Shilin: The Formation of Stone Forests in Various Rock Types (Lunan, Yunnan, China)

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Abstract: Shilin is among the most interesting form of stone forest to occur in karst landscapes. They develop from karren subsoil, and their shapes, entire forests or just individual pillars and their rock relief, depend on the conditions under which they were formed, their location in the karst landscape, and above all on the characteristics of the rock: its composition, stratification, and fissuring. Because of the exceptional characteristics of this karst phenomenon in China, we propose that the term "shilin" be used in the professional literature for this type of stone forest.

Key words: Shilin, karst surface development, rock relief, Lunan, Yunnan

1 Introduction

Stone forests are unique karst surface landforms (Fig. 1). The Lunan stone forests in southern Yunnan Province, SW China developed from underground karren. Where this type of surface is highly developed in China, it is defined as a "shilin". The extensive stone forests composed of many several-meter high pillars (Fig. 2) are an international tourist attraction, and to karstologists they offer a unique insight into the formation of karst landscapes.

The development of stone forests has been presented many times (Yuan, 1991; Sweeting, 1995; Ford et al., 1996, 1997; Song and Wang, 1997; Frančišković-Bilinski et al., 2003; Song and Liang, *in press*), and the descriptions of their forms even more often (Chen et al., 1983; Song, 1986; Hantoon, 1997; Chen et al., 1998; Maire et al., 1991; Song and Liu, 1992; Song and Li, 1997; Yuan, 1997; Yu and Yang, 1997; Zhang et al., 1997a and b; Knez and Slabe, 2001a, b, 2002; Šebela et al., 2004). Increasing emphasis has also been placed on the study of anthropogenic influences on karst landscape and on its protection (Kranjc and Liu, 2001). The development of caves under stone forests and its influence on the formation has also been examined (Šebela et al., 2001). This article compiles our current knowledge about the formation of stone forests and their rock relief, which are the result of the way the rock was formed involving characteristic processes on various carbonate rocks.

The chapter covering the close interdependence of stratification, fissuring, and composition of the bedrock with various processes in diverse conditions in the formation of the karst landscape is the core of this article and is illustrated by the accompanying drawing (Fig. 2). The prevailing process of carbonate rocks formation is their dissolution-corrosion in different conditions and by different factors. During the formation of stone forests the most important factor is dissolution of rock below the sediment and soil and denudation of rock due to rainwater, especially below vegetation. The most effective factor is the first example as organic substances in the soil with increased rate of organic carbon (Slabe 1995; Urushibara-Yoshino and Miotke, 1999) accelerate the dissolution of carbonate rocks.

Of course, our sketch (Fig. 2) is simplified, but it offers a general insight into the interweaving of the diversity of stone forest forms and the pillars that comprise them. The rock relief of the stone forests reveals subsoil processes, the hollowing of the rock by rainwater, and the later diverse transformation of subsoil rock forms by rainwater.

2 Materials and Methods

For ten years, karstologists from the Karst Research Institute of the Scientific Research Centre of the Slovenian Academy of Sciences and Arts have been systematically involved in research into the stone forests of Yunnan Province.

Using various methods we have collected numerous new findings about the formation and development of stone forests, karst landscape, epikarst areas, and the hollowing of the aquifer in the immediate proximity of the developing underground karren.

In the areas studied we conducted geomorphological,

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geological, structural, and hydrogeological mapping and geodetic surveying. In the laboratory in Postojna, SW Slovenia, we conducted experiments in the modeling of rock forms in plaster (Slabe, 2005).

In the field we selected rock samples and in the laboratory made microscopic preparations and conducted lithological, petrological, and stratigraphical studies. Important results of calcimetric analyses of carbonates were made. Many non-carbonate sediments were analyzed using standard paleomagnetic analysis. Dissolving of carbonate surfaces at several locations was tested with micrometric measuring.

3 Geology

The stone forest area consists of Lower Permian carbonates of the Qixia and Maokou formations. These are two of the most important basal formations from which numerous stone forests emerged in southern Yunnan Province of Lunan. Typical for the Qixia Formation are micrite limestone with intercalated dolomite and dolomitized limestone with intervening layers of schist. In the lower part of the Maokou Formation, limestone alternates with dolomite and dolomitized limestone. In the upper part there is a succession of limestone layers that in some places are thin and elsewhere are several meters thick, as well as solid limestone that contains large, several-decimeter chert nodules in particular horizons. The main lithologic properties of the Maokou Formation are roughly similar to those of the Qixia Formation, except that in Maokou carbonates we do not find the major influence of a late diagenetic dolomitization and in some places there is a considerable secondary porosity. However, both show a strong diagenetic alteration of the basic rock, which is undoubtedly also a consequence of intensive volcanic (basalt lava) activity during the transition from the Paleozoic to the Mesozoic eras. The rock contains an extremely high percentage of carbonate.

