Lead isotopes of granitic rocks from the Hida metamorphic belt and some isotopic features of igneous rocks in Japan

AKIRA MIYAZAKI*, KAZUO SATO and NOBUFUSA SAITO

Department of Chemistry, Faculty of Science, University of Tokyo and Earthquake Research Institute, University of Tokyo, Tokyo 113, Japan

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Abstract—Lead isotope ratios have been measured for early Mesozoic granitic rocks from the Hida metamorphic belt, central Japan. A comparison of the data with those of the Hida metamorphic rocks given in a previous work indicates that the lead in some less abundant granitic rocks may have been contaminated with radiogenic leads from the metamorphic rocks, whereas the lead in the predominant intrusives may not have been subjected to such contamination. The lead isotope ratios of the latter group are further compared with the available data for late Mesozoic granitic rocks and Cenozoic volcanic rocks in Japan. The lead in the granitic rocks from the Hida area is similar to that in the basaltic rocks from the Oki Islands in the Japan Sea and is distinctly less radiogenic than the lead in the granitic rocks occurring in central Japan closer to the Pacific coast, suggesting the presence of a lateral isotopic variation analogous to the general trend found in the Cenozoic volcanic rocks. The applicability of the existing models for lead isotopes in island arcs is discussed.

INTRODUCTION

Lead isotopes in igneous rocks from island-arc regions have been the subject of great interest for the last few years. The isotopic data for island-arc volcanic rocks have been found to be consistent with some of the current ideas on the generation of volcanic magmas in such environments (TATSUMOTO, 1969; ARMSTRONG, 1971). Detailed isotopic studies of the Japanese Cenozoic volcanic rocks (KURASAWA, 1968; HEDGE and KNIGHT, 1969; TATSUMOTO and KNIGHT, 1969) have established a general trend of isotopic variation which can be correlated with the zonal arrangement of basalt magma types along the island arcs (KUNO, 1959, 1966; SUGIMURA, 1960).

On the other hand, only a few lead isotopic studies have been reported for plutonic rocks from Japan. The plutonic rocks so far analyzed are late Mesozoic
granitic rocks from central and northeast Japan (SHIMIZU, 1970; SAITO and MIYAZAKI, 1972). This paper is concerned with a lead isotopic study of early Mesozoic granitic rocks from the Hida metamorphic complex, which are exposed on the Japan Sea side of the central part of the Japanese Islands (Fig. 1). It is also the purpose of this paper to see if a lead isotopic pattern such as has been observed in the Cenozoic volcanic rocks exists in pre-Tertiary plutonic rocks in Japan.

Fig. 1. Sample locations of igneous rocks in Japan for which lead isotopic data are available. Shaded areas indicate pre-Tertiary granitic rocks (after SATO et al., 1960). The island arc systems are indicated after UYEDA and SUGIMURA (1970).

DISTRIBUTION OF PRE-TERTIARY GRANITIC ROCKS IN JAPAN AND LEAD ISOTOPIC DATA

The intrusion of pre-Tertiary granitic rocks in Japan is related mostly to the regional metamorphism which took place repeatedly along zones parallel to the general trend of the Japanese island arcs. The metamorphic belts may be grouped into two classes which MIYASHIRO (1961) called the paired belts. The older pair lies on the Japan Sea side of the central and western parts of the Japanese Islands and consists of the Hida and Sangun metamorphic belts. The younger pair extends on the Pacific Ocean side and consists of the Ryoke-Abukuma and Sanbagawa metamorphic belts. In the younger (outer) pair, late Mesozoic granitic rocks are widely distributed in association with the regional metamorphic rocks of the Ryoke-Abukuma metamorphic belt. Their radiometric ages range mostly from 60 to 80 m.y (BANKS and SHIMIZU, 1969; NOZAWA, 1970; YAMAGUCHI and YANAGI, 1970). The lead isotope ratios have
been reported by Shimizu (1970) for the granitic rocks from the Abukuma and Sidara areas of this belt (Fig.1). The late Mesozoic granitic rocks are also exposed in many localities other than the areas mentioned above. Of these plutonic bodies, some K-feldspar samples from the Miyazu, Ena, Kurobera, and Ishikawa areas (Fig.1) have been isotopically analyzed by Saito and Miyazaki (1972).

