Petrography of the Upper Palaeozoic Sandstones from the Yatsushiro Area, Kyushu : With Notes on the Chichibu Geosyncline

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Petrography of the Upper Palaeozoic Sandstones from the Yatsushiro Area, Kyushu*

By

Koji FUJII**

With Notes on the Chichibu Geosyncline

By

Koji FUJII, Kametoshi KANMERA and Tatsuro MATSUMOTO

Abstract

The representative formations of various geological ages from Silurian to Cretaceous are developed in the Yatsushiro Area, which belongs to the western part of the Outer Zone of Southwest Japan. This paper contains the results of the petrographical study of the Upper Palaeozoic sandstones of this area.

The examined specimens are feldspathic sandstones in some cases and muddy sublithic and muddy feldspathic sandstones in other cases.

The detritus is derived primarily from crystalline metamorphic and acid plutonic rocks and subordinately from volcanic and sedimentary rocks.

Further comments are given on the characteristic features of the sedimentary group and on the sources of the clastic materials so as to improve our knowledge of the Chichibu geosyncline.

Contents

* Received October 31, 1961

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Introduction

1. Purpose of study

The Palaeozoic rocks constitute the most important part of the geology of Japan. Aside from the metamorphosed part, which is mostly uncertain in age, the formations from Silurian to Permian are known on the palaeontological and stratigraphical grounds. The whole series of these formations is generally considered as the product of a geosyncline, sometimes called the Chichibu Geosyncline, but the petrographical study of the sediments is very incomplete.

Of several contributions to the petrography of the Palaeozoic rocks of Japan the following may be specially noted. MINATO and his co-workers (1959) attempted to summarize the stratigraphic occurrence of the volcanic and pyroclastic rocks in the Palaeozoic sequence of Japan. KANO (1958–59) did outstanding contributions to the petrography of the pebbles in the Palaeozoic and Mesozoic conglomerates from various areas in Japan. Results of the petrographic studies have been published by MIZUTANI (1957) for the Upper Palaeozoic sandstones from the Mugi area near Nagoya, Inner Zone of Southwest Japan, by KIMURA (1958) for those from the eastern part of Kii Peninsula, Outer Zone of Southwest Japan, and by SHIKI (1959) for those from the Maizuru belt, northwest of Kyoto, Inner Zone of Southwest Japan, respectively.

The Yatsushiro area, Kumamoto Prefecture, Kyushu, belongs to the western part of the Outer Zone of Southwest Japan. The area has been investigated by many geologists. MATSUMOTO and KANMERA [1952, 1953 and 1962 (in press)] have recently made clear that the representative formations of Silurian to Cretaceous ages are developed in this area and that they are important to analyse the Palaeozoic and Mesozoic history.

On referring to the geological study of MATSUMOTO and KANMERA, I have been engaged in the petrographical study of the sandstones of the Palaeozoic and Mesozoic formations in the Yatsushiro area. In my previous paper (1956 in Japanese), I described the petrography of the Mesozoic sandstones from this area and discussed some problems about the classification of sandstones and its relation to the conditions which controlled the sedimentation in the successive stages of the tectonic development.

The purpose of the present paper is to describe the petrographical characters of the Palaeozoic sandstones from the Yatsushiro area and further to inquire into the provenance of the deposits, thus attempting to make some contributions to the geological history of the so-called Chichibu Geosyncline.

The Silurian formation is very narrowly exposed in the present area and has no remarkable sandstone. The Devonian is not clearly proved by fossil evidence.

Therefore the petrography of the sandstones in this paper is mainly concerned with the Upper Palaeozoic formations ranging in age from upper Lower Carboniferous to Upper Permian.

2. Acknowledgements

At the suggestion of Professor MATSUMOTO this study was primarily carried out while I was in the Department of Geology, Faculty of Science, Kyushu University. This study was partly carried out in aid of a grant from the Ministry of Education.

I wish to express my most sincere thanks to Professor Tatsuro MATSUMOTO of Kyushu University who gave me valuable advice in many respects and critically read the manuscript and to Dr. Kametoshi KANMERA of the same University who helped me from his precise knowledge of the Palaeozoic stratigraphy and has placed at my disposal his collection of sandstones. Professor MATSUMOTO and Dr. KANMERA kindly collaborate with me in describing a comprehensive problem as an appendix. I am much indebted to Professor Tôru TOMITA of Kyushu University for instructive advice on petrographic work. I wish, further, to express my hearty thanks to many gentlemen who have given me kind help and encouragement in continuing this study since I removed to the Onoda Cement & Co., Ltd.: especially Executive Director Tatsuhide NAKAO and Mr. Kengo HYAKUTAKE of Department of Mining of the Onoda Cement & Co., Ltd., Dr. Teiroku SUENO of Central Research Laboratory of the same company. I am indebted to Dr. Hakuyu OKADA for fruitful discussions, to Dr. Fumiko SHIDO and Mr. Tatsujiro UNO for their help in taking photomicrographs and to Miss Mitsuye ISHIKAWA and Miss Chizuko OKAMURA for their assistance in drafting and typing.

3. Method of study

The specimens studied are mostly collected by myself from the outcrops along the main routes which were designated as type sections of Upper Palaeozoic formations by KANMERA, who also placed courteously at my disposal his collection of sandstones of the Kakisako and Kuma formations.

I have studied those specimens in laboratory through both thin section observation and heavy mineral separation. As the procedure was written in my previous papers (1955 and 1956), the details are omitted in the present paper. Concisely speaking, the grains of heavy minerals which are separated by THOULET's solution are counted on the slide glass. The percentages of mineral components are measured in these sections by means of the microintegrator.

The mean grain size and standard deviation (sorting index) are calculated from the largest diameter of a quartz grain which is measured by a micrometer eye-piece through a thin section, following the formula which was postulated by KRUMBEIN and PETTIJOHN (1938).

The angularity of quartz grains is decided with reference to the charts of KRUMBEIN (1941) and WHALSTROM (1955).

4. General stratigraphy

Table 1 shows the nomenclature and geologic ages of the Palaeozoic formations which are developed in the researched area. It is principally reproduced from the laborious works of KANMERA (1952, 1953) and MATSUMOTO and KANMERA (1962 in press).

Fig. 1 (adapted from MATSUMOTO and KANMERA 1962 in press) and Fig. 2 (adapted from KANMERA 1952 a and b) illustrate the distribution of each formation and show the places where specimens were collected.

Geotectonically this area belongs to the Chichibu Terrain of Southwest Japan. The Palaeozoic formations are developed in the tectonic belts of NEE-SWW trend separated by parallel faults or sheared zones. Only the Tobiishi and superjacent Shimodake formations are in direct, conformable contact. Recently it has become clear that the Permian formations developed in different tectonic belts represent different sedimentary facies of almost the same geological age.

Generally speaking, the Upper Palaeozoic deposits in question consist of conglomerate, sandstone, clay slate, chert, limestone, basic tuff and basic lava. Naturally a combination of certain rock species is predominant in one formation and that of others is in another.

Some geologists interpret that the Palaeozoic deposits of Japan are of geosynclinal character, but their detailed geological features have not yet been thoroughly clarified.

Petrography

1. Characters of sandstones

Before entering into the description, I ought to give general remarks on the classification of sandstones. There are many proposals for the classification of sandstones. Although several debatable questions remain, it is not denied that many authors try to classify as quantitatively as possible by measuring through thin sections the relative amount of mineral components, grain size and angularity of grains.

It is true that the particular types, such as arkose and graywacke in the original sense, can be distinguished according to the definitions of authors, but many intermediate types are found in the actual cases. In our country the sandstones of Palaeozoic formations were often called graywacke in spite of the situation that the petrographical characters were not elucidated by detailed study. Recently

Table 1. The Summary of the stratigraphy of the Palaeozoic formations in the Yatsushiro area.

Formation name	Lithologic constituent	Pebble of conglomerate	Fossil zone & geologic age
Fukami formation	limestone, light green tuffaceous shale		*Halysites* Silurian
Kakisako formation	Lower part (330 m) clay slate, chert, limestone, conglomerate or conglomeratic sandstone	porphyrite, diabase, quartz-porphyry, aplite, sandstone	*Millerella japonica* zone (*Kueichouphyllum* zone). upper part of Lower Carboniferous
	Upper part (250 m) basic tuff, lava, tuff breccia, chert, limestone, clay slate		
Amatsuki formation	Lower part (400 m) sandstone (predominant), sandstone and slate alternation, chert		
	Upper part (230 m) slate, basic tuff, limestone, sandstone, chert		*Fusulinella bocki* zone. middle part of Upper Carboniferous
Tobiishi group	1000 m basic tuff, lava, tuff breccia, Lower / Middle / Upper } Yayamadake limestone (450 m)		"*Fusulina*" or *Beedeina* zone- *Triticites* zone- *Pseudoschwagerina* zone. middle to upper part of Upper Carboniferous- Lowest Permian
Shimodake formation	Lower part (150–200 m) sandstone, shale, Middle part (500 m) chert, clay slate Upper part (500 m) clay slate, sandstone		Probably Lower Permian
Shizo formation	300 m$\sim$600 m chert (predominant), clay slate, basic tuff, with limestone lens		*Schwagerina japonica* zone. upper Lower Permian
Yoshio formation	1500 m sandstone (predominant), shale, chert, with limestone lenses		*Neoschwagerina craticulifera haydeni* zone in the upper part
Yonaku formation	Lower part (500 m) slate and sandstone Middle part (200 m) chert and slate Upper part (300 m) slate, sandstone, chert and limestone		*Neoschwagerina simplex* zone *Yabeina globosa* zone. Middle Permian
Hashirimizu formation	500 m phyllitic slate, chert with limestone lenses		*Neoschwagerina margaritae* zone. Middle Permian
Kozaki formation	conglomerate, sandstone, shale, limestone, chert	leucocratic granite, quartz-porphry, porphyrite, andesite	*Neoschwagerina simplex* zone- *Yabeina globosa* zone. Middle Permian
Kuma formation	Lower part (180 m) black shale (predominant) Middle part (500 m) conglomerate, sandstone Upper part (250 m) alternation of sandstone and shale	granitic rock, aplite, leucocratic granite, adamellite, diorite, tonalite, diabase, gabbro, serpentinite, basalt, andesite, chert, limestone	*Lebidolina toriyamai* zone. Upper Permian
Kônose formation	basic tuff, basic lava, tuff breccia, limestone, clay slate, chert		Undifferentiated for the most part, *Yabeina globosa* zone at least in the lowest part

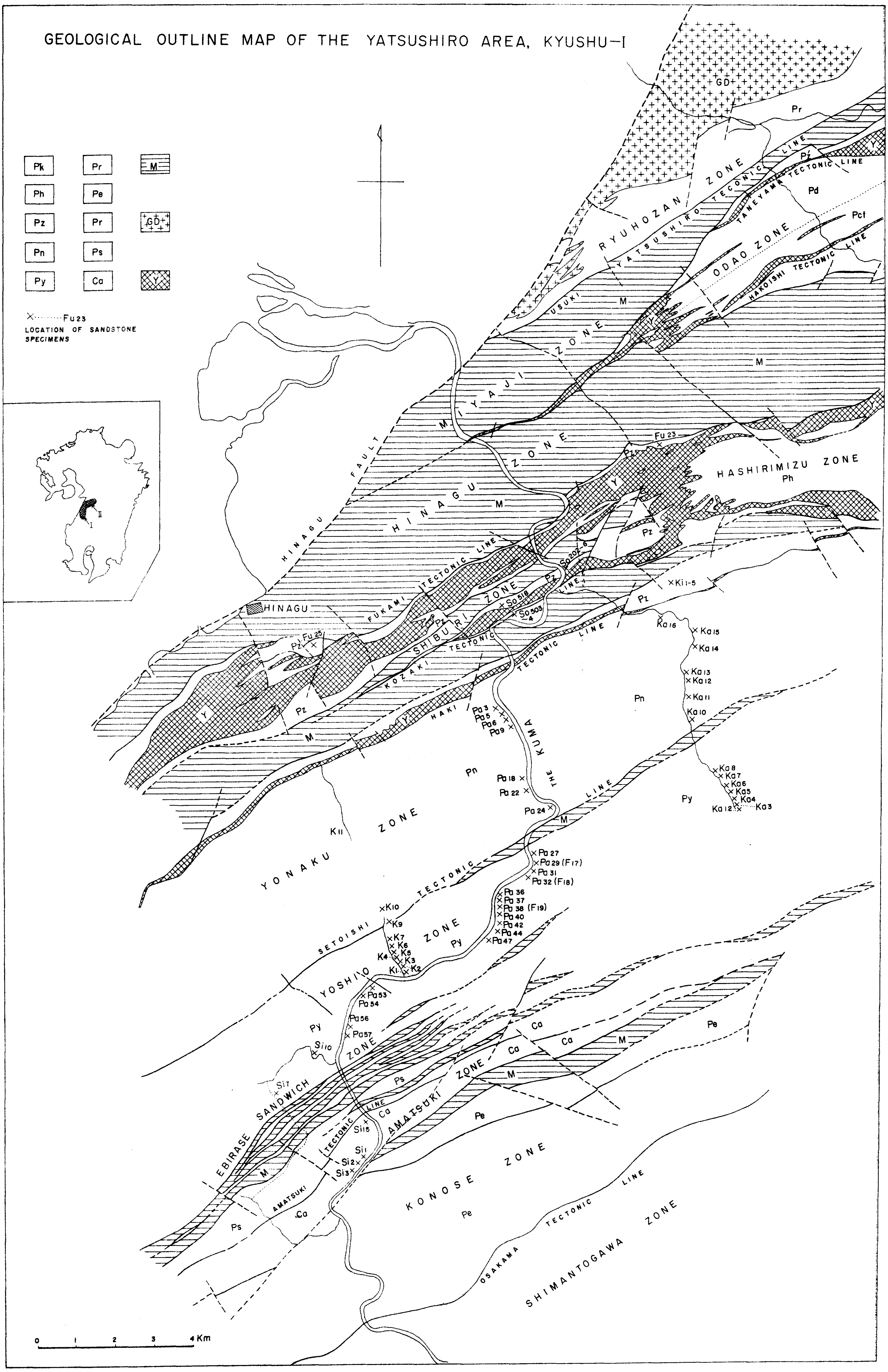

Fig. 1. Geological outline map of the Yatsushiro area, Kyushu—I

M: Mesozoic formations, GD: Miyanohara granodiorite, Pk: Kuma formation, Ph: Hashirimizu formation, Pz: Kozaki formation, Pz': Hirodaira formation, Pn: Yonaku formation, Py: Yoshio formation, Pr: Ryuhozan formation, Pe: Kônose formation, Ps: Shizo formation, Pd: Shimodake formation, Pct: Tobiishi group, Ca: Amatsuki formation, Ck: Kakisako formation, Y: Yatsushiro igneous and metamorphic rocks

1: Kasamatsu, 2: Rokuro, 3: Tobiishi, 4: Mt. Yayamadake, 5: Otogawa, 6: Futae, 7: Kawaiba, 8: Yokote

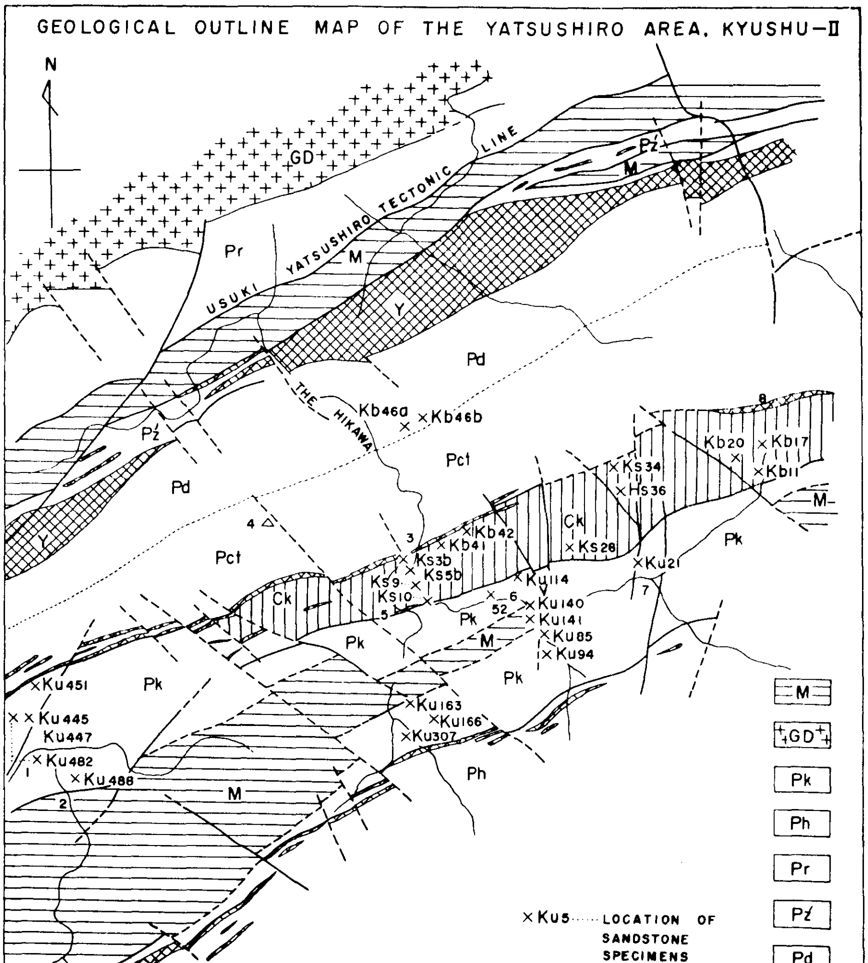

Fig. 2. Geological outline map of the Yatsushiro area, Kyushu—II
For further explanation see Fig. 1 (bottom)

Boswell (1960) and Pettijohn (1960) have pointed out that it is necessary to reexamine and redefine "Graywacke."*

* In this connection it is important to reexamine the original or typical material. Fortunately there are two recent studies of the graywacke in the Harz Mountains where the term graywacke seems to have been first applied 120 years ago. In one of them, Mattiat's conclusion is "This rock should once more be characterized as a graywacke, on the average consisting of 27 percent quartz, 19 percent feldspar, 21 percent interstitial material (chiefly chlorite and mica), 30 percent rock fragments, 2 percent heavy minerals, 1 percent other infrequent constituents." (quoted from Pettijohn, 1960).

