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Thickness of the Crustal Layer Consisting of Deformed Geosynclinal Sediments

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Abstract

The thickness of the crustal layer consisting of deformed geosynclinal sediments is examined, where the Chichibu Palaeozoic Formation, ranging from the middle Silurian to the upper Permian, is taken up as an example. The surface area of each System, though the Silurian and Devonian are combined, is measured on geological maps, and is compared with the stratigraphical thickness.

As the surface area and thickness of each System are not in proportion to each other, the overall structure, in spite of the apparent complication, is inferred not to be deep isoclinal folds. The extremely large area of the upper strata compared with the small area of the lower strata indicates a broad and flat syncline including steeper folds of lower order (Fig. 7).

The thickness of the crustal layer in question is inferred to be a little larger than, and scarcely attaining two times as large as, the aggregate stratigraphical thickness of the constituent strata.

Introduction

Thickness of geosynclinal sediments is estimated in many orogenes, and is regarded generally as ranging from 10 to 20 km. These values represent generally the thickness of the sediments as accumulated nearly horizontally at the end of the geosynclinal subsidence. On the other hand, the thickness that we just wish to know from the standpoint of geotectonics is not such as mentioned above, but is that of the present state, namely that of the folded and faulted sediments as a whole. In other words, it is the thickness of the crustal layer which is composed of deformed geosynclinal sediments. There is no adequate means of estimation as yet to obtain this kind of thickness of deformed geosynclinal sediments, of which the basement rocks, generally, are scarcely exposed.

In this paper the writer assembles various facts, well known but not adequately appreciated, concerning the Palaeozoic sediments of Japan, and he attempts to infer some aspects of deformed geosynclinal sediments that would be significant for the thickness estimation.

Acknowledgements : The writer is indebted to Messrs. T. HOMMA and K. ITO, the graduates of the Department of Geology, who rendered assistance in compilation of Tables 1 and 2. Thickness data, especially of the Carboniferous and Permian, were gathered by Mr. ITO, and the area of each System was measured by Mr. HOMMA. The writer wishes to express his gratitude to the gentlemen and also to the staffs of the Department of Geology for their friendly discussion and criticism.

Outline of the Chichibu Palaeozoic Formation

The Palaeozoic sediments of the Japanese Islands, geosynclinal in nature and ranging in age from the middle Silurian to Permian, are the deposits of the Honshu Geosyncline (N. YAMASHITA, 1957; M. MINATO *et al.*, 1965), and are called collectively the Chichibu Palaeozoic Formation or the Chichibu System*. It is developed within the Honshu Province (N. YAMASHITA, 1957; M. MINATO *et al.*, 1965) which comprises most of Honshu, Shikoku and Kyushu Islands together with the southwestern part of Hokkaido Island. To the south, the Honshu Province is limited, in Southwest Japan, by a long and remarkable fault line called the Butsuzo-Itogawa Tectonic Line (also called the Butsuzo Line for short), beyond which there extends, toward the Pacific, the Shimanto Province, which is composed almost exclusively of the late Mesozoic and early Cainozoic sediments.

Rocks of the Chichibu Formation are metamorphosed, in some areas, into gneisses and crystalline schists, and are replaced in many areas, by large and small intrusive bodies. Furthermore the Chichibu, both of metamorphic and non-metamorphic rocks, is concealed largely beneath later sediments and volcanics. Thus the surface exposure of the Chichibu Formation at present is quite limited, though it is the principal and fundamental constituent of the Honshu Province.

The Chichibu Formation is composed, in lithology, mainly of sandstones and

* The name of the Chichibu System was first used by T. HARADA (1890). Later in 1958, H. YABE published a paper in which he restricted the name to the upper part, inclusive of the upper Devonian, the Carboniferous and the Permian, of the Japanese Palaeozoic, and proposed, at the same time, a new name of the Kitakami System for the rest, i.e. the Silurian and the lower and middle Devonian. In this paper, however, the writer follows the traditional usage of the term Chichibu System or the Chichibu Palaeozoic Formation. Because he considers that the hiatus at the base of the upper Viséan Onimaru Series is of no less importance than that between the middle and upper Devonian. A tripartite classification would be more appropriate than YABE's bipartite classification, if subdivisions are necessary.

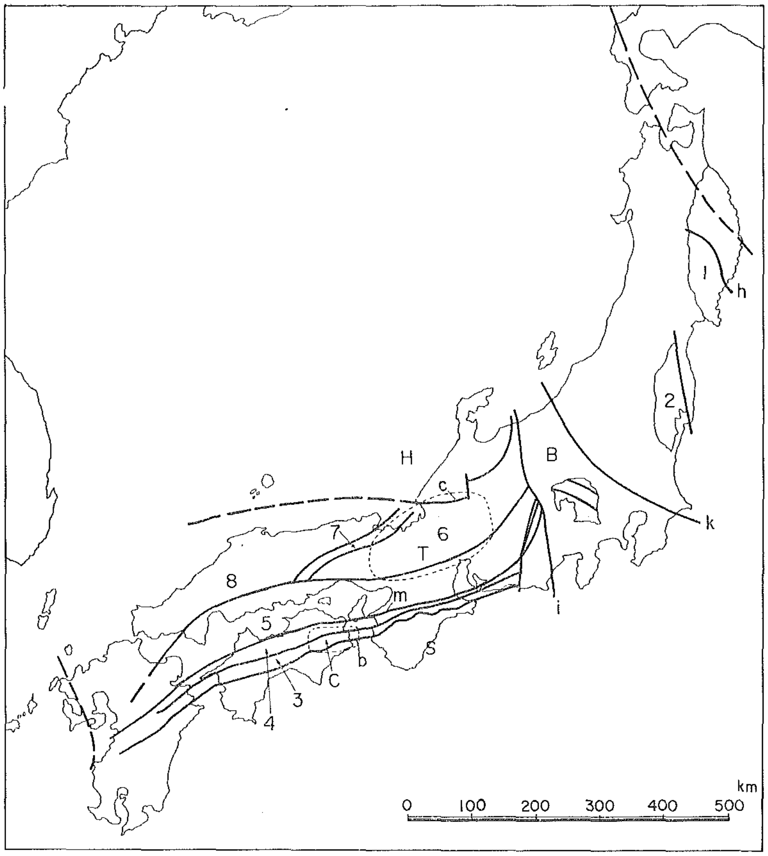


Fig. 1 Geological provinces of the Japanese Islands

Provinces :

1–8 : Belts, i. e. subprovinces within the Honshu Province, H : Hida Province, S : Shimanto Province, B : Shin'etsu-Bozu Zone

Belts within the Honshu Province :

1 : Southern Kitakami Belt, 2 : Abukuma Belt, 3 : Chichibu Belt, 4 : Sambagawa Belt, 5 : Ryoke Belt, 6 : Tamba Belt, 7 : Maizuru Belt, 8 : Chugoku Belt

Tectonic Lines :

h : Hayachine Tectonic Belt, k : Kashiwazaki-Choshi Tectonic Line, i : Itoigawa-Shizuoka Tectonic Line, c : Circum-Hida Tectonic Zone, m : Median Tectonic Line, b : Butsuzo-Itogawa Tectonic Line

(Two areas, T and C within dotted lines, and the area 1 are measured, and the results are given in Table 2.)

(Provinces, Belts and Tectonic Lines that are necessary for this paper are shown.)

mudstones of graywacke suit, with some intercalations of limestones, cherts, and basic to acidic volcanics. Among them cherts and volcanics, very thick in some areas, show that the Honshu Province was a eugeosyncline at the time of sedimentation. Fossils are rather rare, and most of the rocks are barren. But Fusulinids are found generally and often gregareously in limestones. Other fossils, chiefly of Brachiopods, are rarely found in clastic sediments, but are not uncommon in the Southern Kitakami Belt of Northeast Japan.

Stratigraphy of the Chichibu Formation has been studied in various parts by many students. But preciseness and reliability are variable from place to place according to lithology and also according to kinds and amount of fossils therein. Naturally it is most precise and reliable in limestone areas, where fossils are abundant. But these areas are widely separated from each other by more extensive areas of clastic, volcanic and cherty sediments which are barren in general.

