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A Geochronological Study of the Ryoke Metamorphic Terrain in the Kinki District, Japan

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Abstract

The Rb-Sr and K-Ar age determinations were carried out on samples of biotite, muscovite, microcline and hornblende from the Ryoke metamorphic terrain in the Kinki district. 24 samples of granitic rocks, pegmatites and banded gneisses were collected mainly from the western part of the terrain. The results obtained in this study suggests that the metamorphism and plutonic activity in the Ryoke metamorphic terrain had continued almost throughout the Cretaceous period ranging from 130 m.y. to 70 m.y., culminating 110–90 m.y. The Rb-Sr ages on biotites of granitic rocks are well converged to 110–90 m.y. No great difference had existed in the time of the emplacement among the granitic rocks in this metamorphic terrain. The Rb-Sr ages on pegmatites are 90–70 m.y., which suggest that the metamorphism and plutonic activity in the terrain ended approximately 90–70 m.y. ago. The K-Ar and Rb-Sr ages on banded gneisses revealed quite discordant age pattern, which is discussed in detail.

Introduction

The age of the metamorphism, which produced the Ryoke and the Sanbagawa metamorphic terrain, has been the subject of recent investigations. There have been hot disputes among geologists as to the time of the metamorphism of the Ryoke and the Sanbagawa metamorphic terrain. Two sharply opposed opinions have been prevailing:

Kobayashi (1941) considered that the Ryoke metamorphism had occurred in a certain stage in his Sakawa Orogenic Cycle, which ranged from middle Jurassic to middle Cretaceous. On the other hand, Yamashita (1957) and others considered that the metamorphism took place in late Palaeozoic or early Mesozoic era. Recently, K–Ar age determinations on several granitic rocks in the Ryoke metamorphic terrain have been reported. But only a few Rb–Sr age measurements which utilize the radioactive decay of Rb^{87} to Sr^{87}, have been made so far.

The author has been studying the geology of the western part of the Ryoke metamorphic terrain in the Kinki district. In 1962, a mass spectrometer for *geological age determination was loaned, on a long term, to the Geological and* Mineralogical Institute, Kyoto University, through the courtesy of the Department of Terrestrial Magnetism, Carnegie Institution of Washington.

Dr. L.T. Aldrich of D.T.M. visited the Institute and the geochronological work begun in this year.

The author has collected the samples used in this study from the Ryoke metamorphic terrain in the Kinki district, mainly from the western part of the terrain where he had been engaged in his field work. Recently, by Yoshizawa et al.[33], the geology of the Ryoke metamorphic terrain in the Kinki district has been studied in detail. This geochronological study, by the author, has been carried out along with this geological study.

This paper will describe the geochronological study of the metamorphic and granitic rocks in the Ryoke metamorphic terrain, in the Kinki district.

I Experimental procedure

General statement

In this investigation, all determinations of the concentration of rubidium, strontium and some of potassium were made by isotope dilution method (Webster 1960).

The method involves following procedures; a known amount of "spike" is added to a known weight of a sample. The "spike" is a solution of the element to be analyzed whose isotopic composition has been greatly enriched by one or two of the isotopes of this element.

After reaching equilibrium, the element to be analyzed is separated from other elements by chemical procedures. The isotopic ratio measurement is made on a mass spectrometer on the separated element which is a mixture of the "spike" and the element having normal isotopic composition. Knowing the amount and the isotopic composition of the "spike", the amount of the element to be analyzed in the sample is calculated.

The determination of the concentration of argon was also made by isotope dilution method of analysis. In this case, a known amount of gaseous "spike" is added to released gas from a known weight of a sample.

Instead of chemical procedure, gas purification technique was used. Constants used are as follows:

Rubidium 87: $\lambda = 1.39 \times 10^{-11}$ yr.$^{-1}$

$Rb^{85}/Rb^{87} = 2.59$

Potassium 40: $\lambda_e = 0.585 \times 10^{-10}$ yr.$^{-1}$

$\lambda_\beta = 4.72 \times 10^{-10}$ yr.$^{-1}$

K^{40}/Total K $= 0.000119$ atomic ratio

1. Sample preparation

All sample specimens were collected so as to provide freshest material as possible. Most of rock specimens were collected at fresh road cuttings and quarries. The mineral samples analyzed in this study were mostly biotite. A few muscovite, potassium feldspar and hornblende were also analyzed. All mineral samples were prepared using isodynamic separator and standard heavy-liquid techniques, excluding pegmatitic micas which were cut by a scissors into fine flakes.

For preparation total rock samples, fresh rock specimens were crushed in a clean steel mortar to pass 100 mesh screen and thoroughly mixed. In case of coarse-grained or heterogeneous rock sample, about 500–1000 grams of the rock was crushed.

2. Determination of rubidium and strontium

i. Reagents and Apparatus

As the isotope dilution method such as used in this study deals with μg or sub μg quantity, extreme cares should be exercised to avoid any contamination through chemical reagents and apparatus.

The water was deionized through a commercial mono-bed type ion exchange column, which was further purified by redistilling in a quartz still.

The A.R. grade hydrochloric acid was redistilled as constant boiling acid in the quartz still. Both water and hydrochloric acid were stored in polyethylene bottles. The A.R. grade hydrofluoric acid was redistilled in a still made of Teflon placed in a electric furnace regulated by a convenient slidac. The A.R. grade perchloric acid and sulphuric acid were used without further treatment.

Glass wares used in this study were all made of quartz or Pyrex glass. Teflon beakers, covers, stirring rods and all glass wares were cleaned in hot hydrochloric acid at least overnight prior to use.

The ion exchange columns have no stop cocks and were cleaned by washing with quartz-distilled HCl repeatedly. After the cleaning, the resin was slowly settled in a Pyrex tube, nearly 20 cm length and 1 cm in diameter.

ii. Chemical Procedure

The chemical procedure used in this study is essentially identical with that described by Aldrich et al. (1956).

The procedure was made simple as possible, because complicated treatment might introduce contamination. To speed up the analyses, six samples were treated at one time. For this purpose, six Teflon beakers, and six Pyrex made ion exchange columns were prepared. The columns had been already traced for Sr and Cs (instead of Rb) using radioactive tracer technique, so that approximate places for these two elements were known. As a result no Sr radioactive tracer was added to each sample in this study.

A typical chemical procedure was carried out in the following manner:

1. Mineral sample (approximately 300 mg for biotite, 200 mg for muscovite and 100 mg for potassium feldspar) was weighed out into a clean Teflon beaker.

2. A known amount of Sr^{86-84} spike solution was added to the sample from a calibrated pipette.

3. 5∼20 ml HF and then 5 ml $HClO_4$ were added. With a cover on the beaker, the sample was heated on a hot plate in a fume hood and decomposed. When the mineral flakes went all into solution, the cover was taken. Until $HClO_4$ fume nearly ceased being evolved, heating was continued.

4. The residue was then dissolved in quartz-distilled water and diluted to about 80 ml in the Teflon beaker. The water solution may be stirred by a clean Teflon stirring rod to dissolve any residue present.

If the residue is not dissolved easily, 2.5N or 6.2N quartz-distilled HCl may be used, instead of water.

5. If the residue went all into solution, this solution was left for one or two days to assist the mixing of the Sr spike and Sr in the sample to be complete. In this step cares must be exercised to be sure that the solution is completely homogenized.

6. A 1∼3 ml fraction, the weight of which was measured gravimetrically, was poured into the 10 ml quartz beaker which contained appropriate amount of Rb^{87}-K^{41} spike solution. This solution was diluted to 8∼10 ml and homogenized by adding quartz-distilled water. 1∼2 drops of H_2SO_4 were added and evaporated to dryness to convert to sulphate. This was set aside for rubidium analysis.

7. The original solution was evaporated to dryness. About 2 ml of 2.5N quartz-distilled HCl was added to the dried perchlorate. The content was poured into a 2 ml Pyrex made centrifuge tube and centrifuged.

Precipitates consisting largely of KCl, $BaCl_2$ etc. were deposited in the bottom. Most of strontium was left in the solution.

8. The strontium was separated from other elements by cation exchange techniques using Dowex-50, 200–400 mesh, 12% cross linked ion exchange resin and 2.5N quartz-distilled HCl as eluant. The ion exchange columns were cleaned between successive runs by washing with 80–100 ml 6.2N quartz-distilled HCl and then with 2.5N HCl. The top of the resin was then leveled and approximately 1 ml of the sample solution was placed on the column by means of a pipette. After the solution was absorbed on the resin, it was eluted with 65 ml of 2.5N HCl. The column was then eluted with an additional 25 ml of 2.5N HCl. The 25 ml fraction containing most of strontium was collected in a 30 ml Pyrex beaker. Several drops

of $HClO_4$ were added to this aliquot to destroy any resin present. The content was then evaporated to dryness. This was stored until it could be analyzed on the mass spectrometer.

In preparation for the isotope analysis, the strontium perchlorate in the 30 ml beaker was dissolved in a few drops of quartz-distilled water.

This solution was deposited in the center of the outgassed tantalum filament in the source by means of a medical syringe using a clean Pyrex capillary tip. The filament temperature was raised for an instance, until that at which the fume evolve to expell occluded gas from the sample, to convert the perchlorate to oxide. The source was reassembled and placed in the tube of the mass spectrometer.

iii. Mass Spectrometric Analysis

Instrument

The instrument used in this study was a first order direction focusing 60° sector, 9 inch radius of curveture, solid source mass spectrometer which was built at D.T.M., Carnegie Institution of Washington.