In this paper, I describe the sandstones in reference to the following points. Tables 2 and 3 show the mean size and standard deviation of quartz grain and the percentage composition of the Upper Palaeozoic sandstones from the Yatsushiro area.

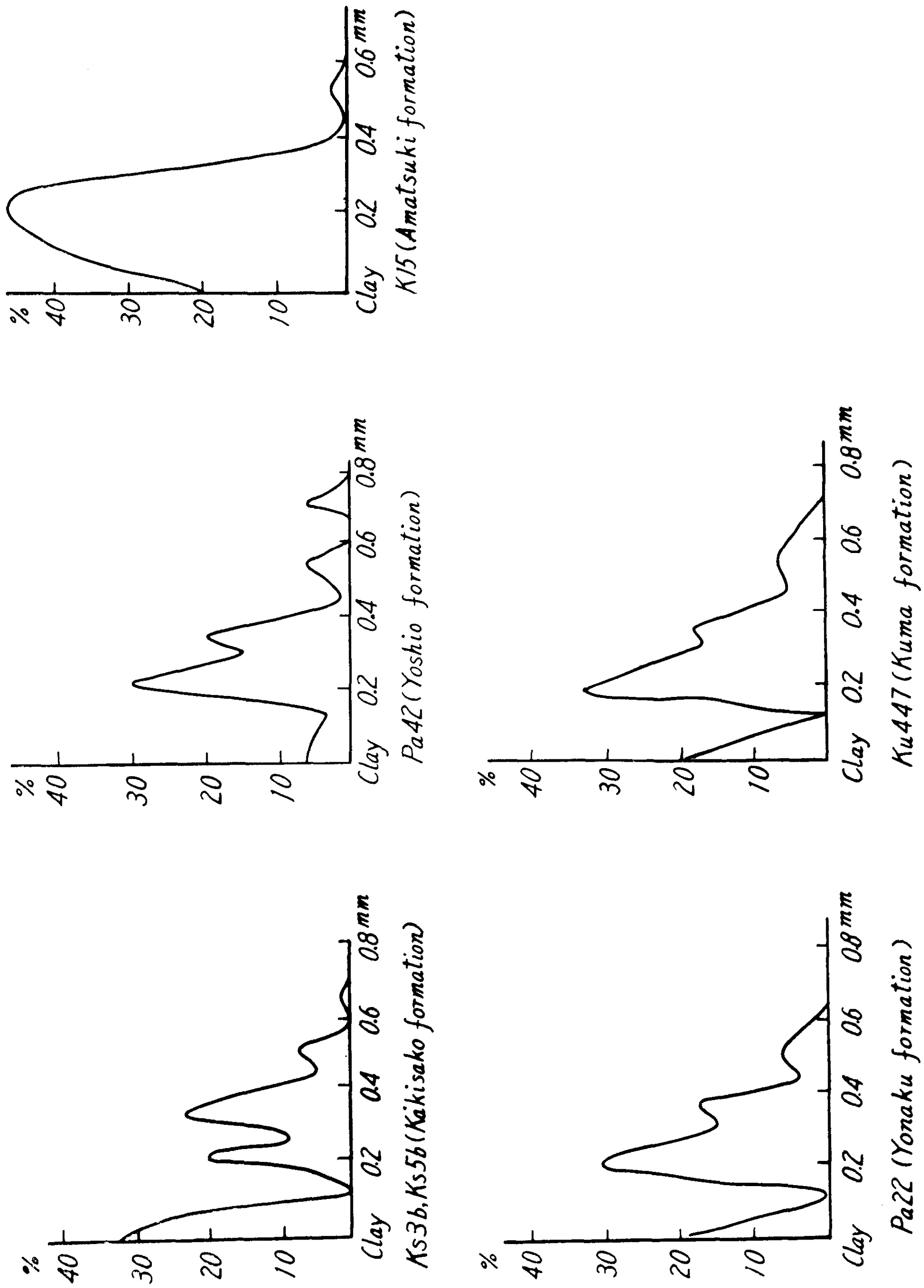

Fig. 3. Some examples of size distribution of quartz grains.

Table 2. The mean size and standard deviation of quartz grain, and the mineral composition of the Upper Palaeozoic sandstones from the Yatsushiro area. — No. 1

Sp. No.	M.S.	S.D.	Quartz	Matrix	Feld.	Ro. Fr.	Chert	Ac. Mi.
Kakisako formation								
Ks 3b	0.37	0.30	19.1	29.1	28.3	22.4	0.4	0.7
Ks 5b	0.38	0.10	18.9	33.0	38.5	7.7	1.6	0.3
Ks 9	0.32	0.26	11.9	22.1	50.7	14.4	0.1	0.8
Ks 10	0.43	0.25	20.5	19.4	41.2	13.8	4.2	0.8
Ks 28	0.29	0.05	15.7	24.7	54.3	3.7	0.5	1.1
Kf 20	0.20	0.27	13.2	47.2	24.9	11.0	3.7	
Kf 37	0.30	0.13	27.8	21.3	46.5	3.1	0.9	0.2
Kf 41	0.23	0.11	15.0	31.8	40.2	3.5	7.7	1.8
Kf 42	0.37	0.25	19.0	27.1	46.8	2.4	4.0	0.7
Amatsuki formation								
Si 1	0.52	0.19	39.9	19.6	38.7	0.8	0.5	0.5
Si 15	0.51	0.30	41.9	7.5	44.5	3.6	0.2	2.3
Shimodake formation								
Kf 46	0.52	0.20	24.7	16.8	46.2	5.4	5.4	1.5
Yoshio formation (*muddy type, **intermediate type)								
Pa 27*	0.23	0.11	13.5	68.3	13.0	2.9	0.7	1.6
Pa 29*	0.25	0.18	20.9	31.2	46.5		1.4	
Pa 31	0.55	0.14	45.0	6.5	36.8	9.9	1.8	
Pa 32**	0.32	0.17	38.2	21.9	27.1	6.2	2.3	4.3
Pa 36	0.52	0.17	32.3	19.6	39.6	5.2	2.6	0.6
Pa 37**	0.24	0.06	48.8	21.0	27.1	3.1		
Pa 38**	0.36	0.12	38.3	22.3	37.2	1.7	0.7	
Pa 40	0.34	0.14	43.6	11.2	35.0	5.1	5.1	
Pa 42	0.41	0.17	47.0	7.6	34.6	5.0	5.8	
Pa 52	0.50	0.14	34.1	7.2	56.0	1.1		1.6
Pa 57	0.37	0.25	40.0	9.5	45.5	5.0		
Fu 17	0.30	0.11	40.0	18.3	35.0	1.3	2.4	3.0
Fu 18	0.32	0.13	34.8	14.8	43.0	3.7	0.5	3.2
Fu 19	0.31	0.14	34.6	17.0	42.4	2.0	1.6	2.4
K 1	0.53	0.20	35.6	6.7	51.4	6.0	0.3	
K 3**	0.45	0.16	29.0	23.7	43.7	2.0	0.6	1.0
K 4			29.4	17.0	49.8	2.0	0.6	1.2
K 5	0.41	0.16	34.7	15.4	48.0	1.3		0.6
K 6	0.30	0.17	38.0	12.1	45.7	2.2	0.9	1.1
Ka 1	0.38	0.12	28.6	20.2	49.7	1.2	0.1	0.2
Ka 2*	0.25	0.14	26.9	45.1	27.0	0.4	0.1	0.5
Ka 3c	0.40	0.19	30.6	18.6	48.9	0.4	1.1	0.4
Ka 5*	0.31	0.08	25.6	28.1	44.6	0.5	0.8	0.4
Ka 6	0.37	0.15	36.0	19.1	42.1		1.4	1.4
Ka 6b	0.38	0.16	28.5	6.5	55.4	8.5	1.1	

Table 3. The mean size and standard deviation of quartz grain, and the mineral composition of the Upper Palaeozoic sandstones from the Yatsushiro area. — No. 2.

Sp. No.	M.S.	S.D.	Quartz	Matrix	Feld.	Ro. Fr.	Chert	Ac. Mi.
Kozaki formation								
Sa 202	0.29	0.18	28.9	28.9	34.8	5.6	1.6	0.2
Sa 204	0.29	0.12	22.9	36.7	40.0	0.1	0.2	0.1
Sa 205	0.36	0.19	21.7	23.0	32.0	22.0	1.2	0.1
Sa 206	0.31	0.14	22.8	28.9	42.1	2.2	2.2	1.8
Sa 503			19.1	32.6	36.2	10.8	1.1	0.2
Sa 504	0.23	0.14	14.1	32.0	31.4	21.9		0.6
Sa 518	0.35	0.20	27.7	17.9	26.7	25.9	0.3	1.5
Fu 23			19.5	37.7	18.8	22.0		2.0
Yonaku formation (*muddy type)								
Pa 3			21.4	27.5	42.8	5.1	2.1	1.1
Pa 4	0.62	0.11	31.4	5.8	29.0	33.1	0.7	
Pa 5*	0.30	0.12	32.2	40.6	23.8	2.5		0.9
Pa 6	0.52	0.44	40.5	14.8	39.7	3.7		1.3
Pa 9	0.32	0.26	27.3	16.0	46.4	4.1	5.2	1.0
Pa 18	0.44	0.08	25.7	14.2	56.6	2.2	1.3	
Pa 22	0.39	0.10	36.2	20.8	34.6	2.8		5.6
Pa 24*	0.25	0.14	29.8	42.1	28.1			
Ka 11*	0.40	0.20	31.7	27.1	26.6	12.4	1.8	0.4
Ka 12*	0.41	0.18	22.1	42.4	34.4	1.1		
Ka 14*	0.24	0.09	12.5	80.0	7.5			
Ka 15*	0.31	0.17	22.0	30.0	43.0	1.0	4.0	
Ka 16	0.59	0.23	39.7	17.0	30.2	1.7	1.3	0.1
K 10*	0.26	0.11	21.9	60.0	11.4	1.9	3.3	1.5
K 11*	0.40	0.22	31.7	27.7	26.6	2.0	1.8	0.2
Kuma formation								
Ku 5			23.8	23.4	44.9	5.3	0.6	2.0
Ku 21	0.36	0.18	19.0	18.8	62.2			
Ku 52	0.26	0.09	22.0	23.2	44.9	6.5	1.2	2.2
Ku 163	0.43	0.23	22.1	22.3	45.4	6.0	0.6	3.6
Ku 166	0.42	0.18	18.7	23.6	52.4	4.1	0.5	0.7
Ku 307	0.29	0.16	16.1	29.3	54.4		0.2	
Ku 447	0.43	0.15	24.1	19.0	42.4	13.6	0.5	0.4
Ku 445	0.39	0.13	23.6	18.0	52.1	2.4	1.8	2.1
Ku 482	0.42	0.14	21.5	15.2	55.4	1.4	0.4	6.1
Kf 31	0.42	0.14	23.8	18.6	55.7	1.4		0.5

(1) ***Size distribution.***—This is summarized in Fig. 3. As can be understood from this figure, the sandstones treated show rather a polymodal than a bimodal distribution.

(2) ***Relationship between the amount of clay matrix and the mean size of quartz grain.***—This is shown in Fig. 4, which indicates that there is no linear relation between the amount of clay matrix and the mean size of quartz grain, but that the amount of clay matrix decreases notably when the mean size of quartz grain comes over 0.5 mm.

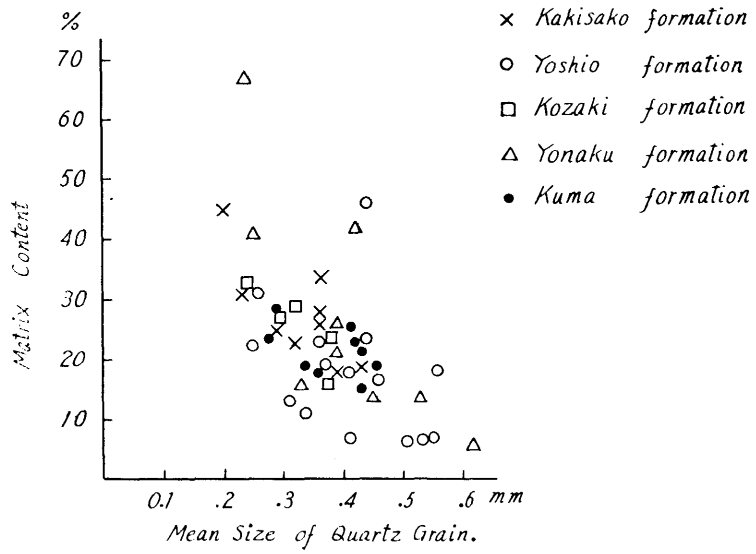

Fig. 4. Relation between the amount of clay matrix and mean size of quartz grain.

(3) ***Relationship between the mean size of quartz grain and the standard deviation (sorting index).***—As shown in Fig. 5, there is no reciprocal relation between the mean size of quartz grain and the standard deviation.

(4) ***Relationship between the amount of clay matrix and the standard deviation.***—This is summarized in Fig. 6, which shows that there is no intimate relation.

From the facts that are written in items (2), (3) and (4), it is inferred

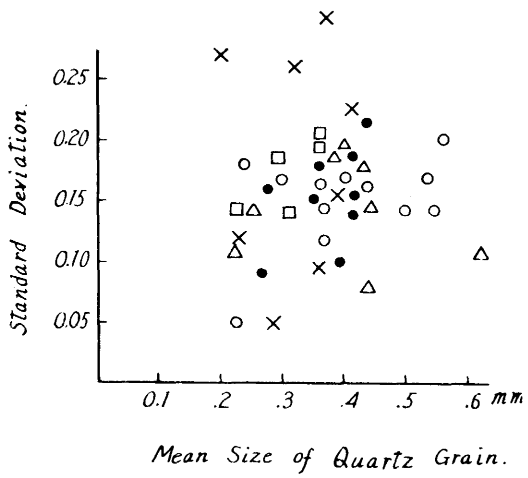

Fig. 5. Relation between the mean size of quartz grain and the standard deviation.

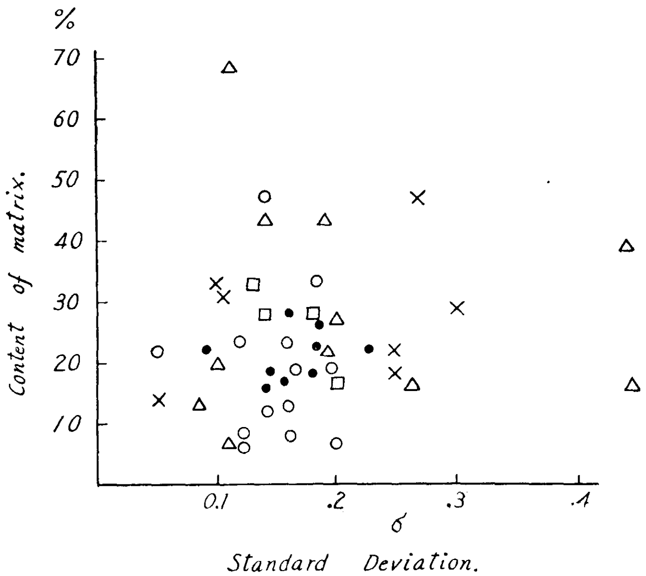

Fig. 6. Relation between the amount of clay matrix and the standard deviation.

that the sand grain and the clay matrix independently acted during transportation and deposition.

(5) ***Relationship between the amount of feldspar or quartz or rock fragments and the mean size of quartz grain.***—This is respectively illustrated in Figs. 7, 8 and 9. These figures clearly show that there are no definite relations between these factors.

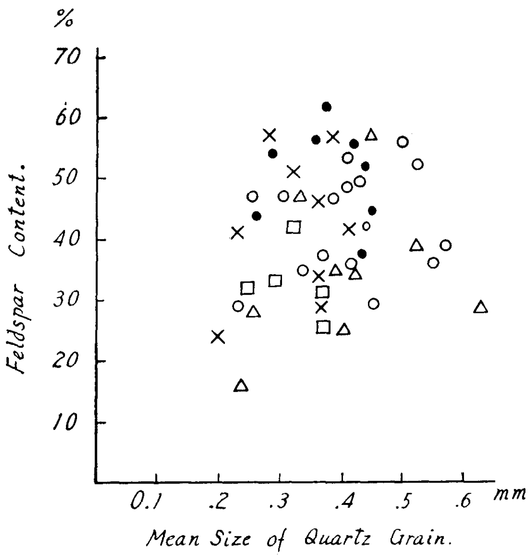

Fig. 7. Relation between the amount of feldspar and the mean size of quartz grain.

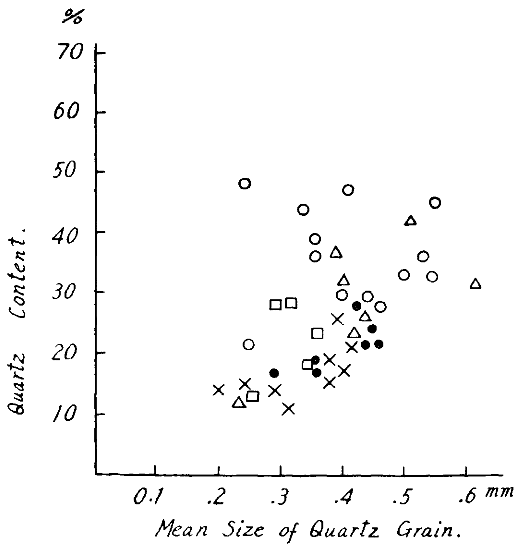

Fig. 8. Relation between the amount of quartz grain and the mean size of quartz.

In his study of the sandstones of the Maizuru Zone, northwest of Kyoto, SHIKI (1959) has pointed out the following relations. The mineral composition of sandstone is closely related with the size of grains. The larger the mean size of grains, the more quartz and the less feldspar are contained. The higher the maturity of studied sediments, less distinct becomes the relation. From my own study of the sandstones of the Yatsushiro area, the linear relations are not recognized as mentioned above. This point may be one of special characters of the Upper Palaeozoic sandstones of this area.

