Journal of the Korean Nuclear Society
Volume 15, Number 1, March, 1983

《**Original**》

Geochronological Study on Gyeonggi Massif in Korea Peninsula by the Rb-Sr Method

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(Received December 6, 1982)

경기편마암 복합체의 Rb-Sr 연대측정연구

주승환 · 김동학 · 제원목**

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(1982. 12. 6 접수)

Abstract

In the previous studies on Rb-Sr geochronology, Gyeonggi Massif was known as the oldest rock in Korea Peninsula but the detailed sequence of geochronology was not studied yet. In the present study, some of whole rock isochrons considered here can be geochronologically grouped as follows: The ages of leucocratic gneisses at Yangpyeong, and augen and banded gneisses at Anyang show 2200 to 2300 m.y. which may represent the time of the Massif formation or an igneous intrusion. The age of the granite gneiss distributed in Yangpyeong area shows about 1400 m.y., which apparently represents the intrusion time of the gneiss. The age of the extremely altered metamorphic rock shows about 500 m.y., which may represent the time of a Caledonian orogenic event probably with hydrothermal activities. The other episodic ages of 800 to 900 m.y. which was widely observed through the Massif, may represent the ages of Precambrian igneous activities or regional metamorphism in the Massif. It seems to be reasonable that the ages of 120 to 270 m.y. show the times of Mesozoic and Late Palaeozoic Plutonisms in the Massif.

요 약

한반도에 분포하는 암석으로서 최고기의 암석으로 알려지고 있는 경기편마암 복합체중, 양평지역에 분포하는 우백질 편마암과 화강편마암류 및 시흥 지역에 분포하는 호상—안구상 편마암류를 대상으로 Rb-Sr법에 의한 암석 연대측정 연구를 실시하였다. 그 결과, 우백질 편마암과 호상—안구상 편마암류의 생성연대는 22억 내지 23억년으로 밝혀졌고, 화강편마암류의 관입시기는 14억년으로 측정되었다. 양평지역에서 채취한 시료중, 심하게 변질된 편마암류의 연대는 5억년이었다. 이 연대는 아마도 열수작용을 동반한 Caledonian 조산운동의 시기와 밀접한 관계가 있을 것이다. 기타 여러지역에서 채취한 편마암류들에서 공통적으로 8-9억년의 연대가 측정된 것은 경기편마암 복합체가 받은 선캠브리아기의 화성 활동 혹은 광역변성 작용의 시기일 것으로 생각된다. 편마암류에서 분리한 흑운모는 시료채취 지역에 따라 1억2천만년에서 2억7천만년으로 측정되었으며 이 연대는 본 지역에도 중생대 내지는 고생대 화성활동이 있었음을 뜻한다.

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1. Introduction

In the past decade Rb-Sr geochronological workes[1,2,3] have been successfully established in methodology and applications to geosciences.

Since first Rb-Sr study on Hongjesa granite in the Korea Peninsula by D.H.Kim, S.H. Choo, and D.J. Lee,[4] the Age Dating Annual Project has been carried out at Korea Institute of Energy and Resources (KIER). This study summarizes a part of the project covering Gyeonggi Massif which consists mainly of polymetamorphosed and multiply deformed gneisses. Emphasis is given to leucocratic gneiss and granite gneiss at Yangpyeong, and augen and banded gneisses at Anyang. Some of results on the gneisses have been already published by S.H. Choo et al.[5].

In the earlier works of geological mapping (1:1,000,000) which was published in 1956 by the Geological Survey and the Geological Society of Korea, Gyeonggi Massif was divided into two groups, namely, Yeonchun Crystalline System of the Archaean which occupies mostly the northern part of the Massif, and the granite gneiss of the Proterozoic widely scattered in the Massif.

In the previous geological works on the Massif O.J. Kim[6] suggested on the base of the stratigraphy of quartzites that the Yeonchun Crystalline System might consist of at least three stages differentiated during Precambrian. The three stages of tectonic activities caused by the polymetamorphism, were designated as the Gyeonggi orogeny of early Precambrian, the Jangraksan orogeny of middle Precambrian, and the Chunsung disturbance in ascending order, respectively. It was considered as a post tectonic block faulting occurred in the Massif during the pre-Mesozoic period. Although Gyeonggi Massif has been thought as one of the oldest groups in the southern part of the Peninsula, its detailed sequence of geochronology is so far unknown.

