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Caves and karst of southwestern Sarawak – Geonotes

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Abstract: The karst geomorphology of southwestern Sarawak is spectacular and varied, but little studied. This paper summarizes the geology; revives some historical geomorphology; and suggests some areas that lack adequate data and mapping for other than superficial geomorphological analysis. The first reported occurrence of speleothem-hosted photokarren is noted. Current data are provided as supplementary files for use in Geographic Information Systems, together with a viewer and notes on how they might be used and improved.

Keywords: geology, geomorphology, hydrology, photokarren.

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Figure 1 (above): *A panorama viewed, in 1989, westwards from Bunuk towards the sandstone landscape of the Bungoh Range, looking over relatively low, dissected, hill-country formed in clastic rocks, with limestone flats punctuated by towering karst.*
*[**Note**: All figures are by the Author unless stated otherwise.]*

Southwestern Sarawak can be characterized as a swampy coastal plain rising to mountainous ridges that separate it from Kalimantan. Precipitous hills puncture the green forest canopy of the plain (Fig.1): some form a curving archipelago and embayment, reflecting their origin as coral reefs; others are igneous intrusions. The most recent extensive accounts of the cave and karst geomorphology, which are now 60 years old (Wilford, 1964; Wilford and Wall, 1965), deserve a more detailed appraisal and revision than could be provided within a relatively recent, wide-ranging, thematic review (Gillieson, 2005). This paper summarizes the present state of local karst studies, and suggests some approaches to adopt in areas where knowledge is lacking.

Geology

Three distinct rock groupings are found in and around the karst (see Fig.2 of Badang *et al*., 2015 or Breitfeld *et al.*, 2023 for a map; see Fig.2 here for a stratigraphical column):

- Igneous: Intrusive rocks comprise the Jagoi Granodiorite, a range of, predominently, granodiorite stocks and laccoliths, with, mainly felsic, dykes. The extrusive Serian Volcanic Formation comprises a broad range of lithologies of andesitic to basaltic composition, including lavas, breccias, and tuffs.
- Clastic sediments: shales and sandstones of the Pedawan, Sadong, Kedadom, and Kayan formations, and the Krian Member of the Bau Formation), locally metamorphosed to form skarns.
- Limestones of the Bau and Terbat formations, which are metamorphosed to marble locally.

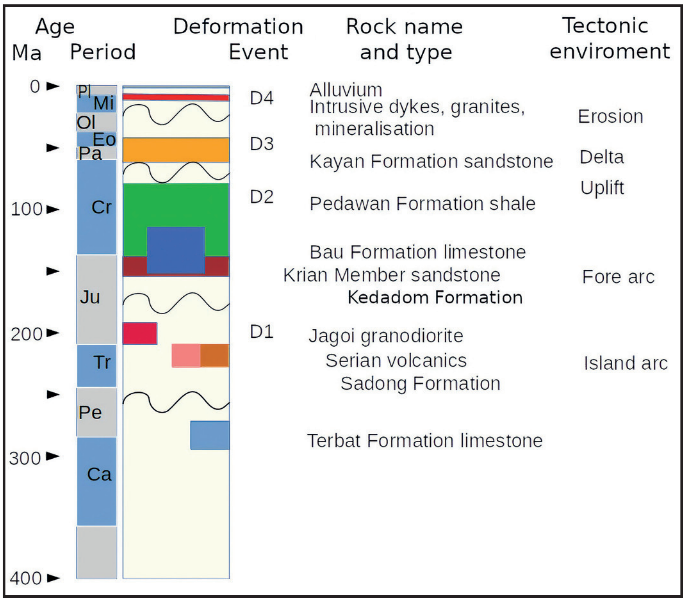

Figure 2:
The geological sequence of the karst of southwestern Sarawak.
[Compiled by Martin Laverty, after G E Wilford, and others.]

Much of the lower land is covered by unconsolidated clastic sediments. These are dominantly represented by alluvium, with thin spreads of mineral or skeletal organic soils at higher levels.

In the past, most geological attention has been focussed upon the gold and antimony mineralization that was associated with dyke intrusion during Miocene times. This consideration concentrates on aspects of the limestone. Formerly this has been perceived and studied more as an extractable resource than as a valuable and irreplaceable asset to be protected, although the potential for exploitation via geotourism has not been ignored (Banda *et al*., 2004). Most geological investigation of the region's limestone has taken place in the Bau area, where it was largely incidental to the earlier economic interest in its mineralization and that of its adjacent shales. Latterly interest has been boosted by the ever-increasing need for stone, aggregates and cement for buildings and roads.

Prominent limestones forming the Bau–Serian outcrop belong to the lower part of the Bau Limestone Formation of Late Jurassic to Early Cretaceous age. They originated as reef build-ups formed by colonies of various organisms, including rudists (cone-shaped fossil bivalve molluscs), during the Cretaceous Period. Studies of the foraminifera show that deposition continued into the Jurassic Period. Individual beds are lenticular, with a total thickness of 600m near Bau, reaching a maximum of 830m (Wilford, 1955; Bayliss, 1965; Wilford and Kho, 1965; Wolfenden, 1965; Wilford and Wall, 1965; Pimm, 1967). Several field studies have been conducted since Wilford's contributions (Jantan, 1969; Lau, 1970, 1971, 1973; Johari, 1978; Yanagida and Lau, 1978; Lim, 1980; Bait, 1980; Hon, 1981; Bojei, 1982; Ting 1990, 1992; Coo and Lau, 1997; Kakizaki and Kano, 2009). Maps published by the Geological Survey Department of Malaysia (Sarawak) show the extent of the limestone outcrops, but access to them might still be restricted. Locally, moderate to steep folding and jointing have deformed the limestone, which is poorly bedded and generally massive, displaying a high purity overall, with little chert and a generally low magnesium content (Banda *et al*., 2004).

