

Genesis and Geological Significance of Granite Caves in Laoshan of China

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Under the action of weathering and gravitational collapse on the joints and fractures of granite in Laoshan of China, a host of tourism geological landscapes have been developed such as "marvelous peaks, grotesque caves and bizarre rocks". At present, more than 40 granite caves have been discovered in Laoshan. Granite caves can be classified into two types, primary and subsequent according to their genesis. The former consists of only one type, large miarolitic cave (or bubble-like cave), and the latter consists of three types, rolling stone piled cave, fracture rolling stone cave and weathered slipping cave. The research of granite caves not only presents important tourism values, but also is significant for understanding the paleogeographic environment in the Last Glacial and the primitive environment of magma. The primary granite cave of Laoshan is currently the largest granite miarolitic cave ever known in China and also the second granite bubble-like cave discovered. As an extremely rare geological relic, it is also of great value for sightseeing and science popularization.

1. Introduction

The formation process of a granite cave is complete different from that of common limestone karst caves and volcanic lava caves. At present, more than 40 granite caves have been discovered in Laoshan and can be divided into primary and subsequent caves according to their cause of formation. The existence of these caves is an important symbol of the paleogeographic environment or primitive environment of magma. They are small, but they are significant in constituting the tourism geological landscapes of Laoshan. Among the "top twelve scenes of Laoshan", three are based on caves.

2. Geological Setting

Laoshan, a massive granite mountain, is located east of the urban area of Qingdao city, covering an area of 446km². The main peak Laoding (Jufeng) has an elevation of 1,132.7m, around which are mostly lower mountains between 500 and 1,000m high. Under the action of weathering and gravitational collapse on the joints and fractures of the granite, the peak-forest landform has developed. Most stone columns are in the shape of "Gu" (hill with steep sides and a flat top). Pictographic rocks and caves are very common (Figure.1). Therefore, the tourism geological landscapes of Laoshan have been summed up as "marvelous peaks, grotesque caves and bizarre rocks"[Committee of Qingdao Chronicles Compilation (1999) has reported].

The granite rock mass of Laoshan is a composite mass formed after several times of emplacement along the deep fracture in the late Yanshan Period, which can be mainly divided into three sub-superunits, Mount Fu, Stone Gate Mountain and Laoding Peak[Institute of No.4 Geological Prospecting in Shandong Province(2003) has reported, Zhao et al(1996) has reported]. The coarse grain alkaline granite of Laoding

sub-superunit is light grey, greyish white or light flesh red, which is miarolitic granite. The main minerals are potassium feldspar and quartz. The rocks feature coarse-grain granite texture, porphyritic-like texture or graphic texture and are of massive structure or miarolitic structure. The miarolitic caves developed are in different sizes, with diameters of generally 1-3 cm or even dozens of centimeters. Cairngorm or amethyst crystals often occur in the miarolitic caves [Song et al (2012) has reported, Song et al (2013) has reported].

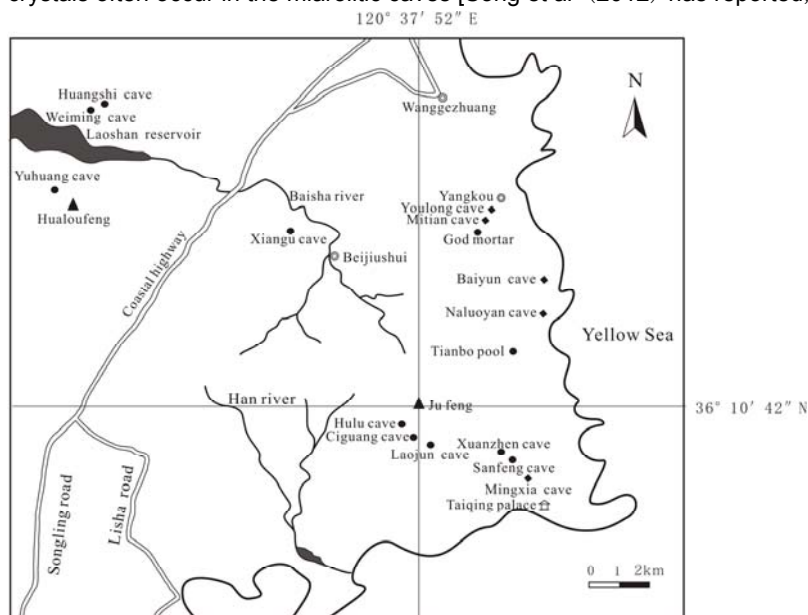


Figure.1. Location of main granitoids cave in Laoshan

3. Genesis of Granite Caves

Among the granite caves of Laoshan, some are subsequent caves which have been formed under the destructive effect of internal and external forces, while some are primary caves which have been formed from condensed magma (Table 1).

