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Autor: Yamaguchi, Masaru / Yanagi, Takeru

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Geochronology of Some Metamorphic Rocks in Japan

by MASARU YAMAGUCHI and TAKERU YANAGI

Department of Geology, Kyushu University, Fukuoka, Japan

ABSTRACT

Four main belts of regional metamorphic rocks in Japan have been considered as being grouped into two pairs, the older and the younger. The Hida metamorphic belt (available isotopic ages, 250 to 180 m.y.) and the Sangun metamorphic belt (330–205 m.y.) constitute the older pair on the north side, and the Ryoke metamorphic belt (100–70 m.y.) and the Sambagawa metamorphic belt (110 to 70 m.y.) constitute the younger pair on the south (Pacific) side of the island.

In the Hida metamorphic belt, Rb-Sr whole rock isochron ages of acid volcanic rocks indicate the deposition at about 500 m.y. with the initial Sr 87/86 = 0.703 which suggests their source region to be the upper Mantle. The age of maximum temperature of metamorphism in this metamorphic belt may be about 240 m.y. as indicated by the concordant U-Pb ages of zircon and sphene in gneisses and schists. In the younger pair, the spread of the isotope ages is rather small. The initial Sr 87/86 ratios of some metamorphic and granitic rocks in this pair are 0.708.

Correlation of the metamorphic grade to the Rb-Sr and K-A mineral ages is suggested, i.e. the younger mineral age is observed in the higher grade zone. The spread of the mineral ages within a metamorphic belt may be related on one hand to the migration of metamorphism and on the other to the different duration of cooling among several zones of metamorphic grade after the late history of metamorphism.

Introduction

Regional metamorphic rocks are most widespread in southwest Japan. The most remarkable feature of the metamorphic rocks is the zonal arrangement of the four main metamorphic belts running roughly parallel to the main trend of the island arc of Japan (Fig. 1). These metamorphic belts are called from the north to the south the Hida metamorphic belt, the Sangun metamorphic belt, the Ryoke metamorphic belt, and the Sambagawa metamorphic belt respectively.

The ages of the metamorphisms and the age relationship between the metamorphic belts, whether these metamorphic belts are independent or mutually related, are a matter of controversy. Systematic geochronology of these metamorphic rocks in Japan has started rather recently and available isotopic age data are not so sufficient to be conclusive. However we have attempted to present some ideas on the meaning of the isotopic ages determined on these metamorphic rocks.

In this paper, U-Pb, Rb-Sr, and K-Ar ages previously reported by many authors are combined together with our new measurements. Attention is focussed on the time of the main event of metamorphism and the correlation of the metamorphic grade to the mineral ages.

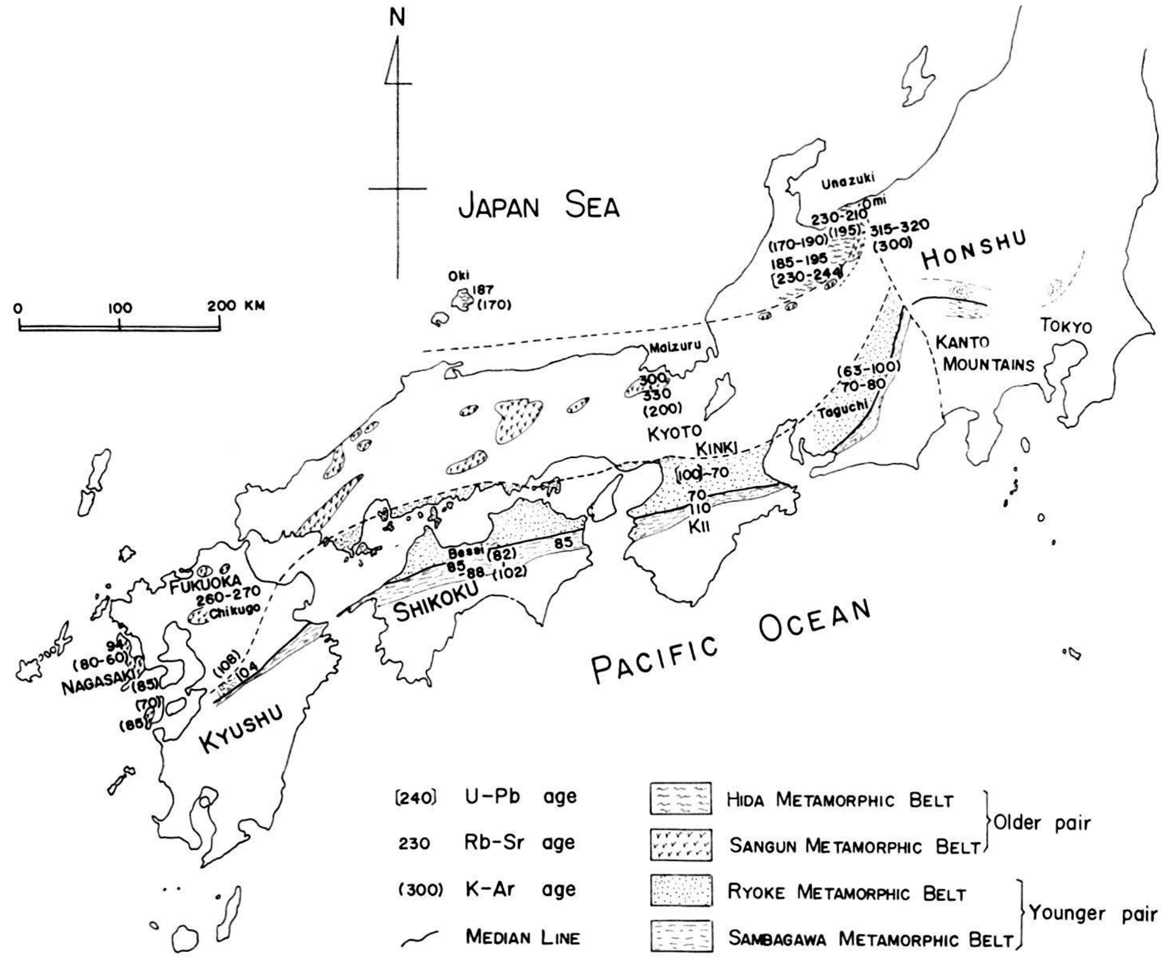

Fig. 1. Distribution of four metamorphic belts in southwest Japan including available isotopic ages in m.y.

Brief Historical Review of the Geology and Petrography of the Metamorphic Belts

Japan, belonging to the circum-Pacific orogenic zone, has been the site of thick geosynclinal sedimentation since the Paleozoic. The oldest fossiliferous formation is the Silurian developed in Shikoku and Kyushu. A synthetic geological study on the tectonic development of the Japanese Islands was made by KOBAYASHI (1941) who recognized two orogenic movements, the Akiyoshi and the Sakawa. According to KOBAYASHI, the Hida and the Sangun metamorphic belts form the axial core of the Akiyoshi orogenic zone. The age of the formation of overthrust structures developed during this orogenesis in some limestone formations is believed to be Permo-Triassic. He also concluded that the Ryoke and the Sambagawa metamorphic belts are the product of the Middle Cretaceous Sakawa orogenic movement.

