

# Statistics and Formation Mechanism Analysis on the Basin-Range Patterns of Granite Bodies in Hunan Province, China

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## Research Article

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# Abstract

This paper presents the results of statistical analysis on the basin-range relations between the granite rock bodies and surrounding rocks in Hunan Province of China. Among the 44 granitoids in Hunan Province, 28 are basins, 14 are ranges, and only 2 cannot be directly classified. The basin-range properties of granite bodies are closely related to the lithology of surrounding rocks. Among the 28 granite basins, 24 are surrounded by slate, 3 by sandstone, and only 1 by glutenite, while 11 of 14 ranges are surrounded by carbonate rocks. From the perspective of endodynamic process, tectonic movements played an important role in the evolution of the terrain in the granite areas. Firstly, tectonism shaped the large-scale tectonic framework which determined the distribution of some granite mountains in Hunan Province. In addition, tectonic compression or extension formed some granite compressional uplifts or horsts, which present as ranges now. From the perspective of differential weathering, the difference of resistance to weathering between granite and their surrounding rocks is an essential factor for the development of granite basin or range. When their surrounding rocks are carbonate rocks, the granite areas mostly present as ranges for the high solubility of carbonate minerals. When their surrounding rocks are slate rocks, the granite areas are mostly basins for their lower resistance to weathering than slate rocks determined by their more unstable minerals to weathering and more conductive soils to rainfall infiltration.

## 1. Introduction

Basin and range are the basic geomorphic forms of the earth, which are widely distributed on the land and essential parts of the gorgeous submarine topography. Basin and range evolution mechanisms have always been the forefront research topic of geology, geography, geophysics, and other geosciences that involve a wide range of fields such as tectonics (Li et al. 2013), magmatism (Wang et al. 2003), geomagnetic evolution (Sun et al. 2019), and rock weathering (Cui et al. 2019). Basin-range pattern has an obvious scale effect. The formation mechanisms of basin-range patterns within different spatial scales are often quite different. Large-scale basin-mountain systems are usually controlled by global-scale tectonic movements, among which Tibetan-Ganges Plateau-Basin system is a typical example (Powell et al. 1973; Zhou et al. 2005). On the medium scale, basins are mostly the results of local tectonic subsidence. For example, the Dongting Lake Basin, which is located in south-central China, was formed after multistage intraplate tectonic movements (Pi et al. 2001). From a small-scale point of view, the formation of basins and ranges is related to both tectonic movements and the differences of the adjacent rocks' resistance to weathering (Cui et al. 2007).

China is one of the countries with the most extensive distribution of granite masses in the world, with a total area of 909,000 km<sup>2</sup>, of which about 60% are distributed in southern China. Granites with different ages, genesis, and lithology types different geomorphic forms in different climatic zones, altitudes, and different areas of exogenous force.

Based on morphological laws, some scholars have systematically summarized the main geomorphic features and types of granite (Twidale 1982; Twidale et al. 2005). They have divided the main granite landforms into boulders, inselbergs, slopes, topology, and plains, and considered boulders as the primary geomorphic manifestation of granite. In China, as early as the 1960s, Zeng (Zeng. 1960) divided the granite landforms into five types according to China's granite characteristics, which are alpine granite terrain, tropical granite terrain, dry area granite terrain, egg terrain, and gully terrain respectively. Later, Cui et al. (2007) divided the granite landform into four categories from the perspective of weathering and erosion in the formation process of granite landforms. Geomorphic system results from the interaction of internal and external forces on the surface (Yang et al. 2012), and the landform in granite area is also affected by three main factors, namely lithology, tectonic movement and climate.

Up until now, scholars have done many researches on the geomorphology and formation mechanisms of granite areas and have obtained numerous results. Among those studies, most are carried out from the perspective of morphology, mainly focusing on micro-topography, while little attention is paid to the macro scale basin-range characteristics of granite. For a single rock mass, if there is no obvious influence of tectonic uplift or subsidence, the basin-range pattern is mainly determined by the difference of resistance to weathering between the rock mass and its surrounding rock. Anti-weathering characteristics of different lithologies often vary with diverse climate backgrounds. Under certain circumstances, the characteristics may have completely opposite results. (Cui et al. 2007).

Granite bodies are widely distributed in South China, with variable surrounding rocks and structural characteristics that cause complex basin-range patterns. Understandings on the basin-range formation mechanisms vary. (Li 2008).

In order to deepen the understanding of basin-range formation mechanisms of granite bodies, statistics on the basin-range patterns of the 44 granite bodies in the Hunan Province, where the spatial distributions of granite are relatively simple, were carried out based on the digital elevation data (DEM) and the previous geological survey results. Then, the mechanism of spatial basin-range pattern was revealed based on the combined analysis of tectonic movement and mineral composition.

## 2. Materials And Methods

### 2.1. Introduction to Granite in Hunan Province

The total outcropping area of Granitoids in Hunan Province is about 17,000 km<sup>2</sup>, which formed in different tectonic periods, including Wuling Period (Early Neoproterozoic), Caledonian Period (from Early Silurian to Middle Silurian), Indosinian Period (from Middle Triassic to Late Triassic), and

Yanshanian Period (from Middle Jurassic to Late Jurassic). Among them, the second stage of Caledonian (Early Silurian), Indosinian Period (Middle Triassic) and Early Yanshan Period (Middle Jurassic) are the three main peak periods of granite magma intrusion in this area (Fig. 1).

