Chapter 3

Natural Hazards

Seismicity

Earthquakes are one of the most harmful geological hazards that occur in the region. Due to its tremendous destructive force, the seismicity should be taken into account in regional engineering planning. Regional seismicity can be evaluated by studying the historical records of strong earthquakes, the fault activity, pattern of micro-seismic destribution, and the recent stress fields in the earth's crust. For regional planning and site selection, the classification of terrain blocks, in terms of tectonic stability, can be studied for an assessment of potential seismic intensity.

Historical Records of Earthquakes

In the research region, 33 strong earthquakes (M5) have been recorded from 116 A.D. to 1980 A.D. Among these the largest recorded magnitude was 7.7, two earthquakes were higher than seven and 10 shocks had magnitudes of between six to seven.

The spatial distribution of the strong earthquakes in the region demonstrates a close relationship to active faults. The epicentres of strong earthquakes were mostly located along regional faults such as the Anninghe, Zemuhe, and the Maoniushan-Xigeda (Figure 8).

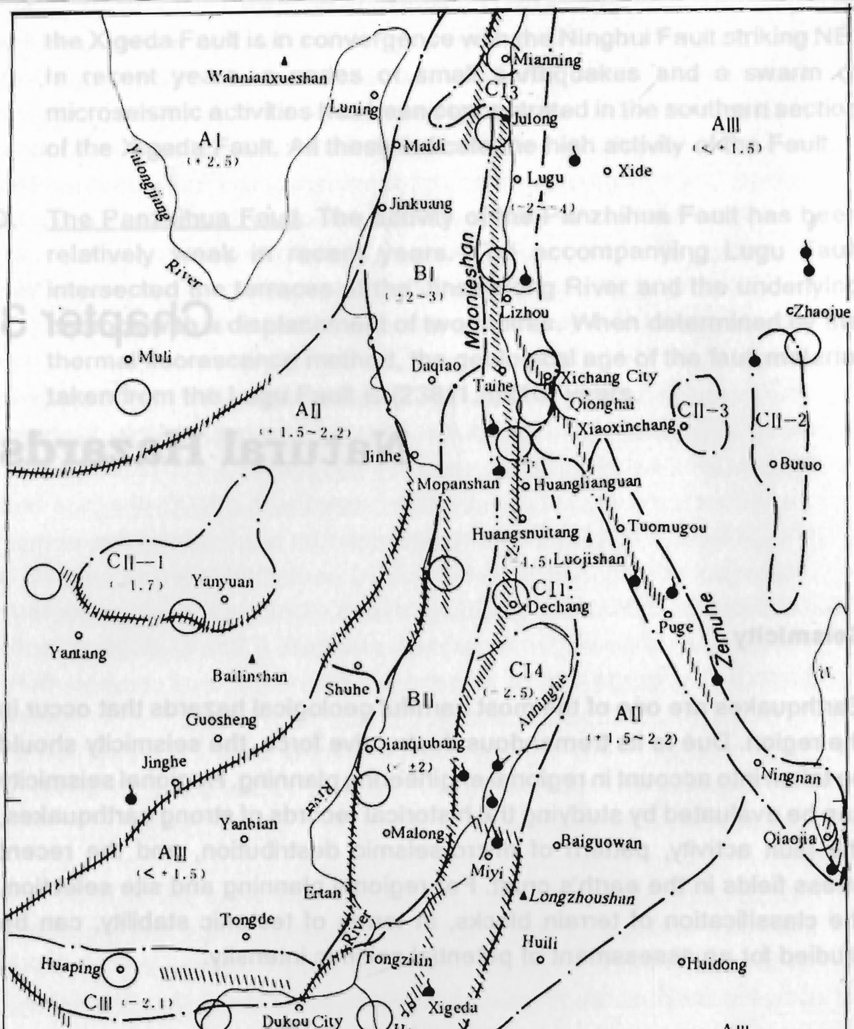

Fig. 8: Regional Neotectonic Zonation (after Xu Xuehen, 1988)

1. Lithospheric Fault 2. Epicentre of medium and strong earthquakes 3. Hot spring
4. Zonation boundary of elements of grade I 5. Boundary of subzonation

