Geo. Soc. Malaysia, Bulletin 29, July 1991; pp. 1 – 100

Magmatism, tin mineralization and tectonics of the Main Range, Malaysian Peninsula: Consequences for the plate tectonic model of Southeast Asia based on Rb-Sr, K-Ar and fission track data

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Abstract: The Malaysian Peninsula belongs to the Southeast Asian tin belt. It is divided by a sutùre into two different magmatic provinces of S- and I-type characteristics. Three areas within the S-type granitoid province of the Main Range have been studied. New K-Ar mica and fission track zircon and apatite ages were established, and Rb-Sr whole-rock data from literature have been reinterpreted in the light of these new data. The results were compared with existing Rb-Sr isochrons of the I-type granitoid province and with the one reported from the northern extension of the belt stretching into Thailand. This integrated study led to the better understanding of: a) the behavior of the different isotopic systems in different geological environments, and b) the complex magmatic, tectonic and cooling history of Southeast Asian granitoids.

Applying the intrusion extrapolation method, based on the evolutionary trend of decreasing Rb-Sr ages and increasing initial $^{(87/86)}$Sr (Kwan *et al.*, paper submitted), periods of 300, 250, 210, and 90 Ma for the Main Range and of 260, 240, 210 and 90 Ma for the I-type granite province became evident. The best evaluated initial $^{(87/86)}$Sr for the source regions of the granitoids are 0.708 to 0.709 and 0.704 respectively. the major magmatic event in the Main Range dates of the late-Permian.

The close time range of individual magmatic periods and their spatial distribution can best be explained in the context of plate tectonics by northward motion of compositionally different arcs; by their collision to one another and to the East Asian Continent; subsequent deformation; subduction reversal; following the model of Hamilton (1988).

The most crucial event for the Main Range granitoids was the intrusion of the highly evolved, late-Triassic post-collision granites. They induced a regional hydrothermal convection system, which is considered to have lasted for a maximum of 40 Ma dependent upon the crustal level. This hydrothermal system was responsible for the major tin mineralization processes and the entire granite alteration. Biotite of the crystallized granitoids is considered to be the main Sn supplier.

The K-Ar and fission track ages indicate a slow post-orogenic cooling in the range of 1-5°C/Ma. With FT zircon ages different crustal levels can be distinguished within the Main Range, and the discordant K-Ar mica and the differently reset Rb-Sr whole-rock ages can be correlated with depth.

After the early-Cretaceous the Main Range has been dominated by tectonic activities, such as differential vertical uplift of the Main Rage combined with the juxtapositioning of blocks, thrust faulting close to the Bentong-Raub suture and Tertiary left-lateral displacement, which is inferred from isotopic and petrological evidences.

INTRODUCTION

The tin belt of Southeast Asia with its length of about 3,500 km is one of the most important metallogenic provinces in the world. In Thailand, the Malaysian Peninsula and NW Indonesia many investigations have been carried out in attempts to unravel the genesis of tin ore formation in space and time. As generally accepted, the tin ore of Southeast Asia is related to acid magmatism of S-type characteristics (Beckinsale, 1981; Hutchison, 1983; Liew, 1983; Cobbing *et al.*, 1986; Pitfield, 1987). Tin associated granites are a product of plate tectonic related reworking of continental crust (Mitchell, 1979; Pitcher, 1985; Hutchison, 1988). Nevertheless, known cassiterite associated granites are of limited distribution within the magmatic belt. The question arises why we find within the enormous volume of highly evolved granites only few tin-bearing granites of economic importance. It is still a matter of discussion whether the Sn is concentrated by fractional crystallization in a single stage magmatic process, or if it has an inherited origin from a source rock and was remobilized and concentrated by multi magmatic processes (Hutchison and Chakraborty, 1979; Pollard *et al.*, 1983; Eugster, 1985; Lehmann, 1982 & 1989).

Radiometric age dating can be a powerful tool to unravel a poly-magmatic sequence and to determine the time of tin mineralization. Nevertheless, the existing isotopic data of the Western Granite Province (Main Range) are very controversial. In Thailand magmatic cycles are suggested in Permian, during the late-Triassic, during the Cretaceous and during Tertiary times (Beckinsale *et al.*, 1979). In the Malaysian Peninsula Carboniferous, late-Permian to late-Triassic and Cretaceous magmatism was suggested by Bignell and Snelling (1977) whereas Liew (1983) and Darbyshire (1987) found only evidence for major late-Triassic and minor Cretaceous granites. The latter two magmatic cycles were found in the Tin Islands of Indonesia (Prime *et al.*, 1975). According to intrusion relations observed in the field and combined with isotopic data, the tin mineralization in Thailand is suggested to be of Cretaceous to Tertiary age, of late-Triassic age in the Malaysian Peninsula and NW Indonesia. The tin of Tasmania (Australia), which is proposed to be connected with the Southeast Asian tin belt, is related to Permian granites (Hamilton, 1979; Newnham, 1988).

The main problem of all isotopic investigations in these areas is that several thermal events could have influenced the isotopic systems. Interpretation of whole-rock and mineral ages is thus difficult. The occurrence of concordant and highly discordant ages of different isotopic systems suggests that such overprinting may be different in space depending upon the individual geological setting within the large magmatic belt. Presumably the reason will be found in spatial distinct plate tectonic activities inaugurating magmatism, conductive heat flow, hydrothermal convection and block displacement along faults (Kwan *et al.*, paper submitted). Generally, two fundamental questions arise to geochronologists:

a) How can intrusions be dated?

b) How can mineralization be dated?

For granites the Rb-Sr and U-Pb methods are conveniently used to determine the time of rock crystallization, which is assumed to be identical to the intrusion age. The Rb-Sr method has caused in Southeast Asian granitoids enormous problems to establish acceptable whole-rock isochrons (Bignell & Snelling, 1977; Beckinsale *et al.*, 1979; Prime *et al.*, 1975; Darbyshire, 1987; Lin *et al.*, 1988; Kwan *et al.*, paper submitted). The variation in age and initial $^{(87/86)}$Sr is large and has to find its cause in geological and not analytical reasons. Kwan, Krähenbühl and Jäger (paper submitted) could show in a detailed study on Penang Island that the isotopic Rb-Sr system of pre-Triassic granites was intensely disturbed in late-Triassic time. Therefore the Rb-Sr whole-rock ages need not necessarily document the age of emplacement, even if well defined isochrons may be established. The variation in reported late-Triassic U-Pb zircon population ages is small but in some locations the ages are significantly lower than the corresponding Rb-Sr whole-rock age (Liew, 1983; Kwan *et al.*, paper submitted). This indicates that also the U-Pb ages do not necessarily document time of intrusion.

Previous workers constrained tin mineralization by dating of the host granite or pegmatite without considering of above mentioned problems. A further attempt was made to date the muscovites from greisen bodies or greisen bordered mineralized veins. The resulting age must not be identical with the time of ore formation, because it could have been reset by a younger regional or local superimposed thermal event.

The aim of this work is to use different isotopic methods in areas of different geological settings to verify the meaning of the reported ages. The studied areas are shown in figure 1. The Kinta Valley is known as the richest alluvial tin field. The cassiterite is expected to be supplied from surrounding tin-bearing granites. Kuala Lumpur is a further tin-rich area but the plutons are highly disrupted by a dense fault net. And the Malacca area is almost tin-free, sited close to the Eastern Granite Province of I-type characteristics. The influence of any Cretaceous (hydro-)thermal overprint might be the strongest in this area because local granite intrusions of that age are suggested (Bignell & Snelling, 1977). Concerning the isotopic investigations, an attempt was made to answer the following questions:

1. What Rb-Sr whole-rock regression lines are isochrons defining the crystallization age of the granites?
2. What Rb-Sr mineral and K-Ar mica ages define a cooling age of a crystallized granite?

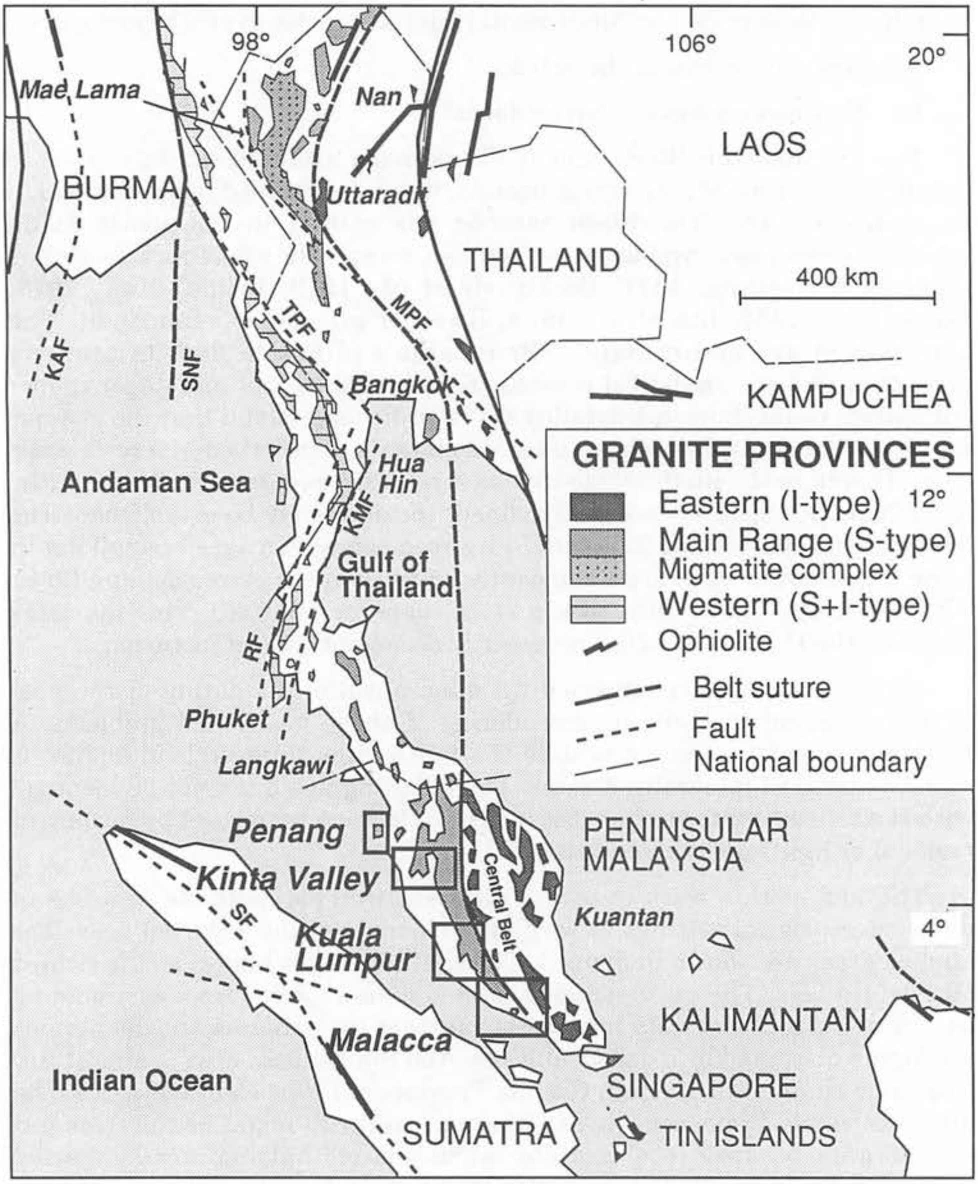


Figure 1: Map of Southeast Asia showing the different granite provinces and the suggested sutures between belts of different evolution. The compiled base map is from Cobbing *et al.* (1986); Hutchison (1975) and Lin *et al.* (1988). The squares indicate the studied areas. Name of faults (F): KAF: Kabaw-Andaman; SNF: Sagaing-Namyin; TPF: Three Pagoda; MPF: Mae Ping; RF: Ranong; KMF: Khlong Marui; SF: Semangko.

3. What mineral ages have been reset by one or more regional or local thermal events?

New K-Ar mica and fission track (FT) zircon and apatite ages have been established. The Rb-Sr data from Bignell and Snelling (1977) have been used to plot Rb-Sr evolution diagrams following same approach as carried out in Penang Island and the suggested model of intrusion age extrapolation based on the age versus initial $^{(87/86)}$Sr diagram is tested for granites in described area (Kwan *et al.*, paper submitted). All available isotopic data from the literature are used for discussion. Using this approach it is hoped to be able to gather more reliable information on the geological evolution of the western magmatic belt:

1. Clarify whether further Palaeozoic granites exist;
2. Estimate the volume of the late-Triassic granites in the belt;
3. Influence of Cretaceous and Tertiary thermal overprint;
4. Recognition of tectonic displacements;
5. Timing of the tin mineralization;
6. Path of erosion and supply of heavy minerals into the alluvial.deposits;
7. Evaluation of plate tectonic models;

GEOLOGICAL BACKGROUND

Geology of the Malaysian Peninsula

The Malaysian Peninsula is divided into two major longitudinal belts separated by a suture (fig. 1). The Eastern Belt consists of a large epizonally emplaced acid to intermediate magmatic province of calc-alkaline characteristics (Liew, 1983; Hutchison, 1983, 1986). The Permian to Triassic I- and S-type plutons intruded Carboniferous and Permian clastic and volcanoclastic sediments. Regional metamorphism, folding and uplift probably occurred in the late-Palaeozoic followed by deposition of continental sediments (Khoo and Tan, 1983). Contact metamorphic aureoles are reported in the vicinity of plutons. In the southern part of the Eastern Belt regional metamorphism is of greenschist facies.

The eastern extension towards the Bentong-Raub suture bordering to the Western Belt is called Central Belt. It consists of the same granite province and is suggested to built one unit with the Eastern Belt. This graben like belt is underlain predominantly by by Permian to Triassic clastics, volcanics and limestones. Uplift and recumbent style folding terminated marine sedimentation in late-Triassic time and subsequent continental deposition continued until the early-Cretaceous (Khoo and Tan, 1983). Granitoids built N-S chains both sides of the belt and a few small Cretaceous plutons (Darbyshire, 1988) in marginal position are epizonally emplaced. The Bentong-Raub suture divides two different magmatic provinces. It is a steeply eastward dipping, mélange-like schist belt containing inclusions of ophiolites (Hutchison, 1983). The whole belt is covered by Mesozoic sediments.

The Western Belt comprises a voluminous magmatic suite which becomes larger towards the NW. This magmatic belt is called Main Range. Most granites of S-type characteristics are mesozonally emplaced into Palaeozoic sediments. Regional metamorphism is low grade. Granites in the NW are epizonally emplaced showing contact metamorphism and the metasediments of shelf facies show evidence of mid-Permian folding (Khoo and Tan, 1983). Subsequent uplift and increasing clastic sedimentation is expected to culminate by the late-Triassic orogenic event. In the southern Kinta-Malacca sector, deposition of Palaeozoic argillaceous and calcareous sediments was followed by limestone in the Kinta Valley and by clastic in the Kuala Lumpur region. No Permian volcanic rocks and no Mesozoic (except Triassic) sediments are known from the Western Belt. The major NW-SE striking faults show left-lateral displacement of up to 50 km and the intersited blocks are disrupted by normal faults.

Models of plate tectonic evolution

The plate tectonic evolution of the Malaysian Peninsula cannot be viewed in isolation as it is part of the East Asian Continent. At the margin of the triple point of the Indian-Australian, the Pacific and the Eurasian plate the tectonic situation is very complex because cratons and amalgamized belts became disrupted and displaced during geological times.

Attempts to unravel the tectonic evolution are based on stratigraphic, palaeontological, palaeoclimatological, geophysical, geochemical and isotopic investigations. A subdivision of Southeast Asia into belts and blocks of same evolution seems rather difficult. Basically, there are two major events determining the actual situation. Firstly the formation of an enormous East Asian Continent comprising rigid crustal fragments to which mobile belts were amalgamated (Hutchison, 1988). Secondly, a disruption of this newly formed craton into irregular blocks which were largely eastward displaced and sheared against one another, initiated by the north motion and collision of India to Eurasia (Tapponnier *et al.*, 1982).

The formation of the East Asian Continent and their accretionary belts imply enormous crustal shortening leading to closure of basins, to new crust formation and to widespread volcanism and magmatism. The East Asian

Continent comprises southern China (Yangtze platform) and the northern mobile belt, consisting of Indochina (Indosina: Laos, Kampuchea, eastern Thailand; see fig. 1), eastern Peninsular Malaysia, western Kalimantan and southern Sumatra (Hutchison, 1988). This northern belt, to which some authors included the Central Tibet (Mitchell, 1981), is suggested to be welded on to the South China platform along the Kun Lun-Red River suture in late-Devonian or early-Carboniferous (Helmcke, 1985; Hutchison, 1988) and its rifting from Gondwanaland was proposed in the early-Palaeozoic. Audley-Charles (1983) extended the belt from the Central Tibet into Iran and Turkey. Mitchell (1981) suggested a collision of this belt to the South China platform in late-Triassic time.

The next belt located further south comprises southern Tibet, Peninsular Thailand-Burma (Main Range), western Peninsular Malaysia (Main Range) and possibly northern Sumatra. This unit is found in literature to be called Shan-Thai, or Sibumasu, or Sinoburmalaya block/belt with small modifications in composition (Bonupas & Vella, 1978; Stauffer, 1974; Hutchison, 1988). It is suggested that the belt was rifted from Gondwanaland during the Carboniferous (in Devonian, Ridd, 1971) and was attached to the East Asian Continent in the late-Triassic by the formation of the collision-related Main Range (Mitchell, 1977; Liew, 1983). The suture is expressed as the northern Transhimalya lineament, the Cheng Rai medial zone (Nan-Uttaradit ophiolite zone) and the Bentong-Raub suture of Peninsular Malaysia. Continental rift elements with rift infill deposits (pebbly mudstone series of Phuket and Langkawi Island) and pre-rift A-type granites are suggested to be found in the NW sector of the Western Belt of the Malaysian Peninsula (Ridd, 1980; Hutchison, 1988). Where the palaeogeographical position of this belt within Gondwanaland was is still matter of discussion. North of Africa-Arabia, adjacent to India, NW or NE of Australia and adjacent to New Guinea were proposed (Ridd, 1971; Stauffer, 1974; Mitchell, 1981; Audley-Charles, 1983; Burrett & Strait, 1985).

Situated further south, the Burma plate was suggested to collide with Sinoburmalaya in the late-Cretaceous. This according to the plutonic arc of S- and I-type characteristics of Cretaceous age which extends southwards to Phuket (see fig. 1; Hutchison, 1988).

Helmcke (1985) suggested that India was the only continent derived from Gondwanaland. He could not find any evidence for a postulated Palaeo-Tethys north of mentioned mobile belts. Hence, he proposed that these belts were assembled to Pangaea forming the sutures in Thailand, Vietnam and Yunnan already in the Palaeozoic. The Central Belt of the Malaysian Peninsula is generally assumed to belong to the East Granite Province and is considered to be a remnant of a closed marginal or oceanic basin. Gravity studies of an E-W profile revealed a maximum in the Central Belt.

Nevertheless, the interpretation that this is indicative for a thin oceanic crust is not absolutely conclusive. Near surface dense igneous rocks covered by sediments could show the same features (Ryall, 1982). The Bentong-Raub suture at the west border of the Central Belt comprising scattered ophiolites is a suture marking the site of a suggested west dipping subduction zone of Palaeozoic age (Hutchison, 1975). The northern extension of this suture is generally correlated with the Uttaradit-Nan ophiolite zone of Thailand (Bonupas & Vella, 1978; Hutchison, 1983). In latter case blueschists of probably pre-Permian age are reported by Barr and Macdonald (1987), which may represent an inner-trench.

The Main Range S-type granites are suggested to be a product of the crustal thickening or underplating in a continent-continent collision regime originating from the amalgamation of the Sinoburmalaya block to the East Asian Continent. The Eastern Belt of calc-alkaline and alkali-calcic magmatic nature is suggested to be a continental island arc of the Andean type (Hutchison, 1986). Chakraborty (1988) argue that the Eastern Belt could also be of an intraplate extensional setting related to failed continental rifting or a continental back-arc basin. The latter would require a westward subduction east of the Eastern Belt. Due to spatial and chronological problems within all existing tectonomagmatic models he also doubted that the Main Range granites originate from a continent-continent collision regime (Chakraborty, 1987).

The post-Triassic evolution of the consolidated East Asia Continent is well studied. Cretaceous I-type magmatism in Thailand, Peninsular Malaysia, Sumatra and Kalimantan is suggested to be related to the north and east subduction of the Indian plate (Achache *et al.*, 1983; Suensilpong *et al.*, 1983). Whereas Hutchison (1988) proposed an amalgamation of the Burma plate to be responsible for the Cretaceous magmatism. The direction of the Indian-Australian mega-plate motion changed from SE-NW between 125 and 85 Ma, towards N between 85 and 45 Ma and towards NE after 30 Ma (Hamilton, 1979). The disruption of the consolidate East Asian Continent has to be seen in relation to the north drifting of India and its collision with Eurasia in *Cenozoic* time (Tapponnier *et al.*, 1982). For consequence the Indochina block was squeezed towards the southeast and displaced 800 to 1,000 km. The South China block was less far eastward transported and both blocks, including the Malaysian Peninsula, were rotated clockwise. Differential rotation of the South China and the Indochina block along the left-lateral Red River fault resulted in the opening of the South China Sea. A subsequent counter-clockwise rotation of about 40° of the Indochina block and the attached Thai-Malay Peninsula block is suggested from palaeomagnetic studies (Achache *et al.*, 1983). This reversal changed the strike slip sense at the Red River suture. A rotation of the Sunda platform, including the Malaysian Peninsula, northern Sumatra and western Kalimantan is suggested to have taken place in Tertiary because the Cretaceous granites were displaced (Holcombe, 1977). The main shear plains of the rotation were found in the Ranong and Khlong-Marui faults of SW Thailand and the Semangko fault in central Sumatra (fig. 1). Differential counter-clockwise rotation between the Malaysian Peninsula and the Indochina block could cause a pull apart effect opening the Gulf of Thailand. If the belt sutures were involved, then the differential rotation produced a tensional regime in the Central Belt leading to volcanic activity (Achache *et al.*, 1983; Hamilton, 1979). The N-S structures are related to a Sunda shearing that post-dates the rotation. Large northward block displacement in order of 400 km with a displacement rate of 3.7 cm p.a. since Miocene is recorded from the Burma plate. A double arc was formed shearing the southern block adjacent to the northern under opening of the Andaman Sea.

Granites of the Malaysian Main Range

The Main Range granites are referred in literature as those granites appearing in the Western Granite Province, which is correlated with the Main Range granites of western Thailand (fig. 1). Biotite granites dominate whereas amphibole-bearing, quartz-rich and two-mica granites have only a subordinate distribution. Muscovite bearing granites are often associated with tourmaline. Hutchison (1983) suggested a secondary origin for muscovite due to greisenization processes but in some cases also a primary origin was suggested (Cobbing, 1987). K-feldspars occurs mostly as megacrysts or phenocrysts and vary from perthite to maximum microcline. The latter often occurs together with muscovite and is related to deeper located granite intrusions (Hutchison, 1977, 1983; Kwan *et al.*, paper submitted). In some locations pink granites occur where the color originates from the K-feldspar and they are suggested to be of high level emplacement (Hutchison, 1983). Plagioclase is mostly of albite to oligoclase composition and is sometimes zoned. In the latter case cores were analysed with 71% albite and 29% anorthite whilst the rims are of 91% and 9% respectively (Romang, 1922). Accessory minerals include brownish zircon of high U content, monazite, xenotime, allanite, apatite, ilmenite, magnetite and further opaques. Granites in association with the tin mineralization are usually quartz-enriched and comprise various amounts of muscovite, tourmaline, fluorite, topaz, chlorite, wolframite and sulfides.

Most granites have a coarsely crystalline texture characterized by K-feldspar megacrysts. The transition to medium and finely crystalline granites with remnant K-feldspar phenocrysts, and to equigranular leucogranites are abundant in all plutons. Coarsely crystalline granites of primary magmatic texture are called primary textured granites (PTG; Cobbing *et al.*, 1986; Cobbing, 1987). Finely crystalline granites are called secondary textured granites (STG). Granites showing both textures are referred to transitional types (TTG). The PTG underwent subsolidus mineral reactions leading to a grain size diminution due to suggested interaction with late stage magmatic fluids infiltrating primary textured granites. Most granites are unfoliate and in cases where they are deformed they can usually be related to fault zones. Dark enclaves and xenoliths are restricted to some plutons and are suggested to be of sedimentary origin. Pegmatites and aplites of various mineralogical composition are common in all plutons and may have irregular shape.

The Main Range granite association vary from granodiorites to highly evolved, peraluminous granites which are exclusively of S-type characteristics (Hutchison, 1977; Ishihara *et al.*, 1979; Liew, 1983; Cobbing *et al.*, 1986). Variation in major elements are in weight %: SiO_2 68-77, Al_2O_3 13-15, total Fe 1-4, TiO_2 0.1-0.7, CaO 0.5-2.5, Na_2O 2.5-4, K_2O 4.5-6. Systematic fractionation trends in the transition from PTG to STG are reported from a study of the Dindings pluton, near Lumut (Cobbing *et al.*, 1986). Major elements show increasing SiO_2 and Na_2O and decrease in Al_2O_3, K_2O, TiO_2, total FeO, MgO, CaO and P_2O_5 contents. Minor elements show an increase in Rb, U, W, Sn and to a lesser extent of Y, and a decrease in Ba, Sr, Th, Zr, V, Cu, Zr, and LREE.

Comprehensive field mapping and geochemical investigations were carried out in the Main Range of Thailand, the Malaysian Peninsula and down to the Tin Island of Indonesia by Cobbing, Mallick and Pitfield from the British Geological Survey (BGS). Subdivision and classification of plutons in terms of orogenic setting, metallogenic regime and compositional source regime was the main target of these investigations. Therefore they used only PTG for the geochemical analysis where secondary processes leading to element exchange could be excluded (Pitfield, 1987).

State of isotopic investigations

The oldest reported ages from the intrusives of the Western Granite Province are 1,500-1,700 Ma obtained from U-Pb zircon reverse discordía ages (Liew, 1983). They are in general agreement with Proterozoic Nd model ages calculated based on a depleted mantle evolution model (Liew & McCulloch, 1985). Concordant U-Pb zircon population ages and highly discordant patterns yield a maximum age of 220 Ma (Liew, 1983). A Proterozoic basement and a single late-Triassic magmatic episode were suggested for the Main Range. This was supported by Rb-Sr whole-rock ages of Darbyshire (1987). In fact, the whole magmatic belt was suggested to have originated within a time span of 200-230 Ma, and magmatic processes as fractional crystallization and assimilation were discussed (Liew, 1983). These findings are in contrast to reported Palaeozoic Rb-Sr whole-rock ages (Bignell & Snelling, 1977; Liew, 1983; Kwan *et al.*, paper submitted). Liew (1983) suggested that Palaeozoic Rb-Sr whole-rock ages are a product of inherited radiogenic strontium trapped in the late-Triassic granites by assimilation of Palaeozoic metasediments. However, it is evident that all existing Rb-Sr analyses of Peninsular Malaysia plotted in the isochron diagram give a general correlation of late-Triassic age but in addition, there is a wide scatter for data with a ratio of ($^{87}Rb/^{86}Sr$) < 40 (fig. 2).

The main problems of Rb-Sr whole-rock dating were to verify what samples have to be regressed and to find a statistically good fit of the data points. The reasons originate either in the problem of distinguishing single plutons by field mapping and geochemical investigations (Beckinsale *et al.*, 1979; Pitfield, 1987) or by the tectonic juxtapositioning of granites of different

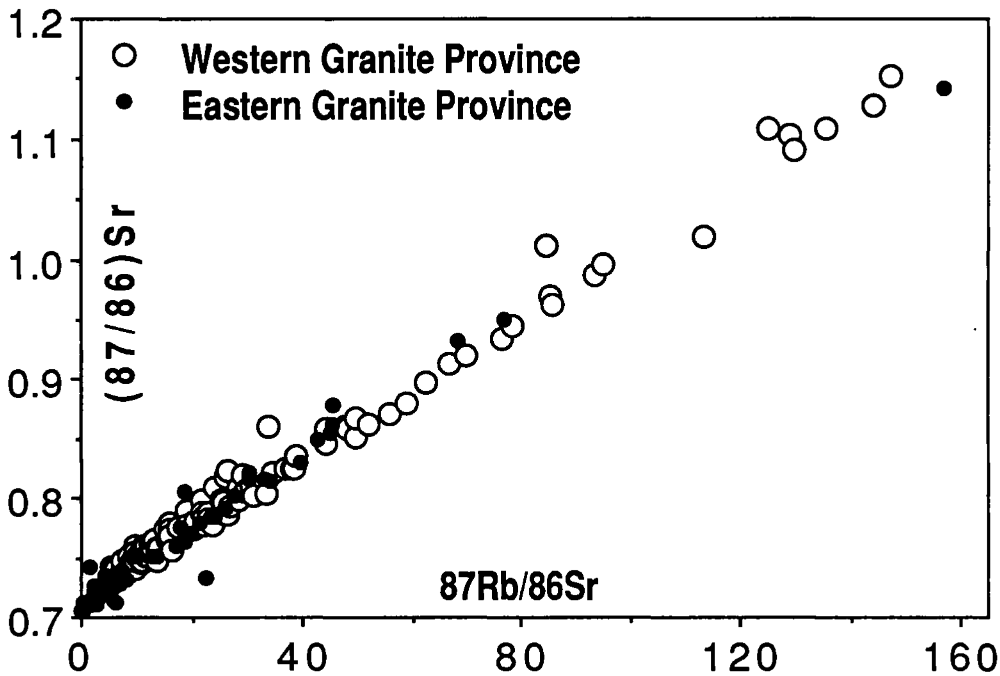


Figure 2: Rb-Sr isochron diagram including all from literature available whole-rock analyses for Peninsular Malaysia (Bignell & Snelling, 1977; Liew, 1983; Darbyshire, 1988; Kwan *et al.*, paper submitted). A large scatter for data points with a ($^{87}Rb/^{86}Sr$)<40 and a general better correlation for those which exceed this ratio is evident. Errors do not exceed the symbols.

and/or same intrusion age (Kwan *et al.*, paper submitted). In a case study of Penang Island, Kwan *et al.* (paper submitted) could show that an incomplete radiogenic Sr homogenization in late-Triassic time was responsible for the disappearance of pre-Triassic ages. The systematic trend to lower ages and increasing initial $^{(87/86)}$Sr showed that the homogenization took place within a kinetic equilibrium between the granitoids and the fluid phase of a hydrothermal conductive convection system, which was induced by the late-Triassic granites. Using the Rb-Sr intrusion age extrapolation method periods of 307±20 Ma, 251±16 Ma and 211±3 Ma were suggested and the best estimated initial $^{(87/86)}$Sr at time of intrusion for all granites was 0.708. Rapid cooling of the late-Triassic Feringgi-type granite from Penang Island down to 300±50°C was estimated of 1-3 Ma due to coinciding Rb-Sr intrusion and K-Ar mica cooling ages.

The majority of the K-Ar mica ages are either in good coincidence with the late-Triassic Rb-Sr whole-rock and U-Pb zircon population ages, or they are younger showing a large age variation of 210-59 Ma. The first group is interpreted as cooling ages of the late-Triassic intrusives (Bignell & Snelling, 1977; Kwan, 1984 & 1986). It dates the time at which for a particular isotopic system and mineral phase the temperature below felt the blocking temperature (Wagner *et al.*, 1977). The wide spread of post-Triassic K-Ar mica ages of the second group was attributed to considerable argon loss caused by extensive cataclasis in fault zones (Bignell & Snelling, 1977). Hutchison (1983) related them to the effect of slow cooling in deeper crustal levels and in addition, Kwan *et al.* (paper submitted) showed that they are also dependent on various degrees of hydrothermal overprint. The first late-Permian K-Ar biotite ages are reported from the Bujang Melaka at the southeast border of the Kinta Valley and are inferred to be late-Permian cooling ages (Kwan, 1989).

K-feldspar is suggested to give in many cases an age close to the crystallization of the granites using the Rb-Sr method (corrected with 0.708) and plagioclase is used to control the Rb-Sr system concerning any disturbance, as plagioclase is one of the main radiogenic Sr acceptors.

Fission track ages of zircons are known from Langkawi Island (Khoo, 1986) and from Penang, in the latter case together with apatite ages (Kwan *et al.*, paper submitted). They indicate together with the mica ages a very slow post-Triassic cooling regime in order of 1–3.5°C/Ma. Episodes of differential to blockwise uplift in Cretaceous and Oligocene/Miocene, and subsequent isostatic cooling at different crustal levels became evident (Kwan *et al*, paper submitted). Volcanic rocks are so far not reported to be dated by radiometric methods.

From the *Eastern Granite Province* late-Permian and middle-Triassic intrusion periods are documented. Good agreement between Rb-Sr whole-rock (Bignell & Snelling, 1977) and U-Pb zircon population ages (Liew, 1983) defined intrusion ages around 260 Ma and at 230 Ma. Whereas Darbyshire (1988) found also evidence for younger Rb-Sr whole-rock ages in a range of 200-240 Ma. K-Ar mica ages frequently coincide with the corresponding Rb-Sr whole-rock ages and vary from 200-265 Ma (Bignell & Snelling, 1977).

The Rb-Sr and K-Ar age patterns in the northern extension of the Western and Eastern Belt into Thailand are principally similar. The reported Rb-Sr whole-rock ages of granitoids are: Carboniferous (Main Range and Thai-Burma belt); late Permian (Main Range); late-Triassic and Cretaceous (southern Thai-Burma belt; Beckinsale *et al.*, 1979; Suensilpong *et al.*, 1983). Most initial $^{(87/86)}$Sr are enhanced and rise to a reported maximum of 0.823 for a 186 Ma granite from Huai Yang. Mica ages show a broad scatter between 32 Ma within the Khlong-Marui fault to 229 Ma at the border of Thailand and Malaysia. In addition, in the southern extension of the Peninsula Malayan Belts to the Tin Island of Indonesia and to Sumatra relicts of pre-Triassic ages are reported, although there occur more Tertiary and Quaternary K-Ar ages of volcanic rocks (Prime *et al.*, 1975; COOP, 1982).

SAMPLE PREPARATION AND EXPERIMENTAL PROCEDURES

Granites of the largest possible spread in composition, texture and alteration were sampled along N-S and E-W profiles where the local conditions allowed. Samples from the Bujang Melaka were collected by the Geological Survey of Malaysia (GSM; Kwan, 1989).

The collected samples (each 30 kg) were jaw-crushed and concentrates of pure biotite and muscovite were obtained using standard mineral separation procedures. The grain size fraction <90 mesh was used for zircon and apatite separation and subsequent FT analysis. Wilfley-table, heavy-liquid and magnetic separation techniques were used gathering pure apatite and zircon concentrates. A plain Wilfley-table without horizontal ripples was constructed after the principle of commercially used tables in the amang factories. By employing this table the use of heavy-liquids could be reduced.