The granites of Wuling Period were found only in Liuyang City, northeast Hunan Province. They were controlled by an EW geological structure of this period and invaded into the strata of Lengjiayi Group. In Late Silurian Period, the main episode of Caledonian tectonism began, mainly represented by intracontinental orogeny. In Late Caledonian Period, large-scale granitic magmatism occurred in the regions east of Chengbu-Xinhua Fault in the post-collisional environment of weakening compression and stress relaxation (Bai et al. 2006). The rock masses are mainly distributed in some areas surrounding the Late Paleozoic basin in Central Hunan, including Wangyang-Zhuguang Mountain, Penggongmiao, Banshanpu, Baimashan, Miaoershan, Yuechengling, and Jiuweishan.

The Caledonian granite bodies exhibit a widespread and large distribution throughout the study area, most of which were shaped in the second stage of Caledonian Period, and some of which formed compound rock bodies with later intrusive rocks. The Caledonian granites are mainly biotite monzogranite, granodiorite, and syenite granite, of which Baimashan Body, WangyangShan Body, and MiaoerShan Body are the representative granite bodies.

The main episode of Indosinian Movement began in Late Middle Triassic Period. This tectonic movement produced many NNE folds with the help of NWW compression stress (Bai et al. 2005; Bai et al. 2007). At the beginning of Indosinian movement, some granite bodies were formed in the process of tectonic collision, mainly distributed in Guandimiao, Baimashan and Sheshanshan. In Late Triassic Period, the Late Indosinian rocks were formed in the post-collisional environment of stress relaxation, including the Yangmingshan, Wawutang, Guandimiao, Taojiang, and Baimashan rock bodies.

From Mid Jurassic Period to Late Jurassic Period, Yanshanian Movement produced the largest area of granite bodies in the southeast of the Province (Shu. 2012). The late Yanshanian granitic magma activity is the end of magmatism in the Province, and the outcropping area is very small.

## **2.2. Research Framework and Data**

In this paper, the statistics for the basin-range pattern of the 44 granite bodies were carried out firstly based on the digital elevation model (Aster GDEM 30m resolution DEM). Then, the basin-range mechanisms were analyzed from two aspects of tectonic action and weathering resistance. Finally, the erosion levels of basins with different dominant lithology were compared based on the material flux analysis.

In order to support the above study, this research got 394 granite samples and 98 slate samples from all over Hunan Province and sent them to Hunan Province Geological Testing Institute for mineral analysis.

In addition, sediment daily monitoring data from 1961 to 2019 of 10 hydrological stations with different geological background and water monthly quality monitoring data from 2014 to 2018 of 8 stations in Xiangjiang River Basin were collected to carry out material flux analysis (Fig. 1). Both the sediment data and water quality data were the results of the regular monitoring of hydrological stations of Hunan Hydrology and Water Resources Survey Bureau.

In 1987, Zhang et al carried out a large-scale investigation of river water chemistry in the Xiangjiang River Basin of Hunan Province (Zhang et al. 1987), which gained a lot of high-quality water chemistry data. In this paper, a small part of their work is cited to support the material flux analysis.

## **3. Results**

### **3.1. Analysis of Basin-range Relationship between Granite Mass and Surrounding Rock in Hunan Province**

Based on the Aster GDEM data, the topographic map of Hunan Province was drawn and the granite distribution map was nested to obtain the topographic and granite mosaic map of Hunan Province (Fig. 2). Based on Fig. 2, the basin or range properties of all granite bodies were identified. Table 1 shows the basin-range type of the main granite bodies.

Table 1  
Basin-range framework and main surrounding rocks of Granite in Hunan Province

