Formaition setting and karst development characteristics of red beds in Wuhan, Hubei Province, China

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Abstract. The red beds in Wuhan are mainly Cretaceous–Paleogene Donghu Group (K–Edn) strata, and the main lithologies are purplish red semi-cemented and weakly cemented mudstone, sandstone, and conglomerate. The formation setting of the red beds in Wuhan is analyzed from the regional tectonic movement and sedimentary environment. In addition, the karst development characteristics of red beds in Wuhan are studied on the basis of a large number of karst borehole data. The results show that the karst development of red beds in Wuhan is mainly controlled by the tectonic position and stratigraphic lithology. The soluble rock in the red beds of Wuhan is a calcareous cemented conglomerate, and the gravel component of conglomerate is mainly limestone. The karst phenomena in the red beds are mainly karst caves and karst fissures, while the surface karst phenomena, such as karst ditch and karst trough, are not prominent. The karstification is mainly weakly developed, and the degree of karstification positively correlates with that of the underlying karstification belt. When the lithology of the underlying formation of the red beds is carbonatite, the red bed karst is developed; by contrast, when the lithology of the underlying formation is insoluble clasolite, the red bed karst is not developed. The filling mode of the karst cave in the red beds may also be from top to bottom. The filling material mainly comes from the disintegration of the red beds themselves, and part of them comes from the overlying Quaternary strata.

Keywords. Red beds, Red bed karst, Formation setting, Karst development characteristics, Wuhan area

1. Introduction
Red beds are mainly referred to as the red terrestrial clastic rock and its weathering laterite in the Mesozoic–Cenozoic era, including the lacustrine, fluvial facies, inter-bedded lacustrine–fluvial, and piedmont diluvial deposits. Red beds are mainly made of conglomerate, sandstone, mudstone, siltstone, and shale, as well as small amounts of limestone, rock salt, and gypsum\(^1\)\(^-\)\(^3\). Red bed karst are developed in red clastic rock formations. Red bed karst is a type of karst system, developed only in rock types with high contents of soluble components in the red beds. There are two types of red bed karst:

a) the cement of the red beds is soluble calcium or other soluble substances;
b) the clastic composition of the red beds is carbonate rock.

Among them, the calcareous conglomerate karst is a typical representative. Some scholars call the red bed karst “pseudo-karst,” which is different from the typical “true-karst” of carbonate rocks\(^4\). The study of red bed karst can deepen the research on the mechanism and characteristics of karst development and re-solution, thus enriching the theory of karstology. In addition, many engineering
constructions have been performed in red bed areas, and in recent years, some engineering sites have revealed karst caves, karst grikes, and other karst phenomena in red beds. Therefore, it is beneficial for the safe construction and use of the building to study the formation setting and karst development characteristics of red beds\(^5\)\(^-\)\(^8\).

At present, many experts and scholars have studied karst problems in Wuhan. They mainly focused on cave detection, karst development law, karst control, and prediction studies. Studies on the distribution of red beds and the problem of karst development of red beds are less. To our best knowledge, the research on the development characteristics of red beds of Mesozoic and Cenozoic strata in Wuhan and its surrounding areas, as well as karst development of red calcareous conglomerate in Cretaceous–Paleogene Donghu Group (K-Edn) is analyzed only in references 9 and 10.

Many red beds karst phenomena, such as karst caves and karst grikes, have been revealed in the process of investigation in Wuhan in recent years, which provides a lot of basic data for in-depth study of the red bed karst in Wuhan. Based on these data, this paper discusses the formation setting and karst development characteristics of red beds of Cretaceous–Paleogene Donghu Group (K-Edn) in Wuhan.

2. Formation setting of red beds in Wuhan

Since the Mesozoic Era, the crust of Wuhan has undergone multiple tectonic movements. At the end of the Middle Jurassic, the Yanshanian movement started, and the pre-Jurassic strata were strongly folded under the action of the south–north lateral compression, which laid the basic structural framework of Wuhan.

During the middle and late Yanshanian movement, Wuhan and its surrounding areas began to sink generally, and continental clastic rocks were deposited, thereby forming continental clastic rock series represented by Cretaceous–Paleogene Donghu Group (K-Edn).

The Xiangfan-Guangji Fault is a controlling structure in Wuhan. Under the control of the Xiangfan-Guangji Fault, red clastic rocks with thicknesses of more than 1,000 m were deposited in the Huangpi-Xinzhou area in northern Wuhan and Liangzi Lake Basin in southeastern Wuhan during Cretaceous–Paleogene. The Qianjiang depression in western Wuhan has deposited continental strata with a thickness of more than 20,000 m since the Cretaceous period.

