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Karst Geomorphology

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TROPICAL AND SUBTROPICAL PINNACLE KARST AND SHILIN LANDSCAPE IN CHINA

ABSTRACT: SONG L., *Tropical and Subtropical Pinnacle Karst and Shilin Landscape in China.* (IT ISSN 0391-9838, 1998).

Pinnacle karst and shilin (stone forest) landscapes are widely developed in south China. This paper describes three main pinnacle and shilin karst landscapes. Xianan Pinnacle karst is located on Hainan Island in the tropical climatic zone. The pinnacles form shapes resembling needles, knives etc., and the landform is covered by tropical rain forest. Linyun shilin karst developed in Upper Carboniferous grey-black thick limestone and Lower Permian dark black limestone with silicon chert is located in an area of 1.23 km^2, 13 km to the south Yongan city, Fujian Province. The climate is monsoon sub-tropical. The height of stone columns with solution karren vary in the range of 2 m to 34 m, with stone teeth less than 5 m high occupying about 49.7% of the total, and the rest being the higher stone columns. Xianan pinnacle karst and Linyun shilin have developed on limestone hills covered by forest, and exhibit solution shafts and fissures inset into limestone blocks. The Lunan shilin landscape has mainly developed in the tropical and subtropical climates since the lower Permian limestone was deposited. The karst developed under the soil, then soil erosion exposed the stone teeth and columns, and rain water reshaped the upper parts. At the present, the Lunan shilin is found on limestone hills, hill slopes and in depressions at 1,700 m to 1,900 m a.s.l.

KEY WORDS: Exokarst, Stone Forest, Tropical Karst, China.

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INTRODUCTION

Pinnacle karst is defined as tropical karst characterised by vertical rock blades fretted sharp by dissolution processes. It is practically indistinguishable from arete karst and tsingi, and includes the variety of karst known as shilin (James, 1997; Waltham, 1997). The term shilin (or stone forest) arises from the tree-like appearance of the individual karst landforms. The landscape is developed by sub-soil corrosion, exposed by soil erosion and then reshaped by rain water. The solution karren is well developed on the top of stone columns with a height of more than 5 m (Song, 1986, 1997). Pinnacle and shilin karst landscape are broadly developed in Hainan, Yunnan, Guizhou, Sichuan, Hunan, Zhejiang, Fujian provinces. They are distributed in the tropical and subtropical climatic zones, and in Cambrian, Ordovician, Silurian, Carboniferous, Lower Permian and Middle Triassic limestones and dolomitic limestones. They are found in limestones that have a wide range of dips. The most impressive pinnacle and shilin karst landscapes occur in lower Permian limestone, for example, Lunan shilin, Linyun shilin, Luta shilin and Xingwen shilin. Pinnacle and shilin karst landscapes in different climatic zones have different morphologies. In this paper the Xianan Pinnacle karst in Hainan, Linyun shilin in Fujian and Fuqi shilin in Zhejiang, and Lunan Shilin in Yunnan will be used to illustrate this.

XIANAN PINNACLE KARST LANDSCAPE

The Xianan pinnacle karst has developed on a Qingan Silurian limestone hill at 625-782 m a.s.l. at 18°36' N and

