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Fengcong, fenglin, cone karst and tower karst

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Abstract*: Fengcong and fenglin are the two major types of karst terrain as defined in Chinese literature. They correlate only loosely with the Western terms of cone and tower karst respectively. With its isolated towers rising from a karst plain, fenglin is the most extreme form of karst landscape, and much of it may evolve from fengcong where tectonic uplift is critically slow, but overall it appears to be polygenetic. It is suggested that fengcong and fenglin are more useful karst terms with genetic implications and should take precedence, while cones and towers should be used purely as descriptive terms.*

Key words*: karst, cone, tower, fengcong, fenglin, China, evolution.*

Introduction

There is considerable confusion in the wider literature on karst over the terms cone and tower, especially when related (or not related) to fengcong and fenglin. To the extent that the Editor of Cave and Karst Science once said how he would like to see a descriptive and illustrated clarification, this review is meant to provide just that. Much of the earlier literature was weakened because few authors had seen the definitive Chinese karst before the "bamboo curtain" drew slowly back in the late 1970s. In its extent, its scale and its variety, the Chinese karst (Fig. 1) is so important that its terms – fengcong and fenglin – should really take over as the primary international terms, but perhaps their slow acceptance is at least partly rooted in continuing confusion whereby Western and Chinese geomorphologists utilise contrasting parameters to define their own karst types.

This essay is only concerned with the macro-features within karst landscape profiles, specifically fengcong and fenglin from the Chinese terminology. The other widely-known Chinese term, shilin, translates to stone forest, and applies to a giant form of micro-relief; it is essentially a large form of karren or pinnacle karst that forms the surface texture superimposed on many of the fengcong and fenglin profiles (Song et al, 1997). Though its largest form relates to arete karst (Jennings, Bik, 1962), which may have the local relief of some fenglin karsts, shilin is not normally a part of the genetic sequence that may link fengcong to fenglin, so is not here considered further here.

Cones and towers in the West

Western karst literature initially emanated from the doline karsts of temperate climatic zones, notably in Kentucky and terrains now within Slovenia and Croatia. Only when the early scientists started to travel abroad did they see a difference in the tropical karst regions, where individual hills were more distinctive than the intervening depressions. Cone karst was the very appropriate term that grew to describe these landscapes of endless conical hills; kegelkarst was its predecessor in the German language. The term was introduced by Otto Lehmann (1926) to describe the Guizhou karst seen on Heinrich Handel-Mazetti's primarily botanical expedition to China. Unfortunately, the classic description of cone karst, of that in Gunung Sewu (Thousand Hills) in Java by Herbert Lehmann (1936), virtually set the type example of cone karst as an area of hills that are rather more domed or hemispherical than conical in profile (Fig. 2). The cone karst of Jamaica had already been described, but these hills also tend towards domed profiles; they were also described as cockpit karst (Danes, 1911; Sweeting, 1958), following local usage that was more concerned with the cockpit depressions than with the intervening hills. Only some decades later were the truly magnificent and very conical karst hills of Guizhou, in China, more fully appreciated by Westerners.

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China was then an almost inaccessible land, but a few travellers got there and a trickle of photographs came out. The incredibly dramatic landscapes of almost vertical-sided limestone hills in Guangxi were glimpsed enough to generate their description as tower karst. The best examples are in the Yangshuo region, though they were (and are) commonly ascribed to Guilin, the larger city that lies not far away in a rather more subdued variety of karst landscape (Fig. 3). Turmkarst is the German term introduced by von Wissmann (1954) to describe the Chinese landscapes, from which the description as tower karst appears to have emanated. Tower karst became the objective and dream of every karst scientist who could not then visit the closed land of China, and the term was applied to various other craggy landscapes of steep-sided limestone hills, most of which do not really warrant the description. Hence the definitions were clouded and confusion was perpetuated; only to be exacerbated when the Chinese terminology, applied to their own hugely important karst terrains, was found to differ in that it is based on different parameters.

Fig. 1. Limestone hills that may be described as either towers or cones in the fengcong karst adjacent to the Li River in Guangxi, China.

Fig. 2. The rounded hills classicly described as cone karst in Gunung Sewu, Java; some hills have artifical stone walls to create terraces for farming.

Fengcong and fenglin in China

Chinese geomorphologists distinguish their karst types (in the warm and wet environments) not by the shape of their hills but by the presence or not of a karst plain between the hills. The origins of the terms

Fig. 3. The city of Guilin, Guangxi, stands on areas of alluvial plain between the limestone towers of its well-known fenglin karst.

lie buried in a karst literature that stretches back for 1200 years (Zhu, 1988), though the fenglin term was probably formalised only by Xu Xiake in 1637.

Fengcong (pronounced *fungtsung* and translating as *peak cluster*) is a karst with roughly conical hills separated by deep closed depressions, all standing on a common bedrock base so that it forms a continuous terrain of steep slopes and significant relief. It is sometimes known as fengcong-depression or fengcong-doline topography, and a variant is fengcong-valley karst where there is more interconnection between the dolines. Slope angles and individual profiles of the hills are irrelevant to the terminology. It is however clear that entirely vertical sides cannot exist on hills that are clustered together, though some areas of fengcong do have hills with slopes close to vertical on the middle part of their elevations (Fig. 4).

