The Genetic Types of Baiyun Cave in Lincheng County of Hebei Province

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Abstract Baiyun Karst Caverns in Lincheng County, Hebei Province, is a rare karst caverns in subhumid climate region of the north. It was developed in carbonatite strata, particularly in Zhangxia formation of the Middle Cambrain series. Erosion-corrosion landscape and chemical deposition landscape are abundant, They are various shapes, curtain drapery, cave flag, cave shield, stalactite, stalagmite, cave flowers, botryoid, soda straw are developed, especially heligmite, soda straw, cave flowers are the most characteristic.

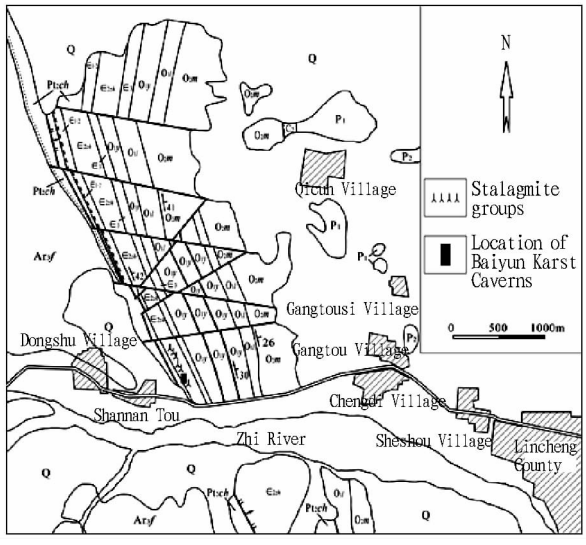
Key words Baiyun Cave in Lincheng County, Landscape, Genetic types

Baiyun Karst Caverns is located in the south of Kongshan lying in the east of Shannantou town, Xishu Village, Lincheng County, Xingtai City, Hebei Province. Geographical coordinates of Baiyun Karst Caverns is 114°25.9′E and 37°27.36′N. Baiyun Karst Caverns is the major component of national geological park, Lincheng County, Hebei Province. At present, Baiyun Karst Caverns includes 5 different styles of caves, such as the earth cave hall, the paradise cave hall, the inferno cave hall, the maze cave hall and the dragon cave hall, where erosion-corrosion landscape and chemical deposition landscape developed. Through discussion of genetic type of two typical cave landscapes, the reference for research on karst cave in northern China and the scientific basis for development and protection of local tourism resources are provided.

1 Developmental basis of Baiyun Karst Caverns

1.1 Lithostratigraphy Main lithostratigraphy exposed in Kongshan area includes the Archaeozoic Fuping Group, Mesoproterozoic Changcheng System, Lower Paleozoic Erathem Cambrian – Ordovision System, Upper Paleozoic Erathem Carboniferous – Permain and Cenozoic Quaternary System (Fig. 1). Baiyun Karst Caverns develop in Lower Paleozoic Erathem Cambrian – Ordovision System stratum in which the lower part of Zhangxia Fomation of Middle Cambrian is mid-thickness oolitic limestone with dark grey mid-thickness oolitic limestone, argillaceous limestone mingled shale and a small amount of wormkalk; the upper part are thickness – mid – thickness oolitic limestone and bioclastic oolitic limestone, its total thickness is about 180 m, which is the key layer of development of Baiyun Karst Caverns.

1.2 Geologic structure The main strata of kongshan is carbonatite strata in Early Paleozoic era, Geomorphic feature is characterized by monoclinal mountain which leans to the east, the relative height difference is about 100 m, the general stratum trending is NNW, the tendency is NEE and the dip angle is 40° (Fig. 1).



Note: Ar_3f – Archaeozoic Fuping Group; Pt_2ch – Mesoproterozoic erathem Changcheng System; $\in_{1-2}$ – Middle – Lower Cambrian; $\in_2 zh$ – Zhangxia Group of Middle Cambrian; $\in_3$ – Upper Cambrian; O_1y – Lower Ordovician Yeli Fm; O_1l – Lower Ordovician Liangjiashan Fm; O_2m – Middle Ordovician Majiagou Fm; C_2 – Upper Carboniferous; P_1 – Lower Permian System; P_2 – Upper Permian System; Q – Quaternary Diluvial Layer.

