GEOSEA V Proceedings Vol. I, Geol. Soc. Malaysia, Bulletin 19, April 1986; pp. 349–367

Some aspects of southern granitoid complex and tin mineralization in the northern part of Bangka, Indonesia

R. SOERIA-ATMADJA*, D. DARDA** and D. HASANUDDIN*

*Dept. of Geology, Institut Teknologi Bandung, Jalan Ganesa No. 10,
Bandung, Indonesia
**Geological Research & Development Centre, Jalan Diponegoro No 57
Bandung, Indonesia

Abstract: The southern granitoid complex in this study refers to granitoid exposures in the areas of Menumbing-Tempilang along the southern coast and Pelangas-Kelapa further north, south of Kelabat intrusive complex. Petrographically the rocks consist of medium to coarse-grained porphyritic monzogranite, syenogranite and monzonite. The main minerals are quartz, K-feldspar, plagioclase and biotite.

In a southerly direction from Pelangas-Kelapa to Menumbing-Tempilang complex, the following changes have been observed, viz. disappearance of hornblende, increase of myrmekitic, granophyric and micrographic textures, development of replacement-type microperthite, increase of Rb/Sr, Nb, F, Sn, normative corumdum, and decrease of CaO/MgO and Ba.

Nearly all granitoids plot in the S-type field; generally they show low magnetic susceptibility suggesting Ilmenite Series. Tin mineralization in the granitoid and country rocks took place mostly along westnorthwest, northnortheast and nearly north-south directions, and they seem to be more related to Late Triassic deformation.

INTRODUCTION

Bangka is one of the Indonesian tin-islands within the tin-bearing granitoid belt which can be followed further northwest through Peninsular Malaysia, Thailand and Burma (Fig. 1). Along this belt tin mineralization exhibits close relationship with granitoid intrusions and regional tectonic setting. Hutchison (1977) recognized four major tectonic regimes in Peninsular Malaysia, each characterized by different tectonic histories namely Western Stable Shelf, Main Range, Central Graben and Eastern Belt. He found that each tectonic regime is marked by different nature of intrusive bodies, country rocks, thermal metamorphic effects, geochemistry and structural state of K-feldspar. According to Hosking (1973, 1977), there are essential differences in tin mineralization, mineralogical character, trace-element content of the granitoids, and type of deposits in the Malaysian tin belt. He divided the Southeast Asian Tin Province into Eastern and Western Belts.

Bangka consists of isolated outcrops of granitoid plutons which are separated by extensive areas of alluvial deposits and strongly folded metasediments; there are about 14 granitoid masses of which Klabat and Buluh are the largest exposed intrusions (Fig. 2). Dating by Priem *et al.*, (1975) gives the age of granitoids of Bangka, Belitung and Pulau Tujuh Islands as Late Triassic; Rb/Sr age (217 my) is closely similar to K/Ar age. Hosking (1977) and Kumar (1981) included Belitung in the Eastern Belt of Peninsular Malaysia. However, according to Hutchison (1977) their initial $^{87}Sr/^{86}Sr$ ratios (0.715)

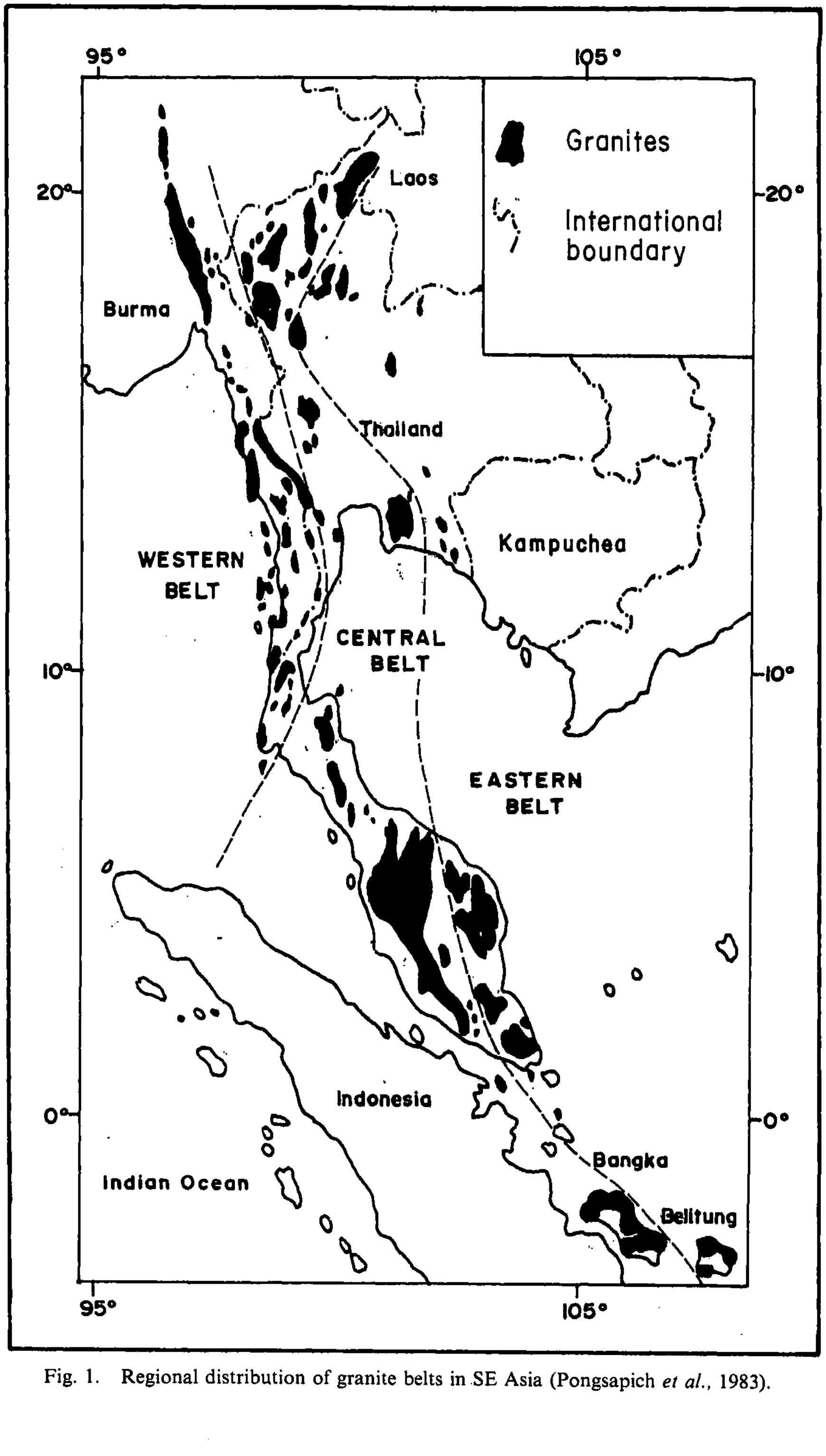

Fig. 1. Regional distribution of granite belts in SE Asia (Pongsapich *et al.*, 1983).

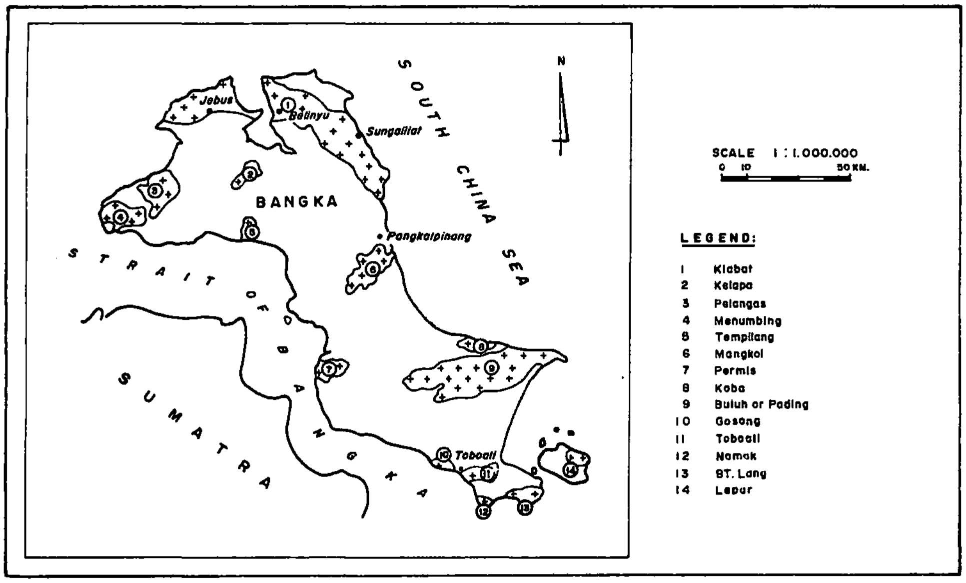

Fig. 2. Distribution of granitoids, Bangka.

are higher than those of the Eastern Belt granitoid. Similarly Pongsapich *et al.*, (1983) included Belitung together with Eastern Malaysia and Eastern Thailand into the Eastern Granitic Belt of Thailand and considered Pulau Tujuh, Singkep, Bangka and the Main Range as parts of the Central Granitic Belt.

