A comparison of the South China karst World Heritage nomination with similar areas under the Earth's history criterion

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中国南方喀斯特世界遗产提名地与相似地区关于地球历史标准的对比研究

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Abstract: Any site to be listed as a world heritage should be of outstanding universal value. The "South China Karst" is now in application for world natural heritage. The nominated property (Phase 1) comprises three internationally acclaimed karst areas in Yunnan, Guizhou and Chongqing in south China (Table 1). The problems that whether the South China Karst is of outstanding universal value and how it is characterised are urgent to be solved. The paper have the South China Karst compared with similar sites both at the national and international levels, both on the world heritage list and not. Comparative analysis of the South China Karst with the similar karst areas in the world under the world natural heritage criterion (viii) (earth's history) have been made from the point of view of geology, landforms and their evolutions. Uniqueness of the South China Karst is discovered and come to the conclusions that it can be well satisfied the criterion (viii).

Keywords: The South China Karst, Comparative analysis, Earth's history criterion

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摘要:任何地点要想成为世界遗产都必须具有突出全球价值。"中国南方喀斯特"正在申报世界自然遗产。其第一批申报地由中国南方的云南、贵州、重庆的三个具有世界典型性的著名喀斯特地组成(表1)。"中国南方喀斯特"是否具有突出全球价值、其价值如何体现等问题都亟待解决。本文将中国南方喀斯特与相似地区(既包括国家范围内的也包括国际的, 既包括世界遗产地也包括非世界遗产地)进行对比, 着重按照世界遗产第八条评定标准(地球历史), 从地质、地貌及其演化等角度进行对比分析。发掘"中国南方喀斯特"的独特性, 并得出"中国南方喀斯特"充分达到世界遗产第八条评定标准的结论。

关键词:"中国南方喀斯特", 对比分析, 地球历史标准

1. Introduction

China has more than 1,250,000km² of carbonate rock outcrop (China karst research group, 1979) that occupies 13% of the total country. Thus it has one of the highest proportions of karst in the world. The South China Karst area, covering nearly 500,000km², lies mainly in Yunnan, Guizhou and Guangxi, but extends into parts of Chongqing, Sichuan, Hunan, Hubei and Guangdong. It contains an outstanding series of karst landforms - from tropical to subtropical - plains, hills, mountains and plateaux. *The South China Karst* is the title of this serial world heritage nomination by the Chinese government. It is being serially nominated for world heritage listing because, although not contiguous, the nominated areas are located in the same geological-geomorphological region, unified by their karst topography, and because the nominated areas incorporate a range of features within a single geographical region (karst region of south China). Each of them represents a typical karst landform and its on-going process, thus are irreplaceable parts of the entire nominated property. It covers a total area of 146,016ha; with the core zone and buffer zone separately 47,588ha and 98,428ha

Pursuant to the Operational Guidelines (Paragraph 132), for a nominated property, "A comparative analysis of the property in relation to similar properties, whether or not on the World Heritage List, both at the national and international levels, shall also be provided." All sites of the serially nominated South China Karst (first phase) are proposed to meet the criterion N(viii) – in that they are outstanding examples representing major stages in the earth's history including the record of life, significant ongoing processes in the development of landforms and significant geomorphic and physiographic features; so the comparative analysis of the South China Karst with the similar sites in the world under the criterion (viii) is specially important.

Table 1 Geographical coordinates and areas of the South China Karst (Phase 1)

Nominated Sites	Coordinate (Central)	Region (County and Province/City)	Area (ha)
Shilin Karst	N 24° 47' 30" E 103° 16' 30"	Shilin Yi Nationality Autonomous County, Kunming City, Yunnan Province	Area of nominated sites: 12,070 Buffer zone: 22,930 Total: 35,000
Cone Karst	N 25° 13' 15" E 107° 58' 30"	Libo County, Southern Guizhou Buyi and Miao Nationalities Autonomous Prefecture, Guizhou Province	Area of nominated sites: 29,518 Buffer zone: 43,498 Total: 73,016
Gorge Karst	N 29° 13' 48" E 107° 54' 12"	Wulong County, Chongqing City	Area of nominated sites: 6,000 Buffer zone: 32,000 Total: 38,000

2. Physical Geography

2.1 Terrain

The South China Karst is situated in the second and third Geographical Altitude Zones (GAZ) of China, extending 1,380km from west to east and 1,010km from north to south. The Yunnan-Guizhou Plateau is located in the second GAZ with an altitude ranges from 2,000m to 1,500m in the southeast. The plateau has been deeply incised by rivers as much as a 1,000m. Here the relief amongst the karst landforms ranges from 100m to 300m. The terrain of Shilin Karst Site is high in the east and north, low in the west and south, rising from 1,720m to 2,203m. Libo Karst Site is high in the west and low in the east, with a mean altitude 747m. Wulong Karst Site slopes down to the Wujiang R. from south to north.