During the Himalayan cyclic period from Cenozoic, the crust uplifted, resulting in the shifting of the river valley and forming of new faults. After long-term evolution since Quaternary, only sporadic red clastic rocks remain in central Wuhan, while red beds are widely distributed in the north and south (Figure 1).
Figure 1 indicates the distribution of carbonate rocks in Wuhan is controlled by geological structure. There are nine karst belts from north to south, namely Tianxingzhou Belt (B1), Daqiao Belt (B2), Baishazhou Belt (B3), Zhuankou Belt (B4), Junshan Belt (B5), Hannan Belt (B6), Fasi Belt (B7), Ma’an Hill Belt (B8), and Husi Belt (B9).

3. Distribution of red beds in Wuhan

In addition to Huangpi District, Xinzhou District, Liangzi Lake area, and other areas in the far urban, red beds are only distributed in central Wuhan.

According to the regional geological data and drilling exposures in Wuhan, there are 12 red bed distribution areas of Cretaceous–Paleogene in central Wuhan (see Figure 1). These red bed distribution areas are zonal or ellipse like, with general striking NWW-SEE, which is consistent with the direction
of the main tectonic line (Table 1). The thickness of the stratum is only a few meters to more than hundred meters. Compared with the surrounding areas, the sedimentary thickness is much smaller.

Table 1. Statistical characteristics of Cretaceous–Paleogene strata residues in central Wuhan \(^9\)

| Item                | Direction /° | Length /km | Width /km | Aspect ratio | Area /km\(^2\) |
|---------------------|--------------|------------|-----------|--------------|-----------------
| maximum value       | 312          | 56.7       | 19.4      | 15.3         | 526.8           |
| minimum value       | 250          | 1.2        | 0.4       | 1.3          | 0.4             |
| average value       | 281          | 9.0        | 2.9       | 4.2          | 50.7            |

4. Karst development characteristics of red beds in Wuhan

4.1. Red bed karst development area

The shallow karst in Wuhan is covered or buried karst and the surface karst phenomena are relatively rare. According to the ground investigation and borehole analysis, the karst of red beds is not developed in the southern and northern Wuhan. The red bed karst exposed by drilling is mainly distributed in karst belts B1–B5 areas in central Wuhan. The red beds are widely distributed in the upper part of the middle Silurian clastic rocks, and no karst caves are found in a large number of boreholes.

Figure 1 indicates that the karst development area of the red beds in Wuhan, that is, the B1–B5 zones, are all located in the south of the Xiangfan-Guangji Fault. A more detailed study reveals that the lithology below the region of karst development in the red beds is carbonatite, such as limestone of the Triassic, Permian, and Carboniferous. When the lithology of the underlying red beds is clasolite of the Devonian, Silurian, and other ages, karst is not developed in the red layer. Therefore, the development of karst in the red beds in Wuhan is mainly controlled by the tectonic position and stratigraphic lithology.

4.2. Scale of karst development

The scale of karst development generally refers to the shape and size of various types of karst, such as the undulating size of the surface karst, depth of the karst ditch and groove, height of the rock bud, and size of the karst cave. The phenomenon of red bed karst in Wuhan is mainly karst cave \(^9,10\). For a covered karst cave, the vertical height of the karst cave can be revealed by drilling to reflect the development scale of the karst cave, thus indirectly reflecting the scale of karst development.

A total of 693 boreholes have been counted in the red bed area of Wuhan. Among them, 142 boreholes have been found with 234 caves. Figure 2 shows the cave height statistics of these caves.
As Figure 1 shows, the cave height of red beds is mainly distributed in within 0–6 m. According to the statistical results, the average height of red bed karst caves is 2.6 m; 151 karst caves are less than the average height, accounting for 64.5% of the total number of caves; the height of 1/3 karst caves is less than 1.3 m, 50% of the caves are less than 1.9 m, and 90% of the caves are less than 5.2 m; there are only three caves with cave height greater than 15 m, and the maximum cave height is 20.9 m.

The above statistical analysis shows that the karst of red beds in Wuhan is characterized by shallow karst—the scale is not large, basically small karst caves (with vertical height < 5 m), a small number of medium-sized karst caves (with vertical height = 5–10 m), and few large-scale karst caves (with vertical height > 10 m).

4.3. Karst cave development degree

The karst development degree refers to the degree of karst rock being eroded and altered in spatial form. It is generally reflected by the rate of karstification in geological or geotechnical engineering. The karst rate is a quantitative index reflecting the scale and density of karst space within a certain range, and the commonly used indexes are the linear karst rate and the borehole encountering rate of the karst cave\textsuperscript{[11]}. The linear karst rate is the percentage of the length of the karst space pattern per unit length. The borehole encountering rate is the percentage of the total number of exploration boreholes in the condition of a certain depth or stratum in which the karst cave is exposed.

