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K-Ar ages of granitoids in central Sumatra, Indonesia

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Abstract: The K-Ar ages of biotites from three granitoid plutons in the central Barisan Mountains of Sumatra were determined. Tourmaline-bearing biotite granite from the Sijunjung pluton north of Sijunjung was dated at 247 Ma, indicating an episode of Permian to Triassic magmatism in Sumatra which may correspond to granitoid magmatism accompanied by tin mineralization in the Eastern Belt of Malay Peninsula. The other two rocks of granodiorite to tonalite composition were collected near the Sumatran Fault zone; the Lassi pluton east of Solok and the Padangpanjang pluton south of Bukittinggi were dated at 56 Ma and 64 Ma, respectively. These plutons are of late Cretaceous to Paleocene age, but their petrographic features are distinct from the late Cretaceous Hatapang pluton in northern Sumatra; the latter was recently found to be accompanied by tin-tungsten mineralization and was dated at 78-81 Ma for biotites. The two dated rocks from near the Sumatran Fault zone are sodic, poor in tin, and contain magnetite, while the Hatapang granitoids are potassic and tin-rich, similar to the Sijunjung granite. More radiometric ages and petrochemical data for granitoids in Sumatra are necessary to establish the granitoid and metallogenic provinces and related tectonic framework of the region.

Introduction

Granitoids and mineral deposits in Sumatra are distributed along the Barisan Mountains (e.g., Van Bemmelen, 1970; CGMW/UNESCO, 1986). Petrographic features and ages of the granitoid plutons, and their genetic relation to mineralization are not well documented, although recent mineral exploration has provided some reliable data (Clarke and Beddoe-Stephens, 1987). Radiometric age data for granitoids have been previously reported (e.g., Katili, 1973 a,b; Hehuwat, 1976; Wikarno *et al.*, 1988), but most were cited from unpublished material; the original data, including detailed locations and lithology of the dated specimens, have rarely been described. Therefore, it is often difficult to evaluate quality and geological meaning of the reported data. Complete data sets have only been reported by Clarke and Beddoe-Stephens (1987) and JICA/MMAJ (1985) for the Hatapang pluton in northern Sumatra. As a consequence, it is necessary to accumulate further reliable age data for granitoids in order to discuss magmatism, mineralization and the related tectonic framework in Sumatra.

In this report, three K-Ar mineral ages are reported with some petrochemical data, and the results are discussed in comparison with previous data for granitoids from the tin belt in Indonesia, Malaysia and Thailand. The dated rock samples were obtained during the "Rock Magnetism Project" (1981-1983) which was organized by RMRDC (Regional Mineral

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Keywords: K-Ar age, granitoid, biotite, Indonesia, Sumatra, Padang, Sijunjung, Lassi, Padangpanjang, tin mineralization