2. Experiment

2-1. Sample Preparation

A relative geological map and sampling localities are shown in Fig. 1 except some of uraniferous rocks and core samples.

Detailed procedures for a sample preparation were described in previous report[5]. Brief procedures will be given here.

The 46 fresh and unweathered samples and 17 drilled core samples were carefully selected. Each rock sample was taken more than 10 kg in the field. One rock piece selected from each sample sack was reserved for making a thin section. The other rock fragments were washed with distilled water, dried out in air, and carefully crushed in size less than 1cm by a precleaned jawcrusher. About 100 g of each sample splitted from crushed fragments was powdered to less than 200 mesh. The rests for separation of biotite were pulverized by a crusher controlled in particle size again and sieved in size between 40 and 60 mesh. Each biotite was separated was separated by using a belt magnetic separator, and purified by grinding and by a agate mortar with an addition of alcohol. Pure biotite under binocular was 120-180 mesh in grain size.

2-2. Chemical Procedure

About 0.2 g of powdered sample was weighed by a semi-micro chemical balance and spiked with both working spike solutions, ^{87}Rb(Ref. 190101), obtained from Oak Ridge National Lab., and ^{84}Sr (NBS. 988) from National Bureau of Standards. The spiked sample in 100 ml Pt dish was added with about 10 ml $HClO_4$(Merck 571) and 30 ml HF(Merck 335), and put on the temperature controlled hot plate. The sample was dissolved in a specially designed hood kept at an over pressure by filted air. After the sample was completely dissolved and dried out, 5 ml of