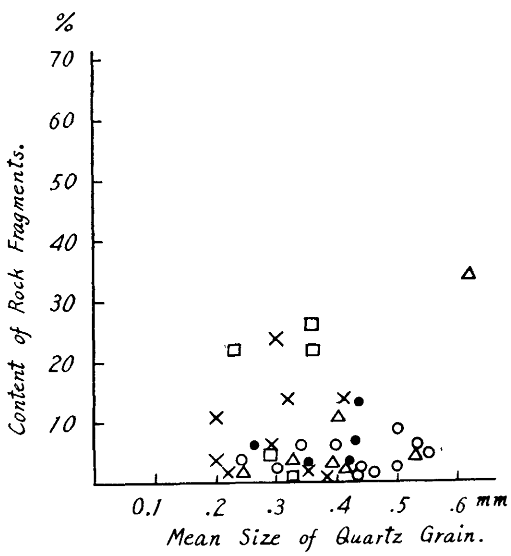

Fig. 9. Relation between the amount of rock fragments and the mean size of quartz grain.

Since no intimate relation is found between the mean grain size and the mineral composition, it is necessary to construct a classification of sandstones on the basis of both texture (mean grain size, standard deviation and size distribution) and mineral composition.

I ought to give, furthermore, some remarks on the technical terms which are employed for denoting the petrographical characters of sandstones.

Maturity.—As to maturity of sediments, two kinds are discriminated, that is, textural maturity and mineralogic maturity.

(a) *Textural maturity.*—According to FOLK (1954 and 1960) the scheme of textural maturity is as follows:

Immature: sands with more than 5 per cent clay matrix

Submature: sands with smaller amounts of clay matrix but poor sorting.

Mature: sands containing smaller amounts of clay matrix with well-sorted (ϕ under 0.5) but not well-rounded grains.

Supermature: sands with well-sorted and rounded grains.

(b) *Mineralogic maturity.*—According to WELLER (1960) the scheme of mineralogic maturity is as follows:

Immature: sands composed of ferromagnesian minerals, feldspars, quartz and heavy minerals

Submature: sands composed of feldspars, quartz and heavy minerals

Mature: sands composed of quartz and heavy minerals

As to mineralogic maturity, PETTIJOHN (1954) and DAPPLES *et al.* (1953) postulated maturity factor or quartz index respectively, which is the ratio of the amount of quartz and chert to that of feldspars and rock fragments or the ratio of the amount of quartz and chert to that of feldspars, rock fragments and clay matrix.

The sandstones examined are texturally and mineralogically immature, especially those of the Kuma formation are extremely immature, containing abundant ferromagnesian minerals such as pyroxene and amphibole and a rather large amount of clay matrix.

Provenance factor.—As the measure of source rocks from which materials were delivered, the following schemes are postulated:

(a) *Provenance factor.*—The ratio of the amount of feldspars to that of rock fragments are considered as by PETTIJOHN (1954).

(b) *Source rock index.*—Following the proposal of DAPPLES *et al.* (1953), the ratio of the amount of K-, Na-feldspars to that of rock fragments and clay matrix is counted. The measure shows how much the sandstones depend upon the source of granitic (arkose) and other unstable rocky (graywacke) terrains.

Fluidity factor (density and viscosity indices).—The ratio of the amount of mineral grains to that of clay matrix is measured as in PETTIJOHN's paper (1954).

Sorting index.—The ratio of the number of class in modal two-thirds to that in

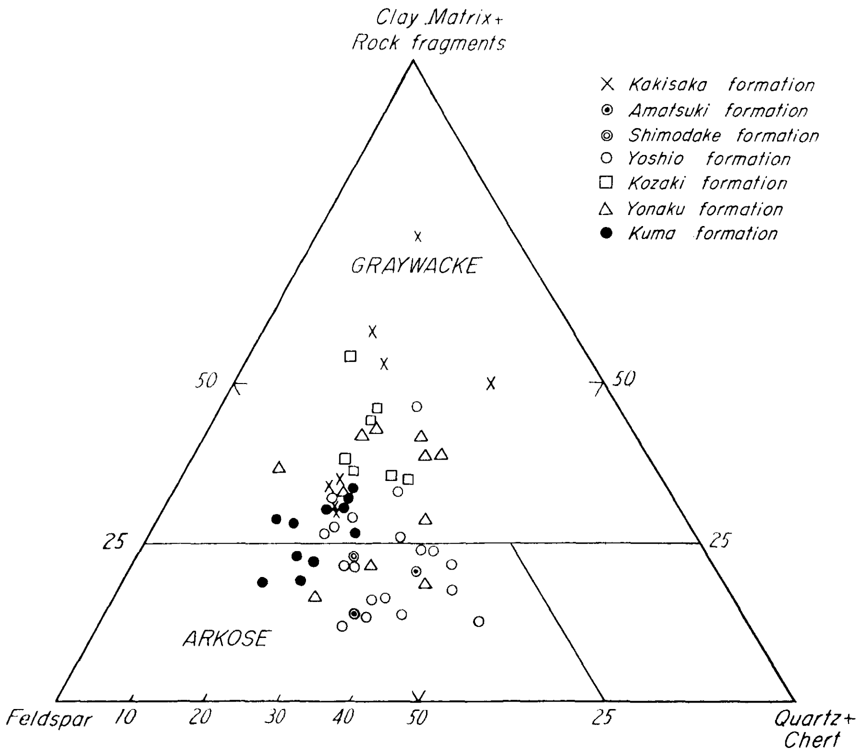

Fig. 10. Composition diagram of the Palaeozoic sandstones of the Yatsushiro area (on the scheme of DAPPLES *et al.*).

the entire size range is considered as in the work of DAPPLES *et al.* (1953).

In the following pages is given the description of the representative sandstones of each formation. The precise naming of the varieties of sandstones is difficult and their definitions differ considerably among different authors. For descriptive convenience the schemes of DAPPLES *et al.* (1953), PETTIJOHN (1957)* and my own (FUJII, 1955 and 1956)** are used in this paper. Figs. 10 and 11 show the composition

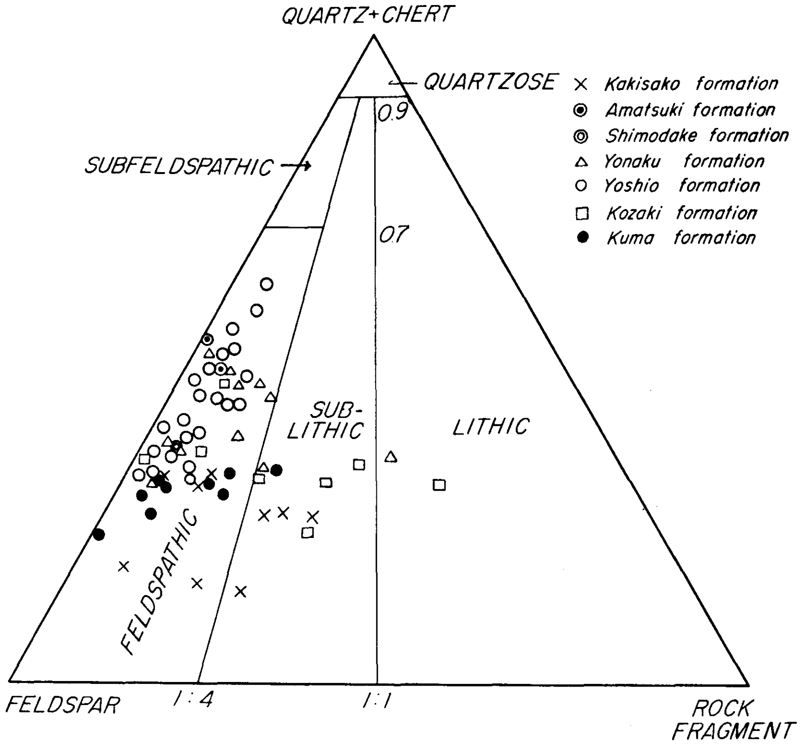

Fig. 11. Composition diagram of the Upper Palaeozoic sandstones from the Yatsushiro area. (on the scheme of FUJII).

* The classification of sandstones proposed by PETTIJOHN (1957).

Void-filler (matrix or cement)		Detrital matrix > 15% < 75%		Detrital matrix absent or scanty (< 15%). Voids empty or filled with chemical cements			
Sand or detrital fraction	Feldspar > rock fragments	GRAYWACKES	Feldspathic graywacke	ARKOSIC SANDSTONES: Arkose	ARKOSIC SANDSTONES: Subarkose or feldspathic quartzite	ORTHOQUARTZITES	chert < 5%
Sand or detrital fraction	Rock fragments > feldspar	GRAYWACKES	Lithic graywacke	LITHIC SANDSTONES: Subgraywacke	LITHIC SANDSTONES: Protoquartzite	ORTHOQUARTZITES	chert > 5%
	Quartz content	Variable, generally < 75%		< 75%	> 75% < 95%	> 95%	

** In my scheme of classification muddy sandstone is discriminated from sandstones by the amount of clay matrix (20% in 1955 and 25% in 1956). After reexamining many specimens, the boundary between the two types is placed at the 20 per cent of clay matrix.

diagrams and classification of the analysed sandstones.

(1) *Kakisako formation* (upper part of Lower Carboniferous).—In the Kakisako formation sandstones occur in a lenticular form at various horizons of the lower part. They are dark gray with a green tint and medium- to fine-grained. The composition is as follows: (average percentage of eight measured specimens) quartz 16.6, clay matrix 29.3, feldspar 40.6, rock fragments 9.8, chert 2.9 and accessory minerals 0.8 per cent. The average size of quartz grains is 0.29 mm. The standard deviation is 0.18. Speaking synthetically, this is a graywacke (in the scheme of DAPPLES *et al.*), a feldspathic graywacke (PETTIJOHN, 1957) or a muddy medium sublithic sandstone (FUJII's scheme) (see Plate 28). The matrix consists of chrolitic clay mineral and the boundary between the sand grain and the matrix is distinct. The quartz grain is sub-rounded in the finer fraction, e.g. 0.12–0.20 mm, perhaps being originated from the sedimentary rocks.

In short, the sandstones of the Kakisako formation are distinguished from those of other formations by a large amount of clay matrix and the moderate amount of volcanic and sedimentary rock fragments.

(2) *Amatsuki formation* (probably lower part of Upper Carboniferous in its lower half and middle part of Upper Carboniferous in its upper half).—The sandstones occur in rather thick beds (30 to 50 m) and are of dark gray colour. The composition is as follows: (average percentage of two measured specimens) quartz 40.5, clay matrix 13.6, feldspar 41.6, rock fragments 2.3, chert 0.5 and accessory minerals 1.5 per cent. The mean size of quartz grain is 0.52 mm. The standard deviation is 0.24. This is an arkose (DAPPLES *et al.*) or an arkose (PETTIJOHN, 1957) or a coarse-grained feldspathic sandstone (FUJII) (see Plate 29, Figs. 1–4). The sandstone of this formation is distinguished from others by the large amounts of feldspar and quartz, the smaller amount of clay matrix and the scarcity of rock fragments and accessory minerals.*

(3) *Shimodake formation* (upper part of Lower Permian).—In this formation sandstones are predominant, occupying the lower member of 150–200 meters in thickness. They are white gray or dark gray and coarse- to medium-grained. The composition of a representative specimen is as follows: quartz 24.7, clay matrix 16.8, feldspar 46.2, rock fragments 5.4, chert 5.4 and accessory minerals 1.5 per cent. The mean size of quartz grain is 0.52 mm. The standard deviation is 0.20. This is an arkose (DAPPLES *et al.*) or a feldspathic graywacke (PETTIJOHN, 1957) or a coarse-grained feldspathic sandstone (FUJII) (see Plate 29, Figs. 5–6). The sandstones of the Shimodake formation are distinguished from those of other formations by the lesser amount of clay matrix and the moderate amount of rock fragments and chert.

* As is described in page 198, the sandstone is characterized by a simple assemblage of heavy minerals: zircon, tourmaline, garnet and biotite.

(4) *Yoshio formation* (Middle Permian in its upper part).—There are three kinds of sandstones, that is, the coarser sandstone, the finer muddy sandstone and the intermediate sandstone. The first is exceedingly predominant over the others and occurs in rather thick beds, accompanied with chert, clay slate and alternating thin beds of shale and sandy siltstone. The finer type sandstone occurs as smaller lenses in the clay slate and is accompanied with chert and limestone.

In the coarser type the mineral composition is as follows: (the average percentage of seventeen measured specimens) quartz 36.0, clay matrix 13.4, feldspar 45.4, rock fragments 2.9, chert 1.5 and accessory minerals 0.9 per cent. The mean size of quartz grain is 0.41 mm. The standard deviation is 0.15 This is an arkose (DAPPLES *et al.*) or an arkose (PETTIJOHN, 1957) or a medium-grained feldspathic sandstone (FUJII) (see Plate 30, Figs. 1–2). The quartz grain is angular to subangular. The matrix consists of bituminous and chloritic clay minerals as well as biotite shreds. The amount of clay matrix is relatively small and the existence of large grains of quartz, feldspar and rock fragments (1–2 mm) is particularly noted.

Although some of the specimens contain abundantly patches of black shale of probably contemporaneous origin, the sandstones on the average contain a large amount of feldspar.

The muddy type has the composition of quartz 21.7, clay matrix 43.2, feldspar 32.8, rock fragments 0.9, chert 0.8 and accessory minerals 0.6 percent (the average percentage of four specimens). The mean size of quartz grain is 0.26 mm. The standard deviation is 0.13. This is a graywacke (DAPPLES *et al.*) or a feldspathic graywacke (PETTIJOHN, 1957) or a muddy medium-grained feldspathic sandstone (FUJII). There is an intermediate type between the two types above mentioned. The intermediate type has the composition of quartz 39.6, matrix 21.9, feldspar 34.3, rock fragments 3.2, chert 0.8 and accessory minerals 0.2 per cent (the average percentage of four specimens). The mean size of quartz grain is 0.34 mm. The standard deviation is 0.13. This is a graywacke (DAPPLES *et al.*) or a feldspathic graywacke (PETTIJOHN, 1957) or a muddy medium-grained feldspathic sandstone (FUJII) (see Plate 30, Figs. 3–6).

(5) *Kozaki formation* (Middle Permian).—This formation is distributed rather narrowly and discontinuously along the Yatsushiro igneous and metamorphic rocks which are squeezed out through the faults or sheared zones. Sandstones mostly occur in massive bodies, being accompanied with conglomerete. They are of dark colour—almost black. The composition is as follows: (the average percentage of eight measured specimens) quartz 22.1, clay matrix 29.7, feldspar 32.7, rock fragments 13.9, chert 0.7 and accessory minerals 0.9 per cent. The rock fragments are primarily those of volcanic rocks. The mean size of quartz grain is 0.30 mm. The standard deviation is 0.17. This is a graywacke (DAPPLES *et al.*) or a feldspathic graywacke (PETTIJOHN, 1957) or a muddy sublithic sandstone (FUJII). The examined specimens

of the Kozaki formation actually range from muddy feldspathic, through muddy sublithic, to less muddy lithic sandstones (see Table 3, Text-figs. 10-11 and Plate 32, Figs. 1-4). The last type sandstone is thin-bedded, while others are massive.

(6) *Yonaku formation* (Middle Permian).—Sandstones occur as intercalates in or between chert and clay slate. There are two kinds of sandstones. One is the finner muddy sandstone and the other is the coarser sandstone. The former occurs in very thick masses (of ten meters or so) and the latter in beds of moderate thickness (4 to 5 m). The muddy type (Plate 33, Figs. 1-4) has the composition of quartz 26.7, clay matrix 33.1, feldspar 33.9, rock fragments 3.9, chert 0.5 and accessory minerals 1.9 per cent (the average percentage of six measured specimens). The mean size of quartz grain is 0.29 mm. The standard deviation is 0.14. This is a graywacke (DAPPLES *et al.*) or a feldspathic graywacke (PETTIJOHN, 1957) or a muddy medium-grained feldspathic sandstone (FUJII).

The coarser type (Plate 33, Figs. 5-6) has the composition of quartz 31.5, clay matrix 16.0, feldspar 43.2, rock fragments 6.9, chert 1.3 and accessory minerals 1.7 per cent (the average percentage of eight measured specimens). The mean size of quartz grain is 0.45 mm. The standard deviation is 0.24. This is an arkose (DAPPLES *et al.*) or a feldspathic graywacke (PETTIJOHN, 1957) or a medium-grained feldspathic sandstone (FUJII). In both types the clay matrix consists of bituminous clay mineral, biotite shreds and its alteration products. The quartz grain is angular to subangular. The grains of vein quartz of more than 2 mm are seen in the coarser types.

(7) *Kuma formation* (Upper Permian).—The Kuma formation, which is about 930 meters thick, consists of beds or bodies of conglomerate, sandstone, black shale, and alternating sandstone and black shale, with a subordinate amount of arenaceous limestone in a small lenticular form. Sandstones occur in beds of various thickness, sometimes alternating with shale or sandy shale and some other times forming thick beds or massive bodies. They are dark gray green. The composition is fairly variable but on the average (of ten measured specimens) as follows: quartz 21.5, clay matrix 21.1, feldspar 50.9, rock fragments 4.1, chert 0.6 and accessory minerals 1.8 per cent. The mean size of quartz grain is 0.37 mm. The standard deviation is 0.15. This is a graywacke (DAPPLES *et al.*) or a feldspathic graywacke (PETTIJOHN, 1957) or a medium-grained muddy feldspathic sandstone (FUJII) (see Plate 31, Figs. 1-6). The quartz grain is angular. Matrix consists of chrolitic clay minerals as well as biotite shreds. The sandstones of the Kuma formation are distinguished from those of other formations by a relatively larger amount of accessory minerals such as amphiboles and pyroxenes which are well recognized even in thin sections.*

2. Mineral composition

* As there is a variety (0-6.1%) in the amount of accessory minerals among different specimens, the average is only 1.8 per cent. Corresponding to this variation there is a lateral change in the composition of sandstones, too.

The mineral composition of the Palaeozoic sandstones from the Yatsushiro area is indicated in Tables 4 and 5.

Major constituents are described under this heading.

(1) *Quartz.*—Quartz is common in the examined sandstones, although it is next to feldspars in the order of abundance.

WEAVER (1955) discriminated the following types of quartz of different origins.

(a) *Plutonic quartz* (MACKIE, 1896; GILLIGAN, 1920; TYLER, 1936; KRYNINE, 1940). This has no or moderate strain shadow and relatively few inclusions. In many cases bubbles or vacuoles (cavities) of the following types are contained:

(i) small dissected bubbles

(ii) bubble trains or planes

(iii) elongated and dendritic vacuoles

Crystal inclusions are rutile needles; brown, olive and gray tourmaline; colourless zircon; apatite and quartz (rounded, prismatic inclusion). KRYNINE (1944) pointed out that plutonic quartz is crystallographically single with a straight extinction and has few vacuoles.