Number	Rock Body (Group)	Type	Granite		Surrounding rockⅡ		Surrounding rockⅢ	
			Category	Geological Period	Lithology	Geological Period	Lithology	Geological Period
1	Taohuashan	Range	Monzogranite	Jurassic	Clay	Quaternary	Slate	Neoproterozoic
2	Mubushan	Basin	Monzogranite	Jurassic	Slate	Neoproterozoic	Sandstone	Neoproterozoic
3	Wangxiang	Basin	Monzogranite	Jurassic	Slate	Neoproterozoic	Sandstone	Neoproterozoic
4	Jingjin	Basin	Monzogranite	Jurassic	Slate	Neoproterozoic		
5	Dingziwan	Basin	Monzogranite	Jurassic	Slate	Neoproterozoic	Sandy clay	Quaternary
6	Lianyunshan	Basin	Monzogranite	Jurassic	Slate	Neoproterozoic	Sandstone	Cretaceous
7	Changsanbei	Basin	Monzogranite	Neoproterozoic	Sandy slate	Neoproterozoic	Sandstone	Neoproterozoic
8	Jiaoxi	Basin	Monzogranite	Jurassic	Slate	Neoproterozoic	mudstone	Devonian
9	Taojiang	Basin	Monzogranite	Triassic	Sandy slate	Neoproterozoic	Calcareous slate	Neoproterozoic
10	Yanbaqiao	Basin	Monzogranite	Triassic	Sandy slate	Neoproterozoic		
11	Sanchuangpu	Basin	Monzogranite	Triassic	Sandy slate	Neoproterozoic	Sandy clay	Quaternary
12	Tieshanpu	Basin	Monzogranite	Silurian	Sandy slate	Neoproterozoic		
13	Weishan	Basin	Monzogranite	Triassic	Slate	Neoproterozoic	Sand shale	Devonian
14	Xiema	Basin	Monzogranite	Triassic	Slate	Neoproterozoic	Mudstone	Paleogene
15	Ziyunshan	Basin	Monzogranite	Triassic, Silurian	Slate	Neoproterozoic	Mudstone	Paleogene
16	Nanyue	Range	Monzogranite	Triassic	Glutenite	Cretaceous	Sandy slate	Neoproterozoic
17	Wuji	Basin	Granodiorite	Silurian	Sandy slate	Neoproterozoic	Glutenite	Devonian
18	Yajiangqiao	Basin	Monzogranite	Triassic	Slate	Neoproterozoic	Glutenite	Cretaceous
19	Guandimiao	Basin	Monzogranite	Triassic	Slate	Ordovician	Sandstone	Ordovician
20	Denghuxian	Basin	Monzogranite	Jurassic, Triassic	Sandstone	Cretaceous	Sand shale	Devonian
21	Xitian	Basin	Monzogranite	Triassic	Sandstone	Cretaceous	Sand shale	Devonian
22	Wufengxian	Range	Granodiorite	Triassic	Carbonate	Devonian	Carbonate	Permian
23	North Zhuguangshan	Unidentifiable	Monzogranite, Granodiorite	Silurian, Triassic, Jurassic	Slate	Neoproterozoic	Argillaceous limestone	Cambrian
24	Dongfeng	Basin	Monzogranite	Silurian	Glutenite	Ordovician	Sand shale	Devonian
25	Penggongmiao	Basin	Monzogranite	Silurian	Slate	Cambrian	carbonate	Devonian
26	Dayishan	Range	Monzogranite	Jurassic	Carbonate	Carboniferous	Argillaceous limestone	Devonian
27	Tashan	Range	Monzogranite	Triassic	Carbonate	Carboniferous	Sandy slate	Ordovician
28	Tuao	Basin	Monzogranite	Triassic	Sandstone	Ordovician	Glutenite	Cambrian
29	Yangmingshan	Basin	Monzogranite	Triassic	Sandy slate	Ordovician	Glutenite	Devonian
30	Qitianling	Range	Monzogranite	Jurassic	Carbonate	Permian	Carbonate	Carboniferous
31	South Zhuguangshan	Basin	Monzogranite	Jurassic	Slate	Cambrian	Sandy slate	Neoproterozoic
32	Dadongshan	Range	Monzogranite	Jurassic	Carbonate	Devonian	Carbonate	Carboniferous

Number	Rock Body (Group)	Type	Granite		Surrounding rock		Surrounding rock	
			Category	Geological Period	Lithology	Geological Period	Lithology	Geological Period
33	Xishan	Range	Monzogranite	Jurassic	Carbonate	Devonian	Slate	Cambrian
34	Jingjiling	Range	Monzogranite	Jurassic, Triassic	Carbonate	Devonian	Sandstone	Cambrian
35	Xuehuading	Range	Monzogranite	Jurassic	Carbonate	Devonian	Sandstone	Cambrian
36	Guposhan	Range	Monzogranite	Jurassic	Carbonate	Devonian	Sandstone	Cambrian
37	Yuechenling	Range	Monzogranite	Triassic	Carbonate	Devonian	Sandy slate	Ordovician
38	Miaoershan	Basin	Monzogranite	Jurassic, Silurian	Sandy slate	Nanhua system	carbonate	Devonian
39	Wutuan	Range	Monzogranite	Triassic	Sandy slate	Neoproterozoic	Sandy slate	Nanhua system
40	Wawutang	Basin	Monzogranite	Triassic	Slate	Ordovician	Slate	Silurian
41	Chongyangpin	Basin	Monzogranite	Triassic	Slate	Ordovician	Slate	Cambrian
42	Baimassi	Unidentifiable	Monzogranite	Silurian, Triassic, Jurassic	Slate	Neoproterozoic	Sandy slate	Ordovician
43	Tianmashan	Range	Monzogranite	Triassic	Carbonate	Devonian	Slate	Cambrian
44	Chenshan	Basin	Monzogranite	Triassic	Sandy slate	Neoproterozoic	Sandstone	Cambrian

Table 1 shows that, among the 44 granite bodies (including granodiorite) in Hunan Province, 28 are granite basins, 14 are ranges, and only 2 granite body masses, including North Zhuguangshan and Baimasi, cannot be directly classified. According to the statistical results of surrounding rocks, the basin-range properties of granite are closely related to the lithology of surrounding rocks. Among the 28 granite basins, 24 are surrounded by slate, 3 by sandstone, and 1 by glutenite, while 11 of 14 ranges are surrounded by carbonate rocks.

## 3.2. Analysis of Basin-range Characteristics in Composite Rock Masses

As mentioned above, the basin-range characteristics of North Zhuguangshan rock mass and Baimasi rock mass are unidentifiable. In fact, the North Zhuguangshan and Baimasi rock masses are both typical composite rock masses that share basin and range inlay characteristics.

The Northern Zhuguangshan rock mass is located in Luoxiao Mountain in the southwest of Hunan Province, which was formed from Early Silurian Period to Late Jurassic Periods (Fig. 3). The Baimasi rock mass is located in Xuefeng Mountain in the middle of Hunan Province, that was formed from Middle Silurian Period to Late Jurassic Period (Fig. 4) (Liu et al. 2016).

