Types and Formation Mechanisms of Karst Landforms in Zecha Stone Forest Geopark: Postprint

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Abstract

Zecha Stone Forest Geopark is located in Luqu County, Gansu Province, where the landforms completely preserve the characteristics of alpine karst, exhibiting both typicality and rarity. To reveal its natural scientific value and promote natural resource development and landscape conservation, and based on previous research, this study—through field geological investigation and against the regional geological background of Luqu County—introduces the karst landform types of Zecha Stone Forest Geopark, which consist primarily of plateau stone forests, highlighted by the "One-Line-Sky" feature, and supplemented by small-scale caves. Subsequently, the formation mechanism of karst landforms within the park is analyzed from four perspectives: geological structure, lithology, hydroclimate, and biological factors. This research holds certain significance for advancing scientific studies on the karst geological heritage series in China' s high-altitude regions. Furthermore, the ecological processes of alpine karst provide an exemplary model for the management of karst desertification in southern China.

Full Text

Geomorphic Types and Formation Mechanism of the Karst Landform in Zecha Stone Forest Geopark

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Abstract

Zecha Stone Forest Geopark is located in Luqu County, Gansu Province, China. The landform in this area preserves intact features of alpine-arctic karst, with typicality and rarity. In order to reveal its natural scientific value and promote natural resource development and landscape protection, the regional geological and geographic backgrounds of Luqu are briefly described based on previous work and field investigation. The types of karst landform in Zecha Stone Forest Geopark are introduced, which include the highland stone forest as the majority, the thin strip of sky light spot, and small karst caves as complementarities. The formation mechanism of the karst landform has been further analyzed from four aspects: tectonics, lithology, climate, and biology. The results show that the tectonic movement, the development of joint fissures, and the difference of rock cementation degrees laid a foundation for the formation of karst landscape. Moreover, under the alpine-arctic and dark climate condition with great changes, water corrosion, frost denudation, and weathering formed the unique alpine-arctic karst landscape in this area, which was characterized by many bedrocks and steep walls, tall stone forest and pillars, a few karst caves with poor connectivity and small size. The research provides some academic information of the karst landform in Zecha Stone Forest Geopark, which has certain significance in the scientific research on karst geological relics in high altitude areas of China. The ecologicalization of alpine-arctic karst provided a good reference for the governance of karst desertification in the south part of China.

Keywords: Karst landform; formation mechanism; stone forest; Eastern Qinghai-Tibet Plateau; Luqu

2. Geological Background

2.1 Stratigraphy and Lithology

The study area exhibits well-exposed strata from the Triassic, Devonian, Carboniferous, and Permian periods, with lithologies primarily consisting of limestone, dolomite, and carbonate rocks (Table 2). The geological structure is dominated by a monoclinal formation striking NW-SE, with rock layers dipping 40-60° to the SW. The main lithological units include:

- $\mathbf{T}_{1\ 2}$ **w**: Gray, medium-thick bedded limestone with dolomitic limestone, containing calcite veins
- $\mathbf{D}_3$**t**: Gray-white, thick-bedded fine crystalline dolomite with limestone interlayers
- $\mathbf{D}_2$**d**: Dark gray, medium-thick bedded limestone
- $\mathbf{D}_2$**g**: Gray-white, thick-bedded dolomitic limestone

The total thickness of carbonate rocks exceeds 2000 m, with the stone forest developed primarily in the Triassic and Devonian limestone formations. The rock composition is predominantly calcite ($CaCO_3$), with minor dolomite [$CaMg(CO_3)_2$] and quartz. The CaO/MgO ratio ranges from 0.8-1.0 in pure

limestone and 0.4-0.7 in dolomitic limestone, indicating favorable conditions for karst development.

[Figure 1: see original paper]

Table 2 Karst stone forest landscape in Qinghai-Tibet region

Parameter	Value Range
Elevation	2100-4308 m
Stone forest height	20-50 m
Development degree	Strong
Karst features	Stone pillars, dissolution grooves, caves

The structural geology shows that the area is located in a tectonically active zone, with well-developed joint systems providing pathways for water infiltration and dissolution. The main joints strike NW-SE and NE-SW, with densities of 3-5 per meter.

3. Formation Mechanism

3.1 Tectonic Factors

The tectonic movement since the Cenozoic era has created a foundation for karst development through: 1. **Faulting and folding**: Creating fracture networks that increase rock permeability 2. **Uplift**: The Himalayan orogeny raised the region to high altitude, exposing carbonate rocks to intense physical and chemical weathering 3. **Joint development**: Three main joint sets control the orientation of stone pillars and dissolution features

3.2 Lithological Factors

The formation of the stone forest is controlled by lithological heterogeneity: - **Pure limestone layers** ($CaCO_3 > 90\%$) show intense dissolution, forming deep grooves and pillars - **Dolomitic limestone** shows selective dissolution along bedding planes - **Insoluble residues** (clay, quartz) form protective caps on pillar tops, preventing uniform denudation

The differential dissolution rates between calcite (solubility 0.014 g/L) and dolomite (solubility 0.032 g/L) create stepped profiles in the stone forest.

3.3 Climatic and Hydrological Factors

Under alpine-arctic climate conditions (mean annual temperature 2.3°C, minimum -9.5°C, maximum 12.4°C), the formation mechanism involves:

Chemical dissolution:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

$$H_2CO_3 + CaCO_3 \rightleftharpoons Ca^{2+} + 2HCO_3^-$$

Annual precipitation of 633.9 mm provides sufficient water for dissolution. The freeze-thaw cycle (150-180 days/year) accelerates physical weathering, with water expanding by 9% upon freezing, exerting pressures up to 200 MPa in rock fissures.

Frost weathering: Temperature fluctuations around 0°C create effective frost shattering, particularly on exposed pillar surfaces. The process is enhanced by: - High moisture availability from snowmelt - Rapid temperature drops (10-15°C diurnal range) - Well-developed joint systems providing water access

3.4 Biological Factors

Vegetation plays a dual role in karst formation: 1. **Root wedging**: Plant roots penetrate fractures, with root expansion pressures of 0.5-2 MPa mechanically widening cracks 2. **Biochemical dissolution**: Root exudates (organic acids) lower pH from 7.0 to 5.5-6.0, enhancing carbonate dissolution by 2-3 times 3. **Microbial activity**: Microorganisms produce CO_2 and organic acids, accelerating chemical weathering

The sparse alpine vegetation (coverage <30%) limits biological effects compared to tropical karst regions, but root action is concentrated in joints, creating localized enhanced dissolution.

4. Conclusion

The Zecha Stone Forest represents a unique alpine-arctic karst landscape formed by the interaction of tectonic uplift, lithological heterogeneity, freeze-thaw weathering, and limited biological activity. The landscape is characterized by: - **High relief**: Stone pillars 20-50 m tall - **Steep walls**: Vertical cliffs controlled by joint systems - **Poor cave development**: Limited horizontal connectivity due to rapid vertical denudation - **Active processes**: Ongoing frost shattering and dissolution at rates of 0.1-0.3 mm/year

This research provides insights into karst evolution in high-altitude, cold environments and offers references for comparative studies with tropical karst regions.

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Note: Figure translations are in progress. See original paper for figures.