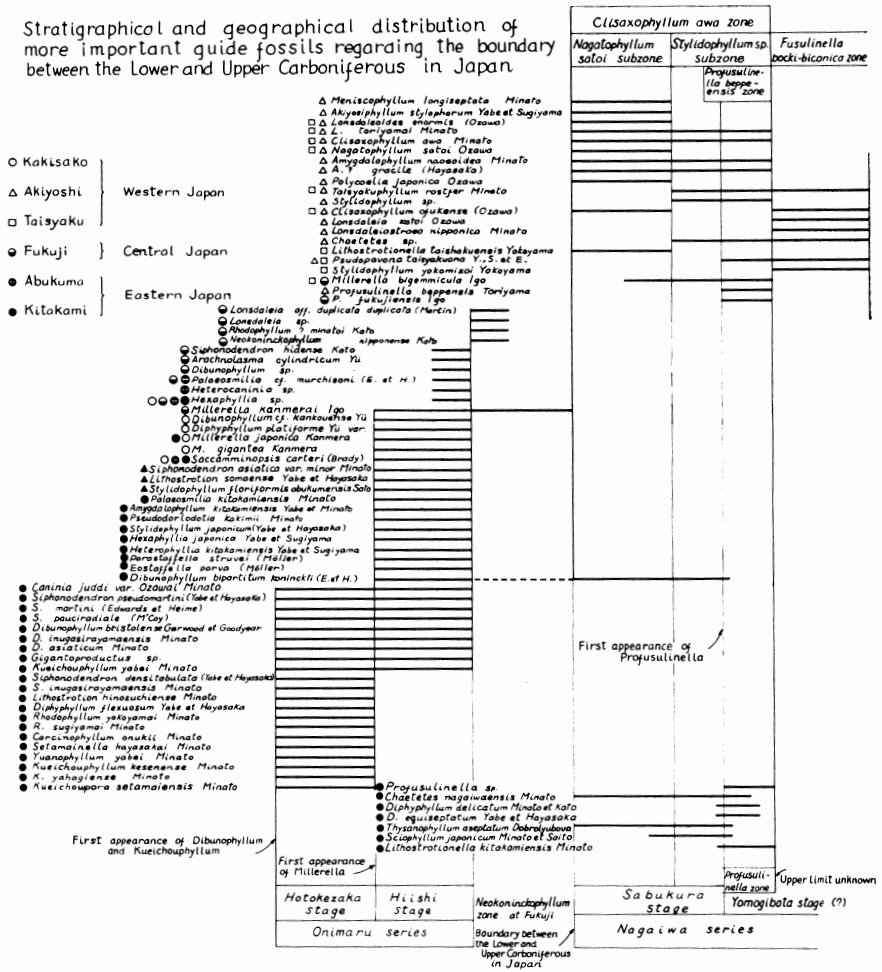
It then becomes a problem how to explain the differences in the coral faunas of the *Nagatophyllum satoi* subzone and the lower half of the *Stylidophyllum* sp. subzone. In this regard, Fujimoto (1952) and Kobayashi (1941) once held the view that at least the *Nagatophyllum satoi* zone may represent a still older age than that of the Sabukura Stage in the Kitakami district; they assigned the *Nagatophyllum satoi* subzone to the Upper Viséan. But such a view is by no means acceptable.

First of all, the Hiishi Stage, the upper half of the Onimaru Series or its equivalent formations are widely known elsewhere in Japan from the Kitakami district as far as Kyushu. In those formations which can be correlated to the Hiishi Stage, no signs of elements characteristic of the corals of the *Nagatophyllum satoi* subzone have been found. On the other hand, no trace of the Onimaru coral fauna has ever been detected either from the *Nagatophyllum satoi* subzone or from the lower half of the *Stylidophyllum* sp. subzone, either in their type area or in any other districts where formations equivalent to these two coral zones have been developed.

