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).

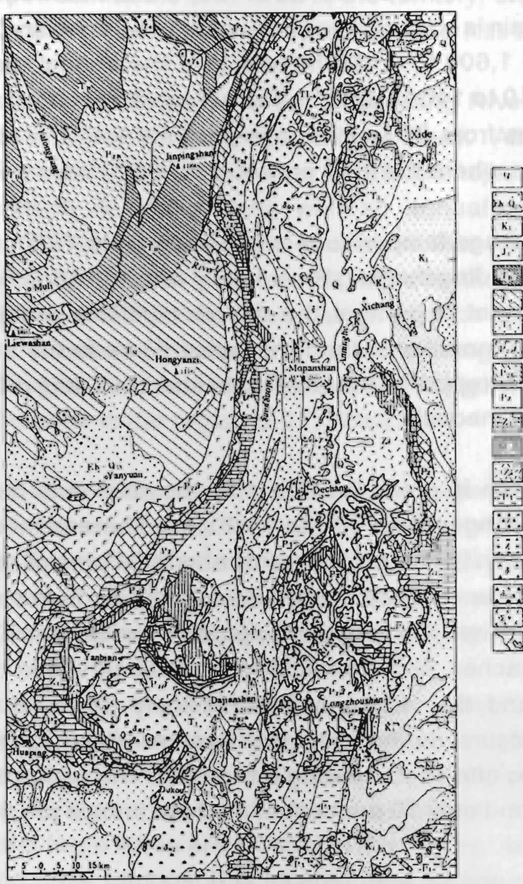

Fig. 2: Types and Distribution of Rock Formations in the Region (after Huang Dingcheng et al., 1990)

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. <u>Eh-Q1x Alluvial and Lacustrine Deposits in the Yanyuan Basin</u>. 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. J23--The Clastic Rock Formation of the Upper and Middle Jurassic series.

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° E-N10° 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°-90° E, forming isoclinal folds of a NEE-EW orientation. The schist that is distributed along the Yalongjiang River is formed by the N60° -90° E strike with cleavages of a N20°-40° W orientation. The schists and metamorphic sandstone exposed near Puwie strike in a N 80° E-EW direction with superimposed cleavages of a N10° E-N20° W direction.

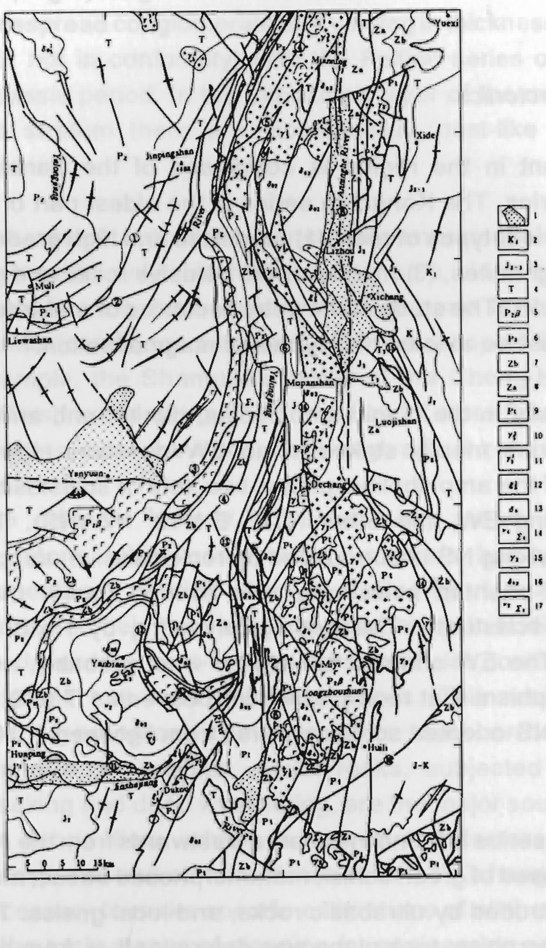

Fig.3: Sketch of Regional Geological Structure

(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.