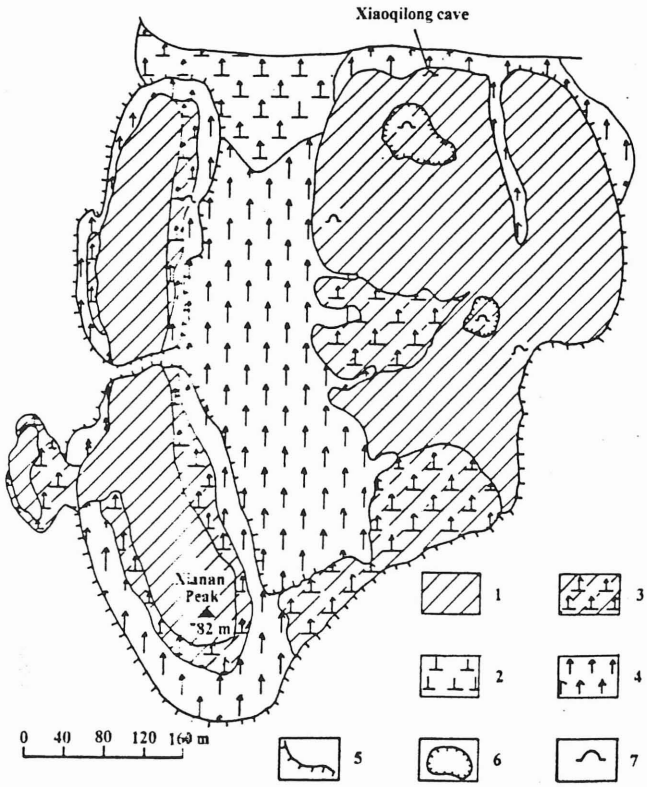

FIG. 1 - The distribution of Xianan Pinnacle Karst landscape (after Yang Shixing, 1994): 1. Pinnacle landscape; 2. Bush; 3. Pinnacle karst and bush; 4. Rainforest; 5. Cliff; 6. Depression; 7. Cave.

109°34' E. It belongs to the Southern Hainan Hilly region. It is located 30 m-50 m higher than the nearby shallow basin and surrounding the karst hills. The pinnacle karst area of 0.34 km^2, can be divided into 3 sub-regions (fig. 1):

1. pinnacle karst with the gullies;
2. forest, bush and pinnacle karst;
3. pinnacle karst covered by forest.

In sub-region 1, stone teeth and columns combined with solution gullies constitute the karst landscape. 49.7% of the pinnacles are 3-5 m high, 30% 10-15 m high. The rest are higher with a maximum of 35 m. The gullies are generally 5-10 m deep, the deepest to 25 m. The largest one is 110 m long, 20-25 m deep and 2-4 m wide.

The pinnacles are very sharp like the needles, knives, swords and long nails. Some of them are shaped like different animals (fig. 2). All the features have developed in Silurian limestones, dolomites and marbles, which are covered by the quartz sandstone. The limestone contains 53-55% CaO and dips at an angle of 63-72°. It has been well fractured during tectonic movements. The karst area is located in the tropical climatic zone with an average annual temperature of 23.2°C. In the hottest month (August), the average temperature is 26.3°C and in the coldest month (January), the average temperature is 18.7°C. The annual average precipitation is is up to 1930 mm. The rain water dissolves the limestone along the fractures enlarging the openings. Caves in the karst are common, they contain few speleothems, for example, Xiaoqilong cave, Panlong cave, Guanyin Cave. Generally, solution shafts without soil and surrounded by the pinnacle columns on the surface, are directly linked to the caves. The entrances to the caves are at the foot of the cliffs close to the basin floor.

LINYUN SHILIN IN FUJIAN AND FUQI SHILIN IN ZHEJIANG

The Linyun shilin is located in the Dahu Community, 13 km from the south of Yongan city, 117°25'48" – 117°25'48", E, 26°00'35" – 26°02'48", N. It covers 1.23 km^2. The Linyun shilin landscape was developed in Upper Carboniferous grey-black thick limestone and Lower Permian dark black chert thick limestone, the limestones are strongly fractured with the main joints N30°E, N65°W, SN and N80°E. The shilin landscape is covered by red soil and by forest and bush. The shilin developed on limestone of Mantuo hill, Hongshan hill and other nearby hills (fig. 3).

The Linyun area belongs to the subtropical humid monsoon climatic zone (Wang Guoqing, 1994). The annual average temperature is 19.1°C, the extremes of temperature being 40.5°C to –7.6°C. The hottest monthly mean temperature (July) is 28.1°C and lowest monthly mean temperature is 8.6°C. The annual mean precipitation is up to 1,569 mm, with 50% of the total rainfall falling in the period from April to June. The annual average number of foggy days is 70, maximum of 107 days. The potential evaporation is 1,333 mm. The humid weather is favorable for bush and forest growth on the limestone hills, though there is a lack of soil and hence vegetation on the top of the shilin.

The shilin landscape predominantly developed on Mantuo Hill at 270-320 m a.s.l. and Honghyun Hill at 260-300 m a.s.l. The 0.44 km^2 of shilin on Mantuo Hill is known as the Linyun shilin, and the 0.53 km^2 of shilin on Honghyun hill is called the Hongyun shilin. The Dahu karst basin surrounding the karst hills is at 220 m a.s.l.