4.3.1. Linear karst and borehole encountering rates of the karst cave

| Area                  | Average cave height /m | Height of 1/3 of the caves is less than | Height of 50% of the caves is less than | Height of 90% of the caves is less than |
|-----------------------|------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| B1 karst belt area    | 2.4                    | 1.3                                    | 2.1                                    | 5.1                                    |
| B2–B5 karst belt area | 2.7                    | 1.3                                    | 1.7                                    | 5.4                                    |
| Summary               | 2.6                    | 1.3                                    | 1.9                                    | 5.2                                    |

As Figure 2 shows, the distribution of karst cave height for the red bed karst.
Table 3 shows the linear karst and borehole encountering rates of the cave in red bed karst. According to the table, their averages are 3.9% and 20.5%, respectively, both of which are relatively low.

**Table 3.** Linear karst and borehole encountering rates of the karst cave in red bed karst

| Area                        | B1 karst belt area | B2–B5 karst belt area | Summary |
|-----------------------------|-------------------|-----------------------|---------|
| Linear karst rate /%        | 2.9               | 4.9                   | 3.9     |
| Borehole encountering rate /%| 19.0              | 21.8                  | 20.5    |

Comparing karst belt B1 and karst belts B2–B5, the average linear karst rate of karst belt B1 is one order of magnitude lower than that of karst belts B2–B5—the average linear karst rate of karst belt B1 is 2.9%, less than 3%, and karst is weakly developed; the average karst rate of karst belts B2–B5 is 4.9%, more than 3%, and the karst is moderately developed.

4.3.2. *Variation of linear karst and borehole encountering rates with buried depth*

Figure 3 shows the variation curve in the buried depth of the linear karst and borehole encountering rates. From the top of the red beds, the linear karst rate gradually increases with increasing buried depth, reaches the maximum value of 7.3% at 2–4 m, and then decreases gradually. The line karst rate fluctuates around 3% below the buried depth of 12 m and then decreases to less than 3%. This indicates that there is no strong karst development zone below the bedrock surface. The thickness of the karst medium development zone is approximately 12 m, below which is the stable weak karst development zone.

![Figure 3](image-url)

**Figure 3.** Variation curves of linear karst and borehole encountering rates of the karst cave with buried depth for red bed karst

4.4. *Filling of karst cave*

Table 4 summarizes the statistics of karst cave filling types in red beds. Clearly, the red bed karst is dominated by fully filled caves, accounting for 62.4% of all caves in this belt, followed by semi-filled caves, accounting for 26.1%, and non-filled karst caves, accounting for 11.5%. The buried depth of red bed karst cave roof in karst belt B1 and karst belts B2–B5 zones is broadly similar to the overall.

**Table 4.** Statistics of karst cave filling types in red bed karst

| Item            | Filling types     | Percentage/% | Average buried depth of karst cave roof /m |
|-----------------|-------------------|--------------|-------------------------------------------|
| Summary         | Fully filled      | 62.4         | 7.36                                      |
According to the drilling boreholes, the cave fillings of red bed karst are mainly brownish-yellow plastic clay and gravel soil, with small amounts of fluid-plastic, soft-plastic, and hard-plastic clay with gravel.

According to the analysis of the buried depth and filling lithology of each filling type of karst cave, the filling mode of karst cave in red beds may also be transported from top to bottom. The fillings mainly come from the disintegration of red beds themselves and partly from the overlying Quaternary strata.

5. Conclusion
In Wuhan, the Indo-China movement and the Yanshanian movements formed a series of continental basins in different periods and parts, respectively, thereby accepting red bed deposits of the Jurassic, Cretaceous, and Paleogene. During the Cretaceous–Paleogene period, the red beds represented by Donghu Group (K-Edn) were formed, and the main lithologies are red semi-cemented and weakly cemented mudstone, sandstone, and conglomerate.

The soluble rocks in the red beds in Wuhan are calcareous cemented conglomerates, and the gravel composition of the conglomerates is mainly limestone. The karst development of red beds in Wuhan is mainly controlled by the tectonic position and stratigraphic lithology. When the underlying formation lithology of red beds is a carbonate rock, karstification is developed in red beds; by contrast, when the lithology of underlying formation is insoluble clastic rock, karstification is rudimentary in red beds. The degree of karst development positively correlates with that of the underlying karst belt. The filling mode of karst caves in red beds may also be from top to bottom. The fillings mainly come from the disintegration of red beds, and some of them come from the overlying Quaternary strata.

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