The analyzer tube had two pumping leads, one near the source and the other near the collector and was evacuated by two CEC 40 l/sec mercury diffusion pumps backed up by a Hitachi 100 l/min mechanical pump. Two large cold traps were located between the analyzer tube and the diffusion pumps and were cooled with dry ice.

The vacuum was measured by Penning gauge mounted on the top of each cold trap. Operating pressure was usually $1 \sim 2 \times 10^{-6}$ mmHg.

A magnetic sweep was employed and scanning was made by rapid switching of the magnetic field. Ion beam was collected on a usual Faraday cup or on a electron multiplier.

In a earlier stage of the study, D.T.M. 9 stage Au-Mg electron multiplier was used and later Mitsubishi 12 stage Cu-Be multiplier replaced this.

The overall voltage 2,520V was supplied to the multiplier from dry batteries. The usual gain of the Mitsubishi multiplier was $2000 \sim 3000$.

Ion current was amplified by a Cary model 31 or Takeda 84 HS vibrating reed electrometer. $10^{9}\Omega$ resistor was used for electron multiplier detection and $10^{11}\Omega$ resistor for direct collection.

Ion peaks were recorded on a Honeywell-Brown strip chart recorder which had 1/4 second responce time.

In this investigation, single filament surface ionization ion source was used. Sample was placed on a $.001 \times .020''$ tantalum ribbon which was spot welded to posts in the ion source. The main parts of the ion source were made of tantalum so that they may be washed in HNO_3.

Isotopic Measurement

In isotope analysis of Sr, cares should be exercised to avoid contamination due to Rb. Because both parent and daughter element have essentially the same mass. Mass 87 due to Rb will interfere the determination 87/86 ratio of Sr sample. Rb contamination in Sr analysis arises from two sources; one is the Rb contained in the Sr sample due to poor chemical separation between Rb and Sr, and the other is due to the ion source itself in the mass spectrometer.

The Rb contamination in the ion source arises also from two sources; one is due to the normal Rb which is contained in the tantalum ribbon, the other is due to the Rb accumlated in the parts of the ion source near the filament from previous analysis. To avoid such contamination in the mass spectrometer, all ion source parts exposed to the filament were cleaned in $HNO_3+1\%$ HF solution between successive runs.

In addition the filament was outgassed in a outgassing device for several hours by passing electric current through the filament before mounting the sample. After these treatments, no Rb ion was detected at the higher filament current than those normally employed for Sr ion emission.

After the sample was mounted on the filament, the ion source was returned to the mass spectrometer tube and fastened with Allen head bolts. A new aluminum gasket was used for each run to ensure a tight seal.

Rb analysis was made as soon as the vacuum was lowered to the ragne of 10^{-6} mmHg. From 10 to 20 scans for 87/85 ratio were recorded.

In Sr analysis, however, the filament current was turned on and the sample was conditioned for overnight at the filament temperature just below that at which Sr ion emission began.

This conditioning burned off the contaminating Rb in the sample and gave most stable ion current. After the pressure had fallen to approximately 1×10^{-6} mmHg, the filament current increased until the eimssion of Sr ions began to increase spontaneously.

When the peak height was great enough to be in the range, usually more than 100 mV range of the electrometer, the ratio 88/86, 87/86 and 86/84 were recorded repeatedly. Usually from 10 to 30 scans for each set were recorded without further change of the filament current. Constant checking of the mass 85 position was made and it was ensured that there was no Rb contamination.

From the replicate measurements on several specimens, the probable error in the Rb-Sr age measurements is believed to not exceed 8 per cent.

3. Determination of argon* and potassium

i. Description of fusion system

The argon extraction system used in this laboratory is a flux fusion system essentially the same as described by Wetherill, Tilton, Davis and Aldrich (1956).

Three mercury cut-offs were used to isolate pumping system from fusion system and also to isolate extraction line from purification line.

The pumping system consists of a Nier-type two stage mercury diffusion pump backed up by a fore pump.

The fusion system is constructed by Pyrex glass and mounted on a transite base.

The extraction line consists of a nickel crucible, Ar^{38} spike, cold traps, CuO trap and pirani vacuum guage. The nickel crucible was charged with 40–50 grams of fresh NaOH and was outgassed at 600°–650°C by means of a removal electric furnace. A new aluminum gasket was used for sealing for each run. Two cold traps located each side of CuO trap, were used to freeze out water vapor at liquid nitrogen temperature.

The CuO trap was used to convert H_2 to H_2O, which was outgassed and operated at 500°–550°C. A glass pirani gauge was used to follow the releasing of the gas from the sample during the fusion.

The purification line consists of a charcoal trap, titanium sponge, sample take-off ampule and pirani gauge.

Titanium sponge filled in a bent quartz tube, was outgassed at 1000°–1100°C and operated at 900°–950°C. Charcoal trap and sample take-off ampule were outgassed at 450°C. A pirani gauge was used to follow the outgassing of the purification line and the cleaning up of the released gas.

The fusion system, except for the nickel crucible, is mounted by a oven shell and can be baked by 1.5KW strip heaters placed on the transite base. The whole system was baked normally at 200°C.

A timing device was used to turn off the heater automatically to allow the system cool to room temperature by morning.

ii. Mass spectrometric analysis

Instrument

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* K-Ar measurements were carried out on eight mineral separates (3 hornblende, 3 biotite and 2 muscovite).
Argon extraction and isotopic measurement of one biotite and one muscovite were made at Tohoku University by Prof. Ueda through the courtesy of Profs. Kawano and Ueda. Argon extractions of three hornblende samples were carried out at the Department of Physics, Osaka University and of the remaining samples at this laboratory. Argon isotopic analyses on these samples were made by static runs using the mass spectrometer at the Osaka University.
The argon extraction systems employed at the laboratories of Tohoku Univ. and Osaka Univ. were fully described elsewhere[17)26)].

The mass spectrometer used for the argon analyses, was a 90° sector field 20 cm radius of curveture gas source mass spectrometer at Osaka Univeristy.

This instrument was described in detail by Okano et al. (1960). Only brief description will be given here.

The analyzer tube was evacuated by a 300 *l*/sec oil diffusion pump and a mechanical fore pump, through a liquid nitrogen and a dry ice trap.

The normal vacuum attainable was about 5×10^{-9} mmHg measured by a B–A vacuum gauge.

Mitsubishi 12 stage Cu–Be electron multiplier was used for ion detection. The ion current was amplified by a Cary 31 vibrating reed electrometer and the ion peaks were recorded by a Minneapolis Honeywell 1/2" strip chart recorder. Normal operative condition was as follows:

Accelerating voltage; 2000 V
Total emission current; 100 μA
Overall voltage supplied to electron multiplier; 1700 V

An all metal bakeable valve was located between the analyzer tube and the pumping lead. Sample gas was introduced into the source region through a needle valve from the gas inlet system.

Isotopic measurement

All argon analyses were made by static runs. The analysis was typically performed in the following manner:

The ampule containing Ar sample was blown onto the gas inlet system, which was pumped down and baked for several hours at 200°C.

Then the residual gas in the gas inlet system was analyzed dynamically by scanning from the mass 12 to the mass 45. After it was ascertained that peaks at the mass 36, 38 and 40 were sufficiently small for making static run, the gas inlet system was isolated from the pumping system by means of two greaseless cocks. A cold trap in the gas inlet system was cooled with liquid nitrogen.

Before the argon measurement, background peaks were recorded under static operation. The background peaks from the mass 36 to the mass 40 were scanned 7–8 times. After a series of background spectrum was recorded, the valve was opened and the analyzer tube was evacuated.

When the vacuum recovered to that at which back ground measurement was made, the argon analysis was started. The sample gas in the gas inlet system was introduced through the needle valve into the source region.

The magnet coil current was adjusted so that the top of Ar^{38} peak was recorded on a chart. The needle valve was opened slowly and Ar^{38} peak began to increase. If Ar^{38} peak top reached 60–80 divisions of the chart, the needle valve was closed.

Scanning from 36 to 40 was repeated, usually 7–8 times. Ar^{36}/Ar^{38} and Ar^{40}/Ar^{38} ratio were obtained through the correction for the background Ar^{36}, Ar^{38} and Ar^{40} peaks.

iii. Potassium analysis

Potassium was determined for three hornblende samples using flame photometer and for all of mica samples by isotope dilution method.

Flame photometric analyses were carried out by Dr. Ishibashi of Kyushu University. It is believed that the error in potassium analyses with flame photometer is 3 percent or less (private communication, Ishibashi).

From the reproducibility of the results by isotope dilution analyses, the error in the potassium analyses using isotope dilution method is believed to not exceed 5 percent.

A standard biotite M.I.T. B–3203 was analyzed by isotope dilution method to estimate the accuracy of the potassium analysis. This standard biotite yielded 7.58 percent potassium content, which is in good agreement with the reported value 7.61 percent K for this standard biotite (average of 12 analyses)[27].

II Age measurements on the granitic and metamorphic rocks of the Ryoke metamorphic terrain in the Kinki district

General statement

Age determinations were made, mainly by the Rb–Sr method, on 24 samples collected from the Ryoke metamorphic terrain in the Kinki district.

Biotite, muscovite, hornblende and potassium feldspar were separated from the rock specimens. The Rb–Sr age measurements were carried out on biotite, muscovite and potassium feldspar. But unfortunately, because of high Sr/Rb ratio, the Rb–Sr measurements on potassium feldspars were unsuccessful, except for one sample from pegmatite. Several K–Ar measurements were also made on biotite, muscovite and hornblende.