Second, there have never been found any good guide fossils indicating Upper Viséan age either in the *Nagatophyllum satoi* subzone or in the *Stylidophyllum* sp. subzone. Accordingly it has long been the writer's view that the *Nagatophyllum satoi* subzone together with the lower half of the *Stylidophyllum* sp. subzone may be almost synchronous with the Sabukura Stage and not be correlated with the Onimaru Series. However, the formations represented by the two coral zones noted above and the Sabukura Stage may be heterotopic in origin with each other, as is suggested by the different association of coral species.

TABLE 1

Stratigraphical and geographical distribution of more important guide fossils regarding the boundary between the Lower and Upper Carboniferous in Japan



As has been stated in detail, the Sabukura Stage is widely developed in the Kitakami district. Its fauna is quite distinctive in comprising species showing a northern aspect, like *Sciophyllum japonicum* Minato and Saito, *Chaetetes nagaiwaensis* Minato, *Thysanophyllum aseptatum* Dobrolyubova, *Lithostrotionella kitakamiensis* Minato, besides *Dibunophyllum bipartitum koninckti* (Edwards and Haime). All these species have a strong affinity to those which have been known in Alaska or northeast China, the Ural and Moscow Basin, or even in western Europe. On the contrary, formations characterized by corals of the *Nagatophyllum satoi* subzone and *Stylidophyllum* sp. subzone in their type areas are found only in southwestern Japan, more western than Central Honshu. The coral fauna of those formations show a strong affinity to that of south China, Malay, or even eastern Australia. For instance, *Lithostrotionella taishakuensis* Yokoyama is allied to *L. tingii* Chi, one of the Weiningian ele-

ments of south China, *Amygdalophyllum* are frequently found in south China, Malay, and Australia, while *Nagatophyllum* is extremely near *Symplectophyllum*, an Australian coral. Furthermore, *Lonsdaleoides*, found abundantly in southwest Japan, is somewhat like *Kionophyllum*, a Weiningian coral of south China.

Such being the case, the Sabukura Stage is almost equivalent to the formations represented by the *Nagatophyllum satoi* subzone together with the lower half of the *Stylidophyllum* sp. subzone, but those two may have been deposited in a different basin in which a different fauna was living at the same time. The Sabukura Stage may have been deposited, to be sure, under the sea water which was directly united with that of the northern ocean, through the Penchi Basin, while the sea covering southwestern Japan in those days may have been in more intimate relation with the southern ocean through the south Chinese Basin. In short, northeastern Japan belonged to the boreal province, whereas southwestern Japan belonged to the south Chinese province.

If such be true, it seems clear that the very base of the *Nagatophyllum satoi* subzone would be best interpreted as the boundary between the Lower and Upper Carboniferous in southwestern Japan, as the base of the Nagaiwa Series in northeastern Japan.

As to the length of the break indicated by the unconformity at the base of the Nagaiwa Series, the Carboniferous deposits at Fukuji, central Japan should be reviewed in more detail. According to Igo (1956, 1957), the lowest formation of the Carboniferous developed there is characterized by the presence of *Millerella*. The entire thickness of the *Millerella* zone is not very great, and yet it is divisible, according to Igo, into two subzones: the lower, the *Millerella kanmerai*, and the upper, the *Millerella bigemmicula* subzone.

The *Millerella bigemmicula* subzone is only 5 meters thick and is made up of limestones, in which only such primitive fusulinids as *Millerella*, *Pseudostaffella* and *Paramillerella* are found, as stated in the preceding pages, but there is a lack of other kinds of fossils. However, in the Taisyaku region, some 220 kilometers eastward from Akiyoshi, *Millerella bigemmicula* Igo was lately found by Yokoyama in limestone bearing numerous corals quite similar to those which have already been described from both the *Nagatophyllum satoi* and the *Stylidophyllum* sp. subzones at Akiyoshi (see table 1). Accordingly, the *Millerella bigemmicula* subzone at Fukuji may be almost equivalent to the two coral zones at Akiyoshi although the former is very slight in its thickness. So the underlying formation like the *Millerella kanmerai* subzone established by Igo at Fukuji should certainly be regarded as still older than the *Nagatophyllum satoi* zone on the basis of stratigraphical position.

