CHAPTER IX

TIN MINERALIZATION

Phuket Island is the birth-place of tin mining and of dredging in Thailand (Buravas in Brown, et al., 1951; Jones, 1925). As reported by Garson and others (1975), Phuket was annually producing tin concentrates much more than any province in Thailand from 1961 to 1970. They also noted that the central mining part of the island, i.e. the present-studied area, has certainly been the richest on-land producing area for its size. It can be compared with the Kinta Valley in Malaysia, the most important tin-producing district in the World (Taylor & Huchinson, 1978), in its contribution to the average of the total annual tonnage of tin mined in Thailand. In addition to this, Tantitamsophon (1980, per. com.) suggested that more than sixty five percent of tin concentrated produced in Phuket annually come from this studied area. Data from the mining district of Phuket in 1980 reveals that from a total of 56 mines in Phuket Island, approximately sixty percent of mines have been operated in the area. Table 8 shows the production of tin in concentrated (in metric tons) in Phuket from 1971-1976 (Mineral Statistics, DMR, 1976). The distribution of tin mines and mining leases is shown in Map 4. Tin mining processes in Phuket are gravel-pump mines, hydraulic mines, and both on-land and sea dredgings. There are also some productions of tin by panning methods (dulang washing) by local Phuket people.

Table 8. Production of some ores in concentrated

(in metric tons) in Phuket.

ores	1971	1972	1973	1974	1975	1976
tungsten	17	18	7	6	4	-
monazite	36	-	-	-	-	-
zircon	1,000	62	200	206	61	-
tantalite	-	7	1	6	31	4
tin	6,458	6,596	6,144	5,645	5,804	4,645
total Thailand tin production	26,609	30,132	28,561	27,767	22,397	27,921

There has been small but intermittent recoveries of other economic minerals (as shown in Table 8). Tungsten minerals, mainly wolframite, has seldom exceeded 5 metric tons per year and has been derived mostly from the mines around the Kathu Valley, especially at Tor Soong Mine. Monazite, once recoveried in 1971 about 36 metric tons, is mostly from Chao Fa Mine. Zircon and tantalite have been dressed and recoveried more than 50 and 5 tons, respectively, each year.

9.1 Types of Tin Deposits

The occurrence and classification of tin deposits has been previously summarized by a number of geologists (Hosking, 1965; Itsikson, 1967; Sainsbury, 1969, Stemprok, 1970). Schuling (1967) demonstrated the correlation between the frequency of the different types of tin deposits and ages. Hosking (1973) noted several types of primary tin deposits in

Malaysia and demonstrated that different types of tin mineralization might be related to different ages of granites. Most recently, Mulligan (1974) has suggested nine types of tin deposits may be recognized, these are listed and examples of each are given below.

1) Magmatic disseminations : Zaiplaats, S.Africa (Hunter & Lenthall, 1971); Hadd Sompan type, Thailand (Aranyakanon, 1961).

2) Pegmatites : Manona, Congo (Sainsbury and Hamilton, 1967); Central and West Africa (Varlamoff, 1972).

3) Metasomatic and Skarn deposits : Devonshire, England (Sharkawi & Dearman, 1966); Pin Yok, Thailand (Hosking, 1969).

4) Pneumato lytic-hydrothermal : Ergebirge, German Democratic Republic (Janeeka & Stemprok, 1967); Gyoja, Japan (Traub & Moh, 1978).

5) Subvolcanics : Bolivia (Ahlfed, 1967; Turneure, 1971; Sillitoe et al., 1975).

6) Fumaroles : Mexicc (Sainsbury & Hamilton, 1967; Ypma & Simon, 1969).

7) Massive sulfide deposits : Bleikvassli, Norway (Vokes, 1963); NW Tasmania, Australia (Newnham, 1975).

8) Metamorphosed fossil placer : Isergebirge (Jaskolski, 1963).

9) Placer deposits : Symetian, Congo (Anthoine et al., 1967).

In the area under study, at least four major types of tin-deposits based on this classification are encountered, i.e., magmatic disseminated, pagmatite, pneumatolytic-hydrothermal, and placer deposits.