According to the basin-range relationships among different rocks formed in different geologic periods, the two rock masses both show the same characteristics that, younger rocks are more inclined to develop into ranges than their adjacent older rock masses. Specifically, all the Silurian rock bodies of the North Zhuguangshan rock masses are basins, while the adjacent Jurassic and Triassic rock bodies are ranges (Fig. 3), and all the Jurassic rock bodies of the Baimasi rock mass are all ranges, while the adjacent older rock bodies are basins.

## 4. Discussion

### 4.1. Influence of Tectonism on Basin-range Pattern of Granite Masses

As illustrated in the classical geomorphology theory, tectonic movement plays a decisive role in controlling the large-scale geomorphology on the earth (Summerfield. 1986). The multistage tectonic movements have also determined the large-scale basin-range pattern of Hunan Province. The magmatic activities in Hunan Province are mostly controlled by the post-collisional or the intracontinental post-orogenic extensional tectonic environment. The Mesozoic magmatic movements in this area also showed evident zonation, and the spatial distribution of the magmatic rocks exhibits the same zonal characteristics (Yang et al. 2012).

In general, there are always intense magma movements along an orogenic belt with the influences of the tensile activities of the faults along the belt and the delamination of mantle and lower crust (Wang et al. 1991). Controlled by the large-scale tectonic framework, some granite concentrated zones are formed along some mountain ranges, including Xuefeng Mountain, Luoxiao Mountain, and Nanling Mountain. Meanwhile, many granite mountains are formed, such as Wanyang mountain, Zhuguang mountain, Dadong mountain, Yuecheng mountain, Jiuyi mountain, miao'er mountain, Baima Mountain and Wangyun mountain.

After the Caledonian magmatism, some other tectonic movements occurred successively, such as Yanshanian movement and Indosinian movement, and produced many large-scale tectonic systems. The earlier rock bodies may be affected by the later tectonic movement, resulting in some compressional uplifts and staggered faults, which controlled the basin-range evolution processes of some granite masses. For example, the Xupu-Chengbu Fault in the east of the Xuefengshan tectonic belt experienced a strike-slip in the Yanshan Period, which cut off the Caledonian Baimashan rock mass, Indosinian Wawutang rock mass and Indosinian Wutuan rock mass in the north-south direction. For a specific rock mass, the uplifted part tends to develop into range, such as the Wutuan rock mass.

From the Early Cretaceous to the Paleocene, the tectonic evolution of Hunan Province turned be a new stage characterized with a series of deep-seated extension systems, which produced many horsts and grabens. During this process, some granite bodies were up-lifted and finally developed into ranges, of which Nanyue rock mass is the most representative example.

Since the Miocene Period, the Neotectonics movements have been influencing the surface morphology of most areas in Hunan Province. In this stage, the crustal uplifts in eastern, southern, western and north-western Hunan are obvious and continuous, while the Dongting Lake area in the northeast has been intermittent subsidence (Bo et al. 2011). The crustal uplift accelerated the denudation of overlying strata of granite rock masses and exposed some deep granite bodies to the surface (Bell 2016).

## 4.2. Comparative Analysis of Resistance to Weathering

### 4.2.1 Comparison of mineral compositions between granite rocks and their surrounding rocks

According to the previous statistics, the surrounding rocks of the granite basins in Hunan Province are mainly slate, and of the granite ranges are mainly carbonate rocks. Hunan has the subtropical monsoon climate with relatively high temperature and large rainfall and chemical weathering is the dominant weathering type. The carbonate areas always present as basins just because of the higher solubility of calcite and dolomite than granite minerals (Pye 1986; Cui et al. 2007). It can also be proved that the difference of mineral contents between granite and slate determines the basin-range relationship between them.

The granites in Hunan Province are mainly monzonite, with less amount of granodiorite. The average mineral compositions of granitic bodies in different geological ages can be obtained based on statistical analysis of the mineral compositions of 394 granitic samples (Table 2).

Table 2 shows that, the average contents of K-feldspar, plagioclase, quartz and mica for 394 samples are 31.1%, 33.1%, 29.3% and 5.7% respectively, and the mineral contents of rock masses in different geological ages are obviously different. The average contents of plagioclase and biotite in the Silurian Period and Middle Triassic Period are significantly higher than the later geological ages, while the average contents of K-feldspar and quartz are lower than the later ages. Goldish and Carroll (Goldish 1938; Carroll 2012) summarized the mineral-stability series in weathering, namely quartz > muscovite > K-feldspar > plagioclase > biotite > hornblende > pyroxene > olivine. According to this series, the rock bodies of the Silurian Period and the Middle Triassic Period is more likely to be weathered than the later rock bodies, that is the main reason why the younger rock bodies are more likely to develop into ranges in a composite rock mass.

Table 2  
Average mineral content of granite in different periods in Hunan Province

Geological age	Number of samples	Quartz (%)	Potash feldspar (%)	Plagioclase (%)	Biotite (%)	Total (%)
Silurian	67	26.4	24.1	39.5	7.9	97.9
Middle Triassic	72	31.3	25.4	35.7	7.5	99.9
Late Triassic	97	29.6	35.9	29.9	4.3	99.8
Middle Jurassic	109	30.1	31.7	32.6	5.4	99.8
Late Jurassic	49	29.2	38.4	27.9	3.6	99.1
Average	79	29.3	31.1	33.1	5.7	99.3

The slates in Hunan Province mainly formed in the Wuling Period and Caledonian Period under the influence of regional tectonic movements, which are distributed in the strata of the Proterozoic Lengjiaxi Group, the Proterozoic Banxi Group, the Nanhua Period and the Silurian Period (Zhang et al. 1987). Statistical results of the average mineral contents of different types of slate were given in Table 3. Table 3 shows that, sericite and quartz are dominate minerals for the main types of slate. Except for carbonaceous slate, the content of sericite and quartz of other types of slate accounts for more than 80% at least.