However, the distribution of epicentres along a fault is not uniform and they are usually located in some sections and at intersections with accompanying second order faults. The most intensive seismic belt is located along the Anninghe Fault Zone. Strong shocks have mostly occurred in the Xichang, Yuzha-Lazha, and Mianning areas where the Anninghe Fault converges with the Zemuhe, Minghui, and Nanhe faults. The Yanyuan seismic zone experiences certain types of swarm shocks which were concentrated in the western margin of the Cenozoic Yanyuan Fault depression. The third seismic zone in the region is the Huaping-Dukou seismic zone which experiences strong earthquakes of less than five in magnitude. According to the distribution and deformation characteristics, the Huaping-Dukou seismic belt can be considered to be a deep-seated fault zone.

Evaluation of Tectonic Stability

The activity of the earth's crust can be comprehensively expressed by tectonic stability zonation which provides a scientific basis for determining the basic intensity for the purposes of planning and design in engineering. According to the theory of geomechanics, the tectonic stability of crustal terrain is controlled by the geodynamic characteristics of the tectonic structure of the crustal terrain mass. The tectonic structure of the earth's crust is considered to be composed of tectonic blocks and fault zones. For evaluation of tectonic stability, the characteristics of the two, above-mentioned, structural elements should be determined. Tectonic blocks can be characterised by their type, dimension, and intactness, while the type, dimension, and activity of faults or fault zones surrounding tectonic blocks are used for evaluating the seismicity of faults and fault zones.

For this purpose, the structural planes can be classified into five types: (1) overburden faults, (2) basement faults, (3) crustal faults, (4) lithospheric faults, and (5) tectonic zones. The activities of structural planes can be identified through the geological age of major movements, displacement rate, and seismicity.

Tectonic Stability Zonation

Based on the above-mentioned evaluation, Li Xingtang (1988) suggested dividing the region into 17 areas, including seven stable terrain blocks, seven sub-stable, faulted terrain blocks, and three unstable faulted blocks (Figure 9).

A. <u>Seismically Stable Areas (I)</u>.

Jinlong-Wali Area (Ia). In this area only occasional basement faults, which are mostly stable, are observed. The uplift of the terrain block is fairly uniform. The gravitational gradient is also uniform and is from 1.2 to 2.5mm gal/km. The expected magnitude of earthquakes according to crustal strain energy (3) is assessed to be less than five. The basic seismic intensity should be less than seven and most can be assessed as VI.

Jinpingshan Area (Ib). Some boundary faults in this terrain block are active, although they are basement faults. A mosaic structure of the block is formed by local overburden faults. The area is as stable as area Ia, i.e., it has an intensity of more than VII.

Yuanlong Area (Ic) and Yanbian Area (Id). Some basement faults have developed and the intactness of the block is relatively low. However, the crust is characterised by uniform uplift, and the magnitude of a few recorded earthquakes has been less than V. The seismic intensity should be from within VI to VII.

Yunren Area (Ie), Huili Area (If), and Lianshan Area (Ig). In these areas basement faults are occasionally observed. The terrain block is subject to uniform uplift and no late Pliocene activity has been observed. The crustal strain energy is less than N3, the expected maximum magnitude is less than five, and the basic seismic intensity is VI or >VI.

B. <u>Seismically Sub-stable Areas (II)</u>.

Xiaoxinlin Area (IIa). The faulted terrain block is surrounded by deep-seated faults. The intactness of the block is relatively poor. The uplift of crust amounts to three millimetres per year. An obvious gravitational gradient reaches from 1.3 to 1.6 m^3/km. The crustal strain energy amounts to N3--75N3, i.e., the energy amounts to 1.1×10^{20}. Earthquakes within the area have a maximum magnitude of about five and the basic intensity lies between VII and VIII.

