Study on Controlling Factors of Formation and Evolution of Earth Forest in Yuanmou Area, Yunnan, China

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Abstract. Earth forest is a kind of unique landscape. The earth forest whose formation, development and evolution is affected by many factors. This paper deeply analyses the causes and characteristics of the formation and evolution of earth forest from four aspect of tectonic movement, composition and structure, climate and human activities.

1. Introduction
Earth Forest is a kind of unique landscape formed by water erosion (figure 1), which is composed of many different and imposing soil column and wall. Because of looking like the forest composed of soil column, it is called “earth forest” in China.

Earth forest are found in many areas of China. Such as Zhada basin of Ali area of Tibet, Datong of Shanxi, Xichang of Sichuan, Tianshui of Gansu, Yuanmou of Chuxiong, Nanjian of Dali, Jingdong of Pu'er, Yongde of Lincang. But no matter of size, quantity, density and landscape can't be compared with these of Yuanmou in Yunnan, which is the most typical and highly ornamental.

Yuanmou basin is famous in the world due to Yuanmou man. The earth forest landscape also developed greatly in this place. The Stratigraphic and structural profiles exposed in this and the surrounding areas, which sequence is complete, well exposure, rich in ancient animals, ancient human and mammalian fossils. It has always been the standard section of Quaternary in South China, which provides an objective basis for regional stratigraphic correlation in China, on which many scholars have done a lot of work. International Symposium on Quaternary geology has taken Yuanmou as the main research site. Therefore, earth forest in Yuanmou plays an important role in the study of Quaternary geology, and has high value of scientific research.

It is known that earth forest exists in many other parts of the world, such as the United States, Turkey, and Poland. But because of differences in cognitive and communication barriers, we don't know much about the earth forest landscape in these countries. In this paper, we only analyse and take research on the controlling factors of formation and evolution of earth forest in Yuanmou area of Yunnan province.

2. Literature review
2.1. The study history of Yuanmou basin
The earliest research on sequence stratigraphy in Yuanmou area began from the discovery of fossils. Granger found some fossils of horse, artiodactyls, elephant and rhino on the south side of the city in eastern basin. According to the characteristics of these fossils, he defined them as the early Pleistocene species [1]. Subsequently, Meinian Bian found Stegodon fossil in sedimentary strata near the willows.
village, who also collected some fossils of horse (Equus sp.), cattle (Bovinae) and deer (Cervidae) from the strata near Matou Mountain, and defined these fossils of strata as the late Pliocene era [2]. Colbert [3] studied the collection of fossils from Granger, and believed these fossils were similar with that from Upper Irrawaddy in Burma. So he concluded that the Yuanmou animal group era were equivalent of Upper Irrawaddy animal group era, which was early pleistocene.

![Figure 1. Earth Forest in Yuanmou](image)

Through the study of the giant otter (Enhydridon cf. falcneri Pligrim, Mingzhen Zhou [4] thought it was similar to the fossils from Dhok Pathan in Midwest India and the time of giant otter was the late Pliocene.

In the following study, Qian Fang, etc established the stratigraphic sequence of the Yuanmou Formation and determined the geological age of the Yuanmou Formation [5].

Zhang Zongku, Liu Pinggui, etc made a comprehensive and systematic study on the late Cenozoic strata in Yuanmou basin. They determined that the lower limit era of Quaternary in the Yuanmou basin was about 2.48MaBP. Then they divided the strata of Quaternary in the basin and defined the lacustrine facies strata as Yuanmou group according to the specification [5].

The above is for the study of the Yuanmou basin, but we find that the researches were mainly focus on the southeastern part of the basin, especially where the yuan-mouensis were founded. But on the other hand, the earth forests mainly distribut in the western basin, which are far from the study area before. Because of this, it is necessary to do further research on the earth forest area.

2.2. The study history of Earth forest

The study on earth forest began from Professor Qian Fang of Chinese Geological Sciences Institute of geom mechanics in 1965. Pro Qian Fang named this geomorphic phenomenon as "Earth Forest" in the paper of Quaternary glaciation and Stratigraphy in Yuanmou Basin [6]. As a special kind of geomorphologic landscape, the earth forest has received more and more attention since the last 90s. From this time on, earth forest had been found one after another in many areas of China. For all these earth forests, the one in Yuanmou is the most widely distributed, the largest, highest ornamental. But on one hand, the attention on earth forest are mainly about its aesthetic and tourism value. On the other hand, the study of science on earth forest are little.