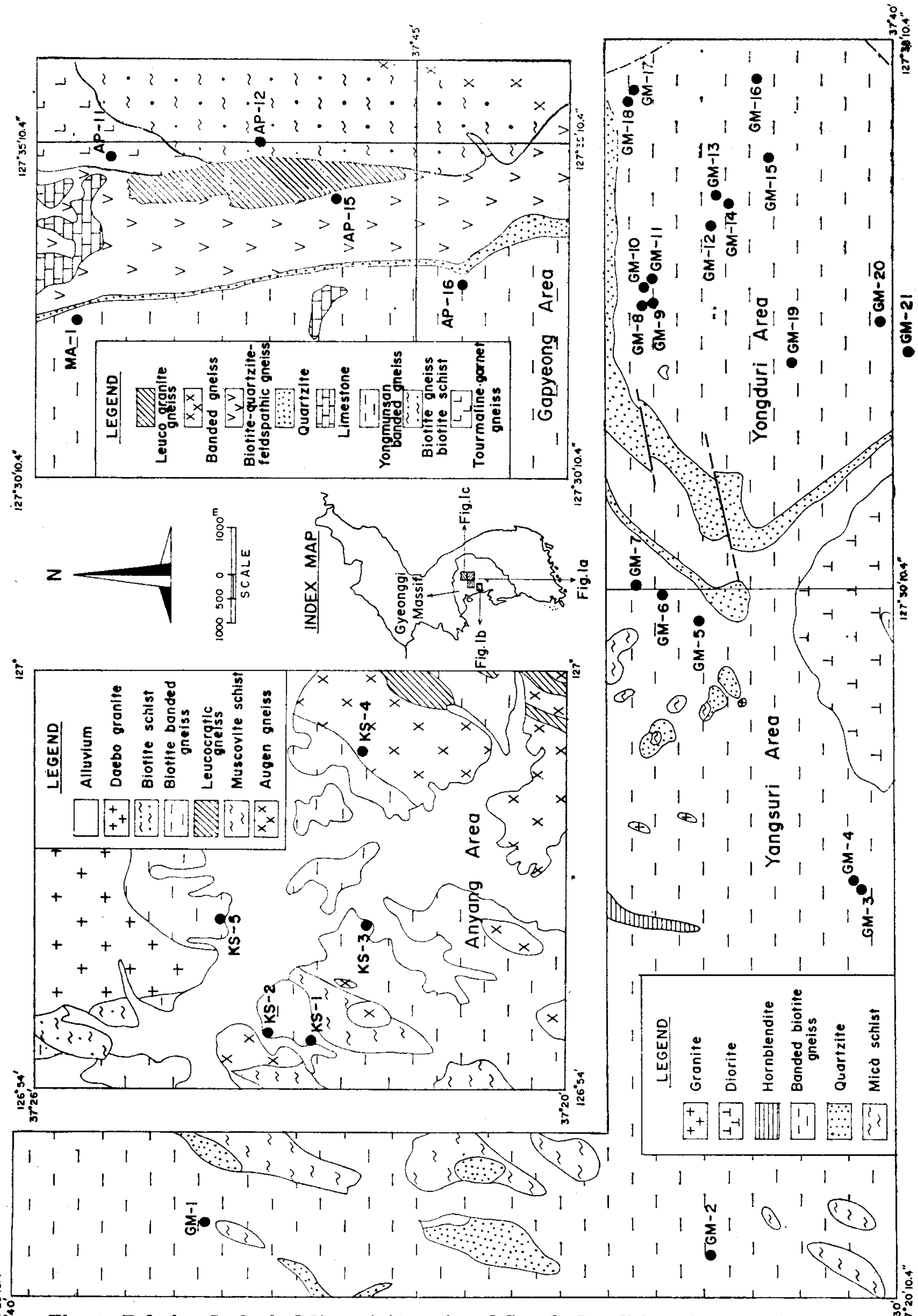

Fig. 1. Relative Geological Maps (1/50,000) and Sample Localities. The Geological Maps were cited from four Quadrangles; Yangsuri, Yonduri, Anyang and Gapyeong.

2.2 N HCl (Merck 318) was added. The dissolved solution was transferred to a small quartz centrifuge tube and centrifuged out. Supernatant liquid for the Sr ion separation was transferred into a quartz column in size of 1 cm$\phi\times$25 cm filled with Dowex 50-8x cation exchange resin (Fig. 2). The residual precipitation was purified with alcohol and kept for a measurement of Rb isotopes by the mass spectrometer. Sr ion was eluted in the fraction between 135ml to 175ml of 2.2 N HCl while the column condition for the separation of Sr was tested by 0.1 μ Ci ^{82}Sr tracer (Fig. 3).

The eluted Sr ion was dried in Pt dish, transferred into a quartz centrifuge tube with a few drops of HNO_3 (Merck 441) and triple distilled water, and kept for a measurement of Sr isotopes by the mass spectrometer. Special