As a fine-grained type of muscovite, sericite is the product of low and medium temperature alterations or shallow metamorphisms, and has stable chemical properties (Yang et al. 2006). Experiencing more tectonic movements accounts for the higher fracture rate of the slates in Hunan Province which formed ahead of Silurian, whereas their mineral compositions are more resistant to weathering.

Table 3  
Average mineral contents of different types of slate in Hunan Province

Lithology	Average mineral composition (%)					
	Sericite	Quartz	Feldspar	Biotite	Muscovite	Organic matter
Sericite slate	88 ~ 95	5 ~ 10	/	/	/	/
Silty slate	70 ~ 74	25 ~ 35	1 ~ 5	/	/	/
Gravelly sandy slate	48 ~ 54	35	3	1 ~ 2	1 ~ 5	/
Carbonaceous slate	15	3 ~ 10	/	/	/	37 ~ 45
Siliceous slate	25 ~ 30	70-75	/	/	/	/

## 4.2.2 Comparative analysis of soil infiltration conditions between granite and slate

In those areas dominated by chemical weathering, rainfall infiltration plays an essential role in the weathering process. The more rainfall infiltrates into the soil, the more opportunities for water-rock interaction and accordingly the faster the weathering.

Determined by the unique characteristics of mineral compositions, weathered soil of granite is characterized by high sand and gravel content, loose soil, and large permeability (Nesse 2012). According to the statistical result completed by Zheng and Bennett (2002), the permeability coefficient of weathered granite soils is generally in the range of 0.25 ~ 2.50m/d.

Slate is mainly formed by light metamorphism of mudstone, argillaceous siltstone or tuff, and the weathering products on its surface are mostly clay or loam. The permeability coefficient of this soil is generally between 0.001 and 0.01 m/d (Zhang et al. 2009), which is much lower than that of granite weathered soil. As a result, it may be argued that the rainfall infiltration in granite area is greater than that in slate area, which is another important reason why the weathering rate of granite is larger than slate in hot and humid climate.

## 4.2.3 Comparative analysis of material flux analysis

For a closed basin, material flux of the export can roughly reflect the average weathering rate of the basin if without considering the impact of human activities (Gurumurthy et al. 2012). The average sediment transport modulus and chemical flux modulus of each catchment area determined by related hydrological station were calculated based on the collected sediment and water quality data and the results were showed in Table 4 and Table 5.

It can be concluded from Table 4 and Table 5, that the sediment transport modulus and chemical flux modulus of all basins are closely related to the dominant lithology. Table 4 shows that, the basins dominated by carbonate rock and slate have the smallest sediment modulus with the maximum value of  $101.1 \times 10^3 \text{ kg/km}^2\text{-a}$ , and the clastic sedimentary rock basin is in the middle, while the two granites basin show the highest sediment transport modulus, of which the Oushui basin is  $219.9 \times 10^3 \text{ kg/km}^2\text{-a}$  and the Wushui basin even reach up to  $655.3 \times 10^3 \text{ kg/km}^2\text{-a}$ . In 2007, Xiao et al (2007) pointed out that, there are three small basins with the sediment transport modulus over  $200.0 \times 10^3 \text{ kg/km}^2\text{-a}$  in Hunan Province, including the Oushui Basin, Wushui Basin, and Wujiang Basin, which are all granite basins.

Table 5 shows the characteristics of hydrochemical flux modulus of different basins, which are quite different from those of sediment transport flux modulus. The carbonate basins have the highest hydrochemical flux modulus, which is generally more than  $150 \text{ kg/km}^2\text{-a}$ . The average hydrochemical flux modulus of clastic rock areas is only lower than that of carbonate rock basins. Different from the huge difference in sediment transport flux, both the slate basin and the granite basin present the characteristics of low hydrochemical flux. The average hydrochemical flux modulus of the 4 basins dominated by slate rock in the Table 5 is about  $57.4 \times 10^3 \text{ kg/km}^2\text{-a}$ , and the maximum value is only  $74.6 \times 10^3 \text{ kg/km}^2\text{-a}$ . Contrary to the highest value of the sediment transport modulus, the granite basin is characterized by the lowest hydrochemical flux modulus with an average value of about  $45.0 \times 10^3 \text{ kg/km}^2\text{-a}$ , and the maximum value is only  $53.9 \times 10^3 \text{ kg/km}^2\text{-a}$ . In 1999, Chen et al carried out a comparative study on the hydrochemical flux modulus of different lithologic areas in the Pearl River Basin adjacent to Hunan Province (Chen et al. 1999). They proposed a hydrochemical flux sequence of carbonate rock > clastic rock > slate rock  $\approx$  granite rock for different geological background basins. According their statistics, the average hydrochemical flux modulus of the 4 types of basins are  $269.8 \times 10^3 \text{ kg/km}^2\text{-a}$ ,  $151.5 \times 10^3 \text{ kg/km}^2\text{-a}$ ,  $54.3 \times 10^3 \text{ kg/km}^2\text{-a}$  and  $71.1 \times 10^3 \text{ kg/km}^2\text{-a}$  respectively, which are well consistent with the results of this paper.

