The distribution of formation lithology and its control on geological disasters in the Bailong River basin of southern Gansu Province, China

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Abstract. Formation Lithology is one of the key parameters that determine sediment yield, and geology structure, thus its importance has grown in studying the magnitude and frequency of debris flows and landslide disaster. In this paper, we analyze the distribution of Formation Lithology and its relationship with the geology disaster in the Bailong River Basin in China's Gansu Province. The soft rock strata exposed in Bailong River Basin, like limestone, phyllite, slate, shale and Quaternary loess, are more susceptible to geological effects, because they are weak and broken, and with poor erosion resistance. Landslides and collapses are easily formed under the endogenetic and exogenic forces to the mountain, which provide abundant material conditions for the development of debris flow. It indicates that the long-timely exposed strata distributes more widely in this area, which, with large rate of weathering and poor erosion resistance, is easily influenced by external conditions and sudden factors, thus providing favorable conditions for the occurrence of debris flow. Therefore, it is also a high risk area for debris flow.

1. Introduction

Geological Disasters are caused by natural factors, such as river erosion, torrential rains, earthquakes, and flows of underground water and by human activities. Under the effects of gravity, unstable earth or rocks on slopes flow down the slope. Because of the severity of the damage, it is necessary to understand the factors that contribute to the development of Geological Disasters, their distribution, and how they evolve once movement of the materials begins [1].

In the southern part of China’s Gansu Province, intense neo-tectonic activity, frequent seismic activity, concentrated rainfall, and a fragile ecological environment combine to produce frequent geological disasters. Landslides in Longnan City alone totaled more than 12 000, including more than 6400 debris-flow gullies, and the population of 610 000 people are repeatedly threatened by these geological disasters. Zhouqu County, in southern Gansu Province, China, has a high range of elevations, a complicated geological structure, large quantities of shattered rock and soil, and moderately high annual rainfall (an average of 436 mm annually). These factors create a high risk of severe debris flows and landslides, such as those that occurred after the magnitude 8.1 Wanchuan Earthquake in 2008. At dawn on 8 August 2010, an unusually large debris flow occurred in the Sanyanyu and Luojiayu of the Zhouqu town, resulting in the death of 1501 [2]. However, the
relationship between Formation Lithology and geology disaster such as debris flows and landslide is less clear. Because of complex of formation lithology and structural systems in the Bailong River Basin in China's Gansu province, it is therefore crucial to determine the relationship between Formation Lithology and geology disaster and its spatial variation in this region. This relationship will help environmental managers predict the risk of debris flows and landslide. The objectives of the present study were to evaluate the spatial and temporal distribution of Formation Lithology, and to analyze the relationship between Formation Lithology and geology disasters activity from a semi-quantitative perspective.

2. Study area and materials
The Bailong River Basin is located in a transitional zone between the Qinghai-Tibetan Plateau and the Northwest Plateau of Sichuan Province, and lies at the boundary between the subtropical and warm temperate zones of western China. The study area covers approximately $17.8 \times 10^3$ km$^2$ in Gansu Province (32°36'N to 34°24'N, 103°0'E to 105°30'E) and lies in the Qinling orogenic region, which has precipitous terrain, with many criss-crossing ravines and gullies, high mountains, steep slopes, and deep valleys [3]. The mean elevation ranges from 550 m to 4536 m asl, and the peak height is at Qingshui Liang, in Zouqu County. The study area is dominated by a typical mid-latitude subtropical monsoon climate, with mean annual air temperatures ranging from 12°C to 14.0°C, depending on the elevation, solar radiation, topography, and other local factors. The temperature decreases with increasing elevation, with the mean annual air temperature below 5°C at elevations above 2500 m and an extreme minimum daily temperature of -16.9°C at Dangchang. The vegetation community in the study area is dominated by *Rhododendron fastigiatum*, *Quercus liaotungensis* broadleaved mixed forest, *Pinus tabulaeformis*, and grass–*Picea asperata*, moss–*Abies fargesii*, *Rhododendron–Abies fargesii*, and bamboo–*Abies fargesii* communities [2].

3. Formation Lithology Characteristics

3.1. Geological structure
The Bailong River Basin is located at the junction of several structural systems, including Qinling folded belt, Songpan-Ganzi folded belt, and Wudu epsilon-type structure. The large complex fold structure in this area is developed in the Xiqinling orogenic belt, and they are Dacaotan anticlinorium, Dangchang synclinorium, Bailong River anticlinorium from north to south. The fault structure is most developed in the Xiqinling tectonic belt, and the boundaries of the tectonic units are all large fault zones, all of which length are more than hundreds of kilometers, and with a generally trend towards north-west direction. Diebu county is located in the Qinling east-west complex tectonic belt. The strong north-south extruding gravity results in not only large closed linear fold and a series of small structures such as cleavage, schistosity, overturned strata and fold, but also many northwest-west arc-shaped lengthways compressional fault. These faults with long-term activities, have controlled and destroyed the sedimentary basins after the Jurassic [4]. The front arc of the Wudu epsilon-type structure is located in between of the Chiba-Jugan, and is composed of a series of arc-shaped faults and synclinoriums that protrude southwards. The fault zones which composed of roughly parallel compression arc-shaped faults and shear arc-shaped faults, cut the strata of the Silurian, the Devonian, the Carboniferous, the Permian, the Jurassic and the Tertiary. Since the Quaternary, the tectonic movement mainly took the vertical motion, formed the special topography of alpine and deep valleys, and deposited the V--VIII terraces of valleys with a height difference of 350m. The ravine cut downward to form a “V” shape with the height differences ranging from 1000m to 1500m. Wenxian County is located in south of Wudu epsilon-type structure system, and its southeast part adjoin Longmenshan north-east tectonic belt. The confluence of different tectonic belts and the repeated action of tectonic movement make the fold form complex.