Elsewhere in the Bau area, intrusive igneous rocks are prominent and have had a considerable effect both on the modern topography and on the local economy. Whereas they now stand out in the form of prominent hills, at the time of their emplacement the parent magma was the source of the area's mineralization.

The oldest limestone known at outcrop in Sarawak, dated as Early Permian, is at Selabor (or Silabur), a towering hill lying west of the village of Lobang Batu, south of Serian. This hill rises to 400m and comprises fossiliferous, cherty, pale grey to black limestones with thin shale beds, belonging to the Terbat Formation. This generally dips steeply, with some bedding planes near-vertical. The age of the limestone is based on its sporadic content of fossil conodonts (Metcalfe, 1985).

Soon after Wilford *[See Note 1]* left Borneo in 1968, plate tectonics became the explanatory basis for large-scale – global – geology, so at least some of his ideas and terminology would benefit from updating. A revised analysis of the observed stratigraphical, structural, and mineralogical features, based on this new paradigm, was provided by Schuh (1993). The absence of rocks older than late Carboniferous in the Bau–Serian area, considered alongside the lack of tin mineralization, has been interpreted as showing that no remnant sialic continental-type crust lies beneath. Instead, there are only ocean floor deposits from a possible Precambrian landmass to the southeast, overlain by reef carbonates (dated as Early Permian at Selabor and Jurassic at Bau-Serian) not far from a subduction zone that moved gradually northwards to establish Sundaland (van Bemmelen, 1949). Eventually the reefs were overwhelmed, by clastic material deposited from muddy inputs. There is then a break in the known stratigraphical record until terrestrial conglomerates and sands were deposited following uplift and emergence during the late Cretaceous, continuing through into the Eocene.

Four distinct phases of deformation, which were identified by Schuh (1993), are associated with both igneous activity and hydrothermal mineralization:

D1: Early Jurassic extension — E- to ENE-trending normal and strike-slip faults. Patch reefs developed in a fore-arc basin as an island arc migrated eastwards.

D2: Late Cretaceous strong compression — NW-trending tight folds (with axial jointing and en-echelon opening of D1). Anticlockwise rotation of the Kuching zone begins (Metcalfe, 1985).

D3: Mid Eocene moderate compression — E- to ENE-trending gentle folds. Rotation ends.

D4: Mid to Late Eocene extension — NNE-trending faults; reactivation of D1 faults.

Nodes at the intersections of D1 and D4 fractures are especially associated with mineralization.

To the south of the Bau karst, which straddles the WSW–ENE-trending Bau Anticline (Percival *et al*., 1990), is the Bungoh Range, which forms a spectacular scarp rim to the synclinal basin now housing the Bengoh Dam and rising to the complementary scarp formed by Gunung Penrissen to the south. To the east the limestone outcrop encircles the eroded core of an anticlinal dome: whether the current annular outcrop also reflects relict reef topography is not clear.

Normal faults (which are commonly near-vertical) are widespread, along with irregular and widely spaced joints. In contrast, most bedding planes are poorly developed (Wilford and Wall, 1965).

Hydrology

Little seems to have been written about the hydrology of the karst in southwestern Sarawak since a sketch map by Everett (1878) showed Sungei Siniawan, apparently rising near Bau and then running across the plain to sink into a cave and run through the limestone hill south of Jambusan, only to re-emerge and flow onward to debouch into the Sungei Sarawak Kanan at Siniawan: a straight-line distance of some 9km. Being already familiar with: '*the bizarre configurations and peculiar outlines which are known to geologists as Karst phenomena',* Geikie (1905) wrote: *'As might have been expected, the limestone is abundantly tunnelled by underground water. Caves, therefore, are numerous and many of the existing streams follow in part underground courses.*' In contrast, Wilford (1964) mentioned streams, their sinks, and resurgences only in passing, and published maps of Sarawak rarely depict accurate, or full, courses of surface streams and rivers, except where they have provided past routes for travel by boat.

Probably incomplete data collected by Wilford (1964) and Gill *et al*. (2025) include identification of 19 sinks and 28 resurgences. Nine streams can confidently be linked from sinks to eight resurgences, with seven through routes. None of these connections are recorded as having been traced formally, but local observations of flood behaviour and pollution (including that from chicken farms) are likely to be available. That there are almost 50% more resurgences than sinks reflects how much recharge will be provided by direct infiltration from the hilltops; as yet, how the surface fissures integrate into passage drainage networks is unknown. Whether there are drainage networks beneath the limestone flats is similarly unknown.

***[Note 1]**: The doyen of Sarawak karst (Gill* et al.*, 2023; Laverty, 2025).*

Geomorphology

The geological maps of the Geological Survey, British Territories in Borneo, differentiate between the rugged, high-relief, steep- to vertical-sided, limestone blocks and the low-relief, alluviated, limestone flats that commonly border or surround them (Fig.3). Areas adding-up to about 107km² of hills are identified and mapped by Gill *et al*. (2025), whereas the total area of flats is rather greater.

Karst Hills

Gunung Gigi (Tooth Mountain), a towering limestone hill, featured as an illustration in one of the earliest books describing Sarawak (Laverty, 2025). Such imposing aspects of the landscape are iconic of ‘tropical tower karst’. Nevertheless, a broad spectrum of forms remains, yet to be described and characterized in detail (Figs 4A, 4D).

