Typical Zone Division of Karst Development in China

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Abstract. Determining the typical area of karst development in China would provide positive reference for theoretical research of engineering geology in karst areas in China. By quantitative or semi-quantitative analyzing on the distribution characteristics, climatic conditions and formation lithology of carbonate rocks in China, regional difference characteristics of karst development in carbonate rock regions in China is evaluated, and finally the representative karst zone in China is reasonably and theoretically delineated and demonstrated. Results show that: the pure carbonate rocks in southwest of China in tropical and subtropical climate zone which are very favorable for karst development, distributes continuously and massively, and therefore can be considered as the most typical karst area, this is also a very explanation that karst morphology develops completely. Especially, karst in the zone including Guangxi Zhuang Autonomous Region, southeast and north-east of Guizhou province, and southeastern of Chongqing Municipality, is the most representative karst region in southwest of china because of its the purest carbonate rocks.

1. Introduction

China is one of the regions with the largest distribution area of carbonate rocks and the most typical karst development in the world. These provinces or regions including Guangxi Zhuang Autonomous Region, Guizhou Province, Yunnan Province, Sichuan Province, and Chongqing, are recognized as the most typical karst development areas in China due to the fact that the carbonate rocks distributes continuously and massively, the karst landforms and karst forms are well developed, and the karst geological problems are particularly prominent[1-3].The macroscopic division of China's karst development areas is of positive significance for the study of karst geology, karst hydrogeology and karst engineering geology in China.

As a unique adverse geologic action and geological form, karst had been macroscopically classified and zoned before the 1990s. The research results show that climate, lithology, and groundwater are the main factors affecting karst development, the karst forms and geomorphological features directly reflect the intensity of karst development[4-6], and these factors are the main content and basis for evaluating karst characteristics[7-11] in a regional or small area. However, in the field of karst research, there are still obvious differences in the current discussion on whether China’s most typical karst development area is in Guizhou or Guangxi Zhuang Autonomous Region. The main reason is that the relevant theory of regional macro division of karst is still immature, and the relevant research needs to be in-depth.
Based on the existing research results, by quantitative or semi-quantitative analyzing on the distribution characteristics, climatic conditions and formation lithology of carbonate rocks in China, regional difference characteristics of karst development in carbonate rock regions in China is evaluated, and finally the representative karst zone in China is delineated and demonstrated.

2. Main distribution characteristics of the carbonate rocks in China

Formation lithology and water dissolution capacity are basic factors affecting the dissolution capacity of carbonate rocks\[5\]. As shown in Figure 1 Map of carbonate rocks outcropping distribution feature in china, the carbonate rocks in southwest provinces including Guizhou, Yunnan Province, Guangxi Zhuang Autonomous Region, outcrops continuously and massively, and most famous karst cities in China, such as Guilin, Liuzhou, Hechi, Laibin, Guiyang and Kunming, distributes in this area. The distribution area of carbonate rocks in the central region represented by Hunan Province and Hubei Province is second only to the south-west region. South China areas including Guangdong Province and Fujian Province also have large karst areas, and the carbonate rocks in this area can be roughly integrated with the car-bonate rocks in the southwest area, which can be regarded as the extension of the carbonate rocks in the southwest area. The distribution area of carbonate rocks in Xishan of Beijing and Taiyuan of Shanxi has a certain scale, in Eastern China and Northeast China is only scattered, and in Tibet and Xinjiang is also very considerable. Therefore, in terms of the distribution range of carbonate rocks, the southwest karst area should be the most typical karst development area in China.

3. Analysis of the influence of regional climate on dissolution intensity

Karstification is a comprehensive geological action that is carried out by groundwater and surface water on soluble rocks, and is characterized by chemical dissolution including mechanical erosion of water and the material migration and redeposition. Hydrogen ions are the fundamental substance that groundwater dissolves carbonate rocks. The higher hydrogen ion concentration, the stronger dissolution of carbonate rocks. Hydrogen ions mainly come from acidic substances, and the source and content of these acidic substances are closely related to regional climatic conditions. Different climatic conditions make the composition and source of acidic substances significantly different. According to statistics, the proportions of acidic substance types in different climate zones are shown in Figure 2 below\[3\].

Figure 1. Map of carbonate rocks outcropping distribution feature in china.

Figure 2. Map showing the proportions of acidic substance types in different climate zones.
Figure 2. Dissolution factors source content in different climate zones.

According to Figure 2, acidic substances can be divided into two categories: carbonic acid and non-carbonic acid. Carbonic acid mainly includes atmospheric carbonic acid from atmosphere, biological carbonic acid produced by biological activities, and inorganic carbonic acid produced by inorganic substances. The content of this carbonic acid in high latitude, humid temperate zone, Mediterranean zone, dry zone and tropical zone is 80%, 70%, 67%, 45% and 53% respectively. Except for the Mediterranean zone, the content of carbonic acid in other areas is more than 50%. The karst areas in China are typical tropical, subtropical and temperate karst areas\[4,7\]. Its main erosive components are carbonic acid, among which biogenic carbonic acid and inorganic acid are the main sources of erosive substances in karst areas in China.