In the area studied we find considerable variations in thickness, porosity, and degree and type of dolomitization, in the components of inclusions, and in the color of individual layers, which are reflected in the formation of the stone forests (Knez, 1998).

Macroscopically most noticeable in the geological profiles is the different thicknesses of layers, which vary from ten centimeters to many meters, and, according to some data, even more than thirty meters (Song, 1986). In the stone forests we encounter rock sequences composed of several meter-thick homogeneous and compact layers where karstification is advancing considerably faster on the tops, along bedding planes and individual fissures, and below the surface, as well as sequences of thin-layered (10 cm and more) limestone where intensive karstification is already accelerating along numerous lithologic junctions. In the geological profiles there is also alternation of thickly and thinly stratified carbonate. Where the layers are thinner, the pillars can be much thinner due to more rapid corrosion.

In some places thicker segments of very porous layers are encountered where the intercrystal porosity generally exceeds 20%. Typically these are dolosparite and dolomicrosparite grainstone types. Diameters of light brown and in some places extremely pure and almost completely transparent dolomite grains reach one millimeter while their average diameter is one third of a millimeter. In contrast to the homogeneous and compact rock, a segment of the porous layers does not karstify merely along the lithotectonic junctions but across the whole profile in accordance with the stage of porosity. The rate of karstification of such rock is substantially greater and additionally accelerated locally below the surface.

Late diagenetic dolomitization is also typical of some layers. Where increased porosity and dolomitization appear in the same layers, more intensive karstification is found. A special example is the dolomitization of only individual smaller areas such that otherwise-homogeneous, compact, and impermeable rock becomes freckled. Dolomitized limestone is therefore less influenced by karstification than pure thickly stratified limestone. To a lesser degree, we see that dolomite fields, usually with a diameter of a few centimeters, protrude from the rock.

In the profiles layers with inclusions more resistant to karstification protrude. One example is a chert that is the result of allochemical early diagenetic processes. Less soluble inclusions macroscopically influence only slower local karstification whereas microscopic corrosion is substantially more intensive at the junctions between the inclusions and limestone.

4 Formation of Stone Forests

More or less horizontal layers of rock of various thicknesses and composition are criss-crossed by vertical fissures or cracks. Each of these features can influence the formation of a network of stone pillars in a forest, their size and shape, and consequently also the rock relief (Fig. 2). They interact in various combinations, fostering the vast diversity of stone forests. As a rule, however, one of the features of the rock or one of the factors of their formation is dominant:

influence of fissuring of rock on the shape of the forest and size of stone pillars;

influence of rock strata on the shape of stone pillars;

influence of rock composition on the shaping of stone pillars;

influence of subsoil factors on the shape of the stone forests.

Exposed subsoil karren is reshaped by rainwater. The

Fig. 1. Stone Forest as a unique landform on karst surface landscape.

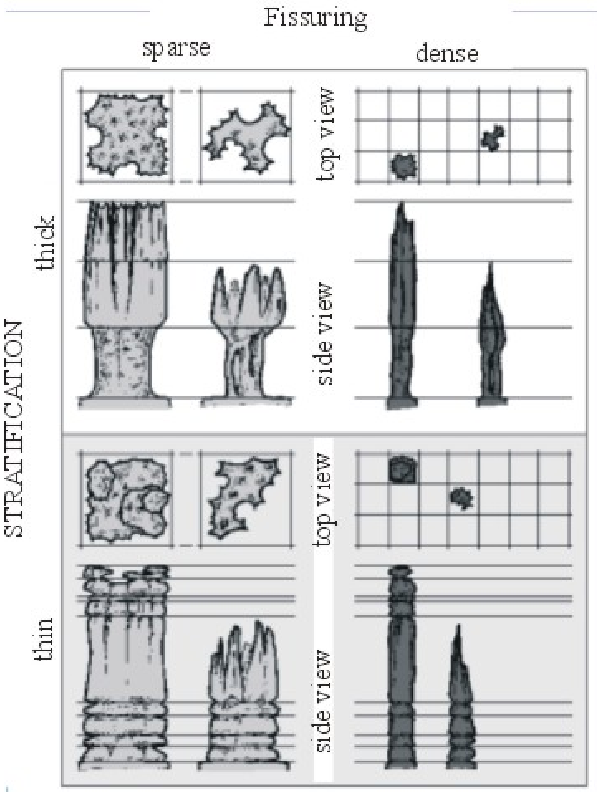

Fig. 2. Sketch to show typical shapes of pillars in the Lunan stone forests.