The granitic rocks analyzed in the present work belong to the older (inner) pair. Brief descriptions of the samples are given in Table 1. Their localities are shown in Fig.2. The geology of the Hida metamorphic belt has been studied by many workers (Nozawa, 1959; Minato et al., 1965). The lead isotopes of the metamorphic and sedimentary rocks of the area have been studied by Miyazaki et al. (1973). The

Table 1. Isotopic composition of lead in granitic rocks from the Hida metamorphic terrain

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample and locality</th>
<th>206Pb/204Pb</th>
<th>207Pb/204Pb</th>
<th>208Pb/204Pb</th>
<th>(87Sr/86Sr)₀ (age in m.y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6740</td>
<td>old dike, Tchibora mine, Gifu Pref.</td>
<td>(k) 18.76</td>
<td>15.68</td>
<td>38.66</td>
<td>*0.705 (181)</td>
</tr>
<tr>
<td>6714</td>
<td>granite, Funatsu, Gifu Pref.</td>
<td>(w) 18.07</td>
<td>15.52</td>
<td>38.12</td>
<td>*0.706 (341)</td>
</tr>
<tr>
<td>6742</td>
<td>mylonite, Kamioka, Gifu Pref.</td>
<td>(k) 18.06</td>
<td>15.58</td>
<td>38.22</td>
<td>*0.714 (73)</td>
</tr>
<tr>
<td>6717</td>
<td>granite, Kanakido, Gifu Pref.</td>
<td>(w) 18.80</td>
<td>15.86</td>
<td>39.13</td>
<td></td>
</tr>
<tr>
<td>6750</td>
<td>granodiorite, Amo, Gifu Pref.</td>
<td>(w) 18.41</td>
<td>15.91</td>
<td>39.36</td>
<td>*0.706 (181)</td>
</tr>
<tr>
<td>6730</td>
<td>adamellite, Amo, Gifu Pref.</td>
<td>(k) 18.02</td>
<td>15.67</td>
<td>38.98</td>
<td></td>
</tr>
<tr>
<td>1602</td>
<td>augen gneiss, Toichi, Gifu Pref.</td>
<td>(w) 18.21</td>
<td>15.68</td>
<td>39.34</td>
<td>*0.714 (73)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(k) 18.10</td>
<td>15.66</td>
<td>38.61</td>
<td></td>
</tr>
</tbody>
</table>

*: UENO (1968)  (w): whole-rock sample  (k): K-feldspar sample

Fig.2. Locations of granitic-rock samples analyzed in the present work. The distribution of Hida metamorphic complex is based on the geological map compiled by Nozawa.
predominant intrusives in this area are granitic rocks of a type called Funatsu granite. Other types of plutonic rocks, such as Amo granitic rocks, are also exposed on a relatively small scale. Most radiometric ages of the Funatsu granitic rocks concentrate at about 180m.y (NOZAWA, 1968; SHIBATA et al., 1970). The Hida metamorphic terrain constitutes the innermost part of the zonally-arranged basement complexes of the central and western Japan. If the lead isotopic data for the granitic rocks from this area are combined with those available for the granitic rocks from other areas, it may be possible to obtain an outline of the lead isotopic pattern for granitic rocks across the central part of the Japanese Islands.

**LEAD ISOTOPE RATIOS OF GRANITIC ROCKS FROM THE HIDA AREA AND THEIR INTERPRETATION**

Lead isotope ratios were obtained by the same method as reported previously (MIYAZAKI et al., 1973). All data were normalized to the Broken Hill standard lead. The values used were: $^{206}\text{Pb}/^{204}\text{Pb} = 16.11$, $^{207}\text{Pb}/^{204}\text{Pb} = 15.54$ and $^{208}\text{Pb}/^{204}\text{Pb} = 36.09$ (the mean of the two sets of data reported by KOLLAR et al., 1960 and MOORBATH et al., 1969)*. The estimated uncertainties are less than 0.3% for $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{207}\text{Pb}/^{204}\text{Pb}$, and less than 0.4% for $^{208}\text{Pb}/^{204}\text{Pb}$.

