AIMS Geosciences

AIMS Geosciences, 10(1): 141–171.
DOI: 10.3934/geosci.2024009
Received: 17 November 2023
Revised: 14 February 2024
Accepted: 28 February 2024
Published: 11 March 2024

http://www.aimspress.com/journal/geosciences

Research article

Sustainable development of geological resources: the Characteristics of Red Karst Landscape and Tourism Development in Tongren, Guizhou

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Abstract: China is rich in karst resources and famous for its karst landscape. As a part of karst, the popularity of red karst is obviously low and has received little attention; moreover, the related scientific research and tourism development are relatively immature. Therefore, this paper takes the red karst in Tongren, Guizhou as the research object, analyzes the characteristics and causes of the red karst, comprehensively evaluates its landscape value, and puts forward development strategies and protection suggestions. Through the above research, the following three research results are obtained. (1) On the basis of a field investigation and a literature review, the geographical situation, background, and landscape characteristics of the red karst landform and its surrounding areas in Tongren City were investigated in detail. It forms isolated peaks, rock walls, protruding rocks, stone pillars, and other forms. The most prominent features of the red karst landscape in Tongren City are that the color is red and white, and the shape is concave and convex in order. (2) Geochemical test and structural data collection and analyses of the collected samples were performed. The obtain concave layer rock is dolomitic limestone, and that convex lay rock is argillaceous dolomitic limestone. Because the convex layer rock sample is high in silicon element content, the convex layer rock sample is not easy to be weathered, is rich in clay mineral, and is not easy to be corrode; the convex layer rock sample gradually protrudes with the passage of time to form an uneven shape. The red karst landform is developed in either the rock stratum or tectonic zone with moderate tectonic deformation intensity. First, the formation of a single-layer honeycomb morphology requires that the rock stratum is subjected to a sufficient horizontal compressive stress at a certain burial depth. Second, it is necessary to widely exist

in areas with relatively gentle rock formation occurrence; too strong of a structural deformation will make the rock formation occurrence steep, which is not conducive to the occurrence of differential dissolution between adjacent strata. (3) Through the construction of an evaluation index system, the red karst in Tongren City is evaluated, and it is concluded that the geological heritage value is high, and the development and utilization conditions are weak. The conclusion of this article is a supplement to the geological and geomorphological system characteristics of southern karst. From the perspective of world natural heritage, the study enriches the academic evidence of red karst and enables its exemplary role to be well played. From the perspective of the tourism development value, more people should be made aware of the diverse types of karst landforms, which provide experience and suggestions for the value of landforms, tourism resources, and tourism development in similar areas.

Keywords: Guizhou; red karst; Potential Value; Geological Features

1. Introduction

Karst physiognomy refers to the physiognomy produced by the comprehensive geological action of water on soluble rocks (carbonate rocks, sulfate rocks, and halide rocks), and is characterized by chemical dissolution. Its main forms are peak forest, peak cluster, cave, karst ditch, and so on. The area of karst in the world is about 20 million km^2, which accounts for 12% of the total area of the world. Karst is widely distributed in China, with a total area of 3.443 million km^2, which accounts for about 1/3 of the total land area. [1,2]

The "Southern Karst" with Guizhou as the center, which covers an area of about 1.12 million km^2, has formed a rich and colorful karst landscape in southwest China, and has always been a key area for scientific research. From 2019 to 2022, Fuwei Jiang, Youzhi Chen, Ning Yu, and other scholars from the scientific research group of Guizhou Institute of Technology conducted a field geological survey in Tongren, Guizhou Province, and found that the unique red eaves karst physiognomy, which looks like palaces, fortresses, and ravines, is a precious karst geological relic with important scientific and ornamental values. It is worth noting that there are no reports and discoveries in the previous national geological and general surveys of tourism resources in Guizhou Province. On the basis of consulting and comparing the domestic and foreign literature, and through the systematic and detailed study of geology, petrography, and mineralogy, we believe that red karst is a new type of karst physiognomy, and put the concept of red karst forward within the field. This paper takes the red karst developed in Tongren area of Guizhou as the research object, collects and analyzes the data of the characteristics and causes of the red karst, makes a supplementary test and analysis of the samples, comprehensively evaluates the landscape value of this area, and puts forward targeted development strategies and protection suggestions. The discovery of red karst is not only a supplement to the karst physiognomy, but also brings direct benefits to the local economy, which has a high scientific research value and social benefits (Figure 1) [3–6].

Figure 1. Top view of red karst (Drone photography).

2. Materials and methods

This paper focuses on the characteristics of the red karst landscape and its tourism development strategies in the study area through the methods of geo-chemical analysis, literature research and analysis, expert consultation, and field visits.

We inquire and read domestic and foreign literature, collect relevant information, and lock in the research object. By reading a large number of domestic and foreign literature related to karst landforms, we can understand the research status and progress of karst landforms at home and abroad, and focus on consulting the research related to red karst and its tourism development. On this basis, the research framework and content of the characteristics of red karst landscape and its tourism development in Liantang Village are determined. According to the geographical and geological situation of the study area, the area of the resource investigation and the specific content of the work are determined.

Through many field investigations, we fully understand the characteristics of the red karst landform in Liantang Village, the relationship between different landscape landforms and stratigraphic lithology, and discuss the conclusions of the field investigation with experts in related research fields.

Through the geochemical analysis of rock samples, the lithology of red karst in Tongren is determined, the development process is understood, and the genesis of appearance characteristics is analyzed.

Based on the investigation of the red karst geological heritage resources in the area, combined with the standard requirements, the evaluation index system is constructed, the quantitative evaluation is made by the index analysis method, the characteristics and value of the red karst in Liantang, Jiangshan are analyzed, combined with its development status, its advantages are brought into full play,

the reasonable tourism development strategy is studied, and then the protective suggestions are put forward.

3. Geological distribution and morphological characteristics of red karst

3.1. Overview of regional geology

The exposed strata in northeastern Guizhou mainly include the Lengjiaxi, Banxi, and Fanjingshan Groups of the Neoproterozoic Qingbaikou System, the Lianghejie, Tiexiao, Datangpo, and Nantuo Formations of the Nanhua System, the Doushantuo Formation of Sinian System, the Niutitang, Mingxinsi, Jindingshan, Qingxudong, and Gaotai Formations, and the Loushanguan Group of the Cambrian System, the Ordovician Tongzi, Honghuayuan, Dawan, Shizipu, Baota, Jiancaogou, and Wufeng Formations, the Lower, Middle, and Upper Silurian, the Permian Qixia, Maokou, Wujiaping, and Changxing Formations, the Mesozoic Yelang, Jialingjiang, and Guanling Formations, and the Cenozoic.

Northeast Guizhou is located in the circum-Pacific tectonic domain and is also affected by the subduction of the Pacific plate and the mantle plume in eastern China. Because it is far away from the tectonic high belt of the orogenic movement, with the middle Nanling Mountains as the core, the fold deformation has a large range, though its influence depth is shallow; it belongs to the category of thin-skinned structures, and the granitic magma emplacement of the crust-derived and crust-mantle mixed source has not been affected. The magmatic activity is the emplacement of calc-alkaline lamprophyre in the intraplate stage. Calc-alkaline lamprophyre magma related to the subduction of the Pacific plate and the mantle plume in eastern China was emplaced along the fault zone displayed by the nearly north-south gravity gradient zone, from the Late Cretaceous period of the Mesozoic era to the Paleogene of the Cenozoic era, in the extensional stage after the Yanshan movement at the end of the Early Cretaceous period. The Himalayan magma around the study area was emplaced by mantle-derived calc-alkaline lamprophyric magma in an extensional environment [7–11].

Metamorphic rocks in the area have experienced a complex and multi-stage metamorphism and deformation. Due to the different tectonic positions, formation ages, tectonic conditions, physical and chemical conditions, and protolith formations, the metamorphic rocks in different areas have created complex and changeable metamorphic rock features. Metamorphic igneous rocks include the following: basic-ultrabasic intrusive rocks and acidic intrusive rocks of the Fanjingshan Group are metabasic rocks, metaultrabasic rocks, and metaacidic intrusive rocks formed by later metamorphisms. The main rocks are metaperidotite, metapyroxene peridotite, metaperidotite pyroxenite, metagabbro, metagabbro-diabase, metamorphic spilite-quartz keratophyre, metamorphic quartz albite porphyry, and metamorphic muscovite granite. Metamorphic clastic rocks include the following: Qingbaikou system slate, blastoclastic sandstone and conglomerate, Nanhua System metamorphic moraine conglomerate, and the Xiajiang Group metamorphic sandstone and conglomerate. Metamorphic minerals include sericite, chlorite, biotite, tourmaline, pyrite, zircon, and other accessory minerals. Metamorphic pyroclastic rocks include the following: metamorphic volcanic tuff of the Fanjingshan Group, metamorphic sedimentary tuff, metamorphic tuffaceous rock, blastoclastic volcanic agglomerate, blastoclastic volcanic breccia, and metabasic volcanic rock. The rocks are of either blastoclast texture or blastclast sedimentary tuff texture. Metamorphic minerals include sericite, chlorite, biotite, actinolite, albite, quartz, epidote-zoisite, pumpellyite, and calcite. Metamorphic

