Geol. Soc. Malaysia, Bulletin, 11, Dec. 1979; pp. 111–136.

The Kinta Tinfield, Malaysia

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Abstract: This paper reviews the present state of knowledge of the geology and mineral resources of the Kinta tinfield, Malaysia. It identifies areas where knowledge is wanting and where further research is warranted.

The Kinta tinfield, in the State of Perak, is an extensive area located in a valley flanked by granitic ranges to the east and west. The bedrock in the valley is composed mainly of crystalline limestone with minor argillaceous and arenaceous rocks of Silurian to Permian age. The sedimentary strata generally strike north to northwest, dip steeply with beds folded or overturned. The granitoids, intruding into the sedimentary sequence, are of probable Triassic age.

Since 1890 the Kinta Valley area has been the largest and most productive tinfield in the world, and to date has contributed approximately 30 per cent of Malaysia's total recorded tin production. Much of the tin is recovered from alluvium by dredging and gravel pump methods. Ilmenite, monazite, zircon, xenotime, scheelite, wolframite, gold, columbite and struverite are the chief by-product minerals of tin-mining operations.

INTRODUCTION

The purpose of this paper is to review briefly the geology of the Kinta tinfield, which is the world's richest, amounting for about 10 percent of the world's output. The Kinta tinfield is located in the Kinta Valley, in the state of Perak near the western coast of Peninsular Malaysia (Figure 1). The valley is about 48 km (30 miles) long and 24 km (15miles) at its widest part, and trends approximately south-southwest.

The valley floor of the tinfield is gently undulating. It is flanked to the east by the Main Range and to the west by the Keladang Range. The major river, the Kinta River drains practically the whole length of the valley from north to south, and is joined by a number of small tributaries.

The mountain ranges consist essentially of granitoids whose original sedimentary covers have been removed by weathering and erosion. The greater solubility of the limestones is responsible for their generally much lower relief; marked exceptions to this are the conspicuous limestones hills (mogotes). Schists, interbedded with limestone, usually form low hills rising from the valley floor, or foothills flanking the granitic ranges.

PUBLISHED LITERATURE

De la Croix (1882) and de Morgan (1886) gave early accounts of mines and rocks in the Kinta Valley. Other descriptions of tin deposits were given by Hampton (1887, 1899) and Penrose (1903). The latter provided an account of the mode of occurrence of alluvial and lode tin deposits. Scrivenor (1913) gave information on the geology and mines working around 1913. This report was later revised by Scrivenor and Jones (1919). Willbourn (1924) wrote on the occurrence of lode tin deposits in the Kinta Valley; and Jones (1925) described the main mines of Kinta. Much additional information concerning Kinta is given in Scrivenor's publications (1928, 1931).

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The first authoritative map of Kinta published on the scale of an inch to a mile (1:63,360) was compiled by Scrivenor (1927). Because of much disagreement in the interpretation of the geology of Kinta, such as the origin of Gopeng beds, the presence of granitoid of two distinct ages, and the structure and succession of sedimentary beds, the Geological Survey sought the independent opinion of Rastall (Rastall 1927a, 1927b, 1931). Between 1927 and 1939 the Geological Survey continued examining mines in the valley and kept pace with mining developments. During the Japanese occupation of Malaya, however, the Geological Survey did not function.

Investigation of the Kinta Valley by the Geological Survey was resumed in the early nineteen-fifties. The most recent and comprehensive report on the geology of Kinta was the memoir by Ingham and Bradford (1960) compiled from data gathered up to about 1953 from which most of the information for this review has been freely obtained. In addition, this review contains information obtained from published and unpublished studies carried out largely by members of the Geological Survey and the University of Malaya since the last comprehensive report of Ingham and Bradford.

Many mining companies have carried out extensive exploration over this tinfield. However most of their findings are not available. As such it is not possible to incorporate their data in this paper. Other relevant publications are given in the bibliography.

GEOLOGY

General

The geology map of the Kinta tinfield based on the work of Ingham and Bradford (1960) and on the *Geological Map of West Malaysia, 7th Edition* (1973) is produced in Figure 1.

The Kinta Valley is underlain by a sequence of sedimentary rocks ranging in age from Silurian to Permian, which have been intruded by granitoids and associated late phase minor intrusives of probable Jurassic to Triassic age (Fig. 1).

Most of the sedimentary rocks in the valley are Devonian in age. Rocks of Silurian age are present in the northern part, whereas rocks of Carboniferous underlie areas in the southwestern part of the valley. Locally, outcrops of Permian limestone are also known. Alluvium covers almost the entire valley.

The sedimentary rocks have been affected both by thermal and regional metamorphism brought about by the intrusion of the granitoids, and by earth movements that preceded and continued during and after the granitic emplacement.

Calcareous Rocks

The sedimentary rocks underlying the Kinta Valley are chiefly calcareous. They comprise relatively pure limestone, dolomitic limestone, dolomite and ferroandolomite and occupy about 673 sq km (260 square miles) of the valley. Generally, the limestone has recrystallized to form a crystalline marble. The resulting calcite crystals show great variation in grain size. Locally, the calcareous rocks maybe interbedded with argillaceous beds. The limestone, with irregular pinnacles and forming a karst topography, has commonly been exposed in mines working on stanniferous alluvium. In Kinta, limestone hills arising from the alluvial plain and forming a striking topographical feature occur particularly in the eastern portion of the valley.