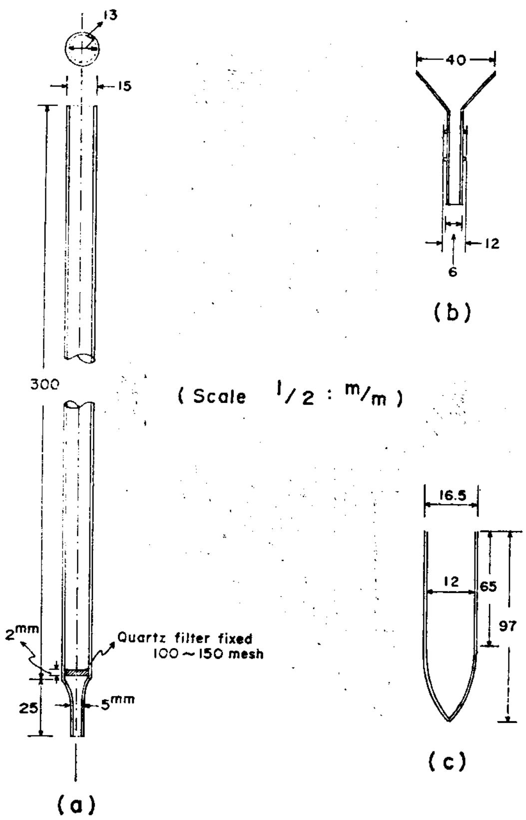

Fig. 2. Quartz Glasswares.
(a) column (b) funnel (c) centrifuge tube

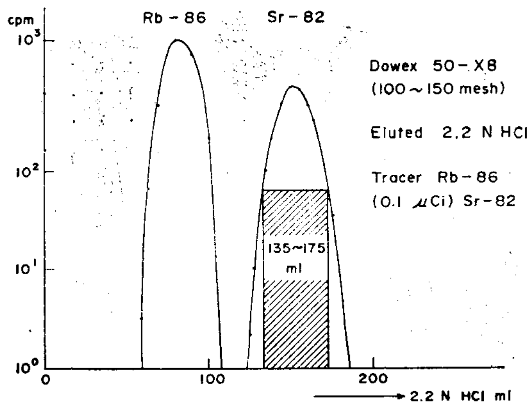

Fig. 3. Separation Condition of Rb and Sr Elements.

care was taken to decontaminate the residual Sr in the column. The results tested by blank are normally less than 15 ng of both strontium and rubidium elements.

2-3. Mass Spectrometry

Isotopic analyses were made with a 21.4 cm radius, 90° sector mass spectrometer TH-5, Varian Matt, at KIER. The vacuum system in the analyzer is equipped with three getter ion pumps maintained a pressure of about 2×10^{-8} torr during operation. The dual rhenium filament was used and loaded with less than 2 μg of the sample for a measurement. Faraday cup ion collector and Kompensograph recorder were used to measure isotopic ratios.

The arithmetic mean value of ^{87}Sr/^{86}Sr ratio of NBS-987, isotopic standard of strontium, 0.7106$\pm$0.0005, has been measured from June 1977 to December 1981 at KIER. The measured ^{87}Sr/^{86}Sr ratios were normaliged to the ^{87}Sr/^{85}Sr ratio of 8.3752. In most cases Sr isotopic measurement were carried out when ^{85}Rb mass peak had completely burned off. It was founded that burning time of ^{85}Rb on the filament depended upon the loaded amount of Sr sample and degree of purificatin.

2-4. Age Determination

We attempt here to give only a basic equation of Rb-Sr geochronology so that the nature of this method can be appreciated. Rb-Sr geochronology is fundamentally based on the fact that ^{87}Rb isotope decays to radiogenic ^{87}Sr isotope by beta emission, as follow;

$$^{87}Rb = {}^{87}Sr + \bar{\beta} + v + Q \qquad (1)$$

where $\bar{\beta}$=beta particle, v=neutrino, and Q= maximum decay energy, 0.275 Mev.

Using low of radioactive decay, Eq (2) can be derived from Eq (1), as follow;

$$^{87}Sr = ({}^{87}Sr)i + {}^{87}Rb(e^{\lambda t} - 1) \qquad (2)$$

where $(^{87}Sr)i$=initial value of ^{87}Sr atoms remained in the rocks or minerals when decay time $t=0$, and λ is decay constant of ^{87}Rb isotope.

Dividing Eq(2) by ^{86}Sr atoms, it is obtained that

$$\frac{^{87}Sr}{^{86}Sr} = \frac{^{87}Sr}{^{86}Sr}i + \frac{^{87}Rb}{^{86}Sr}(e^{\lambda t} - 1) \qquad (3)$$

where

$\frac{^{87}Sr}{^{86}Sr}i$; the atom ratios at the time of analysis;

$\frac{^{87}Sr}{^{86}Sr}$; the atom ratios remained independently in the rocks or minerals when they were crystallizing;

t; the time elapsed since last crystallization or isotopical homogenization of the samples.

From Eq (3), the age t can be calculated by the computer program.

The isochron parameters in this paper were calculated by a Least Squares Analysis with a computer program[7,8]. The physical constants including ^{87}Rb decay constant were used with the new constants[9] adopted internationally. Each group of calculated isochron parameters are presented in tables 1, 2 and 3.

3. Results and Discussion

3-1. Yangpyeong Area

The 21 samples were taken in Yangpyeong area. The samples are mainly multimetamorphosed and extremely folded gneisses except some of granitic and leucocratic gneisses which are

Table 1. Whole Rock Isochron Parameters.

