The Geology of the Xizhuang Watershed, near Baoshan, West Yunnan

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Abstract

The Xizhuang watershed is geologically complex. It comprises a tectonic ring structure integrated in the Qinghai-Tibet-Yunnan-Burma-India-Nepal longitude-parallel tectonic belt. A series of intricate faults and folds contribute to the landform and landscape development within the watershed. The rock formations belong to the Upper Cambrian, the Ordovician, and the Quaternary lithostratigraphy; carbonate rocks make up 40 per cent of all the bedrock in the watershed. As a result of a series of tectonic movements, fault activities, and the formation of rock cracks, this watershed is rich in underground aquifers and springs. To date, seven underground rivers and seventeen major springs have been identified. Nine of these springs were discovered during the geological survey carried out by PARDYP, the results of which are reported here. The survey also showed that except for one spring (No. 16, whose water supply is unclear), almost all the underground water supplies originate from within the Xizhuang watershed. The influence of the rocks on soil formation, the occurrence of landslides and erosion instabilities, and effective measures to control geological hazards are also described.

Introduction

The Xizhuang watershed is located in the northwest of Banqiao Township, Baoshan City, extending from 99° 06′ to 99°13′ E and 25°13′ to 25°17′ N. Within this watershed, there are three administrative villages: Xizhuang, Qingshui, and Lijiasi. The Xizhuang River originates from the mountain ridge in Yiwanshui. There are two tributaries in the upper reaches of the watershed: the Lijiasi River to the east and the Shenjia River to the west. They converge near Qingshui Village. In the lower reaches, the Xizhuang River flows into the Donghe River, which finally joins the Nujiang (Salween) River System—the system that drains the entire Baoshan Basin.

In order to understand the key features of geology, tectonics and lithosphere, and terrain stability, a preliminary geological survey was undertaken in the watershed in 1997. There are many springs in this watershed, and this raises questions about the geological origin of the water and how to arrive at water balance calculations for the watershed. The purpose of the survey was to identify the geological influence on the hydrological cycle, to describe the movement of the underground water through the geological formations, and to determine the influence of the bedrock on soil formation and terrain stability.

Lithostratigraphy

The Xizhuang watershed is in the southern part of the Hengduan Mountains, and is traditionally considered to be composed of two main tectonic elements, the so called Qinghai-Tibet-Yunnan-Burma-India-Nepal tectonics and longitude-parallel tectonics. These tectonics are extremely complex with intricate faults and many incomplete folds. The three different tectonic structures that occur in the watershed include the Qinghǎi-Tibet-Yunnan-Burma-India-Nepal tectonics, the longitude-parallel tectonics, and the ring-like tectonics.

The tectonic movement in this watershed has two characteristics: an interval and unconformable movement of the crust and the successive activities of faults. The formation of valley terraces and the development of gullies and caves are influenced by the uplift and downthrust movement of the crust. For example, there are a series of pebbly-mud stone successions in the west banks of both the Lijiasi River and the Qingshui River located 10 to 20 metres above the riverbeds, whereas some caves like the Shihua and Tiger caves are observed along the riverbanks. In general, the left bank of the river is the uplift region and the right side is the decline region. Overall, the western margin of the Baoshan Basin (including the Xizhuang watershed) is a region of uplift, while the eastern margin is in an area of downfaulting. This is responsible for the eastern flow direction of the stream and the creation of the asymmetrical landform. Tectonic activity along the main faults has resulted in frequent earthquakes leading to the formation of fault basins during the Cenozoic era.

The field survey showed that the stratigraphy is well developed and falls within the Paleozoic, Mesozoic, and Proterozoic stratigraphic periods. The lithostratigrapic outcrops in this region are shown in Table 79. Three geological transect profiles were made through the watershed.

Underground Water

The water-containing rocks are mainly intercalated and banded carbonate and clastic rocks of Paleozoic origin. As a result of successive tectonic movements, small cracks have occurred in these rocks. This watershed is a typical result of the longitude-parallel tectonics contained within the overall ring tectonics. These ring tectonics result in the development of tectonic cracks of which the radial distribution of cracks near Shuangmaidi is an example. The result is that more of the rain falling in higher elevation areas seeps into the ground through the cracks between rocks.