The Neotectonic movement is very active in Bailong River Basin. Influenced by the Himalayan movement, the mountain intensively uplift and the water drastically cut down, forming the typical
alpine-valley topography, where the altitude and the relative height difference are mostly above 1000 meters. The peak slope is steep and the ravines are dense, and the ravines are mostly narrow “V” shape with a large vertical gradient. The dense water system developing on Bailong River, Baishui River and eight rivers besides, lays the foundation for the formation of landslides and debris flows. The intensively uplift of the crust makes the valley terrace developing widely in Bailong River and Baishui River, and forms a total of eight terraces. VIII terrace of valleys is 350-370 meters higher than riverbed. The ancient debris flow fan deposited on the river valley and the early accumulation of debris flow are dissected, forming terraced accumulation platform. The ancient debris flow fan is 30-35 meters higher than the riverbed. In addition to Bailong River and Baishui River, other large rivers in this area are also developed with multistage terraces.

3.2. Formation Lithology
Bailong River Basin strata belong to the Qingling stratigraphic subdivision, and its formation lithology characteristics are complex. Each of the stratigraphic age, from Silurian to Quaternary, is with fully exposed, and Silurian, Devonian, Carboniferous, Permian and Triassic are widely distributed. According to the geological time scale, the formation lithology characteristics are as in Figure 1.

![Figure 1. The distribution of strata in different geological ages showing the relationship of debris flow in Bailong River Basin](image)

The Quaternary system is mainly distributed on valleys and slope beams of large tributaries. There are many type of sediments, which mainly include alluvial deposit, pluvial deposit and aeolian deposit, while slope deposit and colluvial deposit are widely distributed in some areas. The accumulation types of the sediments mainly include the gravel bed, the clayey gravel and breccia bed, the debris pebbles bed, and the overlaying loess.

The Cretaceous distributes in the wings and periphery of the back and belly of the Bailong River. The types of minerals and rocks are mainly thickly-bedded conglomerate, sandy conglomerate, sandstone, marl, limy shale, coal series, and etc. The Jurassic strata, with complex gravel composition, are distributed in a small amount in the Bailong River Basin. The under layer of the Jurassic strata is usually thickly-bedded conglomerate, purple and tan, with poor sorting and psephicity. There are
purple sandstone, tan sandstone, and mottled sandstone, clay stone, coal-bearing shale and carbonaceous shale above the under layer. The upper layer of the Jurassic strata is purple mudstone, clay stone and tawny conglomerate.

The Permain distributes on both sides of Bailong River, which is a stable shallow sea deposit, with large thickness and little phase transition. The Triassic distributes as a zonal narrow strip along NWW-SEE direction. The south of the Permain is in fault contact, and the northern boundary is in fault contact with the Xihanshui Group. The Devonian are more developed in the Bailong River Basin, and are distributed on both sides of the Bailong River. The Silurian, the oldest strata for this region, is banded along the both sides of the river and forms the anticlinal axis of the Bailong River. Therefore, there are two types of rocks in Bailong River Basin: one is weak rock containing more clay and silt, such as phyllite, shale, slate, pelite and loess, and the other is hard rock like magmatic rock and limestone. These two types of rocks are superimposed intercalately or alternately [5].

4. The results and conclusion

The distribution of formation lithology has a certain relationship with the development and distribution of debris flow. The process of formation, movement and accumulation of debris flow is the process of erosion, transportation and deposition of various unconsolidated deposits after rock destruction. The occurrence of debris flow depends to some extent on the weathering resistance and erosion resistance of the rocks. Different types of rocks differ in mineral composition and physics-mechanical properties, correspondingly differ in resistance to destruction and weathering rates, which influence the characteristics of forming and the property of debris flow.

Lithology is an important factor in the development of debris flow disaster. Different types of rock composition, structure and weathering rate cause different development level of debris flow disaster. The weaker the formation is, the more serious the weathering rate is, and the more unconsolidated solid matters are. It provide rich source conditions for the occurrence of debris flow. Easily weathered rock mass, weak rock mass and their accumulations usually provide rich source for debris flow. The area where these rock mass distributed is prone to debris flow. The unweathered hard rock mass, with good density, hard to break, is a stable rock mass. The area where these rock mass distributed is not prone to debris flow.