Rock	Sample No.	Slope 10^{-3}	Intercept	$\sqrt{\frac{\chi_i^2}{n-2}}$ *	Age (m.y.)
Leucocratic gneiss, Yangpyeong area.	GM-10, AP-15, GM-12B	31.45±0.47	0.7419±0.0007	1.0	2,181±33
〃	GM-13, GM-2A GM-15, GM-5 GM-6, GM-7	30.87±0.45	0.7128±0.0010	0.8	2,141±32
〃	GM-2C, AP-11 GM-19, AP-16 AP-12, AP-20 AM-1	32.09±0.12	0.6976±0.0007	2.2	2,224±12
Granitic gneiss, Yangpyeong area.	GM-2B, GM-4 GM-9, GM-12A	20.12±0.26	0.7128±0.0007	0.7	1,401±18
Augen, banded gneiss, Anyang, Shiheung area.	KS-2, KS-3 KS-4, KS-5	32.59±0.62	0.7009+0.0017	4.5	2,260±40
Uraniferous rock, Yangpyeong area.	KU-1, TA-15 TA-31, 32, 941A.B,	7.44±0.08	0.7260±0.0006	6.7	520±20

*Weighted mean of the squared deviations.

Table 2. Two Point Isochron Parameters and Biotite Ages.

Sample No.	Slope. 10^{-8}	Inter-cept	Age(m.y.)
B_2-13 bi	3.08 ±0.105	0.8480	216±7
B_2-14 bi	3.925±0.125	0.8372	276±8
B_2-15-4 bi	2.957±0.0894	0.8579	208±6
B_1-24.5 bi	2.966±0.023	0.8406	209±2
B_2-84 bi	3.038±0.065	0.8446	214±4
B_2-85 bi	2.949±0.0412	0.8520	207±3
GM-1 bi	1.704±0.013	0.8401	120±0.9
GM-2B bi	3.608±0.042	0.7288	254±2
GM-3 bi	3.002±0.035	0.7513	211±2
GM-4 bi	3.88 ±0.007	0.7329	273±5
GM-5 bi	2.757±0.033	0.7914	194±2
GM-6 bi	2.749±0.027	0.8059	207±1
GM-7 bi	2.834±0.035	0.8451	199±2
GM-8A bi	2.203±0.018	0.7500	155±1
GM-9 bi	1.746±0.02	0.7965	123±1
GM-10 bi	2.310±0.016	0.7667	162±1
GM-11A bi	2.435±0.12	0.7776	171±0.8
GM-11B bi	2.514±0.027	0.7607	177±2
GM-13 bi	2.276±0.031	0.7475	160±2
GM-14 bi	2.411±0.055	0.7582	170±4
GM-15 bi	2.184±0.042	0.7600	154±3
GM-16B bi	2.155±0.033	0.7403	152±2
GM-19 bi	1.807±0.027	0.7547	127±2
GM-21 bi	2.370±0.012	0.7538	167±0.8
KS-1 bi	2.592±0.014	0.8312	182±1
KS-2 bi	2.948±0.015	0.8200	207±1
KS-3 bi	2.646±0.010	0.7578	186±0.7
KS-4 bi	2.927±0.015	0.8033	206±1
KS-5 bi	2.440±0.010	0.7526	172±0.7

bi : biotite

widely distributed in the Massif. Therefore, zoning of the rocks based on their field occurrences is difficult because of drastic alteration (age unknown), later metamorphic activities, or deformations.

In order to estimate the particular states of isotopical homogenizations occurred in the rocks, all of the isotopic data obtained are plotted in Fig. 4. A set of three isochrons for the leucocratic gneiss and an isochron for the granite gneiss in Fig. 5 show much older age than others.

Of these the three isochrons for the leucocratic gneiss that are the ages ranging from 2141±32 m.y. to 2224±12 m.y. with the initial $^{87}Sr/^{86}Sr$ ratios ranging from 0.6976±0.0007 to 0.7419±0.0007, respectively. An approximately parallel tendency of the isochrons is caused probably by the alteration of the leucocratic gneiss by an addition of Rb element or loss of Sr. These changes in chemical composition might be caused by chemical weathering[10] or contamination with some preexisting rocks during the intrusion of the gneiss. On the other hand, a whole rock isochron for the granite gneiss is an age of 1401±18 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7128±0.0003. Besides the difference in age, both are lighologically different from the granite gneiss containing more mafic minerals and sho-

Table 3. Model Isochron Parameters Based on this Study and the Published Data Related to the Gyeonggi Massif.

