The Rb-Sr isochron ages were determined for the granitic rocks in the Tsukuba district, Japan. The Coarse-grained granite gives a mineral isochron age of $60.2\pm0.4$ Ma and whole rock isochron age of $61.6\pm4.3$ Ma. The Porphyritic granodiorite has a mineral isochron age of $59.5\pm2.7$ Ma. Pegmatite dikes in the Yamanoo area, which are the products of final stage granitic activity in the Tsukuba district, yield whole rock and mineral isochron ages of $59.9\pm4.0$ Ma and $58.3\pm2.3$ Ma, respectively.

The Rb-Sr ages in this study and published K-Ar mineral ages for the granitic rocks in the Tsukuba district are concentrated in very narrow range, mostly 59-62 Ma, irrespective of intrusive stages, indicating that the magmatic activities in the Tsukuba district occurred during short time interval (less than 3 Ma). Concordance of the Rb-Sr whole rock age and K-Ar mineral ages suggests that the granitic magma cooled rapidly after emplacements.

Introduction

The granitic rocks of Early Paleogene age are widely distributed in the Tsukuba district and are correlated to the granitic rocks of the Ryoke and San-yo belts in the inner zone of southwest Japan based on geologic background and petrographical characteristics (Yamada et al., 1977; Takahashi and Fujii, 1984). Detailed geological and petrographical studies revealed that the granitic rocks in the Tsukuba district were composed of seven different units and three or four stages of granitic emplacements (Takahashi, 1982a). Isotopic ages (mineral ages) for the granitic rocks were determined by K-Ar method and they are concentrated around 60 Ma (Kawano and Ueda, 1966; Shibata, 1968; Shiba et al., 1979). These ages are clearly younger than those of the granitic rocks in Ryoke and San-yo belts (80-100 Ma) in spite of above geological similarities.

In this paper, we determined the Rb-Sr isotopic ages for the granitic rocks in the Tsukuba district in order to clarify their emplacement ages and to estimate the age range of magmatic activities occurred in this district.

Geologic setting

Granitic rocks in the Tsukuba district expose with N-S trending form as a whole, but each body is roughly disposed in E-W direction (Fig. 1). The rocks are classified into following seven bodies (units), based on petrographical features and mode of occurrences (Takahashi, 1982a). They are, from north to south, Coarse-grained granite, Fine-grained granodiorite, Medium-grained granodiorite, Kabasan fine-grained granite, Yamanoo fine-grained granite, Porphyritic granodiorite and Two mica granite.
These seven granitic units are mostly granitic or granodioritic in composition and frequently contain metasedimentary xenoliths. A small mass of gabbroic rocks is cropped out in the central part of the Porphyritic granodiorite in Mt. Tsukuba. Pegmatite dikes are associated with the Yamanoo fine-grained granite.

The country rocks in the northern part are sedimentary piles which are composed of many slices or blocks of Jurassic shale and sandstone, and of Permian-Triassic bedded chert and limestone (Sashida et al., 1982; Aono et al., 1981).

The Tsukuba metamorphic rocks are made up of pelitic and psammitic gneisses and are exposed between the Porphyritic granodiorite and the Two mica granite and within the granitic masses as large scale xenoliths (Fig. 1). These metamorphic rocks show amphibolite facies mineral associations and are characterized by the existence of sillimanite, andalusite, cordierite (Shiba, 1979). K-Ar biotite and muscovite ages (58–62 Ma) were measured for pelitic metamorphic rocks (Shibata, 1968; Shiba et al., 1979).
Detailed description of the petrography and mineralogy of the granitic rocks were given by Takahashi (1982a and b) and Takahashi and Fujii (1984).

**Samples**

Three units were selected for Rb-Sr age determination. The Coarse-grained granite and the Porphyritic granodiorite were used for analysis because they are judged to be the products of first stage magmatic events (Takahashi, 1982a). Pegmatite dikes, which intruded at the final stage, were also selected for age determination.