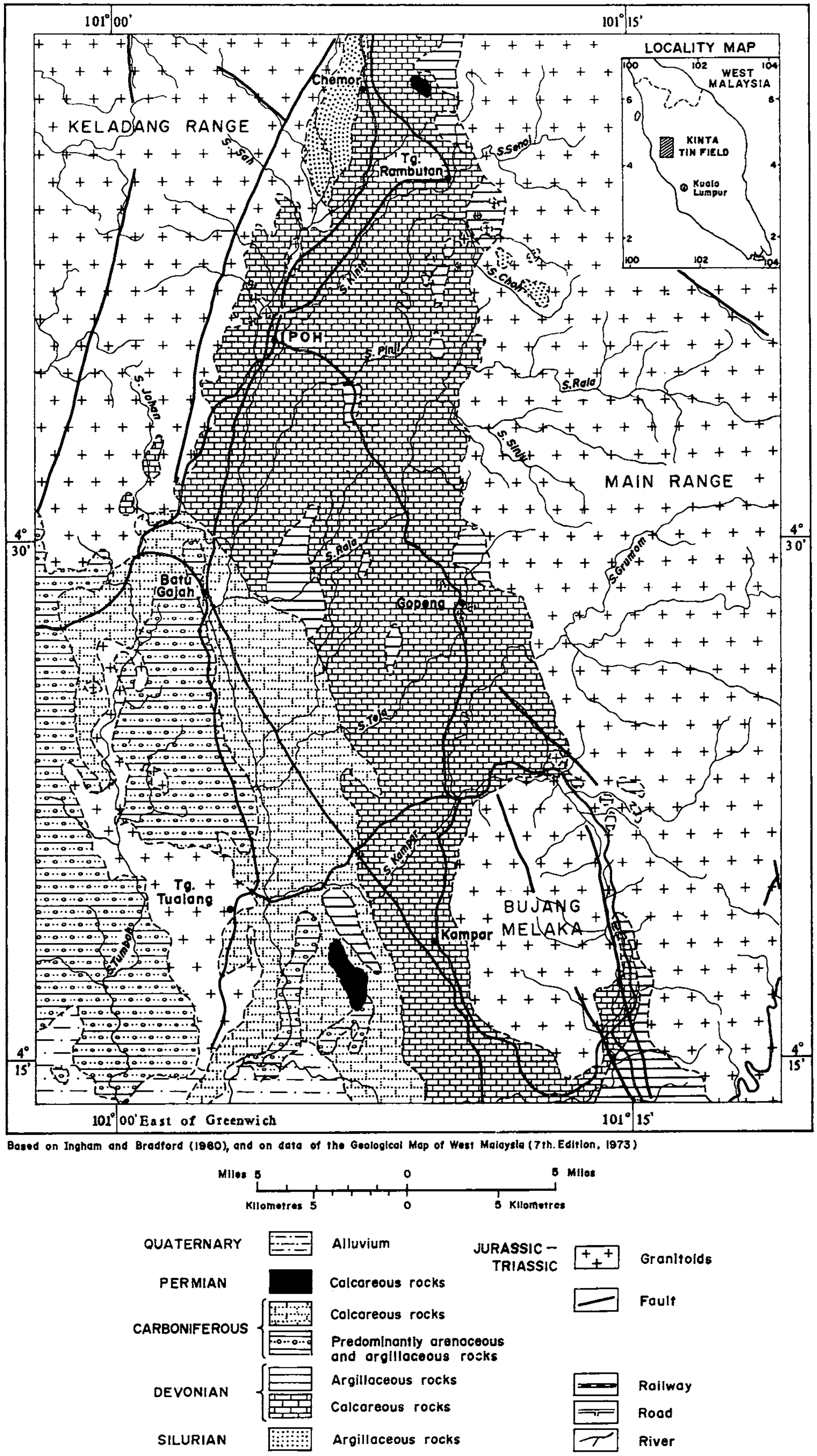


Fig. 1. Geology of the Kinta Tinfield

Limestone Hills. The origin of the limestone hills has provoked much discussion by writers on the geology of Kinta. Scrivenor (1913) considered it to be due to block faulting, based on the erroneous assumption that the 'clays' (termed by him as the 'Gopeng Beds') flanking the bases of some of the hills were of a much older age; though stratigraphically younger than the limestone. Jones (1917), however, suggested a sub-aerial denudation of well-jointed limestone for the formation of the limestone hill. Cameron (1925) suggested that the hills are the result of unequal denudation of a strongly jointed limestone lying unconformably on a floor of older and sheared limestone and schist. Rastall (1927b) thought that the present lines of limestone hills represent three parallel anticlinal ridges overfolded from the west and separated by low-lying areas and suggested that they were subsequently modified by block faulting in different directions and by denudation. Reed (1949) modified this hypothesis by suggesting that the hills are remnants of a nappe or beds overthrust from the east and resting on a thrust plane.

From the many exposed sections studied, the limestone of the valley floor appears to pass without break into the limestone of the hills. Moreover, no horizontal breaks or large near-vertical fault zones have been found. Ingham and Bradford (1960) noted that folding in the limestone appears to be so complicated that it cannot be stated with certainty, as was suggested by Rastall (1927b), that three distinct anticlinal ridges are present. According to them, although the north-south alignment in two portions of the valley is conspicuous, it is probable that faulting, jointing, folding and denudation, have all played their part in varying degrees in the sculpturing of the limestone hills. Paton (1964) reassessed the various hypotheses on the origin of limestone hills and concluded that the lithology appears to be the dominating factor and that the steep slopes were the result of subaerial erosion along joint planes.

Age. de Morgan (1886), Wray (1894) and Collet (1903) believed that the limestone was younger than the other sedimentary beds. Scrivenor (1912, 1913) regarded the limestone as Carboniferous and considered it to be older than the phyllites and quartzites. Rastall (1927a) indicated that the limestone is Carboniferous or Permo-Carboniferous. Ingham and Bradford (1960) referred to the calcareous rocks, which are, in places, interbedded or interlayered with argillaceous rocks, as the Calcareous Series and thought them to be of Carboniferous age. This was based on poor fossil evidence and on lithological resemblance to hill-forming limestone in Pahang, which was thought to be Visean.

The discovery of Lower Palaeozoic fossils between 1956 and 1959 in the Calcareous Series in Batu Gajah and northwest of Chemor was footnoted but not discussed by Ingham and Bradford (1960). In recent years, a number of fossil localities have been discovered in the limestone, mainly by the Geological Survey. These have yielded faunas of Silurian, Devonian, Carboniferous and Permian ages (Jones and others, 1966). A study of the stratigraphy in the southern part of the valley, west of Kampar, has shown an apparently continuous Devonian to Permian limestone succession (Suntharalingam, 1968).

Devonian fossils were first recognized from the Kanthan limestone hill, near Chemor (Alexander and Muller, 1963). These were conodonts and included Lower, Middle, and Upper Devonian species; there appears to be a continuous Devonian sequence. Immediately west of the hill, mudstone interbedded with dolomite has yielded Silurian tabulate corals (Jones, 1968; Thomas and Scrutton, 1969). Other Devonian fossil localities occur at the southern end of the valley, mainly in the Kampar area. Here the faunas include tabulate corals, stromatoporoids, gastropods, onocerid nautiloids and brachiopods; the details are given in Gobbett (1973).

Limestone of Carboniferous age is extensively exposed in the southern half of the valley, best known west of Kampar and near Batu Gajah. Though fossils are common in the limestone, they are usually poorly preserved. The fauna in many places is dominated by gastropods. Other fossils recorded include cephalopods, brachiopods and corals. These have been described by Jones and others (1966) and Gobbett (1973).

Permian limestone is known to be present north of Tanjong Rambutan and west of Kampar. Richly fossiliferous limestone of Lower to Middle Permian age has been found forming the bedrock of open-cast mines near Kampar (Ishii 1966, Sunthara-lingam 1968 and Batten, 1972). The fauna, the details of which are given by Gobbett (1973), include brachiopods, crinoids, gastropods, fenestellid polyzoa, dasycladacean algae, ostracodes, nautiloids, and fusulines.

Argillaceous Rocks

The argillaceous rocks consist essentially of shale, phyllite and schist with subordinate siltstone and sandstone (quartzite). The earlier authors (Scrivenor, 1913 & 1928; Rastall, 1927a) have referred to these rocks as the Triassic or the Schist Series. Ingham and Bradford (1960), however, referred to them as the argillaceous facies of the Calcareous Series.

The argillaceous strata are well exposed in numerous parts of the valley. The largest outcrops extend from Batu Gajah to Tanjong Tualang and form a stretch of undulating country. These rocks are commonly contorted and deformed and commonly occur as lenticular beds in the limestone. Economically, the argillaceous rocks are significant for they host a number of stanniferous deposits. These rocks have been intensely weathered to clay, forming the 'Western Boulder Clays', the 'Tekka Clays', and the 'Gopeng Beds'. Such deposits of boulder beds and boulder clays along both margins of the valley and near the base of hills were regarded by Scrivenor (*in* Scrivenor and Jones, 1919) as being Permian and Carboniferous glacial deposits—'Gondwana'. Later, Scrivenor (1931, 1949) recognized them as Post-Mesozoic and probably Pleistocene sediments.

The Western Boulder Clays. These beds occur on the western side of the valley and form undulating country in the Papan and Pusing areas. They were described by Scrivenor (1913) as of glacial origin, and discussed at some length by Jones (1917) and Rastall (1927a).

The Western Boulder Clays are characterized by the presence, in a matrix of stiff clay, of boulders of tourmaline-corundum rock and schist. Jones (1917) showed that some of the clays were eluvial and is traceable into unweathered schistose or phyllitic bedrock; this view was accepted by Rastall (1927a). Willbourn (1936), however, noted that the weathering and collapse of schist, which is interstratified with limestone, has resulted in the formation of most of these clay beds.

The Tekka Clays. These clays occur on the eastern side of the valley and are well exposed in the Tekka and Kramat Pulai areas. Scrivenor (*in* Scrivenor and Jones, 1919) considered them to be of glacial origin. Usually some boulders occur in the clay and they commonly include vein-quartz, schist, tourmaline rock and corundum. The clays contain cassiterite, usually in significant quantity to enable the beds to be mined profitably.

Jones (1917) and Rastall (1927a) showed that the clays had been derived most probably from the alteration and weathering of schist. Willbourn (1936) indicated that there is strong evidence to suggest that the beds were residual deposits resulting from the weathering of schist. According to Ingham and Bradford (1960), the bulk of the cassiterite has no doubt been derived from mineralized veins injected into the schist from the adjacent granitoids.

The Gopeng Beds. These beds form highly undulating land in the southeastern part of the valley, mainly in the Gopeng area. The beds reach a height of more than 76 m (250 ft) above the limestone floor, but most of the higher portions have now been removed by mining. They consist mainly of sandy clay and clay with pebbles and boulders, and exhibit a distinct bedding in most places.

Scrivenor (1912a) originally thought that the Gopeng Beds were of glacial origin and Permo-Carboniferous in age, but he later (1931) discarded the glacial theory. Jones (1917) classified them as alluvial but later (1925a) suggested they were eluvial and derived from weathered stanniferous schists. Rastall (1927a) interpreted the Gopeng Beds as high-level (Old) alluvium. Ingham and Bradford (1960) pointed out that the presence of beds of peat, interstratified with typical Gopeng material, indicates that most of the beds are alluvial. They, however, considered that clays resting immediately on the surface of the limestone are remnants of weathered schist.