Fenglin (pronounced *funglin* and translating as *peak forest*) is a karst with isolated hills rising from a plain that is normally formed of limestone bedrock overlain by a veneer of alluvium. It is sometimes known as fenglin-plain topography, and fenglin-polje, fenglin-valley and fenglin-basin are variants determined by the type and extent of the plain between the hills. Slope angles and individual profiles of the hills are again irrelevant. The best known fenglin is that with vertical sided towers rising from the alluvial plains, but many fenglin hills are more truly conical in profile. The Chinese perception of fenglin also extends to terrains with isolated hills that have very low conical profiles.

By dint of his Hungarian nationality, the extensive travels of Denes Balázs could take him behind the "bamboo curtain", so that he saw more karst than most colleagues of his time. He found the division of tropical karst into tower and cone types unsuitable, and classified karst hills purely on their diameter/height ratios (Balázs, 1973a), though this crossed over between definitions of fenglin and fengcong. His Yangshuo type (d/h = <1.5) is named after the fenglin towers in China, his Organos type (d/h = 1.5-3.0) is named after the mogote variety of fenglin karst in Cuba but would include much of the fengcong of Guizhou, his Sewu type (d/h = 3-8) is named after the domed fengcong of Java, and his Tual type (d/h = >8) is named after a karst of low relief in the Indonesian Moluccas. These are useful descriptive terms but they do not contribute to understanding of the karst genesis.

Fengcong and cone karst

Even though defined by different parameters, the Chinese fengcong and the Western cone karst are, to a large extent, the same. Even though there are some notable exceptions, this is now a widely accepted generalisation (Zhu, 2005).

Typical fengcong terrain consists of roughly equally-spaced conical hills and deep dolines, with local relief that is anything from 30 m to over 300 m. This has often been labelled as egg-box topography, a conveniently descriptive term for the crowded hills with intervening depressions largely devoid of integrated valley systems, but this degree of perfection is rarely attained. The best examples are found in the Guizhou karst in China, where huge swathes of land are formed of very well developed cones that are close to symmetrical and rise to relatively sharp summits (Fig. 5). Detailed measurements across large sectors of the fengcong in western Guizhou revealed remarkably uniform slope angles of 45-47º on cones of all sizes (Xiong, 1992). However mean cone slopes in the fengcong are steeper than 50º in the Shuicheng area (Fig. 5), and many are 55-60º in the Anshun area, both also in Guizhou.

Variations in slope angles and cone profiles are created by contrasts within the bedrock lithology. Many cones, even in Guizhou, have more ragged or stepped profiles influenced by stronger beds within the limestone sequences (Fig. 6), and some in the Guilin karst have assymetrical escarpment profiles in steeply dipping limestones. Guizhou cones of weaker, shale-rich limestones have rather lower slope angles (Xiong, 1992). Much of the Caribbean cone karst is also more irregular, due to strong lithological variations in Puerto Rico (Monroe, 1976) and to a host of geological factors in Jamaica (Aub, 1969b).

The Gunung Sewu area of Java (Lehmann, 1936; Waltham et al, 1983) is often referred to as the type example of cone karst, yet its hills have domed profiles with rounded summits (Fig. 7), and noticeably lack the much sharper summits of the true cones in the Guizhou fengcong. Their profiles approach hemispherical except that their lower flanks never steepen to beyond about 30º. The same applies to the karst

Fig. 4. Very steep sided hills in the splendid fengcong karst just west of Caoping in the Guilin-Yangshuo karst of Guangxi.

Fig. 5. Sharply pointed conical hills on the western side of the Shuicheng polje in the classic fengcong of Guizhou.

Fig. 6. Various hill profiles in the fengcong karst east of Caoping, Guangxi.

Fig. 7. Low domed hills that are typical of the fengcong karst in Java's Gunung Sewu.

hills of the Cockpit Country in Jamaica (Sweeting, 1958), though these are not quite so regular in profile and some do steepen into cliffs around their lower margins. Similarly low domed hills are known in Guizhou where they are formed on dolomitic limestones, and Balázs's Tual type of very low domes are formed in young and soft limestones. While the latter two cases are clearly influenced by the carbonate lithology, both the Javan and Jamaican karsts are formed in strong and hard limestones that may be indistinguishable from those in any other karst. It may be that the domed profiles of their hill have formed beneath a thicker soil cover that has been retained over their crests. Java's Gunung Sewu lies in an area where soils are regularly replenished by thick volcanic ash, and Jamaica's Cockpit Country has its allogenic soils that are locally valued as bauxite resources. The Chocolate Hills of Bohol, in the Philippines, have slope angles of about 40º, intermediate between those of Guizhou and Sewu, and further demonstrate the multiple variations that exist in karst.

Sub-types of fengcong include those based on the lateral extent of the clustered cones and their position relative to trunk rivers, karst plains and allogenic catchments (Zhu, 1988) and those based on progressive alluviation where base level is approached by regional surface lowering (Smart et al, 1986). Some of the very crowded fengcong just west of the Li River in the Guilin karst, in Guangxi, has slope profiles steeper than 60º (Fig. 4). Towards its margin this area west of Caoping has hills with nearly vertical sides rising from low pediments that keep them apart; morphologically this provides almost the perfect transition from fengcong cones to fenglin towers, though the genetic relationship is perhaps clouded by lithological influences.