K-Ar dating. Potassium was determined by flame photometry with an accuracy of ± 1% standard error. Argon analysis were made using the isotope dilution method (Dalrymple & Lanphere, 1969). Argon degassing, purification and measurement procedures, calibration and data handling followed Flisch (1986). The required data are blank ($3*910^{-9}$ cc STP) and discrimination corrected. The one sigma error on the calculated age is ± 1% and the reproducibility ± 0.6%, yielded for eleven LP-6 standard analysis done within a two-month period by different users.

Fission track dating. Apatite and zircon were analysed using the external detector method (EDM) because of expected high uranium content (Gleadow &

Duddy, 1981; Hureford, 1986). Apatite mounts were etched in 1N HNO_3 at 20°C for 22 seconds, zircon teflon-mounts in a NaOH-KOH eutectic at 220°C for 8–12 h and all mica detectors in 40% HF at 20°C for 45 min after irradiation. Different zircon mounts of populations separated from the heavy mineral concentrates of the alluvial deposits were etched for different periods of time. This procedure is carried out to make sure that zircons of different etching behavior could be included into the counting statistics. Approximately ten crystals per sample were counted using a Leitz Orthoplan microscope at a nominal magnification of 1250 with dry objectives for apatite and an oil-immersion objective for zircon. For zircons from the alluvial deposits 20–40 crystals were counted. Thermal neutron irradiation was carried out in Dido reactor at Harwell in the UK. Neutron fluence was monitored by counting detectors against the uranium dosimeter glasses SRM 612 and CN–1. For each sample mount the particular neutron fluence was calculated. FT ages were calculated using established zeta factors 113±2 (CN–1) for zircons and 300±16 (SRM 612) for apatites (Hureford & Green, 1982; 1983). Poisson error was calculated including uncertainty of zeta calibration (Green, 1981). Mounts of zircons obtaining very high track density of $>200*10^5$ tr cm^{-2} have been counted more than once to check the reproducibility.

Rb-Sr whole-rock isochron calculation. All Rb-Sr whole-rock data from Bignell and Snelling (1977) were used for regression line calculations. The analytical data are found in (Bignell & Snelling, 1977). Regression line calculation and error estimation was undertaken with PDP–11 computer using a program based on York (1969). The recommended decay constant of $1.42*10^{-11}$ for ^{87}Rb (Steiger & Jäger, 1977) was used also for mineral age recalculations. The isochrons were established using the reported uncertainties of ± 2% for the ($^{87}Rb/^{86}Sr$) and ± 0.01% for the $^{(87/86)}Sr$ ratios (Bignell & Snelling, 1977). A two sigma error is given on the ages and initial $^{(87/86)}Sr$. To choose the samples for isochron calculation the same approach was used as for Penang Island. Samples collected from a close area or from the same localities were regressed independently of texture and mineralogy of the granitoids.

The term isochron is only used for a Rb-Sr whole-rock regression line that indicates the intrusion age. In cases where the geological meaning of a regression line is doubtful this term is presented within inverted commas, e.g. "isochron".

THE KINTA VALLEY AREA

Geological setting

The Kinta Valley is suggested to be a sediment covered sutured graben, bordered by NW-SE tending faults in the east and NNE-SSW striking ones in the west (Romang, 1922; Scrivenor, 1923). The valley is surrounded by two voluminous granite massives, the Kledang Range and the Main Range (Fig. 3). The latter term is generally used for the Western Granite Province of Peninsular Malaysia and Thailand but is locally also used for the granites exposed at the east side of the Kinta Valley. The Bujang Melaka is an isolated pluton in the SE that borders on the Main Range.

The sedimentary cover is composed mainly of calcareous series interbedded with psammitic and pelitic rocks. Beneath the tin rich alluvial deposits Devonian limestones with karst topography are widespread (Rajah, 1979). The underlying argillaceous schists, phyllites and slates of Ordovician/Silurian age are of low grade regional metamorphism. Studies from east of the Bujang Melaka do not suggest any break in deposition from the early Devonian to the Mid-Permian, although the latter has only a very limited occurrence east of Kampar (Khoo and Tan, 1983). These shelf-type sediments have been suggested to contact metamorphism in the proximity of the granites. Marbles from the calcareous series and hornfelses of variable mineralogical composition from the pelitic series are reported by Romang (1922). No Triassic to Tertiary sediments are found in, nor southwards of the Kinta Valley. Their absence is interpreted to result from either mid-Permian to Triassic uplift and no deposition or by post-Triassic uplift and complete erosion (Khoo and Tan, 1983).

Coarse grained biotite granites containing varying amounts of K-feldspar megacrysts seem to be the most dominant rock type in the surrounding granites. This is assumed from the limited outcrops available in an area of thick tropical vegetation. The Bujang Melaka is composed by a coarse grained biotite granite (Bujang Melaka-type) and an increasing content of medium to fine grained muscovite-bearing and two-mica granites with various amounts of tourmaline in its core (Relau-type; Askury, 1985). Pegmatites and aplites are rare whilst xenoliths are only of local occurrence (for example, in the Kuala Dipang quarry at the NW end of the Bujang Melaka). Thick quartz veins are frequently associated with the dominant NW-SE and SW-NE tending faults (Tjia, 1972). Small quartz veins containing tourmaline are mainly found in association with mineralized granites and/or in highly altered ones.

The main primary tin ore mineralization occurs in veins and is related to granites in contact with the sedimentary cover (Hutchison, 1986). Sheet mineralized vein systems are found in the Ordovician/Silurian argillaceous pelitic metasediment series (SE of Tapah, Bidor, Sen Hyen Mine). Primary tin ore deposits are best developed in the Kledang Range (Rajah, 1979). Skarns, lodes and pipes occur at the east margin of the Kinta Valley in the contact zone of granites to sediments (Romang, 1922). From the only underground mine near Menglembu two mineralization types are reported

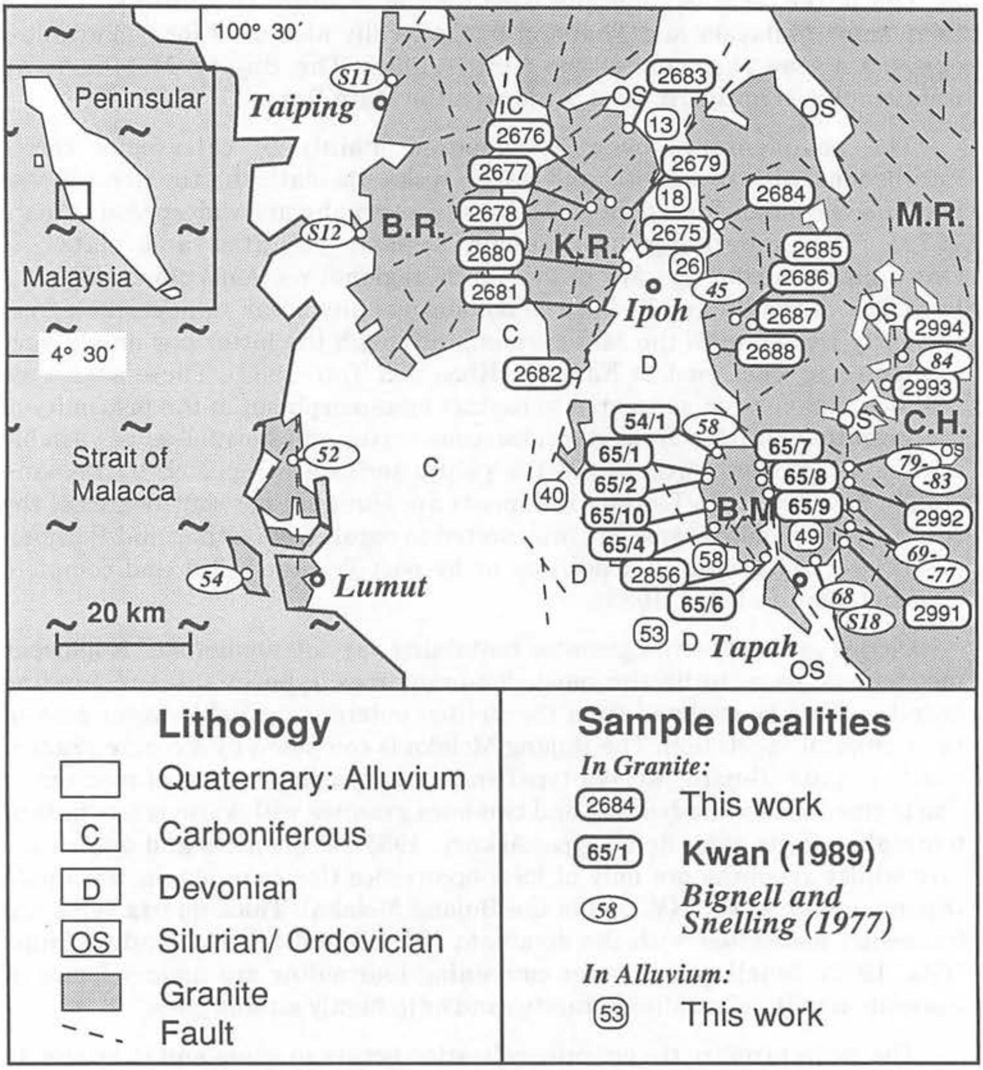


Figure 3: Map of the Kinta Valley area showing lithology and sample locations. Base map is the geological map of Peninsular Malaysia, Santokh Singh (1985) compiled with the structural map from the GSM, Lai (1987). B.R.: Bintang Range; K.R.: Kledang Range; B.M.: Bujang Melaka; M.R.: Main Range; C.H.: Cameron Highlands.

(Ingham & Bradford, 1960). Quartz-cassiterite veins cut on earlier sheeted vein system. The investigations of Romang (1922) showed that the tin mineralization and the associated mineral composition of the limestones is remarkably different than those in the underlying pelitic series. In marbles of contact metamorphic origin the tin is associated with tourmaline, fluorite, calcite and calcic garnet due to metasomatism. Mineral associations comprising chlorite, pyrite, arsenopyrite, galena and sphalerite are suggested to be of hydrothermal origin. In non-metamorphic limestones stocks and pipes with a low tin content but abundant sulphides (pyrite, arsenopyrite, chalcopyrite, covellite, stibnite and stannite) occur. They are suggested to be of low temperature origin and to be sited far off the granite pluton. Whereas in the metamorphic argillaceous pelites tin mineralizations occur together with hornfels comprising minerals of various compositions (e.g. tourmaline, magnetite, spinel, diaspore and corundum). These are suggested to be of pneumatolytic origin due to contact metamorphism. Intensely altered and greisenized granites in areas of primary tin mineralization are known from the Tekka mine at the foothill of the Main Range (SE of Ipoh, location KAW 2688), from the Asia mine (south end of the Bujang Melaka) and from Ulu Petai in the center of the Bujang Melaka. Cassiterite is associated with muscovite, lepidolite, tourmaline, topaz, fluorite, chlorite, kaolin, ilmenite together with subordinate wolframite and arsenopyrite.

Fluid inclusion studies of primary inclusions in quartz from the mineralized zones of the Tekka mine yield homogenization temperatures of 327°C. Further investigations in Thailand indicate a 1–molal NaCl solution what is suggested to be significant for the mineralizing fluids at the time of tin deposition (Jackson & Helgeson, 1985). Quartz inclusions indicate a temperature range of 240–440°C and a pressure of approximately 1 kb in the Ulu Petai mine (Schwartz and Askury, 1989). The mineralizing aqueous fluid is reported to be low in salinity, pH and partly mixed with CO_2. The biotites and muscovites are reported to be of high Sn content (153–644 ppm) but there is no obvious correlation with changing granite texture and mineralogy.

Tin of commercial value was mined in the alluvial deposits of the Kinta Valley. Almost the whole area has been mined and sometimes even re-worked using more sophisticated heavy mineral concentrating equipment. In the southern part of the valley gravel pump mines penetrate down to 40 m to the bedrock, which are usually steeply dipping calcareous rocks. Mining activities have become less since 1985 because of falling tin prices. As a consequence, most mines are today flooded and geological outcrops have disappeared for ever.

Previous isotopic investigations

Several radiometric age determinations were established by Bignell and

Snelling (1977; Rb-Sr and K-Ar) and by Kwan (1989; K-Ar). For biotite granites of various textures collected from the Cameron Highlands road up to the Highlands, a Rb-Sr "isochron" of 290±14 Ma and initial $^{(87/86)}Sr$ of 0.7096 was established (Bignell & Snelling, 1977). All the five samples have ratios of ($^{87}Rb/^{86}Sr$) <40. Four samples including one of a high Rb/Sr ratio of 124 yielded an age of 227±9 Ma and a Sr intercept of 0.7132 but this age was dismissed by the authors to be of geological significance. Six biotite granites from the cover of the Bujang Melaka, comprising a small Rb/Sr ratio of 9–16, define a "isochron" of 218±5 Ma and a Sr intercept of 0.7165. A six point "isochron" including some samples from Bignell and Snelling (1977) gave an age of 207±14 Ma and Sr intercept 0.7193 whilst four samples of a tourmaline biotite granite yielded one of 194±23 Ma and a Sr intercept of 0.7222. The first age was established by the BGS (Darbyshire, 1988) and the second by the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR; Schwartz and Askury, 1989). From the Kledang Range only four granite samples were taken by Bignell and Snelling (1977) for Rb-Sr analyses and these were plotted onto an isochron diagram together with samples from the Bintang Range further to the east. These did not fit to any regression lines.

K-Ar biotite ages for the Main Range area are in a range of 102–211 Ma (Bignell & Snelling, 1977), 131–253 for the Bujang Melaka (Kwan, 1989) and 198–207 Ma for three samples of the Kledang Range (Bignell & Snelling, 1977). The ages lower than late-Triassic are explained to result from fault reactivations. The late-Triassic and the three late-Permian ages are explained as cooling ages of the granite intrusions. Muscovites of greisen bodies and greisenized veins yielded late-Triassic ages of 206–208 Ma and are interpreted to date the tin mineralization.

RESULTS

Sample description

A sample location map is given in figure 3. This also includes samples from Bignell & Snelling (1977) and Kwan (1989). Exact coordinates and altitude is presented in table I. It has to be noted that due to the lack of exposures in the field and to the common change of mineralogy, texture and alteration of the granitoids it was not possible to distinguish between different plutons. In the following description therefore only the geographical names will be used to define where the following described granites occur. Samples for K-Ar and FT analysis were collected over the widest spread of different granitic rocks and grade of alteration.

E-W profile of the Kledang Range: In this profile through the Kledang Range along the new highway from Ipoh to Kuala Kangsar the following

Table 1 Localities and rock-types of the Kinta Valley and Kuala Lumpur area

Field no.	Laboratory no. (KAW)	Locality	Co-ordinates (m)	Altitude (m)
Sampled by present author:		**Kinta Valley area:**		
85/1	2675	Kledang Range	514'700/344'100	30
85/2	2676	Kledang Range	518'800/337'300	250
85/3	2677	Kledang Range	519'100/335'800	150
85/4	2678	Kledang Range	519'400/330'500	20
85/5	2679	Kledang Range	516'900/340'600	100
85/6	2680	Kledang Range	509'600/339'000	10
85/7	2681	Kledang Range	507'900/335'400	580
85/8	2682	Kledang Range	500'500/336'000	40
85/12	2683	Kledang Range	532'000/343'000	50
85/24	2684	Main Range	517'000/357'000	70
85/28 a)	2685	Main Range	517'000/357'000	70
85/28 b)	2686	Main Range	505'500/356'700	1100
85/30	2687	Main Range	504'000/357'000	700
85/31	2688	Main Range	496'000/356'000	40
87/1	2991	Cameron High. road	467'800/369'400	80
87/2	2992	Cameron High. road	482'000/371'700	590
87/3	2993	Cameron Highlands	493'000/375'600	1350
87/4	2994	Cameron Highlands	498'500/379'500	1700
Sampled by the GSM:				
54/1	2689	Bujang Melaka	485'000/355'000	40
65/1	2690	Bujang Melaka	478'800/352'000	40
65/2	2691	Bujang Melaka	479'000/352'500	40
65/3	2692	Bujang Melaka	475'400/352'800	40
65/4	2693	Bujang Melaka	475'000/352'800	40
65/5	2694	Bujang Melaka	468'800/357'700	40
65/6	2695	Bujang Melaka	469'500/359'500	40
65/7	2696	Bujang Melaka	479'800/360'700	100
65/8	2687	Bujang Melaka	477'500/361'400	60
65/9	2698	Bujang Melaka	476'400/361'100	60
65/10	2699	Bujang Melaka	475'600/362'200	40
Sampled by present author:		**Kuala Lumpur area:**		
87/6/1	2995	Ulu Langat	345'000/429'000	70
87/6/2	2996	Kampung Lui	371'000/422'000	350
87/6/3	2997	Jelebu	344'000/452'000	230
87/6/5	2998	Kuala Klawang	326'000/457'000	140
87/6/6	2999	Gap road	395'000/415'000	150
87/6/8	3088	Genting Highlands	374'000/422'000	1700
Sampled by present author:		**Kinta Valley tin mines**		
85/13		Kin Poh mine, no. 842	530'000/344'000	50
85/18		Min Fat mine	521'000/345'000	40
85/26		U Meng mine, no. 810	503'000/349'000	40
85/40		Leong Fong Yuan mine no. 720	477'000/336'000	40
85/49		Luan Hin Loong mine	476'000/361'200	60
85/53		MMC mine	463'000/353'000	30
85/58		Sungei Batu, no. 734	469'000/354'000	40

GSM : Geological Survey of Malaysia, Kwan (1989) rocks were collected:

KAW 2675 is a medium grained muscovite-bearing biotite granite exposed in the Wing Sang Cheong quarry west of Ipoh. Greisen bordered cassiterite-quartz-tourmaline veins strike N-S and were mined some years ago. Thin sections show a primary crystallization texture; predominantly perthitic K-feldspar, moderate albitization along grain boundaries; unzoned, fully sericitized plagioclase; biotite is completely chloritized with exsolutions of Ti-Fe-oxides; tiny muscovite flakes randomly replace biotite and K-feldspar; minor fluorite, tourmaline and corundum is dispersed in the mineral assemblage; the feldspar phenocrysts are not disrupted; quartz exhibits weakly ductile deformation. This medium grained PTG shows mineral alteration due to ingress of fluids.

KAW 2676 is a greenish medium to fine grained felsic, muscovite-bearing leucogranite (STG) from the north entrance of the Kuala Kangsar highway tunnel. Rounded bluish quartz, plagioclase and few K-feldspars phenocrysts give a porphyritic look to the rock. Thin sections show poikilitic K-feldspar (cross hatch twins and perthite exsolution laminae) replaced by albite and quartz forming the fine grained texture; plagioclase is fully sericitized; biotite is chloritized or completely dissolved; epidote, titanite and Ti-Fe-oxide exsolutions occur parallel to 001; chlorite is light green; fine muscovite flakes randomly grow within K-feldspar and biotite. Tourmaline-quartz veins are rare and fluorite growth in NW-SE and NE-SW striking joints. Cataclastic rocks within shear zones contain a finely crystalline mineral assemblage of chlorite, epidote, albite and quartz. This granite is suggested to be an almost fully recrystallized granite related to hydrothermal alteration.

KAW 2677 was taken in the vicinity of a NE-SW striking fault. It is a highly disrupted and altered granite (PTG) containing large K-feldspar megacrysts. Thin sections show an entirely disrupted mineral assemblage and weakly ductile deformed quartz clusters. The fractures are filled mainly with quartz, calcite and minor fluorite. Tourmaline grows into the cleavage of K-feldspar; biotite is chloritized with epidote and titanite exsolutions and K-feldspar intersites parallel 001; plagioclase is sericitized and kaolinized towards fractures; minor silicification and albitization occur; muscovite flakes are accessory in plagioclase and biotite. Zones of 40 meter long and up to 30 cm wide occur where the rock consists of about 70% kaolinite. The granite is of a PTG type with hydrothermal alteration limited to fractures.

KAW 2678 is a fresh biotite granite (PTG) with weak alignment of K-feldspar phenocrysts and biotite. In thin section most minerals show intense ductile deformation; kinked plagioclase twinning laminae, some cores are brittle deformed comprising fluorite and muscovite in the cleavage; biotite is kinked; cross hatch twins occur in micro shear plains of K-feldspar; quartz contains large subgrains. Primary biotite contains zircon, apatite and allanite inclusions and parallel 001 K-feldspar; oligoclase is fresh but includes tiny muscovite flakes; albitization is limited to K-feldspar grain boundaries. This granite is a weakly foliate, predominantly ductile deformed PTG showing no hydrothermal alteration.

KAW 2679 is a coarse grained biotite granite (PTG) with 5 cm large K-feldspar megacrysts. It was collected from a fresh, perfectly rounded boulder of car size and is suggested to originate from a higher altitude. Two different plagioclase phenocrysts occur: a) fully saussuritized, b) unaltered twinned oligoclase; biotite is dark brown (primary) or light brown (secondary) with exsolutions of ilmenite flakes, sagenite, epidote and shows pseudomorphic growth after amphibole (?) is inferred; quartz occurs as clusters; muscovite is absent. This underformed granite show almost no interactions with a fluid.

N-S profile of the Kledang Range: KAW 2683 is a foliate biotite granite of transitional texture (TTG) collected in the contact of the pluton to the sediments at the northern end of the Kledang Range (Weng Hing mine). A NE-NW striking fault zone cuts through the outcrop disrupting the contact metamorphic marble. Fluorite gravels of green to violet colors are common. The mined tin is of alluvial and eluvial nature. Primary ores are composed predominant of sulphides. The non-mineralized biotite granite in the contact zone is strongly kaolinized and mineral grains have lost their coherence. Tourmaline-quartz veins of various dimensions are offset by younger shear zones. In thin section the granite shows a brittle to ductile deformed mineral assemblage. K-feldspar phenocrysts are granulated and elongated plagioclase is disrupted; both are healed with albite and quartz; strain induced quartz grain recrystallization (0.05 mm) outgoing from sutured grain boundaries suggests a temperature range <300°C (Voll, 1976). Primary biotite is mostly fresh and minor sericite occurs in fissures of feldspar. This foliate TTG is a strongly deformed rock where the influence of hydrothermal overprint does not seem to be extensive.

KAW 2680 was collected from a quarry at the foothill of the Kledang Range northwest of Ipoh. A biotite granite is characterized by few K-feldspar phenocrysts and 5 cm sized spheroid tourmaline-biotite clusters. This TTG is brittle to ductile deformed. The cores of K-feldspar and plagioclase phenocrysts are disrupted and filled with few muscovite, fluorite, sericite and allanite; K-feldspar phenocrysts show newly formed rims. Tourmaline is intergrown with biotite and infiltrates into the shear deformed cleavage of feldspar; minor primary and major secondary, and/or chloritized biotite occurs; silicification and albitization is evident. Tourmaline-rich veins in the outcrop strike NW-SE and quartz rich ones N-S. This granite is a disrupted TTG showing intense hydrothermal fluid rock interaction.

KAW 2681 is the sample collected from the highest altitude (580 m) but located still close to the Kinta Valley. The coarse to medium grained granite (TTG) has large K-feldspar phenocrysts. Ductile to brittle deformation is of local occurrence. Primary biotite is in domains fully chloritized (light green) including epidote, Ti-Fe-oxide exsolutions and major K-feldspar in 001; silicification is intense and violet-colored quartz grains include ore minerals, zircon and fine oxy-biotite needles (stilpnomelane ?); plagioclase phenocrysts are saussuritized including chlorite, muscovite, fluorite, Ti-Fe-oxides, calcite and remnant K-feldspar. Fractures are filled with quartz, chlorite and fluorite. This TTG is suggested to be a recrystallized, locally disrupted rock that underwent fluid alteration outgoing from fractures.

KAW 2682 is a sample from a granite quarry near Papan at the southern end of the Kledang Range where a medium to fine grained felsic leucogranite is exposed (STG). Cross hatch twinned K-feldspar phenocrysts are disrupted. The residual predominant fine grained secondary texture is mylonitic. Ductile deformation and dynamic quartz recrystallization (0.01 mm) indicate a temperature range of <300°C. Yellow-appearing plagioclase is completely sericitized and kaolinized; bended primary biotite is free of inclusions or it may be completely dissolved; muscovite is absent. This granite is a deformed, mylonitic granite having only subordinate interactions with a hydrothermal fluid.

***N-S profile of the Main Range*:** Most samples could only be taken adjacent to the Kinta Valley because roads in the east direction into the Main Range are not existing:

KAW 2684 is a coarse grained muscovite bearing biotite granite (PTG) comprising large K-feldspar megacrysts; they are cross hatch twinned, comprising perthite exsolution laminae; quartz is bluish; primary biotite is within clusters; muscovite is bounded to biotite and K-feldspar; plagioclase has sericitized cores; no albitization or silicification is observed. Deformation is weak and varies from brittle to ductile with the occurrence of quartz subgrains. Some infiltration of tourmaline is present. This granite is typical for the Main Range.

KAW 2685 and *KAW 2686*, both samples originate from the same locality east of Ipoh at the altitude of 1100 m and are sited presumably in the vicinity of a NE-SW striking fault zone. KAW 2685 is a entirely kaolinized, maximum altered granite occurring in a 20 m wide zone. Only quartz clusters have survived the kaolinization but in thin section remnant K-feldspars and muscovite flakes occur occasionally; plagioclase, biotite and apatite are completely dissolved whilst zircon survived within quartz; quartz shows the same deformation style as the previous sample. From 60 kg of sample only zircon and no apatite could be extracted.

KAW 2686 is a corresponding but less altered medium to fine grained leucogranite (TTG). It looks porphyritic and comprises large subgrains of quartz; few remnant K-feldspar phenocrysts are highly deformed; intensely disrupted plagioclase includes muscovite flakes and fluorite in the core and is surrounded by new albite rims. The fine grained texture consists of an almost equigranular K-feldspar, plagioclase, quartz assemblage where K-feldspar contains resorbed grain boundaries and quartz of 0.5 mm size shows triple points; muscovite and small secondary biotite with large zoisite spheroids is included in quartz. This granite is suggested to be entirely recrystallized, ductile to brittle deformed, and subsequently kaolinized.

KAW 2687 is a granite where mineral grains have completely lost coherence by kaolinization. It was collected close to a contact zone to the marble. The granite was originally coarse to medium grained and up to 3 cm K-feldspar phenocrysts are still observed.

In the Tekka mine (Tong Seng mine) the granites are in close contact to the marble. Primary tin occurrence is widespread and restricted to quartz-tourmaline-cassiterite and quartz-cassiterite-wolframite veins, which cut through two biotite granites of different composition and texture.

KAW 2688 is a medium grained equigranular felsic leucogranite with no K-feldspar phenocrysts. The second not sampled granite variety is a highly altered medium to fine grained granite comprising K-feldspar phenocrysts. In the first mentioned granite the mineralized veins are up to 20 cm wide and bordered with muscovite-quartz greisen. Tourmaline and sulphides (mainly arsenopyrite) occur in the rock matrix. Lepidolite occurs in association with arsenopyrite. All vein types are cut by younger E-W striking, 20 cm wide and completely kaolinized shear zones. The strongly altered biotite TTG (KAW 2688) is intensely disrupted. Domains of primary biotite and fully chloritized ones occur; plagioclase shows sericitized cores; muscovite and sericite occurs within fissures. Thin sections of the felsic biotite granite show a K-feldspar phenocrystic origin where quartz and corundum replace it; infiltration and formation of tourmaline, topaz, fluorite and muscovite is abundant; remnant biotite is slightly brownish (secondary) containing almost no opaque minerals. Deformation style in both varieties is the same. Large quartz subgrains and sutured grain boundaries are even found in vein quartz.

Bujang Melaka: The following described samples were collected by Kwan (1989) and Bignell and Snelling (1977) see figure 13:

4/1, S15, 57–59 were collected from the Kuala Dipang quarry at the NW end of the Bujang Melaka. The exposed rock association is rather unique compared to the one known from the Kledang Range. It is dominated by a coarse grained biotite granite containing K-feldspar megacrysts. Dark, fine grained and biotite rich, completely recrystallized xenoliths are frequent.

Almost parallel orientated aplites of 5 to 20 cm in width and composed of biotite-free and biotite-rich domains cut through the outcrop. Veins of quartz-tourmaline- arsenopyrite are dispersed. In the youngest joints and shear zones chlorite and fluorite is present. Thin sections within the dominated coarse grained granite show cross hatch twinned microcline; saussuritic plagioclase, containing epidote of 0.1 mm size; remnant amphiboles are resorbed by muscovite, plagioclase and tourmaline, others are completely chloritized including exsolved iron oxides, large titanite, apatite and calcite; idiomorphic plagioclase contains fluorite and amphibole inclusions; tourmaline grows along the K-feldspar cleavage. The amphibole occurrence has been reported from hornfels enclaves of the same quarry by Santokh Singh and Yong (1982). Xenoliths show an extremely high content of thin apatite needles enclosed in quartz and plagioclase; newly formed biotite within a fully recrystallized texture and remnants of amphiboles are present. Tourmaline and fluorite are dispersed in all rock types. The style of deformation is weakly ductile. It is suggested that the protolith was rather granodioritic in composition and was entirely altered.

Residual samples were collected from the Bujang Melaka-type granite by the GSM (Kwan, 1989; see Fig. 13). Samples nos. *65/1–4, 65/7* and *65/8* are coarse grained PTG's. The large K-feldspar megacrysts are exclusively perthites; plagioclase is fully sericitized containing calcite; primary biotite is strongly pleochroic from brown to very dark greenish-brown and remarkably different to the ones observed from the Kledang and Main Range; the grade of chloritization is variable dependent on rock fracturing and seems to correlate with tourmaline and fluorite infiltration; muscovite is absent; quartz is undulary. The deformation is predominantly brittle like in the Kuala Dipang quarry:

65/8 is located in the vicinity of a NNW-SSE striking fault which shows strong ductile to brittle deformation similar to the one described from the Tekka mine (KAW 2689). Biotite is recrystallized with exsolved Ti-Fe-oxides at the grain boundaries; plagioclase shows brittle deformation comprising muscovite in the cleavage interstices; muscovite replaces the K-feldspar and biotite.

At the Asia mine *(KAW 2856; 65/5)* in the very south of the Bujang Melaka the contact zone of the Melaka-type granite to a medium grained equigranular pink granite is exposed. The latter is highly kaolinized. A pure muscovite-quartz greisen body is outcropping and seems to be connected to the pink granite. The pink color is given by the fine laminar perthitic K-feldspar with resorbed grain boundaries; dark greenish and secondary, light brown biotites are present, showing occasionally pseudomorphism to amphibole; ilmenite flakes border hexagonal crystals and show often a rhombic zoning within the biotite; chlorite replacing biotite is light green and contains almost no opaque minerals; plagioclase has grown as twinned crystals or comprises sericitized cores with fluorite, epidote and minor muscovite flakes. This granite is considered to be almost fully recrystallized.

Cameron Highlands road: The four samples collected along the Cameron Highlands road into the Highlands are all primary textured biotite granites (PTG):

KAW 2991–2994 are sited in a N-S tending fault zone showing brittle to ductile deformation. Feldspars are disrupted and healed with quartz and albite. The quartz deformation in the samples of the southern profile is different than the one in the Highlands. In the first case a weakly deformed granite display dynamic quartz recrystallizations along sutured grain boundaries in the 0.05 mm grain size, suggesting a higher temperature range than the one from the Highlands. In the second case quartz is only recrystallized in 0.01 mm grain size and limited to micro-shear zones, indicating a temperature range <300°C; K-feldspar is predominantly perthitic; primary and secondary biotite of the Main Range style occur; fibres of chlorite/muscovite mixtures show pseudomorphic growth (amphibole ?); plagioclase is zoned with saussuritized cores; muscovite is absent; tourmaline growth is variable.

KAW 2992 contains remnants of amphiboles replaced by chlorite and muscovite showing titanite exsolutions. This locality contains dark xenoliths and aplites.

KAW 2993 is a slightly chloritized disrupted muscovite-bearing biotite granite collected from the quarry 5 km south of Tanah Rata. Tourmaline is common; albitization and silicification is evident; pegmatites and biotite-rich xenoliths occur; in the youngest joints yellow uranium oxides are present.

Summary: Almost no granite is free of alteration and subsolidus reactions. The main part of the Bujang Melaka-type granite and the western Kledang Range are only weakly affected from subsolidus reactions. Some granites of the Bujang Melaka, the Main Range and the Kledang Range were originally more basic in composition. Fragments of amphibole, primary biotite and anorthite-rich plagioclase occur including their exsolution products. Their replacement by K-feldspar and albite-rich plagioclase indicate a general enrichment in alkalies. Two different types of biotite are frequent; dark brown in PTG and light brown comprising Ti-Fe-exsolutions in TTG and STG. Few granites are almost fully recrystallized and same time the biotite content drops dramatically; biotite is replaced by typical light green chlorite and the opaque minerals are almost absent. Any transitions to partly altered granites with different stage of F and B mineral infiltration occur. Growth of muscovite is in all cases of secondary origin. Intense kaolinitization is abundant in granites close to contact with sediments and in shear zones. The style of deformation is variable and in most cases fault related. Granites bordering the Kinta Valley are all ductile to brittle deformed assuming a temperature range <300°C estimated from dynamic quartz recrystallization. A further fault related brittle and cataclastic deformation is superimposed and can be accompanied by additional kaolinitization. In cases where disrupted cores of feldspar megacrysts are surrounded by undeformed albite rims and/or disrupted and healed phenocrysts, the possibility has to be considered that such deformation predates the subsolidus reactions.

Geochemistry

In table II the X-ray florescence (XRF) analysis for major and minor elements are listed. Figure 4 shows variation diagrams of TiO_2 versus major and minor elements plotted for different granites from both sides of the Kinta Valley.

Geochemical analysis have been carried out on the same 30 kg samples which were used for age dating. The reason was to obtain information about element behavior during rock alteration. Understanding of element behavior could be important for the interpretation of the highly discordant reported K-Ar mica ages. It is noted that the number of analysis is small and that only a limited statistics is possible. Further existing analysis from the Geological Survey of Malaysia (GSM) and of the one of the UK (GBS) have been added (Askury; Cobbing & Pitfield, personal communications).

Generally, in the TiO_2 versus major and minor elements diagram any magmatic differentiation trends may be observed with decreasing TiO_2 content. In addition, this diagram any hydrothermal alteration can be detected best as Ti behaves as one of the most immobile of the major elements. Any element mobility can be observed in their vertical variation disturbing the linear differentiation pattern. In the almost fully recrystallized leucogranites the TiO_2 is lowered due to lower biotite contents and silicification (KAW 2675–76, 2685) what may be superimposed upon any differentiation trend.