The lead isotopic data obtained are given in Table 1 and are plotted in Figs.3 and 4. The data for the Hida metamorphic rocks reported in the previous paper (MIYAZAKI et al., 1973) are also included in Figs.3 and 4 for comparison. The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and Rb-Sr ages given by UENO (1968) for some of the granitic rocks are listed in the last column of Table 1. In the present work, both whole-rock and K-feldspar samples were analyzed isotopically for five granitic rocks, while either a whole-rock or a feldspar sample was analyzed for two granitic rocks. The whole-rock samples appear more radiogenic than the corresponding feldspar samples, but, with one exception (No. 6750), the differences are small. The radiometric ages (Table 1) and a preliminary fission-track investigation of the uranium content of the granitic rocks indicate that the fractional change in the isotopic composition of lead after their formation is insignificant.

As seen from Fig.3, the lead in the granitic rocks shows a large variation in the $^{206}\text{Pb}/^{204}\text{Pb}$ ratios. An inspection of the figure indicates that some of the samples are less radiogenic than the metamorphic rocks, while the data for other samples have a spread overlapping those for the metamorphic rocks. On this basis, the granitic

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* This adjustment was made for convenience in comparing the present results with the data for other Japanese samples, which were obtained by ordinary mass spectrometry. The approximate absolute ratios of the samples may be estimated from the absolute values for the Broken Hill standard given by COOPER et al. (1969) or by STACEY et al. (1969).
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Fig. 3. $^{207}\text{Pb} / ^{204}\text{Pb}$ vs. $^{206}\text{Pb} / ^{204}\text{Pb}$ plot for the Hida area. Granitic rocks (this work), open circles; gneisses (MIYAZAKI et al., 1973), solid circles; (w) and (k) represent whole-rock and K-feldspar samples, respectively.

Fig. 4. $^{208}\text{Pb} / ^{204}\text{Pb}$ vs. $^{206}\text{Pb} / ^{204}\text{Pb}$ plot for the Hida area. The legends are the same as in Fig. 3.

rocks may expediently be divided into two groups. One of them shows a relatively small variation in isotopic composition and is characterized by $^{206}\text{Pb} / ^{204}\text{Pb}$ ratios of
less than 18.2 except for the whole-rock sample of Amo granodiorite (No. 6750) (Group I). In the other group, the \(206\text{Pb}/204\text{Pb}\) ratio exceeds 18.3 and varies up to 18.8 (Group II).

In Group I are included Funatsu granite (No. 6714), Amo granodiorite (No. 6750), and Amo adamellite (No. 6730). The lead in whole-rock and K-feldspar samples from the Funatsu granite is the least radiogenic among all the samples studied. The Funatsu samples have a model age of about 200 m.y which is close to their radiometric age (180 m.y). The \(206\text{Pb}/204\text{Pb}\) ratios of the Amo samples are similar to that of the Funatsu granite except for the whole-rock sample of the granodiorite. Their \(207\text{Pb}/204\text{Pb}\) and \(208\text{Pb}/204\text{Pb}\) ratios are slightly higher. A discordant Rb-Sr age pattern has been reported for these Amo samples (UENO, 1968; see Table 1). The initial \(87\text{Sr}/86\text{Sr}\) ratio obtained for the adamellite is 0.714, higher than those for other granitic rock samples from the Hida area. This observation may be correlated with the petrogenetic interpretation (NOZAWA, personal communication) that the Amo adamellite may have partially assimilated pre-existing metamorphic rocks in the Amo district. The lead isotope ratios of the whole-rock sample of Amo granodiorite are significantly higher than those of the feldspar sample. However, the lead in the adamellite samples exhibits no such modification of the isotopic pattern except that their \(208\text{Pb}/204\text{Pb}\) ratios appear slightly variable.

Of the Group II samples, the isotopic composition of the K-feldspar from the augen gneiss (No. 1602) is very similar to that of the K-feldspar from one of the Hida gneiss samples (No. 1605) (Figs. 3 and 4). The whole-rock sample of the augen gneiss is also isotopically similar to the whole-rock sample of the Hida gneiss (No. 1605) except for the higher \(208\text{Pb}/204\text{Pb}\) ratio of the augen gneiss. The values for all these samples are distinct from the isotopic composition of the Funatsu granite. In this respect, it must be noted that SHIBATA et al. (1970) obtained the initial \(87\text{Sr}/86\text{Sr}\) ratio of 0.708 for another sample of augen gneiss which was slightly higher than the values obtained for the Funatsu granite (0.705), though the collecting sites of the two augen gneiss samples are separated by a distance of about 50 km.