long-lasting development of stone forests allows the creation of large karst forms. Due to the development of caves beneath the forests and the erosion of alluvium and soil that previously covered the carbonate rock, exposure takes place faster than the dissolution of rock by rainwater.

4.1 Fissuring of rock and its influence on the shape of the forest and size of stone pillars

The networks of distribution of the pillars, that is, the ground plans of the stone forests, are congruent with the fracturing of the rock, in this case largely vertical, taking various shapes (Fig. 2). The pillars can be linked in rows

Fig. 3. Naigu Stone Forest.

Fig. 4. Pu Chao Chun Stone Forest with distinctive and in the upper part of rock pillars thin rock strata

between distinct fault areas, or close together, or the stone forest or parts of it can consist of individual wide or narrow pillars. Cracks between the pillars have thus been corroded to various widths ranging from a few dozen centimeters to ten meters or more. This diversity in the network of pillars can occur in the same forest, as for example in the Naigu Forest (Fig. 3, Knez and Slabe, 2001a), see *Example 1.*

As a rule, pillars with smaller cross sections occur with a dense network of fissures, provided that they are not diminished primarily by corrosion, and larger pillars occur with a sparser network. The latter in thickly-stratified rock, which can also be described as larger rock masses, have broader tops dissected into several points.

Example 1: Naigu Stone Forest

The Naigu Stone Forest (Fig. 3) lies 20 km east of the Major Stone Forest (of Lunan) and is an important tourist site. This stone forest is composed of larger rock masses and smaller pillars that stand together or individually. The unique form of the forest is defined primarily by the amount of fracturing and texture of the various beds of rock from which the stone forest formed at different levels. Joints and fissures that vertically crisscross the layers of rock dictate the dimensions of the pillars. The shape of the pillars, which are frequently undercut, and their rock relief clearly reflect the importance of subsoil formation and the reshaping by rainwater, which progresses slowly down the pillars.

The stone forest lies alongside two tectonically slightly elevated ridges. The joints that border the joint zone are extremely strong, and the intermediate joints, which run largely in a NW-SE direction, are several kilometers long and deep. The pillars formed on a package of Lower Permian carbonate rock of the Qixia Formation more than 100 m thick. The properties of the rock throughout the geological cross-section are very different, and from a morphogenic viewpoint, therefore, we have divided the beds into three groups from the bottom up: (a) layered micrite and nonporous limestone; (b) porous and heavily dolomitized limestone; and (c) massive and striped dolomitized limestone.

The pillars developed on different levels of the described rock beds and their shapes correspond to this. The most characteristic shape of the pillars is mushroom-like (Fig. 2), and there are distinct notches along the porous and heavily dolomitized beds. This is the consequence of faster underground corrosion and hollowing of the most porous part of the rock, whose surface disintegrates relatively quickly. The pillars whose tops are in porous and heavily dolomitized beds are narrower and mostly without characteristic or regular shapes dictated by the factors of their development. Stratified and nonporous limestone often forms wider bases of the pillars composed of porous and heavily dolomitized and massive and striped dolomitized limestone. The shape of subsoil rock teeth, pillars lower than 5 m (Song, 1986) as a rule does not reflect the different texture of the rock.

The most distinctive rock forms are termed subsoil and composed. Subsoil rock forms include large channels on the walls of pillars and channels on the broader tops. Composed forms include channels leading from the subsoil channels or subsoil cups found on the tops. The deepening of subsoil cups and water flowing along the channels caused the dissection of the tops of the pillars, particularly the larger ones, into points with funnel-like notches between them.

Subsoil rock forms, as a rule larger ones, developed on all types of rock in the Naigu Stone Forest. The rock influenced their shape, especially that of the smallest, which on dolomitized rock often have jagged edges. Flutes hollowed by rainwater are a less distinctive rock form at Naigu. Their occurrence and development is primarily influenced by the texture of the rock. Subsoil rock forms developed on the majority of beds of different rocks, but only a few are found on porous and heavily dolomitized beds. Here we find subsoil tubes. When these beds of rock are found at the tops of pillars, smaller rock forms hollowed by rainwater hardly occur. In places these are only rainwater pits or the rainwater shapes that larger subsoil rock forms. The rock relief therefore developed relative to the position of the beds in the pillars.