Based on the above analysis of the sediment transport and chemical flux modulus, the overall material flux without considering water of the basins can be roughly compared. In the slate basin, the sediment transport modulus and chemical flux modulus are both small, that means the basin's weathering is also at a low level. Although granite basins present low hydrochemical flux modulus, the total material flux modulus are much higher than slate basins for its highest sediment transport modulus. Controlled by the characteristics of easy-dissolved, the hydrochemical flux modulus of carbonate rock basin is much higher than that of other types of basins, which makes its total material flux the highest, though it has lower sediment transport flux modulus.

Table 4  
Average annual sediment transport modulus of typical stations

Station	River	Dominate lithology of the basin	Average sediment transport modulus 10 <sup>3</sup> kg/km <sup>2</sup> .a
Laobutou	Xiangjiang	Carbonate rocks	78.8
Hengyang	Xiangjiang	Multi-lithology	88.8
Xiangtan	Xiangjiang	Multi-lithology	105.5
Daoxian	Xiaoshui	Carbonate rocks	101.1
Zhaiqian	Oushui	Granite	219.9
Shenshantou	Zhenshui	Multi-lithology	107.3
Jingtoujiang	Wushui	Granite	655.3
Ganxi	Mishui	Multi-lithology	117
Shuangjiangkou	Liuyanghe	Slate	78.8
Daxitan	Lushui	Clastic rock	167.2

Table 5  
Average annual hydrochemical flux modulus of typical stations

Station	River	Main lithology of the basin	Average sediment transport modulus
			10 <sup>3</sup> kg/km <sup>2</sup> .a
Daoxian	Xiaoshui	Carbonate rock and slate	155.3
Laobutou	Xiangshui	Carbonate rock and slate	156.2
Loudi	Lianshui	Carbonate rock	307.1
Lianyuan	Lianshui	Carbonate rock	343.9
Shuangfeng	Meishui	Carbonate rock	209
Shuangjiangkou	Liuyang	Slate	47
Daxitan	Lushui	Clastic rock	112.2
Shenshantou	Zhenshui	Clastic rock and slate	64.8
Loulingqiao	Jinjing	Slate and granite	74.6*
Tongtang	Lushui	Clastic rock	166.6*
Shimenkan	Zhenshui	Clastic rock and slate	70.5*
Guiyang	Xiangjiang	Carbonate rock	147.6*
Mazaidu	Shiqihe	Carbonate rock	154.2*
Jiangyong	Yongming	Slate and limestone	60.7*
Jiangyong	Tuojiang	Slate and granite	47.4*
Jiahe	Zhongshui	Carbonate rock and granite	128*
Ningyuan	Lengshuihe	Carbonate rock and slate	124.9*
Xintian	Xintian	Carbonate rock and slate	104.5*
Xihe	Xishui	Carbonate rocks	199.1*
Chenzhou	Chenjiang	Granite and carbonate rock	49.2*
Wenming	Wenming	Granite and sandstone	41.3*
Zhaiqian	Oushui	Granite	53.9*
Wulipai	Mianshui	Granite	35.2*
Anren	Yongle	Clastic rock and granite	56.7*

## 5. Conclusions

In this paper, a statistical study on the basin-range relations between the granites and their surrounding rocks in Hunan Province was carried out, and the formation mechanisms were analyzed from two main aspects of tectonic evolution and the differences of anti-weathering between the granites and their surrounding rocks. The result was verified by the analysis of material flux.

Among the 44 granitoids in Hunan Province, 28 are basins, 14 are ranges, and only 2 cannot be directly classified. According to the statistical results of their surrounding rocks, the basin-range properties of granite bodies are closely related to the lithology of surrounding rocks. Among the 28 granite basins, 24 are surrounded by slate, 3 by sandstone, and only 1 by glutenite, while 11 of 14 ranges are surrounded by carbonate rocks.

Tectonic movements determined the large-scale basin-range pattern of granites in Hunan Province. Controlled by the large-scale tectonic framework, some granite concentrated zones are formed along some mountain ranges, including Xufeng Mountain, Luoxiao Mountain, and Nanling Mountain. The earlier rock bodies may be affected by the later tectonic movement, resulting in some compressional uplifts and staggered faults, which controlled the basin-range evolution processes of some granite masses, such as the Wutuan Rock Mass and the Nanyue Rock Mass.

The difference of resistance to weathering between granite and surrounding rock is a controlling factor for the development of granite basin or range. Because of the high solubility of carbonate minerals, the weathering speed in carbonate area is the fastest, so the granite rock areas always present as

ranges when their surrounding rocks are carbonate rocks. The minerals of slate rocks in Hunan Province have higher resistance to weathering than granite minerals. In addition, the surface soil in granite area is more conducive to rainfall infiltration than slate area, which means that the granite has more chances of weathering. Controlled by the above two factors, the weathering rate of the granite areas in Hunan Province is higher than that of the slate areas, so that when the surrounding rocks are slate rock, the granite areas always present as basins. The differences of resistance to weathering between different types of rock basins are verified by the analysis results of sediment transport modulus and hydrochemical modulus.