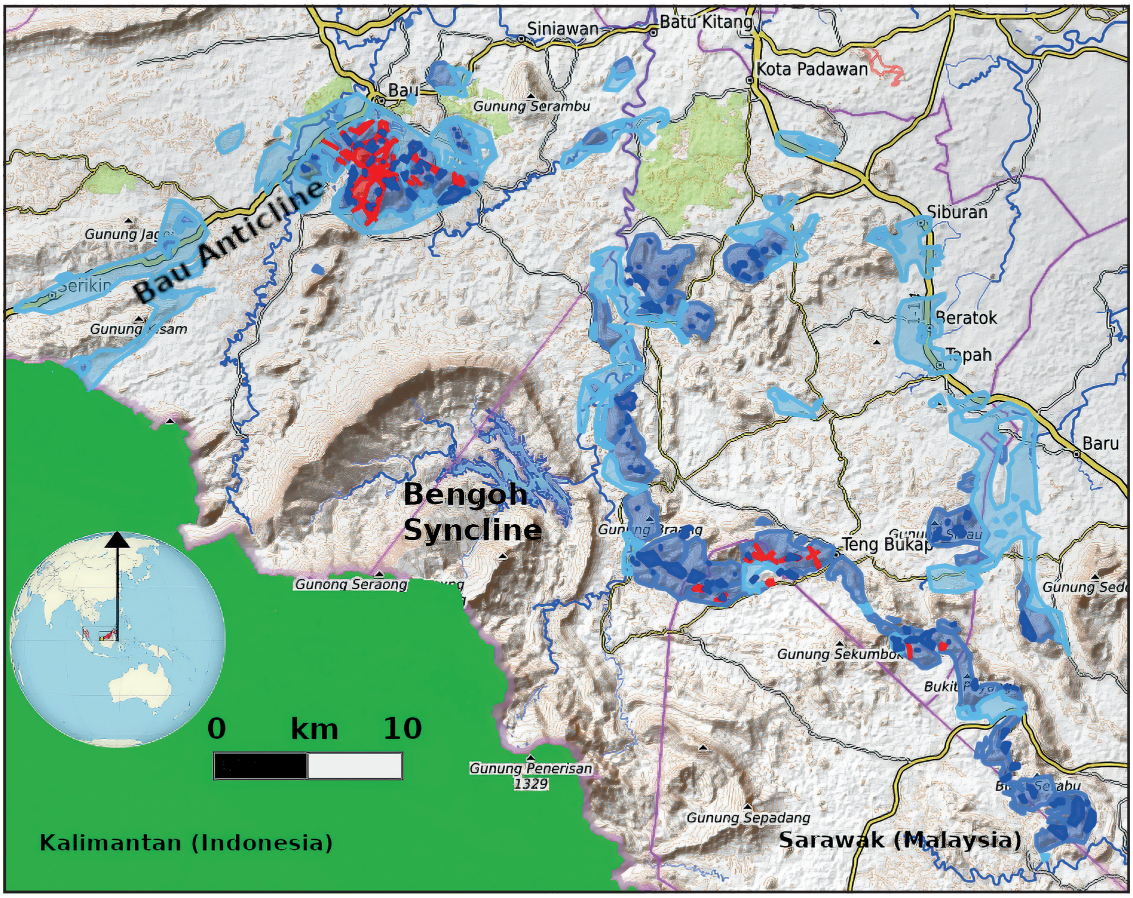

Figure 3*:* *[OpenTopoMap base] with sketched details of:*

limestone hills *(darker blue shades);*

depressions *(darkest blue);*

limestone flats *(paler blue shades), and*

main ***igneous intrusions*** *(red) within the mapped limestone outcrops.*

Note that the shaded relief of the map base helps to emphasize major structural elements such as the two labelled (named) folds.

Supplementary material (see note on p.23) gives access to more detailed views.

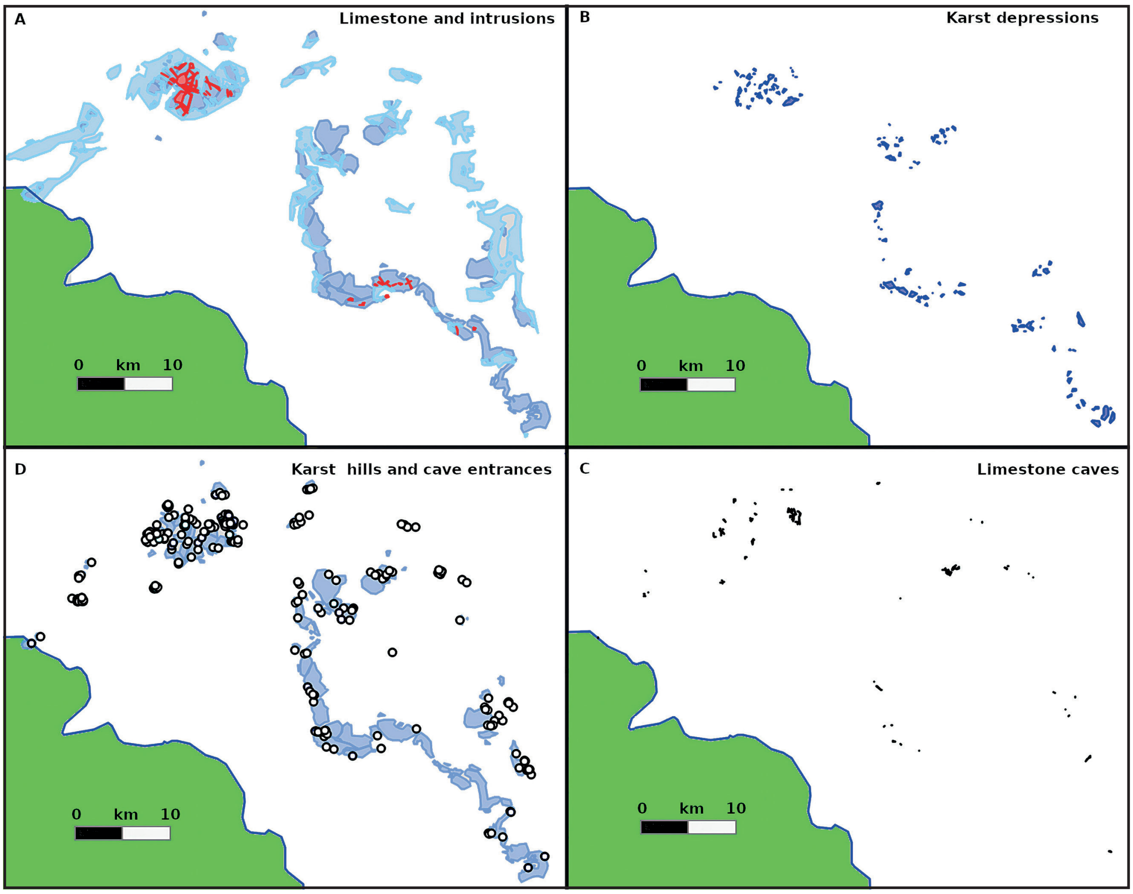

Figure 4*:* *Sketch maps illustrating (clockwise from top left) the locations and known extent of:*

A*: limestone hills (dark blue), limestone flats (pale blue), and igneous intrusions (red);*

B*: karst depressions;*

C*: cave passages;*

D*: karst hills with currently recorded cave entrances (rimmed white circles).*

As in Figure 3 (above), the green-shaded segment in the southwestern corner of each pane is part of Kalimantan.