The granitoids group basically into two fields. More TiO_2 rich, less evolved granites are those of the Bujang Melaka-type and the PTG of the Kledang Range. In the second field plot the TiO_2 depleted TTG and STG of the Kledang Range and the granites and leucogranites bordering the Kinta Valley. Vertical scatter due to granite alteration is predominantly observed within the second field. Therefore a division into two fields at an empirically chosen value of 0.3 for TiO_2 seems reasonable. Elements with a vertical variation occur for SiO_2, Al_2O_3, CaO, for the alkalies, for Y, Rb, U, Th, Sn, W, Pb, Zn, Th and to a lesser extent for Sr. A remarkable increase of N_2O and decrease in K_2O with decreasing TiO_2 in the field of the TTG and STG might

Table II. Chemical analyses from the granites of the Kinta Valley area

Sample no.	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	Cr_2O_3	NiO	Loi	Total
Kledang Range														
KAW 2675	74.87	12.63	1.52	0.03	0.32	0.56	3.05	5.39	0.15	0.07	0.02	0.02	0.72	99.34
KAW 2676	74.73	12.43	1.25	0.03	0.40	0.87	3.18	4.99	0.19	0.04	0.01	0.02	0.71	98.86
KAW 2677	74.96	12.02	1.68	0.04	0.42	0.70	2.19	5.45	0.22	0.05	0.01	0.02	1.03	98.79
KAW 2678	71.77	13.42	2.42	0.04	0.50	1.36	3.01	5.38	0.24	0.06	0.02	0.02	0.60	98.84
KAW 2679	70.57	13.80	2.42	0.05	0.88	1.85	2.70	5.37	0.43	0.13	0.02	0.02	0.51	98.73
KAW 2680	74.50	12.35	1.68	0.04	0.36	0.85	2.51	5.27	0.22	0.08	0.01	0.02	0.61	98.53
KAW 2681	75.17	12.08	1.58	0.05	0.29	0.83	2.78	5.30	0.15	0.04	0.02	0.02	0.61	98.91
KAW 2682	75.03	11.81	1.55	0.03	0.32	0.77	2.48	5.46	0.20	0.04	0.02	0.02	0.48	98.23
KAW 2683	73.00	12.94	1.93	0.04	0.56	1.04	2.41	5.36	0.30	0.10	0.02	0.02	0.88	98.59
Main Range														
KAW 2684	73.39	13.08	1.65	0.03	0.36	0.66	2.58	5.80	0.21	0.08	0.02	0.02	0.75	98.64
KAW 2685	75.15	13.31	0.36	0.01	0.13	0.15	4.75	2.99	0.16	0.03	0.01	0.02	1.02	98.08
KAW 2686	74.33	12.58	1.54	0.04	0.21	0.68	2.75	5.37	0.17	0.05	0.01	0.02	0.80	98.55
KAW 2687	73.63	13.96	0.99	0.04	0.16	0.01	0.36	5.36	0.11	0.03	0.01	0.03	2.64	97.32
KAW 2688	62.23	24.24	6.59	0.17	0.27	0.01	0.04	3.94	0.10	0.03	0.02	0.03	1.05	98.72

Sample no.	Nb	Zr	Y	Th	Pb	Ga	Zn	Cu	Ni	V	Cr	Ba
Kledang Range												
KAW 2675	20	96	59	37	24	12	6	1	5	9	18	71
KAW 2677	19	144	51	68	30	13	22	2	5	15	12	193
KAW 2678	31	185	55	90	49	16	38	1	5	15	17	228
KAW 2681	21	99	84	58	69	12	42	0	5	7	9	103
Main Range												
KAW 2688	30	158	89	87	78	16	56	3	5	9	11	115

Fe_2O_3 = total Fe

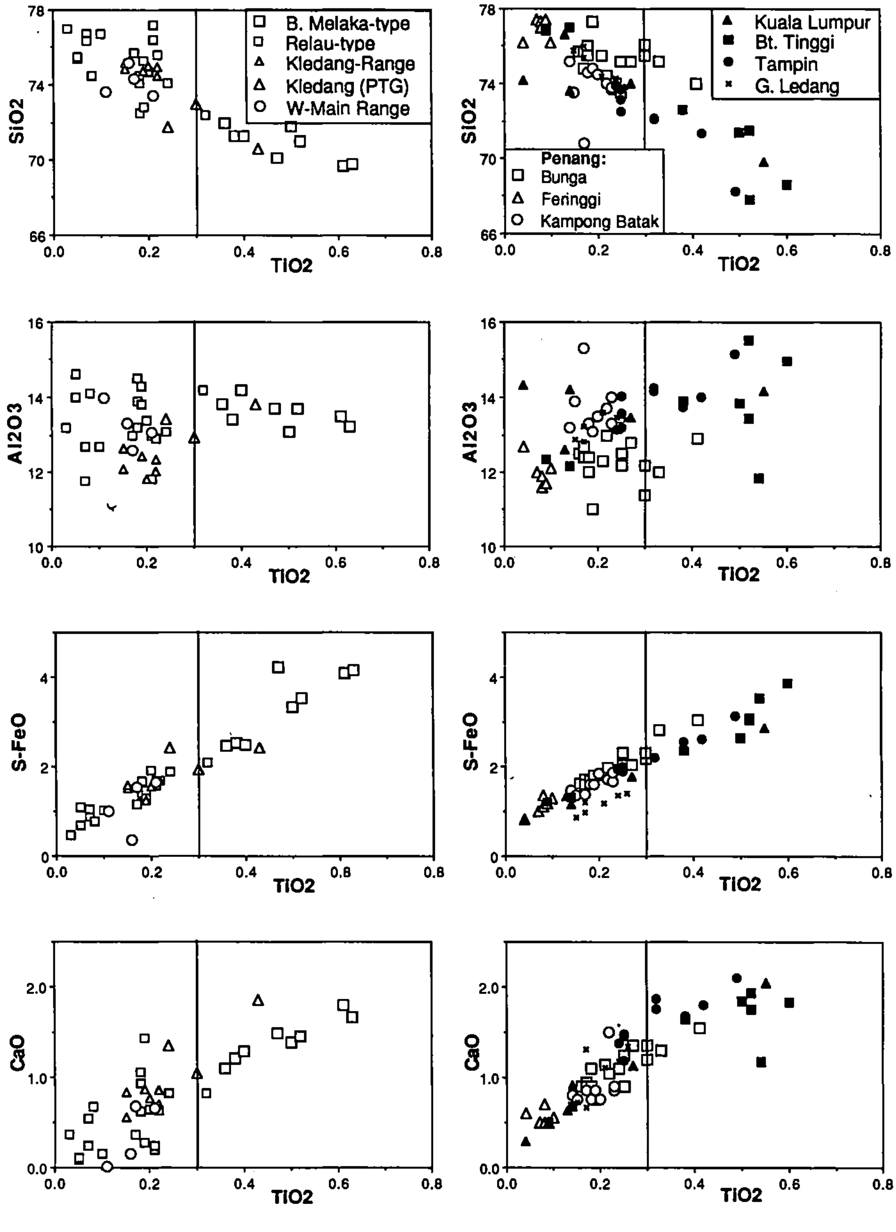


Figure 4a-d: Variation diagrams of TiO_2 versus major and minor elements for granitoids of the Kinta Valley, the Kuala Lumpur and the Malacca area. For comparison the granites of Penang Island are included (Kwan *et al.*, paper submitted). For the Bujang Melaka data are used from Askury (GSM, personal communication) and for Kuala Lumpur and Malacca from Cobbing and Pitfield (BGS, personal communication). Values of no dimension are in wt. %. S-FeO = FeO + Fe_2O_3. The vertical division into two fields at a TiO_2 value of 0.3 was done empirically (discussion see text).

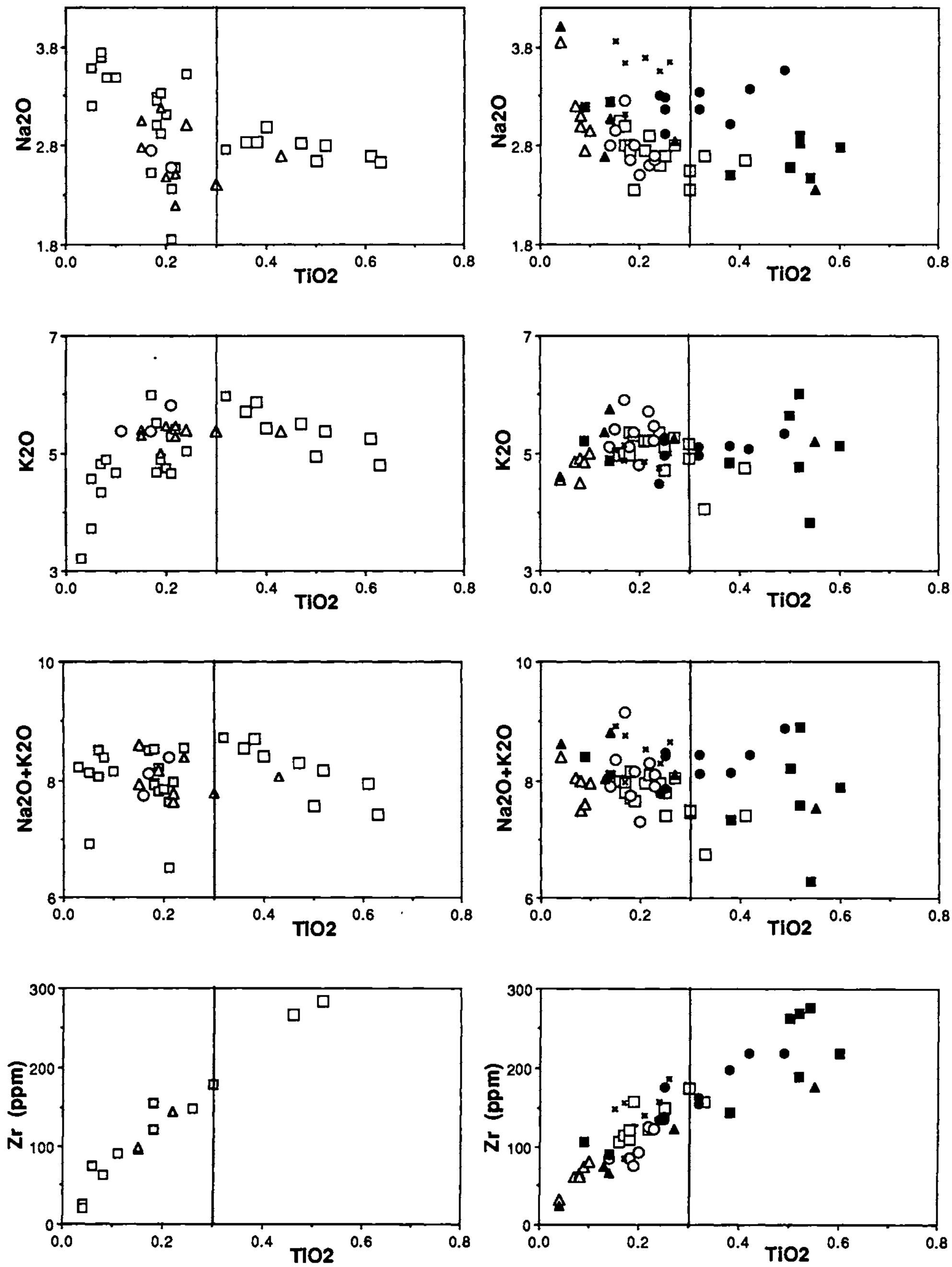
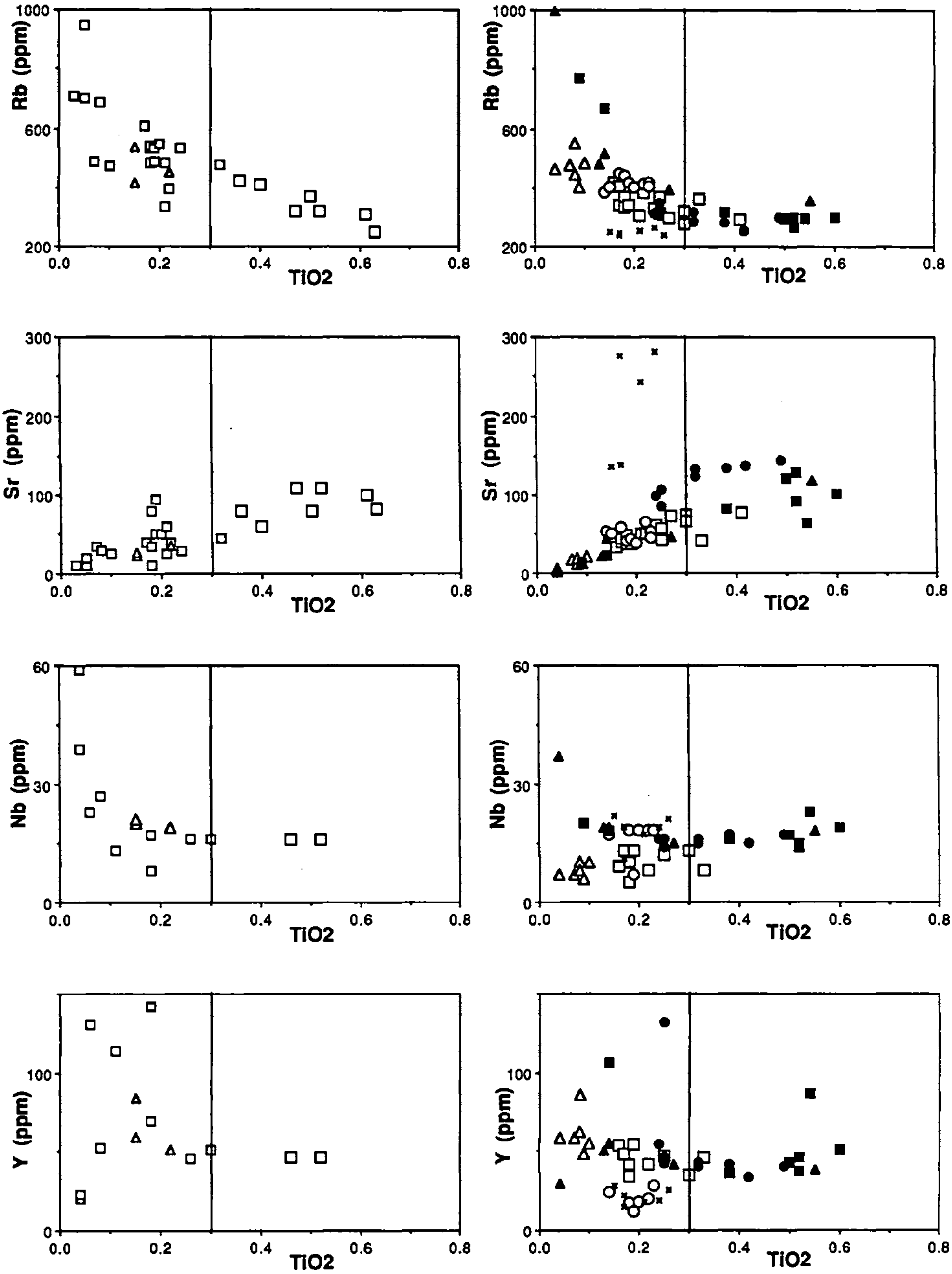


Figure 4b



Rb (ppm)
1000
600
200
0.0
0.2
0.4
0.6
0.8
TiO2
Sr (ppm)
300
200
100
0
Nb (ppm)
60
30
Y (ppm)
100

Figure 4c

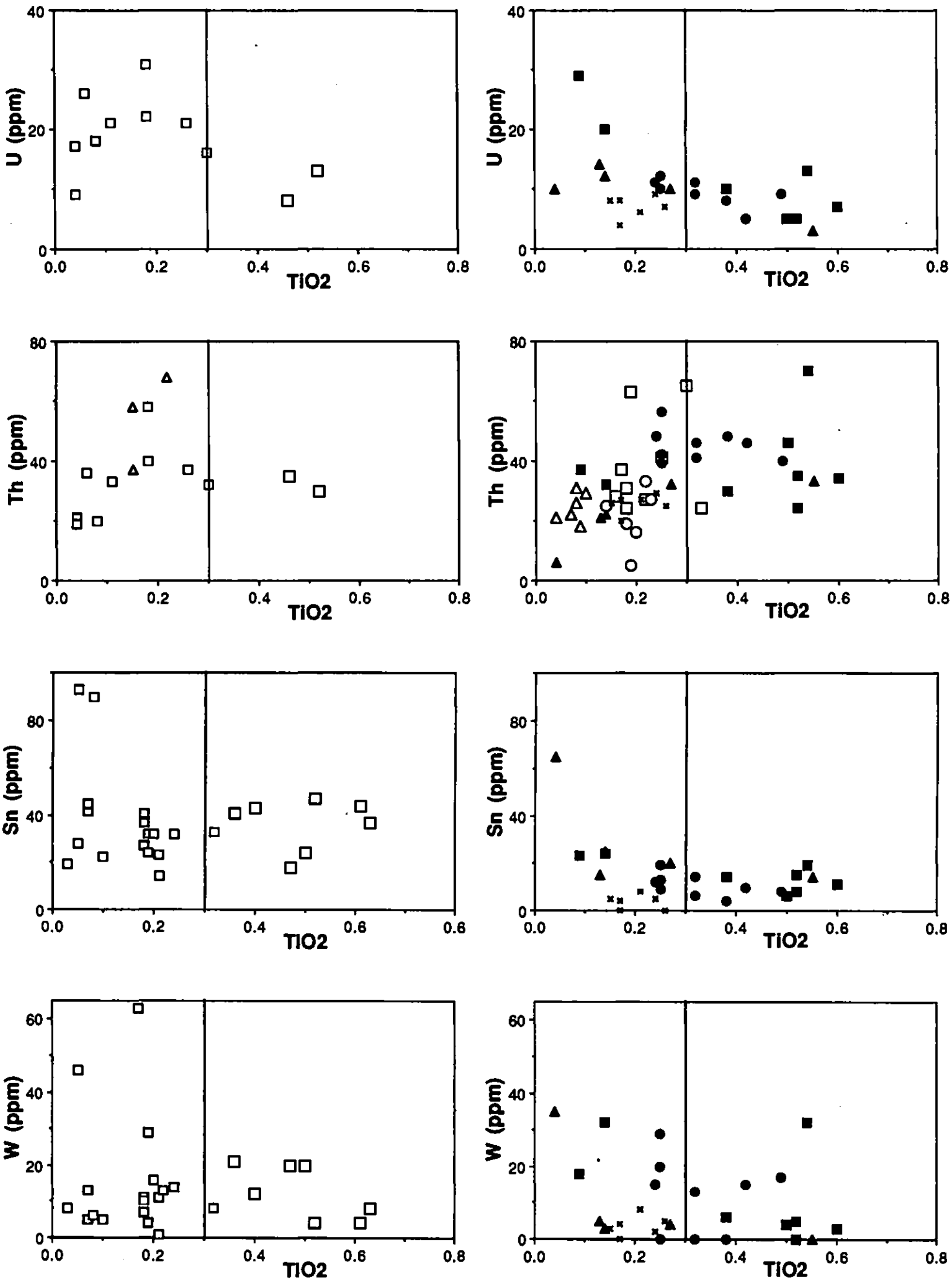


Figure 4d

be due to fractionation with the hydrothermal fluid. A still good linear correlation is found for the Fe total and for Zr and they seem to indicate one magmatic evolution trend. Sample KAW 2688 from the Tekka mine is not plotted in the diagram because the values are far off the scale used. It has aberrant low SiO_2, N_2O, K_2O, TiO_2, CaO contents but extremely high Al_2O_3, Fe total and MnO contents (see table II). This is due to extreme exchange of rock-fluid interactions in a mineralized zone where minerals became dissolved and elements were transported out of the 30 kg sample system. However, the strongly kaolinized leucogranite (KAW 2685) shows no extreme difference of SiO_2 and Al_2O_3 compared to the weakly kaolinized granites. The radioactive elements Th, U, and K, which are responsible for the main heat production in the rocks (Plant *et al.*, 1985), are with mean values of 40 ppm, 12 ppm and 5.1 wt % K_2O respectively, clearly above the average of granites (Wedepohl, 1969).

Rb-Sr whole-rock ages

In table III the calculated Rb-Sr whole-rock ages and the sample numbers used are shown. Analytical data are listed in Bignell and Snelling (1977).

For the Bujang Melaka three "isochrons" have been established. Three PTG comprising a small ($^{87}Rb/^{86}Sr$) ratios of 12–16 yield an whole-rock age of 253.8±3.4 Ma and a reasonable $^{(87/86)}Sr$ initial of 0.7089±0.0007. Two other "isochrons" give a calculated age of 219.6±0.7 Ma and 200.0±9.2 Ma with a Sr intercept of 0.7167±0.0005 and 0.7197±0.0014 respectively, depending on whether the fine grained biotite granite sample no. 59 with a high ($^{87}Rb/^{86}Sr$) ratio of 94 is included or not (Fig. 5). For the Cameron Highlands profile four "isochrons" were established. Two samples of different texture from same locality at Jor Dam Site (nos 81, 82), together with the one from the quarry 5 km south of Tanah Rata yield an age of 290.8±0.8 Ma and reasonable Sr intercept 0.7094±0.0002. Two "isochrons" calculated for further samples collected from same locality, but comprising different ($^{87}Rb/^{86}Sr$) ratios gave late-Triassic ages with Sr intercepts higher than 0.72 (Fig. 6). Five samples from localities of the most southern part of the N-S profile and from close to the Kinta Valley define a still younger age of 186.4±1.3 Ma and an even higher Sr intercept of 0.7328±0.0007. Plotting the Rb-Sr "isochrons" into the age-initial $^{(87/86)}Sr$ diagram (Kwan *et al.*, paper submitted), including those established by the BGS and BGR, two evolution lines can be regressed (Fig. 7). These intersect at the level of an initial $^{(87/86)}Sr$ of 0.709, indicating an intrusion age of 253±20 Ma. This is in good agreement to the 254±3 Ma "isochron" obtained from the Bujang Melaka.

Table III. Calculated Rb-Sr whole-rock "Isochrons" for Main Range granites
Established from data of Bignell and Snelling (1977)

Locality	Ag ±2s (Ma)	Initial (87/86) Sr ± 2s	No. of samples	Sample no.
Bujang Melaka	253.8 ±3.4	0.7089 ±0.0007	3	61, 64, 65
	219.6 ±0.7	0.7167 ±0.0005	4	S16, 57, 59, 67
	200.0 ±9.2	0.7197 ±0.0014	3	S16, 57, 67
Cameron Highlands	290.8 ±0.8	0.7094 ±0.0002	3	81, 82, 84
	218.0	0.7215	2	70, 71
	198.6 ±3.9	0.7264 ±0.0009	3	80, 82, 83
	186.4 ±1.3	0.7328 ±0.0007	5	S18, 68, 69, 76, 77
Kuala Lumpur				
(Gap Road)	203.7 ±0.6	0.7274 ±0.0007	6	S20, 98, 104, 109, 110, 112
	190.7 ±2.6	0.7378 ±0.0044	3	91, 92, 95
	176.1 ±2.0	0.7295 ±0.0009	8	87, 90, 93, 99, 106, 113, 114, 115
	168.4 ±3.1	0.7233 ±0.0009	5	86, 100, 102, 103, 105
(Ulu Kali)	190.7 ±0.6	0.7223 ±0.0009	3	136, 137, 138
(Kuala Lumpur)	189.0 ±2.3	0.7439 ±0.0056	4	154, 155, 156, 162
(Bt. Tinggi fault area)	90.4 ±2.8	0.7308 ±0.0004	3	86, 88, 139
samples not used			8	S21, 101, 111, 150, 152, 159, 160, 168
Malacca				
(± Seremban)	274.3±10.0	0.7137 ±0.0017	6	169, 174, 175, 176, 187, S30
(Seremban)	137.7 ±7.0	0.7396 ±0.0020	3	170, 174, 179
(Kuala Pilah road)	213.9 ±2.1	0.7124 ±0.0007	6	180, 181, 183, 185, 186, 188
(Tampin - Bt. Mor)	231.8 ±1.1	0.7092 ±0.0005	7	191, 193, 194, 205, 207, 208, S26
(Batang - G. Ledang)	89.0 +19.9	0.7072 ±0.0011	4	S27, S28, S29, S34
samples not use			4	S24, S25, 178, 190

K-Ar mica ages

In table IV the analytical data for all established K-Ar analyses for different micas, grain size fractions, aliquots of different chlorite content and check-analysis are listed. Regional distribution of the K-Ar biotite and muscovite ages is shown in figure 8. Muscovite ages show a smaller spread than biotite ages. Samples where both micas could be separated show older muscovite than biotite ages except in case of the sample KAW 2688 from the Tekka mine, where muscovite yielded 194 Ma and biotite 204 Ma. In the Kledang Range the biotite ages become younger from E to W. In general, the biotite ages are independent of granite texture and alteration (KAW 2676, 2677, Kledang Range). In the Main Range the oldest age of 212±2 Ma is obtained from the Cameron Highlands. The youngest biotite age from the southern

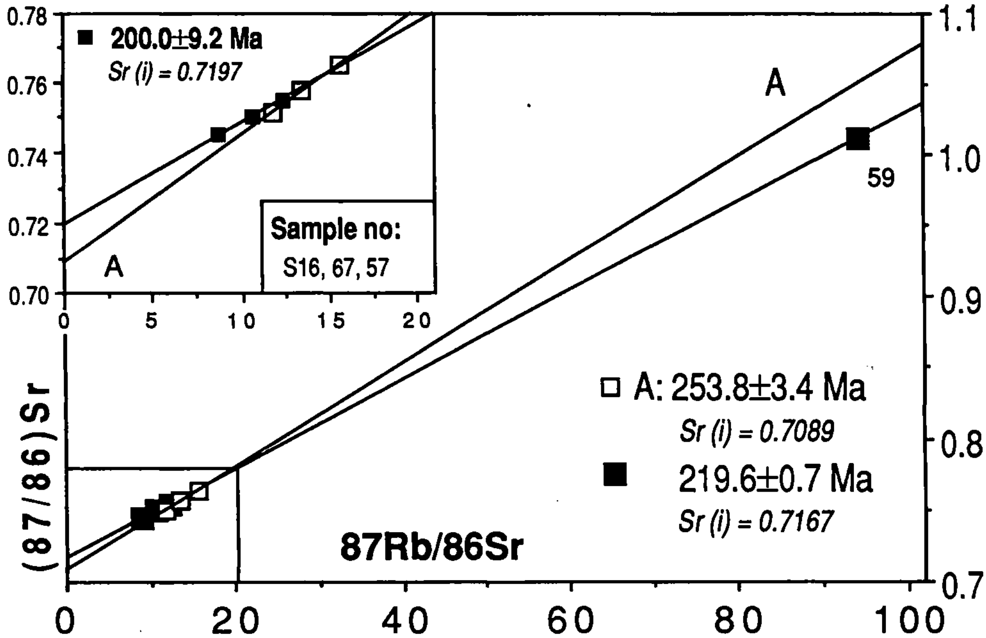


Figure 5: Rb-Sr evolution diagram with whole-rock "isochrons" from the Bujang Melaka. Data were used from Bignell and Snelling (1977). Samples nos. 61, 64, 65 (see fig. 13) define a late-Permian isochron and the corresponding K-Ar ages (Kwan, 1989) are within same range.

road cut of the same profile are Cretaceous (102–118 Ma).

From the most western sample (KAW 2678) of the Kledang Range the grain size fraction 50–90 mesh consists of ~80% light brown, secondary biotite. The fraction 80–100 mesh consists of ~80% of dark brown, primary biotite. The first concentrate yielded 174.3±2.1 Ma and the second 178.1±2.0 Ma showing that the ages for primary biotites are within trend older than the secondary, although they are equal within the error margins.

For the almost fully recrystallized granites no pure biotite concentrates could be separated because chlorite dominates. Generally low potassium contents and the occurrence of chloritized and bleached biotites open the question of the validity of such K-Ar ages. Biotites of highly altered granites are clearly lowered in %K (KAW 2676–77, 2686–88). Therefore many grain size fractions and aliquots of different chlorite content were analyzed. There is not always a strong correlation between microscopically estimated chlorite content and percentage of analyzed potassium. A variation diagram K-Ar age versus %K shows a systematic decrease of age and %K with increasing

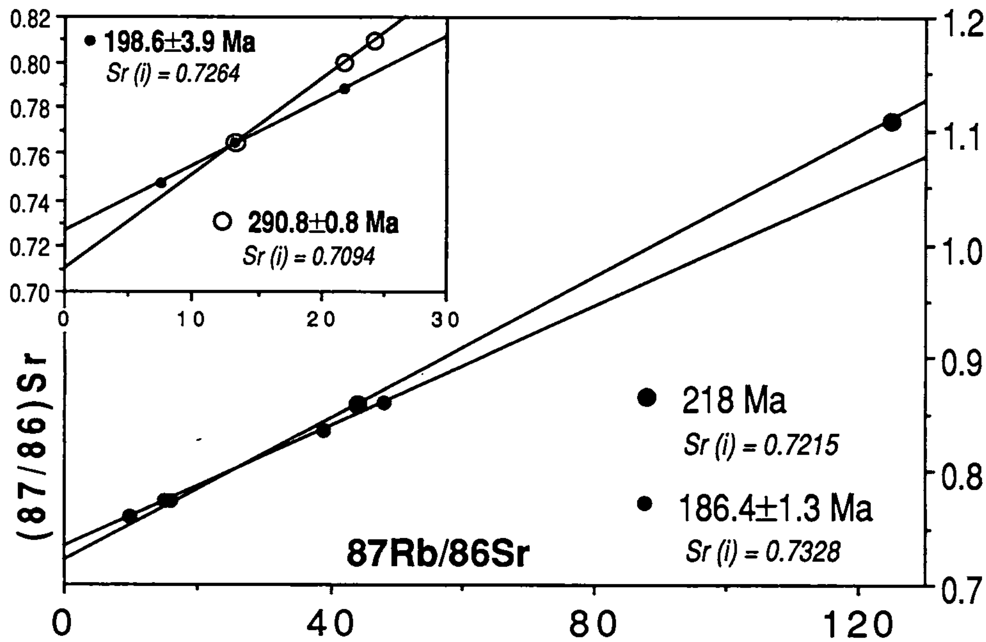


Figure 6: Rb-Sr whole-rock "isochrons" for the Cameron Highlands road established from data of Bignell and Snelling (1977). Three samples from the northern part of the profile and from the highest altitude define a Carboniferous age with reasonable initial $^{(87/86)}Sr$ (see inset). Towards the south younger ages with variable enhanced Sr intercept occur. The age of 218 Ma is defined by two samples, of a primary (PTG) and a secondary textured granite (STG) from same locality.

chlorite content (Fig. 9). It can be seen that down to a K content of 5% the age of biotites does not change and must be geologically significant. It is also evident that not all chlorites behave the same. The larger age decrease for chlorites of sample KAW 2677 (Kledang Range) compared to KAW 2675 can be correlated with an increasing granite alteration (see sample description). In the case where K-Ar biotite ages of same sample are significantly different, the one with the smaller chlorite content is considered to be the more reliable.

Fission track zircon and apatite ages

The tables V and VI show the fission track results for zircons and apatites, together with the results of standards used. Figures 9 and 10 show the regional distribution of calculated ages including those determined from alluvial samples.

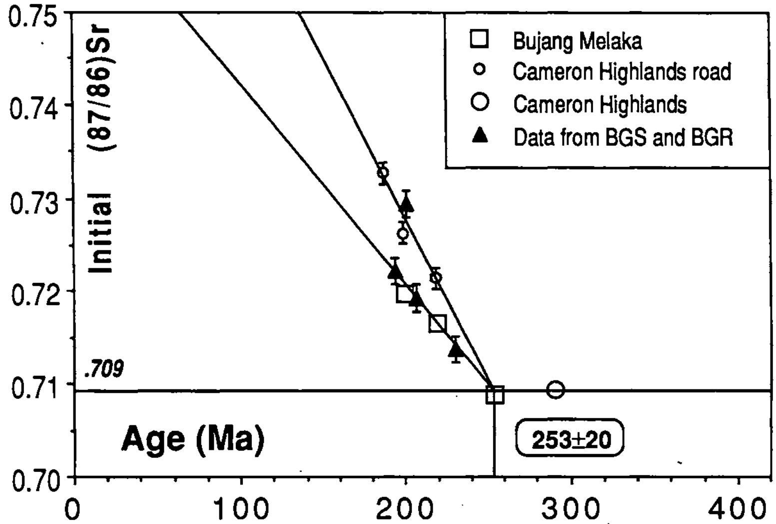


Fig. 7a

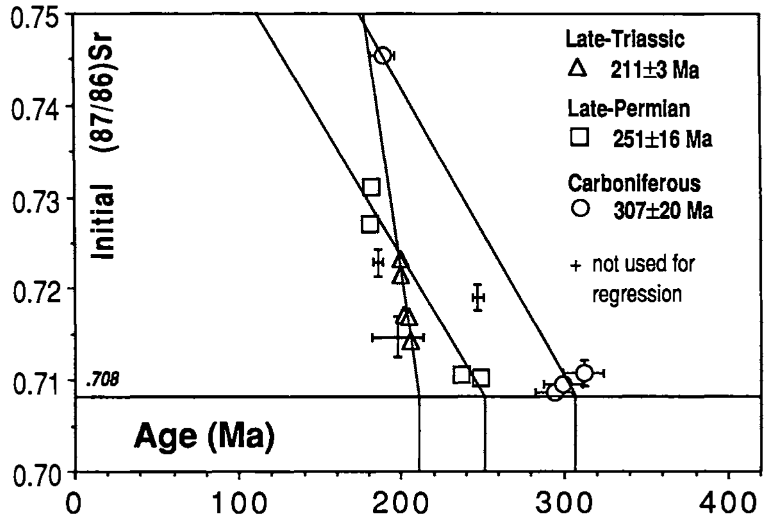


Fig. 7b

Figs. 7a-b: Age versus initial $^{(87/86)}$Sr diagram including all Rb-Sr whole-rock "isochrons" of the Bujang Melaka and the Cameron Highlands area (**7a**). Data established by the BGS and the BGR (Darbyshire, 1988; Schwartz and Askury, 1989) are included. The symbols representing individual Rb-Sr "isochrons" define two straight lines of different slope, which are due to different (^{87}Rb/^{86}Sr) mean values of the granitoids. The late-Permian intrusion age of 230±20 Ma can be extrapolated at the intersection of both regression lines and a starting initial $^{(87/86)}$Sr of 0.7090 can be inferred. The resulting age coincides with the Rb-Sr whole-rock isochron of the Bujang Melaka and the K-Ar biotite ages (see Fig. 5) For comparison the age versus initial $^{(87/86)}$Sr diagram for the granites of Penang Island is included (**7b**; Kwan *et al.*, paper submitted). In addition, good coincidence is evident for the late-Permian age extrapolation and for the Carboniferous age of the Cameron Highlands. Note that the best evaluated starting initial $^{(87/86)}$Sr of the Penang granites is with 0.7080 lower.