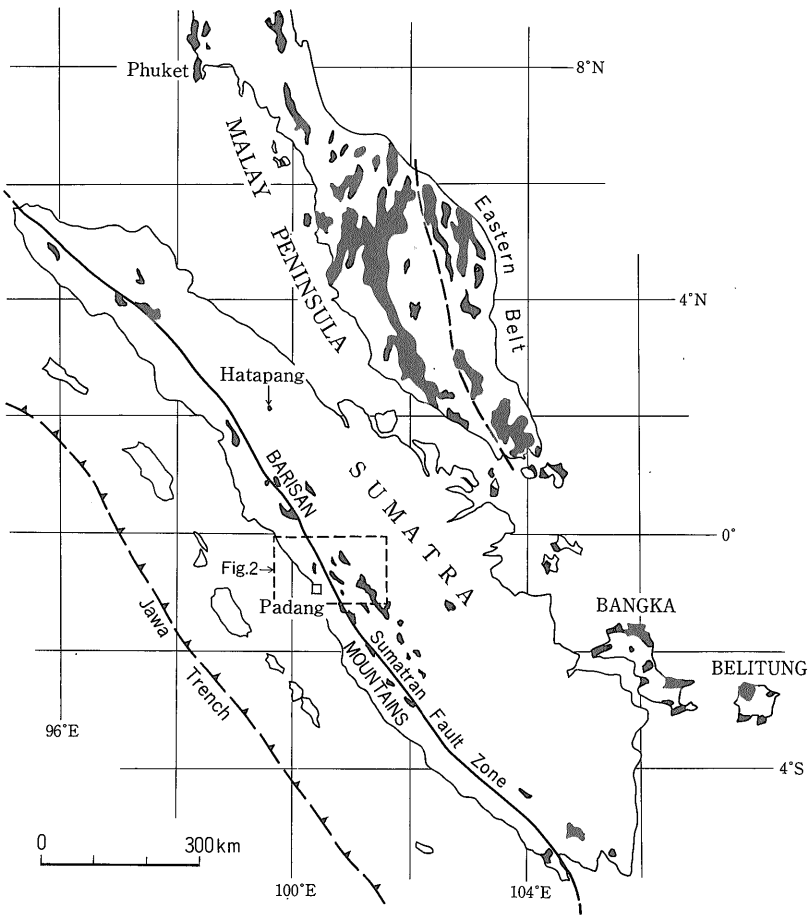

Fig. 1 Distribution of granitoids (solid part) in Sumatra, the Malay Peninsula and the Tin Islands ; simplified from Hamilton (1979) and Hutchison (1983).

Resources Development Centre)/ESCAP ; the project focused mainly on a preliminary, regional examination of the physical properties of rocks for future geophysical exploration in Southeast Asia (e.g., Sano *et al.*, 1988). Two specimens were collected during a field survey in the Padang Highland on June 17 and 18, 1983 (Sato, 1983, 1984). One specimen was provided by GRDC (Geological Research and Development Centre) of Indonesia, an organization cooperating with this project.

Outline of Geology

Granitoids in Sumatra are distributed along the Barisan Mountains near the southwest coast, as shown in Figure 1. The Barisan Mountains are a geanticline of old rocks surmounted by the volcanic rocks of the active magmatic arc parallel to the Java Trench (e.g., Hamilton, 1979). To the northeast is the low-lying foreland basin bearing oil fields. The craton is located further to the northeast, in the Tin Islands (Bangka, Belitung and others)-Malay Peninsula region. The northwest structural and topographic trend of Sumatra is a Cenozoic phenomenon (Hamilton, 1979). The pre-Tertiary basement rocks outcrop beneath young volcanic and sedimentary rocks along the Barisan Mountains. The upper Paleozoic and Triassic strata are of continental-shelf or platform facies, composed of limestone, shale

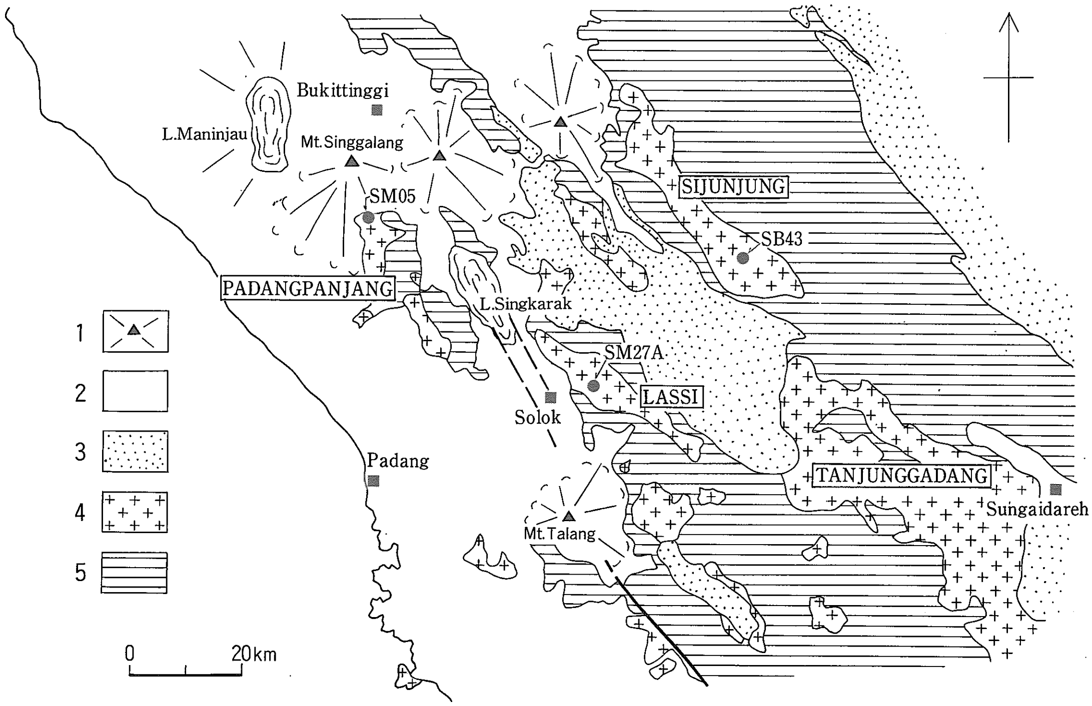

Fig. 2 Geological sketch map of central Sumatra showing sample localities.
Geology based on the 1:250,000 quadrangle geologic maps by Kastowo and Leo (1973), Silitonga and Kastowo (1975) and Rosidi *et al.* (1976).
1: Major volcanoes, 2: Tertiary to Quaternary volcanic rocks and aluvial deposits, 3: Tertiary sedimentary rocks, 4: Granitoids, 5: Permian to Triassic sedimentary and volcanic rocks.