***Figure 5**: Notch profile (apparently marine) and dissolution tube at Kayu, Kampung Merembeh, Jambusan.*

A review of the theories describing the development of karst hills in SE Asia, provided by Twidale (2006), forms a useful starting point for study of the 121 distinct blocks identified, among which the highest peak is Braang (685m). Of these, 41 blocks have only one summit, and may be described as cones (steeply sloped), lenses (gently sloped, in some cases on a sloping base), or towers (with notable cliffs). Some are best considered as more or less jagged ridges with multiple peaks. Some of the larger blocks are tabular, with one or more summit levels, and more-or-less noticeably indented by dolines and uvalas in a variety of sizes; less commonly, sloping surfaces are corrugated by linear valleys. Cliffs are common around the bases of the hills, commonly with curved (marine?) notches (Fig.5). In some cases, they are punctuated by foot caves or swamp notches (Fig.6), typically with flat roofs. Whereas these testify to etching back of the hill bases, the extent of this erosion has not been quantified – it might be relatively insignificant compared to the scale of uncovered, residual, sedimentary relief created by the accreting reef and its detrital components. Ideas of significant marine influence (Everett, 1874; Scrivenor, 1905; Geikie, 1905) might be discounted for the substantial period around the last glacial maximum (21 Ka), during which sea levels were as much as 120m lower than at present. Currently, however, there is no locally applicable chronology for tectonic or isostatic effects, and global sea-levels were up to 80m higher around 4 Ma, and 20m higher around 1.2 Ma and 0.4 Ma (Marine Isotope Stage 11).

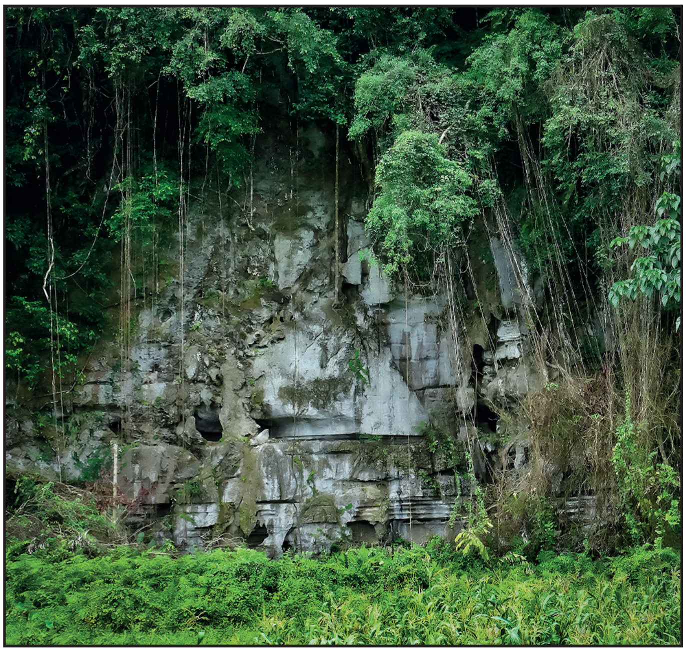

***Figure 6**: Cliff, with notches at various levels, near Kampung Skiat, Jambusan.*

In the Bau area, the limestone outcrop surrounds a major igneous intrusion, and is dissected by swarms of dykes. Perhaps contrary to expectation, the igneous rock has eroded more readily than the limestone to give the appearance, at least in aerial photos, of an exaggerated limestone pavement. Dykes that have been observed and examined underground, also appear to be less resistant to erosion than is the surrounding limestone.

Surface features

Lapiés

Typically, the surface relief of almost all exposed limestone is jagged, with rounded forms apparent only on some dolomitic, and metamorphosed, exposures, or on those exhumed recently from beneath the subsoil. Various karren types are developed, including rillenkarren and rundkarren. Flutes developed on sloping surfaces also cut back to produce pinnacles, while solution cups deepen and puncture to produce 'a skeletal honeycomb'. Distinctive sub-horizontal ripple markings (about 0.25″ (*c*. 6.5mm) apart and projecting up to the same distance) have been reported on vertical to overhanging surfaces; these are attributed to the effects of surface flow of thin sheets of water during periods of heavy rainfall (Wilford and Wall, 1965; Sweeting, 1972).

Roots

Commonly, roots extend from the surface and penetrate into caves, probably opening fractures as their dimensions increase over time. They leave '*small, irregular, tubular grooves formed along joint fractures ... probably the result of erosion by root exudates*', and parts of similar features are also preserved on exposed rock surfaces (Wilford and Wall, 1965).

Scree

Accumulations of block scree are commonly present at the foot of limestone cliffs. These are described in more detail, for example, by Wilford and Wall (1965).

Fires

It was noted by Everett (1874) that Jambusan and other hills had suffered fires recently and that regrowth of vegetation was slow. He expected that the heating of the surface would enhance denudation by calcination of the rock and by subsequent dissolution, as well as by the burnt vegetation freeing fragments it had been binding; perhaps more important though was the removal of protection and support. He did not consider the possibility of any adverse effects on soil formation and retention, or on revegetation, all of which could contribute to reduced aggressiveness of percolation water related to lack of biogenic CO_2 and organic acids. Nowadays, historical imagery available via, for example, Google Earth, can be used to help constrain the dates of any fires that revealed a bared rock surface, and thence to track the extent and progress of regrowth.