The Coarse-grained granite has main mineral associations of quartz, plagioclase, K-feldspar, biotite and hornblende with accessories of allanite, zircon, apatite and ilmenite. The granodiorite has inhomogeneous textures, from equigranular to porphyritic, and partly shows concordant structures with that of the metamorphic rocks. The sample for analysis is porphyritic type of rock and is mainly composed of quartz, plagioclase, K-feldspar and biotite. Pegmatite dikes are constituted of main body and small branch sheets. Main

### Table 1. Rb-Sr analytical data

<table>
<thead>
<tr>
<th>Sample</th>
<th>Rb (ppm)</th>
<th>Sr (ppm)</th>
<th>$^{87}\text{Rb}/^{86}\text{Sr}$</th>
<th>$^{87}\text{Sr}/^{86}\text{Sr}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse-grained granite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CG02 W.R.</td>
<td>100.0</td>
<td>177.5</td>
<td>1.632</td>
<td>0.71436</td>
</tr>
<tr>
<td>CG03 W.R.</td>
<td>95.84</td>
<td>208.1</td>
<td>1.334</td>
<td>0.71420</td>
</tr>
<tr>
<td>CG05 W.R.</td>
<td>91.15</td>
<td>185.9</td>
<td>1.419</td>
<td>0.71412</td>
</tr>
<tr>
<td>CG12 W.R.</td>
<td>137.2</td>
<td>166.2</td>
<td>2.390</td>
<td>0.71499</td>
</tr>
<tr>
<td>CG13 W.R.</td>
<td>133.4</td>
<td>165.1</td>
<td>2.340</td>
<td>0.71495</td>
</tr>
<tr>
<td>CG14 W.R.</td>
<td>91.21</td>
<td>157.0</td>
<td>1.682</td>
<td>0.71440</td>
</tr>
<tr>
<td>TK-2 W.R.</td>
<td>91.44</td>
<td>207.0</td>
<td>1.279</td>
<td>0.71414</td>
</tr>
<tr>
<td>TK-61 W.R.</td>
<td>112.2</td>
<td>156.7</td>
<td>2.069</td>
<td>0.71500</td>
</tr>
<tr>
<td>Pl</td>
<td>11.32</td>
<td>261.7</td>
<td>0.1253</td>
<td>0.71331</td>
</tr>
<tr>
<td>Kf</td>
<td>203.4</td>
<td>242.8</td>
<td>2.432</td>
<td>0.71524</td>
</tr>
<tr>
<td>Bt</td>
<td>622.0</td>
<td>16.5</td>
<td>109.2</td>
<td>0.80660</td>
</tr>
<tr>
<td>Porphyritic granodiorite</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pgd02 W.R.</td>
<td>146.7</td>
<td>331.1</td>
<td>1.282</td>
<td>0.71177</td>
</tr>
<tr>
<td>Pl</td>
<td>9.37</td>
<td>392.1</td>
<td>0.0692</td>
<td>0.71069</td>
</tr>
<tr>
<td>Kf</td>
<td>160.1</td>
<td>290.3</td>
<td>1.597</td>
<td>0.71190</td>
</tr>
<tr>
<td>Bt</td>
<td>507.2</td>
<td>11.14</td>
<td>131.8</td>
<td>0.82250</td>
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<tr>
<td>Pegmatite dikes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG02 W.R.*</td>
<td>40.6</td>
<td>9.9</td>
<td>11.9</td>
<td>0.71855</td>
</tr>
<tr>
<td>Kf</td>
<td>46.63</td>
<td>30.96</td>
<td>4.36</td>
<td>0.71331</td>
</tr>
<tr>
<td>Mus</td>
<td>1654</td>
<td>2.82</td>
<td>1698</td>
<td>2.1180</td>
</tr>
<tr>
<td>PG03 W.R.</td>
<td>86.71</td>
<td>20.37</td>
<td>12.33</td>
<td>0.72178</td>
</tr>
<tr>
<td>PG04-1 W.R.</td>
<td>780.5</td>
<td>41.11</td>
<td>54.97</td>
<td>0.75865</td>
</tr>
<tr>
<td>PG04-2 W.R.</td>
<td>500.4</td>
<td>35.34</td>
<td>41.00</td>
<td>0.74686</td>
</tr>
<tr>
<td>PG08 W.R.</td>
<td>72.33</td>
<td>20.82</td>
<td>10.06</td>
<td>0.72009</td>
</tr>
</tbody>
</table>

W.R., Whole rock; Pl, Plagioclase; Kf, K-feldspar; Bt, Biotite; Mus, Muscovite.