The drainage of fengcong karst is almost entirely underground, entering either by fissure percolation or through open sinks at the ends of short ephemeral stream courses within the dolines. Water tables commonly lie far beneath the doline floors, and long vadose cave passages may form dendritic systems. It is noticeable but not surprising that, where long caves have been mapped through fengcong karst, the passages lie beneath both dolines and cone hills with no correlation to the surface topography (Fig. 8). Phreatic loops do occur within the fengcong caves, and survive until

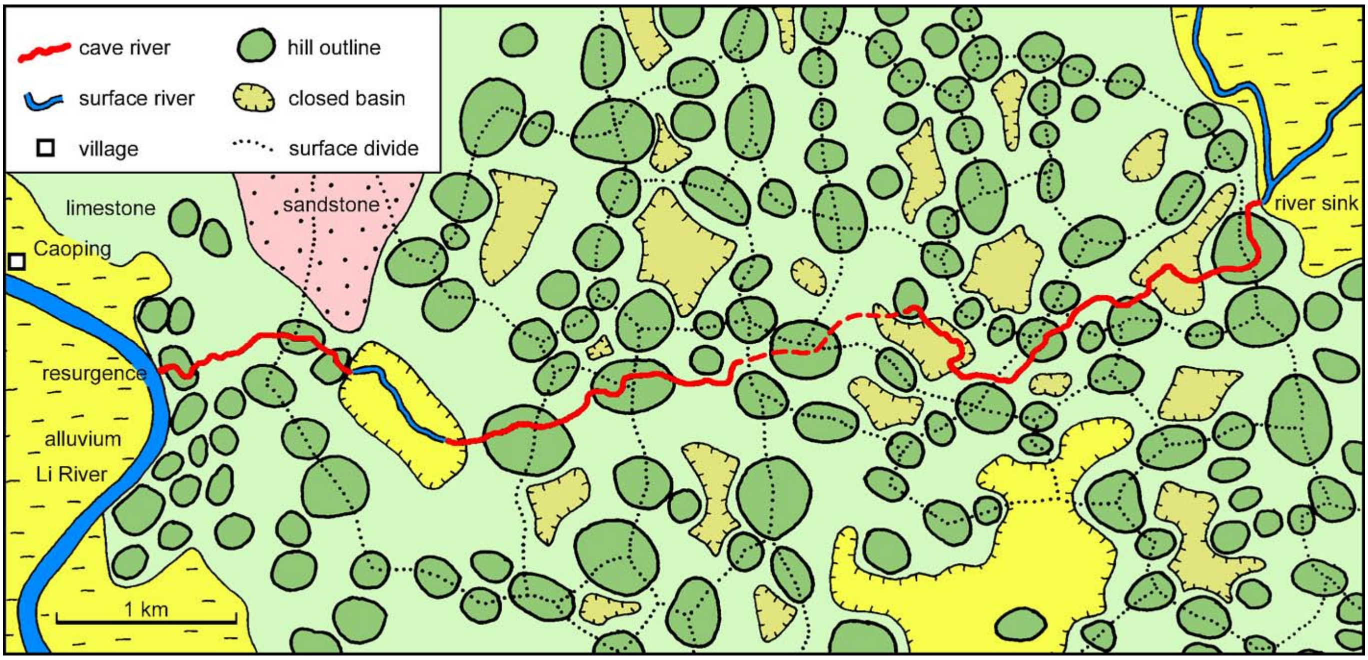

Fig. 8. The river caves of the Guanyan system draining through the fengcong karst and into the Li River between Guilin and Yangshuo, Guangxi (cave surveys by China Caves Project, 1985).

development of graded profiles, while old passages are commonly abandoned and perhaps subsequently intersected at multiple high levels. The laterally extensive, vadose, cave drainage further distinguishes fengcong from fenglin.

The extensive and spectacular fengcong karst of Guizhou (and northwestern Guangxi) is already recognised as the definitive example of its type. It should also replace Gunung Sewu as the definitive example of cone karst, wherever that term is retained for descriptive purposes. Fengcong karst is widely distributed through the wet tropical regions of the world, but none quite matches the extent and scale of that in Guizhou.

Fenglin and tower karst

Again there is widespread similarity between the Chinese fenglin and the Western tower karst. Almost all true tower karst can be described as fenglin, though the latter term does include some landscapes that comprise conical hills instead of towers. Even with these exceptions, some writers are now accepting that fenglin and tower karst are essentially the same (Zhu, 2005).

The finest of the fenglin is the dramatic landscape of isolated, steep-sided towers rising from an alluviated plain, which is commonly covered in rice paddies (Fig. 9). The fenglin of Yangshuo, at the southern end of the Guilin karst, represents the geomorphological extreme that has so often been the subject of traditional Chinese paintings and drawings. Numerous individual towers are well over 100 m tall. Balázs (1973a) defined his Yangshuo type of karst hills as having a diameter/height ratio of <1.5, but many in the area have ratios of less than 0.5, so that they are two or three times as tall as they are wide, and thereby form one of the world's most spectacular landscapes (Zhu, 1988).

Many towers do have vertical sides (Fig. 10) and are the more dramatic when they lack any aprons of talus around their bases; some of those around Yangshuo, nearby Fuli and Qifeng (near Guilin) are among the finest anywhere (Fig. 11). Others in the same areas are more truly conical, notably in the immediate vicinity of Yangshuo town. Measured profiles in a small sample area of the fenglin near Yangshuo revealed a mean slope angle of 75º (Tang, Day, 2000). The same survey found no significant difference between slope angles in the fenglin and fengcong (in sample areas between Guilin and Yangshuo); this may have been due to the locations and small sizes of the sample areas, as it is not supported by visual observation that is admittedly non-quantitative (comparing Figs. 6 and 9 as an example). Most fenglin towers do have sides steeper than are found on most fengcong cones. There is however a transition through many fenglin towers that have more irregular profiles, but are still distinguished from fengcong by having the alluviated karst plain between them. There is also a transition through towers that have multiple peaks and through very small clusters of hills in the middle of a karst plain; the latter have been described as insular fengcong (Zhu, 1988). Lithology influences profiles, creating asymmetrical or even conical towers in steeply dipping limestones (Fig. 12) and lower profiles in weaker rocks, while the vertical sided towers can only survive in strong and almost horizontally bedded limestone (Fig. 13).