Stone teeth, columns, karren, solution shafts and small depressions are well developed on the karst hills. According to a preliminary count, there are 334 stone teeth and stone columns, in which the height of 166 stone teeth is less than 2-5 m. 75 stone columns whose height varies from 5-10 m, 14 columns from 10-20 m and 79 higher than 20 m (maximum, 34 m) (fig. 4). The higher columns are linked by solution shafts developed along the fissures. The columns take tower, conical and irregular shapes. Karren is well developed on the top of stone teeth and columns. The solution karren near Two Dragon Scenic Spot constitutes a 2nd order drainage system, and with a main grove 2 m long, 51 cm deep and 55 cm wide. The karst development is controlled by NS and N80°E joints.

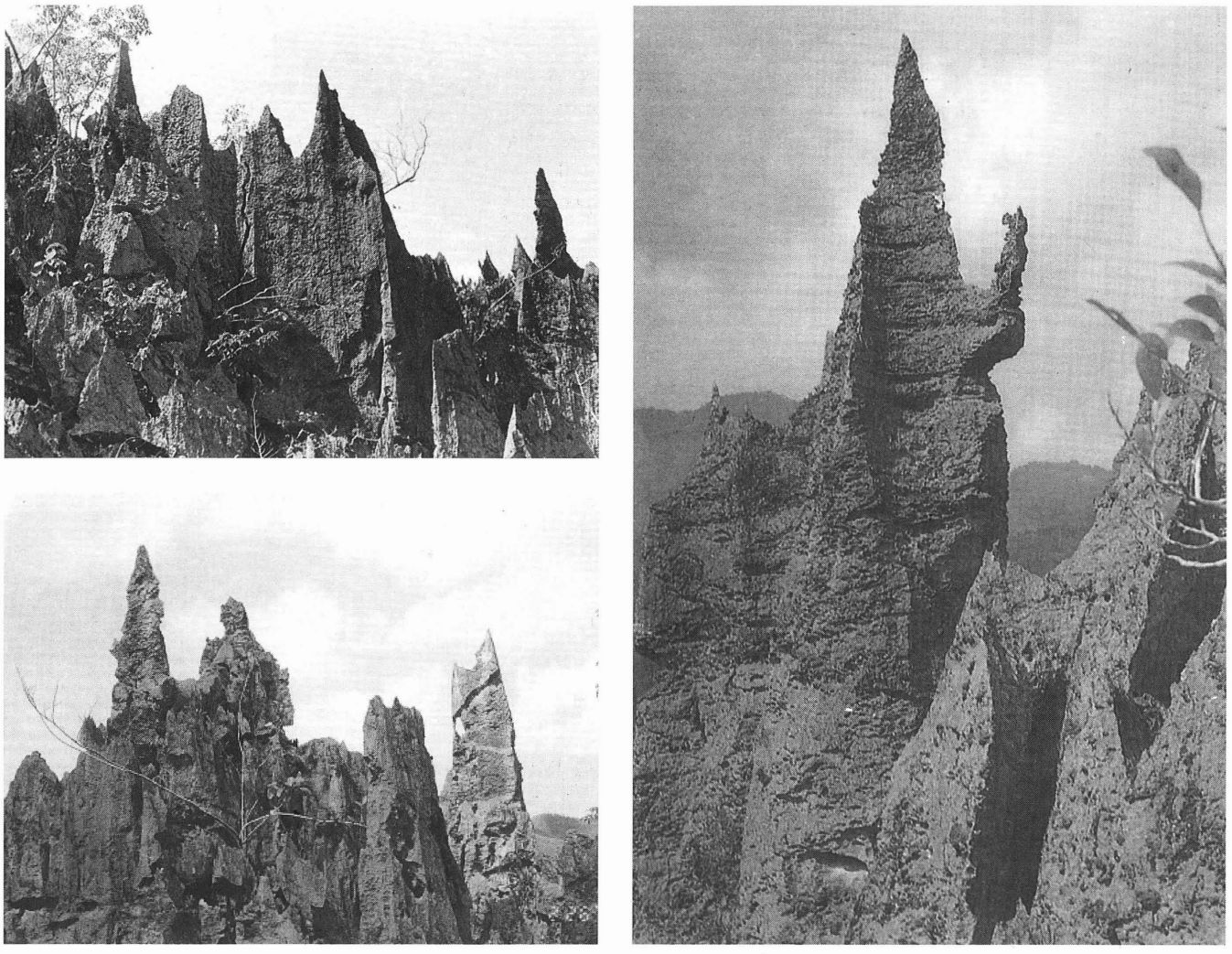

FIG. 2 - Pinnacle Karst features in Xianan, Hainan Province.