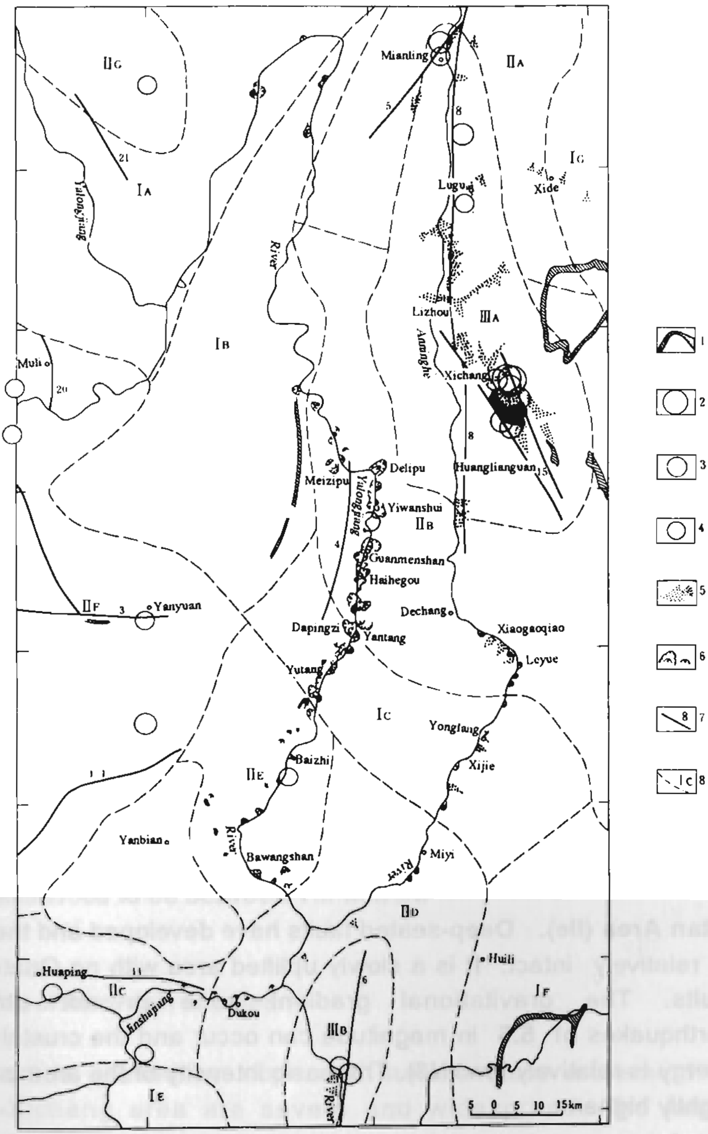

Fig. 9: ***Zonation on Regional Tectonic Stability and Natural Hazards (after Huang Dingcheng, 1990)***

1. Salt-containing formation 2. Epicentre M>=7 3. Epicentre 7>M>=6 4. Epicentre 6>M>5
5. Gully with active debris flow 6. Large and middle-scale landslides 7. Quaternary active faults
8. Zone of tectonic stability

Jinghe-Dechan (IIb). This faulted terrain block is bound by deep-seated lithospheric faults, and the intactness of the block is damaged. The western part of the area is uplifted, while its eastern part suffers from subsidence. An obvious gravitational gradient of from three to 3.5mm gal/km has been observed. The expected maximum magnitude of earthquakes is 5.5 and the basic seismic intensity is assessed to be between VII and VIII.

Huaping Area (IIc). Relatively speaking, deep-seated faults have developed and the crust is fractured. The layers of the early and middle Pleistocene deposits in the Huaping-Dukou depression are intersected by faults of the late Pleistocene epoch. The gravitational gradient is not obvious, the expected maximum magnitude of earthquakes is five, and the crustal strain energy amounts to from N3 to 19N3. The basic sesmic intensity is assessed to be VII.

Dukou-Miyi Area (IId). Deep-seated faults have developed and the crust is characterised by fractures and a mosaic structure. The area was subjected to depression in the early and middle Pleistocene epoch, and some late Pleistocene faults have been found in the Dukou sub-area. An obvious gravitational gradient zone having from three to 3.5mm gal/km has been observed. The expected earthquake magnitude is 5.5. The crustal strain energy amounts to from N3 to 40N3. The basic seismic intensity is defined to be V for most of the area, although it can reach VIII on the southern boundary.

Ertan Area (IIe). Deep-seated faults have developed and the crust is relatively intact. It is a slowly uplifted area with no Quaternary faults. The gravitational gradient zone is not obvious. Earthquakes of 5.5 in magnitude can occur and the crustal strain energy is relatively low (N3). The basic intensity of the area is VII or slightly higher.