The granite from Kanakido (No. 6717) has lead with the highest isotope ratios among all the samples. It appears significant that the sample No. 6717 is isotopically similar to one of the metamorphic rock samples (No. 1607). The sample No. 6742, a mylonite from Kamioka, is thought to have been derived from the Funatsu granite (NOZAWA, personal communication). The isotopic compositions of these two types of rock are different from each other. However, the whole-rock and K-feldspar samples of the Funatsu granite and those of the mylonite appear to be linearly related in both the \(207\text{Pb}/204\text{Pb}\) vs. \(206\text{Pb}/204\text{Pb}\) and \(208\text{Pb}/204\text{Pb}\) vs. \(206\text{Pb}/204\text{Pb}\) diagrams (Figs. 3 and 4), indicating that the mylonite is presumably a product of the mixing of the Funatsu granite with some more radiogenic material. Detailed petrological data are not available for the "old dike" from the Tochibora mine (No. 6740).
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lead isotope ratios obtained for this sample also fall in the range of isotopic variation of the Hida metamorphic rocks, suggesting some genetic relation.

To summarize, the radiogenic character and variability of isotopic composition for Group II samples may be due to the fact that the lead in these rocks was more or less contaminated with the lead from the Hida metamorphic rocks. On the other hand, the abundant and typical intrusives in the Hida area, such as the Funatsu granite, are thought not to have been affected by the metamorphic rocks. Their isotopic composition is possibly representative of the granitic magma generated on a grand scale in the Hida area.

**Preliminary Investigation of Lead Isotopic Pattern of Japanese Igneous Rocks**

The island arcs in Japan and the adjacent areas can be divided into two systems, i.e. the East Japan Island Arcs (the eastern arc system) and the West Japan Island Arcs (the western arc system) (UYEDA and SUGIMURA, 1970). The boundary lies near the Izu-Mariana arc (Fig.1). In each of these two systems, the lead isotope ratios of the volcanic rocks have been found to show a regular trend of variation across the three Cenozoic petrographic provinces established by KUNO (1959, 1966). In the western arc system, the lead isotopic data for basaltic rocks from central and western Japan (MASUDA, 1964; COOPER and RICHARDS, 1966; TATSUMOTO, 1966, 1969; KURASAWA, 1968; TATSUMOTO and KNIGHT, 1969) indicate that the lead in primary basalts becomes less radiogenic from the tholeiite province (Pacific Ocean side) to the alkali-olivine basalt province (Japan Sea side). The data for the high-alumina basalt province fall, in general, between the data for the tholeiitic and alkali-rock provinces. Also, in the eastern arc system, HEDGE and KNIGHT (1969) have observed that the radiogenic character of the volcanic rocks from a traverse across northern Honshu decreases slightly toward the west (Japan Sea side).

For convenience in comparing them with the data for volcanic rocks, we divide the isotopic data for granitic rocks into two groups after the manner of grouping of the island arcs. That is, the Abukuma and Ishikawa areas belong to the eastern arc system, while the Miyazu, Hida, Ena, Sidara, and Kurobera areas belong to the western arc system.

A plot of $^{207}\text{Pb}/^{204}\text{Pb}$ vs. $^{206}\text{Pb}/^{204}\text{Pb}$ for both the volcanic and plutonic rocks from the western arc system is shown in Fig.5. The data used to represent the Hida area are those for the Funatsu and Amo granitic rocks; other samples were excluded because they appear to have been contaminated with the leads from metamorphic rocks as has already been discussed. The data for volcanic rocks are mostly the values for basalts and andesites.