(b) *End phase quartz* (Hydrothermal quartz).—All sorts of quartz which crystallized in the late stage of magmatic differentiation, including a pegmatitic and a vein quartz, are called the end phase quartz. This quartz is characterized by the flame extinction, the comb structure and the abundance of parallel bubble trains.

FOLK (1960) identified the vein quartz, in his study of Silurian sections by the semicomposite, blocky extinction and by the abundance of tiny vacuole inclusions.

(c) *Metamorphic quartz.*—The metamorphic quartz grains are composed of tightly locked crystals each of which ranges in size from 10 to 50 microns and has a border of various degrees of crenulation. The extinction in all cases is undulatory; in some grains anomalous blue interference colour can be seen. A few bubbles and occasionally minute crystals of sillimanite may be included.

(d) *Volcanic quartz.*—This occurs as a lath-shaped grain. In many cases it is made up of several individual quartz units.

(e) *Microcrystalline quartz.*—It occurs

(i) as a detrital, second cycle grain

(ii) as a nodule and as a cementing matter in a quartzite.

This is recognized under the microscope as tightly packed minute crystals of quartz each of which ranges in size from less than one to 60 microns in diameter, 5–10 microns on the average.

In this study I discriminate the following four types of quartz grain, taking into account the above explained classification of WEAVER.

(a) *Plutonic quartz* (common quartz).—The grain which consists of several crystallographic units, each of which shows the straight extinction, is also included herein as a variety a′. Grains composed of (a) or (a′) type of quartz and K-feldspar or microcline are frequently recognized. From this and other facts this group of quartz is inferred to have been originated probably from the granitic rock (see Plate 32, Fig. 6).

(b) *End phase quartz* or *hydrothermal quartz* or *vein quartz.*—The quartz grains which show semi-composite and blocky extinction are regarded as belonging to this group. Some of them exceed 2 mm in diameter (see Plate 32, Fig. 5).

(c) *Metamorphic quartz.*—This quartz grain (Plate 32, Fig 7) is identified by the diagnosis given by WEAVER. Naturally the mosaic quartz grain which may be of hornfelsic origin is included herein. Mylonitic quartz grains occur in the Yoshio, Yonaku and Kuma formations.

(d) The grain which is recognized as an unmistakable *volcanic quartz* is not found in the sandstones studied.

(e) *Aggregates of micro-* or *cryptocrystalline quartz.*—The grain composed of microcrystalline, tightly packed minute crystals of quartz belongs to this type. It is not certain whether these grains were originated from siliceous sediments, aphanitic igneous rocks, groundmass of porphyritic rocks, or certain metamorphic rocks.

In the examined specimens all kinds of quartz from (a) to (e), except (d), are found, but a certain type is characteristic of a particular formation. In the Kakisako formation, for example, type (a) is common and a small amount of type (c) is seen, too. In the Yoshio and Yonaku formations type (a) is common, also type (a′) is not infrequent, and types (b) and (c) are subordinately seen. In the Kuma formation type (a) is predominant, while other types are rare.

(2) *Feldspars.*—Feldspars are the chief component of the Upper Palaeozoic sandstones of the Yatsushiro area. Nearly all the grains are fresh and few grains have a clouded appearance, being suffered from some alteration.

(a) *K-feldspar* is discriminated by the absence of twin and by the refractive index lower than that of quartz. K-feldspar is common in all the formations except in the Kakisako and Kozaki formations. Perthite is found in the Shimodake, Yoshio and Amatsuki formations.

(b) *Microcline.*—The grain showing the grid twinning (the so-called microcline structure) is observed in all the formations except in the Kozaki and Kuma formations. This is conventionally called the microcline, although the identification is is not accurate.

(c) *Plagioclase* occurs commonly in all the formations, being fresh or slightly altered. Plagioclase grains are angular to subangular and show commonly albite twin lamella and rarely Carlsbad twin. Plagioclase species are determined chiefly by the method of the maximum extinction angle (WHALSTROM, 1955). As far as the examined specimens are concerned, the plagioclase species belong mostly to the oligoclase-anorthite and do not seem to vary with the formation.

(d) *Myrmekite* occurs in every formation scattering in a larger or smaller

Table 4. Mineral composition of the Upper Palaeozoic sandstones from the Yatsushiro area.—No. 1.

Sp. No.	Quartz (a)	(b)	(c)	(e)	Feldspar (K)	(P)	(Mi)	(My)	R.F. (I)	(M)	(S)	Tm	Zr	Gt	Ru	Tn	Am	Px	Hy	Ep	Zs	Bi	Ms
Kakisako formation																							
Ks 3b	x			x		x			x		x	▲	●	▲	△			×	×	▲		▲	
Ks 5b	x			x		x			x	x	x		○		×		△	△		○	△		
Ks 9	x			x		x			x	x	x	▲	●				▲	△		▲	△	△	△
Ks 10	x			x		x		x	x	x	x	△	●	▲			△	▲		▲			
Ks 28	x		x	x		x	x	x	x				●			▲							
Kf 11	x					x							●		×								△
Kf 17	x			x		x							●		×								△
Kf 20	x		x	x		x	x		x	x	x		○	▲		○	△	△		▲			
Kf 37	x			x		x					x	▲	○	○		△				▲		▲	
Kf 41	x					x		x	x			▲	○	○		▲						▲	
Kf 42	x		x	x		x			x	x		△	○	○					△			▲	
Amatsuki formation																							
Si 1	x		x	x	x	x			x		x	△		△								△	
Si 2												△	●	△	△					×		△	
Si 4												△	●	△								△	
Si 15	x		x	x	x	x			x			△	●	△	×							△	
Shimodake formation																							
Kf 46a	x			x	x	x			x	x	x	▲	●	▲				×		▲	▲		
Kf 46b	x		x	x	x	x			x	x	x	▲	●	▲						▲	△		
Yoshio formation (*muddy type, ** intermediate type)																							
K 1	x			x	x	x	x		x	x	x	▲	○	○				▲		○		▲	▲
K 2*	x			x	x	x	x		x	x	x	△	▲	○			▲	▲		▲	△	▲	▲
K 3**	x			x	x	x	x		x	x		△	○	○		▲				▲		△	
K 4	x			x	x	x				x		△	○	○		△			△	△		△	
K 5*	x			x		x	x	x		x		▲	○	○						▲	▲		△
K 6	x			x	x	x	x		x			▲	○	○			△	▲				▲	△
K 7	x			x	x	x			x				△	●						▲	▲		×
K 8												△	○	△				△		○	○		
Ka 1	x				x	x	x			x			○	○			△					▲	
Ka 2	x			x	x	x	x		x				○	○		△		△		×			
Ka 3c	x		x	x	x	x				x			○	○		△	×	×		△			
Ka 4												△	○	○		▲		×	△	▲	△		△
Ka 5	x			x	x	x					x	△	○	○				▲		○		△	
Ka 6	x				x	x				x	x	△	▲	○			▲	▲		○		▲	
Ka 7	x			x	x	x			x	x	x	▲	○	▲		×	×	×		△	△	○	△
Ka 8													○	○						○		×	
Pa 27	x	x	x	x		x			x	x	x		○	○								○	
Pa 29*	x		x	x		x	x		x	x		△	▲	▲			▲	○					△
Pa 31	x		x	x		x	x	x	x	x	x	△	○	○								▲	×
Pa 32**	x			x								△	○	○								▲	×
Pa 36	x		x	x		x	x		x		x		▲	○			△			▲	▲	△	△
Pa 37**	x					x	x					△	○	○				△		△		▲	
Pa 38**	x				x	x	x			x	x	△	○	▲				▲	×	▲	▲	△	
Pa 40	x					x						△	○	○			△			▲		▲	
Pa 42	x		x			x	x						○	○				△		△		△	
Pa 47	x					x																	
Pa 52	x		x			x	x		x			×	○	○		△	×					△	
Pa 54	x					x			x		x	△	▲	○		×		×	△	▲		△	
Pa 56	x				x	x	x				x		○	△				△	○	○	△		
Pa 57	x			x	x	x	x	x		x	x	△	○	○				△		△		△	

Table 5. Mineral composition of the Upper Palaeozoic sandstones from the Yatsushiro area.—No. 2.

Sp. No.	Quartz (a)	(b)	(c)	(e)	Feldspar (K)	(P)	(Mi)	(My)	R·F. (I)	(M)	(S)	Tm	Zr	Gt	Ru	Tn	Am	Px	Hy	Ep	Zs	Bi	Ms
Kozaki formation																							
Sa 503	x		x	x		x			x		x	×	▲	▲		●	×			▲	×		
Sa 504	x			x		x			x	x	x	×	○	▲		▲				○	▲		
Sa 202	x			x		x			x				△	▲						○	○		
Sa 204	x			x		x			x				△	▲						●			
Sa 205	x			x		x			x				△	▲						○	○		
Sa 206	x			x		x			x				○	△						▲	○		
Ki 1												△	△	△				○		○	▲		
Ki 2													△	△				○		○	▲		
Ki 3													△	△				○		○	△		
Ki 4													△	△				○		○	△		
Ki 5													▲	△				○		○	△		
Yonaku formation (*muddy type)																							
Pa 3	x		x	x	x	x				x	x	▲	▲	▲				▲		▲		▲	
Pa 4	x		x	x		x	x	x	x	x	x	△	▲	▲	×	▲		▲	△	▲		▲	×
Pa 6	x	x	x	x		x	x	x	x	x	x		△	▲						○			▲
Pa 9	x	x	x	x		x	x	x	x	x	x	▲	▲	△	×					○	▲		
Pa 18	x			x	x	x	x		x		x	△	○	○								△	△
Pa 22	x		x	x	x	x	x			x	x	△	▲	○		△						△	
Pa 24*	x		x	x	x	x	x	x	x	x		△	▲	○			△	△		○			
Pa 26	x		x	x	x	x			x	x		△	○	○				△		△	△	△	
K 9	x			x		x		x	x	x	x		●	▲								△	△
K 11*	x			x	x	x				x			●										
K 12*	x	x		x	x	x	x			x	x		○	○		▲		×		○	△		
K 13	x		x		x	x				x	x		○	○						○			△
Kuma formation																							
Ku 5	x			x	x	x			x				▲			△		○		▲	○		
Ku 21	x		x	x		x			x	x			△	△			▲	○			▲		
Ku 52	x		x	x		x			x	x			△	△			▲	○		○			
Ku 94													△	△			○	△		○			
Ku 114													△	×			▲	○		▲	○		
Ku 163	x		x	x		x			x	x	x		△	×				○		○	○		
Ku 166	x		x	x	x	x			x				△	×				×		○	○		
Ku 307	x					x			x				△	×		△		○		○			
Ku 445	x			x	x	x			x				●										
Ku 451													●			△				▲			
Ku 482	x		x	x		x		x	x	x			△		△		●			△			
Ku 488													▲				▲	▲		▲			▲
Kf 38													▲			▲	▲			▲	▲		

Explanatory notes for tables 4–5.

Quartz
- (a) plutonic
- (b) end phase
- (c) metamorphic
- (e) aggregates of cryptocrystalline quartz

Feldspar
- (K) K-feldspar
- (P) plagioclase
- (Mi) microcline
- (My) myrmekite

R.F. (Rock Fragments)
- (I) igneous rocks
- (M) metamorphic rocks
- (S) sedimentary rocks

Heavy Minerals
- Tm: tourmaline
- Zr: zircon
- Gt: garnet
- Ru: rutile
- Tn: titanite
- Am: amphibole
- Px: pyroxene
- Hy: hypersthene
- Ep: epidote
- Zs: zoisite
- Bi: biotite
- Ms: muscovite

- ● predominant (more than 60 per cent)
- ○ abundant (59–20 per cent)
- ▲ fairly abundant (19–5 per cent)
- △ common (4–1 per cent)
- × rare (less than 1 per cent)

amount. It is especially common in the Yoshio and Yonaku formations.

(3) *Rock fragments.*—Many kinds of rock fragments are contained in all the formations as sand grains. They are relatively abundant (10 per cent or more) in some of the Kakisako and many of the Kozaki formation.

(a) *Volcanic rocks.*—The grains showing the andesitic or basaltic textures occur in variable amounts in almost all the formations, being common in the Kakisako, Kozaki and Kuma formations. Some dike rocks may be included in the category of volcanic rocks. The volcanic rock in the grains of the Kakisako formation is regarded as acid to intermediate, because the plagioclase is oligoclase to andesine.

(b) *Metamorphic rock.*—The fragments which are of metamorphic origin are as follows:

- (i) quartz-sericite schist
- (ii) quartz-biotite schist
- (iii) hornblende-quartz schist
- (iv) hornfels
- (v) graphite-quartz phyllite

A grain which can be called tourmaline-quartz schist is seen in the sandstone of the Yoshio formation (Sp. No. Pa 57). The fragments of metamorphic rocks are observed in every formation, although in variable amounts.

(c) *Sedimentary rocks.*—The fragments of chert, sandstone and clay slate are found in all the formations. The chert grain which was replaced by the iron ore is seen in the sandstone of the Kakisako formation. Fragments of acid pyroclastic rocks occur in the Kakisako and Shimodake formations.

(d) *Granitic rocks.*—The fragments of granitic rocks consisting of quartz and K-feldspar or microcline or myrmekite with a hypidiomorphic granular texture occur abundantly in the Yonaku and Yoshio formations.

(e) *Basic* or *ultrabasic rocks.*—The grain which is considered to be derived from basic or ultrabasic rocks such as serpentinite and pyroxenite are rarely found in the Kakisako, Yoshio and Kuma formations.

(4) *Accessory minerals.*—Accessory minerals such as titanite, epidote, pyroxene and amphibole occur in all the formations in variable amounts as a fraction of major constituents. Especially in the Kuma formation abundant amphiboles and pyroxenes are observed even in thin sections.

3. Heavy minerals

In the following pages the heavy minerals are described in the general order of abundance.

(1) *Zircon.*—Zirzon is contained in every specimen, but it is variable in its kind and abundance. Varieties of zircon are classified according to their colour, crystal habit and roundness for mere descriptive purpose. Following are typical varieties:

colourless	euhedral	A
	rounded	B
light purple	euhedral	C
	rounded	D
purple	euhedral	E
	rounded	F
broken crystal		G

The distribution of these types in the examined specimens is summarized in Table 6 with average percentage.

Table 6. The distribution of zircon varieties in the Upper Palaeozoic sandstones from the Yatsushiro area.

Zircon type / Formation	A	B	C	D	E	F	G
Kakisako formation	47	23		1			29
Amatsuki formation	60	16	4	2		4	14
Shimodake formation	6	22					72
Yoshio formation	23	25		12	6	23	11
Yonaku formation	65	21	3	6		2	3
Kuma formation	50	50					

The type F zircon, which is characterized by the dark purple colour, dark spot-like inclusions and nearly perfect roundness, probably belongs to what TOMITA (1954) called the Archean granite zircon. It occurs in the Amatsuki, Yoshio and Yonaku formations. The amount of zircon (of various types) is large in the sandstones of those formations. In some parts of the Yoshio and Yonaku formations garnet and granitic materials are abundant as sand grains. This is interesting for the interpretation of the source rocks.

(2) *Garnet.*—Garnet is common in every formation, especially abundant in the Yoshio and Yonaku formations. The varieties are mostly colourless to pink or light brown. The grains show abraded features in the Kakisako formation. In the Yoshio and Yonaku formations the garnet is euhedral and freshly fractured. The garnet of the Shimodake formation is characterized by the mosaic development of rectangular facets.

(3) *Epidote.*—Epidote is common in all the sandstones studied.* The three types of grains are observed. The first is prismatic. The second is the flake frac-

* As was mentioned in my previous paper (1956), epidote is absent or rare in the sandstones of the Sakamoto formation (Jurassic) of this area. Therefore, epidote can be called the index mineral to the Upper Palaeozoic sandstones in contrast to the Sakamoto formation. This fact is useful to discriminate the Upper Palaeozoic formations from the Sakamoto formation.

tioned on 001 plane, exhibiting the partial (compass-needle) interference figure, due to emergence of one optic axis. The third is pale yellowish-green subangular grains like small chips of broken "bottle-glass."

(4) *Zoisite.*—The colourless or light green grains of zoisite occur in every formation. The grain shows abnormal interference colour (ultrablue) and does not exhibit a perfect extinction.

(5) *Pyroxene.*—Pyroxene is seen in almost all the formations, especially abundant in the Kuma formation. It is colourless or light brown and prismatic in shape.

(6) *Biotite.*—Biotite occurs in every formation, especially commonly in the Yoshio and Yonaku formations. The biotite flakes are mostly brown or yellowish brown cleavage blades, showing no pleochroism.

(7) *Muscovite.*—Muscovite occurs in every formation, especially commonly in the Yoshio and Yonaku formations.

(8) *Amphibole.*—Amphibole occurs in every formation although it may be sparse. It is not distributed uniformly in a formation, for the mineral may be intensely affected by the sorting agents. In a certain sandstone of the Kuma formation it is abundant.

Amphibole of the Kuma formation is green with bluish tint, has $\widehat{cz}$ 15°–20°, and thus seems to be of alkali-rich type.

(9) *Tourmaline.*—KRYNINE (1946) attempted to trace the varieties of tourmaline up to their original rocks. He classified the following types (Table 7).

Table 7. The varieties of tourmaline group.

Mother Rocks	Size	Colour	Morphology	Inclusion
Granitic tourmaline	small or medium	dark brown	idiomorphic	fill of bubbles & cavities
Pegmatic	very large	blue (mouve & lavender)		rare
Pegmatic tourmaline and Metamorphic tourmaline	smaller than granitic tourmaline · very small	brown colourless pale brown	variable	black carbonaceous inclusion

(After KRYNINE, 1946)

Tourmaline occurs in every formation, although it is sparse. The distribution of the varieties is as follows:

Kakisako formation .... yellowish green, and greenish brown euhedral grains
Amatsuki formation .... brown euhedral grain with inclusions
Yonaku formation, Yoshio formation .... yellowish brown, greenish brown, pale green, bluish green; euhedral and rounded grains, some of which have carbonaceous inclusions

Kuma formation .... brown, rather large grains

Most of the tourmaline grains without carbonaceous inclusions may belong to the granitic tourmaline according to KRYNINE. But the tourmaline which is contained in the grains of tourmaline-quartz schist in the sandstone of the Yoshio formation is of green colour without inclusions and would be called the "granitic type," Therefore more study is necessary to trace the tourmaline types to their mother rocks. It is possible that some of KRYNINE'S granitic tourmaline may be originated from metamorphic rocks.