and sandstone, and are intercalated with intermediate to silicic volcanic rocks to the east. No ages older than Late Carboniferous have yet been found in Sumatra (Hamilton, 1979). The strata are intruded by granitoids in many areas, and are thermally metamorphosed. The exposures of granitoid massess are relatively small, compared with those in the Tin Islands and Malay Peninsula (Fig. 1), partly due to overlying volcanic and sedimentary sequences. The granitoids in Sumatra are considered to range at least from Permian to Tertiary in age (Hamilton, 1979 ; Hutchison, 1983, 1989), but precise radiometric dates are so few that the tectonic framework of the granitoid magmatism is not well known.

Granitoids studied here are exposed in the central part of the Barisan Mountains between the equator and latitude 1° S. This area is called the Padang Highland. A geological sketch map of the area is shown in Figure 2, which was compiled from the 1:250,000 quadrangle geologic maps published by the Geological Survey of Indonesia. This area consists of pre–Tertiary basement rocks, Tertiary sedimentary and volcanic sequences, and Quaternary volcanic rocks. The pre–Tertiary units are exposed mainly to the northeast of the Sumatran Fault zone, which extends through Bukittinggi, Lake Singkarak and Solok, whereas its southwestern side is largely covered by Quaternary volcanic rocks. Volcanoes in this area reach nearly 3,000 m in altitude. The pre–Tertiary sedimentary sequences, mainly of Permian to Triassic age, are dominated by sandstone, shale and limestone with local occurrences of intermediate volcanic rocks. They are intruded by granitoid plutons which show elongated exposures trending northwest–southeast (Figs. 1 and 2).

A similar trend is also recognized in the Tertiary coal-bearing Ombilin Formation (Silitonga and Kastowo, 1975) located to the east of Solok.

Description of Dated Granitoids

Granitoid samples were collected from road cuts between Padang and Padangpanjang and along the Asian Highway Route No.25 from Bukittinggi to Sungaidareh through Solok (Sato, 1983, 1984). Magnetic susceptibility and radioactivity were measured at each outcrop, and an outline of the measurements has been reported (Sano *et al.*, 1988). Three specimens were selected for K-Ar dating. One of them was collected from the Sijunjung mass by Dr. Dodo of GRDC. The Tanjunggadang pluton has the largest exposure in this area (Fig. 2), though fresh rock suitable for dating was not found. The localities of the dated specimens is shown in Figure 2, and photomicrographs of the specimens are shown in Plate 1. Chemical analyses of the rocks are listed in Table 1. Followings are the descriptions of the dated rocks.

SM 05 : The sample was collected on a roadcut (0°28′30″ S, 100°20′49″ E) about 6 km west of Padangpanjang. The sample site is located at the north end of the granitoid exposure of about 17 × 10 km in size (Kastowo and Leo, 1973), named the Padangpanjang pluton in this paper. This pluton was emplaced in pre-Tertiary metasediments composed of shale, sandstone and quartzite, and is overlain by Quaternary andesite of the Singgalang volcano at its northern margin. Kastowo and Leo (1973) supposed the pluton to be of Tertiary age, but no radiometric age has been reported. Magnetic susceptibility measured by a Kappameter KT-5 was 1-2 × 10^{-3} SI on the outcrop and 2.5 × 10^{-3} SI on the sawed flat surface of the specimen. The specimen is a fairly fresh

Table 1 Chemical composition of dated granitoids and tin granitoids in the Hatapang pluton, northern Sumatra and in the Tin Belt.