Geological structure of the Chichibu is complicated, and is characterized generally by high angles of bedding planes. Overturned strata and hence reverse sequence are said to be not uncommon. The rocks are fractured and sheared, in many cases, so severely that such sedimentary structures as bedding planes and laminae are hardly discernible. But the structural complication, though really observed at exposures, is often so overestimated as will be examined later in this paper.

Basement of the Chichibu Palaeozoic Formation

The oldest sediments in Japan with fossil evidence are the Silurian. But the rocks older than the Silurian are also present in Japan.

In the Kurosegawa Tectonic Zone (K. ICHIKAWA *et al.*, 1956), stretching along the axial part of the Chichibu Belt, Southwest Japan (Fig. 2), there occur strange composite bodies composed generally of three kinds of heterogeneous rocks, i. e. the Mitaki Igneous Rocks mainly of granites*, the Siluro-Devonian sediments mainly of acidic volcanics with some limestones, and the Terano Metamorphic Rocks of amphibolite and biotite schists with some gneisses. Among the three, the latter two occur as xenolith-like masses half enclosed in the Mitaki Igneous Rocks. Of the latter two, the Terano Metamorphic Rocks are older than the Siluro-Devonian, and represent the basement of the latter. Also the Mitaki, though it is intruded occasionally into the Carboniferous-Permian sediments around the composite bodies, is considered as essentially older than the Siluro-Devonian. Namely the protoclastic texture of the granites and their very slight contact effect on the wall rocks are explained as indicating remobilization of the granitic rocks originally old and deep-seated. As the composite bodies occur

* Lead-alpha ages of zircon from the Yatsushiro Granites (equivalents of the Mitaki Igneous Rocks) of west Kyushu are 360 m. y. and 600 m. y., while Rb-Sr ages of biotite from several localities are 407–434 m. y. (Y. KARAKIDA and T. W. STERN, 1970 ; I. HAYASE and K. ISHIZAKA, 1967).

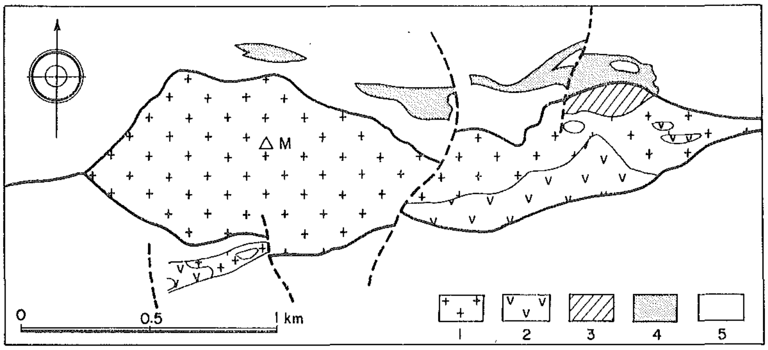


Fig. 2 The Mitaki Lenticular Body, Ehime Prefecture, an example of the composite bodies in the Kurosegawa Tectonic Zone
1 : Mitaki Igneous Rocks, 2 : Siluro-Devonian Okanaro Group, 3 : Terano Metamorphic Rocks, 4 : Ultra-basic rocks, mainly of serpentinite, 5 : Permian and Mesozoic formations M : Mt. Mitaki
(After K. ICHIKAWA *et al.*, 1956 ; simplified.)

frequently, though each of them is very small, along so extensive a zone as long as 450 km from west Kyushu to west Kii, and as lithology and mutual relations of the constituents are invariably the same throughout the whole length, it is safely inferred that the rocks of the Terano type and also of Mitaki type are generally present beneath the Chichibu Formation as the basement.

Rocks that are probably from the basement of the Chichibu Formation are also known in other parts of the Honshu Province. In the northern part of the Nagato Tectonic Zone, Yamaguchi Prefecture, westernmost Honshu, gneissose granitic rocks occur as xenolith-like blocks in serpentinite. Around the Tectonic Zone the Carboniferous-Permian and the Mesozoic sediments are extensive at the surface. The gneissose rock gives a K-Ar age of 424 m. y. (Y. KAWANO *et al.*, 1966) and a Rb-Sr age of 406 m. y. (I. HAYASE and K. ISHIZAKA, 1967), which are probably rejuvenated from a still older age through later tectonism.

The Komori Metamorphic Rocks (H. KANO *et al.*, 1959) or the Maizuru Metamorphic Rocks (S. IGI *et al.*, 1961), consisting mainly of biotite gneiss, banded gneiss and amphibolite, occur in association with the Yakuno Basic Rocks in the Maizuru Zone, which separates the Chugoku Belt to the west and the Tamba Belt to the east. Here the older age of the Komori Metamorphic Rocks is not conclusive and still disputed, but the exotic lithology and the isolated occurrence are nearly identical with those of the Terano Metamorphic Rocks in the Kurosegawa Tectonic Zone.

In central Japan the problems of the Hida Metamorphic Rocks have been disputed in these years, but the present state of knowledge is summarized as follows.

The Hida Metamorphic Rocks cover the most extensive area among the probable basement rocks of the Japanese Islands. They are composed mainly of sialic gneisses and amphibolites together with some crystalline limestones. The concentration of K-Ar ages around 180 m. y. encouraged once certain geologists who asserted the Hida metamorphism younger (S. BANNO and J. MILLER, 1961). But the Rb-Sr and U-Pb ages, obtained later and attaining 1,500 m. y. at the maximum, suggest that they are the regenerated rocks from the older ones. The Devonian sediments are found in the Circum-Hida Tectonic Zone (S. KAMEI, 1955) surrounding the south of the Hida Metamorphic Rocks in the form of small, exotic masses. Though the stratigraphical relation between the Hida Metamorphic Rocks and the Devonian is yet inconclusive, it is inferred that the former is older than the latter, and is probably of Precambrian age. This estimation is reinforced further by the lithology and internal structures of the metamorphic terrain that are similar with those of the middle Precambrian of North China and Korea.

An important discovery was made recently by T. SOMA (oral communication), who found boulders of orthoquartzite in the conglomerates of the Jurassic to Cretaceous Tetori Group developed in the Hida Province. Orthoquartzite, one of the common sedimentary rocks in continental regions and weakly metamorphosed in this case, is not known in Japan as sediments in situ throughout the whole sequence from the Silurian to the Recent. But it is found generally in China and Korea as the chief constituent of the Sinian System, the late Precambrian of these areas. Therefore the orthoquartzite boulders in the Tetori Group relate eloquently the late Precambrian sediments once existed somewhere around the Hida Province. Furthermore, the Sinian age of the weakly metamorphosed orthoquartzite boulders suggests a still older age of the highly metamorphosed Hida Metamorphic Rocks, or, in other words, the pre-late Precambrian age of the Hida Metamorphic Rocks.

Another discovery of importance was made in the Kamiaso district, Gifu Prefecture, about 50 km to the south of the Hida Province, by M. ADACHI (1971). There, boulders of sillimanite gneiss and garnet gneiss are found together with pebbles of orthoquartzite in the Permian conglomerates. The K-Ar ages of biotite in the gneisses are 1,500-1,700 m. y. (K. SHIBATA *et al.*, 1971). It supports also the older age of the Hida Metamorphic Rocks, wherefrom the gneiss boulders were undoubtedly brought to the Permian conglomerates.

In the Abukuma Belt of southern Northeast Japan the oldest sediments with fossil evidence are the upper Devonian. It is underlain by siliceous phyllites and crystalline schists of the Matsugadaira Metamorphic Rocks (T. SATO, 1956). In the main part of the Abukuma Belt, on the other hand, the granites, gneisses and crystalline schists, that constitute the main part of the Belt almost exclusively, have been regarded by some geologists simply as of the late Mesozoic. But the recent discovery of kyanite and staurolite (RESEARCH GROUP OF THE ABUKUMA PLATEAU, 1959), that are quite disharmonic with the high-temperature and low-pressure metamorphism of the present rocks of this area, shows that the rocks were originally different from those now they are, and that they have been reworked later.

