Geo-environmental Considerations in Strategic Development Planning

The Panxi Region

Eastern Hengduan Mountains, China

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ICIMOD

International Centre for Integrated Mountain Development

Kathmandu, Nepal

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Foreword

The use and management of natural resources is one of the important concerns of integrated mountain development. Within the mountain areas themselves,although the general picture has been one of over-exploitation, there are some fairly large areas in which rich resources have not as yet been exploited, or where they remain underexploited. The dilemma here is the fact that, critical though these resources are, they are found within a part of one of the earth's most fragile ecosystems, the Hindu Kush-Himalayas.

Although this particular work by Professor Wang Sijing, under ICIMOD's Fellowship Monograph Series, appears to be very technical, it should be kept in mind that, because of the concern for the impact of resource extraction on the environment as a whole, and, in this case, on the environment of the Hindu Kush-Himalayas in particular, a work of this nature is valuable because of its broader implications for resource extraction and use in similar areas across the region. Most of Professor Wang Sijing's information and observations are useful in this respect.

I would like to thank Professor Wang Sijing for his painstaking efforts in producing this important piece of research on the Panxi Region of China. I would also like to thank the Ford Foundation for providing the grant that made this study and its publication possible. I believe it will be of some assistance to all those working in the area of resource extraction and use in the Hindu Kush-Himalayan Region.

E.F. Tacke
Director General

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Chapter 1

Introduction

This monograph deals with strategic planning for integrated development in the Panxi Region of China. The context of this planning includes natural resources, the environment, and hazards. The Panxi Region is located on the eastern front of the Hengduan Mountains of southern China. Problems in strategic planning, related to the conditions of natural resources and the environment, are discussed. For effective implementation of planned engineering projects, a system of engineering facilities is suggested and a geo-environmental evaluation given. Measures for environmental protection and hazard mitigation are also discussed. Such a systematic study can form the basis for a scientific approach to the strategic planning of integrated development of the Hengduan Mountains of the Hindu Kush-Himalayas.

To determine the strategic goals of economic development, the condition of natural resources and the characteristics of the natural environment in the region should be taken into account. At the same time, the surrounding system and the status and level of socioeconomic development should also be studied. According to the strategic goals of regional development, a series of engineering projects should be planned and the locations of these key projects considered in accordance with the regional geo-environment. Then the environmental protection and hazard reduction measures should be studied in order to design corresponding counter-measures. Therefore, sound and reasonable planning of regional development should be based upon systematic study and an in-depth understanding of the geo-environment of the region. Because economic development can not be realised without engineering development, the conditions for engineering construction should be taken into account in regional planning. The integration of resource development and environmental protection into economic and engineering development is one of the important characteristics of this research.

This monograph consists of seven chapters. Chapter One gives an introduction to and the background of natural and socioeconomic conditions for development in the region. The descriptions of natural resources and the environment are included in Chapters Two, Three, and Four. Chapter Five is devoted to the strategic planning of economic development in the region. The geo-environmental considerations for the development of engineering are given in Chapter Six, and the last chapter discusses measures for environmental protection and hazard mitigation.

The aim of this research paper is to help attain rapid progress in the integrated development of the Hengduan Mountain Region.

Background of Strategic Development

Natural Resources and Environment

In order to carry out a case study of the conditions for integrated development, its planning, and policies pertaining to it in the Hengduan Mountains, detailed investigation and an appraisal in a selected second order region are required. This would be a practical and feasible approach. The territory of the Hengduan Mountains is vast, and the characteristics of natural resources and environment vary from place to place although they do have certain commonalities. Therefore, investigating and comparing several sub-regions are useful exercises. The eastern front of the Hengduan Mountains is the most suitable region in which to carry out such an investigation. The topographical elevation is not too high, although incised canyons do exist. The region is rich in natural resources and has a rather rugged topography. Panxi is one of the most suitable regions for a case study. A good selection of mineral resources and hydropower potential, as well as convenient transportation, will make this region one of the key developing regions in southwestern China by the end of this century. Therefore, a study of this region is of practical significance.

Panxi Region is in the southern part of Sichuan Province, stretching from Panzhihua to Xichang City and between the Yalongjiang River and the Anninghe River. This region belongs to the Liangshan Yi Autonomous Prefecture and includes Xichang and Panzhihua municipalities and Dechang, Miyi, Yanyuan, Yanbian, Mianning, Huidong, Huili, Yuexi, Meigu, and Zhaojue counties (Figure 1).

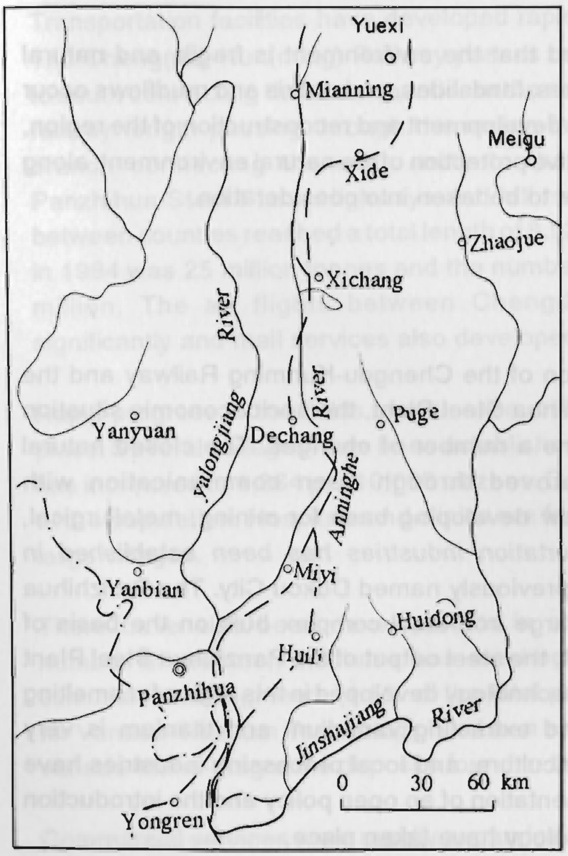


Fig. 1: Sketch of Prefectural Administration of Panxi Region

The Anninghe River and the Chengdu-Kunming Railway pass longitudinally from north to south through the middle of the region. Located where Yunnan, Sichuan, and Guizhou provinces meet, Panxi Region is in an economically strategic position.

In this region the topography in the northwestern region is higher than in the southeast. The elevation varies from 4,000m in the high mountains to 2,000m in the middle mountains. The mountain ranges extend from north to south. The large rivers, such as the Jinshajiang, Yalongjiang, and the Anninghe, flow from north to south. The Jinshajiang and Yalongjiang rivers have narrow valleys, but the Anninghe River has a wide one, and the fault depressions are distributed between the mountains.

The region is characterised by the monsoon climate of the southern subtropics which has abundant precipitation. As a result of spatially different.climates, it is rich in agricultural and forest resources. Quaternary alluvial deposits are distributed throughout the wide valleys and inter-montane basins, forming the basis for grain production, therefore the region is known as the "granary" of southern Sichuan. Forests, rare birds, animals, and valuable plants are abundant in the mountains. As a result of the Paleozoic rift process (Bolin 1988), metallic mineral deposits, especially vanado-titano-magnetite, and base metals, such as zinc, copper, and lead, are widely distributed throughout the region. Therefore, the conditions are extremely favourable for industrial development.

However, it should be noted that the environment is fragile and natural hazards, such as earthquakes, landslides, and debris and mudflows occur frequently. Therefore, in the development and reconstruction of the region, rational utilisation and effective protection of the natural environment, along with hazard mitigation, have to be taken into consideration.

Socioeconomic Situation

Since 1960, after completion of the Chengdu-Kunming Railway and the establishment of the Panzhihua Steel Plant, the socioeconomic situation in the region has undergone a number of changes. The closed natural economy was partly improved through open communication with neighbouring regions. A new developing base for mining, metallurgical, coal, electric, and transportation industries has been established in Panzhihua City which was previously named Dukou City. The Panzhihua Steel Plant (Plate 1) is a large iron-steel complex built on the basis of national technology. In 1984, the steel output of the Panzhihua Steel Plant was fifth in the country. The technology developed in this region for smelting vanado-titano-magnetite and extracting vanadium and titanium is very advanced. The forestry, agriculture, and local processing industries have developed recently. Implementation of an open policy and the introduction of foreign capital and technology have taken place.

In 1984 the total industrial and agricultural production reached 2.78 billion *yuan*[1] (equivalent to one billion U.S.dollars), 65.8 per cent of which was of

(1) There are approximately 5 *yuan* to one U.S. dollar.

industrial production quality. The main products were iron ore, iron steel, rolled steel, vanadic powder, coal, coke, cement, wood, and sugar. The total installed capacity of electricity reached 456 MW. Some of the products of rolled steel and vanadic powder are exported to more than 10 Asian and European countries.

In 1984 the total agricultural production reached 0.95 billion *yuan*, with grain production of 1.5 million tonnes. Agriculture partly supplied the needs of the mining industrial complexes and urban needs. The main agricultural products were tobacco, pigs, and sheep.

Transportation facilities have developed rapidly during the last 20 years. The Cheng(du)-Kun(ming) Railway passes through the region from north to south connecting the main counties in the region with Kunming. The total railway length passing through the region is 526km. There is a railway branch connecting the main route to the Panzhihua Mine and the Panzhihua Steel Plant. Highways and hill roads built for communication between counties reached a total length of 8,924km. The cargo transported in 1984 was 25 million tonnes and the number of bus passengers was 12 million. The air flights between Chengdu and Xichang improved significantly and mail services also developed.

Rapid progress in the fields of education, culture, and science has taken place. Several colleges have been established and the number of students has increased to 1,364 per 10,000 citizens. Doctors make up 2.18 per cent of the population. Hospitals and clinics are found in most of the towns and large villages.

There have also been developments in science and technology. The number of research institutes has reached 36, with more than 36,000 scientists and engineers (1.5% of the total population). A National Centre for Vanado-Titanium Technology has been established because of the rich vanado-titano-magnetite deposits found in the region.

Commercial services were rapidly expanded in order to promote economic development. More than 16 thousand commercial service centres have been established with 600,000 thousand persons involved.

In general, the socioeconomic situation has improved substantially during the last two decades. This provides a sound basis for further modernisation.

However, the development in the region is unbalanced and the resources are still not used rationally. The development potential in the region is sufficient to enable the establishment of an economic centre in southwestern China to support the future development activities of the Hengduan Mountains and the Qinghai-Tibetan Plateau. Therefore, a comprehensive study for strategic planning is urgently needed.

Strategic Position and Conditions for Development

After the founding of the People's Republic of China, the national government, in its attempts to establish this area as an important industrial and agricultural base in the southwestern area of the country, paid more attention to its development and construction. In the middle of the 1980s, this area became well developed in energy and mineral resources. The development of this region plays an important role in bringing about strategic changes in the production pattern of southwest China and of the country as a whole. Harnessing of large-scale hydropower resources; development of mining, metallurgical, and chemical industries; and agriculture will be the objectives of reconstruction in the 1990s.

Abundant mineral and energy resources exist in the region. The hydropower resources in this area account for 22 per cent of the total resources in southwestern China (including Yunnan, Guizhou, and Sichuan). The iron resources account for 71 per cent, and the non-ferrous metals, such as zinc, copper, and aluminum, account for 20 per cent. At present, national steel production is concentrated mainly in the eastern part of the country, and the steel output in the southwest is only seven per cent of that of the whole country. Therefore, a lot of steel has to be imported over a long distance. The production of steel in this region is expected to reach about one million tonnes per annumby the end of the century, and, correspondingly, different types of steel are also to be developed.

In the present energy structure of the country, coal accounts for 73.2 per cent, oil 20.9 per cent, and hydropower for only four per cent of the total power. The development of hydropower in this region, including the Yalongjiang, Ertan, and Jinping hydropower projects along the Jinshajiang River, with a total installed capacity of two million kilowatts, will play an important role in improving the energy structure of the country as a whole.

Hydropower, which is an important energy resource in this area, is cheap and does not pollute the environment.

The production of steel products and the harnessing of hydropower energy and vanadium and titanium metals will facilitate the comprehensive use of associated rare valuable metals and will contribute to the modernisation of science and technology. Titanium metal, with its low specific gravity, erosion resistance, and high strength, has an important function in aviation and space technology. Vanadium is an important element in the production of metal alloys. Using vanadium dregs to extract gallium is important for the development of third generation semiconductors. To use high quality resources fully in this area will be a key step in the modern development process.

Proper environmental management of the middle and lower stream regions of the Yangtze River Basin should be undertaken. Soil erosion in this area affects about 30,000 kilometres. Up to 233 million tonnes of sand is silted into the Jinshajiang River annually, accounting for 28 per cent of the total sand silted into the Yangtze River. The use, management, and protection of the land resources in this region will not only control mountain disasters but will also mitigate the problem of siltation to a certain extent.

In addition, this is a region where minority nationalities (principally the *Yi* nationality), whose economy and culture are underdeveloped, live in compact communities. Therefore, the development of this region can provide a number of lessons and experiences for the development of the southwestern mountainous regions.

To sum up, economic improvement and industrial and agricultural development occupy an important strategical position in the development of southwestern China and in the improvement of the production pattern of the country as a whole.

Chapter 2

Natural Environment

Topography

Panxi Region is located on the eastern boundary of the Hengduan Mountains and belongs to the transitional zone that stretches from the Qinghai-Tibetan Plateau to the Sichuan Basin. The topography is higher in the northwest and lower in the southwest. The highest peak in the region is Shaotouji Mountain which has an elevation of 5,958m and is located in Muli County. The Jingshajiang River Valley floor has the lowest elevation of 305m. Due to the influences of the Himalayan orogenic process from the late Tertiary period onwards, the earth's crust in the region has been subjected to rapid uplifting and the surface has been cut deeply by the river system, forming the recent landscape of the eastern Hengduan Mountains. The high mountains of more than 4,000m with deep canyons are in the western part of the region, while the middle mountains, with elevations ranging from 2,000 to 3,000m, are dominant in the eastern part of the region.

The mountain ranges in the region generally strike in a north-south direction. To the east of the Anninghe River are located Liangshan, Lujieshan, Lunanshan, and Longzhoushan, and, to the west, are Maonieshan, Mupanshan, and Jingpingshan. Further inside the high mountains, the Jinshajiang River (the upper stream of the Yangtze River) and its major tributaries, the Yalongjiang and Anninghe, reach deeper inland forming narrow valleys and broad basins. The mountains occupy more than 70 per cent of the total area of the territory, broad valleys and basins only 10 per cent, and mountain plateaux and hills 20 per cent.

The major rivers in the region are the Jinshajiang River (Plate 2), the Yalongjiang River (Plate 3), and the Anninghe River. All of these rivers have many tributaries. The mainstream of the Jinshajiang River flowing through the region is 754km long with an annual average flow of 4,660m^3/sec and a longitudinal gradient of more than two per cent. The Jinshajiang River flows from west to east and constitutes the boundary between the Yunan and Sichuan provinces. In addition to the Yalongjiang River, there are a series of tributaries of the Jinshajiang River such as the Da, Pulong, Zangyu, Daqiao, Haishui, Xixi, and Meigu rivers. The basin area of the tributaries in the region is 27,095sq.km.

The Yalongjiang River is the largest tributary in the region of the Jinshajiang River. The mainstream flowing through the region is 552km long. The annual average flow is 1,860 m^3/sec with a longitudinal gradient of two per cent and a tributary basin area of 34,048sq.km. The main tributaries of the Yalongjiang River are the Anninghe, Ganyu, Litang, and the Eole.

The Anninghe River is the main tributary in the lower reaches of the Yalongjiang River. The Anninghe River stretches from north to south in the middle of the region. The valleys and basins of the Yalongjiang River are broad and the quaternary deposits have developed into a series of terraces. Several large lakes are located in the region. Among them, the Qionghai is the most famous. It is located near Xichang City in front of Lushan. The elevation of the lake is about 1,510m. The water surface occupies an area of more than 30sq.km. with a water storage capacity of 320 million cubic metres. The Qionghai Lake is rich in aquatic products and it can be developed as a tourism and recreation spot.

Climate

Owing to the complexity of the geographic environment and of its geomorphology, the climate is characterised by combinations of various types. Differences caused by verticality in climate, plantation, and soil are obvious. Under the alternating actions of the strong currents of the west wind and the southwest monsoon, wet and dry seasons are distinguished by cool summers and warm winters. The annual variation in temperature is relatively low, while the difference in temperature between day and night is quite high. Rain is concentrated in summer. The sunshine hours are quite long, reaching 1,600 to 2,400 hr/year, and the annual thermal radiation ranges from 110 to 140 kcal/cm^2. The period of frost is short and, in most areas, it ranges from 60 to 120 days per year with the exception of the Liangshan area where the frost period is over 120 days per year.

The annual average temperature is generally 14 to 18°C, although it can reach 20°C in the Jingshajiang River Valley where the southern subtropical climate is dominant. In general, the climatic condition varies, based on the elevation of the mountains, from the valley floors to the mountain peaks and from the subtropical to the temperate and, thus, four different seasons can exist simultaneously.

The region is rich in precipitation but its distribution is not uniform. The annual rainfall ranges from 600 to 1,400mm. There is more precipitation in the north than in the south. The most abundant precipitation (2,400mm) occurs in the upper reaches of the Anninghe River. In the middle reaches of the Anninghe River, the annual precipitation varies from 800 to 1,200mm. In the lower reaches, less than 800mm was observed in the Jinshajiang River Valley and the Yanyuan Basin. Ninety per cent of the annual precipitation occurs during the rainy season which lasts from May to October; storms often occur during this period. The period from November to April is dry, and only 10 per cent of the total annual precipitation occurs then.

Rock Formation

According to the combinations of rock formations, the area can be divided into six areas (Huang Dingcheng et al. 1990).

(1) *The Muli-Jinpingshan Area*

The Muli-Jingpingshan area is located in the northwest. In this area, the low-metamorphic series of the Indo-Chinese epoch is broadly developed with intrusions of Yanshanian granite and quartz-diorite massive. The rock formations in this area can be divided into Tb and Pzb groups (Figure 2).

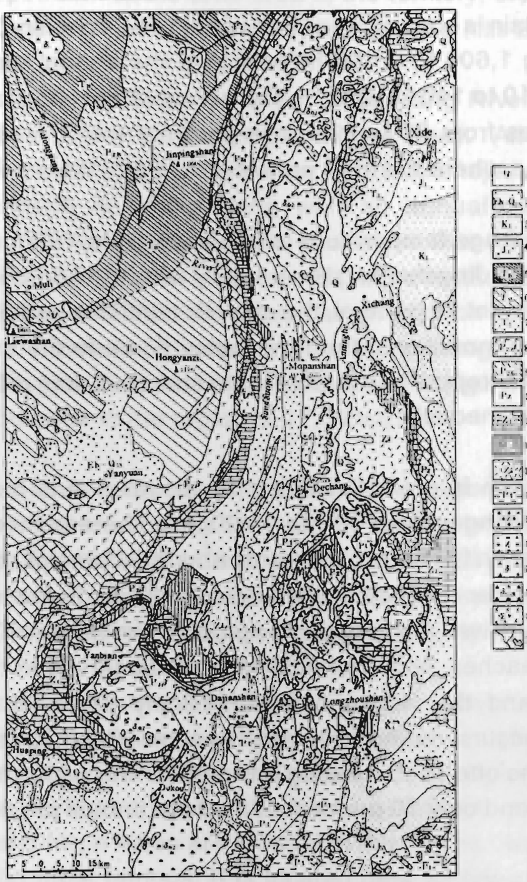


Fig. 2: Types and Distribution of Rock Formations in the Region (after Huang Dingcheng et al., 1990)

1. Quaternary deposits 2. Formation of river and lake facial clastic rock of the Cenozoic era in Yanyuan Basin 3. Formation of continental facial clastic rock of Early Cretaceous period; 4. Formation of continental facial clastic rock of Middle and Late Jurassic period 5. Formation of low grade metamorphic, marine clastic, and carbonate rocks 6. Formation of clastic rock of alternative facies of shallow water, marine, and continental of Triassic period 7.Formation of continental clastic rock of Triassic period 8. Ermeishan basalt of Late Permian period 9. Formation of low grade metamorphic clastic rock of Palaeozoic era 10. Formation of marine clastic rock of Palaeozoic era 11. Formation of marine carbonate rock of Late Sinian period 12. Formation of marine clastic rock of Late Sinian period; 13. Formation of volcanic rock of Early Sinian period 14. Formation of metamorphic rock of Proterozoic era 15. Granite 16. Syenite 17. Diorite 18. Granodiorite of Jinning period 19. Basic and ultrabasic rocks 20. System of surface water

A. Tb. According to lithological characteristics, the group Tb can be divided into subgroups Tb1 and Tb2.

Tb1 is a metamorphic, marine carbonate formation. It includes the Shemulong series of the late Triassic period and the Beishan and Yantan series of the middle Triassic period. The Shemulong series consists mainly of limestone interrelated with metamorphic siltstone of from 150 to 800m thickness. The Beishan series consists of blocks or thick-layered grey or white marble, intercalated with reddish dolomitic marble. The thickness of the Beishan series varies from 800 to 2,500m. The Yantan series consists of two parts. The upper part is composed of thin-layered marble, intercalated with slate seams, metamorphic sandstone, sandy slates interbedded with chlorotic schists, and basalts. The thickness is from 2,500 to 3,000m. The lower part consists of chlorotic schists, metamorphic basalts, and thin layers of marble, marl, and slates with a total thickness of from 1,300 to 1,600m.

Subgroup Tb1 forms high mountain peaks, such as the Jinpingshan Mountain, due to its hard rock layers - marble, sandstone, and metamorphic basalts. Because of the interbedding of marble, slates, and schists, the groundwater flows along layers causing an inflow of water into tunnels or underground excavations.

Tb2 is a low grade, metamorphic marine clastic formation consisting of thin-layered grey or black slates interbedded with feldspar-quartz sandstone, siltstone, and limestone. The total thickness is up to 2,500m.

B. Pzb. This is a Paleozoic, slightly metamorphic, marine clastic formation and is widely distributed throughout the area west of the Jinping Fault. This group includes the stratigraphic units given below.

Lower Ordovician. The upper part consists of phyllite interbedded with metamorphic siltstone, the middle part is of quartzite interbedded with sericite-quartz schists and chlorite schists, and the lower part is of sericite schists and mica-quartz schists.

Lower Silurian Siliceous Rocks include siliceous slates and phyllites of from 100 to 400m in thickness.

Middle and Upper Carboniferous System. This system consists of siliceous banded limestone interbedded with slates. The thickness varies widely from less than a metre to 1,200m in thickness.

Lower Devonian. The upper part consists of metamorphic sandstone, slate, and siliceous slate of from 1,000 to 7,000m in thickness. In this formation the sandstone, siliceous rock, limestone, and metamorphic basalt are hard rocks and can be used as building material. However, because they are interbedded with weak rocks, geo-engineering problems do exist because of the geological structure. Several disconformities between Ordovician and Silurian, Silurian and Devonian, Devonian and Carboniferous strata form water conduits.

(2) *The Yanyuan-Hulushan Area*

The Yanyuan-Hulushan area is located towards the south of the Muli-Jinpingshan area and the Xiaojinghe Fault forms its boundary. The eastern and southern boundaries are determined by the Jinghe-Qinhe Fault and the Houlongshan-Yanyuan Fault divides the area into east and west. In the western section, Triassic deposits, mostly developed in the Yanyuan Fault depression, are predominant. In the eastern section, both the Palaeozoic and Sinian series have developed.