*Rb and Sr concentrations were measured by XRF method. The uncertainty of $^{87}\text{Rb}/^{86}\text{Sr}$ ratio is estimated to be ±5%(1σ) for the sample, PG02.
body is constructed by several compositional layers. Main minerals are quartz, K-feldspar, muscovite and biotite with accessories of garnet, beryl, zircon, monazite. Samples for analysis were picked up from main body.

Analytical methods

Samples of 1-2 kg (3-4 kg in the case of pegmatite) were used for analysis. Minerals were collected using magnetic separator, heavy liquid and hand picking method. Fraction of Rb and Sr were concentrated by ion exchange using cation exchange resin.

Rb and Sr concentrations were measured mostly by isotope dilution method, and one sample by X-ray fluorescence method. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were measured using VG-Micromass MM-30 double collector type mass spectrometer. All the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were normalized to the $^{86}\text{Sr}/^{88}\text{Sr}$ ratio of 0.1194. Repeated analyses of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio for the NBS 987 SrCO$_3$ standard during this study gave an average of 0.71030 ± 0.00005 (2σ). The measuring errors of $^{87}\text{Rb}/^{86}\text{Sr}$ ratios are estimated to be ±1% (1σ) for isotope dilution method, and that for $^{87}\text{Sr}/^{86}\text{Sr}$ ratios is ± 0.0035% (1σ). Errors of the calculated ages and initial ratios were quoted at 2σ level by the York method (York, 1969). The decay constant of $^{87}\text{Rb}$ used in this work is 1.42 × 10$^{-11}$/y.

Analytical data are shown in Table 1.

Results and discussion

Rb-Sr isochron ages

1. Coarse-grained granite

One whole rock sample (TK61) and its separated minerals (plagioclase, K-feldspar and biotite) of the Coarse-grained granite give an isochron age of 60.2 ± 0.4 Ma with an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.71320 ± 0.00004 (Fig. 2). This age is nearly equal to or slightly younger than the K-Ar biotite ages of 61.4 Ma (Shibata, 1968) and 64.5 Ma (Kawano and Ueda, 1966) which were recalculated using new decay constants of Steiger and Jäger (1977).

Eight whole rock samles of the Coarse-grained granite yield an isochron age of 61.8 ± 13.5 Ma with an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.71291 ± 0.00034 (Fig. 3). Considering the field occurrences that the Coarse-grained granite contains various scales of metasedimentary xenoliths whose initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are markedly high (0.7150-0.7300) (Arakawa and Takahashi, 1987), the large uncertainty of the age may be attributed to the interaction with metasedimentary xenoliths or country rocks. In this case, it is possible that the lower base line in the isochron diagram gives a real age. The regression of five whole rock samples (CGO2, 05, 12, 13 and 14), forming lower base in Fig. 3, results in an isochron indicating an age of 61.6 ± 4.3 Ma. This age is almost the same as the above age calculated from eight samples. Therefore, the age of 61.6 Ma is interpreted to show the emplacement age of the Coarse-grained granite. As shown by these data, there is no remarkable age discrepancy between the Rb-Sr whole rock and K-Ar mineral ages for the Coarse-grained granite.

2. Porphyritic granodiorite

The Porphyritic granodiorite is the product of first stage granitic activity in the Tsukuba

![Fig. 2. Mineral isochron diagram of the Coarse-grained granite (TK61).](image-url)
district likewise the Coarse-grained granite (Takahashi, 1982a). Plagioclase, K-feldspar, biotite and whole rock sample constitute an isochron with an age of 59.5±2.7 Ma and an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.71063±0.00008 (Fig. 4). This age is placed between the published K-Ar ages of 52.9 Ma and 62.9 Ma by Shiba et al. (1979).