## Declarations

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## Figures

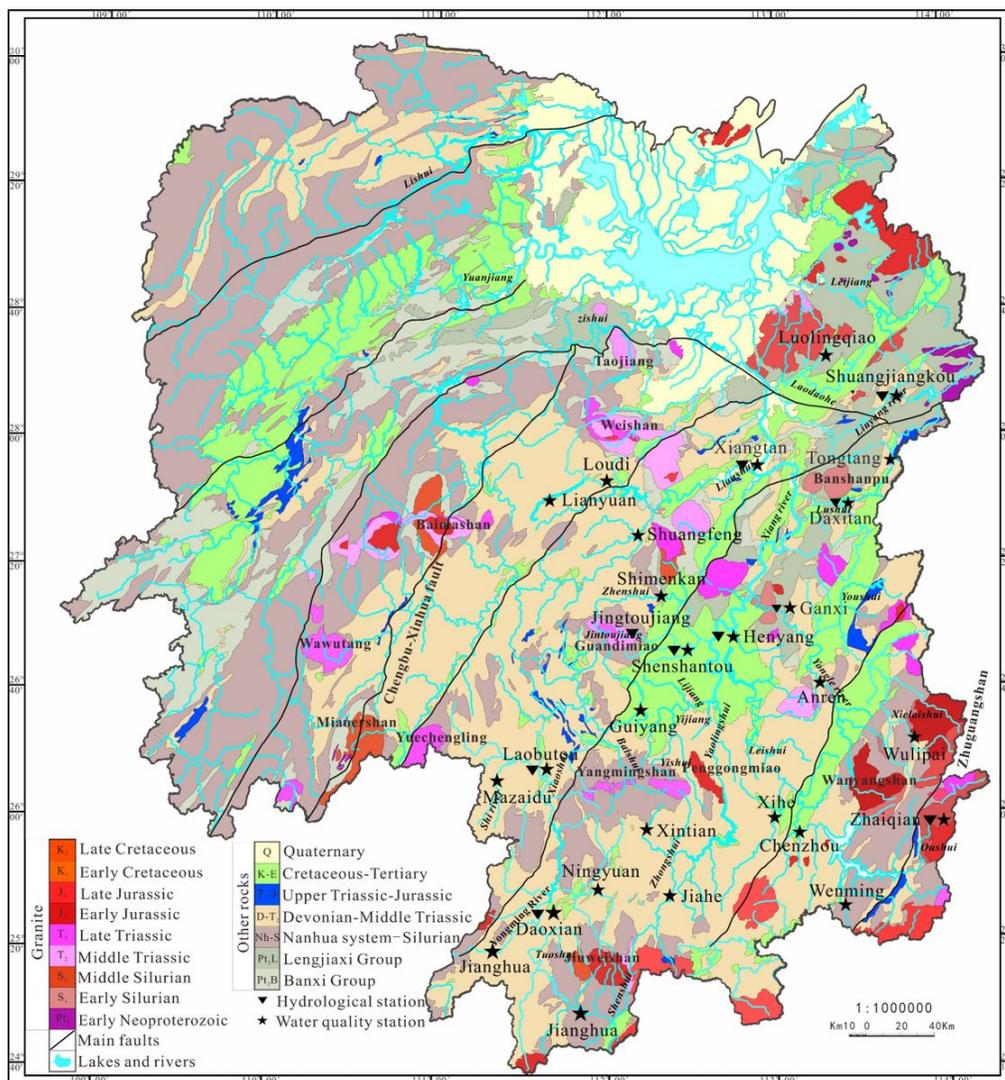


Figure 1

Hunan geological map and data sources points.