2.2 Climate

The South China Karst is in three climate zones: subtropical warm-temperate, humid-

temperate and humid-monsoon. The southeast monsoon from the Pacific Ocean, the southwest monsoon from the Indian Ocean and the cold airflow from the Tibetan Plateau combine to generate a large climatic gradient. The mean annual maximum temperatures across the region range between 14°C and 26°C, the mean annual rainfall ranges from 1,100mm to 2,300mm, and the mean annual evaporation ranges from 1,000mm to 1,800mm. The wet season is between April and September and contributes between 72% and 86% of the annual total.

2.3 Regional Geology

The South China Karst is on the carbonate rocks of the Yangtze Massif. The stratum outcrops are of the Sinian, Cambrian, Ordovician, Devonian, Carboniferous, Permian and Triassic periods. Limestones, dolomites and dolomitic limestones are the main rock types with some mudstones and shales. South China was subjected to a number of ocean invasions before the Mesozoic in which the carbonate strata were laid down. In the late stage of Triassic, these were uplifted, folded and faulted by tectonic activity during the Indo-China, Yanshan and Himalayan Movements. The earliest carbonate sediments are the Dengying Formation of Sinian and then more carbonates were widely deposited in the Palaeozoic, especially during the Devonian, Carboniferous, Permian and Triassic periods. Resulting in a great depth of carbonate rocks (up to 10,000m in Guizhou and Guangxi) that are both folded and faulted; these strata are rich in fossils.

2.4 Karst Landforms

In the complex geological structure and favourable tropical-subtropical climate, a suit of karst landforms is well developed, such as cone karst, tower karst, stone forest karst, gorge karst and so on. The three sites of the South China Karst World Heritage Nomination (Phase 1) are respectively the represents of the landform sequences. It is regarded as the classical manifestation of a series of karst landscapes that have largely developed in a humid subtropical climate.

2.5 Hydrology

The South China Karst has two major catchments, which are the Yangtze River and the Pearl River separated by the mountains Nan, Miao and Wumeng. In the northwest, the Yangtze River has cut three deep gorges. Its tributaries, for example, the Wujiang, also cut deeply into the Yunnan–Guizhou plateau to form gorges. In south, the Pearl River rises in the Shilin of Yunnan its tributaries the Nanpanjiang, the Beipanjiang and the Hongshuihe are also deeply incised into the edge of the Yunnan-Guizhou plateau and Guangxi Basin to form gorges. The Shilin Site is positioned in the Nanpanjiang catchment on the upper reaches of the Pearl River; the Libo Karst Site is located on the middle reaches of the Dagouhe and the Hongshuihe in the Pearl River System. The rivers that influence karst development of Wulong Gorge Karst are the Furongjiang, Yangshuihe and Muzonghe of the Yangtze River.

3. Comparative Analysis under the World Natural Heritage Criterion (viii)

3.1 Geology

The geology of the South China Karst is very unique. Two distinct features set it apart.

First, the virtually uninterrupted sequences of massive crystalline limestone and dolomites outcropped in the South China Karst is very hard, huge, thick, pure and old, spanning from Cambrian to Triassic Period. The carbonate rocks can accumulate to the thickness of several kilometres, with rock type-diversity and global significance. This is ideal for the development of karst. But in the main karst areas of other countries, the karst regions mainly distribute on younger carbonate rocks characterised by less diagenesis and soft lithology. For example, in southern Australia, Mediterranean coastal areas, London basin, Central Europe and Eastern Europe, there are massive Mesozoic carbonate outcropped. Although there are the Mesozoic carbonate in central America (Cuba), the Tertiary carbonate is most broadly outcropped (Puerto Rico and Jamaica); in addition, the Neogene and Paleogene carbonate are main rocks in the Nullabor plain of southwestern Australia, Paris basin, several states of eastern America and Caribbean karst regions. The wonderful

pinnacle karst in Mt Kaijende, Assegai karst of Palawan, Tsingy de Bemaraha, Gunung Mulu National Park are much younger than that of Shilin Stone Forest of the South China Karst. The formations of Libo and Wulong sites are also older than many other similar sites. Therefore, the South China Karst earns the best geology conditions for the karst development and keeps a lot of old information of the earth's history.