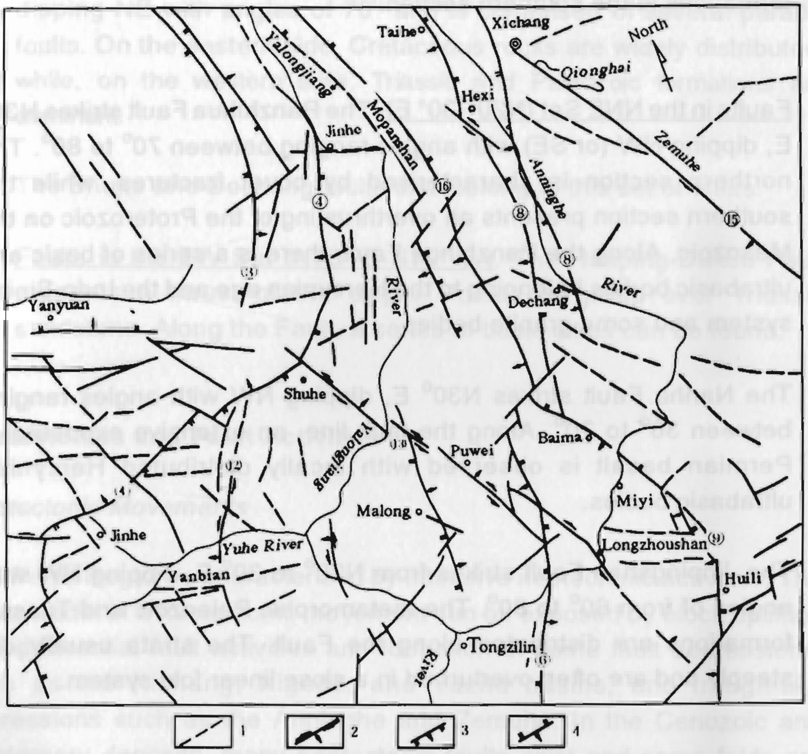

Fig. 4: Sketch of Regional Structure Lines Interpreted by the Image of LANDSAT (after Wang Tingling, unpublished material)

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

The Maoniushan-Xigeda Fault strikes NS-N15^{o} E, dipping NW (or SE) with angles of from 70^{o} to 80^{o}. 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^{o}. 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. <u>Faults in the NW Set (N20°-50° W)</u>. 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. <u>Faults in the EW Set (N70° E-N70° W)</u>. 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.

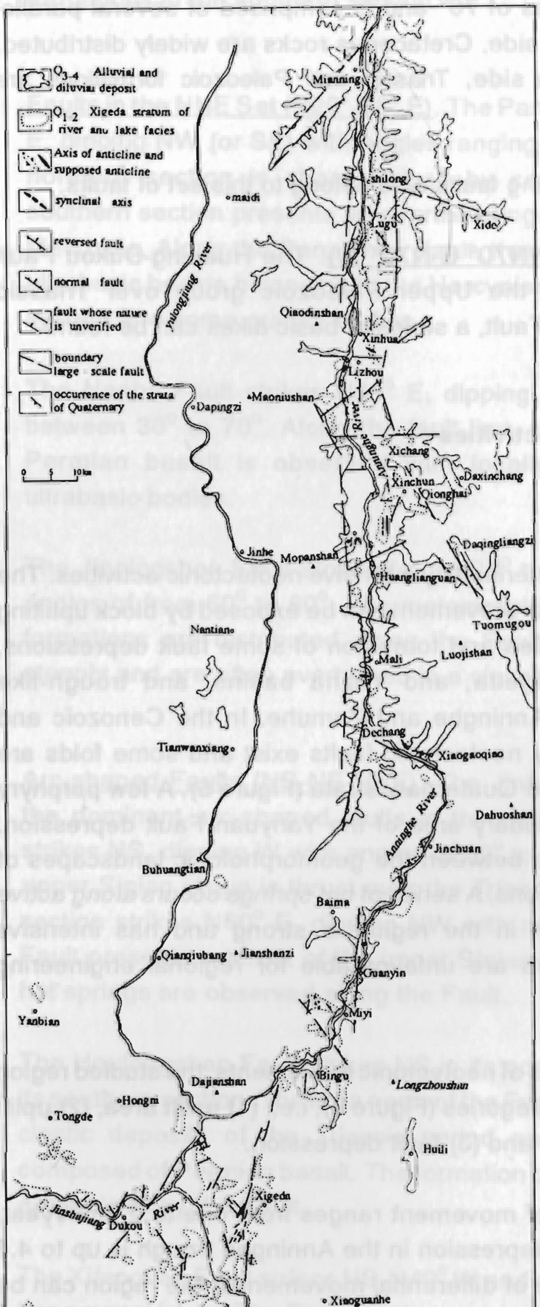

Fig. 5: Sketch of Quaternary Tectonic Deformation along the Anninghe River (after Xu Xuehen, 1988)