Qian Fang, Ling Xiaohui, etc. preliminarily divided the types of earth forest in Yuanmou and took certain degree of research on the cause of earth forest [7-8]. Qian Fang, Zhou Xingguo described the formation conditions of this landscape, the development process and the types of earth forest in the book named "Yuanmou Quaternary Geology and ancient human", [5].
Xie Hongzhong, Yang Shiyu, et al. analysed the landscape features of Yuanmou earth forest, and put forward the formation factors of Yuanmou earth forest mainly include lithology, tectonic movement, suitable climate, water erosion and the protection of iron cementation layer, and finally put forward the measures of tourism development and protection.

Chen Shuyun, Zhang Jianyun, et al. took certain degree research on formation conditions and material composition of earth forest in Yuanmou. They concluded that the formation time of earth forest was 960–6490 years B.P., whose upper time limit was Middle Holocene the Atlantic period and lower time limit was Subatlantic period. They calculated the developmental rate of earth forest and the average erosion rate of it was 6.16–4.16mm/a, whose erosion rate was 120–830 times than the dissolution rate of Eastern Yunnan Karst [9].

He Yanhua took a more in-depth research on the formation age and period of Yuanmou earth forest, and clearly identified the sequence stratigraphy of this area.

Base on the previous research and the current work, the author thinks that the main controlling factors of formation and evolution of earth forest are about: the tectonic movement, the material composition, the column self-protection mechanism, the climatic and the human activities.

3. The controlling factors of formation and evolution

3.1. Tectonic movement

Yuanmou County is located at the inner side of the western wing of the E-shaped tectonics in Yunnan Province. The “Big Fault of Yuanmou Dongshan (literally “the east mountain”)” and its derived tectonics control the Yuanmou geological topography. The Big Fault formed in the pre-Sinian period, and has had different degrees of resurrection in the tectonic movement of the subsequent periods. The fault zone runs through Yuanmou in north-south direction and is located at the foot of Yuanmou Dongshan, north into Huili, Sichuan, and extends southward to Shuangbai Yuanmou-lvzhijiang big fault [10]. The fault was a torsional fault, and the Yuanmou section is basically in the “red layer in Yunnan”, coupled with the cutting, handling and accumulation of Longchuan River, causing the slopes in Yuanmou steep, soil erosion serious and more floods. Three units have been formed based on the geological tectonics: the mountainous landform of the Dongshan eroded tectonics, the hilly landform of the Xishan (literally “the west mountain) eroded tectonics and the accumulational landform of the basin depression. Yuanmou is located in the depressed basin, surrounded by mountains, and Yuanmou earth forest is mostly distributed in the river-lake facies area of the basin edge. Kunyang group and bedrock hill formed by granite of Jingningian Period can be seen at the surrounding or basement of the northern tiger-leaping beach earth forest and Banguo earth forest, which divide the entire Yuanmou Basin into a series of small basins such as Wumao Basin and Banguo Basins. The division prepares the conditions for the development of Yuanmo earth forest in a more closed and unitary environment.

The Yuanmou Basin is located in the middle of the north-south tectonic belt of Sichuan-Yunnan. In this tectonic belt, a series of Pilocene-Early Pleistocene river-lake facies depositional basins, such as Hanyuan, Xichang, Yanyuan and Hongge in Sicuan, Yuanmou, Kunming and Mouding in Yunnan is intermittently distributed. These basins have been formed by neotectonic movements and gone through a long process of sedimentation. After Act I of the Himalayan orogeny, the ancient rift valley landscape of the Sichuan-Yunnan north-south tectonic belt completely ended, and was replaced by long-term erosion and leveling. By Act II, a strong and extensive tectonic movement began in the area. At the late Miocene, the west side of basin began to rift, the stratum of the Pliocene Xiaohe Formation and Yuanmou Formation was accumulated.