Second, this area has undergone crust movements from the late stage of Triassic, especially Himalayan Movement from the late stage of Tertiary, a slow epeirogenic uplift during the Cenozoic Era, exposing broad plateaus of gently dipping to horizontal carbonate strata (Sweeting, 1978). Plentiful fissures and joints developed, which greatly increase secondary penetrability and create favourable flowing passage, consequently leading to hasten corrosion and erosion. The movements have intensively effected the development of the South China Karst and the wonderful pinnacle karst, cone karst and gorge karst formed and well developed. Take Wulong gorge karst for example, these old, massive and hard limestones were folded and fractured during the numerous tectonic uplifts that occurred at Wulong and raised the area as part of the Yangtze massive. The fracturing of limestone increased secondary permeability of the carbonate rocks allowing penetrating waters to establish underground routes that with time resulted in extensive cave systems and deep river gorges. The last uplift took place in the Quaternary and the limestones were uplifted over a 1000m. So, the Wulong site not only exhibits the gorge karst system, but also reflects the earth's history. Similar phenomenon can hardly found in other parts of the world that recorded the evolution history of the world.

3.2 Landforms

With the impacts of the very unique geological conditions and the ideal climate for the development of karst, a wide variety of typical landform types with global significance occurred in the South China Karst Nominated Property. Because of crust movement from the late stage of Triassic, especially Himalayan Movement from the late stage of Tertiary, these broad karst areas were tilted uplifted to form gigantic slope areas with the elevation difference of 2,000m, high in northwest and low in southeast, in which typical pinnacle karst, cone karst and gorge karst have been developing and form a entire tropical – subtropical karst landform succession. In addition, each type of the succession can be compared with the similar landscapes in the world to gain the uniqueness.

In the Shilin Stone Forest, the shape of Shilin stone forest is very typical and greatly varied. A stone pillar or column may take the shape of pillar, needle, tower, mushroom and so on. The pinnacles are decorated with karren as fins and flutes. There are emergent pillars called "stone teeth". Therefore, they have been the focus of substantial research into stone forest development and are generally accepted to be among the most varied in the world. The Shilin Stone Forests display pinnacles of highly diverse morphology when with other major pinnacle karsts in the world which are dominated by one main shape.

The cone karst of the Libo sites also is better developed with more typical cones in many diverse environments than those of Jamaica, Cuba or other areas. The height of cones in Libo varies from 100 to 300m, the slope ranges from 45° to 47° and cone symmetry is outstanding. Whereas, the majority of cones in other areas are mainly hemispherical, with slopes about 30° and heights are less than 100m. Specific examples are the cone karsts of Gunung Sewu of Java and the Arecibo-Manati region of Puerto Rico. In the Cockpit Country of Jamaica, the slopes are 20-30° (Sweeting, 1989) and the height of the cones is even smaller. The height differential between the Libo cones and those of the world is a result of the greater tectonic uplift that has taken place at Libo. The cone karst is the dominant landform at Libo, but in many sites with similar conditions and in the subtropics cones are mixed with towers in varying proportions. Besides, the sites contain many generations of cones in the following karst assemblages fengcong-depression, fengcong-valley and fengcong-gorge, providing supporting evidence for the geo-history of the area, evidence that is often not available in other karst areas in the world.

In the Wulong area, the Yangshui River drops 1,415m over a distance of 26km, producing the steep gradient required to incise the limestone

plateau and form a gorge. Its tributary rivers have also incised the karst. Thus in the nominated site, there are many canyons and gorges. These illustrate that the gorges form from the combination of processes, they are mechanical erosion, chemical solution and the opening of cave passages by collapse of the bedrock.

In addition to the outstanding examples of Shilin Karst in Yunnan, Cone Karst in Guizhou and Gorge Karst in Chongqing, a wide variety of surface and subsurface karst landforms occur in the nominated sites including fengcong, fenglin, karst hills, stone teeth, depressions, dolines, natural bridges, multi-level caves and plentiful speleothems.

In a word, the most typical tropical – subtropical karst landforms and significant geomorphic and physiographic features have been exhibited in the South China karst. Most other sites just include one main karst features. It is difficult to find another place in the world that shares such a diversified and classic karst landform succession in such a not large continuous area.

3.3 Evolutions

Compared with other celebrated karsts of the world, the evolution and morphogenetics of each site of the South China karst are very complex, very long and a lot of information has been keeping, which makes the South China karst the model site for the researching of tropical – subtropical karst landform evolution.