Event	Sample No.	Slope. 10^{-8}	Intercept	$\sqrt{\frac{\chi_i^2}{n-2}}$ *	Age(m.y.)
1	1[1], GM 7, AP-12	12.98±0.49	0.7980±0.0020	0.9	908±35
2	G18-1[2], G18-2[2] GM-6, P-5[3]	13.40±0.39	0.7727±0.0011	1.5	937±27
3	G18-4[2], GM-5 P-2[3]	10.54±0.0016	0.7688±0.0045	3	739±113

1) Na and Lee (1973)
2) Choo et al. (1980)
3) Fullagar and Park (1975)

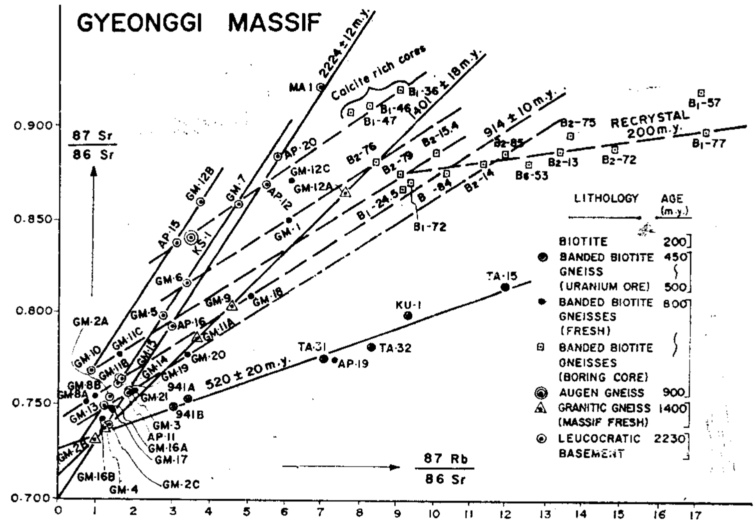

Fig. 4. General Situations of the Whole Rock Isochrons from the Centeral Part of Gyeonggi Massif,

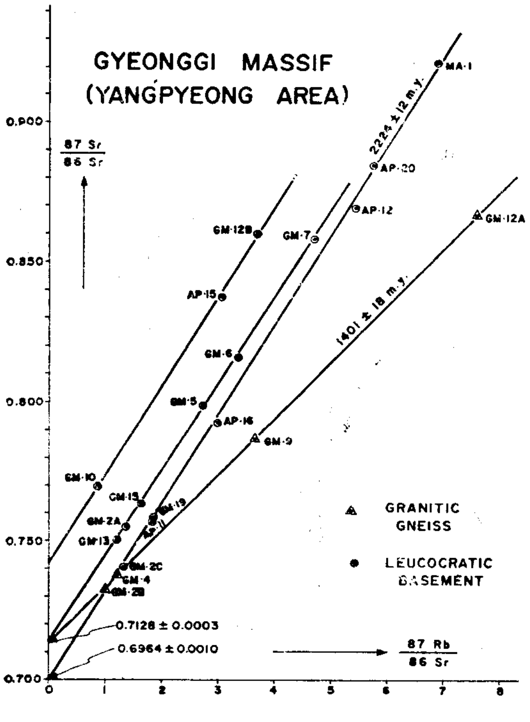

Fig. 5. Isochron Diagrams for the Whole Rock of the Lucocratic Basement and the Granitic Gneiss in Yangpyeong Area.

wing a granular texture in comparison with leucocratic gneiss. Similarly, S.H. Choo et al.[11] reported the two episodic isochron ages, 2370± 50 m.y. and 1420±70 m.y., obtained from the granite gneiss at Seosan in the Southern part of the Massif. The ages at Seosan are slightly older than the ages of this report. By the geological mapping in the area it has been proved that the granite gneiss at Seosan intruded iron-bearing quartzite, but the isochron is not parallel. It is considered that a later plutonism, probably accompanied with some alterations, occurred more strongly in the north than in the south.

