Investigation on Distribution Characteristics of Deterioration in Helan Pass Rock Arts

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Abstract. The Helan Pass rock arts in Ningxia Province, China, have undergone severe decay and showed some typical forms of deterioration, including scaling off, crack, and collapse. These three forms of deterioration in the Tiger Town region to water-off were quantitatively counted to analyze their distribution characteristics. The statistical windows were used for crack studies to investigate distribution regularities of ten aspects such as attitude, class number, and spacing. The findings reveal that 17 of the 25 rock arts in the Helan Pass study area developed scaling off in the rock masses’ surfaces. A total of 130 cracks in the 19 statistical windows were located predominantly in the lower part of the mountain. In addition, 15 collapses occurred and were mostly in the upper part of the mountain. The crack locations with different filling types were concentrated. Further, the crack apertures were related to their filling types, and the apertures of siliceous filling cracks were generally larger, whereas the argillaceous filling cracks were mostly medium apertures. In addition, the apertures of grouting cracks were varied, and the apertures of nonfilling cracks were small.

Keywords: Helan Pass Rock Arts, Sealing Off, Cracks, Collapses.

1. Introduction

Rock arts have surfaced in 150 regions across 70 countries as carriers of ancient tribal culture, ancient people’s living habits, and important historical events. The rock arts in the Helan Relics Park, Ningxia province, China are concentrated in the Helan Pass [1]. Helan Valley has complex occurrence conditions, and torrents are frequently caused by sudden rainstorms and snowstorms. The rock mass surface is frequently subjected to rapid temperature and humidity alternation, thereby sustaining severe damage. Thus, it is imperative to preserve the rock arts in Helan Pass.

Studies on colored rock paintings have recently proliferated, including infrared thermal imaging deterioration detection technology [2-3] of Huashan rock paintings in Guangxi and prevention of rock paintings’ pigment fading [4], investigation of Lascaux Cave paintings’ microbial disease in France [5], and Altamira Cave paintings in Spain [6]. However, research on the carved rock paintings in northern China is limited to archaeological methods [7] and regional distribution characteristics [8]. The study of the weathering mechanism and reinforcement scheme of the carved rock paintings from the cultural protection perspective is only beginning.

This study performs a quantitative analysis of the distribution characteristics of the three forms of rock art deterioration in Helan Pass, such as scaling off, crack, and collapse. This
investigation forms the basis of a more in-depth investigation into the deterioration factors of rock arts and serves as a guide for analyzing the structural and local stress characteristics at different locations throughout Helan Pass, calculating the stability of rock mass, and taking reinforcement measures.

2. Methods of Investigation on Rock Arts Deterioration

The rock arts are mainly distributed at the entrance of the valley in Helan Rock Arts Relics Park, thus the survey area is from Tiger Town to Water Off, as shown in Fig. 1. The development of scaling off is closely related to the rock arts as they are attached to the rock surface, and it gradually denudes the carved paintings and damages their integrity (Fig. 2a). Fig. 2b shows that the coexistence of scaling off and crack have resulted in severe damage to the rock arts; collapse poses a significant threat to the rock arts (Fig. 2c).

![Fig. 1. The distribution of rock arts in Helan Pass.](image)

In this paper, the distribution characteristics of rock art deterioration in the study area are statistically analyzed, and their overviews are listed in Table 1. The number of rock arts with scaling off in the study area was obtained, and the proportion of scaling off range was statistically evaluated.

The statistical window, 4–8 m long and 1.5–5 m wide, was used to investigate the cracks, of which the length was near the horizontal direction with the ground. The following crack contents were quantitatively estimated: 1) Geological compass can quantify the occurrence of each crack in the statistical window, which reflects the stability of historical and current rock mass. 2) The crack parameters in the statistical window were recorded and the average class spacing was calculated since crack intensity is demonstrated by the class number, spacing, crack continuity, and block size. 3) The cracks can be divided into three grades based on the roughness, namely, smooth, flat, and rough, and the joint roughness coefficient (JRC) index was employed for the statistics. 4) The crack aperture not only affects the stability of the rock mass but is closely related to the crack’s protection scheme. Therefore, the aperture was evaluated using the feeler gauge and caliper. 5) The cracks are divided into four types based on their filling types: siliceous filling, argillaceous filling, grouting, and no filling, and the statistics were made. 6) Field investigation was conducted on the crack sidewall’s compressive strength and seepage characteristics.
3. Distribution Characteristics of Deterioration

3.1. Scaling Off

Scaling off was widely observed on the rock surface. There are 17 rock arts with scaling off among the 25 rock arts in the study area. There are up to four spalling layers, each of which is mostly 3–6 mm thick. The scaling-off area accounted for about 40% of the rock surface in the study area. The rock arts are at risk of disappearing at any moment due to the scaling off; thus, reinforcement measures should be implemented to slow down the progression of scaling off.