The Shilin Stone Forest has a long and multi-phased evolution, which has been influenced strongly affected by the basalt and basalt tuff lying on the thick and pure limestone and by the Eocene red sediments. These covering rocks have allowed the subjacent karst development. This has not been the case in other pinnacle karsts. Under a humid and hot tropical environment, denudation and planation have taken place (Budel, 1977). The pure and massive carbonate rocks of lower Permian were corroded beneath Eocene "red beds" to develop rounded forms. After the late Neogene, particularly in mid Pleistocene, the area was uplifted and formed the Yunnan Plateau 1,700 to 2,000m above sea level. At present, the stone forests are being exhumed. The first phase of stone forest evolution was as early the early Permian and the last, the fourth phase, still in proceeding (Liang Yongning, 2000). The Madagascar, Malaysian and Papua New Guinea pinnacles have a single-phase evolution. The evolution of Madagascar karst is very much younger and more simple than Shilin Stone Forest; the limestones are younger (Jurassic to Miocene), the modern morphology developed during the Pliocene and Pleistocene, and the geological structures are more simple (faulted monoclinal relief). The Mulu pinnacles in Malaysia and the Mt Kaijende pinnacle arête karst in Papua New Guinea have developed over the last few million years, whereas the Shilin Stone Forests have a multi-phase evolution spanning some 270 million years. The Shilin Stone Forests are therefore of considerably greater geomorphological and geological interest (Ford, Salomon and Williams, 1997).

The evolution of Libo cone karst is very valuable in that two different evolution models can be found in a very short area: the west and east banks Zhangjiang R. In the west bank of Zhangjiang, trending eastwards from the plateau around Mawei, the cone karst has undergone rejuvenation from fenglin-valley to fengcong-valley to fengcong-depression to fengcong-gorge, with the linear distance and landform elevation difference are approximately 40km and 720m respectively. However, cone karst evolution on the eastern bank of the Zhangjiang is different that it is in a normal sequence: fengcong depressions to fengcong valleys. Caves are found at four levels in the cones, testimony to cone karst evolution and change since the Neogene. There are violet-red travertine and grit deposits in the highest caves, which are the peneplain sediments from the late stage of the Pliocene. It is not easy to find such different evolution models in the world.

The evolution of Wulong karst shows how the gorge karsts form under the interactions among caves, rivers, natural bridges and giant dolines (tiankengs). The Tianlong, Qinglong and Heilong Bridges together with the Qinglong Tiankeng and Shenying Tiankeng and the associated caves illustrate how a deeply incised large river can form a series of natural karst features. They together compose a unique karst gorge system. The river first forms a cave by mechanical erosion and chemical corrosion,

then collapse processes form large cave chambers, which may evolve into tiankengs. Wall retreat of these giant dolines further opens the cave into a gorge in which small remnants of the cave roof remain as bridges. The final stage will be the collapse of the bridges and only a gorge or canyon remains. It is extremely rare to see all these evolution stages of a gorge karst in one area.

In summary, the South China Karst exhibits many paleokarst features and very complex evolutions from last stages of the Sinian, Silurian, Permian, Triassic (the late stage of Indo-China Movement), Mesozoic and Paleocene. Each of these periods of karstification provides evidence as to the evolution of the earth's history.

4. Conclusions

Compared with the similar sites of the world under the criterion (viii) of earth's history, the South China Karst nominated property is unique at least in the following aspects.

- The South China Karst has a distinctive character, which arises from both its geological and climatic history. It spans almost all eras of geological history and so many areas are very ancient. The limestone primarily comprises early hard and compact rocks of low porosity. While some areas remain virtually as they were first deposited, others have been subject to extensive tectonic change. Few areas have similar physical characters in the same latitudes.
- The South China Karst demonstrates richest karst landform diversity, containing classic pinnacle karst, cone karst and gorge karst. Their geomorphological morphogenetics, the development series from the watershed and paleo planation surface to valley, plain and modern gorge are unique. It is difficult to find another place in the world that shares such a diversified and classic karst landform succession in such a not large continuous area.
- The South China Karst comprehensively reflects a remarkable complex evolution of karst landscape features with well-preserved historical evidence. Similarly, the structural integrity of the limestone provides for large and relatively stable caves and other subsurface forms. Thus, many features of the karst only occur in China and are not truly comparable with landforms of somewhat similar superficial appearance in other countries.

To sum up, the Stone Forest in Yunnan is obviously different from the pinnacle karst of tropical islands. Its development is a result of a combination of fissure and both sub-aerial and sub-soil corrosion; the cone karst in Guizhou is a combination of both rejuvenation development, a renewal of features on the older karst geomorphology and a normal evolution of the most typical cone karst. The karst landscapes in the nominated sites of Wulong are dominated by a gorge karst system as the result of tectonic uplifts from the Quarternary. The three sites jointly display on-going geological processes and reflect karst development and evolutionary processes under different geological conditions. The South China Karst demonstrates the unique geological history, evolutionary processes and on-going karst geological processes at different locations, development stages, types and successions. In view of its extremely richest array of karst features and their on-going complex evolution processes, the South China Karst (Phase 1) Nominated Property provides exceptional "textbook" examples in this field unequalled by continental sites elsewhere and it can be well satisfied the criterion (viii).

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