Previous work by Katili (1968) led him to conclude that crossfolding in Bangka is the result of Mesozoic deformation superimposed on earlier Palaeozoic orogeny. His interpretation was based on Kahr's unpublished reports which indicated two trends of fold-axes in the Pemali open-pit mine—NW-SE and NE-SW. The present study has revealed that the regional structure of Bangka is dominated by almost east-west trending fold axes.

The purpose of this investigation is to present recent findings on the petrology, chemistry of granitoids in the southern intrusive complex of Northern Bangka and their relation to primary tin mineralization. We believe that this presentation will contribute to the understanding of granitoid petrology and tin mineralization in the Indonesian part of the tin province. However much more work needs to be done on the sequence of magmatic activities and tin mineralization.

GEOLOGICAL SETTING

The southern part of West Bangka is underlain mostly by strongly folded and contorted Palaeozoic and Triassic metasediments and lowgrade metamorphic rocks, with major fold-axes striking almost east-west. Statistical studies of fold axes reveal three different directions—northeast-southwest, northwest-southeast and almost east-west successively representing Palaeozoic, Late Triassic and post-Triassic deformations. The rocks include meta-quartzite, quartz-arenite, claystone, siltstone, phyllite and low-grade schist. In some parts they are intruded by Late Triassic granitoid and covered by extensive alluvial deposit.

Four granitoid intrusions have been studied in the area, two along the south coast at Menumbing and Tempilang, and two further north at Pelangas and Kelapa (Fig. 3). The contact of these intrusions with surrounding country rock is mostly concealed by younger Quaternary deposit. The nature of contact is commonly discordant indicating emplacement at a late tectonic stage of Late Triassic deformation. So far no indications of mappable thermal aureoles have been observed around the granitoid intrusions. However, petrographic studies of few samples point to hornfels thermal metamorphism.

The largest granitoid outcrop at Menumbing consists of light grey, coarse-grained

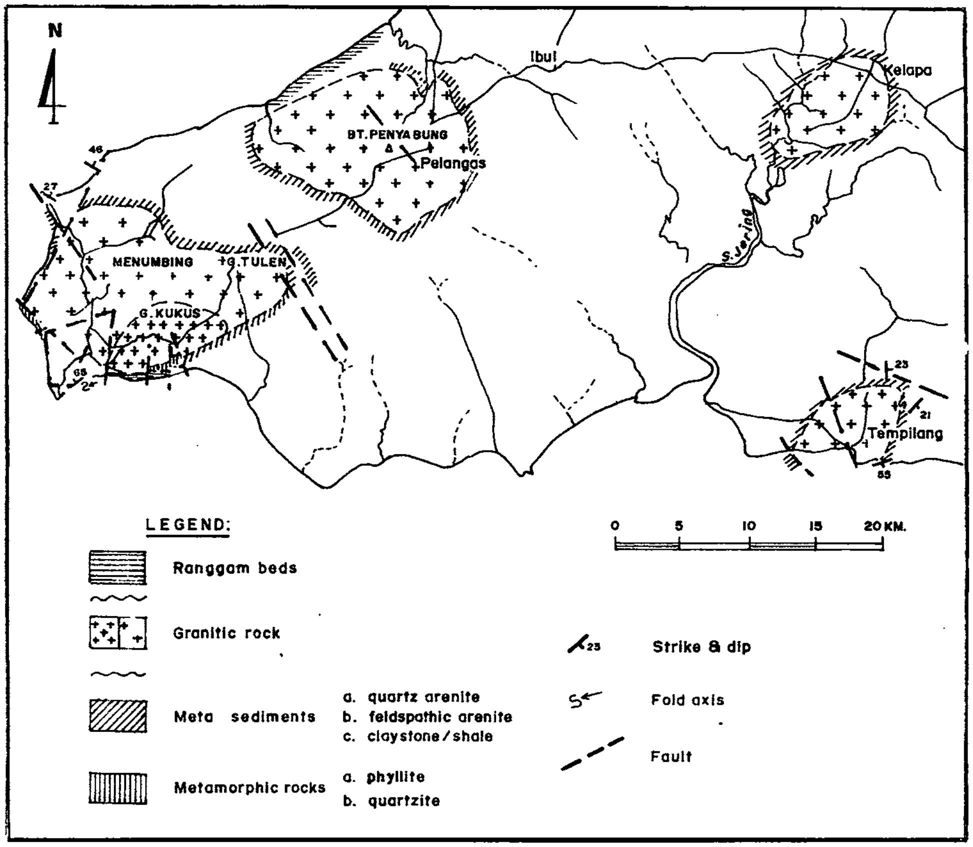

Fig. 3. Geologic sketch map of Menumbing-Tempilang-Pelangas-Kelapa, southern part of Northern Bangka.

porphyritic rock, chiefly syenogranite, carrying basic xenoliths (basalt and diabase) and elongated segregations of mostly biotite; occasionally some primary structures may be observed such as parallel-oriented K-feldspar, lens-shaped basic segregations or xenoliths. In the southeastern part of Menumbing intrusion, at Kukus, the rocks are less prophyritic and have relatively finer groundmass. The relationship between the two rock types in the field is not clear, but petrographic studies suggest that Kukus granitoid intruded Menumbing granitoid. Other features are cassiterite-tourmaline veins, tourmalinization patches, pegmatite and aplite dikes. Unlike the smooth and rounded surface of granitoid outcrops at Menumbing, those at Tempilang appear as elongated blocks as a result of jointing.

Other structural features in the investigated area are jointing and faulting; the former is developed in both the granitoid and country rock. The joint patterns obtained from systematic measurements seem to correspond to two principal stress directions representing Late Triassic and post-Triassic deformations. Presumably faulting is mostly related to post-Triassic deformation including strike-slip and normal faults; they cut across both granitoid and country rock.

PETROGRAPHY OF GRANITOIDS

Kelapa Intrusion

Petrographic studies reveal that the rocks are mainly porphyritic monzogranite with coarse-grained hypidiomorphic-granular matrix. Phenocrysts include K-felspar, biotite and quartz (4–40 mm in size). Poikilitic texture is very characteristic in these rocks in whick feldspar and quartz contain abundant inclusions of plagioclase and biotite.

Plagioclase (andesine) is mostly clouded with sericite, muscovite, clay and iron-oxides. Zonation and polysynthetic twinning are very common. Sometimes plagioclase crystals have thin myrmekite jackets. Microperthite shows inclusions of plagioclase, hornblende, biotite and other accessories (apatite, zircon and titanite). In the matrix, quartz occurs as fillings between other crystals and shows replacement of feldspar, biotite and hornblende along cleavage traces.

Biotite and its chloritization products make up not more than 15% of the rock sections; the crystals are tabular with sutured boundaries and exhibit strong pleochroism from reddish brown to pale colors. Secondary alterations of biotite often give chlorite-sphene-epidote-iron oxides. Common inclusions are zircon and apatite. Green hornblende is less than 4% consisting of weakly-pleochroic prismatic crystals and basal sections. Usually hornblende occurs as isolated clusters consisting of feldspar-hornblende intergrowths. Some hornblende crystals exhibit marginal biotite (primary or secondary).