The watershed is located on a major fault zone. The fault zone has relatively flat rock layers made up of conglomerates, which encourages water to seep underground. For example, a series of spring outcrops occur in the Qingshui river along this fault line. The discharge from these springs generally varies from 20 to 30 l/s, but in the largest spring (No. 17) the discharge reaches 277 l/s. The regional tectonic and lithographic characteristics determine the stream flow, the aquifers, and the occurrence of springs.

Table 79: The lithography of Xizhuang Watershed

Era	Period	Epoch	Formation	Symbol	Thickness (m)	Description of lithography
Cenozoic	Quaternary	Holocene		Q_n^{d+pl}	0.5-20	Alluvium, flood; sand, conglomerate, and rudaceous soil; HCO_3-Ca.Mg water
				$Q_n^{'d+el}$	0.5-15	Slope and vestige sediments; rudaceous and sandy soil
		Pleistocene		Q_p	0-665	Alluvium and lake sediments; soil with sand and conglomerate
Lower Paleozoic	Ordovician	Middle	Shidian	O_2S	100-464	Sandstone, shale, slates; HCO_3-Ca water
		Lower	Laojianshan	O_1^3	743	Purple and greyish-green shale intercalated sandstone
			Mantang	O_1^2	404	Grey-white quartz sandstone, sandstone
			Yanqing	O_1^1	450	Grey-white quartz sandstone intercalated limestone, shale
	Cambrian	Upper	Upper Baoshan	$\in_3^{3-3}$	308-800	Grey-green shale intercalated sandstone, mud-banded limestone, and fish-egg-like limestone
			Lower Baoshan	$\in_3^{3-1}$	890	Siltstone, shale intercalated mud-banded limestone
			Upper Shahechang	$\in_3^{3-1}$	218	Shale, siltstone
			Lower Shahechang	$\in_3^{2-3}$	286	Upper is fish-egg-like limestone, lower is shale intercalated limestone
			Upper Hetaoping	$\in_3^{2-2b}$	300	Upper is limestone and fish-egg-like limestone, lower is shale and slate
			Lower Hetaoping	$\in_3^{2-2a}$	500	Shale, sandstone, phyllite
			Shuangmaidi	$\in_3^{2-1}$	750	Phyllite, slate, sandstone

Notes on the Lithography

Upper Cambrian ($\in_3$): The base contains deposits of clastic rocks intercalated with carbonate of presumed shallow marine origin. The lithographic elements consist mainly of yellow and grey-yellow sandstone, siltstone, shale, and greyish and grey medium to thick laminate mud-banded limestone, fish-egg-like limestone, and mud limestone, which are intercalated alternately in different thicknesses. The total thickness ranges from 610 to 2,973 metres. This type is mostly distributed in the central and southern parts of the watershed.

Ordovician (O): This was basically built up through shallow marine deposits, and the lithography is usually variable. Clastic rock intercalated with carbonate is the major element. This type is mainly distributed in the northern part of watershed.

Quaternary (Q): This was formed through a series of alluvial, flood, and sedimentary activities and is mainly composed of sand, conglomerate, and soil. This type occurs in the riverbed and on some mountain slopes.

Table 80: **The Characteristics of the Underground Rivers in the Xizhuang Watershed**

No.	Water supply region	Catchment area (sq. km.)	Stream length (km)	Lithostratigraphy	Relevant spring no(s).	Discharge (l/s)
1	Yiwanshui to Shuangmaidi	6.5	4.0	Developing along fault belt, limestone	S2, S3, S4	60.6
2	Baiyan'ao to Zhangjiawan	6.0	3.5	Developing along laminate limestone	S6	50
3	the Pass of Houzilu to Langmaidi	4.0	2.5	Developing along fault belt	S10	20
4	Da'aozi to Qingshui River	6.5	4	Intercalated limestone and sandstone	S12	51.5
5	Sange'naozi to Lengshuiqing	6.0	2.5	Along fault belt	S14	25.2
6	Houpo to Xiangcao'ao	6.5	4.0	Intercalated limestone and shale	S16	55
7	Whole watershed	32	12	Along fault belt	S17	262.3

Note: Underground river No.7 receives all the underground water in the watershed. The discharge was measured as 276.8 l/s in April 1979, and as 490 l/s in February 1997.