The gradual and diverse development of the stone forest, which is in turn connected with the development of the caves below them, is also confirmed by the traces of development in the Bayun cave below central part of Naigu shilin (Šebela et al., 2001). in its central part. From the cave sediments and the rock relief we can distinguish several periods of development in the epiphreatic part of the aquifer, then a rapid drop of underground water probably caused faster growth of the stone forest (Šebela et al., 2001).

4.2 Rock strata and their influence on the shape of stone pillars

The rock from which the stone forests developed consists of strata of different thicknesses and composition. This is reflected in the shape of the stone pillars, particularly in their cross sections, the shape of their tops, and their rock relief.

The shape of the pillars that develop on thick and uniformly composed rock strata shows hardly any influences but rather reflects a more or less uniform development from subsoil karren to stone forest. The central part of the Lunan stone forests is an example. Narrower pillars have pointed or blade-like tops and relatively flat or subsoil undercut walls. Wider stone pillars, however, often have broad tops dissected into many points with notches between them.

Longitudinal sections of pillars on thin rock strata (Pu Chao Chun), see *Example 2* (Fig. 4, Knez and Slabe, 2001b) are often jagged since they are dissected by wall notches occurring along the bedding planes, or their shapes reflect the uneven resistance of the different rock strata to the factors of their formation (Figs. 2, 4). Cross sections of the pillars are of various sizes and shapes (Fig. 2). Thinner strata disintegrate faster and therefore the pillar tops are relatively flat and have the typical Pu Chao Chun rock relief (Fig. 4). Where the strata are thinner, as a rule the pillars are narrow. Subsoil tubes occurring along bedding planes can develop into subsoil channels when they occur on the top of a stone pillar or they can be reshaped by rainwater.

Example 2: Pu Chao Chun Stone Forest

The Pu Chao Chun (Fig. 4, Knez and Slabe, 2006) is a smaller stone forest located 15 km S of the Major Stone Forest. Its rock pillars are located on a ridge, where their network is densest, and on the hill slope below. Its shape is defined primarily by the unique distribution of variously thick beds of rock, mostly thin in the upper parts, on which the stone forest developed at different levels. Joints and fissures that vertically crisscross the

Fig. 5. Subsoil channel at the edge of the pillar.

Fig. 6. Flutes and channels carved by rain.

rock beds dictated the dimensions and oblong form of the pillars. The shape of the pillars and the subsoil rock forms clearly reflect their subsoil formation and their transformation by rainwater slowly progressing down the pillars.

The rock changes little across the geological profile. Throughout, we trace mainly biomicrosparitic limestone with an almost one hundred-percent proportion of $CaCO_3$; limestone that in this profile shows similar sedimentation conditions and that, regardless of the thickness of the beds shows the same response to the influence of erosion and corrosional processes. The thickness of the beds has a decisive influence and clearly reflects the morphological appearance of the individual rock pillars.

In the upper part of the stone forest, the pillars are mostly individual and of smaller diameters, and the rock beds are the thinnest here. The lower parts of the pillars, which are formed on the thicker beds of rock, are stouter and stand closer together. Along the thinner beds there are distinct notches. Here, the beds disintegrated faster and the tops left beneath them are often flat, whereas if the superposed beds are thicker, the tops are sharp. In the lower part of the stone forest, where there are fewer rock pillars, the pillars formed on thick beds of rock and as a rule, therefore, are wider at the bottom narrowing toward the top.

All the types of subsoil rock forms that reveal the development of a stone forest are well developed. These include large subsoil channels and scallops, as well as channels and solution cups on the wider tops. The latter channels often developed from subsoil tubes along bedding planes, which were uncovered when the upper beds disintegrated. Subsoil notches developed where long-lasting layers of soil surrounded the walls. A distinct proportion of the rock relief consists of composed rock forms. These are divided into those that occurred due to direct interaction of subsoil factors and rainwater and those whose unique shape is the consequence of transformation of subsoil forms by rainwater. The composed rock forms are channels that lead from subsoil channels (Fig. 5) and cups at the tops and hollows between the bedding planes of the rock (Fig. 4). Funnel-shaped mouths formed on the edges (Fig. 4). Exposed subsoil rock forms were transformed by rainwater, which hollowed flutes, channels (Fig. 6), and rain pits. Rain scallops formed by water trickling down the rough surface of the rock are found on vertical and overhanging walls. Solution pans most often occur on the bottoms of exposed subsoil rock forms.