A. Eh-Q1x Alluvial and Lacustrine Deposits in the Yanyuan Basin. Since the Cenozoic era, the Yunnan Basin has been formed, as a result of the movement of the Yanyuan Fault. The southern part of the basin is subject to the most subsidence (1,600m). Deposits of the Eocene, Oligocene, Pleistocene, and Holocene series have developed in the depression.

Early Pleistocene (Q1x). The Xigeda stratum of the early Pleistocene period consists of yellow siltstone and black-grey claystone. The thickness varies from 60 to 370m.

Late Oligocene (N2). The Yanyuan series of the late Oligocene period with a thickness of 240m is composed of interbedded siltstone and claystone with 79 layers of brown coal and some conglomerate lenses in the lower part.

Eocene (Eh). The Hongyiezi series with a thickness of 970m consists of violet conglomerate, feldspar-sandstone, and siltstone.

There are several geo-engineering problems: (1) the shear strength along the bedding planes between the siltstone and claystone in the Xigeda layer is quite low, and this is one of the reasons why numerous landslides occur in the Xigeda layer; (2) the illite and montmorillonite contents in the Xigeda claystone cause it to swell and disintegrate, making it unfavourable for construction purposes; (3) the Yanyuan series (N2) contains a lot of conglomerate brown coal seams and lenses giving it anisotropic properties; and (4) the Eocene conglomerate is heterogeneous from the geo-engineering aspect.

B. Tm--Shallow Marine and Littoral Clastic Formation. The Triassic deposits in the area are composed of four series of shallow marine and littoral clastic formation.

The upper Triassic deposits are mainly distributed throughout the area north of Yanyuan County. This is a coal series consisting of interbedded feldspar-sandstone, feldspar-quartz sandstone, and shale in the upper part and interbedded marl, feldspar-sandstone, and shale in the lower part of the section. The total thickness ranges from 1,200 to 2,300m.

The Beiyunshan series of the middle Triassic deposits consists of dolomitic limestone, siltstone, and limestone; the latter contains hematite lenses of different sizes. The total thickness ranges from 280 to 1,800m.

The Yantang formation of the middle Triassic period is from 300 to 1,263m thick and consists of sandstone with intercalations of marl and gypsum seams in the lower part. Three salt domes have been found in the Yanyuan Basin. The thickness of the salt deposits is from 700 to 800m (shallow). Because of this and the high content of haloids, a chlorine-alkaline industry could be established in the Yanyuan area.

The Qingtianbo formation of the lower Triassic period consists of sandstone, siltstone, mudstone, and shale with a conglomerate at the bottom. The thickness ranges from 345 to 983m. The upper part of the series contains copper sandstone and some coal seams are contained in the middle of the section.

The above-mentioned formation of clastic and carbonate deposits with abundant mineral resources is a variable one. However, the geological properties of the coal seams should be considered from the engineering aspects .

C. P2--Upper Permian Emeishan Basalt. In the whole region, a series of basaltic eruptions occurred in the late Permian period leading to a type of continental rifting. In this area, the basalt flow is controlled by the Houlongshan and Jinhe-Qinhe faults.

The total thickness of Emeishan basalt is from 1,838 to 3,230m and it is characterised by massive, amygdaloidal, and porphyritic structures. The base of the basalt lava consists of tuff, tuffaceous breccia, and brachiated lava.

Basalt is generally a hard, massive rock that can be used for construction. In the period between eruption and flow, some loose material can be deposited on the surface of the basaltic lava forming weak intercalations. The cooling joints can then damage the intactness of the basalt.

D. Pz--Paleozoic Marine Carbonate Formation. The most complete section of the Paleozoic group is observed in this area. It is a marine formation localised in a zone between the

Houlongshan and Jinhe-Qinhe Faults. The general strike of the stratum is NNE.

The Leping Series (P2). The Leping Series is a series of feldspar-sandstone, siltstone, coal shale, and limestone with epicontinental and littoral facies. It is widely scattered with a thickness of from less than a metre to 830m and overlies the Emeishan basalt. The problems of weak intercalations and coal seams have to be considered if construction is to take place. The contact area between the Leping series and the basalt has the characteristics of a palaeo-weathered zone and can cause some geo-engineering problems.

Lower Permian Epicontinental and Littoral Carbonate Formation. This formation can be divided into two series. The Maokou series with thicknesses of from 147 to 270m consists of limestone with a disconformity between the limestone and the Emeishan basalt. In the contact area, there are some iron ore deposits which are locally mined. The existence of weak seams and lens-like groundwater bodies causes the main geo-engineering problems.

The Qixia series with a thickness of from less than a metre to 21m consists of limestone.

The Liangshan series constitutes the base of the lower Permian formation and has a thickness of from 30 to 130m. This series consists of strata containing sandstone and mudstone with lenses of marl or limestone. The upper and middle Carboniferous series are composed of marl limestone, marl intercalated with siltstone and limestone lenses, and siliceous, banded limestone. The thickness of the series is from 130 to 300m.

The middle Devonian series is more than 1,925m thick and consists of limestone, organic limestone, mud-banded limestone, and limestone with siliceous concretion. The lower series contains ferro-clastic quartzite and sandstone with siltstone and limestone lenses.

The total thickness of the Silurian stratum is from 670 to 900m, of which the upper series is made up of siliceous rock; the middle series of marl limestone, shale, and silt; and the Maxi formation of the lower series of mudstone and carbonaceous shale with marl limestone.

The Qiaojia group of the middle Ordovician period is 65m thick and is composed of porphyritic limestone and limestone with mudstone. The Hongshiya group of the lower Ordovician period is 935m thick and is made up of quartz sandstone, feldsparthic quartz sandstone, and siltstone interlayered with mudstone or conglomerate.

In short, the section from the lower Ordovician period to the lower Permian period is a complex geological mass with shallow marine facies and a set of carbonate and clastic series. Besides some weak interlayers, there are numerous disconformities, mostly caused by interbedded slips. Therefore, the geo-engineering problems between stratigraphic units are serious and obvious. Moreover, because of the interbedding of permeable and impermeable layers, different water-bearing strata are present. In addition, the development of karst is controlled not only by the geological structures but also by the rock formation characteristics. Engineering construction can be influenced to a great extent by these problems.

E. Zt--Carbonate Formation of the Upper Sinian. This is a set of carbonate formations with shallow marine facies, mainly composed of dolomitic limestone, dolomite, and siliceous concrete limestone, intercalated with sandy shale and phosphorous sandy shale. The problem with this kind of formation is mainly the void-cavern formation caused by karstic action. The hydraulic condition of karst water is complicated; the existence of weak interlayers of impermeable strata causes concentration of groundwater flow, resulting in corrosion of the upper rock layers and forming weak and potentially dangerous slide planes in rock masses. In addition, there are outcrops of Guangyinya sand-shale of the upper Sinian period and Hercynian ultrabasic rock masses. Their features will be discussed together with some relevant formations later.

(3) *The Yanbian--Baiposhan Area*

The Yanbian-Baiposhan area is located in the mid-western part of the Panxi Region. It is bordered by the Yanyuan-Hulushan area in the northwest and the Daqiao-Tianwan area in the northeast. The Limingjiu Fault passes along its eastern border and the Huapin-Dukou Fault along the southern border.

The distribution of strata in the area is characterised by a double-layered structure of the platform type. Its foundation consists of the Proterozoic Yanbian group and the Ginning granodiorite mass, and its depositional cover consists of the Sinian and Paleozoic groups. Some Caledonian and Hercynian basic and ultrabasic intrusives and syenites are found in the area.

There are some differences between the Paleozoic strata in the area and those in the Yanyuan-Hulushan area. First, the stratum of purplish-red, feldspathic quartzose sandstone with fine sand and silt is interbedded with dolomitic sandstone, sandy shale, and argillitic (or dolomitic) limestone of the lower Cambrian series in the first area. Second, the clastic rocks are more developed than those of the rock series in the whole Paleozoic strata. Third, there are depositional discontinuities between the lower Cambrian and lower Ordovician, upper Silurian and middle Devonian, upper Carboniferous and lower Permian, and the top and bottom of the Emeishan basalt groups.

Attention should be paid, in particular, to the fact that the solid limestone and sandstone are intercalated with weak and soft seams which are easily liable to argillation. In the case of the Paleozoic group as a whole, it is possible that various geo-engineering problems are caused by the heterogeneity of strata with an unfavourable combination of structures and geomorphological conditions. In the lower section of the middle Devonian, for example, shale, schistose shale, and sandstone are interbedded with intercalations that can cause landslides during road excavations on rock slopes.

A. Zs--Marine Facies with Clastic Rock Formation of the Upper Sinian Epoch. This group includes the Guanyinya and Lieguliu series with a total thickness of from 550 to 1,500m, composed mainly of pelithic sandstone, feldspathic quartzose sandstone, argillitic silt, fine-grained sandstone, gravelly coarse sandstone, and shale, interlaced with lens-shaped dolomite and, occasionally, argillaceous limestone.The geo-engineering characteristics of the series depend on the composition of strata at the specific location of an engineering project. Problems of heterogeneity in the strength of rock masses can arise due to the existence of shale intercalations. In this case, the intrinsic deformation and shear resistance properties of the rock mass are not easily recognised in a section occasionally interlayered with limestone lenses.

B. Z--Lower Sinian Volcanic Rock Formation. The Kaijianqiao series of volcanic rock formations of the lower Sinian epoch is exposed mainly at Baiposhan and Xiaoxiangling on the Panxi and Luojiushan faults.

At Baiposhan, this series is composed of andesite-dacite with a thickness of up to 3,125m. Its upper part is dacite porphyry and andesitic dacite porphyry. The top is made up of a dacite-andesitic volcanic breccia, the lower part of andesitic porphyrite, and the bottom of gravelly lithic tuff.

In the Xiaoxianling and Luojiushan districts, there is mainly a series of volcanic clastic rocks with a total thickness of 2,830m. The upper part contains purplish dacite tuff lava, tuff, tuff breccia, and tuffaceous sand-shale, and the lower part contains coarse sandstone, rhyolitic tuff, rhyolite, and tuffaceous sand-shale.

This formation originated under hypabyssal conditions. The complex variety of rocks and the wide difference in thickness lead to the variable properties of rock masses. The zone between layers and the contact plane with an underlying metamorphic rock series causes grave problems from the geo-engineering aspect.

C. Pt--Yanbian Series with Metamorphic Rock Formations of the Lower Proterozoic Group. This series is found mainly near Yanbian County, located towards the west of the Xifan Fault with fragments outcropping west of the Anninghe River. It is composed mainly of sericite slate, carbonaceous sericite slate, carbonaceous slate, dolomitic slate, sandy slate, quartz slate, sandy phyllite, metamorphic basalt, and metamorphic sandstone. Deep in the metamorphic zone, there are green schists, graphitic schists, gneisses, hornblende schists, and jasper stones (plate-like siliceous rocks). Generally, the series shows thin to extremely thin, layer-like textures, with schistosity, slab cleavage, and striped planes. This leads to folding and arching deformations, and the graphitic schists and the hornblende schists are, normally, most intensely deformed and faulted.

D. So2--Ginning Granitic (quartzose) Diorite. This series is found in the Tongde rock mass, Yongren rock mass, and Dajianshan rock mass as batholiths which have very favourable geo-engineering properties with homogeneity and high strength. The rock masses have been cut by joints and faults caused by later tectonic movements, and their geo-engineering properties have been weakened through weathering. Rock masses in major faulted zones have not only been mylonitised but also deeply weathered.

There are two obvious problems arising due to the basalt rock masses (P_2 β) in the area. The first is that the alteration caused by tectonic action and intrusion of magma leads to heterogeneity of strength and deformation properties. This phenomenon is considered the result of dynamo-metamorphism, contact thermal metamorphism, and autometamorphism, in which the first two processes play major roles. The second is that the granite with porphyritic texture is weathered into separate boulders.

(4) *The Daqinao--Tianwan Area*

The Daqiao-Tianwan area is located in the central part of the Panxi Region, ranging from the western hills of Maoniushan in the north, across Daqiao, the Xiangshuihe river mouth, and Limingjiu to Pausoyan in Wuben. It is a continental clastic formation of a rift zone(T1) stretching south-north. The sediments in the geosyncline trough are mainly from the Baiguowan series of the upper Triassic period overlaid by the Yimen series of the Jurassic period in the middle section of the area.

The T1-upper Triassic, continental clastic formation is mainly made up of interbedded sandstone with fine sandstone and silt rock alternated with shale and interlaced with coal seams or coal lenses. There are very thick layers of coarse sandstone; from 500 to 600m.

In the sandy shale layer with clastic texture, seen either on natural slopes or on artificial slopes, sliding failures occur along weak surfaces (mainly soft strata). Disasters are caused by landslides and mud-debris flowing into the Jinhe River towards the Xiangshuihe River mouth along the valley of the Yalongjiang River. In the coal series, there are problems of groundwater and deformation of galleries in soft rocks, and, in the conglomerate stratum, the basic problems are the heterogeneity of its texture and the difference in cementation.

(5) *The Mianning--Miyi Area*

This area covers the main part of the Panxi Fault belt. In the area, igneous rock masses of various types and sizes are composed of the lower Proterozoic metamorphic rock series, the Sinian formation, and fragmentary outcrops of the Paleozoic group. On the eastern boundary, the Liangshan Fault zone is dominant. Mesozoic strata are found in the border district.

A. Igneous Rocks. There is a great variety of magmatic rock masses in the area.

a) Yanshanian acid intrusive rocks: potash, feldspathic granite, biotite granite, quartz diorite, and alkali-granite.

b) Indo-Sinian intrusive rocks: granite, plagio-granite, granodiorite, quartz diorite, alkali-granite, quartz syenite, and syenite.

c) Hercynian basic and ultrabasic rocks: gabbro, coulsonite-titanomagnetite, and gabbro-diabase masses.

d) Caledonian basic and ultrabasic rocks.

e) Later Proterozoic porphyroid biotite granite, granodiorite, and quartz diorite.

There is no doubt that the geo-engineering properties of igneous rocks are favourable. Attention should be paid to the degree of weakness after tectonic deformation and secondary evolution. The shear sliding problem, particularly, can be present in the relationship between a clastic rock mass cut by faults and an engineering structure. Moreover, the clastic zones of rock masses in contact with surrounding rocks and alteration zones are mostly the weak parts that can lead to deformation and failure of engineering constructions.

B. Pt--Metamorphic Rock Formation. The Huili Tianbao, Fengshanying, and Tongan series are found in the eastern Anninghe and Tinshang river areas.

The Tianbao series is mainly composed of yellow-green, quartz sericite schist, intercalated with marble, metamorphic rhyolite-porphyry, and quartz porphyry.

The Fengshanying series is a grey, thin (layer-like to sheet-like) limestone of shallow water origin with a few thick, layer-like crystalline limestones.

The Limahe series is an interlacing of quartz slate and biotite quartz schist with a layer thickness of from 10 to 15m.

The Tongan series is mainly composed of slate, phyllite, and sericite schist with some marble (each intercalation is from 10 to 80m thick).

The Kangding series, distributed throughout the southern part of the area (along the Dukou--Datian--Pingdijie and Miyiyakou to Huiligou zones), is composed of a moderate to high grade metamorphic rock series. This series includes migmatite, gneiss, amphibolite, mica diorite, hornblende anorthosite, and other plutonic metamorphic intrusive rocks and biotite leptite and biotite migmatite gneiss.

In general, metamorphic rocks have a very complicated formation. Normally, geo-engineering conditions in marble, crystalline limestone, quartzite, migmatite, and gneiss (if fresh) are good, but in schist and phyllite they are not so good. Schistose structures, gneiss structures, and oriented arrangements of minerals, under metamorphic conditions, form the basic data for specific geo-engineering conditions. The tensile rupture along discontinuities, with a weaker cohesive force, leads to the deformation and failure of rock masses which are characterised by outstanding heterogeneity and anisotropy (e.g., the physical and mechanical properties of rocks vary greatly in directions that are normal and parallel to the axis of the anisotropy).

Some Sinian, Palaeozoic, and Triassic formations exist in the area and are fragmentally dispersed (with the exception of the Sinian formation).

(6) *The Xide-Huili and the Yizi-Zhiju Area*

The Xide-Huili area is located on the eastern boundary of the region, and the Yizi-Zhiju area is in the southwestern corner where mainly the Mesozoic, Triassic, Jurassic, and Cretaceous series can be found.

A. <u>J23--The Clastic Rock Formation of the Upper and Middle Jurassic series</u>.

a) The Feitianguan series of the Upper Jurassic period, with a thickness of from 300 to 700m, is composed of interbedded layers of grey-purplish, purplish-red, carbonaceous, fine-grained sandstone and mudstone, and the bottom part is composed of carbonaceous conglomerate in contact with (but not in conformity with) the Guangou series below it.

b) The Guangou series of the Middle Jurassic period, with a thickness of from 350 to 650m, is composed of purplish-red, carbonaceous mudstone and siltstone and marl intercalated with shale and fine-grained sandstone.

c) The Niugunshui series of the Middle Jurassic period, with a thickness of from 580 to 800m, is composed of bright red mudstone, carbonaceous mudstone, carbonaceous siltstone, and fine-grained sandstone.

d) The Xincun series of the Middle Jurassic period, with a thickness of from 550 to 1,000m, is composed of purplish carbonaceous mudstone, siltstone, feldspathic quartz sandstone, and marl and the bottom layer is composed of feldspathic sandstone and conglomerate.

e) The Yimen series of the Middle Jurassic period, with a thickness of from 140 to 400m, is composed of purplish-red mudstone intercalated with siltstone in its upper layer and siltstone interlaced with quartz sandstone and marl in its lower layer.

From comprehensively surveying the strata texture of the Upper Jurassic series, it is clear that this is a set of clastic rock formations with land facies of mudstone, siltstone, and fine-grained sandstone intercalated with marl, shale, and conglomerate and that its strength varies with lithology. Some sedimentary discontinuities exist between the Feitianshan and Guangou series and the Xincun and Yimen series. The geo-engineering condition depends upon the degree of tectonic deformation. In tectonic fault zones and weak layers, the mechanical strength is low. This series of strata is slightly permeable or relatively impermeable. Its hydro-geological condition depends upon the degree of tectonic influence. The strength and deformation characteristics of the strata are heterogeneous and show a fairly obvious groundwater effect. The strength decreases sharply under the influence of groundwater.

B. K1--The Continental Clastic Rock Formation of the Lower Cretaceous period. The Cretaceous strata outcropping in the studied area are mainly from the Xiaoba series of the lower Cretaceous period and are more than 25,500m thick. The strata consist of a set of brown-red siltstone and sandstone interlaced with mudstone and marl. At the bottom there is a widespread conglomerate bed varying in thickness. It contacts (but not in conformity) with the Feitian series of the Upper Jurassic period. In the sandstone layer of the middle part of the stratum there are, occasionally, nest-like deposits of gypsum.

This set of red strata is normally impermeable or slightly permeable only. However, along both sides of a fault, a water-bearing zone or a water-rich zone is formed under certain conditions because of the developed fissures. For example, the Shamulata tunnel of the Cheng-Kun Railway suffers from water gushing at a flow of more than 2,000 tons per hour, because it passes through a fault zone in the strata.

The different sets of red strata vary greatly in strength. Mudstone, which contains clay minerals, has typically poor properties of rending when dry, falling apart, or expanding in water, and being subjected to weathering. In addition, the thin interlayered or nest-like gypsum strata also contain mirabilite, chlorotic salt, and salt substances. This results in poor hydro-geological characteristics and corrosion of the concrete. In addition, weak rocks, subjected to tectonic breaking and deep weathering, are the major source material for debris flow, which is one of the factors leading to widespread and serious disasters in the Xichang district. It is necessary to make specific estimations of all these problems in the early stages of planning for engineering activities.

Tectonics

The research region is tectonically located on the western border of the Yangtze block. Bayankela and the three-river fold belts are distributed westwards and southwards respectively. The southern boundary is formed by the Jinsha-Red River Fault. The tectonic evolution of the region is characterised by processes of basement and cover development. The basement was formed during the Ginning orogeny (900 m.a) and is mostly overlaid by gently folded cover rocks with intensively developed fault systems. The regional faults usually intersect the basement and control magmatism and cover sedimentation in the region (Fig. 3).

Basement Tectonics

The basement in the region is composed of the Yanbian, Huili, and Kongdian series. The Kongdian series is the oldest part of the basement and includes four types of rock: (1) moderate and high grade metamorphic rocks, (2) migmatites, (3) metamorphic intrusive rocks and gneiss, and (4) ultramafic rocks. The study of the petro-tectonics of metamorphism shows that there must be at least two cycles of magmatisation.

The gneissosity in the plagio-amphibolite, diorite, and anorthosite of the Kongdian series mostly strikes in an EW direction. However, in some exposures of the amphibolitic gneiss, two sets of schistosity are obvious. One is striking EW, the other N10^{o} E-N10^{o} W (NS). The area with schistosity striking NS is surrounded by rock massive, supporting the fact that the EW-oriented schistosity was formed earlier than the set of NS-oriented schistosity. The geological dating by Rb-Sr confirms this conclusion. The EW-oriented schistosity was, probably, associated with the metamorphism that took place from between 1.7 to 2.0 billion years ago and the NS-oriented schistosity was from between 1.04 to 1.15 billion years ago.

The Yanbian series is found in the area westwards from the Anninghe River and is composed of green schist, metamorphosed basalt, metamorphosed sandstone intruded by ultrabasic rocks, and local gneiss. The age during which metamorphism took place was determined as from between one to 1.1 billion years. The schistosity of green schists exposed near Yanbian County strikes N60^{o}-90^{o} E, forming isoclinal folds of a NEE-EW orientation. The schist that is distributed along the Yalongjiang River is formed by the N60^{o} -90^{o} E strike with cleavages of a N20^{o}-40^{o} W orientation. The schists and metamorphic sandstone exposed near Puwie strike in a N 80^{o} E-EW direction with superimposed cleavages of a N10^{o} E-N20^{o} W direction.

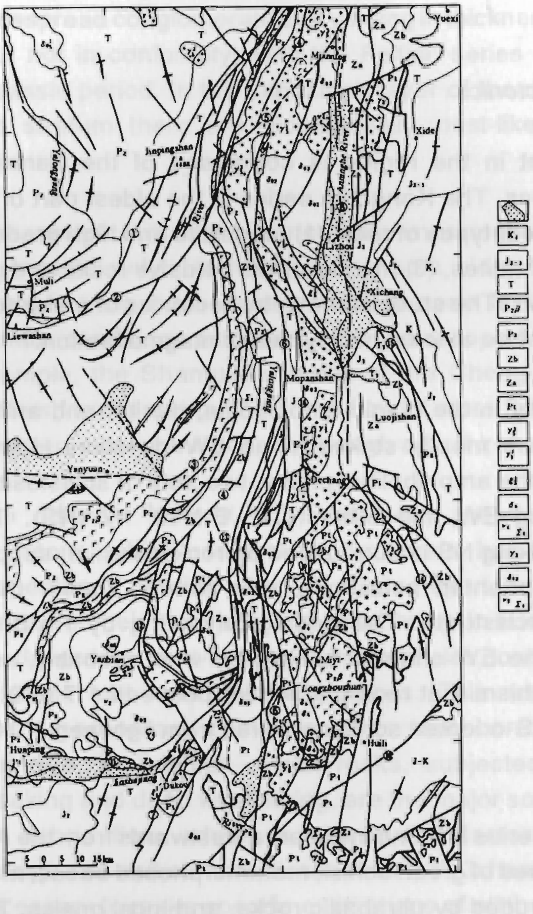


Fig.3: Sketch of Regional Geological Structure

(after Huang Dingcheng et al., 1990)

1. Sedimentary basic of Cenozoic era 2. Lower Cretaceous period 3. Middle and Upper Jurassic periods 4. Triassic period 5. Ermeishan basalt of Permian period 6. Palaeozoic era 7. Upper Sinian period 8. Lower Sinian period 9. Proterozoic era 10. Granite of Yanshan orogeny 11. Granite of Indo-Sinian orogeny 12. Syenite of Indosinian period 13. Diorite of Hercynian orogeny 14. Basic and ultrabasic rock of Hercynian orogeny 15. Granite of Caledonian orogeny 16. Basic and ultrabasic rock of Caledonina orogeny 17. Granodiorite of Jinning orogeny.