Table IV. K-Ar analytical data for micas from granites of the Kinta Valley area

Locality KAW no.	Mineral	Size fraction (mesh)	40Artotal E-8 (mol/g)	1/36Artotal E+12 (mol/g)	40Ar (%)	K (%)	Chlorite (%)	Age ± 1s (Ma)
Kledang Range								
2675	mus	> 122μ	0.3401	9.7850	99.1	8.88		206.6 ± 2.2
	biotite	50-60	0.2224	7.6788	98.3	6.03	15	197.8 ± 2.3
	biotite	50-60	0.1774	4.1173	99.6	4.85	30	198.7 ± 2.7
	biotite	50-60	0.0997	5.4621	94.6	2.78	50	185.8 ± 3.5
2676	mus	>130μ	0.3050	7.7420	98.8	8.52		193.1 ± 2.1
	biotite	60-80	0.1905	5.8030	97.3	5.61	< 3	181.2 ± 2.4
2677	mus	40-60	0.2880	6.8531	98.5	7.91		195.8 ± 3.1
	mus	40-60	0.2866	6.6105	98.5	7.91		194.8 ± 2.1
	biotite	40-60	0.1597	5.8619	96.9	4.68	20	181.1 ± 2.4
	biotite	40-60	0.8384	29.2141	98.8	3.03	50	151.1 ± 1.9
	biotite	40-60	0.0735	15.3570	97.4	2.78	70	142.8 ± 2.9
	biotite	40-60	0.0283	16.1097	93.6	2.04	90	73.2 ± 1.7
2678	biotite	50-90	0.2279	9.4757	98.6	7.08	< 6	174.3 ± 2.1
	biotite	80-100	0.2398	10.5009	98.8	7.30	< 1	178.1 ± 2.0
2679	biotite	50-90	0.2701	15.7965	99.3	7.36	< 3	198.8 ± 2.2
	biotite	50-80	0.2677	8.5100	98.7	7.22	< 4	199.6 ± 2.1
	biotite	50-80	0.2707	4.0271	97.3	7.17	< 2	200.3 ± 2.2
	biotite	80-100	0.2883	14.8340	99.3	7.65	< 5	203.8 ± 2.2
	biotite	> 75μ	0.2761	7.1361	98.5	7.22	< 4	205.1 ± 2.5
2680	biotite	50-60	0.2830	9.5516	98.9	7.30	< 4	208.5 ± 2.5
	biotite	80-100	0.2876	31.9018	99.7	7.44	< 2	209.5 ± 2.3
	biotite	80-100	0.2813	16.9040	99.4	7.13	< 6	213.0 ± 2.7
2681	biotite	35-50	0.2791	4.6242	97.7	7.18	< 5	206.7 ± 2.6
	biotite	50-80	0.3065	1.8926	94.9	7.62	< 3	207.7 ± 2.5
2682	biotite	40-60	0.2938	4.7801	97.9	7.45	< 1	209.9 ± 2.4
2683	biotite	40-60	0.2808	12.1460	99.1	7.31	< 3	207.2 ± 2.2
	biotite	20-40	0.2835	4.5554	97.7	7.29		206.8 ± 2.2
Main Range								
2684	mus	35-40	0.3445	3.6444	97.7	8.84		207.1 ± 2.4
	mus	40-60	0.3394	4.7860	98.2	8.87		204.6 ± 2.2
	biotite	40-60	0.2212	7.2025	98.2	6.20	< 3	191.4 ± 2.2
	biotite	40-60	0.2222	9.5422	98.6	6.26	< 3	191.3 ± 2.2
2686	biotite	40-60	0.2636	14.2468	99.2	7.13	< 2	200.0 ± 2.2
	biotite	40-60	0.2555	26.1832	99.6	7.03	< 5	197.4 ± 2.2
2687	mus	40-60	0.3046	7.1222	98.7	8.31		197.3 ± 2.2
	biotite	40-60	0.2247	4.1187	96.8	6.76	< 6	176.6 ± 2.2
2688	mus	40-60	0.2846	11.0079	99.1	7.94		193.9 ± 2.3
	biotite	35-40	0.2532	24.9385	99.5	6.73	< 1	204.0 ± 2.3
	biotite	40-60	0.2442	43.0794	99.7	6.65	< 4	199.7 ± 2.4
	biotite	40-60	0.2311	21.4037	99.4	6.33	< 10	198.0 ± 2.1
2694	mus	60-80	0.3425	7.4497	98.9	8.81		209.0 ± 2.5
2856	mus	40-60	0.3224	6.7412	98.7	8.28		208.9 ± 2.3
Cameron Highlands								
2991	biotite	40-80	0.1499	8.0244	97.6	7.75	< 1	105.6±1.3
#	biotite	40-80	0.1517	4.8568	96.0	7.75		105.2±1.3
2992	biotite	35-60	0.1478	3.0980	93.6	6.53	< 9	118.2±1.5
#	biotite	35-60	0.1494	2.9029	93.2	6.53		118.9±1.7
2993	biotite	60-80	0.2571	2.9042	96.1	6.55	< 11	205.3±2.3
	biotite	60-80	0.2734	4.8551	97.8	6.87	< 5	211.5±2.4
2994	biotite	35-40	0.3080	6.7668	98.6	7.75	< 1	212.9±2.3
	biotite	40-80	0.3057	5.3932	98.2	7.67	< 2	212.7±2.3

check-analysis

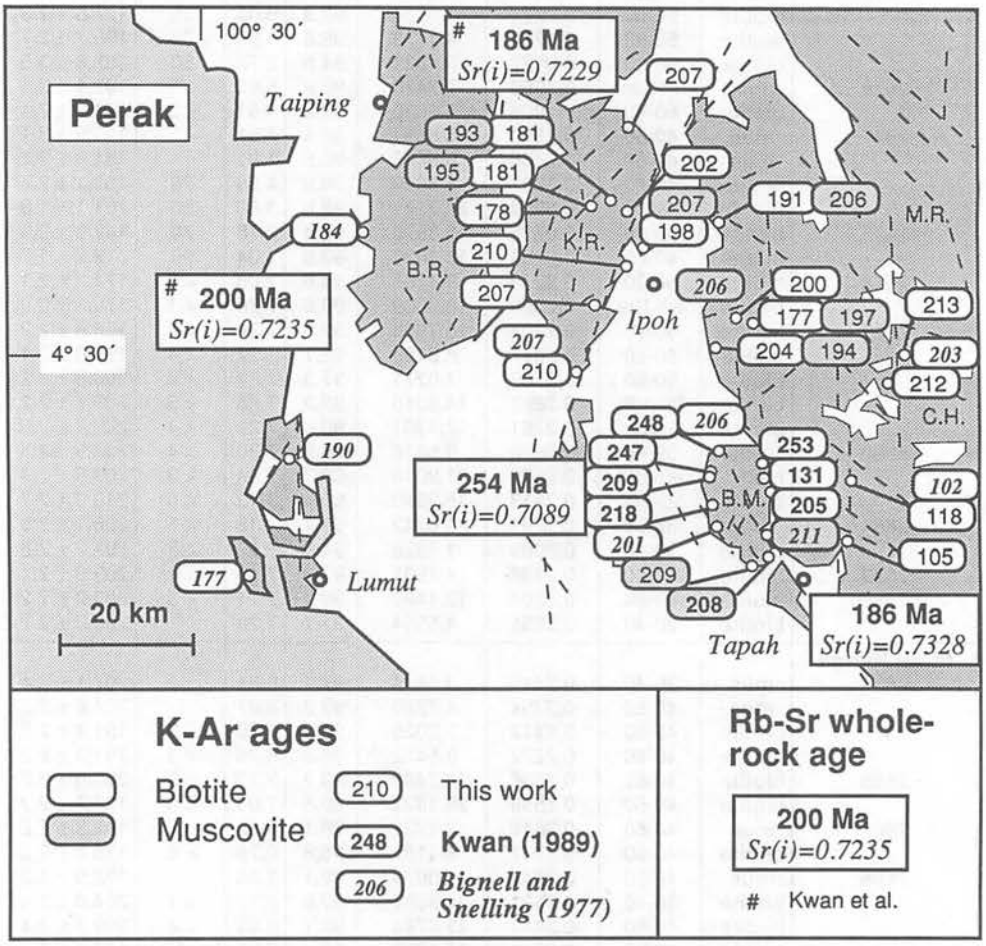


Figure 8: Map of the Kinta Valley area showing regional K-Ar mica and Rb-Sr whole-rock age distributions. Notice that the micas age are grouped in 247-253 Ma, 176-213 Ma and 102-131 Ma.

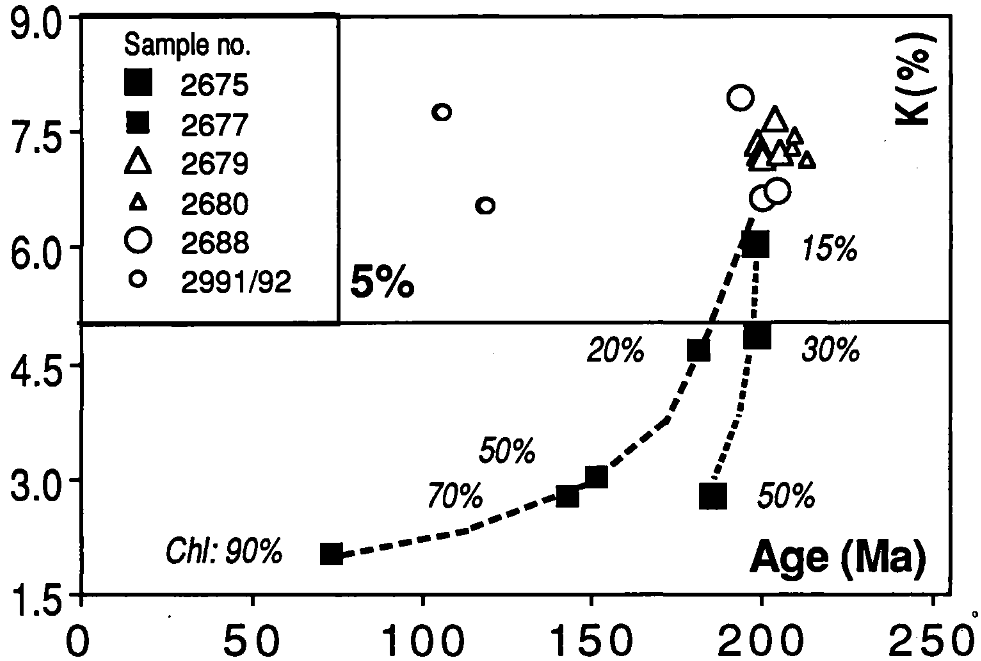


Figure 9: K-Ar ages plotted versus potassium content for biotite, and biotite/chlorite fractions from samples of the Kinta Valley area. The microscopically determined percentage of chlorite is indicated in italic numbers. For general, down to a potassium content of 5% the biotite ages are still preserved within the error margins.

The morphology, U-distribution and the length of tracks in zircons vary. Generally two clearly different type of zircons occur. One is composed of short prismatic rather large crystals of zoned U-content and a lot are metamict. The second type is composed of long prismatic to needle shaped crystals. These are always light in color or transparent, never zoned and are considered to be of the latest crystallization. In most cases they are associated with the short prismatic ones. The recrystallized leucogranites contain more long and clear zircons (Kledang Range, KAW 2676; Main Range, KAW 2686; KAW 2688) comprising short fission tracks. The PTG contain increasing amounts of short prismatic crystals (KAW 2682, 2685, 65/3–4) and usually have long tracks. Most zircons of the Bujang Melaka-type and within granites of the Cameron Highlands profile show inclusions of mostly rounded zircons and monazites.

In table I the altitude of the collected samples is recorded and six samples originate from higher altitude. The zircon ages show a big spread between 124–60 Ma. Generally older ages are obtained from the Kledang Range and NW Bujang Melaka whilst younger ones occur in the Main Range (Fig. 10).

Table V. Fission track results for zircons from granites of the Kinta Valley area

KAW no.	Irradiation no.	No. of crystals	Ns	ps (E+5 tr cm-2)	Ni	pi (E+5 tr cm-2)	Ns/Ni	ps/pi	Dosi-meter	Age ± 1s (Ma)
Kledang Range:										
2675	Be-36	10	1692	227±6	309	41 ± 4	5.476	----	CN-1	104.7 ± 7.4
2676	Be-36	20	2890	151 ± 3	616	32 ± 1	4.692	----	CN-1	89.4 ± 5.0
2676	Bern-H9	8	730	153 ± 5.6	204	43 ± 3	3.578	----	CN-1	85.1 ± 7.1
2677	Be-36	8	1523	231 ± 6	276	32 ± 3	5.518	----	CN-1	104.1 ± 7.7
2678	Be-36	13	2614	210 ± 4	396	32 ± 2	6.601	----	CN-1	123.8 ± 7.9
2678	Bern-H9	9	880	200 ± 7	166	38 ± 3	5.301	----	CN-1	122.6 ± 10.8
2679	Be-36	9	1906	208 ± 5	344	38 ± 2	5.541	----	CN-1	103.2 ± 7.3
2680	Be-36	10	2581	151 ± 3	389	23 ± 1	6.635	----	CN-1	123.4 ± 7.9
2681	Be-36	10	2214	221 ± 5	372	39 ±2	5.683	----	CN-1	104.4 ± 6.8
2682	Bern-H9	9	802	173 ± 6	179	39 ± 3	4.480	----	CN-1	106.4 ± 9.0
2683	Be-36	13	3318	163 ± 3	570	28 ± 1	5.821	----	CN-1	106.5 ± 6.1
Main Range:										
2684	Be-36	12	1336	102 ± 3	324	225 ± 1	4.1223	----	CN-1	75.3 ± 5.3
22685	Bern-H9	6	559	163 ± 7	155	45 ± 4	3.606	----	CN-1	85. ± 8.0
2686	Be-36	11	1122	102 ± 3	301	27 ± 2	3.7228	----	CN-1	67.5 ± 5.0
2687	Be-36	13	1019	79 ±2	2287	22 ± 1	3.551	----	CN-1	63.7 ± 4.8
2688	Be-36	7	791	196 ± 7	171	42 ± 3	4.626	----	CN-1	80.7 ± 7.4
2991	Bern-H9	9	1417	98 ± 3	539	37 ± 2	2.629	----	CN-1	60.2 ± 3.5
2992	Bern-H9	10	1767	112 ± 3	615	39 ± 2	2.873	----	CN-1	68.0 ± 3.6
2993	Bern-H9	8	1358	141 ± 38	330	34 ± 2	4.115	----	CN-1	97.0 ± 6.4
2994	Bern-H9	10	1826	156 ± 4	505	43 ± 2	3.616	----	CN-1	85.5 ± 4.8
Bujang Melaka:										
54/1	Be-36	10	2055	138 ± 3	331	22 ± 3	6.208	----	CN-1	107.3 ± 7.3
65/1	Be-36	17	2638	126 ± 2	398	19 ± 1	6.628	----	CN-1	113.6 ± 7.2
65/2	Be-36	11	1477	137 ± 5	231	27 ± 2	6.394	----	CN-1	108.8 ± 8.6
65/3	Be-36	9	1400	139 ± 6	210	36 ± 3	6.667	----	CN-1	112.5 ± 9.2
65/4	Be-36	10	2193	209 ± 5	381	36 ± 2	5.756	----	CN-1	96.5 ± 6.3
65/6	Be-36	9	1296	154 ± 4	248	29 ± 2	5.226	----	CN-1	86.4 ± 6.7
65/7	Be-36	18	1567	94 ± 2	379	23 ±1	4.158	----	CN-1	67.2 ± 4.5
65/8	Be-36	9	1015	132 ± 4	236	31 ± 2	4.301	----	CN-1	70.0 ± 5.6
65/9	Be-36	10	933	102 ± 3	188	21 ± 1	4.963	----	CN-1	80.1 ± 7.0
65/10	Be-36	12	1410	214 ± 6	245	37 ± 2	5.755	----	CN-1	91.3 ± 7.1

Table V. Fission track results for zircons from the Kinta tin mines and from granites of the Kuala Lumpur area

KAW no.	Irradiation no.	No. of crystals	Ns	ps (E+5 tr cm-2)	Ni	pi (E+5 tr cm-2)	Ns/Ni	ps/pi	Dosi-meter	Age ± 1s (Ma)
Mines:										
85/13	Bern-H9	40	4017	170 ± 0.1	771	33 ± 0.5	----	5.208	CN-1	122.5 ± 4.2
85/18	Bern-H9	17	1740	164 ± 4	382	36 ± 2	----	4.990	CN-1	109.4 ± 8.2
85/26	Bern-H9	25	1600	75 ± 2	551	26 ± 1	----	3.026	CN-1	67.8 ± 3.8
85/40	Bern-H9	30	22978	135 ± 2	800	36 ± 1	----	4.483	CN-1	99.6 ± 8.4
85/49	Bern-H9	20	1699	102 ± 2	600	36 ± 1	----	2.911	CN-1	64.5 ± 3.7
85/85	Bern-H9	25	2582	127 ± 3	635	31 ± 1	----	4.586	CN-1	108.3 ± 9.5
85/53	Bern-H9	25	22413	112 ± 2	860	41 ± 1	----	3.020	CN-1	71.5 ± 6.1
Kuala Lumpur:										
2995	Bern-H9	8	570	130 ± 5	183	42 ± 3	3.115	----	CN-1	73.8 ± 6.5
2996	Bern-H9	8	567	128 ± 5	238	46 ± 3	2.761	----	CN-1	65.8 ± 5.2
2997	Bern-H9	9	879	136 ± 5	276	43 ± 3	3.185	----	CN-1	75.5 ± 5.5
2998	Bern-H9	10	1148	140 ± 4	341	42 ± 2	3.367	----	CN-1	79.2 ± 5.2
2999	Bern-H9	10	1066	132 ± 4	402	49 ± 2	2.652	----	CN-1	63.0 ± 4.0
3088	Bern-H9	3	299	153 ± 9	104	52 ± 5	2.886	----	CN-1	67.8 ± 7.9

Table VI. Fission track results for apatites from granites of the Kinta Valley and Kuala Lumpur area

KAW no.	Irradiation no.	No. of crystals	Ns	ps (E+5 tr cm-2)	Ni	pi (E+5 tr cm-2)	Ns/Ni	ps/pi	Dosi-meter	Age ± 1s (Ma)
Kledang Range:										
2675	Bern-37	18	227	3.9 ± 0.4	1054	18.3 ± 0.5	0.215	--	SRM 612	32.7 ± 2.9
2676	Bern-37	12	70	2.4 ± 0.3	381	13.3 ± 0.7	0.184	--	SRM 612	25.2 ± 3.5
2677	Bern-37	12	43	1.6 ± 0.2	249	8.9 ± 0.6	0.173	--	SRM 612	23.3 ± 4.0
2678	Bern-37	12	90	1.5 ± 0.2	528	8.9 ± 0.4	0.170	--	SRM 612	24.8 ± 3.1
2679	Bern-37	10	232	5.7 ± 0.4	1231	30.2 ± 0.9	0.188	--	SRM 612	28.8± 2.5
2680	Bern-37	12	367	8.8 ± 0.5	1806	43.2 ± 1.0	0.203	--	SRM 612	30.9 ± 2.3
2681	Bern-37	15	161	3.2 ± 0.5	690	13.7 ± 0.5	0.233	--	SRM 612	32.2 ± 3.2
2682	Bern-H8	8	62	3.2 ± 0.4	154	7.7 ± 0.6	0.403	--	CN 1	27.3 ± 4.3
2683	Bern-37	13	298	5.6 ± 0.3	1179	22.3 ± 0.7	0.253	--	SRM 612	33.4 ± 2.7
Main Range:										
2684	Bern-37	10	239	5.9 ± 0.4	1319	33.0 ± 0.9	0.181	--	SRM 612	26.6 ± 2.3
2685	Bern-H8	8	65	4.3 ± 0.5	158	10.4 ± 0.8	0.411	--	CN 1	27.8 ± 4.3
2686	Bern-37	14	226	3.7 ± 0.2	1068	17.7 ± 0.5	0.212	--	SRM 612	28.1 ± 2.5
2688	Bern-37	7	106	4.2 ± 0.4	619	24.4 ± 1.0	0.171	--	SRM 612	25.6 ± 3.0
2991	Bern-H8	10	407	16.1 ± 0.7	1003	39.6 ± 1.3	0.406	--	CN 1	27.6 ± 2.0
2993	Bern-H8	10	425	21.1 ± 1.0	812	40.3 ± 1.4	0.523	--	CN 1	35.9 ± 2.7
2994	Bern-H8	10	569	22.2 ± 0.9	1092	42.5 ± 1,3	0.521	0.537	CN 1	36.4 ± 3.0
Bujang Melaka:										
65/1	Bern-37	10	175	4.3 ± 0.3	964	23.8 ± 0.8	0.182	--	SRM 612	27.3 ± 2.6
65/2	Bern-37	10	160	3.4 ± 0.3	850	18.0 ± 0.6	0.188	--	SRM 612	26.7 ± 2.7
65/4	Bern-37	10	142	3.9 ± 0.3	734	20.2 ± 0.7	0.193	--	SRM 612	26.0 ± 2.7
65/6	Bern-37	12	150	3.2 ± 0.3	953	10.4 ± 0.7	0.157	--	SRM 612	22.8 ± 2.3
65/7	Bern-37	10	169	4.8 ± 0.4	885	24.9 ± 0.8	0.191	--	SRM 612	28.3 ± 2.8
65/8	Bern-37	7	149	10.2 ± 0.8	799	54.9 ± 1.9	0.186	--	SRM 612	24.9 ± 2.5
65/10	Bern-37	8	111	5.1 ± 0.5	615	28.3 ± 1.1	0.180	--	SRM 612	26.3 ± 3.0
Kuala Lumpur:										
2996	Bern-H8	10	412	25.5 ± 1.2	1125	69.7 ± 2.1	0.366	--	CN 1	25.1 ± 1.8
2998	Bern-H8	9	164	9.0 ± 0.7	350	19.2 ± 1.0	0.469	--	CN 1	32.0 ± 3.4
2999	Bern-H8	9	129	12.6 ± 1.1	268	26.1 ± 1.6	0.481	--	CN 1	33.3 ± 3.9
3088	Bern-H8	11	202	8.9 ± 0.6	400	17.6 ± 0.9	0.505	--	CN 1	35.8 ± 3.5

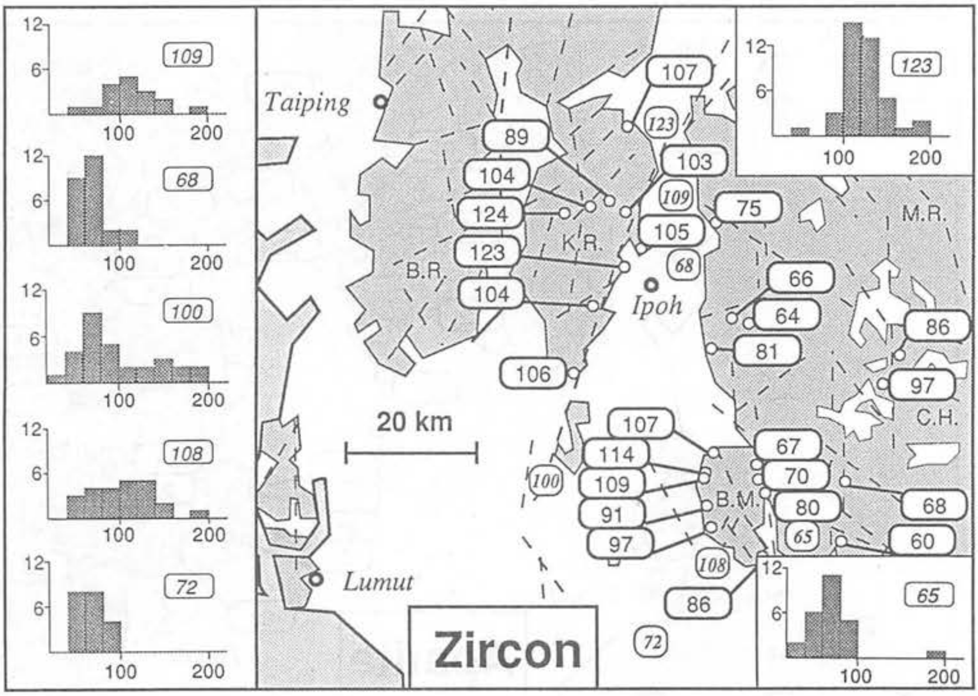


Figure 10: Map of Kinta Valley area including fission track zircon ages from granites (plain numbers) and from tin mines (italic numbers). The higher zircon ages within the granites of the Kledang Range and the NW Bujang Melaka represent areas of higher crustal levels. The age distribution of analysed zircon populations from the alluvial deposits are presented in age (Ma) histograms. The main supply of heavy minerals in the Kinta Valley originates from the Main Range and the source for zircons containing individual ages between 130-180 Ma is suggested to originate from higher eroded levels.

The regional age distribution of the zircons follows generally the same trend as those of the K-Ar biotite. Notice that the error of zircon ages is much higher at 7%. In a few cases there is an increased age difference between biotite and zircon ages, as in sample KAW 2678 from the most western part of the Kledang Range and samples KAW 2991 and 2992 from the southern Cameron Highland profile. In latter case the zircons are within same age trend than others from the west border of the Main Range. No correlation between age and altitude could be obtained for zircons.

The mean age value of the zircon from the alluvial deposits are in good correlation to the ages from the surrounding source rocks. In the northern part of the Kinta Valley a narrow age distribution with a mean age of 123 Ma indicates a major supply from the Kledang Range. Whereas further towards the south the contribution of younger zircon ages (60–86 Ma) from the Main Range is evident (Fig. 10). This is indicated in the histograms which show the

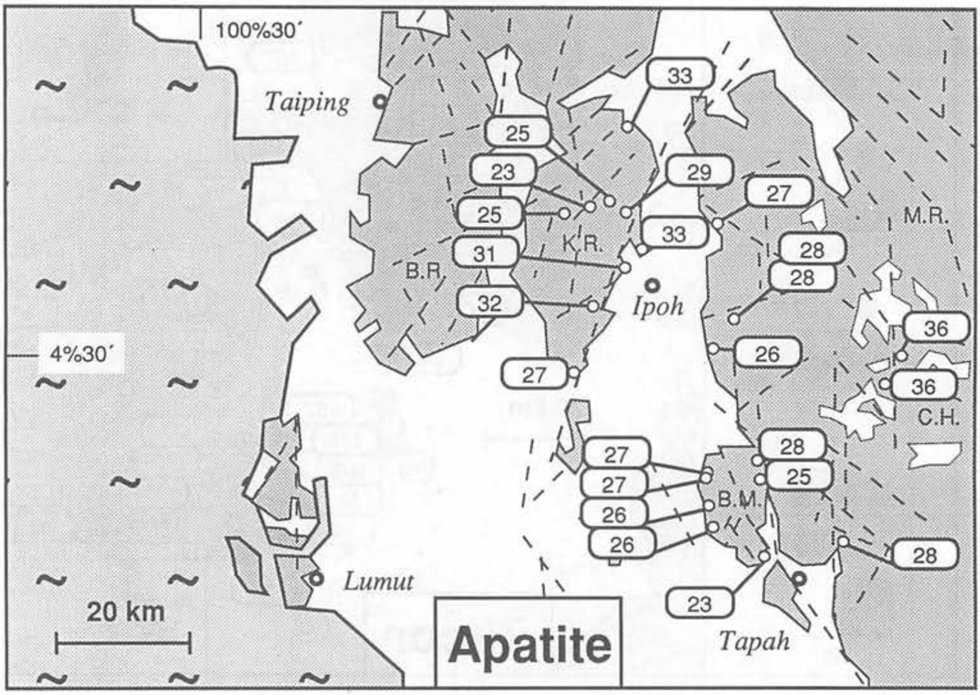


Figure 11: Fission track apatite age distribution for the Kinta Valley area indicating more uniform age patterns than for zircon (Fig. 10) The enhanced apatite ages of 36 Ma originate from an altitude of 1700m.

zircon age distribution by lower mean zircon age values and a higher standard deviation. The apatite ages show a spread of 23–36 Ma and samples from same locations show the same age. Their regional distribution is more uniform compared to the zircon ages (Fig. 11). The most remarkable feature is the older ages of samples from the Kledang Range bordering to the Kinta Valley. The two ages of 36 Ma originate from higher altitude of the Cameron Highlands (1700 m). A correlation between age and altitude is only found for three samples (KAW 2991, 2993, 2994) from the Cameron Highlands profile indicating an uplift rate of 0.17 mm/a.

In figure 14 cooling patterns are drawn for age versus blocking temperature diagrams for the Kledang Range, the Main Range and Bujang Melaka, using K-Ar mica, FT zircon and apatite ages. The cooling of the Kledang Range and the western Bujang Melaka is similar and with 1–3.5°C/Ma of very slow rate. The Main Range indicate a slight faster cooling after Cretaceous time and two samples bordering to the Kinta Valley indicate a even faster cooling compared with the samples from the eastern Bujang Melaka.

DISCUSSION

Intrusion ages

From the case study of Penang Island it became evident that the Rb-Sr "isochrons" do not necessarily determine the time of rock crystallization (Kwan *et al.*, paper submitted). Therefore it has to be verified what the meaning of obtained Rb-Sr whole-rock ages is.

The coincidence of the Rb-Sr "isochron" of 254 Ma obtained from the PTG of the Bujang Melaka and the late-Permian K-Ar ages of 247–253 Ma from primary biotites (Kwan, 1989) provide good evidence for a crystallization age of the Bujang Melaka-type granite. Hence, the 254 Ma three point "isochron" is an isochron indicating the age of granite emplacement. It can be assumed that this pluton cooled rapidly due to the almost coinciding age of emplacement and the K-Ar biotite cooling ages. The residual Rb-Sr whole-rock ages in the range of 186–220 Ma from the Bujang Melaka-type granite and the Cameron Highlands profile plot to two age-initial $^{(87/86)}$Sr evolution lines indicating an intrusion age of 253±20 Ma. The good correlation of the "isochron" points in the age-initial $^{(87/86)}$Sr diagram (Fig. 7a) results in the fact that they originate from one single pluton. This late-Permian age is in close agreement with the extrapolated intrusion age of 251±16 Ma for the Bunga-type-granite of Penang Island (Kwan *et al.*, paper submitted; Fig. 7b). Few granites of the Relau-type granite show a close geochemical affinity to the Ferringi-type granite from Penang Island and could therefore originate from late-Triassic intrusions. The Carboniferous Rb-Sr "isochron" of 291 Ma obtained for samples of similar localities from the northern Cameron Highlands profile yielded an initial $^{(87/86)}$Sr of 0.7094, which is slightly higher than the best estimated initial $^{(87/86)}$Sr of 0.708 at time of granite crystallization (Kwan *et al.*, paper submitted). This value was used for the intrusion age extrapolation of the Carboniferous Kampong Batak microgranite from Penang Island defining an age of 307±20 Ma. Therefore it can be assumed that the obtained age of 291 Ma is weakly distorted.

In case of the Kledang Range no Rb-Sr "isochron" could be obtained for the four samples collected by Bignell and Snelling (1977). Although no radiometric information about the age of the granite intrusions exist, the following points give rise to the suggestion of an additional late-Permian complex:

a) The zircon morphology of the PTG is identical to the one observed in the Bujang Melaka-type granite. b) The geochemistry patterns are almost identical to the ones of the Bujang Melaka. The granites plot to the TiO_2-rich and to the depleted group. So far the only verified late-Triassic granite, located at Penang Island (Feringgi-type

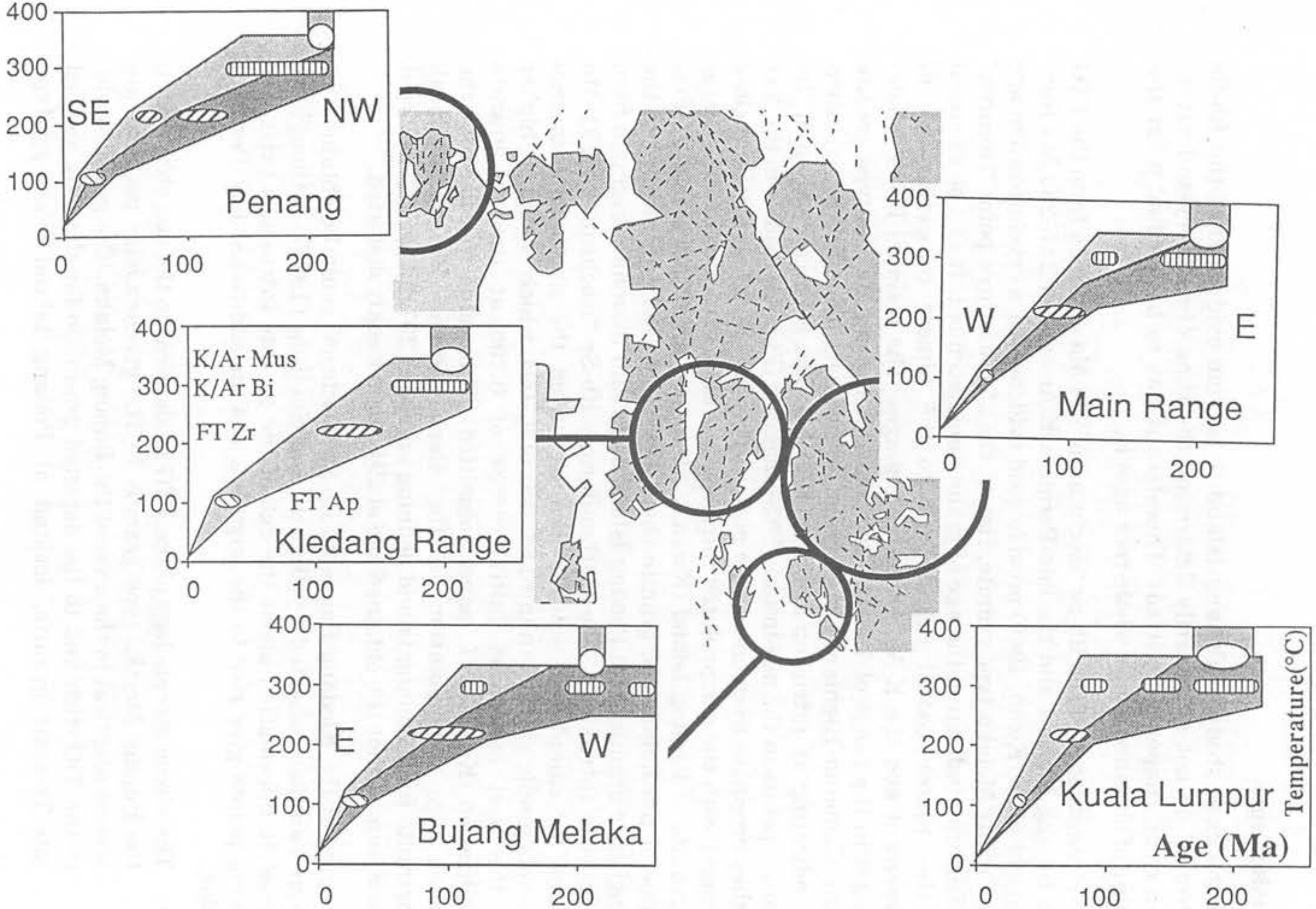


Figure 12: Cooling patterns obtained from K-Ar mica and fission track zircon and apatite ages between mineral-pairs for Penang Islang (Kwan *et al.*, paper submitted); Kledang Range; Bujang Melaka; Main Range and Kuala Lumpur area. The fields shown incorporate the errors. Local difference of cooling rates indicated by same mineral-pairs is related to Cretaceous differential uplift and the regional faster cooling regime to an uplift phase starting in Oligocene/Miocene (discussion see text).