Shulli--Yanyuan Area (IIf). Curved crustal faults have developed. The crustal structure is relatively intact. The Sili sub-area is an uplifted block, while the Yanyuan sub-area is a relatively subsiding zone of from 1.4 to 3.5mm gal/km. The basic intensity for most part of the area is VII, although in some limited zones it goes up to VIII.

Maidilong Area (IIg). Only basement faults have developed and the crust is relatively intact. An obvious gravitational gradient zone of 2mm gal/km has been observed. The maximum recorded magnitude in the area is 5.7. The crustal strain energy amounts to N3 and the basic intensity is from VI to VII.

C. Seismically Unstable Area (III).

Xichang Area (IIIa) and Hongge Area (IIIb). Deep-seated faults have developed and the crust is fractured and faulted. These areas are located in the Anninghe Fault depression. Quaternary graben is observed in the Mianning--Xichang zone. The two terraces of the Anninghe and Jingshan rivers are intersected by faults of the late Pleistocene epoch. An obvious gravitational gradient zone of from two to 3.3 has been observed. The maximum recorded magnitude of earthquakes in the Xichang area (IIIa) is 7.7. The crustal strain energy is between 75 to 100 N3, and the basic seismic intensity is assessed to be between VIII and XI. For the Hongge area (IIIb) the maximum recorded magnitude is 6.7 and the basic intensity is between VIII and XI.

Yantan Area (IIIc). Deep-seated faults with intersections have developed and the crust is fractured. The area is characterised by the uplift of fault blocks. The gravitational gradient zone is not obvious. The maximum recorded magnitude of earthquakes is 6.9, the present crustal strain energy is 40 to 100 N3, and the basic seismic intensity is assessed to be between VIII and IX.

Instability of Mountain Masses

The hazards caused by slope and surface mass movement in the Dukou-Xichang area are severe and widespread. The initiation, development, and spatial distribution of hazards caused by mass movement are characterised by the features discussed below (Wang Sijing 1987).

The basic causal factors behind gullies of active debris flow (Plate 4) in a developing stage and landslides of medium and large size, or swarmed landslides (Plate 5), are always associated with geological structures.

From the spatial distribution, it can be seen that most landslides in the area are controlled by fault zones or have developed in the interbedded sandstone and claystone of the Triassic and Jurassic periods which are severely fractured by faults. There are less developed landslides in Quaternary deposits with gentle slopes. Rocks and soil masses that cause landslides are fractured, loose, and weak, or have soft material of very low strength.

The Anninghe Fault Zone strikes parallel to the Anninghe River and the Maoniushan-Xigeda Fault Zone is parallel to the Yalongjiang River. These geological features are unfavourable for the slope stability of the river bank (Figure 9).

In areas where igneous rocks or limestones are usually exposed, medium and small-sized landslides are observed and their number is relatively small, some regressive or intermittent debris flows also exist. Landslide and debris flow hazards caused by neotectonic differential activities are prominent in this area.

The geomorphological factor is an important condition for the occurrence of landslides and debris flow. For instance, the Xiahuangtian rockfall slides have a funnel-like topography which enables the land to accumulate surface water. The elevation of the rockfall slide area is 1,820 to 1,250masl and the mouth of the outlet gully has an elevation of 1,094m. The former's condition is conducive to rockfalls or slides, while the latter causes slided mass to be transported by the stream due to its steep gradient.

The cyclicity of landslides and debris flows is determined by seismicity because the shocks of earthquakes tend to accelerate the cyclic occurrence of landslides and debris flows, including the process of slope mass movements. For example, the Hetaoping earthquake (M=5.5) downstream of the Shuhe River caused the Xiahuangtian rockfall slide. The debris flow in Hetaoping was caused by an earthquake.

The activity period of landslides and debris flow is often connected with rainfall periods. The difference between dry and wet seasons is obvious in this region. Ninety to ninety-five per cent of the annual precipitation is concentrated in the period from June to October. The climate is wet and hot, and usually storms and heavy rain occur during this period. Landslides increase and debris flows, particularly rainstorm debris flows, also become active. For example, the heavy rainfall (143.6mm) in the Miyi--Yanyuan area from June 24 to 27, 1981, caused extensive debris flows in the area.

