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THE LITHOLOGY, SHAPE AND ROCK RELIEF OF THE PILLARS IN THE PU CHAO CHUN STONE FOREST (LUNAN STONE FORESTS, SW CHINA)

KAMNINSKE IN OBLIKOVNE ZNAČILNOSTI TER SKALNI RELIEF STEBROV V PU CHAO CHUN KAMNITEM GOZDU (LUNANSKI KAMNITI GOZDOVI, JZ KITAJSKA)

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Martin Knez & Tadej Slabe: Kamninske in oblikovne značilnosti ter skalni relief stebrov v Pu Chao Chun kamnitem gozdu (Lunanski kamniti gozdovi, JZ Kitajska)

Lunanski kamniti gozdovi so se razvili iz podtalnih škrapelj. Oblika kamnitih stebrov in njihov skalni relief sta splet značilnosti različno debelih skladov kamnine, na katerih se na različnih nivojih razvijajo in sledi podtalnih dejavnikov ter deževnice.
Ključne besede: karbonatna kamnina - litologija, oblika kamnitih stebrov, skalni relief, lunanski kamniti gozdovi.

Abstract UDC: 551.435.8(510)

Martin Knez & Tadej Slabe: The lithology, shapes and rock relief of the pillars in the Pu Chao Chun stone forest (Lunan stone forests, SW China)

The Lunan stone forests developed from subterranean limestone karren. The shape of the rock pillars and their rock relief result from a combination of the characteristics of varyingly thick rock strata, on which they developed at various heights, and the effects of underground factors and precipitation.
Key words: carbonate rock - lithology, shape of the rock pillar, rock relief, Lunan stone forests.

INTRODUCTION

Pu Chao Chun is a minor stone forest (Fig. 1) 15 km south of the central Lunan stone forest. The rock pillars are situated on a ridge, where their configuration is the densest, and on the slope below it. The pillars in the upper part of the stone forest can be divided into two types: high and low. The latter are often lower than 5 m and could be called rock teeth were it not for their development - they are the remains of pillars and can be clearly distinguished from the real rock teeth, which are conical and protrude up from the earth. They are wide, rather than high, and they stand close to one another. Their tops are relatively flat and at an equal level. The higher pillars reach up to 10 m. They stand alone or in groups of two or three and their cross-sections are usually quadrangular and only slightly tapered at the top. Their rims are toothed, which is the result of the various cracks between the relatively thin rock strata. They are often broader in the direction of the ridge and distributed in parallel rows, which is a characteristic of this type of crushed rock zone. In the lower part of the stone forest the pillars are larger and fairly evenly conical.

The pillars are bare, due to the removal of vegetation from them, and at many locations the tops are missing. The local population collect the soil at the feet of the pillars.

The development of the rock pillars on the various rock beds indirectly determined the relief, which clearly indicates their evolution from underground limestone karren into a stone forest.

The basic characteristics of the Lunan stone forests were presented in the book *South China Karst* (1998). These are, however, diverse, largely as a result of the rock on which they developed. Here we explain these differences in more detail. We have already described the characteristics of the Naigu stone forest (Knez & Slabe 2001); here we add to this our discoveries concerning the particular shape of the Pu Chao Chun stone forest.

CHARACTERISTICS OF THE ROCK FROM WHICH THE STONE FOREST DEVELOPED

The Pu Chao Chun stone forest consists of lower Permian carbonates of the Maokou formation (Huang & Liu 1998). The formation is one of the more important base formations from which numerous stone forests in the Lunan region of southern Yunnan develop. The main characteristics of the Maokou formation are roughly similar to the Qixia formation, except that in the Maokou carbonates there are no major traces of dolomitisation. There are considerable diagenetic changes in the basic rock, which is undoubtedly the result of the intense volcanic activity (basalt lava) during the period between the Palaeozoic and the Mesozoic (Knez 1998); the rock is homogeneous and slightly cracked, there is practically no secondary porosity, and the carbonate content is exceptionally high.

Limestone dominates in the older part of the formation, altering with dolomites and dolomitic limestone. In the upper part it is possible to trace the sequence of limestone that is in some places thin-bedded and elsewhere forms strata several metres thick, and massive limestone which in individual horizons contains chert nodules up to several decimetres in diameter.