Along with the analytical data of each district, brief geological settings will be stated. The geological map of the Ryoke Metamorphic terrain is shown in the article by Yoshizawa et al. (1966).

I. Western district (Ikoma-Kongo district)

Geological setting

This area is situated in the east of the Osaka Plains, constitutes the mountain range from Mt. Katano to Mt. Kongo and is the western marginal part of the Ryoke metamorphic terrain in the Kinki district. It constitutes an isolated mountain range, nearly trending in N-S direction. Except for the southern part, this mountain range is isolated by the Nara basin from the so-called "Yamato Plateau" which consists of the Ryoke metamorphic terrain.

Concerning this district, no systematic gelolgical study has been conducted. The author has studied the geology of this area, mainly on the granitic rocks of the Mt. Katsuragi-Mt. Kongo area.

This area, from Mt. Katano to Mt. Kongo, is composed almost entirely of granitic rocks and is extremely scanty of metamorphic rocks of sedimentary origin. An isolated banded gneiss block is situated in the southeast of Mt. Ikoma, constitutes the Mt. Matsuo mountain block and is the only metamorphic sedimentary rock mass in this district.

The area in the north of Mt. Ikoma consists almost entirely of biotite granite, except for a small amount of quartz diorite and hornfels. In the south of Mt. Ikoma, which is composed of metanorite, several knids of granitic rocks develop: Hornblende-biotite granite is mainly distributed in the southern part of Mt. Ikoma. This granite is, in general, weakly foliated and porphyritic. Judging from the similarity in the rock phase, this granite may correspond to the so-called Yagyu granite in the Kasagi district. Fine-grained granite and gneissose biotite granodiorite develop in the south of Mt. Shigi. The latter is remarkably foliated and quite varied in its rock facies. Hornblende-biotite gneissose granodiorite phase is observed in several localities, for example near Takayasuyama.

The area between River Yamato and Mt. Nijo is covered by the Nijo volcanics and the sediments of the Osaka Group, so that the granitic or metamorphic rocks do not crop out in this area, except for a few, small outcrop.

In the area south of Mt. Nijo, develop several kinds of granitic rocks: In the northern part of this area, granites, partly foliated and gneissose granodiorite with fairly large amount of basic metamorphic rocks are distributed. In the southern part, namely in the Mt. Katsuragi-Mt. Kongo area, a large quantity of non-foliated granodiorite occur. The rock constituting Mt. Katsuragi is medium- to coarse-grained hornblende-biotite granodiorite. Basic rock xenolithes and dikes are extremely few in this rock body. Mt. Kongo is composed of medium-grained hornblende-biotite granodiorite in which fairly large amount of basic rocks develop. The southern part of the granodiorite body is turned into sheared rocks of various grade. This granodiorite contact the Izumi Group with fault or is covered uncomformably by it in the south of Mt. Kongo.

Discussion on age measurement

Four granitic rocks and one banded gneiss were collected and analyzed. The ages measured on the rocks of this district are presented in Table 1. The analytical data are also presented in Table 2.

Table 1. Age determination from the Ikoma-Kongo district

Sample	Rock	Locality	Mineral	Apparent age (m.y.)	
				K-Ar	Rb-Sr
R-2099	Hornblende-biotite granite	South of Mt. Ikoma	Biotite		94
R-2117	Hornblende-biotite granite	South of Mt. Ikoma	Biotite		113
R-2014	Gneissose hornblende-biotite granodiorite	Takayasu	Biotite		98
R-2253	Banded gneiss	Mt. Matsuo	Biotite		162
R-1100	Gneissose hornblende-biotite granodiorite	Hiraiwa	Biotite		103
			Hornblende	115	

The Rb-Sr ages on biotite of the granitic rocks in this district converge into 110–90 m.y. The specimens R–2099 and R–2117 were collected from the hornblende-biotite grainite (Yagyu granite). At the exposure where R–2117 was collected, the granite shows typical "Yagyu granite" appearance; the granite is coarse-grained and fairly distinctly foliated, being porphyritic.

The specimen R-2099 was collected at the quarry situtaed directly south of the Ikoma metanorite body. The rock is medium-grained biotite granite with a small amount of phenocrysts of alkali feldspar. The Rb-Sr ages on biotite of these two granites are 113 m.y. and 94 m.y., respectively.

There is a slight difference in age between these two granites, but this may not have much meaning; both granites are different phase of the same granite body.

R-2014 was collected at Takayasuyama from dark colored, hornblende-biotite gneissose granodiorite which was remarkably foliated.

The Rb-Sr age on biotite is 98 m.y. R-1100 was also collected from the hornblende-biotite gneissose granodiorite at Hiraiwa, south of Mt. Nijo.

This rock is remarkably foliated, in which granular texture is observed under the microscope. The Rb-Sr age on biotite is 103 m.y. Hornblende was separated from this specimen, on which the K-Ar measurement was made.

The K-Ar age 115 m.y. was obtained on this hornblende. The Rb-Sr age on biotite and the K-Ar age on hornblende are in considerably good agreement, indicating that this gneissose granodiorite was emplaced approximately 110 m.y. ago.

R-1100 and R-2014 are considered to correspond to the so-called "older" granitic rock. But the result obtained from R-1100 shows that the age on the "older" granitic rock is almost identical with that on the "younger" granitic rock (Yagyu granite). This means that there may not be much intrusion-time-gap between the "older" granitic rocks and the "younger" granitic rocks.

A banded gneiss sample, R-2253, was collected from the Mt. Matsuo banded gneiss block. The Rb-Sr age on biotite 162 m.y. is significantly older than the age of the granitic rocks, which is approximately 110 m.y.–90 m.y. This result will be discussed later together with the other results of the banded gneiss of other districts.

Table 2. Analytical data

Sample	Mineral	Ar^{40*} ppm	Ar^{40*}/Ar^{40}	K percent	Sr^{nor} ppm	Sr^{87*} ppm	Sr^{87*}/Sr^{87}	Rb ppm
R-2099	Biotite				1.96	0.311	0.69	838
R-2117	Biotite				3.50	0.175	0.42	393
R-2014	Biotite				4.09	0.217	0.43	558
R-1100	Biotite				6.38	0.248	0.36	613
	Hornblende	0.00485	0.66	0.574				
R-2253	Biotite				5.72	0.163	0.29	254

II. Northern district (Kasagi district)

Geological setting

This district is located in the northeast of Nara City and occupies the northern part of the so-called "Yamato Plateau". This district has been known as the "Kasagi district" among geologists and has been studied by many investigators, compared with other districts in the Kinki Ryoke metamorphic terrain where only a few detailed studies have been carried out.

Arita (1949) and Matsumoto (1947) carried out petrographical studies on the rocks in this district. Recently Nakajima (1960) conducted a detailed geological and petrographical study. The geological setting of this district is mainly indebted to the work of Nakajima.

This district comprises several kinds of granitic rocks and various metamorphic rocks of sedimentary origin. In the northern part of this district, low grade metamorphic rocks of sedimentary origin deveolp widely and grade into unmetamorphosed Palaeozoic formation. A part of the Palaeozoic formation is considered to be middle Permian in age, judging from the fossils contained in the limestone bed.

The metamorphic and granitic rocks in this district are classified by Nakajima into two groups; the older and the younger.

As to the granitic rocks in this district, Arita distinguished two kinds of granitic rocks; "Koya granite" and "Yagyu granite". He considered that the Koya granite is older than the Yagyu granite, judging from the relationship between the granites and metamorphic rocks.

Nakajima further divided the granitic rocks in this district into six phases, as a result of his field study. The granitic rocks were divided into the following six phases, according to the sequence of intrusions.

1. Sugawa gneissose granodiorite
2. Koya granite
3. Yagyu granite
4. Ideminami granite
5. Ōmine quartz diorite (granodiorite)

Besides these, he further distinguished fine-grained granite, whose intrusion time is not known clearly. Among these granitic rocks, the Sugawa gneissose granodiorite is approximately concordant with the metamorphic rocks in structure and was assumed by Nakajima to have intruded in the "older metamorphism".

The Koya granite was assumed to have intruded from the later stage to the end of the "older metamorphism". The Yagyu granite is most widely distributed in this district. Two blocks are recognized; the Narukawa-Yamashiro block and the Yagyu block. This granite was considered to be the "younger granite", which had intruded after the completion of the "older metamorphism". The Idemimami granite has a close genetic relation with the Yagyu granite and was also considered to be the "younger granite".

The Ōmine quartz diorite (granodiorite) was considered to be the youngest intrusive body among the granitic rocks in this district.

The fine-grained granite was assumed to be the "older granite", though much was not known about this. Brief description will be given with each granitic rock.

The Sugawa gneissose granodiorite is medium-grained, dark colored and remarkably foliated, in which the direction of the foliation is nearly definite throughout the body. It extends approximately in a sill. Abundant hornblende of dark green variety is contained. Diopside and garnet vein are found.

The Koya granite has two phases; one, distributed in the southern part of Kizu River, is dark colored, medium- to fine-grained garnet bearing biotite granite. This granite is usually foliated and is greatly varied in its rock facies. It trends N40°W, forming a pluton, which is subconcordant with the metamorphic rocks in structure. The other, lying north of Kizu River, is medium-grained, leucocratic biotite granite, being non-foliated. Small porphyroblasts of alkali feldspar develop in this granite. It intrudes into the weakly metamorphosed Palaeozoic formation and gives contact metamorphism to it. Although these two phases are considerably different in their appearances, they are assumed to form a single granite body.