Seven underground rivers have so far been identified in this watershed from the field observations and surveys (Table 80). These rivers are described below.

- No. 1. This underground river is 4 kilometres long, has a catchment area of approximately 6.5 sq.km., and is located near the Yiwanshui and Shuangmaidi villages. The river develops and extends along a fault in a northwest direction. The southern part of the fault is composed of Upper Cambrian limestone intercalated with shale and sandstone and receives water from many sources. The northern side consists of Middle and Lower Ordovician sandstone and shale, which can stop the water from flowing into other regions. As a result of this, the ground water flow along the fault belt is generally poor. Only three springs, Nos. 2, 3, and 4 were found in this belt. The total discharge of these three springs is more than 60.6 l/s.
- No. 2. This river section is about 4 km long. The water-supply area is situated near the Baiyan'ao and Zhangjiawan villages. The catchment area is 6 sq.km. Banded limestone rocks belonging to the Upper Cambrian period are the source of many aquifers. The shale at the river bottom prevents water from seeping further into the rock formation. The discharge of spring No.6, found along this river, is 50 l/s.
- No. 3. This river section is also about 4 km long. The water supply catchment area is 6.5 sq. km and stretches from Houzilu pass (Monkey Road) to Langmaidi. The main rocks consist of Cambrian mud-banded limestone and intercalated lutites. The spring from this river outcrops near the Qingshui Primary School and discharges 51.5 l/s of water.
- No. 4. This underground river is 4km long and has a catchment area of 6.5 sq.km. The water supply area is near the Da'aozi and Qingshui Rivers, and originates from intercalated limestones and sandstones.
- No. 5. This river is 2.5 km long, and the catchment area covers 6.0 sq.km. It is located between Sange'naozi (Three Brains) and Lengshuiqing hamlets, and

comprises an underground water supply that converges along a fault belt, and runs in a north-west to north-easterly direction. Upper Cambrian limestone and shale are the dominant bedrock. The outcrop of this river is exposed in the upper reach of Lengshuiqing stream (1975 masl) and discharges at 25.2 l/s in spring No.14.

- **No. 6**. The water supply of this river has not been determined and is likely to originate from an adjacent watershed. The outcrop of the river is near the watershed divide, and the spring discharge (No. 16) is about 55 l/s.
- **No. 7**. This river is 12 km long, with a catchment area of 32 sq. km. Its spring is located near the Tiger Cave (1740 masl). The discharge was 277 l/s in April 1979, and 490l/s in February 1997; the latter measurement was made by the Baoshan Hydrological Station.

So far the PARDYP team has identified more than 200 springs in the watershed between Tiger Cave and Lijiasi, seventeen with a discharge of more than one l/s. The highest spring was found at 2425 masl, the lowest near Tiger Cave at 1740 masl. During the 1997 fieldwork, nine new springs with a discharge of more than 1 l/s were discovered with a total discharge of 191.9 l/s. Previous investigations had only recorded eight springs of more than one l/s. If spring No.17 is excluded, the total discharge is 372 l/s. The details of the springs with a discharge of more than one litre are shown in Table 81.

The challenge is to understand the water balance in the watershed and the contribution and behaviour of these springs and their discharges. For example, is the spring water in Tiger Cave from this watershed or supplied from other watersheds? Spring No. 16 is at an elevation of 1975 metres. As this is nearly as high as the watershed divide (2075m) the discharge of 55 l/s from this spring probably comes at least partly from another watershed. Thus it is quite possible that a small amount of the water in spring No. 17 comes from other watersheds since it accepts all Xizhuang underground water.

Main Soil Types

The formation of soil is correlated with base rock characteristics. In the Xizhuang watershed, carbonate and clastic rocks are dominant although metamorphism has taken place in the lithography as a result of successive tectonic movements. In general, the red soils and yellow-red soils have developed from mud-banded limestone, limestone, and mud limestone, and the brown and red-brown soils from sandstone, shale, and phyllite. The soil types in the watershed can also be classified by elevation (Table 82).

The thickness of the soils varies with the soil type and the location in the watershed. On gentle slopes, mountain bottoms, and the river valley, the soil is relatively deep, for example, the soil of the left river bank of the Shuangmaidi is 10 to 15m thick, and in the basin area and Lijiawan and Zhangjiawan hamlets, 5 to 10m thick. In contrast, on steep mountain slopes and near limestone outcrops soil depth can be as little as 0.5 to 3m.