Therefore, the primary folding system includes schistosity and bedding, and the cleavage system was formed in a secondary folding cycle of 700 m.a.

The Huili series is distributed in the area east of the Anninghe River. It was formed during the middle Proterozoic period. The Huili series contains crystalline limestone, marble, and quartzite and has an EW strike. The minor folds and cleavages in the series are mainly oriented from N70^o -80^{o}E, superimposed by NS folds (local). In general, there are two sets of folding systems in the Precambrian basement. The EW set (N70^o-80^{o}E) is influenced by the tectonic system of the NS set (N20^{o}W-N10^{o}E). Therefore, the former was formed earlier than the latter.

Tectonics of the Cover System

The sedimentary cover in the region consists of upper Sinian sandstone, shale, and carbonatite; Proterozoic clastics and carbonates; and Mesozoic clastic deposits. The sedimentary facies and thickness of formations vary in Muli-Jinping, and in the Yanyuan area extremely thick marine deposits exist. The Mesozoic group in the Panxi area are continental red clastic deposits, and the thickness of the Paleozoic group is reduced, missing some layers locally. Along the Anninghe Fault zone, the thickness of the Paleozoic group is considerably large and the thickness of the Jurassic and Cretaceous systems is the largest in the region.

On the boundary between the Paleozoic groups and the Jurassic-Cretaceous strata, no angular disconformities were found within the whole region. Only locally, near some major regional faults, can disconformity of a small angle be observed. Therefore, the fold system in the sedimentary cover must have been formed during the Yanshan tectonic movement.

The dimension, type, and orientation of the fold system in sedimentary covers vary among different areas. The formation of the fold systems in the region was connected with deep-seated slip and cover sliding. The activity of the deep-seated faults caused the formation of folds of a higher order. For example, along the Jinhe-Qinghe Fault, the Paleozoic strata were strongly folded with angles dipping up to 45^o and overturned locally. The axes of the fold belts are usually parallel to the fault strike or at a small angle with the fault trend, showing a high compressional deformation.

The second order folds in the region were associated with rotation and differential movement of basement blocks. The echelon arrangement of folds and the arc-shaped folds within the Yanyuan Fault block belong to this tectonic type. The fold belt developed in the northwestern region belongs to the Indo-Sinian Orogeny with the fold axis striking NNE, showing the EW regional compression.

The Fault System in the Sedimentary Cover

The major fault systems constitute the tectonic framework and control the tectonic evolution of the region. The different sedimentary formations and volcanic rocks in different areas were also controlled by the major fault systems.

The interpretation of the landsat image shows five sets of linear structure (Figure 4), i.e., (1) NS (N10° W-N10° E), (2) NEE (N29°-30° E), (3) NE and arc-shaped (N40°-60° E), (4) (N30°-50° W), and (5) EW (N70° W or N70° E). The fractures of the NNE and NS sets are intersected by the fractures of the NW, NE, and NNE sets. The fractures of the EW set are intersected by those of other groups. The characteristics of the major tectonic fractures are given in the following passages.

A. Faults in the NS Set (N10° W-N15°E). In the region, some of the most significant faults, such as the Anninghe Fault, Longzhoushan Fault, Maoniushan-Xigeda Fault, and the Mupanshan Fault, belong to the NS set of fractures.

   The Anninghe Fault strikes NS-N15° E, dipping SE with an angle of from 70° to 80°. It consists of several parallel fractures. Along the fault belt, the Cenozoic Fault and geothermal activities are associated with the Fault. The Jurassic red sandstone was subjected to metamorphism and cleavage. The width of the influencing zone stretches for several kilometres and the mylonites in some localities are as thick as 200 to 300m. The Longzhoushan Fault is the southern extension of the Anninghe Fault. Emeishan basalt is exposed in the western area of the Fault. The thrusting of the Sinian system over the Cretaceous formation shows its compressive character. The Fault, in some areas, serves as the boundary of Mesozoic depressions.

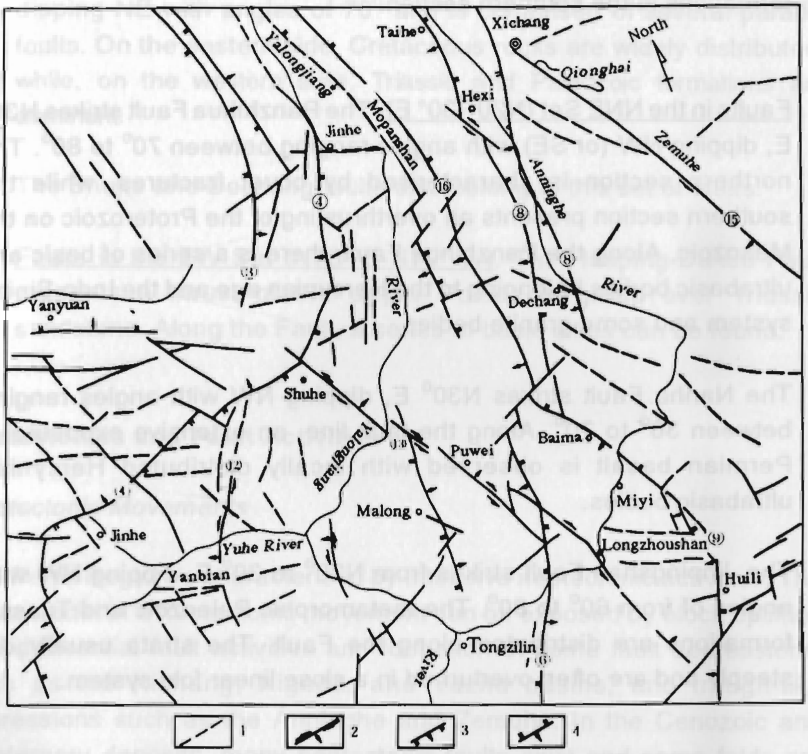


Fig. 4: Sketch of Regional Structure Lines Interpreted by the Image of LANDSAT (after Wang Tingling, unpublished material)

1. Lineament 2. Strike-slip Fault 3. Normal Fault 4. Thrust Fault.

The Maoniushan-Xigeda Fault strikes NS-N15° E, dipping NW (or SE) with angles of from 70° to 80°. Along the northern section of the Fault, some granite masses occurred and the Mesozoic clastic series was strongly folded. In the southern section, Proterozoic metamorphic rocks developed with occasional hot springs exposed on the fault line. A series of Cenozoic Fault depressions has developed along the Fault. The Muopanshan Fault strikes north-south, dipping westwards with angles of approximately 80°. Along the fault line, some diabase intrusions were found. The Fault intersected Jurassic rocks and igneous bodies in the northern section and upper Paleozoic formations in the southern section.

B. Faults in the NNE Set (N20°-30° E). The Panzhihua Fault strikes N30° E, dipping NW (or SE) with angles ranging between 70° to 80°. The northern section is characterised by cover fractures, while the southern section presents an overthrusting of the Proterozoic on the Mesozoic. Along the Panzhihua Fault, there is a series of basic and ultrabasic bodies belonging to the Hercynian age and the Indo-Sinian system and some granite bodies.

The Nanhe Fault strikes N30° E, dipping NW with angles ranging between 30° to 70°. Along the fault line, an extensive exposure of Permian basalt is observed with locally distributed Hercynian ultrabasic bodies.

The Jinpingshan Fault strikes from N20° to 30° E, dipping NW with angles of from 60° to 80°. The metamorphic Paleozoic and Triassic formations are distributed along the Fault. The strata usually dip steeply and are often overturned in a close linear fold system.

C. Arc-shaped Faults (NS-NE-NEE). The Jinhe-Qinghe Fault is one of the dominant arc-shaped faults in the region. Its northern section strikes NS, dipping W with angles of 60° to 80°. Along the Fault, the upper Sinian group is thrust over the Triassic system. The southern section strikes N60° E, dipping NW with angles of 40° to 60°. The Fault presents a thrust of the upper Sinian on the Paleozoic. Some hot springs are observed along the Fault.

The Houlongshan Fault strikes NS in its northern section and EW in its southern section. The area north of the Fault is composed of marine clastic deposits of the Triassic period and the southern area is composed of Permian basalt. The formation of the Yanyuan Basin was determined by the Fault.

The Xifengtian Fault strikes NS-N40° W and dips W-SW. The fault belt has several faults. The Proterozoic group is overthrust on to the Upper Sinian and on to the Paleozoic system.

D. Faults in the NW Set (N20°-50° W). The Zemuhe Fault strikes N30°W, dipping NE with angles of 70° and is comprised of several parallel faults. On the eastern side, Cretaceous rocks are widely distributed, while, on the western side, Triassic and Paleozoic formations are dominant.

The Shuhe and Dechang faults also belong to this set of faults.

E. Faults in the EW Set (N70° E-N70° W). The Huaping-Dukou Fault presents a thrust of the Upper Paleozoic group over Triassic sandstone. Along the Fault, a series of basic dikes can be found.

Neotectonics and Fault Activities

Neotectonic Movements

The Panxi Region is characterised by intensive neotectonic activities. The basic model of a neotectonic movement can be exposed by block uplifting with differential fault activities and formation of some fault depressions, such as the Xichang, Xigeda, and Yuzha basins, and trough-like depressions such as the Anninghe and Zemuhe. In the Cenozoic and Quaternary deposits, many neotectonic faults exist and some folds are occasionally observed in the Quaternary strata (Figure 5). A few porphyry dikes are found in the boundary area of the Yanyuan Fault depression. Contrasts can be observed between the geomorphologic landscapes of uplift plateaux and depressions. A series of hot springs occurs along active faults. Crustal deformation in the region is strong and has intensive seismicity. All these factors are unfavourable for regional engineering development.

Based on the characteristics of neotectonic movements, the studied region can be divided into three categories (Figure 6), i.e., (1) uplift area, (2) uplift with differential movement, and (3) fault depression.

In the uplift area the rate of movement ranges from one to 2.5mm/year, and the maximum rate of depression in the Anninghe trough is up to 4.5 mm/year. The average rate of differential movement in the region can be two to three millimetres per year. The above-mentioned figures show that the region belongs to the active neotectonics' category.

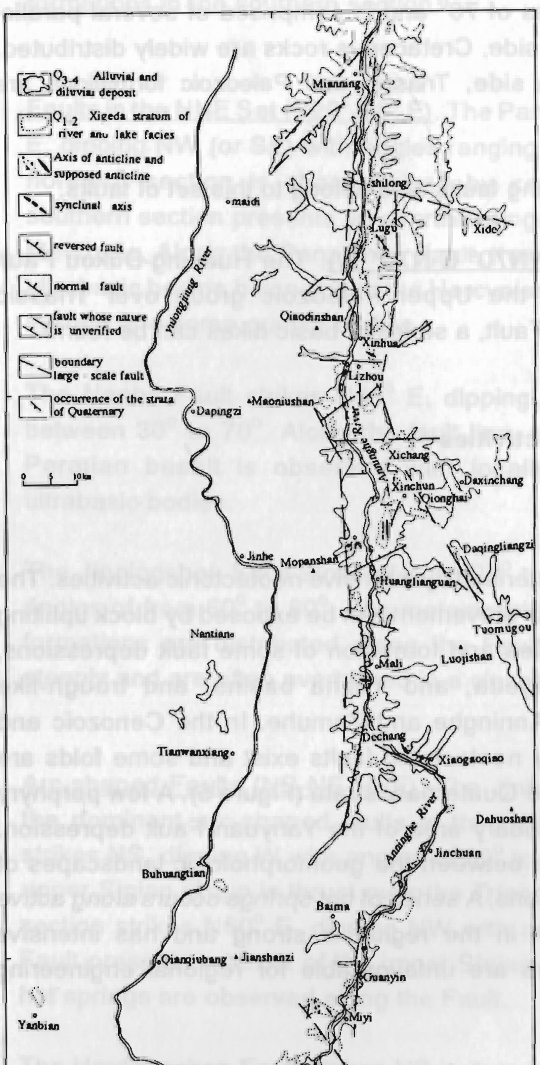


Fig. 5: Sketch of Quaternary Tectonic Deformation along the Anninghe River (after Xu Xuehen, 1988)

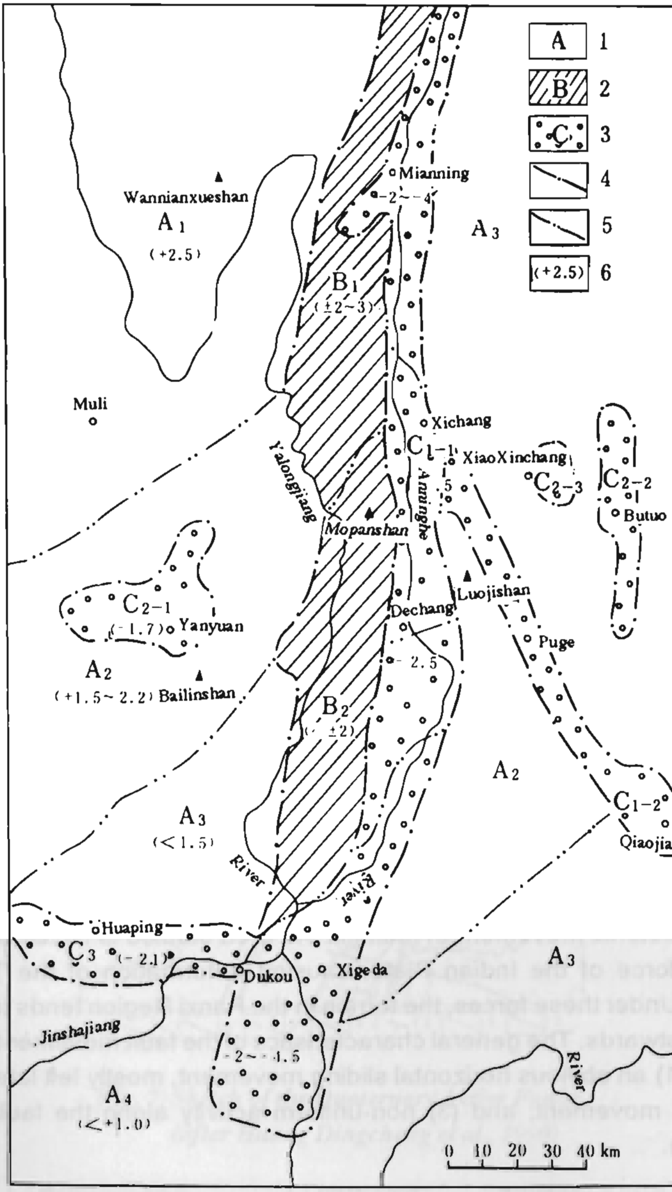


Fig. 6: Neotectonic Geomorphologic Zonation (after Xu Xuehan, 1988)

1. Mountain of uplift block 2. Mountain of block with differential movement 3. Trough and basin of subsiding block 4. Boundary of zone of order I 5. Boundary of zone of order II 6. Displacement rate mm/y, +uplift, -subsidence, +-differential movement

Fault Activity

Despite different mechanisms and origins, all active faults are the outcome of rapid deformation and the movement of the earth's crust, which is subject to slow deformation. The active faults have direct and objective evidence of recent crustal movement. A study of active faults is of great importance for both seismic prediction and the evaluation of seismic effects of faults. Because of the extremely active tectonism found in the Hengduan Mountains, many active faults have developed in the region to varying degrees. During site selection for any important engineering activities, the fault movements in the construction area should be evaluated. The damage of a building, even if it were well reinforced, would be unavoidable if it were located on an active fault or in its close vicinity. The construction of the Oburn Dam in California, U.S.A., had to be discontinued because of an active fault found under the foundation of the dam. For engineering development in active tectonic belts like the Hengduan Mountains, it is important to distinguish the active faults from the non-active ones, to determine the period over which they have been active, and to evaluate the speed of displacement. However, a fundamental study of neotectonics and Quaternary evolution in the region has to be undertaken first. Strictly speaking, active faults are those faults having continuous movement at the present time. From the aspect of consistency, the first step of the study should cover the whole system of Quaternary faults, and, on this basis, classification and gradation can be made through geo-dating and displacement measurements.

The neotectonic movement of faults in the area studied is dictated by the pushing force of the Indian Plate, causing deformation of the Tibetan Plateau. Under these forces, the terrain in the Panxi Region tends to move south-eastwards. The general characteristics of the fault movement are as follows: (1) an obvious horizontal sliding movement, mostly left lateral; (2) a vertical movement; and (3) non-uniform activity along the fault strike (Figure 7).

A. <u>The Anninghe Fault Zone</u>. The Anninghe Fault Zone is an old lithospheric fault formed in the Precambrian period and has a long history of repeated movement. The section north of Dechang County is the most active part at present. During the Quaternary period, a graben or fault depression was formed with a large amplitude of subsidence.

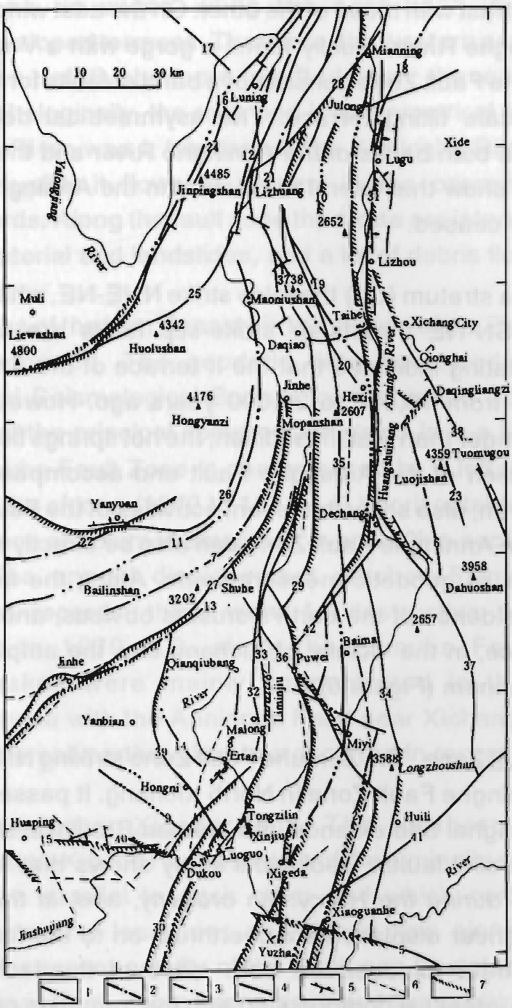


Fig. 7: Sketch of the Quaternary Active Faults
(after Huang Dingcheng et al., 1990)

1. Lithospheric Fault
2. Crustal Fault
3. Basement Fault
4. Sedimentary Cover Fault
5. Quaternary Fault
6. Conjecture Fault
7. Zone of Intensive Activity.

The fault trough is intersected by a series of faults striking northeast or eastwest, and the amount of subsidence appears to be different along the Anninghe Fault Zone. Xichang is the centre of the deepest subsidence (Figure 5). The topographic features of one fault wing strongly contrast with those of the other. On the east wing, the tributary of the Anninghe River usually forms a gorge with a V-shaped valley. The Anninghe Fault Zone consists of a band of faults forming a graben or an imbricate tilting terrace. The asymmetrical development of tributaries on both banks of the Anninghe River and the difference in its entrance show that lateral movement in the Anninghe Fault Zone has recently ceased.

In the Xigeda stratum (Q1) the folds strike NNE-NE, while in the strata of Q1-Q3, SN-NE thrusts or strike-slip faults are found. The C geological dating indicates that the II terrace of the Anninghe River was formed from 16,000 to 26,000 years ago. However, the faults must be younger than that. In addition, the hot springs flowing out from the intersection of the Anninghe Fault and accompanying faults at Xide, Hongyan, also show the recent activities of the Fault. The recent activity in the Anninghe Fault Zone can also be directly demonstrated on the basis of geodetic measurements. Along the fault zone, the vertical subsidence of the earth's crust is obvious, and at the centre of subsidence, in the vicinity of Xichang city, the amplitude is up to 90mm per annum (Figure 6).

B. Zemuhe Fault Zone. The Zemuhe Fault Zone striking NNW converges with the Anninghe Fault Zone in North Xichang. It passes southwards through Qionghai and extends into Yunnan Province. It consists of a series of parallel faults. Geological study shows that this fault zone was formed during the Hercynian orogeny, and, in the Indo-Sinian orogeny, a shear displacement overthrust on to the fault zone. The Cenozoic strata exposed on both sides of the fault zone were subjected to intensive compression with the formation of closed folds, tectonic lenses, and dense breakages. On the fault plane, inclined slickensides show its shear character. Hot springs occur along the fault zone. The Quaternary deposits subjected to neotectonic deformation were intensely faulted and folded as observed in Qionghai and Daqingliangzi.

Geomorphologically, a series of linearly arranged fault scarps and troughs is observed. Typical fault scarps of triangular forms are also found. The fault depressions of the Quaternary period are distributed along the Zemuhe River like a string of beads. The west bank of the

Zemuhe River is well-terraced and the river bed, located west of the fault zone, is wider, while the east bank is steep and has underdeveloped terraces. Therefore, the western part of the fault zone has been relatively more uplifted than the eastern one, and, geomorphologically, the river bed is asymmetrical in its section. The Zemuhe River was a tributary of the Anninghe River. As a result of tectonic uplift, it flows at present in the opposite direction, i.e., southwards. Along the fault zone the strata are intensively broken into loose material and landslides, and a lot of debris flows occur.

The tombs of the Han Dynasty in the vicinity of the Zemuhe Fault Zone were deformed. The geodetic data measured by the Sichuan Provincial Seismological Bureau for the period from 1958 to 1977 show that the principal compressive stress is in a NNE direction and the Zemuhe Fault Zone is characterised by a left lateral movement. The results of long (1272 to 1977 A.D.) horizontal levelling indicate a subsidence of 26mm in amplitude over a 40km section along the fault zone. The annual displacement reached 5.2mm. According to historical records, there were 14 destructive earthquakes from 111A.D. to 1979 A.D. along the Zemuhe Fault Zone. These earthquakes were mainly concentrated in the vicinity of its convergence with the Anninghe Fault near Xichang city. However, a series of small earthquakes has occurred in recent years.