Karst depressions

Negative relief (Fig.4b) has been cited as a – or ***the*** (Cvijić, 1893; Sweeting, 1972; Ford and Williams, 1989; Ćalić, 2011) – definitive characteristic of a karst landscape. This landscape attribute has not been a focus of attention in Sarawak, although Wilford and Wall (1965) noted that '*the surfaces of most limestone hills are irregular and broken by numerous shallow to deep depressions*'. The latter authors illustrated a lack of alignment with joints on Bigau (Sibau), noted '*linear depressions in some parts of the Bau region where steeply dipping lenses of impure limestone have been eroded more rapidly than the adjacent purer beds*', and remarked that '*except on a few small parts...the depressions and the peaks between them do not exhibit regular patterns or symmetry of form such as...the Cockpit Country of Jamaica or and the Kegelkarst... in Java*'. Forest cover has made identification of surface relief from aerial photography highly imprecise; in contrast a LiDAR digital terrain model would facilitate landscape analysis beyond what has formerly been possible only in areas cleared by fire.

A cursory survey, mostly using NASA's SRTM (Shuttle Radar Topography Mission) heights (as used in most contoured online maps, such as OpenTopoMap), shows examples of depressions that might be categorized as:

Blind valleys

A depression at the head of Rumbang Cave exemplifies a stream draining from a catchment area underlain by impermeable sediments. Another low-lying area north of Kampung Seromah appears to be similar, albeit of unusual width. Depths of these depressions are site specific, presumably reflecting local factors, but that west of Nambi appears to be the deepest yet identified at around 50m. At Temurang Wah, and to the east of Gunung Peyang, the appearance of closed depressions suggests the presence of sinks several hundred metres above the likely resurgence level.

Poljes

A large flat-floored depression within the limestone outcrop between Gunung Sawah (northwest of Kampung Bunuk) and Gunung Kom might be referred to as a polje, although whether seasonal flooding occurs has not been recorded. East of Kampung Temurang, three steep-sided closed depressions have flat floors: the first, at least, is crossed by a stream and its alluviated floor is punctuated by rounded karren. The deepest depression of this type might be that lying to the west of Gunung Kedadom, with a depth of some 120m, compared to depths of around 50m in the Temurang area.

Solution dolines

Several forms of these characteristic karst landforms have been recognized. Some are more-or-less conical hollows in bedrock, a few metres in diameter and depth, which do not coalesce on low-gradient surfaces (as observed, for example, on the burnt area of Grigar in the Bau hills). Larger hollows that coalesce to form small uvalas are also evident, and features that could be described as cockpits can be seen on a few elevated areas (e.g. on the eastern side of Gunung Duya, 4km southeast of Bau).

Uvalas

Opinions differ regarding the definition and usefulness of the term uvala (e.g. Ćalić, 2011). Tropical karst has not featured significantly in these discussions, but several examples in southwestern Sarawak fit a description of large, elongated depressions (more than 1km in at least one dimension) with uneven floors. Hence, the term might be applicable here, perhaps north of Seromah (shallow, but also describable as a blind valley), or (deeper examples) west of Gunung Nambi and west of Gunung Kedadom.

Collapse depressions

Some of the low- and higher-level caves south of Kampung Jambusan (e.g. Niang and Tupak) are connected through vertical-walled depressions floored by large boulders. None of those yet recognized reach the defining dimensions of a tiankeng (Gunn *et al*., 2019).

Lowland karst 'flats'

The limestone flats (Fig.7, Fig.8, Fig.9) – "*areas overlain by typically poorly drained alluvium from which project pinnacles of limestone bedrock...typically widest on the dip-slope side of limestone hills*" (Wilford and Wall, 1965) – were remarked on as much as were the hills by early writers, from:

> "*A considerable tract of country between the limestone hills, is covered with an alluvium of gravel and clays, the surface of which is very undulating, and in this the gold-washing is principally carried on. It seems to rest upon the limestone, which often pierces through it in strange water-worn peaks, which resemble ruined buildings, or ancient monuments.*" (Wallace, 1856)

to:

> "*... a rapid succession of interosculating ridges and hollows; resembling a series of waves suddenly petrified; there again detatched masses have been so eaten into by acidulated water that it would seem as if a slight push might cause them to topple over. Acute ridges and points, however, are the more common surface-features. They are of every size and every degree of sharpness; and their presence in the jungle makes walking anything but a pleasure.*" (Geikie, 1905)

Apart from their distinctive form, and covering a greater area than the hills, the flats were sources of economic wealth in antimony and gold, the extraction of which accounts for the unusual presence of several lakes on the limestone around Bau.

Figure 7: *Karst features on two scales: a jagged pinnacle and a tower near Kampung Sumur, Bunuk.*

Figure 8: *A block near Jambusan. Where this is now freed of its former vegetation cover, a jagged surface – scored by karren and probably also pocked by the effects of bioerosion – is revealed.*