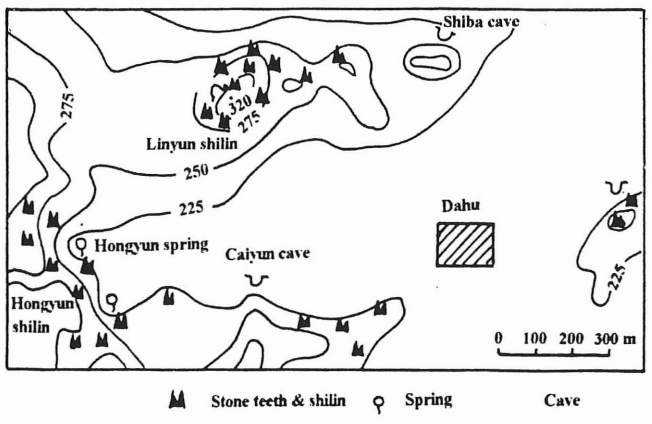

FIG. 3 - The Linyun shilin in Yongan, Fujian Province, China (after Wang Xueyu, 1997).

Caves are well developed in the area. Shiba Caves (eighteen caves) have developed in lower Permian limestone. They form a vertical cave system with several branches. Red soil from the surface has been deposited in the caves and the stalactites, stalagmites and flowstone have been strongly weathered and are polluted. The speleothems have acquired a black veneer from being touched by visitors. Many stalactites have been broken by shock waves from blasting in the nearby limestone quarry. The bedrock in the caves has dissolved to form hanging stone teeth and on an intermediate level, clay and gravel have became a hanging plate around a stone column when water erosion removed the surrounding sediments. The bottom of Shiba Caves system is blocked by gravels and soil.

The Fuqi shilin is located in the Qiandaohu (Lake with Thousands of Islands) National Park of China in Chunan

FIG. 4 - Linyun shilin landscape,Yongan, Fujian province, China.

County, Zhejiang Province. It is situated at N 29°30' and is the most northern example of shilin in China. The Fuqi shilin area has subtropical monsoon climate (Wang Zhongren, 1986). The annual average temperature is 17°C, with a large range, for example,the temperature reached 41.8°C (August 8, 1961) and dropped to –7.6°C (February 6, 1969). The annual average precipitation is 1,838 mm. There are 155 rainy days a year, with the rain falling predominantly from April to September. The yearly mean relative humidity gets as high as 76%. The Fuqi shilin developed in a 5 km^2 of pure, thick Carboniferous limestone. The limestone is cut by NE and NW fissures to form a maze. The Camal Corridor, striking NW, is 96 m long, 10.5 m deep and 0.8 m wide and the Drunk Corridor is 23.5 m long, 10.12 m deep and 1.46 m wide. The stone teeth and columns are covered and the fissures and connecting holes are filled with red soil. The evidence suggests that the shilin features have developed by sub-soil erosion or by soil water dissolution since the Quaternary. The height of the stone columns varies from 5 m to 20 m, with some more than 20 m, but most are in the range of 10-20 m. The sharp karren has formed on the tops of stone teeth and columns (fig. 5) as a result of rainwater dissolution.

LUNAN SHILIN KARST LANDSCAPE

The shilin karst landscape is well developed in Lunan County, Yunnan Province. It occupies 400 km^2, of which 350 km^2 have been protected within the Lunan Shilin National Parks. The shilin area belongs to the southern subtropical monsoon and plateau climatic zone with an annual average temperature of 16.3°C, neither hot in the summer nor cold in winter. The mean annual precipitation is 936.5 mm, of which 70-80% falls from June to October. The shilin landscape developed in the Lunan Syncline of Lower Permian limestone dipping about 10° or less. Joints N20-50°W and N40-60°E have dips greater than 70°. The composition of the limestones are shown in table 1.