After the Yuanmou Formation was deposited, a strong new tectonic movement has occurred in this area, which could be called the Yuanmou movement. The Yuanmou movement not only over-thrust the Dongshan’s Jurassic and Cretaceous strata to the Yuanmou Formation, but also produced a gentle tilt, folds, fractures and vertical joints for the Yuanmou Formation. After the Yuanmou movement, the Yunnan-Guizhou Plateau also uplifted as a whole due to the strong uplift of the Qinghai-Tibet Plateau. At this time, Yuanmou Basin turned into a gap uplift from the fault depression, so that the Yuanmou Formation constituted the hill of the basin edge and terrace base of the Longchuan River and its tributary.
The tectonic movement has produced joints and fissures within the rock stratum. The occurrence of the original fissures controls the direction of the surface water, thus largely controlling the direction of the earth forest’s development. There are three groups of main joints in the area with directions of 295°, 55° and 360°. Of which the 295° joints control the main trench direction of the earth forest. In addition, there are sub-level joints that cut the semi-diagenetic soil into more pillar bodies, while the lifting effect of the new tectonics increases the ground slope. During the strong undercutting of the Jinsha River, the surface water scours and erodes along the weak tectonics surface to form criss-crossing ditches. With time, these ditches will become earth pillars and earth forest. The new tectonic movement has lifted the west side of the basin and tilted the rock stratum eastward with a normal inclination of 5°-10°. The low angle rock stratum has a relative stability, which is also a favorable condition for the preservation of the earth forest.

Therefore, the recent strong uplift of the Yuanmou Basin is one of the important conditions for the formation of earth forest.

3.2. The composition and structure of earth forest
The strata of the Yuanmou earth forest is mainly a river-lake facies depositional strata which is composed of three stratigraphic sequences, namely, (1) Layer 1: iron cementation layer (figures 2 and 3); (2) Layer 2: fine-grained sediment layer (figure 6); and (3) Layer 3: Coarse-grained sediment layer (Figure 4). Among them, Layer 1 is mainly located at the top of the earth pillar, with a thickness of 0.5-1.5m. In some local sections, it is also found at the middle part of the pillar body, but the thickness would be thinner (no more than 30cm). Layers 2 and 3 are interbedded to form multiple, as many as 10, sedimentary cycles (figure 5). The specific stratification features are shown in Table 1.

| Layer                  | Thickness | Lithology                                                                 | Deposition characteristics                                                                 |
|------------------------|-----------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| 1) Iron cementation     | 0.3-1.5m  | Mainly brown red and brown yellow. The main components are the breccia, gravel and coarse sand. Most of the gravel is angular, sub-round with a mediocre roundness. Its mother rock is mainly composed of quartz sandstone, quartzite and sandstone. The chemical composition is mainly Fe₂O₃, SiO₂ and Al₂O₃. The intensity is generally high. | It is a silicon aluminium-iron type formed under the hot and humid conditions according to the chemical composition analysis. |
| 2) Fine-grained layer   | 0.3-0.6m  | Mainly greyish white and greyish yellow, and the main components are silty clay, fine sand and clay. | It reflects the hydrostatic sedimentary environment, which is lake facies or slow river facies sediment. |
| 3) Coarse-grained layer | 0.6-2.5m  | Mainly greyish yellow and greyish white, and the main components are gravel, coarse sand, mixed with a small amount of clay and fine sand. Gravel is mostly sub-circular, with a medium roundness. Its mother rock is mainly composed of quartz sandstone, quartzite and sandstone. Local part is mixed with the thin layer of iron cemented or clay glued lens body. | It reflects an obvious fluvial alluvia facies sedimentary environment, and represents the impingement cone sediment of the river into the basin. The large plate-like bedding, the oblique bedding and the parallel bedding reflect the river bed facies in the unidirectional flow, which is a kind of high-flow gravel sediment. |
For Layer 1, the iron cementation layer, the intensity is higher. When the crust is lifted, the river undercuts, the gully develops to form the earth screen, earth wall and earth pillar, this layer of hard iron cementation weathering shell, and the lens-shaped iron cementation gravel layer and the argillaceous cemented gravel strata in the pillar body will protect the soft layer at the lower part. Like an “iron cap”, it isolates the erosion of the upper surface water down to the soil, the lens in the middle of the pillar body enhances the stability of the entire pillar body to a certain extent. And some earth pillars without the “iron cap” on the top are slowly “sharpened” under the rain and river scouring effect, piece erosion, gradually brush down to collapse, and finally disappears.