The age of uraniferous rocks at Joongwon-ri was also determined in this study. A set of the whole rock isochron represents an age of 520± 20 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7260 ±0.0006 as shown in Fig. 6. In previous studies the rock was known as a component of Gyeonggi Massif. However, the isotopic data obtained in this study differ from the Precambrian age. S.H. Choo[12] reported 450 m.y. for the K-Ar age of biotite which was separated from the rock at Cheonpyeong. This age also supports that of an younger mass of Ordovician distributed in the area. If so, this younger age may reflect an Caledonian orogeny, which has not been reported in the Korea Penisula.

Other core samples which belong to the

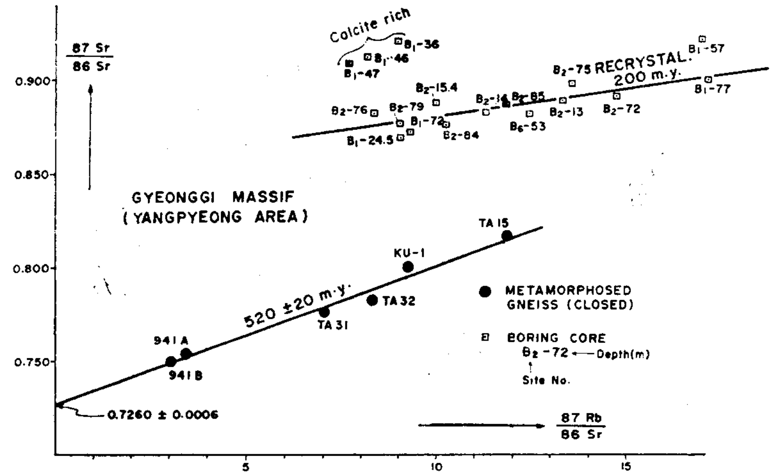

Fig. 6. A Fitted Isochron Diagram for the Younger Gneissic Rocks and a Demonstration of Scattered Data Points of Boring Core from Chloritization Zone around Bonabsan Area.

uraniferous rocks at Bonabsan near Gapyeong area, do not show a distinctive isochron but Fig. 6 suggests an estimated age of 200 m.y. The age may represent the time of later recrystallization or rehomogenization of radiogenic Sr.

Additionally, two point isochrons of biotite separated were studied. Biotite ages obtained are given in table 2. The ages between 120 to 270 m.y. depending on the sampling localities seem to indicate Mesozoic plutonic events.

3-2. Siheung area

To compare each of the isochron parameters of the local rocks related with the Massif, 6 whole rock samples of the augen and banded gneisses at Anyang were studied. A set of 4 data points is an isochron for an age of 2260 $\pm$40 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7009 ± 0.0017 as shown in Fig. 7.

Two data points, KS-1A and B, superimposed at one point in Fig. 7, fall out of the line of the representative isochron. It is uncertain whether a deviation of KS-1A and B points from the isochron line is due to different ages of their formation or was caused chemical weathering actions. In lighology the samples of the

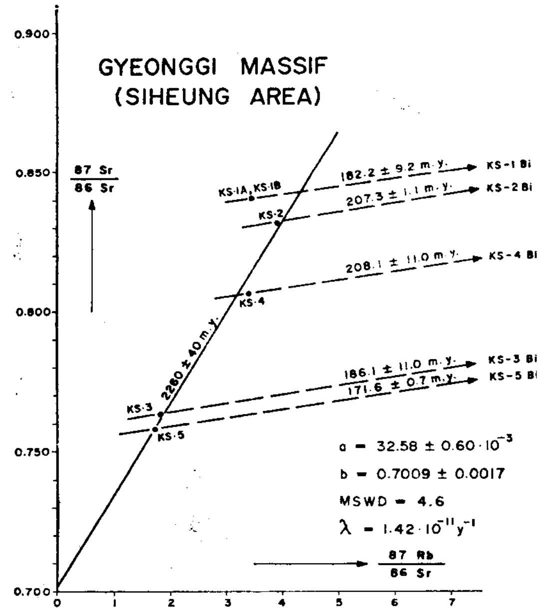

Fig. 7. Isochron Diagram for the Whole Rock Samples and Each Biotite Mineral Separated from Banded Biotite Gneiss. Siheung Area.

KS-1A and B are more schistose in muscovite than the others.