(10) *Hypersthene.*—It occurs rarely as fresh, prismatic grains in the Kakisako, Yoshio and Yonaku formations. The mineral is easily identified by the characteristic pleochroism.

(11) *Titanite.*—Although in a small amount, titanite occurs in every formation.

4. Heavy mineral suites

In the Upper Palaeozoic formations of the Yatsushiro area a simple suite of heavy minerals is shown only in one case, that is by the sandstones of the Amatsuki formation. In other formations composite suites are concluded from the heavy mineral analysis of numerous sandstone specimens. In spite of this composite situation the sandstones of a particular formation have a particular type of heavy mineral assemblage which is distinguished from other types of other formations.

Even if two formations are similar in the assemblage of heavy minerals, they may be different in the relative abundance of mineral species and in the detailed character of minerals such as colour and crystal habits. Thus the following heavy mineral suites are observed in the respective formations.

(1) *Kakisako formation.*—The non-opaque heavy mineral is rather small in the amount. The broken crystals are abundant but their size is uniform.

(a) suite .... zircon, biotite, titanite, garnet, epidote

(b) suite .... garnet-epidote-pyroxene-amphibole; epidote-amphibole-zoisite

(c) suite .... biotite, garnet

(2) *Amatsuki formation.*—The heavy mineral grains are 0.17–0.10 mm in size and rather of mixed grade. The amount of the separated heavy minerals is moderate.

(a) suite .... zircon, biotite, tourmaline, garnet

(3) *Shimodake formation.*—The heavy mineral grains occur in a large amount and are angular in shape.

(a) suite .... zircon

(b) suite .... epidote, garnet, zoisite

(4) *Yoshio formation.*—The heavy mineral grains are moderate to large in amount and angular to rounded. As to the zircon, for example, the tiny perfectly rounded grains (30–50 microns) are mixed with coarser euhedral ones. This fact

Table 8. The general summary of sandstone types, major constituents, heavy mineral compositions and the inferred source rocks.

Formation	Types of sandstone	Heavy minerals			Quartz	Feldspar	Rock fragments	Source rocks
		Amount	Roundness	Suites				
Kakisako formation	graywacke or feldspathic graywacke or muddy medium sublithic ss.	moderate	subangular and subrounded	(a)...Zr., Bi., Tn., Gr., Ep. (b)...Gr.-Ep.-Px.-Am. (c)...Bi., Gr.	1. Type a 2. Type c 3. Type e	1. Pl. 2. Mi. ...rare 3. My. ...rare	1. vol. 2. sch. 3. sed. 4. hor. 5. pyr.	green. r....fa. pred. vol. r. ...... „ „ phy. ....subord. sed. r. ...... „ gran. r. ...rare
Amatsuki formation	arkose or coarse feldspathic ss.	moderate	angular subangular	(a)...Zr., Bi., Tm., Gr.	1. Type a 2. Type c 3. Type e	1. K-fe. 2. Pl. 3. Mi.	1. gra. 2. sch. 3. phy. 4. sed.	gran. r. ...pred. schist ......rare. phy. .... „ sed. r. ...... „
Shimodake formation	arkose or feldspathic graywacke or coarse feldspathic ss.	large	angular	(a)...Zr. (b)...Ep., Gr., Zs.	1. Type a 2. Type c	1. K-fe. 2. Pl. 3. Mi.	1. pyr. 2. sed. 3. vol.	gran. r. ...pred. volc. (pyrocl.) subord. sed. r. ...... „ sch. .... rare
Yoshio formation	arkose or arkose ss. or medium feldspathic ss.	moderate large	angular rounded	(a)...Zr., Bi., Tm. (Ep.) (b)...Gr.-Ep.-Px.-Am.; Ep.-Am.-Zs. (c)...Bi., Gr.,Ms.	1. Type a 2. Type b 3. Type c	1. K-fe. 2. Pl. 3. Mi. 4. My.	1. gra. 2. vol. 3. sch. 4. sed.	gran. r. ...pred. (gneiss) sch. ....subord. green. r. ... „ sed. r. ...... „ volc. r. ......rare
Kozaki formation	graywacke or feldspathic graywacke or muddy sublithic ss.	large	angular	(a)...Zr. (b)...Gr.-Ep.-Px.; Ep.-Zs.	1. Type a 2. Type c 3. Type e	1. K-fe. 2. Pl.	1. vol. 2. sed. 3. sch.	volc. r. ...pred. sed. r. ......fa. abund. sch. ....rare gran. r. ... „
Yonaku formation	(1) graywacke or feldspathic graywacke or muddy medium feldspathic ss. (2) arkose or feldspathic graywacke or medium feldspathic ss.	moderate large	angular rounded	(a)...Zr., Bi., Tm. (b)...Gr.-Ep.-Px.-Am.; Ep.-Zs. (c)...Bi., Gr., Ms.	1. Type a 2. Type b 3. Type c 4. Type e	1. K-fe. 2. Pl. 3. Mi. 4. My.	1. sch. 2. gra. 3. sed. 4. phy.	gran. r. ...pred. (gneiss) green. r. ...subord. volc. r. ...... „ sed. r. ......rare
Kuma formation	graywacke or feldspathic graywacke or medium muddy feldspathic ss.	large	angular	(a)...Zr., Am., Bi. (b)...Ep.-Px.-Gr.-Am.; Ep.-Am.-Zs. (c)...Px.	1. Type a 2. Type c 3. Type e	1. K-fe. 2. Pl. 3. My.	1. vol. 2. pyr. 3. sch. 4. sed.	gran. r. ...pred. volc. r. ...subord. green r. ... „ sch. ....rare sed. .... „

suggests the polymictic origin.

(a) suite ....zircon, biotite, tourmaline, (epidote)

(b) suite ....garnet-epidote-pyroxene-amphibole; epidote-amphibole-zoisite

(c) suite ....biotite, garnet, muscovite

Euhedral pyrite is abundant in all these suites.

(5) *Kozaki formation.*—The amount of heavy minerals is large. The mineral grains are angular.

(a) suite ....zircon

(b) suite ....garnet-epidote-pyroxene; epidote-zoisite

(6) *Yonaku formation.*—The heavy mineral suite of the Yonaku formation is similar to that of the Yoshio formation, but the type F zircon is rare in the Yonaku formation. The amount of the separated heavy minerals is large to moderate. The grains are angular to subangular.

(a) suite ....zircon, biotite, tourmaline, (epidote)

(b) suite ....garnet-epidote-pyroxene-amphibole; epidote-zoisite

(c) suite ....biotite, garnet, muscovite

Euhedral pyrite is abundant in all the three types, but it is certainly of secondary origin.

(7) *Kuma formation.*—A large amount of angular heavy minerals occur in this formation. The mafic minerals such as pyroxenes and amphiboles are more abundant than the minerals such as zircon and garnet.

(a) suite ....zircon, amphibole, biotite

(b) suite ....epidote-pyroxene-garnet-amphibole; epidote-amphibole-zoisite

(c) suite ....pyroxene

5. Source rocks

The source rocks of a given sandstone can be inferred generally from its heavy mineral suites as well as from its major constituents. When a bed of conglomerate is intercalated between the sandstones the kinds of pebbles are taken into consideration, too. The conglomerate-bearing formations and their pebbles are listed in Table 1. As the sandstone becomes more mature, it is more difficult to interpret the provenance. Fortunately, since the examined standstones are immature, it is possible to deduce the source rocks from the mineral composition of the sandstones.

The source rocks for the Upper Palaeozoic sandstones of the Yatsushiro area consist of granitic rocks, metamorphic rocks of various grades such as phyllite, schist, green rocks and perhaps gneiss, basic to acid volcanic rocks and sedimentary rocks such as clay slate, sandstone and chert. Although the kinds of rocks constituting the provenance are similar throughout from Carboniferous to Upper Permian, the predominant types vary from time to time. Table 8 shows the general summary of the sandstone types, the heavy mineral composition, the major constituents and the inferred source rocks. It is noticeable that the provenances are polygenetic and that the granitic materials were supplied in a considerable large amount. The combination of the major constituents of plutonic quartz, microcline and K-feldspar and the heavy mineral suite of euhedral zircon-granitic tourmaline* clearly indicates the granitic origin. The provenance factors are shown in Table 9.

It is inferred that the granitic materials were abundantly supplied into the Amatsuki, Yoshio, Yonaku (in part), Shimodake and Kuma formations. The type F zircon is found chiefly in the arkosic sandstone. The amount of garnet is large in the Yoshio and Yonaku formations, in which perfectly rounded tiny grains of the colourless zircon (30–50 microns) as well as those of the type F zircon occur, too. This fact suggests that the material may have been derived at least partly from the gneiss of granitic composition.

Table 9. The provenance factors

	Kakisako formation	Amatsuki form.	Shimodake form.	Yoshio form.			Kozaki form.	Yonaku form.		Kuma form.
					**	*			*	
Feldspar / Rock[1)] fragments	4.2	18.7	8.6	15	10	3.6	2.4	8.6	6.2	12.4
Feldspar / Rock[2)] fragments + Clay matrix	1.0	2.6	2.0	2.8	1.3	0.7	0.7	0.9	1.8	2.0

1) according to PETTIJOHN (1954), 2) to DAPPLES *et al.* (1953)
* muddy type, ** intermediate type

In conclusion the source rocks for the sandstones of the Upper Palaeozoic formations in the Yatsushiro area are as follows:

Kakisako formation
- green rocks .... fairly predominant
- volcanic rocks.. fairly predominant
  (including pyroclastic rocks)
- phyllite .... subordinate
- sedimentary rocks .... subordinate
- granitic rocks .... rare

Amatsuki formation
- granitic rocks .... predominant
- schist .... rare
- phyllite .... rare
- sedimentary rocks .... rare

* Although some of KRYNINE's granitic tourmaline may be originated from the metamorphic rocks, as is mentioned in the preceding chapter, the brown euhedral grain is considered to be of granitic origin.

Shimodake formation
granitic rocks .... predominant
volcanic rocks... subordinate
(including pyroclastic rocks)
sedimentary rocks .... subordinate
schist .... rare

Yoshio formation
granitic rocks .... predominant
(including gneissose rocks)
schist .... subordinate
green rocks .... subordinate
sedimentary rocks .... subordinate
volcanic rocks... rare

Kozaki formation
volcanic rocks... predominant
(including dike rocks)
sedimentary rocks .... fairly abundant
schist .... rare
granitic rocks .... rare

Yonaku formation
granitic rocks .... predominant
(including gneissose rocks)
schist .... rare
green rocks .... subordinate
volcanic rocks... subordinate
sedimentary rocks .... rare

Kuma formation
granitic rocks .... predominant
volcanic rocks... subordinate
basic plutonic and green rocks........................ subordinate
schist .... rare
sedimentary rocks .... rare

Sedimentation and tectonics

1. General remarks

In this chapter some remarks are given on the types of the sandstones of this area and their relation to the geological conditions.

Generally speaking, the factors that controlled the sandstone types are (1) the kind of rocks from which the materials were derived, (2) the mode of weathering and transportation that are related to the maturity of the sediments, (3) the degree of sorting that the materials have undergone, (4) the rapidity of deposition and (5) the site of deposition.

(1) *Kinds of mother rocks.*—As has been mentioned in the preceding chapter, the kinds of mother rocks are similar among the above described formations. It might be possible that the disintegrated mother rocks of one and the same mineral assemblage are differentiated into the varieties of sandstones by the sorting agents (e.g. the strength of currents) and by the difference of the distance from the source. When the sandstone is immature, the type of the sandstone would be much controlled by the kinds of mother rocks. The sandstones of the Kozaki and Kuma formations show equal mineralogic maturity, but the former contains more rock fragments than the latter. Likewise the Shimodake and the Yonaku formation have different mineralogical composition, although they have a similar mineralogic maturity (see Table 10).

(2) *Mode of weathering.*—As the mafic minerals such as pyroxene, amphibole and micas and also fresh feldspar are abundant, the effect of the chemical weathering may have been relatively small.

Table 10. Mineralogic maturity

Age	Carboniferous		Lower Permian	Middle Permian						Upper Permian
	Kakisako formation	Amatsuki form.	Shimodake form.	Yoshio form.			Kozaki form.	Yonaku form.		Kuma form.
					**	*				
Quartz+Chert / Feldspar+Rock fragments [1]	0.37	1.0	0.58	0.7	1.0	0.5	0.47	0.8	0.6	0.4
Quartz+Chert / Feldspar+Rock fragments+Clay matrix [2]	0.25	0.6	0.4	0.6	0.6	0.2	0.3	0.2	0.4	0.2

[1] defined by Pettijohn (1954), [2] by Dapples *et al.* (1953)
* muddy type, ** intermediate type

(3) *Degree of sorting.*—One of the characteristic differences among the examined sandstones is the amount of clay matrix. The sorting index is similar among the sandstones of different formations. The amount of clay matrix seems to depend on the strength of currents and also on the rapidity of deposition. Taking one formation as a unit, the larger the mean size of grains, the smaller the amount of clay matrix is. The clay may be removed by such processes as winnowing.

(4) *Rapidity of deposition.*—All the sandstones studied are concluded to have deposited rapidly, because unstable minerals are abundant and the sorting of the grains is poor. This is supported by the great thickness of a formation.

(5) *Site of deposition.*—All the formations are marine, as clearly indicated by

the contained fossils. The data concerning the depth of deposition are rather scarce. The chert layers occur in all the formations except in the Kuma formation. The origin of chert has been discussed by many geologists. KIMURA (1954) pointed that a chert is intimately related with "schalstein" and that the volcanic activities may supply some silica to sea water or may give a favorable condition for the formation of chert. In the Yatsushiro area chert is abundantly accompanied with pyroclastic rocks in the Kakisako and Kônose formations. The genesis of chert is not necessarily related to the depth of the sea. Therefore, the chert cannot be an index to the depth of the depositional area. In this connection it should be noted that the chert is accompanied with the thick bedded coarse-grained sandstones in the Yoshio formation. Limestone beds or masses containing fusulinids, corals, calcareous algae, etc. may suggest a relatively shallow sea deposition, but more studies on the facies and the petrographic characters of the limestones are necessary.

2. Carboniferous

In the Carboniferous Period, the Kakisako and Amatsuki formations show variable changes in the sedimentary facies and are characterized by basic igneous activities in their upper part. Comparing the sandstones of the upper Lower Carboniferous Kakisako formation with those of the lower Upper Carboniferous Amatsuki formation, the former occurs in lenticular forms and is a graywacke type containing a wealth of clay matrix and a moderate amount of rock fragments, while the latter occurs as thick beds and is rather an arkose type containing a relatively small amount of the clay matrix. The Kakisako formation shows the heavy mineral assemblage of zircon, garnet, epidote, zoisite and pyroxene, which is rather of complex suites, while the Amatsuki formation indicates that of zircon, garnet, biotite and tourmaline, which is a simple suite. Thus the sandstones of the two formations are different in the occurrence and the petrographical characters. Therefore, a distinct difference is concluded between the two formations in regard to the provenance, sedimentary and tectonic environments. A minor evolutional tendency from the Kakisako to Amatsuki formations seems to be recognized from Table 10.

3. Permian

As regard to the Permian in the present area, formations of different sedimentary facies of almost the same age or of overlapping ages are developed in several tectonic belts separated by the fault or sheared zone.

The data obtained are summarized in Table 11 for comparing the Permian sandstones.

(1) *Lower Permian.*—The sandstone of the Shimodake formation is similar to those of the Yoshio formation (coarser type) in the petrographical characters, although the former is slightly lower than the latter in the mineralogic maturity (Table 10).

Table 11. The mean size and sorting index of quartz grain and the average composition of Permian sandstones.

Formation	Shimodake formation	Yoshio form.			Kozaki form.	Yonaku form.		Kuma form.
		(1)*	(2)*	(3)*		(1)**	(2)**	
Mean size	0.52	0.39	0.34	0.26	0.30	0.45	0.29	0.37
Sorting index	0.18	0.16	0.13	0.13	0.17	0.24	0.14	0.15
Quartz	24.7	36.0	39.6	21.7	22.1	31.5	26.7	21.5
Clay matrix	16.8	13.4	21.9	43.2	29.7	16.0	33.1	21.1
Feldspar	46.2	45.4	34.3	32.8	32.7	43.2	33.9	50.9
Rock fragments	5.4	2.9	3.2	0.9	13.9	6.9	3.9	4.1
Chert	5.4	1.5	0.8	0.8	0.7	1.3	0.5	0.6
Accessory minerals	1.5	0.9	0.2	0.6	0.9	1.7	1.9	1.8

(1)* coarser type, (2)* intermediate type, (3)* muddy type
(1)** coarser type, (2)** finer type

(2) *Middle Permian.*—The formations which belong to the Middle Permian in geologic age show the lateral variation in the lithologic constituents. Although all the examined sandstones of Permian formations are more or less immature, there are minor differences among the Kozaki, the Yonaku and the Yoshio formation, as seen in Tables 10 and 11. This fact may suggest that there were irregularity and instability in the tectonic conditions which controlled the sedimentation.

(3) *Upper Permian.*—The Kuma formation is discriminated from other formations by the abundance of conglomerate and by the scarcity of chert and pyroclastic rocks. The sandstones of the Kuma formation are low in the mineralogical maturity, showing a renewed erosion and sedimentation under an unstable tectonic condition.

Appendix

Notes on the Chichibu Geosyncline

By

Koji FUJII, Kametoshi KANMERA and Tatsuro MATSUMOTO

The Upper Palaeozoic rocks of the Japanese Islands are generally regarded as product of an orthogeosyncline, which is called the Chichibu geosyncline. In this paper we do not intend to review historically the concept of the Chichibu geosyncline and to summarize its tectonic evolution, but should like to give some notes which may contribute to improve the knowledge of the Upper Palaeozoic geological history. The remarks concern primarily with the two subtitles, the characteristic features of the sedimentary group itself and the sources of the clastic materials.

Naturally the remarks are given primarily from our study of the Upper Palaeozoic sediments of the Yatsushiro area, which may indeed represent those of the Outer Zone of Southwest Japan. For more comprehensive understanding of the Chichibu geosyncline, however, studies of the Palaeozoic sediments of various other regions in Japan are needed.