In the Southern Kitakami Belt the upper Devonian Tobigamori Group is underlain by the Motai Metamorphic Rocks, that are similar in lithology with the Matsugadaira Metamorphic Rocks of the Abukuma Belt. The original rocks of the Motai and Matsugadaira, though they are certainly older than the upper Devonian, may be middle-lower Devonian or the Silurian, because the Motai is reported to be transitional with the upper Devonian Tobigamori (M. SHIMAZU, 1954).

Probable Precambrian basement rocks in the Southern Kitakami Belt are the Tsubonosawa Gneiss (K. ISHII *et al.*, 1960) included in the Hikami Granite, which is one of the older granite bodies of the Southern Kitakami Belt. The Tsubonosawa Gneiss is composed mainly of biotite schist and banded gneiss together with some amphibolite. Another occurrence of gneissose rocks is the Unoki Metamorphic Rocks found in the Kuroishi Tectonic Zone (S. KANISAWA, 1964, 1969; H. KANO and S. KANISAWA, 1966). Though they are separated far from the Devonian and Silurian sediments, these crystalline schists and gneisses, being higher in grade of metamorphism and their structure being discordant with that of the Motai, are most probably older than the Silurian.

From the above lines one can see that there are many rocks in Japan which are probably of pre-Silurian or rather of middle Precambrian age. They really occur in the form of very small bodies in many cases, but are scattered wide in the Honshu Province. They are brought upward most probably from the depth. These facts, i. e. the wide distribution and the special mode of occurrence, show that such metamorphic rocks as crystalline schists and gneisses together with granites are present in the form of basement generally beneath the Chichibu Palaeozoic Formation.

Certain authors are quite suspiceous of the pre-Silurian age of these rocks, and suspect them to be the metamorphosed Chichibu Formation. But neither transitional superposition nor intermediate rocks to connect them are found between the Chichibu and the probable basement rocks. In the case of the Motai and Matsugadaira, they do not represent the basement, but the hiatus in grade of metamorphism is obvious between these and the Tsubonosawa Gneiss or the Unoki

Metamorphic Rocks.

Absence of the Cambrian and Ordovician in Japan

Since the beginning of the modern geology of Japan, the Chichibu Formation had long been known as the Anthracolithic or the Carboniferous-Permian. And it was as late as 1933 that the next older System, the Devonian, was discovered for the first time by M. NODA (H. YABE and M. NODA, 1933; M. NODA, 1934) at the Tobigamori district in the west central part of the Southern Kitakami Belt. It was followed immediately by the discovery of the Silurian by Y. ONUKI (1938) also in the same Belt, but, this time, at the eastern part. Since then new localities of the Devonian and Silurian, essentially the same in lithology and in fossil contents, have been added year after year, and now they attain some twenty areas under three (or four) provinces. But, no locality new has been reported for the last eighteen years since 1954. It seems that the old-fossil rush has gone.

On the other hand geologists have had enthusiasm, since 1938, for the still older sediments, i. e. the Ordovician and Cambrian, that might be present. But the Cambrian and Ordovician are yet unknown. According to the writer's confidence, however, the search for the Cambrian and Ordovician sediments will never be rewarded. In other words, the conditions of geology as a whole indicate the absence of these older sediments in Japan. It is explained in the following lines.

As already mentioned, the oldest sediments with fossil evidence in Japan are the Silurian. It is found in many places from west Kyushu to the Kitakami Mountainland. In each locality its area of distribution is quite limited. The mode of occurrence is special, being brought up from the depth, or, in other words, from the basal part of the Chichibu Formation. Moreover, it is associated, generally in the Kurosegawa Tectonic Zone, with the pre-Silurian basement rocks such as the Terano Metamorphic Rocks probably of the middle Precambrian. The Cambrian and Ordovician, if they are present in the depth, must underlie the Silurian and overlie the Terano-type basement rocks. It follows that the Cambrian and Ordovician, if present in the depth, must be exposed at the land surface as equally and frequently as the Terano and the Silurian. But it is not the case. Therefore, their absence at the land surface means necessarily their absence in the depth. The same kind of inference applies to the other provinces, though not so conclusively as in the case of the Kurosegawa Tectonic Zone.

Thickness of the Chichibu Formation

Stratigraphy of the Chichibu Formation is here reviewed with special reference to the thickness and mode of distribution.

The Silurian

The Silurian is found developed in two provinces, i. e. in the Kurosegawa Tectonic Zone of the Chichibu Belt, Southwest Japan, and in the Southern Kitakami Belt, Northeast Japan. In both cases it consists of the Wenlockian and Ludlovian or of the middle and upper Silurian, and is associated intimately with the Devonian.

In the Kurosegawa Tectonic Zone the Silurian and Devonian, as mentioned already, occur together as one of the three constituents of the exotic composite bodies. They are most extensive at the Gionyama area in Kyushu and also at the Yokokurayama area in central Shikoku. They are composed mainly of acidic volcanics, including coarse- to fine-grained tuffites, lavas and tuff breccias, which are associated with lenticular limestones. At certain localities in Shikoku thin layers of conglomerates are intercalated occasionally, and contain small pebbles of crystalline schists, gneisses and granites (N. YAMASHITA, 1958). Of the maximum thickness of 1,400 m, the lower 300 m to 500 m, though somewhat inconclusive, are alloted to the Silurian, and accordingly the upper 900 m to 1,100 m to the Devonian (T. HAMADA, 1961).

In the Southern Kitakami Belt the Silurian occurs near Ofunato City (Fig. 8) in the southeastern part of Iwate Prefecture. There it occurs, as will be explained later, in a narrow strip of the older sediments including the Devonian and the lower half of the Carboniferous. The Silurian here is about 350 m in aggregate thickness, of which the lower 325 m are composed mainly of limestones and mudstones with intercalations of tuffites. The upper part, 25 m thick, is composed of chert.

From the above lines the Silurian of Japan, being composed mainly of acidic volcanics and limestones, is about 350 m to 500 m in thickness.

The Devonian

The Devonian formations in Japan are classified into three (or four) groups according to their lithology, stratigraphy and areas of distribution. The first is those in the Kurosegawa Tectonic Zone, that are already described in the foregoing lines.

The second group includes those of the Southern Kitakami Belt as well as of the Abukuma Belt. They are subdivided further into two subgroups, i. e. the subgroup of the lower to middle Devonian lying on the Silurian of the Ofunato district and that of the upper Devonian including the Tobigamori Group of western Kitakami and the Ainosawa Formation of the Abukuma Belt.

The lower Devonian Ono Group, 400 m in thickness, lies conformably on the Silurian, and consists of acidic volcanics with intercalations of mudstones and limestones. The middle Devonian Nakazato Group, 750 m thick, covers the Ono

Table 1 Outline of the Chichibu Palaeozoic Formation

System	Series: Europe & N. America	Series: Japan	Chichibu Belt: West Kyushu	Chichibu Belt: East Kyushu	Chichibu Belt: West Shikoku	Chichibu Belt: Central Shikoku	Chichibu Belt: East Shikoku	Chichibu Belt: Kanto Mounts	Chugoku Belt: Yamaguchi	Chugoku Belt: Hiroshima	Chugoku Belt: Okayama	Tamba Belt: Tamba	Tamba Belt: Akasaka	Ashio Mts.	Circum-Hida Zone	Abukuma Belt	Southern Kitakami Belt
Permian	Chideruan	Kuma	Kuma		Doi	Yasuba	Haigyu									Yumiori-zawa	Toyoma
	Guadalupian	Akasaka	Kozaki / Yonagu	Tsukumi Is	Yusukawa	Shirakidani	Kenzan / Hisone	Kami-yoshida	Akiyoshi Is / Ota	Uyama / Yoshii	Yukawa	Tamba	Akasaka Is	Adoyama	Sorayama	Oashi	Kanokura
	Artinskian	Nabeyama			Nomura			Mamba			Sabuse			Nabeyama			
	Sakmarian	Sakamotozawa		Okukawachi	Onji								Oishi	Izuru		Uwano	Sakamotozawa
Carboniferous	Orenburgian / Uralian	Hikawa	Yayamadake Is / Tobiishi					Kashiwagi					Otaki		Ichinotani		
	Moscovian	Kuriki / Akiyoshi			Itadori-gawa	Shogase	Daigo		Akiyoshi Is	Taishakugawa	Kotani						
	Namurian	Nagaiwa	Kakisako	Yuzuruha													Nagaiwa
	Viséan	Onimaru									Nagoe					Tateishi	Onimaru
	Tournaisian	Odaira / Arisu															Odaira / Arisu
	Etroeungtian	Hikoroichi														Mano	Hikoroichi
Devonian	Famennian / Frasnian	Tobigamori				Yokokurayama									Kiyomi	Ainosawa	Tobigamori
	Givetian / Eifelian	Nakazato		Gionyama											Takara-gawa		Nakazato
	Coblenzian / Gedinnian	Ono													Fukuji		Ono
Silurian	Ludlovian	Takainari	Fukami		Okanaro		Miyaga-tani										Takainari
	Wenlockian	Kawauchi															Kawauchi
	Llandoverian																

Group with a parallel unconformity, and is composed of mudstones and acidic volcanics. The aggregate thickness of the lower and middle Devonian is 1, 150 m.