MIYASHIRO (1961) also directed attention, based on his metamorphic facies series, to the presence of two pairs of metamorphic belts in Japan. The Hida and the Sangun metamorphic belts constitute the older pair while the Ryoke and the Sambagawa metamorphic belts constitute the younger pair. In each of the two pairs, the metamorphic belt on the northern side is of the andalusite-sillimanite type and/or low-pressure intermediate group accompanied by abundant granitic rocks, whereas that on the southern side is of the glaucophane type and/or high-pressure intermediate group accompanied by abundant ultrabasic rocks. His opinion concerning the age of the orogenies and metamorphisms was the same as that proposed by KOBAYASHI.

However, the ages of the metamorphism and the tectonic relation of each metamorphic belt is still a matter of controversy. The Hida metamorphic belt is often believed to be Pre-Cambrian (TOMITA, 1954, FUJIMOTO, 1962, MINATO et al., 1965, SATO, 1968). MINATO et al. (1965) considered that both the Ryoke and the Sambagawa metamorphic belts were formed by the Permian and the Triassic movements. SEKI et al. (1964) suggested that the age of the Sambagawa metamorphism was later than late Jurassic but earlier than early Cretaceous. They also suggested the possibility that the metamorphism may have lasted for a long period of time since the late Paleozoic.

Age Data on the Four Metamorphic Belts in Japan

Available isotopic age measurements by the U-Pb, Rb-Sr, and K-Ar methods recently published are summarized in Table 1 which includes our new measurements. Some details will be discussed later.

1. The Hida metamorphic belt

The Hida metamorphic rocks are overlain by the Middle Jurassic-Lower Cretaceous Tetori Group with a distinct unconformity. A fossiliferous Carboniferous formation in the north of the Hida metamorphic belt is weakly metamorphosed (KONISHI, 1954) and unconformably overlain by the Tetori Group. No geological evidence exists indicating the older limit of the time of deposition or metamorphism.

Some fine-grained schists collected from Unazuki, in the northeastern part of the Hida area, give a whole rock isochron age of about 500 m.y. (YAMAGUCHI and YANAGI, 1967) which is shown in Figures 2 and 3. Analytical data are given in Table 2. The original rocks of these schists are believed to have been lava or tuff of acid and intermediate composition (the so-called leptite formation about 100 meters in thickness; ISHIOKA and SUWA, 1956). One schist called black leptite, probably of tuffite or shale origin, intercalated in this formation, does not lie on the above isochron. This may indicate that the original compositions of the rocks are preserved during the metamorphism. For this reason, the whole rock isochron indicates the deposition of volcano-sedimentary rocks of about 500 m.y. The isochron gives the initial Sr 87/86 = 0.703 which is close to the composition of the Upper Mantle (HURLEY, P.M. 1967).

Concordant U-Pb ages determined on zircons and sphenes in Gneisses and schist (Table 1, YAMAGUCHI 1966, ISHIZAKA and YAMAGUCHI, 1969) from this area strongly indicate the main event of metamorphism to have occurred at about 240 m.y. The Rb-Sr mineral ages of these metamorphic rocks range from 230 to 184 m.y.

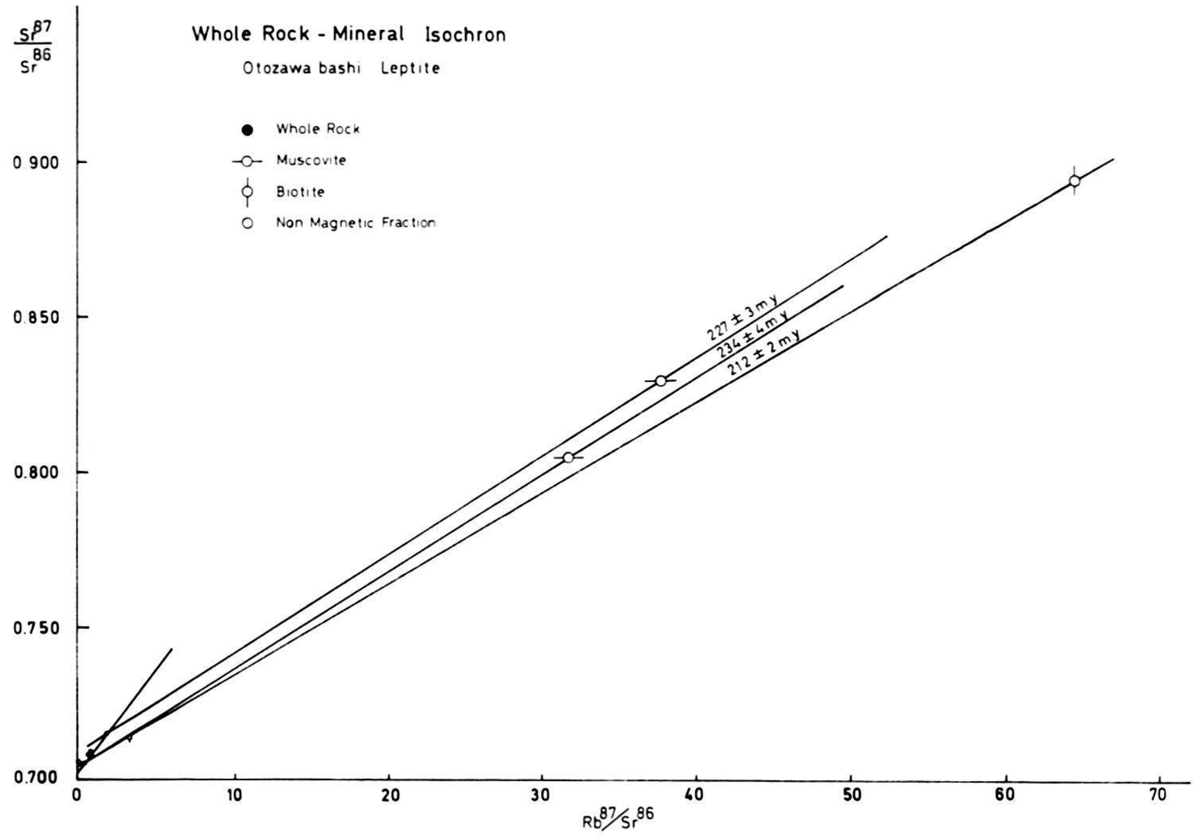

Fig. 2. Whole rock-mineral isochron of the leptites, Otozawabashi, Unazuki.

2. The Sangun metamorphic belt

The Sangun metamorphic belt treated here includes in addition to the typical part, the Omi schists in the eastern part of the Hida area, the Maizuru schists, north of Kyoto, and the Chikugo metamorphic rocks in north Kyushu. The metamorphic grade of most of the Sangun metamorphic rocks is so low and the recrystallization is so incomplete that only biotite is occasionally found. The metamorphic rocks are mostly slates and phyllites intercalated with many basic igneous rocks as well as serpentinite. BANNO (1958) divided the Omi schists into a chlorite zone and biotite zone. Epidote-glaucophane schists occur in the chlorite zone.