Fig. 1 Geologic map of Kongshan

Three steep and extensional groups of fault structure such as running NNW, NE and nearly EW are mainly developed in the Kongshan area. According to the incision relation of each group of faults formed in different geological times (Fig. 1), the running NNW fault formed earlier produced in the uplift phase of Zanhuang palaeohigh during the Yanshan movement[1]. Its scale is larger, which runs from south to north. Development procession of geological landform of Kongshan was controlled. The running NE and nearly EW faults have small scale which formed later. But since

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Cenozoic when the faults formed, they have strong activity, and especially landform development of Kongshan is controlled obviously by Left transtensional activities of nearly EW fault. Not only nearly EW graben and horst formed in the movement of differential uplift of fault made most of surface valleys extending nearly EW, but also the Left transtensional activities dislocated the mountain, making different sections of the mountain moved left obviously.

In addition, along with formation and activity of multi – phase faults, multi-groups of joints (or cracks) with trending of NW, NE, NWW and NEE are developed.

Above various fault structure as the infiltration channel between atmospheric precipitation and surface water and the runoff network of groundwater and the connection channel between the inside cave and the outside world are the key conditions for development of the Baiyun Karst Caverns.

1.3 Neotectonic movement Along with intermittent uplift of Taihang Mountain since the Quaternary Period, Baiyun Karst Caverns in Lincheng County has undergone four tectonic uplift movements at least. Based on the previous researches on Taihang Mountain[2], the four period of uplift movements are the early Middle Pleistocene (0.7 – 0.6Ma BP), the early stage of Late Pleistocene (0.12Ma BP – 50Ka BP), the middle and later period of Early Holocene (10 – 7.5Ka BP) and the terminal stage of Middle Holocene(3 – 2.5Ka BP).

In the control of intermittent tectonic uplift movements, Baiyun Karst Caverns karst cave system distributes in layers (Fig. 2). The first layer (the upper layer) includes the Earth cave hall, the Paradise cave hall, the inferno cave hall, its altitude is 140 – 170 m; the second layer includes the main part of the Maze cave hall and the upper part of the Dragon cave hall, its altitude is 125 – 135 m; the third layer (the lower layer) is the lower part of the Dragon cave hall, its altitude is 115 – 120 m.

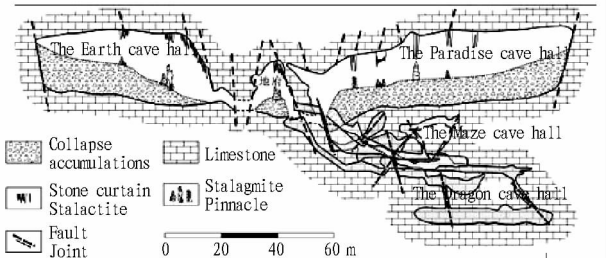

Fig. 2 Cave system of Baiyun Karst Caverns

1.4 Climate Baiyun Karst Caverns in Lincheng County formed mainly in the quaternary period, the change of climate is remarkable in temperature, dry and wet. Coupling of the uplifting earth crust stage with the warm-humid climate is beneficial to the down-cutting of surface water and the formation of terraces and ravine, while the coupling of the stable earth crust stage with the warm and humid climate is beneficial to the development of geomorphic surfaces, caves and various cave landscapes[3].

In modern times, the climate of Baiyun Karst Caverns in Lincheng County is sub-humid warm temperate continental monsoon in the North Temperate Zone, where the spring and autumn is short, the summer and winter is long, the annual average temperature of Baiyun Karst Caverns in Lincheng County is about 13℃ – 14℃. Because of lower annual average temperature, Karstification is weak.

2 The genetic types of Baiyun Karst Caverns

Landscapes of Baiyun Karst Caverns are well developed, which have complex types and varied shapes, and they distribute intensively. There is are only various chemical deposition landscapes formed under the action of a large amount of seepage, but also the chemical corrosion landscapes formed under the corrosion and erosion of groundwater or water flow in the cave.