siliceous rocks include the following: siliceous rocks associated with spilite-quartz keratophyre in the Fanjingshan Group, often with a microgranoblastic texture, and mineral assemblages of siliceous, chlorite, sericite, quartz, and titanium-bearing minerals. The study area is located at the junction of four provinces, with Wuling Mountain running through it. The whole basin is a mountainous landform with a complex terrain, continuous mountains, and ravines. The highest point of the terrain is located in the Fenghuang Mountain (2572 m above sea level) among the Wuling Mountains. The main mountain trend is consistent with the tectonic line. Except for the dome landform of the Fanjing Mountain, the other areas are mainly karst landforms. The main peaks in the study area are the Fanjing Mountain (2572 m), the Laoling Mountain (1523 m), the Fodingshan Mountain (1869 m), and the Songtaolar Mountain (1300 m). The main strata of karst landform development in the study area are dolomite from the upper part of the Lower Cambrian to the lower part of Lower Ordovician and dolomite of the Lower Triassic. The degree of karst development is not high, mostly forming hill cluster landforms, including hill cluster mountains and hill peak valleys, followed by karst landforms such as peak cluster valleys, peak cluster canyons, fault valleys, and ridge troughs. Due to the difference of topographic conditions, the cone shape can be divided into two types: one is the gentle hill and round hill cone peak distributed in the wide and gentle watershed and flat basin; the other is the hill cluster mountain formed by overlapping mountain slopes, which is mostly located near the hill peak with large slope. There is a lack of closed depressions and funnels between hills and peaks in the study area, while dense dry gullies, valley bottoms, and dendritic surface rivers are developed [12–18].

3.2. Morphological characteristics of red karst

According to the field investigation results of Jiang Fuwei, Yu Ning, and others, the exposed area of red karst in the study area is about 140.1 km^2. The exposed area of red karst in the east is 40.7 km^2, mainly distributed in the Mengxi Town, the Jiujiang Township, the Huangban Township, the Yajiang Town, and the Panshi Town in the easternmost part of the study area. It is distributed in the north-northeast (NNE) and northeast (NE) directions in a strip shape, with good comprehensive landscape formation conditions. There are 21 world-class geological relics of red karst. The red karst in the middle of the study area is poorly developed and sporadically exposed. It covers an area of 1.6 km^2 and is located in the northeast of the Wuluo Town, showing a strip distribution in the northeast direction, with poor comprehensive landscape formation conditions. The red karst in the west of the study area is well developed, with an exposed area of 97.8 km^2, mainly distributed in the areas of the Heshui Town, the Muhuang Town, the Tiantang Town, the Daoba Township, the Yongan Township, the Ganxi Town, and the Xiaojing Township in a NNE and NE direction and in a strip shape. The red karst distributed near the Tiantang Town has poor landscape formation conditions due to the structural development in this area. The structure of other areas is relatively simple. Due to the influence of topography and rock occurrence, the comprehensive landscape formation conditions are general.

3.2.1. Color characteristics

The red karst geological relics are mainly red, supplemented by white, and the two are embedded in each other (Figures 2–4). On the profile, the color of the red karst geological relics has obvious stratification. For example, the red karst exposed in the La'er Mountain Scenic Area is divided into five layers from top to bottom: red, white, red, white, and red. The thickness of the white rock layer is

7–8 m, accounting for about 20% of the total thickness. Locally, the color of red karst geological relics is characterized by red and white inlay; for example, the rock stratum dominated by white is inlaid with red. From the degree of embedding, it can be divided into three types. The first is a red and white uniform interbedding type: the thickness of the red stratum is the same as that of the white stratum, and one layer of white and one layer of red are mutually superimposed, mainly distributed in the transition area of the red and white stratum rock surface. The second is a white strip embedded type: the horizontal white strip with a thickness of 1–3 cm is embedded in the rock surface, which is generally colored, with a small white area, mainly distributed in the thick-bedded red layer. The third is a white spot type: white appears in an independent area with a small spatial distribution area, surrounded by red, mainly distributed at the bottom of Dawan Formation.

Figure 2. Overall in Red.

Figure 3. Local white mainly.

Figure 4. Red and white interbedded type.

3.2.2. Morphological characteristics

According to the detailed investigation of the outcrop points of the red karst geological relics, its overall morphological characteristics have three typical characteristics: concave and convex orderly, vertical and horizontal ravines, and grotesque rocks. The concave-convex order is the biggest characteristic of red karst, and its shape is reflected in the superposition of concave and convex layers. According to the field survey and statistics, the thickness of the concave and convex layers is basically the same (i.e., the layer thickness is about 30–40 cm), and the concave-convex degree of adjacent rock surface is very uniform, mainly about 20–40 cm, up to 1–2 m locally (Figure 5). Among them, the total number of visible concave-convex layers in the red karst of Laer Mountain is between 90–100, which has a strong sense of concave-convex and gives people a strong visual impact and shock. This is different from other karst landscapes, such as karst caves, peak clusters, peak forests, underground rivers, Tiankeng, stone forests, and so on. Usually, the geological relics with the characteristics of concave-convex order in morphology basically have the characteristics of red and white layers in color, and the strong contrast of morphology and color is mainly developed in world-class geological relics.

Figure 5. Surfaces with varying roughness.

The vertical and horizontal ravines are the product of the crustal uplift movement of the red karst strata. It cuts the red karst development strata into different shapes of blocks and provides an interface for the transformation of geological agents in the later stage. In the red karst outcrop area of La'er Mountain, there are dense gullies, with a general depth of 6–8 m, more than 30 m in some areas, and a width ranging from tens of centimeters to several meters. The minimum plane size of the rock block formed by cutting is 100 cm^2, that is, the length and width are about 10 cm (Figure 6). Compared with other rock surfaces, the concave-convex degree of the interface on both sides of the gully is 10–20% higher, and the interfaces are very close to each other; therefore, the concave-convex and gully combination forms a shape with more impact and shock.

Figure 6. Vertical and horizontal ravines (taken by UAV).

Another important feature of red karst is the presence of grotesque rocks, which is the result of later geological agents on the basis of gully cutting, and concave and convex rock surfaces. On the surface of the red karst stratum, there are many abrupt rocks with irregular shapes, which have great differences in shape. The rock surface is uneven, with a general height of 0.5–2.0 m and a volume of less than 1 m^3. In the red karst outcrop area of La'er Mountain, various types of grotesque rocks stand in great numbers and are arranged irregularly, thus forming a beautiful landscape (Figure 7).

Figure 7. Interesting and Irregular red karst.

3.2.3. Micro-dynamic characteristics

The overall morphological characteristics reflect the large outline of the red karst appearance, but it contains rich and colorful micro-morphology. These microscopic forms shape the beauty of red karst. According to the investigation in the red karst outcropping area of La'er Mountain, we have summarized nine basic forms of the red karst appearance, that is, the appearance is composed of one or more types. The main forms are listed below.

Box-shaped: It is mainly developed in the relatively pure limestone layer, and its shape is similar to a box. Cut by two sets of vertical parallel joints, the rock mass is cut into angular cuboids. In the later stage, under the corrosion of groundwater, the edges and corners are gradually corroded and gradually evolve into arcs. However, due to the small difference in the mineral composition of the rock mass, the dissolution rate is small, and the whole mass remains box-shaped.

Conical: It is mainly developed in the rock formation where the carbonate composition gradually decreases from top to bottom. The upper part is mainly developed in relatively pure limestone, which is strongly corroded by groundwater due to the high content of carbonate. Due to the long-term corrosion of groundwater, the upper rock mass is gradually corroded and degenerates into a sharp cone. The content of carbonate in the lower basement decreases, while the content of argillaceous increases gradually. In the process of carbonate dissolution by groundwater, the argillaceous components play a role in either isolating or delaying the contact between groundwater and carbonate components, thus

resulting in a slower dissolution rate. Due to the difference of carbonate and argillaceous components, it forms a cone with a sharp top and a wide bottom.

Boat-shaped: It is composed of multiple layers of oval rock strata of different sizes, with a strong sense of concave-convex, and the color has obvious characteristics of red and white. The shape of the ship is a cuboid stone column cut by two sets of parallel joints, and the groundwater along the fissures shows the differential dissolution of the stone column. The rock layer with fast dissolution is concave, thus forming the shape of the ship bottom. The rock layers with slow dissolution are relatively convex, thus forming the shape of the ship's side. The horizontal rock surface forms the deck form, while the upper multi-layer concave-convex rock surface forms the multi-layer cabin structure.

Mushroom-shaped: It is composed of large rocks at the top and small at the bottom, which are located on the rock surface. The rock composition is different: the upper rock has a low carbonate content and high argillaceous content, while the lower rock has a high carbonate content and a low argillaceous content. There are two basic stages in its formation: first, the rock mass is cut into cuboids by two sets of parallel joints; and second, the rock masses with different mineral contents are corroded by groundwater. The lower part of the concave rock dissolution is faster, thus forming a mushroom foot, while the upper part of the convex rock dissolution is slower, thus forming a mushroom cap. Finally, it develops into a mushroom stone.

Columnar: It is a feldspathic column cut by grid-like joints. Under the corrosion of underground water, the edges and corners of the stone column are gradually flattened and develop into a columnar shape. Due to the difference of carbonate rock content in the rock mass, the rock surface of the pillar is uneven, and the size is different between the upper and lower parts. However, due to the uniform degree of differential dissolution, it has not developed into a concave and convex layer.