Geological hazards due to slope mass movement, such as landslides and debris/mudflows directly threaten productive activity and life. Initiation, development, and spatial distribution are determined and controlled by the lithological composition of surface geological formations, tectonic background, neotectonic environment, geomorphological features, hydrogeological structures, hydrodynamic characteristics, and recent climatic conditions. They are also connected with human activity itself. Therefore, the surface mass movement is not a separate phenomenon. It is associated with various factors within the system.

River valleys and gullies of large tributaries are the places in which landslides, debris/mudflows, and other surface mass movements are most likely to occur. Because river valleys are also a suitable place for industrial and agricultural development, the investigation of the distribution of slope failure is of great importance for regional planning. In this section, the Yalongjiang, Anninghe, and Jingshajiang rivers are studied in the context of problems associated with landslide and debris/mudflows.

Landslides along the Yalonjiang River

Intensive uplift is observed in parts of the Jinpingshan Mountains which lie along the upper reaches of the Yalongjiang River. The river bed cuts deeply into the rock terrain forming differences of 2,600 to 3,000m in elevation. This part of the territory is characterised by a combination of high mountains and deep canyons. The longitudinal valley, with steeply dipping strata parallel to the river, is very often subjected to large-scale landslides. In the Luning and Qingha sections on the high natural slopes, the bending and buckling of thin-layered schists often cause large landslides (Wang Sijing and Huang Dingcheng 1990).

The Jinhe-Xiangshuihe section of the Yalongjiang River is located in an area of slow, block uplift which has varied and intermittent movement. The river bed is usually asymmetrically V-shaped. The valley slope is longitudinally composed of interbedded sandstone and shale of the Triassic and Jurassic periods. Entrenched by the Maoniushan Fault Zone, the rock slopes are severely fractured. All 75 gullies (resulting from debris flow) and 157 landslides occurred along the Yalongjiang River in a 73km-long section. Landslides such as the Delipo, Yiwanshui, Guanmanshan, Haihegau, Gatan, Dapingzi, Yantang, and Rongpingzi are large and active and often supply the debris for heavy flows. The Yantang and Dapingzi landslides are located on the two opposite banks of a section. The instability of these landslides can form a dam to block the Yalongjiang River (Figure 10).

A. Yantang Landslides. This is a group of five landslides. The slopes are composed of Triassic sandstone and claystone. The largest one was reactivated in 1978. The slope of the landslide group is 800m long, 400m wide, and 10 million cubic metres in volume. The slope evolution tends to enlarge the landslide by joining the group of landslides.

B. Dapingzi Landslide. This is a landslide caused by fractured intersection of the layers. It is located on the opposite bank of the Yantang Landslide. The ancient Dapingzi Landslide is 1,800m long, 2,400m wide, and 300 million cubic metres in volume. The front of the landslide is subjected to minor sliding and collapsing which pushes the river bed towards the opposite bank.

Downstream from Xiangshuihe, the Yalongjiang River area is a relatively subsidence-prone zone. Some medium and small-sized landslides are scattered along the banks of the Yalongjiang River. The instability of a slope depends upon the geological structure. The typical mechanism is that of bending and toppling in schists. Limestone and dolomite landslides are often observed along the bedding planes.

C. Bawangshan Landslide. The Bawangshan Landslide lies along the bedding planes. It is 750m long, 1,600m wide, and 20 million cubic metres in volume. The dolomitic limestone layer is parallel to the river bank with dipping angles of about 45^{o}. The dolomitic limestone is intercalated with marl seams which also form sliding surfaces. In this limestone, two sets of fractures have developed with occurrences of 175/85 and 75/85. The fractures intersect the river bank and form the boundaries of the Bawangshan Landslide. The Yalongjiang River was blocked by the landslide, forming the base for a second terrace of the river. Now the landslide is stable.