9.1.1 Magmatic Disseminations

It is unfortunate that the tin mineral has not been found in the granitic rocks from this area though the biotite-muscovite granites of various types, as mentioned in the previous section, have a tendency to become tin-bearing granite. However Garson and others (1975), found cassiterite occurs as disseminated small grains mostly in biotite-muscovite granites in this area. The grade of cassiterite-rich granites is uneven and uncertain without detailed investigation; a very rough estimate is that the worked patches contain about 0.05 up to 0.5 percent cassiterite (Garson, et al., op. cit.). Yttrotatalite & ilmenorutile (Garson, et al., op. cit.), monazite (Gocht, et al., 1975), and ilmenite are important associated minerals.

According to Pitakpaiwan (1969), the denudation of granite mountains due to surface processes might accumulate cassiterite into placers. Probably in some areas, north of Phuket town, the cassiterite which is also found along the stream channel passing through Phuket Town possibly come from Khao Rang and Khao To Sae. In the valley between Khao Samkong-Panthu Rat and Khao Sapam, numerous mines (as shown in Map 4) have been operated in placers suggesting that the cassiterite there tends to be derived from tin-bearing granites around this valley.

9.1.2 Pegmatite and Granitic Stockworks

It is also noted that most of the cassiterite worked in the alluvial deposits or related ones was derived originally from the erosion of zones of stockwork at the margin of G-1 (see Map 3). These exocontact zones extend upto one kilometers from the igneous contact, and intrude in the hornfelsed rocks resulting a network of narrow veins, dykes and sheet of quartz, aplite, pegmatite, and fine-grained muscovite granite. At several of the most productive tin mines in the Ban Kathu Valley, the floors of the mines consist of weathered stockwork of this type of material now being worked below the level of the tin-rich alluvial sediments. The hornfels itself contains virtually no cassiterite although tourmalene may be present, while the invading plexus of veins and dykes, only trending in NNE to NE direction, are often rich in grains and sometimes lumps of cassiterite varying in sizes from fraction of a millimeter up to 3 cm. At Tor Soong Mine, the cassiterite forms yellowish brown patches up to 15 mm. across, however much of the cassiterite is in dark-grey subhedral to euhedral grains closely associated with tourmalene. Columbite, tantalite, wolframite, monazite, and some zircons are found as important heavy minerals (Gocht & Pluhar, 1979).

Out of six classified pegmatites in this study, at least 4 types are the cassiterite-bearing pegmatites, they are :

(1) Tourmalene-muscovite pegmatites (at Tor Soong Mine, Chao Fa Mine).

(2) Lepidolite-rich pegmatites (at Ban Nguan and Chao Fa Mine).

(3) Quartzo-feldspathic pegmatites (at Tor Soong Mine).

(4) Muscovite pegmatite (at Pin Yoe Mine).

The details of these tin-mineralized pegmatites have been previously mentioned in Section 4.4.

9.1.3 Pneumatolytic-hydrothermal Deposits

Cassiterite also occurs in greisen muscovite-rich granite and dykes or pneumatolytic-hydrothermal deposit. The most common type area is at Sahakit Mine, Khao Kao, southwestern slope of Khao Sapam. Cassiterite is found disseminated throughout the greisen granites and aplites. It varies from yellowish tint to dark brownish subhedral grains ranging in sizes from 0.1 cm in granites up to more than 0.5 cm in aplite. Accessories are tantalite & columbite (Garson, et al., 1975); and monazite & zircon (Gocht, et al., 1978). According to Gocht and others (op. cit.), tin content in zircon was analyzed as high as 10,000 ppm and tin in monazite was up to 90 ppm. The minor pheumatolytic-hydrothermal deposits are at southern slope of Khao To Sae, and south and northeast of Khao Panthu Rat.

In general, the rock is fine-to medium-grained muscovite-rich granite with small amount of tourmalene and trace biotite. The rock is highly friable due to the kaolinite formation. The aplites and some pegmatites intrude along the NNE fracture zones of granite and is rather hard with relative to the granite host. Its mineral compositions are quartz, feldspar, muscovite, and tourmalene, with cassiterite and wolframite (?) as trace amount.