Figure 9: *Rounded pinnacles unearthed in Temurang polje.*

Rock mazes

An early mineral surveyor observed that "*the abrading of the surface is in great measure due to the Bornean rains, which fall very copiously. The limestone under the surface shows great crevices, some of them thirty-six feet* [*c*. 11m] *deep, sixty feet* [*c*.18m] *in length, and from one foot* [*c*. 0.3m] *to twelve feet* [*c*. 3.7m] *in width. These occur a few feet above the level of the river.*" (Russell, 1863). In their 1965 paper, Wilford and Wall noted that mining had typically removed up to a metre [*c*. 3.3 feet] of alluvium, leaving: "*a smooth and almost horizontal limestone surface is broken by parallel channels commonly 2 to 3 feet* [*c*. 0.6 – *c*. 0.9m] *across and as much as 15 feet* [*c*. 4.6m] *deep, and by lines of pinnacles rising 6 to 8 feet* [*c*. 1.8m to *c*. 2.4m] *above the surface*" and that they had also found: "*a sub-circular alluvium filled depression 100 feet* [*c*. 30.5m] *wide extend[ing] 60 feet* [*c*.18.3m] *below the surface*". These descriptions could also apply to several areas that have recently been cleared of prolific vegetation to expose bedrock pavements separated by networks of alleys several metres wide and deep: they have been called rock mazes or, where just karren-sculpted blocks and pinnacles are left, e.g. in front of the Bau Civic Centre, rock gardens. They resemble the *bogaz* of Slovenia (Wilford and Wall, 1965; Sweeting, 1972). Their walls are commonly grooved, and some have small dissolution passages leading off. It has been suggested for the example opposite Paku school that these are collapsed cave passages (https://www.responsibleborneo.com/pakurockmazegarden) but, considering the lack of much collapse debris, they might have been surface watercourses, or even coastal inlets (as possibly indicated by some preserved notch forms).

Figure 10*: An igneous dyke (~25cm wide) eroded back into the wall of the Turn Red showcave in Gunung Kapor.*

Caves

Caves (Fig.4 c,d), which are the speleologists' measure of karst, are abundant in SW Sarawak (Gill *et al*., 2025), but attention has most commonly been given to their potential economic (mineralogical, biological, and touristical) or archaeological value, rather than to their intrinsic potential for providing biological, geological, geomorphological, or palaeoclimatic insights.

Speleogenesis

The first geologist known to have reported a cave in Sarawak (Hiram Williams, 1848) was undoubtedly correct in attributing a part of its formation to the agency of water on limestone ("*Their sides are smooth, bearing every appearance of being water-worn*"), rather than local lore asserting petrifaction of villages for morally offensive behaviour. Other factors, and details of possible water sources have, however, been suggested. The next geologist to discuss the topic, James Russell (1863), thought that preferential erosion of igneous intrusions accounted for at least some of the caves that he saw. Subsequently, the polymath Alfred Hart Everett (1880), suggested that past sea-levels had been higher and so contemplated a marine origin for the caves. Still later, the respected Italian biologist Odoardo Beccari (1904) advanced the idea that the caves were enlargements of residual cavities between the branching structures of the fossilized reef-building madrepore corals that formed much of the limestone.

By the mid-20th century ideas had evolved and been refined, so Wilford (1964) was happy to accept the then prevailing paradigms of phreatic and vadose development (e.g. J Harlen Bretz, 1942). Wilford also appears to have recognized — for foot caves, at least, and as later noted in Mulu (McDonald and Ley,1985) — what is now described as paragenetic development (Farrant and Smart, 2011). An illustration by Wilford and Wall (1965) showed the Jahara River following an underground course along the line of a felsic (acid) igneous dyke, and Eavis (1981) noted that igneous dykes were important in guiding passage development in '*a cave in Gunong Bakian*' — presumably the Johara River Cave System (Crabtree and Friedrich, 1982). In contrast, the Turn Red showcave in Gunung Kapor crosses a dyke that has merely been eroded back into the limestone wall (Fig.10). The potential for igneous influence was also invoked by Schuh (1993), at a time when evidence of hypogenic origins began to be recognized in some caves.

The flank margin model of cave formation (e.g. Mylroie and Carew, 1990; Mylroie, 2004) also provides a basis for reconsidering marine origins. A recent model for karst development suggested for the Gomantong Caves in Sabah might also be considered: Lundberg *et al*. (2017) analysed wall scallops indicating up-dip flow from what they thought must have been a distant artesian source via Darcian flow through (now eroded) non-karstic rocks. This sort of inception might also be considered in southwestern Sarawak, where the limestone passes laterally into sandstones and shales; alternatively, recharge might have been from a limestone surface and egress could be into permeable sandstone. This water could have had its aggressiveness raised by soil activity and, if sourced through sandstone, this aggressiveness would not have been depleted by prior dissolution within the epikarst. The effect might be similar to that of flank margin development — ringing the outcrop and not penetrating as far as the centre unless fractures were present.

Cave levels

Only a few of the available cave surveys include published height information or surveyed cave elevations, but it appears that there might be distinct levels of cave development. Tang Baan/Raya has passages rising to 90m above the surrounding plain level; its main horizontal development is at 60m, with other development recorded at around 30m, descending to sumps close to plain level. Fairy Cave also has its main development at about 60m above the plain, and the entrance to Sireh is also at that level, with its main passage some 30m lower. Maraja Cave appears to be significantly higher, at around 300m.

***Figure 11**: Swiftlet nests in cups within a wall of brecciated limestone in the 'MYFH' entrance to Teruma Cave, Siburan.[Photo: Jos Burgers.]*

It is to be hoped that future surveying of the caves will reveal whether there is a regional pattern of distinct cave levels and, if so, what its significance might be in terms of base-level changes due to bary/eustatic sea-level changes and regional uplift, whether isostatic or otherwise.

Cave passage orientation, distribution, and size

Passages are typically developed preferentially along joints and down the dip or along the strike of bedding planes but whereas some caves have just one main path (as in Fairy, Maraja, and Sireh caves), networks of passages are also found. Lobang Angin is notable for having almost entirely hollowed-out its hill, with a spoke-like arrangement of passages. Elsewhere, as for example in the caves currently known at Siburan, passages appear to show an annular relationship within the circumference of the hill. Perhaps the largest passage known (50 to 100m wide, 10m high, for about 300m) is in Baan/Raya: it has only small entrances at the level of the main passage, but two larger passages, one forming the largest entrance, extend obliquely upwards from it.