	SM05	SM27A	SB43	Hatapang(n=10)	East Belt(n=49)
SiO_2	70.45	66.82	72.71	75.49(72.9-77.8)	72.52(64.9-79.5)
TiO_2	0.35	0.31	0.32	0.11(0.07-0.20)	0.27(0.1-0.7)
Al_2O_3	14.87	17.58	14.05	13.20(12.2-14.8)	14.12(10.3-17.22)
Fe_2O_3	1.09	0.98	0.55	0.42(0.06-0.76)	
FeO	1.51	1.52	1.57	1.11(0.70-1.28)	2.92(1.3-8.7)†
MnO	0.05	0.06	0.06	0.02(0.00-0.06)	0.06(0.0-0.2)
MgO	0.52	0.44	0.29	0.19(0.07-0.4)	0.61(0.1-2.8)
CaO	2.31	3.62	1.21	0.85(0.3-1.23)	1.90(0.1-5.7)
Na_2O	5.12	5.89	3.24	3.23(2.99-3.48)	3.32(0.9-4.4)
K_2O	2.81	1.40	5.12	4.91(4.70-5.8)	4.16(2.2-5.6)
P_2O_5	0.10	0.08	0.19	0.04(0.01-0.10)	0.12(0.0-0.6)
H_2O+	0.66	0.93	0.63		
H_2O-	0.05	0.15	0.07		
Total	99.89	99.78	100.01	100.65(99.76-101.67)	
Sn(ppm)	0.8	0.4	9.2	49(15-130)	6(2-15)
$\kappa(\times 10^{-3})$*	2.5	13.6	<0.2	<0.2**	

Analyst : Major oxides, H. Oonuki ; Sn, S. Terashima for SM05, SM27A and SB43.
* : Magnetic susceptibility (SI unit) measured by a Kappameter KT-5.
** : JICA/MMAJ (1985) † : Total iron as FeO.
Data for the Hatapang pluton and granitoids in the East Belt, Malay Peninsula are based on Clarke and Beddoe-Stephens (1987) and Hutchison (1983), respectively.

medium-grained biotite granodiorite. Hornblende was not observed. Biotite occurs as subhedral grains up to 3 mm. Chlorite partially replaces biotite (10–20%). Core of plagioclase is slightly altered to sericite, chlorite and epidote. Potassium feldspar is small in amount and it occurs as interstitial grains with microcline texture. Accessory minerals are sphene, apatite and opaque oxides. Opaque oxides are magnetite and ilmenite, and they occur among salic minerals and occasionally coexist with sphene.

SM 27 A : The sample was collected from a roadcut (0°46′30″ S, 100°44′3″ E) about 10 km east of Solok. The sample site is located in the central part of the Lassi pluton which has a northwest elongated exposure of about 38 × 9 km. This pluton was emplaced in Carboniferous to Triassic sedimentary and volcanic sequences (Tuhur and Kuantan Formations) (Silitonga and Kastowo, 1975), and a Rb–Sr age of 112 ± 24 Ma was reported for biotite by Katili (1962), although the sample site is not known. The pluton consists of various rock facies of high magnetic susceptibility values ($5–50 \times 10^{-3}$ SI), including granite, tonalite, quartz diorite and diorite. Alteration is often significant, and biotites are replaced by chlorite and epidote, but the dated specimen is relatively fresh. The specimen is a coarse-grained biotite tonalite showing a magnetic susceptibility of 13.6×10^{-3} SI on a sawed flat surface. Hornblende was not observed. Biotite is generally 2–5 mm in size, but some tabular crystals reach 1 cm. It is partially (about 20%) replaced by chlorite. Plagioclase is slightly sericitized. Potassium feldspar is very small in amount and shows ambiguous microcline texture. Accessory minerals are

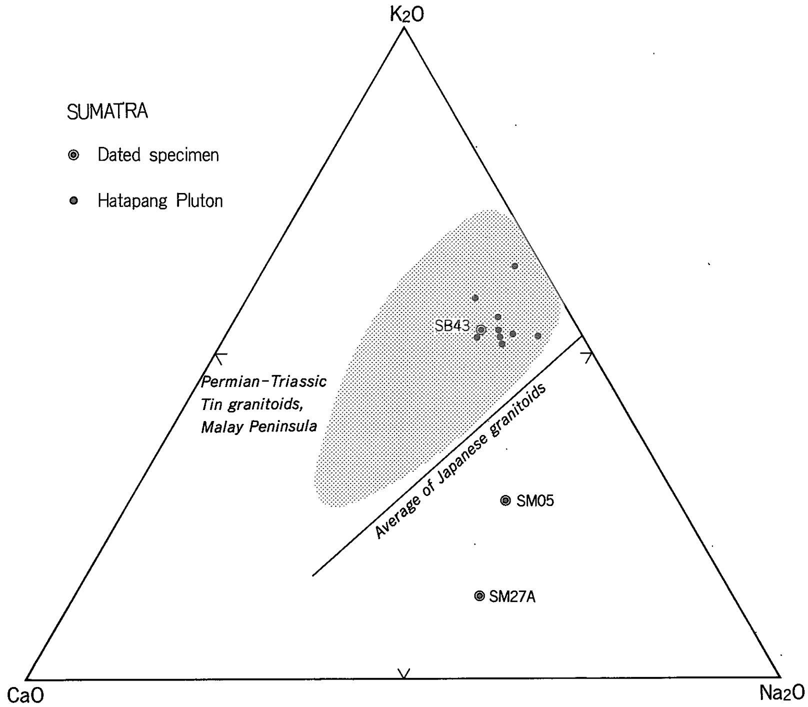

Fig. 3 $CaO–Na_2O–K_2O$ weight ratio of the dated granitoids and the Hatapang pluton. Data for the Hatapang pluton are from Clarke and Beddoe-Stephens (1987). Also shown are the range of composition of granitoids in the Tin Belt, Southeast Asia (Rajah *et al.*, 1977 ; Ishihara *et al.*, 1980), and the average composition of Japanese granitoids (Aramaki *et al.*, 1972).