The content of each acidic substance in Figure 2 is the relative percentage of the acidic substance content in the climatic zone, which cannot be directly compared between different climatic zones. It is generally believed that the carbon dioxide content in the atmospheric composition on the earth is relatively stable. If the atmospheric carbonic acid content is regarded as the basic range of the dissolution capacity, the other acidic substances content is converted into the relative value of the atmospheric carbonic acid content, and the dissolution capacity of different climatic zones can be compared. The transformation formula of relative dissolution capacity in different climatic zones is as follows:

\[
k_d = \sum_{i=1}^{5} \frac{X_i}{X_1}
\]

In the formula: \(k_d\) is the relative dissolution capacity of karst water, and \(X_1, X_2, X_3, X_4, X_5\) are the percentages of atmospheric carbonic acid, inorganic carbonic acid, biological carbonic acid, inorganic acid and organic acid respectively in Figure 2.

According to formula (1), after calculating the relative dissolution capacity of karst water in different climatic zones, the histogram of relative dissolution capacity of karst water in each climatic zone can be drawn, as shown in Figure 3.

Figure 3. Relative dissolution capacity of water under different climate zones.

It can be seen from Figure 3 that the relative dissolution capacity of tropical regions is 200, which is much higher than that of karst water in other areas. Therefore, it is the most favorable climate zone for carbonate dissolution, followed by Mediterranean climate zone and humid temperate zone, with the relative dissolution capacity of 25 and 14.29.
As can be seen from Figure 1, carbonate rocks widely distribute in China, with altitudes ranging from a few meters in the coastal areas of southeast China to more than 4,000 meters in Tibet. From south to north, they span tropical zone, subtropical zone, humid temperate zone, dry cold zone and other different climatic zones—South China is located in a tropical climate with abundant rainfall and high average annual temperature; Southwest China is located in the subtropical climate, with rainfall and average annual temperature second only to South China, and it also belongs to the paleotropical climate; The climate in Central China is similar to the subtropical Mediterranean climate; North China and Northeast China with temperate climate; Northwest China belongs to a dry climate zone with little rainfall; The Tibetan Plateau, with an altitude of more than 4000m, has an alpine climate.

To sum up, in terms of climatic conditions, south China is more suitable for karst development than north China. According to the relationship between the five types of climatic zones and the intensity of carbonate karst dissolution in Figure 3, the intensity of carbonate karst dissolution in China can be correspondingly divided into five grades from strong to weak, and the corresponding regions of each grade are as follows:

A1={South China}={Guangxi, Guangdong, Fujian}
A2={Southwest China}={Yunnan, Guizhou, Chongqing}
A3={North, Central, East, Northeast China}={Shanxi, Shandong, eijing, He-bei, Hunan, Hubei, Zhejiang, Anhui, Jilin, Liaoning, Hmongjiang}
A4={Northwest China}={Xinjiang, Qinghai, Shanxi, Gansu, Ningxia, Inner Mongolia}
A5={Tibet}

4. Differences in the dissolution capacity of regional rock formation combinations

Depending on different combinations of rock formations, carbonate strata in China can be divided into four categories: the pure carbonate strata (Pure Strata for short), the interlayer strata (Interlayer Strata for short) composed mainly of carbonate rocks (content > 75%) and a few non-soluble rocks, the interlaced strata (Interlaced Strata for short, carbonate rock content 25~75%) formed by carbonate and nonsoluble rocks alternately and the interval strata mainly composed of insoluble rocks and a thin layer of carbonate rock (Interval Strata for short).rom the mechanism of carbonate dissolution, under other factors in the same condition, the purer the carbonate lithology, the better the solubility of the rock, the higher the degree of foundation dissolution, and the more complete the karst development form. Thus it may be known, The ranking order of the dissolution degree of carbonate formations from strong to weak is: Pure Strata → Interlayer Strata → Interlaced Strata → Interval Strata. Based on Figure 1, it can be seen that the pure carbonate rocks in Guangxi Zhuang Autonomous Region District, Eastern Guizhou Province, Southeast Chongqing and Southeast Kunming City distributes continuously and massively. The pure carbonate strata in North China mainly distributes in the narrow zone from southwest Beijing to Taiyuan City, Shanxi Province, and the distribution area is much smaller than that in Southwest China. herefore, in terms of lithologic purity, the material conditions for karst development in Southwest China are the best, followed by North China, then Central China and Northwest, Tibet and Northeast China are the worst.

