The environmental geological issues of typical cities in southwest China and city planning

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Abstract: Kunming, Chongching and Chengdu in the southwest China are respectively lakeside city in the Yungui Plateau, mountain city and plain city with different geological settings. Since 1980's many environmental geological issues, which are nearly correlated with sustainable development, have occurred in these cities owing to their fast development. Kunming is confronted with land subsidence and soft foundation. Frequent landslides and rockfalls have obstructed Chongqing's development and expansion. Due to high-speed development of Chengdu, located on the groundwater reservoir in the West Sichuan Plain, recharge, runoff and discharge of the giant groundwater system in Min river fluvial-alluvial fan have been seriously harmed. Environmental geological issues should be the most important factor to be considered in city planning, and reasonable city schemes should be implemented to effectively inhibit geological environmental settings from deteriorating.

Résumé: Les villes Kunming, Chongqing et Chengdu du sud-d'ouest sont au plateau et au bord du lac et au long des fleuves et à la plaine. L'environnement géologique est différent. Au fur et à mesure du développement des villes aux années 80, il surgit le problème géologique moins et plus correspondant étroitement au développement continu des villes. La ville Kunming est confronté au problème de l'enfoncement du sol et la fondation souplesse. La catastrophe de l'éboulement et glissement de terrain fréquents restreinte le développement et l'élargissement de la ville Chongqing. La ville Chengdu au plateau ouest de la province Sichuan au dessus de la citerne enterrée, le développement rapide de ville a détruit gravement le parfait du système de l'eau souterraine du dépôt alluvial de la fleuve Ming et la capacité alternative des riviers. Le problème de l'environnement et de la géologie doivent être considé premièrement le facteur pour la planification de la ville. La planification raisonnable et les réglementations qui sont les moyens efficaces empêchent la détérioration de l'environnement et de la géologie.

Keywords: Typical cities in the southwest China, environmental geological issue, sustainable development, land subsidence, slope hazards, groundwater resources

INTRODUCTION

Urbanization level, which is a ratio of urban population to total population, means economic development level to some degree. In 1800 urbanization level in the world was only 3%, and reached 13.6% in 1900. However it suddenly rose to 55% now (Q. F. Wang & Y. Wang, 2002). At present high urbanization level has occurred in developed countries, and in developing countries urbanization level has achieved a fast progress. It is predicted that by 2030 urbanization level in the world will add up to 60% (Stephen Faulkner, 2004). In 1978 only 18% of the population in China lived in cities, however in 2004 it added to over 35%. It is estimated that population of cities will increase greatly in the coming decades (X. C. Bai & K. Ling, 2004). The general geological setting that is made up of atmosphere, superficial water, groundwater, organisms and rock and soil bodies etc. is not only carrier of the cities but also partial resources of human race that are supplied to the cities for their existence and development under many cases. Construction and development of the cities can disturb surrounding geological setting. Geological setting makes response to the disturbance so as to attain the equilibrium. When the geological setting is brittle, or excessive man-made disturbance leads to very strong response, environmental and geological issues will be created. Once the problems appear, cost of urban expansion is heightened, or urban development is stagnated, even whole city has to be migrated, as badly restricts process of urban sustainable development.