9.1.4 Placer Deposits

Virtually all the tin currently produced in the area and its adjacent comes from secondary (placer) deposits, that is, those derived from primary sources in bedrocks and incorporated in the detrital deposits. The present form of these deposits depends upon the surface processes involved. As Gobett & Hutchinson (1972) found such cases in Malaysia, secondary deposits have taken place since Pleistocene Age.

The deposits are those of the colluviums and alluviums. The examples are Sappayakorn Mine and Sapnaidee Mine of colluvial type, and Utai Mine and Keng Nguan Mine of alluvial type.

Nearly all the tin placers lie along well-defined, buried channels which are strongly manifested by composite concession records and can be traced headward to modern streams (Map 4). They are from a few inches to several feet thick and are composed of moderately to well-rounded, light-coloured gravel, with varying amounts of white vein quartz, some highly angular to subrounded. Cassiterite occurs throughout the placers but mostly concentrate near the base or on bedrocks. Wolframite is a minor constituent of the placers as well, however, it is more abundant along the heads of modern stream (Hummel & Phawandon, 1976).

Cassiterite in the alluvial mines occurs in the coarse gravelly basal layers (pay derts) as previously discussed, but in several mines, bedrocks of weathered cassiterite-rich granite, pegmatite, and stretches of weathered cassiterite-rich stockwork of quartz, aplite, and pegmatite veins have been excavated by hydraulicking.

9.2 Relationship between Tin-mineralization and Granites

The greisen granites and muscovite-biotite varieties have tendency to become tin-bearing granites rather than the other types of granites.

This is quite consistent with those found by Suensilpong (1977), where tin-related granites are generally fine-to medium-grained granites typically with biotite and muscovite and sometimes with tourmaline. They are often referred to as leucogranite (Aranyakanon, 1961; Teggin, 1975). These types of granites probably correspond to tin-bearing granites of Pitakpaiwan (1969).

All types of the granites of Phuket-Plutons have more or less undergone, to some extent, fractionated differentiation. It has also been known that within the welknown tin granite belt, not all varieties of granites (though fractionation may be invoived) have tendency to bear tin mineralization, as previously reported by Hosking (1967), Pitakpaiwan (1969), or recently discussed by Sheraton & Labonne (1978), Taylor (1979). As shown in Map 4, most mining lease areas can be overlain upon the greissen granites and the G-4 type granite, particularly at Khao Rang and Khao To Sae. However, within the areas covered by sedimentary rocks of Phuket Group, tin deposits are concentrated around the exocontact zone (i.e., pegmatites). The map also shows that the east side of the area are more abundant in tin-deposits in ralation to the west side. Based on the tin distribution as shown in the map together with the geochemical result, it is possible therefore to make a tentative suggestion, that the highly potassic, biotite-muscovite unfoliated leucocratic granites is the most important phase of rock with regard to tin mineralization. This geological develop development is quite similar to and comparable with some, though not all, of the other countries, for instances, Burma (Muang Thein, 1973), Malaysia (Taylor & Hutchison 1978), India (Mitchell & Garson, 1976). This phenominon is also in good agreement with the evidence found in Alaska, where Sainbury and others (1969) also quoted that most tin deposits are associated with potassium-rich unfoliated biotite-muscovite granites of Late-Cretaceous or Early-Tertiary ages.

9.3 Model for tin-granites and Mineralization

The model for tin-bearing granites and mineralization which is introduced by Groves & McCarthy (1978) for the Blue Tier Batholith, Australia and the Bushveld Complex, S. Africa, is one of the most recently reliable systems. This model postulates fractional crystallization and differentiation through removal of crystals from the system. They calculated the partitioning of Ba, Rb and Sr between the crystals and melts to develop the model for crystallization of tin-bearing granites and tin mineralization, as protrayed graphically in Figure 36. However they did not state the exact source of magma or melt. The application of this model to the delineation of the whole development, leading to the tin mineralization of the Phuket Plutons is still doubtful. This is probably due to the difference in geological evolution. However, it may be applied to certain types of granites in the other regions.