Pelangas Intrusion

Pelangas granitoid consists of porphyritic monzogranite, monzonite and syenogranite; the groundmass is coarse-grained hypidiomorphic-granular in which phenocrysts of K-feldspar, plagioclase and quartz are embedded. The size of phenocryst varies between 8–70 mm. Several sections contain green hornblende.

Microperthite is commonly anhedral in the matrix but more subhedral in phenocrysts; inclusions of plagioclase are not common. Partial replacement by silica gives intergrowth textures and secondary alterations give argillic matter. Exsolution microperthite shows minor albitization (patch-perthite). Plagioclase andesine, occurs as coarse subhedral prisms, and may show discontinuous marginal myrmekite. The crystals are commonly dusted with clay and sericite. Quartz shows evidence of recrystallization and may be present along fractures as well as intergranular filling in the matrix. Larger quartz grains often contain inclusions of zircon, apatite and opaque ore particles.

Biotite, not more than 12%, is generally dark brown in colour but some are reddish brown with strong pleochroism. It shows corroded crystal boundaries against feldspar and quartz. Some biotite crystals are present along fractures. Secondary alterations give among others chlorite, sphene and iron-oxides. Several sections exhibit relicts of primary green hornblende (not more than 1.5%) with alterations to chlorite and iron-oxides.

Tempilang Intrusion

A large part of Tempilang granitoid consists of porphyritic syenogranite with medium-grained hypidiomorphic-granular matrix. Phenocrysts up to 5 cm in size, include microperthite, plagioclase and quartz. The rocks are characterized by the development of granophyric and micrographic textures, and the formation of muscovite. The latter is disseminated in the groundmass usually between quartz and feldspar.

Microperthite (40–64%) exhibits various stages of albitization (patch- and vein-perthite); most crystals are subhedral to anhedral with sutured boundaries against quartz. Several sections exhibit partial replacement by fluorite. Andesine crystals (8–17%) are prismatic with compositional zonation and polysynthetic twinning. Myrmekite occurs as thin margins around plagioclase grains and also as individual anhedral crystals. The feldspars often show alteration to clay-sericite and partial replacement by muscovite.

Quartz (23–43%) shows sutured anhedral crystals, and are commonly intergrown with K-feldspar to form granophyric and myrmekitic textures. Quartz is found as fine aggregates with feldspar, muscovite and biotite between coarse crystals. Vein quartz is associated with sericite and muscovite. Biotite and its alteration products vary between 1–8%. Brown and reddish colored biotite are abundant.

Biotite, quartz and feldspar also occur as fracture fillings. Tourmaline and fluorite are usually closely associated with biotite. Chloritization of biotite gives sphene and iron-oxides with relicts of pleochroic halos. Replacement of biotite by quartz, sericite and muscovite is very common.

Menumbing Intrusion

A large part of the intrusive body consists of medium- to coarse-grained porphyritic granitoid whereas the southeastern corner, Kukus, is made up of fine-grained granitoid. The rocks consist chiefly of syenogranite, some monzonite and monzogranite.

The fine-grained variety at Kukus is also porphyritic and is marked by granophyric and micrographic textures with abundant albitization. The development of muscovite in these rocks is very characteristic. Generally microperthite (46–57 %) shows evidence of albitization (patch-and vein-perthite) and is usually clouded with sericite and clay. Partial replacement of microperthite by biotite, fluorite, tourmaline and quartz is commonly observed. Tourmalinization is generally limited to matrix feldspar.

Andesine (11–28.4 %) often shows marginal myrmekite. The latter may also be present between microperthite and plagioclase. Polysynthetic twinning is more common than normal zoning. Plagioclase often exhibits corrosion by K-feldspar and partial replacement by quartz. Turbid appearance of plagioclase is due to sericite, muscovite and clay. Quartz (14–35.5 %) occurs as corroded phenocrysts and often contains inclusions of tourmaline. Matrix quartz usually has irregular shape. Dark brown biotite (up to 8 %) is usually present in the groundmass. Inclusions in biotite are zircon, apatite and sphene. Reddish colored biotite is present as slender prisms or fibrous aggregates and it occurs as intergranular filling. Biotite may show chloritization and partial replacement by tourmaline, muscovite and quartz. Beside zircon and apatite the characteristic accessories consist of fluorite, tourmaline, biotite, muscovite, quartz and cassiterite.

The main granitoid body of Menumbing is made up of weathered coarse-grained porphyritic syneogranite. Phenocrysts of K-feldspar and quartz (8–60 mm in size) are embedded in coarse-grained (4–6 mm in size) hypidiomorphic-granular/matrix; the latter shows isolated spots consisting of very fine aggregates between the coarse fraction which is very much similar to the matrix of Kukus granitoid. Microperthite (28–59 %) is marked by albitization and shows partial replacement by muscovite, quartz, tourmaline, topaz and biotite. Secondary alterations give sericite and clay. Twinned plagioclase prisms, andesine (9–37 %), exhibit alterations to sericite and partial replacement by muscovite and quartz. In the fine aggregates plagioclase and microperthite are intergrown with quartz, biotite and other secondary minerals. Biotite and chlorite make up to 8.5 % of the rock and contain inclusions of zircon, apatite, topaz, tourmaline, fluorite, cassiterite. Several sections exhibit veinlets of biotite, muscovite, quartz and fluorite. Quartz is generally anhedral as phenocrysts and matrix constituent.

The development of secondary minerals such as fluorite, allanite, tourmaline, topaz, cassiterite, muscovite and biotite is limited to the coarse-grained rock matrix. The presence of muscovite, tourmaline, fluorite and topaz suggests that pneumatolitic activity has affected these rocks.

GEOCHEMISTRY

Major Elements

For this study 54 samples of granitoids have been analyzed for major as well as minor elements. Chemical analyses for the major elements were done at the chemistry laboratory of Directorate of Mineral Resources using wet method and AAS. The granitoid samples consist of 31 samples from Menumbing and 11 samples each from Tempilang and Pelangas, whereas the granitoid from Kelapa is represented by only one sample (Table 1).

Results of chemical analyses reveal that SiO_2 contents exhibit a limited variation ranging between 70.5–76.5 %. Granitoids from Pelangas and Kelapa vary in their SiO_2 contents between 70.5–73.5 % whereas Menumbing and Tempilang show SiO_2 content of 71.5–76.5 % and 72.5–74.5 % respectively. There is a tendency of SiO_2 to increase from the Pelangas-Kelapa intrusive complex toward the Menumbing-Tempilang

TABLE 1

CHEMICAL COMPOSITIONS AND CIPW NORMS OF GRANITOIDS

Chem. comp. (Wt. %)	Menumbing							
	1	2	3	4	5	6	7	8
SiO_2	75.98	72.90	71.88	72.91	74.71	74.01	73.26	75.30
Al_2O_3	12.00	15.60	15.30	14.90	14.83	13.14	14.50	15.78
Fe_2O_3	0.62	0.71	2.15	1.80	1.30	1.44	0.87	—
FeO	1.56	2.23	2.01	2.16	1.41	2.68	2.38	0.76
MgO	0.22	0.43	0.43	0.65	0.27	0.38	0.38	0.43
CaO	1.45	1.74	1.74	1.74	1.74	1.74	1.60	1.59
Na_2O	1.87	1.78	1.80	1.70	1.80	1.75	1.83	1.80
K_2O	3.40	3.60	3.40	3.00	2.75	3.50	3.85	3.45
H_2O^+	0.09	0.10	0.06	0.16	0.11	0.08	0.07	0.17
H_2O^-	0.34	0.26	0.43	0.25	0.25	0.35	0.36	0.25
TiO_2	0.18	0.28	0.36	0.35	0.27	0.27	0.19	0.26
P_2O_5	—	—	—	—	—	—	—	—
MnO	0.04	0.07	0.08	0.07	0.06	0.13	0.07	0.003
LOI	2.65	0.58	0.80	0.68	0.78	0.89	0.97	0.58
Total	100.40	101.28	100.44	100.37	100.28	100.36	100.33	100.373
CIPW Norm								
Q	49.00	43.24	43.73	46.25	49.47	44.97	42.77	47.44
or	20.64	21.41	20.26	17.85	16.39	20.88	23.00	20.52
ab	16.26	15.16	15.36	14.49	15.36	14.95	15.65	15.33
an	7.39	8.69	8.71	8.69	8.70	8.72	8.02	7.94
c	2.68	5.65	5.54	5.73	5.78	3.34	4.46	6.23
hy (en)	2.75	4.28	2.56	3.68	1.87	4.52	4.45	2.06
mt	0.92	1.04	3.14	2.63	1.90	2.11	1.27	—
il	0.35	0.54	0.69	0.67	0.52	0.52	0.36	0.50
ap	—	—	—	—	—	—	—	—
di	—	—	—	—	—	—	—	—
Total	99.99	100.01	99.99	99.99	99.99	100.01	99.99	100.02

TABLE 1 (contd.)