1. Characteristic features of the sedimentary group

The following ten points may be counted as the characteristic features of the Upper Palaeozoic formations observed in the Yatsushiro area.

(1) *Thickness of the sedimentary group.*—The thickness of the Upper Palaeozoic formations in Japan, as measured in the Yatsushiro area, is relatively greater than that of the well known sediments of the same geological ages. Although the formations of the successive ages are often in fault contact in this area, they are presumed to have been originally conformable, because no signs of significant unconformity are found. The whole sequence from the upper part of the Lower Carboniferous to the Upper Permian would exceed 5000 meters. The Permian formations are especially thick, as exemplified by the Lower Permian Shimodake (1200 m), Middle Permian Yoshio (1500 m) and Upper Permian Kuma (930 m) formations. They are altogether nearly as thick as the Permian sediments in the Ural Vordeep, somewhat thicker than those in the Midland and Delaware Basins in the region of Texas and New Mexico and much thicker than those of the Yangtze Basin of China or the contemporary sediments in the Salt Range of India.

(2) *Rapid sedimentation.*—The great thickness of the sediments may owe to the accumulation of the submarine volcanic eruptions in some cases, as in the Upper Carboniferous—lower Lower Permian Tobiishi group (about 1500 m), but in many cases to the rapid supply of clastic materials from a rising uplift to a downwarping basin or trough. The rapid sedimentation is manifested in the characters of the constituting sandstones such as the abundant occurrence of unstable minerals and the poor sorting of grains with a considerable amount of clay matrix. The poorly sorted boulder-bearing conglomerate, which occurs as irregular masses at several levels in the Middle Permian Kozaki and Upper Permian Kuma formations, also indicates the rapid sedimentation. This implies the topographic high relief and the tectonic instability during the period of sedimentation.

(3) *Constituents of the sedimentary group.*—The Upper Palaeozoic sedimentary group, which is called the Chichibu supergroup, consists of shale or clay slate, various kinds of sandstone, chert, limestone, volcanic and pyroclastic rocks. The proportion of the constituting rocks in the group varies from place to place and also from age to age. Although there was a proposal of dividing the sediments of the Chichibu geosyncline into several facies on the basis of the predominant rocks and the tectonic arrangements (e.g. KOBAYASHI, 1951), more analytical studies are

necessary before the generalization. Even in the Upper Palaeozoic of the Yatsushiro area the predominant constituents vary from a formation to another.

The clastic ratio, for example, is very small in the Tobiishi, Shizo and Kônose formations, which consist primarily of limestone, chert, basic lava and tuffaceous rock, with some slate. The ratio is extremely large in the Upper Permian Kuma formation. Even between the formations of the same age there is a variation. In the Middle Permian, for instance, the Yoshio formation has predominant sandstone, the Yonaku a higher proportion of shale to sandstone, the Kozaki little limestone and remarkable conglomerate and the Ryuhozan group (which is distributed on the north side of the Usuki-Yatsushiro Tectonic Line) has predominant limestone.

The belt of predominant limestone, basic volcanic rock and chert with little clastics, as exemplified by the Kônose group, can be traced in the southern part of the Palaeozoic terrain in the Outer Zone of Southwest Japan. This is, however, stratigraphically not precisely divided and correlated, because of the very scarce occurrence of fossils. The relatively coarse-grained, Middle Permian sandstones occur likewise in a particular belt of the same region, which is close to the north of the Kônose belt, as are exemplified by the Yoshio formation of the Yatsushiro area in western Kyushu, the corresponding one in the northern part of the Meiji belt in the Usuki area, eastern Kyushu (FUJII, 1954), the sandstone rich formation in the third belt (of the four belts from the north) in Shikoku (ICHIKAWA *et al.*, 1956) and the Nomisaka facies in Kii Peninsula (KIMURA, 1957).

The above two examples would be allocated to certain parts in the scheme of the facies classification in space and time which should be established on the basis of further systematic studies through stratigraphic and petrologic analyses.

(4) *Heterogeneity.*—We are still far from the perfect understanding of the general rule which controlled the facies distribution in space and time. What can be concluded in the present state of our knowledge is the heterogeneity in the sedimentary facies. The best example is in the Middle Permian formations as explained in the preceding paragraph. This is seen within a relatively short distance, although the original breadth of the Yatsushiro Palaeozoic area must have been considerably shortened by folding and thrusting. The heterogeneity in sedimentary facies may imply a variable physiographic background which, in turn, reflects an unstable tectonic condition in and outside the area of sedimentation.

There might have been a certain stage in which the sedimentary condition was relatively uniform. The stage represented by the Kakisako formation possibly belongs to such a case. This corresponds to the Onimaru-stage in the Kitakami Massif and other areas. The apparent uniformity in this stage came from the faunal similarity in the coral limestones that represent the Upper Viséan transgression, but the associated sandstone and other sediments have not yet been fully examined and compared between separated regions.

The variation in the thickness of the sediments is also considerable, but we have many things to do before showing the isopach maps for the successive ages of the Upper Palaeozoic.

(5) *Limestone.*—Limestones are generally regarded as negligible or poor in many examples of the sedimentary groups in geosynclines in which shales and graywacke predominate. In the shelf facies, on the contrary, the orthoquartzite—carbonate association is characteristic, as is written by PETTIJOHN (1949, 1954). How far this statement can be kept is, in our opinion, a problem which should be examined by the studies of many examples of geosynclines. The Mesozoic group in the Alps and the Himalaya is said to be geosynclinal sediments, but contains a great amount of limestone and dolomite. In the case of the Chichibu geosyncline of Japan fairly thick masses of limestone occur. There are of course various types in the mode of occurrence of the limestone in the Japanese Upper Palaeozoic. The celebrated Akiyoshi limestone, for instance, in the Inner side of Southwest Japan is a thick body of massive, very pure limestone, without virtual bedding, containing corals, brachiopods, and calcareous algae near the basal part and abundant fusulinids at many levels. It is rather extraordinary that nearly pure calcium carbonate continued to be precipitated from the middle of Carboniferous to the end of Permian period, although there is a cessation in the late Carboniferous. In spite of the remarkable advances in biostratigraphic work (e.g. TORIYAMA, 1958) the Akiyoshi limestone has much to be done from the standpoint of sedimentation. There are two working hypotheses in this respect. One holds that there was a belt of calcareous sediments on the northern side of the Japanese Upper Palaeozoic and that the Akiyoshi limestone is an exotic mass tectonically brought to the present position from that northern belt. This seems to imply the calcareous facies in the marginal part of the Chichibu geosyncline. The other considers the Akiyoshi limestone as a kind of bioherm in situ which rapidly merges laterally into thick sediments of shale, sandstone and chert. In this case the Akiyoshi limestone represents a special lithotope within the major basin of the Chichibu geosyncline.

Now in the Yatsushiro area the Yayamadake limestone is similar, if not identical, to the Akiyoshi limestone in the sedimentary feature. According to KANMERA (1952b) it is massive, about 450 m in the maximum thickness, without virtual bedding, white to greyish white and pure. It contains abundantly fusulinids and calcareous algae and occasionally corals. Owing to the precise zonation by KANMERA the age of the Yayamadake limestone is determined to range from the middle part of Upper Carboniferous to the lower part of Lower Permian. Layers rich in oolitic and pisolitic structures are recognized at horizons. This limestone is not exotic but rests on and is also laterally interfingering with the non-calcareous part which is composed mainly of basaltic lava, tuff-breccia and tuff with some slate, chert, siliceous shale and smaller masses of limestone.

The limestone in the Kônose group is again thick, massive and closely associated with basic submarine lava, tuff and chert, without notable clastic matters. This is, however, very poor in fossils.

Smaller bodies of fusulinid limestone occur in the Shizo (Lower Permian) and the upper part of the Amatsuki (middle Upper Carboniferous) formation. They are again intimately associated with the basic tuff. The Shizo formation consists mainly of chert and has no sandstone. In the Amatsuki formation sandstone predominates in the lower part but less so in the upper part where limestone occurs.

In the Middle Permian Yonaku and Hashirimizu formations, which consist primarily of slate with some sandstone and chert, limestone occurs in masses of various sizes and forms. One of the limestone bodies is considerably thick (30–70 m), extends for a long distance and is, at least partly, associated with basic tuff. Others are contained in the argillaceous rocks and sometimes black and impure but contain fusulinids. Owing to the tectonic deformation, erosion and incomplete exposures the three dimensional shape of a limestone body and the variation within the body are not necessarily known, although certain well developed quarries may enable us to observe various interesting features in detail.

The Shimodake and Yoshio formations, which are characterized by medium- to coarse-grained, feldspathic sandstones (which may be called arkoses by some authors) have little or no limestone.

Small irregular masses of black impure limestone are characteristic of the Kozaki and Kuma formations, which consists primarily of black shale with boulder-bearing conglomerate and muddy sandstones. The characters of this particular type of limestone and the surrounding rocks of these two formations were described in detail by KANMERA (1953, 1961).

(6) *Volcanic rocks.*—Basic volcanic rock and associated agglomerate and tuff occur remarkably in the Upper Palaeozoic of Japan, as has been stratigraphically summarized by MINATO *et al.* (1959). They are mostly submarine, because they are intimately associated with fossiliferous limestones and radiolaria-bearing chert. The pillowed structure is occasionally observed but in many cases unpreserved due to the intense deformation. Little work has been done for the petrology of the basic rocks. They are more or less altered and metamorphosed to the so-called "schalstein" or the green rocks, like many other examples in orthogeosynclines. Serpentinized ultrabasic rocks are frequently intruded into the Upper Palaeozoic rocks, although the intrusion may be of later ages.

In the Yatsushiro area the basic volcanic rocks occur in the upper part of the Kakisako formation (above the Viséan limestone-bearing lower formation), in the upper part of the Amatsuki formation (middle part of Upper Carboniferous), in the

Tobiishi group (middle to upper parts of Upper Carboniferous and basal Permian) in a large amount and at many levels, in the Shizo formation (upper Lower Permian) in a smaller amount, and in the Kônose group (not yet differentiated but Middle Permian in a certain part) in a remarkable amount. A much smaller amount of the basic rocks is seen in the Yonaku formation (Middle Permian) but the conglomerate-bearing Kozaki (Middle Permian) and Kuma (Upper Permian) formations are almost free from them.

In the Ryuhozan group (undifferentiated but Middle Permian in a certain part), which is affected by regional metamorphism, the intermediate igneous rocks are recognized in addition to the basic ones.

There may have been a belt (or belts) of volcanism within the Chichibu geosyncline and it (or they) may have been shifted in the tectoic evolution of the geosyncline. We are, however, far from the situation to lead the general conclusion about these points.

(7) *Chert.*—Chert occurs very frequently in the Upper Palaeozoic formations of Japan. In the Yatsushiro area it occurs in almost all the formations, except in the Upper Permian Kuma. The upper Lower Permian Shizo formation is especially characterized by the predominance of chert over other rocks.

Some layers of the Palaeozoic chert contain radiolarian remains, as have been reported by previous authors. The radiolaria are found also in the chert of the Yatsushiro area but have not yet been palaeontogically worked out.

KOBAYASHI and KIMURA (1944) described the faunal and stratigraphical analyses of the radiolarian rocks and their bearing on the geotectonics of Japan. Little work, however, has been done about the sedimentary petrography of the cherts in Japan. SAKAGUCHI (1960) reported interesting examples in the mode of occurrence of chert in the Lower to Middle Permian near Kyoto. According to his observation there are two kinds of occurrence; one is a massive, irregular body of various dimensions; the other is bedded and extended in a layer form, often interbedded with shales. This statement can be applied to the cherts in the Upper Palaeozoic formation in the Yatsushiro area. SAKAGUCHI attributed the origin of chert to the silica dissolved, or suspended as colloids, in the sea water, although the silica may have been partly derived from the submarine volcanism. He also regarded the chert as syngenetic with the associated sediments deposited in the central deeper part of the geosyncline. We have no objection against this conclusion. In fact the conglomerate-bearing Kozaki and Kuma formations have little or no chert, but in the Yoshio formation layers of chert are frequently interbedded with the relatively coarse-grained sandstone and clay slate. The depositional environment of the Yoshio formation is, however, by no means certain.

(8) *Types of sandstones.*—Sandstones in the geosynclines are generally regarded as graywackes. Unfortunately there is incongruence among authors as regard the

definition of the term graywacke. We do not like to be involved in the discussion of the terminology, but should like to present what kinds of sandstones are actually observed in the Upper Palaeozoic of the so-called Chichibu geosyncline.

The sandstones from the Yatsushiro area are described in detail in the foregoing chapters. Summarizing the description, the examined sandstones are mostly feldspathic graywackes in PETTIJOHN's (1957) scheme, but many of the specimens from the Amatsuki and Yoshio formations are better described as arkoses. Less muddy, feldspathic sandstones in FUJII's scheme are found in the Amatsuki, Shimodake, Yoshio and parts of the Yonaku formations. Muddy feldspathic sandstones in this scheme are in the rest of the Yonaku formation and the Kuma formation. Muddy sublithic sandstones are in the Kakisako and Kozaki formations. Thus the Upper Palaeozoic sandstones from the Yatsushiro area are never of a single type, but ranges in considerably various types, although no examples of orthoquartzite and subgraywacke are found. Probably the conditions which controlled the deposition changed to a considerable extent from a formation to another, and the so-called Chichibu geosyncline was by no means monotonous, even if the Palaeozoic belt in the Outer Zone of Southwest Japan only is taken into consideration.

(9) *Argillaceous sediments.*—The muddy sediments constitute an important part in most of the formations in the Yatsushiro area. They are intensely deformed, often cleaved and in many cases altered to slate or phyllite. Accordingly the original clay minerals cannot be examined. In a few cases shales or slates form a unit of considerable thickness, as in the lower part of the Kuma formation but in many other cases they are interbedded with sandstones, cherts, limestones and basic volcanics.

Owing to the intense deformation little is known about the original sedimentary features of the muddy rocks. In the Kozaki and Kuma formations the shale is often deep black and contains authigenic pyrite, but the euhedral crystals of pyrite in the slate and sandstone of the Yonaku formation are probably secondary.

In the sandstone-shale association the graded bedding is not so frequently and so clearly observed as would be expected. Sandstones often occur as thick beds or massive bodies. The thin bedded sandstone and shale in alternation, which are found in certain parts of the Kozaki and Kuma formations and between the thicker sandstones of the Yoshio formation, sometimes show grading. Several kinds of current structure, which should be important for deducing the direction of the current flow, have not been clearly recognized.

(10) *Conglomerate.*—Conglomerates occur only in certain particular formations of the Upper Palaeozoic of Japan. The Permian Kuma and Kozaki formations are the best studied examples of them. As they were precisely described and discussed on other occasions (KANMERA, 1953; 1961), the remarks are omitted in this paper.

2. Sources of the clastic materials

As is explained in the foregoing article, the sedimentary group in the Chichibu geosyncline consists of the clastic sediments, calcareous and siliceous deposits and submarine volcanic ejecta. Since the clastic sediments constitute the important part of the group, it has a fundamental significance to make clear the sources of the clastic materials.

Conglomerates in the Kakisako, the Kuma and the Kozaki formation in the Yatsushiro area have already been scrutinized by MATSUMOTO and KANMERA (1949) and KANMERA (1953, 1961). Now in this paper the sandstones of the various formations in the same area are analysed by FUJII. From these results attempt is extended to the more general problem of the provenance.

(1) *Sources of the conglomerate.*—The kinds of the pebbles in the conglomerates of the three formations are summarized as follows:

(a) Acid to intermediate volcanic or dike rocks, such as quartz-porphyry, porphyrite and aplite; diabase; sandstone (subordinate) in the Kikisako formation (Viséan)

(b) Acid to intermediate volcanic and dike rocks, such as andesite and its tuff and tuff-breccia, quartz-porphyry and porphyrite; diorite; leucocratic granite in the Kozaki formation (Middle Permian)

(c) Granitic plutonic rocks, such as aplite, leucocratic granite, adamellite, granodiorite, tonalite, quartz-diorite; acid to intermediate volcanic and dike rocks, such as rhyolite, andesite, quartz-porphyry, porphyrite; basic igneous rocks, such as diabase, gabbro, diorite or granitized basic rock, basalt, etc.; ultramafic rocks, such as pyroxenite, serpentinite; penecontemporaneous sedimenatry rocks, such as sandstone, shale, marl and limestone in the Kuma formation (Upper Permian)

Some of the igneous rocks, including the granitic rocks, occur as boulders and well rounded cobbles in the Kuma and the Kozaki formation. The conglomerates are poorly sorted often with matrix of gritty mud. Therefore the source area must not have been much separated from the basin of deposition.

(2) *Provenance of the sandstones.*—As is described in the preceding chapter, the sources of the examined sandstones from the Yatsushiro area consist largely of crystalline rocks such as granitic and metamorphic rocks.

Although the material may have been supplied from the penecontemporaneous sediments to some extent, the debris from the older sedimentary rocks were not predominant, being subordinate or rare. It is inferred that the crystalline source areas continued to rise and supplied the materials to the sedimentary basin from early Carboniferous to the end of Permian. Examining in more detail, a serial change of supply can be traced from the Kakisako to the Amatsuki formation. The difference in the characters of sandstones between the Kozaki, Yoshio and Yonaku formations may imply at least partly a difference in respect to the provenance and to the site of deposition but may partly show a change with age (see page 216). The Kuma formation, which is characterized by boulder conglomerates and muddy sandstones, probably represents a renewed rapid transportation from a rising upland of plutonic complex with some volcanic rocks.

As the sorting effect is generally small, the materials of the sandstones do not seem to have been supplied from a great distance.

(3) *Reference to older crystalline basements.*—In connection with the problem of provenance, rocks of possibly older ages outcropping within the Japanese Islands as well as the pebbles of conglomerates in the Palaeozoic formations should be referred to.

Recently the petrographical knowledge has been increased about the possibly older rocks of Japan which might have supplied the material into the Upper Palaeozoic clastic sediments. Also the petrographical characters of granitic and metamorphic pebbles in the conglomerate of Palaeozoic formations have recently been clarified by KANO (1958–59) and others.

The so-called older rocks listed below should be taken into consideration as one of the possible sources of material to the Palaeozoic sandstones. The constituting minerals follow the name of the identified rock.

