Perlis is the smallest state in Malaysia, and also the northernmost, situated in the northwest corner of the peninsula, with the border to Thailand wrapped round its northern margin. It has the southernmost limestone range on the mainland of Southeast Asia, the remainder of the limestone within Peninsular Malaysia occurs as isolated outcrops and towers. The Setul Boundary Range is riddled with caves, many of which have active streams that are rarely found elsewhere in the peninsula. This limestone range is unique because it is the longest such range in the peninsula, it is formed of the oldest limestone in the country and the natural caves have been mined extensively for the tin minerals within their alluvial sediments. Nowhere else in the world has tin been mined to such an extent from deep within limestone caves.

There are two groups of limestone hills within Perlis (Fig. 1). The Setul Hills form a continuous belt of mountainous country along the western border of the state (Fig. 1). They form steep polygonal karst, with fewer cliffs, more subdued slopes and more forest cover (Fig. 3). The highest peak of the Setul range is Bukit Pelarit at 553 m. The Setul Hills contain the caves with the tin deposits, mainly in the area around Kaki Bikit.

In contrast, in a north-south belt through the centre of the state, the Chuping Hills are formed of eroded fragments of a strong, white, Permian limestone lying within the core of north-south synclines. They form a spectacular landscape that comprises a series of steep-sided hills and isolated towers rising from alluvial plains, and are clad in dense but stunted vegetation except on tall cliffs.

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of bare rock (Fig. 2). They contain a variety of cave passages and undercut foot caves.

Between the Setul and Chuping Hills, sandstones form hills rising north to the Thailand border, and are overlain by alluvial plains towards the south.

**GEOLOGY OF THE SETUL HILLS**

This long range of rugged hills is formed in an anticline of the dark, thick-bedded limestones of the Setul Formation, of Ordovician to Lower Devonian age. Limestone was not laid down continuously over this period, but was formed during distinct phases separated by intervals of non-deposition; it contains many argillaceous impurities and bands of mudstone, as well as chert and iron oxide. The sequence was folded in Mesozoic times, when it was also intruded by granite (Fig. 1). The Bukit China granite forms the highest land in northern Perlis, the tallest peaks being Bukit China at 724 m and Khao China which is across the border in Thailand and is 741 m. This is the southern end of a granite body that extends northwards for more than 100 km into southern Thailand.

The granite has all the features of late-stage mineralisation in its marginal zones, with hydrothermal veins, pegmatites, aplite dykes and greisen. Tourmaline and topaz are common, as well as cassiterite (tin oxide), with relatively minor sulphides. Some of the contacts between the granite and the Setul Limestone are clean, with meta-
morphic recrystallisation of the calcite to form marble. Other parts exhibit reaction between the limestone’s carbonate and the granite’s silica to create complex skarn deposit minerals. Lamprophyre dykes reach far into the limestone and are exposed in a quarry at Kaki Bukit and also in one wall of a cave passage in Gua Kelam 2.

Granite weathers rapidly in the tropical climate. Its feldspars and other silicate minerals break down to clays that are rapidly carried away by streams. The quartz and other resistant minerals produce coarse alluvial gravels that fill adjacent valleys and create wide floodplains. Within these alluvial gravels, the cassiterite and other heavy minerals are concentrated because of their greater density, forming lenses, strings and horizons of tin in quantities that are sufficiently rich as to have made mining of them economically attractive. The tin ores are found both in valley alluvium and in the caves (Fig. 4).

The alluvial tin on the surface occurs in the floors of deep valleys and depressions within the karst; these are generally surrounded by high cliffs or steep slopes, and are known locally as wangs, though not all have floors of alluvium. Wang Kelian is the first big depression south of the granite contact zone (Fig. 1). Wang Tangga is the next alluviated valley to the south. Wang Kelian has surprisingly little tin in its alluvium and has never been mined, but Wang Tangga has tin-bearing alluvium up to 15 m deep and has been extensively mined.

Tin-rich alluvium has been swept into the caves since the formation of the karst, and has proved to include some of the richest ore. In most passages the cave alluvium is only a few metres thick, but it reaches much greater thicknesses in large chambers (Jones 1978). At some sites, notably where the current was checked at the foot of waterfalls, the heavy cassiterite is concentrated in lenses and pockets within the alluvium. One pocket in a cave at Wang Mu, south of Kaki Bukit, contained 90% cassiterite and in 1938 yielded tin worth more than a million Malayan dollars (at that time 60 Malayan dollars = 7 British pounds). But tin values are very variable, with good ore typically carrying between 1% and 5% tin, and much of the alluvium was barren. Alluvial tin occurs in active stream caves, but most now lies in abandoned phreatic passages and chambers. Some of the alluvium is partially cemented by calcite, and in places it is capped by thick calcite flowstones that have been dated to approximate ages of 280–400 ka (Smart et al. 1984). The main caves containing the tin lie between Wang Tangga and Kaki Bukit, some 6.5 km south of the granite (Fig. 5), and also in caves further south as far as the Alor Kangar mine, less than 8 km from Kaki Bukit.