3. Pegmatite dikes

Five whole rock samples were used for isochron calculation, three from central layer and two from outer layers. The former has quartz (38%), K-feldspar (55%), muscovite (4%), biotite (1%) and others (2%). The latter is K-feldspar predominant layers, one sample (PG04-1) from the layer being composed of over 95% of K-feldspar and one (PG04-2) from the layer showing mosaic textures of K-feldspar (72%) and quartz (25%) with small amounts of muscovite (less than 2%). The regression calculation for all five samples shows an age of 59.9±4.0 Ma (Fig. 5). The layered structures observed in the pegmatite dikes are generally thought to have been formed by progressive
fractional crystallization from margin inwards during and just after the emplacement, and/or by subsequent metasomatism (Černý, 1982a and b). No strong evidence of metasomatic effects as represented by albitization can be observed in samples used for this study. Two samples from adjoining layers in outer part (PG04-1, PG04-2) yield an age of 59.3 Ma and this age is in good accordance with the age calculated for five samples. This agreement of ages indicates that these layered structures of main body were formed at same time and from isotopically homogeneous source. Therefore, this whole rock age (59.9 Ma) is interpreted to be the emplacement or crystallization age for the pegmatite dike. The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.71138 ± 0.00088 for five samples is placed on the range of those of wall rocks (Yamanoo fine-grained granite) (0.7105-0.7124) (Arakawa and Takahashi, 1987). This suggests that the pegmatite dike was formed from the same magma source as that of the Yamanoo fine-grained granite. One whole rock sample (PG02) and their separated minerals (K-feldspar and muscovite) produce an isochron with the age of 58.3 ± 2.3 Ma (Fig. 6) and this age is nearly equal to or slightly younger than the above whole rock isochron age.

**Age range for emplacement and cooling of the granitic magmas**

The discordances of isotopic ages between the Rb-Sr and K-Ar systems are well known in many granitic batholiths. In many cases, the K-Ar mineral ages are younger than the Rb-Sr whole rock ages for the same granitic mass and these discrepancies were interpreted to be the age differences between the emplacement and some period during subsequent cooling (e.g., Hart, 1964; Harrison et al., 1979; Harrison and McDougall, 1980). The comparison of the Rb-Sr whole rock and K-Ar mineral ages of the granitic rocks in Japan were performed by Shibata and Ishihara (1979). They concluded that there were three groups on concordance-discordance mode; nearly concordant, discordant with the age difference about 50 Ma, and grossly discordant. Furthermore, they pointed out that the Rb-Sr whole rock ages of Mesozoic–Tertiary granitic rocks were, in many cases, 4–9 Ma older than the correspond-
Fig. 6. Mineral isochron diagram of the pegmatite
dike (PG02).
WR, Whole rock; Kf, K-feldspar; Mus, Muscovite.

ing K-Ar biotite ages.

The Rb-Sr ages from this study and previously published K-Ar mineral ages for the granitic rocks in the Tsukuba district are summarized in Fig. 7. No remarkable difference of ages for the Coarse-grained granite can be recognized between Rb-Sr whole rock and K-Ar mineral systems. These ages for the Coarse-grained granite are quite equal to the K-Ar biotite age of 60.7 Ma (Kawano and Ueda, 1966) for the Fine-grained granodiorite which intrudes the Coarse-grained granite. The Rb-Sr biotite age of the Porphyritic granodiorite does not agree with two K-Ar biotite ages (62.9 and 52.9 Ma) by Shiba et al. (1979). Considering two K-Ar biotite ages (60.5 Ma determined by Kawano and Ueda, 1966) for the Two mica granite which intrudes the Porphyritic granodiorite, however, the age of about 61 (±2) Ma is expected to be fitted for Rb-Sr and K-Ar biotite ages for the Porphyritic granodiorite.

The Rb-Sr whole rock age of the pegmatite
dike agrees with the mineral age within analytical error, and the large age difference can not be detected.