The Yagyu granite is coarse-grained, hornblend-biotite leucocratic granite. Generally this granite contains phenocrysts of alkali feldspar and looks porphyritic.

Foliation is weak in general, but in some exposures, it is considerably foliated. This granite is a part of a very large basin-shaped batholith, located in the northern part of Ueno City.

The Ōmine quartz diorite is fine- to medium-grained, non-foliated hornblen de-biotite quartz diorite. This rock forms a small stock, intruding into the Palaeozoic formation. The fine-grained granite is, in general, garnet bearing two mica granite, although the content of muscovite is remarkably variable. Usually, it is intimately associated with the banded gneiss.

Discussion on age measurement

Seven specimens were collected and analyzed. The ages measured with the rocks of this district are presneted in Table 3 and the analytical data are presented in Table 4.

The specimens were collected from the following rock units.

Biotite granite (Koya granite): R-4302, R-4304 The former was collected from the non-foliated phase, lying north of Kizu River and the latter, from the gneissose granite phase, south of Kizu River.

Hornblende-biotite granite (Yagyu granite): R-4188, R-4303
The former was collected from the Narukawa -Yamashiro body and the latter from the Yagyu block.

Hornblende-biotite gneissose granodiorite (Sugawa gneissose granodiorite): R-4286

Hornblende-biotite quartz diorite (Ōmine quartz diorite): R-4301

Fine-grained quartz diorite: R-4226

Age measurements obtained by the Rb-Sr method on biotites of six granitic rocks range 130 m.y.–86 m.y., except for R-4303.

No distinct age-gap is observed among the Sugawa gneissose granodiorite, the Koya granite and the Yagyu granite, as seen in Table 3, although Arita and Nakajima distinguished the "older" and the "younger" granitic rocks.

With the specimen R-4188, the K-Ar age measurements were also carried out on biotite and hornblende. The results show somewhat complicated age patterns. The K-Ar age on biotite yielded fairly young age 69 m.y., which is discordant with the Rb-Sr ages on biotites of the granitic rocks which are usually 110 m.y.–90 m.y. Shibata et al. (1961) reported the K-Ar age on biotite from the Inagawa granite, indicating approximately 70 m.y. age. The Inagawa granite is coarse-grained hornblende-biotite granite, occurring in the northwestern region of the Ryoke

Table 3. Age determination from the Kasagi district

Sample	Rock	Locality	Mineral	Apparent age (m.y.)	
				K-Ar	Rb-Sr
R-4301	Hornblende-biotite quartz diorite	Ōmine	Biotite		130[a]
R-4302	Biotite granite	North of Koya	Biotite		96
R-4304	Gneissose biotite granite	Nakamura	Biotite		111[b]
R-4188	Hornblende-biotite granite	Narukawa	Biotite	69	86
			Hornblende	146	
R-4286	Gneissose hornblende-bitotie granodiorite	Sugawa	Biotite		91
R-4226	Hornblende-biotite quartz diorite	Northwest of Sugawa	Biotite		111
R-4303	Hornblende-biotite granite	Ōgawara	Biotite		156

a: the mean of duplicate measurements 133 and 126
b: the mean of duplicate measurements 106 and 116

metamorphic terrain in the Chūbu district.

According to Katada et al. (1959) this granite is considered to correspond to the Yagyu granite in the Kinki district. The Inagawa granite develops in a batholith shape on the north western margin of the metamorphic terrain, from the banded gneiss zone to the low grade metamorphosed sedimentary rock zone. All these observations are quite similar to those on the Yagyu granite.

The K-Ar age obtained on R-4188 is in good agreement with that obtained on the Inagawa granite. On the other hand, the K-Ar age on hornblende of R-4188 is highly discordant with the K-Ar and Rb-Sr age on biotite of this specimen. Judging from the geological considerations on this granite, the K-Ar age on hornblende 146 m.y. may not represent the real age of the emplacement of the Yagyu granite; firstly, the Yagyu granite, having nearly N-S trend, intrudes in the region where the metamorphic rocks and gneissose granodiorite develop with nearly E-W trend.

This means that the Yagyu granite intruded discordantly with the structures of the metamorphic rocks and gneissose granodiorite. Undoubtedly it cuts the structure of the metamorphic rocks. Consequently this granite may not be far older in age than the metamorphic rocks and gneissose granodiorite which are assumed to have been produced approximately 110–90 m.y. ago.

Secondly, the Yagyu granite grades into the "Cretaceous granite" without distinct boundary, for example in the northeastern region of Kasagi.

The Hiei granite which is considered to be the "Cretaceous granite", is dated

90 m.y. by Hayase (1961). Even if there might exist a time-gap in the emplacement between the Yagyu granite and the Hiei granite, it may be small. Consequently the time of the emplacement of the Yagyu granite is assumed to be in the range 110–90 m.y., not so far from 90 m.y. The Rb-Sr age on biotite 86 m.y. is preferred for the age of the emplacement of this granite. As to the discordant K-Ar age 146 m.y. on hornblende of R-4188, the author considers as follows: In spite of the fact that the Yagyu granite generally contains a small amount of hornblende, the granite body from which R-4188 was collected contains a fairly large amount of hornblende.

In the northeastern region of Ueno City, the hornblende-biotite granite develops; this can be correlated to the Yagyu granite from the similarity in the rock facies. This granite body contains a considerably large amount of basic inclusions, ranging from metadiabasic to quartz dioritic rock. This fact probably indicate the existence of the reaction between this granite magma and the pre-existing basic rocks.

Judging from the similarity in the rock phase between the granite mentioned above and the Yagyu granite, the granite from which the specimen R-4188 was collected may have been contaminated with the pre-existing basic rocks. The possibility that the hornblende contained excess Ar^{40} is considered.

The Rb-Sr age 130 m.y. is obtained on biotite of the Ōmine quartz diorite, which is considerably older than the Rb-Sr ages on biotites of the granitic rocks in this district. Judging from the fact that this quartz diorite intrudes into the Palaeozoic formation in shape of stock and gives contact metamorphism to it, the Rb-Sr age 130 m.y. may indicate the time of the emplacement of this quartz diorite. That the location of the quartz diortie is isolated from any other granitic rock in this district and that this rock is quartz dioritic in nature, may indicate the fact that the quartz diorite magma had no relationship with other granitic magma in this district.

In connection with this rock, small quartz diorite masses, for example the Kurama quartz diorite, near Kyoto City, are developed in the Palaeozoic formation (Tamba zone). These quartz diorites have been considered by geologists to be related to the granite developing around the quartz diorite masses; these quartz diorites are approximately contemporaneous with the granite. The result obtained in this study, however, suggests that the quartz diorite masses in Tamba zone may have been an intrusion preceding that of the granite developing around the quartz diorite masses.

These quartz diorites, the author considers, may be related to the diabase and the noritic rock which intruded into the Ryoke metamorphic terrain.

The Rb-Sr age on biotite 156 m.y., obtained from R-4303, is open to question; this specimen was collected at a large quarry situated 1 km south of the Ōgawara station, Kansai Line. The specimen looks quite fresh in appearance and biotite shows no sign of alteration by microscopic observation.

But at the quarry, quartz was observed to be stained to pale reddish-brown color in a considerable part of the granite exposure. This fact suggests that the granite may have suffered alteration by hydrothermal solution.

Consequently this was discarded from the interpretation. R-4226 was collected from the quartz dioritic rock which is considered to be a hybrid rock derived from intrusive basic rock.

The Rb-Sr age on biotite is 111 m.y., which is approximately concordant with these obtained on the granitic rocks.

Table 4. Analytical data

Sample	Mineral	Ar^{40*} ppm	Ar^{40*}/Ar^{40}	K percent	Sr^{nor} ppm	Sr^{87*} ppm	Sr^{87*}/Sr^{87}	Rb ppm
R-4301	Biotite				26.26	0.215	0.11	410
					30.67	0.225	0.10	453
R-4302	Biotite				8.32	0.339	0.37	893
R-4304	Biotite				49.68	0.316	0.084	694
					43.46	0.302	0.091	715
R-4188	Biotite	0.0346	0.77	6.93	6.63	0.171	0.26	498
								468
	Hornblende	0.00531	0.76	0.490				
R-4286	Biotite				2.53	0.206	0.53	572
								523
R-4226	Biotite				6.28	0.148	0.25	337
R-4303	Biotite				5.80	0.235	0.37	383
					6.41	0.227	0.34	

III. Middle district (Nara-Sakurai district)

Geological setting

This district is located in the east of the Nara basin and trends from north to south. This area, comprising the western margin of the "Yamato Plateau", corresponds to the southern extension of the Kasagi district and to the western extension of the Ikoma-Kongo district.

A reconnaissance study was made on this area by Nakajima et al. (1956). More recently, this district was fully investigated by Yoshizawa et al. (1966).

This district comprises mainly granitic rocks, basic metamorphic rocks and metamorphic rocks of sedimentary origin.

The eastern part of this district is covered widely by the Muro volcanic rocks and sediments in Tertiary age. Generally speaking, the northern part of this district is occupied by banded gneiss and fine-grained granite, the central part by granitic rocks and basic metamorphic rocks and the southern part by gneissose granodiorite.

The banded gneiss (Tahara-Takamado block) develops widely in the eastern part of Nara City, having a complex folding structure. This banded gneiss block is assumed to be the western extension of the banded gneiss block which constitutes the Kasatori mountain range in the southeast of Ueno City.