apatite, zircon, magnetite and ilmenite. Opaque oxides tend to occur with biotite.

SB 43 : The sample was collected from the southern part of the Sijunjung pluton (ca. 0°33′ S, 100°58′ E). This pluton was emplaced in Carboniferous to Permian sedimentary sequences (Kuantan Formation) and has a northwest-trending exposure of about 50 × 10 km (Silitonga and Kastowo, 1975). A K-Ar age of 206.5 ± 2.5 Ma for a granite specimen collected near the southwestern margin of the pluton was reported in the explanation text of the geologic map by Silitonga and Kastowo (1975). The specimen dated here is a coarse-grained toumaline-bearing biotite granite without evidence of alteration. Magnetic susceptibility is less than 0.2×10^{-3} SI on the sawed surface. Biotite is subhedral (up to 2 mm in size) and deep brown in thin section. Potassium feldspar is perthitic. Accessory minerals besides tourmaline are allanite, apatite and zircon, while opaque minerals are very rare. The mineral assemblage and chemistry (Table 1) resemble those of granitoids in the Tin Belt, but are quite different from the above two granitoids (Fig. 3).

Age Determination and Results

Biotite concentrates were prepared for K-Ar dating using an isodynamic separator and heavy liquid (methylene diiodide). Contamination of the concentrates was estimated to be less than 1 percent. Biotite fractions of 40-60 mesh (SM 05) or 40-80 mesh (SM 27 A, SB 43) were used for the age determination, conducted by Teledyne Isotope Co. Ltd., U.S.A.. The results are shown in Table 2.

Ages of 64 Ma and 56 Ma for SM 05 and SM 27 A, respectively, indicate that the Padangpanjang and Lassi plutons were emplaced in the late Cretaceous or Paleocene time. On the other hand, the Sijunjung pluton is of Permian to Triassic age. The age of 247 Ma for SB 43 is the oldest among the K-Ar data for granitoids in Sumatra (Fig. 4).

Discussion

The biotites dated here are considered to have closure temperatures of about 300°C (e.g., Dodson and McLelland-Brown, 1985). The K-Ar age of biotite, therefore, represents the age when the host rock cooled down to about

Table 2 K-Ar biotite ages of granitoids in central Sumatra, Indonesia.

Sample No. (Pluton)	Rock	K (%)	$^{40}Ar^*$ (scc/gm$\times 10^{-5}$)	$^{40}Ar^*$ (%)	Age (Ma)
SM05	Bt-Gd	6.18	1.55	84.2	63.2±3.2
(Padangpanjang)		6.22	1.57	84.0	64.0±3.2
					63.6±3.2(av.)
SM27A	Bt-Tn	7.03	1.53	78.7	55.2±2.8
(Lassi)		7.02	1.59	82.3	57.3±2.9
					56.2±2.8(av.)
SB43	Bt-Gr	6.21	6.36	93.2	247.0±12.4
(Sijunjung)		6.15	6.33	96.3	245.9±12.3
					246.6±12.3(av.)

Coordination : SM05 =0°28′30″S, 100°20′49″E
SM27A =0°46′30″S, 100°44′ 3″E
SB43 =0°33′± S, 100°58′± E

Abbreviation : Bt, biotite ; Tn, tonalite ; Gr, granite ; Gd, granodiorite

Constants for age calculation : $\lambda_\beta = 4.962 \times 10^{-10}$/y, $\lambda_e = 0.581 \times 10^{-10}$/y, $^{40}K/K = 0.01167$ atom % (Steiger and Jäger, 1977). Error is for 2σ * : radiogenic

300°C. On the basis of studies of the cooling histories of granitoid plutons in Japan (e.g., Sato *et al.*, 1986, 1989, 1990 ; Shibata *et al*, 1988), it is not uncommon that the time of intrusion is estimated to be 3–10 Ma older than the biotite age. With these observations in mind, the results are discussed below in conjunction with previous age data.