TABLE 1 - Lithology and chemical composition of carbonate rocks in the Lunan shilin

ages	lithology	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	CO_2
P_{1q}^1	limestone	0.23	0.13	0.01	55.32	0.04	0.00	0.01	43.13
P_{1q}^2	lime-dolomite	0.06	0.21	0.00	31.21	21.10	0.00	0.14	46.69
P_{1q}^3	fine lime-dolomite	0.17	0.21	0.00	31.24	20.45	0.08	0.11	46.79
P_{1q}^t	fine lime-dolomite	0.17	0.42	0.08	31.49	20.65	0.04	0.11	46.55
P_{1m}^b	mid & fine dolomite	0.29	0.33	0.00	31.95	20.60	0.06	0.11	46.54
P_{1m}	bio-debris limestone	0.29	0.05	0.00	56.12	0.05	0.08	0.18	43.42
P_{1m}^t	bio & fine limestone	0.04	0.06	0.03	55.33	0.08	0.03	0.18	43.22
P_{1m}	crystal bio-limestone	0.46	0.11	0.16	55.61	0.16	0.16	0.18	42.88
P_{1m}	crystal bio-limestone	0.37	0.11	0.00	55.45	0.16	0.16	0.16	42.94

Stone teeth and columns develop on the top and slope of karst hills and in depressions or dry valleys. The main, magnificent shilin landscape evolved in depressions. In the

FIG. 5 - Fuqi shilin landscape in Chunan, Zhejiang Province, China.

Shilin – Bimoutan area, basalt and tuff were laid on the hills covering and roasting the stone teeth and columns (fig. 6). The shilin evolution continued below the basalt and tuff cover. Near Qingshuitang, Tertiary conglomerate filled the fissures and covered the stone teeth and columns (fig. 7). Stone teeth, columns with through holes, horizontal solution troughs and chairs etc. evolved below this red soil cover. Finally in both areas, soil erosion exposed the stone columns and teeth, which then were solution modified by rainwater.

The stone teeth in the Shilin area take the form of teeth, pillars, and many other irregular shapes. The stone columns have many shapes which with a little imagination resmble, for example, towers, columns, rockets, mushrooms, and swords.

Under the shilin landscape are the caves White Cloud Cave, Ziyun Cave, Jibailong Cave and others. Micro-speleothems, hanging pipes, helictites, small stalactites and stalagmites are found in Jibailong cave. White Cloud Cave is just 10-20 m below the shilin ground surface, and stalactites, stalagmites, columns and solution troughs are found on the cave walls, and solution holes and karren on the cave ceiling. Underground rivers and lakes are found in the Shilin indicating that an underground drainage system is well developed below its surface. For example, the water supply source of the Shilin Hotel is from the underground drainage system.

Helongtan Spring discharges water at a velocity greater than 0.5 m^3/s from the underground drainage system.

ENVIRONMENT OF PINNACLE AND SHILIN KARST LANDSCAPE DEVELOPMENT

The Xianan pinnacle karst has not been systematically studied, however, the pinnacle karst is still covered by tropical rain forest. The high temperature and rainfall mean that limestone is still being dissolved to form a sharp land-

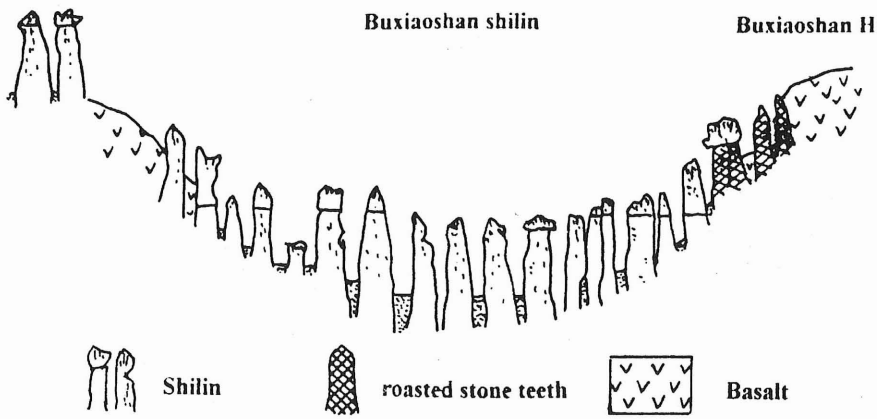

FIG. 6 - Relation of shilin landscape with basalt in Buxiaoshan area, Lunan.