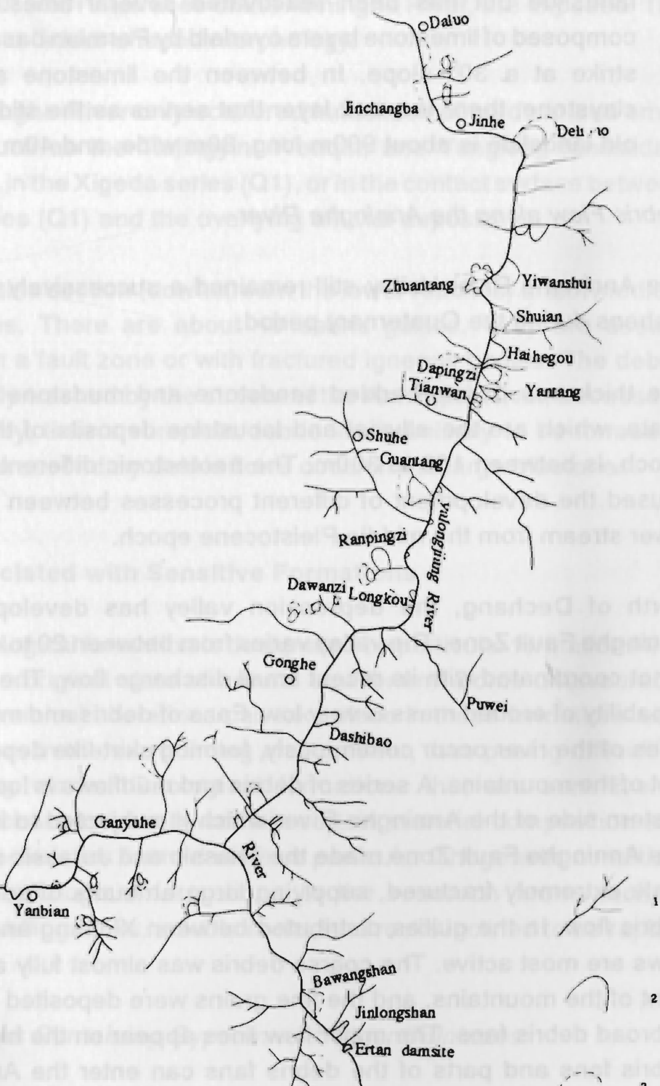

Fig. 10: Distribution of the Landslides in Ertan Reservoir Area

1. River system 2. Boundary of landslide talus 3. Boundary of landslide

D. Jinlongshan Landslide. The Jinlongshan Landslide is an ancient landslide but has been reactivated several times. The slope is composed of limestone layers overlaid by Permian basalts. The layers strike at a 30^{o} slope. In between the limestone and underlying claystone, there is a soft layer that serves as the sliding plane. The old landslide is about 900m long, 80m wide, and 40m thick.

Debris Flow along the Anninghe River

The Anninghe River Valley still remained a successively active zone of grabens during the Quaternary period.

The thickness of interbedded sandstone and mudstone of the Xigeda strata, which are the alluvial and lacustrine deposits of the Pleistocene epoch, is between 100 to 300m. The neotectonic differential movements caused the development of different processes between the upper and lower stream from the middle Pleistocene epoch.

North of Dechang, the depression valley has developed along the Anninghe Fault Zone. The valley varies from between 20 to 40km wide and is not coordinated with its recent small discharge flow. The transportation capability of eroded mass is very low. Fans of debris and mudflow on both sides of the river occur continuously, forming skirt-like deposits along the foot of the mountains. A series of debris and mudflows is located along the eastern side of the Anninghe River which is subjected to intensive uplift. The Anninghe Fault Zone made the Triassic and Jurassic sandstone and shale extremely fractured, supplying large amounts of solid material for debris flow. In the gullies distributed between Xichang and Lugu, debris flows are most active. The coarse debris was almost fully accumulated in front of the mountains, and the fine grains were deposited on the surface of broad debris fans. The major flow lines appear on the high elevation of debris fans and parts of the debris fans can enter the Anninghe River. Debris flows have also developed in the tributaries of the Anninghe River - for example, as in the Nanhe (in Lichou). For example, from 1971 to 1972 bursts of debris flow occurred three times at the entrance of the Sunshuihe into the Anninghe River. The debris cannot enter the Anninghe River at once, but it can cause secondary debris flows to occur from the tributaries.

In the lower reaches of the Anninghe River, south of Xide County, is a relative uplift zone and the river floor cuts the terrain into depths of 300m.

The layers of the early Pleistocene deposits, which often constitute the base of the II, III, and IV terraces of the Anninghe River, are exposed. The river valley has a ladder-shaped morphology.