In the northern and eastern region of the Tahara-Takamado banded gneiss block, fine-grained granite develops widely. Especially the fine-grained granite block located in the eastern region of the banded gneiss block, constitutes the largest block among the fine-grained granite masses in the Kinki Ryoke metamorphic terrain.

In the southern region of the banded gneiss block, hornblende-biotite granite which is presumably equivalent to the Yagyu granite, develops widely, although this granite contains a considerably large amount of basic rock inclusions of various sizes, differing from the Yagyu granite which is considerably scanty in this kind of inclusions.

This granite reveals a S-shaped fold structure. But this fold structure is considered to show a sort of flow structure which was formed at the intrusion of this granite.

A large metanorite block, similar to the Ikoma metanorite body, occurs at Mt. Miwa, trending approximately N70°W.

Around Sakurai City, the hornblende-biotite gneissose granodiorite, remarkably foliated, is widely distributed. In the southern region of the gneissose granodiorite, the hornblende-biotite granodiorite develops, which is equivalent to the granodiorite of Mt. Kongo area, extending to the Median tectonic Zone.

A large pegmatite, ranging 1 km $\times$ 1 km wide, occurs in the vicinity of Nara City, intruding into the basic metamorphic rock body. This pegmatite has been mined for raw materials for glass industry. It may have derived from the Yagyu granite developing in this region. Brief descriptions, except for the basic metamorphic rocks from which no specimens were taken, are given below.

1. Banded gneiss [Tahara-Takamado block]

This banded gneiss block consists of psammitic and pelitic banded gneiss containing sillimanite in the case of the pelitic geniss, which can often be recognized easily with the naked eye. The mineral assemblage in the pelitic gneiss is almost identical with that of the Nunobiki block. A large amount of graphite is contained in the pelitic gneiss.

2. Fine-grained granite

Fine-grained granite, when closely associated with the banded gneiss, usually becomes garnet bearing two mica granite. In the north of Mt. Miwa the two mica granite is remarkably foliated and is concordant with the accompanying banded gneiss in structure. At Fukawa, where R-4305 was collected, this granite is a fine-grained biotite granite which is non-foliated and quite homogeneous in rock facies throughout the body.

3. Hornblende-biotite granite

Although the typical Yagyu granite is coarse-grained and fairly homogeneous in its appearance, the granite in this district is considerably varied in its rock facies. Generally it is coarse- to medium-grained and weakly foliated. The granite occasionally turns into medium-grained biotite granite, when it approachs a large basic rock body. R-3335 was collected from this phase.

4. Hornblende-biotite gneissose granodiorite

This rock is dark colored, remarkably foliated and contains a large amount of hornblende. It is quite similar to the gneissose granodiorite occurring at Hiraiwa in the western district.

5. Pegmatite

The pegmatite found at Obara in the east of Sakurai is small in its scale and intrudes into the fine-grained granite which is quite varied in its rock facies. The minerals contained in this pegmatite are muscovite, microcline and quartz. The pegmatite found at Takai consists of biotite, muscovite, microcline, garnet and quartz. Biotite is of green variety. Both muscovite and biotite are typical "book mica".

Discussion on age measurement

Seven samples were collected and analyzed. The results of the age determinations and the data are presented in tables 5 and 6, respectively.

A suite of pegmatitic minerals were obtained from the pegmatite mine at Takai. Both muscovite and biotite are large crystals, reaching to 5∼8 cm in diameter. Microcline is a good shaped crystal, approximately 15 cm long and 8 cm wide at the maximum, showing perthite texture under the microscope.

It is commonly considered that mostly reliable ages are those measured on pegmatitic minerals. The minerals of the Takai pegmatite are highly radiogenic in Sr^{87} as is seen in Table 6. Consequently it is expected that a high precision of determination could be achieved.

Table 5. Age determination from the Nara-Sakurai district

Sample	Rock	Locality	Mineral	Apparent age (m.y.)	
				K-Ar	Rb-Sr
R-4006	Pegmatite	Takai	Biotite		72
			Muscovite		93
			Potassium feldspar		95
R-4005	Banded gneiss	Takamadoyama	Biotite	72	101
			Muscovite	97	162
R-4305	Fine-grained granite	Fukawa	Biotite		105
R-3662	Gneissose biotite granodiorite	North of Mt. Miwa	Biotite		95
R-3335	Hornblende-biotite granite	North of Hase	Biotite		109
R-4311	Pegmatite	Obara	Muscovite		71
R-4300	Gneissose hornblende-biotite granodiorite	Asako	Biotite		106
			Hornblende	131	

The Rb-Sr ages on microcline and muscovite of the Takai pegmatite are 95 m.y. and 93 m.y. respectively, which are in excellent agreement.

The concordant pegmatite ages are interpreted as both the age of injection of the pegmatite and the age of the end of metamorphism and plutonism of the terrain, because the pegmatites presumably were emplaced near the end of the metamorphism and plutonism.

Thus the concordant Rb-Sr ages obtained on the microcline and muscovite of the Takai pegmatite indicate that the metamorphism and plutonic activity had ended approximately 90 m.y. ago in the Ryoke metamorphic terrain in the Kinki district.

One more pegmatite sample collected at Obara yielded the Rb-Sr age 72 m.y. on muscovite. This age is slightly younger than that of the Takai pegmatite. It is assuemd that the pegmatite activities in this terrain had continued up to approximately 70 m.y. ago, although they may not have been intensive.

The Rb-Sr age on biotite of the Takai pegmatite is 72 m.y., which is slightly discordant with those on other co-genetic minerals. A quite similar phenomenon has been reported by Hayase (1961). He measured the Rb-Sr ages on biotite and muscovite of the pegmatite, collected at Mikawamiyazaki, Aichi Prefecture, in the Ryoke metamorphic terrain in the Chūbu district and obtained the Rb-Sr age 101 m.y. on muscovite and 40 m.y. on biotite.

More recently, Zartman (1964) reported anomalously low Rb-Sr ages on pegmatitic biotite of the Lone Grove granitic pluton in the Llano Uplift, Texas.

The average Rb-Sr age on microcline, muscovite and biotite of the granitic rocks of the Lone Grove pluton is 1020 m.y., while the Rb-Sr ages range 955 m.y. to 655 m.y. for the biotite in the pegmatite.

Co-genetic microcline from the pegmatite yielded normal Rb-Sr age. As for the low Rb-Sr age on pegmatitic biotite, it is most probable that the loss of daughter element has produced these low Rb-Sr ages. However, the mechanism responsible for these low Rb-Sr age is not known exactly.

He suggested it is possible for the rubidium so to distort the crystal lattice that the mineral becomes extremely unstable to strontium migration, from the fact that the biotite have highest rubidium content.

It may be noted that the biotite in the Takai pegmatite has very high rubidium content compared with the co-genetic microcline and muscovite.

The Rb-Sr ages on biotites of four granitic rocks in this district are well summarized to 115–95 m.y. R-3662, on which the Rb-Sr age 95 m.y. was obtained, is remarkably foliated biotite gneissose granodiorite. Garnet veins are often observed to develop in this granodiorite.

R-4300 was collected from the hornblende-biotite gneissose granodiorite which is considered to be the eastern extension of the Hiraiwa gneissose granodiorite in the western district. The K-Ar age 131 m.y. on hornblende of R-4300 is slightly discordant with the Rb-Sr age 106 m.y. on co-existing biotite. This K-Ar age on

Table 6. Analytical data

Sample	Mineral	Ar^{40*} ppm	Ar^{40*}/Ar^{40}	K percent	Sr^{nor} ppm	Sr^{87*} ppm	Sr^{87*}/Sr^{87}	Rb ppm
R-4006	Biotite				3.21	2.420	0.92	7630
	Muscovite				2.66	0.581	0.76	1596
					2.69	0.583	0.76	1592
								1479
	K-feldspar				1.46	0.458	0.82	1224
R-4005	Biotite	0.0391	0.86	7.53	2.51	0.247	0.59	622
					3.16	0.236	0.52	
	Muscovite	0.0569	0.74	8.22	28.41	0.169	0.077	266
R-4305	Biotite				31.09	0.238	0.099	574
R-3662	Biotite				2.38	0.213	0.56	569
R-3335	Biotite				3.05	0.208	0.49	485
R-4311	Muscovite				1.12	0.771	0.83	2764
R-4300	Biotite				5.47	0.193	0.33	467
	Hornblende	0.00442	0.63	0.454				

the hornblende may be interpreted as the maximum age of the granodiorite emplacement.

The K-Ar age and Rb-Sr ages on biotite and muscovite of the banded gneiss sample R-4005, revealed discordant age pattern. The discussion about the results will be given together with those obtained with the eastern district.

Eastern district (Ueno-Nabari district)

Geological setting

In the southeastern region of Ueno City, a large area of metamorphic rocks of sedimentary origin develops. This metamorphic rock block forming the Nunobiki mountain range, runs nearly N-S and is the largest metamorphic sedimentary rock block exposed in the whole Kinki district. A large part of the metamorphic rocks consists of banded gneiss. The northern part of the block consists of schistose hornfels. Most of the banded gneiss in this block is derived from psammitic sediments, interbeded with pelitic sediments.

In general, the mineral assemblage observed in the pelitic banded gneiss is as follows: sillimanite-cordierite-garnet-biotite-muscovite-alkali-feldspar-plagioclase-quartz.

In the interior of this metamorphic rock block, no granitic rocks were observed to intrude, except for fine-grained granites of small scale.