Eaves: It is the most basic element that constitutes the form of red karst geological relics. It is composed of red and white rock layers with a thickness of 30–40 cm. Morphologically, it has a strong feature of one concave layer and one convex layer, and the concave-convex layer is 20–40 cm. Limestone layers with more calcareous components are strongly corroded by groundwater, and the corrosion rate is fast and concave. The argillaceous limestone with fewer calcareous components is weakly corroded by groundwater, and the corrosion rate is slow and relatively convex. Because the attitude of the rock stratum is nearly horizontal and the concave-convex layer extends for a long time, the shape of the eave is formed (Figure 8).

Figure 8. (1) Box (2) Conical (3) Boat Shape (4) Mushroom-shaped (5) Columnar (6) shape of the eave capitalized.

4. Geochemistry

4.1. Major element

In this study, a total of 9 fresh rock samples were collected in the red karst area, numbered TR 01-TR 9, including 4 concave rock samples, convex rock samples, and 2 thick limestone samples. Samples were sent to the Wuhan Shangpu Analysis Technology Co., Ltd. for major element testing of

rock samples. The sample was manually ground through a 200-mesh using an agate mortar, thus ensuring no contamination during the grinding process. The 200 mesh sample was dried in a 105 ℃ oven for 12 hours. Next, 1.0 g of the dried sample was weighed and placed in a constant weight ceramic crucible. Then, the sample was burned in a 1000 ℃ muffle furnace for 2 hours. The sample was removed and cooled to room temperature before weighing, and the loss on ignition was calculated. Then, 6.0 g of flux, 0.6 g of sample, and 0.3 g of oxidant were weighed and placed in a platinum crucible. The crucible was melted at 1150 ℃ for 14 minutes in a sample melting furnace. The crucible was removed and transferred to a refractory brick for cooling. Finally, the glass sheet was taken out for X-ray fluorescence spectrometer (XRF) testing. The main element content of the entire rock was analyzed by the Wuhan Shangspectrum Analysis Technology Co., Ltd. using the Japanese Primus II XRF. The data obtained after XRF testing is shown in Table 1.

Table 1. Principal element analysis data of red karst.

Number	TR01	TR02	TR03	TR04	TR05	TR06	TR07	TR08	TR09
location	Convex	Concave	Convex	Concave	Convex	Concave	Convex	Thick limestone	Thick limestone
SiO2	29.34	18.14	33.17	15.16	36.15	17.32	33.45	28.15	24.07
TiO2	0.58	0.23	0.76	0.21	0.62	0.22	0.81	0.22	0.53
Al2O3	4.92	2.51	6.94	2.48	6.75	2.48	8.13	2.38	6.65
FeO	0.58	0.32	1.32	1.04	0.37	0.79	1.33	1.57	1.37
TFe203	2.64	0.57	3.94	1.41	3.07	1.24	4.12	2.34	2.23
MnO	0.08	0.12	0.13	0.26	0.09	0.08	0.11	0.16	0.06
Mg0	2.94	0.91	4.81	3.74	3.14	1.28	3.97	16.21	12.14
Ca0	29.13	43.02	21.72	39.97	27.24	38.19	23.05	23.24	20.27
Na20	0.02	0.01	0.03	0.01	0.02	0.01	0.03	0.03	0.05
K20	3.87	1.72	3.87	1.43	3.35	1.47	4.12	1.37	3.63
P205	0.11	0.07	0.17	0.07	0.15	0.11	0.15	0.05	0.17
CaO/MgO	9.91	47.27	4.52	10.69	8.68	29.84	5.81	1.43	1.67

According to the data in the table, it can be observed that the CaO content in all samples was relatively high, close to the theoretical value of dolomite, though the MgO content in dolomite was high. According to the delimitation of chemical composition of sedimentary rock, it can be seen that the chemical composition of these samples is more consistent with limestone. Generally speaking, the concavity and convexity of the rock stratum is the product of surface differential weathering. The rock stratum with weak weathering resistance was concave in an inward direction, and the rock stratum with strong weathering resistance protruded outward. According to the field survey, the lithology of the convex layer of red karst is marl, and the lithology of the concave layer is limestone. From the strength of the rock mass mechanics, the anti-weathering ability of limestone should be stronger to form a convex layer, and the anti-weathering ability of marl containing marlstone should be weaker to form a concave layer. However, the actual situation is the opposite. The anti-weathering ability of the concave limestone rock mass was weak, and the anti-weathering ability of convex marl containing marlstone was strong. The red karst has a concave-convex orderly shape, which is very different from the weathered concave-convex layer on the surface of the common landform landscapes such as the

Yadan and Danxia landforms, which indicates that weathering of red karst may only play a small role in becoming the current shape, and other roles still need to be discovered.

Because the sedimentary environment affects the enrichment, dispersion, and migration of elements, the contents of various elements in sedimentary rock are closely related to their sedimentary environment, and their geochemical characteristics are also different. In sedimentary environments, pure carbonate rocks are often formed in still water environments, while flowing water disrupts the still water environment and brings mud, often forming limestone containing mud and sand. The ratio of elements can reflect ancient salinity, thereby restoring the sedimentary environment [19]. The content of Mg2+in carbonate rocks is one of the methods used to indicate ancient salinity. When the ratio of CaO/MgO is low, it indicates that the rock layers were formed in sedimentary sites in coastal and shallow sea areas, with high water temperatures and shallow water depths, which are more easily disturbed and belong to unstable carbonate rock facies. When the ratio of CaO/MgO is high, it indicates that the rock layer was formed in a deep-sea low water temperature environment and belongs to a relatively stable carbonate rock facies. According to the results of major element testing, it can be seen that the numerical difference in the CaO/MgO ratio of the convex layer sample in the red karst concave layer is significant. The convex layer rock is deposited in a shallower coastal environment with more disturbance and can directly receive the supply of terrestrial materials, and the ratio of the concave layer sample is relatively high; the convex layer of red karst is developed in a relatively deep seawater environment, with fewer disturbances and the ability to receive a supply of terrestrial materials. However, compared to the convex layer rocks, it is relatively less, and the rocks are more pure. From this, it can be concluded that the convex layer rocks were deposited in a coastal environment and received a large amount of terrestrial material, thus forming muddy dolomite limestone. Concave rocks are limestone containing white clouds that are formed in deeper seawater environments and receive less terrestrial materials.

4.2. REE element

Ten carbonate rock samples were selected and sent to the Guangzhou Aoshi Test and Analysis Center for trace element test in an inductively coupled plasma mass spectrometry (ICP-MS) laboratory (Table 2). The test standard is DZ/T0223-2001, and the analysis error is less than 5%. The results of the rare earth element analysis and testing are shown in Table 1 after the standardization of chondrites. The rare earth elements in the North American Average Shale (NASC) and the Australian Post Archean Shale (PAAS) are used to represent the characteristics of rare earth elements in the crust. The NASC and PAAS shales are rich in light rare earth elements, with a stable content of heavy rare earth elements and significant negative Eu anomalies. The distribution of rare earth elements in the Dawan Formation - Guniutan Formation of La'er Mountain is similar to that of NASC and PAAS, with enrichment of light rare earth elements and negative anomalies in Ce and Eu [20] (Figure 9).

Table 2. Analysis data of trace elements in red karst.

Sample	Lithology	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Tr-D-1	Bioclastic limestone	65.06	44.17	42.61	33.7	15.34	13.35	15.03	14.25	12.17	11.15	11.01	10.77	11.19	16.36
Tr-D-2	Purple red limestone	84.31	57.56	53.3	41.01	19.15	15	16.82	15.86	13.55	12.28	12.22	12.16	12.89	18.06
Tr-D-3	Nodular limestone	52.02	35.49	33.86	27.06	11.65	$12.02	13.06	12.62	10.73	9.87	9.75	9.61	9.88	15.05
Tr-D-4	Nodular limestone	64.03	45.75	43.37	35.1	16.83	15.57	16.29	15.8	13.71	12.41	12.09	11.79	7.21	12.38
Tr-D-5	Argillaceous limestone	416.7	69.98	260.8	216.07	134.84	85.34	99.65	107.03	100.37	87.98	82.11	74.45	72.45	77.62
Tr-D-6	Detrital limestone	83.69	56.48	50.88	38.93	17.58	15.41	16.22	15.48	13.32	12.1	11.96	11.83	12.3	17.47
Tr-D-7	Limestone	64.29	45.74	41.59	33.3	15.74	14.75	15.74	15.17	13.08	11.81	11.53	11.22	11.48	16.65
Tr-D-8	Purple red limestone	90.06	53.83	50.95	40.01	18.32	16.04	17.59	16.54	14.36	13.14	12.8	12.37	12.67	17.84
Tr-D-9	Limestone	66.74	44.12	40.54	31.29	13.60	13.82	14.24	13.82	12.03	11.06	11	11.07	11.65	16.82
Tr-D-10	Purple red limestone	87.57	61.98	57.56	45.99	23.88	18.35	19.84	19.02	11.41	14.81	14.52	14.23	14.86	20.03

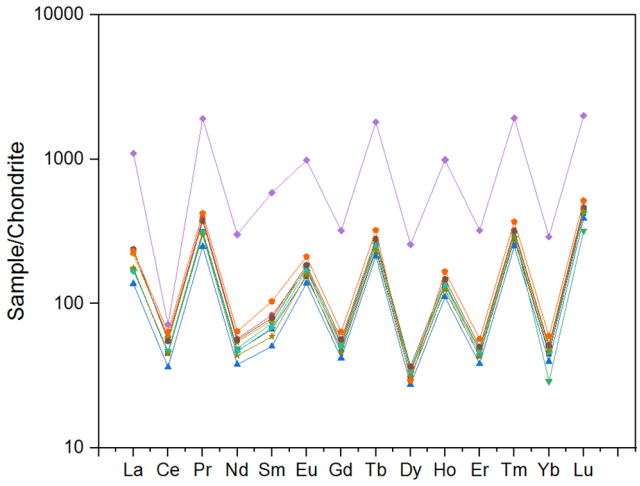

Figure 9. Standard of the chondrite from the rare earth element distribution model.