4.3 Rock composition and its influence on the shaping of stone pillars

Rock composition, particularly if it is diverse, can decisively influence the shape of the stone pillars, as much in their longitudinal sections as in the size of the cross sections.

Porous strata are often perforated below the ground and disintegrate more rapidly on the surface as a result (e.g., at Naigu, Lao Hei Gin, Fig. 5, see *Example 3*). Pillars are most narrow at the level of porous strata, with tops most often of irregular shape and here break fastest. Above them occur forms typical of overhanging walls and below, gently sloping wall sections.

Rock strata with less soluble components usually protrude from the walls. If such rock beds are at the top of a pillar, the tops are broader than the lower parts and the pillars therefore acquire characteristic mushroom shapes (Figs. 2, 5). These are particularly distinct if the pillars occur on rock whose lower strata are relatively more soluble, porous, or disintegrate rapidly, as at Naigu.

Example 3: Lao Hei Gin Stone Forest

The Lao Hei Gin Stone Forest (Fig. 7; Knez and Slabe, 2006) lies 18 km N of the Major Stone Forest. Individual and clustered rock pillars and larger blocks of rock transformed by corrosion and erosion occupy about two square kilometers. Where the pillars are clustered, there are only cracks or fissures between them. The pillars developed on various levels of almost horizontal rock beds, and their shapes correspond to this (Figs. 2, 7). The larger clusters of stone pillars are composed of several dozen pillars. In one relatively large area of the stone forest, there are only individual pillars and rock "teeth" (Fig. 8). Some pillars have the shape of square towers and others of mushrooms (Figs. 2, 5). They are often composed of several blocks, the remains of rock beds between bedding planes and fissures. Individual pillars are either relatively large, wide, and high (up to 20 m) or low teeth (1–2 m) and wide (up to 10 m).

The original limestone in this stone forest is heavily diagenetically altered. Under the microscope, we can observe subhedral to euhedral grains of dolomite that form hipidiotopic to idiotopic structures. With the exception of the upper part, the rock pillars are roughly built of dolosparites and dolomicrosparites of the grainstone type.

Important differences in individual packages of layers are determined by the various degrees of secondary porosity and recrystallization, which are also reflected in the morphological appearance of the stone pillars. The lower parts of the pillars are composed of dolosparites to dolomicrosparites of the grainstone type in which secondary porosity is barely noticeable. The central part of the pillars is composed of secondary, very porous dolomites. On average, the crystals of dolomite are smaller and less pure than those in the lower package of layers. The upper parts the pillars are again composed of secondary almost nonporous limestone and dolomites. Only the tops are composed of recrystallized secondary nonporous limestone. The dolomite disintegrates mostly into grains.

The strongly secondary porous central parts of pillars below the ground as well as on the surface weather and disintegrate faster. As a rule, tall pillars therefore have a distinct mushroom shape because the nonporous beds are more durable and extensive (Fig. 7). In places, the upper parts of pillars no longer exist, and only low pillars, which formed in the lower nonporous rock and protrude from the ground like basalt, remain. The heavily porous rock in the central part of the pillars is often hollowed by subsoil tubes that were formed by trickling rainwater. The rare tops of pillars formed on such rock have irregular shapes in most cases (Fig. 7).

The rock relief is composed of all the characteristic groups of subsoil and composed rock forms, including those hollowed by rainwater. Texture of the various rock beds determines their features to a considerable extent.

The first complex of subsoil forms includes various subsoil channels that were formed by continuous water flow along the contact of the wall and the sediment that covered the rock filling cracks along the vertical fissures. The diameter of the largest channels reaches 3 meters. Tchannels dissect all four complexes of beds. On the tops of the tallest pillars, they were transformed by rainwater, while the porous middle beds weathered too quickly for the channels to remain for a long time. Thus the channels are mostly a characteristic of lower pillars and rock teeth. Subsoil scallops, which occur at relatively permeable contacts between the rock and sediments, are also preserved as a rule on the nonporous beds or on only recently uncovered heavily porous beds.