A remarkable fact in Fig.5 is that, within a given region (the Japan Sea side or the Pacific Ocean side), there appears to be no marked difference in isotopic com-
Fig. 5. $^{207}\text{Pb}/^{204}\text{Pb}$ vs. $^{206}\text{Pb}/^{204}\text{Pb}$ plot for igneous rocks from the western arc system. Plutonic rocks, solid circles; volcanic rocks, open circles; some of the data for Sidara granitic rocks falling in the range of central Honshu volcanic rocks are designated as S.

position between plutonic and volcanic rocks. For the Pacific Ocean side, as has already been pointed out by SHIMIZU (1970), the granitic rocks from the Sidara area are isotopically similar to the late Cenozoic tholeiites from central Japan. As may be seen from Fig. 5, the lead isotope ratios of the Ena pegmatite are also similar to those of the tholeiites and high-alumina basalts from central Japan (Oshima, Hakone and Fuji). The isotopic similarity between granitic rocks and basalts in the Japan Sea side is evident from the data now available for the granitic rocks from the Hida metamorphic terrain. As the Hida metamorphic rocks are exposed not only on central Honshu but also on the Oki Islands, western Japan, it seems reasonable to compare the data for the granitic rocks from the Hida area with those for the alkali-olivine basalts from the Oki Islands of late Cenozoic age reported by KURASAWA (1968). It may be seen from Fig. 5 and Table 1 that the Funatsu granite is isotopically similar to the Oki Island basalts. The Amo granitic rocks also have similar $^{206}\text{Pb}/^{204}\text{Pb}$ ratios, though their $^{207}\text{Pb}/^{204}\text{Pb}$ ratios are slightly higher.

As is self-evident from the isotopic similarity in a given region, the granitic rocks from the western arcs exhibit an isotopic pattern similar to that found in the volcanic rocks. In Fig. 5 it is clear that the granitic rocks from the Japan Sea side (Hida and Miyazu areas) have $^{206}\text{Pb}/^{204}\text{Pb}$ values (< 18.2) smaller than those of the granitic rocks from the Pacific Ocean side (> 18.3). The data for the Miyazu area give a model age of about 500 m.y, which is greater than the known radiometric (Rb-Sr and K-Ar) ages (60 m.y, NOZAWA, 1970). The model ages of the samples from the Pacific Ocean side (Sidara, Ena, and Kurobera) range from zero to a negative (future) value, which is smaller than their radiometric ages (10 to 70 m.y, NOZAWA, 1970).
In Fig. 6 are plotted the available data for the eastern arc system. Although the samples of volcanic rocks studied by Hedges and Knight (1969) have been selected from a traverse across northern Honshu, no lead isotopic data have been reported for granitic rocks from the Japan Sea side. The general pattern of isotopic variation cannot be obtained for granitic rocks in this arc system. On the Pacific Ocean side (the eastern part of the traverse), the granitic rocks from the Abukuma area are observed to be isotopically similar to the volcanic rocks from Iwate and Moriyoshiyama. However, the pegmatites from the Ishikawa area, which is near the Abukuma plateau, are isotopically not similar to the volcanic rocks from the eastern part. The $^{206}\text{Pb}/^{204}\text{Pb}$ ratios of these pegmatites are close to the values of the volcanic rocks from Ichinomegata, the western part (Japan Sea side) of the traverse.

![Fig. 6. $^{207}\text{Pb}/^{204}\text{Pb}$ vs. $^{206}\text{Pb}/^{204}\text{Pb}$ plot for igneous rocks from the eastern arc system. Plutonic rocks, solid circles; volcanic rocks, open circles; A: Abukuma, K: Kampu-zan.](image)

The isotopic coherence of the leads in plutonic and volcanic rocks is not clear in the $^{208}\text{Pb}/^{204}\text{Pb}$ vs. $^{206}\text{Pb}/^{204}\text{Pb}$ plots (Figs. 7 and 8), although a similarity appears to be present on the Pacific Ocean side of both central and northern Honshu. The data for the Ishikawa area lie close to those for the volcanic rocks from the Japan Sea side, also in this type of plot.