C. The Maoniushan-Xigeda Fault. The northern section of the Maoniushan-Xigeda Fault consists of the Limingjiu and Manong faults, which are parallel to each other and which control the intensive development of landslides and debris flow along the Yalongjiang River. The recent activity of the Fault can be detected based on the Quaternary Fault depressions arranged like a string of beads along the Fault. The bottom of the Puwei Basin inclines westwards with a long and wide proluvial fan and a higher topographic level in the east than in the west, which has an accumulative deposit. The difference between the elevations of exposed Pliocene strata on the two sides of the Fault is up to 200m. All these are evidence of vertical movement. The geological dating of fault material by the thermal fluorescence method gives an age of (583)x10 years. The geodetic measurement indicates an obvious subsidence along the Fault. Hot springs can be observed in Yuzha and other places along the fault line. On 23 September, 1955, a strong shock (M=6.9) occurred at Yuzha where the Xigeda Fault is in convergence with the Ninghui Fault striking NE. In recent years, a series of small earthquakes and a swarm of microseismic activities has been concentrated in the southern section of the Xigeda Fault. All these indicate the high activity of the Fault.

D. The Panzhihua Fault. The activity of the Panzhihua Fault has been relatively weak in recent years. The accompanying Lugu Fault intersected the terraces of the Jinshajiang River and the underlying bedrock with a displacement of two metres. When determined by the thermal fluorescence method, the geological age of the fault material taken from the Lugu Fault is $(23811.8)\times10^{4}$ years.

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).

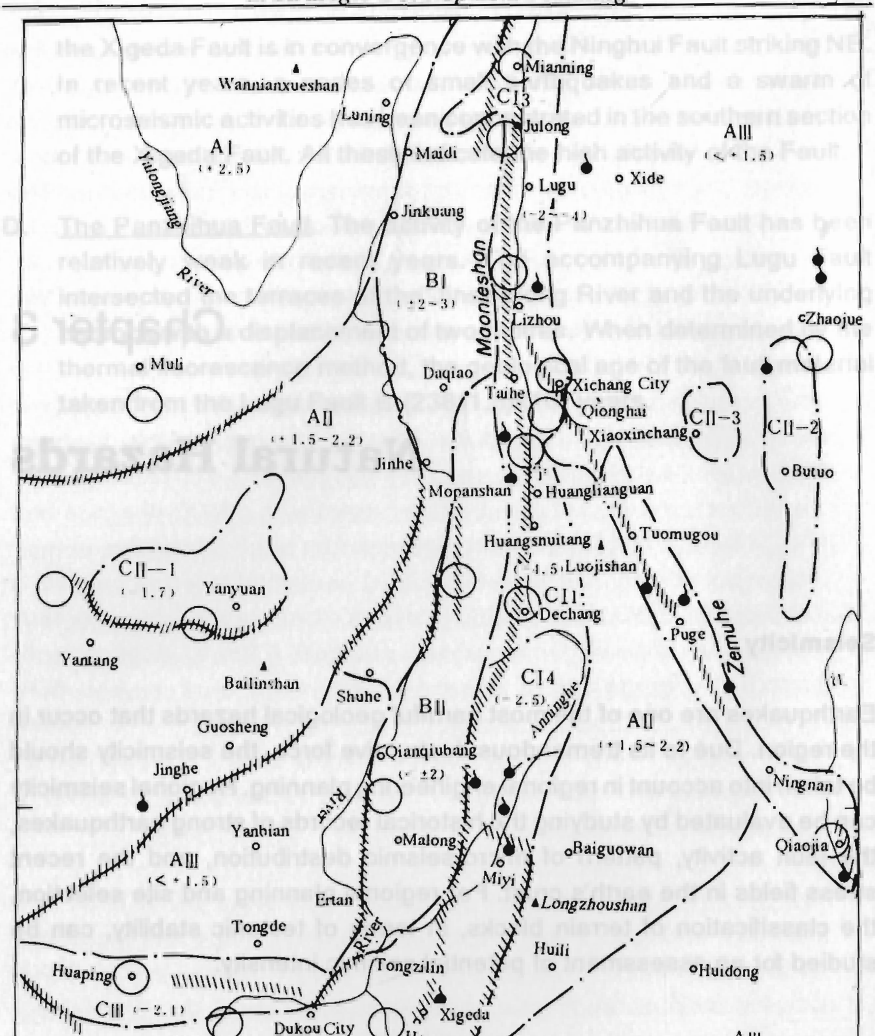


Fig. 8: Regional Neotectonic Zonation (after Xu Xuehen, 1988)

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. Seismically Stable Areas (I).

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. Seismically Sub-stable Areas (II).

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 $1.1x10^{20}$. Earthquakes within the area have a maximum magnitude of about five and the basic intensity lies between VII and VIII.

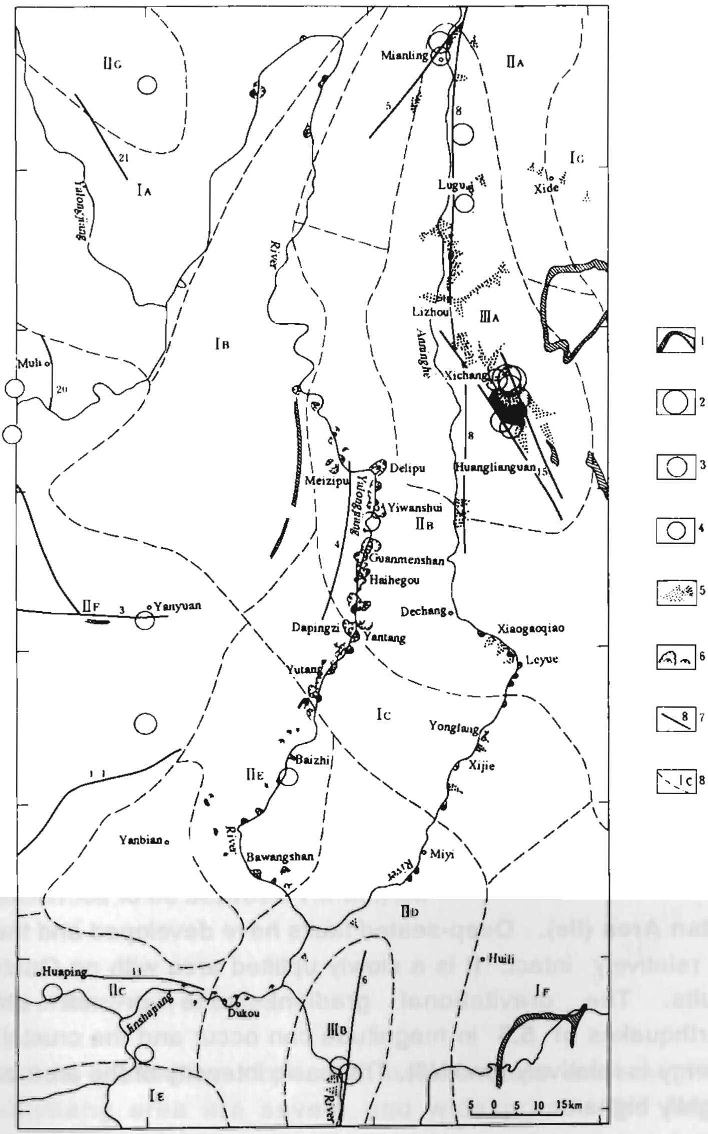


Fig. 9: Zonation on Regional Tectonic Stability and Natural Hazards (after Huang Dingcheng, 1990)

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°. 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.

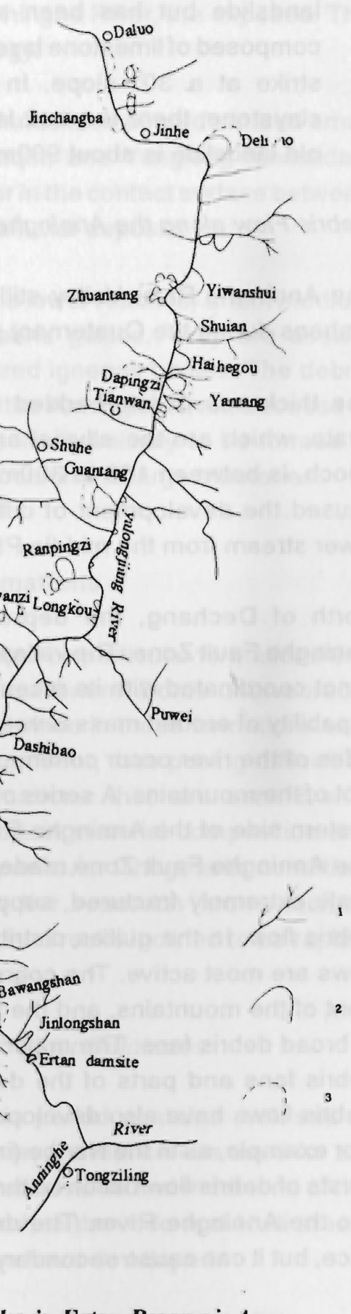


Fig. 10: Distribution of the Landslides in Ertan Reservoir Area

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° 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.

Chapter 4

Natural Resources

Mineral Resources

The research region is located at the southern end of the N-S Tectonic Zone which is well-known for its geological structures in the context of the tectonic and magmatic movements to which the area has been subjected. The geological study shows that a paleo-rift zone occurred in the region from the Paleozoic era to the Triassic period. The tectonic evolution of the paleo-rift provided favourable conditions for the formation of various metallic mineral deposits of magmatic origin (Lu Binguang et al. 1988) (Figure 11). Therefore, the region is one of the main bases for mineral resources in southwestern China. The principal types of mineral deposit discovered in the region are iron, copper, lead, zinc, nickel, tin, gold, and rare earth elements.

Iron Deposits

Iron deposits are among the richest deposits in the region. The main type of iron deposit is associated with vanado-titano-magnetite. The mines (Plate 6) are distributed along the deep-seated Anninghe Fault belt. The largest vanado-titano-magnetite mine now being exploited is located near the Panzhihua Metallurgic Company.

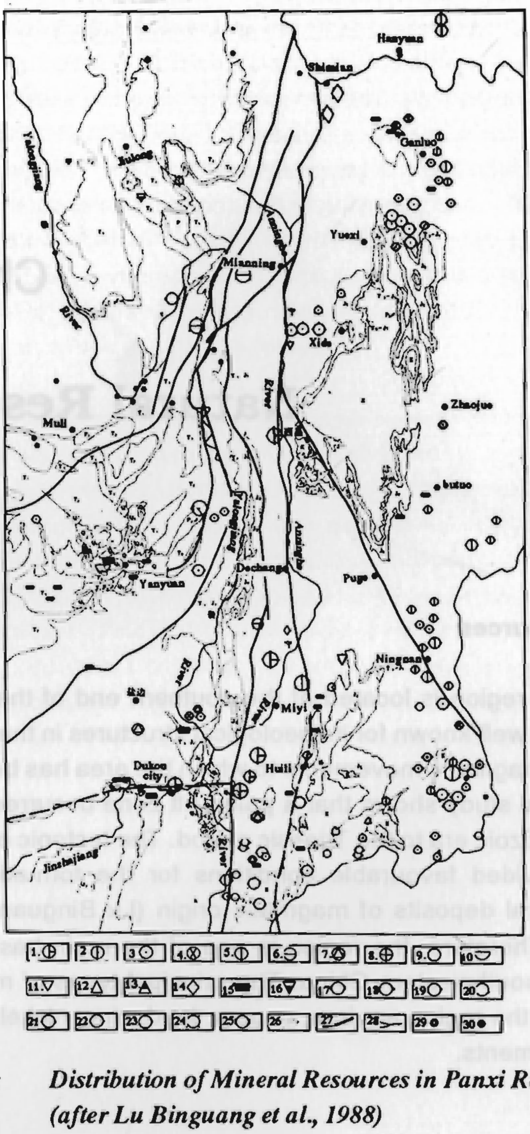


Fig. 11: ***Distribution of Mineral Resources in Panxi Region (after Lu Binguang et al., 1988)***

1. Vanadic titano-magnetic deposit 2. Manganese-cobalt deposit 3. Iron, containing iron ore deposit 4. Bauxite deposit 5. Lead-zinc deposit 6. Rare earth element deposit 7. Copper-nickel deposit 8. Gold deposit 9. Copper deposit 10. Halite salt deposit 11. Tin deposit 12. Sulpho-iron deposit 13. Tungsten deposit 14. Asbestos deposit 15. Coal deposit 16. Beryllium deposit 17. Sedimentary type 18. Sedimentary and metamorphic type 19. Volcanic rock type 20. Hydro- thermal type 21. Silica rock type 22. Eluvial type 23. Magma condensation type 24. Sandstone silt type 25. Magma differential condensation type 26. Sedimentary strata 27. Regional fault 28. River 29. County town 30. City

The ore-containing body is a basic and ultrabasic complex composed of gabbro-diorite. The ore deposit formation is considered to be a late differentiation of magma. The ore-containing body intruded into the Denying limestone of the Sinian system in monoclinal layers and beds. The ore layers or lenses are 50 to 100m thick, and the main mineral composition of the ore is titano-magnetite with 25 to 30 per cent of iron. The associated elements are titanium, vanadium, chromium, cobalt, nickel, copper, manganese, sulphur, and platinum. Resources such as vanadic oxide, titanic oxide, and metallic cobalt were perhaps explored first of all here. There are large-scale deposits of metallic nickel, copper, and chromium oxide.

In addition to vanado-titano-magnetite, there is a large number of iron deposits of other origins, such as hydro-thermal and contact metamorphism. The iron mines of Tiekuangshan and Lugu are located on the outer contact between the granite massive and the Precambrian metamorphic strata. The ore is mainly composed of magnetite with rich iron content. The ore body is associated with veins of metallic sulphide which mainly consist of tin ore. The content of the latter reaches 0.579 to 0.7 per cent.

The iron ore deposits in Huili and Yanyuan counties were formed in connection with the hydro-thermal processes of volcanism. The iron content is quite high in deposits of such origin. Some iron deposits are associated with basic magmatism during metasomatic processes.

The iron deposits in the Manyinggou Mine were caused by regional metamorphism. The ore bodies exist in the lower part of the Shuanshuijin series of the Precambrian group of hematite and limestone. The average content of iron in the ore reaches 52 to 62 per cent. Iron deposits of this type are found in many areas of the region, for example, Xichang, Huidong, and Huili.

Copper Deposits

Copper deposits are found in the region; the salient characteristics are given below.

A. Lalachang Mine in Huili County. The Lalachang copper mine is large. The ore bodies are associated with the metamorphic volcanic strata of the Huili system of the Precambrian group. The length of ore strata controlled by fractures and layers stretches from several hundred to a thousand metres; showing stability of the ore-containing body. The total thickness of the ore bodies reaches more than 80m. The ore contains contaminated or laminated copper masses, associated with molybdenite. The copper content on average is 0.88 per cent. Besides copper, there are several other components, such as Au, Ag, and Ni.

B. Liwu and Tongan Copper Mines. These two mines are a result of hydro-thermal enrichment in metasedimentary rocks. Deposits of this type have prospects for further exploration.

C. Datongchang Copper Mine. The Datongchang copper deposits with ore bodies in the Cretaceous sandstone and conglomerate are of sedimentary origin. There are six ore layers in the mine, including 13 ore blocks in lengths of up to 2,000m and thicknesses of from 1.86 to 5.43m. The copper content ranges from one to 2.13 per cent with associated elements such as Ag, Se, and Au. The basins of Cretaceous sediment in the region may well contain this type of copper deposit.

Other Metallic Deposits

The geological formations in the region are rich in mineral deposits of many metallic elements such as lead-zinc, copper-nickel, tin, gold deposits, and deposits of rare earth elements.

A. Lead-Zinc Deposits. The Dalianzi Mine in Huidong County and the Tianbaoshan Mine (Plate 7) in Huili County are the main lead-zinc deposits of hydro-thermal origin in the region. The metal content is high. Some rare and dispersed elements are associated with lead-zinc ore. Among them are Cd, Ag, and Ce.

B. Copper-Nickel Deposits. Copper-nickel deposits are found in southern Huili County. The largest one is the Tongmahe copper-nickel mine. The deposits were formed in the late magmatic stage. The intrusion of basic and ultrabasic magma containing nickel was controlled by the faults striking from north to south. The ore bodies occur at the bottom of the intrusive mass and on outer contact with altered limestone. In addition to copper and nickel, the ore contains dispersed components of cobalt.

C. Lead Deposits. The lead deposits found in the region are mainly of contact-metasomatic and hydrothermal origin, for example, Zhahe Mine in northern Huili County. The ore body occurs in the skarn on the outer edge between granite massive and limestone of the Pre-cambrian Tianbaoshan group. The content of tin in the ore is high and is found in association with tungsten, beryllium, copper, and bismuth.

D. Gold Deposits. Gold deposits are distributed widely throughout the region. Gold placers are found in the Yalongjiang and Jinshajiang river valleys. In the Wali district of Yanyuan County, a gold nugget weighing 2,560g was found. Vein gold deposits are found in Mianning County.

E. Rare Elements and Rare Earth Elements. Mineral deposits of rare elements, rare earth elements, and dispersed elements are found in several districts in the region. Beicao and Lugu districts of Huili County are prospective mining areas for pegmatite and albite which are found sandwiched between basic and ultrabasic rocks and syenite and granite dykes. The ore bodies mainly contain Nb and Ta, associated with Zr and Bi. The contents of these elements are high and can be extracted for industrial use.

Deposits in the Deyizite district are composed of placer yttrium of deluvial and alluvial origin. The country rocks are granites with relevant minerals. The associated mineral is zircon.

The deposits in the Mulo and Sanchaohe districts of Mianning County are composed of light rare earth minerals of hydro-thermal metasomatic origin. The ore bodies are located in marble or diabase at the outer contact with granite massives. Sometimes deposits are in the form of vein nets. Since the deposits are spread over a large area, this district has prospects for mining light, rare earth elements.

Non-metallic Deposits

The region is rich in coal resources. There are several coal mines in the Panzhihua, Ertan, and Yimen districts. The largest one is Baoding Coal

Mine (Plate 8) located near Panzhihua city. The coal seams are found in the Baoding series of the Triassic system. The total thickness of the coal series reaches 1,800m with 111 coal seams with a total thickness of 60.25m. The structure of coal seams is simple and stable, with a low content of mud, sulphur, and phosphor. The coal can be used for production of coke in steel metallurgy. Rock salt deposits are rich in the Yanyuan Basin with its thick Triassic system which contains salt seams.

Land Resources

The research region is located on the south-eastern boundary of the Tibetan Plateau and on the northern border of the Yunnan Plateau. The geomorphology of the region is characterised by higher and middle mountains with deep valleys. The typical plateau monsoon is predominant with distinct dry and wet seasons.

The landscape and agricultural production as well are affected by vertical differentiation. In general, three different types of landscape and agricultural land use can be classified, ranging from deep valleys to mountains.

A. *Areas Having Elevations of Less than 1,300masl*

A southern subtropical climate prevails in these low elevation areas. The climate is typical of deep valleys. The annual average temperature ranges from 19.5°C to 20.5°C. The accumulated temperature of 10°C is as high as 6,500 to 7,500°C. The annual precipitation ranges from 800 to 1,000mm.

The main vegetation consists of grassy slopes with sparse woods and thick bushes (Plates 9). The valley slopes are covered by reddish soil which is typical of mountain areas. There are three harvests a year. Rice (Plate 10) is harvested twice. Sugarcane (Plate 11) and tropical plants can be cultivated. Temperate vegetables (Plate 12) and temperate and subtropical fruits (Plates 13 to 16) are grown.

B. *Areas Having Elevations Ranging from 1,300 to 2,200masl*

The areas with elevations of from 1,300 to 2,200m range from high mountain slopes to middle mountain plateaux. The climate is warm and subhumid and typical of middle subtropical zones. The average annual temperature is from 13.5 to 19.5°C. The accumulated temperature of 10°C is 4,500 to 6,500°C. Occasionally, frost appears in winter. Annual precipitation is from 800 to 1,000mm. The vegetation consists mainly of mixed pine with oak and Yunnan pine as well. The soil is red. There are two harvests a year. Vegetables suitable for cool climates and temperate fruits can be cultivated.

C. *Areas Having Elevations Higher than 2,200masl*

There are high mountain slopes in these areas where northern subtropical and temperate humid climates are prevalent. The annual average temperature is 9.5 to 13.5°C. The accumulated temperature of 10°C is as low as 2,500 to 4,500°C. The frost period is relatively long. The annual precipitation reaches 1,000 to 1,400mm. The vegetation consists mainly of green wide-leaved oak, i.e., evergreen chinquapine and mixed pine and oak. The natural slopes are covered by yellow-brown soil. There is one harvest a year. The crops are usually dryland grains rather than wheat and rice.

Land use in the region is controlled by the geomorphological and climatic conditions and can be classified into 10 types, i.e., farmlands, vegetable gardens, forests, grasslands, urban and rural towns, mining and industrial areas, land for transportation, water surfaces, and land for other uses.

The distribution of different types of land use and land combinations is uniform and depends on the land characteristics of the region.

(1) The Broad Valley and Inter-Montane Basin Area. The broad valleys of the Jinshajiang, Yalongjiang, and Anninghe rivers and some of the inter-montane basin and lake areas come under this landform category. The valley beds, basins, and terraces are usually composed of alluvial sediments which provide thick and fertile soils. The slopes are gentle and farmland is concentrated in this area. The population density is also relatively high and the most important agricultural land is located in this area. Irrigated rice fields and sugarcane are cultivated on the low terraces, while vegetables and southern tropical fruits grow on high terraces and hill slopes. Towns and industrial lands are situated on the high

terraces and in the hills along the Jinshajiang and Anninghe rivers.

(2) The Narrow Valley and Canyon Area. The area of narrow valleys and the canyons of the Jinshajiang, Yalongjiang, and Anning rivers are characterised by steep slopes and intensive erosion. The soil in this area is very thin. The grass slopes are usually covered by sparse woods and thick bushes. Exposed deluvial and proluvial sands and rock fragments from rockfalls and landslides are often found on the river banks. Therefore, it is difficult to use the land in this area.

(3) The Hilly Land Near the River Valley Area. The hilly land area is usually located near broad valleys and is characterised by grass slopes and mountain rice fields. The forest cover is sparse and the slopes are mostly covered by bushes, sparse wood, and middle hill forests. Usually the southern slopes are covered with woodlands and the northern slopes with grasslands. Farmland is sparse and consists of gentle slopes and terraced land. The irrigated rice land areas are usually hot in winter and productivity is low. There is limited cultivation of tea, fruit, and shellac.

(4) The Middle Mountain and Continental Plateau Area. The middle mountain and continental plateau area on high elevations is located far from the river valleys. The climate is cool and wet. The most important forest is located in this area. The plantations are well preserved and forest cover is dense. The vegetation mainly consists of mixed pine with oak, broad-leaved, and coniferous trees. Farmlands are usually on steep slopes (25^0) and on marginal land.

(5) The High Mountain Area. The high mountain area is unsuitable for forestry and agriculture. Most parts of the area are waste, mountainous land covered with snow and ice or exposed rocks.

Water Resources

Water resources are plentiful in this area. The average runoff into the rivers is 622mm and the total annual amount of water is $1.7262 \times 10^{11} m^3$, of which

$3.3688 \times 10^{10} m^3$ is obtained from this area and $1.3674 \times 10^{11} m^3$ from outside.