We have divided the rock sequences in Pu Chao Chun from the lithostartigaphic and morphostructural aspects into two parts, lower and upper (Fig. 2). The lower part consists of light

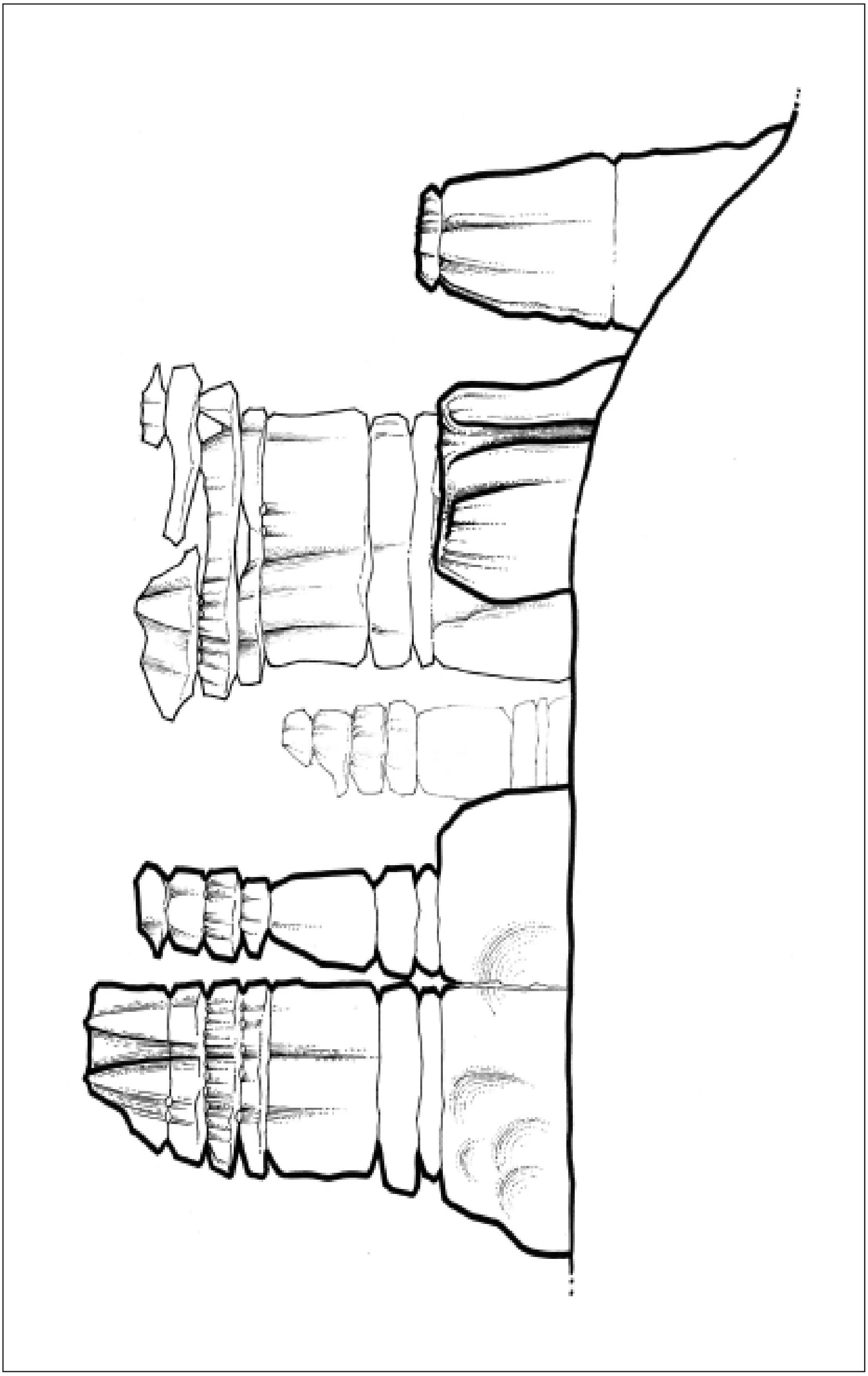

Fig. 2: Cross-section of the Pu Chao Chun stone forest.
Sl. 2: Prerez Pu Chao Chun kamnitega gozda.

grey to white thick-bedded to massive limestone, while the upper part consists of beds of almost completely white limestone several tens of centimetres thick (Fig. 3). Both are tectonically deformed with numerous sub-vertical faults running in various directions. Lithostratigraphically, they are genetically connected, with no stratigraphic gaps between them. They also indicate a similar depositional environment. The diagenetic influences through their geological history are evenly expressed across the entire profile.

