Geomorphology 322 (2018) 66–75

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Horizontal and vertical zoning of carbonate dissolution in China

Mingming Luo [a], Hong Zhou [b,*], Yongping Liang [c], Zhihua Chen [a], Rubing Chen [a], Xinlong Li [b], Hamza Jakada [a]

[a] School of Environmental Studies, China University of Geosciences, Wuhan, Hubei 430074, China
[b] Geological Survey of China University of Geosciences, Wuhan, Hubei 430074, China
[c] Institute of Karst Geology, Chinese Academy of Geological Sciences, Guilin 541004, China

ARTICLE INFO

Article history:
Received 7 May 2018
Received in revised form 29 August 2018
Accepted 29 August 2018
Available online 30 August 2018

Keywords:
Carbonate dissolution rate
South-North karstification boundary
Vertical karstification boundary
China

ABSTRACT

Natural dissolution and denudation are the essential processes of karstification; however, their intensities depend on geographic and climatic conditions. Field dissolution tests of carbonate tablets were conducted in Hubei Province over a three years period to determine the impact of precipitation, lithology, altitude, vegetation and soil on carbonate dissolution. Results from the study show that carbonate dissolution rates vary from 1.23 to 2.86 mg cm^{-2} a^{-1}. In addition, a comparative analysis of our results with those from 28 other sites reveal two lateral regional boundaries of karstification, one trending from South to North China, the other from North to Northwest China, with regional precipitation variations appearing to be the primary control factor. Comparison of the dissolution rate of carbonate tablets set up on the surface (150 cm above ground surface and on the ground surface) with those beneath the surface (20 cm and 50 cm beneath the ground surface) at different elevations reveal a vertical karstification boundary in the mountainous areas along the South-North karstification transition zone. The results also show that surface dissolution rates (1.50–2.18 mg cm^{-2} a^{-1}) are higher than subsurface dissolution rates (0.53–1.61 mg cm^{-2} a^{-1}) in high altitude areas. Conversely, in low altitude areas, the subsurface dissolution rate (3.94 mg cm^{-2} a^{-1}) is much higher than surface dissolution rate (1.78 mg cm^{-2} a^{-1}). Therefore, the horizontal and vertical karstification boundaries in China highlight the main karstification function based on local elevation as well as varying geographical conditions. It was also found that the magnitudes of carbonate dissolution are consistent with recent karstification degree, which is critical for modeling karst landform evolution in the near future.

1. Introduction

Both carbonate dissolution and denudation act on the surface and immediate subsurface of a rock body. This is where the main processes of karstification begin. Karstification is the basis for processes such as karst geomorphological evolution, karst carbon sinks, global carbon cycle, hydrochemistry of karst water, karst water system development (Han and Liu 2004; De Waele et al. 2009; Li et al. 2010; Cao et al. 2012).

Due to the dramatic differences in climate, hydrology, lithology, geological structure as well as neotectonic movement between Northern China and Southern China, two completely different karst landscapes have evolved. Southern China is characterized by peak clusters, tower karst, grooves, closed depressions, sinkholes, underground rivers, large caves and several other secondary karst phenomena such as stalactites and stalagmites. However, Northern China is characterized by regular (less deformed) mountains, small karren, dry valleys, large springs and small caves. The Tai-Lu to Qingling Mountain belt binds these karst landforms from east to west in Central China (Yuan 1992). It is thus considered to be the geographical boundary between Southern and Northern China.

To study the karstification function and environmental changes in China, seven field stations were established in different geographical sites to monitor karst system dynamics. Another eleven field sites were selected for testing carbonate dissolution rates (Yuan et al., 2002). In the Erdos Basin in Northern China, Liang et al. (2007) tested the field carbonate dissolution rates at eight sites and established the existence of a zone of subsurface carbonate rocks in which the degree of corrosion was equivalent to that of a surface zone situated from South to North China. Hence, a transitional zone can be defined from South to North China based on the differences in both karst landforms and geographical conditions. However, the relationship between these boundaries and carbonate dissolution rates remains unclear; thus, further investigation is required.

Most exposed karst areas in China are dominated by rocky carbonate mountains with varying relief. The differences in altitudes create polarizing geographic conditions where certain mountainous areas are characterized by dry and arid surfaces covered in ice whereas valleys have thick vegetative cover during both winter and spring. To evaluate differences in vertical karstification processes at varying elevations, Xiangxi River basin was selected as the ideal test site to conduct the

* Corresponding author.
E-mail addresses: luomingming@cug.edu.cn (M. Luo), zhouhong@cug.edu.cn (H. Zhou).

https://doi.org/10.1016/j.geomorph.2018.08.039
0169-555X/© 2018 Published by Elsevier B.V.

field dissolution experiments on carbonate rocks. Xiangxi River basin is situated adjacent the Shennongjia Mountains which is regarded as the Ridge of Central China. By comparing the results obtained in the present study to field dissolution rates of other relevant sites in China (Yuan and Cai 1988; Yuan et al. 2002; Liang et al. 2007), the present paper discusses the underlying differences in carbonate dissolution and karstification processes along the horizontal and vertical plane and their controlling factors.