Fenglin karst can exist with low conical hills, commonly due to lithological influence. That in Guizhou is mainly formed

Fig. 9. The dramatic landscape of the fenglin towers on the alluvial plain between Yangshuo and Fuli, Guangxi.

Fig. 10. An almost perfect tower with vertical sides in the fenglin near Yangshuo, Guangxi.

Fig. 12. A conical tower that is effectively a hogsback escarpment in steeply dipping limestone in the Hpa An fenglin of southern Burma (photo: Liz Price).

Fig. 11. The splendid fenglin karst near Qifeng, south of Guilin, Guangxi (photo: Zhu Xuewen).

Fig. 13. A spectacularly narrow fenglin tower in the Hpa An karst of Burma (photo: Liz Price).

Fig. 14. A river on the karst plain flows through a cave right through the base of a tower in the Tam Coc fenglin, Vietnam.

in thinly bedded dolomite carbonates. The Chocolate Hills of Bohol, in the Philippines, are also low cones, and are in pure limestone, though this is young and friable (Balázs 1973b); it may be that the intervening plains, that define most of them as fenglin, have developed by more alluviation than exists in fengcong terrains with similar hills, such as Gunung Sewu.

Sub-types of fenglin include those prefixed by the terms basin, polje or valley in order to further describe the extent of the plain areas between the towers (Zhu, 1988). Karst margin fenglin describes terrains with isolated towers that lie between areas of fengcong and non-karst, reflecting the significance of allogenic sediment in the development of fenglin (see below).

Drainage in fenglin is primarily on the alluviated plains between the towers, where substantial dendritic systems of surface rivers can survive. Within the limestone, a relatively stable water table is maintained at the level of these rivers. It is likely that there is significant phreatic flow through the limestones beneath the plains, in the style of underflow (Worthington, 2004), though there are few large risings in the fenglin that could indicate any degree of maturity in such flooded caves. Foot caves abound within the towers, which are also penetrated by some caves that happen to carry the plain's rivers through them (Fig. 14). Vadose drains within the towers are close to vertical, and commonly intersect old, high-level passages that originated as foot caves at past plain levels.

The famously spectacular fenglin karst of the Guilin-Yangshuo region in eastern Guangxi is already recognised as the definitive example of fenglin. True fenglin tower karst is almost entirely restricted to the limestone regions of Southeast Asia, extending from Guangxi into northeastern Vietnam and then only into isolated patches through the rest of Vietnam, Thailand, Burma and Indonesia. Caribbean mogote karst, notably in Belize, Cuba and Puerto Rico, may be regarded as a variety of fenglin with generally reduced local relief.

Fengcong evolution

It is widely accepted that fengcong karst is a natural evolutionary progression from doline karst, created when the dolines enlarge towards coalescence, leaving residual hills that ultimately tend towards conical in both plan view and profile. What is open to debate is the extent of any early stage of valley systems within the fengcong. Some parts of Java's Gunung Sewu karst have the remains of dendritic valley systems that are clearly identifiable, both in plan view and also by thalwegs only just broken into chains of dolines between the conical hills. It is likely that these valley systems were superimposed from a non-karstic cover now totally removed from the limestone; such valleys would have survived on the limestone until such time as efficient underground drainage was developed, when new sinks along the valleys would progressively deepen into strings of dolines. Valley incision into the limestone when it was sealed in periglacial environments, as was the case in many fluviokarsts of higher latitudes, could not have happened in the tropical fengcong terrains.

Other parts of the Gunung Sewu karst lack any recognisable linear patterns within their dolines, as appears to be the case in much of Guizhou's fengcong, but continued maturation of the fengcong is eventually likely to remove all trace of inherited valley patterns. Alignment of dolines, and their low intervening saddles, creates corridors through some areas of fengcong karst (Fig. 15). At many sites these can clearly be attributed to geological controls, either by major fractures or

Fig. 15. The remains of valleys provide low-level corridors through the deeply dissected fengcong karst near Bama, in northwestern Guangxi.

by individual beds within steeply dipping limestone sequences. Such corridors have been interpreted in Jamaica's cockpit karst (Sweeting, 1958; Aub, 1969b), but this may be a circular argument in such heavily forested terrains where the geology is largely interpreted from air photographs.

Collapse features that may add to the morphological complexity of the fengcong include the giant dolines known as tiankengs (Zhu, Waltham, 2005). There are even suggestions that a significant proportion of the dolines within the high-relief fengcong in China could have originated by collapse (Klimchouk, 2005), though collapse is generally dismissed as of little importance in the development of the cone karsts of lower relief outside China (Sweeting, 1972). Within the well watered, forested, cockpit karst of Jamaica, it has been noted that, once established, deep dolines are self-perpetuating by diversion of rainwater, and hence dissolutional effort, towards their low centres (Aub, 1969a; Smith et al, 1972).