Chem. comp. (Wt. %)	cont'd							
	9	10	11	12	13	14	15	16
SiO_2	73.22	74.76	76.38	74.16	74.44	75.96	75.45	73.76
Al_2O_3	15.50	14.80	12.10	15.30	13.36	14.39	14.30	15.57
Fe_2O_3	2.21	1.29	0.93	2.19	1.54	0.95	1.03	0.16
FeO	0.89	1.56	0.68	1.34	1.78	1.56	0.89	1.72
MgO	—	0.38	0.43	0.16	0.11	0.54	0.59	0.27
CaO	1.45	1.30	1.02	0.87	1.31	0.73	1.02	1.11
Na_2O	1.91	1.80	1.72	1.78	1.83	1.75	1.83	1.91
K_2O	3.90	3.00	4.10	3.00	3.40	2.90	3.75	3.60
H_2O^+	0.04	0.11	0.34	0.10	0.05	0.15	0.10	0.06
H_2O^-	0.44	0.30	0.17	0.35	0.33	0.48	0.34	0.19
TiO_2	0.26	0.32	0.18	0.20	0.22	0.20	0.20	0.18
P_2O_5	—	—	—	0.35	—	—	—	—
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04
LOI	0.59	0.70	2.41	0.93	0.91	0.91	0.88	0.95
Total	100.42	100.33	100.37	100.74	99.29	100.53	100.39	99.52
CIPW Norm								
Q	44.37	49.26	48.97	51.27	48.02	52.03	47.62	45.58
or	23.20	17.87	24.83	17.85	20.50	17.31	22.37	21.64
ab	16.27	15.35	14.92	15.16	15.80	14.96	15.63	16.44
an	7.24	6.50	5.19	2.37	6.63	3.66	5.11	5.60
c	5.54	6.28	3.05	8.32	4.37	7.12	5.43	6.62
hy (en)	—	2.25	1.30	0.74	1.96	3.14	1.96	3.54
mt	2.16	1.89	1.38	3.20	2.28	1.39	1.51	0.24
il	0.50	0.61	0.35	0.38	0.43	0.38	0.38	0.35
hem	0.73	—	—	—	—	—	—	—
ap	—	—	—	0.72	—	—	—	—
di	—	—	—	—	—	—	—	—
Total	100.01	100.01	99.99	100.01	99.99	99.99	100.01	100.01

Chem. com., (Wt. %)	cont'd							
	17	18	19	20	21	22	23	24
SiO_2	74.84	73.75	72.71	71.53	72.91	73.85	72.53	73.71
Al_2O_3	14.98	14.87	16.75	16.71	15.46	14.98	15.64	15.87
Fe_2O_3	0.10	0.34	0.10	0.27	0.60	0.38	0.27	0.16
FeO	1.50	1.99	1.58	2.05	1.96	1.74	2.46	1.94
MgO	0.15	0.29	0.19	0.44	0.49	0.83	0.39	0.19
CaO	0.95	1.26	0.95	1.58	1.42	1.11	1.42	0.95
Na_2O	1.93	1.80	1.87	1.75	1.76	1.76	1.78	1.91
K_2O	3.65	3.90	4.00	3.50	3.30	3.50	3.60	3.50
H_2O^+	0.04	0.05	0.02	0.02	0.01	0.03	0.01	0.04
H_2O^-	0.17	0.15	0.13	0.17	0.22	0.17	0.22	0.28
TiO_2	0.14	0.26	0.22	0.48	0.45	0.32	0.39	0.26
P_2O_5	—	—	—	0.05	0.02	0.03	—	—
MnO	0.03	0.05	0.05	0.06	0.06	0.05	0.06	0.06
LOI	0.96	0.80	0.93	1.04	1.09	0.97	1.01	0.83
Total	99.44	99.51	99.50	99.65	99.75	99.72	99.78	99.78
CIPW Norm								
Q	47.06	44.50	43.74	43.44	45.92	46.25	44.27	48.16
or	21.95	23.39	24.01	21.01	19.81	20.99	21.37	21.15
ab	16.62	15.46	16.08	15.04	15.13	15.11	15.13	16.52
an	4.80	6.34	4.79	7.63	7.02	5.39	7.08	0.96
c	6.24	5.48	7.74	7.41	6.56	6.44	6.26	8.79
hy (en)	2.92	3.81	3.07	4.02	3.75	4.58	4.75	3.67
mt	0.15	0.50	0.15	0.40	0.88	0.56	0.39	0.24
il	0.27	0.50	0.42	0.93	0.87	0.62	0.74	0.50
ap	—	—	—	0.12	0.48	0.07	—	—
di	—	—	—	—	—	—	—	—
Total	100.01	99.98	100.00	100.00	100.42	100.01	99.99	99.99

TABLE 1 (contd.)

Chem. comp. (Wt. %)	cont'd						
	25	26	27	28	29	30	31
SiO_2	7.165	72.64	73.64	72.21	73.20	71.71	68.29
Al_2O_3	16.01	15.62	14.78	15.88	15.61	16.01	14.75
Fe_2O_3	0.98	0.12	0.10	0.52	0.10	0.17	0.29
FeO	1.82	2.70	2.99	2.65	2.72	2.76	5.46
MgO	1.27	0.49	0.39	0.49	0.24	0.44	0.68
CaO	1.74	1.42	1.90	1.58	1.11	1.26	1.58
Na_2O	1.68	1.80	1.68	1.70	1.64	2.13	2.65
K_2O	3.10	3.50	2.50	2.75	3.00	3.65	2.65
H_2O^+	0.03	0.04	—	—	—	—	—
H_2O^-	0.26	0.26	0.11	0.12	0.10	0.10	0.17
TiO_2	0.42	0.39	0.39	0.42	0.38	0.41	0.86
P_2O_5	—	0.04	0.04	0.01	—	0.01	—
MnO	0.06	0.06	0.07	0.07	0.05	0.06	0.15
LOI	0.83	0.83	1.13	1.09	1.45	0.87	2.28
Total	99.91	99.72	99.49	99.60	99.60	99.58	99.49
CIPW Norm							
Q	44.07	43.68	48.27	46.75	48.40	40.60	37.37
or	18.55	20.94	15.00	16.35	18.08	21.87	16.14
ab	14.40	15.42	14.43	14.63	14.15	18.28	20.31
an	8.74	6.87	9.30	7.91	5.62	6.27	8.08
c	6.81	6.46	6.04	7.38	7.80	6.38	5.33
hy (en)	5.18	5.61	5.95	5.18	5.07	5.53	10.65
mt	1.44	0.18	0.15	0.77	0.15	0.25	0.43
il	0.81	0.75	0.75	0.81	0.74	0.79	1.68
ap	—	0.10	0.10	0.02	—	0.02	—
di	—	—	—	—	—	—	—
Total	100.00	100.01	99.99	99.98	100.01	99.99	99.99