It can be evidently seen in figure 1 that the differences of the integrity of the pillar body with or without “iron cap” are large, the pillar body with “iron cap” is tall and perfectly straight. And the pillar body without the “iron cap” protection is significantly lower in height, and gradually shows a sharpened state from the top.
For Layer 2, the fine-grained layer, the soil is relatively soft which makes it easy to be flushed away under the erosion of the water, the trace of vertical erosion can be clearly seen in figure 5.

For Layer 3, the coarse-grained layer, the intensity is higher than that of Layer 2, which is the “skeleton” of the earth pillar and plays the support role. The water erosion rate of Layer 3 is much slower than that of Layer 2. It can be apparently seen in figure 6 that the coarse-grained layer is protruded outward because the fine-grained layer between the two coarse-grained layers is continuously washed by water and the coarse-grained layer remains intact.

It is worth noting that the materials of the fine-grained layer that are washed away by water will slowly solidify and cement again in the lower part of the earth pillar body to form a layer of mud- or calcium-cemented materials with high intensity, which requires the geological hammer to vigorously dig to remove the sample (figure 7).

In some sections, this secondary consolidation is abnormally developed, and even completely wraps the lower part of the pillar body from the outside; as the coarse particle layer protrudes the surface of the earth pillar. These materials of the secondary consolidation vertically grow downwards along the prominent edge, and when it reaches the earth’s surface, it can even form a hollow space between the surfaces of the original lower earth pillar (figure 7).

These mud or calcareous cements are like “a pair of pants” for the lower part of earth pillar, which also play an important role to improve the intensity of the earth pillar body.
Overall, the stratigraphic composition and tectonics of the pillar body of the earth forest ensure the stability of the earth pillar, so that the earth pillar or earth wall can be stored on the earth’s surface for decades or even hundreds of years.

3.3. The climate
The Yuanmou Basin has a southern subtropical climate. The rainy season is dominated by the southwest monsoon of the Indian Ocean, while the dry season by the tropical continental air mass, and the foehn effect is obvious. The average annual temperature of the basin is 21.9 °C. The extreme maximum
temperature is 42 °C, with the minimum temperature of -0.1 °C. The annual sunshine duration is 2,670.4 hours, with the average annual sunshine hours of 7.3h/d and the sunshine percentage of 60%. The basin is southeast wind-dominated, hot in summer and warm in winter. The dry and wet seasons are clearly demarcated, with abundant sunshine. It is natural greenhouse suitable for crop growth. The average annual rainfall is 611mm, of which 90% are mostly in the rainy season from June to October. The perennial amount of precipitation is very uneven, precipitation of dry season is very little and it could last as long as 8 months. The area is generally arid and the amount of precipitation is too concentrated, which provides favourable conditions for the infiltration and erosion of precipitation.

The landscape in the basin is the tropical savanna, the common vegetation is mainly Bombax ceiba, shea nut, Miyouzhi tree, tamarind tree, acacia, euphorbia royleana boiss, cactus, sisal, jatropha, heteropogon contortus and so on. The soil formed in this bio-climate zone is dry red soil. It has a low fertility, inadequate organic matter, and poor soil aggregate tectonics, which makes it vulnerable to desertification and trenches from rain strokes during the rainy season.

As the vegetation in the soil is scarce and the soil is poor, the infiltration rate is low in the summer, and a large number of trenches are formed. The erosion is intense, widens and deepens the trenches, and eventually leads to many earth pillars. Due to drought and inadequate rain in the dry season, weathering and erosion effect on the earth pillar almost does not work, so the earth pillar can stand for a long time. On the contrary, if it often rains in the basins, with large humidity, the water can gradually penetrate into some clay or sub-clay layer in the earth pillar. Consequently, the clay can accelerate the collapse of the earth pillar due to water swelling and uneven changes of shrinkage after dry.