The area is very rich in hydropower resources. The Jinshajiang and Yalongjiang rivers flow rapidly over precipitous terrain and thus are sources of abundant hydropower resources. In this area, the mainstream of the Yalongjiang River has a natural drop of 1,290m and the Jinshajiang River, 667m. The precipitation of their branches ranges from 500 to 2,000m. The hydropower storage in this area reaches 3.69678×10^7kW, of which 3.10248×10^7 kW can be exploited giving an electrical capacity of 1.80694×10^{11} kW-hour/year. The hydropower which can be exploited per square kilometre in this area totals 2.8×10^6 kW-hours/year.

The advantages of the exploitation of hydropower resources in this area are little submergence loss, little investment, advantageous dynamic indexes, and coordinative distribution with large-scale mines and smelting bases which can meet not only the national, large-scale strategic energy needs but also medium and small-scale energy needs for development of the local economy. At present, the energy resources have not been exploited and therefore prospects are quite substantial. The mainstreams have not been exploited and their branches have been under-utilised. For example, only 1.2 per cent of the hydropower potential of the branches of the Jinshajiang River has been exploited. The Yalongjiang accounts for only 0.4 per cent. Hydropower stations in this area not only supply electricity to Sichuan Province but also actively contribute to the development of energy resources in southwest China and the country as a whole.

Chapter 5

Outlines of Strategic Development Planning

Strategic Development Goals

In determining the strategic goals of a region, their importance to national economic development should be taken into account, and the national conditions and resources should also be considered. The region has sufficient social and economic potential to make the goals feasible. The development and reconstruction of the area will play an important role in the economic development of the upper reaches of the Yangtze River and of southwestern China. Because of its rich mineral and energy resources, the establishment of mines and hydropower stations will favourably readjust the structure and distribution of steel and energy resources in southwestern China. Moreover, the rich energy resources are an advantage in developing heavy industries. Therefore, the development of the region is also an important component in the development strategy of the southwestern area.

Since it is a region with minority nationalities and the social economy and culture are less developed than in other areas, proper use of resources, construction of industries, and economic development help in the social development of the area. Therefore, the development of this region must be in accordance with strategic planning and with the regional development requirements of southwestern China. It should not only guarantee economic self-reliance but also make full use of the local resources, in order to set up a strong mining-metallurgical and energy resource system and form an important base which can support and ensure the development of southwestern China.

Socioeconomic Planning

Any strategic programme should be based on the resource characteristics and economic situation of the region. One important guideline is to make full use of the local resources of the area and to consider the support and cooperation provided by neighbouring areas to regional development.

The main characteristics of the study region are its rich resources, i.e., an abundant energy supply and forest and land resources. Basically, a strategic programme should make full use of these resources to promote the all-round development of the economy. At the same time, it should also take into account the support facilities that must be set up for the full use of resources, aiming at effective coordination of the principal strategic tasks. Primarily, a strategic programme in the area should coordinate exploitation of mineral resources; power supplies; agriculture and forestry; traffic and the environment; and the social, economic, scientific, technological, cultural, and educational development goals should be handled correctly. The main strategy should focus on the exploitation of resources and on comparison of different resources, i.e., minerals, energy, agriculture, and forest resources, so as to determine the dominant development sectors.

Agricultural and forest resources in the region are limited. Because of the rugged topography and deeply cut valleys, only some wide valley sections of the Anninghe and Jinshanjiang rivers and some smaller basins can be used for agricultural purposes. For this reason, agricultural development may be unable to bring about the all-round development of the economy in the region and ensure that it occupies a position of strategic importance in southwestern China. Similarly, although rich in woodland, it is only a potential resource. Furthermore, tree plantation is necessary. Hence, forestry does not play a dominant role in the region's economic development.

Minerals are the most important resource in the region because of their wide variety and abundant reserves. The efficient exploitation of mineral resources can promote the development of metallurgical and raw material industries, further develop processing industries, and result in the formation of an industrial base in the southwest. Moreover, rich coal and hydropower resources provide favourable conditions for mineral exploitation. In the context of a development strategy for the regional economy, exploitation of mineral resources should be chosen as the primary target in order to integrate industrial, agricultural, social, and economic development.

The exploitation of mineral resources will lead eventually to the formation of an industrial base for mining-metallurgical industries, raw materials, and heavy industries. The development of an energy base is possible through the exploitation and use of minerals and the abundant electricity derived from hydropower can be supplied to neighbouring areas, including Sichuan Province and the Yangtze River Valley, to increase the capacity of the electricity corporation of southwestern China or even of the whole nation. Development of hydropower resources can strengthen the economy and enhance the strategic importance of the region.

Agriculture plays a key role in the regional economy. Agricultural land resources are limited, but the development of agriculture is necessary for the successful growth of the mining-metallurgical industries. Transportation is difficult because of the rugged topography, and sufficient farm products cannot be obtained from neighbouring areas easily. Therefore, agriculture and forestry should be developed in the area so as to ensure self-sufficiency, provide raw materials for light and processing industries, and increase export to neighbouring areas.

As stated above, the exploitation of mineral resources, the growth of energy resources, and the development of agriculture and forestry constitute the framework of the regional economic strategy. However, for the steady and continual growth of an economic system, socioeconomic growth and the exploitation of secondary resources, such as light-chemical and building-material industries, must be taken into account. Such resources are limited. A support system consisting of transport; urban construction; environmental harnessing; engineering; and scientific, cultural, and educational undertakings should be developed.

Production Programme

In the second stage of the strategic programme, the dominant fields in each secondary development system should be taken into consideration for growing industries which are gaining in economic prominence. When deciding upon the leading industries, their potential, development feasibility and the role they play should also be considered.

The prominence of minerals is a result of the complex geologic structure and strong magmatic activities which led to the formation of the Panxi Paleo-rift metallogenic zone. A great variety of minerals has been found and these minerals are widely distributed throughout the region. However, they vary in significance and exploitation possibilities. In the context of a strategic programme, it is necessary to select minerals with potential for exploitation and give them investment priority.

Vanado-titano-magnetite is the most remarkable mineral. Its total reserves amount to ten billion tonnes. The iron reserves are the second largest in China and the vanadium and titanium reserves are the largest in the world. There are other associated minerals such as nickel, cobalt, copper, cadmium, and scandium. For this reason, the comprehensive use of vanado-titano-magnetite, including in mining, ore dressing, and smelting, as well as in steel material processing and related industrial fields, should be considered the most important objective in the regional programme.

The area is also considerably rich in non-ferrous metallic ores such as lead, zinc, and copper. Three large lead-zinc deposits, belonging to one of the major lead-zinc metallogenic zones of China, are distributed in the area near Huili and Huidong, and their total reserves amount to several million tonnes. There are large copper deposits with reserves amounting to one million tonnes. In the lead-zinc copper deposits, there are some paragenetic components of gold, cobalt, silver, and molybdenum, etc. The rare-earth deposit here is the only large-scale one in Sichuan Province, and its reserve of heavier rare-earth elements reach several million tonnes, of which the cadmium resource is the most plentiful in China.

There are more than twenty types of non-metallic deposit in the area. Among them, salt deposits and building materials have great potential for future use. In the context of a strategic programme, halo-chemical and building material industries can be developed as secondary link industries. The salt, halo-chemical industry, and some special raw materials can contribute to the region's economic development.

Hydropower resources in the area reach four million MW and the remaining potential amount is approximately three million MW. Exploitation of the plentiful hydropower resources should be given top priority. The generation of hydropower could meet not only the industrial and agricultural needs of the region but also partially meet the requirements of other areas. This will increase the capacity of the grid network in southwestern China and even throughout the whole nation.

Coal is another energy resource in this region. In spite of limited reserves, coal is valuable because the coal field is close to the vanado-titano magnetite deposits. For the purposes of power supply and cooking fuel, coal mining should be developed. If coal supplies are inadequate in the locality, they should be imported from the neighbouring Province of Guizhou. Vanado-titano-magnetite deposits should be mined to develop the coal industry.

The area is comparatively rich in land resources, especially land for forestry and animal husbandry. However, because of geographical constraints it is impossible to obtain more arable land. The comprehensive development of farming and forestry should be promoted, i.e., developing forestry and animal husbandry on the basis of sufficient production of grain crops and farming products. When food reserves are sufficient in the area the exploitation of minerals and power potentials of the region will ensue. The vast areas of grazing land and fine grass are conducive to the development of animal husbandry which will help to improve agricultural capabilities. Agriculture should be integrated with industry which is crucial for the development of the mining and metallurgical industries.

To ensure the achievement of strategic goals, support and link industries should be developed, for example, building materials, coal, agriculture, forestry, and animal husbandry. In addition, the most important task is to provide power and develop the transportation network. The exploitation of hydropower resources is considered to be one of the main tasks in the development strategy and it can ensure the development of the area. Transportation is not sufficiently developed in the region, therefore, the construction of highways is absolutely necessary. However, from a long-term point of view, building railway lines to outside areas is also an important task. Moreover, development of air transportation will promote trade in domestic and overseas' products and consequently promote socioeconomic development. Since transportation facilities are inadequate, traffic engineering will be an important problem for regional development.

Urban expansion is the inevitable result of industrial and agricultural development. With the growth of the mining and metallurgical industries, the residential areas around mines or large-scale industrial enterprises will expand and the markets, administrative departments, cultural and educational facilities, and service trades will also develop. There is already an urban system with two municipalities and several counties. It is easier to make programmes for further development on the basis of existing residential centres and city/town facilities. Panzhihua, located on the banks of the narrow Jinshajiang River Valley, has a limited capacity for further expansion. Some new industrial cities have to be built, along with the establishment of a new mining and metallurgical base for utilisation of vanado-titano-magnetite deposits, in order to reduce the population pressure on existing cities.

Environmental conservation is extremely important for regional development. Effective measures should be taken to preserve the fragile, natural environment and to avoid frequent disasters. Environmental management is a key factor in the steady development of the regional economy and society. The main areas of focus are agriculture, industry, and disaster-prone zones. In the wide valley area of the Anninghe River and some intermontane basins, programmes for environmental conservation and disaster prevention and mitigation should be carried out along with industrial and agricultural programmes.

Because of socioeconomic, cultural, and educational backwardness, resources cannot be properly used to promote economic prosperity. Therefore, industrial and agricultural plans should be integrated into cultural, educational, and scientific programmes. Education should be strengthened, especially in primary, middle, and polytechnical schools. Training of local talent is an important measure to ensure that the goals are achieved. Along with the development of industry and agriculture and the construction of cities and towns, science, technology, and higher education should also be developed.

Project Programme

On the basis of the analysis of the two stages mentioned above, the third stage, the project programme can be formulated.

To increase the effective use of iron deposits and to establish ferrous metallurgical industries, it is necessary to enlarge the Panzhihua steel base and vanado-titanio industrial facilities. At the same time, the second phase construction of the Baima, Taihe, and Hongge mines should commence in order to form a mining and metallurgical industries, base for vanado-titano-magnetite around the Panzhihua Steel Plant.

The Ertan Hydropower Station is focal to the development of energy resources in the region. Consequently, the regulating projects of Jinping and Tongzilin along the Yalongjiang River should be established, preparing for the final stages of the Jinshanjiang River scheme as a means to establishing a hydropower base at Ertan.

The objective of industrial development in the region is to exploit non-ferrous metal resources, including zinc, lead, and copper. Some mines are in a favourable situation and can be developed right away (Lalachang Copper Mine and Tianbaoshan Lead-Zinc Mine in Huili and Daliangzi Lead-Zinc Mine in Huidong). To use these resources and develop the area's mining-metallurgical base for non-ferrous metals, the foremost task is to accelerate the construction of smelteries.

Another industrial objective is salt mining to ensure regular salt supplies and to build up facilities for chloro-alkali products. At the same time, it is necessary to use local funds to develop building material industries and light industrial products, e.g., to build cement factories in Jinjiang, Miyi, and Dechang.

To guarantee the efficient construction and operation of major industrial projects, it is necessary to speed up the construction of a series of associated industries, e.g., such as extending the Baoding Coal Mine, electrifying the Cheng-Kun Railway, and building highways and mountain highways. The following medium and small cities should be developed - Panzhihua, Xichang, Dechang, Huili, Yanyuan, Zhaojue, and Huidong. Cultural, educational, and scientific research in the area should be promoted through the development of the urban system and the major mining and metallurgical enterprises. In environmental management, the first priority should be given to the Anninghe River and Panzhihua, and, at the same time, environmental conservation and disaster prevention programmes should be implemented in other cities.

Territorial Economic Complexes

Recognition of objective and equitable distribution of productive forces and determination of proper principles are important preconditions for national planning. Regional distribution of environmental and natural resources is a prerequisite to productive construction, and it is important to ensure that each region has the best possible combination of activities. Establishing an economic network that focusses on the end product and which is supported by relevant associated industries should be the emphasis of an overall planning strategy.

In different districts of a zone, production priorities should be set in order to promote regional economic development through exploitation of local resources and key industries. Economic development should be promoted throughout the region, taking the distribution of resources and the prevalent economic conditions into consideration. First, the Cheng-Kun Railway and the economic zone along the Anninghe River should be used to promote the overall development of the regional economy.

According to the key objective of the strategic programme for the Panxi Region, the territory is divided into five economic complexes in accordance with the distribution of key industries and the natural conditions and resources of different regions (Figure 12).

The Panzhihua District Economic Complex (I)

The Panzhihua district economic complex is located in the south in the zone intersecting the Anninghe, Yalongjiang, and Jinshajiang rivers. The administrative range includes Panzhihua City, Miyi County, and Yanbian County with an area of 7,514 sq.km. (11.3% of the Panxi Region) and a population of 830,000 (20% of the Panxi Region). The total industrial and agricultural output is 55 per cent of the regional output. The mineral resources are rich in this zone. In addition, the hydrothermal conditions are excellent. Transport is convenient because the Cheng-Kun Railway crosses the district, the Panzhihua Railway branches off here, and, in the future, the Jinshajing can be used for shipping. Panzhihua City and Panzhihua Steel Base are important support industries for the exploitation of local resources. The Panzhihua Steel Mine, the Baima and Hingge mines, the Baodien Coal Mine, the Ertan Hydropower Station, and the Panzhihua Power Station are the major industries for developing steel, electric power, coal, and non-ferrous metallurgical industries. The use of vanadium and titanium in the production of alloys, as well as the relevant soda chemical, phosphorous, building materials, mechanical, and sugar industries, should be developed concomitantly.

The Anninghe River Valley in Miyi County is the principal agricultural base for the production of rice, sugarcane, vegetables, and subtropical fruits. Panzhihua City is a medium-sized city with quite a high level of culture, education, and scientific development as well as a fairly well-developed commercial system that can help to promote the development of Miyi and Yanbian counties.

The Xichang District Economic Complex (II)

Xichang district is located in the north of Xichang area, which includes Xichang City, Dechang City, and southern Mianning County, with an area of more than 8,000 sq.km. (12.5% of the regional area) and a population of more than 800,000 (19% of the regional population). The industrial and agricultural outputs of this district

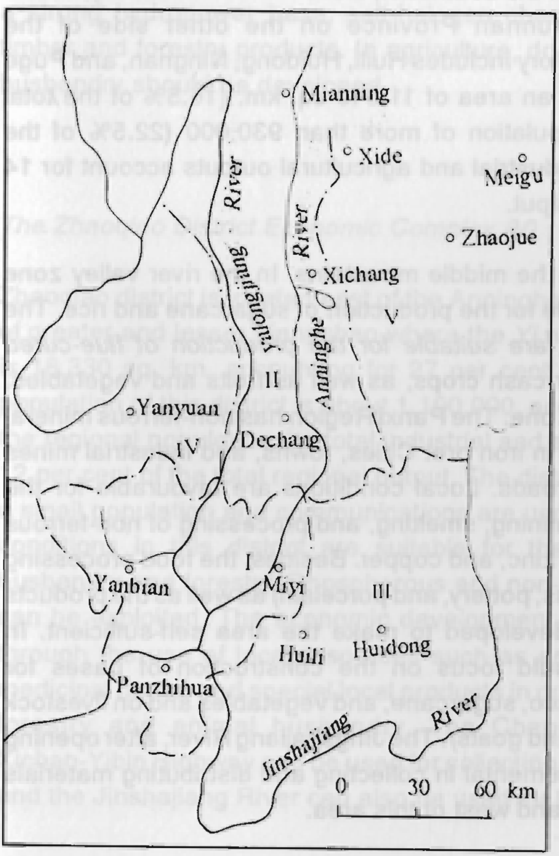


Fig. 12: Planning of an Integrated Economic Complex

constitute 13 per cent of the output of the Panxi Region. This district lies near the middle and upstream area of the Anninghe River, where the climate is moderate and rainfall plentiful, and has a wide river valley which is suitable for agriculture. The Cheng-Kun Railway crossing from north to south, together with criss-crossing highways, is an important link connecting the eastern and western areas of this district. The economic complex should aim at agricultural development to increase the production of grain, oil, pork, and vegetables and to develop a major agricultural base. At the same time, local conditions are favourable for timber processing, food, plastics, and light industrial products for daily use. In this district, both the Taihe and Baima mines could be developed as the second steel base in the region.

The Huili-Huidong District Economic Complex (III)

Huili-Huidong district lies in the southeast, close to Panzhihua City, and in the neighbourhood of Yunnan Province on the other side of the Jingshajiang River. Its territory includes Huili, Huidong, Ningnan, and Puge counties. This district has an area of 11,040 sq. km. (16.5% of the total regional area), with a population of more than 930,000 (22.5% of the regional population). Its industrial and agricultural outputs account for 14 per cent of the regional output.

The district falls mainly in the middle mountains. In the river valley zone the warm climate is suitable for the production of sugarcane and rice. The hilly zones of this district are suitable for the production of flue-cured tobacco, maize, and other cash crops, as well as fruits and vegetables. This district is an important one. The Panxi Region has non-ferrous mineral resources and is also rich in iron ore. Cities, towns, and industrial mines are mainly linked by hill roads. Local conditions are favourable for the construction of bases for mining, smelting, and processing of non-ferrous metals such as aluminum, zinc, and copper. Besides, the food processing industries (sugarcane, glass, pottery, and porcelain) as well as the products of light industry can be developed to make the area self-sufficient. In agriculture, attention should focus on the construction of bases for producing flue-cured tobacco, sugarcane, and vegetables and on livestock development (pigs, oxen, and goats). The Jingshajiang River, after opening to navigation, can be instrumental in collecting and distributing materials along the river in the east and west of this area.

The Yanyuan District Economic Complex (IV)

Yanyuan district is located in the west, on the upper reaches of the Yalongjiang River. The territory includes Yanyuan County, Muli County, and the area in the north-west of Mianning. The district has a large area but a small population. The area of the district is about 21,000 sq. km. accounting for 32.5 per cent of the total regional area. The population is about 350,000, accounting for only 8.5 per cent of the regional population. Its total industrial and agricultural output is five per cent of the total regional output. The elevation of this district is high and the climate is moderate, making it suitable for developing forestry and animal husbandry. Forest resources are plentiful, and the Yalongjiang and Jinshajiang rivers provide convenient transportation for wood. The Yalongjiang and Jinshajiang rivers can be exploited to generate electricity. In this district, the prospects for mining salt and brown coal resources are also good. These resources can enable the establishment of a chemical industrial base in the district. The economic development of the district should focus on the construction of a strong hydropower base, salt-halogen chemical centres, and use of timber and forestry products. In agriculture, dry plants, fruits, and animal husbandry should be developed.

The Zhaoqiao District Economic Complex (V)

Zhaoqiao district is located east of the Anninghe River, between the zones of greater and lesser Liangshan where the *Yi* nationality resides. Its area is 18,330 sq. km. accounting for 27 per cent of the regional area. The population of this district is about 1,190,000, accounting for 29 per cent of the regional population. Its total industrial and agricultural output is about 12 per cent of the total regional output. The district is wide in area but has a small population and communications are underdeveloped. The natural conditions in this district are suitable for the development of animal husbandry and forestry. Phosphorous and non-ferrous mineral resources can be exploited. The economic development of this district is possible through the use of local resources such as animal husbandry, forestry, medicinal herbs, and special local products in order to construct a base for forestry and animal husbandry. The Cheng-Kun Railway and the Xichan-Yibin Highway can be used for collecting and distributing materials, and the Jinshajiang River can also be used for transportation.

The five economic complexes (districts) mentioned above, based on the combination of key industries and local products respectively, with different priorities and characteristics, constitute the total economic complex of Panxi Region. The local specialties of each district can be promoted, avoiding overlapping among different districts and, therefore, this programme is beneficial for regional development.

Chapter 6

Engineering Construction and Geo-environmental Assessment

Construction of Mining-Metallurgical and Chemical Projects

Mining-Metallurgical and Chemical Projects

Regional conditions are favourable for the development of mining-metallurgical and chemical industries. The research region is rich in mineral deposits with a variety of accompanying elements and supplementary metals. Water resources are extremely abundant.

The regional plan has emphasised the steel industry's production plan. In steel production, the index for production of vanadium and titanium is determined, and, on this basis, the extraction rate of iron mines, production, and the supplementary inputs are planned. At the same time, construction plans for non-ferrous metallurgical and chemical industries and for the exploitation of non-ferrous metallic mines are drawn up according to the location of raw materials. Figure 13 shows the structural plan for mining and metallurgical projects in this region.

The deposits of vanado-titano-magnetite in this region can meet the raw material requirements needed to produce 10 million tonnes of steel. Increasing the regional steel yield to six million tonnes annually by the end of this century and to 10 million tonnes in the first half of the 21st century is feasible. Therefore, the Panzhihua Steel Company can expand to increase its annual production capacity to an iron yield of three million tonnes and 2.5 million tonnes of steel by 1995. Limited by the landform conditions, other sites must be chosen for expansion. It will be more beneficial to select sites inside this region rather than outside because of the local mineral resources and inexpensive electricity.

After the extension of Panzhihua, it will be able to supply up to six million tonnes of iron ore. About four million tonnes of good quality coal can be provided by the Baoding, Huaping, and Hongni coal mines, and any shortfall can be overcome by importing coal from the Liupanshui district of Guizhou Province. Until the establishment of Ertan Hydropower Station, the demand for electricity can be met by Panzhihua Power Station by increasing the current installed capacity of 0.15 million kW.

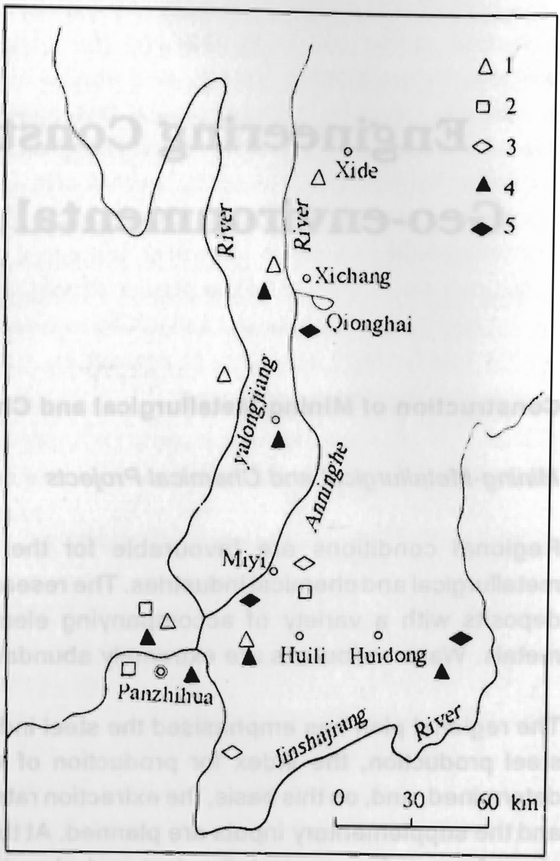


Fig. 13: Planning of Mining -Metallurgical Industry

1. Iron mine 2. Coal mine 3. Copper-lead-zinc mine 4. Steel plant 5. Non-ferrous metal smeltery

The construction of a second steel plant, which will be as large as the extended Panzhihua Steel Plant, is planned (i.e., with an annual capacity of three million tonnes of steel and three million tonnes of iron). The corresponding annual demand of 25 million tonnes of iron ore can be provided by the Taihe and

Baima mines. Brown coal may be supplied by the Yanyuan Coal Mine and anthracite can be supplied by the Hongni Coal Mine in Yanbian. The shortage of fuel can be supplemented by fuel from the Chuxiong District in Yunnan Province. The energy resource for the second steel base will be provided by Ertan Hydropower Station. The building materials can be provided by local factories (Plate 17). Along with the construction of the steel plant, vanadium, titanium, and other metals can be extracted and used for the production of alloys and a vanadium and titanium pilot plant can be built during the construction of the second steel base.