In the lower part of the profile we can trace only a single textural variant. The limestone contains numerous bioclasts, some reaching several centimetres in diameter, and pellets. According to texture the limestone is micritic to microsparitic, most often biopelmicrosparitic. Only exceptionally are there calcite veins in the rock. There are no trace of secondary porosity. A rock of such characteristics allows the development of subcutaneous rock features as well as the features carved by rainfall.

In the geological profile the beds of the upper part follow in succession. The layers are 10 to 50 cm thick (only the lowest bed of the upper part exceeds 1 m). The latter shows a kind of logical depositional transition between the massive lower part and the more thin-layered limestone of the upper part. All the nine beds are equally resistant to corrosion and erosion. They form the narrower part of the pillar above the wider and much more resistant part.

The limestone in all the beds contains numerous bioclasts and pellets. Often the bioclasts account for up to 80% of the volume. The basic rock varies between micritic and sparitic - the microsparitic dominates - and the limestone of the upper part can thus be called biosparitic and biomicritic, the biomicrosparitic type dominating. Neither dolomitisation nor secondary porosity are expressed in the limestone. In some places there are stylolites with non-soluble residue alongside them.

THE SHAPE OF THE ROCK PILLARS

In terms of shape the rock pillars can be divided into two types, defined mainly by the stratification of the rock from which they formed. In the upper part of the stone forest the characteristic shape of the pillars are a result of the thin rock beds. The upper parts of the pillars (Fig. 1, 2) are relatively narrow; the largest consist of nine relatively thin beds of rock. Well expressed notches and subcutaneous holes have formed in the contact zone. The lower parts of the pillars are stout and made from a single thick rock bed. The narrower rock pillars are narrowest where the strata are thinnest. The pillars are oblong, which is due to the cracked rock. The tips of the pillars are relatively level where the top beds of the rock were thin and swiftly disintegrated. Only the thicker beds of rock have become tapered and are marked by funnels and rock formations carved out by rainwater. More or less distinctly shaped subcutaneous rock features are dominant in the first type. Most often only small and sharp rocks remain as the tips.

In the lower part of the stone forest, which developed in the thick rock beds, the rock pillars are of a more even shape: stout at the bottom, if they were not thinned by the subcutaneous action, and tapered towards the top, with relatively sharp tips. Distinct subcutaneous features, holes as well as features on the rock surface, have also formed between the beds of this type. The transition between the various different stone forests is gradual, depending on the position of the rock pillars and the rock beds (Fig. 3).

THE ROCK RELIEF OF THE STONE FORESTS

The rock features of the stone forest pillars can be divided into subcutaneous, rock features carved by rainwater and combined rock features, formed by subcutaneous factors as well as rainwater (Slabe 1998, 51). This particular, specifically shaped stone forest also has its characteristic rock relief.

The subcutaneous rock features that formed below deposits and the soil are divided into those that formed below the deposits and the soil because of the water flowing along the contact surface between them and the rock, those that formed because of water permeating into soil that only partially covers the rock, and those that formed at the level of the deposit or soil enveloping the rock (Slabe 1999).

Large subcutaneous channels (Fig. 3) formed as a result of the water flowing along the contact surface between the rock and the deposits that covered the rock and filled the vertical cracks. The diameter of the largest exceeds one metre. They cannot be recognised on the upper parts of the larger pillars because these were reshaped by later processes. Their features are more expressed on the lower part, on the thicker rock bed which has not been exposed for as long. In some cases three quarters of the channel is etched into the rock face. It then continues under the current ground level. Only narrow edges have remained between them. The rock teeth also are most often partitioned by subcutaneous channels and their beginnings - mouths.

Subcutaneous notches have formed where more long-lasting soil enveloped the rock face. Under the ground their rims are broken up by semi-circular indentations - scallops - where the water percolated evenly. Sometimes channels lead to the upper indentations; these are larger. The rock is hollowed out under the overhanging edges of the largest notches.

The other type of subcutaneous channels (Fig. 4) are the horizontal ones, which were formed under soil and overgrowing vegetation which only partially covered the rock. The mesh of subcutaneous channels can cover the entire horizontal tip of a pillar. These are semi-circular and at the bottom often wider than the opening. Their diameter can reach up to 1 m. Individual channels can be narrowly deepened where the soil covers only their bottoms. The deeper channels have minor subcutaneous channels along their walls. Funnel shaped notches form at the ends of the channels situated on the rims of the tops. Water drains through them down the face, and the above-described vertical subcutaneous channels, especially under the largest ones, are located where it reaches the earth. These often develop from subcutaneous holes that where exposed when the

Fig. 1 (on page 135): The Pu Chao Chun stone forest - upper part.
Sl. 1 (na strani 135): Pu Chao Chun kamniti gozd - zgornji del.