Chem. comp. (Wt. %)	Tempilang							
	32	33	34	35	36	37	38	39
SiO_2	73.22	72.79	74.45	73.48	73.39	73.49	73.65	72.40
Al_2O_3	15.37	16.57	15.21	14.75	14.98	15.76	15.01	13.87
Fe_2O_3	0.22	0.10	0.19	0.10	0.14	0.80	0.10	0.89
FeO	1.68	2.21	1.39	1.99	2.16	0.32	2.56	1.90
MgO	0.10	0.10	0.15	0.24	0.24	0.19	0.24	0.29
CaO	1.74	1.26	1.11	1.42	1.58	1.11	1.26	1.58
Na_2O	1.94	1.80	2.13	1.90	1.86	2.18	1.76	1.60
K_2O	3.65	3.25	3.35	3.50	3.65	3.35	3.25	3.89
H_2O^+	—	—	—	—	0.04	—	0.01	—
H_2O^-	0.21	0.23	0.09	0.12	0.13	0.47	0.16	0.13
TiO_2	0.19	0.18	0.18	0.22	0.27	0.09	0.21	0.33
P_2O_5	—	0.08	—	0.04	0.03	0.02	0.03	0.03
MnO	0.07	0.07	0.05	0.06	0.08	0.15	0.05	0.06
LOI	1.23	1.01	1.12	1.38	0.96	1.84	1.35	2.80
Total	99.62	99.65	99.42	99.20	99.51	99.77	99.64	99.75
CIPW Norm								
Q	43.65	46.26	46.47	45.28	44.04	46.54	46.90	45.01
or	21.97	19.51	20.15	21.17	21.92	20.31	19.57	23.50
ab	16.72	15.47	18.35	16.45	16.00	18.92	15.18	13.98
an	8.80	5.82	5.61	6.94	7.77	5.51	6.17	7.89
c	5.16	8.12	6.17	5.48	5.25	6.75	6.50	4.41
hy (en)	3.02	4.12	2.61	4.01	4.22	0.54	5.06	3.14
mt	0.32	0.15	0.28	0.15	0.20	1.19	0.15	1.33
il	0.37	0.35	0.35	0.43	0.52	0.17	0.41	0.65
ap	—	0.19	—	0.10	0.07	0.05	0.07	0.07
di	—	—	—	—	—	—	—	—
Total	100.01	99.99	99.99	100.01	99.99	99.98	100.01	99.98

TABLE 1 (contd.)

Chem. comp. (Wt. %)	cont'd			Kelapa		Pelangas		
	40	41	42	43	44	45	46	47
SiO_2	74.53	72.38	72.81	70.99	72.79	73.12	73.01	72.49
Al_2O_3	14.99	16.18	15.19	15.70	14.52	14.10	14.70	14.16
Fe_2O_3	0.10	0.10	0.26	2.24	1.05	1.37	0.88	1.93
FeO	1.56	2.19	2.68	1.56	2.23	1.49	2.38	1.79
MgO	0.19	0.29	0.19	0.86	0.49	0.81	0.54	0.27
CaO	1.42	1.26	1.58	2.47	2.90	2.61	2.35	2.90
Na_2	2.08	1.60	1.76	1.63	1.73	1.73	1.60	1.90
K_2O	3.25	3.15	3.65	2.85	3.25	3.65	3.25	3.00
H_2O^+	—	0.11	0.03	0.05	0.17	0.06	0.11	0.03
H_2O^-	0.16	0.97	0.19	0.55	0.25	0.32	0.26	0.31
TiO_2	0.36	0.18	0.29	0.40	0.24	0.32	0.54	0.55
P_2O_5	—	0.08	—	0.17	0.18	0.08	0.11	0.07
MnO	0.05	0.07	0.08	0.004	0.01	0.003	0.01	0.01
LOI	0.75	1.95	1.05	1.08	0.53	0.66	0.55	0.85
Total	99.44	100.51	99.76	100.554	100.34	100.323	100.29	100.26
CIPW Norm								
Q	46.31	47.70	43.60	44.85	42.82	42.33	44.76	43.58
or	19.49	19.09	21.90	17.03	19.32	21.72	19.33	17.89
ab	17.86	13.89	15.12	13.95	14.73	14.74	13.62	16.23
an	7.15	5.88	7.96	11.27	13.29	12.51	11.01	14.06
c	5.55	8.25	5.55	5.92	3.33	2.77	4.57	2.71
hy (en)	2.79	4.61	4.92	2.53	4.09	3.12	4.14	1.49
mt	0.15	0.15	0.38	3.28	1.53	2.00	1.28	2.82
il	0.69	0.35	0.56	0.77	0.46	0.61	1.03	1.05
ap	—	0.19	—	0.41	0.43	0.19	0.26	0.17
di	—	—	—	—	—	—	—	
Total	99.99	100.01	99.99	100.01	100.00	99.99	100.00	100.00

Chem. comp. (Wt %)	cont'd						
	48	49	50	51	52	53	54
SiO_2	72.71	70.60	72.29	72.03	71.68	70.45	70.56
Al_2O_3	15.27	16.40	15.00	15.30	15.05	15.70	14.79
Fe_2O_3	0.34	0.55	0.84	1.70	0.88	1.05	2.00
FeO	2.76	2.68	2.38	1.94	2.83	2.08	2.38
MgO	0.59	0.65	0.54	0.49	0.81	0.97	0.59
CaO	2.18	2.47	2.61	2.76	2.03	2.61	2.63
Na_2O	1.71	1.73	1.71	1.76	1.60	1.63	1.73
K_2O	3.25	3.75	3.25	2.75	3.75	3.85	3.85
H_2O^+	0.10	0.05	0.14	0.10	0.08	0.03	0.04
H_2O^-	0.32	0.40	0.22	0.30	0.28	0.30	0.21
TiO_2	0.39	0.31	0.40	0.44	0.53	0.44	0.53
P_2O_5	0.13	0.14	0.11	—	0.18	0.12	0.13
MnO	0.01	0.01	0.01	0.004	0.004	0.004	0.01
LOI	0.60	0.64	0.78	0.78	0.59	1.06	0.55
Total	100.36	100.38	100.28	100.354	100.294	100.294	100.00
CIPW Norm							
Q	43.54	38.79	42.81	44.34	41.61	38.95	39.08
or	19.33	22.32	19.37	16.38	22.31	23.00	22.93
ab	14.56	14.74	14.59	15.01	13.63	13.94	14.75
an	10.03	11.42	12.33	13.81	8.95	12.30	12.30
c	5.32	5.38	4.22	4.45	5.13	4.44	3.33
hy (en)	5.67	5.63	4.42	2.68	5.66	4.70	3.36
mt	0.50	0.80	1.23	2.48	1.28	1.54	2.92
il	0.75	0.59	0.76	0.84	1.01	0.84	1.01
ap	0.31	0.33	0.26	—	0.43	0.29	0.31
di	—	—	—	—	—	—	—
Total	100.01	100.00	99.99	99.99	100.01	100.00	99.99

complex. The increase in SiO_2 is in accordance with the change in rock types from monzonite-monzogranite to syenogranite.

K_2O/Na_2O ratios of the granitoids are generally higher than 1.0 with an average of 1.9; rocks from Menumbing and Tempilang show K_2O/Na_2O ratios of 1.86 and 1.9 respectively whereas Pelangas and Kelapa show an average of 2.0 and 1.8 respectively. The average percentage of K_2O and Na_2O of the granitoids is 3.3% and 1.7% respectively. Generally the rocks contain more modal K-feldspar than plagioclase.

The whole granitoid intrusive complex has large variations of CaO and MgO with MgO of 0.11–1.27% and CaO of 0.27–2.90%. Menumbing and Tempilang granitoids exhibit an average MgO of 0.4% and 0.2% respectively whereas granitoids from Pelangas and Kelapa contain higher MgO, 0.61% and 0.86% respectively. Similar trends are shown by CaO where the average CaO is 1.36% in Menumbing and 1.39% in Tempilang, both intrusive bodies have lower average CaO than Pelangas (2.25% CaO) and Kelapa granitoids (2.47% CaO). These differences are reflected in the presence of hornblende beside biotite in the rocks of Pelangas and Kelapa. From the chemical patterns of MgO and CaO, it is believed that the southern granitoid complex (Menumbing and Tempilang) represents later phase of magmatic differentiation. This