Table 81: **The Main Springs along the Fault Belt in the Xizhuang Watershed**

No.	Locality	Altitude (m)	Litho-stratigraphy	Type	Tectonic structure	Geomorphology	Discharge (l/s)
*S1	Damaidi (SW)	2215	$\in^{3}_{3-2}$	decline spring	fault belt (EW)	cross of two valleys	8
S2	Damaidi (SE)	2100	$\in^{3}_{3-1}$	decline	fault complex (NW and NE)	mountain bottom near highway	34.6
*S3	Damaidi (SE)	2090	$\in^{3}_{3-1}$	decline	fault complex	mountain bottom near highway	16
*S4	Damaidi (SE)	2089	$\in^{3}_{3-1}$	decline	fault complex	mountain bottom near highway	10
S5	Lijiasi (N)	1980	$\in^{3}_{3-2}$	decline	fault complex	left side of river bed	29.8
*S6	Zhangjiawan (N)	2045	$\in^{3}_{3-2}$	decline	fault complex	slope bottom	50
*S7	Wangjiawan (SE)	1975	$\in^{3}_{2-2b}$	decline	fault complex	in river valley	5
*S8	the middle reach of Shui'ao river	2125	$\in^{3}_{2-2a}$	decline	fault complex	left side of river valley	15
S9	the middle reach of Longziqing river	2195	$\in^{3}_{2-2a}$	decline	fault belt (NE)	cross of two valleys	19
*S10	Langmaidi Primary School	2000	$\in^{3}_{2-3}$	decline	fault belt (NE)	cross of two valleys	20
S11	Shihua Cave	1930	$\in^{3}_{2-2a}$	decline	fault belt (NE)	left side of river bed	1.0
S12	Qingshui Primary School	1875	$\in^{3}_{3-1}$	uplift	fault complex (NW and NE)	basin margin	51.5
S13	Lengshuiqing behind Yinjia Settlement	1870	$\in^{3}_{3-2}$	decline	fault complex	left side of valley	19.5
S14	Lengshuiqing behind Yinjia Settlement	1975	$\in^{3}_{2-3}$	decline	fault complex	right side of valley	25.2
*S15	opposite Dajiayan	1850	$\in^{3}_{3-1}$	decline	fault belt (EW)	mountain bottom	12
*S16	upper reach of Heyuan'ao	1975	$\in^{3}_{3-2b}$	decline	fault complex (NE and NW)	two sides of valley	55
+S17	Tiger Cave	1740	$\in^{3}$	decline	fault complex	river bed	276.8

Note: * Springs discovered during the fieldwork in February 1997. Total discharge of the nine newly identified springs is 191.9 l/s.
+ Spring No. 17 receives all the underground water in the Xizhuang watershed. The discharge was measured as 276.7 l/s in April 1979, and as 490 l/s in February 1997.

Table 82: Dominant Soil Groups According to Elevation

Elevation	Soil Colour	Soil Structure	Fertility Status	Water holding capacity
Above 2600m	Brown	Good	Good	High
2000-2600 m	Red-Brown	Poor	Acidic, low P & K	Poor
Below 2600 m	Yellow-Red or Red	Adequate	Acidic, moderate	Poor - Moderate
Paddy soils	Usually Grey	Good	Fertile	High

Geological Hazards

Natural instabilities and degradation processes induced by human activities cause environmental hazards. Landslides, mudflows, slope failures, and terrace collapses commonly create problems for the local inhabitants through road damage, erosion along riverbanks, flooding, and slope failures. These affect crop production and interrupt market and transport activities. As a result of active tectonic movement, the metamorphic lithography, and the distribution of faults, landslides are a frequent phenomenon on the steep slopes, especially on the eastern side of the Lijiasi River. The field observations identified twelve sites where landslide risk is high. The largest landslide observed was approximately 200m wide and 80m long; its depth was approximately 5m, and its total sediment source was estimated at 175,900 cu.m. In most cases, landslides occur in areas dominated by sandstone and shale formations (Table 83).