The ages obtained from leucocratic gneiss at Yangpyeong, granite gneiss at Seosan, and augen and banded gneisses at Anyang, mostly range

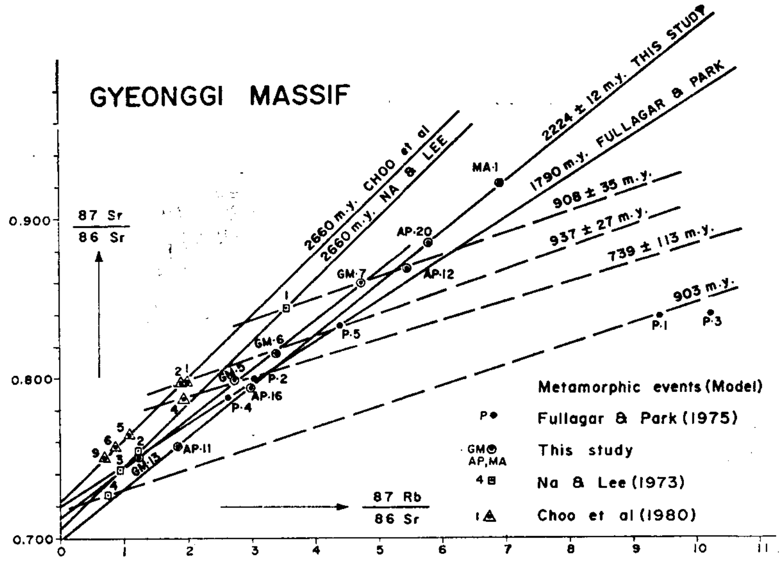

Fig. 8. Demonstrations of Relationships between Previous Data and This Study.

from 2200 to 2300 m.y. which may represent an important time for the primary formation of the gneissic rocks in the Massif.

The biotite ages shown in Fig. 7 and in table 2 may present the time range of plutonic activities during Mesozoic and Palaeozoic.

4. Conclusion

It is found that the previous geochronological data in the Massif reported by K.C. Na and D.J. Lee[13] (2600±40 m.y.) and S.H. Choo et al.[14] (2660±80 m.y.) are older than the present data. Both ages undoubtedly represent the oldest ages in Korea Peninsula, but there arises a question of how are they different from the rocks having ages ranging from 2200 to 2300 m.y.. In this study, it can only be suggested that the ages ranging from 2200 to 2300 m.y. may present a Precambrian intruson of leucocratic materials, very likely that originated from the mantle. A group of the ages around 1400 m.y. may represent a later plutonism in the area. On the other hand, it is pointed out that the ages of 800 to 900 m.y. can be obtained from the new sets of isochrons if one can combine with some data points like the dotted lines on Fig. 4. These ages strongly support an episodic substage in which the Massif had been regionally recrystallized or deformed by metamorphic activities at the time. The same results, for example, can be obtained from four sets of the isochrons by resetting the date[13,14,15] available like the dotted lines of Fig. 8.

Consequently the four groups of ages for Gyeonggi Massif were determined by the Rb-Sr method. The ages of the four groups considered here, are tentatively 2600 m.y. of Lower Archaean, 2200 to 2300 m.y. of Lower Proterozoic, 1400 m.y. of Late Proterozoic, and 500 m.y. of Lower Ordovician. The age distribution of 2200 and 2300 m.y. is most abundant and this means a time of the representative formation of the Massif. Based on the results of this study the metamorphic histories that occurred in the Massif can be tentatively summarized as the following; a main episode had regionally occurred during the time range of 800 to 900 m.y. and a minor occurred locally during Ordovician Period. The rocks of Ordovician age seem to be hardly observed in the Massif at the present time, although some radiogenic Sr disturbed by the activities of Mesozoic plutonisms are reported in places.

Acknowledgements

We are most grateful to Dr. M.S. Jin at KIER for helpful discussions in geology through this study and to Dr. J.D. Kim and Mr. C.H. Oh for some of the gneisses of the core samples and the leucocratic. We also thank the President of KIER for permission to publish this paper. The Geochron Laboratory of KIER provided the experimental facilities for this study. We are grateful again to all of cooperators through this work.

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