Age. Scrivenor (1913) considered the argillaceous rocks, which he termed as the 'Younger Gondwana Rocks', older than the limestone (Carboniferous). Mapping carried out in the Sungei Siput area immediately to the north of Kinta (Savage, 1937) and in Tapah—Telok Anson area in the south (Ingham, 1938) indicated that the argillaceous beds are not part of the Triassic Series as originally thought by Scrivenor, but are interbedded with limestone and form part of the Calcareous Series (Ingham and Bradford, 1960). With the discovery of fossil localities in the limestone, it seems likely that the argillaceous rocks are Silurian, Devonian and Carboniferous in age.

Arenaceous Rocks

The arenaceous rocks are composed mainly of sandstone (quartzite) with minor interbeds of conglomerate, siltstone and shale. These rocks are found mainly in the west and southwest of the valley.

Scrivenor (1912 a & b) originally grouped both the argillaceous and arenaceous rocks of Kinta into one unit. Ingham and Bradford (1960), however, included the greater portion of them in the Calcareous Series. They termed the arenaceous beds of larger areal extent as the Arenaceous Series which they believed to be of Triassic age, on lithological similarity to the Middle Triassic Semanggol sediments in the Taiping area, Perak. To date, however, Triassic sediments have not been recognized in Kinta.

Tourmaline-Corundum Rocks

The term tourmaline-corundum rock was coined by Scrivenor (1910b) to describe this unusual type of rock, composed essentially of tourmaline and corundum. In Malaysia, it occurs only in the Kinta Valley and appears to be limited to the western side of the Kinta River, whereas pure corundum rocks seem to be present only on the eastern side.

The tourmaline-corundum rocks are found chiefly as boulders. *In situ* outcrops have been found to be always associated with schists. In some localities, the rock is weathered to a greyish clay showing pisolitic texture (Ingham and Bradford, 1960).

Origin. The pisolitic texture of the tourmaline-corundum rocks suggests met morphism of a pisolitic bauxite. The pisolites were thus considered by Scrivenor and Jones (1919) to be premetamorphic in origin. Willbourn (1931) discarded the theory of origin of pisolitic sediments in favour of an origin from argillaceous bands in limestone, altered by metamorphism to a type of spotted schist, such as is commonly found in metamorphic aureoles and pointed out that low grade metamorphism could have produced this rock-type.

Ingham and Bradford (1960) noted that it would be interesting to determine whether the excess of alumina in the rocks is solely due to the composition of the original sediment, or whether additional alumina has been introduced by the granitoids. Hutchison (1973b) indicated that the corundum could have resulted from greenschist facies metamorphism of rocks that were pisolitic and rich in aluminium, as in the case of pisolitic bauxitic clays. The tourmaline was introduced as a result of tourmalinization from the adjacent granitoid bodies.

Granitoids

Granitic rocks, in the shape of a giant horse-shoe, encircle the sedimentary strata that form the basement of the valley. They underlie an area of about 738 sq km (285 square miles), i.e. about half the area of Kinta. Ingham and Bradford (1960) divided the granitoids into four major masses: (a) the Main Range granite flanking the east of the Kinta Valley, (b) the Keladang Range granite forming the western boundary of Kinta, (c) the Bujang Melaka mass forming a dome-shaped boss, jutting out from the Main Range near Kampar, and (d) the Changkat Khantan-Tronoh-Tanjong Tualang mass, representing an irregular intrusion extending some 24 km (15 miles) southward, in line with the Keladang Range axis.

The Main Range and Keladang Range granites coalesce to the north. All the major granitoid masses appear to belong to the same intrusive. Riley (in manuscript) considered the contact between the granitoids and the metasediments to be predominantly discordant, although in places it appears to be concordant. The metamorphic aureole is not extensively developed; its extent varies from place to place within the valley.

In the marginal areas of the granitoid bodies, there are microgranite, granite porphyry and granophyre, which are late-stage differentiates of the parent mass. Tourmalinization is a very common phenomenon along the margin of the granitoids. Tourmaline is commonly found partly replacing feldspar or biotite in the granite, causing the formation of tourmaline granite, or it may crystallize together with quartz and feldspar, forming tourmaline aplite. Where feldspar is completely absent, the rock becomes an aggregate of quartz and tourmaline and is known as schorl rock. Greisenization and some kaolinization are also associated with the emplacement of the granitoids. Inclusions of hornblende-bearing granitic rocks have been recorded recently (Santokh Singh, personal communication) along the northern margin of the Bujang Melaka intrusive.

In addition to the major granitoid masses, there are isolated outcrops of vein-quartz, aplite, quartz porphyry and pegmatite, together totalling about 5 sq km (2 sq miles).

There is no marked difference in chemistry or mineralogy among the granitoids in Kinta. The granitoids are predominantly medium to coarse-grained granite, though a fine-grained variety is also present. Porphyritic varieties of both the fine and coarse-grained types are common. According to Riley (in manuscript), some rocks are highly silicified and at first glance resemble the fine-grained granite; however, on detailed examination they commonly reveal a coarse-grained, and not uncommonly a porphyritic texture. The commonest rock type seen in exposures in the Main Range and Keladang Range is a grey, medium-grained, moderately porphyritic granite, which can be considered to be the typical rock (Scrivenor, 1931).

Generally the granites contain the usual quartz, orthoclase, perthite, microcline, plagioclase (An_5—An_{30}), biotite or chloritized biotite and muscovite. Accessory minerals, not always present, include tourmaline and fluorite. The coarser-grained rocks predominantly show allotriomorphic with hypidiomorphic tendencies, whereas the finer-grained varieties indicate allotriomorphic with granoblastic tendencies. Ropy and myrmekite microtextures are present; numerous grain-boundary reactions between quartz-perthite and plagioclase have taken place.

Age. Scrivenor (1931) regarded the granitoids as Hercynian (late Paleozoic). Jones (1925b) believed them to be much older than Mesozoic. Cameron (1924) suggested the existence of two granites of different ages in Kinta; an older, sheared stanniferous granite, and a younger, porphyritic, unsheared stanniferous Mesozoic granite separated by a period of sedimentation. Ingham and Bradford (1960) noted that there is no known field evidence in support of Cameron's view and concluded that no reliable evidence of a granite older than Mesozoic has yet been established in Kinta.

Radiometric age determinations indicated that the granitoids and related rocks from Peninsular Malaysia have closely similar age (Snelling, 1965 & 1967; Anon, 1966). Details of the radiometric age determinations on specimens from the Kinta tinfield collected by the Geological Survey are given in Table 1.

Recently, Bignell (1972) supplied the following for Kinta: K-Ar dating on biotite from the Keladang Range granite of Papan quarry gave an age of 203 m.y. whilst Rb-Sr dating on a sample from the same granite gave an age of 200 m.y. K-Ar dating on the Main Range granite gave the following result: fine- and coarse-grained granites from Kuala Dipang—200m.y. and 230 m.y. respectively; granite from Kampar—180—200 m.y; and pegmatite from Ampang New Village—200 m.y.

Based on stratigraphic and radiometric evidences, the granitoids of Kinta are generally Triassic and were emplaced in the mesozone/lower epizone (Hutchison, 1973a; Santokh and Ahmad, 1974). Snelling and others (1968) postulated three distinct phases of granitic intrusions in Peninsular Malaysia; the granitoids of Kinta fit into their Middle Triassic phase. According to recent estimates of the absolute age of the Triassic-Jurassic boundary, Bignell (in Gobbett, 1971) pointed out that the radiometric dates place the granitic intrusion at the very end of the Triassic.

Alluvium

Alluvium covers most of the broad expanse of the Kinta valley plain. Its thickness varies considerably; in the valley, the thickness increases southward from about 6 m (20ft) near Ipoh to more than 30 m (100 ft) in the southern part. From an economic point of view, the alluvium is the most important formation in the valley for it is commonly stanniferous.