2.1 Chemical deposition According to the different genetic type of deposition landscapes, the chemical depositions can be roughly divided into the gravitational water deposits, the non-gravitational water deposits and the synergetic deposits.

2.1.1 Gravitational water deposits. According to difference in the hydrological mechanism, the gravitational water deposits can be divided into the running water deposition, the dripping water deposition, the splashing water deposition, and so on.

(1) The running water deposition. Curtain drapery The shape of curtain drapery is cloth or stage curtain, its character is layered accumulation. The development procession is strictly controlled and affected by water flow and the way of movement, joint, fracture *etc*. Take the Flying Waterfall (Fig. 3, 1) with 8.5m height and 6 width in the Paradise cave hall and giant stone curtain (Fig. 3, 2) developed on the east wall of the Earth cave hall for example, the scale is large.

Cave shield and shield curtain Cave shield is usually formed simultaneously with the shield drop, both of them are collectively known as the shield curtain. The binding force between two shield boards is limited, so the lower shield board falls for the gravity. Typical Cave shield in the Baiyun Karst Caverns include: the shield curtain developed on the east side of the Earth cave hall (Fig. 3, 3) and "kongquekaiping" which remained on the side wall and its lower shield board falled (Fig. 3, 4), "Cactus", "Longnv Cixiu" and "Feast of dragon palace" (Fig. 3, 5) in the Dragon cave hall. In addition, heligmite of non-gravitational water deposits was developed on the shield boards of "Feast of dragon palace".

Cave flag The cave flag is schistose and secondary $CaCO_3$ deposition, which has banding structure and a certain of transparency, it is white in itself, but it turns to yellow or red, *etc*., when infiltration aqueous solution contains mud or iron materials, *etc*. For example, "yulongzhuantian" (Fig. 3, 6) with about 16 m length developed on the west side of the Paradise cave hall, "shuangeryutu" (Fig. 3, 7) which is remarkably true to life and "Colorful curtain drapery" in the Maze cave hall *etc* (Fig. 3, 8), especiallythe "Grilles curtain" (Fig. 3,9) combined by many cave flags, it is one of wonder landscape of Baiyun Karst Caverns, which is rarely founded in other karst caves.