The age of 64 ± 3 Ma for SM 05 indicates that the granitoid formed in late Cretaceous to early Paleocene time. This age is clearly younger than the biotite ages of 78–81 Ma for the Hatapang pluton, which comprises magnetite–free two–mica granite accompanied by tin–tungsten mineralization (Clarke and Beddoe-Stephens, 1987). Sample SM 05 of the Padangpanjang pluton is more sodic and poor in tin compared with the Hatapang granite (Table 1 ; Fig. 3), and contains magnetite, although the magnetic susceptibility is not very high. These points suggest that the two plutons belong to different granitoid provinces. Additional measurement of magnetic susceptibility is needed on the Padangpanjang pluton, because sample SM 05 was collected near the margin of the pluton, and the low content of magnetite might have been related to local reduction of magma by sedimentary wall rocks at the site of intrusion, as recognized in the Miocene Kofu complex, central Japan (Sato and Shibata, 1986 ; Sato, 1990).

The age of 56 ± 3 Ma for SM27A from the Lassi pluton indicates that this rock formed in Late Cretaceous to Paleocene time. The age is significantly different from the Rb–Sr biotite age of 112 Ma reported by Katili (1962) for the same pluton but of unknown locality. The reason for this difference is not known. Further investigation is required, considering the various rock facies and alteration observed in the Lassi pluton. The age obtained here is younger than that of the Padangpanjang pluton, but the chemistry and magnetism suggest that these plutons are assigned to the same group, which is different from the Hatapang pluton.

The age of 247 ± 12 Ma for the Sijunjung pluton is the oldest K–Ar age among the data reported to date for granitoids in Sumatra. Katili (1973 b) also reported a Rb–Sr age of 257 ± 24 Ma for a granitoid near Sibolga, northwestern Sumatra, although the original data set including detailed locality and lithology of the sample was not described. These ages are equivalent to the ages for granitoids in the Eastern Belt of the Malay Peninsula (Figs. 1 and 4), indicating the occurrence of Permian to Triassic granitoid magmatism in Sumatra as well. The chemistry and magnetism of SB43 resemble those of tin–related granitoids in Hatapang, the Tin Islands and the Malay Peninsula, suggesting the possibility of tin mineralization around the Sijunjung pluton. The difference between 247 Ma obtained in this study and 206 Ma reported by Silitonga and Kastowo (1975) is not yet resolved, but it might reflect a complex cooling history of the pluton, as recognized in the Tin Belt (e.g., Bignell and Snelling, 1977). In any case, these old ages suggest that Sumatra, at least the Sijunjung area, forms part of the massif of the Malay Peninsula and Thailand (Hutchison, 1983, 1989).

Figure 4 summarizes the K–Ar age data for granitoids in Sumatra, including the data presented in this report. Also shown are approximate ages for granitoid magmatism in the Tin Islands, Malay Peninsula and Phuket area of Thailand. The K–Ar ages shown in the histogram are widely scatterred between 8 Ma and 247 Ma. Although the data are limited, at least two episodes of granitoid magmatism recognized in Sumatra appear to correspond to those in the Tin Belt. It is noted, however, that the late Cretaceous to Paleocene plutons such as the Padanpangjang and Lassi plutons are petrographically distinct from the tin granite in Hatapang and Phuket. Cretaceous to Paleogene magmatism may be divided into two groups in space and/or in time. Cretaceous to Paleogene granitoids in the central and southern Sumatra tend to have an oxidized nature showing relatively high magnetic susceptibility (Sato, 1984), but the petrographic features of granitoids in northern Sumatra except for the Hatapang pluton are not known. Jurassic ages (142–182 Ma) were reported for three hornblendes from the Muarasipongi