The geological relations of the Sangun metamorphic rocks to the non-metamorphic Paleozoic formations in the Chugoku province, in south-west Japan are discussed by NUREKI (1969). The Sangun metamorphic rocks are commonly overlain by the non-metamorphic Paleozoic formations which are younger than Pennsylvanian, but in most cases the two groups are bordered by faults. This author also divided the metamorphic rocks into four zones based on the metamorphic facies series, i.e. the pumpellyite-actinolite zone, glaucophane zone, epidote-actinolite zone, and epidote-hornblende zone. The pumpellyite-actinolite zone is regarded as the lowest grade of the Sangun metamorphism.

Age determinations executed so far on this metamorphic belt are not sufficient yet. The available data of Rb-Sr and K-Ar ages range from 330 to 205 m.y.

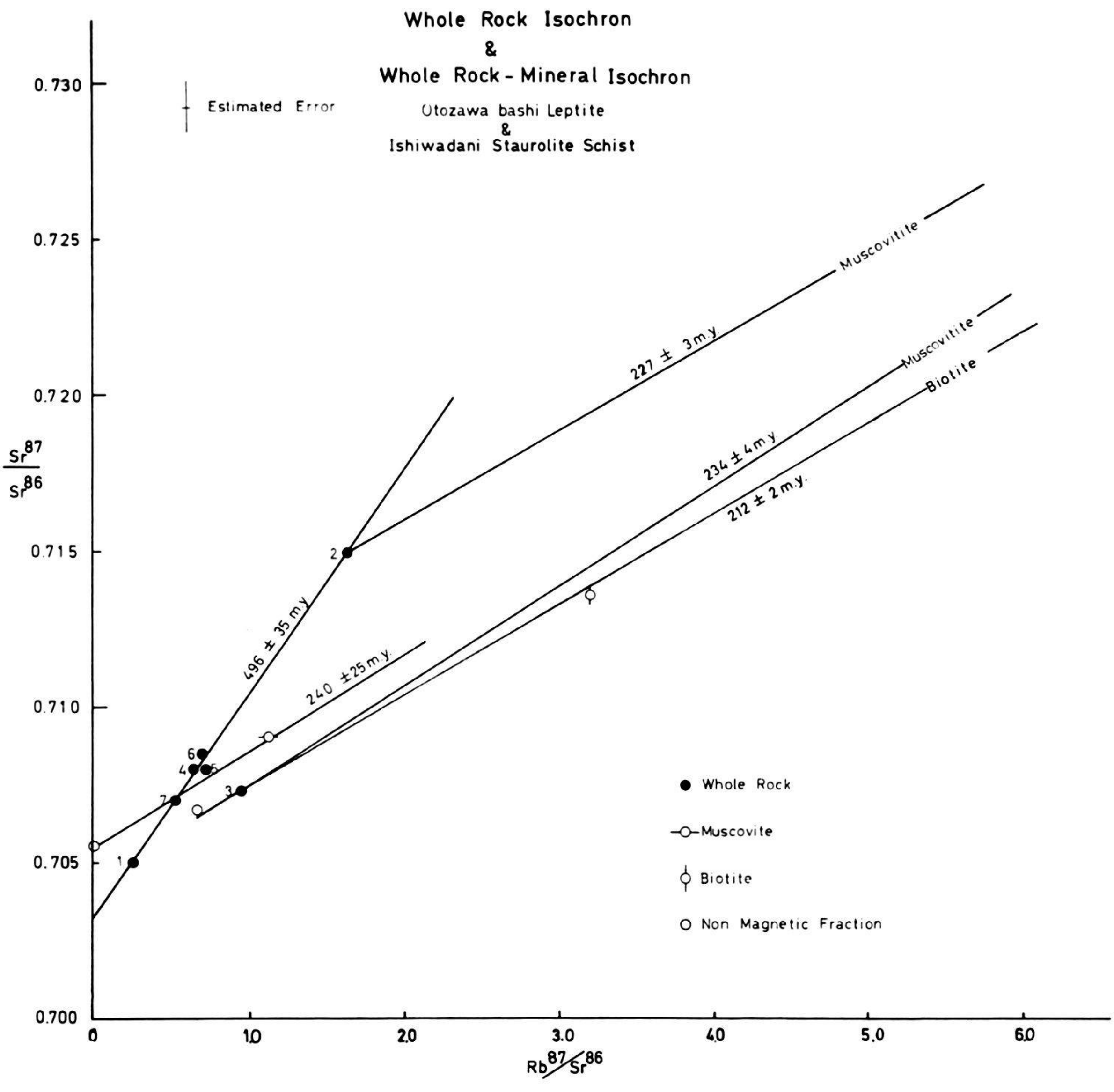

Fig. 3. Whole rock isochron and whole rock-mineral isochron of Otozawabashi leptites and Ishiwadani staurolite schist, Unazuki.

3. The Ryoke metamorphic belt

The Ryoke metamorphic belt is developed along the northern side of the Median Tectonic Line, from central Honshu to central Kyushu. The eastern extension of this metamorphic belt beyond the Fossa Magna are the metamorphic rocks of the Kanto Mountains (north area), Tsukuba district, and the Abukuma Plateau.

The Ryoke metamorphic belt is mainly composed of mica schist, mica gneiss, and schistose biotite hornfels, accompanied by a small amount of amphibolite, and hornblende gneiss. The original rocks are sandstone, clayslate, chert and other material probably of Permian age. The metamorphic rocks are intruded abundantly by synkinematic and post-kinematic granitic rocks. Sillimanite, andalusite and/or cordierite are found in the pelitic rocks of the higher-grade zone. The lowest-grade zone is the biotite zone. The chlorite zone is missing. Rb-Sr mineral ages determined on biotite and manganophyllite from the Kinki district and Taguchi area range from 100 to 70 m.y. The K-Ar ages are also close to this value. ISHIZAKA (1969) reported a Pb-Pb age of 1782 m.y. from well-rounded zircons in the biotite gneiss from Kimigano in this metamorphic belt. The similarity in age and nature of the zircon to that from the Hida metamorphic belt (Table 1, YAMAGUCHI 1967, MATSUMOTO et al., 1968) may suggest a similar source for the sediment in both belts during the Paleozoic. Concordant U-Pb age on zircon from some granites in this belt (ISHIZAKA 1969) indicates the main event of granite activity and metamorphism was about 100–90 m.y.