Disturbance degree of geological setting is always determined by human technical and economic conditions and urban scale. Since 1950's due to ceaseless expansion of urban scale (in 1990 in the world there were 8 coastal supergiant cities with over 8 million population, and will be 20 cities in 2010 (Robert J. Nicholls, 1995)), accumulation of wealth and increasing improvement of technical conditions there are more and more disturbance of cities on geological setting. Many urban environmental and geological issues that badly affect sustainable development have increasingly appeared. For example, active fracture and earthquake disaster issues in Rome etc. in the middle of Italy and Delhi in India (F. Galadini & P. Galli, 2000; Imtiyaz A. Parvez, F, 2004), Petrópolis in Brazil (such geological disasters as 1161 floods, landslips and debris flows etc. happened for 50 years from 1940 to 1990), coast disasters in Manizales in Colombia and Hongkong of China (Antonio Guerra, 1995; Anne-Catherine Chardon, 1999; Wyss W. -S. Yi, 1996), debris flow in Ibague, Colombia and pyroclastic flows in Yogyakarta, Indonesia (Jean-Claude, 1994; Franck Lavigne, 1999). There have been land subsidences caused by excessive groundwater extraction in Venice and Ravenna, Italy, San Jose in Costarica, Tokyo and Osaka in Japan, Bangkok in Thailand, Jakarta in Indonesia, Houston in USA, Mexico City in Mexico and Shanghai in China etc. (Thomas L. *et al.*, 1985; T. L. Zhang, 1992; S. J. Wang, 1996; Hasanuddin Z. *et al.*, 2001; Chongxi Chen *et al.*, 2003; J. B. Wang, 2004; P. Teatini *et al.*, 2005). Moreover, severe ground sinking disasters appearing in Zaragoza, Orléans and Kerman, Spain, and Tangshan in China etc. (H. Atapour *et al.*, 2002; S. J. Liu, 2004; Q. J. Zhu *et al.*, 2004; F. Gutiérrez-Santolalla *et al.*, 2005; Pierre Thierry *et al.*, 2005).

Yunnan, Chongqing and Sichuan in the southwest China are located at the southeast of the Qinghai-Tibet Plateau, terrain landform and geological settings of which are complex and various. Although Kunming, Chongching and Chengdu show different foundation structures they share common problems. Since 1980's, especially since West China Development policy was implemented, gross population, space and scale of these cities rapidly have developed. At the meantime environmental geological issues closely linked with city sustainable development have occurred.

ENVIRONMENTAL GEOLOGICAL ISSUES IN TYPICAL CITIES, SOUTHWESTERN CHINA

Kunming's geological setting and main environmental geological issues

Kunming's geological setting

Kunming lies in the middle of Yunnan-Guizhou Plateau. Its mean elevation is 1891 meters above sea level. It is surrounded by mountains on three sides, leaving one side facing the Dianchi Lake to its south. Besides the middle city Dali by the Erhai River, Dengjiang, Jiangchuan, Haitong and Shiping four counties are lakeside cities like Kunming in Yunnan province. The Dianchi Lake, at 1,887.5 meters above sea level, is the largest lake in Yunnan Province and the eighth largest lake in China (298 square kilometers in surface area). Bow-like, it is 39.5 kilometers in length from north to south, and 12.5 kilometers in width from east to west. Its average depth is 4.4 meters and its water storage is 15×10^8 cubic meters. Average temperature of Kunming is 15°C, and 19.7°C in the hottest month and 7.5°C in the coolest month. Annual average rainfall is 1000 mm. 85 percent of the rainfall occurs from May to October.

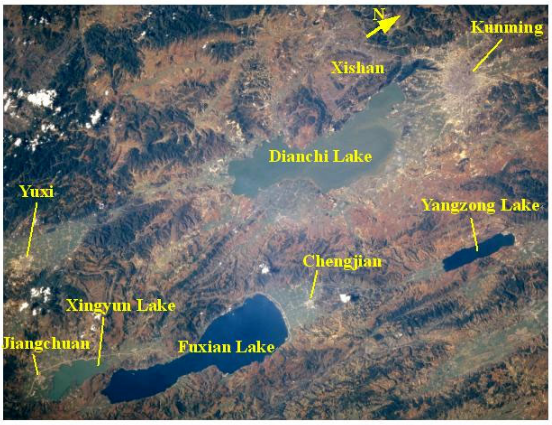

Figure 1. Aerial photograph of Kunming City and its periphery, Yunnan (After http://eol.jsc.nasa.gov/)