4.3. Analysis

The environment where water and carbonate dissolution occur is the red karst formation environment. The ability of water to dissolve carbonates is related to the H+ solubility (or pH) of the water; under natural conditions, H+ is formed by the reaction between CO_2 and H_2O (dissolved in water). Therefore, red karst is formed in acidic environments. Due to the fact that the red karst morphology is the result of dissolution, and corrosive groundwater containing a high amount of H+is the driving force of dissolution. In general, corrosive groundwater is more abundant at interfaces such as joints and fissures. Therefore, the degree of concavity and convexity formed by dissolution on the interface is often strong. The amount of CO_2 dissolved in groundwater determines its corrosiveness. Usually in areas with lush vegetation (weeds), the soil contains a high amount of microorganisms, which produce more CO_2 through metabolic processes. Therefore, the CO_2 solubility in areas where weeds grow is greater than in areas without grass. The formation process of red karst is shown in Figure 16. The material basis for the formation of red karst is the red-white interbedded limestone argillaceous limestone. Among them, gray-white limestone is often formed in shallow still water environments, while muddy limestone is often formed in disturbed muddy water environments. Due to the tectonics, the crustal uplift makes the limestone argillaceous limestone in the shallow sea exposed on the surface. Under surface weathering, limestone argillaceous limestone and its overlying strata are continuously eroded, and the generated soil remains in place, thus covering the parent rock. These overlying residual soil block the denudation of the parent rock by surface weathering. In addition, the high concentration of CO_2 generated by microbial interactions in soil dissolves in groundwater, and the generated carbonate (corrosive groundwater) has a corrosive effect on carbonate. Corrosive groundwater has a promoting effect on the dissolution rate of carbonate rocks, which is related to the carbonate content. Limestone has a high carbonate content and a fast dissolution rate, while muddy limestone has a low carbonate content [21]. Moreover, mud blocks the corrosion reaction between corrosive groundwater and carbonate, thus resulting in a slow dissolution rate of muddy limestone. The difference in dissolution rate under this soil leads to the sinking of sedimentary strata with a fast dissolution, and the protruding of sedimentary strata with a slow dissolution, thus forming a red karst with concave convex order.

4.4. Discussion

According to the research of many scholars, the "red karst" rock series of the Dawan Formation and the Guniutan Formation of Middle-Lower Ordovician in western Hunan, southeastern Chongqing, and northeastern Guizhou is composed of purplish red and greyish green carbonate rocks. Zhao Jun [19] found the red karst stratum was mainly divided into two parts. The first part was the purplish red Dawan Formation with greyish-green nodular limestone and argillaceous limestone, which was widely distributed in the southern margin of the Yangtze block. The second part was located above the Dawan Formation and below the Baota Formation, with purplish red nodular limestone and argillaceous limestone intercalated with grayish green bioclastic limestone, interbedded locally, and small cracks were generally developed in this set of strata.

Based on the field outcrop observation, microstructure analysis, and element geochemical analysis, Chen Youzhi [20] discussed the causal relationship between uplift and red karst landform from the perspective of tectonic deformation. They believed that the Caledonian Guniutan Formation was formed in a dry and hot climate environment, and the development of Qianzhong-Xuefeng uplift affected the salinity of sedimentary water and the content of clay minerals in the strata, which limited the geomorphological development area and basic morphological framework. During the late Indosinian-early Yanshanian period, NE-trending cleavages were formed, which were affected by the northwestward thrusting of the Xuefeng uplift and developed along the "tortoise crack" structural weak zone in the penecontemporaneous period, and the limestone gravels were enclosed by cleavages and stylolites, and honeycomb-like cleavages were formed by the differential dissolution of groundwater in the later period. During the late Yanshan-Neotectonic period, the Xuefeng uplift continued to thrust northward, and the study area was dominated by uplift and denudation, thus forming multiple sets of conjugate joints. The red karst strata were uplifted to the near-surface, and the groundwater was eroded along the joints, eventually forming the red karst landform (Figure 10).

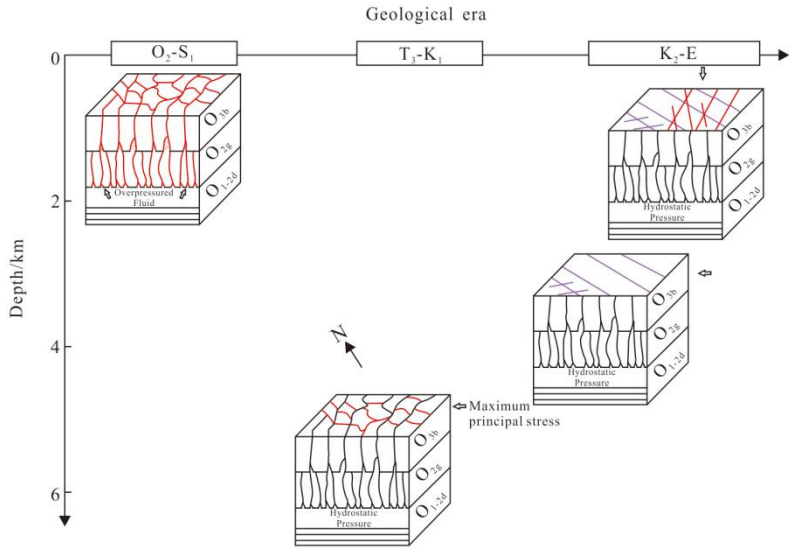

Figure 10. Red karst geomorphologic evolution pattern(modify).

Jiang Fuwei [21] identified that the shaping force of red karst was differential dissolution and the plastic environment was soil coverage through surface water pH, soil pH, and CO_2 solubility tests and rock thin section identification. The formation conditions of red karst are the topography and geomorphology with parent rock exposed surface, the lithology of purplish red argillaceous limestone intercalated with grayish white limestone, the erosive groundwater with dissolution, the covering soil layer provides the development site of dissolution and the joint fissure provides groundwater infiltration. The formation process of red karst is as follows: shallow sea environment-formation of limestone-argillaceous limestone; exposure of the surface to weathering; formation of the covering soil layer in the original place of weathered soil residual; dissolution of the high-solubility CO_2 in soil into groundwater to form erosive groundwater; formation of concave-convex masses ordered red karst by differential dissolution of limestone-argillaceous limestone.

Cui [22] selected the red karst weathering crust of Hunan-Guizhou-Guizhou-Yunnan-Tibet for systematic comparison. The results of regional comparison show that there is no obvious regional difference in the chemical composition, mineral assemblage, and grain size composition of the red karst weathering crust. Cui believes that this may reflect the roughly similar landscape conditions at the same latitude when the unified planation surface was formed, thus indicating that it is possible to use the weathering crust to study and solve the planation surface correlation in large areas. In the red karst weathering crusts, different weathering and leaching indices indicate different development stages of the weathering crusts, and the analysis results of high silica-alumina ratio and silica-alumina-iron ratio in the clay, cation exchange capacity, and clay mineral assemblage show that the red karst weathering crusts have different development stages. It shows that clay minerals are dominated by the type and other indicators reflect that the weathering crust is in a low degree of development, the effect of desilication and aluminum enrichment is weak, the degree of base leaching and relative leaching rate are small, the weathering degree of soil is high, the content is low, the content of milk particles is high, and the ratio of silt to clay is large, which reflects the high stage of weathering crust development. The gentle relief is not conducive to the drainage of surface water, which greatly inhibits the effective leaching of the weathering crust, resulting in the weak desilication and alumina-enrichment of the weathering crust and the high silica-alumina ratio, which verifies the existence of a unified planation surface from the side. At the same time, the geochemical characteristics of the weathering crust on the planation surface are revealed. The landscape of the planation surface under the humid and hot climate conditions were generally characterized by poor drainage and shallow groundwater depth, which is conducive to the formation of clay particles; however, the long-term stagnant environment limits the migration of silicon, resulting in the dominant type of clay mineral association. Additionally, this reveals that the characteristics of clay mineral assemblage of weathering crusts on the planation surface and the content and value of weathering crust have obvious differentiations in the east-west direction, thus reflecting the difference of modern environmental conditions in the east-west direction of the study area; therefore, this kind of index has no paleoenvironmental significance.