4. The Sambagawa metamorphic belt

This metamorphic belt runs along the southern side of the Ryoke metamorphic belt. The two belts are divided by a long fault, called the Median Tectonic Line. Metamorphic rocks of the Ryoke type are often mylonitized along this fault. The rocks of the Sambagawa metamorphic belt are crystalline schists regarded as mostly derived from the Paleozoic Chichibu system. They are accompanied by abundant ultrabasic and basic rocks such as serpentinite, dunite, gabbros and basaltic rocks. Granitic rocks related to this metamorphism are not found. Usually the crystalline schist is separated from the non-metamorphosed or weakly metamorphosed Paleozoic formation by faults. At certain places transitions are observed, however. The Mikabu metamorphic rocks consist of phyllites and green rocks the latter being derived from basic lava, tuff, and intrusives, forming a belt between the Sambagawa crystalline schist and the weakly or non-metamorphosed Paleozoic formation. Generally, the metamorphic grade is lowest in the Paleozoic formation in the south, and increases toward the Median Line in the north. The grade of metamorphism appears to be related to tectonic depth within the metamorphic belt, but not to the stratigraphical position in the geosynclinal pile (MIYASHIRO, 1961).

The highest grade of metamorphism in the Sambagawa metamorphic belt is of the green-schist facies, and rarely of the epidote amphibolite facies. Porphyroblastic albite spots are frequently found in the higher grade rocks. BANNO (1959) divided the rocks in the Bessi district, Shikoku, into four zones characterized by the occurrence of actinolite and pumpellyite (zone Ia), actinolite (zone Ib), common hornblende (zone II), and of biotite (zone III). Glaucophane occurs in zone Ia, Ib, and the lower-grade part of zone II. Diopside and kyanite occur in zone III.

Metamorphic rocks of the Nomo and Sonoki areas, Nagasaki Prefecture, Kyushu may be included in the Sambagawa metamorphic belt. The metamorphic rocks may be divided into 2 zones; one is characterized by the occurrence of pumpellyite (western part), and the other by that of the actinolite (eastern part) (IWASAKI, 1963). In the central part of the Kii Peninsula, the Jurassic formation is weakly metamorphosed. SEKI et al. (1964) concluded that, in this area, the lower grade metamorphic rocks progressively become higher grade rocks from south to north where they grade into the spotted schist zone of the Sambagawa metamorphic belt. The relation of metamorphic grade to the apparent isotope age will be discussed in some detail in a later chapter. The above mentioned geological observations indicate that the original rocks of the Sambagawa metamorphic belt are composed of Paleozoic and Mesozoic formations. Sambagawa metamorphic rocks are found in the form of boulders and pebbles in the Upper Cretaceous Onogawa formation in Kyushu.

In the Kii district, the metamorphosed Paleozoic formation at Yuasa is overlain unconformably by the Lower Cretaceous Yuasa formation (MATSUMOTO, 1947, HIRAYAMA and TANAKA, 1956). These lines of evidence give the upper age limit of the metamorphism as early Cretaceous.

The isotopic mineral ages measured on rocks from different areas in this metamorphic belt range from 110 to 70 m.y. It is believed, as discussed later, that the age of 110 m.y. given by the Rb-Sr isochron of three whole rocks would give the age of the main event of metamorphism in this metamorphic belt.

Correlation of the Metamorphic Grade to the Mineral Ages

1. Age of the Sambagawa metamorphic rocks in the Kii district

In the central part of the Kii Peninsula, Sambagawa crystalline schist, Paleozoic (Permian) and Mesozoic (Jurassic) sedimentary formations are exposed. The latter two formations are composed of shale, sandstone, chert, limestone, basic and acid lava and tuff. The crystalline schist includes muscovite quartz schist, graphite biotite muscovite schist, actinolite muscovite chlorite schist and phyllite, all derived from sandstone, shale, chert and mafic volcanic rocks. The schists are divided into two zones by the occurrence of the albite porphyroblast in the rock: the spotted schist zone on the north, and the non-spotted schist zone on the south.

A simplified geological map is shown in Figure 4. Detailed stratigraphical and geotectonic study has been done by SHIIDA (1962). The peculiar geotectonic feature of this area is the presence of the low-angle thrust fault (Kawakami nappe) where the Permian Kawakami Formation in the north has been thrust over the Jurassic Obamine Formation in the south. Triassic rocks are not present in this area.

SEKI et al. (1964) revealed that all these formations are regionally metamorphosed, the metamorphic grade being progressively increased from the south to the north where spotted schist appears. According to the distribution of metamorphic minerals such as prehnite, chlorite, pumpellyite, and actinolite in the mafic volcanic rocks, they divided the area into the following three metamorphic zones:

Zone I An assemblage of prehnite-chlorite-quartz-sodic plagioclase is most characteristic. Actinolite is not stable. Pumpellyite and epidote are commonly found.

Zone II An assemblage of colorless actinolite-epidote (-pumpellyite)-chlorite-sodic plagioclase is widely found. Prehnite is not stable.

Zone III Both pumpellyite and prehnite are not stable. Pale bluish-green actinolite-epidote-chlorite-sodic plagioclase assemblages are most characteristic.

The isograds based on this metamorphic zoning are not related to the local fault or the boundary of the different formations, but cross the large low-angle thrust lying between the Permian and the Jurassic. The isograds are displaced locally by a fault of NNE–SSW direction. On the basis of the above-mentioned geological relations, the