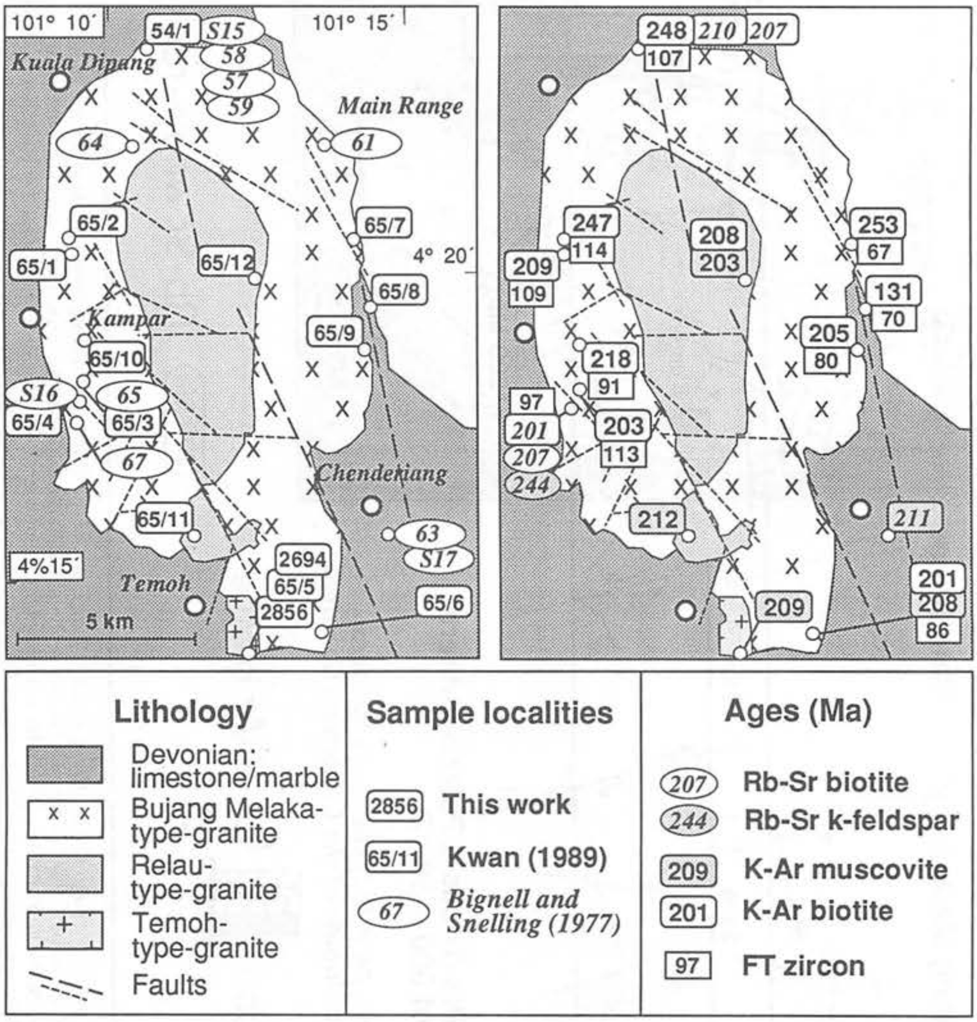


Figure 13: Map showing lithology, sample locations and mineral ages of the Bujang Melaka. Base map is of the Geological Survey of Malaysia (Askury, 1985). Notice the big spread of mica ages from samples of same or close localities.

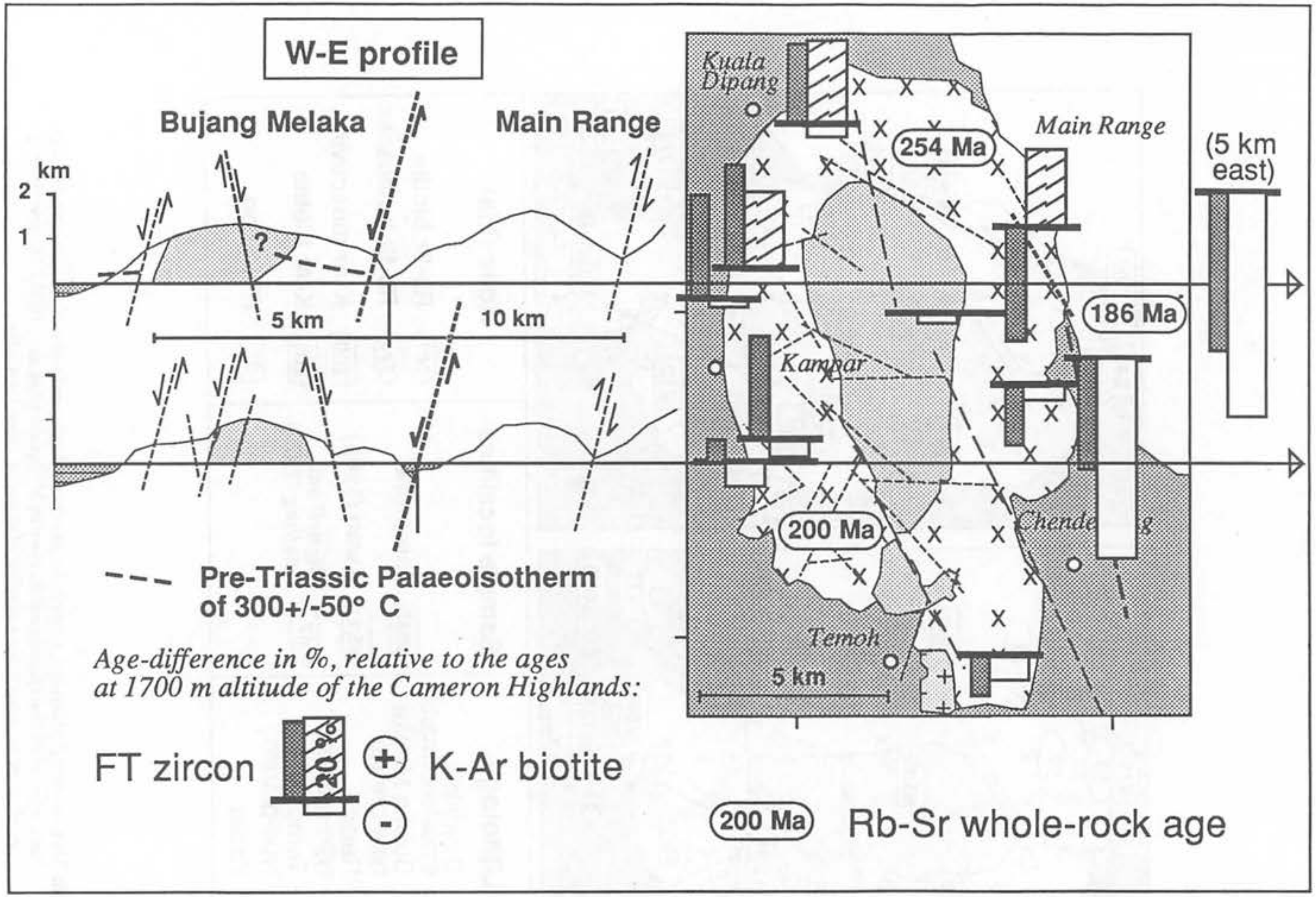


Figure 14: Two W-E profiles trough the northern and southern part of the Bujang Melaka pluton are drawn with their eastern extension into the Main Range. Bars (right side) indicate the age differences for same mineral systems related to the ages of the Cameron Highlands (at 1700m altitude). Samples with bars facing upwards indicate that they passed the isotherm, defined by the blocking temperatures, earlier than those of the Cameron Highlands and reverse. Blocking temperature for K-Ar biotite: 300±50°C; for FT zircon: 220±20°C. Samples with late-Permian K-Ar ages (hatched patterns) survived the late-Triassic hydrothermal metamorphism and reached in pre-Triassic time a crustal level, which was above the 300±50°C isotherm.

granite) shows a distinct geochemical behavior compared to the Kledang Range. c) Some PTG show a slight foliation that never could have been observed in the late-Triassic granites. Nevertheless, it has to be assumed that small late-Triassic intrusives exist in the Kledang Range because of the observed strong rock alteration and its associated tin mineralization of the vein style.

Reset Rb-Sr whole-rock ages and post-Triassic tectonic activities

The individual Rb-Sr whole-rock ages determine the time at which no exchange of radiogenic Sr occurred within the sampled area. The Rb-Sr "isochrons" follow a systematic trend in the age versus initial $^{(87/86)}Sr$ diagram, therefore the Sr homogenization took place in a kinetic equilibrium between the fluid and the granites (Kwan *et al.*, paper submitted). Consequently, the question arises what particular geological setting is responsible for the observed big variation in Rb-Sr whole-rock ages. For Penang Island decreasing Rb-Sr whole-rock ages could be correlated to deeper crustal levels.

In case of the Bujang Melaka and the adjacent Main Range there occur at least three significantly different Rb-Sr whole-rock ages of 254 Ma, 200 Ma and 186 Ma. There are several indications that the Cameron Highlands were originally sited at a level that was below the present-day altitude of the Bujang Melaka, and was uplifted to the actual level in Cretaceous/Tertiary time (Figs. 13, 14):

a) The FT zircon ages in the northern and western Bujang Melaka are significantly higher than those of the Highlands, indicating that they passed the 220±20°C isotherm almost 20 Ma earlier. However, the FT zircon ages of the Bujang Melaka pluton are not more consistent because of its tectonically high disruption what is evident from field studies. b) There are few remnant late-Permian K-Ar biotite ages in the suggested highest parts of the Bujang Melaka (Kwan, 1989) which survived the late-Triassic global mica resetting. This is an indication that in pre-Triassic time this part of the Bujang Melaka was already above the 300±50°C isotherm. Whereas in the Cameron Highlands profile the K-Ar biotite ages vary from north to south with decreasing altitude from late-Triassic to Cretaceous indicating different exposed crustal levels. c) The cooling patterns for the Main Range (Fig. 12) show a faster cooling since Cretaceous time than the ones of the western Bujang Melaka and the Kledang Range. This can be explained by differential uplift of the Main Range and the eastern Bujang Melaka. This corresponds well with the major supply of zircons from the Main Range found even 40 km west in the alluvial deposits of the Kinta Valley (Fig. 10).

The recorded dense fault net in the Main Range indicates intense tectonic activity and block displacements have to be expected. The dominant NW-SE faults of the Bujang Melaka and the southern Cameron Highlands profile could be interpreted as a normal fault system (Fig. 14) that was induced by differential uplift of the Main Range. Assuming a palaeo-thermogradient of 30°C/km, the K-Ar biotite ages of 102-118 Ma from the southern Cameron Highlands profile should still be in an environment of 350±50°C, at the time the ones from the Highlands (213 Ma at 1700 m altitude) passed the 300±50°C isotherm. Hence, the biotite of Cretaceous age would still remain in an isotopic open system behavior due to suggested isostatic cooling. For consequence, it can be assumed that also the Rb-Sr biotite system was open, which may have affected the Rb-Sr whole-rock system in sense of decreasing age as it could be shown in Penang (Kwan *et al.*, paper submitted). Hence, the Rb-Sr whole-rock age of 186 Ma from five samples located in the southern Cameron Highlands profile and the "isochron" of 200 Ma is considered to correlate with varying deeper crustal level.

The K-Ar ages in the range of 212–218 Ma from the western Bujang Melaka and the Cameron Highlands, which are slightly higher than the extrapolated ages of 211±3 Ma for the late-Triassic intrusives (Penang), are expected to be mixing ages. Some of the biotites in the analysed concentrate may still contain a late-Permian isotopic memory.

The FT zircon ages of the northern and southern part of the Cameron Highlands profile passed the 220±20°C isotherm around 86–97 Ma and 60–68 Ma respectively, but they show a smaller age difference compared with the K-Ar biotite ages. Thus, an episode of uplift in Cretaceous/Tertiary time can be assumed. The dynamic quartz recrystallization in an estimated temperature range <300°C might be a product of this tectonic activity and its distinct development in the northern and southern part of the profile (see sample description) is due to discussed crustal level dependent temperature difference. The decreasing K-Ar biotite age trend towards the east within the Kledang Range can be seen in the light of westward tilting of the pluton. This tilting may have involved the Bintang Range and the Dindings pluton as well because the mica ages are within same range (see Fig. 2). Despite, the zircon ages do not completely mirror particular trend. This can be explained by subsequent block movements but may also be the result of the relatively poor resolution of the FT zircon ages.

Differential uplift is observed from older FT apatite ages along the NNE-SSW fault bordering the Kledang Range compared to younger ones towards the east. This can be explained in terms of a west tilting of the pluton what is in opposite sense to the one observed from the biotite and zircon ages. According to the FT apatite ages the fault activity has to date younger than Oligocene. The superimposed brittle deformàtion in all granites may be a result of this tectonic movements.

Summary: There is strong evidence that the main part of the Bujang Melaka and most part of the Cameron Highlands consist of late-Permian intrusives. Local Carboniferous intrusives may occur in the Cameron Highlands as suggested by Bignell and Snelling (1977). The Jurassic whole-rock ages can be related to deeper crustal levels. The K-Ar muscovite ages are formation ages, indicating time of late-Triassic hydrothermal granite alteration leading to the enormous spread in observed granite texture and mineralogy. At least part of the late-Permian granites were sited above the 300±50°C palaeoisotherm before the late-Triassic granites intruded. The majority of the K-Ar biotite ages are crustal level dependent cooling ages indicating regional late-Triassic cooling. Slight tilting of the whole belt towards the east is suggested. From FT zircon ages a differential faster uplift along the NE-SW tending faults with a maximum since Cretaceous is indicated for the Main Range. Tectonic activity within the NW-SE striking faults in Tertiary time is suggested from FT apatite ages what is in good agreement with the observed low temperature deformation style of the affected granites.

THE KUALA LUMPUR - MALACCA AREA

Geological setting

The Kuala Lumpur-Malacca area is the most southern extension of the Main Range and the transition zone to the Eastern Granite Province (Fig. 1). The area is located 200 km south of the Kinta Valley area. Hutchison (1986) suggested that the Main Range continues down-faulted beneath the Straits of Malacca and re-appears after a left-lateral offset at the Tin Islands of Indonesia. The Kuala Lumpur area underwent intense faulting. Granitoids and sediments became aligned along a series of NW-SE and WNW-ESE striking steeply dipping left-lateral faults within the order of 20 km displacement (Tjia, 1972). The NW-SE tending faults cut the Bentong-Raub suture and find the southeastern extension in the Mersing fault zone which displaces intrusives of the Eastern Belt in the same way.

The Main Range in mentioned area is composed of several large plutons which intruded Silurian to Carboniferous sediments of more clastic composition compared to those of the Kinta Valley. The granite belt has been divided into several plutons which are differentiated by distinct granite-types (Cobbing, 1987). North of the Bukit-Tinggi fault appears the *Bukit-Tinggi pluton* which consist of the *Gap unit* and the *Ulu Kali* unit in its center (Fig. 15). Mapping of the two granite-types was difficult because of large variation in texture and the effects of intense deformation within both units (Cobbing,

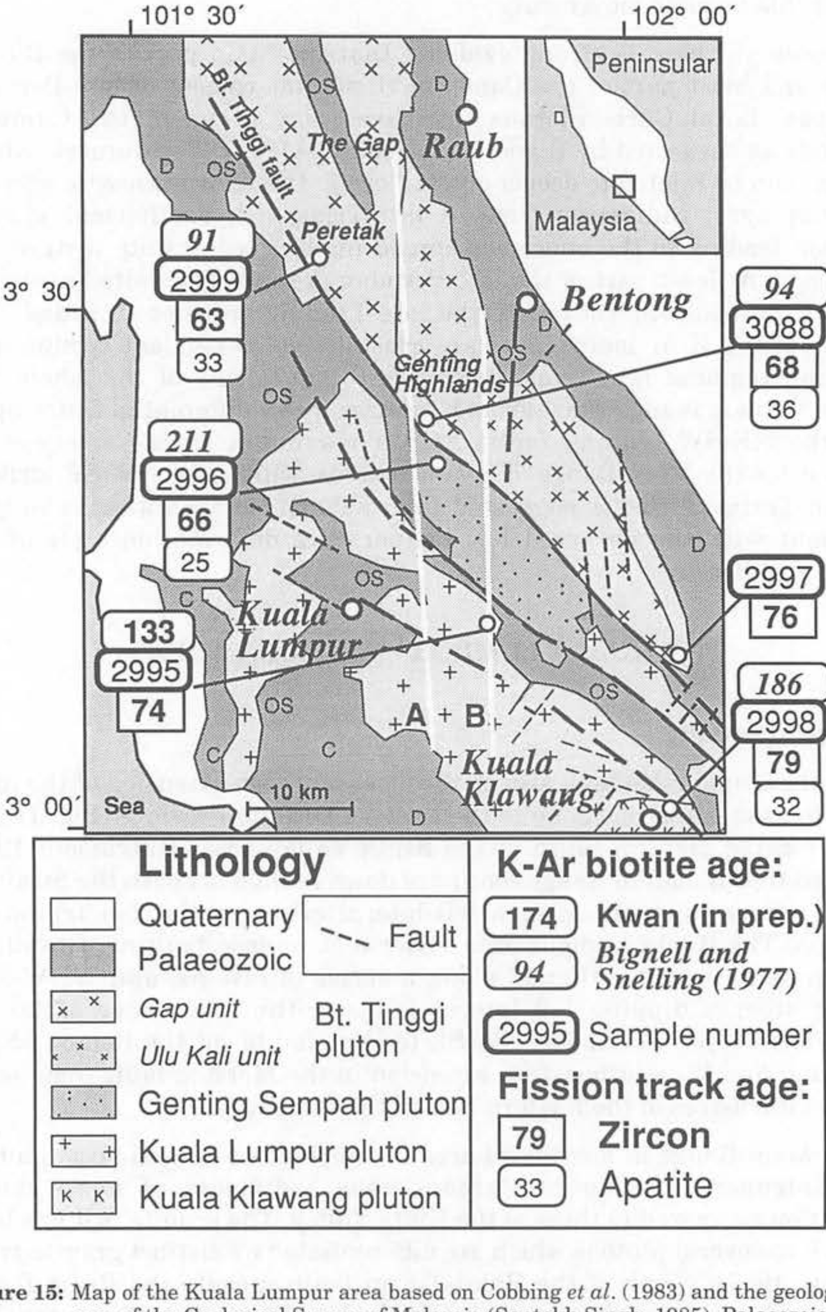


Figure 15: Map of the Kuala Lumpur area based on Cobbing *et al.* (1983) and the geological map of the Geological Survey of Malaysia (Santokh Singh, 1985). Palaeozoic Lithology: C: Carboniferous; D: Devonian; OS: Silurian/Ordovician. Sample no., FT and K-Ar biotite ages from same localities are included. Two lines (white; A, B) indicate where the N-S age profiles were established.

1987). Sheared granites comprising augen-gneisses, mylonites together with large quartz veins striking in the fault direction are abundant (Tjia, 1972). The pluton intrudes Silurian schists, phyllites and slates. South of The Gap primary tin is associated with small bodies of micrograintes and granites of porphyric texture. Bignell and Snelling (1977) suggested that the mineralization is concentrated in the roof and is dependent upon overlying sediments. Alluvial tin mines occur on both sides of the pluton and the largest are at the western side where the granites occur in contact with Silurian sandstones.

Rock descriptions are summarized here from the extensive work of Cobbing (1987). The extremely coarse, primary textured Gap granite has a wide distribution and its remarkable mineral features are: pleochroic, pale brown to dark brown biotite, often chloritized; green biotite is associated with sphene and allanite; minor primary muscovite is reported; K-feldspar is cross hatch twinned. Strong deformation is widespread. The Ulu Kali granite is medium to coarse grained; biotite is similar to the one of the Gap unit but shows exclusions of ilmenite and sphene; muscovite is rare and secondary of origin; l-feldspar is mainly perthitic. Microgranites (Sungei Rodah) of variable character appear in the Gap and Ulu Kali units as dykes, sill, stocks and small plutons. They are not foliate but have undergone "cataclastic" deformation. Biotites are highly corroded and chloritized; the amount of muscovite is small; K-feldspar consists of perthite exsolution laminae and cross hatch twins; plagioclase phenocrysts are highly altered.

In south direction the *Genting Sempah pluton* occurs between the Bukit-Tinggi and the Konkoi fault. This granitoid contains rhyolitic compounds and is suggested to be of high level emplacement. The medium grained, equigranular microgranite contains perthitic K-feldspar; fresh orthopyroxene overgrown by reddish brown biotite; plagioclase is of composition oligoclase to labradorite. No tin occurrence is reported.

Further south of the Konkoi fault the *Kuala Lumpur pluton* occurs, which is associated with a major pegmatite vein net cutting through all units. Primary tin occurrence is reported from these pegmatites and from small microgranite bodies. Most alluvial tin mines are located close to the western side of the pluton where the granites are in contact with Carboniferous phyllites, slates, shales and sandstones. Skarns forming bedded deposits are bordering the granitoids which occur locally in the western Kuala Lumpur pluton and greisenized veins in marbles east of Kuala Lumpur are reported (Hosking, 1988). The two kinds of southern tending branches in which the pluton is exposed appears to be separate parts of the pluton. It is a predominantly coarsely crystalline grey and some times intense blue colored muscovite bearing biotite granite. Biotites is pleochroic, light to dark brown; large muscovite flakes replace biotite and K-feldspar; the latter is perthitic

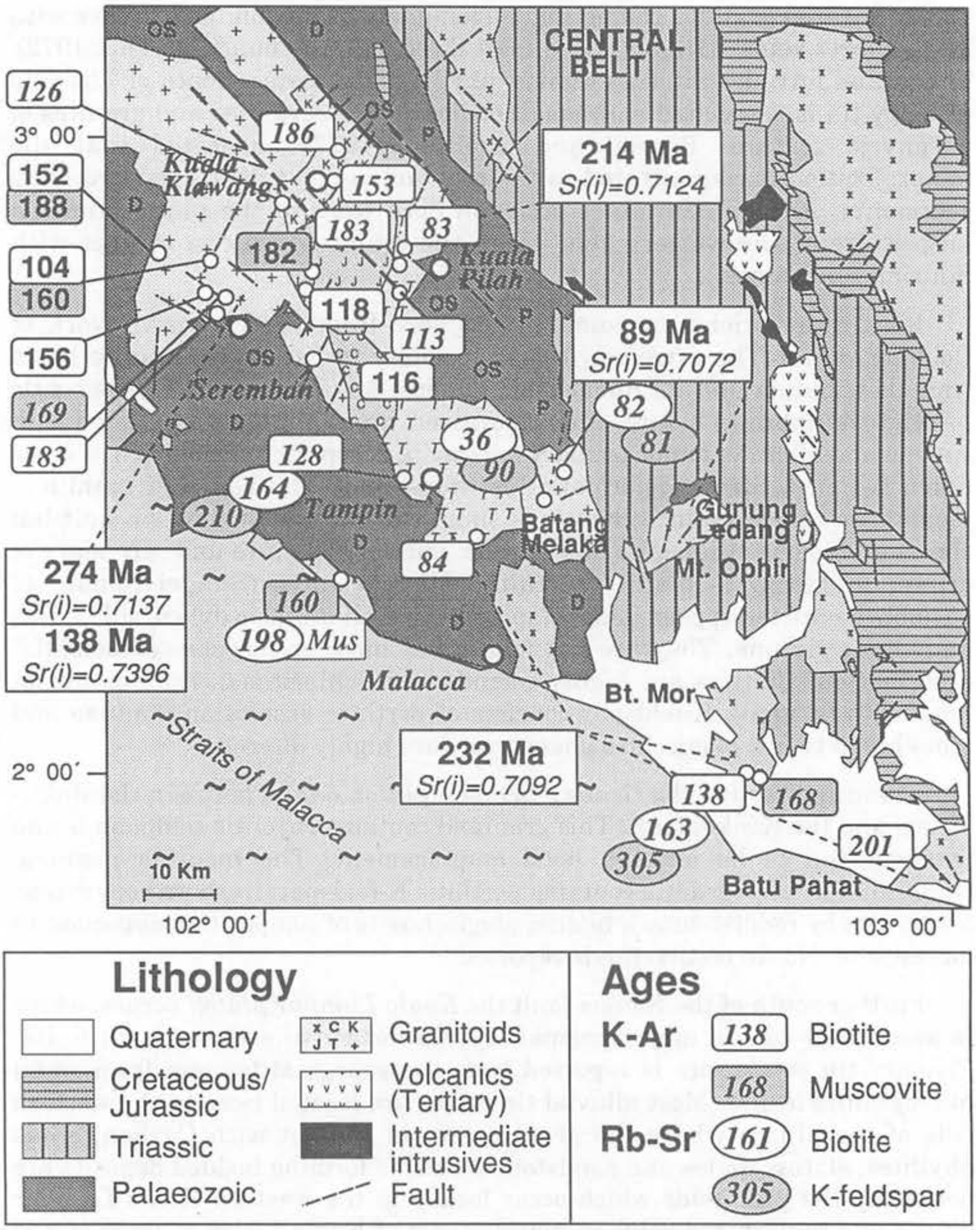


Figure 16: Map of the Malacca area compiled after the geological map of the Geological Survey of Malaysia (Santokh Singh, 1985) and after Cobbing *et al.* (1983). Lithological Palaeozoic subdivision is as in figure 15; P: Permian. Subdivision of plutons: K: Kuala Klawang; J: Jelebu; C: Chembong; T: Tampin. The Triassic to Cretaceous sediments belong to the Central Belt. K-Ar mica and Rb-Sr mineral ages in italic are from Bignell and Snelling (1977) and those in plain/bold numbers are from Kwan (in prep.). Rb-Sr mineral ages are corrected with an initial $^{(87/86)}$Sr of 0.7080. The coinciding mineral ages in the range of 81-90 Ma from the Batang Melaka and the poorly defined Rb-Sr whole-rock "isochron" of 89 Ma give good evidence for the existence of a Cretaceous intrusive.

and/or cross hatch twinned in megacrysts; clear microcline occurs in the groundmass. Finer crystalline to micrograntic and porphyritic varieties occur locally.

The southeastern extension of the Kuala Lumpur pluton towards Malacca continues in a N-S stretching belt of small plutons surrounded Silurian sediments in the north and bordered by Devonian ones in the south. From the north towards the south the plutons are referred to as the Kuala Klawang, Jelebu, Chembong and Tampin pluton (Cobbing, 1987; Fig. 16). They are predominantly coarsely crystalline biotite granites containing variable amounts of K-feldspar megacrysts. An increase in the foliation towards the southern plutons is observed and the Tampin granite shows the strongest deformation. No tin is associated with these plutons. The *Kuala Klawang pluton* is small in size and outcrops in the area of the town. It is cut by the Kuala Lumpur pluton. with 10–15% biotite it is one of the most mafic, medium to coarsely crystalline granitoid of the area. The *Jelebu pluton* consists of two small round units sited within the Kuala Klawang, Chembong and Tampin plutons east of Seremban. They are rather homogeneous, fine to medium grained equigranular granites with few K-feldspar phenocrysts. The *Chembong pluton* is located south of Seremban and Kuala Pilah. It is less foliate than the Tampin pluton. Moderate to strong foliation is reported from the Seremban-Kuala Pilah road. The granitoids of the *Tampin pluton* (PTG) comprise primary and secondary biotite and cross hatch twinned K-feldspar megacrysts. Variations to microgranites are rather subordinate. In the most southeastern part of this pluton belt hydrothermally modified pink granites with red and green colored feldspar are exposed. They belong to the Cretaceous Batang Melaka and *Gunung Ledang pluton* (Mt. Ophir) and are displaced by WNW-ESE striking left-lateral faults (Hutchison, 1986; Bignell & Snelling, 1977). The *Batang Melaka pluton* may consist of two bodies. The pink colored-appearing granites are of highly variable texture. Biotites are dark greenish-brown to pale brown and include major zircons, apatites, sphene and opaques; few muscovite sheets occur in plagioclase and large ones are intergrown with biotite and epidote; K-feldspar shows patchy cross hatch twinning and is resorbed by plagioclase and quartz myrmekite. This granite seems to have a close affinity to the pink granite reported from the southeastern Bujang Melaka pluton in the Kinta Valley. No tin mineralizations are known from this area.

Further to the southeast occur isolated round plutons of the Bukkit Mor and Batu Pahat which are situated within the Central Belt and are covered by Triassic sediments. The *Bukit Mor granite* is a typical Main Range granite similar to the one of Tampin. It is cut by small dark microgranites. Tin-associated pegmatite dykes intersect all rocks. The *Batu Pahat pluton* is composed of fine to medium grained biotite granite comprising a highly variable texture. K-feldspars vary from grey to pink and are characterized by tiny blebbies of quartz dispersed over all minerals.

Geochemistry

Geochemistry patterns (data from Cobbing & Pitfield, personal communications) of the described plutons are plotted in the variation diagram TiO_2 versus major and minor elements (Fig. 4). Generally, the geochemistry patterns are similar to the ones of the granites from the Kinta Valley area. Some granites of the Bukit-Tinggi and one of the Tampin pluton are a little more basic than the one of the Bujang Melaka-type granite. More limited vertical variation compared to the Kinta Valley area are found in the Bukit-Tinggi pluton, for Al_2O_3, for the alkalies, Y, Sr, Th, W, Pb, Zn. All residual plutons show limited vertical variation of the mobile elements. The reason may be that Cobbing (1987) collected predominantly PTG for geochemical analysis, which were generally less affected by the influenced of hydrothermal alteration. It is evident that the vertical variation occurs to a limited extent also in the field of the less evolved granites. Two different magmatic trends may be observed from Zr but cannot be related to the division into Gap and Ulu Kali unit. Liew (1983) concluded from variation diagrams of SiO_2 versus La, Th, and Y that the Ulu Kali unit is a different magmatic suit or derived from a difference in fractionated crystallization.

The Gunung Ledang granites (of suggested Cretaceous age; Bignell & Snelling, 1977) show in most diagrams a different trend than all other granites and, with the exception of Sr, individual samples group within a narrow range. For SiO_2, Al_2O_3, Th, Nb and Y they plot together with the Carboniferous Kampong Batak granites of Penang Island. Liew (1983) suggested that the Cretaceous granites are I-type and of anorogenic origin.

Previous isotopic investigations

These have been carried out by Bignell and Snelling (1977), Liew (1983), Darbyshire (1988) and Kwan *et al.* (paper submitted). The best evaluated Rb-Sr whole-rock age for granites of various textures from the Gap unit is reported of 206±2 Ma with a Sr intercept of 0.7110 (Bignell & Snelling, 1977). From the coarse grained variety Liew (1983) obtained a highly discordant U-Pb zircon population age of 208±2 Ma where from two points plot to the concordia. Two further concordant U-Pb ages of 206±2 Ma and 198±2 Ma were obtained from a sheared porphyritic biotite granodiorite of the Gap unit, located adjacent to the Bukit-Tinggi fault, and from a two-mica granite in the Bentong quarry within the Ulu Kali unit respectively. A fine grained biotite, and a two-mica granite of porphyritic textures, collected 400 m apart at the east side of The Gap (sample nos. 110, 111) yielded an age of 251 Ma

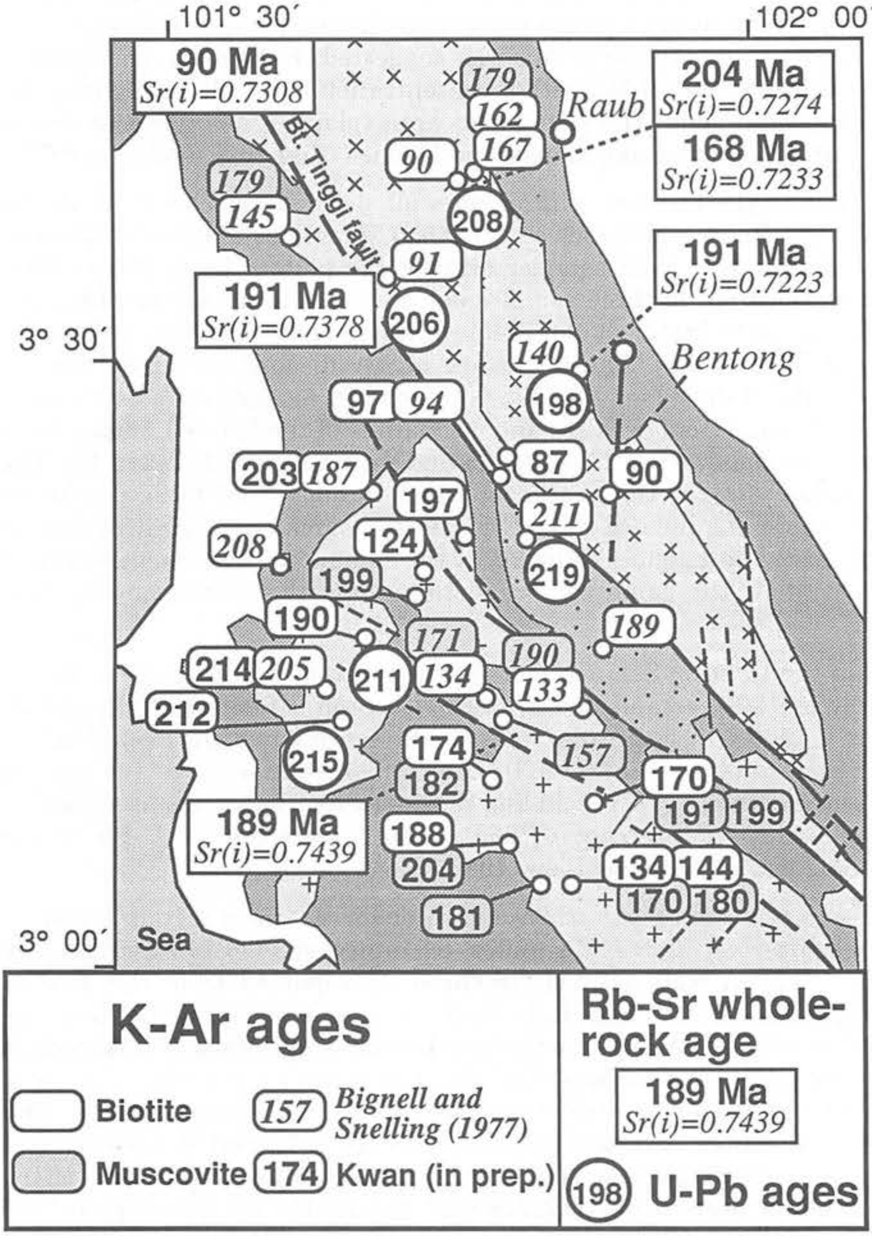


Figure 17: K-Ar mica and Rb-Sr whoe-rock regional age distribution in the Kuala Lumpur area. The U-Pb zircon population ages are from Liew (1983). The Rb-Sr whole-rock age of 204 Ma from The Gap is in good agreement to the highly discordant U-Pb age of 208 Ma. The younger Rb-Sr age of 168 Ma coincides with some K-Ar biotite ages. A relatively good age coincidence between U-Pb and Rb-Sr is observed for samples of the Ulu Kali unit. Whereas the coinciding Rb-Sr whole-rock, and the K-Ar biotite ages of about 90 Ma in the vicinity of the Bt. Tinggi fault are clearly younger than the concordant U-Pb age of 206 Ma (discussion see text).

and a Sr intercept of 0.7071 (Bignell & Snelling, 1977). From further coarse grained granites from same profile together with samples from different units a Carboniferous age of 290±10 Ma was suggested. K-Ar mica ages show a wide spread from 87–179 Ma with a concentration of 90 Ma ages along the Bukit-Tinggi fault zone. The young ages are explained by argon loss due to thermal disturbances related to major fault zones (Bignell & Snelling, 1977).