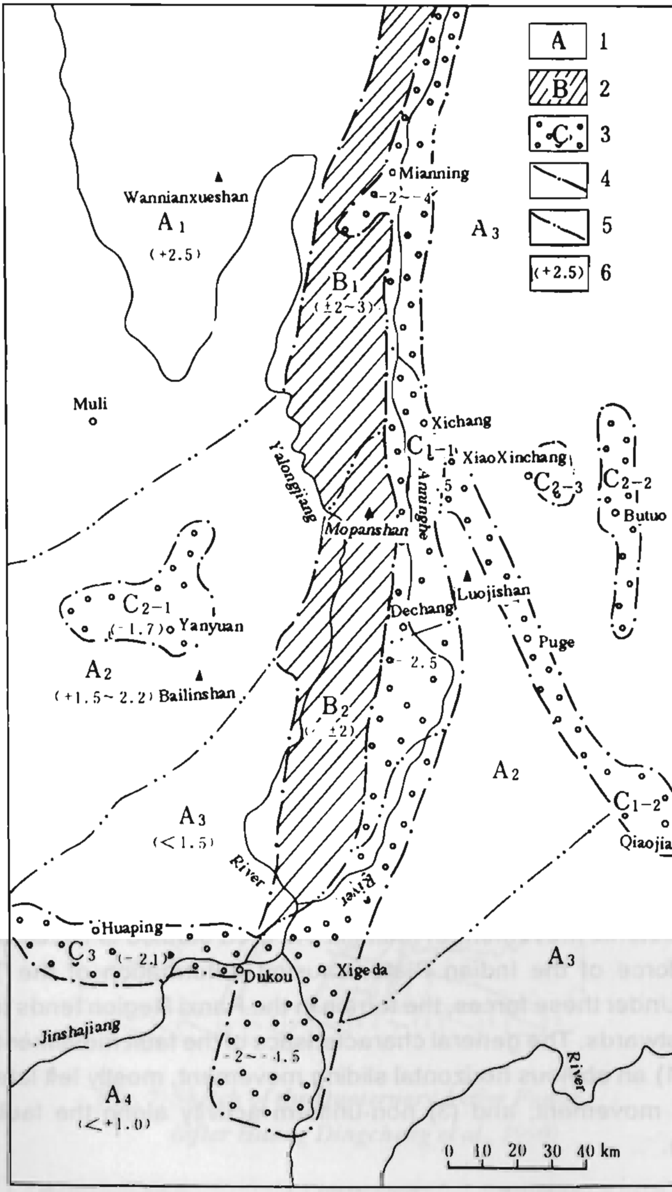

Fig. 6: Neotectonic Geomorphologic Zonation (after Xu Xuehan, 1988)

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.

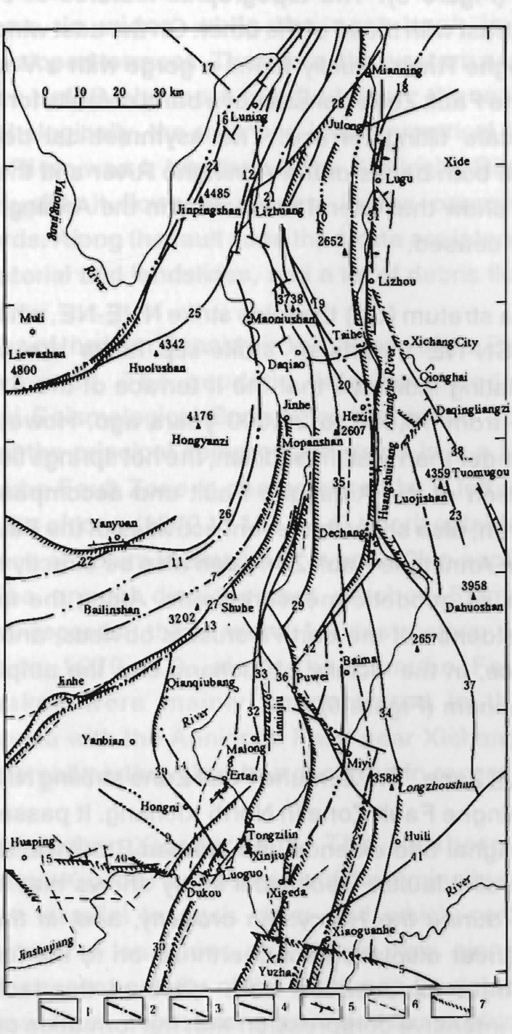

Fig. 7: Sketch of the Quaternary Active Faults (after Huang Dingcheng et al., 1990)

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. <u>Zemuhe Fault Zone</u>. 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 $(23811.8)x10^4$ years.