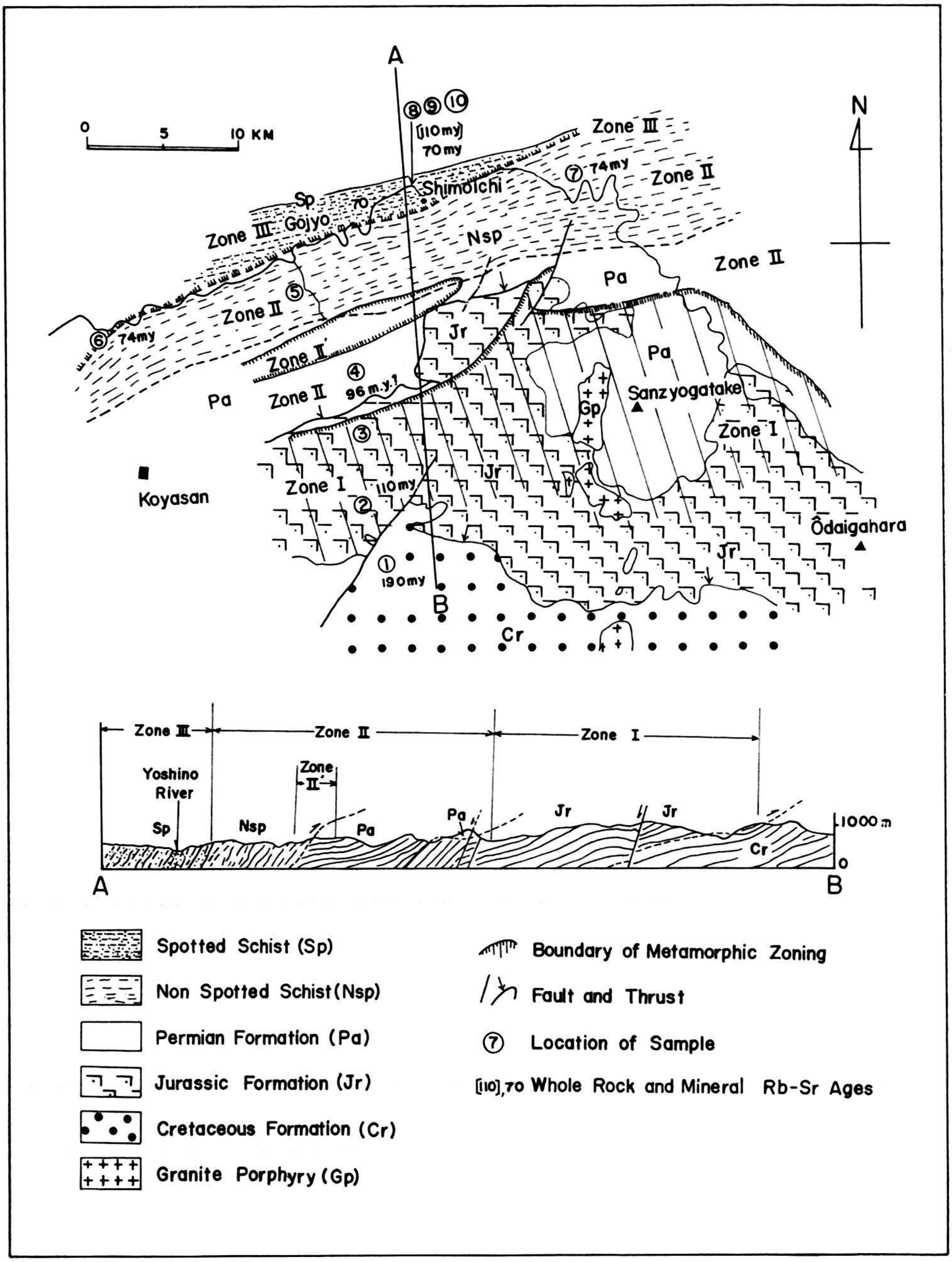

Fig. 4. Geologic map, metamorphic zoning (compiled from *Shiida*, 1962 and *Seki* et al. 1964), and Rb-Sr ages of minerals and rocks from the metamorphic rocks in the central Kii area.

age of the metamorphism is believed to be contemporaneous with, or younger than, the movement of the thrust and older than what is unprecisely dated as Cretaceous.

Preliminary Rb-Sr age determinations on selected samples from this area are presented in Table 1 (Rb $\lambda = 1.39 \times 10^{-11}$/years). The specimens were collected from the non-metamorphosed Cretaceous formation in the immediate south of this area and from metamorphic rocks of the respective metamorphic grades. Sample locations are given in Figure 4. Non-metamorphosed or weakly metamorphosed siliceous slates were treated first with the ultrasonic cleaner, and the sericites were concentrated by the gravity separation in the distilled water. Analytical results are given in Table 3. Technical aspects of the isotopic dilution analysis was given previously (YAMAGUCHI et al. 1969). The Rb-Sr isochron diagram is shown in Figures 5 and 6. The age of sericite in non-metamorphosed slate of the Cretaceous formation is estimated to be about 190 m.y. which indicates that the mineral was transported from an older basement during sedimentation. The initial Sr ratio is estimated at 0.708. Sericite in the siliceous slate of zone I gives an age of 110 $\pm$ 25 m.y. The initial Sr ratio is also estimated to be 0.708, taking the Sr ratio of the whole rock into consideration. The rock represents the lowest grade of metamorphism in this area. Rocks of the lowest metamorphic grade and those non-metamorphosed are divided by a fault.

Three whole rocks collected from the spotted schist zone (zone III), the highest grade of metamorphism, give an age of 110 $\pm$ 20 m.y.

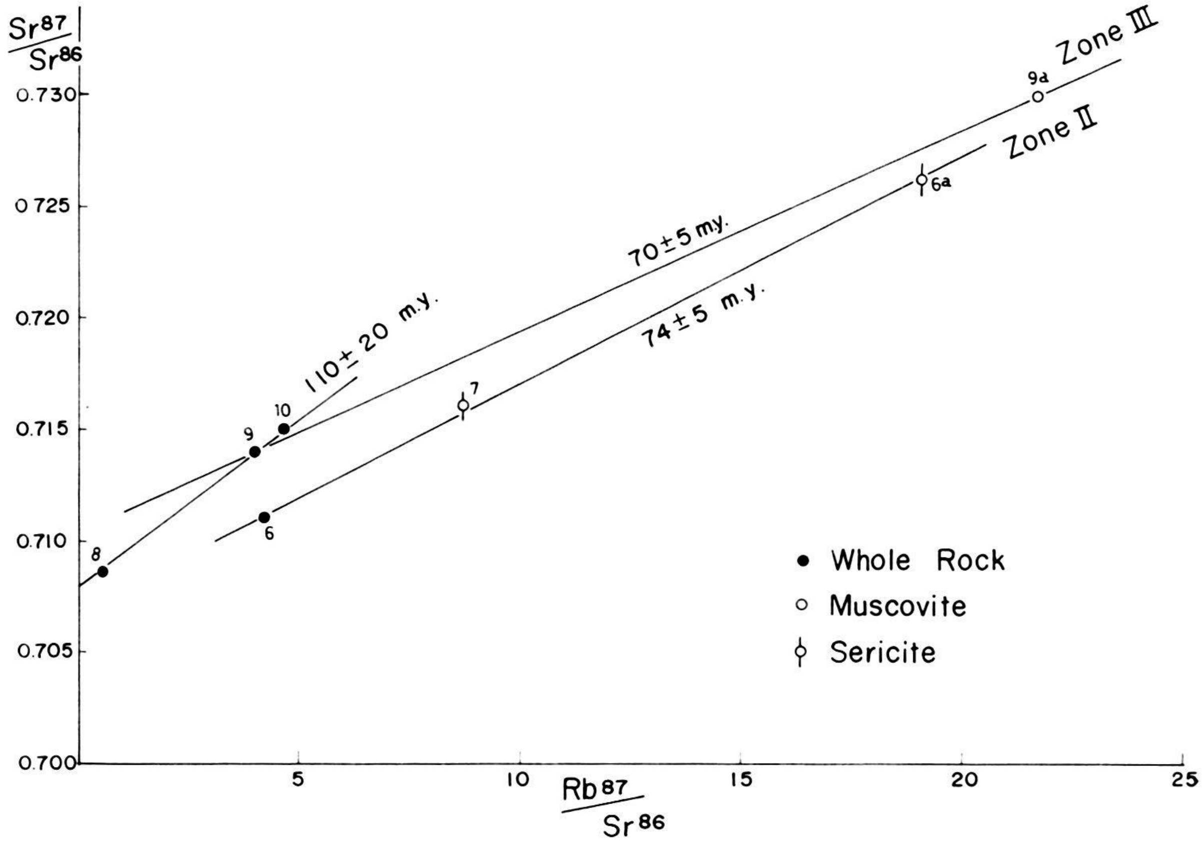

Fig. 5. Rb-Sr isochron on rock and minerals from the metamorphic rocks in the central Kii area.