TABLE 1

RADIOMETRIC DATES OF GRANITOIDS AND ALLIED ROCKS FROM THE KINTA TINFIELD

Nature and location of samples	Age (m.y.)		
	K-Ar	Rb-Sr	Other
Lepidolite from pegmatite, Gopeng N4° 28′ 00″ E101° 9′ 30″		183± 8	
Lepidolite from pegmatite, Chenderiang N4° 16′ 00″ E101° 14′ 00″		186± 0	
Alluvial monazite, Pulau Attap N4° 18′ 00″ E101° 5′ 00″			U175±10
Porphyritic biotite granite, Kuala Dipang N4° 23′ 00″ E101° 11′ 20″	B*232±10		
Porphyritic biotite granite, Talam quarry, Kampar N4° 17′ 30″ E101° 10′ 25″	B*188± 8		

m.y. — million years
B* — determination on biotite

Walker (1955) recognized the following four types of alluvium: Boulder Beds, Old Alluvium, Young Alluvium, and Organic Mud and Peat. Although the peaty deposits occur as lenses and layers within both Old and Young Alluvium, the other three types could be age equivalent. The Boulder Beds and Old Alluvium together are approximately equivalent to the 'high-level alluvium' of Rastall (1927a); they are the principal sources of alluvial tin-ore.

Boulder Beds. These consist mainly of the 'Gopeng Beds', although Walker (1955) also included the 'Western Boulder Clays' and part of the 'Tekka Clays' within this group. The boulder beds are exposed as discontinuous strips along the valley sides, for example in the Gopeng area, and as infilling of small tributary valley heads as at Menglembu.

The boulder beds consist essentially of subangular to rounded vein-quartz, granitoid and schist boulders and cobble conglomerates with sandy clay and clay matrix The rocks are weathered to varying degrees.

There was controversy on the origin of these deposits. They have been thought as (a) glacial sediments (Scrivenor, 1912a), (b) weathered bedrock (Jones, 1917), and (c) alluvial sediments (Rastall 1927a; Scrivenor 1931). Walker (1955) regarded them as water-washed boulder gravels.

Old Alluvium. This is probably the thickest alluvial deposit in the Kinta Valley. It includes gravel, sand, silt, and clay in all possible mixtures, together with peaty sediments, peat, and accumulations of partly lignitized wood and logs. The colour of the alluvium is variable but generally shows pale tints.

The bedrock underlying the greater part of this alluvium is limestone; the alluvium itself is mostly derived from granitoids. The alluvial material has therefore been drawn from farther up the valleys or from valley slopes and the Boulder Beds. In detailed stratigraphy, the Old Alluvium is complex and consists of numerous extremely lenticular and discontinuous beds and irregular masses of different lithologies. Thus, the detailed correlations between localities have not been proven possible (Stauffer, 1973).

Walker (1955) pointed out that the Old Alluvium covers the major part of the valley in Kinta and occurs up to an an elevation of 70 m (210 ft) above sea level. Like Rastall (1927a), he ascribed this to a former higher stand of sea level. In spite of having attributed to *in situ* weathering for much of the clay, Walker concluded that they were laid down in deep, quiet water, as in a lake, sea, or large estuary based on their fine grain size and the presence of true bedding. This conclusion, however, has been challenged by Sivam (1969) and Newell (1971) both of whom provided evidence for a fluvial origin for most of the deposits based on their textrual parameters, sedimentary structures and palaeodrainage systems.

Sivam (1969) interpreted the Old Alluvium as consisting of channel and overbank deposits. The channel deposits are coarse-grained sand and gravel, generally found at the base of the local sequence and less commonly as lenses higher up. The overbank deposits, which form the bulk of the Old Alluvium, are generally finer grained and range from laminated fine sand to clay. This abundance of overbank deposits suggests that deposition of the Old Alluvium took place during rather rapid infilling of the valley floor.

Sivam (1969) found that the distinction made by Walker (1955) between the Old Alluvium and Young Alluvium could be applied in the field and that it represents a significant stratigraphic division marked by an unconformity. The Old Alluvium can be differentiated from the Young Alluvium on the basis of its stratigraphic and lithological differences, the degree of weathering, thicker soil profile, partial consolidation, and abundance of palaeo slumping and disturbance.

Young Alluvium. This deposit is found in the valley of the present rivers, and in isolated patches overlying the Old Alluvium and Boulder Beds as well as the bedrocks. It consists of unconsolidated deposits of sand and gravel, with some clay and peat having a thickness commonly less than 2 m (7 ft). It commonly contains beds of organic mud and tree trunks. It shows bedding structures which are generally well preserved. Clasts found in it are unweathered or slightly weathered.

The stratigraphic section in the Young Alluvium at any particular locality commonly exhibits a simple graded sequence from gravel at the base, through sand to finer material at the top. The proportion of coarse material—gravel and sand, is markedly higher than in the Old Alluvium (Stauffer, 1973).

Abundant primary sedimentary structures including lenticular bedding and channel forms, trough and tabular cross-bedding, and clast imbrication in the gravel suggest that the Young Alluvium is fluvial in character (Sivam 1969; Newell 1971). The fluvial system depositing the Young Alluvium is probably related to the existing river system.

Organic mud and peat. Organic mud or peat layers, up to a few metres thick, are locally interbedded with the alluvium. They contain much vegetative matter and sporadic tree trunks. Carbonaceous material with no trace of organic structure has been reported from near Siputeh, it is similar in appearance to that of coal veins in alluvium described by Ingham (1938).

Age. Evidence concerning the exact age of the alluvium is scanty. Scrivenor (1928) considered the age of the (high-level) alluvium to be probably earlier than the end of Pleistocene and later than Miocene. Fossils other than plants are not common. An elephant tooth obtained from this alluvium at the northern end of the Kinta Valley was identified as belonging to an extinct and characteristically Middle Pleistocene species (Hooijer, 1963). A collection of vertebrate bone fragments in the Old Alluvium from Batu Gajah includes those of rhinoceros, suid, deer, turtle shells and a spine of a catfish. Hooijer (referred to by Stauffer, 1973) regarded the age of this collection as probably Pleistocene. Radiocarbon age dating on wood and peat (Sivam, 1968) from the Old Alluvium from the site near Batu Gajah that yielded the vertebrate bones gave an age of 39,900 years B.P., although the range of detection of this method on these particular samples is uncertain.

The Boulder Beds are closely associated with the Old Alluvium but never overlie it, and are also likely to be Lower to Middle Pleistocene. In some places, they could, however, be older (Stauffer, 1973). The maximum age of the Young Alluvium is indicated by its unconformable relation to the Old Alluvium; the minimum age as the present day. Fossils found in the Young Alluvium are uniformly of modern varieties. The occasional teeth of modern elephant reported (Jones and others, 1966) are probably from the Young Alluvium. Radiocarbon dating on wood samples from the Young Alluvium gave ages ranging from 3070 ± 100 years B.P. to 39,900 B.P. (Sivam, 1968). These dates indicate that some of the Young Alluvium is Holocene whereas others are Pleistocene.

STRUCTURE

The structure of the Kinta Valley and the surrounding hills is relatively complicated. The Main Range and the Keladang Range dominate the area. Most of the rock structures in the valley were developed during the emplacement of these granitic ranges during Mesozoic times (Ingham and Bradford, 1960). The sedimentary rocks were folded into a series of synclines and anticlines, fractured, faulted, jointed, sheared and cut by a large number of strike-slip or low-angle oblique faults.

Some dip-slip fault movements have been recorded. Jointing is common both in limestone and the granitoids and exhibits in trends. Linear structures and shearing are common near the margins of granitoid bodies.

The characteristic 'trough and pinnacle' topography developed in the limestone bedrock in the valley floor is believed to be the final result of solution along well-developed joint system and the formation of pot holes.

Although the trend of joints, fractures, faults and veins exhibit a considerable range, 325° and 045° directions are the dominant trends throughout the area, being visible on aerial photographs and have been confirmed by ground observations (Riley, in manuscript). From aerial photographs, Gobbett (1971) noted numerous lineations with a dominant northwest trend and a subsidiary east-northeast trend and interpreted them as conjugate shear joints along which strike-slip movement has occurred, usually in a sinistral sense.