THE MINING INDUSTRY

The centre of the tin mining industry was the small town of Kaki Bukit, on the eastern side of the limestone hills in northern Perlis; its name means ‘at the foot of the hill’. Tin mining was an important industry in Perlis from the early 1900s to the 1960s. As it was relatively easy to extract the tin from the cave alluvium, many of the caves in the Setul range have been mined.
Little is known of the early history of the tin mining industry in Perlis. Mining had definitely started by the first years of the 20th century, but it is fairly certain that Chinese settlers began to exploit the deposits on a small scale well back in the 19th century. Prior to the First World War, primitive methods were used to work the deposits, then European miners arrived in Perlis with more modern systems. This enhanced production figures and brought Perlis to prominence as a tin-producing state. However, mining the alluvium from deep within the caves was difficult and arduous work, and the production of tin ore from Perlis only amounted to 0.7% of the total recovered in Malaya, which at one time was one of the world’s main producers of tin.

Records of the mining are known from 1909, but detailed records were only kept after 1952 when the mines came under the jurisdiction of the Federation Department of Mines. After the Second World War, Malaya was occupied by the Japanese, during which time the mining industry was virtually dormant, and also many records were lost. The main mines were located within a radius of 4 km of Kaki Bukit. In 1953–1961, there was an average of 25 mines working, of which all were in caves except for two surface workings. Some were small operations, with perhaps around five labourers, while others were huge fully equipped mines. Where possible, the tin miners just followed the natural cave passages, but they also drove access tunnels into some of the caves (Fig. 6).

The mining methods were fairly straightforward, as the tin-bearing alluvium is generally free of, or only loosely consolidated by calcite. Some mines, especially those where the alluvium was cemented by calcite, used simple methods where the ore was dug with picks and shovels and taken out by trolley. Out in daylight, the ore was crushed and then separated by dulang washers - hand washing using large gently-dished wooden pans to wash the light quartz sand away from the granular cassiterite (Fig. 7).

In other mines, high pressure water hoses, known as monitor pumps, were used to wash out the alluvium as a mobile slurry. The pumps were supplied with water pumped in from outside and fed through pipes to the working face. Water storage tanks were also built in some of the caves. In Gua Baba, the upper part of the cave system was dammed to provide a high level water supply with the necessary pressure to operate the monitors. Separation of the tin ore took place either in the mine or where the washings were pumped out to daylight for processing. Both underground and on the surface, the tin ore was mainly separated in conventional wooden sluices, locally known as palongs; these had riffle bars to collect the heavy ore mineral as the alluvium was washed.
Numerous cave entrances and resurgences fringe the valley floors at the base of the limestone range, but entrances are also located high up in the hills. According to the miners, many of these cave systems are connected. Many of the caves still contain mining relics. Several still have the rail tracks for the trolleys, some have wooden walkways suspended by wire cables, and Gua Kelam 2 has an engine room with huge diesel generators. Some of the caves are home to a variety of cave fauna, such as bats, large toads, fish, crabs, and invertebrates such as centipedes, crickets, millipedes and spiders (Fig. 8). Some of the major caves are listed below.

Gua Kelam 1 is a natural cave that gives access through the hill from Kaki Bukit into Wang Tangga (Fig. 9). In 1935, an English miner had a 370 m wooden suspended walkway built above the stream through the entire length of the cave (Fig. 10). This allowed the miners to transport tin ore out from Wang Tangga without wading in the cave stream and to pass cascades of flowstone from high-level inlets that almost block the stream passage (Fig. 11). Today the cave is set up as a tourist cave. It is electrically lit with multi-coloured lights, there are information boards. A small entrance fee is charged.

Gua Kelam 2 is 3,748 m long and has four entrances (Fig. 9). The hard calcite-cemented alluvium was dug by pick and shovel and transported from the mine in rail trolleys. The material was crushed by mechanical foot stamps and the ore separated by dulang washing. By 1957 the main cave had been worked for a distance of about 610 m, and was cleared of tin-bearing alluvium to a depth of 110 m. Today Gua Kelam 2 is used as a show cave and for adventure caving. Visitors enter on a trolley train, then walk along a concrete walkway for about an hour, passing artefacts that include old water pipes and mining tools (Fig. 12), and also wooden bridges across the cave lakes. Part of the cave floor has been polished by the stream action to reveal white and black banding in the impure limestone sequence. The exit is from a high level passage in the other side of the hill, below which lies a streamway entrance (Price 1993).
Gua Baba is a resurgence cave south of Kaki Bukit, and was mined from the 1940s until 1958 (except during the period of the Japanese occupation) as the Khai Fatt Tin Mine (Jones 1978). A narrow stream passage continues upstream through five large chambers. The fourth chamber contained alluvium 10m deep that was famously rich in tin, and yielded more than 10 tonnes of tin per month through 1955. A diesel engine pumped water to hydraulic monitors at the work face, and gravel pumps, water pumps and a palong sluice were constructed underground, with dulang washing sheds built outside the entrance. The miners’ wooden walkways are still in place,

Fig. 9: Survey of Gua Kelam (by the Malaysian Nature Society Cave Group; redrawn by T. Waltham).

Fig. 10: The miners’ walkway over the stream through Gua Kelam 1 (Photo: T. Waltham).

Fig. 11: A large bank of flowstone in the Gua Kelam 1 stream passage (Photo: L. Price).
although many are now submerged by water. By 1957 the mining had worked into the cave for a distance of 610 m. The passages are now known to connect to Lo Po Sang which has an entrance high up on the hill, in a system that is around 2,400 m long.

Gua Wang Mu is another resurgence cave containing some large chambers. The Foh Thye Mine has an entrance up on the hill above Wang Mu (Price 2000). It worked gravels from natural cave passages that descend through some large chamber and small streamways, and has been surveyed to a length of 2,100 m.

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