Figure 2. The stratigraphic distribution of Bailong River Basin in different years.

According to the lithologic types of Bailong River Basin, they are divided into 9 groups, which are respectively: 1) sandstone, aleurolite, slate; 2) limestone, crystal limestone; 3) phyllite, slate, mudstone;
4) metamorphic aleurolite, mudstone, slate; 5) silicate, slate, metamorphic aleurolite; 6) thickly-beded conglomerate, sandy conglomerate; 7) metamorphic conglomerate, metamorphic aleurolite, phyllite; 8) limestone, dolomite, schist; 9) gray-green slate, tuff. Debris flow disasters are widely distributed in group 3, 4 and 5. Rocks of these groups are weak rocks, which are relatively fragile and prone to debris flow activities.

Among them, the distribution of debris flows in the phyllite, slate and mudstone group is the largest, indicating that the lithofacies in this group are strongly weathered, the weathering layers are thick, the structures are loose, and the strata are mostly interbedded with soft and hard phases, which provide a rich source for debris flow. It is easy to form debris flow under rainfall conditions. The distribution of debris flow disaster in areas where thickly-beded conglomerate and sandy conglomerate are distributed is the least. Because the rock mass in this group is hard rock, which, with good stability, good density, is hard to break. So it cannot provide sufficient loose material, and it is not prone to debris flow activities. The analysis shows that the weakness of the rock formation is closely related to the distribution of debris flow disasters, which is the necessary condition to affect the distribution of debris flow activities.

The age of stratigraphic exposure affects the formation of unconsolidated solid matter. The longer the strata are exposed, the more weathering the rock becomes. The rate of weathering determines the stability of strata. After a long period of evolution, the stability of rock strata deteriorates, the degree of fragmentation increases, and the solid loose matter is easier to form, which, in the condition of short diachronic and heavy rainfall, washed down with the flow, causes debris flow.

According to spatial analysis and statistics, the stratigraphic distribution of Bailong River Basin in different years is shown in Table 2-5, with Cretaceous 5.34%; Permian 3.63%; Carboniferous 7.20%; Devonian 17.03%; Triassic 31.14%; Jurassic 5.89%; Early Tertiary 0.44%; Silurian 13.14%; Late Tertiary 0.03%; Quaternary 1.58%; Sinian 11.97%; Ordovician 2.60%. The Triassic strata are most widely distributed in most parts of Bailong River Basin, followed by the Devonian, Silurian and Sinian, but the Early Tertiary and Late Tertiary strata are less distributed. It indicates that the long-timely exposed strata distributes more wildly in this area, which, with large rate of weathering and
poor erosion resistance, is easily influenced by external conditions and sudden factors, thus providing favorable conditions for the occurrence of debris flow. Therefore, it is also a high risk area for debris flow.

In Figure 1, the strata, from old to new, are exposed in this region, mainly including: clasolite, slate, phyllite and limestone of Silurian, Devonian, Carboniferous and Permian; slate, sandstone, conglomerate and shale of Triassic, Jurassic and Cretaceous; red sandstone, conglomerate, mudstone and loess of Tertiary, Quaternary.

The more weathered strata are concentrated in the clasolite, slate, phyllite, limestone of Silurian, Devonian; the slate, sandstone, shale of Triassic; and the red sandstone, mudstone and loess of Quaternary. The rock strata formed in these times, with poor stability and large degree of fragmentation, is not prone to debris flow.

Figure 3 shows the relationship of the distribution of landslides in Bailong River Basin and the distribution of strata in different geological ages. Within the four attribute categories of Devonian, Lower Jurassic, Silurian, Neogene and Quaternary, the main types of rocks are phyllite, limestone, aleurolite and mudstone, which, with seriously rock weathering, more broken and loose, provide the source condition for the development of the landslide.

5. Conclusion
The distribution of formation lithology has good relationship with the development and distribution of debris flow. The occurrence of debris flow depends to some extent on the weathering resistance and erosion resistance of the rocks. Different types of rocks differ in mineral composition and physics-mechanical properties, correspondingly differ in resistance to destruction and weathering rates, which influence the characteristics of forming and the property of debris flow.

The soft rock strata exposed in Bailong River Basin, like limestone, phyllite, slate, shale and Quaternary loess, are more susceptible to geological effects, weak and broken, with poor erosion resistance. Landslides and collapses are easily formed under the endogenetic and exogenic forces to the mountain, which provide abundant material conditions for the development of debris flow.

The more weathered strata are concentrated in the clasolite, slate, phyllite, limestone of Silurian, Devonian; the slate, sandstone, shale of Triassic; and the red sandstone, mudstone and loess of Quaternary. Within the four attribute categories of Devonian, Lower Jurassic, Silurian, Neogene and Quaternary, the main types of rocks are phyllite, limestone, aleurolite and mudstone, which, with seriously rock weathering, more broken and loose, provide the source condition for the development of the landslide.

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