Besides the vanado-titano-magnetite resource, this region is very rich in other kinds of metallic resource, many of which are of good quality and have a variety of accompanying components. Minerals suitable for producing alloys that are easy to separate and can be efficiently exploited are present in concentrated deposits. Twelve kinds of metallic resource have been surveyed in this region which is abundant in zinc, aluminum, copper, silver, and rare earths. Since there is already a steel industry, non-ferrous metal bases can be established here. The construction of a Sichuan Non-ferrous Metal Smeltery, which will obtain raw materials from the mines in the region, is planned. The Tianbaoshan Lead-Zinc Mine in Huili and the Lalachang Copper Mine and Daliangzi Lead-Zinc Mine in Huidong will be constructed and extended to use the resources available.

According to the plans for developing the local economy, the medium and small mines will be worked step by step; of these 12 lead-zinc mines, three tin mines, and 14 copper mines will supply the Sichuan Non-ferrous Metal Smeltery.

This region is also very rich in chemical resources. Besides sulphuric acid, which can be extracted in large amounts during the exploitation of non-ferrous metals, the halite deposits in the Yanyuan Basin can be used to build up systematic production based on chloric soda (Figure 14). There is a large amount of low grade phosphate ore inside the Huidong Mine which can be used to produce sulpho-phosphate compound fertilisers.

Geo-environmental Problems in the Construction of Mining-Metallurgical and Chemical Projects

For the systematic development of mining, smelting, and chemical industries, an adequate number of smelteries, iron mines, coal mines, non-ferrous metallic mines, salt mines, and building sites must be established and/or extended. Many geo-engineering and environmental problems will have to be studied before their construction.

A. <u>Site Selection for a Smelting Base and Its Geo-environmental Problems</u>. According to the plan, the primary projects are the extension of the Panzhihua Steel Plant, the construction of a second steel base and Sichuan non-ferrous metal smeltery, and some processing plants for steel and raw materials.

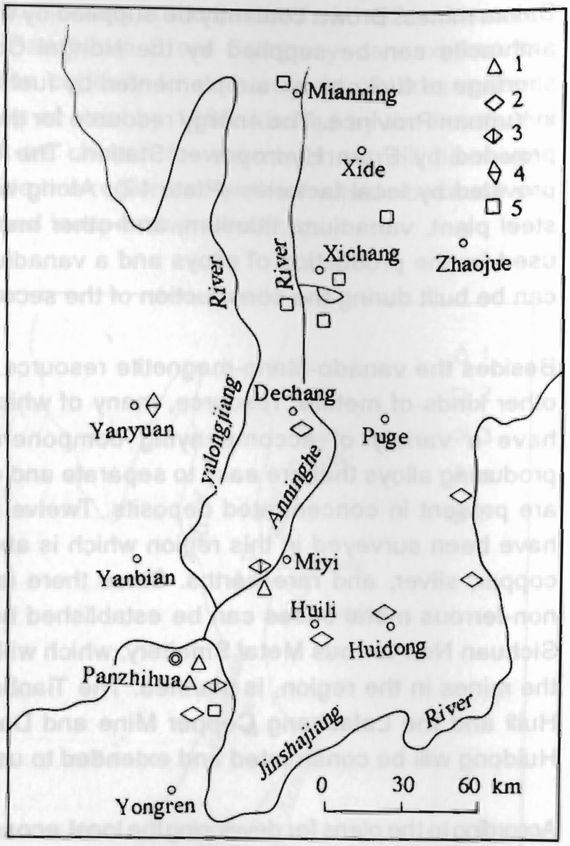


Fig. 14: Regional Planning of Chemical and Processing Industries

1. Chemical factory 2. Sugar plant 3. Timber processing 4. Salt plant 5 Light industry

Sites should be selected taking geological conditions and engineering possibilities into account. They should be selected near mines to facilitate the transportation of ore. At the same time, they should be close to the main highways to facilitate the export of metal and other products and shorten the construction period. Therefore, the big smelteries, in principle, should be located near the Cheng-Kun Railway, in the section approximately south of Panzhihua and north of Xichang. Considering the support provided by the Panzhihua Mine and Baoding Coal Mine for the extension of the Panzhihua Steel Plant, the plant should be established in Panzhihua. The production of the extended plant is dependent upon the Taihe Iron Mine near Xichang and the Baima Iron Mine in the north of Miyi. The plant should be located in Dechang to avoid the Xichang high intensity seismic zone. The zone between Dechang and Miyi is a comparatively stable massive and is more stable than Xichang. The conditions in the zone are even more favourable than those in Panzhihua. The plants can use the water from the Anninghe River and are close to Ertan Hydropower Station. The Sichuan Non-ferrous Metal Smeltery was to be built in Xichang, but the seismic intensity of Xichang is high, and, even though it is located near Cheng-Kun Railway, the distance from Xichang to the non-ferrous metal mines is comparatively long. Therefore, it is more convenient for the smeltery to be located in Miyi, because the distance between the smeltery and the Xichang seismic zone, as well as that between the smeltery and the Yuzha seismic zone, are both more than 100 km. The smeltery is close to the relevant mines as well. Therefore, the new plants should be located in the wide valley of the Anninghe River where there is a rich agricultural base.

In light of the experiences gained during the construction and operation of Panzhihua Steel Plant, a series of environmental and geo-engineering problems must be considered. The smelteries are located at sites with open landforms where often semi-cemented Xigeda strata exist. Such strata are widely distributed throughout the valley and basins of the Anninghe River. The Xigeda strata are a kind of intermountainous lake facies, the sandstones of which often contain soft silty layers which render the strata liable to sliding and swelling. During the excavation of the strata and their use as a foundation, landslides and foundation swelling often occur and, therefore, cause significant hazards in the construction of key projects. Landslides in the Xigeda strata cause a number of slope failures at locations inside Panzhihua Steel Plant (Figures 15 and 16), resulting in heavy economic losses and delays in construction. For example, during the excavation of the foundation of a blast furnace which had to be extended, there was a landslide in the Xigeda strata and the cost of reparation was as high as 30 million *yuan*.

The amount of slag dumped annually from large-scale steel enterprises totals up to 10 million tonnes, and, therefore, the site must be carefully selected. Inappropriate site selection will cause secondary landslides, debris flows, or the contamination of rivers. Similar problems have often arisen in Panzhihua Steel Plant. Along the Jinshajiang River, the debris flow is extensive, causing severe hazards during industrial construction (Figure 17).

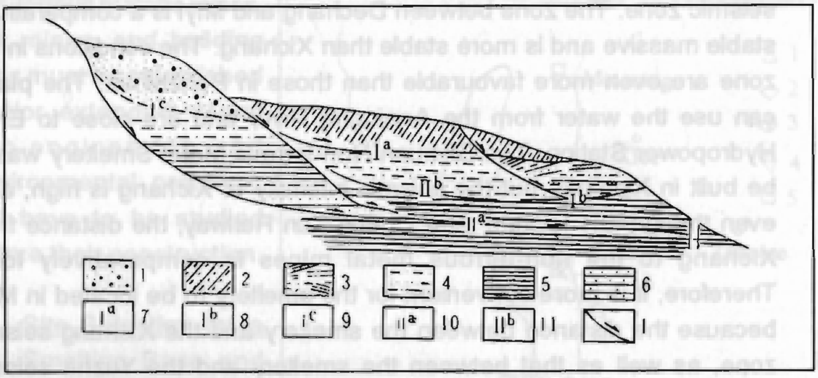
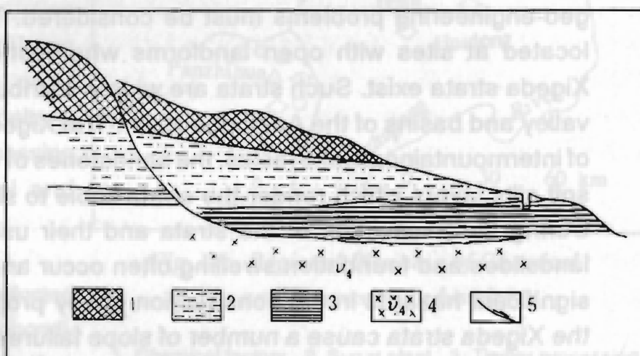


Fig. 15: Landsliding in Xigeda Strata

1. Gravel 2. Silt 3 .Xigeda siltstone 4 .Xigeda silt-sandstone
5. Xigeda clay stone 6. Xigeda sandstone
7,8,9. Sliding on upper layer 10,11. Sliding in middle layer

Fig. 16: Landsliding on Bottom of Xigeda Strata

1. Artificial filling material
2. Xigeda siltstone
3. Xigeda claystone
4. Intrusive bedrock
5. Sliding surface



When deciding on the site of a plant, the landform factor should be taken into account. The gorge of Jinshajiang River was selected as the site for Panzhihua Steel Plant. The elevation is low, the climate is moist, and the dispersal of smoke is difficult and aerial pollution is a problem.

B. Geo-environmental Problems in Mining. Many of the vanado-titano-magnetite deposits and non-ferrous metallic deposits are exposed and so the method of open cast mining can be adopted. Underground mining methods should be adopted for coal mines having thin coal seams and unfavourable mining conditions.

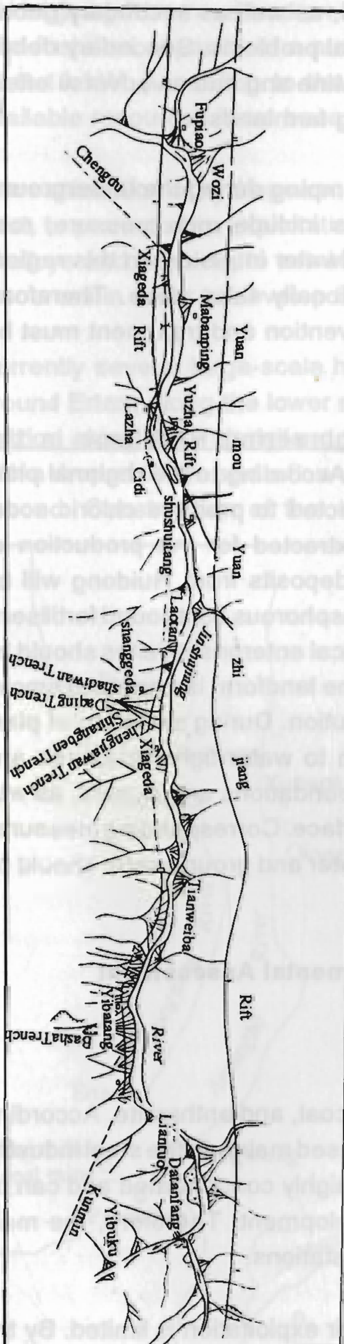


Fig. 17: Debris Flows along the Jingshajiang River Valley

Panzhihua vanado-titano-magnetite deposits occur at the contact point with gabbro and marble. The rock mass around the ore is faulted and contains weak interlayers with mud and weathered hornblende schist. The slopes in the lower wall of the deposits are often excavated along the bedding plane, and, therefore, the fractured layer composed of hornblende schist can form a sliding plane, influencing slope stability. Vanado-titano-magnetite mines located in Taihe, Baima, and other places will be extracted by open cast mining also. Therefore, when the depth of excavation is more than 100m, slope stability must be carefully assessed.

The most serious landslide in a mining area was the H2 landslide that occurred in 1981 in Panzhihua Limestone Mine. The volume of the landslide was about $5x10^6$ cubic metres and it held up production. The slope in the open pit of the limestone mine is composed of Yangxing limestone of the Permian period and is overlying Denying dolomite of the upper Sinian period. The stratum dipped towards the pit at between 30 to 40.5 hours, after the foot of the slope was cut by blasting, and a large landslide occurred.

In mining projects, a great amount of waste is produced annually and the sliding of dumps and tailing dams, as well as secondary debris flows, are also important environmental problems. Secondary debris flows also occurred in the Panzhihua Mine and had an adverse effect on project facilities and on surrounding farmlands.

In addition to the problem of waste dumping during the underground mining of coal mines, other problems include rock pressure, rock burst, coal burst, and gas and groundwater intrusion. In this region, rock pressure and coal burst occasionally take place. Therefore, during coal-mining, measures for prevention and treatment must be taken.

C. Geo-environmental and Geo-engineering Problems in the Construction of Chemical Industries. According to the regional plan, rock salt from Yanyuan is to be extracted to produce chloric soda, limestone from Panzhihua will be extracted for the production of polyvinyl chloride, and phosphorate deposits from Huidong will be mined for use in producing sulphur-phosphorous compound fertilisers. Before the construction of these chemical enterprises, sites should be carefully selected at locations where the landform is open and smoke can disperse easily to prevent air pollution. During selection of plant sites, more attention should be given to water-tight structures and hydrogeology in the strata on which foundations are located, as well as to the distribution of runoff on the surface. Corresponding measures to prevent contamination of surface water and groundwater should be taken.

Hydropower Planning and Geo-environmental Assessment

Projects for Hydropower Development

This region is primarily rich in coal, coking coal, and anthracite. According to the prevailing conditions, coal should be used mainly in the steel industry. The hydropower resource in this region is highly concentrated and can be exploited for large-scale hydropower development. Therefore, the main energy policy is to build large hydropower stations.

Hydropower resources are plentiful but their exploitation is limited. By the end of 1984, only one medium-scale hydropower station (Mofanggou II

Power Station) had been built. This station used a branch of the Yalongjiang River and had an installed capacity of only 37.5x10 kW. The total installed capacity of a number of small hydropower stations is only 92.5x10 kW. According to the electricity yield, only 0.3 per cent of the available resources have been exploited.

The exploitation of hydropower resources in this region has two objectives. First, to promote the exploitation of mineral resources and the production of alloys and, second, to establish an energy base, mainly of hydropower resources in order to develop Sichuan and southwestern China.

Currently several large-scale hydropower stations are being constructed around Ertan, along the lower reaches of the Yalongjiang River. The river section along the Yalongjiang from Jinping to Panzhihua is 360km long, with a drop of 678m and a flow capacity of 1,235 to 1,935 cubic metres per second. Construction of five hydropower stations--Jinping I, Jinping II, Guandi, Ertan, and Tongziling -- on the mainstream of the Yalongjiang River (Figure 18) has been planned. Ertan and Tongziling, particularly, have favourable conditions for communication and construction. After the establishment of the five hydropower stations, the total installed capacity will amount to 10.8 million kW. The annual electricity yield will amount to 6.884×10^{10}. At present, the construction of Ertan II and Tongziling,

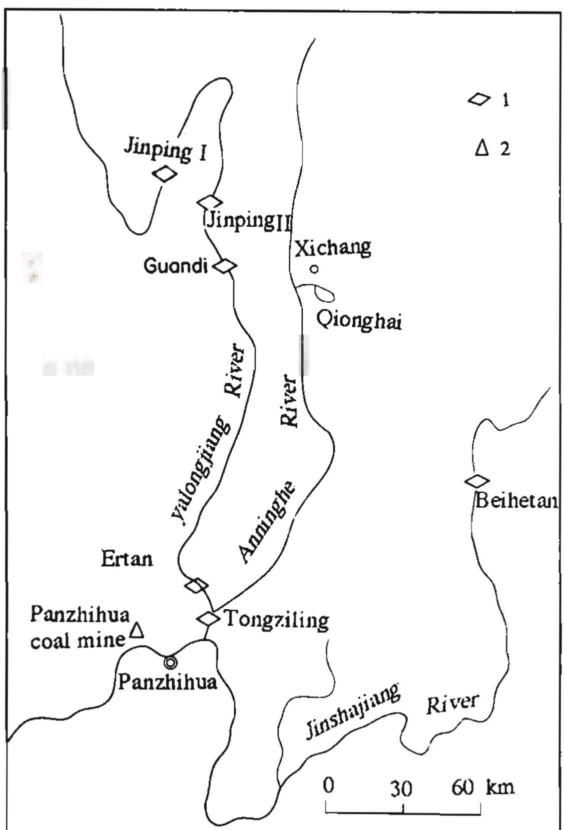


Fig. 18: Planning of Energy Development

1. Hydropower station
2. Thermal plant

located along the lower reaches of the Yalongjiang River, will be stressed and it is expected that construction will be completed by the year 2000 A.D. It will not only meet the needs of steel industries in Panzhihua and Dechang but will also supply electricity outside the region. Along with the exploitation of the hydropower resources of the Yalongjiang River, preliminary preparations should be made for the exploitation of the Jinshajiang River. Along the Jinshajiang River, from Banbianjie to Yibin, five cascade, large-scale hydropower stations can be constructed with a total installed capacity of 25 million kW.

Medium and small hydropower stations (Plates 18 and 19) are being constructed on the tributaries of the Anninghe River concurrently with the construction of the large-scale hydropower station on the Yalongjiang River. They are located in the centre of the region and have the advantages of favourable conditions for power generation and relatively small investment needs and, thus, are suitable in both the economic context and in the context of local development. More than 30 small hydropower stations have been established. Before the year 2000, a number of small and medium-scale hydropower stations will be constructed, such as Mofanggou I and Heshuihe, with an installed capacity of 0.3 million kW, in order to meet the needs of the local consumers and to mitigate the shortage of electricity in this region.

Geo-environmental Assessment for Hydropower Development

The regional plan focusses on the key hydropower stations of Ertan and Tongziling. A lot of preliminary survey work has been carried out to assess their feasibility and construction conditions. At present, Ertan Hydropower Station has entered the construction stage.

Ertan Hydropower Station lies along the lower reaches of the Yalongjiang River, 40km from Panzhihua City, and 18km from Tongziling Station on the Cheng-Kun Railway. The function of the hydropower station is mainly to yield electricity, but it also facilitates the transportation of timber, navigation, and the water supply for industries and cities. Because of its climate and fishing facilities it is suitable for tourism. Ertan Hydropower Station is the supplier of electricity in this region and has an installed capacity of three million kW, an annual electrical yield of 1.62x10 kW/h, and is running at a profit.

Ertan Hydropower Station contains a 245m high arch dam, lying in the Ertan Gorge section. The river valley is in the form of a "V", with steep slopes reaching 35$ to 40$. The strata at the dam site belong to the basalt of the Upper Permian period ($P_2\beta$) and syenite intruded in the Indo-sinian Period. The syenite massive is in the EW direction and is six kilometres long and one kilometre wide. The dam site is located at the southwestern end. The slope of the right bank is composed mainly of syenite and the left is mainly of basalt (Figure 19).

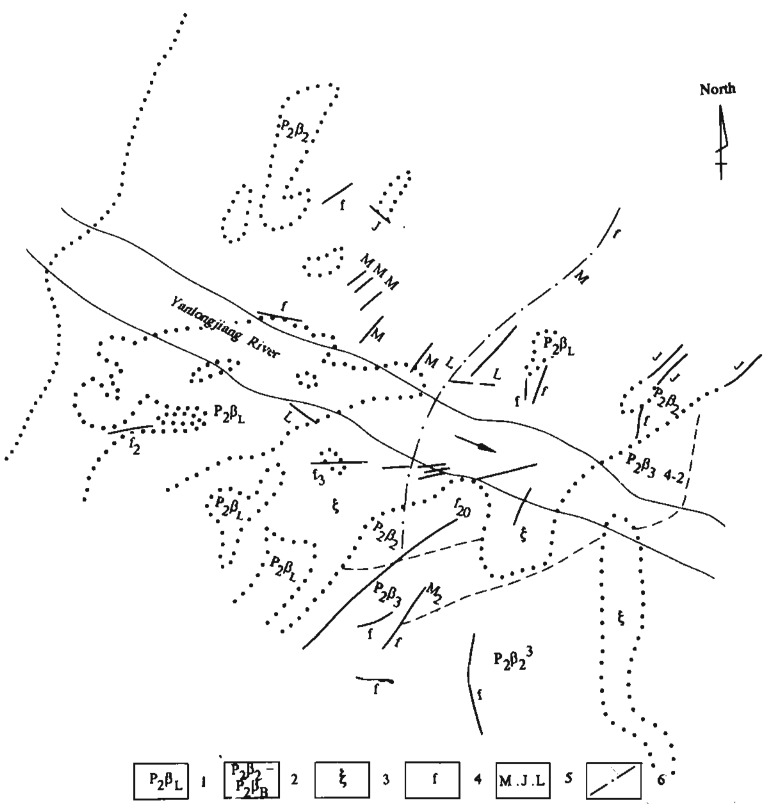


Fig. 19: Geological Sketch of Ertan Dam Site

1. Altered basalt 2. Basalt 3. Syenite 4. Fault 5. Fractured weathering zone (L), zone of dense joints (M), fissures (J) 6. Dam axis

The syenite at the dam site is grayish white, dense, and strong, with a cryptomerous structure. The basalt at the dam site mainly contains P_2B_2, $P_2B_3H_2$, and P_2B_2 layers. Layer P_2B_2 is a kind of micrograin-cryptocrystalline basalt with a dense rock property that is homogeneous, strong, and brittle and which is comparatively fractured due to local alteration. The filling material in the P_2B_2 layer is mainly chlorite, with unfavourable geo-engineering properties. The chlorite is sensitive to weathering and hence subject to reduction in rock strength. P_2B_2 is a kind of grayish basalt with a fine grain structure, or a kind of concentric, massive volcanic clastic rock with open pores in which pellet weathering easily occurs. P_2B_2 is a kind of altered basalt, with a non-homogeneous structure and low resistance to weathering.

The rock mass at the dam site is comparatively intact, and the weak structure planes are not well developed. A few faults, most of them occurring in the form of small faults or shearing zones and joints, can be observed.

The geo-engineering condition of the dam site is suitable for the construction of a high arch dam and underground plant with a large span. From the point of view of environmental and geo-engineering the assessment of Ertan Hydropower Station is as follows.

(1) The dam site is located on the Gonghe faulted block which is comparatively stable. Its eastern and western boundary faults are prone to minor earthquakes, with a historic record of earthquakes of M=5 in the past. Considering the influence of strong earthquakes from Xichang and Yuzha outside the region, the basic seismic intensity of this dam site is VII. The main buildings of the Ertan project are designed to avoid damage from earthquakes up to a seismic intensity of VIII. It is difficult to select a zone with a seismic intensity of VII for a dam site near the lithospheric active fault in the basin of the Anninghe River with its strong seismicity.