2. Field site description

The Xiangxi River basin is located in Xingshan County, west Hubei Province, which is the first large tributary along the north bank in the upper reaches of the Three Gorges Dam (Fig. 1; Fig. 2). Three tributaries join the Xiangxi River, including the Gaolan River in the east, the Gufu River in the middle reaches and the Nanyang River in the west that originates from the Shennongjia Mountains. In addition, Xiangxi River basin falls within the northern edge of the subtropical monsoon climate zone of Central China (Fig. 1). This zone is characterized by four seasons with abundant rainfall in summer, and the annual average precipitation is between 900–1200 mm. The catchment is characterized by erosion and denudation landforms characteristic of the Daba Mountain area which has highly fluctuating topography (Fig. 2). The geomorphology of the basin is dominated by karst hills and peak clusters, characteristic of a relatively juvenile stage of karst evolution compared to the isolated peaks (tower karst) in Southwest China such as those in Guangxi Province. The basin is clearly relatively young due to the vast distribution of closed depressions, and small sinkholes (Luo et al. 2016).

The influence of elevation (vertical) on carbonate dissolution rates was determined by establishing four measurement sites at varying elevations in Xiangxi River basin (Fig. 2; Table 1). The first site, Mengjialing, is located at the top of the Mengjialing Mountain situated on the left bank of Xiangxi River with an elevation of approximately 1551 m above sea level (a.s.l.). The surface area is overlain by gravelly mixed soil and thick grass cover. The second site, Huangliang, is situated on the edge of a large karst depression. This location has an elevation of 930 m a.s.l. Huangliang is also covered by gravel mixed soil but with sparse grass cover. The third location is Qinghua, which is located along hilly slopes of approximately 618 m a.s.l. Qinghua is overlain by clayey soil with no vegetation cover. The fourth site, Xiakou, is situated on the right bank of Xiangxi River with an elevation of 217 m a.s.l., with gravelly soil covered with thick grass.

3. Material and methods

Several methods can be used to determine the rate of carbonate dissolution or denudation (Plan 2005; Furlani et al. 2009; Gabrovšek 2009; Akiyama et al. 2015), such as direct measurement of the carbonate rock surface or its change in height over time (Spate et al., 1985; Haeuselmann 2008). Other methods include monitoring mass loss of exposed carbonate tablets after natural dissolution (Zhang 2011; Galdenzi 2012; Song et al. 2017), calculation of mass balance from hydrochemical and hydrological observations (Judson and Ritter 1964; Gunn 1981; Li et al. 2010; Hattanji et al. 2014; Radolović et al. 2015) as well as the application of in-situ cosmogenic ^{36}Cl (Xu et al. 2013). Among the methods mentioned above, the mass loss method of standardized limestone tablets is the most common and useful method, and is conducted within the soil matrix and/or exposed above the ground surface. Furthermore, the mass loss test of standardized limestone tablets has been conducted using an industry standard program for carbonate dissolution developed by the International Union of Speleology (Gams 1985; Zhang 2011).

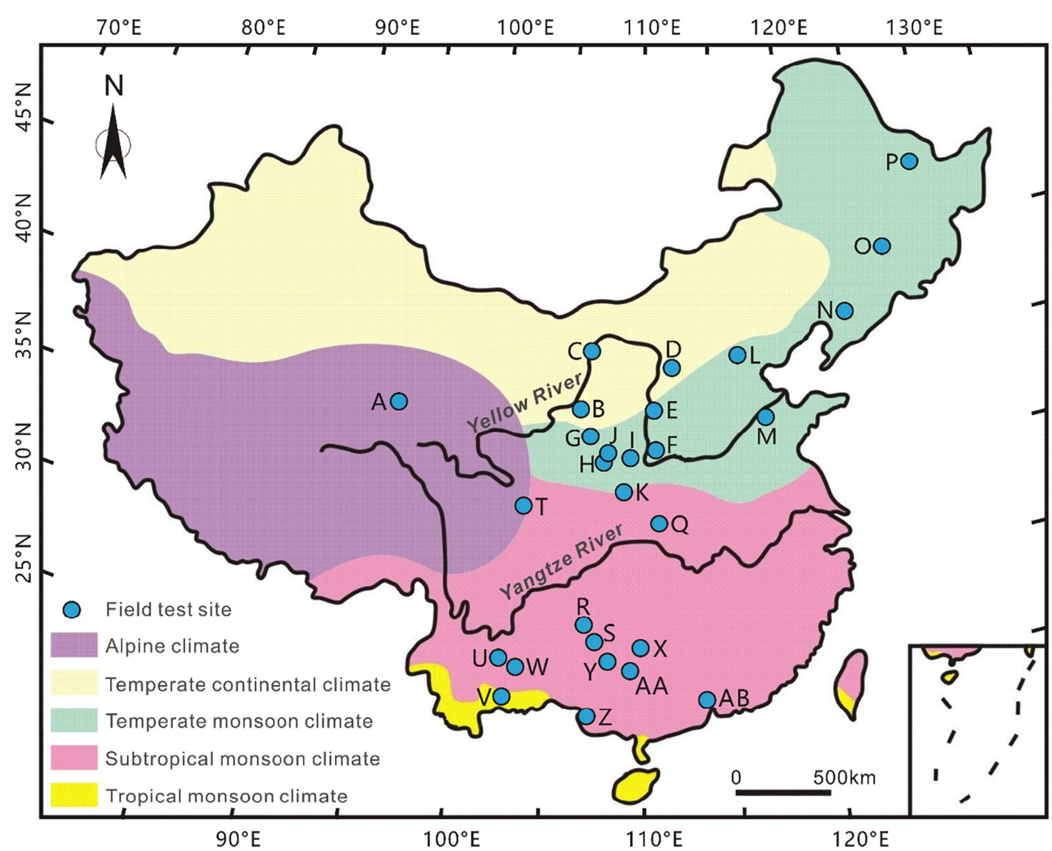

Fig. 1. Climate zoning in China and the locations of the field test sites whose numbers are linked to Table 5.