5. Red karst landscape evaluation

At present, the evaluation methods of the geological heritage resources are mainly composed of qualitative and quantitative analyses. A qualitative analysis is based on the evaluator's own knowledge, experience, and personal experience of the value of geological heritage resources and their natural characteristics.Although qualitative evaluation can be performed in an evaluation result, which is

generally recognized in a relatively short period of time and have the characteristics of conciseness and prominent features, these depend on the subjective ideas of the evaluators, and different evaluators may have different views. Therefore, it is necessary to use a quantitative analysis to evaluate the red karst landscape resources in the Tongren area qualitatively and quantitatively. The analytic hierarchy process has the characteristics of high systematicness and logicality, as well as the flexibility and conciseness. The quantitative analysis method of this study was to use the analytic hierarchy process to quantitatively evaluate the value of red karst geological heritage resources [22–26].

5.1. Qualitative evaluation

5.1.1. Value of scientific research

As a kind of geological relic resource, the red karst landform is non-renewable. The formation of red karst landscape in the Tongren area has a long history, and it is one of the strata that are easy to form the karst landscape in China. This place sank below the sea level in ancient times, and after the vicissitudes of life, it formed the red karst that stretches for several miles today. The red karst in this area is mainly composed of argillaceous dolomitic limestone and dolomitic limestone, which are rare in karst landforms in China. At present, most of the research on "South China Karst" at home and abroad is still concentrated in the first batch of heritage sites (Shilin in Yunnan, Libo in Guizhou, Wulong in Chongqing); there are few reports on red karst and karst in Tongren area. Although Tongren red karst is not a typical representative at home and abroad, it can play a certain role in filling in the study of karst geography in the world natural heritage.

5.1.2. Aesthetic and ornamental value

Red karst has formed a unique landscape after hundreds of millions of years of vicissitudes, corrosion, weathering, and other external forces, as well as chemical and biological effects. Based on the Chinese aesthetic tradition, the natural beauty of mountains and rivers includes the beauty of image, color, dynamic, line, static, auditory senses, and olfactory senses. Summarizing the beauty of red karst, we can obtaining three characteristics: image beauty, color beauty, and line beauty. Image beauty is the basis of natural beauty of famous mountains and great rivers. The overall shape of the red karst shows the characteristics of concave-convex order, which is composed of columnar, pagoda, boat, funnel, wall, and hole. The landscape is ever-changing and colorful, and in the core landscape area, there are craggy rocks, such as "Immortal House", "Longyou Gate", "Champion", "Buddhist Sutra Tube", and "Millennium Kiss". The texture of these water-like stones is unique. After years of carving, they have different shapes and are lifelike. Some are like mussels, some are like turtles, and some are like lions. They look interesting and the color is beautiful. One of the characteristics of red karst is that the rocks mainly show red, thus forming a red and white layered structure. As seen from a distance, the mountains seem to have numerous well-dressed brides to be married, and the crimson colors and the green trees in the mountains add radiance and beauty to each other, which is very lively. The color of rocks will change with the change of sunshine or weather. On a cloudy day, the rocks look yellow as a whole. At noon on a sunny day, the color of the rocks is particularly bright. Purple and gray tones add radiance and beauty to each other. The sunset glow in the evening not only dyes the sky red, but also makes the red karst look more ruddy, just like a shy girl hiding in the mountains.

Moreover, there are beautiful lines. The concave-convex order is another major feature of red karst. The protruding red rock layer and the concave white rock layer are superimposed on each other, flat, and rhythmic. From a distance, the red karst looks like layers of coral reefs, which are very beautiful. From a closer look, it looks like the pages of a book, which are stacked layer by layer, with different colors and are beautiful [23].

5.1.3. The value of popular science education

The origin of the sea, land, mountains, and rivers, and the causes of strange mountains and rocks naturally arouse people's infinite reverie. At present, the red karst landscape area is developed from the carbonate rocks discovered earlier. It has gone through the vicissitudes of life to form what it looks like today. This is a natural classroom given to us by nature, vividly talking about the changes of the earth over millions of years. Through the popular science education of the formation process of red karst, tourists can learn about the changes of the earth's land and sea, as well as the differences of karst landforms, why red karst forms phenomena such as concave-convex layers, red and white alternations, and crisscross knife cutting patterns, to improve their knowledge and self-cultivation. Additionally, it can let tourists understand the evolution process of the geological environment, promote people to look at the world with a more scientific perspective, strengthen historical materialism, and stimulate the interest of tourists and middle school students to explore the world and learning science. In addition, by popularizing the differences between the Yadan landform, the Danxia landform, and red karst, we can raise people's attention to these landform types, expand the publicity, and attract experts, scholars, geoscience enthusiasts, and primary and secondary school students to study and observe.

5.2. Quantitative analysis

Understanding the basic resource attributes of geoscience tourism resources is the premise of tourism development, and mastering the types and grades of resources can achieve the rational development and utilization of resources. This quantitative analysis divides Tongren red karst tourism resources according to the classification criteria of geoscience tourism resources in the Dictionary of Tourism Geoscience, establishes a comprehensive evaluation model of geoscience tourism resources from the perspective of the tourist’s needs, and then evaluates red karst tourism resources by using techniques and methods such as a network data crawler, a quantitative text analysis, and the analytic hierarchy process. Preparations are made to develop and utilize resources in the later stage.

5.2.1. Types of geoscience tourism resources

In order to deeply understand and study the geological tourism resources of red karst in Tongren, develop and utilize the geological tourism resources of red karst in Tongren more scientifically and rationally, meet the tourism needs of tourists to a greater extent, and bring greater economic benefits to tourism enterprises, it is necessary to understand the universal law of the formation mechanism of various geological tourism resources. According to the principles of the landscape attribute, homogeneity, and systematicness in the classification of tourism resources, this paper explores the differences among various geoscience tourism resources, summarizes the characteristics of various resources, and reasonably and scientifically classifies geoscience tourism resources. The principle of

landscape attribute is as follows: the tourism development and utilization of tourism resources is not a single element or scene, but a comprehensive landscape composed of a certain number of tourism resources with various characteristics in a certain geographical space. Therefore, the classification of geoscience tourism resources should follow the principle of landscape attribute, based on the basic concept and connotation of resources, and takes the landscape attribute and attraction value of tourism resources as the main indicators of classification. The principle of homogeneity is as follows: the classification of geoscience tourism resources should first distinguish the categories of geoscience tourism resources with large differences in resource attributes according to the principle of homogeneity of tourism resources and divide the Geosciences tourism resources with the same attributes into one category, and the same category of Geosciences tourism resources at the same level should have certain common points or similarities; and second, there must be some differences between the same category of geoscience tourism resources in the category of tourism resources divided according to homogeneity, which need to be divided into different types of geoscience tourism resources according to these differences. The systematic principle is the principle of combining the classification and the grading of tourism resources. First, tourism resources can be divided into sub-systems of different levels and different categories. Therefore, it is necessary to combine the classification and grading of tourism resources, classify them step by step, avoid logical errors in cross-level classification, and avoid overlapping and duplication of various types of tourism resources. Second, different classification principles should be adopted for the classification of different levels of tourism resources, and the same classification principles should be adopted to classify the same type of tourism resources into sub-level types, so as to avoid overlapping classifications of tourism resources. According to the sphere structure of the earth, the tourism resources are divided into 6 giant systems, 17 resource systems, 47 landscape types, and 159 landscape subtypes in the Dictionary of Tourism Geoscience. According to the classification principle of tourism resources and the factors such as material composition, geographical distribution, causes of formation, morphological combination and resource characteristics of Tongren red karst geoscience tourism resources, Tongren red karst geoscience tourism resources are classified into 47 landscape types, including the stratum tourism landscape, the internal dynamic geological process tourism landscape, the tectonic geomorphology tourism landscape, and the rock geomorphology tourism landscape [24].

5.2.2. Establishment of comprehensive evaluation system

In this paper, the evaluation of geoscience tourism resources is based on the perspective of tourists' demand for geoscience tourism, and the evaluation of geoscience tourism resources depends on the value demand of tourists. Maslow's hierarchy of needs theory divides individual needs into five levels, from low to high, as physiological needs, security needs, social needs, respect needs, and self-actualization needs. In the process of tourism, with the abundance of material and the improvement of the quality of life, the demand for tourism has changed from the initial single sensory demand to the spiritual demand of high-level self-actualization, which is manifested in geoscience tourism as follows: tourists have changed from a single sightseeing tour to an experience tour of natural scenery and human history. Moreover, there is a demand to grow the scientific and cultural needs of people to explore the law of nature and understand the earth. Geoscience tourism resources show different tourism values in different levels of tourism demand. Based on previous studies and according to the characteristics of

geoscience tourism resources, this paper divides the value of geoscience tourism resources into ornamental and recreational values, historical and cultural values, and a popular science research value.