Cave features

Floor features ranging from egg-cup-like holes to rounded pinnacles; wall features such as scallops (large, commonly shallow and symmetric, and small, asymmetric), notches and nest niches (Fig.11); and bell holes in the, frequently flat, roof are not unique to this area of humid tropical karst. Hornaday (1885) described the "*limestone floor ... quite honeycombed with small round holes*" here: they have now been named *guano holes* (Calaforra *et al*., 2018; Farrant *et al*., 2023). Bell holes were the subject of early investigation at Niah (Harrisson and Medway, 1959) and Mulu (James, 2012). Nest niches in Maraja Cave were discussed by Medway with Wilford and Wall (Medway, 1965, 1967).

Results of recent work in Mulu (Farrant *et al*., 2025) suggest that ammonia generated from bat guano and dispersed by draughts undergoes oxidation, mediated by microbes, to produce nitric acid, which erodes walls and speleothems except where flowing water films or drips have a protective effect through flushing. It might be that floor pinnacles (Fig.12) are similarly related to microbial oxidation of sulphur (which is predominant over nitrogen in swiftlet guano but subordinate in bat guano) to sulphuric acid on floors. Selabor Cave is renowned for its spectacular vertical or near-vertical fluting (Fig.13), comparable to the *apse-flutes* described in Sabah (Lundberg and McFarlane, 2012b)

***Figure 12**: A typical passage in Chupak. Floor pinnacles rise above mixed bat and bird guano, which might be implicit in their formation as residuals. The clean walls (with small, eroded, nest cups and large scallops) might indicate bacterially mediated acid erosion. [Photo: Jos Burgers.]*

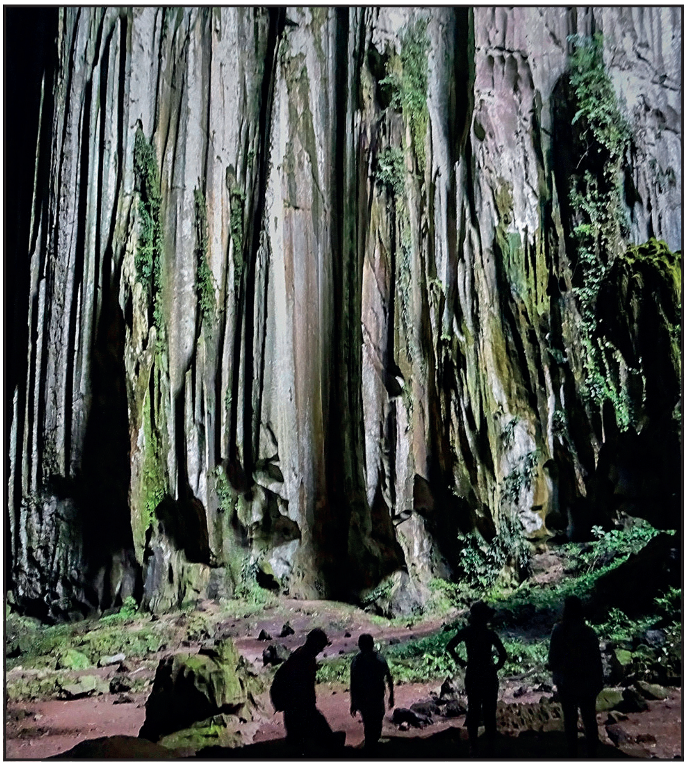

***Figure 13**: Apse-flutes soar upwards towards a ceiling opening in Gua Raya, Selabor.*

Figure 14: *Eroding stalactites inside 'MYFH' entrance, Teruma Cave, Siburan. Similar pale floor sediments in Tang Baan and Tulang (typically consolidated, with a waxy texture and hackly fracture) are likely to be volcanic ash. If not, they might comprise in-situ guano-derived phosphate and sulphate minerals, or could simply be washed-in. [Photo: Jos Burgers.]*

Figure 15: *Stratified sediments in Rooftop Cave, Kampung Sidanu. [Photo: Dave Clucas.]*

Figure 16: *An unusual "hook" of eroding speleothem in Gua Chupak, being discussed by Dave Clucas and Dave Gill. [Photo: Jos Burgers.]*

Figure 17: A distinctive, active, flat-topped boss in Gua Biraji, Siburan. [Photo: Jos Burgers.]

Cave sediments

Despite their early exploitation — for example: "*The [gold] metal is found in smallish grains in the earth covering the floors of the caves and crevices into which the limestone is everywhere worn. It is also found in the stalactites of the caverns, evidently carried into such positions with the water percolating from above*" (Low, 1868) — clastic, biogenic, and chemical sediments remain to be valued for their environmental, rather than mineral, riches. Apart from some archaeological digs in cave entrances (e.g. Harrisson and Tweedie, 1951; Gani, 2010), and speculative trials in search of gold, sediments within the caves have received little attention since the Geological Survey's search for phosphates (Wilford, 1952).

Beds of waxy, cream-coloured, allophane (an amorphous silicate derived from volcanic ash) were identified in Mulu (Laverty, 1982). Rocks of similar appearance occur in Tang Baan, Lobang Stulang, and, perhaps, elsewhere (Fig.14). **[See Note 2]** Stratification observed in a small cave (Fig.15) shows the potential for future detailed sediment studies.

Speleothems are present in most of the caves, but most appear to be inactive and in some cases decaying (Fig.14). Some unusual forms have resulted (Fig.16), even among active examples (Fig.17). No speleothem or sediment samples appear to have been collected for the geomagnetic, isotopic, or optical stimulated luminescence analyses that could provide dating and palaeoclimatic information.

Cave entrance features

Phytokarst in the form of phototropic tufaceous stalagmites (eucladoliths) and directed photokarren (Barton and Breley, 2019; Koether *et al*., 2025) are common: Fairy Cave Nature Reserve marks one such instance with an information board, but a variety of different sizes and morphologies remain to be classified (Figs 18,19). This cave also has examples developed in speleothem (Fig.20); all other reports (now ranging from Greenland to Australia, via Venezuela) appear to relate to bedrock (limestone or sandstone). As yet, no stromatolitic crayback formations, previously studied at Niah and Mulu (Lundberg and McFarlane, 2011; Dodge-Wan and Hui, 2013), have been reported.