(2) The dripping water deposition. Stalagmite It is the Ca-

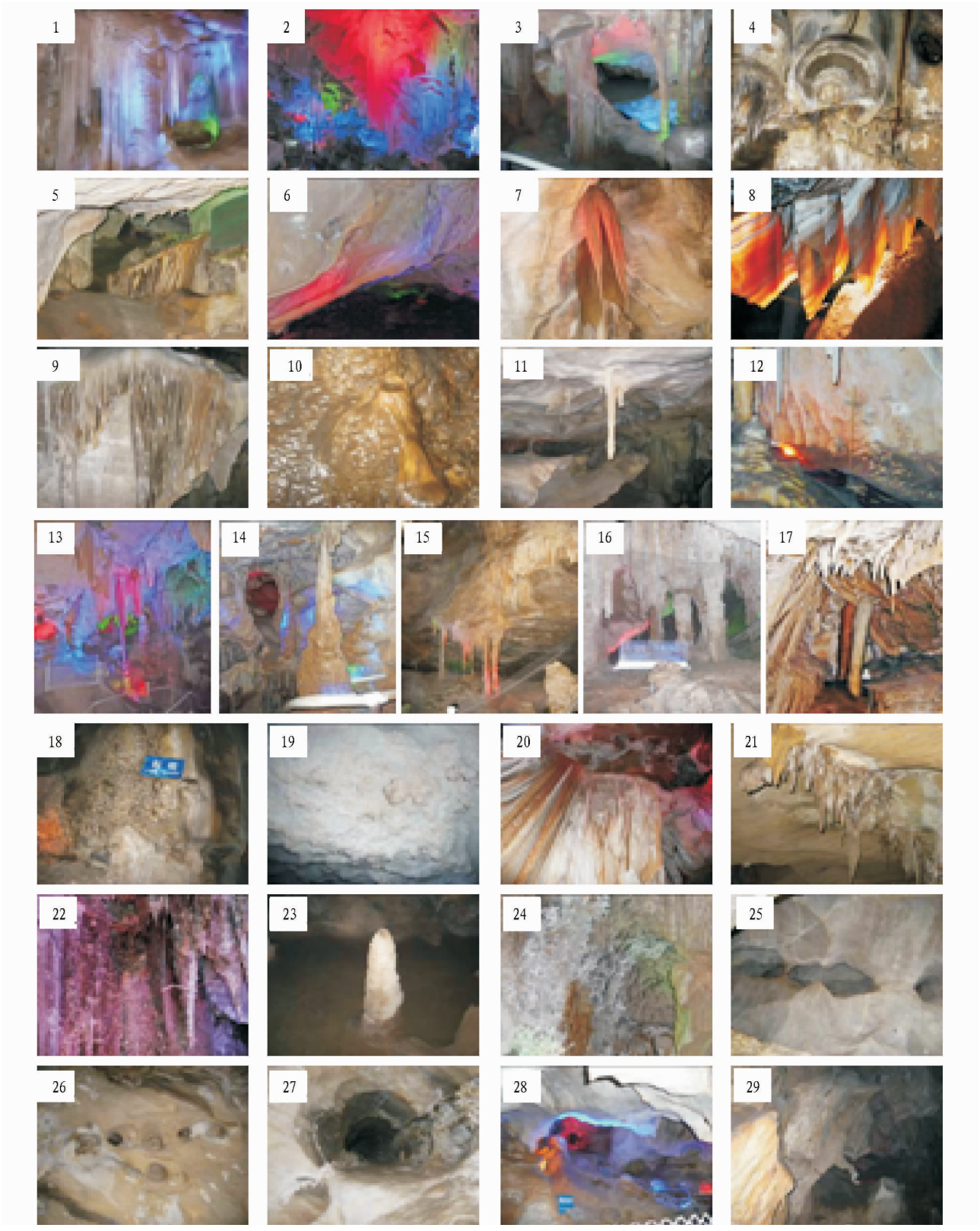

Fig. 3 The genetic types of Baiyun Karst Caverns

CO_3 deposits with shoot shape and laminated structure. Its shape is obviously limited by the height and speed of the drip from the top of cave. When the drip drips from a higher place or at a higher speed, the top of stalagmite is dented (Fig. 3, 10), and on the

contrary, it is protruded.

Stalactite and soda straw Stalactites in all halls of Baiyun Karst Caverns and distributed widely and centrally, which are usually shown in group. "Sanchashenji" (Fig. 3, 11) developed in the west channel from the Earth cave hall to the Paradise cave hall, of which the head of Stalactite was divided into three branches due to blocking on the influent seepage of major pipeline and branching; a soda straw named "chaotianyizhuxiang" (Fig. 3, 12) near the entrance of the Maze cave hall formed by cutting the upper part of stalactite connecting to the top of cave and remaining the lower part, It is one of wonder landscape of Baiyun Karst Caverns, which is rarely founded in other karst caves.

Stone column There are the stone column formed upon connection of stalagmite and stalactite, such as the stone column (Fig. 3, 13) which supports "Hengtian Yizhi" in the Paradise cave hall; the stone column formed upon connection of giant stalagmite and small stalactite, such as "Shuangta Zhengxiong" (Fig. 3, 14) in the Maze cave hall; the stone column formed from the stalactite which is extended to the bottom of the cave, such as "Wutui Shenlu" in the Paradise cave hall (Fig. 3, 15), "Stone fence" (Fig. 3, 16) in the Earth cave hall *etc*. In addition, "Yinyang Yuzhu" (Fig. 3, 17) in the Dragon cave hall is composed of a small red stone column and a small white one, which are close to each other. The water drops to the white stone column only contain $CaCO_3$, which is nearly without any impurities, while the water drops to red stone column contain a certain amount of iron, it reveals that the cave landscape is also affected by the dissolved composition of karst water.

(3) The splashing water deposition. Splashing water deposition landscapes are botryoid, cave flowers, and so on, the shape of which are grape or cauliflower. The splashing water deposition is affected by the flow of water and height of drip. Such as "Cave flower" in the Earth cave hall (Fig. 3, 18).

2.1.2 Non-gravitational water deposits. Non-gravitational water deposits include condensation water deposits and the capillary water deposits in Baiyun Karst Caverns.