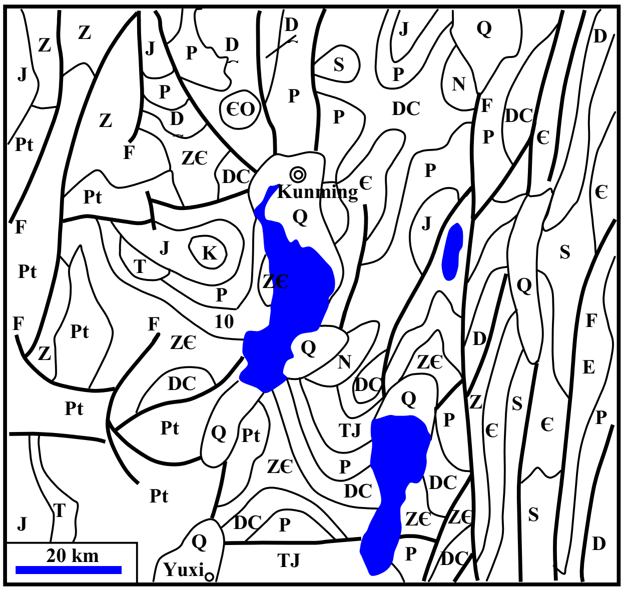

Figure 2. Geological sketch for Kunming City and its periphery (C. S. Li, *et al.,* 1990; Geology and Mineral Bureau in Yunnan Province, 1990)

Kunming, located at the west fold zone of East Dian—second tectonic element of Yangtze quasi-platform, is close to the anticline of the Chuan-Dian bed. Its base stratum is from the Proterozoic, and cover stratum is from the Sinian to the Triassic. After Indo-Chinese Epoch it suffered sediment from the Jurassic to the Quaternary. In Kunming and its periphery exposed strata are metamorphic rocks of the Proterozoic (Pt), shale, sandstone and limestone of the Cambrian (**Є**) and the Ordovician (O), shale, mudstone and sandstone of the Silurian (S), fragmentary and carbonate rock of Devonian System (D), limestone of the Carboniferous (C), fragmentary and carbonate rock of the Permian (P), sandstone, shale, coal measure strata and lime rock of the Triassic (T), shale, mudstone and marlite of the Jurassic (J), mudstone and sandstone of the Cretaceous (K), mudstone, sandstone and conglomerate of the Tertiary (E), unconsolidated sediments of the Quaternary (Q). Although exposed strata are complete there are many fractures quite developed in the region because the region is situated at the N-S-trending Chuan-dian tectonic zone. Therefore space distribution of the strata is disordered, and sometimes show fault contacts among strata units (Fig. 2).

The region of Dianchi basin is a denuded zone from Late Triassic Period to Pliocene Epoch, Late Cainozoic Era. In Late Miocene Epoch Kunming area was uplifted and became a part of original Yunnan Plateau. During Middle and Late Pliocene Epoch, due to the continuing indentation of the Indian Plate on the Eurasia Plate, Qinghai-Tibet Plateau was mightily uplifted to revive main ruptures in Yunnan. Then elevation and subsidence occurred on fractures and Dianchi basin started to come into being. During Middle and Late Pleistocene Epoch Dianchi Lake basin achieved its maximum extent (Geology and Mineral Bureau in Yunnan Province, 1990). Owing to highland downfaulted lake basin formed by neotectonic movement, active fractures of Dianchi basin's periphery with N-S-trending structures are well developed. Since 1300's there happened over 80 inductive earthquakes in Kunming (Fig. 3). For the last 500 years 8 devastating earthquakes happened, earthquake intensity of which was 8 degree. Hence Kunming is regarded as a high earthquake intensity city (Z. Q. Min, 1989; Y. Q. Xie, 1992).