The wider tops of pillars and teeth are dissected by medium-sized and smaller subsoil channels and subsoil cups (Slabe, 1999), which developed under the soil that partially covered the rock, that is, due to the permeation of water through the soil and its flowing along the contact with the rock. The larger channels on the upper parts of pillars are composed rock forms. They occur due to the water flowing from subsoil channels on the wide tops of pillars or lead from funnel-shaped notches. At the bottoms of the latter there are or used to be subsoil cups. At the edges of the tops, therefore, there are larger or smaller funnel-shaped mouths most frequently reshaped by rainwater (Fig. 9). They are especially distinct on the non-porous beds, or when the top is in a limestone bed, they reach to lower-lying heavily porous beds. Their distribution and shape – relatively narrow and deep – are determined by the amount of fracture of the rock and the indentation of the rock circumference by the texture of the rock. Half-bells (Fig. 10) occur at the longer-lasting levels of soil and sediment surrounding the pillars (Slabe, 1998, 1999).

Rock forms hollowed by rainwater, especially smaller ones like flutes and rain pits, do not occur in the rock described above. The rock is coarsely rough, and only those rock forms whose size exceeds individual elements of texture and structure occur. The exception is the smaller, highest-lying part of the area where flutes occur on the tops of limestone teeth. The dissection of most of the tops is therefore determined by the texture and amount of fractures in the rock. A range of forms from subsoil cups distinctly dissected to rough solution pans occur, and only the bottoms of those that are covered by a thin layer of sediment and are overgrown remain flat and relatively smooth. On the upper part of steep walls, there are rough features similar to channels, which in most cases are very narrow and relatively deep, of angular shape with a diameter of one to ten centimeters and two to three meters long.

4.4 Subsoil factors and their influence on the shape of the stone forests

Subsoil factors created the pointed tops of the narrow subsoil teeth and the channels penetrating the broader teeth (Fig. 8) and caused the undercutting of pillars. At the level where sediment and soil surrounded the stone pillars for a long period, large notches or half-bells developed. Below the surface, pillars were most often hollowed out along bedding planes and in more porous rock strata. The narrowest stone pillars can also be subsoil hollowed. Subsoil factors working only on individual parts of the stone pillars, as in cases where the tops are covered with soil and vegetation, most distinctly dissect them vertically when water trickles through the soil and corrodes the rock or when the water flows from the soil down the pillars (Fig. 5). Rainwater sharpens the pillar tops, reshapes the traces of their original subsoil formation, and with time also carves unique shapes distinctly reflected in the rock relief (Fig. 10).

5 Experimental Modeling of Subsoil Formation of Stone Forest and Its Rock Relief in Plaster of Paris

Laboratory experiments using plaster of Paris to model karst rock feature formation, either those appearing in caves or on a karst surface, have proved to be useful (Slabe, 1995, 2005). Highly soluble gypsum, with a solubility at 20°C of 2,531 g/L (Klimchouk, 2000), gives an opportunity to observe in plaster and extrapolate how features change if they are exposed to various conditions and different factors such as water flow, water drainage through fine-grained sediments, water percolating through soil or trickling at the contact of sediment and plaster. The features in plaster are generally similar to those developing on other carbonate rocks, but due to its high solubility they occur faster and, as a rule, on a smaller scale. In general, such experiments help to disclose the way soluble rocks are shaped and so we attempted to verify the descriptions of various subsoil and epikarst rock features with experiments on the formation of subsoil karren (Slabe, 2005).

We sliced a plaster cube into small columns with six-centimeter square cross-sections and heights of 30 cm. The separated columns were placed tightly side-by-side in a large bucket and covered with soil. We tried to recreate the conditions dominating in the Lunan stone forests by drilling small holes in the bottom of the bucket and then filling it with a continuous supply of water to keep the surface five centimeters above the soil surface. Slowly, water started to penetrate the soil and then flowed through the holes in the bottom of the bucket. During the experiment, which with breaks lasted almost 400 hours, small subsidences appeared in the soil. Part of the soil was carried out of the bucket by the water and part of the soil filled spaces where dissolved plaster had been removed. Before the conclusion of the experiment, after a day or two of “dry period,” the water required one to two minutes to fill the cavities between the plaster and the soil and flow out of the bucket through the holes in the bottom.

The results of the experiments can be summed up as follows. The fissured block of plaster generated a subsoil stone forest with single rock pillars controlled by vertical fissures in the plaster and by water flowing vertically through the block of plaster, transporting sediments and dissolving plaster along them. Plaster quickly dissolved along the fissures; two thirds of it dissolved forming distinctive fissures between the pillars. Pointed upper parts of pillars are the effect of uniform vertical water flow through the soil. When karst surface is being denuded due to various interventions, similar subsoil features, stone teeth and stone forests occur.