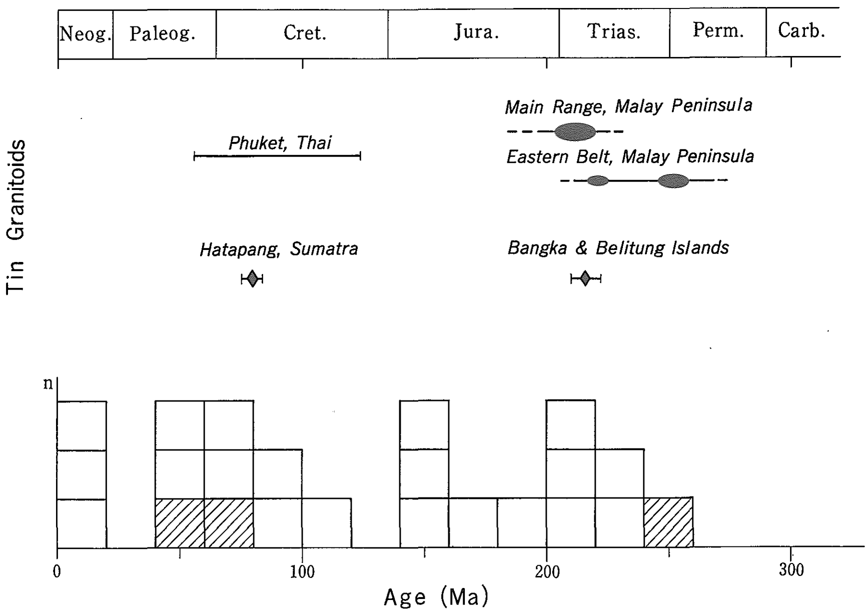

Fig. 4 Histogram showing K–Ar mineral ages for granitoids in Sumatra, with main intrusive episodes of tin granitoids in Sumatra, the Malay Peninsula and the Phuket area of Thailand.
Data source are as follows : Katili (1973b), Hehuwat (1976), JICA/MMAJ (1985), Clarke and Beddoe-Stephens (1987) and this study (shaded boxes) for the histogram ; Clarke and Beddoe-Stephens (1987) for the Hatapang pluton in the northern Sumatra ; Bignell and Snelling (1977), Liew and Page (1985) and Liew and McCulloch (1985) for the intrusive episodes in the Malay Peninsula ; Garson *et al.* (1975) and Suensilpong *et al.* (1983) for the data range of K–Ar mineral and Rb–Sr whole rock ages of granitoids in the Phuket area, Thailand. Geologic ages are after Snelling (1985).

pluton, about 120 km northwest of Bukittinggi (JICA/MMAJ, 1985). This pluton is quartz diorite to granodiorite in composition (generally 50–65% SiO_2) and highly magnetic (10–30 $\times 10^{-3}$ SI), and is accompanied by Cu–Pb–Zn mineralization but not tin (JICA/MMAJ, 1985). These data suggest the occurrence of Jurassic granitoid magmatism of the oxidized type in Sumatra. The wide range of ages in Sumatra, including ages as young as Miocene (Hehuwat, 1976), indicates a long history of granitoid magmatism ; however, reliable basic data are insufficient to establish granitoid and related metallogenic provinces. Further radiometric age determination and petrological examination of granitoids are needed to prospect for and evaluate mineral deposits in Sumatra.

Concluding Remarks

Granitoid magmatism in Sumatra occurred from the Permian to Tertiary. Two episodes of magmatism, Permian–Triassic and Cretaceous–Paleogene, are recognized in the Padang Highland, central Barisan Mountains. The Sijunjung pluton (sample SB 43) can be correlated to Permian–Triassic granitoids in the Eastern Belt of the Malay Peninsula, suggesting that Sumatra is part of the massif of the Malay Peninsula and Thailand. Cretaceous–Paleogene plutons in this area (Padangpanjang (sample SM 05) and Lassi (sample SM 27 A)) are not associated with tin mineralization ; they are characterized by a sodic composition and an oxidized nature, and are thus different from Cretaceous tin granitoids of the Hatapang pluton in northern Sumatra and the Phuket area in Thailand. Therefore, the Cretaceous-Paleogene granitoids in Southeast Asia can be classified into two groups, tin-related and tin-barren granitoids.

It was assumed in the above discussion that cooling rates of the examined plutons were similar to the estimates for Japanese granitoids, because sizes of the plutons are not largely different from those of the Japanese plutons studied in view of the cooling history. For a more detailed examination, however, it is necessary to obtain two or more age dates from minerals of various closure temperatures for a single rock sample. Geologic and petrographic information of the examined plutons is also not sufficient and must be supplememted by field work as well as additional age determinations. It is most important to accumulate reliable radiometric ages and petrochemical data in order to establish the history of granitoid magmatism and related mineralization in Sumatra.

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インドネシア 中部スマトラの花崗岩類の K-Ar 年代

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要　旨

スマトラ島のバリサン山脈中央部パダン高地に分布する花崗岩類につき，黒雲母の K-Ar 年代を求め，マレー半島など周辺域の花崗岩類の年代と比較検討した．スマトラ断層の北東約 40 km 付近に分布する Sijunjung 岩体の電気石を含む花崗岩は 247 Ma の年代を与え，マレー半島のスズ花崗岩に相当する二畳紀-三畳紀の花崗岩活動がスマトラにも生じていた事が明らかとなった．スマトラ断層に近い Lassi および Padangpanjang 岩体はそれぞれ 54 Ma および 64 Ma の年代を与え，後期白亜紀-暁新世に貫入したと考えられる．これらは高い Na/K 比と Fe^{3+}/Fe^{2+} 比で特徴づけられ，北スマトラで発見されたスズ-タングステンの鉱化作用を伴う後期白亜紀の Hatapang 花崗岩岩体（78-81 Ma）とは異なる．スマトラの白亜紀-古第三紀花崗岩類は，岩質と時代により，少なくとも 2 つのグループに分けられるらしい．スマトラの花崗岩活動と鉱化作用の全体像を把握するためには，信頼できる放射年代のデータをさらに蓄積する必要がある．