Therefore, the climate, soil and vegetation conditions in Yuanmou Basin are all favorable to the formation, development and preservation of the earth forest.

3.4. Human activities

In recent years, due to human logging activities, the earth forest area vegetation is getting less and less, and almost not see a tree in the area. The phenomenon of exposed soil water and soil erosion is very serious on the other hand, with the growth of the population, the demand for cultivated land is growing. The earth forest is pulled down, bulldozed, converted into arable land.

In a word, human activities aggravated water and soil erosion, accelerated the formation, development and disappearance of earth forest.

4. Conclusion

From the discussions above, the thesis concludes that:

1. Earth forest is a unique water erosion landform, which plays an important role in the Quaternary geological research and has a high scientific and research value.
2. The tectonic movement made the Yuanmou Formation go through a long process of sedimentation. Then, Yuanmou Basin turned into a gap uplift from the fault depression, while the lifting effect of the new tectonics increases the ground slope. During the strong undercutting of the Jinsha River, the surface water scours and erodes along the weak tectonics surface to form criss-crossing ditches. With time, these ditches will become earth pillars and earth forest.
3. The iron cementation layer on the top of the earth-pillar prevent the earth-pillar from erosion of surface water, and keep the stability of the earth-pillar.
4. Because of the coarse-grained deposition layer by multiple sedimentary cycles, the strength of the earth-pillar has been strengthened. At the same time, the structure makes it easy to form calcareous and argillaceous cementation layer at the lower part of the pillar, which plays the role of self-protection and self-repair.
5. The Yuanmou basin is hot in summer and warm in winter. The area is generally arid and the amount of precipitation is too concentrated. In the rainy season, the gully develops very fast, which provides favorable conditions for the infiltration and erosion of precipitation. Due to drought and inadequate rain in the dry season, weathering and erosion effect on the
earth pillar almost does not work, so the earth pillar can stand for a long time. Therefore, the special climate conditions in Yuanmou Basin are all favorable to the formation, development and preservation of the earth forest.

6. Human activities cause water and soil erosion, at the same time objectively accelerate the formation and disappearance of the earth-pillar.

7. The set of strata, which formed the earth forest, have great difference from the strata of Yuanmou Formation, so the research on the strata of earth forest should be deepened.

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Reference
[1] Granger. W, Roy C. Andrew, "The new conquest of central Asia: Natural History of Central Asia," American Museum of Natural History, New York, vol. 1, pp. 538-541, 1932.
[2] Bien, M. N., "Preliminary observation on the Cenozoic geology of the Yuanmou Basin," Acta Geologica Sinica, vol. 20(2), pp. 179-204, 1940.
[3] Colbert, E.H., "Pleistocene vertebrates colletted in Buram by the American Southeast Asiatic Expedition," Transactions of the American Philosophical Society, vol. 32(3), pp. 395-429, 1943.
[4] Zhou Mingzhen, "In contrast to the Yuanmou otter fossils and mammalian fossils from late third century Yunnan layer," Ancient Spine and Ancient Man. vol. 19(2), pp. 164-167, 1961.
[5] Zhang Zongku, Liu Pinggui et al., "New progress in Late Cenozoic geological research in Yuanmou Basin," Marine Geology & Quaternary Geology, vol. 14(2), pp. 1-17, 1991.
[6] Qian Fang, Pu Qing Yu, Yuan Zhenxin, Zhang Xingyong, etc., Quaternary Geology of China, Geological Press, pp. 55-88, 1977.
[7] Money, Ling Xiaohui, "Preliminary study on the causes and types of forest soil in Yuanmou," Science China (B), vol.4, pp. 412-418, 1989.
[8] Ling Xiaohui, Qian Fang., "Yuanmou forest soil and soil erosion," Soil and Water Conservation in China, vol. 5, pp. 34-36, 1989.
[9] Chen Shuyun, Zhang Jianyun et al., "The formation conditions and development rate of earth forest of Yuanmou". Yunnan Geology, vol. 13(4), pp. 383-391, 1994.
[10] Cheng Yuqi., "Introduction to regional geology in China". Geological Press, Beijing. 1994.