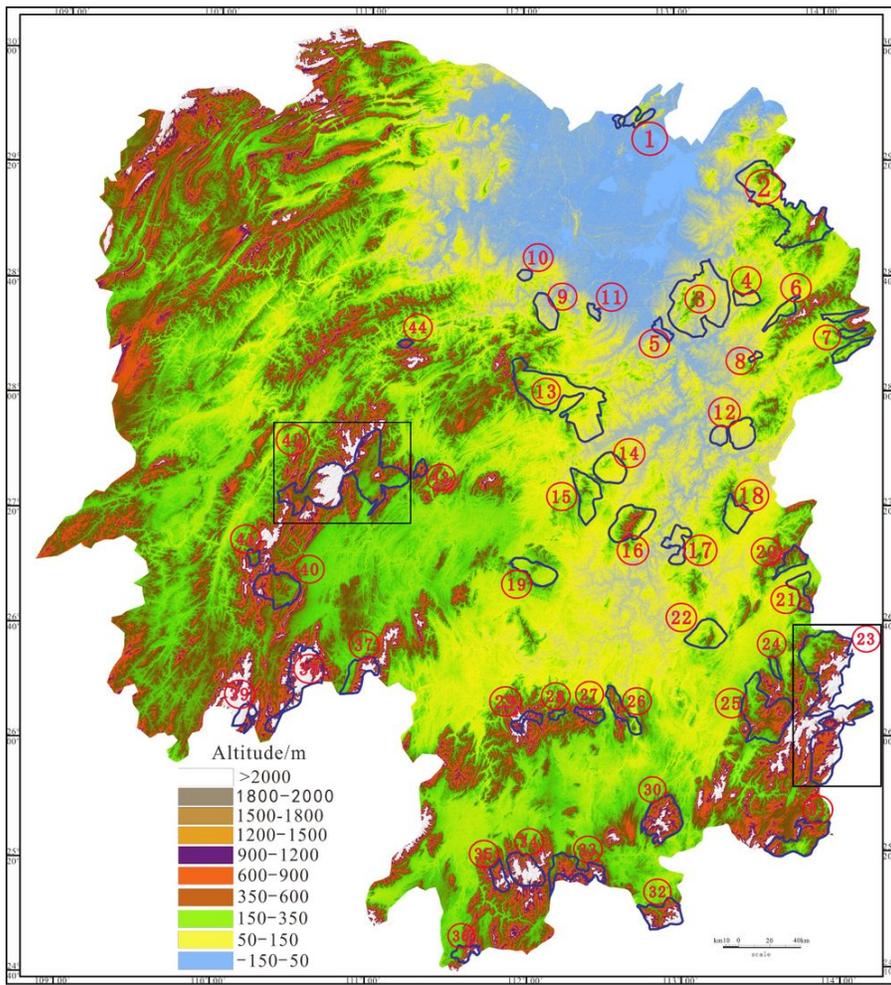


Figure 2

Nested map of granite and topography in Hunan Province.

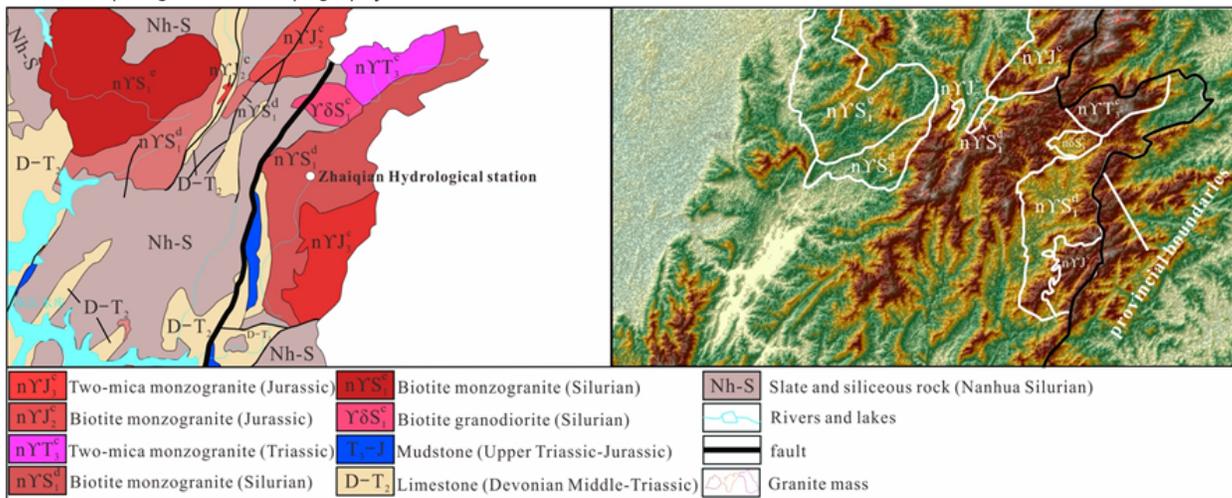


Figure 3

Basin-range framework of the North-Zhuguangshan rock mass.

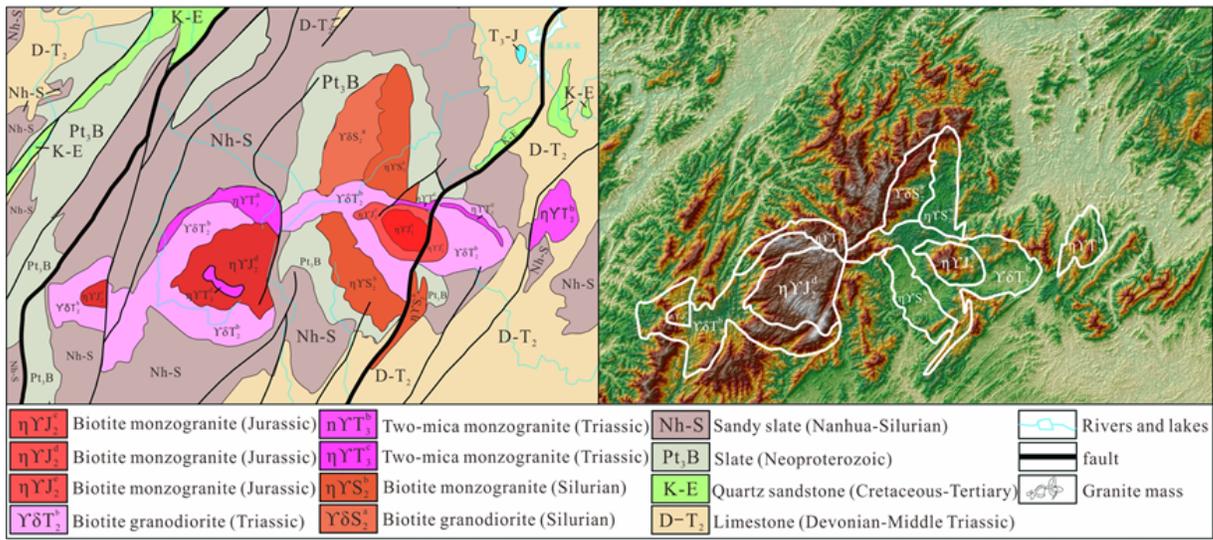


Figure 4

Basin-range framework of the Baimasi rock mass.