(1) Construction of the evaluation index of historical and cultural values, and the ornamental and recreational values of geoscience tourism resources includes the ornamental and recreational values. Ornamental values reflect the tourist's demand for sightseeing and tourism of geographical and geological landscapes. Tourism recreation is based on tourism resources to provide entertainment and leisure services for tourists. Recreational value reflects a tourist's demand for entertainment and leisure services provided by geoscience tourism resources. In the Dictionary of Tourism Geography, the ornamental value is described as the degree of aesthetic feeling that the landscape can bring to tourists, including the degree of pleasure, strangeness, and the integrity of tourism. The greater the degree of pleasure, strangeness, and the integrity of tourism landscape, the greater the ornamental value, and vice versa. The recreational value of tourism resources is the economic value brought by its external tourism carrier. The concept of "value" of the recreational value comes from welfare economics in economics. "Economic value" can replace the "welfare value" to a certain extent. The value of goods can be measured by the purchase decision of consumers. The evaluation of the recreational value of tourism can be carried out by evaluating the potential economic development value of tourism resources. The investment of tourism services and tourism projects determines the economic benefits that tourism resources can bring, and the economic benefits are composed of the cost of tourists participating in tourism projects and the cost of using tourism services. Therefore, this paper selects two indicators to reflect the recreational value of tourism, namely, the amount of tourism service facilities that can be built (including those that have been built) and the amount of tourism projects that can be set up (including those that have been set up), and introduces the concepts of "supply and demand" and "supply and demand balance" to facilitate the quantitative evaluation of the quantity of tourism service facilities and tourism projects. The degree of supply and demand (S) is defined as the ratio of the quantity supplied (Qs) to the sum of the quantity supplied (Qs) and the quantity demanded (Qd). The "degree of balance between supply and demand" is defined as 1/2 minus twice the absolute value of the degree of supply and demand. The value range of the degree of supply (S) is $0 \le S \le 1$. When $0 \le S \le 1/2$, the quantity supplied is less than the quantity demanded. When $S = 1/2$, the quantity supplied is equal to when $1/2 \le S \le 1$, where the supply quantity is greater than the demand quantity. The value of the supply and demand balance degree (F) is $0 \le F \le 1$. When F is 0, S is 0, and the supply and demand are balanced. When the value of F gradually increases, the imbalance between supply and demand is more serious. The natural segment point method is used to divide F into five balance states. When $0 \le F \le 0.2$, it is excellent; when $0.2 \le F < 0.4$, it is good; when $0.4 \le F < 0.6$, it is medium. It is poor when $0.6 \le F < 0.8$, and very poor when $0.8 \le F \le 1$.

(2) Construction of evaluation index of historical and cultural value. The earth's surface is the main place of human activities, and the geographical and geological environment has a profound impact on human activities such as production and life, reproduction and inheritance, cultural exchanges, trade, and war. Geographical and geological relics have a certain relevance to the emergence, development, and preservation of local history, culture, economy, and society. Human activities will leave traces in the local geographical and geological environment, which makes the geographical and geological relics have certain historical and cultural attributes. Tourists will be interested in the historical and cultural attributes attached to geological relics when they are engaged in geological tourism activities, with geological relics as the main body. A tourist's demand for historical and cultural exploration and understanding reflects the historical and cultural value of

geological tourism resources. Historical and cultural values, including historical and cultural values, reflect the high-level spiritual needs of tourists to understand, explore, research, and experience history and culture. The historical value includes the original and derivative values. The original value is the realistic value of a historical subject, which reflects the understanding of the external objective facts of history. It is embodied in the value of the witnessing history, the reflecting history, the proving history, the supplementing history, and the inheriting history. The derivative value is the external subject's understanding of the value of historical facts, which is embodied in the significance and influence of the historical subject on the development of the historical society and the current economic society. The cultural value is the value that local traditional culture and culture with local characteristics can promote social communication and economic development. Based on previous studies on the evaluation and criteria of the cultural value, three basic indicators to evaluate the cultural value are put forward, namely, the spiritual power provided by culture, the effectiveness of promoting social development, and the contribution of promoting civilized interaction. The spiritual power provided by culture is determined by the spirit and emotion conveyed by the culture itself to tourists. The degree to which tourists can feel and recognize the spirit conveyed by culture and the degree to which culture can arouse the emotional resonance of tourists determine the spiritual power provided by culture. The effectiveness of promoting social development is determined by the degree of influence of culture on human production and life, science and education, and social change at that time and in the future. The degree of influence is determined by the breadth of the region and the number of aspects. The contribution of promoting the interaction of civilizations is determined by the influence of culture on the development of social trends of thought and the scope of cultural propaganda and promotion.

(3) Construction of evaluation index for the value of popular science research with the increasing improvement of social and economic level and humanistic quality, people's spiritual needs for self-realization of understanding nature and exploring the mysteries of the earth are becoming increasingly urgent after meeting the needs of simple sightseeing and tourism. As the main channel for the public to understand nature and explore the mysteries of the earth, the value of popular science research of geoscience tourism resources is becoming more prominent and important. Geoscience tourism resources have the value of science popularization and research because they have the value of science popularization and research of geography and geology. The value of science popularization is the function and evaluation of the geo-geological landscape in the dissemination of geoscience knowledge, which is determined by the amount of scientific information, the output mode, scale, and combination. In order to facilitate the quantitative evaluation of the scientific information output, this paper borrows the concept of relative abundance of earth elements, introduces the concept of "information abundance", defines the information abundance (K) of tourism resources as the relative value of the amount of information transmitted by a single point, and uses the measurement method of relative abundance of the earth elements for reference. Because the research object of this paper is geoscience tourism resources, the basic information conveyed by a general geological body is selected as the background value, including stratigraphic, lithological, and structural information. If each contains one piece of information, it is 3 pieces. Therefore, if 3 is selected as the background value of the basic amount of information, then N is the number of pieces of information, n is the background value of information, and the value of n in this paper is 3. This is defined as follows: when $K \leq 1$, the amount of information is small; when $1 < K \leq 2$, the amount of information is small; when $2 < K \leq 3$, the amount has a general meaning; when $3 < K \leq 4$, there is more information; and when $K > 4$, there is more information. The output mode is the way in which information is transmitted to tourists. When

the transmission mode is 1, the output mode is relatively single; when the transmission mode is 2, it is single; when it is 3, it is general; when it is 4, there are various output modes; and when there are more than 4 transmission modes, the output modes are diverse. The scale and combination are determined by the scale of resources and the degree of the information combination and output. When the scale is small and the degree of the information combination is low, the scale and combination are poor; when the scale is small and the level of the information combination is general, or when the scale is medium and the level of information mix is low, the scale and combination will be poor; when the size is medium and the information mix level is medium, the size and combination will be general; when the scale is large and the degree of information combination is medium, or when the scale is medium and the degree of information combination is high, the scale and combination are good; and when the scale is large and the level of information composition is high, the scale and combination are better. The quantitative evaluation criteria and weight of red karst refer to the evaluation system by Saïd Mirari [28]. The evaluation of the geosites and geodiversity sites consists of four parts with different criteria for each component: scientific value (SV), potential educational use (PEU), potential tourism use (PTU), and risk of degradation (DR) (Table 3).

Table 3. General framework of the evaluation.

Parts	Criteria (Scored 0 to 4)	Weighting (%)
Scientific Value (SV)	Representativeness (R)	30
	Key locality (Kl)	20
	Scientific knowledge (Sn)	5
	Integrity (I)	15
	Geological diversity (Gd)	5
	Rarity (R)	15
	Use limitations (UI)	10
Potential Touristic Use (PTU)	Vulnerability (V)	10
	Accessibility (A)	10
	Use limitations (Ul)	5
	Safety (S)	10
	Logistics (L)	5
	Density of population (Dp)	5
	Associations with other values (Av)	5
	Scenery (Sc)	15
	Uniqueness (U)	10
	Observation conditions (Oc)	5
	Interpretative potential (Ip)	10
	Economic level (El)	5
	Proximity recreational areas (Pr)	5
Degradation Risk (DR)	Deterioration geological elements (Dg)	35
	Proximity activities cause of degradation (Pa)	20
	Legal protection (Lp)	20
	Accessibility (Ac)	15
	Density of population (Dpp)	10

5.2.3. Evaluation result

The comprehensive evaluation scores of the red karst resources in Tongren are mostly above 80 points, which indicate that the red karst geological relics resources in this area have a good quality and a high tourism development value. However, it should be noted that the popularity and influence of this area are not high, the brand effect has not been formed, and the infrastructure construction is not good. However, its economic development level is good, the traffic conditions and location conditions have great advantages, and the surrounding tourism resources combination is good; therefore, more support should be given in terms of policies. In the score, the score of the resource endowment is low, and the score of the ornamental value and scientific research value is high, thus indicating that the red karst is rare and has high aesthetic characteristics and scientific value. However, the landscape resources in the area are few, the exposed area is small, and the resource endowment is poor. However, the surrounding tourism resources are greater, and the combination type is better, which can play a good complementary role. In general, it is necessary to strengthen the protection and resource excavation of the red karst, strengthen the infrastructure construction in and around the landscape area, strengthen the policy support, improve the environmental capacity, and enhance the popularity and influence to promote the development of the red Karst in Tongren (Table 4).

Table 4. Evaluation results of red karst geological relics.

No	East longitude	north latitude	elevation/m	exposure range/m^2	Score
YSX001	109°02′07.12″	28°05′55.35″	535.77	250000	83.2
YSX002	109°09′16.63"	28°13′38.61"	580	20000	79.5
YSX003	109°10′30.32″	28°24′07.29″	621	1500000	82.6
YSX004	109°07′57.63″	28°17′31.24″	624	500	84.3
YSX005	109°20′20.49″	28°10′37.03″	1045	4000	95.5
YSX006	109°20′25.64″	28°10′10.49″	1036	10000	87.2
YSX007	109°20′11.70″	28°10′04.58″	1037	10000	92.7

6. Development and protection of karst geological heritage resources

As a natural resource development and utilization mode, red karst development should follow certain development principles to ensure the integrity of resources, the rationality, feasibility, and efficiency of development. Based on following certain development principles, the development ideas shall be clarified in combination with the local socio-economic basis, the tourism development status, the resource status, and other development factors. Under the guidance of the development ideas, strategies and corresponding tourism projects and products should be developed according to specific tourism resources.