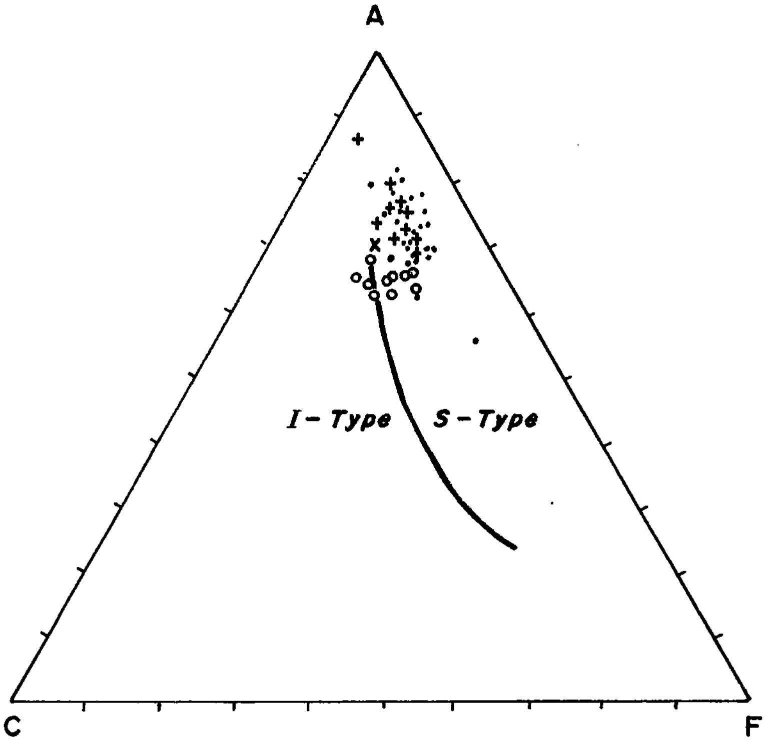

Fig. 4. ACF diagram of granitoids of Menumbing (●), Tempilang (+), Pelangas (o) and Kelapa (×).

is also in accordance with the increase of SiO_2 and progressive change of index of differentiation from 74 to 86 from the northern-toward the southern granitoid complex. The magma must have differentiated in the same direction, leading to highly evolved granitoids.

The alumina content of rocks from the whole intrusive complex varies between 12.0–16.75 and Al_2O_3 is higher than total alkali and lime. Thus the rocks show high normative corundum varying between 2.68–8.32%. Ternary plots of analysed granitoid samples in the ACF diagram (Fig. 4), show that nearly all of them fall in the field of S-type granitoid with a tendency to be concentrated close to the A-apex. Several granitoids from Pelangas seem to be of I-type and they are characterized by much lower normative corundum (2.71 to 5.38%).

Nearly all granitoids of the whole intrusive complex have an average Fe_2O_3/FeO ratio of 0.13. Magnetic susceptibility as determined by Kappameter KT-3 is very low, generally less than 35 × 10^{-6} emu/g. Most rocks exhibit magnetic susceptibility values ranging between 5–11 × 10^{-6} emu/g (Fig. 5). According to Ishihara *et al.* (1979) magnetite-series rocks show magnetic susceptibility values more than 100 × 10^{-6} emu/g whereas ilmenite-series ones have lower values. Thus the majority of granitoids in this investigation belong to ilmenite-series. From this study it has been found that the S-type granitoids correspond to ilmenite-series, although classification of the ilmenite-series/magnetite-series does not correspond exactly with the classification of I-type/S-type.

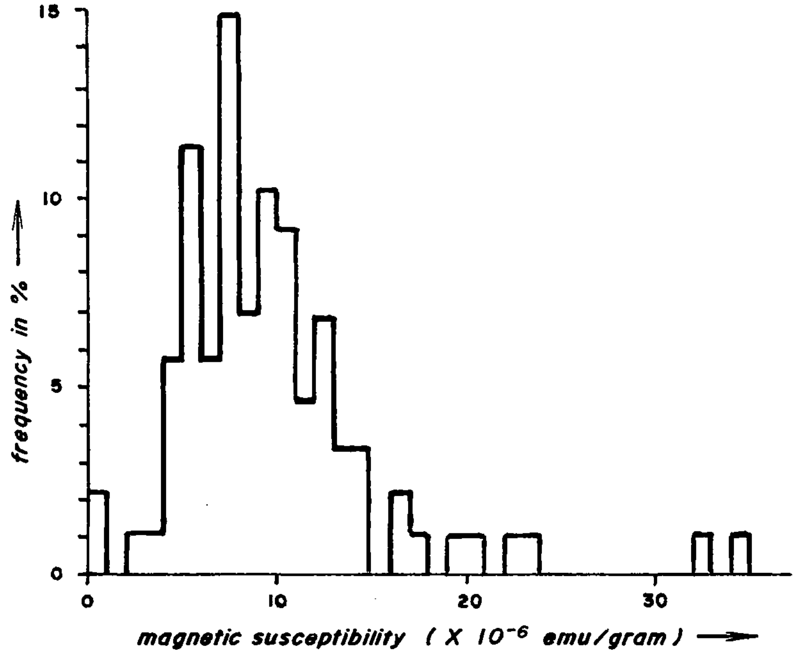

Fig. 5. Histogram of magnetic susceptibility of the whole granitoid complex.

Trace Elements

The granitoid samples have been analysed for Rb, Sr, Ba, Sn, W, Nb, Zr by using XRF, and for F by using selective ion electrode. The analyses were done by the Australian Mineral Development Laboratories in Australia. Generally, the average content of the trace elements are very similar to those of the Western Belt granitoids of Peninsular Malaysia. The notable differences are the higher average values of Sn, Nb and Zr and lower content of Ba than those of the Main Range (Table II). Comparing the analysed trace elements of each granitoid intrusive body in this study, one may notice similarities in the average contents of Rb, Sn and Nb of granitoids from Pelangas and Kelapa (northern granitoid complex) which are lower than those from Menumbing and Tempilang (southern granitoid complex). Sr and Ba contents of the former are much higher. Rb/Sr ratio of rocks from the southern granitoid complex are notably higher than those from the northern granitoid complex (Fig. 6). The relatively low Rb/Sr ratio of Kelapa and Pelangas granitoids suggest involvement of oceanic basement or thin sialic material, whereas higher Rb/Sr values of those from Menumbing and Tempilang strongly indicate a well established continental basement. Moving from the northern granitoid complex toward the southern granitoid complex,

TABLE II

AVERAGE OF TRACE-ELEMENT CONTENT (PPM)

	Rb/Sr	Rb	Sr	Zr	Ba	Sn	Nb	W	F	Number of samples
Intrusive complex	12.9	469	62	177	242	21	24	19	—	54
Menumbing	16.7	564	45	188	182	24	25	23	2851	31
Tempilang	13.5	378	53	129	139	19	25	10	1288	11
Pelangas	2.7	316	120	197	476	15	23	17	981	11
Kelapa	1.3	220	170	160	640	12	16	10	800	1
Main Range (Malaysia)	10.0	531	53	103	365	7.3	7.2	4.3	—	160

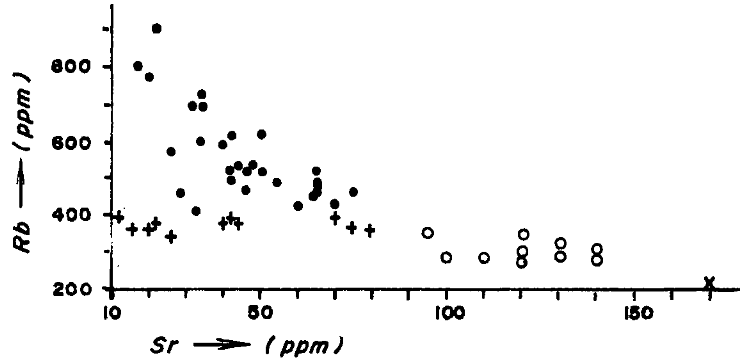

Fig. 6. Menumbing (•), Tempilang (+), Pelangas (o), Kelapa (×), Rb/Sr ratio in granitoids.

the increase of Rb/Sr ratio is accompanied with increase in Sn and F. The positive correlation between tin and fluorine is illustrated in Fig. 7. Fluorine is generally less than 1000 ppm in rocks from the northern granitoid complex whereas the southern granitoid complex has higher fluorine concentrations. In Peninsular Thailand the content of F has been successfully used to distinguish "tin-barren" granite from "tin-bearing" granite (Ishihara *et al.*, 1980).