scape containing deep solution shafts with multi-sharp boundaries. The shafts generally are not filled with soil or sediment and link to the underground solution passages such as those found in Xiaoqilong Cave. Very little sediment has been deposited in Xiaoqilong cave. Many indicators show that the Xianan pinnacle karst landscape has been developing in a tropical humid environment and rain forest ecological system since the Quaternary.

The Linyun shilin is located in the subtropical monsoon climatic zone and in a rich ecological environment. The red soil covering the stone teeth is an indicator that the stone teeth developed in a warm, humid environment. Wang Xueyu (1997) studied the origin of Linyun shilin using analysis of quartz sand surfaces. She identified a period of hot, humid climatic conditions, when the Carboniferous and Permian limestones would have been powerfully corroded. During this period rain water would have dissolved the limestone along the fractures and joints, causing limestone blocks to be segemented into stone teeth and stone columns. The residuals produced by this weathering

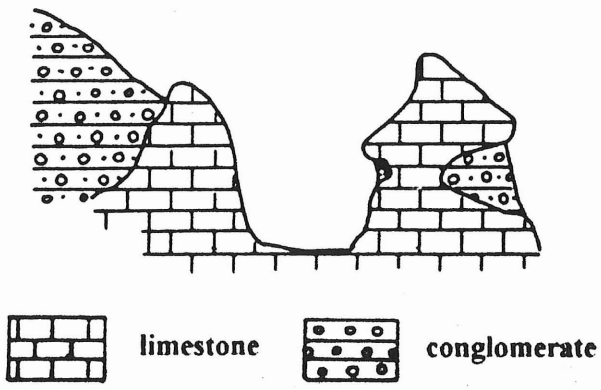

FIG. 7 - Tertiary conglomerate covered on stone teeth near Qingshuitang, Lunan.

accumulated on the site and covered the stone teeth. Subsoil erosion enlarged and deepened the fractures to form stone columns. The exposed stone columns were then reshaped by rain water, resulting in excellent karren on the tops of the columns and limestone blocks. The quartz sand surfaces studies endorsed that the Linyun shilin has developed since the Quaternary.

The Lunan shilin has been in existence for a much longer time. After the lower Permian limestone was deposited, the earth crust was uplifted to be out of water and denudation commenced. The area was then heavily forested and coal was formed near the Shilin area indicating a very wet and warm climate. Stone teeth, stone columns and depressions would have commenced developing. Then volcanoes erupted and covered the karstic surface. Basalt and tuff also filled in the gaps between the stone teeth and columns. In the Mesozoic, the climate was warm and humid and the basalt and tuff were removed by erosion in some areas, and the exposed stone columns and teeth continued developing. At the end of Mesozoic, the Himalayan Tectonic Movement caused the Yunnan Plateau to be uplifted, and reactivating old faults, and forming a faulted basin. In which a great depth of sediment was deposited during the Tertiary. More than 500 m of red sediments were deposited in the Lunan Basin in this hot, humid environment. In Qingshuitan and the western region of the Shilin, Tertiary conglomerate and sediment covered and filled in the shilin landscape. In the Quaternary, the shilin was revealed rapidly in the monsoon climate. The red sediments and Quaternary soil were removed to expose the covered stone columns and which then could be reshaped by rainwater.

The Fuqi shilin in Zhejiang Province is also covered by red soil showing that the landscape commenced developing in a similar warm and humid environment of the tropical /subtropical climate to the other Chinese areas of shilin.

CONCLUSIONS

Shilin landscape develops in warm and humid climatic environments. Initial sub-soil dissolution of the bedrock is the main factor in development of shilin landscapes. The modification of the landscape to produce pinnacles is the result of solution by rainwater in the modern warm and humid climate. The Xianan pinnacle karst is very similar to the pinnacle karst in Gunung Api, Mulu, Sarawak, Malaysia (Waltham, 1997). In the broadest sense, shilin landscape is a special kind of pinnacle karst.

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