(1) Yatsushiro metamorphic and igneous rocks (pre-Silurian)
(MATSUMOTO and KANMERA, 1949; 1962 in press, assisted by KARAKIDA for the identification)
- (a) amphibolites: plagioclase, common hornblende, garnet, quartz, biotite, (pyroxene), apatite, chlorite, sericite, epidote, actinolite, black iron ore
- (b) mica-gneiss: plagioclase, quartz, biotite, muscovite, garnet, zircon, apatite, black iron ore, sericite, chlorite
- (c) gneissose granites: plagioclase, quartz, biotite, K-feldspar, muscovite, zircon, apatite, black iron ore, chlorite, sericite, titanite, epidote

(2) Terano metamorphic rocks in Shikoku
(ICHIKAWA *et al.*, 1956, HAYAMA, 1959)
- (a) amphibolites: green common hornblende, plagioclase, epidote, titanite apatite, magnetite
- (b) mica schists: garnet, biotite, muscovite, quartz, plagioclase, apatite, hematite

(3) Problematic older rocks
Hida metamorphic rocks* (ISOMI and NOZAWA, 1957; NOZAWA, 1958) in Central Japan.

* For the geologic age of this complex, see the recent discussion by KUNO *et al.* (1960).

(a) amphibole gneiss: common hornblende, epidote, diopside
(b) biotite gneiss: biotite, epidote
(c) limestone: calcite

The already described pebbles of conglomerates of the Palaeozoic formations are as follows:

(1) Shohoji conglomerate of the Motai formation
(pre-Tobigamori, Devonian age) (KANO, 1958)
- (a) basaltic or doleritic rock
- (b) biotite quartz diorite and leucocratic biotite granite: quartz, K-feldspar, biotite, (chlorite), epidote
- (c) sericite chlorite quartz schist: quartz, chlorite, sericite, epidote

(2) Natsuyama conglomerate of the Tobigamori formation (Devonian)
(KANO and TAKAHASHI, 1958)
- (a) diorite: plagioclase, biotite, amphibole
- (b) dioritic aplite
- (c) adamellite or granite
- (d) green metamorphic rock: amphibole, epidote, chlorite, quartz
- (e) diabase
- (f) andesite
- (g) chert

(3) Inomine conglomerate in Shikoku (Silurian)
(YAMASHITA, 1958)
- (a) liparite
- (b) andesite
- (c) basalt
- (d) granitic rock: quartz, plagioclase, K-feldspar
- (e) crystalline schist: sericite, biotite, quartz
- (f) biotite gneiss

(4) Conglomeratic gneiss of the Sambagawa crystalline schist
(KOJIMA and MITSUNO, 1959)
- (a) granite: plagioclace, chlorite
- (b) aplitic granite: K-feldspar
- (c) fine-grained biotite quartz diorite
- (d) granite porphyry
- (e) quartz porphyry
- (f) porphyrite
- (g) chert
- (h) clay slate

(5) Usuginu-type conglomerates of Upper Permian
(KANO, 1959)

(a) granitic rocks

(b) metamorphic rocks of igneous origin

 (i) sericite chlorite green rock: epidote, zoisite

 (ii) actinolitic green rock: chlorite, epidote, sericite, albite, actinolite

 (iii) amphibolite: epidote, sphene

(c) metamorphic rocks of calcareous origin

 (i) low grade metamorphic rock: chrolite, epidote, actinolite

 (ii) epidote amphibole bearing plagioclase quartz hornfels

 (iii) almandite garnet quartz hornfels

 (iv) diopside, amphibole, quartz plagioclase hornfels

 (v) almandite diopside plagioclase hornfels

 (vi) amphibole orthoclase albite quartz gneiss

(d) metamorphic rocks of argillaceous sedimentary origin

 (i) spotted micaceous clay slate

 (ii) black or green phyllite

 (iii) muscovite biotite microcline albite quartz hornfels

 (iv) K-feldspar albite quartz augen gneiss

Summarizing the above records in another way, the following heavy minerals could be supplied as grains of sandstones:

amphibole---amphibolites (Yatsushiro gneiss, Terano metamorphic rocks), diorite (pebbles of the Natsuyama conglomerate), green metamorphic rock (ditto), amphibolite (ditto), amphibole biotite trondhjemite (ditto), amphibole-bearing gabbro (ditto)

epidote---amphibolites (Yatsushiro gneiss, Terano metamorphic rocks), gneissose granite (Yatsushiro gneiss), biotite gneiss (Hida gneiss), green metamorphic rock (pebbles of the Natsuyama conglomerate), epidote-bearing quartz hornfels (pebbles of the Usuginu conglomerate), amphibolite (ditto), schistose amphibolite (ditto)

actinolite---actinolitic green rock (pebbles of the Usuginu conglomerate), amphibolite (Yatsushiro gneiss)

zoisite---sericite chlorite green rock (pebbles of the Usuginu conglomerate)

titanite---gneisosse granites (Yatsushiro gneiss), schistose amphibolite (pebbles of the Usuginu conglomerate), diopside amphibole hornfels (ditto)

pyroxene---amphibolite (Yatsushiro gneiss), gabbro (pebbles of the Usuginu conglomerate)

garnet---amphibolite (Yatsushiro gneiss), mica-gneiss (ditto), garnet-bearing hornfels (pebbles of the Usuginu conglomerate)

Comparing the above listed mineral assemblages with those of the sandstones of the Palaeozoic formations in the Yatsushiro area, the inferred source rocks seem to be related to the older rocks and pebbles of conglomerate as far as the kinds of rock are concerned. Although the kinds of source rock can be inferred, the exact position of the provenance remains uncertain. The present outcropping area of the so-called older rocks does not necessarily indicate the very site of the uplift during the Upper Palaeozoic, although they suggest the kinds of the basement.

(4) *Further conjecture.*—Although the mother rock types for the Upper Palaeozoic clastic sediments in the Yatsushiro area have been described and discussed in the preceding pages, where and when the source areas were uplifted and how they were shifted is a fascinating problem in the geologic history of Japan. From the study of the clastic sediments we would suggest the following possible cases:

(a) Volcanic islands caused by geosynclinal volcanism. The volcanic materials which were supplied as sand grains and pebbles are found in the sandstones and conglomerates of the Kakisako and Kozaki formations in a considerable amount. As they are accompanied with the materials which were derived from chiefly superficial rocks such as phyllite and sedimentary rocks, the volcanic materials seem to have been supplied from the geanticlinal uplifts.

(b) The mountainland composed of Pre-Cambrian rocks, which is considered to have been seated in the Asiatic Continent which may have included a part of the Japan Sea of the present day.

As TOMITA's (1954) Archean granite zircon is found in the feldspathic sandstones of the Amatsuki and Yoshio formations which contain a large amount of garnet, it is probable that the Pre-Cambrian rocks were supplied into the Palaeozoic sandstones of the Yatsushiro area. But it is not certain whether the Pre-Cambrian mountains existed close to the north of this area or otherwise. Further research is necessary.

(c) Older tectonic land caused by the Taconic or Caledonian or other early to middle Palaeozoic movements. Although there are no satisfactory evidence for the existence of such movements in Southwest Japan, it is noticeable that the materials from phyllite are contained in the sandstones of the Lower Carboniferous Kakisako formation. In this connection studies in stratigraphy and petrography of the pre-Lower Carboniferous formations are important, although they may belong mostly to the metamorphic group.

(d) The borderland on the Pacific side of Japan. It is interesting to inquire whether or not any material was supplied into the Palaeozoic sandstones of the Yatsushiro area from the south side. Although there is at present no remains of such a southern land, it is noticeable that in the Permian period the coarse-grained feldspathic sandstones of the Yoshio formation were seated to the south of finer Yonaku formation, which, in turn, is situated to the south of the conglomerate-bearing Kozaki formation. This and other records of the Permian formations indicate that the sedimentary facies changed from place to place in a wide region covering the Inner and Outer Sides of Southwest Japan. Thus the possibility of the southern land or uplift should be considered in addition to the northern and median lands or uplifts. To find the current markings will be a key to solve the problem.

As regard to the Yoshio formation, however, there is still an unsettled point in stratigraphy. The narrow northern part of the Yoshio belt is occupied by slates with subordinate sandstones and fossiliferous limestones. This part is very similar to and probably of the same age (Middle Permian) as the main part of the Yonaku formation. The main part of the Yoshio formation, in which the feldspathic sandstones predominate, seems to come below this Yonaku like part. The Kônose belt, which is situated to the south of the Yoshio belt, is almost free from sandstones. Therefore the evidence to deduce the southern borderland is still very incomplete.

(e) Geanticline in the geosyncline itself. As mentioned in item (a), the sandstones accompanied with conglomerate contain the material which is considered to have been derived from older formations including volcanic rocks. Therefore it seems probable that a moderate amount of material was supplied from the geanticlinal mountains or islands. These may correspond to a part of what KAY (1951) and KING (1954) called the tectonic land.

To decide the exact position of the provenance and to make clear the palaeogeographic evolution, the important points to be studied are as follows: (a) a more intensive study of the facies and its lateral changes in each of the successive stages of the Palaeozoic on the foundation of the accurate biostratigraphic correlation, (b) a more systematic petrographical study of the Palaeozoic sediments in various areas of Japan, (c) a more precise correlation of heavy minerals and rock fragments of the Palaeozoic clastic sediments with those of the source rocks by making use of index minerals or key mineral species and (d) a sound interpretation with the aid of the results from facies analysis and studies of sedimentary structures.

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Koji FUJII

Petrography of the Upper Palaeozoic Sandstones from the Yatsushiro Area, Kyushu

Plates 28-33

Plate 28

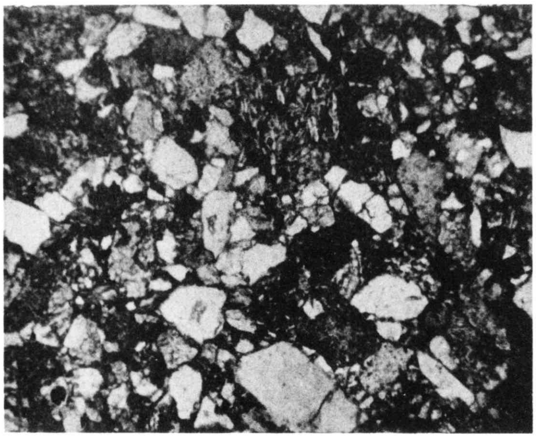
Explanation of Plate 28

Figs. 1–6. Examples of the muddy type sandstones of the Kakisako formation in thin section (photomicrographs).

1 (ordinary light) and 2 (crossed nicols). Ks 3b, ×25, muddy medium-grained sublithic sandstone.

3 (ordinary light) and 4 (crossed nicols). Ks 28, ×25, muddy medium-grained feldspathic sandstone.

5 (ordinary light) and 6 (crossed nicols). Kf 41, ×25, muddy fine-grained feldspathic sandstone.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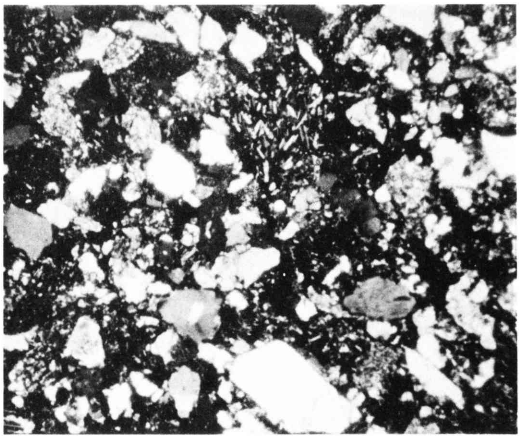
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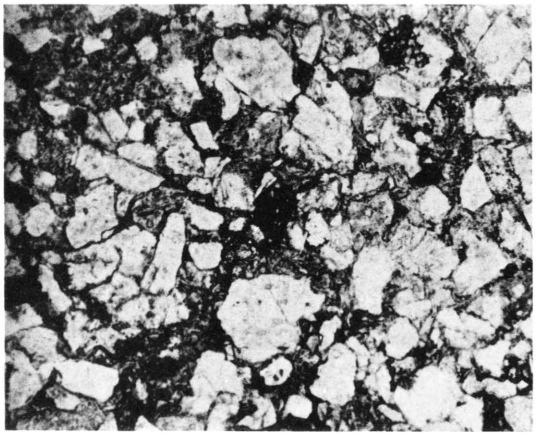
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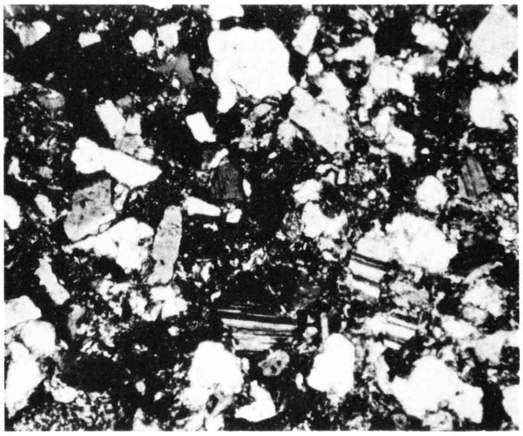
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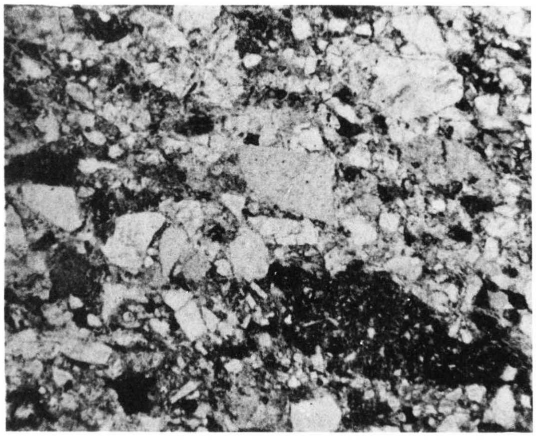
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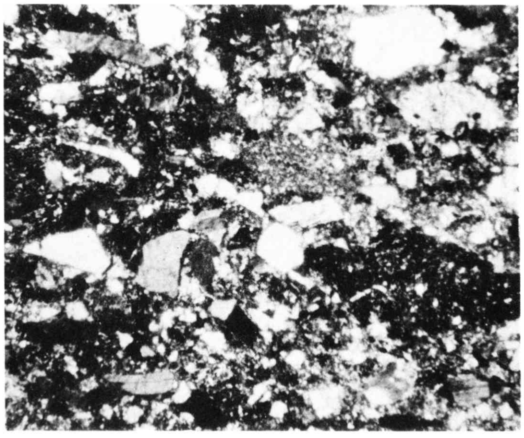
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K. FUJII: Petrography of the Upper Palaeozoic Sandstones

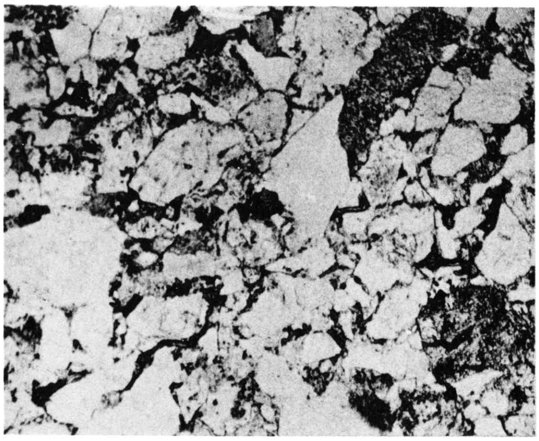
Plate 29

Explanation of Plate 29

Figs. 1–4. Examples of the feldspathic sandstones of the Amatsuki formation in thin section (photomicrographs).

1 (ordinary light) and 2 (crossed nicols). Si 15, ×25, coarse-grained feldspathic sandstone.
3 (ordinary light) and 4 (crossed nicols). Si 1, ×25, coarse-grained feldspathic sandstone.

Figs. 5–6. Example of the feldspathic sandstone of the Shimodake formation.
5 (ordinary light) and 6 (crossed nicols). Kf 46, ×25, coarse-grained feldspathic sandstone.



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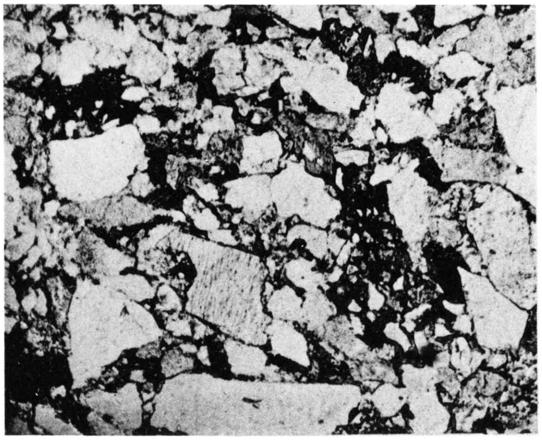

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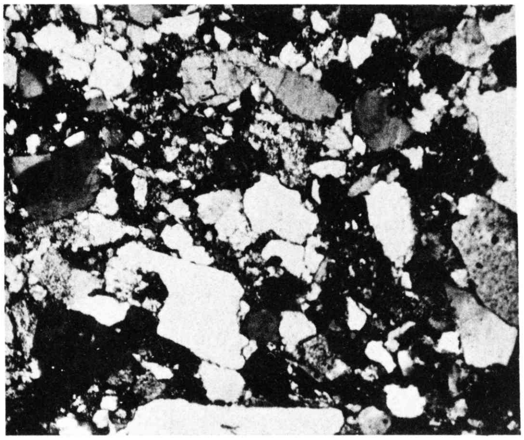

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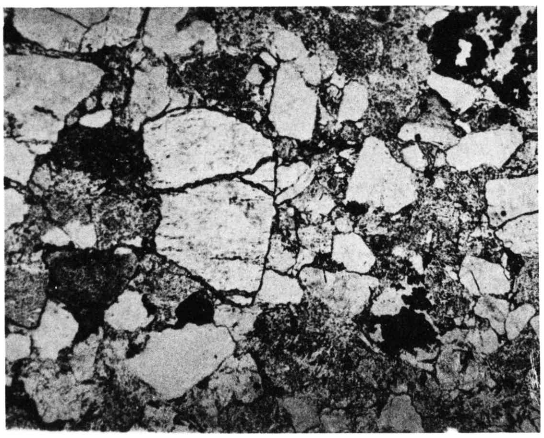

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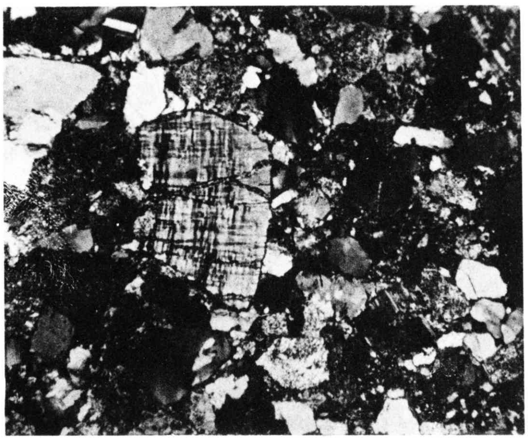

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K. FUJII: Petrography of the Upper Palaeozoic Sandstones

Plate 30

Explanation of Plate 30

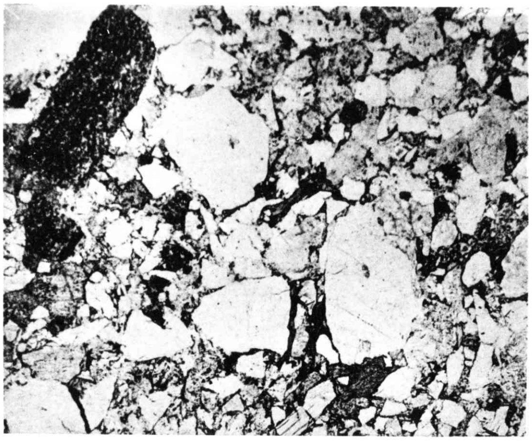
Figs. 1–2. Example of the feldspathic sandstone of the Yoshio formation in thin section (photomicrographs).