Scrivenor (1913) postulated that the main contacts between the granitoids of the Main and Keladang ranges and the sedimentary rocks are faulted, and regarded the Kinta Valley as a graben. Rastall (1927a) referred the west side of the valley as a large fault or systems of faults which bounds the foot of the Keladang Range. Ingham and Bradford (1960), however, dismissed the concept of a faulted granite boundary, and pointed out that the concordant nature of the granitoids and the complexity in detail of its margin are evidence for a normal contact. Gobbett (1971) interpreted the Keladang Range as a granite horst and that the western side of the Kinta Valley is bounded by a major dip-slip fault which was later cut and offset by many minor wrench faults with a dominant northwesterly strike produced by an approximately east-west directed compressive stress. According to him, some faulting may be present along the eastern margin of the valley but it is likely that the granite contact, for most part, is a normal intrusive one.

ECONOMIC GEOLOGY

General

The predominant economic mineral in Kinta is cassiterite. Because of its richness in tin, the Kinta tinfield has aroused the interest of geologists and miners from the time it first became known to them. Tin has been exploited from this field since the late nineteenth century.

Other tin minerals present in minor amounts include stannite, varlamoffite and malayaite. The bulk of the tin is derived from secondary deposits mostly as alluvial deposits concentrated along the margins of the valley, close to the granitoid contacts. Both residual and eluvial deposits are also found in association with alluvial deposits.

The Mineral Distribution Map of Peninsular Malaysia, 7th Edition (1976) recognizes three metal zones (Fig. 2). Tungsten, iron and copper-lead-zinc zones parallel the N-S granitoid contacts of the Main and Keladang Ranges; the tungsten zone is confined to the contact areas whereas the copper-lead-zinc and iron zones are found within the metasediments at some distance from the granitoid contact. The present study, however, shows that there are some indications of distinct zonal relationships for iron and tungsten to the west of the Main Range.

Fig. 3 shows the mineral resources potential map of the Kinta Valley, and areas prospected up to 1977 are shown in Fig. 4.

Tin deposits

Kinta Valley is reputed to possess the largest concentration of alluvial tin deposits in the world. Most of the placer tin has been derived from primary tin deposits believed to be genetically related to the granitic rocks. Some aspects of the genesis of tin deposits have been discussed by Scrivenor (1909). Ingham and Bradford (1960) believed that almost all known tin deposits in Kinta Valley belong to a relatively late, pneumatolytic stage in the emplacement of the granitoids.

According to Santokh Singh (1967), the tin mineralization is mainly associated with the late-phase finer-grained granite, since these minor intrusives are seen cutting and intruding into an earlier coarser-grained variety.

Alluvial tin deposits have been found almost everywhere in the valley. A complete list of various mines operating in the alluvium within the valley up to 1952 is

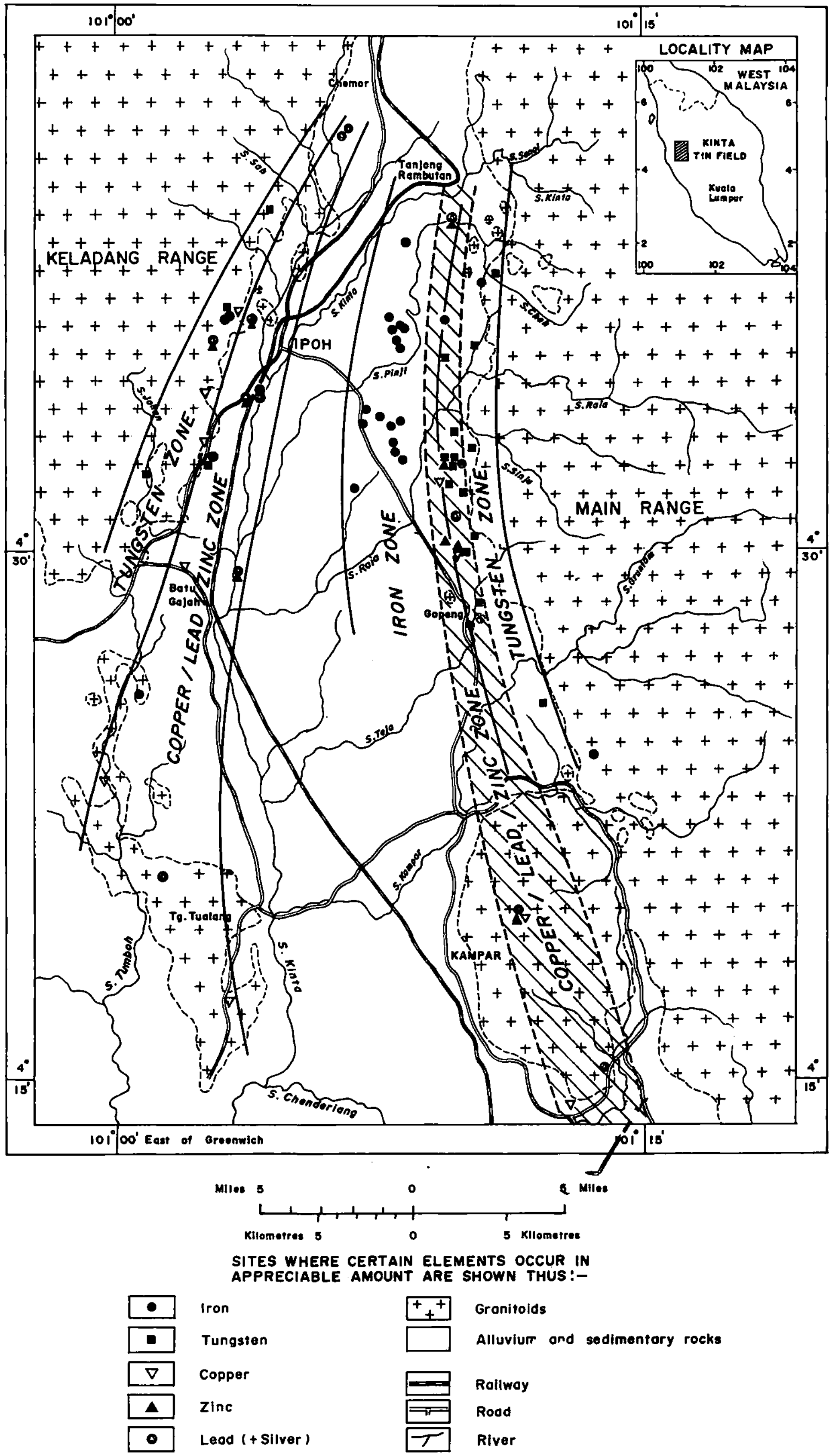
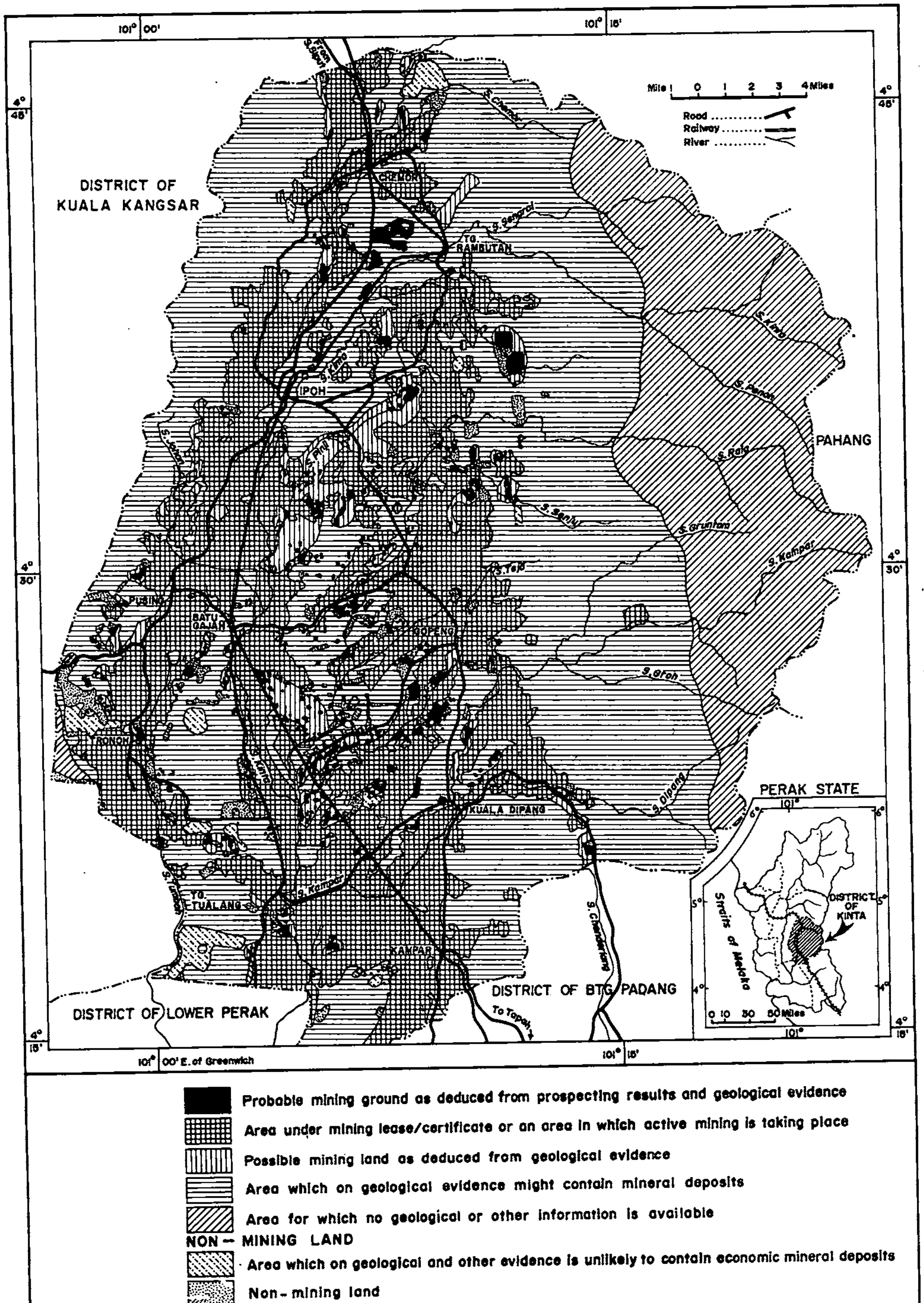