Along the Anninghe River only scattered landslides of medium and small sizes occur, such as the Tiejingyin, Wenqin, and Yonglong landslides, which occurred in the Xigeda series (Q1), or in the contact surface between the Xigeda series (Q1) and the overlying alluvial deposits.

Debris flows in this section (downstream the lower reaches) are of medium and small sizes. There are about 40 debris gullies. They are usually associated with a fault zone or with fractured igneous bodies. The debris material is easily washed by the stream of the Anninghe River, because of the narrow valley, thus a complete debris fan is unlikely to be formed in this area. Some secondary debris flows occur in the large tributaries.

Hazards Associated with Sensitive Formations

A sensitive geological formation is designated by particular formations that can maintain an original state of natural equilibrium. Some unfavourable physical and chemical alterations can take place in these formations as a result of changes in the surrounding environment, thus posing difficulties for engineering works. Geological formations that are sensitive to environmental changes usually contain certain material composition and structural characteristics formed under a particular lithogenetic condition. The sensitive geological formations in the research areas include sedimentary swelling rocks, soluble rocks, and rocks inclined to be rapidly weathered.

Rock Formations Containing Gypsum and Other Sulphates

The Yantang series of the middle Triassic period contains rock salt of substantial thickness and several gypsum layers that can be used for the development of chemical industries. In the sandstone and mudstone of the Xiaba series of the early Cretaceous period, in the Xide and Huili areas, gypsum and $Na_2 SO_4 10H_2O$ intercalations have developed.

Gypsum ($CaSO_4.2H_2O$) is soluble. In fresh water the solubility is only 0.2 per cent while under washing conditions and in a higher (original) mineralised groundwater its solubility can reach 0.3 per cent. Sodium sulphate ($Na_2SO_4.10H_2O$) is highly soluble. The content of gypsum and sodium sulphate in the rock formations can cause the following geological hazards: (1) the mechanical strength decreases due to non-uniform occurrence in the form of intercalations, veins, concretions, etc; (2) the concrete of civil buildings can be subjected to corrosion in groundwater with a certain amount of sulphate unions; and (3) the swelling effect of sulphate hydration causes damage to building foundations.

Rock Inclined to be Rapidly Weathered

Rapid weathering occurs as a result of the difference in moisture between dry and wet seasons. Under the effects of repeated weathering action in dry and wet seasons, the violet and brick-reddish mudstone and siltstone with carbonate or silt cements often tend to be fragmented. The weathering mechanism is the separation and fracturing along micro-schistic and other structural planes under sunshine after rainy seasons. The dry rock tends to collapse in water. Therefore, if the rock is in the original deep-seated condition, the process is very slow. The weathered accumulations are often found along road slopes or excavations in these rock formations. The separation and collapsing rate in this area is much higher than in other rock formations.

The weathered accumulations on the slopes along the river banks are again a potential hazard for landslides and debris flows. The weathered material usually has a higher water content and can be softened. The shear strength of the weathered material is extremely low with frictional angles of about 10 and cohesions of 0.1 bar. Therefore, when the thickness of overburden reaches a certain limit, landslides will lead to the damage of slopes and roads.

Rock in the Xigeda Formation with Swelling Properties

The Xigeda series is distributed along the Anninghe, Yalongjiang, and Jinshajiang rivers. Its large tributaries constitute its IV-V terraces and the bases for lower terraces.

The Xigeda series is composed of interbedded, semi-cemented grey-yellow, grey-white, and green-grey clay, silt, silty clay, sandy clay, and fine sandstone. The total thickness is up to 300m. It has an impervious and weak pervious formation, and it can act as a watertight layer for overburden and loose deposits. The collapsing rate of the green-grey and grey mudstone is the highest, that of the yellow claystone is less, and the lowest is observed in fine-grained sandstone. The collapsing and swelling characteristics of the Xigeda series are caused by the existence of illite in the rocks. The uniaxial compressive strength of mudstone varies from three to 10 bars, the frictional angle varies from 20° to 40°, and the cohesion varies from 0.2 to 0.4 of a bar. Landslides often occur in the overburden along the contact with the Xigeda series because of its watertight properties.