3.2. Crack

The cracks are predominantly developed in the lower part of the mountain. A total of 19 statistical windows with length of 4.0–8.0 m and width of 1.5–5.0 m were designated from the Tiger Town to Water Off (Fig. 1 and Table 2).

Table 1. Overviews of deterioration of rock arts in the study area.

| Forms of deterioration | Status |
|------------------------|--------|
| Scaling off            | Among the 25 rock arts, there are 17 rock arts with scaling off, accounting for about 40% of the rock surface. |
| Crack                  | There are 19 statistical windows with densely distributed cracks, a total of 130 cracks. |
| Collapse               | Collapse occurred at 15 sites in the study area. |

The following features the field examination of the collapses that pose a threat to the safety of tourists and rock arts in the study area: 1) The collapses were classified into five categories based on the formation mechanism, such as toppling, sliding, bulging, pull-apart, and staggered collapses, and the forms of these collapses were investigated. 2) Field measurements of the collapse scale, i.e., the width, height, and thickness, were conducted. 3) The lithological characteristics were investigated. 4) The rock mass weathering degree was also assessed.

Table 2. The results of the statistical window.

| Statistical window number | Specification: m | Occurrence | Class number | Crack number | Average class spacing: m |
|---------------------------|------------------|------------|--------------|--------------|--------------------------|
|                           |                  |            |              |              | Group A | Group B | Group C |
| 1                         | 5.0 × 2.0        | 350° ∠ 40° | 3            | 7            | 1.45    | 0.92    | 0.37    |
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2  4.0 × 3.0  210°  30°  3  9  0.60  1.35  /  
3  4.0 × 2.0  180°  80°  1  4  0.20  /  /  
4  4.0 × 1.5  240°  85°  3  6  1.00  0.28  /  
5  7.0 × 5.0  210°  19°  2  8  0.94  0.86  /  
6  5.0 × 3.0  204°  65°  1  4  0.69  /  /  
7  6.0 × 3.0  193°  80°  3  8  /  0.58  1.29  
8  8.0 × 3.0  130°  44°  1  5  1.31  /  /  
9  7.0 × 3.0  266°  66°  3  6  2.03  0.99  /  
10  6.0 × 3.0  36°  46°  2  8  2.47  1.45  /  
11  8.0 × 3.0  18°  73°  3  9  2.04  1.59  /  
12  5.0 × 2.0  23°  68°  2  6  1.05  0.57  /  
13  5.0 × 2.5  52°  57°  3  7  0.80  1.79  /  
14  4.0 × 2.5  22°  80°  3  5  /  0.62  /  
15  7.0 × 3.0  320°  69°  4  11  0.51  0.41  2.23  
16  5.0 × 2.5  46°  56°  3  6  0.99  /  /  
17  7.0 × 3.0  130°  24°  4  10  0.58  0.50  /  
18  5.0 × 2.5  66°  48°  3  7  1.06  0.82  /  
19  4.0 × 2.5  39°  50°  3  4  0.20  /  /  

Note: "/" indicates no or only one crack.

**Occurrence.** The rose diagram showing the strike, dip direction, and dip angle of the crack was drawn to indicate the main strike of the crack. The strike of 130 cracks was adjusted to NE and NW (where N = North; E = East; W = West), i.e., 270°–90°. The rose diagram of the strike, dip direction, and dip angle was conducted at 10° intervals, such as 0°–9°, 10°–19°, and 20°–39°. The main strike of the cracks in the rock arts is 43° (Figs. 3 and 4).

**Class number, spacing, absolute continuity, and block size.** Cracks are divided into groups A, B, C, etc., denoted as A1, A2, and A3. (Fig. 5). Table 2 indicates a 2–3 class number. The spacing can be applied to characterize crack density. The statistical window’s cracks are categorized and the spacing is measured, subsequently, the average class spacing is obtained. The crack spacing is 0.20–2.23 m, and the average spacing is 0.96 m (Table 2). The crack length is about 3.88 m, thus the continuity is medium. Block size is expressed by the volume crack number (\( Jv \)), using the scan line method. The number of cracks (N) per unit length measured is about 0.877, and K = 2, thereby \( Jv = K \times N = 1.75 \) /m³.