6.1. Development principles

Tourism project products include all kinds of experience activities aimed at sightseeing, leisure, sports, health care, popular science, cultural experience, etc., which are carried out for tourists. Tourism project product development is an activity that plans, designs, develops, and combines resources, facilities, human resources, scenic spots, and other elements according to market demand. In scenic

spots, the tourism project product is the main carrier of the development of tourism. The tourism project product carries the concept of the development of scenic spots, displays the tourism image of scenic spots, and is the main object for tourists to carry out tourism activities. Tourism project products are the main source of tourism income of scenic spots and play a major role in the economic development of scenic spots. The development of tourism project products needs to convey the image of scenic spots, win the market for the development of scenic spots, and provide economic development impetus. The development of tourism project products needs to be comprehensively considered according to the local resource characteristics, transportation facilities, exploitable conditions, funds, and other factors. The developed and constructed tourism project products need to ensure their accessibility and tourist attraction, so that the developed and constructed tourism project products can operate normally. While highlighting the tourism characteristics, it can also ensure a certain tourist source market and promote the sustainable development of scenic spots. The tourism route is a comprehensive tourism product that scientifically and reasonably combines a certain transportation base, basic tourism service facilities, and tourism project products according to the tourist's tourism needs. With the continuous development of the economy and society, people have a sufficient material basis, and the demand for outbound tourism is also increasing. Moreover, the demand for tourism shows the characteristics of diversification, personalization, and flexibility. The monotonous tourism project products cannot meet people's demand for tourism. Therefore, it is necessary to consider the tourism project products, tourism transportation, clothing, food, housing, and other tourism elements in a unified way; moreover, it is necessary to create diversified tourism routes according to the different needs of different people to meet the diverse tourism needs of people. The service object of the tourist route is tourists; therefore, it is necessary to take the tourist demand as the starting point and the tourist behavior as the development basis, and consider the planning of various hardware and software facilities in the tourist route. The development of tourism routes aims to provide more diversified tourism products, provide tourists with diversified tourism experience, attract more tourists for scenic spots, expand the tourist market, and enhance the market competitiveness of scenic spots. Tourism basic service facilities are the basic conditions to ensure the development of tourism activities. They guarantee the basic tourism needs of tourists and are related to the normal development of tourism activities. They are the basis for the start of all tourism activities and the prerequisite for the development of the tourism industry. Tourism infrastructure includes tourism transportation, tourism accommodation, tourism food, and other infrastructure. The development and construction of the tourism infrastructure determines the capacity, accessibility, playability, and tourism experience of the scenic spot. Each element is closely related to the development of the scenic spot. The development and construction of the tourism infrastructure needs to consider the local economic and social conditions, the current ecological environment, and the characteristics of tourism resources. Its development needs to conform to the local economic and social development conditions, maintain the surrounding ecological environment, highlight the tourism characteristics of scenic spots, integrate the construction of infrastructure into the local social culture, display the characteristics of tourism resources, integrate the tourism infrastructure with the local ecological environment, and coexist harmoniously with nature. At the same time, in terms of policy, it should be consistent with the national double-carbon target to reflect the national strategic policy of carbon neutrality and a carbon peak [27].

6.1.1. Adapt measures to local conditions and highlight the characteristics of geoscience tourism resources

Geotourism resources are rich and diverse, with a wide distribution area. The historical, cultural, and recreational values attached to the resources have their own characteristics. Additionally, the economic and social basis, ecological environment protection, and geographical and transportation location of their development are different. Therefore, the development of geotourism products should be based on the resource characteristics and exploitable conditions of the tourism resources. The development of geoscientific tourism resource points should not only highlight the core advantages of resource points, but also consider horizontally to avoid the tourism shielding effect of similar advantageous resources. When developing the same type of geoscience tourism, we should explore the differences between resource points, and carry out differentiated development according to the differences of each tourism resource point, to ensure that the same geoscience tourism resource points develop geoscience tourism products with different focuses and avoid internal competition and the mutual offset of the same products. Developing geoscience tourism products of Cangshan Geopark according to local conditions can not only develop and construct geoscience tourism products in a scientific, reasonable, and feasible way, but also avoid the homogenization of products. While increasing the volume of tourism, it can maximize the diversity of tourism products, provide tourists with diversified tourism products, and meet the diversified tourism needs of tourists. Developing geoscientific tourism resource points according to local conditions can not only maximize the attraction of tourism resources, improve the exposure, popularity, and influence of scenic spots, but also enrich and improve the tourism product system of the geological park, improve the overall level of the park's tourism products, and enhance the overall market attractiveness and competitiveness of the park, which is the catalyst to promote the park's sustained and rapid development.

6.1.2. Insufficient technology research and development and imperfect incentive mechanism

The development of tourism can meet people's increasing material and spiritual needs. Tourism can help people physically and mentally cultivate, increase knowledge, and promote economic and social development. The development of tourism promotes the development of the national economy, whereas the development level of the national economy is the basis for the development of tourism and restricts its development. With the development of economy and society, tourism plays an increasingly prominent role in the national economy. Therefore, the state has made special planning and a design for the development of tourism from the national economic development strategy. Moreover, local governments at all levels will make plans according to the national tourism development strategy and their own economic and social development realities. The national-level tourism industry planning has analyzed the opportunities and threats of the development of domestic and foreign economic society and tourism, in detail, pointed out the development trend of global and domestic tourism, and the governments at all levels have analyzed the development opportunities and crises of tourism according to the economic and social basis and the current situation of tourism development in the region under their jurisdiction, which has a clear guiding significance to develop the local tourism industry. The development of Tongren red karst geotourism should be linked with the development planning of the tourism industry of governments at all levels. It can not only follow the domestic and international trends of tourism development, but also adapt to the development of the

local tourism industry. It can not only provide policy support for the development of geotourism, but also guide the development direction of geotourism in geological parks. The development and connection policy of Tongren geoscience tourism and the upper-level planning can win the first chance for the development of geoscience tourism.

6.2. Suggestions on the Protection of Red Karst

Each functional department is not opposed to the use of heritage, but advocates to play the role of heritage in scientific research, education, culture and tourism, support the rational and scientific use of world heritage, and promote the sustainable development of society, the economy, and the environment of the heritage site and its surrounding areas on the premise of ensuring that the properties of heritage are not changed and conducive to the healthy development of the heritage site. Geological relic landscape resources belong to one-time resources, which cannot be repaired once damaged; therefore, the red karst resources, which cannot be repaired after being damaged, will also reduce its aesthetic value and affect its scientific research and tourism development values. Therefore, in the process of development, we should not blindly pursue interests, carry out commercial construction, destroy the appearance of the landscape, and destroy the ecological environment and tourism resources. During the development, cleaning, and maintenance of the red karst landscape area in Tongren, the special distribution and underground conditions of the rock mass should be fully considered. The construction project should be planned, in detail, on the principle of not damaging the natural rock mass. The buildings should be arranged in the gap area of the natural rock mass to prevent irreversible damage to the landscape resources. Protecting these resources with practical policies and actions is an important basis for ensuring the development of tourism and sustainable socio-economic development.

6.2.1. Improve the protection system and strengthen education and publicity

The normative system can be used to regulate people's thoughts and behaviors. A perfect system can provide restraint and management, improve coordination and management effectiveness, and ensure the orderly and good operation of the system. Specific protection provisions for various tourism resources in the landscape area should be formulated, and the existing laws and regulations should also be fully utilized to protect the red karst and to try to avoid the damage to the landscape caused by the development process or tourists. Moreover, we should strengthen the publicity and education, carry out more popular science to tourists, improve their scientific literacy, and enhance their consciousness.

6.2.2. Establish monitoring system to protect ecological balance

At present, a complete monitoring system and indicators have not been established in karst world natural heritage sites. In order to protect the natural heritage with outstanding value, the dynamic monitoring and early warning mechanism of ecological vulnerability of heritage sites can be established by using satellite remote sensing images and other monitoring methods, when combined with the theories of ecology, geographic information technology, and other disciplines, to strictly control the heritage sites with a high ecological vulnerability.

There are many special geological structure phenomena in the red karst landscape area of Tongren. These geological structures are of a great significance to the study of the geological structure

deformation characteristics of the area, and have good tourism and an ornamental value. Additionally, there are many wild animals and plants around the scenic area, and water resources are also very rich. When developing the scenic area, there should be increased attention to its protection. It is strictly prohibited to collect soil, log, quarry, and kill wild animals in and around the scenic area, and to maintain the ecological balance.

6.2.3. Difficulties in popularization and application of new technologies

The red karst landscape area should adhere to the concept of sustainable development and the principle of educating people, develop in the process of protection, protect in the process of development, combine protection and development, correctly handle the relationship between the overall characteristics of the red karst landscape and other supporting facilities, and grasp the principle of not only protecting the geological beauty, but also displaying the coordinated development of humans and nature in the process of development. The red karst landscape area will be built as both a place to protect geological relics and scientific research, and as a tourist area with rich characteristics. First, take the road of comprehensive development. Then, integrate the red karst landscape area into Guizhou's grand tourism, take the red karst as the starting point, and comprehensively develop other natural landscapes, cultural relics, ethnic customs, and catering culture, etc. It is required that the core scenic spots and service function areas should be properly separated. Next, build it into a base for scientific research and popular science education. Finally, conduct special research on the species protection, ecological characteristics, environmental protection, scientific research achievements, scientific significance, historical status, and other contents in the area to improve the social status and popularity of red karst investments and policies.