The *Millerella kanmerai* subzone is still subdivisible into three members; the upper part, some 20 meters in thickness, is almost barren of fossils, while the middle and lower members are comparatively rich in corals besides primitive fusulinids. From the lowermost member such corals are found as have already been reported by the present author in cooperation with Kato (Minato and Kato, 1957b), viz., *Siphonodendron hidense* Kato, *Arachnolasma cylindricum* Yü, *Dibunophyllum* sp., *Palaeosmilia* cf. *murchisoni* (Edwards and Haime), *Heterocaninia* sp., *Hexaphyllia* sp. and *Syringopora* sp.

Thus, the lowermost member should be regarded as correlative with the Hiishi Stage, the upper half of the Onimaru Series so far as coral fauna is concerned. The coral fauna of the middle member of the *Millerella kanmerai* subzone, though less rich in number of species, shows quite a different aspect from that of the underlying lower member as well as that of the Hiishi Stage which is developed in other districts in Japan.

The middle member is characterized by such corals as *Lonsdaleia* aff. *duplicata duplicata* (Martin), *Lonsdaleia* sp.. *Rhodophyllum? minatoi* Kato, and *Neokoninckophyllum nipponense* Kato. Of these *Lonsdaleia* cf. *duplicata duplicata* (Martin) is close to *Lonsdaleia duplicata duplicata* Martin; the latter is believed to range from D_1 to E_1 in Britain, while it occurs in the Protova bed in Russia, which is believed to be almost equivalent to the Namurian in western Europe. *Neokoninckophyllum nipponense* Kato seems to be most nearly allied to the Lower Pennsylvanian species of *N. gracile*. *Rhodophyllum? minatoi* Kato shows a character somewhat like *R. fukudai* Minato and Kato described from the Lower Carboniferous in Manchuria, presumably almost equivalent to the Upper Viséan. However, the Japanese species (*R.? minatoi* Kato) is quite distinctive in having a broad area occupied by lonsdaleoid dissepiments and seems to be very near *Lonsdaleoides*, except for its solitary form.

Such being the case. the coral fauna of the middle part of the *Millerella kanmerai* subzone, though it comprises only four species, has as a whole, a decidedly younger aspect than that of the lowest member as well as the Hiishi fauna which is widely known throughout Japan.

Therefore it is not improbable that the *Neokoninckophyllum* fauna, found at the horizon immediately above the formation with the Hiishi fauna at Fukuji, may have developed during the time interval represented by the unconformity or by the abrupt change observable between the coral fauna of the Onimaru and the Nagaiwa Series. The present writer is not yet certain whether or not the middle and upper members of the *Millerella kanmerai* zone of Igo are wholly equivalent to the break between the Onimaru and Nagaiwa Series, because the corresponding formations are so thin. However, it may be quite true that the *Neokoninckophyllum* fauna of Fukuji represents at least some part of the time interval between the Onimaru and Nagaiwa Ages.

Boundary between the Devonian and Carboniferous in Japan

Before presenting concluding remarks on the boundary of the Lower and Upper (*s.l.*) Carboniferous in Japan, the writer would like to offer a brief account of the boundary between the Devonian and Carboniferous in Japan.

Formerly some Japanese paleontologists held a view that the lower part of the Hikoroichi Series may be Devonian, but that is by no means certain, because there are to be found numerous fossils of an undoubtedly Lower Carboniferous type even in a lower horizon such as A_0. For instance the following are leading types: *Actinocrinus ohmoriensis* Minato, *A. higuchisawaensis* Minato, *Leptaena analoga* (Phillips), *L. convexa* Weller, *Cliothyridina royssii* (L'Evillé), *Actinocohnchus planosulcata* (Phillips), *Kitakamithyris tyosnijiensis* (Minato) together with numerous spiriferids and productoids.