(1) Condensation water deposits. Typical landscapes of the condensation water deposits are lithostyle, cave flower *etc*., the growth direction of which is not affected by the gravity. These mostly occur in the Maze cave hall and the Dragon cave hall, such as cave flower (Fig. 3, 19) in the Maze cave hall, lithostyle (Fig. 3, 20) on the top of curtain of "longnvshazhang" in the Dragon cave hall *etc*.

(2) Capillary water deposits. Typical landscape of the capillary water deposits is the heligmite, which is the $CaCO_3$ deposition with spiral or twist shape. Because of cave humidity, air flow and the rate of crystal growth, and so on, its growth direction is not affected by gravity. Take the mesh heligmite formed under the condition of capillary water which is similar to loofa and acicular deposits in the Earth cave hall as example (Fig. 3, 21). They grow non-directionally and curly to a net, which is one of wonder landscape of Baiyun Karst Caverns and rarely founded in other karst caves. "Hengtian Yizhi" in the Paradise cave hall (also named as "Jiewai Shengzhi") is the $CaCO_3$ deposition around the capillary, formed after the capillary water leaking from the tiny holes of stalactite and CO_2 flowing out due to the effect of surface tension. The shape of deposition is similar to branch and extends horizontally (Fig. 3, 22).

2.1.3 Synergetic deposits. Synergetic deposits refer to secondary $CaCO_3$ deposition landscape formed under the synactic action of water flow in two or more modes of motions, which is affected by the change of yield of water. Synergetic deposits mainly contain dripping – splashing deposits (Fig. 3, 23), capillary-condensation water deposits (Fig. 3, 24) *etc*.

2.2 Erosion-corrosion landscape Erosion-corrosion landscapes refer to various remains which formed under the erosion and corrosion of ground water and water flow in the roof, bottom and side wall of the karst cave, such as groove, pothole *etc*. There are mainly pothole type, trough and groove type, groove type and cave-wall protruding type in Baiyun Karst Caverns.

2.2.1 Pothole type. Pothole type refers to the round or oval depression or pits of different sizes on the roof, bottom and side wall of karst cave. Potholes in Baiyun Karst Caverns mostly formed on the roof and generally under the condition of undercurrent. Pothole on roof formed not only along the unidirectional cracks, but also along multi-groups of crossed cracks. The potholes distributed moniliformly are mostly related to unidirectional cracks(Fig. 3, 25), while the small potholes distributed in group and in net or cellular are mostly found on the joints of multi-groups of cracks. (Fig. 3, 26).

2.2.2 Trough and groove type. Trough and groove type refers to the well shape, siphonate shape or the tubular shape under the effect of corrosion, erosion or mixed corrosion, which are mostly formed on the roof. Affected by cracks and bedding, they formed not only in underflow zone, but also in vadose zone, such as tubular well pipe in the inferno cave hall formed in vadose zone (Fig. 3, 27).

2.2.3 Groove type. Groove type refers to the horizontal groove formed near the water table under the strong erosion and corrosion of underground water, which is implanted in the side wall of cave and distributed stratformly; they have the relationship with the genetic of cave, which can reflect the position and the relative change process of underground water table in Baiyun Karst Caverns. For example, the horizontal groove on the side wall near "Underwater world" in Dragon cave hall (Fig. 3, 28).

2.2.4 Cave – wall protruding type. Cave – wall protruding type refers to the projection type which projects from the cave wall such as reverse stone teeth, hanging rock, *etc*. Such landscape can be formed not only under the condition of underflow, but also under the condition of vadose. Reverse stone teeth is the projection projecting from the mother rock under the corrosion, which are mostly founded on top board and side wall. Hanging rock is the projection of parent rock formed on roof or cave wall under the condition of corrosion. Development process of them is obviously affected by concentrated cracks, such as "Jingou Daogua" (Fig. 3, 29) in the Paradise cave

hall which is formed under the condition of vadose.