The upper Devonian Tobigamori Group is found developed in the Tobigamori area about 40 km to the west of Ofunato City, so that the stratigraphical relation between this Group and the lower and middle Devonian is indeterminable. The Tobigamori Group is very thick, being about 2, 000 m, and it is composed mainly of black shale with some tuffites. The Devonian of the Abukuma Belt, the Ainosawa Formation, is 70 m in thickness. But it should not be taken into account for the estimation of structural thickness, because it is too meagre in development.

The third group of the Devonian sediments is those found in the Circum-Hida Tectonic Zone, where three areas of development are widely separated from each other. The Fukuji Group of the easternmost locality, most complete and best studied, is about 250 m thick, and is composed mainly of limestones with some acidic tuffites, mudstones and sandstones.

From the above lines, the Devonian of Japan is summarized as follows. It is characterized lithologically by acidic volcanics in general, but mudstones are rich in Kitakami, and limestones in Hida. The thickness is about 900 m to 1, 100 m in the Kurosegawa Tectonic Zone, and 3, 150 m in the southern Kitakami Belt. But the last mentioned 3, 150 m may better be divided into the 1, 150 m of the lower and the middle Devonian and the 2, 000 m of the upper Devonian.

The Carboniferous

The Carboniferous of Japan is classified biostratigraphically into eight Series, of which the lower four belong to the Lower Carboniferous and the rest to the Upper Carboniferous. They are shown together with the European and American standard, in the left-side columns in Table 1. Apart from the biostratigraphical subdivisions, the Japanese Carboniferous sediments, as in many other countries, are divisible into the lower and upper parts on the basis of lithostratigraphy and areas of distribution, though the horizon of demarcation and the lithological contents of each part are more or less different from those of other countries. The dividing surface is found generally at the base of the upper Viséan Onimaru Series. But it seems to descend to the base of the lower Viséan Odaira Series in the Chugoku Belt (Y. OKIMURA, 1958, 1966). So the term "lower Carboniferous" is employed in this paper for those below the dividing horizon, i. e. for the sediments inclusive of the Etroeungtian Hikoroichi, the Tournaisian Arisu and the lower Viséan Odaira Series. Accordingly the term "upper Carboniferous" is used to denote the whole of the formations including not only the Upper Carboniferous in ordinary sense but also the upper Viséan Onimaru Series. The sediments of the lower Viséan Odaira Series within the Chugoku Belt, as understood from the foregoing lines, are included also in the "upper Carboniferous" for convenience' sake.

The "lower Carboniferous" so defined is poorly developed in Japan, being found only in Northeast Japan, i. e. in the Southern Kitakami and the Abukuma Belts. Even in the Kurosegawa and the Circum-Hida Zones, where the Silurian and/or Devonian are exposed not infrequently, the "lower Carboniferous" is missing.

The "lower Carboniferous" of the Southern Kitakami Belt includes three Series, i. e. the Hikoroichi, the Arisu and the Odaira Series, and lies on the Devonian Nakazato Series with a slight unconformity. It is composed mainly of mudstones and volcanics with some intercalated limestones. The volcanics are characterized, in contrast with those of the Silurian and Devonian, by basic to intermediate chemistry. The thickness attains about 2, 500 m in the aggregate. A sequence of strata, slightly different in lithology from the correlative Hikoroichi, is found conformably above the Devonian Tobigamori Series. And another correlative of the Hikoroichi is known in the Abukuma Belt.

In short the "lower Carboniferous" in Japan, in spite of its remarkable thickness observed in the type area, is most limited in distribution.

The "upper Carboniferous" is found rather frequently in many parts of the Honshu Province. Its occurrence is common and general, when compared with the older sediments.

In the Southern Kitakami Belt, it begins with the upper Viséan Onimaru Series composed mainly of limestones. The unconformity at the base of the Onimaru Series indicates an important crustal movement known under the name of the Shizu Folding (M. MINATO, 1950; M. MINATO *et al.*, 1965). It is followed by the Namurian Nagaiwa Series also of limestones. The aggregate thickness of the Onimaru and Nagaiwa is about 800 m. In the Abukuma Belt an equivalent of the Onimaru is called the Tateishi Formation, while in the southern part of the same Belt it is called the Ayukawa Formation. The latter is underlain by a thick series of metamorphosed sediments that may well belong to the "lower Carboniferous" and Devonian.

In the Chichibu Belt of Southwest Japan the Onimaru Series is known in three areas. Among them the Kakisako Formation (K. KANMERA, 1952) of west Kyushu, composed mainly of limestones and shale, is about 600 m in thickness, and is regarded as including the Nagaiwa Series in the upper part of its sequence. The Yuzuruha Formation (N. KAMBE, 1957) of the Kuraoka district in central Kyushu is composed mainly of slates and sandstones. Though the thickness is not given in KAMBE's report, it is probably more than 600 m.

The Moscovian and Uralian (Gzhelian) are defined in Japan by fossil zones of

Fusulinids, i. e. the lower Moscovian Akiyoshi Series roughly by the zone of *Fusulinella*, the upper Moscovian Kuriki Series roughly by that of *Fusulina* and the Uralian Hikawa Series by that of *Triticites*. Among the three the Akiyoshi Series is found most frequently, while the other two are less frequent. Perhaps the unconformity at the base of the Permian is responsible for that hiatus. In any case, they are confirmed in lenticular limestones intercalated in clastic or volcanic sediments, and are from 100 m to 200 m thick respectively.

These values, however, should not be regarded as representative nor typical. Because these limestones, to which fossil occurrence is limited, are very small fractions of the contemporaneous sediments in these areas. And there are vast areas of clastic and volcanic sediments that are far larger in thickness, but are less understood on account of their sterile nature. These barren sediments, however, are also studied in several areas of the Chichibu Belt. The most reliable data on thickness and lithology are as follows.

In west Kyushu the Amatsuki Formation (T. MATSUMOTO and K. KANMERA, 1952, 1964) is about 630 m thick, and is composed mainly of sandstones and slates together with some volcanics, limestones and chert. In eastern Shikoku the Daigo Formation (K. SUYARI, 1954, 1961) is exposed along an axis of a Permian anticline, and is more than 500 m in thickness. On the other hand the Shogase Formation of central Shikoku, being composed of tuffites, yields Fusulinids of the *Fusulinella-Fusulina* zone and the *Triticites* zone. The thickness is estimated at about 1, 100 m. From the above lines the "upper Carboniferous" inclusive of the Viséan Onimaru Series in the Chichibu Belt is estimated at about 1, 000 m thick in general.

In the Chugoku Belt, the Carboniferous formations other than limestone facies are less understood. The thickness of 975 m, however, for the Carboniferous part of the Akiyoshi Limestone (Y. HASEGAWA, 1963) and 2, 000 m for the Gampi Group (R. TORIYAMA, 1954) suggest the thickness ranging from 1, 000 m to 2, 000 m.