(2) According to the aero-remote sensing results and ground test investigations for the dam site, the loss of mineral resources caused by water impounding is small. Only a number of small coal mines are located on the margin of the reservoir. Rare and valuable plants will not become extinct through submergence. The ecology and climate will improve as a result of the reservoir, and it will be possible to

cultivate southern subtropical plants suitable for hot and damp climates.

(3) The ground of the reservoir is well-contained and the problem of seepage will not occur; there are more than 100 landslides in the reservoir zone, which can slide again after storage, but they will not have a negative impact because many of them are located far from the dam site (Figure 10). Protection measures will have to be taken only for the Jinglongshan Landslide located in front of the reservoir. There are 89 active debris flow gullies in the reservoir zone (Figure 20), but only seven lie in front of the reservoir. Since the locations of most gullies are higher than the water table of the reservoir, the flow zone of the debris flows obviously will not change.

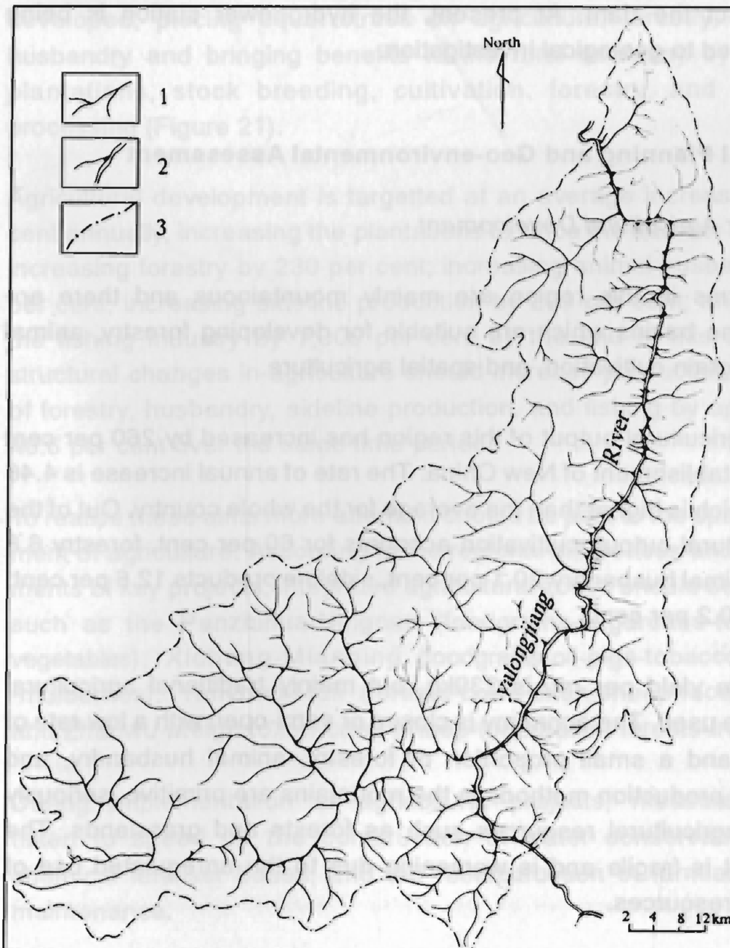


Fig. 20: Debris Flow in the Ertan Reservoir Area along the Yalong-jiang River

1. Surface water system
2. Gully of debris flow
3. Boundary of drainage area in reservoir

(4) The geo-engineering condition is good with the rock mass intact and undeveloped faults. Nevertheless, there are still some problems such as the deep weathering zone caused by unloading in the deep canyon; the breaking of the rockfall around the underground plant due to high geostress; and the scouring downstream by overflow from the dam. However, these problems have been solved by detailed geo-engineering research.

The geo-engineering condition of the Tongziling dam site is less favourable than that of the Ertan dam site. It is located at the southern end of the Liminjiu Fault near the Yuzha seismic zone where the rock mass is strongly weathered and faults are well developed. The Tongziling dam has a low water head, and, after comparative strengthening measures have been taken, it may be possible to construct the dam. At present, the hydropower station is being subjected to geological investigation.

Agricultural Planning and Geo-environmental Assessment

Planning for Agricultural Development

The landforms in this region are mainly mountainous and there are inter-montane basins which are suitable for developing forestry, animal husbandry, grain cultivation, and spatial agriculture.

The total agricultural output of this region has increased by 260 per cent since the establishment of New China. The rate of annual increase is 4.46 per cent, which is higher than the average for the whole country. Out of the total agricultural output, cultivation accounts for 60 per cent, forestry 6.8 per cent, animal husbandry 20.1 per cent, sideline products 12.6 per cent, and fishing 0.2 per cent.

The average yield per *mu* is 239kg, but mainly traditional agricultural methods are used. The economy is closed or semi-open with a low rate of production and a small proportion of forestry, animal husbandry, and fishing. The production methods in the mountains are primitive, seriously damaging agricultural resources such as forests and grasslands. The environment is fragile and is worsening due to the unregulated use of agricultural resources.

The principle of agricultural development is to increase grain production, adjusting the agricultural structure within an ecosystem having many levels and functions, in order to create an open and optimum environment for agricultural production, thereby changing the traditional mode of agriculture to an ecologically favourable one. The following agricultural types can be developed in this region, such as the "integrated" type (processing-cultivation-plantation); the ricefield, ecological type (rice-duckweed-fish); the sugarcane field, ecological type (sugarcane-vegetables-mushrooms); the dryland, ecological type (grain-grass-animals); the orchard, ecological type (fruit-grass-animals); the forest/field, ecological type (forest-grass-animals); and the suburban breeding, ecological type (chickens-pigs-fish).

By promoting the above-mentioned types of agriculture, a structure can be developed, placing equal stress on agriculture, forestry, and animal husbandry and bringing benefits to the rural economy by developing plantations, stock breeding, cultivation, forestry, and agricultural processing (Figure 21).

Agricultural development is targetted at an average increase of 5.4 per cent annually, increasing the plantations to twice the number in 1984; and increasing forestry by 230 per cent; increasing animal husbandry by 130 per cent; increasing sideline production by 279 per cent; and increasing the fishing industry by 1,000 per cent by the end of this century. The structural changes in agriculture should increase production in the fields of forestry, husbandry, sideline production, and fishing by approximately 46.6 per cent over the same time period.

To realise these aims more attention should be paid to the spatial arrangement of agriculture. According to the regional differences and the requirements of key projects, integrated agricultural zones should be established such as the Panzhihua-Ningnan (foodgrains-sugarcane-tobacco-pigs-vegetables), Xichang-Mianning (foodgrains-oil-pigs-tobacco-vegetables -mulberries), Yanyuan-Muli (forests-cows-oxen-sheep-foodgrains-fruit), and Zhaowu-Meigu (oxen-cows-sheep-foodgrains- forests-fruit).

During implementation of agricultural projects, measures should be taken to speed up the construction of water conservation facilities, chemical fertiliser bases, and the reconstruction of farmlands and soil maintenance.

Geo-environmental Considerations for Water Conservation Projects

Water conservation is one of the major measures for the development of plantations and for increasing the unit yields of crops in this region. The dry season in this region is as long as seven months and the climate in the river valleys, which are the principal plantation zones, is characterised by high temperatures, scant rainfall, and strong evaporation. There is a shortage of water in early spring and summer which seriously affects crop yields per unit. In the wide valleys and open basins, the land resources also have not been used fully because of the shortage of water in winter, making replantation very difficult.

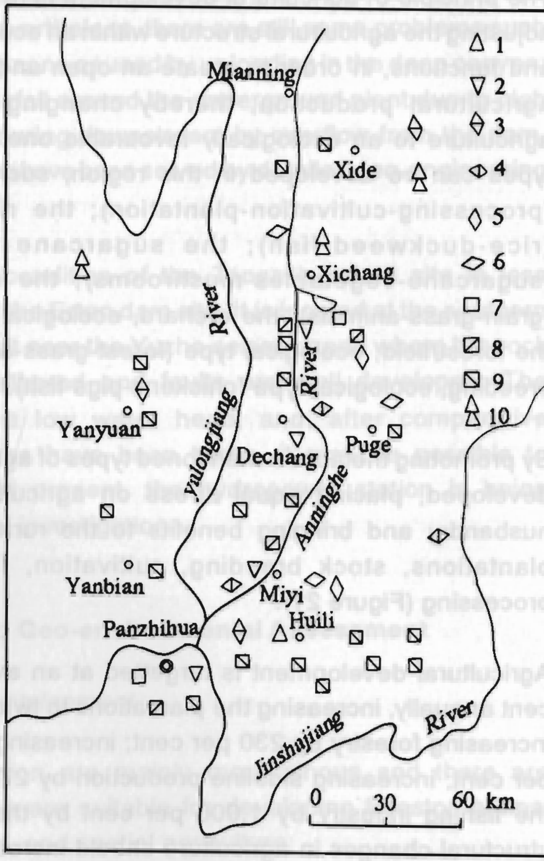


Fig. 21: Agricultural Planning

1. Grains 2. Vegetables 3. Fault 4. Sugarcane 5. Tobacco 6. Silkworms 7. Fishing 8. Poultry 9. Husbandry 10. Forestry.

The available water conservation facilities in this area are mainly diversion works (82%) and storage projects (15%). To meet the target of the agricultural development plan, it is necessary to construct large-scale key reservoirs in a planned manner and to complete construction of the water conservation facilities to increase the area under irrigation. It is planned that, in this century, two large-scale reservoirs will be built in Yanyuan and Mianning and 12 middle-scale and 27 small-scale ones will be built in Shengli (Panzhihua), Xianfeng, Donghexiang (Xichang), Beihe, Xinhua (Huidong), Xiaoshuijing (Huili), and other places, and corresponding irrigation canals will also be constructed. Thus, the area under irrigation will be increased by 1.05 million *mu* which will raise the effective irrigation rate to 39.4 per cent.

The major water conservation projects mentioned above are distributed throughout the wide valleys and their branches as well as throughout the inter-montane basins of the Anninghe River. Therefore, different environmental engineering problems frequently occur. Dam sites are generally located at the exit of a gorge in order to make use of gravity irrigation in the alluvial fan at the base of the mountains until irrigation reaches the central rivers and basins. Generally, the foundations of dams are constructed on bedrock with suitable geo-engineering conditions. For example, the dam site of the reservoir near Mianning Bridge belongs to the metamorphic rock system of the early Sinian period; the dam site of the Penhe reservoir in Huili is composed of granite; and the dam site of the Tianweichun reservoir in Huidong belongs to the basalt of the Permian period. The dam site of the Shengli Reservoir in Panzhihua is composed of quartz-diorite. However, this region is located in an active seismic zone with three epicentres in Yanyuan, Xichang, and Yuzha, and there are active seismicity-prone faults in the region. The geological preconditions for earthquakes, therefore, must be taken into account in selecting dam sites in order to avoid active faults. Appropriate anti-seismic measures should be taken if necessary.

The rapid uplifting of crust and the cutting of rivers caused by neotectonic movements result in steep slopes, and, therefore, slope mass movements, such as landslides, collapses, and debris flows, are violent and frequently threaten the safety of dams and reservoirs. More attention should be paid to the selection of dam sites and to their construction. In particular, investigations should be made regarding the axis position and the contact points of dams with banks to determine whether or not landslides might occur. A small reservoir in mountainous areas does not have a large capacity, therefore, landslides and debris flows can result in silting, leading to the loss of effective reservoir capacity.

Many solid runoffs with a lot of mud and sand, together with the instability of reservoir banks, cause collapses and landslides during the rainy season every year. Thus, many of the reservoirs in this area have a short effective operation time of less than 100 years. Siltation reduces the storage and irrigation capacity of some reservoirs. The maintenance of soil in the upstream area and on the banks of reservoirs, therefore, should receive more attention. Unregulated exploitation of forests must be forbidden and afforestation should be carried out.

The seepage from reservoirs and irrigation canals sometimes causes major damage to the water conservation facilities in this region. One kind of seepage is focussed leakage, such as piping and pouring, into reservoir banks or under dam foundations as a result of karst or faults. For example, the Langtang Reservoir in the Yanyuan Basin, the dam site of which is located in the Triassic limestone zone, has a seepage of nine to 13 million cubic metres annually (taking up 7.2 to 10.5% of its total capacity) as a result of developed karst. Therefore, measures must be taken to prevent leakage during reservoir construction.

Another kind of seepage occurs in some small reservoirs built on alluvial strata. The alluvial strata in mountainous areas often include thick layers of gravel and pebble, and thin or discontinuous layers of clay. Thus, the leakage in dam foundations is often a serious problem for small reservoirs.

The problem of leakage from canals is encountered while carrying out diversion works. When a canal leads out from the front of the reservoir, it often passes an alluvial fan located near the mountains or near the margin of a basin which is composed of coarse pebbles. In such circumstances, construction costs increase because the canals must be lined for prevention of leakage.

Layers of silty soil and the Xigeda strata are liable to softening and swelling on contact with water, and these are present in the basins and river terraces in this region. When canals pass through these soil layers, instability of banks and collapse deformations can often be found, and these require reinforcement measures.

There is no doubt that reservoirs and diversion works play an active role in the agricultural development of this region. But, as a result of the high rate of evaporation in the dry season, more attention has to be given to irrigation as a means of preventing salinisation. During the construction of water conservation projects and the excavation of tunnels, efforts should be made to recover the original landforms, conserve vegetation, and carry out tree plantation to prevent desertification of the silty soil.

To sum up, during the construction of agricultural projects, more attention should be paid to geological hazards and to soil maintenance as well as to the prevention of soil salinisation and desertification so that agricultural production increases.

Urbanisation and Communications' Development

Planning in Urbanisation and Communications' Development

After construction of mining and chemical industries and development of energy resources and agriculture, the population in the area and the pace of socioeconomic development will increase. Consequently, urban construction and the corresponding development of the building materials' industry and transportation and communications will take place.

The reason for the concentration of the urban population in this region is the existence of large-scale mining and smelting bases. By the end of this century, the cities and towns along the Anninghe River and along the Cheng-Kun Railway will develop rapidly.

During the past 20 years, the Panzhihua Steel base has been constructed and farmers have now settled in cities and towns. At present, two cities in this area have populations of more than 0.3 million, i.e., Panzhihua City and Xichang City. In addition, the total population in the other small cities in this area has increased to 0.95 million. The rate of concentration is 23.1 per cent. At the same time, urban communications, postal services, and commerce, as well as tourism and hotel services, have been developed.

While planning the construction of mining, metallurgical, and chemical as well as energy industries, the availability of urban facilities has been taken into account, therefore, some key enterprises are based near existing cities and towns. Urban construction planning aims at developing the existing cities and county towns, such as Panzhihua, Xichang, Dechang, Miyi, Huidong, Huili, and Yanyuan and, at the same time, at rationally adjusting the urban arrangement to ensure the development of key projects. The important cities and towns and the communication and transportation facilities in this area are shown in Figure 22.

With urban development, the building material, light, and agricultural processing industries will also develop. Cement resources are plentiful in this region, and there are gypsum, talcum, marble, granite, kaolin, diatomite, and asbestos as well as glass materials such as dolomite and quartz sandstone. Timber resources are also abundant in this region which is one of the main forest zones in the country.

The construction of Ertan hydropower station needs about 2.2 million tonnes of cement and more cement is needed for urban, industrial, and mining construction. In 1983, the total cement yield was 0.5 million tonnes, and this was inadequate.

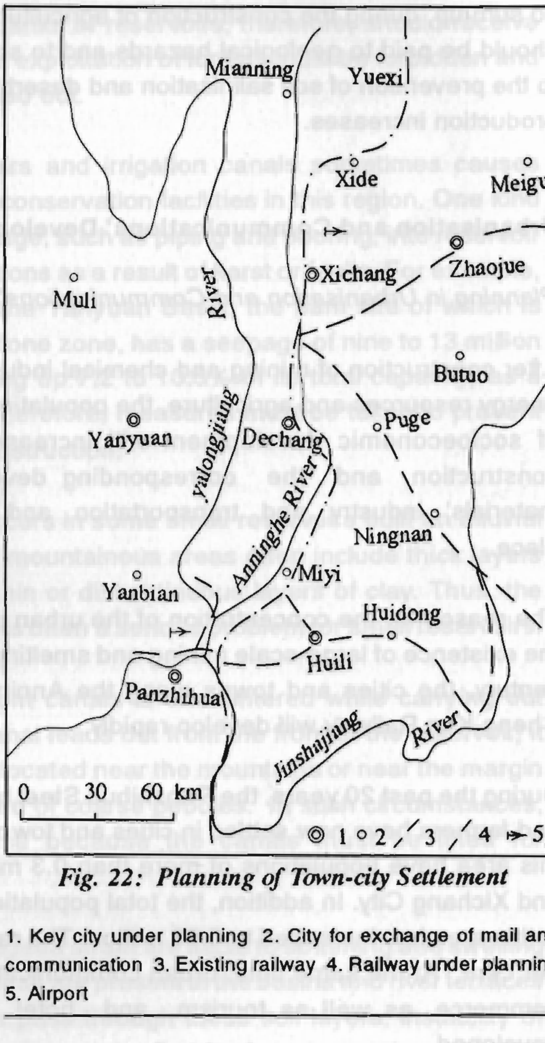


Fig. 22: Planning of Town-city Settlement

1. Key city under planning 2. City for exchange of mail and communication 3. Existing railway 4. Railway under planning 5. Airport

For this reason, construction of limestone mines has been planned in Longdong and Panzhihua. The Panzhihua cement factory will be enlarged. Cement factories will be built in Miyi, Dechang, and other places to meet the regional requirements for cement.

Development plans should focus on industries such as sugar-processing, paper-making, cigarettes, perfume, catering, hide-processing, plastic, hardware, furniture, domestic electrical products, and handicrafts. Light and processing industries should also be established in important urban areas.

Geo-environmental Considerations for Urbanisation

The cities and towns that are to be developed, apart from Panzhihua City which is located in the gorge of the Jinshajiang River, are all geomorphologically located in wide valleys or basins, thus there is enough space for extension.

Constructued only 20 years ago, Panzhihua City, which has mining and metallurgical industries and a population of 0.64 million, is the biggest city in this region (Wang Sijing and Yu Suolong 1987a). Its urban district lies along the Jinshajiang River (Figure 23). The main buildings and streets are situated on the narrow terraces of the river banks. A series of bridges has been built on the Jinshajiang River to facilitate traffic circulation. The administrative section of Panzhihua City is located in Bingchaoguang, which is founded on a terrace composed of a Xigeda stratum. The city has five districts. The centre of the urban district is located in Longlongping and the others are located on several wide terraces along the Jinshajiang River.

The geo-environmental conditions of the Panzhihua urban area are complex and there are many problems (Wang Sijing et al. 1988).

(1) The direct distance between Panzhihua City and the active Yuzha seismic zone is only 30km. The basic seismic intensity of Panzhihua is between VII-VIII (Figure 24) and, because of the steep landforms and developed rock fractures, anti-seismic measures must be taken into account in planning urban construction.

(2) The rock mass in Panzhihua City is fractured and weathered and most urban districts are located on semi-cemented Xigeda strata (Q1x). In road, industrial, and civic construction, the levelling of land and the excavation of slopes often induce landslides and collapses. Many gullies form channels for debris flows. For example, the normal operations of Power Plant No.401 were interrupted because of destruction of its residential quarters by debris flow. The maintenance of slope stability must be taken into account in urban planning. Safety measures, such as tree plantation and improvement of surface runoff, must be taken.

(3) The foundation of Panzhihua City--the Xigeda stratum (Figure 25) and alluvial deposits are often characterised by swellings which cause cracks in the houses as well as collapse. Hence, measures to prevent the swelling of foundations must be undertaken during construction.

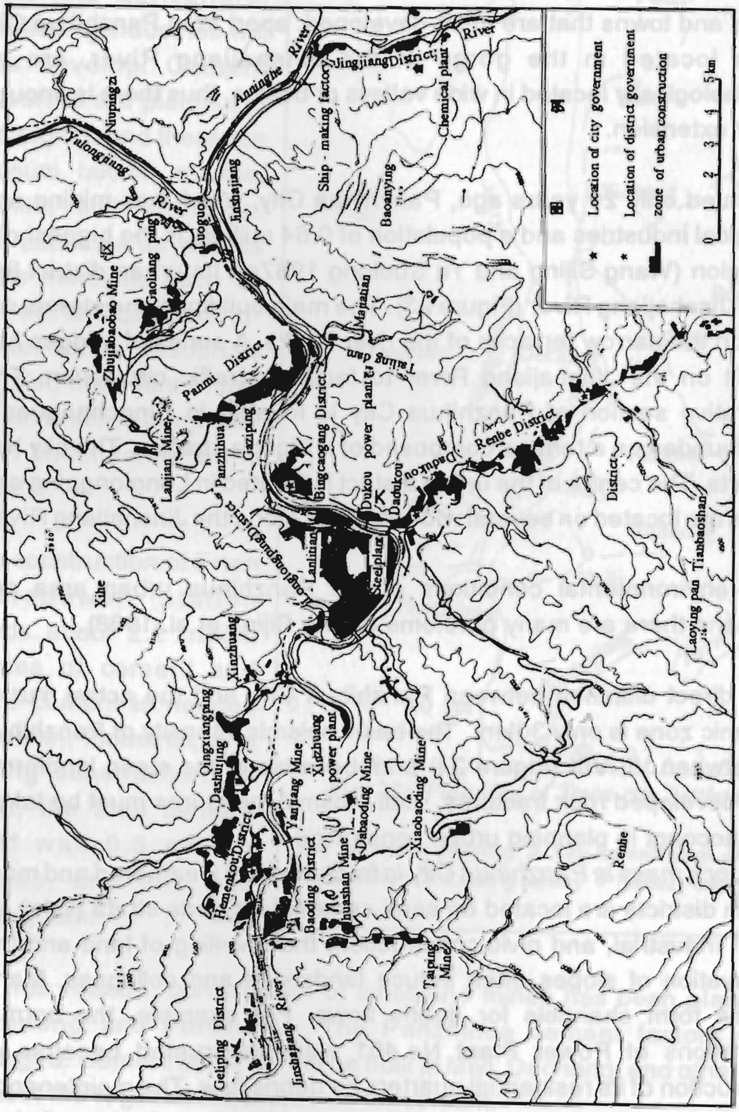


Fig. 23: Urban Area of Panzhihua City

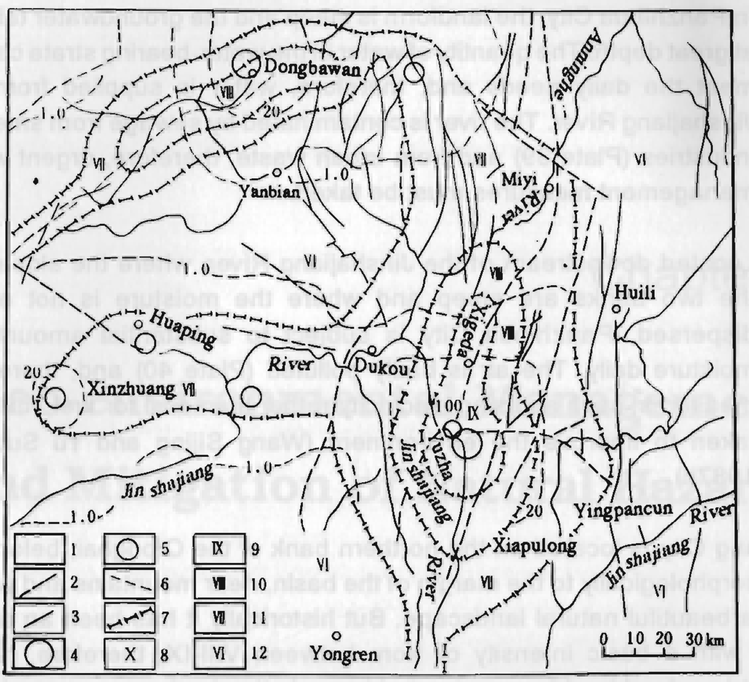


Fig. 24: Seismicity in Panzhihua Area

1. Lithospheric Fault 2. Crustal fault 3. Basement Fault 4. 7.0M=6.0; 5. 6.0M=5.0
6. Cover Fault; 7. Boundary of zone with different intensity 8-10. Intensity value

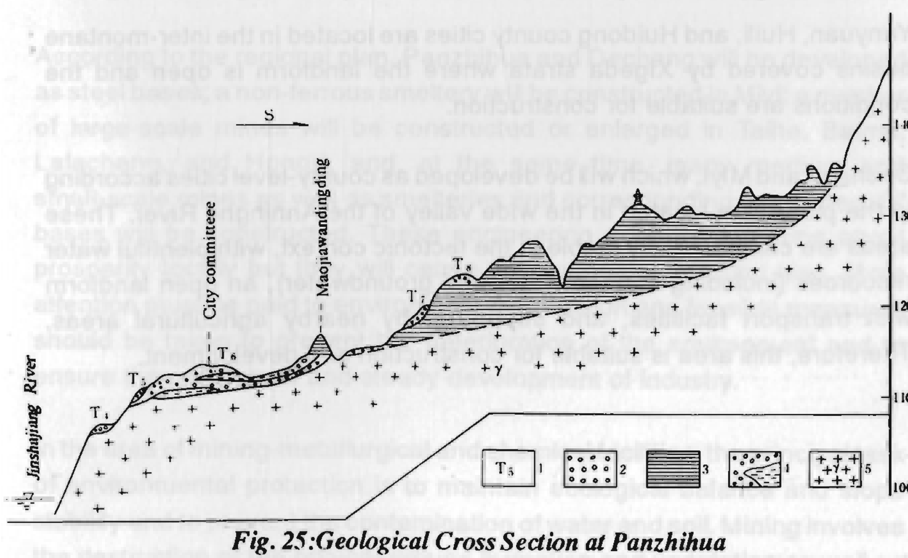


Fig. 25:Geological Cross Section at Panzhihua

1. Terrace 2. Gravel 3. Xigeda stratum 4. Conglomerate 5. Granite

(4) In Panzhihua City, the landform is steep and the groundwater table is at great depth. The quantity of water in the water-bearing strata cannot meet the daily needs and, therefore, water is supplied from the Jinshajiang River. The river is contaminated by sewage from smelting industries (Plate 39) and from urban waste, therefore, urgent water management measures must be taken.