Non-limestone karst

Caves and surface dissolution forms such as karren and closed depressions are found predominantly in limestone (also in gypsum and halite, which are absent in Sarawak), sandstone, and some types of igneous rocks. Wilford (1964, p.36) mentioned linear caves formed along joints in sandstone in several parts of Sarawak. In southwestern Sarawak, sites southeast of Lundu, in the Undan Range, and on the Indonesian border in the Klingkang Range (Medway, 1960), were mentioned: to these can be added several small (to 10m-long) caves, one in a closed depression, in the Bako National Park. Also, Wall and Wilford (1966) drew attention to dissolutional forms akin to karren on the surface of granodiorite exposed in the Bau area.

N.B. *Whereas limited areas of non-limestone karst are known in Sarawak, steep-sided sandstone eminences have also been described – mistakenly – in print as karst and/or limestone: notably Santubong in the southwest and Batu Lawei in the northeast. Also, when viewed casually and at a distance, the morphology of some intrusive-igneous stocks exposed around Bau can potentially be mistaken for limestone tower karst.*

Conclusion

Southwestern Sarawak presents fertile ground for research into many aspects of tropical karst (mainly, but not exclusively, in limestone). In particular, the Bau area is notable for its uncommon association of limestone karst with igneous intrusions; additionally there are large areas of limestone flats; a wide variety of karst depression types; and many interesting cave features and sediments. These topic areas could benefit from receiving more attention than has been given within earlier studies and appreciations of tropical karstology.

[Note 2]: *The ultimate up-wind source of some volcanic ash deposits observed at Mulu has subsequently been traced to the Philippines (Lundberg and McFarlane, 2012a). Indonesian sources (such as Toba) might be more likely in this region.*

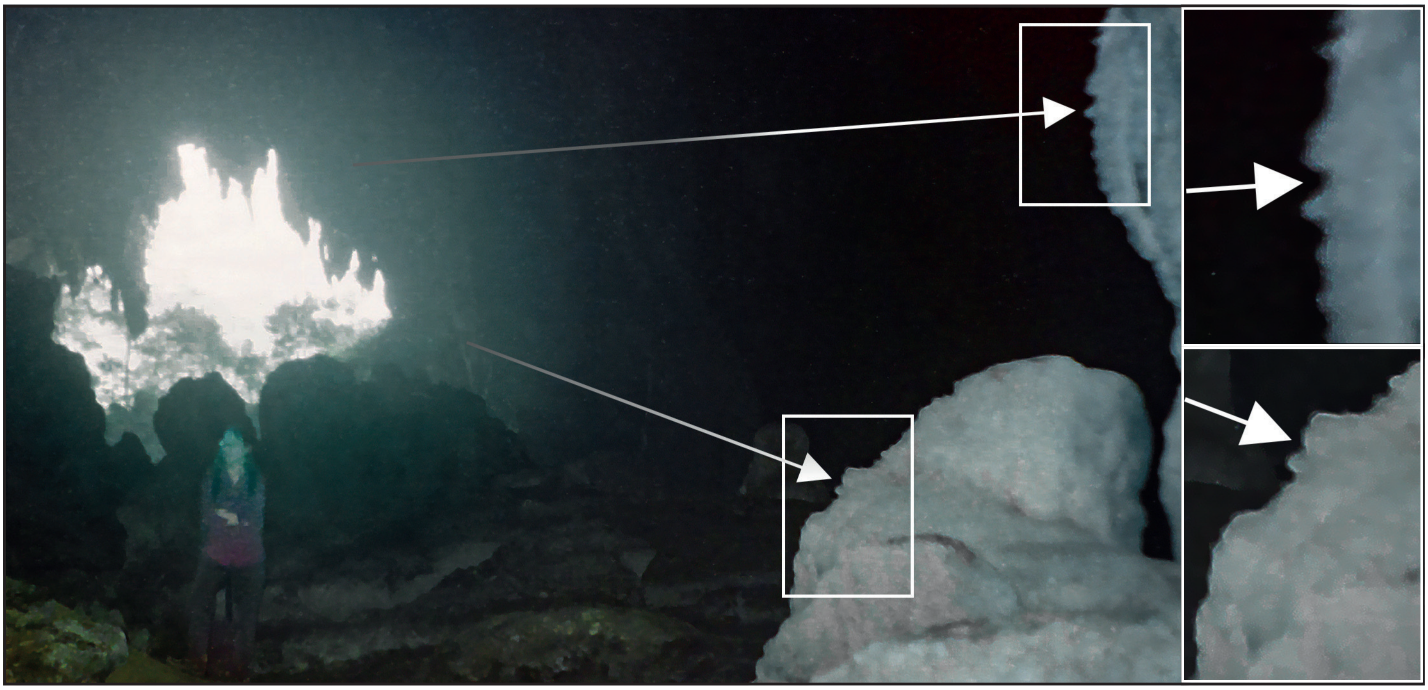

Figure 18*: Delicate, acicular photokarren oriented towards the Fairy Cave entrance, which lies some 60m away.*
Note*: Inset images at the right-hand side show approximately ×2 enlargements of the segments outlined by white rectangles in the main photograph.*

Figure 19*: Robust conical photokarren oriented towards the entrance of Fairy Cave, some 60m away.*

Figure 20*: Robust acicular photokarren, here in speleothem, oriented towards the entrance of Fairy Cave, some 60m away. The joss sticks included in the lower part of the image provide an indication of the scale.*

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Supplementary Material

The online instance of

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includes supplementary material comprising an interactive map with supporting files, and notes describing their creation, modification, and use, as in this "revisit" of Figure 1 (*from 1989*), with Google Earth Pro historic imagery from 2017, showing development along Jalan Puncak Borneo. *[Map data and imagery: Google, CNES/Airbus, Maxar Technologies, Landsat/Copernicus.]*