In the Tamba Belt the "upper Carboniferous" is quite limited, being known only at the northern and northwestern margins, i. e. along the Circum-Hida Zone and also along the Maizuru Zone. The Ichinotani Formation of the Fukuji district in the Circum-Hida Zone is about 300 m, while the Sanakatoge Formation of the Sasayama Basin and the Shuchi Formation of the Sonobe area are 800 m and 1, 200 m thick respectively (S. SAKAGUCHI, 1961).

In short the thickness of the "upper Carboniferous" in the Chichibu, Chugoku and Tamba Belts is estimated at about 1, 000 m in average.

The Permian

The Permian sediments in Japan are variable in lithology from place to place, and are classified mainly by Fusulinids into four Series, i. e. the Sakamotozawa

(Sakmarian or Wolfcampian), Nabeyama (Artinskian or Leonardian), Akasaka (lower-middle Guadalupian or Wardian to middle Capitanian) and Kuma (upper Guadalupian and Chideruan or upper Capitanian to Ochoan) Series in ascending order. The unconformity at the base of the Permian is widespread, but the hiatus below is not very large.

In the Southern Kitakami Belt the lower Permian Sakamotozawa Formation begins with basal conglomerates, and lies unconformably upon the Namurian Nagaiwa Series. The crustal movement shown by the Sakamotozawa Unconformity is named the Setamai Folding by M. MINATO (1942). The Sakamotozawa Formation, composed mainly of sandstones, mudstones and limestones, and about 1,300 m in thickness, is succeeded by the middle Permian Kanokura Group (Nabeyama and Akasaka Series), consisting of sandstones, mudstones with some limestones, about 1,000 m thick.

The upper Permian Toyoma Group is remarkable in its rock facies, being composed of black slates and enormous conglomerates. The thick conglomerates with granite boulders are intercalated in its lower part, and are known under the name of the Usuginu Conglomerate. The thickness of the Permian in this Belt is about 4,100 m in the aggregate.

The Permian of the Chichibu Belt is best studied by K. SUYARI *et al.* (1969) in central and eastern Shikoku. The Kenzan Group of Tokushima Prefecture is composed mainly of sandstones, mudstones, basic volcanics and chert, and ranges in age from early to middle Permian. The thikness of the part of the lower Permian is regarded as 1,500 - 2,000 m, while that of the upper part, the middle Permian, is about 500 m.

The upper Permian of the Chichibu Belt is characteristic in its lithology. Namely, it contains conglomerates frequently, but is free from volcanics and chert. The thickness varies from 900 m of the Kuma Formation in west Kyushu to 300 - 600 m of the Ichinose, Yasuba and Haigyu Formations in Shikoku. Thus the aggregate thickness of the Permian is estimated at about 3,000 m.

The Permian of the Chugoku Belt is best known in such limestone plateaus as Akiyoshi, Taishaku and Atetsu Plateaus. There the Permian is about 500 m to 600 m in thickness. But in the intervening areas the Ota Group, consisting of chert, shales and sandstones, is 2,600 m thick, the Beppu Group 2,000 m, and the Yoshii Group (A. HASE, 1965) is reported as 2,800 - 3,300 m in thickness.

The most remarkable Permian is seen in the Tamba Belt, where it is characterized by the enormous thickness of sediments composed mainly of sandstones and mudstones. Another characteristic of this Permian is the frequent intercalations of chert, from which Conodont faunae are found. The aggregate thickness of the Permian, according to S. SAKAGUCHI (1961), is about 8,900 m.

Problems Concerning the Conodonts

Recently, Conodonts of the Triassic-type are found from chert or cherty rocks that have hitherto been regarded as belonging to the Chichibu Palaeozoic Formation. The problems are now being eagerly studied by certain palaeontologists. In this paper, however, the writer treats the sediments containing the Triassic-type Conodonts as belonging to the Permian. Because the age problem of the sediments in question has nothing to do with the theme of thickness estimation here discussed.

Thickness of the Crustal Layer Consisting of Deformed Geosynclinal Sediments

Improbability of Deep Isoclinal Folds

When we consult the papers dealing with the Chichibu Palaeozoic Formation, we often meet with such words as "isoclinal folds" or "closed folds". And it seems to be admitted generally that the Chichibu Formation is folded isoclinally in general. But the idea can not be accepted as will be explained in the following lines. First, we assume that the Chichibu Formation is folded isoclinally like the case as shown in Figures 3 and 4. Then we examine the relation between the thickness of beds and the areas of the same beds exposed at the land surface.

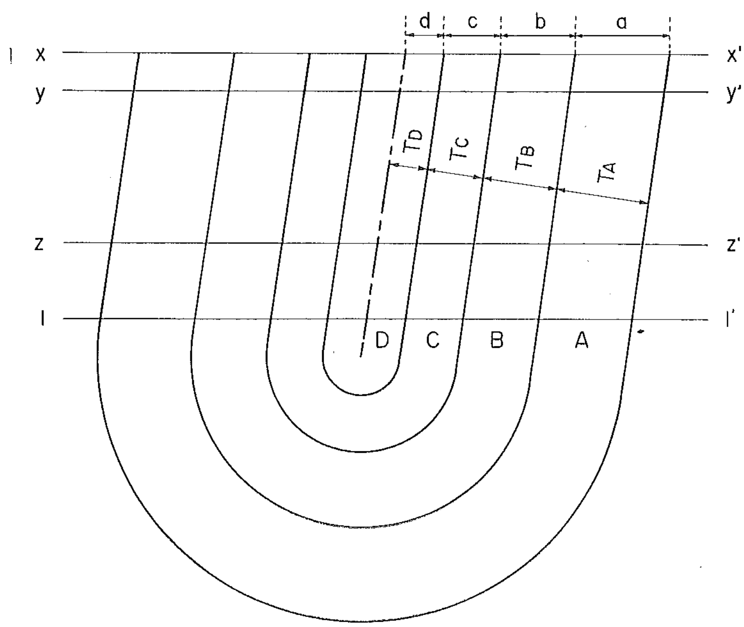


Fig. 3 A cross section of an ideal isoclinal syncline showing the relation between surface area and thickness of strata

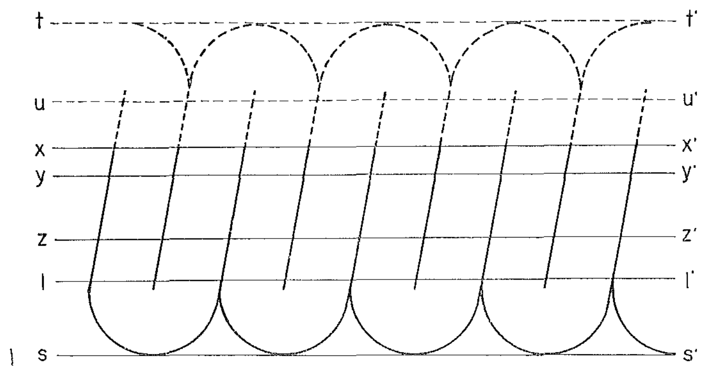


Fig. 4 A cross section of repeating isoclinal folds

Figure 3 shows a cross section of an ideal syncline isoclinally folded. There the land surface is plane and horizontal, and the strike of beds is parallel with each other. The line of cross section may be drawn at random, so far as it is straight and intersects the strike. But it is here drawn conveniently at right angles to the strike. The beds, A, B, C and D, were superposed originally in this order, but are now folded to form an isoclinal syncline. Thickness of each bed (T_A, T_B, T_C or T_D) is assumed to be constant throughout. As the strike of beds is parallel, the area of each bed at the land surface is proportional to the

Table 2 Thickness and area of each System of the Chichibu Palaeozoic

	Chichibu Belt					Tamba	
	thickness (in m)	area (in km^2)	thickness ratio (tr ; in %)	areal ratio (ar ; in %)	ar/tr	thickness (in m)	area (in km^2)
Permian	3000	585.27000	55.55	98.599	1.77	8900	7992.125
Carboniferous	1000	6.17625	18.52	1.041	0.056	1000	38.000
Silurian-Devonian	1400	2.13750	25.93	0.360	0.014	300	6.750

* Among the four provinces examined, the Chugoku Belt is omitted in this Table, because the the other three provinces, measurement of area is performed for the following parts.

Chichibu Belt : the part contained in the geological maps of "Kenzan" in scale 1 : 75,000 by 1958.