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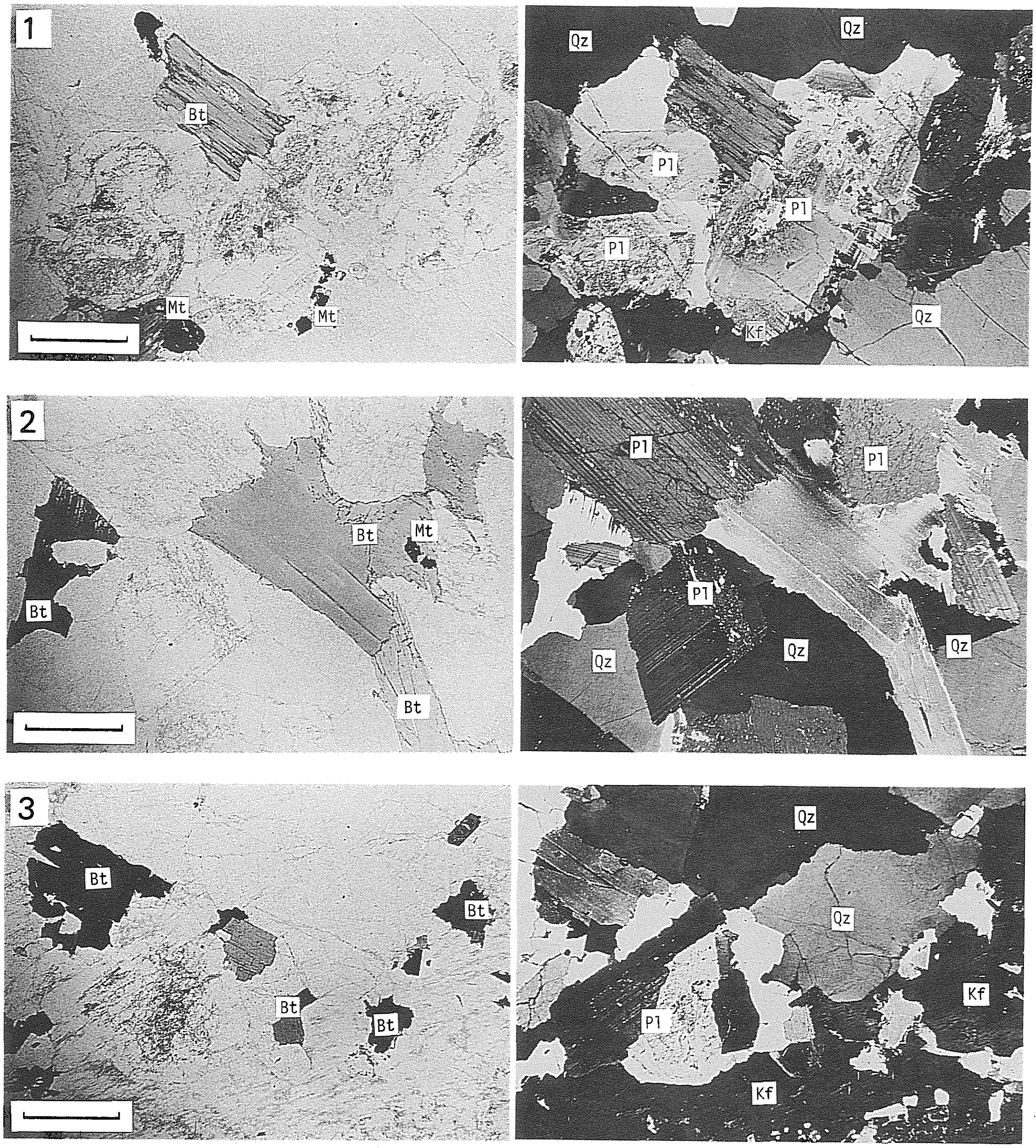

Plate 1 Photomicrographs of the dated granitoids.
1 : SM05, 2 : SM27A, 3 : SB43. Left : lower polar only, right : crossed polars. Scale bar 1 mm. Bt : biotite, Pl : plagioclase, Kf : potassium feldspar, Qz : quartz, Mt : magnetite.