In the model there are clearly visible traces of the various ways water percolates down, in the upper section through the vadose zone and in the lower part with traces of water flowing through the locally flooded section. Water percolates most uniformly in the plaster through the upper, most permeable layer of soil, but it also flows along the contact between the soil and the plaster, carrying grains of soil with it and depositing them on the plaster. Small recesses form characteristic epikarst rock features on rock. Subsoil scallops are found lower on the central section of columns where the contact between rock and soil is still quite permeable. For a sediment, we used soil that preserved a loose contact with the plaster. Subsoil scallops may be found on most vertical and overhanging walls of carbonate rocks; shaped subcutaneously, the scallops are being formed in a vadose zone by water percolation along the uniformly permeable contact between the rock and the sediment around.

In the lower section, a locally flooded zone developed where channels formed. Horizontal notches occur at the upper level of this zone. Such type of carbonate rock formation can be seen in the areas that are often flooded, either when the contact between rock and sediment is poorly permeable or rock is reached by underground water. Along the “bedding planes,” several stories-high networks of above-sediment anastomoses developed. Paragenetic formation of rock in locally flooded areas at the contact of rock and sediment is a frequent characteristic of cave ceilings and more or less horizontal bedding-planes and fissures or basal conglomerates are found in flysch. The origin of ceiling channels was explained by an exact experiment (Slabe, 1995).

In short, the experiments have augmented and in many

Fig. 7. Lao Hei Gin Stone Forest where rock composition decisively influenced the shape of the stone pillars.

Fig. 8. Subsoil channels on the top of a stone “tooth”. Height of tooth is 1 m.

Fig. 9. Reshaping of subsoil features (channels) by rainwater. Height of pillar is 15 m.

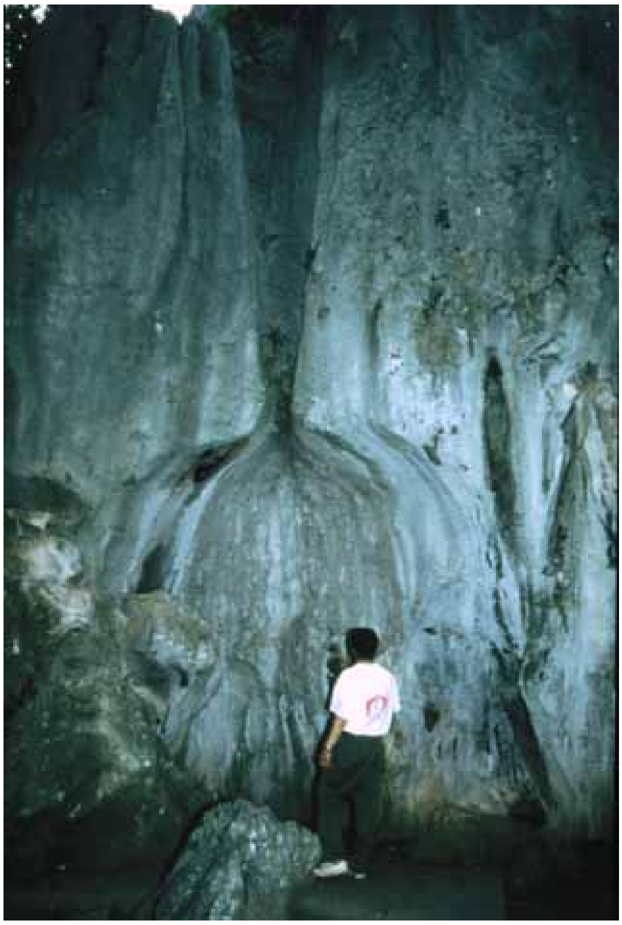

Fig. 10. Half-bell developed at the upper level of soil and sediment surrounding rock pillar.

ways also confirmed our previous knowledge about the formation of rock features (Slabe, 1998; 1999). The experiments proved to be useful this time also, because they confirm and widen the conclusions about the subsoil formation of soluble rock while, of course, exposing only part of the questions, and this is why they must go on.

6 Discussion

Numerous examples of stone forests that developed in almost identical conditions show that the diverse shape of the pillars is primarily a consequence of the properties of the rock, from the distribution and density of joints and fissures in the rock and its stratification to its composition.