Fig. 2. Metal Zones in the Kinta Valley Based on Data taken from the Mineral Distribution Map of Peninsular Malaysia (1976).



Based on data of the Geological Survey of Malaysia

Fig. 3. Mineral Resources Map of Kinta District.

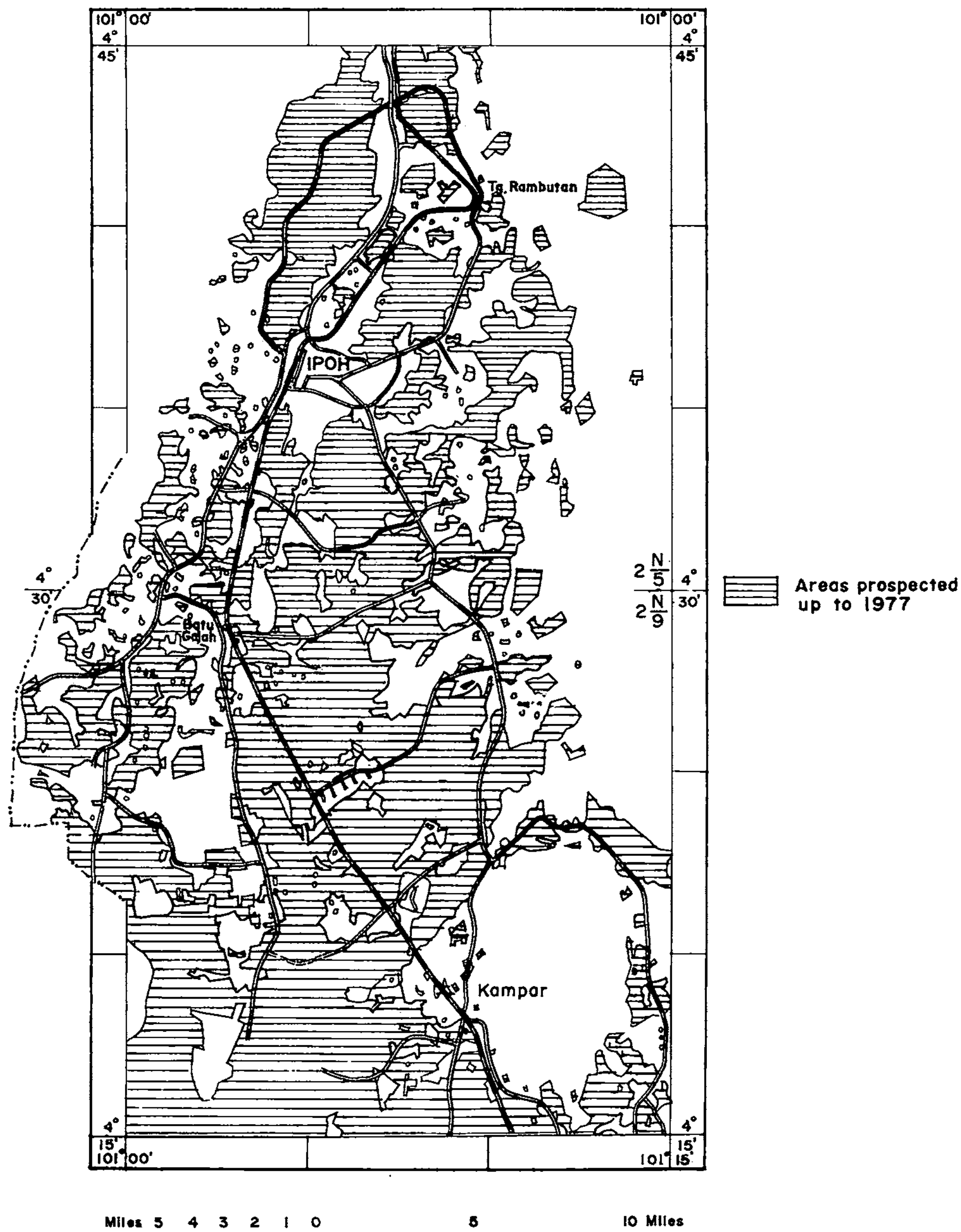


Fig. 4. Plan showing prospected areas in the Kinta Valley, the prospecting results of which are filed in the Archives of the Geological Survey.

given by Ingham and Bradford (1960). The alluvial deposits have been derived from the erosion of tin-bearing veins, pipes, stockworks, greisens and stringers cutting the granitoids or the sedimentary rocks in contact with them. In general, rich alluvial deposits are found where the underlying limestone bedrock forms a trough-and-pinnacle topography and the deep solution channels formed a series of natural riffles which concentrated the heavy grains of cassiterite.

Rich deposits are also present in granite/sediment contact zones. This feature has been described in some detail by Ingham (1949) in which both slumped eluvial material derived from tin-bearing veins or greisens in the roof of the granitoids and alluvial material washed down from eroded lode deposits in the granitoids or in the adjoining limestone or schist, combine to form a rich concentrate in the deep alluvial channel which is commonly found at the foot of the granitic hills. An example of a typical 'contact' mine is shown in Fig. 5.

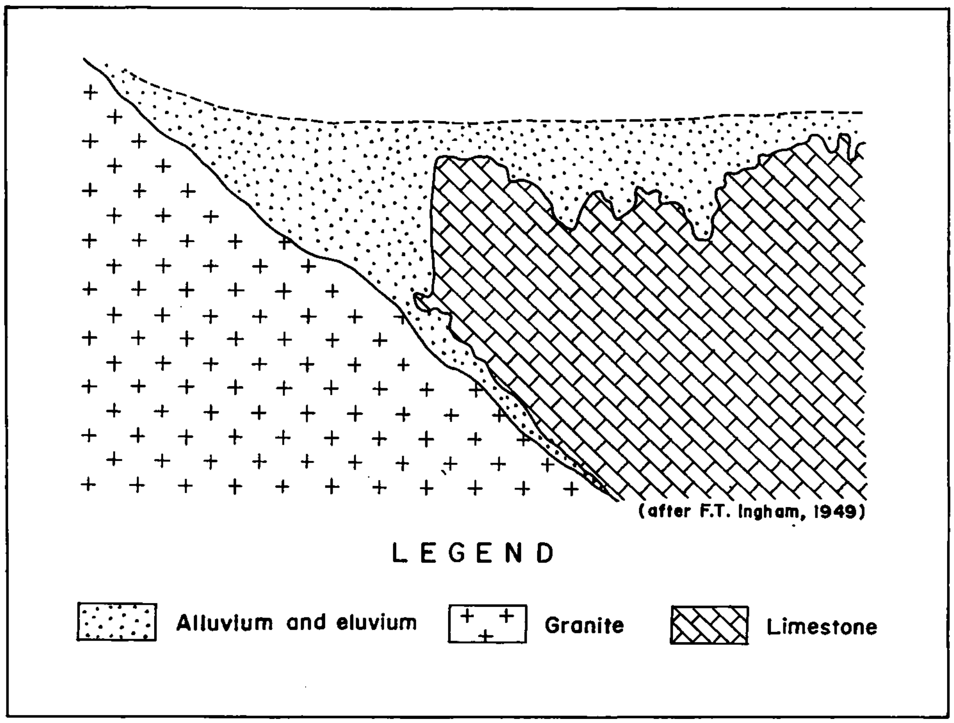


Fig. 5. Diagrammatic cross section of a typical "contact" mine: Kay Tin Mine, Menglembu, 1928.