Fig. 3 (on page 135): The lower part of the Pu Chao Chun stone forest consists of light grey to white thick-bedded to massive limestone. The upper part consists of beds of almost completely white limestone up to some tens of centimetres thick.
Sl. 3 (na strani 135): Spodnji del Pu Chao Chun kamnitega gozda gradi svetlosiv do bel debeloplastnat do masiven apnenec. Zgornji del gradijo plasti skoraj belega apnenca debele do nekaj deset centimetrov.

Fig. 1 - Text on page 134; Sl. 1 - Besedilo na strani 134.

Fig. 3 - Text on page 134; Sl. 3 - Besedilo na strani 134.

Fig. 4 - Text on page 137; Sl. 4 - Besedilo na strani 137.

Fig. 5 - Text on page 137; Sl. 5 - Besedilo na strani 137.

Fig. 4 (on page 136): The flat top of the rock pillar with subcutaneous channels and flutes and remains of sharp pillar tip.
Sl. 4 (na strani 136): Raven vrh stebra s podtalnimi žlebovi, žlebiči in ostankom koničastega vrha.

Fig. 5 (on page 136): The net of flutes and channels, carved by rainwater.
Sl. 5 (na strani 136): Mreža žlebičev in žlebov, ki jih dolbe deževnica.

upper layers disintegrated. They are formed as subcutaneous channels from the point where the level of the soil enveloping the pillars is lower than the channels, therefore also while they are still in the middle of the rock pillars. After they are exposed and there is no more soil in them they are directly eroded by the rain.

The cups are of a similar origin. Subcutaneous channels lead from the largest, while the smaller ones might deepen the bottoms of the large subcutaneous channels. The cups closer the rims of pillar tops can develop with a direct action of rainwater into funnel shaped notches.

Networks of minor subcutaneous holes (Fig. 1) develop along the bedding-planes and also along the cracks.

A significant part of the rock relief consists of combined rock features (Fig. 4, 5). These are divided into those which were formed by direct interaction of underground factors and rainwater and those that acquired their particular shapes through changes to their subcutaneous features caused by rainwater.

The water that drains from subcutaneous channels at the tops of the lower pillars also carves pillars on vertical rock. The diameter of these rarely reaches 20 cm. Funnel shaped mouths are formed at the rims. The funnel shape and the sharp edges are the direct results of the rainwater acting on the rock. Such channels also lead from the dense mesh of holes that were formed along the bedding-planes and are now situated higher on the rock pillar. There are many holes and the channels on the rock face run close to each other, while the funnel shaped notches at their mouths are less expressed since the rainwater reaches them directly only when they are situated on rock strata which protrude from the walls. Rainwater has substantially reshaped the large even pillars' tops criss-crossed by exposed subcutaneous channels and holes. It sharpened the edges between them, their walls became covered by smaller rain pits and flutes, and the subcutaneous channels are often deepened by a narrower channel down which the rainwater drains. On the sharpened tips the remains of the subcutaneous features are the larger funnel shaped notches and, indirectly, also the channels below them.

The relatively homogenous structure of the rock allows the formation of smaller rock features, directly carved by rainwater - these are the rain pits, flutes and individual channels (Fig. 1, 5).

The average diameter of the flutes is 2.5 cm; the largest reach 5.5 cm and the smallest measure 1.2 cm. They are measured on the surface inclined at angles of between 25° and 80°. The larger flutes are mainly those with the greater inclinations and are the most expressed rock feature on the rock tops. The largest flutes are on the upper parts of the steep rock faces and the beds that protrude from the faces. They are no less expressed, but usually shorter, on the rock surfaces with reshaped subcutaneous rock features. On the lesser inclinations of the larger rock tops individual channels have formed in the bottom of the notches between the protruding edges with flutes. Several such channels can cause the formation of minor funnel shaped notches on the rims, with steep sides separated by relatively shallow channels with less expressed edges. Rain pits are formed on the more level sections and rain scallops are formed on the overhanging walls by the water dripping down the rough rock surface. Kamenitze are in most cases formed on the bases of the exposed subcutaneous rock features.

CONCLUSION

The Pu Chao Chun stone forest, as other Lunan stone forests, was also formed from subcutaneous karren. The shapes are determined mainly by the characteristic distribution of the variously thick, and at the top mostly thin rock beds, on which the stone forest developed at various levels. The dimensions and the oblong shapes of the pillars were predetermined by the faults and cracks that vertically criss-cross the rock strata. The rock features and their rock relief clearly point to the importance of their underground formation, while reshaping by rainwater slowly progresses down the pillar.