Isotopic features such as those observed for the igneous rocks across central Japan have been found in the western part of North America. Doe (1967) has measured the isotopic composition of lead in Mesozoic and Cenozoic igneous rocks from the west (Pacific) coast and the interior of the North American continent, and found that the lead from the coastal region is more radiogenic than that from the continental interior. In each region, no clear isotopic distinction has been observed between the volcanic and plutonic rocks. The similarity in isotopic composition between these two classes of rocks has also been found in another suite of samples of Cenozoic
Fig. 7. $^{208}\text{Pb}/^{204}\text{Pb}$ vs. $^{206}\text{Pb}/^{204}\text{Pb}$ plot for igneous rocks from the western arc system. Plutonic rocks, solid circles; volcanic rocks, open circles; H: Hida, S: Sidara.

age from the North American coastal region (Tatsumoto and Snavely, 1969), though the $^{206}\text{Pb}/^{204}\text{Pb}$ ratios reported appear to have a range of variation broader than that observed in the Japanese samples. If the western part of North America is thought to have once had an island-arc structure (Atwater, 1970), the lead isotopic pattern of plutonic rocks and its similarity to that of volcanic rocks observed for both Japan and western North America might be correlated to some processes common to island-arc environments. Then it might be worth examining if the current hypotheses on the generation of island-arc volcanic magmas could also be applied to granitic rocks.

**Discussion of the Origin of Igneous Rock Leads**

Petrological and geochemical studies concerning the genesis of volcanic rocks in island-arc regions indicate that basaltic magmas are generated in the upper mantle, possibly along the deep-earthquake zone (Kuno, 1959, 1966). The isotopic similarity between the late Mesozoic granitic rocks and the younger basaltic rocks has been
interpreted as being due to the fact that the granitic magmas are produced from the basaltic materials or ultimately originate in the upper mantle (SHIMIZU, 1970). Such an interpretation is in agreement with the conclusions derived from strontium isotopic studies (e.g. OZIMA et al., 1967), in which some of the granitic rocks from central Japan have been reported to have low initial $^{87}$Sr/$^{86}$Sr ratios close to the values found in basaltic rocks. The isotopic data obtained in the present work indicate that, on the Japan Sea side, even the early Mesozoic plutonic rocks have lead with an isotopic composition similar to that of the lead in the late Cenozoic volcanic rocks. They have a less radiogenic character, being distinct from the igneous rock leads on the Pacific Ocean side. If these granitic rock leads also come from a basaltic or deep-seated source, some lateral isotopic inhomogeneity of the mantle must have existed since the early Mesozoic time.

TATSUMOTO (1969) has emphasized that the isotopic composition of the tholeiitic rock leads from central Honshu is similar to that of the pelagic sediment leads near the Japan Trench. According to TATSUMOTO, the pelagic sediments incorporated into the mantle by the subduction of the oceanic plate are likely to be the major source of the tholeiitic leads, but farther to the west (the alkali-olivine basalt province) leads in basaltic rocks become less radiogenic because they are less contaminated with the sediment leads. A similar model has also been presented by ARMSTRONG (1971) and ARMSTRONG and COOPER (1971).
The pelagic sediment leads in a given oceanic basin have been thought to come from the specific drainage areas (Chow and Patterson, 1962). Such samples have been observed to have similar isotopic compositions, presumably as a result of homogenization through weathering and transport of the crustal leads. One of the most significant features of the models mentioned above is that the isotopic similarity found in various volcanic rocks from an island-arc region can be correlated to the isotopic uniformity of the pelagic sediment leads occurring close to the arc-trench system. Recently Sato and Sasaki (1973) have pointed out that there is a remarkable coincidence between the lead isotopic data for the Japanese Tertiary ore deposits of volcanic affinity and the Quaternary tholeiitic and high-alumina basalts from central and northern Honshu. As has been mentioned above, the lead in the Japanese late Mesozoic granitic rocks is isotopically similar to the lead in the late Cenozoic tholeiitic rocks. Thus, late Mesozoic to Cenozoic igneous materials of various types have similar isotopic compositions over an extensive area along the tholeite and high-alumina basalt zones. If pelagic sediments of an isotopic composition similar to the present-day value or land masses as the source of such materials had existed in the Mesozoic or some older time, the uniformity of the erosion-averaged isotopic composition of the sediment leads and their incorporation into the subduction zone could explain all the coincidences in the isotope ratios of various igneous materials produced over a span of time since the late Mesozoic.

The compatibility of the models cited here must be studied further. The isotopic data presently available for plutonic rocks are still limited. However, it seems likely from the foregoing discussion that the mechanism responsible for the isotopic pattern of Japanese volcanic rocks operated also on the leads of granitic rocks older than the Cenozoic age.

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