Tamba Belt : the part indicated in Figure 1 ; measured on the geological maps of "Kyoto" by H. ISOMI *et al.*, 1958.

Southern Kitakami Belt : the whole area of this Belt ; measured on the geological map of corresponding fraction (a, b, c or d) of the line x-x′.

On the other hand, as understood from the figure, a fraction (a, b, c or d) of the line x-x′ is in proportion to the thickness (T_A, T_B, T_C or T_D) of the corresponding bed. Then it follows that the area of a bed at the land surface is proportional to the thickness of the same bed. The horizontal line x-x′, or the land surface, may be lowered progressively to y-y′, and to z-z′, with progressive denudation. But the said relation does not change, so far as the horizontal line does not exceed the limit 1-1′.

This proportional relation between thickness and surface area is extended logically to the case where the same type of isoclinal fold repeats many times as shown in Figure 4. There, the total area of a bed at the land surface, even if it is divided into many zones, is proportional to the thickness of the corresponding bed, so far as the beds are constant in thickness respectively and are folded isoclinally.

Contrary to the case assumed and examined above, the proportional relation between thickness and area is not observed in the case of the Chichibu Formation. This is examined in the following lines.

In Table 2, thickness and area of each System are given for each Chichibu, Tamba and Southern Kitakami Belt, both in the form of real value and ratio in percent. The thickness of each System, variable from place to place, is inferred from various sources taking geological conditions into consideration, that are

Formation* (Compiled by N. YAMASHITA, T. HOMMA and K. ITO.)

Belt			Southern Kitakami Belt				
thickness ratio (tr ; in %)	areal ratio (ar ; in %)	ar/tr	thickness (in m)	area (in km²)	thickness ratio (tr ; in %)	areal ratio (ar ; in %)	ar/tr
87.26	99.443	1.14	4100	1433.50	37.61	88.625	2.36
9.80	0.473	0.048	3300	155.25	30.27	9.598	0.32
2.94	0.084	0.029	3500	28.75	32.11	1.777	0.06

Chichibu Formation there is represented only by the Permian and "upper Carboniferous". For

K. HIRAYAMA *et al.*, 1956, and "Awa-Tomioka" in scale 1 : 75,000 by N. YAMASHITA *et al.*,

in scale 1 : 500,000 edited by R. ENDO *et al.*, 1951, and "Kanazawa" in scale 1 : 500,000 edited

"Akita" in scale 1 : 500,000 edited by J. HIRAYAMA *et al.*, 1960.

noticed in the preceding chapter. The area of each System is measured on geological maps.

If the strike of beds is constant and parallel throughout the terrain in question, and hence the zones are constant in width, as is the case assumed in the foregoing examination, evaluation of area would be made easily by measuring the fractions of a cross line on a geological map. But this method is inapplicable to these Belts, where the zones, though the zonal arrangement is distinct, are not only variable in width but also thin out frequently. So the area is measured directly or indirectly on geological maps.

As it is impossible, in most cases, to discriminate the Silurian and Devonian from each other, these two Systems are combined in Table 2. In the same manner the "lower" and "upper" Carboniferous are shown in the aggregate. The area of these three Systems is measured respectively and directly on geological maps, while that of the Permian, being very large and complicated in outline, is obtained indirectly by subtraction of other components from the whole area. In the case of the Southern Kitakami Belt, the whole area to the south and southwest of the Hayachine Tectonic Belt (T. YOSHIDA and M. KATADA, 1964) is measured. Of course many intrusive masses and Mesozoic basins are subtracted. For the other two Belts, a part of each Belt (indicated in Figure 1, and described in the explanation of Table 2) is chosen for measurement.

Consulting Table 2, the following are inferred. In every one of the three Belts, the Permian System, the uppermost of the Chichibu Formation, occupies the most extensive area. It is nearly 100 % in the Chichibu and Tamba Belts, and is nearly 90 % in the Southern Kitakami Belt. The large percentage itself of the Permian would be natural if it is proportional to that of thickness. But it is not. The reason is as follows.

From the foregoing examination, *thickness ratio* would equal to *areal ratio*, if the folds are isoclinal. Therefore the *thickness ratio* obtained from observed values is regarded, in the case of isoclinal folds, as representing probable ratio of surface area. In this sense the *thickness ratio* can be regarded as *probable areal ratio*. On the other hand the *areal ratio* in this table is obtained, though indirectly through the media of geological maps, from observations in the field. Hence it is real. So the ratio of *areal ratio* (*ar*) to *thickness ratio* (*tr*), i. e. *ar/tr*, shows how much the *probable areal ratio* is realized in nature. It would be called *realized ratio*, and is shown in the fifth (right side) column of each Belt. As understood easily the *realized ratio* larger than 1 shows that the surface area of the System is larger than that expected from the *thickness ratio*, and that smaller than 1 the smller surface area. As seen in Table 2, the *realized ratio*, or *ar/tr*, is larger than 1 in the Permian, and becomes smaller downward rapidly and systematically.

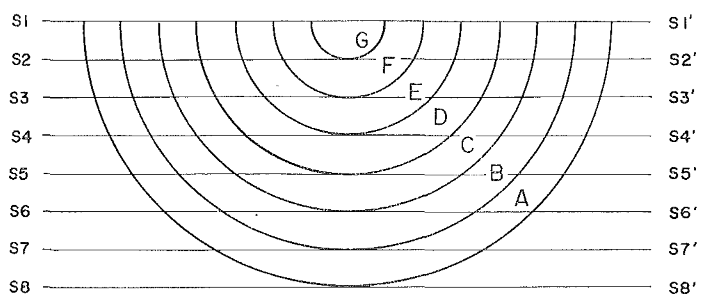


Fig. 5 Relation between surface area and thickness of strata in parallel folding

As seen in Table 2, thickness and area of each System are actually not in proportion to each other. It is far beyond an error. The reason of this significant discordance should be ascribed to the assumption that the Chichibu Formation is folded isoclinally. In other words, folds of the Chichibu Formation are not isoclinal. If the Chichibu Formation were folded isoclinally, though it is not actual, we could not estimate the depth of the folds or the thickness of the folded strata as a whole.

The proportional relation between the thickness and area is invariable even though the horizon of land surface is changed to y-y′ or z-z′, so far as it does not exceed the limit l-l′. It means that the height of the land surface above the critical level (l-l′) can not be estimated from the values of surface area of constituent beds. In other words, there is no means for estimation of depth of isoclinal folds.

Type of Folds of the Chichibu Palaeozoic Formation

In spite of its apparent complication, the folds of the Chichibu Formation, as examined above, is inferred not to be isoclinal. It means that the apparent complication with high-angle dip does not represent the overall structure of the Chichibu Formation as a whole. In other words, the steep folds shown in ordinary geological maps and observed at exposures are nothing other than those of small scale or of lower order, and that the overall structure must be different from those guessed from the small-scale folds. Then what is the kind of its overall structure ? In the following lines two examples as shown in Figures 5 and 6 are examined.

Figure 5 represents an ideal syncline formed by parallel (or concentric) folding. The horizontal lines, s1-s1′, s2-s2′, s3-s3′ et al. represent various cases of land surface, where the distance between them is assumed to be equal with each other for convenience' sake. Apart from the unreal nature of this kind of fold, the following are important.