The rock is practically the same throughout the geological profile. There is biomicrosparitic limestone all along it, with an almost 100% $CaCO_3$ content - limestone which expresses similar sedimentation conditions along the profile and indicates an equal response to erosion and corrosion processes throughout, regardless of the thickness of the layer. The thickness of the layers crucially affects, and is clearly reflected in, the morphological shape of the individual rock pillars.

In then upper part of the stone forest the pillars mostly stand individually. They are smaller in cross-section and the rock stratas are the thinnest. The bottom parts of the pillars formed on thick rock strata are more stout and closer to one another. Where the layers are thinner the notches are more expressed. They disintegrate faster and the tops are thus relatively level. Where the top layers are thicker the tops become sharp. In the lower part of the stone forest, where the rock pillars are fewer, the pillars were formed on thick rock layers and are generally thicker at the bottom and taper towards the top.

All the rock features which reflect the genesis of the stone forest are well developed. The subcutaneous rock features are the large subcutaneous channels on the rock faces and the subcutaneous channels and cups on the larger tops. The combined rock features are the channels that lead from the subcutaneous channels and cups located on the tops and subcutaneous holes between the bedding-planes. The exposed subcutaneous rock features are reshaped by rainwater, which hollows the flutes, channels and scallops.

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Povzetek

Pu Chao Chun je manjši kamniti gozd, ki leži 15 km južno od osrednjega lunanskega kamnitega gozda. Kamniti stebri so na grebenu, kjer je njihova mreža najbolj gosta, in na pobočju pod njim. Temeljne značilnosti lunanskih kamnitih gozdov smo predstavili v knjigi South China Karst (1998). Se pa med seboj razlikujejo, kar predvsem narekuje kamnina, na kateri so nastali. Odločila sva se, da te razlike podrobneje predstaviva, najprej sva opisala značilnosti Naigu kamnitega gozda (Knez & Slabe 2001), tokrat dodajava še spoznanja o oblikovno samosvojem kamnitem gozdu.

Tudi Pu Chao Chun kamniti gozd je kot drugi lunanski kamniti gozdovi nastal iz podtalnih škrapelj. Obliko mu določa predvsem svojevrstna razporeditev različno debelih, v zgornjem delu večinoma tenkih, skladov kamnine, na kateri je v različnih nivojih nastal kamniti gozd. Obsežnost in podolgovatost stebrov pa mu narekujejo tudi prelomi in razpoke, ki pokončno prepredajo sklade kamnine. V obliki stebrov in v njihovem skalnem reliefu se jasno kaže pomen njihovega podtalnega oblikovanja, preoblikovanje z deževnico pa počasi napreduje po stebrih navzdol.

Kamnina se skozi geološki profil praktično ne spreminja. Vseskozi sledimo večinoma biomikrosparitnemu apnencu s skoraj 100%-nim deležom $CaCO_3$, apnencu, ki v tem profilu kaže podobne sedimentacijske pogoje, in ki ne glede na debelino plasti kaže enak odziv na vpliv erozijskih in korozijskih procesov. Debelina plasti odločilno vpliva in se jasno odraža na morfološkem izgledu posameznih kamnitih stebrov.

V zgornjem delu kamnitega gozda so stebri večinoma posamezni in manjših prečnih prerezov, skladi kamnine so tam najtanjši, bolj čokati in tesneje drug ob drugem pa so spodnji deli stebrov, ki se oblikujejo na debelem skladu kamnine. Ob tenkih skladih so izrazite zajede, hitreje razpadajo in pod njimi so vrhovi zato pogosto razmeroma ravni, če pa so na vrhu debelejši skladi, so vrhovi ostri. V spodnjem delu kamnitega gozda, kjer je manj kamnitih stebrov, so le ti nastali na debelih skladih kamnine, zato so praviloma spodaj širši, navzgor pa se ožijo.

Dobro so razvite vse vrste skalnih oblik, ki pričajo o razvoju kamnitega gozda. Podtalne skalne oblike so veliki stenski žlebovi in podtalni žlebovi ter vdolbine na obsežnejših vrhovih. Sestavljene skalne oblike pa so žlebovi, ki vodijo iz podtalnih žlebov in podtalnih vdolbin ter podtalnih votlin. Razgaljene podtalne skalne oblike preoblikuje deževnica, ki dolbe žlebiče, žlebove in vdolbinice.