For the Kuala Lumpur pluton no well defined "isochron" could be obtained and a Rb-Sr whole-rock age of 245±5 Ma was established defined by six points originating from samples all over the pluton. Darbyshire (1988) reported a "isochron" of three samples out of five, with an age of 215±2 Ma and an enhanced Sr intercept of 0.7245, which is in good correlation to the U-Pb ages of Liew (1983). The latter are highly discordant zircon ages of 215±2/–4 and 211+5/–8 (see Fig. 17). Numerous K-Ar ages were established by Kwan (in prep.) from granites and pegmatites of the Kuala Lumpur area. The muscovite ages vary of 157–204 Ma and the biotites of 124–214 Ma. The ages decrease towards the southeast which is suggested to be due to an increasing thermal influence of the Cretaceous magmatism. Detailed study of different muscovite aliquots collected at the same localities from associated pegmatites show the same age trend than from the corresponding host granites.

Within the Genting Sempah labradorite-pyroxene-biotite-granite Bignell and Snelling (1977) established a Rb-Sr "isochron" of 447±109 Ma and Sr intercept 0.7079. An "isochron" of 197 Ma established by Beckinsale is reported from Cobbing *et al.* (1983). Liew (1983) reinterpreted the data of Bignell and Snelling (1977) including new ones and found an "isochron" of 204±13 Ma and Sr intercept 0.7260. A highly discordant U-Pb age of 219+5/–9 Ma was obtained by Liew (1983).

Four samples from north of Seremban define within a certain scatter a Rb-Sr "isochron" of 283±7 Ma and a Sr intercept of 0.7106 (Bignell & Snelling, 1977). A well defined "isochron" is reported from the Jelebu-Chembong pluton of 211±6 Ma and a Sr intercept of 0.7108. Further decrease of the K-Ar mica age towards the Gunung Ledang and Batang Melaka pluton are reported from same authors (Fig. 16). The biotites are within a range of 84–186 Ma and the muscovites of corresponding samples show always older ages than the biotites. A suggested Cretaceous age is defined by a whole-rock-K-feldspar-biotite-plagioclase "isochron" from a pink biotite granite of the Batang Melaka pluton, of 81±2 Ma and reasonable Sr intercept 0.7079 (Bignell & Snelling, 1977). Further mineral ages scatter and do not fit a regression line with the whole-rock mainly because of too low biotite and enhanced plagioclase ages (see table VII).

Table VII. Rb-Sr mineral ages from granites of the Main Range recalculated from data of Bignell and Snelling (1977)

Locality	Mineral	Age # ± 1s (Ma)	Age* ± 1s (Ma)	initial (87/86)Sr*
Penang	bio	189.6 ± 1.9	188.8 ± 22.1	0.7144
(Feringgi-Bunga)	K-feldspar	205.6 ± 2.5	204.0 ± 6.4	0.7093
G. Jerai	bio	39.8 ± 0.3	36.9 ± 0.4	0.8430
	mus	235.8 ± 2.4	229.9 ± 2.7	0.7501
	K-feldspar	234.3 ± 2.9	9.0 ± 6.9	0.8564
	plag	1399.0 ± 17	90.2 ± 3.3	0.8173
	mus	267.1 ± 2.7	265.4 ± 2.9	0.7330
	K-feldspar	285.5 ± 9.2	266.0 ± 3.1	0.7238
	plag	1567.3 ± 22.4	118.9 ± 3.2	0.8035
Langkawi	bio	79.1 ± 0.8	75.4 ± 0.8	0.7606
	K-feldspar	223.8 ± 2.5	224.8 ± 7.8	0.7071
Taiping	K-feldspar		207.3 ± 16.6	0.7083
Bujang Melaka	bio	207.1 ± 2.1	206.5 ± 2.1	0.7187
	K-feldspar	244.2 ± 5.3	151.1 ± 6.7	0.7284
Malacca	mus	198.3 ± 2	197.1 ± 2.1	0.7834
(Tampin)	bio	163.9 ± 1.7	167.0 ± 1.8	0.7250
	K-feldspar	210.0 ± 4.2	137.0 ± 9.1	0.7292
(Bt. Mor)	bio	162.8 ± 1.6	161.0 ± 1.7	0.7207
	K-feldspar	305.4 ± 12.6	195.9 ± 30.9	0.7187
	plag	2098.0 ± 232	236.8 ± 18.9	0.7120
(Batang Melaka)	bio	81.9 ± 1.1	82.1 ± 1.0	0.7077
	K-feldspar	80.7 ± 4.6	81.8 ± 8.7	0.7077
	plag	103.5 ± 103	76.6 ± 11.5	0.7083
	bio		36.4 ± 0.5	0.7080
	K-feldspar	89.5 ± 14	106.8 ± 18.7	0.7068
	plag	1923.6 ± 529.0	-195.9	
Johor	bio	15.8 ± 0.2	15.5 ± 0.2	0.7109
	K-feldspar	83.4 ± 12.4	67.2 ± 20.0	0.7093
	plag	46.9 ± 234	119.8 ± 38	7.0769

Note: # Age corrected with an initial (87/86)Sr of 0.708:
*calculated from whole-rock - mineral regression)

RESULTS

Sample description

Six samples were collected for fission track zircon and apatite analysis from different granite blocks sited between the NW-SE striking left-lateral faults (Fig. 15). Three samples originate from the Gap and Ulu Kali unit north of the Bt. Tinggi fault, one from the Genting Sempah pluton and one each from the Kuala Lumpur pluton and the Kuala Klawang pluton, south of the Konkoi fault.

KAW 2997 and *KAW 2999* belong to the Gap unit (PTG) and were collected in the vicinity of the Bukit-Tinggi fault. They are highly ductile to brittle deformed. Perthitic K-feldspar megacrysts are disrupted and contain exsolution laminae in shear zones; the twinning laminae of plagioclase are bent and kinked, fractures are filled with sericite, chlorite and epidote; kinked biotite is light brown comprising epidote, leucoxene rims and 0.1 mm large sphene is interstitial in clusters; with increasing deformation biotite is gradually replaced by chlorite and disappears completely; in sample KAW 2999 sphene bordered chlorite is pseudomorphic after amphibole; epidote, clinozoisite and allanite are frequent; plagioclase is zoned and the core is usually saussuritized; large elongated grains of quartz are fully dynamically recrystallized in 0.05 mm grain size. Triple grain boundaries are common and a temperature range of ≥300°C is estimated. In 200 m large shear zones parallel to the Bukit-Tinggi fault greenish augen-gneisses are exposed. Thin sections show a mylonitic texture with high strain but only limited quartz recrystallization indicating a superimposed deformation style of clearly low temperature. The Bukkit-Tinggi pluton appears of extremely inhomogenious composition comprising all kind of xenoliths and domains of dioritic texture.

KAW 3088 originates from almost the top of the Genting Highlands (1700 m). The medium to coarse grained biotite granite is less deformed but still shows 0.01 mm quartz recrystallization along sutured grain boundaries; primary biotite is randomly chloritized, newly formed biotite in 0.01 mm size is intersited in quartz and apatite clusters; K-feldspar perthite shows exsolution laminae due to micro-shear zones; plagioclase is sericitized.

KAW 2996 from the Genting Sempah pluton is a deformed subvolcanite. The rounded compounds of K-feldspar, plagioclase and quartz are disrupted; chloritized secondary biotite including ilmenite exsolutions are bent around the constituents; the matrix is almost fully recrystallized and contains tiny quartz, albite and biotite crystals; resorption grain boundaries to quartz grains are frequent.

KAW 2995 is a weakly deformed muscovite-bearing PTG collected from the Kuala Lumpur pluton. Perthitic K-feldspar megacrysts comprise random

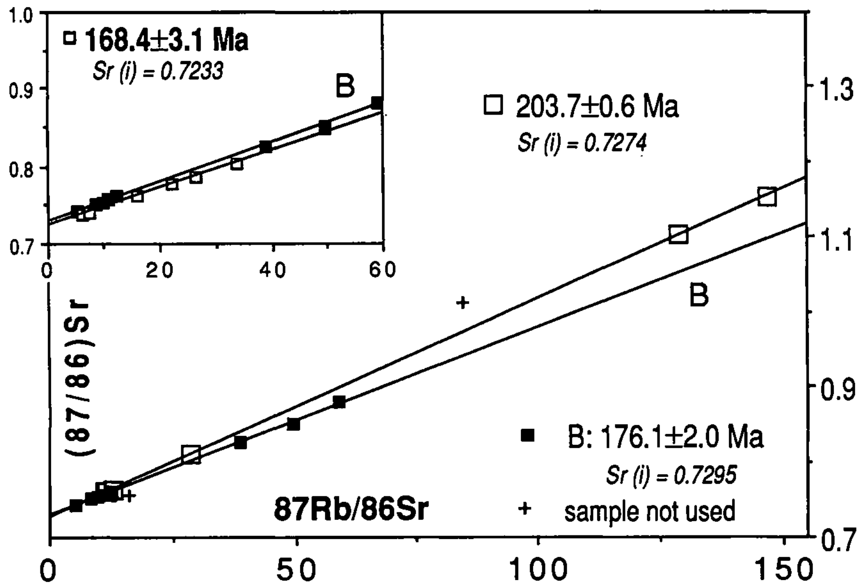


Figure 18: Rb-Sr whole-rock "isochrons" for the Gap road established from data of Bignell and Snelling (1977). Most "isochrons" contain data from granitoids of various texture and mineralogy, and from locations both sides of The Gap. The youngest age of 168 Ma is from five samples originating from a narrow range of 5 km, NE of The Gap (see inset).

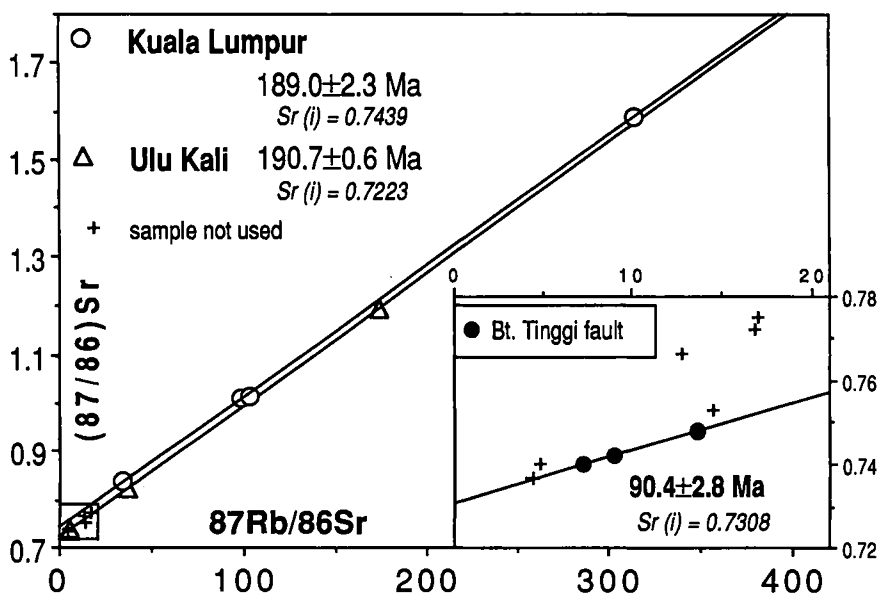


Figure 19: Two subparallel Rb-Sr whole-rock "isochrons" for granites of the Ulu Kali unit and the Kuala Lumpur pluton define an age of 190 Ma but show highly different Sr intercepts. Three samples located close to the Bt. Tinggi fault zone define a Cretaceous age (see inset). Data are used from Bignell and Snelling (1977).

domains of cross hatched twins due to deformation; large bent muscovite sheets replace K-feldspar and chloritized biotite; epidote and allanite are clustered together with chlorite, large disrupted apatite and the whole assemblage may be enclosed in plagioclase phenocrysts; tourmaline is a minor phase; quartz is sutured along grain boundaries and large subgrains occur.

KAW 2998 is a biotite TTG collected from the Kuala Klawang pluton. Biotite is reddish brown containing bleached rims and resorption grain boundaries to quartz; inclusions in biotites are large opaques often sited at the grain boundaries; deformation is very weak with few quartz subgrains.

Rb-Sr whole-rock ages

The established Rb-Sr whole rock ages are given in table III. For the Gap unit four "isochrons" were calculated. Six points originating from east of The Gap yield an age of 203.7±0.6 Ma and Sr intercept 0.7274±0.0007 (Fig. 18). Five samples located within a distance of 5 km including a highly deformed sample south of the Bukit-Tinggi fault yield 168.4±3.1 Ma and a Sr intercept of 0.7233±0.0009. An almost parallel "isochron" of 176.1±2.0 Ma but with a higher Sr intercept of 0.7295±0.0009 is obtained from eight samples originating from both sides of The Gap. Three samples close to Peretak yield the same age of 190.7±2.6 Ma, such as three samples from the Ulu Kali unit (190±0.6), but different initial $^{(87/86)}$Sr of 0.7378±0.0044 and 0.7223±0.0009 respectively (Fig. 19). Three highly deformed samples in the vicinity of the Bukit-Tinggi fault yield a Cretaceous age of 90.4±2.8 Ma and Sr intercept 0.7308±0.0004. One sample from the Genting Sempah pluton plots to same "isochron" what is probably incidental.

For the Kuala Lumpur pluton four samples of extremely high Rb/Sr ratios and spread (34–314) yield an age of 189.0±2.3 Ma and extremely high Sr intercept 0.7439±0.0056. From all established data of Bignell and Snelling (1977) eight samples have not been used for regression calculations including three labradorite-pyroxene-biotite granites of the Genting Sempah pluton.

Generally higher Rb-Sr whole-rock ages were obtained for the south eastward extending Malacca area (Fig. 20). A Carboniferous age of 274.3±10.0 Ma, defined mostly by samples of the Seremban area, yield a Sr intercept of 0.7137±0.0017 and six samples from the Kuala Pilah road gave almost the same Sr intercept of 0.7124±0.0007 but an age of 213.9±2.1 Ma. Two samples from the latter "isochron" are reported to be of "cataclastic" granites. Three samples located between Seremban and Kuala Klawang define an "isochron" of 137.7±7.0 Ma and a Sr intercept of 0.7396±0.0020. Four pink granites from the Batang Melaka, the Mt. Ophir (Gunung Ledang pluton) and the Gunung Pulai in the very southeast yield a poorly defined

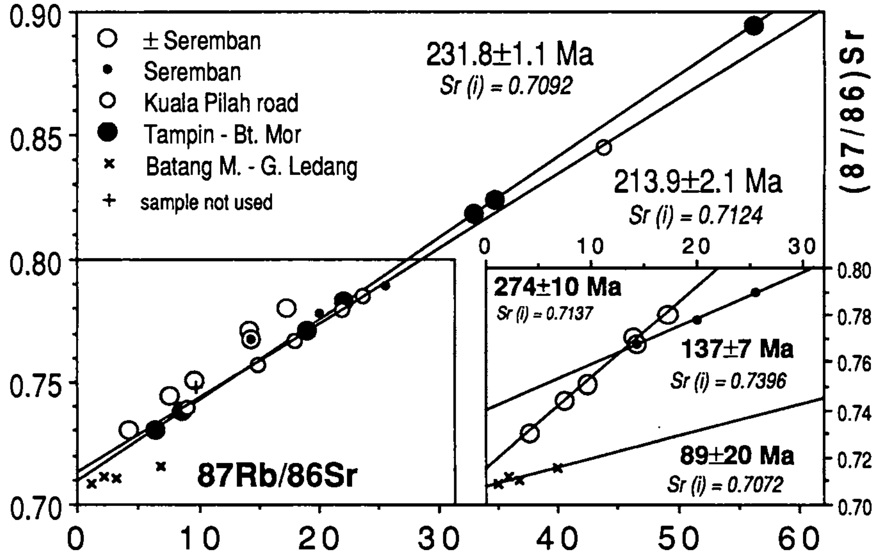


Figure 20: Rb-Sr whole-rock "isochrons" for the Mallaca are established from data of Bignell and Snelling (1977). Four samples from a wide area of Seremban define an age of 274 Ma and an enhanced initial (87/86) Sr of 0.7137. Whereas three samples from a close area near Seremban define an age of 137 Ma and very high Sr intercept 0.7396 (see inset). A poorly defined Cretaceous Rb-Sr whole-rock age is obtained from four samples located close to the border to the Eastern Granite Province.

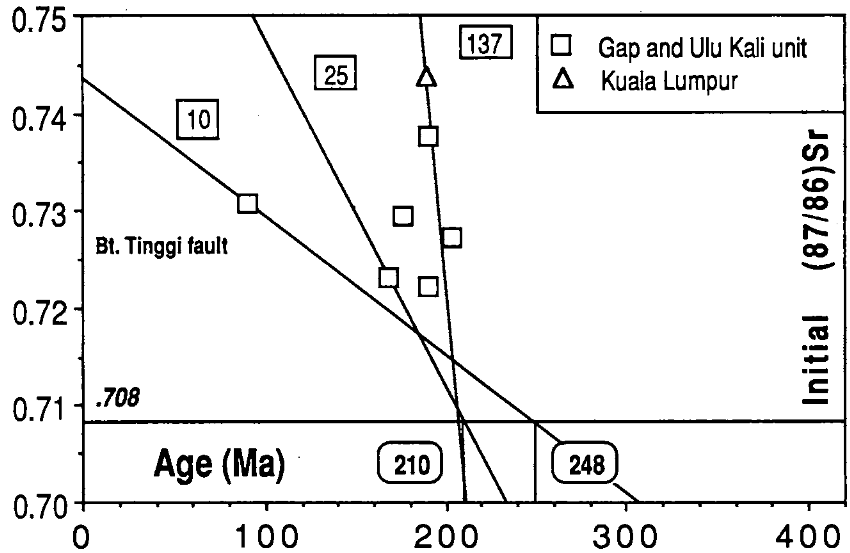


Figure 21: Age-initial (87/86) Sr diagram established from all Rb-Sr "isochrons" of the Kuala Lumpur are. Three age-initial (87/86) Sr evolution lines were calculated for three different (87Rb/86Sr) mean values (number in squares). The mean values were calculated from the individual samples defining the Rb-Sr "isochrons" (Kwan et. al., paper submitted). The evolution line for the Bt. Tinggi fault "isochron" intersects with the horizontal through 0.7080 at 248 Ma indicating a late-Permian origin of these granitoids. The fact, that most "isochrons" plot below the 210 Ma evolution line gives evidence for a regional widespread isotopic homogenization at late-Triassic time (discussion see text).

"isochron" (R: 0.899) of Cretaceous age (89.0±19.9 Ma) and a reasonable Sr intercept of 0.7072±0.0011. Five samples have not been used for regression calculations. One of them is a fine grained muscovite granite from the Kuala Lumpur pluton close to the Chambong pluton comprising a extremely high Rb/Sr ratio of 508. Assuming an initial $^{(87/86)}$Sr of 0.708 an age of 209 Ma can be calculated for particular sample.

Plotting all Rb-Sr "isochrons" into the age-initial $^{(87/86)}$Sr diagram a wide scatter of data points results (Fig. 21). For those "isochrons" defined by samples of a small spread in the (^{87}Rb/^{86}Sr) ratio the age-initial $^{(87/86)}$Sr evolution line was calculated beginning from the whole-rock age and its associated initial $^{(87/86)}$Sr (Kwan, *et al.*, paper submitted). The two evolution lines established from the obtained whole-rock age of 168 Ma from samples east of the Gap and from the 189 Ma "isochron" of the Kuala Lumpur pluton comprising a high mean Rb/Sr ratio of 137, they intersect almost at the horizontal line through 0.708. They indicate an extrapolated intrusion age of 210 Ma. The calculated evolution line for the "isochron" (90 Ma and Sr intercept 0.7308), defined by three samples in the vicinity of the Bukit-Tinggi fault and comprising a low mean Rb/Sr ratio of 10, it intersects at 248 Ma indicating in addition a late-Permian origin. The residual "isochron" points plot below the steeply late-Triassic evolution line defined by the mean Rb/Sr ratio of 137. For those "isochron" points no age-initial $^{(87/86)}$Sr evolution line was calculated. This is because they comprise one or two data points of high Rb/Sr ratio and any calculated mean value would not therefore represent a geochemical mean of the analysed granite. Hence, it is not possible to evaluate from what intrusion episode they could originate.

The Rb/Sr "isochrons" from the Malacca area and the transition zone into the Central Belt were plotted onto the age-initial $^{(87/86)}$Sr diagram (Fig. 22). In addition, all available Rb-Sr data from the Eastern Belt were included (Bignell & Snelling, 1977; Darbyshire, 1988). Two "isochrons" from the Seremban area with extreme age difference of 274 Ma and 138 Ma define an age-initial $^{(87/86)}$Sr evolution line intersecting at 304 Ma with the horizontal line trough 0.708. This is in good correlation with the extrapolated age of 307±20 Ma from the Carboniferous Kampong Batak microgranite of Penang Island (Kwan *et al.*, paper submitted). The 204 Ma "isochron" from the Gap road and two others from the Gap and Ulu Kali unit established from Darbyshire (1988) plot to same 304±5 Ma evolution line and were finally regressed together with the Seremban "isochron" points.

The two "isochrons" from the N-S pluton belt between Kuala Lumpur and Malacca including also samples from the Bukit Mor, the Batu Pahat, the Tampin pluton (Darbyshire, 1988) and four "isochrons" from the Eastern Belt define a further age-initial $^{(87/86)}$Sr evolution line which intersects at an age of 240±5 Ma with the horizontal line trough 0.708. The residual plotted

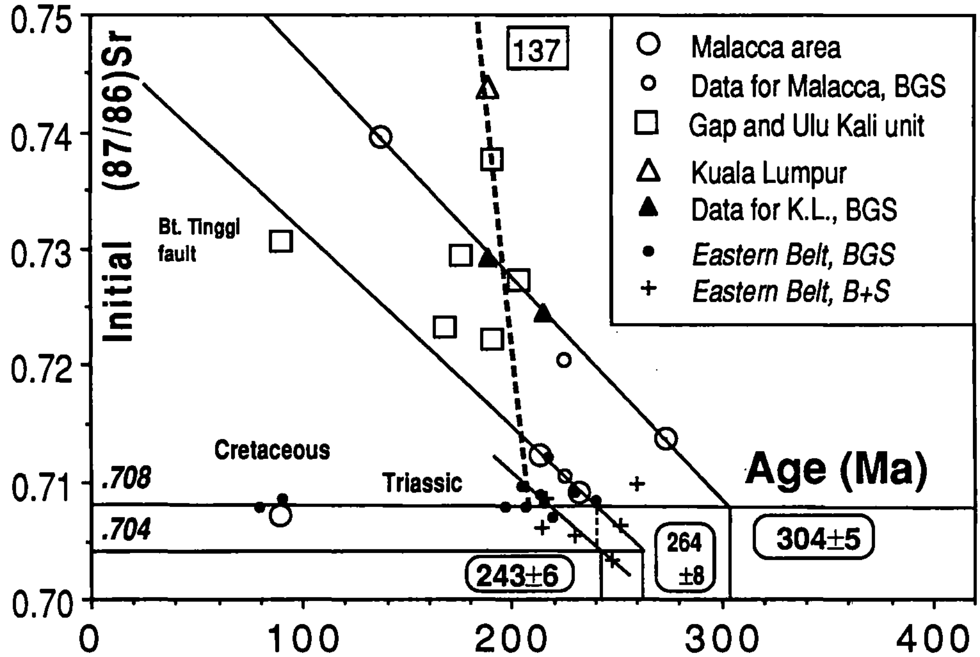


Figure 22: Age-initial $^{(87/86)}$ Sr Diagram including "isochrons" from the Malacca area and those from granitoids of the Eastern Granite Province. The latter were established by Darbyshire (BGS; 1988) and those indicated with crosses were established from data of Bignell and Snelling (B+S; 1977). In this diagram evolution regression lines were calculated through those Rb-Sr "isochrons" which are in a linear array. The two "isochrons" of the Seremban area (big circles) with extreme age spread define an evolution line with an extrapolated intrusion age of 304±5 Ma. The late-Triassic and Cretaceous intrusives group close to an initial $^{(87/86)}$ Sr of 0.7080, which is indicative for post-magmatic undisturbed Rb-Sr systems. Two intrusion episodes of 243±6 Ma and 264±8 Ma can be extrapolated for the granitoids of the Eastern Granite Province using an initial $^{(87/86)}$ Sr of 0.7040 (discussion see text). The "isochrons" from the Jelebu and Tampin pluton plot to the 22264 Ma evolution line. For reference the calculated evolution line for the late-Triassic granites of the Kuala Lumpur pluton is included (dashed line).

"isochron" points from granitoids of the Eastern Belt established from data of Bignell and Snelling (1977) and the ones reported from Darbyshire (1988) plot to an almost parallel evolution line. This intersects with a horizontal through 0.704 defining an age of 243±6 Ma. The reason for assuming an initial $^{(87/86)}$Sr of 0.704 will be discussed later. Note that some "isochron" points of late-Triassic and Cretaceous ages group close to the horizontal line through 0.708.

Fission track zircon and apatite ages

The analytical data are listed in tables V and VI. The zircon ages are with 63–79 Ma in the range of the lowest ones obtained from the Kinta Valley area (Fig. 15). They show over all faults an almost uniform decreasing age trend towards NW, taking in account that sample KAW 3088 from the Gap unit is from an altitude of 1700 m. The residual samples originate from altitudes of 70–350 m.

The four apatite ages show almost an uniform age distribution of 32–36 Ma except the one of the Genting Sempah pluton which is with 25 Ma significantly lower. Between the samples KAW 2999 and 3088 collected within the Gap unit from an altitude of 150 m and 1700 m respectively, an uplift rate of 0.31 mm/a can be calculated as the FT apatite ages are observed to be very accurate. The cooling patterns for the Kuala Lumpur area show a very slow cooling in the order of 1°C/Ma between Triassic and Cretaceous times and a five times faster rate from Cretaceous to present time (Fig. 12).

DISCUSSION

Rb-Sr and U-Pb evidences for pre-Triassic intrusives

The Rb-Sr whole-rock ages show a large spread of late-Triassic to Cretaceous. Principally, they are not in disagreement with the U-Pb zircon population ages as it is the case in Penang Island, where a Carboniferous Rb-Sr emplacement and a highly discordant late-Triassic U-Pb zircon population age is recorded from the Kampong Batak pluton (Kwan *et al.*, paper submitted; Liew, 1983). However, following constraints support the existence of pre-Triassic intrusions in the Kuala Lumpur and Malacca are, despite that only late-Triassic U-Pb ages and Rb-Sr whole-rock ages have been obtained:

a) For the Gap unit the Rb-Sr whole-rock age of 90 Ma within the Bukit-Tinggi fault zone can be extrapolated by its age-initial $^{(87/86)}$ Sr evolution line to a late-Permian age. Bignell and Snelling (1977) reported from two samples collected within 400 m distance east of The Gap an age of 251 Ma and a Sr intercept of 0.7071.

b) That Rb-Sr whole-rock ages of the area became highly distorted is evident for the obtained age of 168 Ma from five samples of narrow locations within the Gap unit. This age can be extrapolated back to a late-Triassic age of 210 Ma which is in good agreement with the intrusion age of 211±3 Ma obtained from the Feringgi-type granite of Penang Island (Fig. 7b).

c) Extreme compositional inhomogenities within the granite, the existence of numerous xenoliths, the observed intense alteration of amphibole bearing rocks and geochemical criteria for two different magmatic suites support a poly-phase evolution.

The reported concordant U-Pb ages of 206±2 Ma and 198±2 Ma from the Gap and Ulu Kali units respectively, are believed to determine late-Triassic intrusion ages (Liew, 1983). In both cases the corresponding reset Rb-Sr whole-rock ages are in close affinity to the concordant U-Pb zircon population ages. The Rb-Sr age of 190.7±2.6 (Bt. Tinggi fault) can be extrapolated to 210 Ma (206 Ma for U-Pb) and the age of 190.7±0.6 Ma (Bentong quarry) is slightly younger than the U-Pb age of 198 Ma (Fig. 17).

The highly discordant U-Pb age of 208±2 Ma originating from The Gap contains two data points plotting to the concordia. The case could occur where a zircon population of a late- and a pre-Triassic granite from a contact zone was analysed or one pre-Triassic granite comprising also a late-Triassic zircon generation. In case of Penang Island, from field relationships it was not possible to distinguish the Permian and Triassic granites from each other and contacts are gradually changing. In addition, the existence of two morphologically and compositionally different zircon populations within same granite-type of the Main Range could be verified. The reported U-Pb zircon ages of 211+5/–8 Ma and 215+2/–4 Ma from the western branch of the Kuala Lumpur pluton are highly discordant. Their highly discordant nature indicates that the population of U rich zircons (1,000–2,400 ppm), of suggested Proterozoic inheritance (Liew, 1983) and crystallized during Carboniferous and/or late-Permian time, have lost approximately 80–90% of their radiogenic Pb. No major Pb loss from late-Triassic to present time can be observed from the data patterns in the concordia diagram (Liew, 1983). Therefore it seems likely that the highly discordant U-Pb ages are indicating the late-Triassic metamorphism.

From the Kuala Lumpur area a late-Triassic Rb-Sr intrusion age of 210 Ma can be extrapolated from an "isochron" defined by samples from a narrow spot east of Kuala Lumpur comprising a very high Rb/Sr ratio of 137. And one microgranite sample of extremely high Rb/Sr ratio of 508 yielded same age of 209 Ma if corrected with an initial $^{(87/86)}$Sr of 0.708. Referring to the suggested reset character of highly discordant U-Pb ages the western branch of the Kuala Lumpur pluton should have also constituents of pre-Triassic age. The suggested Rb-Sr age of 245 Ma (Bignell & Snelling, 1977) is not very confident because samples from different units were used for age calculation. Nevertheless, a further isotopic indication is the good coincidence between the U-Pb and K-Ar mica ages in the range of 211–215 Ma. The K-Ar biotite ages >210 Ma are suggested to be mixing ages of incompletely reset pre-Triassic granitoids as it is evident from the Bujang Melaka of the Kinta Valley area. This seems to be typical for pre-Triassic high crustal level granites, which are located in a certain distance from the late-Triassic intrusives. Hence, this suggests an autochthonous position of the western Kuala Lumpur pluton. According to the geochemistry patterns of the Kuala Lumpur pluton (Fig. 4) and to samples of largely varying Rb/Sr ratios there exist granitoids of the late-Triassic Feringgi-type granite (Penang Island) affinities and others of the late-Permian Bujang Melaka-type-granite and the Bukit-Tinggi pluton.

For the Genting Sempah pluton the highly discordant U-Pb age of 219 Ma (Liew, 1983) lead to assume a pre-Triassic age what is supported by pre-Triassic Rb-Sr whole-rock ages (Bignell & Snelling, 1977) and by the "isochron" of high Sr intercept of 0.7260 (Liew, 1983). Hence, it could be a fingerprint that late-Permian acid volcanics and/or subvolcanics may occur in the Main Range.

The radiometric age patterns change further southeast towards the Malacca area and into the Central Belt. Along the suggested N-S pluton belt extending south of the Kuala Lumpur pluton the range of obtained Rb-Sr ages is large (Fig. 22). Evidence for Carboniferous intrusives are proved by the age-initial $^{(87/86)}$Sr evolution line from the "isochron" points of the Seremban area indicating an age of 304±5 Ma. The reason that "isochron" points of the Gap and Ulu Kali unit (Darbyshire, 1988) also coincide with same evolution line argue for existing Carboniferous intrusives in the Kuala Lumpur area, already suggested by Bignell and Snelling (1977). Further evidence is found from the Bt. Mor by a Rb-Sr K-feldspar age of 305 Ma, corrected with an initial $^{(87/86)}$ Sr of 0.708. This age is probably valid because the K-feldspar is known as the most stable mineral during any kind of granite alteration. The Rb-Sr whole-rock age of 232 Ma originating from samples of several plutons close to the coast line yield a reasonable initial $^{(87/86)}$Sr value of 0.7092. Despite, from the diagram age versus initial $^{(87/86)}$Sr it is evident that this age, together with the one from the Kuala Pilah road (Jelebu and Tampin pluton), show affinity to those of the Eastern Granite Province. Bignell and Snelling (1977) considered that the Rb-Sr whole-rock ages of the Eastern Granite Province are not post-magmatically disturbed due to the coinciding K-Ar mica ages. Despite, the linear array in the age-initial $^{(87/86)}$Sr diagram, typical for post-magmatic isotopic system disturbance (Kwan *et al.*, paper submitted), indicates that this interpretation has to be modified (will be discussed later).