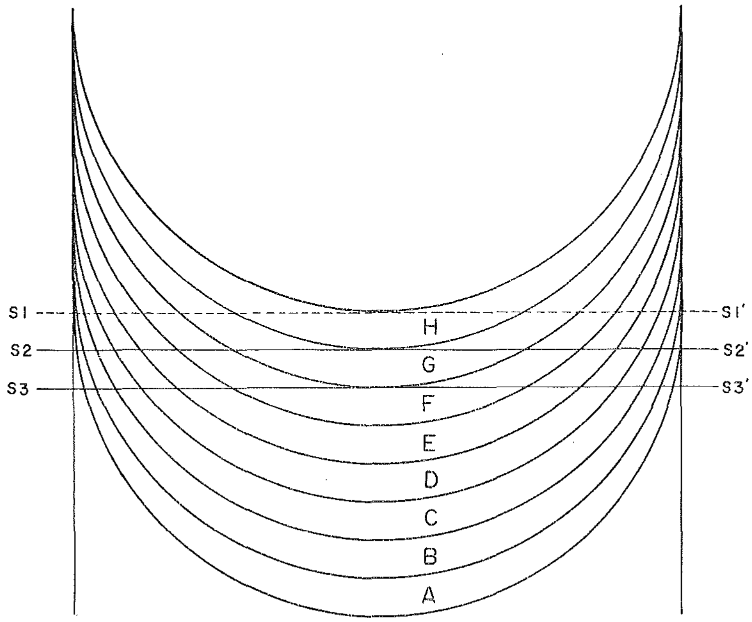


Fig. 6 Relation between surface area and thickness of strata in similar folding

Though the thickness of beds (A, B, C ···) is equal and constant, fractions of the horizontal lines of the same one bed become larger downward according to the decreasing dip of the bed. The same relation, i. e. the larger fractions of horizontal line for the smaller angles of dip, is recognized also along each of the horizontal lines. Namely the fractions of one horizontal line become larger toward the center of this figure. In other words, they become larger toward stratigraphically higher beds with lower inclination. A similar relation is seen in Figure 6, which represents an ideal syncline formed by similar folding. In this case the rate of increase in length of fractions is greater than in the former case.

Comparing the result of examination in these ideal folds with the facts cited in Table 2, it is inferred that the overall structure of the Chichibu Formation is a kind of a syncline or a series of synclines, of which the wave-length is very large in comparison with the amplitude, and that it is a kind of comb-shaped folds with flat and wide synclinal troughs and steep and narrow anticlinal crests.

Such a kind of folded structure as described above is illustrated schematically in Figure 7. In this figure the overall fold, or the first-order fold, of the Chichibu Formation with a flat and wide synclinal trough and steep and narrow anticlinal crests is represented by a heavy broken line ES, which is nothing but an enveloping surface of lower-order folds represented by the heavy lines S_1, S_2, S_3 and S_4. When the formations F_1, F_2 and F_3 are adapted respectively to the Siluro-

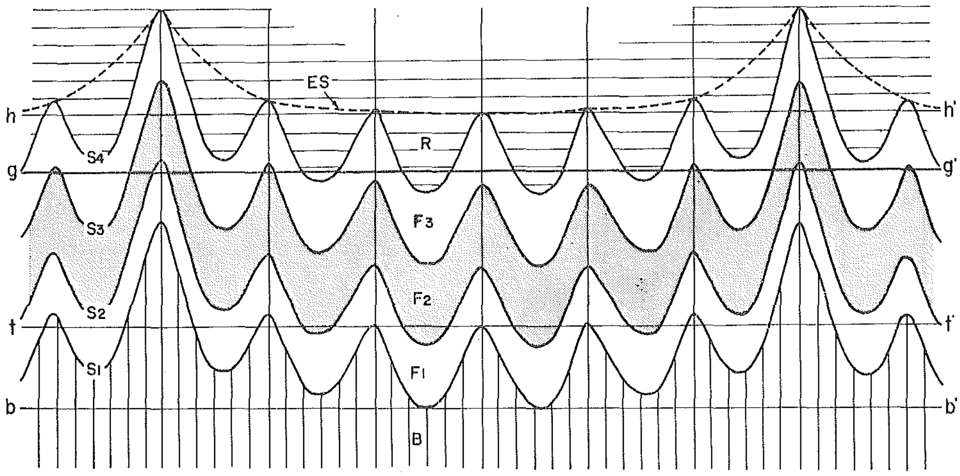


Fig. 7 A schematic illustration of the folded Chichibu Palaeozoic Formation

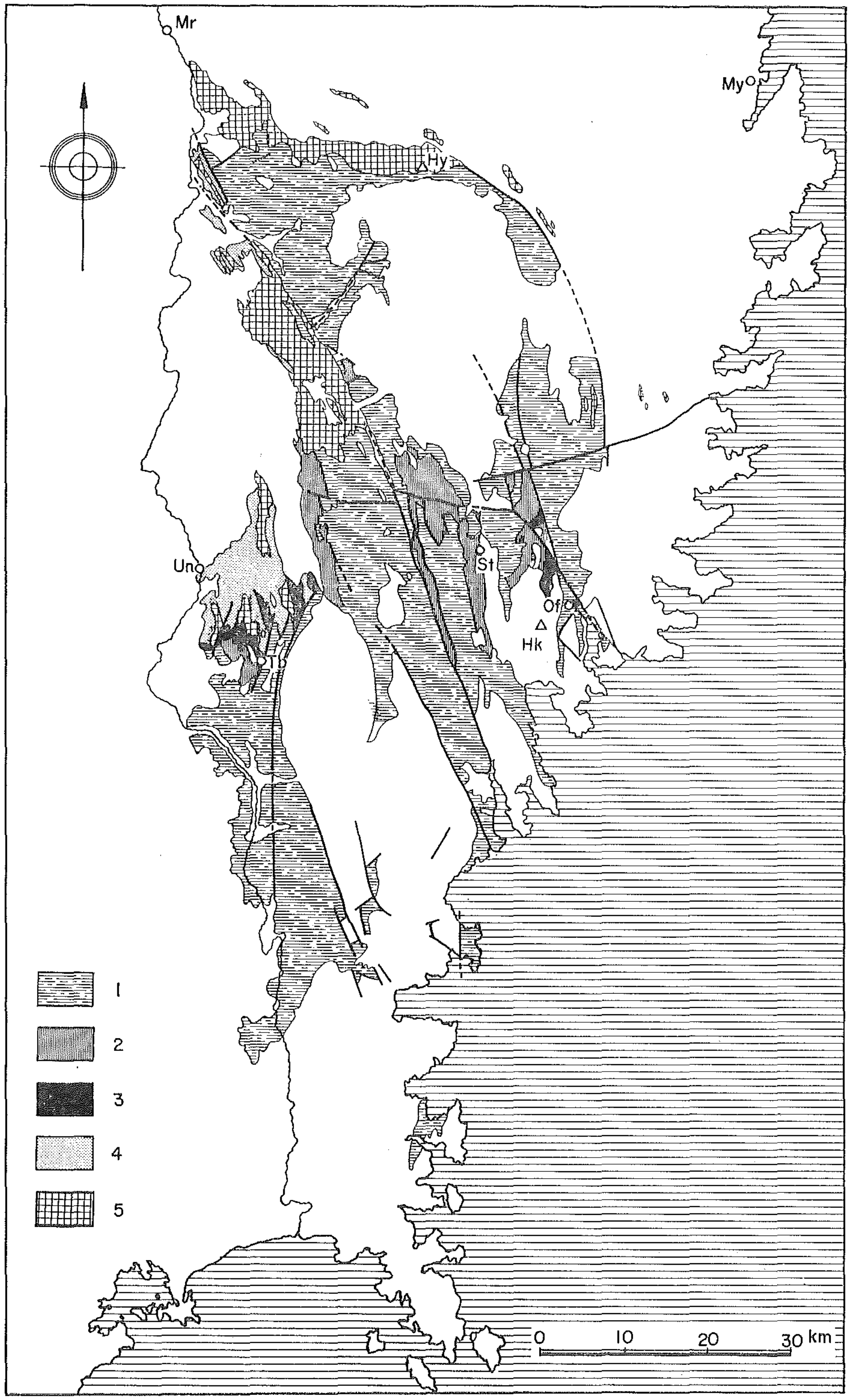
Devonian, the Carboniferous and the Permian, and the horizontal line g-g′ to the present land surface, the extremely large area of the Permian contrary to the quite limited areas of the Siluro-Devonian and Carboniferous is expressed fairly well in this Figure 7.

Folds of the Chichibu Formation in the Southern Kitakami Belt

In the Southern Kitakami Belt the deformation of the Palaeozoic and Mesozoic formations is well observed and well studied.

There, similar folds due to shear folding are observed at exposures in many localities (Plates I and II). According to A. IWAMATSU (1969, 1971) folds due to shear folding are general in the Palaeozoic and Triassic formations, but they are substituted by folds due to flexure folding toward the higher beds of the Jurassic and Lower Cretaceous. Folds due to shear folding are also observed in other parts of the Honshu Province. And it is supposed that an important part of deformation in the Chichibu Formation must be played by similar folds due to shear folding.