Table 83: Landslide Statistics from the Xizhuang Watershed

No.	Length (m)	Width (m)	Average Thickness (m)	Area (sq.m)	Volume (cu.m)	Activity	Location
H1	32.5	150	12	5,000	3,600	Continuous, active	Damaidi
H2	40	150	7	6,000	4,200	Continuous, active	Longziqing River
H3	25	60	2	1,500	3,000	Tentative, stable	Lijiasi River
H4	25	200	3	5,000	15,000	Tentative, stable	Lijiasi River
H5	30	60	4	1,800	7,200	Tentative, stable	Lijiasi River
H6	10	15	2	150	300	Continuous, active	Damaidi
H7	20	70	3	1,400	4,200	Continuous, active	Lijiasi River
H8	30	80	5	2,400	12,000	Continuous, active	Lijiasi River
H9	30	50	6	1,500	9,000	Continuous, active	Lijiasi River
H10	30	35	5	1,750	8,750	Continuous, active	Lijiasi River
H11	80	60	5	4,800	24,000	Continuous, active	Behind Yinjia
H12	60	80	3	4,800	14,400	Continuous, active	Dajiayan
Total	412.5	1,010	-	36,100	175,850	-	-

The formation of gullies is mostly correlated with tectonic movements. Like landslides, most gullies are found near mountain slopes and adjacent to river valleys. In the Xizhuang watershed, there are fourteen areas that are heavily gullied. They are typically 200 to 300m long, 30 to 40m wide, and 8 to 10m deep (Table 84). Mudflows usually occur infrequently because the vegetation cover is generally well developed. Two mudflow sites were identified during the fieldwork. One was located at the end of the Heyuan'ao valley, and was 40m wide and 150m long with an estimated sediment source of 48,000cu.m; the other was at the end of a side valley to the right of Tiger Cave and had a fan-shaped sediment source 180m long and 50m wide with an estimated volume of more than 90,000cu. m.

Table 84: The Active Gullies in the Xizhuang Watershed

Gully No.	Length (m)	Width (m)	Area (sq.m)	Depth (m)	Type	Category of activity	Location
Hd1	380	50	19000	20	"U"	medium	Damaidi
Hd2	280	15	4200	5	"U"	strong	Damaidi
Hd3	220	25	5500	10	"U"	strong	Damaidi
Hd4	130	70	9100	10	"U"	strong	Jizipo
Hd5	370	15	5500	3	"V"	tentative stable	Zhangjiawopo
Hd6	300	40	1200	15	"U"	medium	Yinjia
Hd7	150	40	6000	10	"U"	strong	Yinjia
Hd8	300	30	9000	8	"U"	strong	
Hd9	250	30	7500	8	"U"	strong	Lengshuiqing
Hd10	140	20	2800	4	"V"	tentative stable	Luojiadi
Hd11	150	20	3000	5	"U"	strong	
Hd12	150	30	4500	101	"U"	strong	Dajiayan
Hd13	1000	40	40000	10	"U"	strong	Dajiayan
Hd14	200	20	4000	8	"U"	strong	Xiaoshanpo
Total	4020	445	131,300	-			

Landslides and gullies cause serious damage to the local environment and the properties of the residents, while mudflows are less important as they are less common and less extensive. To control these environmental hazards, long-term strategies are needed to protect existing vegetation and promote reforestation and rehabilitation. In some areas with high landslide potential (such as the right side of the Lijiasi River, where there is an existing landslide already 1-2 km long), the risk of crop and land damage is high and some engineering construction will be necessary to prevent further damage from future slides.

Conclusions

The geology in the Xizhuang watershed is dominated by limestone and metamorphic rocks of the Upper Cambrian, Ordovician, and Quaternary ages. The area is tectonically active as is evident from the series of faults that have shaped the landforms in the watershed. The limestone formations create difficulties in establishing a water balance for the watershed since streams disappear underground in many places. There are also a very large number of springs, suggesting the presence of many aquifers and underground rivers. So far some 21 potential aquifers have been identified. It appears that the majority of the spring water originates from within the watershed, but additional research is needed to identify the source of some of the springs. A survey of existing springs and a tracing of water sources should be considered important research tasks since water shortages are common during the dry season in the lower lying areas of the watershed. Terrain instabilities were observed in those areas where the slopes are steep and tectonic activity is greatest.

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