OPHIOLITE ROCK ASSEMBLAGE

According to Hutchison (1973, 1975) the Malay Peninsula was located along subducting contact between oceanic plate in the east and continental plate in the west in Early Palaeozoic time. The trench occupied the eastern foothills of the Main Range, and is marked by serpentinite, pyroxenite, diabase and basaltic lava flows. These small

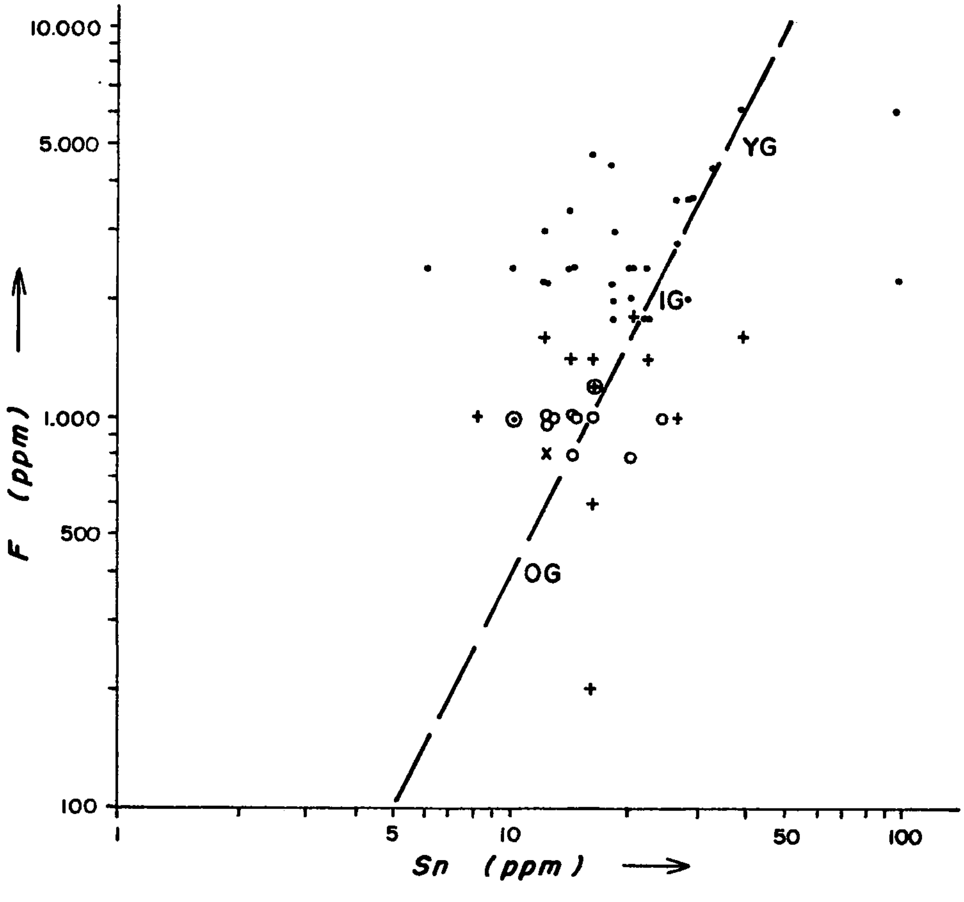

Fig. 7. Tin and fluorine variation of the analysed granitoids of Menumbing (●), Tempilang (+), Pelangas (o), Kelapa (×). Straight line is the general trend of Variscan granites (Tischendorf, 1977); OG, "normal granite", IG, precursor of YG, YG, "tin granite!".

outcrops fall roughly along an NNW-SSE trending line which has been called Bentong-Raub suture by Hutchison (1977). The northward extension of this Bentong-Raub ophiolite line is represented by the Thai ophiolite belt which is marked by basic to ultrabasic plutonic rocks (Panjasawatwong *et al.*, 1983).

The present investigation strongly suggests possible extension of the Bentong-Raub line southwards into Bangka and perhaps also Belitung. Indications of opholite rock assemblage in Bangka have been reported from many places. Xenoliths of basalt and diabase of various shapes and dimensions are known to occur in many granitoid outcrops such as in the areas of Menumbing, Tempilang as well as in the Klabat granitoid complex in northern Bangka. At the northwestern corner of the Klabat Complex a large outcrop of diabase is intruded by the granitoid and exhibits effects of thermal metamorphism of presumably hornblende-hornfels facies. Core drilling in the eastern part of Klabat granitoid in the area surrounding Sungailiat and Pemali show fragments of serpentinite and pyroxenite. According to Suryono & Clarke (1982) over 100 m of serpentinite had been cored in an exploratory drilling in the area of Pemali mine. A small outcrop of foliated serpentinite is also known in the Belinyu area adjacent to a primary tin mine within the Klabat granitoid. All these features strongly suggest dismembered ophiolitic rock assemblage which has been interpreted by the present authors to represent a former subduction zone.

STRUCTURE AND TIN MINERALIZATION

The main structural features in the investigated area are joints, folds and faults. Folds are well developed in metasediments, while joints occur in both granitoid and country rock. Folds which have been measured in metasediments in the area surrounding Tempilang and Menumbing exhibit three different directions of fold axes, these are NE-SW, NW-SE and almost E-W (Fig. 8). The first two directions are likely related to Palaeozoic and Late Triassic folding respectively as was noted previously by Kahr (unpublished report) and Katili (1968). The east-west trending fold-axis represents the result of younger deformation (possibly Cretaceous).

Exposures of primary tin mineralization are known in several localities in the granitoid body as well as in the surrounding metasediments. The latter are often exposed as the result of alluvial tin mining activities. In the present area of investigation tin mineralization has been observed generally along fractures particularly following fringes of granitoid intrusions close to the contacts and in the adjacent metasediments such as in the northern contact zone of Tempilang granitoid and along the southern and eastern margins of Menumbing granitoid. Along these fractures cassiterite mineralization is often associated with black tourmaline, topaz, quartz, muscovite and biotite. Some of the fractures are occupied by greisen and late phase igneous injections.

Fractures which have been measured in the field exhibit the following trends: (1) in the Menumbing area, the most mineralized fractures are trending WNW-ESE and almost N-S in granitoid outcrops; at Tempilang, the most important trends of tin mineralization are WNW-ESE and NNE-SSW fracture directions in both the metasediments and granitoid. They are most likely related to Late Triassic deformation; (2) at several places, tin mineralization of minor importance were found

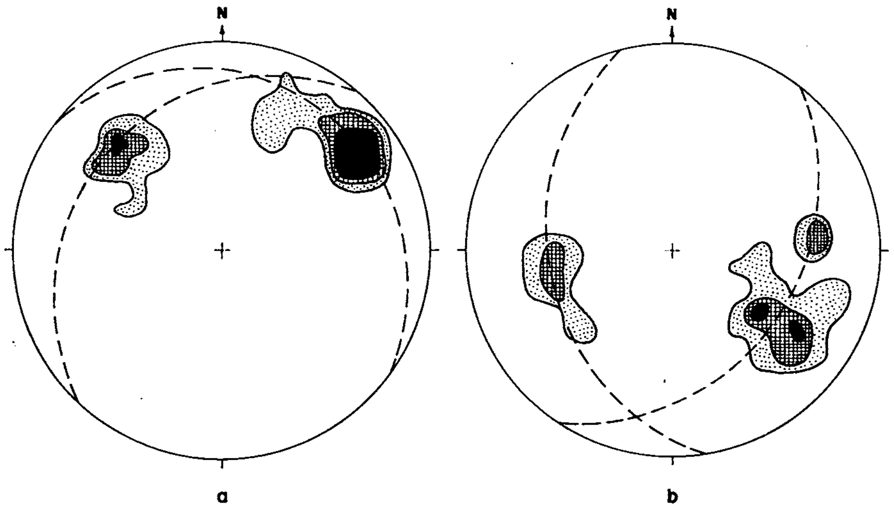

Fig. 8. Contour diagrams of fold axis in metasediments. a. Tempilang (30 measurements); b. Menumbing (20 measurements).

along NNW-SSE and ENE-WSW trending fractures which agree with post-Triassic deformation. The latter often caused lateral displacement of earlier veins along NNW and NNE shear directions. However, it is thought that the main tin mineralization is closely related to Late Triassic fracture pattern.