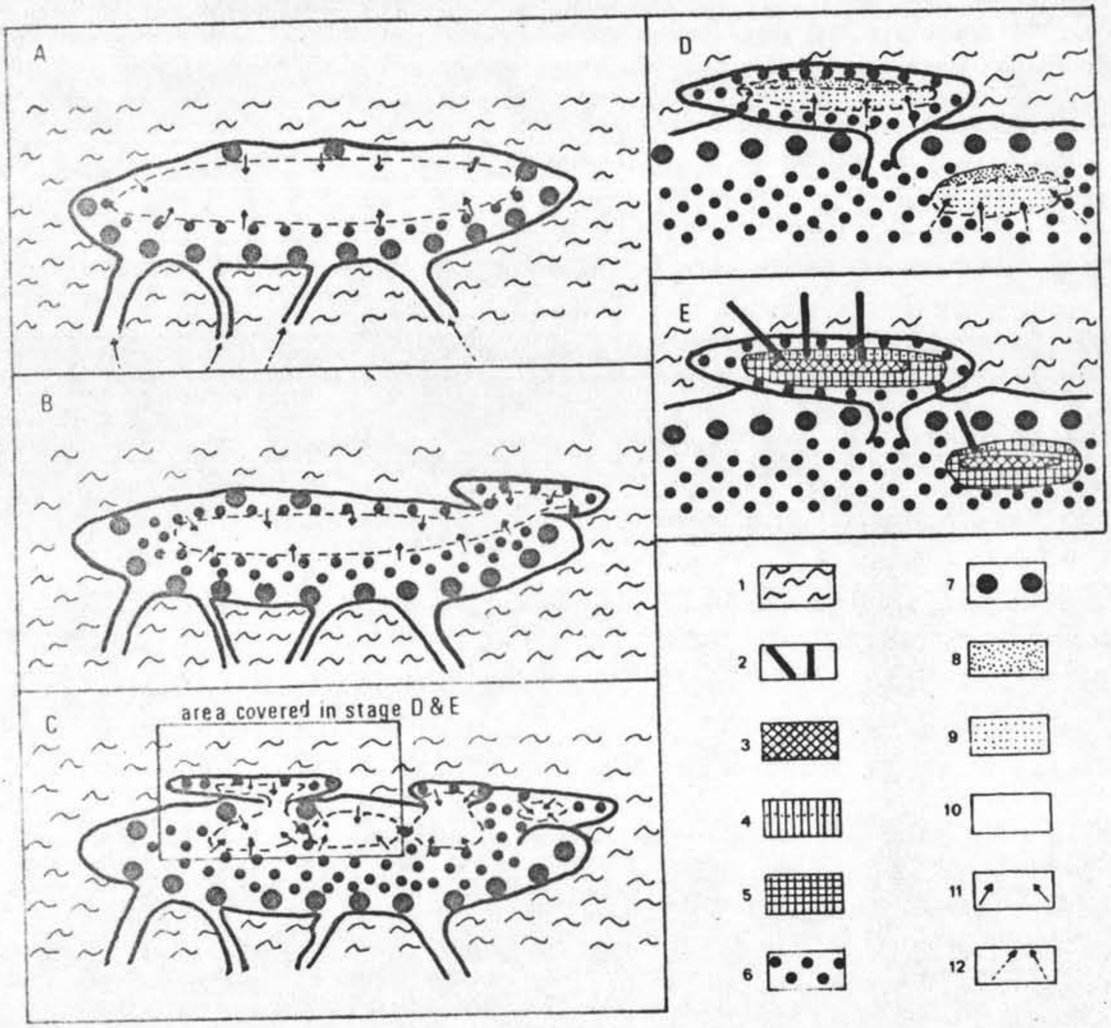

FIGURE 36. Model for tin mineralization (after Groves and McCarthy, 1978).

[Explanation overleaf]

Explanation for Figure 36

A. Intial crystallization of hornblende-biotite granite

B. Continued crystallization of magma, disruption of hornblende-free granite (Biotite granite)

C. Further disruption of early crystals during continuing crystatllization

D. Continuing crystallization with melt achieving water saturation, separation of a tin-poor vapour (tin-barren pegmatites)

E. Water saturated melt crystallizes muscovite-bearing granite, Sn, F and B rich vapour in late state crystallization, greisenization beneath roof zone.