(5) Located downstream of the Jinshajiang River, where the slopes on the two banks are steep and where the moisture is not easily dispersed, Panzhihua City is subject to substantial amounts of moisture daily. The air is badly polluted (Plate 40) and, therefore, measures, such as using electricity rather than coal for fuel, must be taken to improve the environment (Wang Sijing and Yu Suolong 1987b).

Xichang City is located on the northern bank of the Qionghai, belonging geomorphologically to the margin of the basin, near mountains and water, with a beautiful natural landscape. But historically it has been an active zone with a basic intensity of from between VIII-IX, therefore, heavy industries should not be constructed here. Anti-seismic measures should be taken while constructing buildings and the problem of groundwater contamination in the Qionghai River area should be tackled.

Yanyuan, Huili, and Huidong county cities are located in the inter-montane basins covered by Xigeda strata where the landform is open and the conditions are suitable for construction.

Dechang and Miyi, which will be developed as county-level cities according to the plans, are located in the wide valley of the Anninghe River. These areas are comparatively stable in the tectonic context, with plentiful water resources (including surface water and groundwater), an open landform with transport facilities, and supported by nearby agricultural areas. Therefore, this area is suitable for construction and development.

Chapter 7

Geo-environmental Management and Mitigation of Natural Hazards

Environmental Protection in Areas where There Are Mining-Metallurgical and Chemical Industries

According to the regional plan, Panzhihua and Dechang will be developed as steel bases; a non-ferrous smeltery will be constructed in Miyi; a number of large-scale mines will be constructed or enlarged in Taihe, Baima, Lalachang, and Hongri, and, at the same time, many medium and small-scale mines as well as smelteries and corresponding raw materials' bases will be constructed. These engineering activities will bring about prosperity locally but they will cause environmental pollution also. More attention must be paid to environmental protection and feasible measures should be taken to prevent the deterioration of the environment and to ensure the continuous and steady development of industry.

In the area of mining-metallurgical and chemical facilities, the principal task of environmental protection is to maintain ecological balance and slope stability and to prevent the contamination of water and soil. Mining involves the destruction of the original ground formation and vegetation as well as the excavation and transportation of rock, soil, and ore for storage outside the excavation zone. These activities will result in landslides, secondary debris flow, changes in the surface and ground runoff and in the water table, and seepage of polluted material into ground and surface water.

For the prevention of environmental destruction, protection measures must be taken.

(1) Mining should not damage the local environment and the necessary reinforcement and support measures must be taken to maintain the stability of rock and soil masses.

(2) To replace the plants destroyed during mining, excavation, and construction of roads, tree plantation should be carried out.

(3) The waste from smelters should be dumped in suitable places and stabilisation measures should be taken to prevent the formation of secondary debris flow, erosion of farmlands, or contamination of water resources.

(4) To solve the problem of change in natural runoff conditions as a result of mining and industrial building construction, artificial drainage must be constructed to prevent submergence, as well as to prevent a decrease in water quantity and in the quality of groundwater resources.

(5) The waste water and materials from mines as well as smelteries must be dumped in suitable places to prevent soil and groundwater pollution.

(6) Industrial facilities which produce a lot of waste or hazardous gas should be located far away from narrow basins or deep valleys, on terrains or sections with flat ground landform, to reduce the menace posed by smoke and fog concentration and to prevent air pollution.

Urban Environmental Protection

At present, the urban population in this region is not too dense, but, after planned economic development takes place, the population will increase and the scale of light and processing industries will increase rapidly.

Bearing this in mind, measures for environmental protection should be taken into account in urban planning.

This region has a fragile natural environment and suffers frequently from natural disasters. Therefore, while selecting development sites in the city and in making town plans, more attention should be paid to avoid dangerous or hazardous zones such as active seismic zones, landslide zones, and debris flow zones. If construction is carried out in these zones, necessary protection measures must be taken such as anti-shock structures, slope reinforcement, and treatment of ditches and valleys. Both Xichang City and Mianning County are located in an active seismic zone, therefore, anti-seismic designs should be used in construction. Panzhihua City is near the active Yuzha seismic zone on a steep landform and, thus, not only the seismicity but also the possibility of collapses and landslides induced by earthquakes should be taken into consideration.

Urban environmental protection measures, besides concentrating on disaster prevention, should stress the prevention of water and soil contamination, the disposal of waste water from factories and residences, and the management of dumps to avoid pollution of water resources. The problem of water pollution in the cities and towns located in the river valleys and Xigeda basins of Dechang and Miyi counties need to be solved. Since the amount of groundwater supply to these cities and towns is great, there should be protection zones around the concentration of water resources. Disposal sites for solid waste and garbage from cities and towns should also be included when making plans to select suitable sites, and engineering measures should be taken to purify the water and prevent land contamination. Soil contamination will not only result in the pollution of water resources, but it will also influence the use of land, directly affecting the production of vegetables, foodgrains, and livestock in the suburbs.

Another important aspect of urban environmental protection is the adjustment and control of surface runoff and drainage. The climate in this area can be divided into dry and damp seasons, and the rainy season is long. Rainstorms, which are frequent, may cause disasters and mountain floods. While planning, measures should be listed to prevent floods in low-lying locations, thereby reducing their influence on urban areas.

The excavation of land often results in deforestation because of rapid development of urban construction. It makes the land sandy and more desert-like, therefore, plantation of forests and grasses should be carried out in a planned manner to maintain environmental and ecological balance.

The Geo-environment of the Anninghe River

The Anninghe River is the biggest downstream tributary of the Yalongjiang River, flowing from north to south, passing through Mianning, Xichang, Dechang, and Miyi, across the whole region with a total length of 312km. The Anninghe River has a wide river valley with width varying from two to 10km. Along the river, the length of the gorges accounts for only 9.7 per cent of the total length. In the wide sections of the river, water flows slowly and shallows and sandbars exist. Food production and human commerce and habitation are carried out in the wide and open terraced zones of this region.

The climate along the Anninghe River has obvious spatial differences, both horizontally and vertically. The spring and autumn seasons, in the whole Anninghe River area, last for 10 months. The winter in the region is warm and the summer is not hot. In the area south of Miyi there is no winter season and the summer lasts for six months. Rainfall is plentiful, with an average annual precipitation of more than 1,000mm. The precipitation from May to October accounts for 90 per cent of the annual precipitation. The dry and damp seasons are obviously distinguishable.

Most years, the average annual amount of water resources in the whole drainage area totals $7.52 \times 10^9 m^3$; of which the surface runoff is $6.94 \times 10^9 m^3$ and the ground runoff is $5.8 \times 10^9 m^3$. According to the data measured, most years the average discharge is 231 cubic metres per second, which means that the drainage area is full of water. In the drainage area of the Anninghe River, agriculture, forestry, and animal husbandry are more developed than in the nearby suburbs, with plentiful vegetation and a beautiful environment.

However, as a result of the development of mining-metallurgical, chemical, and processing industries, and the increase in the urban population during the past 20 years, the environmental situation of the drainage area of the Anninghe River is deteriorating. Programmes must be developed and measures taken to protect the environment, to improve the management of land, and to use it judiciously.

The environmental management and comprehensive resource exploitation of the Anninghe River include the management of water, soil, and forests, as well as the rational use of water and land resources, afforestation, and water and soil conservation. The principal measures are given below.

(1) *The Management of the Anninghe River*

Active debris flows occur in the Anninghe drainage area, especially along the Xichang and Dechang strip. Floods often occur because debris flows leave deposits on the river floor and silt up the river course. In the dry season, the water supply is inadequate, i.e., the needs of industries and agriculture as well as the daily needs of the urban population cannot be met due to a considerable reduction in flow capacity. Maintaining a stable water supply and developing agricultural irrigation systems are key steps in the afforestation of river valleys, sustainable land use, and environmental protection. Because of water shortages, the deteriorating environment, and the transformation of land into sand, desertification will certainly take place because the vegetation that has been destroyed cannot be recovered. Water management should have priority over soil management. Measures for the management of the Anninghe River should combine dredging and embankment methods. Dredging the 135km long wide valley from Xichang to Dechang is the first step, followed by the dredging of the narrow 130km long valley from Dechang to Miyi. After dredging, the water depth should increase to enlarge the drainage section during flood seasons, creating favourable conditions for increased land use and for carrying out tree plantation in the drainage area.

(2) *The Construction of Reservoirs for the Control of River Runoff*

The drainage area of the Anninghe River is rich in water resources but, at present, their exploitation is limited. In the whole drainage area, 40 small reservoirs have been built. Under normal conditions, the water supply is 5.44×10^8 m^3, accounting for 7.2 per cent of the total water resources, of which 88.9 per cent is supplied by water diversion works, seven per cent by storage projects, and 4.1 per cent by rivers. Eighty-nine per cent of the area irrigated for agriculture depends on water diversion works. During the period from May to March - the time when water use increases - the shortage is very serious. Therefore, an increase in the number of storage projects is one of the key measures in improving the environment of the drainage area. According to the programme, a reservoir will be constructed in Daqiao, Mianning County, and one or two more medium- or large-scale reservoirs will be built near the Sunshuihe and Jingchuanhe rivers. Both of these rivers are tributaries of the Anninghe River and its runoff can be adjusted by these measures, benefitting the overall management of the drainage area of the river.

(3) *Water and Soil Conservation and Tree Plantation*

Economic activities in the drainage area of the Anninghe River caused serious destruction to forests nearby; the Tongshan grass slope expanded; vegetation was destroyed; land destertified; and land in the river valley was transformed into sand. Under these conditions, the capability of land for reducing drought hazards decreased, drainage decreased, and environmental conditions deteriorated. This has had an adverse affect on economic and social development. Tree plantation in the Anninghe River area and the area of its tributaries must be carried out as rapidly as possible in order to recover the natural vegetation. The objective is to increase forest cover to up to 45 per cent of the whole area within this century, to strengthen the capacity for water and soil conservation, to reduce the damage caused by landslides, to maintain the ecological balance, and to change the ecological system for the better.

Because of the concentration of cities and towns, as well as industries and mines, and the presence of the Cheng-Kun Railway in the river valley of the Anninghe River, measures must be taken to prevent contamination of the river by waste.

Mitigation of Hazards in Mountainous Areas

The main mountainous hazards are earthquakes, landslides, debris flows, and floods in river valleys. Disasters, such as rainstorms and hailstorms, often occur. During construction in mountainous areas, hazardous zones should be avoided or effective measures taken for mitigation (Figure 26).

This region is a very active seismic zone, located at the south-eastern end of the N-S seismic zone of China. The zones of high seismic activity include (1) the Mianning- Xichang section, in which the main earthquake-inducing structure is the Anninghe Fault; (2) the Xigeda-Yuzha section, in which the main earthquake-inducing structure is the Mopanshan-Luzhijiang Fault; and (3) the Yanyuan district, in which the main earthquake-inducing structure is the Jinhe-Qinghe Fault. In addition, there is a hazardous zone of medium to strong seismic activity near Huaping. In other places, there are mainly zones where medium to weak earthquakes of M<5 occur. Because this whole region is located in active earthquake zones and the faults, as well as earthquake-inducing structures are distributed extensively, while planning the construction of key projects, the hazardous zones where strong earthquakes occur (>VIII) should be avoided as far as possible and relatively stable zones (<VII) should be selected. Suitable anti-seismic measures must be taken concomitantly to make the engineering constructions safe and economical. In zones such as Xichang, Panzhihua, and Yuzha where the population density is high, earthquake-predicting stations should be established to guard lives and property by analysing the existing phenomena related to earthquakes and by giving forecasts.

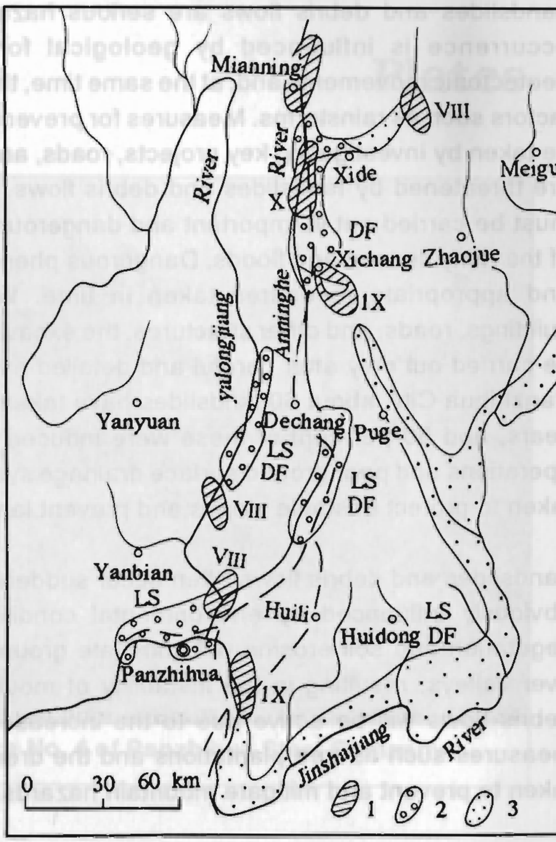


Fig. 26: Sketch of Natural Hazards

1. High intensity zone 2. Priority zone of management
3. Zone of mountain hazards; LS-landslide; DF-debris flow; VIII-X intensity

Landslides and debris flows are serious hazards in this region. Their occurrence is influenced by geological formations, especially by neotectonic movements and, at the same time, they are linked with climatic factors such as rainstorms. Measures for prevention and mitigation should be taken by investigating key projects, roads, and residential zones which are threatened by landslides and debris flows. Necessary examinations must be carried out in important and dangerous zones before the arrival of the rainy season and floods. Dangerous phenomena must be identified and appropriate measures taken in time. While constructing urban buildings, roads, and other structures, the excavation of rock and soil must be carried out only after careful and detailed evaluation. For example, in Panzhihua City, about 60 landslides have taken place during the past 20 years, and 80 per cent of these were induced by excavation and filling operations and poor ground surface drainage systems. Measures must be taken to protect unstable slopes and prevent landslides.

Landslides and debris flows often occur suddenly, but their occurrence is obviously influenced by environmental conditions. The destruction of vegetation and soil erosion will stimulate ground erosion and erosion in river valleys, resulting in the instability of mountain slopes. In addition, debris flows will be active due to the increase of materials. Therefore, measures such as tree plantations and the dredging of runoff should be taken to prevent and mitigate mountain hazards.

Plates

Plate 1: Blast Furnace No. 4 of Panzhihua Steel Company

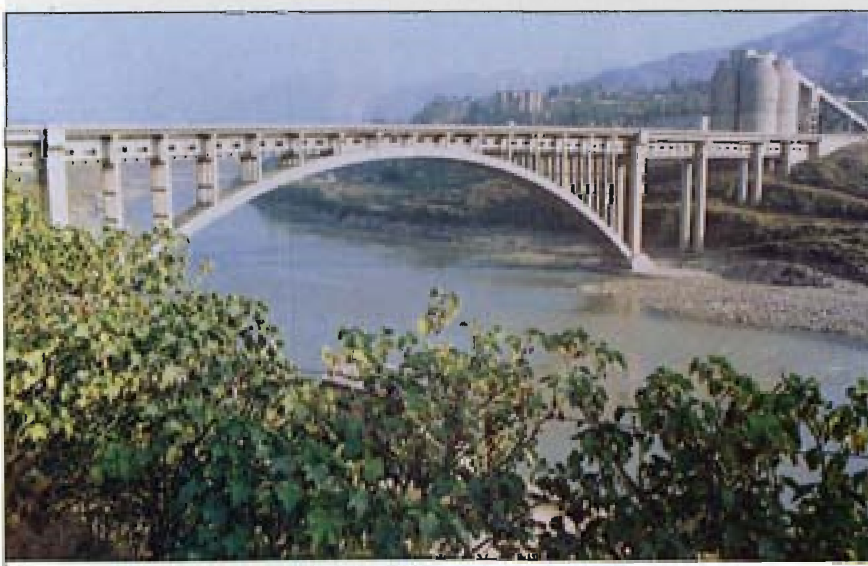


Plate 2: Baoding Bridge across the Jinshajiang River

Plate 3: Bridge at the Mouth of the Yalongjiang River

Plate 4: Heishahe Debris Flow

Plate 5: Nongnonggou Landslide under Treatment

Plate 6: Lanjianshan Open-cast Iron Mine

Plate 7: Yianbaosha Lead-Zinc Mine at Huili

Plate 8: Coal-carrying Cableway at Baoding Coal Mine

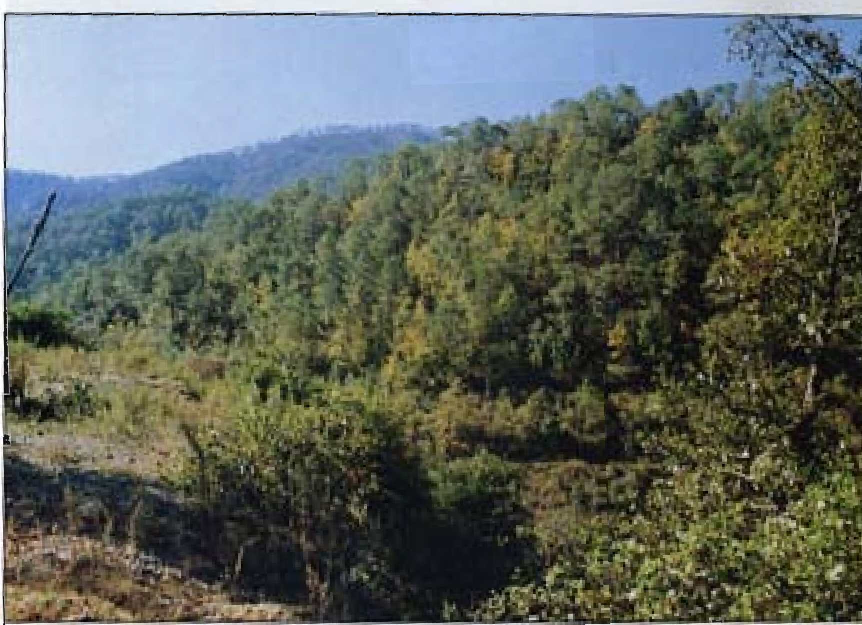


Plate 9: Forestry Area between Huili and Yuzha

Plate 10: Rice Field in the Wide Valley of the Anninghe River

Plate 11: Sugarcane Field Near Dechang

Plate 12: Vegetable Farm

Plate 13: Litchi and Tangerine Forest

Plate 14: Banana Tree

Plate 15: Panzhihua Tree (Kapok Tree)

Plate 16: Chinese Flowering Quince Tree

Plate 17: Full View of the Cement Factory

Plate 18: Mawan Power Plant at Dechang

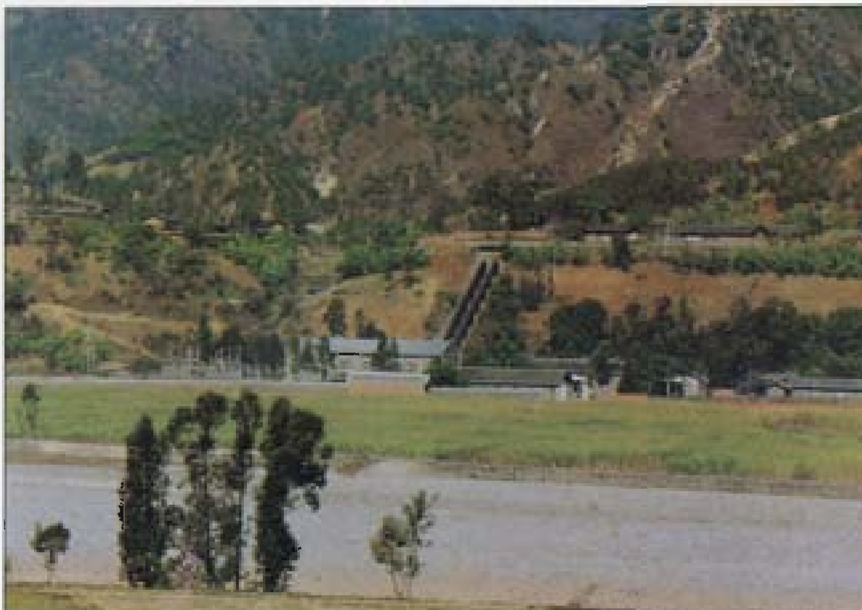


Plate 19: Xijie Hydropower Plant (Miyi)

Plate 20: Factory Building Area of Panzhihua Steel Company

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