Meanwhile, the Tobigamori Series has been ascertained to be unconformably covered by the Hikoroichi Series. The former consists largely of slates, sandstones, porphyroid tuffs, tuffs, and conglomerates, more than 1000 meters in entire thickness. It is characterized by the following fossils: *Cyrtospirifer* cf. *kindlei* Stainbrook. *Cyrtospirifer* cf. *brevipositicus* Stainbrook. *Cyrtospirifer* sp. (= *Spirifer* (*Trigonotreta*) *verneuili* of Yabe and Noda, non Murchison), *Sinospirifer sinense* var. *australis* Maxwell, *Camarotoechia pleurodon* (Phillips), *Chonetes hardrensis* Phillips, besides such plant remains as *Leptopholeum* cf. *australe* (M'Coy) and *Cyclstigma* sp. (Tachibana, 1950). Further the presence of the following species must also be mentioned, although they are not yet described: *Aviculopecten* cf. *losseni* (Koken), *Murchisonia*? sp., *Brachythyris*? sp., *Orbiculoidea* sp., *Schizophoria* sp., and *Spiriferina octoplicata* Sowerby.

There is thus some difficulty in determining the geologic age of the Tobigamori Series on the basis of the fossils listed above because good guide fossils are seldom found indicating with certainty that they are Devonian.

Cyrtospirifers are frequently found in the Tobigamori Series, but all species of this genus found in Japan rather resemble the species described by Stainbrook from the lowest Kinderhookian. Only *Sinospirifer sinense* var. *australis* Maxwell is a species described from the Devonian in Morgan district, western Australia.

However, none of the species of the Tobigamori Series shows a long geological range extending up to the Hikoroichi Series, except for *Spiriferina octoplicata* Sowerby. Moreover, there does certainly exist an unconformity between the Tobigamori and the Hikoroichi Series. Therefore the writer is now inclined to the view that the boundary between the Devonian and Carboniferous would be best drawn in Japan at the base of the Hikoroichi Series.

THE BOUNDARY BETWEEN THE LOWER AND THE UPPER CARBONIFEROUS IN JAPAN

Volcanic activity.—As has been repeatedly stated, the Japanese Carboniferous is divisible into two major sections on the basis of lithologic nature. The lower is composed dominantly of pyroclastic sediments like agglomerates, tuffs with diabasic lavas, and porphyroid tuffs, besides normal sediments like slates, fine-grained sandstones, thin radiolarian cherts, conglomerates and less numerous thin limestones. The upper is mainly comprised of limestones with subordinate tuffs and a small amount of other kinds of sediments. The boundary between these two divisions may be drawn at the base of the Onimaru Series.

In examining the rock facies of the upper divisions more in detail however, it is clear that the Onimaru Series, as well as its equivalents, and also their immediately overlying formation like the *Neokoninckophyllum* zone at Fukuji are wholly lacking any kind of pyroclastic sediments throughout Japan. Further, the tuffs or agglomerates together with diabasic flows are again first to be found at the very base of the *Nagatophyllum satoi* zone or its equivalents. Also similar pyroclastic sediments are frequently intercalated in the ascending formations of the *Profusulinella*, *Fusulina*, *Fusulinella*, and *Triticites* zones.

Fig. 4. Distribution of Palaeozoic rocks (black) in the Japanese islands. Locality numbers show the main areas of fossiliferous Carboniferous deposits. 1. Kitakami; 2. North Abukuma; 3. South Abukuma; 4. Omi; 5. Kufuji; 6. Ibuki; 7. Taisyaku; 8. Akiyoshi; 9. Kakisako.

Thus it easily can be deduced that volcanic activity was extremely violent throughout Japan during the ages of the forming of the Hikoroichi, Arisu and Ohdaira Series, but suddenly suppressed or at least much weaker at the Onimaru and its immediately following age, and again revived after the Sabukura Age or its equivalents.

This revival of volcanic activity in the early part of the formation of the Nagaiwa Series should not be overlooked in consideration of the boundary problem between the Lower and Upper Carboniferous in Japan.