The Cretaceous Rb-Sr "isochron" of 89±20 Ma is poorly defined but several mineral ages (Rb-Sr K-feldspar, Rb-Sr and K-Ar biotite) are in good coincidence (Fig. 16). This makes it reasonable to assume a Cretaceous intrusion age as postulated by Bignell and Snelling (1977). In addition, the reasonable initial $^{(87/86)}$Sr of 0.7072 provides further evidence that this Cretaceous Rb-Sr whole-rock age is not reset. Further Rb-Sr whole-rock data from Darbyshire (1988) from the Eastern Granite Province supports there existence. Some mineral ages of the Cretaceous granites have been disturbed also. Recalculated Rb-Sr mineral ages (corrected with 0.708) yield in case of the Batang Melaka pluton ages of 1924±529 Ma for plagioclase, 90 Ma for K-feldspar and 36 Ma for biotite. The aberrant plagioclase age clearly indicates trapped radiogenic Sr from biotites thus, the isotopic system of the whole-rock did not change. Further Tertiary Rb-Sr biotite ages are reported from Johor (close to Singapore) and within the Central Belt (see Table VII). Therefore further indication is given that also local post-Cretaceous radiogenic Sr re-distribution occurred between mineral pairs. This may be either related to isotopic system disturbances due to the reported volcanic activities in the Central Belt (Khoo and Tan, 1983) or by an open system behavior of biotites below their blocking temperature in deeper crustal levels.

Implications for intrusion episodes of the Eastern Granite Province

The two parallel occurring evolution lines in the age-initial $^{(87/86)}$Sr diagram defined by "isochrons" of the Malacca area and the Eastern Belt (Fig. 22) may be either interpreted by one intrusion episode of granitoids originating from sources of different initial $^{(87/86)}$Sr (0.708 and 0.704), or by different intrusion periods originating from same initial $^{(87/86)}$Sr of 0.704.

The reported K-Ar mica ages from granites of the Kuantan district of the Eastern Belt are cumulating in the range of 253 Ma to 266 Ma (Bignell & Snelling, 1977). Liew (1983) obtained a concordant U-Pb age of a single zircon fraction of 263±2 Ma. The corresponding recalculated Rb-Sr "isochron" yielded 260±2 Ma and an initial $^{(87/86)}$Sr of 0.7099 which provide additional evidence for the existence of an intrusion episode. Therefore in the age-initial $^{(87/86)}$Sr diagram the initial $^{(87/86)}$Sr of the source region at the time of 264 Ma can be extrapolated from the evolution line and yield an approximate value of 0.704. This would be a reasonable initial $^{(87/86)}$Sr for the suggested I-type granites (Liew, 1983). Hence, it is reasonable that the second obtained almost parallel evolution line defined by "isochron" points exclusively from the Eastern Granite Province originate from same source with an initial $^{(87/86)}$Sr of 0.704. The regressed and extrapolated intrusion age is therefore 243±6 Ma. In addition, this suggested intrusion episodes are supported by the three major maximums at 260, 240 Ma and 200 Ma obtained from a histogram where all available K-Ar mica ages of the Eastern Granite Province were plotted (Fig. 23).

There are further features that support the existence of late-Triassic granitoids in the Eastern Granite Province: a) Several "isochron" points group among 210 Ma with an initial $^{(87/86)}$Sr of about 0.708 which indicate undisturbed late-Triassic intrusives (Kwan *et al.*, paper submitted). b) From the age-initial $^{(87/86)}$Sr diagram and the K-Ar mica ages (Bignell & Snelling, 1977) it is evident that some pre-Triassic Rb-Sr whole-rock and K-Ar mica

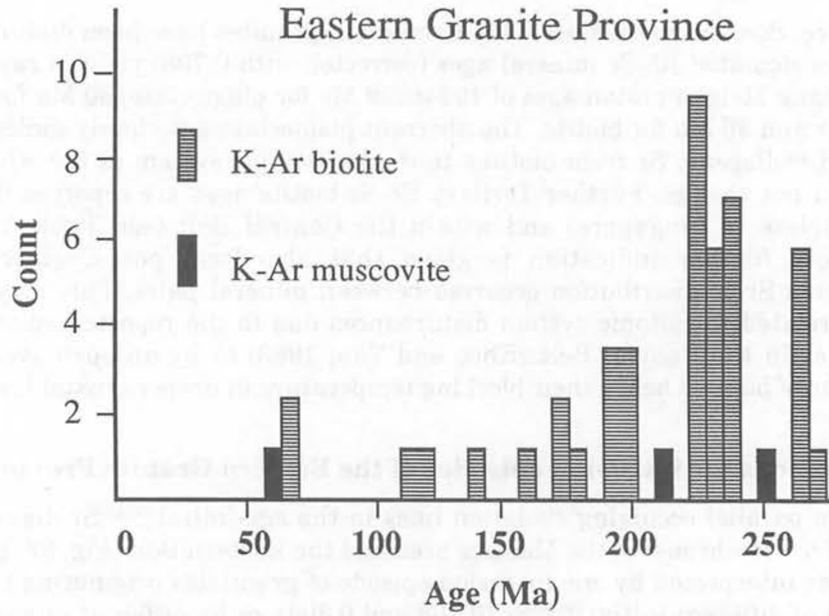


Figure 23: Histogram for K-Ar mica ages from the Eastern Granite Province. The biotites show three major maximums around 260, 2240 Ma and 2200 M, which is in good agreement with the estrapolated Rb-Sr intrusion ages. Data are used from Bignell and Snelling (1979).

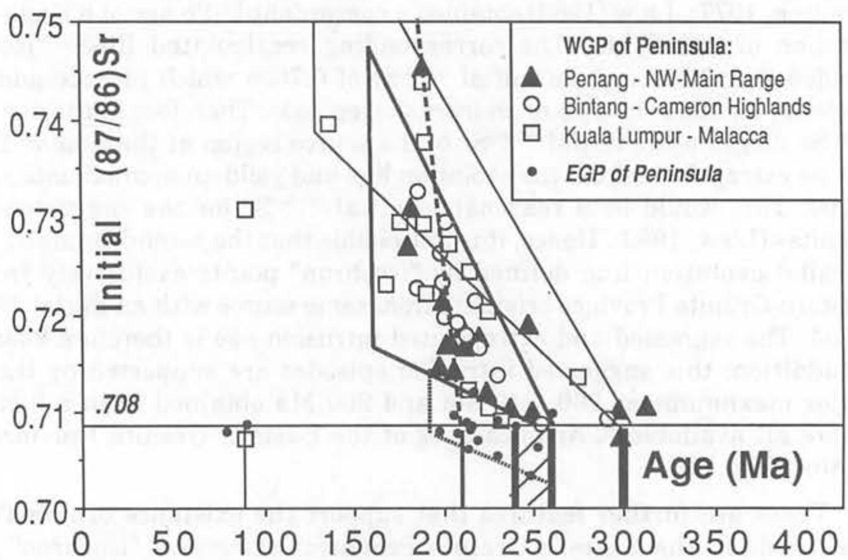


Figure 24: Age-initial (87/86) Sr diagram containing all available Rb-Sr whole-rock "isochrons" from Peninsular Malaysia. The majority of "isochrons" plot into the large sector starting from the late-Permian. Although the late-Triassic granites occur in both magmatic belts, their induced hydrothermal metamorphism affected the Eastern Granite Province (EGP) to a much lesser extent than the Western Granite Province (WGP), as it is evident from less disturbed Rb-Sr whole-rock systems. Granitoids of the Malacca area belonging to the Eastern Granite Province are tectonically displaced into the Western Granite Province.

ages have been partly reset induced by the emplacement of late-Triassic intrusives as discussed in the Main Range. c) The occurrence of limited tin mineralizations associated with S-type granites give rise to the assumption that local late-Triassic mineralizing processes, such as known from the Main Range occurred. Although, the influence of the late-Triassic hydrothermal metamorphism was smaller as it is evident from less disturbed Rb-Sr whole-rock pattern of the pre-Triassic granitoids (Fig. 24).

Tectonic activities

The regional age patterns for the Bukit-Tinggi pluton cause some problems for their understanding. The Rb-Sr whole-rock and K-Ar biotite ages of 90 Ma in the vicinity of the Bt. Tinggi fault coincide. Even the biotites from less deformed granites and high altitude of 1700 m (Genting Highlands) yield 94 Ma and 97 Ma. Those of "cataclastic" granites (Bignell & Snelling, 1977) south of the fault however, yield ages of 145 Ma for biotite and 179 Ma for muscovite, following an expected regional cooling trend (Fig. 17). And the K-Ar mica ages of granites located close to the Bentong-Raub suture are within same range (140–179 Ma). This features can be interpreted in light of three possible cases:

a) Differential uplift with maximum uplift at the fault bringing young ages up to present-day erosion level in sense of an eastward tilting of the pluton, as it is suggested for the Main Range east of the Kinta Valley.

b) Resetting of all K-Ar mica ages in the vicinity of the fault due to moderate heat flow and/or due to rock deformation as suggested by Bignell and Snelling (1977).

c) Vertical block displacements, thrust faulting or limited overthrusting of slabs close to the Bentong-Raub suture.

In two N-S profiles cutting the NW-SE tending faults of the whole Kuala Lumpur area a distance versus age diagram was established (Fig. 25). Within trend the K-Ar biotite ages in the Bukit-Tinggi pluton decreases towards the Bukit-Tinggi fault and they are in good correlation to the younger occurring Rb-Sr whole-rock ages. Remarkable change in ages can be observed between the different faults further to the south of the profile, which is supporting case a) and/or b). The large age gap between the K-Ar muscovite formation and the biotite cooling ages of 171 Ma and 134 respectively in the Kuala Lumpur pluton south of the Konkoi fault correlates with the generally younger Rb-Sr whole rock age of 189 Ma. This is good evidence that this ages represent deeper crustal levels of long lasting hydrothermal convections and slow cooling (Kwan *et al.*, paper submitted). For consequence, the big age gap between K-Ar biotite and muscovite ages of 134 Ma and 170 Ma respectively

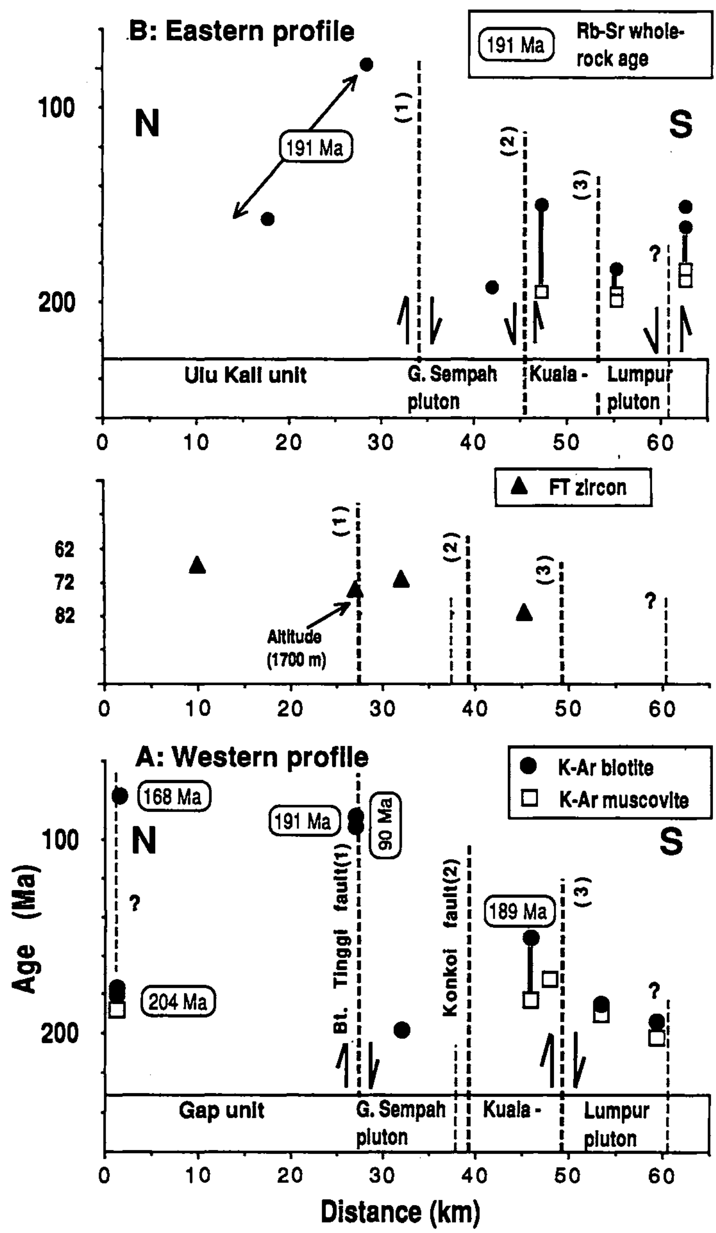


Figure 25: Two N-S age profile 6 km apart of one another from the Kuala Lumpur area (Fig. 15) are shown for K-Ar mica, Rb-Sr whole-rock and for FT zircon ages. Younger K-Ar and Rb-Sr ages indicate deeper crustal level (discussion see text). They show a differential uplift of different blocks bordered by faults. Note that the increasing discordance of K-Ar mica ages can be correlated to deeper levels and is larger in the eastern profile. The FT zircon ages indicate an almost uniform uplift and a slight NW tilting of the Main Range.

at the southern end of profile B, predicts a so far not reported fault bordering to a northern block of older mica ages and therefore higher crustal level. It can be assumed that the young K-Ar biotite ages in the SE part of the Kuala Lumpur pluton (Fig. 15, profile B) represent general deeper crustal levels. However, the coinciding trend of the reported K-Ar mica (Bignell & Snelling, 1977; Kwan, in prep.), the calculated Rb-Sr whole-rock and the reported highly discordant U-Pb zircon population ages between the different faults is rather evidence for juxtapositioning of different crustal levels than thermal or deformation dependent age rejuvenation. The continuing trend to lower K-Ar biotite ages towards the Malacca area could be interpreted as a culmination in the southeastern end of the Main Range. These findings correlate well with the composition of the sedimentary cover. Carboniferous metasediments surround the suggested autochthonous part of the western branch of the Kuala Lumpur pluton and are followed by Devonian ones further to the SE.

The observed complete dynamic quartz recrystallization in the granitoids outcropping in the vicinity of the Bukit-Tinggi fault indicates a temperature range of ≥300°C at the time the fault movements were active, which is in the range of the blocking temperature of biotite for the K-Ar and Rb-Sr system. Because in this granites the biotites are the main Rb carrier they dominate the isotopic whole-rock system, thus the obtained Rb-Sr whole-rock ages are expected to coincide. Hence, from the coinciding Rb-Sr whole-rock and K-Ar biotite ages, the increasing cooling rate (Fig. 12) after 90 Ma and the contemporaneous dynamic quartz recrystallization it is inferred, that the time of this major fault activity was at 90 Ma. The FT zircon ages in the range of 63–79 Ma were extrapolated to one single profile and they do not mirror above mentioned differential uplift any more (Fig. 25). The trend to younger obtained ages towards the NW indicate a change in the tensional regime. This is further evidence that a blockwise uplift and/or thrust faulting has to be expected earlier than 80 Ma ago.

The age patterns for the Ulu Kali unit do not, however, fit completely the suggested interpretation of blockwise uplift. K-Ar biotite ages show a similar NE increase as in the Gap unit, but they are with 87 Ma in the SW and 140 Ma in the NE younger than the ones in the Gap unit (94, 97 Ma and 162, 167 Ma; Fig. 17). In addition, the almost coinciding U-Pb and the Rb-Sr whole-rock ages of 198 Ma and 191 Ma respectively from the NE of the Ulu Kali unit are almost equal to the ones in the SW of the Gap unit (206 Ma and 191 Ma respectively) close to the Bukit-Tinggi fault where the highest uplift is recorded. This could be explained by thrust faulting or limited overthrusting of the Ulu Kali onto the Gap unit. This interpretation is supported by the following arguments:

a) The whole Main Range shows a decrease in size towards the SE what could be a product of a compressional regime leading to overthrusting. b)

Within the complex rock association of the Bentong-Raub suture, metamorphic schists and limestone blocks lay above unmetamorphic mélange due to overthrusting (Hutchison, personal communication). c) Northeast of the Bukit-Tinggi fault a series of sediments with affinity to those of the Bentong Raub suture are sited between the microgranites of the Genting Sempah pluton and the Ulu Kali unit. This can only be explained by overthrusting or folding. d) The local occurrence of the very low Rb-Sr whole-rock age of 168 Ma and 176 Ma in the area of The Gap close to the Bentong-Raub suture, and further K-Ar biotite ages of 90 Ma could in addition be best explained by thrust faulting. Several NW-SE striking small valleys could represent such thrusts.Assuming that the formation of muscovite determines the end of large scale hydrothermal convections as proposed for Penang Island (Kwan *et al.*, paper submitted), the difference between the extrapolated late-Triassic intrusion ages of 210 Ma obtained from the Rb-Sr data, and the lower K-Ar muscovite ages of the southeastern Kuala Lumpur pluton indicate a maximum time span of 20–40 Ma for hydrothermal convections at deeper crustal levels.

From the few FT apatite ages it is evident that the Genting Sempah pluton was squeezed out and preferentially uplifted in post-Oligocene. Its similar K-Ar cooling ages compared to the western Kuala Lumpur pluton and the reset Rb-Sr whole-rock age of 204 Ma (Liew, 1983) suggest a similar crustal level in pre-Triassic time for both plutons. This would favour an almost autochthonous position of this subvolcanite in pre-Triassic times and a high level of emplacement. The dominant brittle deformation style in the mylonitic augen-gneisses from NW-SE striking faults is suggested to be superimposed to the more ductile deformation of the Cretaceous differential uplift. This mylonitization is suggested to be due to the reported left-lateral displacement with reported 20 km offset (Tjia, 1972).

Summary: The age-initial $^{(87/86)}$Sr diagram is found to be a powerful tool for extrapolating the intrusion age of kinetic equilibrated Rb-Sr whole-rock systems and for granitoids of a high mean Rb/Sr ratio. It is evident that by the late-Triassic hydrothermal metamorphism the (^{87}Rb/^{86}Sr) ratio of pre-Triassic granitoids did not change significantly. Plotting all available Rb-Sr "isochron" into the age-initial $^{(87/86)}$Sr diagram it is evident that the major intrusion episode in the Western and Eastern belt occurred in the time span between 240 Ma and 260 Ma (Fig. 24). The best estimate of initial $^{(87/86)}$Sr for the source region in the Main Range is 0.708 and 0.709 for the Bujang Melaka which seem the most evolved of the late-Permian granites. For the Eastern Belt granitoids of late-Permian and early-Triassic age it is 0.704, which corresponds to suggested I-type magmatism. Whereas the late-Triassic S-type granites with its initial $^{(87/86)}$Sr of 0.708 disturbed the Rb-Sr whole-rock system of pre-existing granitoids to a more limited extent than in the Main Range. There is strong evidence for Carboniferous intrusives in the Malacca area and their existence in the Kuala Lumpur area can be expected. The regionally exposed deeper crustal levels in the Kuala Lumpur area document a long-lived fluid convection system, responsible for entire resetting of pre-Triassic Rb-Sr whole-rock and K-Ar mica ages. Pre-Triassic U-Pb zircon population ages were reset by the Triassic hydrothermal metamorphism and occur as highly discordant ages. Only few late-Triassic granites could have been identified. The highly variable K-Ar biotite ages mirror the intense vertical displacement of blocks, and thrust faulting and limited overthrusting of slabs have to be inferred. The timing of this major uplift phase is indicated by the coinciding Rb-Sr whole-rock and K-Ar biotite ages at 90 Ma and is supported by the contemporaneous dynamic quartz recrystallization in a range of the blocking temperature of biotite. The starting uplift phase with maximum north of the Bukit-Tinggi fault is contemporaneous with limited small Cretaceous intrusives comprising the same initial $^{(87/86)}$Sr of 0.708 as the pre-Cretaceous granites. Due to the more brittle deformation style within the NW-SE tending faults the left-lateral displacements are suggested to postdate the uplift and thrusting phase. The overall youngest Rb-Sr whole-rock, K-Ar mica and FT zircon ages of the Kuala Lumpur area indicate the so far deepest exposed crustal level of the Main Range. The small range of the Tertiary FT apatite ages found in the Western Granite Province demonstrate an almost uniform uplift of the whole belt in Oligocene/Miocene.

MAGMATISM, MINERALIZATIONS AND TECTONICS IN TIME AND SPACE

Carboniferous to Permian

Granites of Carboniferous origin are preferentially sited at the most western border of the Main Range and some are still in an autochthonous position. The Kampong Batak pluton of Penang, the Gunung Jerai in the NW Main Range (Kwan *et al.*, paper submitted) and the granites of the Seremban area are all of Carboniferous origin. Less positive evidence for a Carboniferous origin of plutons exists in the Cameron Highlands, within the Gap unit and for the Bukit-Mor, SE of Malacca. Additional Carboniferous plutons could exist but have not been detected either because of their small size or they have partly lost their isotopic memory. Following the suggested model from Hutchison (1988) these granites could be of anorogenic origin and were intruded in a pre-rift phase at time the Sinoburmalaya Belt was detached from Australia. Several features of these granites support an anorogenic origin:

The bodies are small and of rounded shape. Most of them are known to be intruded into early-Paleozoic metasediments. They were high level emplaced according to recorded contact-metamorphism in the sediments (Khoo, 1984).

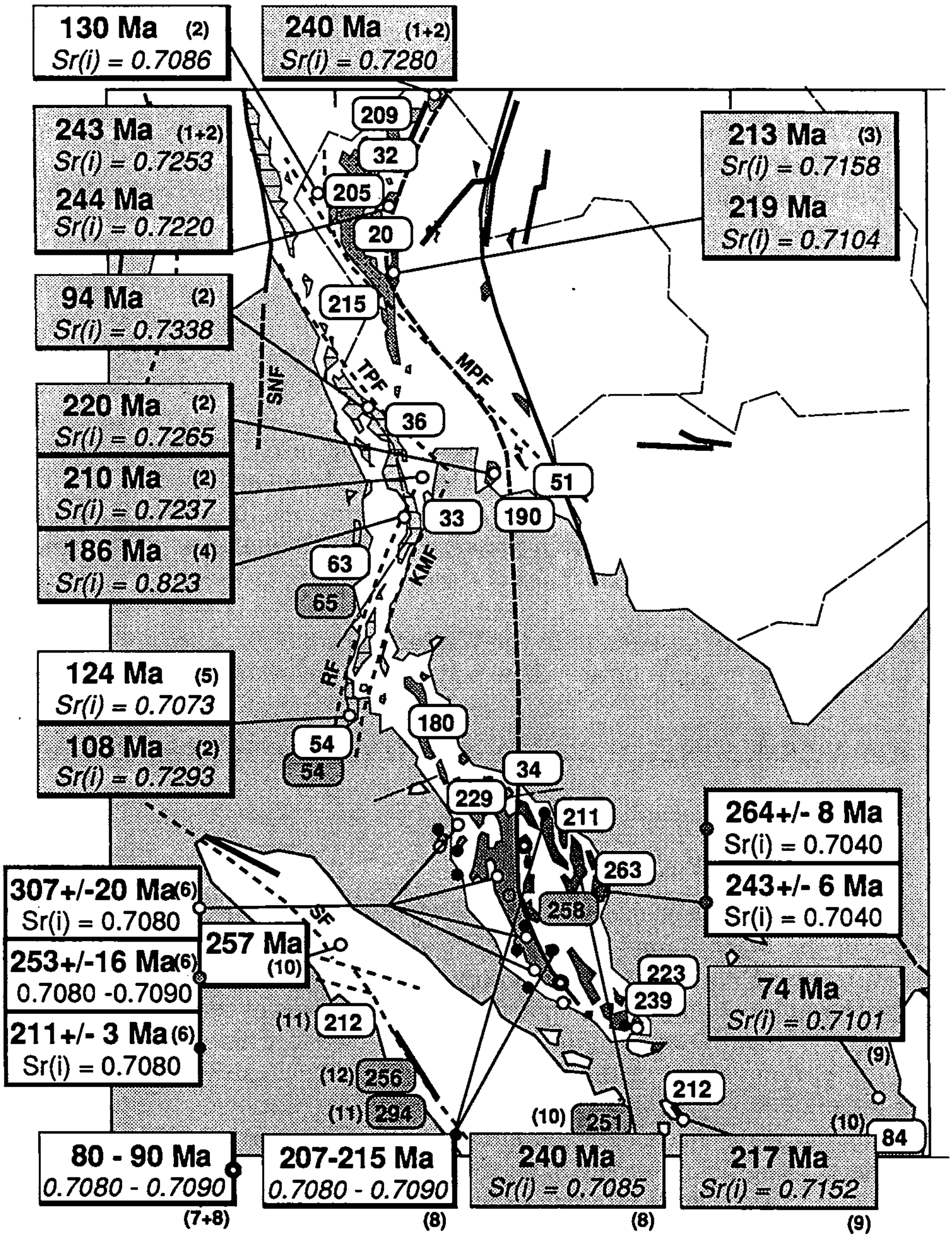


Figure 26: Map of Southeast Asia including Rb-Sr whole-rock (large square) and K-Ar mica (small square) ages. Rb-Sr and K-Ar ages which are printed by screen-process indicate reset "isochrons" and muscovite ages respectively; those on white background indicate the age of granite emplacement and biotite ages respectively. The two early-Cretaceous isochrons of western Thailand indicate a magmatism restricted to fault activities. The Rb-Sr whole-rock age of 94 Ma and its Sr intercept for granites in the Three Pagoda fault zone are in good agreement to those for granites in the vicinity of the Bukit-Tinggi fault of the Kuala Lumpur area indicating a major differential uplift phase within the long arc of the Western Granite Province. Reference: (1) Braun *et al.* (1976); (2) Beckinsale *et al.* (1979); (3) Teggin (1975); (4) Burton and Bignell (1969); (5) Garson *et al.* (1975); (6) Kwan *et al.* (paper submitted); (7) Bignell and Snelling (1979); (8) Darbyshire (1988); (9) Prime *et al.* (1975); (10) Katili (1973); (11) Obradovich/USGS, {CCOP (1980)}; (12) Hehuwat (1975), {CCOP (1980)}.

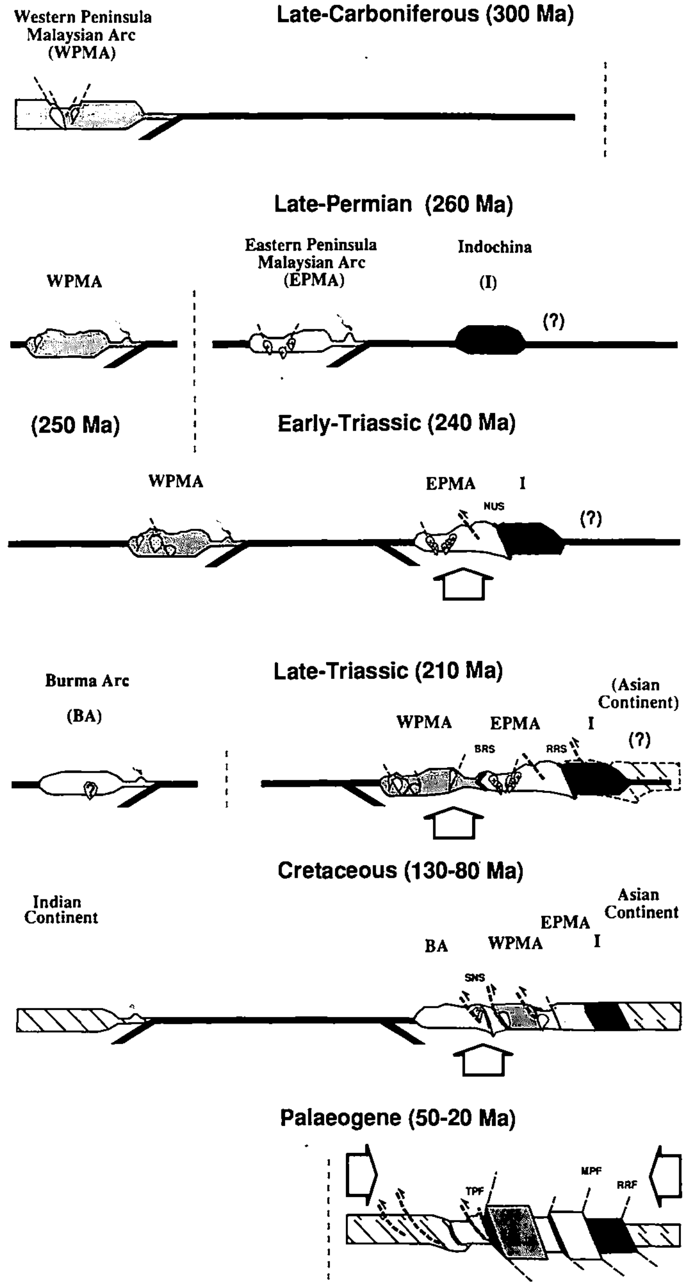


Figure 27: An attempt to reconstruct the evolution of the different Southeast Asian arcs and blocks in time and space, based on the newly interpreted timing of magmatism within the different arcs and on the plate tectonic model of Hamilton (1988). In this model the collision of arcs, deformation, subduction reversal, pressure release, uplift and magmatism within a close time range, are suggested to be the rule. Plutons symboled on white background are suggested to intrude at the indicated time periods. The collision of Indochina with the East Asian Continent is still speculative.

In case of the Gunung Jerai and the Bukit Mor tantalum and niobium minerals are reported (Cobbing, 1987). Further geochemical features probably no longer represent their initial composition according to superimposed Permian and Triassic poly-metamorphism. So far no tin mineralizations are recorded in their contact zones.

The most commonly occurring granitoids are of late-Permian age and with their immense volume they often enclose and surround Carboniferous granites (Fig. 24). The frequent occurrence of xenoliths and the varying inhomogenities in expected contact zones make it probable that partial melting of Carboniferous granites and assimilation could have occurred. A zircon morphology study after Pupin (1988) from a TTG of the Kampong Batak pluton of Penang Island shows a wide spread in the zircon population from a calc-alkaline to typical S-type trend (Müller, personal communication). Zircon crystallization temperature ranges of 800–650°C are extrapolated. This could indicate assimilation by partial melting but more studies are needed. The variation in the mineralogical composition of the late-Permian granites can only be assumed from remnant assemblages containing amphiboles. Geochemically, they show the largest spread within the intrusives of the belt. The best estimated initial $^{(87/86)}$Sr for Carboniferous and late-Permian granitoids is 0.708 and 0.708 to 709 respectively, indicating that differently evolved granitoids occur in the late-Permian intrusion episode.

Focussing to tectonic models, it is evident that the largest volume of Main Range granitoids originate from one episode (250 Ma) whereas the ones of the Eastern Granite Province intruded in two periods (260, 240 Ma). For the unravelling of plate tectonic evolution - of plate and belt motions; of the welding to continents and to one another; of the direction of subducted slabs - the following points in the comprehensive study of the arcs between Sumatra and New Zealand expressed by Hamilton (1988) have to be considered:

"Arcs are not steady-state tectonic systems but instead evolve and change completely and rapidly. Collision between continents commonly are preceded by long periods of subduction. The complex histories of collision, subduction reversals, rifting, and strike-slip and oroclinal deformation are the rule. Arc systems develop where oceanic plates sink beneath overriding plates that can be continental, transitional or oceanic. Descending slabs sink more steeply than they dip and are overridden by advancing upper plates. The common regime in an overriding plate behind a surficial accretionary wedge is extensional, except where a collision is under way. Island arcs migrate by back-arc spreading and are conveyor-belted toward subduction zones, so that island arcs sooner or later collide with one another and with continents. Convergence between mega-plates continues, but the light crust on the subducting plate is too low in density to be subducted, and so a new subduction system on an oceanic side of the new aggregate breaks. A strip of back-arc-basin crust is in many cases left attached to the aggregate, in front of the new trench, and becomes the basement for a fore-arc-basin, the leading edge of which is raised as mélange is stuffed under it. High-pressure metamorphic rocks form beneath overriding plates, not within wedges in front of them.

Large sheets of ophiolites incorporated tectonically into the continents are products of arc magmatism, back-arc spreading, or both together. Arc magmas incorporate much material from the lithosphere through which they rise and vary correspondingly with the evolving composition of that lithosphere"

In the following discussion the so far used term "belt" is replaced by "arc" for those belts which are suggested to represent arcs as mentioned above. The term "belt" is further used for linear striking features within the arcs. The 260 Ma intrusives of I-type characteristic accompanied by major acid to basic Permian volcanics are suggested to intrude in the extensional regime of a continental to transitional arc, which was overriding a south inclined subducted oceanic crust (Fig. 27). There are several tectonic models suggested that comprise a south, respectively present-day west-inclined subduction east of the Malaysian Peninsula (Asnachinda, 1978; Ridd, 1980; Bonupas, 1981; Lin *et al.*, 1988).

The Western Granite Province (Sinoburmalaya) can be understood as a continental magmatic arc. The long arc of continental crust is suggested to override a south inclined oceanic crust after rifting from Australia (?), taking part of the anorogenic Carboniferous pre-rift plutons with it (Fig. 27). In such a case it has thus to be considered that by the northward motion of the Western Peninsular Malaysian Arc (WPMA) a long distance was travelled until the equatorial position was reached in Permian time (McElhinny *et al.*, 1974). An immense volume of oceanic crust must have been consumed inaugurating the melting of the continental crust, the formation of migmatites in northern Thailand and of large batholiths and acid volcanic rocks in the Malayan Main Range. This interpretation is based on the geochemical, mineralogical and Sr isotopic spread found in the granitoids, by the zircons from Penang also showing a partially calc-alkaline trend (Müller, personal communication) and by the orthopyroxene-labradorite-bearing "subvolcanite" (Genting Sempah pluton). These granitoids intruded in the narrow range of 251–254 Ma according to the extrapolated Rb-Sr intrusion ages of the Main Range and the verified Rb-Sr whole-rock isochron of the Bujang Melaka. The same emplacement age of 252±2 Ma can be extrapolated from four Rb-Sr "isochron" (Beckinsale *et al.*, 1979) for granites from Fang-Mae-Suai, Ban Hong and Li of the northern Thai-Main Range (Fig. 26). Potential Permian volcanic sediments are missing because they have probably been eroded during later phases of major uplift. The main opinion that these batholiths of the WPMA are late-Triassic continent-collision related intrusives has to be dismissed.