1. country rocks
2. Tin mineralization in late fractures
3. Greisenized granite
4. tin-barren pegmatites
5. Muscovite-bearing granite
6. Biotite-granite
7. Hornblende-biotite granite
8. Tin-poor vapour
9. Water-saturated melt
10. Water-under saturated melt
11. Direction of crystallization
12. Intrusion of granitic magma

According to McCarthy & Hasty (1976) the early crystallization mode starting with a melt of initially water-undersaturated granitic composition introducing into the high structural level (Figure 36a) causing the crystallization of hornblende-biotite granites and adamellites. This type of granites should has a low concentration of Rb but high concentrations of Ba and Sr. The granites and adamellites of Phuket Plutons confirm such stage of granite emplacement and such elemental concentration in the hornblende-biotite granites is reported by Garson and others (1975, p. 32). The hornblende-biotite granites also occur in several parts of Phuket Islands (outside the study area), e.g., at Khao Prathiu, Ban Karon, NW of Laem Ka, and at the southern tip of the Island (Garson, et al., 1975). The rest magma is continually fractionated and disrupting subsequent culminates forming the hornblende-free body, mostly of biotite granites (Figure 36B). The rock type can be characterized by the more abundances of Rb and more depletion of Sr and Ba. The G-1 and G-2 granites of Phuket Plutons are the examples. Further disruption of early crystallizates during continuing crystallization is shown in Figure 36c. Probably, G-3 can occur in this stage. Fractional crystallization ultimately produces a water-saturated melt which invariably is located toward the roof zone of the intrusive and probably assimilated with the country rocks (Figure 36 d). While crystallization continue on the floor, vapour-bubbles collected in structural high points under the roof. At this late stage of crystallization, quenching of rest melt occurs, producing aplites, and the vapour solidified as tin-barren pegmatites, and at the final stage muscovite-bearing granites will be formed. Should there is no confirmed evidence, the G-4 and G-5 can be delineated McCarthy and Hasty's idea. However, Suensilpong & Putthapiban (1979) indicated that the hornblende-sphene bearing granites and biotite-rich granites at Phuket Island has been affected by an intense tectonic activity prior to the formation of the biotite-muscovite granites, resulted in the formation of lineation in the granites, striking in NW-SE direction. In addition, Pluhar (1979) reported from the heavy mineral investigation that there is a genetic difference in zircon found in the two major types of granites in Phuket Island, i.e. there is one generation of zircon found in the hornblende-biotite granites while the biotite-muscovite granites carry two generations of zircon, and both are not compatible with the sole generation found in the hornblende-biotite granite. He further suggested that the two major types of granites have different source. Garson, et al., (1975) quoted the Rb/Sr age of the hornblende-bearing granites as 124 Ma and a 56 Ma for the two-mica granites.

Based on various reasons as mentioned above it is conceivable that the G-1, G-2 and G-4, G-5 belong to different magmatic episodes and McCarthy & Hasty's model is not applicable in this case.

9.4 Source of Tin Metal and Its Relation to Plate-tectonic Reconstruction

The question of the ultimate source of tin metals has been the subject of considerable discussion, and the answer is quite controversial. According to Beus (1976) in his gravitation-induced model of mantle-lithosphere evolution, Si, K having large ionic radii are continually transported from mantle. These elements are finally accumated in the crust either by solution-carrying or by degassing due to the release of exothemic reaction from thermodynamic disequilibrium while these elements enrich in the upper mantle. This transmagmatic mantle-derived solution is not only charged with Si and K but also Sn and related elements (W, Ta, Mo, etc.) in the complex form with oxygen. Hence it enables to suggest that mantle is probably the primary source of tin. Tin has been transported to the crust and progressively enriched in it through a process of lithospheric evolution.