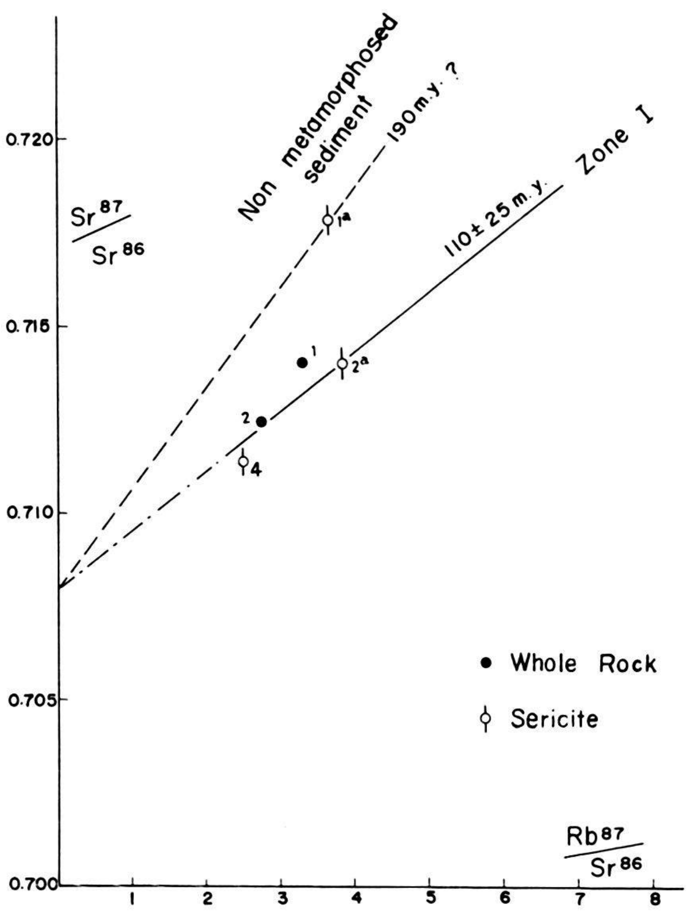

Fig. 6. Rb-Sr age of sericite from non-metamorphosed, and weakly metamorphosed siliceous slate in the central Kii area.

The original rocks of these schists are regarded as an alternation of sandstone, carbonaceous shale, and basic tuff respectively. The distance between collected samples is about five to ten meters.

The lithological similarity and the lack of a sharp boundary of the crystalline schists with the Permian formation in the south indicates that the spotted schists are derived from Permian sediments. The whole rock age of about 110 m.y. is very close to the concordant zircon age of the Ryoke granitic rocks determined by ISHIZAKA (1969). This evidence indicates that the age signifies the time of complete homogenization with respect to Sr during the metamorphism.

Muscovites in these samples give an age of about 70 m.y. Sericite or muscovite in the zone of intermediate metamorphic grade give intermediate ages between 110 and 70 m.y.

These data indicate the correlation of mineral ages to the grade of metamorphism, which means the different extent of disturbance in the parent-daughter relationship after the main event of metamorphism.

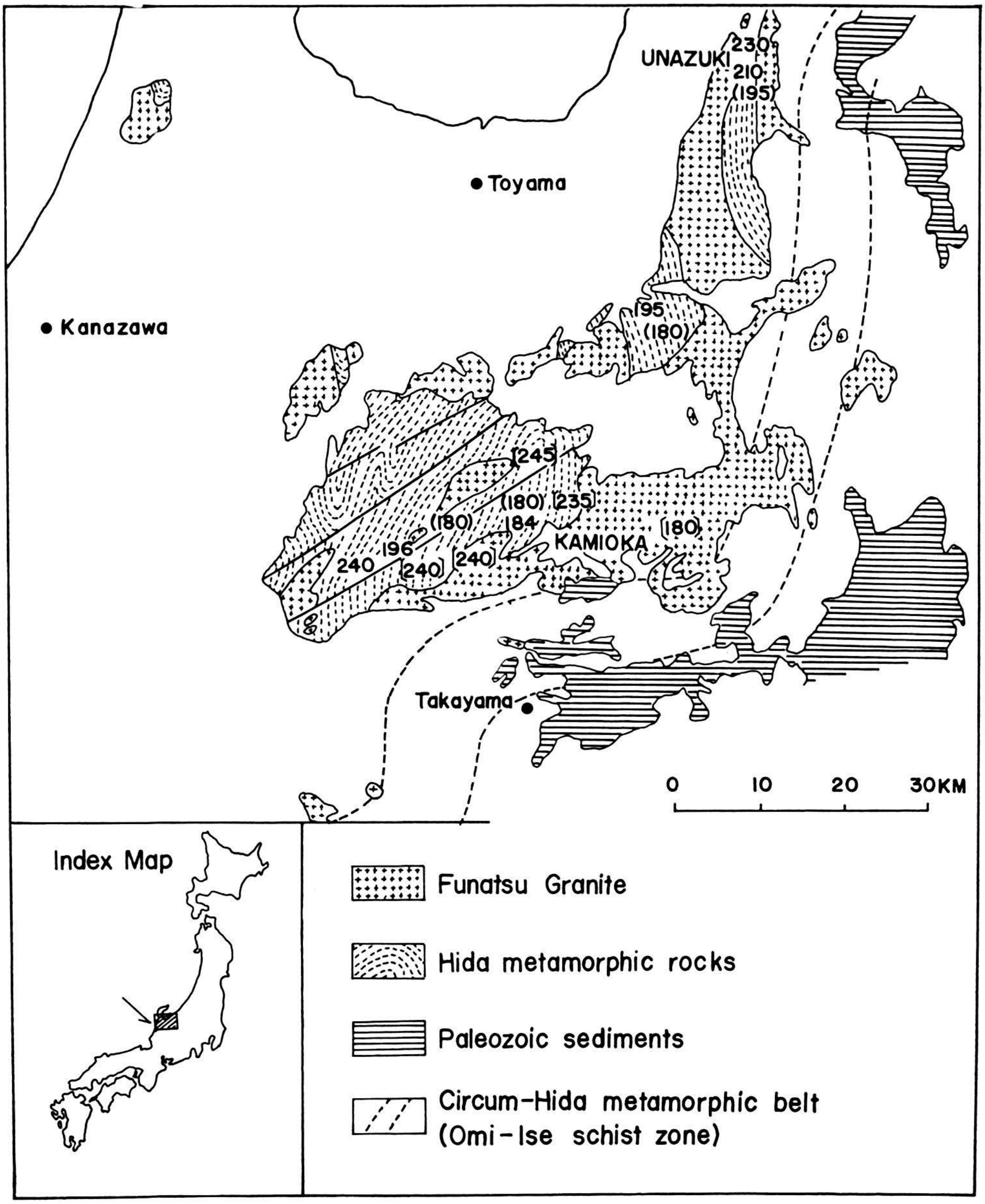

Fig. 7. Age distribution in the Hida metamorphic belt. [240], U-Pb age, 230, Rb-Sr age, (180), K-Ar age in m.y.