![Fig. 3. Rose diagram of dip direction and dip](image)

![Fig. 4. Rose diagram of block size](image)

![Fig. 5. Sketch map of the](image)
the crack strike. angle. statistical window.

**Roughness.** The typical profile of the JRC proposed by N.R. Barton was employed for quantitative statistics of crack roughness in the field investigation, and the results are presented in Table 3.

**Table 3. JRC distribution.**

| Rank | JRC | Number of crack |
|------|-----|-----------------|
| 1    | 0~2 | 7               |
| 2    | 2~4 | 27              |
| 3    | 4~6 | 32              |
| 4    | 6~8 | 23              |
| 5    | 8~10| 14              |
| 6    | 10~12| 9               |
| 7    | 12~14| 8               |
| 8    | 14~16| 6               |
| 9    | 16~18| 3               |
| 10   | 18~20| 1               |

**Aperture.** The crack aperture was measured using a combination of a feeler gauge and caliper. The size of the gauge is 0.02–1.0 mm. The crack aperture in rock arts was classified into narrow (<2.5 mm), medium (2.5–10 mm), and wide (>10 mm) [9]. The aperture of various filling types was analyzed, as shown in Table 4 and Fig. 6. The cracks with wide aperture accounted for 80% of the siliceous filling cracks, with the widest aperture up to 17 cm and the narrowest one close to 0. The argillaceous filling cracks largely consist of medium apertures, accounting for 54.55%, whereas the aperture of grouting cracks varied. Crack grouting is a method used to artificially reinforce cracks. Most unfilled cracks have small apertures, with only 18.48% of them being wide. In general, narrow, medium, and wide apertures of cracks in rock arts account for 25.39%, 46.92%, and 27.69%, respectively. The distribution characteristics of crack apertures can provide a basis for further rock art protection in Helan Pass.

**Table 4.** The aperture distribution of cracks.

| Filling type   | Siliceous filling | Argillaceous filling | Fissure grouting | Non-filling |
|----------------|-------------------|----------------------|------------------|-------------|
| Aperture       | <2.5              | 2.5~10               | <2.5             | <2.5        |
|                | 2.5~10            | >10                  | 2.5~10           | 2.5~10      |
|                | 1                 | 6                    | 4                | 2           |
|                | 8                 | 7                    | 3                | 45          |
|                | 20.0              | 80.0                 | 54.6             | 48.9        |
|                | 9.1               | 36.4                 | 41.2             | 18.5        |
| Cracks number  | 0                 | 2                    | 8                | 0           |
|                | 8                 | 1                    | 6                | 0           |
|                | 1                 | 4                    | 3                | 0           |
|                | 0                 | 0                    | 0                | 0           |
| Percentage: %  | 0                 | 20.0                 | 80.0             | 9.1         |
|                | 8.0               | 1.0                  | 6.0              | 0.1         |

**Filling characteristics.** There are four filling types of cracks in the study area, which include siliceous filling, argillaceous filling, crack grouting, and no filling. Fig. 7 shows that the filling types of cracks are mainly nonfilling cracks, with 92 cracks, accounting for about 70.77% of the total number of cracks. Field investigation demonstrates that only five statistical windows have two or more filling types among 19 statistical windows, and the other 14 statistical windows have only one filling type. Therefore, the location of the siliceous filling, argillaceous filling, and fissure grouting is relatively concentrated. This is due to the influence of light, rain erosion, wind erosion, and other natural environments in different Helan Pass directions. The mechanical properties of filling materials were conducted via a simple manual index field test. Silicone fillings, which are difficult to mark with thumbnail and are hard, are classified as S6 grade and have a uniaxial compressive strength of above 0.5 MPa. Clay filling cannot be moved by the thumb press, but scoring it with the thumbnail is easy. Thus, clay filling is hard and is categorized as S5 grade, with a uniaxial compressive strength of 0.25–0.5 MPa. Nanjing Museum has adopted crack grouting as a reinforcing strategy to preserve rock arts, and the mechanical properties of rock masses have been improved. Unfilled cracks are mainly closed with small apertures, and their mechanical properties depend on the side walls.