The finer-granied biotite-muscovite granite (G-4, G-5) and probably the coarser-grained variety (G-3) of Phuket Plutons were possibly derived by anatexis of sialic crustal rocks. Granitic generation associated with the subduction zone is considered to be the most likely mechanism in this context. The formation of tin and other metal deposits in relation to subduction zones has been recently discussed by several authors (Mitchell & Garson, 1972; Guild, 1972; Saukins, 1972; Silitoe, 1972, Wright & McCurry, 1973, Suensilpong, 1977a, Asnachinda, 1978a, Taylor, 1979). Mitchell (1973) has related the type of mineral deposits to an angle of dipping plate of the Benioff zone. Tin-Tungsten-Fluorite deposits were considered to have been emplaced by gently dipping Benioff zones and porphyry copper deposits above steeply dipping zones. Noble (1974) in his investigation of the distribution of metal provinces in the Western USA considered the role of igneous intrusion in mineraliz ation to be one of structural control rather than source of ore metals, same conclusion of fracture controls was made also in NE Queensland tin field by Black and others (1978).

The important of source-rock composition in the formation of tin-bearing granites has been emphasized by Flinter (1971), Hesp (1971), Suensilpong (1977b) and Muang Thein (1973). Wright & McCurry (1973) proposed that 'geochemical cumulations may exist in the deep curst or upper mantle'. The support for this statement is the development of tin deposits in Nigeria derived from mantle and lower crust (Bowden, 1979). Schuling (1967) has argued that the restriction of the economic tin deposits of the earth to well defined 'tin provinces' indicates an inhomogeneous distribution of the metal in the crust. As ages of mineralization vary within tin belts (Hosking, 1973), it was suggested that the main source of tin must be within the crust. Mitchell (1973) has concluded that since there is no obvious sorce of tin in either the downgoing oceanic crust or in the overlying mantle, a crustal source is probable for this. It would be more difficult to explain the tin distribution in continents if the metal is assumed to originate in the mantle, however it is not possible to entirely rule out mantle-derived source. Data on the Sn contents of possible source materials, such as oceanic crust sediments, are, at present, inadequate for the probability of such an origin to be accessed (Sheraton & Labonne, 1978). Volatiles, such as fluorine, probably expelled from subducted oceanic crust, would be instrumental in the tin-transportation into the upper crust (Mitchell & Garson, 1972).

According to Schuling (1967), the existence of anomalously high Sn content in the crust is needed, in order to explain the presence of tin-bearing granites of the Phuket Plutons. Such a concept would also explain the high Sn contents of granites associated with tin mineralization such as Khuntan Granites, Samoeng Granites, etc. which are contary to some other granites, for instance Tak Granites (Pongsapich & Mahawat, 1977) with which no tin deposits are associated. It is quite possible that a combination of factors, including tin-rich source rocks (Sheraton & Labonne, 1978; Suensilpong, 1977b), well-advanced magmatic differentiation (Groves & McCarthy, 1978, Taylor, 1979) and the presence of volatiles (Tischendorf, 1977; Stemprok, 1979) are necessary if economic tin deposits are to be formed.

In view of the fact that Phuket island lies in the tin belt of SE Asia. The tin mineralization of Phuket and SE Asia (the richest tin resources in the world, Mitchell, 1976) may be explained by plate-tectonic model in term of regional reconstruction. The SE Asia tin-mineralization caused by plate-collisions has been postulated most recently by Teggin (1975), Mitchell (1977), Suensilpong (1977a), Asnachinda (1978a), Suensilpong & Puttapiban (1979) and Beckinsale, et al., (1979). According to beckinsale (1979), and Beckinsale, et al. (1979) the geochronological and geochemical data of Thai granites is in general accord with the plate-tectonic reconstruction proposed by Mitchell (1977). They suggested in line with the proposal made by Mitchell that the east-dipping subduction in the late Permian could account for the Permo-Triassic arc, resulted in the formation of the porphyry copper deposits at Loei. The ages of these granites are 235-240 Ma (Braun, et al., 1976). The suture zone representing the closure of the oceanic or marginal basin in the Triassic is probably located in the possible occurrences in the Uttaradit-Nan area.

(Thanasuthipitak, 1978). The marginal basin closed with a continental collision in Triassic times (about 210-220 Ma) gives the Central Belt of Predominantly S-types granites forming the main tin belt in Thailand (not including Phuket), which may be correlated along strike with the Main Range granite in Malaysia.