It is clear that fengcong karst normally evolves towards higher local relief as long as the surface lowering of doline floors does not reach either the floor of the limestone or the regional base level. Mature fengcong with the greatest local relief therefore requires rapid or intermittent tectonic uplift to keep it rejuvenated with deepening of its dolines. With slower uplift, doline floors reach base level, and there is then a switch from surface lowering towards lateral planation, so that the fengcong may then evolve into fenglin karst.

Within China, the fengcong of Guizhou has been described as a feature of the plateau-canyon karst of the Guizhou type, the latter being a broader term to distinguish it from the peak-forest karst of the Guangxi type (Zhang, 1980). At first this may appear to belittle the fengcong term, but it is significant in recognizing the base-level lowering and rejuvenation that is so important in the evolution of mature fengcong karst.

Fig. 16. A deep dissolutional notch round the base of a limestone tower in the fenglin karst of Guilin, Guangxi.

Fig. 17. A limestone hill now isolated on the fenglin plain so that its lower slopes are being undercut as it evolves from a cone to a tower, near Yangshuo, Guangxi.

Fenglin evolution

A key process in fenglin karst is the enhanced rock dissolution that takes place due to the chemically aggressive water occurring at the water table. This level has very little vertical variation either side of the level of the alluvial plain, in the style of the level control (known by the German term *Vorfluter*) that has long been recognised as critical to the lateral growth of the flat floors in karst poljes. The effect of this is to undercut any rising slopes marginal to the alluviated plain, by the creation of dissolutional notches (Fig. 16) and foot caves.

With subsequent collapse over these undercuts, cliff retreat is accelerated at lower elevations, and the whole process effectively turns a cone into a tower (Fig. 17).

Lateral planation at the expense of reducing hill profiles creates the commensurate extension of the base level plain, and so constitutes a transition from fengcong to fenglin. This does however require a stable base level and water table, and the processes in nature are greatly complicated by the common normal situation of a slowly falling base level. Critical are the relative rates of base level decline, dissolutional lowering of the rock surface beneath the alluvial plain, surface denudation on the karst hills, and sediment input that maintains the evolving alluvial plain. The underlying factor of base level decline is a function of both regional denudation and tectonic uplift. Zhang Zhigan presented the thoughts of himself and others, most notably Lu Yaoru, in an important paper (1980) that established the key role played by the local rates of tectonic uplift in distinguishing the fenglin and fengcong types of karst landscape.

Debate continues over the early evolution of fenglin, but it is recognised that, whatever its origins, fenglin karst only exists where a number of independent factors combine to create the right environment (Fig. 18). The rarity of the perfect combination accounts for the scarcity of mature fenglin worldwide. These factors may be listed (in no particular order) –

1. Limestone that is pure, compact and strong.
2. A huge thickness of limestone, sufficient to allow massive surface lowering, without reaching the base of the limestone, which gives time and space for the karst landscapes to evolve to maturity.
3. A veneer of alluvium overlying the bedrock limestone of a karst plain.
4. A karst water table that is stable and is maintained at the level of the karst plain.
5. Major inflows of allogenic water and clastic sediment that can recharge and maintain the alluvial plain as it evolves through surface and bedrock denudation.
6. Slow tectonic uplift that matches surface denudation and thereby maintains the karst plain as it is lowered through the limestone profile.
7. A hot and wet climate with significant rates of carbonate dissolution in a regime of abundant biogenic carbon dioxide.
8. Equilibrium between rates of surface lowering and lateral planation that allows maintenance of the residual towers while the karst plain is lowered around them.

In simple terms, fenglin is a very mature form of karst terrain that can only evolve during surface lowering through a great thickness of limestone; furthermore it requires long-term lowering of an alluviated karst plain, which is only possible where slow tectonic uplift is matched by both its own bedrock denudation and sediment supplies that maintain its alluvial cover.

There has been considerable debate over whether fengcong and fenglin evolve separately or whether fenglin evolves from fengcong. Most early ideas focussed on separate origins, dependent on bedrock porosity, bedrock fractures, depth of the karst or superficial cover (Jennings, 1985). More recent studies recognise fenglin that is both evolved from fengcong and separate from it, though with the evolved style dominant in the Guilin area (Williams, 1987; Ford, Williams, 2007); the separate style includes various types of non-tropical, geologically controlled tower karst. The more isolated karst hills in Jamaica are ascribed to development where there is more insoluble sediment (analogous to the input of gravel where fenglin evolves), and this is claimed to be independent of development of the more widespread fengcong cone karst (Day, 2004); however the evidence is not conclusive, and studies in Jamaica are justifiably more concerned with depression morphology than with hill profiles.

It is possible to identify a complete genetic sequence that originates from a plain surface, evolves into a doline karst and then into fengcong, and then matures into fenglin, before degrading in old age back to a karst plain (Fig. 19). There is no doubt that this is a simplified sequence of stages,

Fig. 18. Guangxi’s finest fenglin stretching away from Yangshuo, with a concordance of summit heights that suggests a phase of planation within its evolutionary history.