Diastrophism.—In the Kitakami district, unconformities have been detected with certainty at the base of the Hikoroichi, Onimaru and Nagaiwa Series, besides that at the base of the Sakamotosawa Series, the *Pseudoschwagerina*

zone; while in the Abukuma Mountains, especially in the northern part, an unconformity is observable at the base of the formation equivalent to the Hiishi Stage, i.e., the upper half of the Onimaru Series in the Kitakami district. In Kyushu, the presence of an unconformity was proven by Kanmera at the base of the Kuriki Series, the *Fusulina kurikiensis* zone, and also at the base of the Hikawa Series, the *Triticites yayamadakensis* zone. In the Akiyoshi and Taisyaku districts in southwestern Honshu, a marked stratigraphic break is evident between the *Fusulinella bocki-biconica* zone and the *Pseudoschwagerina* zone. In those two regions the formation situated immediately below the *Nagatophyllum satoi* subzone does not crop out on the surface. Accordingly, it is an open question at the present moment whether or not these two formations are conformable with each other, although the presence of an unconformity is highly probable.

Now, of all unconformities which have been detected from the Carboniferous in Japan, the pre-Onimaru one has been most widely traceable and is most worthy of note from the viewpoint of tectonic movement.

In the Kitakami Mountains, those formations ranging from the Ohdaira, Arisu and a part of the Hikoroichi Series are observed to be locally lacking because of the severe denudation which happened in the pre-Onimaru Age: the thickness of those missing formations is now estimated to be nearly as much as 2250 meters at maximum. Further, severe folding and faulting which happened surely prior to the transgression at the dawn of the Onimaru Age are now firmly ascertained elsewhere in the Kitakami district, through detailed stratigraphical surveys by the writer and colleagues.

Also in the Abukuma Mountains, especially in the northern region, some metamorphic complex is now believed to be a product brought about by a metamorphism prior to the Onimaru Age (Minato, 1957). Naturally this metamorphic complex together with other metamorphic rocks found in the Sambagawa-Mikabu metamorphic zone, as well as the Sangun-Motoyama metamorphic zone in Japan, which are widely traceable along the central axis of southwestern Japan, may not be the products of one phase of the metamorphism, but should be considered to have been formed step by step through several phases or orogenic movements. At any rate such metamorphism might also have been in progress in the deep-seated bottom of the geosyncline during the phase of the pre-Onimaru diastrophism.

Meanwhile, it should also be emphasized that the geosynclinal sea covering the Japanese islands in the Carboniferous period did not remain as a mere sinking and depositional area from the dawn of the Sabukura Age until earliest Permian. Sometimes it was converted into land being obliged to suffer severe erosion, as is suggested by the frequent existence of local unconformities in those deposits, which show a marked contrast to the still older ages represented by such formations as the Hikoroichi, Arisu and Ohdaira Series. All those formations are conformable with each other without any stratigraphical breaks. In those older ages, the geosynclinal sea seems to have remained as a continuous depositional area, except for the pre-Onimaru phase.

The writer is now wondering about the probable existence of another unconformity at the base of the so-called *Fusulinella bocki-biconica* zone in

southwestern Japan, although this has not yet been ascertained by field observation. The presence of such an unconformity, however, is suggested by the extreme thinness of the so-called *Profusulinella* zone in southwestern Japan, against a considerable thickness of the corresponding formation, the Yomogibata Stage in the Kitakami district.

At any rate, the Carboniferous deposits in Japan are characterized by the presence of numerous unconformities in the upper divisions above the Onimaru Series, while a lack of unconformities characterized the still older formations of the Hikoroichi, Arisu and Ohdaira Series.

Palaeogeography.—Regarding the fossils found in the Upper Devonian Tobigamori Series, the Japanese fauna of this series shows an aspect quite different from that of south China. The Japanese fauna seems to have a more intimate relation to that described by Diener (Bagdanowitsch and Diener, 1900) from the uppermost Devonian of Ajan, eastern Siberia, facing the Ohkotsk Sea on the one hand, while it also shows some similarity to the fauna described by Maxwell (1951) from the Mt. Morgan district, Australia. There seems to be something similar in the fauna found in the formations ranging from the Hikoroichi through Arisu to the Ohdaira Series. The Japanese faunas cannot be seen to have any similarities to those of south China as a whole, but seem to show some resemblance to the fauna found in eastern Australia (W. G. H. Maxwell, personal communication). For instance, such species as *Syringothyris jumonjiensis* Minato described by the writer from the Jumonji Stage, and *Brachythyris kitakamiensis* Minato of the Ikawa Stage are also believed to occur in the Carboniferous in eastern Australia.