Consequently it is assumed that this banded gneiss block is least affected by the granitic intrusions, among those in the Kinki district. The granite exposure nearest to the banded gneiss block, is approximately 8 km aprt from this block. Two banded gneiss bodies from which R-4307 and R-4306 were collected, occur near Jôryu and Nagase respectively, in the eastern region of Nabiri City. They both occur in the hornblende-biotite gneissose granodiorite which is distributed widely in this region.

No granite such as Yagyu granite develops in this region, though fine-grained granite is distributed considerably.

Discussion on age measurement

Five banded gneiss samples, all of which are sillimanite gneiss, were collected from this district. The age measured in this district and the analytical data are presented in tables 7 and 8.

R-4308, R-4309 and R-4310 were collected from the Nunobiki banded gneiss block, which was chosen as the location for sample collecting to get specimens free from the influence of granitic intrusion; this block consists almost entirely of the banded gneiss in which effects of the granitic intrusion are expected to be slightest.

As is shown elsewhere[33], however, the banded gneiss block as a whole has a low angle dipping. As a result, although the present exposure on the surface, looks quite vast horizontally, the vertical thickness of the banded gneiss body may not be large. Granites may exist beneath the banded gneiss, not so far from it, although the granite exposure occurs as far as 8 km apart from the banded gneiss body. Consequently, it is assumed that the banded gneiss body have been influenced by granites more or less.

Table 7. Age determination from the Ueno-Nabari district

Sample	Rock	Locality	Mineral	Apparent age (m.y.)	
				K-Ar	Rb-Sr
R-4306	Banded gneiss	Nagase	Biotite		181
R-4307	Banded gneiss	Jōryu	Biotite		103
R-4308	Banded gneiss	Nunobiki	Biotite		108
R-4309	Banded gneiss	Nunobiki	Biotite	71	192
			Muscovite	61	231
R-4310	Banded gneiss	Nunobiki	Biotite		107

The K-Ar age measurements on biotite and co-existing muscovite of R-4309 indicate 71 m.y. and 61 m.y. respectively, which are in good agreement with each other. On the other hand, they are discordant with the Rb-Sr age on both biotite and muscovite of this specimen; the K-Ar ages are considerably younger than the Rb-Sr ages on both the granitic rocks and the banded gneiss in this district and others. To account for the result, the following two possibilities may be considered:

1. The K-Ar age on this sample reflects only the "cooling history" of the banded gneiss; the banded gneiss had uplifted 60–70 m.y. ago. Until that time, the banded gneiss had been in high temperature, sitting in the deeper zone, enough to expel the accumlated Ar^{40}. The K-Ar age may represent the time elapsed since, by rapid uplifting, the temperature had been lowered to a degree at which no more Ar^{40} liberation occurred.

2. The banded gneiss, now exposed on the surface, has been affected with thermal influence by some granitic activities. The temperature of the banded gneiss is considered to have been raised high enough to diffuse the Ar^{40} from the minerals.

As to these two possibilities, the author considers as follows:

The K-Ar ages on muscovite and co-existing biotite from two banded gneiss specimens, R-4309 and R-4005, are approximately 70–60 m.y., except for one muscovite of R-4005. These results are practically identical to the K-Ar age 69 m.y. on biotite of the Yagyu granite (R-4188). In the northwestern part of the

Ryoke metamorphic terrain in the Chūbu district, the Inagawa granite and the Naegi granite develop widely, as mentioned previously.

Shibata et al. (1962) reported the K-Ar age measurements on these granites. The K-Ar age on biotite of the Naegi granite is 64–68 m.y., whereas that from the Inagawa granite is 63–72 m.y., indicating seemingly no difference between the time of the emplacement of these two granites.

As to the geological relation between the Inagawa granite and the Naegi granite, they stated, judging from their relation to the Nôhi rhyolite, ". . . . this (Nôhi rhyolite) is a thick volcanic formation, consisting mainly of welded rhyolitic tuff and is distributed over a wide area to the northwest of the Ryoke belt. At its southern margin, the Nôhi rhyolite comes into contact with members of the Ryoke suit where it covers uncomformably the Inagawa granite. In many localities, however, the rhyolite is intruded by the Naegi granite, which leads to the conclusion that there is difference in age between the Inagawa and Naegi granites and that the former is the older of the two." Judging from these geological relations quoted above, it is assumed that the K-Ar age of the Inagawa granite may represent the time of the granitic acitvity which occurred approximately 60–70 m.y. ago, as shown by the intrusion of the Naegi granite; biotite may have lost radiogenic Ar^{40} through the diffusion by the thermal event which had occurred 60–70 m.y. ago. According to Katada et al. (1959), the Inagawa granite is corrlatd to the Yagyu granite in the Kinki district. The Naegi granite is a typical shallow emplaced granite body and may be correlated to the Tanokami and Suzuka granite in the Kinki district, from their petrographical similarities. That the K-Ar age on the Yagyu granite is approximately identical with those on the Naegi and Inagawa granites, may indicate that there existed a granitic activity which emplaced the Naegi granite in the Chūbu district and the Tanokami-Suzuka-Hira granites in the Kinki district.

Thus the K-Ar ages obtained from the Nunobiki banded gneiss blosk may also indicate the thermal event which had occurred 70–60 m.y. ago.

Table 8. Analytical data

Sample	Mineral	Ar^{40*} ppm	Ar^{40*}/Ar^{40}	K percent	Sr^{nor} ppm	Sr^{87*} ppm	Sr^{87*}/Sr^{87}	Rb ppm
R-4306	Biotite				8.36	0.208	0.26	291
R-4307	Biotite				6.53	0.163	0.26	404
R-4308	Biotite				5.60	0.238	0.38	559
R-4309	Biotite	0.0407	0.86	7.91	6.06	0.190	0.31	251
	Muscovite	0.0406	0.87	9.16	40.72	0.200	0.066	220
R-4310	Biotite				4.52	0.211	0.40	500

Total rock analyses

Total rock analyses on the granitic rocks and the banded gneisses were attempted. The rock specimens usually fist-sized, were crushed in a steel mortar and sieved to pass through 100 mesh screen. About 1 gram of the powdered sample was taken and treated with the identical chemical procedure as the mineral samples, except that it was not spiked.

The isotopic composition of reagent $Sr(NO_3)_2$ [Merck G.R.] was measured periodically during the course of the study and the performance of the isotopic analyses on unspiked total rock samples were monitored.

In the later stage of the study, a strontium isotope standard [$SrCO_3$ Eimer and Amend lot No. 492327] was supplied by Dr. L.T. Aldrich of DTM and was also measured for its isotopic composition. The results of the isotopic analyses made on both $Sr(NO_3)_2$ and $SrCO_3$* reagents are presented in Table 9.

The Sr^{87}/Sr^{86} ratio on four granitic rocks and four banded gneisses have been measured to test the feasibility of making age measurements by the total rock

Table 9.

Isotopic abundance of Merck G.R. $Sr(NO_3)_2$

	86/88	87/86	$87/86_{n}$	Date
1.	.1193	.715	.715	5/22/63
2.	.1191	.714	.713	6/1/63
3.	.1190	.714	.713	11/4/63
4.	.1205	.714	.717	11/2/63
5.	.1193	.716	.716	1/9/64
6.	.1195	.713	.713	1/8/64
Mean	.1195	.714	.715	
	$\bar{\sigma}=\pm.0002$	$\bar{\sigma}=\pm.001$	$\bar{\sigma}=\pm.001$	

* The measurement of isotopic composition of this $SrCO_3$ in this laboratory yielded the value of 0.712 for the Sr^{87}/Sr^{86} ratio (see Table 9).
However, the revised Sr^{87}/Sr^{86} ratio for this $SrCO_3$ standard was reported recently, which is in the range. 708–709.[8)]
Recent re-determination of this $SrCO_3$ reagent in this laboratory also lowered the value of the Sr^{87}/Sr^{86} ratio from .712 to .708, as a result of improved vacuum condition; at the time when the Sr isotopic measurements on a series of unspiked samples were carried out, complete resolution between the larger mass 88 peak and the samller mass 87 peak was not obtained; the 88 peak tail was enhancing the 87 peak. Therefore, the Sr^{87}/Sr^{86} values in Table 9–11, may be up to .004 higher than the present day value on the same material. The averages of 8 determinations of this $SrCO_3$ reagent performed recently in this laboratory are:

$Sr^{86}/Sr^{88}=.1198$, $Sr^{87}/Sr^{86}_{n}=.708$ and $Sr^{86}/Sr^{84}=17.88$

Table 9. Continued.

Isotopic abundance of $SrCO_3$ (Eimer and Amend lot. 492327)				
	86/88	87/86	$87/86_n$*	Date
1.	.1206	.707	.711	2/18/64
2.	.1215	.705	.711	2/20/64
3.	.1206	.707	.711	2/24/64
4.	.1204	.710	.713	2/22/64
5.	.1190	.713	.712	2/26/64
Mean	.1204	.708	.712	

* The measured Sr^{87}/Sr^{86} ratios were corrected by adjusting the Sr^{86}/Sr^{88} ratios to 0.1194 and the Sr^{87}/Sr^{86} ratios by half that amount.

method. The analytical results are presented in Table 10.

The principle of this method is based on the assumption that rock as a whole may remain in closed system with respect to radiogenic Sr^{87}; that means Sr^{87*} tends to remain in the rock as a whole even if minerals are in open system to Sr^{87*}. Thus the total rock Rb-Sr age could be highly informative, if they were obtained on several different lithologic phases of the same rock body in which they are of different Rb/Sr ratio.