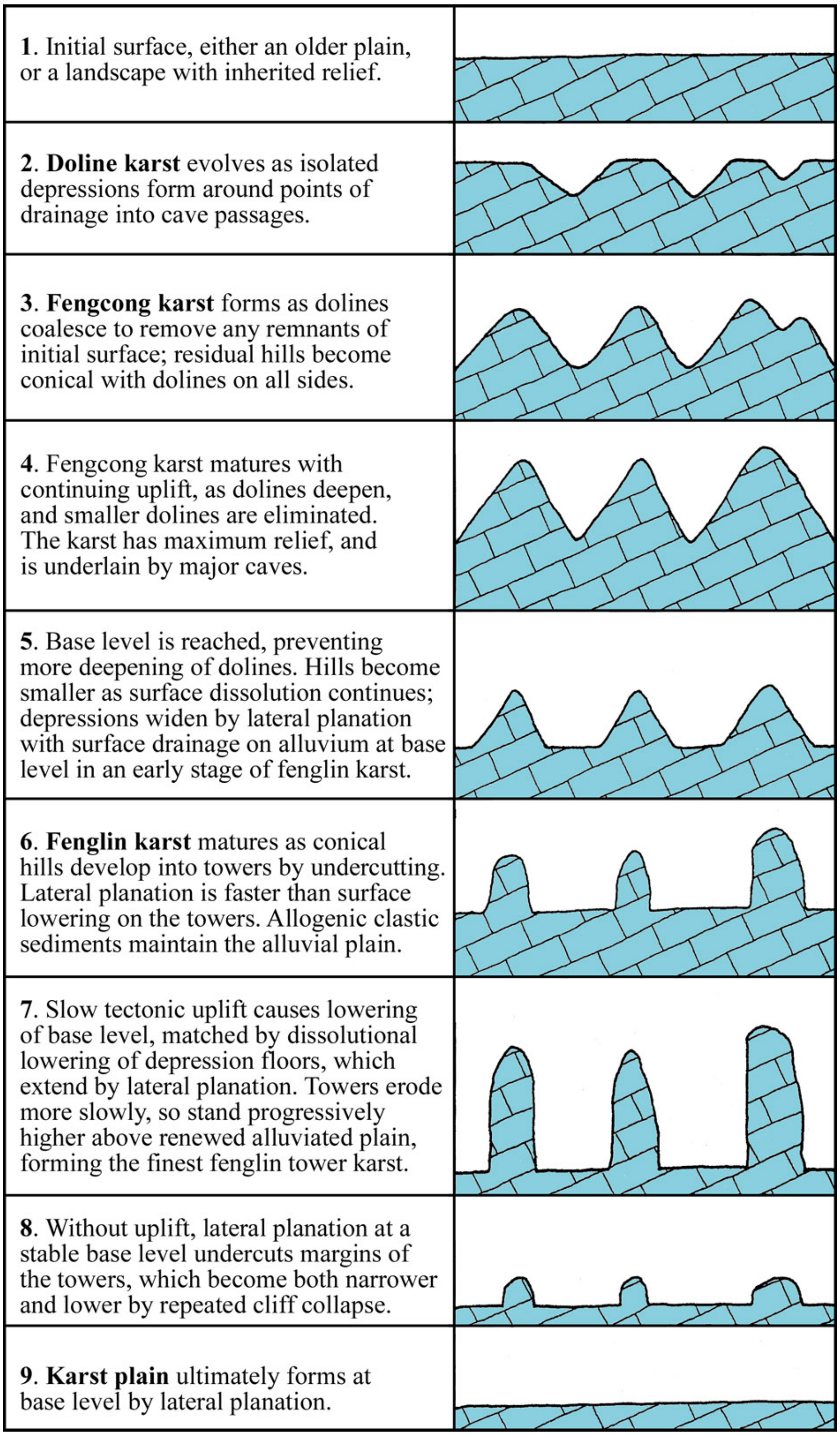

Fig. 19. A diagrammatic sequence that, if completely developed, shows stages in landscape evolution from an initial plain, to doline karst to fengcong to fenglin, and then back to a karst plain.

which is enormously more complicated in nature where both regional and local factors impose. But it incorporates all the factors essential to fenglin development, and its first seven stages do provide a genesis for the tall limestone towers of the classic fenglin karst around Yangshuo. Multiple levels of sets of concordant summits, and tiered profiles of individual cones, both indicate that some areas of fengcong have complex multi-phase histories that reach far beyond the simple sequence in Figure 19.

Within the extensive and varied karst of Guangxi, both fenglin and fengcong appear in such juxtaposition that suggests parallel evolution of the two systems (Zhu, 2005). On a regional scale, this can be accounted for by fengcong evolving through the first four stages in an area of rapid tectonic uplift, while a lower rate of tectonic rise allows fenglin to develop by passing from stage 2 direct to stage 5. But tectonic contrast cannot account for different landforms within units only a few kilometres across; in these cases, the critical factor on such a local scale can only be sediment input (or some influence by bedrock lithology). Zhang (1980) recognised that the evolution of fengcong through rejuvenation of upland terrains could be extended into a landscape sequence that included fenglin; but he suggested that this was an over-simplification because the landscapes were critically dependent on contrasts in tectonic uplift between Guizhou and Guangxi and had not both evolved from the same unified plateau surface. Mature fengcong could diverge from the total sequence at stage 4 and continue to increase its local relief under conditions of rapid uplift and repeated rejuvenation.

Timescales of karst evolution

It is clear that the mature forms of fengcong and fenglin, particularly as seen in the karst terrains of Guizhou and Guangxi, have both evolved over very long periods of time, and there is implication that the fenglin probably has the longer timescale of the two. Some evidence for the lengths of these timescales comes from dated materials in the caves of the fenglin karst around Guilin. Most of these caves are richly decorated with massive deposits of calcite, and stalagmites in the caves of Maomaotou Hill, in the suburbs of Guilin, yield dates ranging from 41 to >350 ka, with deposition in both warm and cold stages through the Pleistocene (Wang, 1986). The karst is clearly much older.