Besides, *Kitakamithyris*, one of the leading brachiopod genera in the Japanese Carboniferous, ranging from the Hikoroichi to the Jumonji Stage, has been found lately (in the Lower Mississippian of the Penn-York embayment in the United States) by Holland.

The Onimaru fauna in Japan is now believed to be made up of numerous south Chinese elements such as *Kueichouphyllum*, *Yuanophyllum*, *Kueichoupora*, *Diphyphyllum platiforme*, *Dibunophyllum kankouense*, *Dibunophyllum asiaticum*, etc., besides numerous European and less numerous Australian elements, as above stated. Accordingly it may be said that the sea of the Onimaru Age covering the Japanese Islands was surely directly united with the sea of south China.

Kueichouphyllum yabei Minato and *Kueichoupora setamaiensis* Minato are known not only in Japan but also in the Antitaurus district, Asia Minor (Flügel and Kiratlioglu, 1956). This indicates that the so-called *Kueichouphyllum* sea covering all the Japanese Islands extended as far as the Antitaurus, through south China. So it is quite certain that, in the Onimaru Age, the sea covering the Japanese Islands was in an isotopic relation at least with the Chinese sea so far as the coral fauna is concerned.

Probably the land mass that once existed in a still older age between the Japanese and Chinese seas as a barrier interrupting the free communication of coral fauna between these two sea basins was submerged at the dawn of the Onimaru Age.

Such a paleogeographical condition was probably maintained in a still younger age represented by the *Neokoninckophyllum* zone at Fukuji but it must be especially emphasized that the condition suddenly changed at the dawn of the Nagaiwa Age, especially in northern Japan which came under the influence of sea water more closely related to the northern sea, although the sea covering southwestern Japan was still in free communication with the waters of the Chinese sea.

These ideas are wholly acceptable as a result of the marked contrast observed in the coral fauna of the Nagaiwa Series in the Kitakami district and the formations with *Nagatophyllum satoi-Stylidophyllum* sp. fauna in southwestern Japan. The former, as stated above in detail, consisted of exclusively northern species, while the latter consisted of southern elements. This shows that a differentiation may have first occurred in the geosynclinal sea in Japan at the dawn of the Nagaiwa Age in respect to the palaeozoogeographical condition, and this may be by no means an unimportant criterion to separate the Japanese Carboniferous into two divisions.

Conclusion.—Because the Carboniferous system was originally established in Europe and has its type localities there, it may appear illogical to draw the boundary between the Lower and Upper (*s.l.*) Carboniferous in Japan without its being in harmony with the European standard.

At the present moment, correlation of the Japanese Carboniferous with any foreign standard section in detail involves, however, many difficulties mainly because of the poverty of good guide fossils in Japan, especially of ammonites and echinoderms.

In spite of this, the writer believes that the Japanese Carboniferous may be correlated with the typical foreign standard section to some extent on the basis of brachiopods, corals, and fusulinids. If such proves true, the Onimaru Series of Japan may be safely assignable to the Upper Viséan while the base of the Yomogibata Stage with its *Profusulinella* fauna can be correlated roughly with the base of the Bashkirian of the U.S.S.R. and the Atokanian of the U.S.A. The Lower Namurian may be represented in Japan by only a very thin formation such as the *Neokoninckophyllum* zone developed at Fukuji.

To sum up the data offered in the foregoing pages, not only the faunal correlations, but also the volcanic activity, diastrophism, and palaeozoogeography, indicate that the boundary between the Lower and Upper (*s.l.*) Carboniferous in Japan would be best drawn at the base of the Sabukura Stage, which is immediately below the *Profusulinella* zone, and which also seems to occupy the horizon above the *Neokoninckophyllum* zone, presumably Lower Namurian in age and also with certainty just younger than the Onimaru Series of Upper Viséan age.

Such being the case, the major divisions of the Mississippian and Pennsylvanian are well acceptable and applicable even in the Japanese Carboniferous. The writer is inclined to admit the independence of the two divisions, like the Mississippian and Pennsylvanian, as systems instead of subsystems.

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