It is essential in the total rock Rb-Sr age measurement to know the initial Sr^{87}/Sr^{86} ratio in the system. Consequently, for this method to be successful, the following conditions must be fulfiled; spreads of the Sr^{87}/Sr^{86} ratio and Rb/Sr ratio are obtained with a number of samples of same rock body, sufficient to construct a isochron from which the initial Sr^{87}/Sr^{86} ratio is determined.

Table 10. Sr isotope analyses on total rock samples

Sample	Locality	86/88	87/86	$87/86_n$	Date
Granitic rock					
R-4301	Ômine	.1184	.7076	.7046	1/20/64
R-4286	Sugawa	.1195	.7118	.7121	1/24/64
R-4303	Ôgawara	.1198	.7149	.7161	1/21/64
R-4305	Fukawa	.1177	.7125	.7074	1/25/64
Banded gneiss					
R-2253	Matsuo-yama	.1189	.7248	.7233	1/10/64
R-4005	Takamado-yama	.1208	.7218	.7261	1/15/64
R-4306	Nagase	.1204	.7229	.7259	1/10/64
R-4307	Jôryu	.1203	.716	.719	1/14/64

But unfortunately, favorable Sr^{87}/Sr^{86} ratios with sufficient spreads were not obtained with the analyzed samples: The spread in the Sr^{87}/Sr^{86} ratio is so small that no precise age is expected to be obtained.

Along with the isotopic analyses of strontium using mass spectrometer, semi-quantitative X-ray fluorescence analyses were carried out on a numbder of total rock samples to estimate their Rb/Sr ratio. The analyses were made on a Norelco X-ray spectrometer with a fluorescence attachment.

The experimental conditions were as follows:

Norelco X-ray spectrometer with W-target tube
Tube run at 50 KV 30 mA — GM Tube detector
LiF analyzing crystal — Scanning time 1°/min
.005 × 4″ source and receiving collimator

The X-ray fluorescence study revealed unfavorable Rb/Sr ratio; the samples analyzed usually contained a large amount of strontium compared with rubidium, the Rb/Sr ratio being small. Thus high content of strontium in these granitic rocks made the total rock analyses unsuccessful.

The Sr^{87}/Sr^{86} ratios in potassium feldspars which were separated from several rock specimens were measured to test the possibility of the use of this mineral for the Rb-Sr age measurement. The results are presented in Table 11. The Sr^{87}/Sr^{86} ratio is expected to be considerably high as a result of enrichment of radiogenic Sr^{87}, if potassium feldspar had not contained much "normal" strontium compared with rubidium.

The Sr^{87}/Sr^{86} ratios measured on four potassium feldspars are very close to the Sr^{87}/Sr^{86} ratio of "normal" strontium, as a result of high content of "normal" strontium, compared with rubidium. Thus the enrichment of radiogenic Sr^{87} was masked by a large amount of "normal" strontium in these potassium feldspars. No Rb-Sr age determinations were carried out on potassium feldspars, except for one pegmatitic potassium feldspar which contained only small amount of "normal" strontium and accordingly had a high Sr^{87}/Sr^{86} ratio.

Table 11. Sr isotope analyses on potassium feldspar

Sampel	Locality	86/88	87/86	$87/86_n$	Date
R-2099	South of Mt. Ikoma	.1178	.718	.713	12/14/63
R-2117	South of Mt. Ikoma	.1196	.712	.713	12/12/63
R-3335	North of Hase	.1189	.718	.716	12/13/63
R-4006	Takamado-yama	.1191	.717	.716	12/11/63

Discussion

The results of the present study indicate that the metamorphism and the plutonic activity in the Ryoke metamorphic terrain had occurred almost throughout the Cretaceous period ranging from 130 m.y. to 70 m.y., culminating in 110–90 m.y. in which most of the metamorphic rocks were produced and the granitic rocks were emplaced.

As to the granitic rocks in the Ryoke metamorphic terrain, the opinion has been prevailing that two distinct different igneous intrusions in age had taken place in this terrain. The granitic rocks in this terrain thus have been divided into two groups; the "older" and the "younger"

The Rb-Sr ages on biotite from several kinds of granitic rocks in the western part of the Kinki Ryoke metamorphic terrain are summarized in Table 12.

Table 12. The Rb-Sr age of the granitic rocks in the western part of the Kinki Ryoke metamorphic terrain

"younger" granitic rock			"older" granitic rock		
Sample	Locality	age (m.y.)	Sample	Locality	age (m.y.)
R-4188	Narukawa	86	R-2014	Takayasu	98
R-2099	South of Mt. Ikoma	94	R-1100	Hiraiwa	103
R-2117	South of Mt. Ikoma	113	R-4304	Nakamura	111
R-3335	North of Hase	109	R-4302	North of Koya	96
			R-4286	Sugawa	91
			R-4305	Fukawa	105
			R-4300	Asako	106
			R-3662	North of Mt. Miwa	95

They are well grouped in the range 110–90 m.y. No intrusion-time-gap is observed between the so-called "older" and "younger" granitic rocks in this district. The K-Ar age 115 m.y. on hornblende, is obtained from the gneissose granodiorite which is considered to be the "older" granitic rock. The K-Ar age on hornblende is approximately concordant with the Rb-Sr age 103 m.y. on co-existing biotite. This result also supports the view that no great difference had existed in the time of the emplacement between the "older" and the "younger" granitic rocks. Most of the granitic rocks of the two groups in this district had intruded successively in the period ranging approximately 110–90 m.y.

The results of the age measurements on mica of the banded gneiss revealed a quite complicated age pattern, compared with that of the granitic rocks which are well converged in the range 110–90 m.y.

The Rb-Sr age on muscovite is always discordant with that on co-existing biotite. One muscovite (R-4309) yielded the apparent Rb-Sr age as large as 231 m.y., when calculated in the customary manner; the usual method of calculation assumes that the isotopic composition of the initial strontium has "normal" strontium isotopic composition, namely $Sr^{87}/Sr^{86} = .708$.

There is, however, no guarantee that this condition was fulfiled for the banded gneiss which was derived from pelitic sediments. Compared with biotite, muscovite contains a large amount of "normal" strontium as seen in the analytical data, inspite of the fact that no strontium-rich minerals are observed in muscovite by thin section study. The high content of "normal" strontium in muscovite samples could not be reduced by further purification procedures. Therefore, it is assumed that muscovite itself contains a large amount of "normal" strontium.

This may indicate that much more strontium had been introduced into muscovite than biotite, when these minerals were formed by recrystallization in metamorphism. The introduced strontium may not have "normal" strontium isotopic composition, but have been enriched in Sr^{87}, because of partial retention of radiogenic Sr^{87} accumulated prior to the metamorphism. It is assumed that the strontium isotope homogenization had not been achieved at the time of the metamorphism.

This assumption may be supported by the following fact: R-4309 and R-4310 were taken from the road cut exposures along the identical road. Two exposures are only a few hundred meters apart. The Rb-Sr ages on biotite of these two samples are 192 m.y. and 107 m.y. respectively.

It may be quite unreasonable to assume that the banded gneiss had experienced two metamorphism which occurred at 192 m.y. and 107 m.y.

This fact may be assigned to the incomplete strontium isotope homogenization at the metamorphism. Of seven Rb-Sr ages on biotite, four of them are well converged to approximately 100 m.y., as is seen in Table 13, which suggests that the banded gneiss had been produced by the 100 m.y. metamorphism.

Table 13. The Rb-Sr age of the banded gneiss

Sample	Locality	Mineral	age (m.y.)
R-4005	Takamadoyama	Biotite	101
R-4307	Jôryu	Biotite	103
R-4308	Nunobiki	Biotite	108
R-4310	Nunobiki	Biotite	107

This is also compatible with the fact that the granitic rocks in this district had intruded in the period ranging 110–90 m.y.

In the Palaeozoic formation, i.e., Tamba Zone, which is situated in the north of the Ryoke metamorphic terrain, granites which have been known as the "Cretaceous granite" among geologists, develop widely. Yoshizawa et al. (1965) divided the granites in this region into the following two groups:

1. Hira-Suzuka-Tanokami group
2. Hiei-Mikumo (Shigaraki) group

The granites of group 1. usually accompany many pegmatites, intrude into the Palaeozoic strata discordantly with its structure and give contact metamorphism to the Palaeozoic strata. These granites are typical "granite" which are medium- to coarse-grained and are considered to have intruded at a shallower depth. The granites of group 2. accompany almost no pegmatite and intrude into the Palaeozoic strata, being approximately concordant with its structure and give also contact metamorphism.

These granites are usually adamellitic in thier rock phase. A samll amount of hornblende is observed rarely in these granites. These two types of the granites were considered to be of co-magmatic origin. The granites of group 1. may have intruded to a shallower depth at a more or less later stage than the granites of group 2. The depth difference and the emplacement time-gap between these two granites may be small.

On these granites, the age measurements were made by Hayase (1961). The results are as follows:

Rock	Mineral	Rb-Sr	K-Ar	
Hiei granite	biotite	93	90	
Suzuka granite (Yunoyama pegmatite)	muscovite	78	61	(in m.y.)

As to the relation of these "Cretaceous granite" to the granite in the Ryoke metamorphic terrain, the following geological relations have been made known[33].

1. At Suzuka Pass, Mie Prefecture, mylonitic rocks exist between the Ryoke granite (Yagyu granite) and the Suzuka granite, running approximately N70°E.
2. In the region of the northwest of Ueno City, the Yagyu granite is transitional into the "Cretaceous granite" in its rock facies, through the mylonitic rock which is assumed to be the western extension of the above-mentioned mylonitic rock.