An important record has come from palaeomagnetic studies of clays in a tiered series of caves within a single tower,

Fig. 20. Seen across the Li River, Chuan Shan (on the left) contains cave sediments that give a timescale for tower evolution.

for both the fengcong and the fenglin until more precise chronological data is available.

Fenglin fengcong distribution

It does not take very long in the field to appreciate the enormous variety of detail in the karst landscapes of Guangxi and Guizhou. It is very clear that multiple factors have been influential, and that not all have been operating at the same time at each site. Consequently there is no simple pattern in the distribution of fenglin and fengcong. On the largest scale, fengcong dominates the uplifted karst of the Guizhou plateau, while fenglin is largely restricted to the more stable lowlands of Guangxi. Both fengcong and fenglin occur within the relatively small karst in the Guilin-Yangshuo basin (Fig. 21). Many of the fenglin areas are associated with sediment

known as Chuan Shan or Tunnel Hill (Fig. 20), which rises on the east bank of the Li River in the southern suburbs of Guilin (Williams, 1987). These cave deposits indicated a mean rate of plain lowering, and therefore of tower emergence, of not more than 23 mm/ka. This is valuable data, though its interpretation shows only the emergence of a tower of constant profile, and makes no indication of the early stages of hill profile from which the tower might have evolved. Data from a range of other sources indicate rather higher rates of surface lowering in the Guilin basin. Zhang (1980) cites 80-120 mm/ka based on dissolution measurements, Zhu (1988) cites around 100 mm/ka from data on fossils in the high-level caves, and Yuan (2004) cites 90 mm/ka from multiple studies. Lu (1986) estimates denudation rates at 100-300 mm/ka, and compares them to tectonic uplift rates of 50 mm/ka in the Pleistocene, increasing in the Holocene.

An approximate figure of 50-100 mm/ka would therefore seem reasonable for the long-term rate of surface lowering in the Guilin karst. The geology indicates that denudation has worked down somewhere in the order of 1000 m of limestone, and this therefore extends the timescale of the karst evolution to around 10-20 Ma. These very approximate figures place the origins of the karst well back into the Tertiary, and this appears to be a very reasonable concept

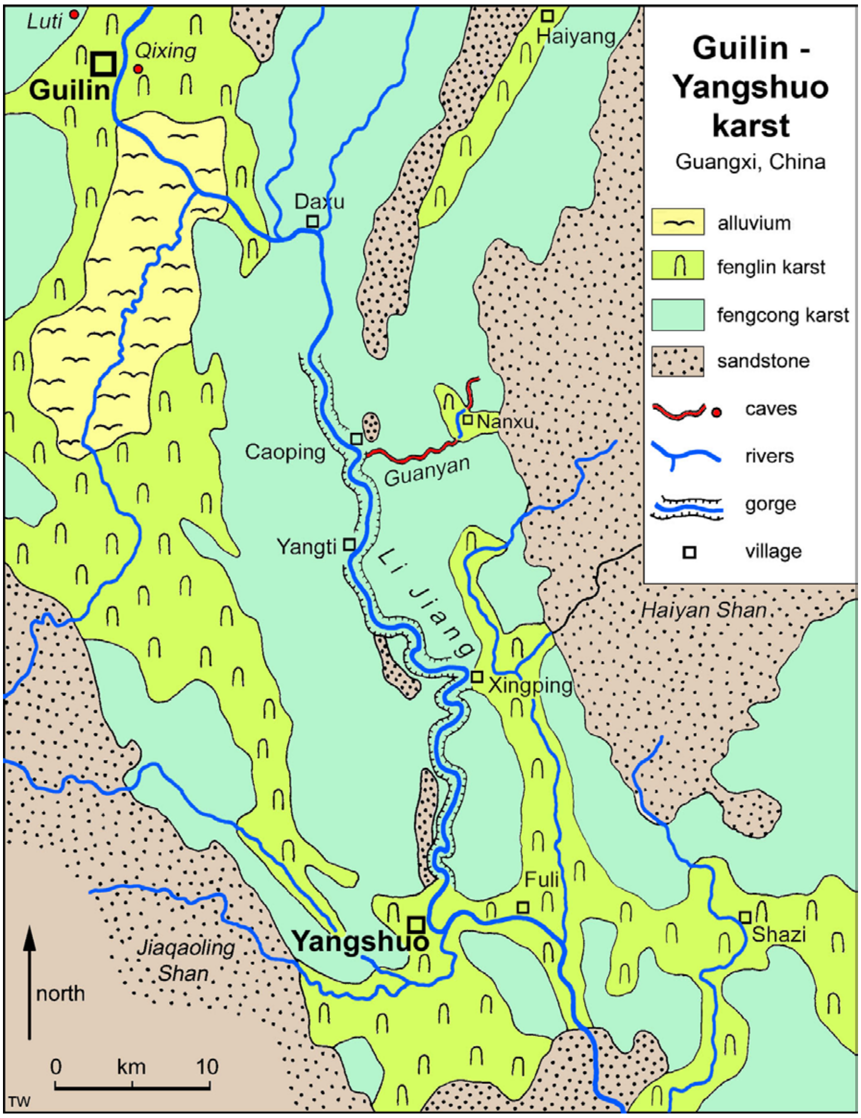

Fig. 21. A very generalised map of the distribution of fengcong and fenglin in the karst between Guilin and Yangshuo, Guangxi.