3 Formation and evolution of Baiyun Karst Caverns

At the middle and late periods of Early Pleistocene (1.0 – 0.78 Ma BP), the structural environment of Kongshan area was stable, and the climate was warm and humid[4], and the surface water and underground water both were activity strongly. The major of surface rivers was lateral erosion and broadening, the forth terrace was formed; the larger first layer of Baiyun Karst Caverns and various landscapes were developed along the NNW – SSE – trending faults nearby the phreatic surface.

At the early period of Middle Pleistocene (0.78 – 0.6Ma BP), the strongly different uplift happened in Kongshan area. The climate was warm and humid, atmospheric precipitation was ample, and surface river strongly deepened, the forth river terrace was formed. The first layer of Baiyun Karst Caverns was uplifted and separated from water table and entered the evolution stage of the vadose zone, a huge number of landscapes formed.

At the middle period of Middle Pleistocene to the initial period of Late Pleistocene (0.6 – 0.12Ma BP), the structural environment of Kongshan area was stable. the climate generally was warm and leaned to cool and dry[5], and the atmospheric precipitation was low, The major of surface river was lateral erosion and broadening, the third terrace was formed; affected by the warm and dry climate and the stable structural environment, the activity of underground water was greatly reduced, karstification frequently processed along antecedent cracks with small scale, the second, reticular and gallery layer of Baiyun Karst Caverns was developed (Fig. 2).

At the early period of Late Pleistocene (0.12Ma BP – 50ka BP), strongly different uplift happened in Kongshan area again. The climate was generally warm and humid[6], the surface water and underground water both were very strong. The major of surface river was lateral erosion and broadening again, the third river terrace was formed. The second layer of Baiyun Karst Caverns was uplifted and separated from water table and entered the evolution stage of the vadose zone.

At the late period of Late Pleistocene to the initial period of Early Holocene (50 – 10 ka BP), the structure environment of Kongshan area was relatively stable, the climate was replaced between warm and humid and wet and dry. The major of surface river was lateral erosion and broadening, but the scale was small, the narrow and second terrace was formed. Seepage from the roof cracks promoted the formation of various landscapes in the first and second layer of Baiyun Karst Caverns. Near the water table, underground water eroded and corroded along cracks, the third and gallery layer of Baiyun Karst Caverns was formed (Fig. 2).

Thereafter, two quick structure uplift activities happened in the Early Holocene(10 – 7.5ka BP) and the later period of Middle Holocene (3 – 2.5Ka BP), the second river terrace and the first river terrace were separately formed. Since the later period of Holocene, the climate is warm and leans to humid, the rainfall is rich, karstification is strong, and various landscapes are developed. However, As the thickness of roof rocks of the first layer of Baiyun Karst Caverns is small and little calcium carbonate material is dissolved when the infiltrated aqueous solution flows through carbonate rocks, new chemical deposits is little, the size of deposition landscapes formed are small. Cool and humid environment is kept in the second and third layers of Baiyun Karst Caverns in a long term, besides chemical deposits, such as the dripping water deposition, the running water deposition and the splashing water deposition, condensation water deposits and capillary water deposits are rich. It should be pointed out that there are various landscapes in Baiyun Karst Caverns, but the early landscapes weathering and damaged seriously and newly landscape developing exuberantly are configurative, both of them mostly show coexistence in spatial relation. For example, curtain drapery and stone columns were partly weathered (or chalked) nearby the "Hengtian Yizhi" in the Paradise cave hall, while the new small stalactites are formed in the site of development of roof fracture. In the Maze cave hall, "Colorful curtain drapery" which is strongly damaged and stalactites coexist with the new small heligmite, lithostyle, and so on, in the branch caves.

4 Conclusions

Various chemical deposition landscape and erosion-corrosion landscape are combined into Baiyun Karst Caverns, which is worthy of high reputation of "modeling of underground Karst Museum", "World Karst landscape Caverns Expo" *etc*. And "reticular heligmite", "grilles curtain", "hosta and clean bottle", "lithostyle", *etc*., are wonder landscapes in the cave, But the chemical and physical damaging of landscapes are extremely serious. The Baiyun Karst Caverns is not only non-renewable geological resources, but also the vulnerable tourist resource, which has low capacity of disaster and difficulty in reverse recovery. Therefore, the protection is the major part in the process of development and utilization of various Karst Caverns landscapes.

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