**Compressive strength and seepage characteristics of crack sidewall.** Field investigation demonstrates the difficulty of scratching the rock mass with a knife and sampling it with a
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gеological hammer. The rock needs to be knocked several times before being destroyed and is
categorized as R5 grade due to its hardness, with a uniaxial compressive strength of 100–250
MPa. Further, the nonfilling crack is waterless, whereas siliceous and argillaceous filling
cracks are moist and have no free water. The crack seepage level of the rock arts in Heilan
Pass belongs to ⅱ level based on the classification standard of crack seepage level in rock
mass [10].

The above analysis indicates that the crack spacing in the study area is generally distributed
in 0.7–1.5 m, and the class number is mostly 2–3. The overall strength of the rock mass is
high, thus, it has a massive structure and is relatively complete [11].

3.3. Collapse
The rock arts in Helan Mountain were subjected to a once-in-a-century torrent from August
21 to 22, 2016. The collapse caused the crushed stones to fall, reducing the stability of the
rock masses, and even damaging or breaking the rock arts. The collapse is mainly distributed
in the upper part of Helan Mountain in the study area.
Categories of collapses. There has been 15 collapses in the study area, with four of them
being toppling collapses. The formation of such collapses is linked to the once-in-a-century
torrent. The width of the cracks between the rockfall and the mountain is 3–5 cm. The
rockfall is cut by cracks and is vulnerable to external forces such as earthquakes and
rainstorms, posing a significant threat to the rock arts in the lower part of the mountain, as
well as tourists, staff, and tour guides of the Helan Rock Arts Relics Park. The other 11
locations are tensile collapse, which protrudes from the mountain like a cantilever beam, with
the size of the protruding part varying (Fig. 8), causing the mountain’s surface to be
noticeably uneven. The upper protruding rock mass is easily knocked down by gravity and
weathering, inflicting significant damage.

Fig. 6. The aperture distribution of cracks. Fig. 7. The filling types of the protruding rocks.

The collapse scale. The collapse scale is closely related to its risk. Statistical investigations
revealed that the volume of the rockfall is 6–150 cm³, all of which are small-scale collapses.

Lithologic characteristics of rockfall. The rock arts in Helan Pass are located in the middle
section of the eastern foothills of Helan Mountain. The rock mass is primarily turquoise with
a little gray and light purple-red. The rock mass is mainly composed of loose Quaternary
alluvial and diluvial strata, and Mesozoic Triassic feldspar and quartz sandstone.

Weathering degree of rockfall. Because the Helan Valley is long and narrow and the
mountain is high, the wind at the gully’s entrance thus increases dramatically, posing a
serious threat to the rock arts. The bedding of the Helan Mountain rock mass is relatively
obvious, with a thickness of 0.2–3.5 m. The overall dip direction is SE (where S = South) and
the dip angle is 35°–50°. The rock mass has many cracks. The joint plane divides the rock
mass into blocks (0.16–2.23 m). Some cracks have been grouted, others are filled with mud or
gypsum, while several others are unfilled or have a small amount of weathering material. The
Helan Pass rock arts have a medium weathering degree according to the Code for Design of Building Foundation [12].

4. Conclusions
1) There are 17 rock arts with scaling off among the 25 rock arts. Scaling off is widely distributed in the rock surface at a certain depth, accounting for about 40% of the rock surface. There are up to four peeling layers, and the layer bonding is weak.
2) There are a total of 130 cracks in the 19 statistical windows located mostly in the lower part of the mountain. The cracks have a class number of 2–3, a crack spacing of 0.20–2.23 m, and a medium continuity level. The crack filling type is mainly nonfilling (accounting for 70.77% of the total). Crack filling characteristics vary by location. The siliceous filling cracks have a big aperture, whereas argillaceous filling cracks have a medium aperture. Grouting crack apertures vary, whereas nonfilling crack apertures are often small.
3) There are a total of 15 collapses developed in the study area, 4 of which are toppling collapses, and the other 11 are tensile collapses, which are mainly distributed in the upper part of the mountain. The volume of the collapse is 6–150 cm3, all of which are small rockfalls, and the mountain’s weathering degree is moderate.

This study only conducted a preliminary analysis and investigation on the distribution characteristics of rock arts in Helan Pass. The degradation of rock arts is a lengthy process that poses a significant challenge for scientists conducting the study. It is exceedingly difficult to protect rock arts. Therefore, more research into the protection and reinforcement strategy is required.

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