3.1 Subsequent Caves

A subsequent cave is formed from exposed granite under the action of weathering, gravity and piling. The joints and fractures of rocks also play a significant role. The subsequent caves consist of the following three types (Figure.2).

Table 1 Typical cave of laoshan

Name	Coordinate	Shape and Size
Mingxia cave	36°09'18"N, 120°39'45"E; 459m	Rolling Stone piled Cave, H:3m, W:6m, D:10m
Youlong cave	36°13'60"N, 120°39'32"E; 220m	Rolling Stone piled Cave, H:2m, W:4m, D:8m
Mitian cave	36°13'46"N, 120°39'13"E; 235m	Fracture Rolling Stone Cave, H:70m, W:6m
Naluoyan cave	36°12'15"N, 120°39'57"E; 450m	Weathered Slipping Cave, H:30m, W:10m, D:36m
Laojun cave	36°10'03.44"N, 120°37'26.59"E; 650m	Ellipsoid, Diameter 1.4m, 0.7m, 1.7m, Smooth wall
Huangshi cave	36°15'23"N, 120°29'45"E; 650m	Two ellipsoidal holes are connected together, the Diameter of inside hole 1.6m, 1.5m, 1.3m; the Diameter of outside hole: 1.2m, 1.2m, 1.1m, Smooth wall
Ciguang cave	36°10'06.14"N, 120°37'25.94"E; 736m	Ellipsoid, Diameter: 2m, 1.9m, 1.3m, Smooth wall
Xuanzhen cave	36°09'21.17"N, 120°39'41.46"E; 536m	Ellipsoid, Diameter: 2.6m, 2.1m, 1.85m, Smooth wall
Yuhuang cave	36°14'02"N, 120°29'40"E; 301m	Ellipsoid, Diameter: 3.1m, 2.6m, 2.4m, Smooth wall

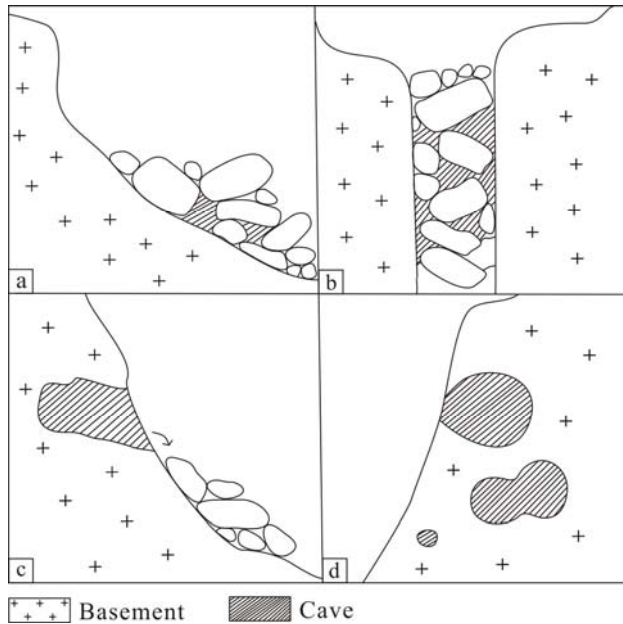


Figure.2. Type of Laoshan Granite caves

a Rolling Stone piled Cave; b Fracture Rolling Stone Cave; c Weathered Slipping Cave; d Primary Cave

3.1.1 Rolling Stone piled Cave

The rolling stone piled cave is also known as rolling stone cave. The granite of Laoshan is situated in a strong physical environment of weathering. Along three groups of joints which are nearly vertical to each other, the rock mass is often cut into many huge cube or cuboid rocks, which keep collapsing and rolling from the cliff under the gravity and become rolling stones broken away from the bed rock. Huge rolling stones can be seen almost everywhere at the slopes and valleys of Laoshan, and their side lengths can reach 5-10m, or even 20-30m. When some rolling stones stack together, the gap left among them might become a "cave"(Figure.2a). This type of caves is the commonest at Laoshan. For example, Mingxia Cave was formed by a huge rock about 20 meters long and three smaller rocks beneath it, which is 3 meters high, 6 meters wide and 10 meters deep (Figure.3a); Youlong Cave was formed by a huge rock and five smaller rocks beneath it(Figure.2b); and Bailong Cave, Mitian Cave and Lianhuan Cave, etc. also belong to this type. This type of caves can also be found at Mount Huangshan, a granite mountain in Anhui Province [Jing (1984) has reported].