Mitchell's idea of east-dipping subduction in Permian ages has been argued by many geoscientists who have support of field evidences, for instance, Asnachinda (1978a) and Suensilpong & Putthapiban (1979). They proposed the idea of west-dipping subduction during late Triassic times. The tectonic reconstruction as cited by Suensilpong & Putthapiban (1979) is based upon the distribution of plutonic and volcanic rocks, and the zone of ophiotite. The Triassic granites whose isotopic ages are in the range of 200 ± 10 Ma are the results of this subduction. The feature of tectonic setting comprising a west-dipping subduction took place in the central part of Northern Thailand (Asnachinda, 1978a) and in Malaysia (Hutchison, 1973) until lower Jurassic (Suensilpong & Putthapiban, 1979) or late Triassic (Asnachinda, 1978a). After these ages, the collision of plates turned to become east to northeast dipping. In Cretaceous times (about 120-130 Ma) I-type granites without tin-mineraliz ation were emplaced in West Thailand at Mae Lama (Beckinsale, 1979) and Phuket Island (Suensilpong & Putthapiban, 1979). These Cretaceous granites are the results of another tectonic episode which Suensilpong & Putthapiban (1979) referred to the idea of Curray & Moore (1977, in Suensilpong & Putthapiban, op. cit.) who proposed the NE-dipping in the Indian Ocean. Based on their view points, the G-1 and G-2 granites as found in this study may be included in this episode of geological evolution. Subsequently, a new phase of granites, which is . to be derived from the anatexis of sedimentary-source rocks, was formed. These new 'S-type' granites including the two-mica granites of G-4 and probably G-3 and G-5 types of Phuket Plutons give isotopic ages in the range of 50-80 Ma, they are often found intruded into the older granites as revealed by the field evidence. This later phase granites have tendency to become tin-bearing as explained by the result of partial fusion in the earth's crust as a consequent to the prolongation of the NE dipping subduction (Suensilpong, 1980, pers. comm.). During the partial-melting process, Sn metal can be enriched (Suensilpong & Putthapiban, 1979; Taylor, 1979). This is the suitable reason to explain how the two-mica granite. of Phuket Plutons is extraordinary rich in tin and very significant for economic tin deposits.

9.5 Guide-line for Further Tin-prospecting by Geochemical Exploration

Tin deposits have always associated with hydrothermal alteration such as sericitization, silification, greisenization, and chloritization (Sheraton & Labonne, 1978), such alteration may be a good indicator for further tin exploration (Plimer & Elliott, 1979). The K/Rb ratio (lowest values) and Rb/Sr ratio (highest values) in rocks would be of an exploration tool in the search for economic mineral deposits (Oyarzun, 1974; Lowrence, 1974). The Ba/Rb ratio of less than 1 may be useful indicator of the ore-bearing potential, tin, tungsten, molybdenum, etc.

In Southern Thailand including the project area, a number of geologists have introduced path-finder elements, and minerals as guide line in tin exploration. Garson and others (1975) found that Li, Mn, and particularly B as well as Be are possible tin path-finders and also indicated from the evidence of survey that the best path-finder for tin deposits is the element 'tin' itself. Gocht and others (1978) found that monazite (with rather low content of Th) is an indicator for the exploration of tin-bearing granites. They also found that Th and Ca in tin-bearing granites (mostly muscovite and tourmaline ones) are much lower than those found in tin-barren granites (mostly coarsely porphyritic granites and hornblende- biotite adamellites). Zircon with high content of Sn up to 1% was used as a mineral indicator for tin- bearing pegmatites and greisen granites associated with tin-deposits (Arndt, 1979). Gocht & Pluhar (1979) pointed out that Ta, Nb, Li, F as a guide line in exploration for tin in pegmatite areas. Besides these, Ishihara and others (1979) found that the enrichment of F and Sn and the depletion of Ca as well as the opaques are limited only in the tin-bearing granites.

The tin-bearing two-mica granites of Phuket Plutons meet nearly all these requirements. It should be concluded that such indicators or parameter can be exactly used as exploration tools for tin deposits in this area and its adjacent without any protestion.