As shown in Fig. 7, the isotopic ages of five granitic units are concentrated in very narrow range, mostly from 59-62 Ma, irrespective of intrusive stages. These data indicate that the activities of granitic magmas in the Tsukuba district occurred during short time interval (less than 3 Ma). Nearly concordant Rb-Sr whole rock age with K-Ar mineral age probably means that the granitic magmas experienced rapid cooling after the emplacement, similar to the granitic masses in the Tottori and Ningyotoge areas (Hattori and Shibata, 1974; Sudo et al., 1983) and Neogene granitic masses of the Nissho area in Hokkaido and the Okueyama area in southern Kyushu summarized by

| Coarse-grained granite | I | II |
| Fine-grained granodiorite | III | B1 | B2 |
| Pegmatite | IV | M |
| Porphyritic granodiorite | I | B1 | B2 | B3 |
| Two mica granite | II | 53 |

Fig. 7. Comparison of the isotopic ages on the granitic rocks in the Tsukuba district.
Open square, K-Ar method; Open circle, Rb-Sr method (this study).
W, Whole rock isochron age; B, Biotite age; M, Muscovite age.
Roman numerals, I-IV, indicate intrusive stages.
Shibata and Ishihara (1979).

Summary and conclusion

Five Rb–Sr isochron ages from three units of the granitic rocks in the Tsukuba district were determined. The Coarse-grained granite yields a well defined mineral isochron with the age of 60.2 ± 0.4 Ma. The whole rock isochron age of the Coarse-grained granite is 61.6 ± 4.3 Ma with an initial 87Sr/86Sr ratio of 0.71291 ± 0.00016. The Porphyritic granodiorite has a mineral isochron age of 59.5 ± 2.7 Ma. The whole rock age of the pegmatite dike in the Yamanoo area is 59.9 ± 4.0 Ma with an initial 87Sr/86Sr ratio of 0.71138 ± 0.00088. This initial ratio is plotted in the range of the ratios for the wall rocks (Yamanoo fine-grained granite), suggesting the derivation from same magma source. The mineral isochron gives nearly the same or slightly younger age (58.3 ± 2.3 Ma).

The isotopic ages determined by this study and published K-Ar mineral ages for the granitic rocks in the Tsukuba district are concentrated in very narrow range, mostly from 59-62 Ma, irrespective to intrusive stages. These data indicate that the magmatic activities in the Tsukuba district occurred during short time interval (less than 3 Ma). Nearly concordant Rb–Sr whole rock age with K–Ar mineral age suggests that the granitic magmas cooled rapidly after emplacements.

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References


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*MAGMA*, 67, 129-134.


筑波地域の花崗岩類の Rb-Sr 年代

荒川 洋二・高橋 裕平

茨城県筑波地域に分布する花崗岩類の Rb-Sr 年代を測定した。測定に用いた試料は、粗粒花崗岩（ステージ I）、斑状花崗閃緑岩（ステージ I）およびベダマタイト岩脈（ステージ IV）である。粗粒花崗岩は、鉱物アイソクロン年代が 60.2±0.4 Ma。全岩アイソクロン年代が 61.6±4.3 Ma を与えた。また、斑状花崗閃緑岩からは 59.5±2.7 Ma を示す鉱物アイソクロン年代が得られた。山ノ尾細粒花崗岩中に貫入しているベダマタイト岩脈の全岩および鉱物アイソクロン年代は、それぞれ 59.9±4.0 Ma、58.3±2.3 Ma を示した。

本研究によって得られた Rb-Sr 年代をすでに報告されている K-Ar 鉱物（黒雲母）年代は、花崗岩類の貫入ステージに関係なく 59-62 Ma に集中する。このことから、筑波地域の花崗岩類を形成したマグマ活動が非常に短期間（おそらく 3 Ma 以内）に生じたことを示している。また、Rb-Sr 全岩アイソクロン年代と K-Ar 鉱物年代の一致は、花崗岩質マグマの急激な冷却を意味しているものと予想される。