The subsequent collision of the Eastern Peninsula Malaysian Arc with Indochina led to a converted north inclined subduction to the south of it inaugurating limited magmatism and acid to intermediate volcanism (Fig. 27). Hence, the former back-arc basin became a fore-arc basin by the formation of an accretionary wedge towards the subducted oceanic crust. This would principally agrees with the suggested "back-arc- or inter-arc-setting" of the correlated Nan-Uttaradit suture in Thailand (Barr and Macdonald, 1987). Although, the remarkable difference reported from the Nan-Uttaradit and Bentong Raub suture could be explained by lateral changes in tectonic conditions within a long arc, it is more likely that the further east located Ching Mai suture (Barr and Macdonald, 1987) is the northern extension of the Tertiary left-lateral displaced Bentong Raub suture due to the extrapolated intrusion ages of 252±2 Ma for granitoids, which are located in their east. Thus, the Nan-Uttaradit suture has to be correlated with a late-Permian south-inclined subduction zone east of Peninsular Malaysia, in present-day Golf of Thailand. This gives further evidence that the Eastern Peninsular Malaysian Belt was a separate arc that became welded to Indochina. For consequence, the plutons of I-type characteristic of extrapolated Rb-Sr intrusion age of 240 Ma intruded the 260 Ma granitoids of the pre-existing magmatic arc behind the newly fore-arc ridge in its south. And the acid to intermediate Triassic volcanics are found further west close to the fore-arc ridge or present-day Central Belt. The timing of the early-Triassic collision is in close agreement with reported late-Palaeozoic folding and uplift phase and the subsequent deposition of continental sediments (Khoo and Tan, 1983).

Mineralizations

Tin mineralizations of the Western Granite Province of the Malaysian Peninsula were so far related to the late-Triassic highly evolved granites. However, it is likely that primary mineralizations occurred in the contact zones where the late-Permian granites intruded the Palaeozoic pelitic and calcareous metasediments. Water can be liberated from the sheet silicates of the schists, slates and phyllites. This can supply the oxygen for cassiterite deposition as suggested by Eugster and Wilson (1985) but additional oxygen from carbonate dissolution may be required as well. Features, such as the rarely observed sheeted vein systems in the pelitic metasediments and metasomatic features (skarns, stokes and loads; Kinta Valley, Romang, 1922) are suggested to be attributed to late-Permian granites. That the Permian granites are the most abundant but not more Sn-mineralizations are known may have following reasons:

a) Where the granites intruded calcareous sediments the dominant mineralizations are sulphides with minor tin (Romang, 1922; Eugster, 1985).

b) Most of the granite cupolas containing potential greisen bodies and sheeted vein mineralizations (Taylor *et al.*, 1985; Plimer, 1987; Hosking, 1988) may no longer be exposed. The granites probably intrude into impermeable sediments where processes such as retrograde boiling, hydrofracturing and subsequent tin deposition were possible. The strong uplift of the eastern part of the Main Range and the thrust faulting of deeper located slabs since Cretaceous resulted in the cupolas becoming eroded.

c) The subsequent late-Triassic tin mineralization preferentially occurred along tectonic weak zones, superimposing potential late-Permian metasomatic mineralization in the contact zones to the late-Permian granites. Additional tectonic vertical displacement in Cretaceous time reworked pre-existing faults between granites and sediments and therefore any reconstruction of late-Permian mineralization is difficult.

d) To date the Permian formation of muscovite as a greisen product is almost impossible with the K-Ar method because the superimposed late-Triassic mineralization is expected to reset them. The only chance to prove this hypothesis could be the use of the Rb-Sr method.

The tin could be generated by partial melting of the highly evolved Carboniferous granites or by fractionation processes in the continental crust the late-Permian magmas were derived from. Separating of an aqueous fluid from the magma, forming of hydrated metal-chlorine complexes, vesiculation and rising in the silica-rich magma along polymerized channels to the plutons cupolas could be the Sn concentrating processes (Eugster, 1985).

The occurrence of lodes associated with limestones, shales, phyllites, meta-acid volcanic rocks, tuffs and quartz-porphyry dikes of suggested Permian age is reported from Kelantan (Eastern Granite Province; Hosking, 1988). Due to a more limited late-Triassic hydrothermal metamorphic overprint in the Eastern Granite Province it seems likely that this mineralization originated in late-Permian like those reported from Tasmania (Newnham, 1988).

TRIASSIC

The Triassic granites have a very limited occurrence and are suggested to be mostly small bodies, sills, stocks and associated pegmatites and aplies. These biotite granites are the most highly evolved with the highest SO_2, Rb, Y and the lowest TiO_2, Zr, $^{(87/86)}Sr$ values compared to all other granitoids. The ($^{87}Rb/^{86}Sr$) ratio is generally >40 and the initial Sr at time of intrusion is 0.708. The granites appear at tectonic weak zones like borders of sediments to plutons (Kinta Valley ?, Kuala Lumpur pluton) and within major faults (Gap unit). Small circular structures observed from landsat photograph analyses were reported within the NW-SE fault zone at Tapah (SE of the Bujang Melaka), in the Kuala Lumpur area and east of Kuala Klawang (Lai, 1987). These could present small late-Triassic plutons. Some granites reached a high level of emplacement where the country rock was already above the 300±50°C palaeo-isotherm (NW-Penang, Bujang Melaka, west Kuala Lumpur pluton). They are of high heat production characteristics according to enhanced K, U and Th content and they induced a pervasive hydrothermal conductive convection system (Kwan *et al.*, paper submitted). The late-Triassic granites occurring in the Western and Eastern Peninsula Malaysian Arcs are expected to originate from one single plate-tectonic process, which affected the two different magmatic provinces (Chakraborty, 1988; Darbyshire, 1988).

Hence, they are suggested to be of post-collision origin intruding the pre-Triassic granites during an extensional regime of an uplift phase induced by the break of a new subduction south of the WPMA (Fig. 27) at time it became welded to the EPMA-Indochina complex. This agrees with the suggested uplift and subsequent continental sedimentation in Peninsular Malaysia (Khoo and Tan, 1983). With the continuing northward motion of the Indian-Australian mega-plate further arcs and the Indian continent were still under way. The late-Triassic granites intruded preferentially in the magmatic arc of present-day Main Range and are expected to be less frequent at greater distance from the subduction zone, in present-day Eastern Granite Province. During the pressure release-related uplift phase along suggested deep faults the post-collision granites and pegmatites were intruded to a high crustal level, produced radioactive heat, initiated a hydrothermal convection system, metamorphosed the host granites and were responsible for the main tin mineralization. The fore-arc basin of the WMPA was squeezed to the former back-arc basin of the EMPA. Most of the mélange from the leading edge in front of the fore-arc basin was presumably stuffed under the former back-arc basin whilst the other part was imbricated above it. Within continued collision of this continental arc the two fore-arc basins became shortened which brought the granitoids of the Eastern Granite Province closer to the Main Range. The whole welded complex was additionally highly deformed with the subsequent Cretaceous collision of the Burma Arc and the one of the Indian continent in Tertiary discussed later. The confusing result is now seen as the Bentong-Raub suture. The collision of the two arcs is expected to have taken place shortly before the intrusion of the post-collision granites determined by the best extrapolated Rb-Sr emplacement age of 211±3 Ma.

Whether in late-Triassic time the whole crustal complex including Indochina was welded to the Asian Continent as suggested by Mitchell (1981), or hypothetically in Cretaceous due to local granitic magmatism occurring even in southern China (Chen *et al.*, 1985), or Indochina was already attached in the late-Palaeozoic (Helmcke, 1985; Hutchison, 1988), can not be verified from this study.

Mineralizations

The late-Triassic tin mineralization model is based on a pervasive hydrothermal conductive convection system. Remobilization of Sn from early crystallizing mineral phases such as biotite, muscovite and ilmenite of the pre-Triassic granites is considered to be the major source. Ore forming elements (OFE) are leached from these minerals in the first stage by a fluid of mainly high chlorine content (Eugster, 1985). Since most of the primary biotite is observed to be recrystallized and is reset in the radiometric ages in late-Triassic time, biotite seems to be one of the major Sn sources. The chlorine is probably sourced from NaCl possibly supplied from saline water or dissolved from the infiltrated sedimentary cover by meteoric water. With boiling of the fluid, hydrolysis of NaCl to HCl may occur which later is important for leaching of OFE under alteration of the host rock (Eugster, 1985). The uplift-related fracturing of the crystallized pre-Triassic granites is suggested to increase the permeability for infiltration of meteoric water to the convecting system. Evidence of such deformation may still be represented by the strongly disrupted feldspar cores of granites at high crustal levels. The small temperature difference between rock and fluid needed for convection (Fehn, 1985) provide great potential for long lasting convection.

The almost fully recrystallized felsic leucogranites observed in the vicinity of primary tin mineralizations (Kinta Valley), which contain accessory muscovite, light brown secondary biotite almost free of opaques, occasionally dissolved amphibole and which is to a high extent albitized, may be the product of rock alteration. The albitization is in agreement with a negative correlation of TiO_2 to Na_2O between PTG of the Bujang Melaka-type and the TTG and STG of the Relau-type granite. The observed conversion of biotite to the light green chlorite could lead to Sn release (Kledang Range). According to Eggleton and Banfield (1985) biotite is considered not to release only bivalent octahedral (BOC; Fe^{2+}, Cu^{2+}, Zn^{2+}), but also large highly charged cations (LHC; Mn^{3+}, Fe^{3+}, As^{3+}, Mo^{4+}, Ta^{4+}, W^{4+}) including Sn^{4+} to the fluid, by redistribution of elements in the octahedral positions. Chloritization may also occur at the latest stage of tin precipitation where HCl is liberated and neutralized by the country rock dissolving carbonates, apatite and magnetite and/or leading to conversion of K-feldspar, plagioclase and biotite to muscovite, or biotite to chlorite, releasing again metal chlorides to the fluid (Eugster and Wilson, 1985). In such a case muscovite is considered to be a major phase. Formation of the muscovite-quartz greisen and in a later stage of kaolinite bodies are the resulting products. The overall low K content in non- or slightly chloritized biotites of the PTG (Main Range of the Kinta Valley), the replacement of biotite by tourmaline and the minor-appearing fluorite infiltration indicate that all granites have been affected by the hydrothermal metamorphism. The presence of fluorine and boron in the fluid is therefore evident.

Cassiterite deposition is suggested to start with increasing oxygen fugacity and pH, and decreasing temperature and salinity. Such sudden changes in the physico-chemical conditions can be induced by mixing of two fluids and/or addition of new meteoric water (Eugster and Wilson, 1985). Redox reactions in the presence of H_3AsO_3 may also lead to cassiterite and arsenopyrite precipitation without significant changes in the physico-chemical conditions (Heinrich and Edington, 1986). The latter is observed in the Tekka mine where the relative abundance of cassiterite correlates positively with the concentration of arsenopyrite.

The vein style of mineralization in the Main Range, composed of mineral phases such as quartz, tourmaline, cassiterite, wolframite and arsenopyrite, are suggested to accommodate Sn from remobilization processes in the host rocks. Tin may be also accommodated from the crystallizing late-Triassic granites itself because petrographic and isotopic evidences indicate that these were also affected by their own induced fluid convections (Kwan *et al.*, paper submitted). By contrast mineralized pegmatites may accommodate the Sn by magmatic processes as discussed for the late-Permian granites.

In the isotopically determined deeper crustal levels (Eastern Kuala Lumpur and Kampong Batak pluton) large scale convection survived to maximum 40 Ma. Some late-Permian granites sited above the 300±50°C palaeo-isotherm had a very short temperature increase with subsequent rapid cooling, showing coincident Rb-Sr and K-Ar mica ages. Conductive convection systems therefore lasted only a few million years. Some 4–6 Ma could be estimated from isotopic evidences in case of northern Penang Island (Kwan *et al.*, paper submitted). Any transition to greater depth and/or closer to the Triassic intrusives may have occurred and will be mirrored in regional distributed lower Rb-Sr whole-rock ages and higher discordant muscovite and biotite ages.

The intense fluid convections redistributed isotopic and geochemical patterns in sense of homogenization. Hence, to determine any original isotopic and geochemical characteristics of pre-Triassic intrusives is almost impossible because the processes of homogenization took place within variable sizes of system. For consequence, the determined initial $^{(87/86)}Sr$ of individual "isochrons" is therefore high and variable, ilmenite is expected to be the major phase in a oxidizing environment and the alkalines and Al_2O_3 is observed to be highly mobile. Y also behaves partly mobile and is known to accommodate fluorine and chlorine complexes in hydrothermal fluids (Humphris, 1984). Hence, local occurring granitoids of originally I-type characteristic lost some of their fingerprints by particular superimposed hydrothermal metamorphism.

The question why some plutons of the Main Range are barren and others are tin mineralized results from a complex scenario of Sn accommodation, transport, ore deposition, tectonic activity and subsequent erosion. For the non-mineralized Penang plutons the following points have to be born in mind:

1.) Carboniferous, late-Permian and late-Triassic granites associated with tourmaline-bearing pegmatites are present. Also different crustal levels are exposed where potential hydrothermal convections lasted for different time spans. Therefore the potential for Sn accommodation should be given. Nevertheless, no known tin mineralizations occur. Due to observed less intense hydrothermal alteration in all granites, supported by small spread in the geochemistry patterns of mobile elements and the presence of observed general less disturbed Rb-Sr whole-rock ages, it has to be assumed that one of the physico-chemical constraints for Sn accommodation and/or conditions for fluid convections were missing. However, the possibility exist that Permian or Triassic mineralizations could have occurred in the plutons cupola but became eroded in geological time.

2.) The valley of the Sungei Perak between the Bintang Range and the Kledang Range (Fig. 3) is not known to host major alluvial tin deposits. The Bintang Range is known to be one of the less evolved granites and the available evidence suggests a late-Permian age. The intruded country rocks are Carboniferous phyllites, shales and schists. From the center of the Kledang Range fault related primary vein mineralizations of the late-Triassic style are known. The Bintang granite may not contain Sn enriched early crystallizing minerals due to the less evolved geochemistry. And the Kledang Range is not expected to supply much cassiterite into the Sungei Perak Valley. Its autochthonous position and small uplift in Cretaceous is responsible that the heavy minerals were not transported far from the pluton as it is evident from FT zircon studies in the Kinta Valley.

3.) The almost autochthonous sited Bujang Melaka pluton with its geochemical high evolved core of the Relau-type granite and surrounded by the less evolved Bujang-Melaka-type granite intruded calcareous and pelitic sediments. Nevertheless, the latter seems to be one of the more evolved granites due to the higher initial $^{(87/86)}$Sr of 0.709 and the reported enhanced Sn content of 27 ppm and up to 500 ppm Sn in the biotites (Schwartz and Askury, 1989), intruding at the end of the late-Permian magmatic suit (254 Ma). Despite, cassiterite deposits are only known from the center of the pluton where fault related late-Triassic intrusives can be assumed. However, no primary tin deposits are known in the contact of the late-Permian Bujang Melaka-type granite to the sediments. This fact could be evidence for general the non-existence of Permian mineralizations. But it could also mean that in the particular geological setting one of the various constraints of the mineralization processes was missing as discussed earlier.

4.) The plutons of the N-S stretching belt in the Malacca area are known not to be mineralized with the exception of the Mt. Mor where tin bearing pegmatites are reported (Cobbing, 1987). Carboniferous, late-Permian and late-Triassic granites intruded mainly Devonian phyllites, slates and schists; the recorded fault net is less intense than in the Kuala Lumpur area. From the Tampin pluton less evolved geochemical patterns are known. Due to the extrapolated initial $^{(87/86)}$Sr ratio of 0.704 the late-Permian granites can be related to the Eastern Granite Province and have affinities to I-type characteristics. Firstly a potential Sn source could be missing and secondly the less disturbed Rb-Sr whole-rock systems indicate that Sn accommodation processes driven by hydrothermal convections were less intense.

Generally, the following points have to be emphasized: Isotopic evidence for Carboniferous, late-Permian and late-Triassic intrusives in spatially close position; the facts, that intense post-Triassic faulting displaced different crustal levels and/or granites adjacent to another, that hydrothermal convection may last for different time intervals, that the dating of muscovites from greisen may not necessarily determine the age of mineralizations, that Permian mineralizations may occur (Kledang Range; Kelantan, East Granite Province; Tasmania) but could be superimposed by late-Triassic ones, that principally also basic dykes and diorites may be associated with tin mineralizations (U.S.S.R.; Wemkui, 1988); all these points indicate the complex scenario tin mineralizations are involved with and the difficulties which must arise to unravel it. All this favours the assumption that any occurrence of tin mineralization is dominated by the question whether the mineralizing processes took place and subordinate on the availability of Sn sources. The kind of processes responsible are described by Eugster and Wilson (1985), Eugster (1985), Fehn (1985), Jackson and Helgeson (1985), Heinrich and Edington (1986), Plant *et al.* (1985), Pollard *et al.* (1987), together with others. Hence, the recognition of such processes which may superimpose one another is important. There are however strong evidences that the major tin mineralization in the Main Range of the Malaysian Peninsula were induced by local highly evolved late-Triassic post-collision granites of HHP characteristics.

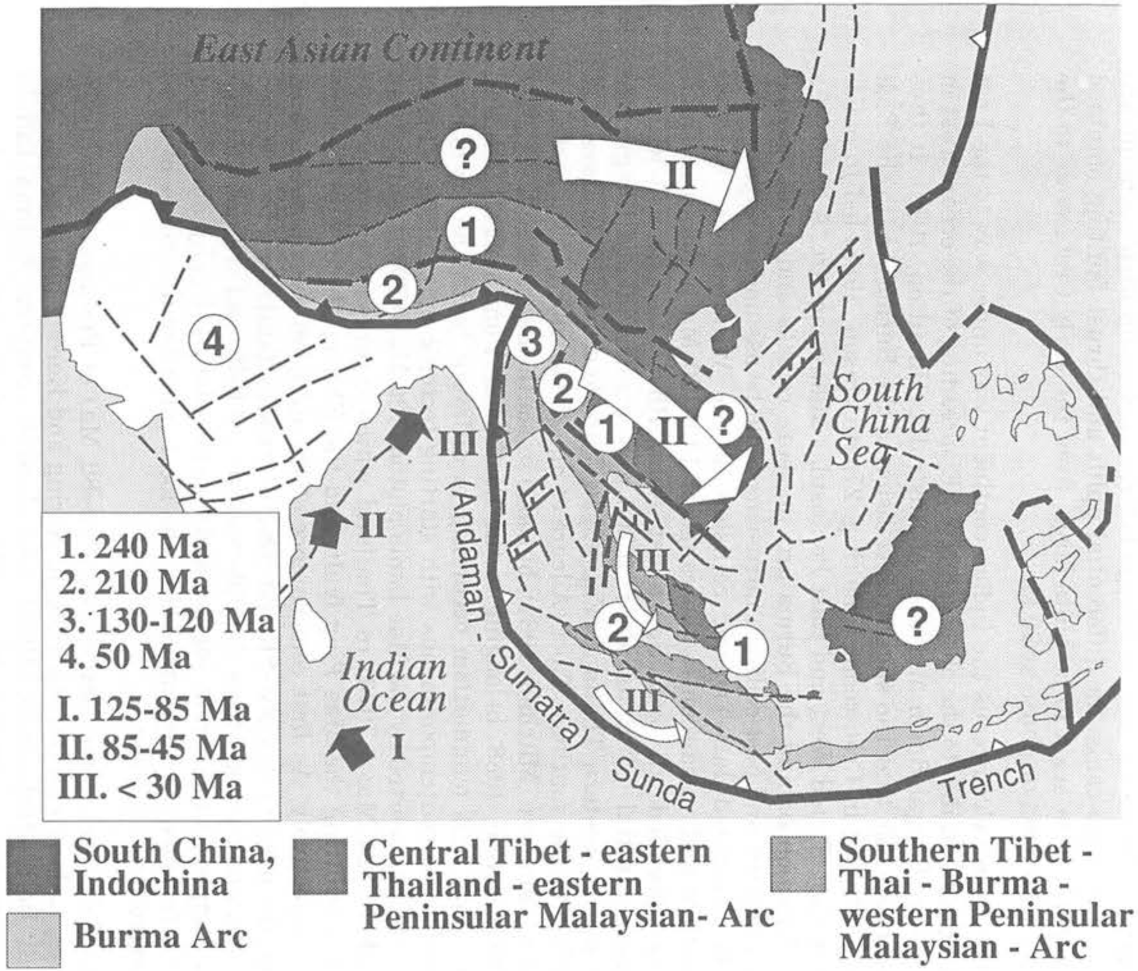


Figure 28: Map of Southeast Asia illustrating the different arcs which became welded to one another and to the East Asian Continent (timing in Arabian numbers), and the tectonically disrupted and displaced blocks (white arrows; timing in Roman numbers), dependant upon geological times. Black arrows indicate direction of the Indian-Australian mega-plate motion (Hamilton, 1979). Base map is compiled from Tapponnier *et al*. (1982), and the structural and seismological map of the state seismological bureau Beijing, China (1981).

CRETACEOUS TO TERTIARY

The Cretaceous and Tertiary of the Peninsular Malaysian Main Range is largely dominated by tectonic movements. According to isotopic evidences and due to observed deformation style of the granitoids, major uplift, subordinate overthrusting and large lateral strike-slip displacement are evident. The time range for differential uplift and thrust faulting obtained from isotopic data seem to be quite large, from the early-Cretaceous to the Tertiary with a major phase at 90 Ma.

In the early-Cretaceous the Indian continent was under way to the East Asian Continent, due to the observed NW-SE spreading of the ocean crust in present-day Bengal Basin and west of Australia (Hamilton, 1979). It thus seems reasonable that the suggested collision of the Burma Arc to the East Asian Continent in Cretaceous time (Fig. 27; Hutchison, 1988) led to major uplift in the affected West and East Peninsular Malaysian Arc. A break of a new subduction behind the Burma arc, pressure release and uplift, partial melting of crust and post-collision intrusions could be assumed, similar to the already discussed late-Triassic collision of the WPMA. The initiated magmatism and volcanism in the range of 140–120 Ma is found in small plutons spreaded all over Southeast Asia. Rb-Sr "isochrons" with a reasonable initial $^{(87/86)}$Sr of about 0.708 give good evidence for granite intrusions in western Thailand (Fig. 26; Beckinsale *et al.*, 1979; Garson *et al.*, 1975), in the southern Tibet (Allegre *et al.*, 1984) which is suggested to belong to same arc (Mitchell, 1981), but also in southeastern China (Chen *et al.*, 1985; McKee, 1988) belonging to the East Asian Continent (Hutchison, 1988). Thus, this magmatism occurring in different belts and cratons is expected to be contemporaneous with starting tectonic movements. This is particularly supported by the Mae Lama pluton (130 Ma; 0.7086) and the one of Phuket (124 Ma; 0.7073) in Thailand which interseats the two fault branches splitting the Mae Ping fault, and the Khlong Marui and Ranong faults respectively. As first consequence of the collision a conjugated fault system (the present day NW-SE and NE-SW striking faults) can be assumed to be activated cutting across the different welded belts and cratons due to a global compressional strain regime and the mentioned, locally distributed early-Cretaceous granites intruded in the local extensional regimes of these conjugated fault systems.

The late-Cretaceous magmatism (90–80 Ma) of Peninsular Malaysia (Gunung Ledang and Batang Melaka; Noring and Kerong pluton of the NW Central Belt, Darbyshire (1988) and possibly western Kalimantan is contemporaneous with the major differential uplift phase inferred from isotopic and petrographic evidences, as in case of the Main Range east of the Bukkit-Tinggi fault in the Kuala Lumpur area. In addition, the very similar age of 93 Ma and initial $^{(87/86)}$Sr of 0.7338 for the Khao Dean granite

(Beckinsale *et al.*, 1979) located in the NW-SE striking Three Pagoda fault (Fig. 26) and the regional distributed Tertiary K-Ar mica ages, indicate a strongly uplifted probable late-Permian granite in the western Thai area. Whether this uplift and magmatism can be correlated with the collision of a further arc of unknown composition, with a hypothetical collision of the Burma-Indochina complex with the East Asian Continent, with the changing direction of the Indian-Australian mega-plate motion towards NNE (Fig. 28; Hamilton, 1979) or with lateral different tensional regimes within one long arc, is a matter of speculations.

At that time the palaeo-position of the Malaysian Peninsula can be assumed to be located close in front of the Burma Arc, in a present-day position west of Bangkok. The NW part of Sumatra could have built the NW extension due to similar radiogenic age patterns. A reported Rb-Sr whole-rock age of 257±24 Ma (Katili, 1973), K-Ar muscovite ages of 294, 287, 256, 251 Ma (CCOP, 1982) and several late-Triassic ages provide good evidence that Sumatra originates from the same arc. The SE extension of Peninsular Malaysia is suggested to be found in west Kalimantan (Hutchison, 1988).

Between 85 Ma and 45 Ma the direction of plate motion changed to the NNE direction (Hamilton, 1979) what may initiated the starting collision of India between 50–40 Ma (Allegre *et al.*, 1984). It can be assumed that changing the sense of plate motion the long distance left-lateral displacements along the NW-SE striking Mae Ping and Three Pagoda faults were initiated. This provoked the SE motion of the Indochina and Sinoburmalayan block along distinct fault plains disrupting the pre-Cretaceous magmatic arcs (Fig. 28; Tapponnier *et al.*, 1982).

The Indian collision caused probably first of all a second uplift phase, thrusting and gentle folding. Further uplift is indicated from the regional trend of increasing cooling rates over the whole Main Range. Limited overthrusting and gentle folding could be a rudimentary form of what is known from the Himalaya and Tibet because the Sinoburmalayan block could escape the compression towards the South China Sea. A gentle folding could be interpreted from the geological map of Peninsular Malaysia. The lateral changing NW-SE striking sediment belts of different lithology and the intervening exposed granite belts of same direction could indicate anticlines and synclines. Down folding of the Main Range beneath the Straits of Malacca and subsequent left-lateral displacement to the Tin Islands of Indonesia was suggested by Hutchison (1986). During the SE motion of Peninsular Malaysia the NW-SE striking faults of the early-Cretaceous conjugated system were reactivated and this fault planes are found in 200 m wide zones within the Bukit Tinggi pluton, composed of mylonitic augen-gneisses comprising a cataclastic texture of almost no quartz recrystallization. This deformation is clearly superimpose upon the late-

Cretaceous uplift related one of regional occurrence. The isotopic determination of the exact ages of the left-lateral displacements is so far not possible. However, a projected range of late-Eocene to early Miocene can be assumed.

The next crucial event moving Peninsular Malaysia to its present-day position is suggested to have taken place after Oligocene. With continuous collision of the Indian plate a crustal triangle was squeezed into south Burma/SW-Thailand and strongly uplifted, inferred from the Tertiary K-Ar mica ages which decrease towards the Three Pagoda and the Khlong Marui faults (Fig. 26). The K-Ar mica ages of 73–33 Ma within the Thai-Burma triangle (western I- and S-type granites, Fig. 1), including Phuket, indicate the uplift exposing deeper sited granites. Assuming that this triangle was originally in a position further southwest it could be considered that in its SE extension, in present-day Straits of Malacca, granites of same belt may be exposed. Hence, the offshore tin deposits in the Straits of Malacca could be supplied by exposed late-Triassic granites. However, this would be supported by the fact that the heavy minerals will not be far transported, as it is evident from FT zircon ages of the alluvials of the Kinta Valley. Probably the uplift in the Thai-Burma triangle and the suggested contemporaneous anti-clockwise rotation of Peninsular Malaysia along the Ranong and Khlong-Marui faults (Holcombe, 1977) under opening of the Gulf of Thailand (Tapponnier *et al.*, 1982), was a consequence of a further change in the direction of the Indian-Australian mega-plate motion towards NE. Volcanism of early-Miocene was found from drill wholes in the Gulf of Thailand (Hamilton, 1988). Most NNW-SSE to NNE-SSW striking faults of Peninsular Malaysia and within the Gulf of Thailand may resulted from this Sunda shear rotation (Holcombe, 1977). Peninsular Malaysia was not affected by major Tertiary differential uplift, which is inferred from the FT apatite ages, and from only few spots in the Main-Range where late-Cretaceous to Tertiary Rb-Sr and K-Ar biotite ages exist: 69 Ma in Penang (K-Ar); 59 Ma (muscovite) and 46 Ma (K-Ar), 40 Ma (Rb-Sr) in the Gunung Jerai; 16 Ma (Rb-Sr) from Johor, near Singapore.

The NE inclined Andaman-Sumatra subduction started around 30 Ma, as suggested by Hamilton (1979) inaugurating a magmatic arc in Sumatra, a transitional one in Java and a mature oceanic island arc in Bali (Hamilton, 1988). Assuming that the differential uplift of the Thai-Burma triangle was a consequence of the changing plate motion towards NE, which was later than Oligocene (Fig. 28), then the break of the Andaman-Sumatra subduction started not before early-Miocene.

The extrusion of Tertiary volcanic rocks in the southern Central Belt of Peninsular Malaysia is suggested to be related to a local extensional regime, which was induced by the changing tensional regime leading to the Sunda rotation. This is inferred from the FT apatite ages of Peninsular Malaysia, which indicate a changing sense of slight differential uplift tilting major blocks of the Main Range towards the NE (Penang, Kinta Valley). In addition, the single young FT apatite age of 25 Ma from the Genting Sempah pluton of the Kuala Lumpur area could be a result of changing opposite shear sense between the Bukit-Tinggi and the Konkoi faults. The interseated block could be uplifted by a resulting local compressional regime (Bally, 1984). Further suggested movements in the Miocene are the doubling of the Burma Arcs under opening of the Andaman Basin (Maung, 1987).

Mineralizations

With respect to potential tin mineralizations in Cretaceous time no tin associations are known from the Cretaceous granites of the Malaysian Peninsula. Despite, the time of the tin mineralization in the southern Thai-Burma Arc was suggested to be of Cretaceous to Tertiary age (Beckinsale *et al.*, 1979). However, the global radiometric age patterns of Thailand are very similar to those of the Malaysian Peninsula. Most of the determined Rb-Sr whole-rock "isochrons" in the whole Thai Main Range and Thai-Burma triangles give high initial Sr values. This suggests that Carboniferous, late-Permian and late-Triassic intrusives occur. Hence, it is likely that the major tin mineralizations are also of late-Triassic age. Nevertheless, from a general overview it cannot be excluded that in addition post-Triassic tin mineralizations in Southeast Asia may occur if the constraints for mineralizing processes were present as discussed earlier. It has to be considered however, that the magmatic and tectonic evolution in time and space is indeed very complex and that several mineralizing systems may be superimposed.

CONCLUSIONS

It is stressed that the magmatic and tectonic evolution in Southeast Asia is very complex and normally of a superimposed setting. Critical examination of existing radiometric ages provides evidence for the following magmatic periods occurring in the Malaysian Peninsula: 300, 260, 250, 240, 210, 90 Ma.

Concerning the magmatic evolution in the Malaysian Peninsula it can be concluded:

1.) There exist granites of Carboniferous age along the west border of the Main Range which could be of an anorogenic origin;

2.) The largest volume of granitoids in the Main Range, which intruded in the narrow range of 251–254 Ma, are suggested to be of a magmatic arc setting of a continental crust;

3.) The small bodies of highly evolved late-Triassic granites intruded at 211±3 Ma in a suggested post-collision regime. They initiated a regional hydrothermal metamorphism. The continuation of the induced hydrothermal conductive convection system is positively correlated with depth and is inferred to have lasted for a maximum of 40 Ma;

4.) The late-Cretaceous granites intruded in a local extensional setting. No regional thermal overprint could be recognized in the host granitoids but a local one cannot be excluded;

5.) With exception of the Carboniferous intrusives the narrow time span of the magmatic periods in the Western and Eastern Granite Provinces can be best explained by north motion, collision and subduction reversals of different mobile arcs;

6.) The similar initial $^{(87/86)}$Sr ratios of about 0.708 for the different magmatic periods intruding in the time range of Carboniferous to Cretaceous support the model of Hamilton (1988), that the composition of any pre-existing crust, which was recycled during poly-phase plate tectonic processes, is responsible for the resulting rock association and therefore the initial isotopic-chemical composition remains about the same;

Post-Triassic tectonic differential uplift brought crustal levels of different cooling behavior adjacent to one another, which is the main reason for the very broad spread observed in the radiometric ages:

1.) No Jurassic intrusives exist. All Rb-Sr whole-rock "isochrons" in the Main Range which have a higher initial $^{(87/86)}$Sr than 0.709 are reset ages of pre-Triassic and late-Triassic granitoids and are dependent on the crustal level and/or the distance to the late-Triassic intrusives;

2.) Highly discordant U-Pb ages from zircon populations indicate the age of the late-Triassic hydrothermal metamorphism;

3.) All reset late-Triassic to Cretaceous K-Ar biotite ages of regional distribution are metamorphic cooling ages indicating different crustal levels. Some surviving late-Permian ages are indicative for rocks that reached in pre-Triassic time a crustal level that was above the palaeo-isotherm of 300±50°C. Biotite ages >210 Ma are mixing, and muscovite crustal level dependent formation ages;

4.) The age-initial $^{(87/86)}$Sr diagram is a powerful tool to extrapolate the intrusion age of reset Rb-Sr whole-rock systems;

5.) The compilation of coinciding Rb-Sr whole-rock and mica ages, of increasing cooling patterns and of the petrographical deformation style allow to date uplift related fault activities;

With respect to the Sn mineralization and accommodation it has to be concluded:

1.) The most critical features for the formation of tin mineralizations are the distinct required processes and to a much lesser extent the availability of Sn sources;

2.) The main primary tin deposition occurred in the late-Triassic and there is evidence for Permian mineralizations in the Malaysian Peninsula;

3.) The leaching of Sn from biotites of pre-Triassic granites is considered to be the major Sn enrichment process.

ACKNOWLEDGEMENTS

I extend my thanks to Prof. Dr. E. Jäger who has supported this work throughout its duration; my thanks are also due to the Director-General of the Geological Survey of Malaysia, Mr. Yin Ee Heng; Mr. Fateh Chand and Mr. Senathi Rajah are also thanked for the granted support. Mr. Marhimuthu and his colleagues kindly helped with sampling in the field. Mr. T.S. Kwan, Prof. C.S. Hutchison, Dr. E.L. Cobbing, Dr. D.P.F. Darbyshire, Dr. P.E.J. Pitfield introduced me to the geology of Southeast Asia for what I am grateful. Discussions with Prof. E. Jäger, Prof. Dr. B. Stöckhert, Prof. K.R. Chakraborty, Dr. M. Flisch, Dr. I. Michalski, Dr. T.T. Khoo, Dr. I. Mercolli, Mr. T.S. Kwan, Mr. A.K. Askury, Mr. K.H. Lai, Mr. M. Giger, Mr. H. Oschidari and my colleagues at the Laboratory for Isotope Geology of the University of Berne were very stimulating and provided a constant source of new ideas. My special thanks to Dr. S.D. Burley who kindly improved my English. The research was supported financially by the "Schweizerischer Nationalfonds zur Förderung der wissenschaftlichen Forschung".

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Manuscript received 21 April 1990