Figure 4 shows the outcropping area distribution of various carbonate rocks in different areas[3] (the southwest region in the figure includes the South China region). It can be seen from Figure 4 that the main types of carbonate rocks in Tibet, northwest and Northeast China are interlayer strata and interlaced strata, and the secondary type is interval strata, with low lithologic purity, which belongs to the strata containing carbonate rocks. The total distribution area of carbonate rocks in East China is not large in which the pure carbonate strata has a very small distribution range, only about 0.22 thousand square kilometers, so it is generally combined with Central China for study. The distribution area of pure carbonate stratum in Central China occupies a certain proportion, but its type is still dominated by interlayer strata and interlaced strata with low-purity carbonate strata lithology. The carbonate strata in North China are dominated by interlayers, and the distribution area of pure carbonate strata in this region also accounts for a large proportion. The southwestern region, where the distribution area of pure carbonate strata exceeds 198,000 square kilometers, is the largest distribution area of pure carbonate strata and carbonate interlayer strata in China, and has a relatively large area of interlayer strata and interlaced strata.
Figure 4. carbonate rocks distribution in China.

Carbonate is the main component of carbonate dissolution. The higher the content of carbonate, the better the solubility of rock. In order to better compare the influence of stratigraphic lithology between different regions on karst development, we can convert the impure carbonate strata into the outcropping area of converted pure carbonate strata based on the carbonate purity. Assuming that in a carbonate formation of 1 square kilometer, the estimated coefficient of Pure Strata is 1, the estimated coefficient of Interlayer Strata is 0.75, Interlaced Strata is 0.5——Because that the dissolution phenomenon in Interval Strata in engineering practice is very weak——and its estimated coefficient is 0.1. According to formula (2), the converted area of pure carbonate strata in different strata can be obtained.

\[ S = \sum_{i=1}^{4} k_i s_i \]  

(2)

In the formula: \( S \) is the converted pure carbonate distribution area of a certain strata after conversion, ten thousand km\(^2\); \( k_i \) is the estimated coefficient, and its value is based on the purity of carbonate strata. The value of pure carbonate strata \( k_1 \) is 1, interlayer strata \( k_2 \) is 0.75, interlaced strata \( k_3 \) is 0.5, and interval strata \( k_4 \) is 0.1; \( s'_1 \), \( s'_2 \), \( s'_3 \), \( s'_4 \) are respectively the outcropping areas of pure strata, interlayer strata, interlaced strata and interval strata in carbonate strata in an area, and valued based on the corresponding strata classification in Figure 3.

According to formula (2), after calculating the outcropping area of converted pure carbonate strata in different zones, the histogram of the outcropping area of converted pure carbonate strata can be drawn, as shown in Figure 5.

Figure 5. Distribution of converted pure carbonate rocks in China.

According to the distribution of carbonate rocks in Figure 5, the solubility of Carbonate strata in China can be preliminarily divided into B1-B5 grades from easy to difficult (south-west China includes all provinces and regions in South China):

B1={Southwest China}={Guangxi, Guangdong, Fujian, Yunnan, Guizhou, Chongqing}
B2={North China}={Shandong, Shanxi, Beijing, Hebei}
5. Determination of typical karst development areas

According to the above analysis, the typical karst development area in China should be the most favorable combination of lithological and climatic conditions for karst development, and should be the intersection of sets A1 and B1 and the intersection of A2 and B1.

\[ A_1 \cap B_1 = \{\text{South China}\} = \{\text{Guangxi, Guangdong, Fujian}\} \]
\[ A_2 \cap B_1 = \{\text{Southwest China}\} = \{\text{Yunnan, Guizhou, Chongqing}\} \]

Studies have shown that the southwestern region almost covers various karst development forms including karst depressions, funnels, subsidences, caves, stone buds, karst troughs, sinkholes, underground rivers, and retained the various karst development stages from juvenile to old age. Various typical karst landforms such as peak clusters, peak forests, dissolution mounds, and dissolution plains were well developed [2-3]. These phenomena are also consistent with the conclusions inferred above.

Combining the pure carbonate rocks distribution feature in Figure 1 for further analysis, it can be seen that karst areas (see the red circle in Figure 1) including in Guangxi Zhuang Autonomous Region in tropical and subtropical, in Southeast and Northeast Guizhou and in Southeast Chongqing have the highest purity of carbonate rocks and are the most representative karst development areas in the Southwestern China.

6. Conclusion

The pure carbonate rocks in southwest of China in tropical and subtropical climate zone which are very favorable for karst development—this is also a very explanation that karst morphology develops completely and the karst landform features are more prominent, distributes continuously and massively, and therefore can be considered as the most typical karst area in China.

In the karst development area of southwest China, karst in the zone including Guangxi Zhuang Autonomous Region, Southeast and North-east of Guizhou province, and Southeastern of Chongqing Municipality, is the most representative karst region in south-west of china because of its the purest carbonate rocks.

7. Acknowledgments

This work was financially supported by Guangxi Natural Science Foundation (2018GXNSFAA138139), the Guangxi Key Laboratory of Rock and Soil Mechanics and Engineering (14-B-05) and Guilin University of Technology Doctoral Research Startup Fund (GUTQDJJ2014031).

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