The time of the emplacement of the Hiei granite is almost contemporaneous with the granite in the Ryoke metamorphic terrain (Yagyu granite).

Therefore the Hiei-Mikumo (Shigaraki) granite, i.e., the "Cretaceous granite" and the Ryoke granite may be co-magmatic, judging from both geologically and geochronologically, although the depth of the emplacement may be different. The granites of group 1. are of a later stage emplacement than the granites of group 2. and the Ryoke granite.

Conclusion

1. With 24 samples of pegmatites, granitic rocks and banded gneisses collected from the Ryoke metamorphic terrain in the Kinki district, mainly from the western part of the terrain, the age measurements were carried out by both the Rb-Sr and K-Ar methods.

The Rb-Sr ages on biotites of the granitic rocks in this district are well converged into 110 m.y.–90 m.y., with several exceptions. The K-Ar age 115 m.y. on hornblende which is approximately concordant with the Rb-Sr age 103 m.y. on co-existing biotite, is obtained on the gneissose granodiorite which was considered to be the "older" granitic rock. These facts suggest that there is no intrusion-time-gap among the granitic rocks and that most of the granitic rocks had been emplaced successively 110 m.y.–90 m.y. ago.

The quartz diorite which yielded the Rb-Sr age 130 m.y. may have been an intrusion preceding those of the granitic rocks in the Ryoke metamorphic terrain in the Kinki district.

2. The age measurements on biotite and muscovite of seven banded gneiss samples revealed a distinct discordance among them; the Rb-Sr ages on biotite and muscovite have a wide scatter ranging from 231 m.y. to 101 m.y.

The wide scatter of the Rb-Sr ages shows that a complete homogenization in strontium isotope had not been achieved at the time of the metamorphism in these banded gneisses. Judging from the fact that the age of the emplacement of the granitic rocks is considered to be approximately 110 m.y.–90 m.y., the banded gneiss may have been produced by the 110 m.y.–90 m.y. metamorphism. The K-Ar age measurements yielded a considerably younger ages than the Rb-Sr ages on them, although a fairly good agreement was obtained among them. The K-Ar age on banded gneiss may represent the time of the granitic activity which occurred 70 m.y.–60 m.y. ago.

3. The Rb-Sr ages on muscovite, biotite and potassium feldspar of the pegmatites in this district are 90 m.y.–70 m.y. This means that the metamorphism and plutonism had ended approximately 90 m.y.–70 m.y. ago in the terrain.

4. As to the relation between the granites in the Ryoke metamorphic terrain and the "Cretaceous granite" in the Tamba Zone, both of the granites are considered to be co-magmatic and in gradual change in their rock facies: The latter may have been emplaced in a shallower depth than the former.

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References

1) ALDRICH, L.T. (1956): Measurement of radioactive ages of rocks, Science, **123**, 871–877.

2) ALDRICH, L.T., L.F. HERZOG, J.B. DOAK and G.L. DAVIS, (1953): Variation in strontium isotope abundances in minerals, part I, mass spectrometirc analysis of mineral sources of strontium, *Trans. Am. Geophys. Union,* **34**, 457–460.

3) ALDRICH, L.T., J.B. DOAK, and G.L. DAVIS, (1953); The use of ion exhcange columns in mineral analysis for age determination, *Am. J. Sci.,* **251**, 377–387.

4) ALDRICH, L.T., G.L. DAVIS, G.R. TILTON and G.W. WETHERILL (1956): Radioactive age of minerals from the Brown Derby mine and the Quartz Creek granite near Gunnison, Colorado, *J. Geophys. Research,* **61**, 215–232.

5) ALDRICH, L.T. and G.W. WETHERILL (1958): Geochronology by radioactive decay, *Annual Review of Nuclear Science,* **8**, 257–298.

6) ALLSOPP, H.L. (1961): Rb-Sr age measurements on total rock and separated mineral fractions from the old granite of the Central Transvaal, *J. Geophys. Res.* **66**, 1499–1507.

7) ARITA, T. (1949): On the Kasagi granitic intrusives and the related metamorphic complex, Yamato district, Japan, *J. Geol. Soc. Jap.* **55**, 99–104 (in Japanese).

8) FARUE, G. and HURLEY P.M. (1963): The isotopic composition of strontium in oceanic and continental basalts: application to the origin of igneous rocks, *J. Petrol.* **4**, 31–50.

9) Hayase, I. (1961): Carnegie Institution of Washington Year Book 61.

10) Herzog, L.F., L.T. Aldrich, W.K. Holyk, F.B. Whiting and L.H. Ahrens (1953): Variation in strontium isotope abundance in minerals, part II, Radioactive Sr^{87} in biotite, feldspar and celestite, *Trans. Am. Geophys. Union.*, **34**, 461–470.

11) Hurley, P.M., H.W. Fairbairn, G. Faure and W.H. Pinson Jr. (1963): New approaches to geochronology by strontium isotope variations in whole rocks, Radioactive dating Symposium, *Int. Atomic Agency, Athens*, 201–208.

12) Ishizaka, K. (1961): On the granitic rocks in the Mt. Katsuragi-Mt. Kongo area, M.S. thesis, *Geol. Min. Inst., Kyoto Univ.*

13) Katada, M, H. Isomi, M. Murayama and K. Kawata (1959): Geology of Japanese central Alps and its western area 1. Ryoke zone of central Alps (The Kiso mountain range), *Chikyu-kagaku*, **41**, 1–12 (in Japanese).

14) Kobayashi, T. (1941): The Sakawa orogenic cycle and it bearing on the origin of Japanese Islands, *Jour. Fac. Sci., Univ. Tokyo, Sec.* II, 5, 219–578.

15) Kobayashi, T. (1951): Regional Geology of Japan, General Remarks, (in Japanese).

16) Koide, H. (1958): Dando granodioritic intrusives and their associated metamorphic complex, Japan Society for the Promotion of Science.

17) Kawano, Y. and Y. Ueda (1964): K-Ar dating on the igneous rocks in Japan (I), *Jour. Jap. Assoc. Min. Pet. Econ. Geol.*, **51**, 128–148, (in Japanese).

18) Long, L.E. (1962): Isotopic age study, Dutchess County, New York, *Bull. Geol. Soc. Am.*, **73**, 997–1006.

19) Miller, J., F. Shido, S. Banno and S. Uyeda (1961): New data on the age of orogeny and metamorphism in Japan, *Jap. Jour. Geol. Geogr.*, **32**, 145–151.

20) Matsumoto, T. (1947): Petrography of Kasagi district, S.B. Thesis, *Geol. Min. Inst., Univ. Kyoto.* (in Japanese)

21) Nakajima, W., I. Shiida, K. Umeda and S. Kokawa (1956): On the mutual relations of the rocks of the Ryoke metamorphic terrain in eastern part of Yamato Plateau (Abstr.), *Bull. Geol. Soc. Japan.*, **62**, 395 (in Japanese).

22) Nakajima, W. (1960): Geology of the northern margin of the Ryoke zone in the Yamato Plateau, *Chikyu-kagaku*, **49**, 1–14, (in Japanese).

23) Nier, A.O. (1938): Isotopic composition of Sr, Ba, Bi, Tl, and Hg, *Phys. Rev.*, **54**, 275–278.

24) Nier, A.O. (1950): A redetermination of relative abundances of the isotopes neon, krypton, rubidium, xenon and mercury, *Phys. Rev.*, **79**, 450–454.

25) Okano, J., Y. Nakajima, T. Noda, N. Morito, I. Makino and K. Ogata (1960): A mass spectrometer for the micro-analysis in Osaka University (I), *Mass Spectroscopy*, **15**, 16–25 (in Japanese).

26) Okano, J. (1961): Quantitative analyses of radiogenic argon in micas by isotope dilution method, *Mass spectroscopy*, **1**, 23–29.

27) Pinson, W.H. (1961): The potassium-argon method: the problem of potassium analysis, *Annals. New York Acad. Sci.*, **91**, 221–224.

28) Shibata, K., J.A. Miller, N. Yamada, K. Kawata, M. Murayama and M. Katada (1962): Potassium-Argon ages of the Inagawa granite and Naegi granite, *Bull. Geol. Surv. Japan*, **13**, No. 4 (in Japanese)

29) Webster, R.K. (1960): Methods in geochemistry, 203–246.

30) Wetherill, G.W., G.R. Tilton, G.L. Davis and L.T. Aldrich (1956): New determinations of the age of Bob Ingersoll pegmatite, Keystone, South Dakota, *Geochim. et Cosmochim. Acta*, **9**, 292–297.

31) Yamashita, N. (1957): The Mesozoic era (in Japanese)

32) Yoshizawa, H., K. Ishizaka, K. Kaneko and M. Kawahara (1965): Geology and Petrography of the Hira Granite and Mutual Relations Between Granites in the Northeastern Kinki District, Japan, *Mem. Coll. Sci., Univ. Kyoto,* Ser. B, Vol. XXXI, No. 4, 279–289.
33) Yoshizawa, H., W. Nakajima and K. Ishizaka (1966): The Ryoke metamorphic Zone of the Kinki district, Southwest Japan: Accomplishment of a Regional Geological Map, *Mem. Coll. Sci., Univ. Kyoto,* Ser. B, Vol. XXXII, No. 4, 437–454.
34) Zartman, R.E. (1964): A geochronologic study of the Lone Grove pluton from Llano Uplift, Texas, *J. Petrol.,* **5**, 359–408.