Figure.3. a Mingxia cave in Taiqing palace;

b Youlong cave in Yangkou

3.1.2 Fracture Rolling Stone Cave

This type of caves were formed when many huge rolling stones were clamped in the gap between two confronting cliffs. They usually occur on the structural fracture belt with a width of only several meters or dozens of meters. Inside the fracture belt, rocks are crushed into pieces most easily under the crustal stress, while the rocks on both sides are relatively complete. The crushed stones, under the action of weathering, underground water and gravity, are gradually displaced, collapsed and piled up. The gaps between stones or between stones and the cliff will form caves (Figure.2b). With the development and evolution of this type of

caves, the stones might be stripped gradually and finally only a lane between two confronting cliffs is left, or it develops into a landform landscape such as "stone gate" or "a thin strip of sky". Fracture rolling stone caves of Laoshan mainly include Mitian Cave at the Yangkou Scenic Spot (Figure.4a). With a vertical height of 70m and a width of several meters, Mitian Cave is divided into five layers by several large rolling stones. Climb along the manmade stairs in the cave, and you can reach straight to the top of Mount Yuanshan. Xuankong Cave was also formed by several huge stones clamped between rock gaps. Besides, at the southeast of Duimen in the Jufeng scenic spot, you can clearly see a row of stones clamped between the gaps, which are a bit small, but are a best reflection of this geological phenomenon. This type of caves are also common to see at Mount Lafa, a granite mountain in the east of Jilin Province, and are known as "structural collapse cave"[which was recently confirmed (Cheng and Chen, 1995)]; this type of caves found at Mount Taimu, a granite mountain in the northeast of Fujian Province, can be several thousand meters long, and are known as "fracture lane cave"[Yao (1995) has reported, which was recently confirmed (Liang and Wen, 2009)]; and the Immortal Cave and Turtle Cave, etc. in Mount Huangshan should also belong to this type[Jing (1984) has reported].

3.1.3 Weathered Slipping Cave

Weathered slipping cave is also called Dismantled Stone Cave, which is a type of prismatic cave embedded into the bed rock on the cliff. Since the fracture joints of granite are cut, in the course of weathering, some stones might slip off the cliff, while the space left will develop into a cave (Figure.2c). The bottom of the stones inclines towards the side of the rock mass high up in the air; under the lubrication of underground water in the melting course, stones will slip off from the rock mass. The major example of this type of caves at Laoshan is Naluoyan Grotto. The cave is 30m high, 10m wide and 36m deep, with an elevation of 340m, where no remains of the ancient coastline have been discovered (Figure.4b). At the top of the cave is a queer small round opening, which is difficult to observe and might be a primary cave (which will be discussed below) that happened to connect with the cave. In fact, the niche-shaped weathered slipping caves are common on cliffs.



Figure.4. a Mitian cave in Yangkou; b indoor scene of Naluoyan cave

Besides, subsequent caves developed from other causes of formation can also be seen in Laoshan. For example, at the areas with a relatively low elevation there are some sea caves and might also be some wind eroded caves at different heights, all of which are not large and not typical in formation and thus have no important status among the landscapes of Laoshan.

3.2 Primary Cave

At present, a batch of primary granite caves have been discovered in the tourist attraction of Laoshan[Committee of Qingdao Chronicles Compilation (1999) has reported, Song et al (2012) has reported, Song et al (2013) has reported], which are commonly called bubble-like caves(Figure.2d).. They are embedded into the bed rocks and usually take the shape of an ellipsoid, with a small entrance and a large cavity. The walls of the cavity are round and smooth, with perfectly preserved mineral crystals. Totally different from the sea caves and wind eroded caves, they show no trace of external forces such as weathering and corrosion. The most typical one should be the Yuhuang Cave at the Hualou Scenic Spot (Figure.5a), which is located below the cliff of Cuiping Rock, with a diameter of 2.5-2.7m. The Bubble-like Caves of Laoshan also

include Huangshi Cave north of Laoshan Reservoir (Figure.5b) etc. These several caves have a diameter of 1-2m.