Lode tin deposits, which are hydrothermal in nature, have been found in granitoids as well as in sedimentary rocks, mainly in limestone and schist. At present however, the production from lode tin deposits is negligible compared to the tin recovered from the alluvial deposits. Willbourn (1924) gave the general location and a brief description of primary tin deposits known within the valley up to 1924. And some of the lode tin deposits working up to 1952 have been described by Ingham and Bradford (1960). A report by Riley (in manuscript) summarizes the findings he made during 1967–1968 on bedrock tin mineralization.

Lode tin deposits in granitoids have been described in detail by Scrivenor and Jones (1919), Jones (1925), Scrivenor (1928), Ingham and Bradford (1960) and Riley (in manuscript). The occurrence of tin in granitoids is best developed in the Keladang Range; most of these deposits consist of small lodes and stringers of cassiterite traversing the granitoids. Small amounts of quartz, pyrite and arsenopyrite accompany the cassiterite nearer the contact of granitoids and sediments. Tin is also present in pegmatite and greisen, and in chloritized shear zones in the granitoids. Examples of deposits in granitoids are the Menglembu, Ulu Petai, Toh Kiri, Keladang and Tekka lodes. Tourmaline is ubiquitous in this type of lodes. The Tekka deposit, however, indicate zoning and is telescoped and was considered by Riley (1967) and concurred by Hosking (1973) as xenothermal.

Tin deposits in limestone are usually in the form of fissure and fracture fillings, 'pipes', veins, and metasomatic replacement bodies. Some of the better known of these deposits, such as the Lahat Pipe (Scrivenor, 1909 & 1914), the Beatrice (pipe) Mine (Willbourn 1926, 1927, 1931 & 1932) and Sin Nam Lee Mine (Riley, in manuscript), were rich ore-bodies reaching considerable depths, usually in an irregular chimney-like shape, commonly described as 'pipes'. For example, the Beatrice Pipe, which is the most important stanniferous skarn deposit ever discovered in Peninsular

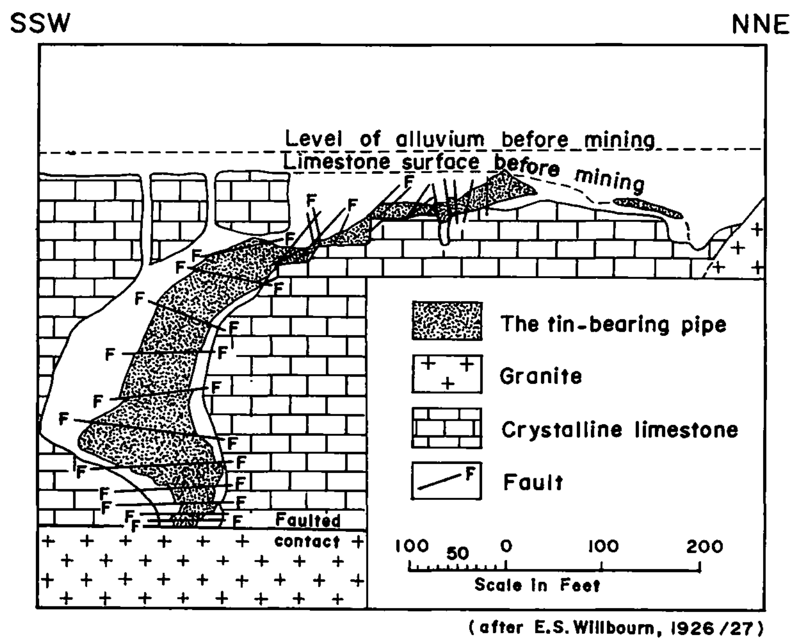


Fig. 6. Section of the Beatrice Mine, Selibin.

Malaysia, was exposed after the removal of a placer deposit extending for about 150 m (500 ft) horizontally and 90 m (300 ft) vertically (Fig. 6). The tin occurred largely as cassiterites with very minor amounts of stannite. The pipe yielded more than 9000 long tons of cassiterite concentrates. Hosking (1970) is of the opinion that stanniferous skarn pipes overlie the granitic cusps, and that these bodies are genetically related to 'small and late epizone granitic cusps'.

Small fissure veins, with irregular bulges of ore owing to local impregnation of the wall rocks, have also been recorded. In contrast to the deposits in granitoids, tourmaline is rare or absent in deposits in limestone; associated minerals are usually pyrite, arsenopyrite, chalcopyrite, fluorite and tremolite.

The tin deposits in limestone are closely related to fracture pattern and are commonly found in any one mineralized zones at the intersection of closely-spaced joint or fracture sets. Some pipes are structurally controlled and are confined within a set of intersecting fractures with the plunge and general form of the ore-body related to the attitude of the planes of intersection of the fractures (Riley, in manuscript). Ong Yeoh Han (quoted in Hosking 1973) indicates that the Sin Nam pipe was developed at the intersection of two fault systems which appear to be of the wrench type. Hosking thus is of the opinion that all pipes in Kinta, both pyrometasomatic and early hydrothermal, may occur at the intersections of two such wrench systems.

Tin deposits in schist and phyllite commonly occur as veins. Cassiterite veins, associated with pyrite or arsenopyrite and/or tourmaline and present as injections in the metasediments, display a concordant relationship with their strike. In most instances, where shearing has taken place, subsequent injections had occured along the line of weakness thus located; replacement along these zones are relatively selective. The injections may be accompanied by aplite or quartz veins. Examples of these lodes occur in the Chemor, Ampang Ridge and Gunung Rapat areas; they have been described by Ingham and Bradford (1960) and Riley (in manuscript).

Other Resources

Few other minerals apart from cassiterite have attained economic importance in Kinta. Associated with the stanniferous deposits are ilmenite, monazite, zircon, scheelite, wolframite, xenotime, columbite, struverite, gold and fluorite. These minerals are being recovered as by-products of tin-mining operations.

Tungsten minerals are fairly widespread in Kinta; particularly in the eastern section of the valley where a fairly distinct tungsten zone fringes the N-S granitoid/sedimentary contact. Both wolframite and scheelite occur; the latter is of much greater economic significance. Only one major tungsten deposit has been discovered and this is the metasomatic scheelite-fluorite body at Kramat Pulai. This deposit was emplaced in limestone beneath two plunging anticlines of schist, close to the granitic exposure of the Main Range (Willbourn and Ingham, 1933). It was actively mined between 1929 and 1939 and the production of scheelite during that period amounted to 8000 long tons. Large quantities of fluorite was also recovered as a by-product from this scheelite mine.

Several iron ore deposits occur in Kinta. The ore is essentially hematite and is of the highest grade yet found in Peninsular Malaysia. A detailed account of the iron deposits in Kinta is found in Ingham (1952) and Bean (1969). The ore is found within limestone along the eastern margin of the valley immediately west of the tungsten zone. The bulk of the ore occurs as scree and detrital deposits along the base of some of the limestone cliffs; in addition, small detrital ore bodies occur in erosional troughs within the limestone hills. Small iron ore bodies, probably occupying shear zones, occur within the limestone and were formed as metasomatic replacement of limestone.

Arsenopyrite is fairly abundant in many localities, commonly associated with cassiterite, especially in pipe deposits. Calcination of the arsenical tin ore from the

Beatrice pipe, resulted in the recovery of saleable amounts of arsenious oxide (Ingham and Bradford, 1960).