Fig. 22. Steep hills near Xingping, showing some degree of undercutting by the Li River where it passes through the mature fengcong karst between Guilin and Yangshuo.

Fig. 23. Isolated towers in a small alluviated valley within the fengcong karst near Anshun, Guizhou.

fans of rivers derived from the adjacent non-carbonate hills, while the lower gradient of the trunk Li River precludes its ability to transport sediment so that it has entrenched a gorge through the finest of the fengcong karst (Fig. 22). On a smaller scale, a valley within the heart of the fengcong karst of Anshun, in Guizhou, contains two perfectly formed towers on an alluvial flat (Fig. 23); this small patch of fenglin clearly developed where there was sediment input, as tectonics could have had no influence on this scale.

Another variation is provided by the Khammouan karst in Laos (Waltham, Middleton, 2000), where large blocks of fengcong have very steep perimeter walls that drop to river valleys and poljes with alluviated floors, but there is almost no fenglin where alluvial plains meet the high hills. The larger hills in Cuba's Sierra de los Organos karst are comparable blocks of fengcong, but the steep marginal cliffs drop to adjacent plains where smaller mogotes form a variety of fenglin (Fig. 24).

It is difficult to define, as either fenglin or fengcong, the smallest clusters of towers that stand on alluvial plains in Guangxi, and also the small, isolated, limestone hills that rise from the poljes and marginal plains within the fengcong of Guizhou. Each of these local situations confirms the role of one or more of the factors, as listed above, that are critical to fenglin development. But there are influences from bedrock geology and pre-existing trunk valleys that are superimposed on the karst processes and are not yet mapped and fully understood. It may be a simplification, or even escapism, but it appears to be a truism that fenglin is polygenetic.

Fenglin variants

With fenglin evolving under a number of different influences, it is hardly surprising that there is considerable variation in the morphology of its towers. The splendid tall towers of the Yangshuo area are merely the extreme form of

Fig. 24. Blocks of fengcong and isolated mogotes in the karst of the Sierra de los Organos, Cuba.

Fig. 25. Conical and domed hill profiles within the fengcong rising above an adjacent karst plain near Zhenning in western Guizhou.

fenglin development. Variations in detail are recognised from contrasting evolutions in the Guizhou karst (Smart et al, 1986), where some areas evolve to fenglin while retaining conical profiles in their residual hills (Xiong, 1992). Comparable conical hills rise from alluvial plains in the Philippines' Bohol karst (Balázs, 1973b) and in some parts of Puerto Rico (Monroe, 1976; Day, 1978); both of these are known as cone karst but are truly varieties of fenglin. The steep-sided mogotes of Cuba's Sierra de los Organos (Panoš, Štelcl, 1968) are low versions of fenglin towers, perhaps representing stage 6 on Figure 19.

Both fengcong and fenglin are essentially features of karst within the hot and humid tropical environments where mean temperatures are above 17ºC and annual rainfall exceeds 1300 mm. Parts of the Nahanni terrain, in the colder climes of Canada, have been described as tower karst (Brook, Ford, 1978). However, these may be viewed as geologically controlled plateau remnants that have evolved from the labyrinth karst (in similar style to buttes developing from mesas in Arizona's Monument Valley). They may be described as towers, but they are not fenglin.

A special variant of fenglin is created where karst plains have been invaded by the sea so that the residual towers are further undercut by wave action and marine dissolution. The 2000 islands of Ha Long Bay, Vietnam, include spectacular examples of both drowned fenglin and drowned fengcong (Waltham, 2000).

Karst definitions

Fengcong and fenglin offer a terminology and classification of karst that has clear genetic implications, and are also the terms established in the world's most extensive and most important karst terrain, in southern China; for both these reasons they should take precedence in good science. Cones and towers are useful descriptive terms for karst landforms, but they have been distorted by different localised usages (Fig. 25). They may be recognised as approximate correlations with fengcong and fenglin, but are better retained as purely descriptive terms with minimal genetic significance.

As a term, tower karst has been over-used in Western literature, largely as a purely descriptive label for a fairly steep, rocky hill. Isolated crags formed in thin and steeply dipping bands of limestone that protrude high above adjacent weaker rocks, in parts of Cambodia, Thailand and elsewhere, have been described informally as towers on numerous occasions. Frost-

Fig. 26. The beautiful limestone towers of the fenglin south of Yangshuo, Guangxi.

shattered crags in Tibet, and even steep crags in reef limestone in the English Peak District, have been similarly labelled. All of these, and many more, may better be regarded as pseudo-towers, as they lack the surrounding karst plains; they certainly cannot be described as fenglin. Some areas of mogote hills in Cuba and Puerto Rico constitute a true variant of fenglin, but too many rocky hills within the Caribbean karsts have been misleadingly described as towers, and none compares with the magnificent fenglin towers of Southeast Asia (Fig. 26). Large swathes of Guangxi have been sweepingly described as tower karst (Sweeting, 1972), whereas fenglin forms only 15% of the karst area within the province (and even only 50% within the Yangshuo area), the remainder being fengcong. Furthermore, the entire subtropical karst of southern China is sometimes described as the fenglin karst system (Xiong, 1992; Zhu, 2005).

Confusion appears to be alive and well within the terminology of karst. It appears that it would be an improvement to use the terms fengcong and fenglin more widely, and relegate cones and towers to descriptive use having only approximate correlation with the Chinese landforms.

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