However, we must also consider the significance of the effect on their shaping of subsoil factors and transformation by rainwater, that is, the course of their development at various periods.

The strata of the Lunan stone forests, which formed in Lower Permian carbonates are mostly horizontal or inclined at five to ten degrees. Due to vigorous tectonic action, the strata are fractured by numerous vertical and subvertical joints and fissures.

The diverse fracturing, stratification, and rock composition are reflected in the shapes of the stone forests and their stone pillars. In the same stone forest, developed from diversely composed rock, pillars may be of various but typical shapes, the consequence of their formation at different levels of the rock column.

The shape of stone pillars occurring on thicker and uniformly composed rock strata reflects primarily the development from subsoil karren into a stone forest, and any traces of subsoil factors are gradually reshaped by rainwater. Cross sections of stone pillars occurring on thin rock strata are often jagged, and their tops (even of thinner pillars), which as a rule are pointed, are often flat, the consequence of the rapid disintegration of thin strata. Porous rock strata are most often perforated below the ground and disintegrate faster on the surface; the pillars are then narrower and the tops have no characteristic shapes. More resistant rock strata can be seen protruding from the pillar cross section. The tops of narrower pillars are sharp, sharpened as much by subsoil factors as by rainwater; by contrast, broader tops are dissected by points and funnel-like cups.

The unique development of the stone forests is also reflected in their rock relief. Rainwater gradually reshapes the subsoil rock relief. The most distinct and particularly the largest rock forms are subsoil and composed rock forms. Subsoil rock forms include scallops, large channels, notches, half-bells, and subsoil channels and cups on broader tops. Composed rock forms include the channels that lead from the subsoil channels or subsoil cups and dissect pillar walls. Many pillars are undercut below the ground, while their tops have been reshaped by secondary subsoil rock forms and forms carved by rainwater. The rock relief of broader stone pillars is unique as well, particularly those with broader tops, either on thick rock strata where secondary subsoil forms occur or on tops that developed due to disintegration of thin rock strata when subsoil tubes occurring along bedding planes developed into subsoil forms or large channels that were reshaped by rainwater. Both forms indirectly influenced the shape of the pillar walls due to water flowing from them and carving channels. As a rule, smaller rock forms do not occur on dolomite rock, on very porous rock, or rock filled with larger inclusions.

The development of stone forests and their rate of growth in a particular period were also influenced by the position and development of karst caves below them, that is, by the manner that the water – and the sediment and soil with it – flows from the karst surface. Various periods can also be determined from the karst caves. In the Baiyun Cave below the Naigu Stone Forest we can identify periods characteristic of cave development in epiphreatic conditions when water flowed rapidly through the cave and deposited gravel; periods of the cave flooding and being filled with fine-grained sediment; followed by a period of rapid deepening of the central tunnel by a strong water current that swept away most of the sediment from the cave. This last event, which was a consequence of the rapid intermittent lowering of the water table below the stone forest, conversely also made possible its faster growth (Šebela et al., 2001).

7 Conclusions

Shilin as a type of stone forest emerged when carbonate rock previously covered with sediment and soil became exposed. Along with subsoil factors, rain, topographical position and karst perforation, the shape and size of stone forests were primarily determined by the rock itself. The forests developed in horizontal or gently sloping rock strata cleft by vertical joints and fissures. Diverse examples of stone forests that formed in almost identical conditions show that the shape of the pillars is mainly a consequence of the distribution and density of fissures in the rock, its stratification, and different rock strata composition. The rock forms on the pillars are divided into subsoil forms, composed rock forms, and forms shaped by rainwater. The composition of the rock enables their creation and influences their shape and distribution.

Acknowledgements

Over ten years our work in China has been supported by the Slovenian Ministry of Science and Technology, now the Ministry of Higher Education, Science, and Technology (Slovenian Research Agency), and the Chinese Ministry of Science and Technology. For many years we successfully competed as the first non-Chinese in the “Shilin Research Foundation” public tender. We thank our friend Liu Hong of the Yunnan Geographical Institute who has taken special care in the preparations for our annual visits to the Chinese karst. We are most grateful to all. The research is also a contribution to IGCP project 448 “World Correlation of Karst Ecosystems” (2000–2004) and its predecessor 379 (1995–1999).

Manuscript received Nov. 22, 2005
accepted April 27, 2006
edited by Xie Guanglian and Susan Turner

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