SUMMARY AND DISCUSSION

Petrographic studies have revealed that granitoids from Pelangas and Kelapa (northern granitoid complex) are very similar in texture and mineralogy, but they differ from Menumbing and Tempilang granitoids (southern granitoid complex). The former is dominantly monzonitic to monzogranitic in composition and contain green hornblende beside brown biotite while reddish colored biotite is relatively rare, sometimes replacing the former. K-feldspar and quartz exhibit poikilitic inclusions of plagioclase and mafic minerals. K-feldspar is represented by very fine exsolution microperthitic intergrowth. The southern granitoid complex is made up chiefly of syenogranites containing more reddish brown biotite while hornblende is lacking. They are marked by the abundance of micrographic and granophyric textures, myrmekite, and albitization. K-feldspar consists of replacement microperthite and bears witness of albitization. Very characteristic is the common presence of fluorite, tourmaline, topaz, cassiterite and secondary muscovite and biotite. The rocks are most affected by late- or post-magmatic reactions.

From north to south in the granitoid complex the following chemical changes have been observed:

(1) decrease in CaO, MgO and Ba contents,

(2) decrease of crystallization index from C.I = 9–14 to C.I = 4–9 and increase of differentiation index from D.I = 74–77.5 to D.I = 78–86,

(3) increase of SiO_2, Rb/Sr, Sn and F. A large part of the granitoid in the investigated area displays a range of normative corundum mostly between 4.4–7.8% which supports the view that they were formed by anatexis of continental sialic basement as it is also suggested by high $^{87}Sr/^{86}Sr$ ratios (Priem *et al.*, 1975). These rocks are very similar to the other anatectic granitoid in Southeast Asia such as Main Range batholith in Malaysia (Hutchison, 1977), Khuntan batholith in Thailand (Suensilpong *et al.*, 1977) and batholiths in South China (Tu *et al.*, 1980).

The granitoids in the present study have characteristics of a high-level intrusion. The presence of a hornfels thermal aureole in some places and the abundance of incorporated country rocks implies that the granitoids were emplaced at near-surface environments. The initial magma has evolved from crystallization index of 14 toward granitic rocks of crystallization index about 4. The latter are represented by the southern direction. Presumably, released gas and fluid phase from solidifying magma were accumulated in the highest part of the intrusive bodies (southern granitoid complex) and precipitated there among others are fluorite, topaz, tourmaline and cassiterite. It is clearly illustrated in the Sn-F diagram (Fig. 7 and in Table II) that Menumbing granitoids have the highest F and Sn concentrations especially those from the southeastern part (Kukus area). These rocks plot near YG and IG whereas, those from the northern granitoid complex plot between IG and OG. Menumbing and Tempilang granitoid seem to represent shallow phase rocks containing much higher Sn and F, and are presumably source rocks for primary tin mineralization and alluvial tin deposits. The major trends of primary tin mineralization are NNE-SSW, N-S and WNW-ESE.

From the present study the authors strongly feel that the Bentong-Raub suture of Malaysia (Hutchison, 1977) can be extended southwards into the Indonesian tin islands, perhaps also through Belitung, along which remnants of mafic and ultramafic rocks exist. Hutchison (1982) presented a model of evolution of the Malay Peninsula. A westward subduction of an oceanic plate in the east during Carboniferous, was followed by the development of a marginal basin by back-arc rifting during Permian. This led to the flipping of the subduction zone eastward across the marginal basin. Later collision of this eastward subducting plates with continental plate cause the formation of granitoids by anatexis. These events resulted in the development of paired subduction-related volcano-plutonic arc (Andean type) and collision-related arc (Hercynian type). Both arcs are represented in the Malay Peninsula by the Eastern Belt and the Main Range respectively. We are inclined to believe that Bangka belongs to the Main Range and that the granitoids are a collision-related batholith system. The S-type ilmenite series granitoid, absence of volcanic sediment association and similarities in trace-element contents of the studied granitoid seem to support this view.

ACKNOWLEDGEMENT

We are grateful to the Management of P.T. Tambang Timah, especially Mr. Sutedjo Suyitno, Head of Exploration Division in Jakarta for their permission to release the new data collected. We also acknowledge the assistance of staff members of the Exploration Division in Bangka who facilitated our work. Thanks are also due to Professor Sukendar Asikin for the valuable discussions.

REFERENCES

HOSKING, K.F.G., 1973. The primary tin mineralization patterns of West Malaysia, *GEOSEA I. Proceedings, Bull. Geol. Soc. Malaysia,* vol. 6, p. 297–308.

HOSKING, K.F.G., 1977. Known relationships between the hard-rock tin deposits and the granites of Southeast Asia. *Bull. Geol. Soc. of Malaysia,* No. 9, p. 141–157.

HUTCHISON, C.S., 1973. Tectonic evolution of Sundaland: A phanerozoic synthesis, *GEOSEA I. Proceedings, Bull. Geol. Soc. Malaysia,* vol. 6, p. 61–86.

HUTCHISON, C.S., 1975. Ophiolite in Southeast Asia. *Bull Geol. Soc. America,* p. 797–806.

HUTCHISON, C.S., 1977. Granite emplacement and tectonic subdivision of Peninsular Malaysia. *Bull. Geol. Soc. of Malaysia,* No. 9, p. 187–207.

HUTCHISON, C.S., 1982. The various granitoid series and their relationship to W and Sn mineralization. *In* J.V. Hepworth & Yu Hong Zhang (Eds.) *Tungsten Geology,* Jiangxi, China, p. 87–114.

ISHIHARA, S., SAWATA, H., ARPORNSUWAN, S., BUSARACOME, P. and BUNGBRAKEARTI, N., 1979. The magnetite-series and ilmenite-series granitoids and their bearing on tin mineralization, particularly of the Malay Peninsula region. *Bull. Geol. Soc. of Malaysia,* No. 11, p. 103–110.

ISHIHARA, S., SAWATA, H., SHIBATA, K., TERASHIMA, S., ARRYKUL, S. and SATO, K., 1980. Granites and Sn-W deposits of Peninsular Thailand. *Mining Geology Spec. Issue,* No. 8, p. 223–241.

KATILI, J.A., 1968. Cross-folding in Bangka, West Indonesia. *Contrib. Geol. Report ITB,* No. 68, p. 61–70.

KUMAR, S.C., 1981. Gabbroic rocks from the Southern Malay Peninsula and their relation to similar rocks of other orogenic zones. *Bull. Geol. Soc. of Malaysia,* No. 14, p. 75–100.

PANJASAWATWONG, Y and YAOWANOIYOTHIN, W., 1983. Igneous rocks of Thailand: A review of plutonic rocks with intermediate-ultrabasic compositions and volcanic rocks. *Proceedings of the Workshop on Stratigraphic Correlation of Thailand and Malaysia,* volume I, Technical papers, p. 233–243.

PONGSAPICH, W., PISUTHA-ARNOND, V. and CHARUSIRI, P., 1983. Reviews of felsic plutonic rocks of Thailand. *Proceedings of the Workshop on Stratigraphic Correlation of Thailand and Malaysia,* Volume I, Techical Papers, p. 213–232.

PRIEM, H.N.A., BOELRIJK, N.A.I.M., BON, E.H., HEBEDA, E.H., VERDURMEN, E.A. Th., and VERSCHURE, R.H., 1975. Isotope geochronology in the Indonesian tin belt. *Geol. & Minjbouw,* 54, p. 61–70.

SUENSILPONG, S., A. MEESOOK, S. NAKAPADUNGRAT and P. PUTTAPIBAN, 1977. The granitic rocks and mineralization at the Khuntan Batholith, Lempang. *Bull. Geol. Soc. of Malaysia,* No. 9, p. 159–173.

SURJONO and CLARKE, M.C.G., 1982. Primary tungsten occurrences in Sumatra and Indonesian tin islands. *In* J.V. Hepworth & Yu Hong Zhang (Eds.) *Tungsten Geology,* Jiangxi, China, p. 217–231.

TISCHENDORF, G., 1977. Geochemical and petrographic characteristics of silicic magmatic rocks associated with rare-element mineralization. *Metallization associated with acid magmatism* 2. Geol. Surv. Prague, 41–96

TU, K.C., WANG, Z.G. and YU, X.Y., 1980. Genesis of granitic rocks in South China and related mineralization. *Mining Geology Spec. Issue,* No. 8, p. 189–196.

Manuscript received 23rd August 1984.