Another interesting fact is seen in the mode of occurrence of the Silurian, Devonian and Carboniferous of this same Belt. In Figure 8 the distribution of each System of the Chichibu Palaeozoic Formation is shown, though the Silurian and Devonian are not differentiated. As seen in this figure the older formations, inclusive of the Carboniferous, Devonian, Silurian and the Motai Metamorphic Rocks, are developed, taking a general view of their distribution, in two areas, i. e. one in the Tobigamori area in the west and another in the Ofunato-Setamai area in the east. In the former area, also taking a general view, the Motai Metamorphics, the lowest formations in this area, occupy the central part, while the higher formations encircle them concentrically, becoming younger outward.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It means that the exposure is a kind of dome, which, however, is destroyed more or less by faults. On the analogy of this "Tobigamori Dome" (N. YAMASHITA, 1957), another dome is perceived in the Ofunato-Setamai area. But this "Setamai Dome" (N. YAMASHITA, 1957) is destroyed so severely that the older formations are now exposed in three, narrow belts along the faults trending in NNW-SSE direction.

This mode of occurrence shows that faults played another important part for the manifestation of such older strata as the Silurian and Devonian.

Overall Thickness of Deformed Geosynclinal Sediments

Summing up the foregoing examinations the overall structure of the Chichibu Formation is inferred to be a kind of comb-shaped fold. Or, it is a broad syncline with a flat trough including steeper folds of lower order as illustrated in Figure 7. Upon the basis of this fundamental concept, the thickness of the crustal layer consisting of the folded Chichibu Formation is estimated as follows, where, however, the effect of faults is disregarded and the folds are regarded as similar folds, though somewhat unreal.

In Figure 7 the average thickness of the three deformed formations in the aggregate (F_1, F_2 and F_3) in and around the central part, disregarding the anticlines on both sides, is equal to the sum total of the stratigraphical thickness. It is represented by the distance between the horizontal lines h-h′ and t-t′.

When the lower-order folds are taken into consideration, the vertical distance between the crests and neighbouring troughs of the lower-order folds must be added to the average thickness mentioned above. This additional thickness in the central part of this figure is represented by the distance between the horizontal lines t-t′ and b-b′.

The amount of this additional thickness, though it can not be measured directly in this deeper part of the earth's crust, can be estimated from the conditions of the surface exposure. That is, from the conditions that the upper surface of the Permian (S_4 : the upper surface of the F_3 bed in this figure) at the troughs of lower-order synclines is nearly at the horizon of the land surface g-g′ (the upper Permian is now preserved fairly well in the Honshu Province), and

Fig. 8 Distribution of the Palaeozoic Systems in the Southern Kitakami Belt
Geological formations :
1 : Permian, 2 : Carboniferous, 3 : Silurian and Devonian, 4 : Motai Metamorphic Rocks, probably of pre-Upper Devonian, 5 : Ultra-basic rocks
Place name :
Hk : Mt. Hikami, Hy : Mt. Hayachine, Mr : Morioka City, My : Miyako City, Of : Ofunato City, St : Setamai, Tb : Tobigamori district, Un : Unoki, the locality of the Unoki Metamorphic Rocks in the Kuroishi Tectonic Zone
(Abstracted from the geological map "Akita" in scale 1 : 500,000, edited by J. HIRAYAMA *et al.*, 1960)

that the top surface of the Carboniferous (= the bottom surface of the Permian; the boundary surface S_3 between the beds F_3 and F_2) is also nearly at the same horizon g-g′ (the Carboniferous exposes rarely but systematically at the axial part of the Permian anticline as typically shown by the Daigo Formation in eastern Shikoku), it follows that the additional thickness is nearly equal to the vertical distance between the lines S_4 and S_3, i. e. to the stratigraphical thickness of the F_3 bed (the Permian). Therefore the total thickness of the crustal layer in question in and around the central part of this figure, i. e. the distance between the horizontal lines h-h′ and b-b′ is obtained by adding the stratigraphical thickness of F_3 bed to the total stratigraphical thickness of F_1, F_2 and F_3 beds.

In the case of the Chichibu Palaeozoic Formation, the thickness of the Permian (Table 2), 3,000 m in the Chichibu Belt, 8,900 m in the Tamba Belt and 4,100 m in the Southern Kitakami Belt, is added to the total stratigraphical thickness of each area, i. e. 5,400 m, 10,200 m and 10,900 m respectively. Accordingly the total thickness of the crustal layer in question is 8,400 m, 19,100 m and 15,000 m respectively.

As understood from the figure the thickness lost by denudation, i. e. the distance between the lines h-h′ and g-g′, must be subtracted, so far as the present thickness is concerned.

In short, the thickness of the crustal layer consisting of deformed geosynclinal sediments, so far as the case of the Chichibu Palaeozoic Formation is concerned, is estimated to be a little larger than, and scarcely attaining two times as large as, the aggregate stratigraphical thickness of the constituent strata.

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Explanation of Plates

Plate I Shear folds in the Southern Kitakami Belt, I

The grey ground is composed of limestone, where folds are indiscernible with the naked eye. The black parts are composed of argillite. The shear planes, though indiscernible in the limestone, are deciphered by the steeply dipping lines constructed by the correlative phases of the folds of the argillite layers. The lower Permian Sakamotozawa Formation.

Locality : Kabayamazawa, a tributary of the Kesengawa (the River Kesen), Sumida-machi, Kesen-gun, Iwate Prefecture

Plate II Shear folds in the Southern Kitakami Belt, II

Shear folds due to slaty cleavage. This exposure continues to that shown in Plate I. The argillite layers become thicker and more frequent.

Plate I Shear folds in the Southern Kitakami Belt, I (For explanation see p. 56)

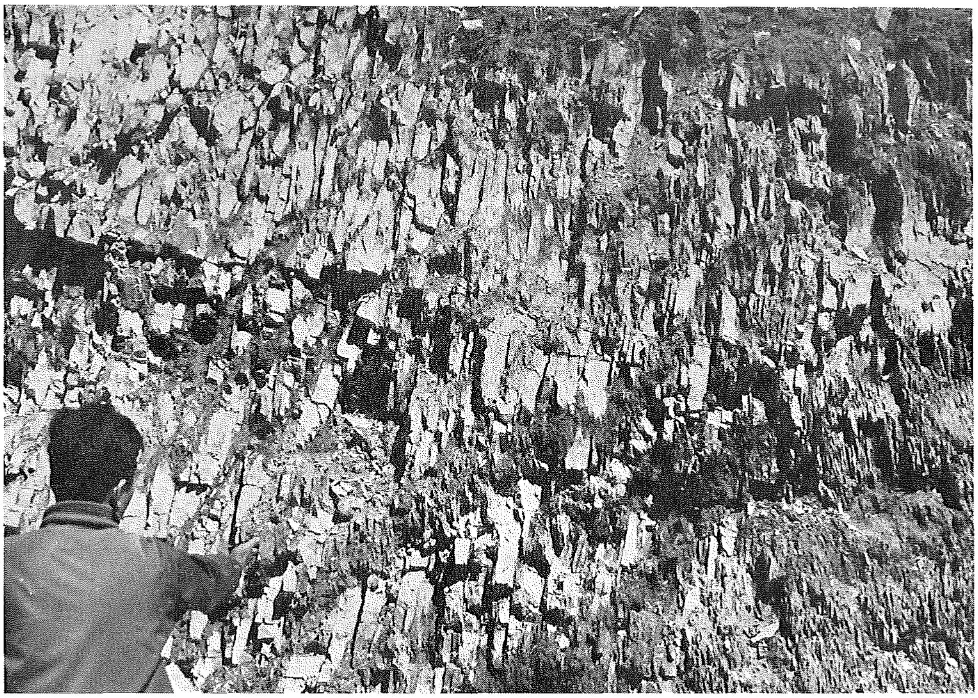

Plate II Shear folds in the Southern Kitakami Belt, II (For explanation see p. 56)