1 (ordinary light) and 2 (crossed nicols). Pa 57, ×25, medium-grained feldspathic sandstone. Note the intermingling of very coarse grains.

Figs. 3–6. Examples of the intermediate type sandstones of the Yoshio formation in thin section (photomicrographs).

3 (ordinary light) and 4 (crossed nicols). Pa 32, ×25, muddy medium-grained feldspathic sandstone.

5 (ordinary light) and 6 (crossed nicols). Pa 37, ×25, muddy find-grained feldspathic sandstone.



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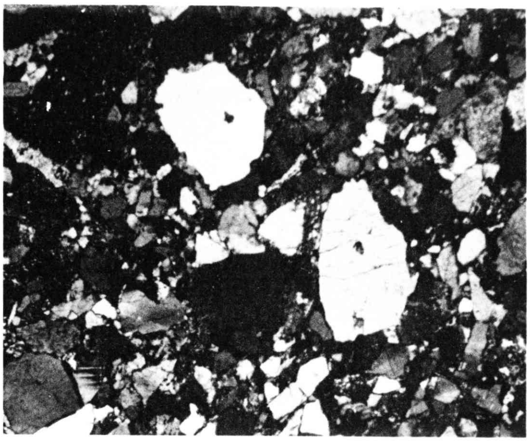

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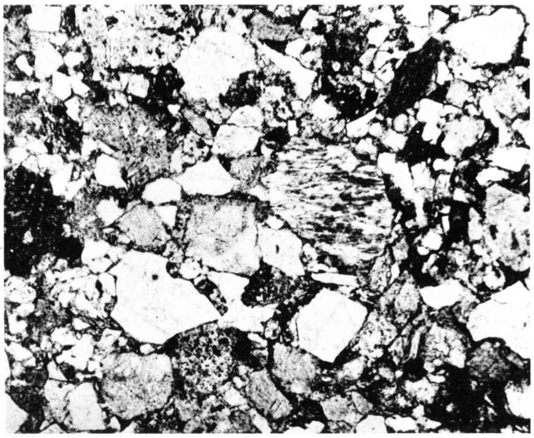

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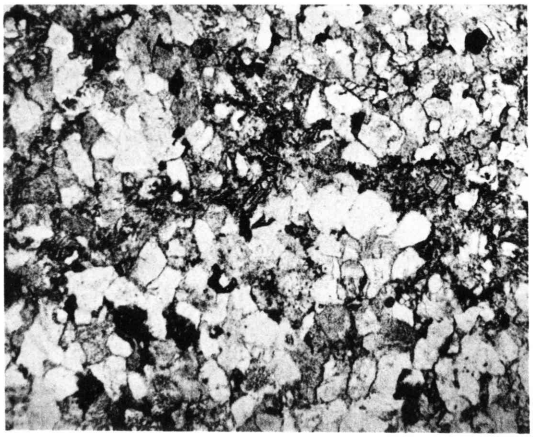

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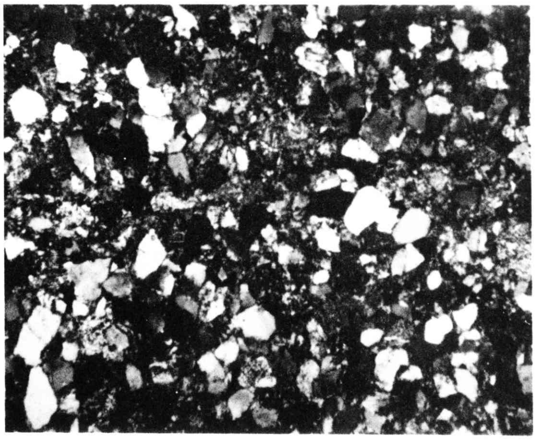

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K. FUJII: Petrography of the Upper Palaeozoic Sandstones

Plate 31

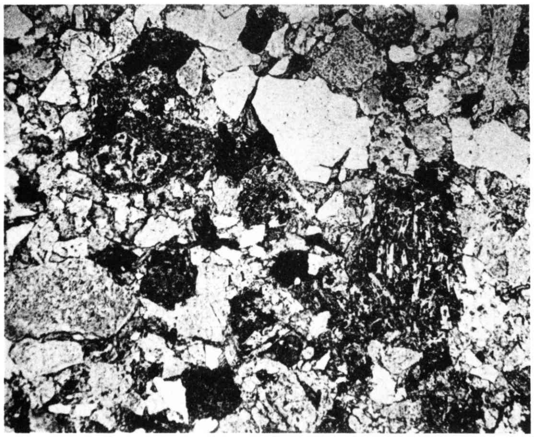
Explanation of Plate 31

Figs. 1–6. Examples of the muddy sandstones of the Kuma formation in thin section (photomicrographs).

1 (ordinary light) and 2 (crossed nicols). Ku 166, ×25, muddy fine-grained feldspathic sandstone.

3 (ordinary light) and 4 (crossed nicols). Ku 482, ×25, muddy medium-grained feldspathic sandstone.

5 (ordinary light) and 6 (crossed nicols). Ku 141, ×25, muddy medium-grained feldspathic sandstone.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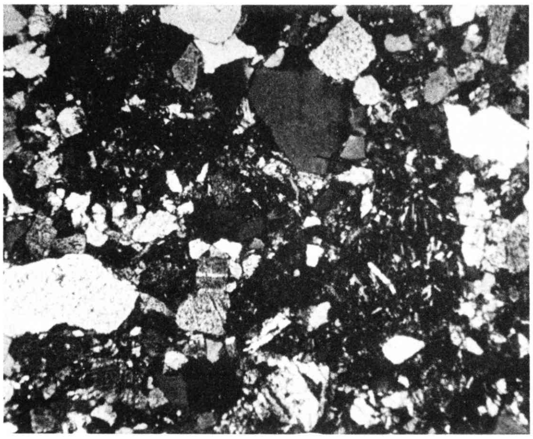
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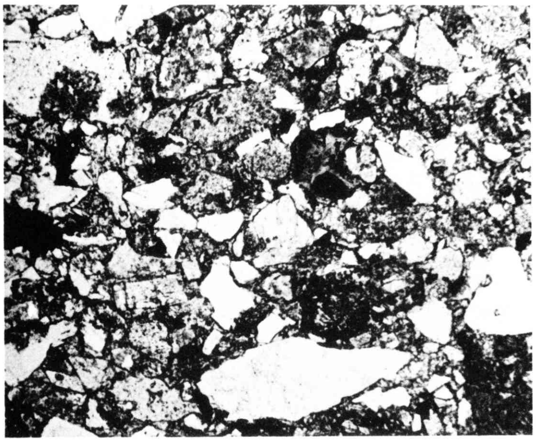
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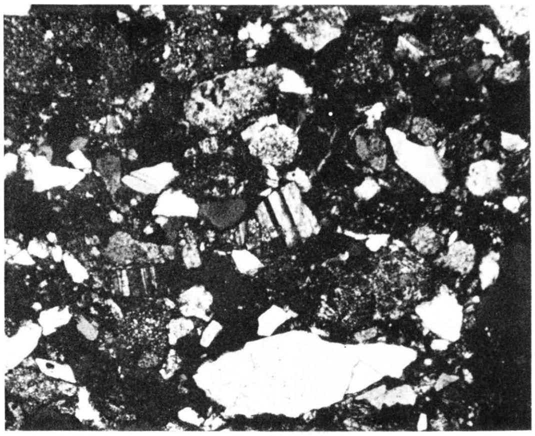
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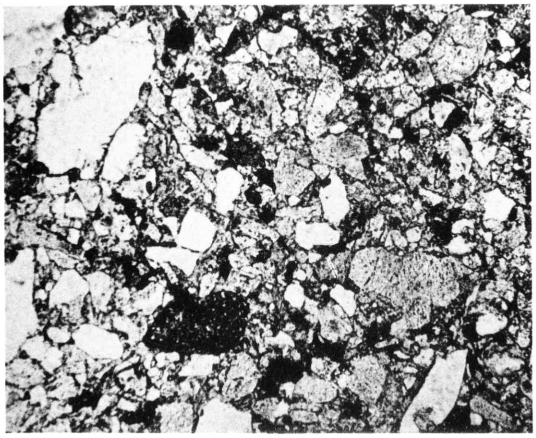
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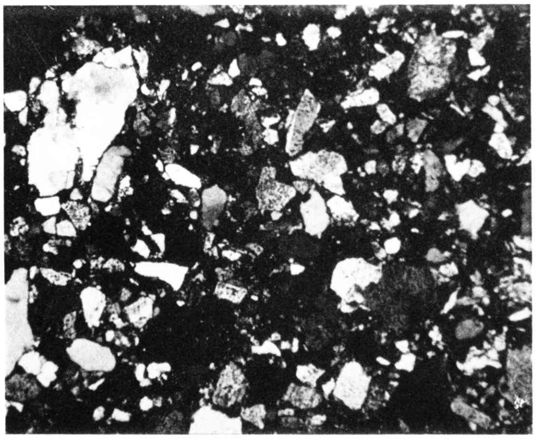
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K. FUJII: Petrography of the Upper Palaeozoic Sandstones

Plate 32

Explanation of Plate 32

Figs. 1–2. Example of the lithic sandstone of the Kozaki formation in thin section (photomicrographs).

1 (ordinary light) and 2 (crossed nicols). Sa 518, ×25, medium-grained sublithic sandstone.

Figs. 3–4. Example of the muddy sandstone of the Kozaki formation.

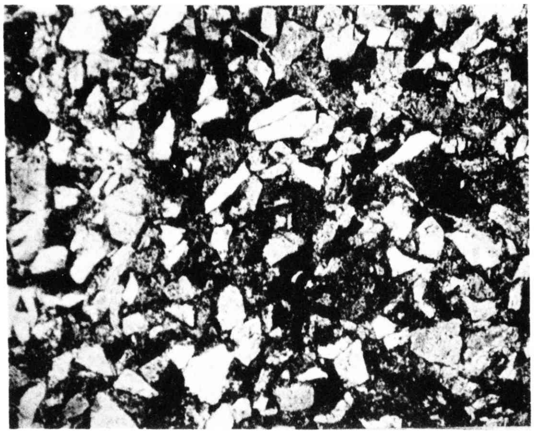
3 (ordinary light) and 4 (crossed nicols). Sa 204, ×25, muddy medium-grained feldspathic sandstone.

Figs. 5–8. Examples of quartz grains contained in the Upper Palaeozoic sandstones. All figures are of crossed nicols: ×25.

5. A variety of vein quartz, Pa 6, Yonaku formation.
6. A grain derived from the granitic rock, Pa 6, Yonaku formation.
7. Metamorphic quartz, Kuma formation.

1

2



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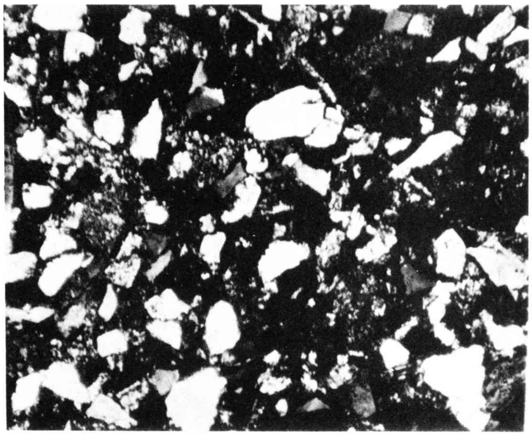

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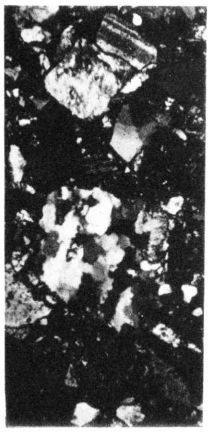

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K. FUJII: Petrography of the Upper Palaeozoic Sandstones

Plate 33

Explanation of Plate 33

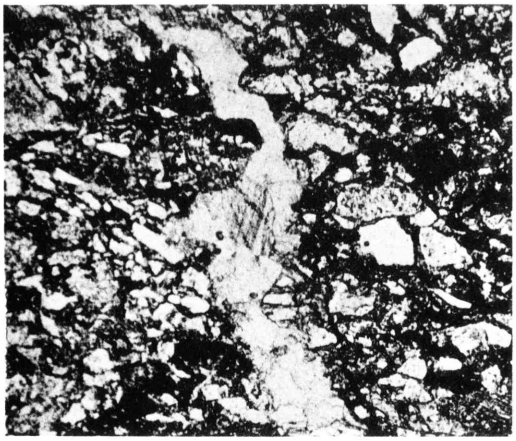
Figs. 1–4. Examples of the muddy medium-grained feldspathic sandstones of the Yonaku formation in thin section (photomicrographs), ×25.

1 (ordinary light) and 2 (crossed nicols). K 10.

3 (ordinary light) and 4 (crossed nicols). Pa 5.

Figs. 5–6. Example of the coarse-grained feldspathic sandstone of the Yonaku formation in thin section (photomicrographs), ×25.

5 (ordinary light) and 6 (crossed nicols). Pa 6.



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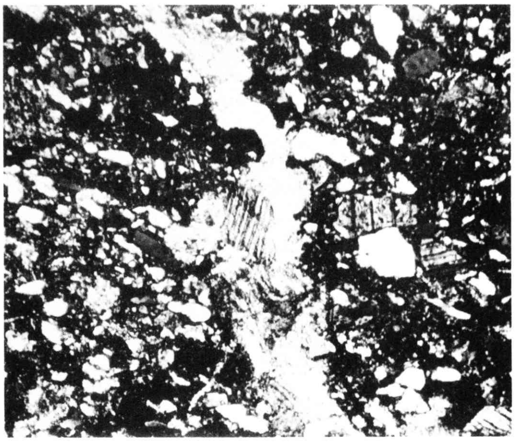

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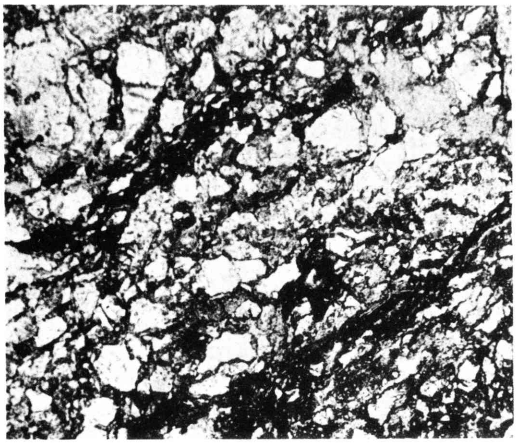

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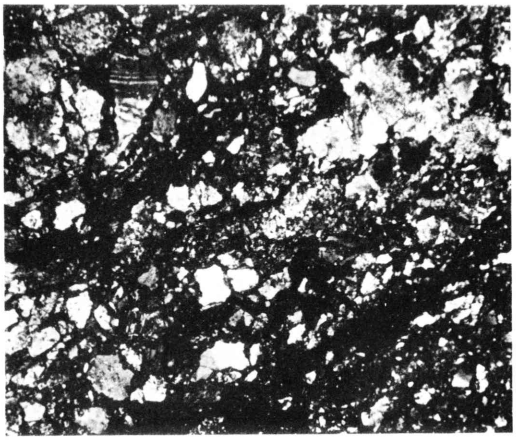

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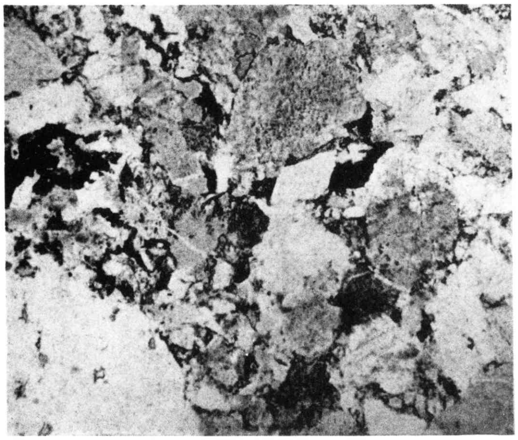

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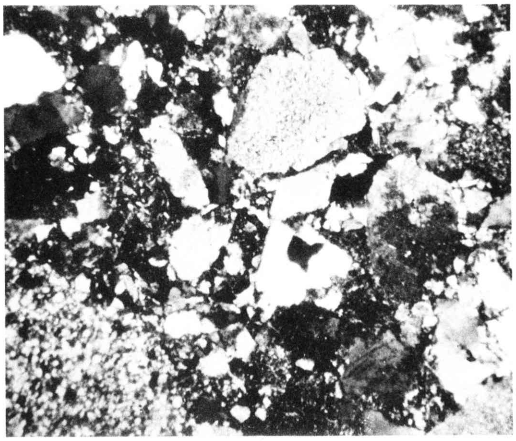

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K. FUJII: Petrography of the Upper Palaeozoic Sandstones