Figure.5 a Yuhuang cave in Hualou; b Huangshi cave in Jufeng

The several caves mentioned above all appear in the miarolitic granites of Laoding sub-superunits. In recent years, there are already quite many researches in the miarolitic granite in China (including Laoshan) [Zhao et al (1996) has reported, Shan et al (2014) has reported], which mainly explore cooling speed and uplifting process of magma through studies of mineralogy, geochemistry and isotopic age [which was confirmed (GAO and Ding (2011)), Wu et al. (2007) has reported]. It's generally believed that miarolitic granite occurs in Type an alkaline granite and is the outcome of craton rift valley tectonic environment of non-orogenic zones [which was recently confirmed (Yuan and Yu, 1994)]. Miarolitic granite belongs to sub-volcanic facies, with a positioned depth not exceeding 3km [Qiu et al. (2002) has reported, Shi et al. (2004) has reported]. A lot of miarolitic development is related with H₂O, C₂O, F and other volatile gas under the gas and liquid phases in the magma. A little gas might be left between crystalline minerals, which develops into very small prismatic magma miarolitic. However, in the magmatic activity process, steam saturation state might occur due to changes of physical and chemical conditions or the infiltration of underground water and meteoric water. They exist in the form of separated liquid drops in the semi-solid magma, and bubble-like (CO₂ is isolated) or boil when the pressure drops in the tensional environment, which will give rise to miarolitics of various shapes. Miarolitic in fact is a kind of huge fluid inclusion. The miarolitics discovered in the past are generally not large. For example, among the miarolitics at the Qianyang rock mass of Fujian Province, the size of several millimeters is common; the size of miarolitics at Kuiqi rock mass is also mostly several millimeters, and 30-50mm at the maximum; the size of miarolitics at the Jiuhuashan rock mass of Anhui province is mostly 5-30mm [Wu et al. (2015) has reported]. The granite miarolitics of Laoshan are indeed relatively large.

In 1995, a huge granite cave was discovered in alaskite of Mount Lafa, Jilin Province. The cross section of the cave is elliptic, with a diameter of 2-3 m and a depth of 22m. The mode of formation of such a huge granite cave might be this way. Since the pressure declined abruptly, or a lot of underground water had infiltrated, large bubble-likes came into being and were condensed into a cave. So it was called "Bubble-like Cave"[Song et al (2013) has reported].

4. Geological Significance and Development Values of Granite Caves

1. The development of subsequent granite caves depends on the characteristics of the rocks (fractures and joints). However, the nature of weathering is more important. Under the warm and damp climatic conditions, granite is mainly weathered chemically and forms a round landform; the landform of Laoshan can only be formed under the ancient environment where the mechanical weathering was very strong. Restored according to the ancient climate, at the last glacial maximum period, the climate in the North China region was extremely dry and cold. Laoshan should be situated at the periglacial belt along the isothermal line with an average annual temperature of 0°C. The granite was mainly weathered mechanically. This period was the period with very strong activities such as gravitational collapse and mudslide as well as the major formation period of subsequent caves. This type of caves not only developed at Laoshan and Jilin with a higher latitude, but also developed in Fujian with a lower latitude. This indicates that during the last glacial maximum period, there was a very vast area based on mechanical weathering in the east of China.

2. The primary granite caves exist in the miarolitic granite in the sub-volcanic facies. The physical and chemical conditions for their formation were very complex [Zhao et al. (1998) has reported]. Currently, the formation process of miarolitics and bubble-like caves still need to be further studied. The bubble-like caves and huge miarolitics are quite different from common miarolitics in size, which might not be simply interpreted with the general crystallization process of water in minerals. It's probably because the pressure declined abruptly when magma reached near the earth's surface, or it was greatly influenced by the formation water and meteoric water, which was more similar to the formation process of bubble-like caves of basalt erupted from a volcano.

3. Viewed from the angle of granite miarolitic, Yuhuang Cave of Laoshan is so far the "largest granite miarolitic" known in China. Viewed from the angle of bubble-like cave, it's also the second bubble-like cave discovered in China, so it is a very rare geologic relic.

4. In recent years, a lot of "natural stone mortars" of granite have been discovered. People are debating on its cause of formation, with theories such as "ice mortar theory", "wind mortar theory" and "flowing water theory". The discovery of primary granite cave at Laoshan at least can explain the cause of formation of some "natural stone mortars" of granite, which is a new inspiration for the scholars believing in the aforementioned theories.

5. In the famous National Tourist Attraction of Laoshan with convenient traffic and a long history, the discovery of bubble-like caves or huge granite miarolitics is of great values for sightseeing and science popularization, and the caves can be rolled out as a new geological tourism product.

Acknowledgments

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