7. Conclusions

This paper utilized the red karst in Tongren area as the research object, analyzed and narrated the geographical background, geological background, landscape characteristics, landscape causes, etc. of the study area, comprehensively evaluated the value of the geological heritage resources in the study area by constructing the evaluation index system, and put forward relative development strategies and protection suggestions according to the development status and problems. In fact, red karst is not a typical representative at home and abroad. This study has filled this gap well. At present, its academic status and value are not reflected. From the perspective of karst in southern China, although there are numerous relevant academic studies, it is still a difficult problem for domestic and foreign academic circles to accurately define the scope and region from the aspects of geological history process and geomorphological continuity, which also leads to a difficulty in accurately refining and summarizing the characteristics of the geological and geomorphological system of the entire southern karst. In addition, from the perspective of world natural heritage, karst still lacks a rich amount of academic evidence to make its exemplary role play well. From the perspective of tourism development value, more people should recognize the diversity of karst landforms, not only the common gray ones, but also the red and white ones, so that more people can recognize the scarcity and value of red karst.

Use of AI tools declaration

We do not used Artificial Intelligence (AI) tools in the creation of this article.

Acknowledgments

This research was supported by Regional Project of National Natural Science Foundation of China (41463003), Surface Project (41573043), Concealed Ore Deposit Exploration and Innovation Team of Guizhou Colleges and Universities (Guizhou Education and Cooperation Talent Team [2015]56), Provincial Key Discipline of Geological Resources and Geological Engineering of Guizhou Province (ZDXK[2018]001), Huang Danian Resources of National colleges and universities Teachers' Team of Exploration Engineering (Teacher Letter [2018] No. 1), Geological Resources and Geological Engineering Talent Base of Guizhou Province (RCJD2018-3), Key Laboratory of Karst Engineering Geology and Hidden Mineral Resources of Guizhou Province (Qianjiaohe KY [2018] No. 486Guizhou Institute of Technology Rural Revitalization Soft Science Project (2022xczx10), Education and Teaching Reform Research Project of Guizhou Institute of Technology (JGZD202107,2022TDFJG01).Thanks to Mr. Jiang ,Mr. Chen and Mr Yu for providing a large number of early field geological data, Mr. Yu Ning and Mr. Sun Shijun for their guidance and help in the field.

Conflict of interest

The authors declare no conflicts of interest.

References

1. Yuan DX (1993) Carbon cycle and global karst. *Quaternary Sciences*, 1–6.
2. Guizhou DST (Guizhou Provincial Department of Science and Technology) (2021) Karst promotional materials. Available from: http://kjt.guizhou.gov.cn/zwgk/kpgz/kjhdz/202108/t20210830_69811278.html.
3. Zhao Xun (2010) Research on karst geomorphology in Fangshan, China. Beijing: Geological Publishing House.
4. Li D, Luo Y (1983) Measurement of the distribution area of carbonate rocks in China. *Carsol Sin* 2: 61–64.
5. Jiang F, Dong Y, Chen Y (2020) Characteristics and genesis of red karst in Guizhou section of Youshui basin. *Carsol Sin* 39: 937–944.
6. Zeng Z, Huang S (1978) Red bed landform in southeast China. *J South China Norm Univ* 1: 56–73.
7. Li Z, Yang Z, Wang S, et al. (2024) The Effects of Coal Floor Brittleness on the Risk of Water Inrushes from Underlying Aquifers: A Numerical Study. *Sustainability* 16: 1489. https://doi.org/10.3390/su16041489
8. Guo F (2007) Environmental functional characteristics and formation mechanism of karst cave interaction zone. Xi'an: Chang'an University.
9. Chi Y, He C (2023) Impact of Land Use Change on the Spatial and Temporal Evolution of Ecosystem Service Values in South China Karst Areas. *Forests* 14: 893. https://doi.org/10.3390/f14050893

10. Jones B, Manning AC (1994) Comparison of geochemical indices used for the interpretation of palaeoredox conditions in ancient mudstones. *Chem Geol* 111: 111–129. https://doi.org/10.1016/0009-2541(94)90085-X
11. Cai Y, Wu F, Han J, et al. (2019) Geoheritage and Sustainable Development in Yimengshan Geopark. *Geoheritage* 11: 991–1003. https://doi.org/10.1007/s12371-019-00348-3
12. Herrera-Franco G, Carrión-Mero P, Alvarado N, et al. (2020) Geosites and Georesources to Foster Geotourism in Communities: Case Study of the Santa Elena Peninsula Geopark Project in Ecuador. *Sustainability* 12: 4484. https://doi.org/10.3390/su12114484
13. Kubalíková L (2019) Assessing Geotourism Resources on a Local Level: A Case Study from Southern Moravia (Czech Republic). *Resources* 8: 150. https://doi.org/10.3390/resources8030150
14. Özgeriş M, Karahan F (2021) Use of geopark resource values for a sustainable tourism: A case study from Turkey (Cittaslow Uzundere). *Environ Dev Sustain* 23: 4270–4284. https://doi.org/10.1007/s10668-020-00773-3
15. Vu HD, Nguyen NTP, Ngo YTH, et al. (2022) GEOTOURISM CURRENT STATE AND FUTURE PROSPECTS: A CASE STUDY IN THE CAO BANG UNESCO GLOBAL GEOPARK, VIETNAM. *GeoJournal Tour Geosites* 43: 1063–1070. https://doi.org/10.30892/gtg.43327-921
16. Weihrich H (1982) The TOWS matrixâ—A tool for situational analysis. *Long Range Plan* 15: 54–66. https://doi.org/10.1016/0024-6301(82)90120-0
17. Peng S (2014) Global Standard Stratotype-section and Point (GSSP, "Golden Spike") and the GSSP research in China. *Earth Sci Front* 21: 8–26.
18. Zhao J (2014) Lithofacies Paleogeography of the Middle Ordovician in the Middle and Upper Yangtze Region. Master Dissertation of Yangtze University, 38–58.
19. Chen Y, Jiang F, Yu N, et al. (2023) Geological conditions and genetic analysis of the formation of red karst landform in Hunan, Chongqing and Guizhou. *Geochemistry* 52: 94–104. https://doi.org/10.19700/j.0379-1726.2021.04.009
20. Jiang F, Dong Y, Chen Y, et al. (2020) Characteristics and genesis of red karst in the Guizhou section of the Youshui Basin. *Karst China* 39: 937–944.
21. Cui Z, Li D, Liu G, et al. (2001) The nature of red karst weathering crust and the formation environment of planation plane in Hunan, Guangxi, Guizhou, Yunnan and Tibet. *Chin Sci (Part D: Earth Sci)* S1: 134–141.
22. Ye Q (2020) Xiangxi UNESCO Global Geopark: Cambrian Golden Spike and karst wonders. *Earth* 9: 6–13.
23. Wu L, Chen W, Rong Y, et al. (2020) Development characteristics and research value of red carbonate stone forest in the Xiangxi geopark. *Carsologica Sin* 39: 251–258.
24. Jiang F, Dong Y, Su X, et al. (2020) Preliminary dicussion on the concept of red karst and its scientific value. *Carsologica Sin* 39: 775–780.
25. Jiang Z, Zhang J, Huang C, et al. (2019) Causes of formation and geo-scientific significance of karst gorge geoup in Xiangxi geopark. *Carsologica Sin* 38: 269–275.
26. Venturini C, Pasquaré Mariotto F (2019) Geoheritage Promotion Through an Interactive Exhibition: A Case Study from the Carnic Alps, NE Italy. *Geoheritage* 11: 459–469. https://doi.org/10.1007/s12371-018-0299-7

27. Zouros N, Pavlides S, Soulakellis N, et al. (2011) Using Active Fault Studies for Raising Public Awareness and Sensitisation on Seismic Hazard: A Case Study from Lesvos Petrified Forest Geopark, NE Aegean Sea, Greece. *Geoheritage* 3: 317–327. https://doi.org/10.1007/s12371-011-0044-y
28. Antić A, Tomić N, Đorđević T, et al. (2021) Promoting Palaeontological Heritage of Mammoths in Serbia Through a Cross-Country Thematic Route. *Geoheritage* 13: 7. https://doi.org/10.1007/s12371-021-00530-6
29. Tomić N, Marković SB, Korać M, et al. (2015). Exposing mammoths: From loess research discovery to public palaeontological park. *Quat Int* 372: 142–150. https://doi.org/10.1016/j.quaint.2014.12.026
30. Yang W, Min Z, Yang M, et al. (2020) Exploration of the Implementation of Carbon Neutralization in the Field of Natural Resources under the Background of Sustainable Development—An Overview. *Int J Environ Res Public Health* 19: 14109. https://doi.org/10.3390/ijerph192114109
31. Mirari S, Aoulad-Sidi-Mhend A, Benmlih A (2020) Geosites for Geotourism, Geoheritage, and Geoconservation of the Khnefiss National Park, Southern Morocco. *Sustainability* 12: 7109. https://doi.org/10.3390/su12177109

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