2. Mineral ages of metamorphic rocks from other areas

The metamorphic grade in the Hida metamorphic belt appears to increase southwestward. In the northeastern end of the Hida belt (Unazuki or Kurobegawa district) the rocks are fine grained and are characterized by the occurrence of muscovite, andalusite, kyanite, staurolite and green hornblende in pelitic and basic rocks; whereas in the southern part of the Kurobegawa area and the southwestern main Hida Plateau, the rocks are coarse grained and are characterized by the occurrence of silimanite in pelitic rocks and of green and brown hornblende in basic rocks. The Rb-Sr mineral ages of 210 to 230 m.y. and the K-Ar mineral age of 190 m.y. determined on the rocks from Unazuki, the lower-grade zone in this belt, and the Rb-Sr mineral ages of about 195 to 185 m.y. and K-Ar mineral ages of 190 to 165 m.y. determined on rocks from the main Hida Plateau, the higher grade zone in this belt, also indicate the correlation of the mineral ages to the grade of metamorphism. Note also that the Rb-Sr age of muscovite is older than the coexisting biotite in rocks from Unazuki (Table 1).

Concluding Remarks

Correlation of the metamorphic grade to the mineral ages suggest that the Rb-Sr and K-Ar mineral ages on metamorphic rocks usually give younger ages than the time of the recrystallization. The higher the metamorphic grade is, the greater the deviation of the apparent mineral age from the true age. This probably means that the disturbance in the decay system in minerals depends on the different durations of cooling in metamorphic zones of different grades after the main event of metamorphism.

From the above relationship, the age of the main event of Sangun metamorphism is estimated to be a little older than 330 m.y. Likewise, the main event of the Hida metamorphism may have occurred about 240 m.y. ago. However, the Rb-Sr biotite age of 270 m.y. and the K-Ar biotite age of 205 m.y. in the Sangun metamorphic belt may indicate the presence of another phase of metamorphism; the latter age is close to the age of the Hida metamorphism. On the other hand, the main events of metamorphism in the Sambagawa and Ryoke metamorphic belts took place about 110 m.y. and 100 m.y. ago respectively, which are very close to each other. Broadly speaking, the metamorphism migrated from the north to the south (Pacific) side.

In the older pair of metamorphic belts, the original sediments range from early Ordovician to Lower Carboniferous, while in the younger pair the original rocks range from Carboniferous to Jurassic. Further, in each of the paired metamorphic belts, older original sediments are found in the belt of andalusite-sillimanite type, while the younger sediments are included in the belt of glaucophane type. The glaucophane metamorphism began earlier in the southern belt of rapid sedimentation and tectonic movement, while the high temperature type metamorphism took place later in the northern belt.

The low initial Sr 87/86 ratio of acid igneous rocks in both older and younger metamorphic belts (leptite formation 0.703, Ryoke granites 0.708) indicate that these rocks are not related to the rejuvenation of the old granitic basement but are related to the upper Mantle.

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Table 1. Isotopic ages in four metamorphic belts, southwest Japan (age in m.y.).

1 a) Hida metamorphic belt

	Description	Mineral	U^{238}–Pb^{206}	Rb-Sr	K-Ar	Reference
North Hida Area	Mus. bio. q. schist	Whole R.-Mus.		234 ± 4		YAMAGUCHI et al. (1968)
	(black leptite),	-Bio.		212 ± 2		YAMAGUCHI et al. (1968)
	Otozawabashi,					
	Unazuki					
	Mus. q. schist (red	Whole R.-Mus.		227 ± 3		YAMAGUCHI et al. (1968)
	leptite), Otozawabashi,					
	Unazuki					
	Mus. bio. staurolite	Whole R.-Mus.		240 ± 25		YAMAGUCHI et al. (1968)
	schist (leptite),					
	Ishiwadani, Unazuki					
	Leptites, Unazuki	6 whole rocks		[496 ± 35]		YAMAGUCHI et al. (1968)
	Limestone, Unazuki	Phologopite			180 ± 10	SAITO et al. (1961)
					210 ± 13	SAITO et al. (1961)
Central Hida Area	Biotite gneiss,	Whole R.-Bio.		194 ± 7		YAMAGUCHI (1967)
	Makawa,			185 ± 9		YAMAGUCHI (1967)
	Toyama Pref.					
	Hor. Bio. gneiss,	Biotite			180	KUNO et al. (1960)
	Kuwashikiyama,					
	Toyama Pref.					
	Bio. granodioritic	Zircon	244 ± 5			YAMAGUCHI (1967)
	gneiss, Mozumi,					
	Kamioka Mine					
	Gar. hor. bio. q. pl.	Biotite		196		HAYASE et al. (1967)
	gneiss, Tsunokawa,				174 ± 9	SHIBATA et al. (1966a)
	Gifu Pref.					
	Hor. bio. gneiss,	Biotite		184		HAYASE et al. (1967)
	Futatsuya, Kamioka					
	Diop. bio. gneiss,	Biotite			170, 190	KUNO et al. (1960)
	Tochibora, Kamioka	Sphene	233 ± 5			ISHIZAKA et al. (1969)
	Mine					
	Graphite gar. hor.	Sphene	239 ± 5			ISHIZAKA et al. (1969)
	diop. gneiss, Amo,	Zircon	(1493, Pb-Pb)			YAMAGUCHI (1967)
	Gifu Pref.					detrital, discordant
						U-Pb ages
	Hornblende gneiss,	Zircon	243 ± 3			ISHIZAKA et al. (1969)
	Noguchi, Gifu Pref.	Sphene	231 ± 5			ISHIZAKA et al. (1969)
	Augen gneiss, Toichi,	Zircon	245 ± 3			ISHIZAKA et al. (1969)
	Gifu Pref.	Sphene	236 ± 5			ISHIZAKA et al. (1969)
Oki Island	Graphite bio. gneiss,	Biotite		187		HAYASE et al. (1967)
	Saigo, Oki island				170	SHIBATA et al. (1966a)

1 b) Sangun metamorphic belt

	Description	Mineral	U^{238}-Pb^{206}	Rb-Sr	K-Ar	Reference
Omi Area	Gar. mus. bio. pl. q. schist, Hashidate, Omi-cho	Biotite			309 ± 16	SHIBATA et al. (1968)
	Omi schist	Biotite		315		HAYASE et al. (1967)
				320		HAYASE et al. (1967)
Maizuru Area	Graphite bio. schist, Maizuru	Biotite		332		HAYASE et al. (1967)
	Graphite bio. schist, Maizuru	Biotite		306		HAYASE et al. (1967)
					205	SHIBATA et al. (1966)
	Graphite bio. schist, Oye, Kyoto Pref.	Biotite		269		HAYASE et al. (1967)
Chikugo Area	Mus. graphite schist, Manako, Chikugo	Muscovite		260 ± 130		YANAGI (1967)
	Sandstone schist, Manako, Chikugo	Muscovite		270 ± 80		YANAGI (1967)