Other minerals, which are of little or no economic importance, are present in the valley; these include galena, chalcopyrite, sphalerite, stibnite, jamesonite, copper, bismuth, stolzite, psilomelane, yttrotungstite, tremolite, beryl, fluoborite, talc and topaz.

The Kinta Valley is endowed with clays for brick and pottery, an abundant supply of granitoids for road metal, and limestone for cement and agricultural purposes. At present there are two cement plants in the valley. Kaolin, derived from the feldspar of pegmatite veins intruding the sedimentary rocks adjacent to the granitoids as well as hydrothermal origin, are present.

Production

Production of tin from Kinta dates back to 1876 and has been continuous to the present day (Fig. 7). The Kinta tinfield has, since 1890, held the unchallenged position of being the largest producer of tin-ore in the world, and to date has contributed about 30 per cent of Malaysia's total recorded tin production. The total production during the 100-year period, from 1876 to 1976, amounted to about 1,800,000 long tons of metallic tin. The present annual production average 20,000 long tons of metallic tin, of which some 10 percent is recovered by dredges.

Most of the tin is produced from alluvial deposits, mainly by gravel-pump and dredging methods. In many dredged-out areas, gravel-pump mining has been introduced to recover the cassiterite lodged in the crevices of limestone pinnacles and which could not be reached by the dredge buckets. It is estimated that 80 percent of the gravel-pump mines in Kinta are presently working on previously dredged areas; in fact, some of these areas have already been dredged three to four times by dredges themselves prior to gravel-pump mining. It is possible to introduce gravel-pump mining in dredged-out areas because of various favourable factors such as high tin price and improved technology in gravel-pump mining. Today, the cut-off grade in alluvial ground for dredging average 0.20 lb per cubic yard cassiterite and for gravel-pump mining 0.26 lb per cubic yard cassiterite. The production from lode tin deposits is exceedingly small, although during 1900 to 1954 some 24,000 long tons of cassiterite were produced from 15 known properties (Riley, in manuscript). Unless more attention is paid to the search for primary tin, production from this source will continue to decline indefinitely.

The production of tin concentrate for the 10-year period from 1968 to 1977 is given in Table 2 (Mines Department, private communication). It is noted that production as of 1973 indicates a diminishing trend. There were 396 tin mines operating at the end of 1977 of which 383 were gravel pump mines, 9 dredges and 4 of other types; almost 22,000 workers were employed in tin mining. The number of units operating for the past 10 years from 1968 to 1977 is shown in Table 3. The number of operating units as of 1971 similarly indicate a decreasing trend; the main reduction being the gravel pump mines.

Iron ore has been mined since 1926; its production reached its peak in 1960–1962, but has since declined. At present there is only one mine in operation. The total production of iron ore during the 50-year period, from 1926 to 1976, amounted to approximately 9,300,000 long tons.

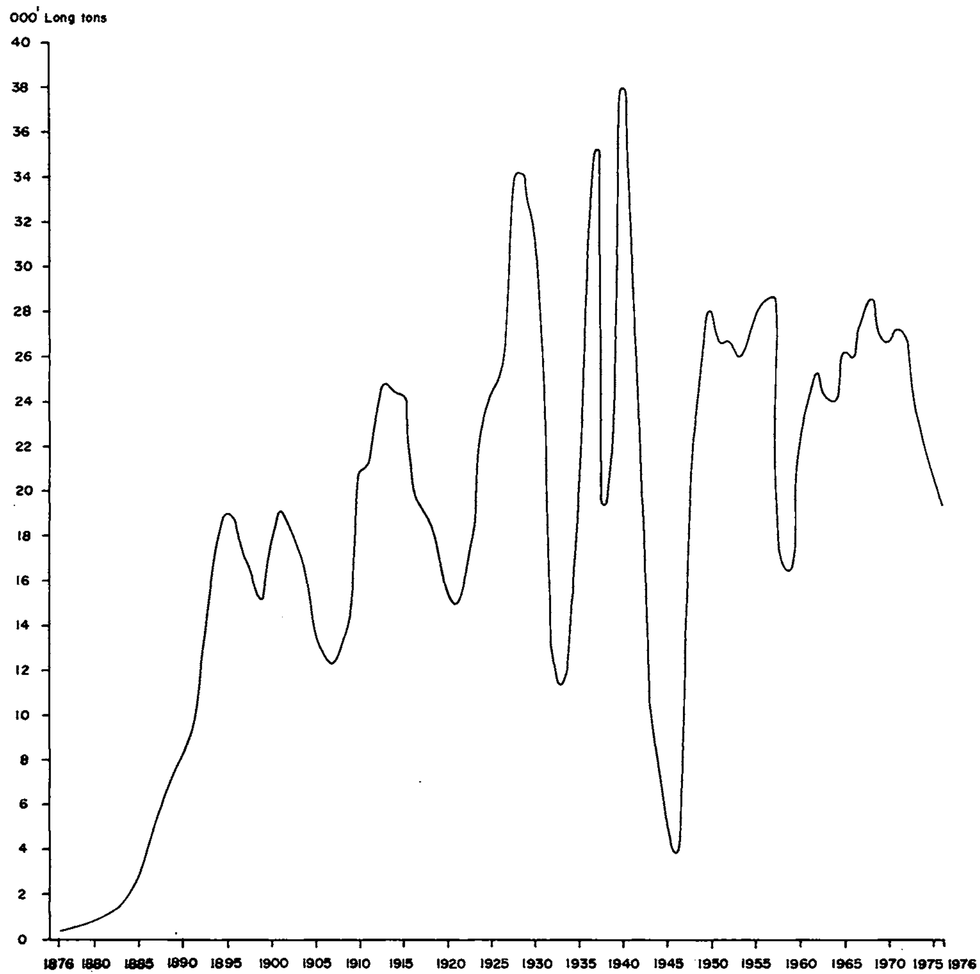


Fig. 7. Production of tin, Kinta Valley, 1876–1976.

TABLE 2

PRODUCTION OF TIN CONCENTRATES IN KINTA, 1968–1977

Year	Long tons
1968	38312
1969	36066
1970	35578
1971	36368
1972	36024
1973	32449
1974	30315
1975	27871
1976	25927
1977	22190

TABLE 3

NUMBER OF MINES IN OPERATION IN KINTA, 1968–1977

Mining Method	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Dredge	15	15	12	12	12	11	11	11	9	9
Gravel pump	515	526	518	499	499	464	484	404	383	383
Open cast	—	—	—	1	2	2	2	2	—	3
Hydraulic	3	3	2	2	2	—	—	—	—	—
Underground	2	1	2	1	—	—	—	1	3	—
Other methods*	5	2	4	7	5	—	2	1	1	1
Total	540	547	538	522	520	477	499	423	398	396

*Dulang washing, lampaning, hydraulicing

By-products of tin mining are few and generally incomplete for Kinta. Since 1973 to 1976, about 500,000 long tons of clay were produced.

CONCLUDING REMARKS

Kinta Valley is presently the richest known tinfield in the world and the most lucrative source of tin in the country. The mineral wealth of the 'Valley of Tin' is still far from being exhausted even after a century of intense mining. Several attempts have been made to assess the reserves and to estimate the life of the field, but all attempts have proven to be far from accurate.

Tin will no doubt continue to be produced in Kinta for many years, probably at a decreasing rate because the placer grounds which have always produced the greater part of tin are faced with gradual exhaustion. This is indicated by the noticeable drop in production of tin concentrates in the past few years (Table 2).

Since the publication of the important contribution by Ingham and Bradford (1960), considerable progress has been made in the Kinta tinfield, there seems to be little doubt that much work still remains for the future, in particular the need for more detailed studies on stratigraphy, structure, geochronology and bedrock mineralization. In addition, detailed work is also warranted to study the alluvium to locate deep-seated placers to the south of the valley.

It is pertinent to note that, because of the readily exploitable tin in alluvium, very little attention has been paid to lode tin and other economic commodities. With the present decline in production of alluvial tin and due to the increasing difficulty of finding new workable deposits, it is recommended that a systematic exploration should be carried out to search for primary tin and other exploitable economic deposits in the Kinta tinfield.

ACKNOWLEDGEMENTS

The writer gratefully acknowledges his thanks to his colleages, in particular D. Santokh Singh, for helpful criticism of the manuscript.

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