1c) Ryoke metamorphic belt

	Description	Mineral	U^{238}-Pb^{206}	Rb-Sr	K-Ar	Reference
Taguchi Area	Manganophyllite rhodonite gneiss, Taguchi Mine	Rhodonite-manganoph.		80 ± 3		YAMAGUCHI et al. (1969)
	Yoshimuraite mang. rho. gneiss, Taguchi Mine	Rhodonite-manganoph.		71 ± 3		YAMAGUCHI et al. (1969)
	Biotite gneiss, Taguchi	Biotite			69 ± 3	BANNO et al. (1965)
					63 ± 3	BANNO et al. (1965)
	Quartz diorite, Kiyosaki type, Damine	Biotite			94	MILLER et al. (1961)
					91 ± 7	BANNO et al. (1965)
	Granodiorites at Kiyosaki and Mitsuhashi, south-west of Taguchi	Whole rock -biotites		76 ± 6		OZIMA et al. (1965)
		Biotites			70	OZIMA et al. (1965)
	Hor. bio. granodiorite Sumikawa type, Inabu	Biotite			101 ± 8	BANNO et al. (1965)
Kinki Area	Granite, Kimigano	Zircon	94			ISHIZAKA (1969)
	Granodiorite, Kiryu	Zircon	88			ISHIZAKA (1969)
	Banded gneiss, Kimigano	Zircon	[1782, Pb-Pb]			detrital, discordant U-Pb ages
Higo Area	Gar. bio. gneiss, Ogawa-cho, Kumamoto Pref.	Biotite			108 ± 9	SHIBATA et al. (1965)
	Biotite gneiss, Ogawa-cho, Kumamoto Pref.	Biotite		104		HAYASE et al. (1967)

1d) Sambagawa metamorphic belt

	Description	Mineral	U^{238}-Pb^{206}	Rb-Sr	K-Ar	Reference
Central Kii Area	Graphite bio. mus. q. schist, Zone III, Shimobuchi, Shimoichi-cho	Whole R.-Mus.		70 ± 5		This paper
	Mus. q. schist, Graphite bio. mus. q. schist, and Albite epidote mus. actinolite chlorite schist, Shimobuchi	3 Whole Rock		110 ± 25		This paper
	Sericite, q. schist, Zone II, Kudoyama	Whole R.-Ser.		74 ± 25		This paper
	Sericite q. schist, Zone II, Nagasaki, Yoshino-cho	Sericite		74 ± 25		This paper
	Phyllite, Zone II, Sakatani, Nishi-yoshino	Sericite		96?		This paper
	Siliceous slate, Zone I, Yamagiwa, Sarutani Water Reservoir	Sericite		110 ± 25		This paper
	Siliceous slate, non-metamorphosed Cretaceous sediment, Heikun, Daito-mura	Sericite		190?		This paper
Bessi Area	Mus. q. schist, Bizan, Tokushima	Muscovite		85		HAYASE et al. (1967)
	Gar. chl. bio. schist, Besshi mine, Zone D	Biotite		88		HAYASE et al. (1967)
	Graphite gar. chl. mus. alb. q. schist, Bessi district, Zone D	Muscovite			102 ± 8	BANNO et al. (1965)
	Gar. chl. mus. alb. q. schist, Bessi district, Zone D	Muscovite			89 ± 7	BANNO et al. (1965)
					87 ± 7	BANNO et al. (1965)
	Bio. gar. hor. schist, Bessi district, Zone D	Biotite			93 ± 7	BANNO et al. (1965)
	Graphite olg. bio. hor. schist, Bessi, Zone D	Biotite			82 ± 7	BANNO et al. (1965)
Nagasaki Area	Chl. mus. hema. q. schist, Muramatsu	Muscovite		94		HAYASE et al. (1967)
	Garnet mus. schist, Muramatsu	Muscovite			70 ± 6 83 ± 6	MILLER et al. (1963)
	Ep. gar. graph. chl. mus. alb. q. schist, Konoura	Muscovites			60, 70, 79	UEDA et al. (1963)
	Ep. chl. mus. alb. q. schist, Mogi, Nagasaki City	Muscovite			68, 83, 86	UEDA et al. (1963)
	Gar. stilp. chl. mus. alb. q. schist, Takahama, Amakusa island	Muscovite			81, 85, 86	UEDA et al. (1963)

Table 2. Results of isotopic dilution measurments of rocks and minerals from fine grained schists (the so called leptites from Otozawa-bashi and a staurolite schist from Ishiwadani), Unazuki, in the northeastern part of the Hida metamorphic belt.

No.	Description		Rb ppm	Sr ppm	Sr^{87}/Sr^{86} a)	Rb^{87}/Sr^{86}
1	Biotite hornblende schist	Whole rock	73.9	907.6	0.7053	0.236
2	Muscovite quartz schist	Whole rock	77.6	134.9	0.7150	1.667
	(Red leptite)	Muscovite	353.3	27.3	0.8295	37.94
3	Muscovite biotite	Whole rock	108.1	333.7	0.7072	0.938
	quartz schist	Biotite	378.8	17.3	0.8940	64.48
		Muscovite	345.5	32.7	0.8046	30.91
	(Black leptite)	Biotite (impure)	125.9	114.2	0.7136	3.19
		Non magnetic fraction	40.5	179.0	0.7068	0.655
4	Muscovite biotite quartz schist (Banded leptite)	Whole rock	71.6	328.5	0.7080	0.631
5	Muscovite biotite quartz schist (Banded leptite)	Whole rock	75.8	321.9	0.7080	0.682
6	Muscovite biotite quartz schist (Gray leptite)	Whole rock	109.3	466.2	0.7085	0.679
7	Staurolite schist	Whole rock	32.2	180.8	0.7070	0.516
		Muscovite	143.2	376.2	0.7093	1.114
		Non magnetic fraction	6.29	265.8	0.7055	0.069

Table 3. Results of isotopic dilution measurements of rocks and minerals from the metamorphic rocks in the central Kii area.

No.	Kyudai No.	Description	Rb ppm	Sr ppm	Sr^{87}/Sr^{86} a)	Rb^{87}/Sr^{86}
1	KS-48	Siliceous slate, Whole rock, Heikun	149	130	0.7140	3.34
1a	KS-48-3	Sericite, impure	87	69	0.7178	3.65
2	KS-49	Siliceous slate, Whole rock, Yamagiwa	106	113	0.7125	2.71
2a	KS-49-4	Sericite, impure	131	99	0.7140	3.84
4	KS-54	Sericite, impure in phyllite, Sakatani	70	81	0.7114	2.51
6	KS-68	Sericite q. schist, Whole rock, Kudoyama	87.8	62.0	0.7110	4.10
6a	KS-68-1	Sericite	194	29.6	0.7263	19.0
7	KS-1B	Sericite in Sericite q. schist, Nagasaki	221	73.3	0.7164	8.72
8	KS-26	Alb. epid. mus. actino. chlorite schist, Whole rock, Shimobuchi	75.1	375	0.7087	0.58
9	KS-28	Graphite bio. mus. q. schist, Whole rock, Shimobuchi	105	77.4	0.7140	3.92
9a	KS-28-1	Muscovite	367	51.9	0.7300	21.6
10	KS-27	Muscovite q. schist, Whole rock, Shimobuchi	41.5	26.1	0.7147	4.62

a) Ratios normalized to 86/88 = 0.1194.

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