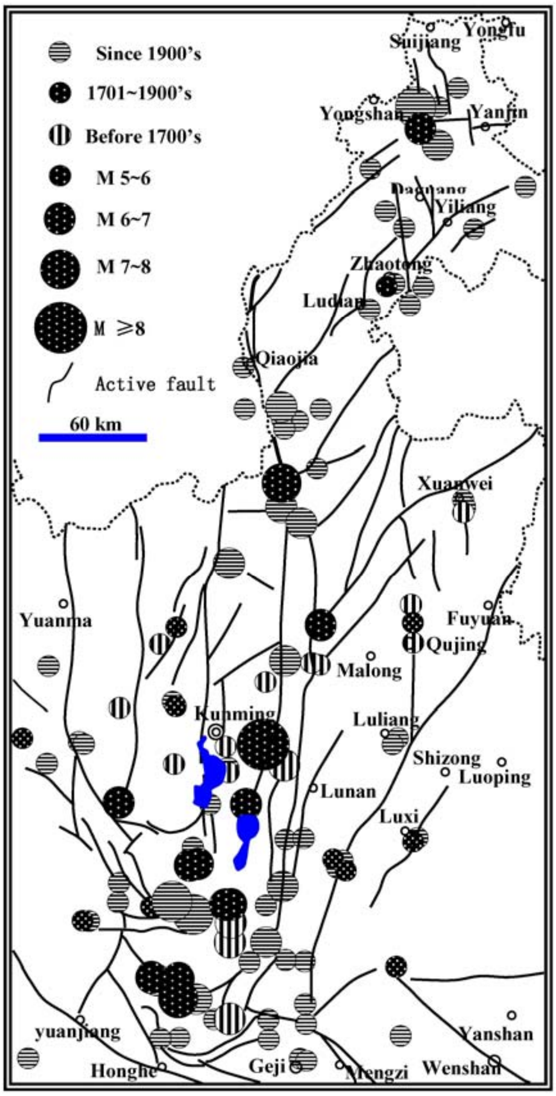

Figure 3. Active faults and epicenters of intense earthquake (C. S. Li, *et al.,* 1990)

Ground settlement issues

Dianchi basin's base is the Lower Palaeozoic strata, and its cover strata are from the Quaternary (Fig. 4). The Quaternary is mainly composed of Dianchi lake facies, including partial marsh facies, alluvial facies and deluvial facies. From the top down there are light green, gray-black fine silts, clay containing black-brown organic clay and mud of Holocene Series (Q_4), gray, brown ravel stratum including gritty stratum, celadon-taupe fine silts including brown clay of Upper Pleistocene Series (Q_3), carbon sandy clay, dust color massive clay including interbedding of bergmeal and silt of Middle Pleistocene Series (Q_2), mottle clay, organic clay and brown coal etc. of Lower Pleistocene Series (Q_1). Total thickness of the Quaternary cover strata varies from 20 meters to 800 meters: the closer to Dianchi Lake, the greater its thickness. The thickness in the urban zone varies from 50 meters to 200 meters.

Gross water resource in Kunming isn't abundant because silts and clays mainly constitute the sediments of Quaternary System with fine particles and limited storage capacity. In 1975 gross water of 3.3×10^4 m^3/d could be obtained from the civil defense engineering and the wells. However by 1982 there were 241 pumping wells and gross exploitation water was 16.2×10^4 m^3/d, which provided 32% of daily supply water in Kunming. Excessive exploitation of limited water resources results in rapid fall of underground water level. Water table of the urban region and Beijiaochang descended 10 to 12 meters, 8 meters in Jinmasi district of the east suburb, 6 meters in Liangjiahe district of the south suburb, 3 to 5 meters in Nanba zone of the south suburb and 6 to 11 meters in Majie region. (X. D. He, 1991).

Due to intense facies change of the Quaternary, aquifers of Dianchi's periphery generally possesses groundwater potential. There are mainly fine sands and silts with high porosity and high compressibility in the aquifer of the region. On the basis of Terzaghi's principle of effective stress, extraction of groundwater causes ground subsidence. Since 1986 survey teams in Yunan Province Earthquake Bureau had made second-order leveling of 350 km city construction. It was found that marked ground subsidence had happened in Kunming, and that the center of the subsidence lay near the East Railway Station. From 1979 to 1986 maximum accumulative subsidence was 71.0 mm and the rate of subsidence was 10.1 mm/a (Fig. 5) (C. S. Jiang, *et al*., 2001).

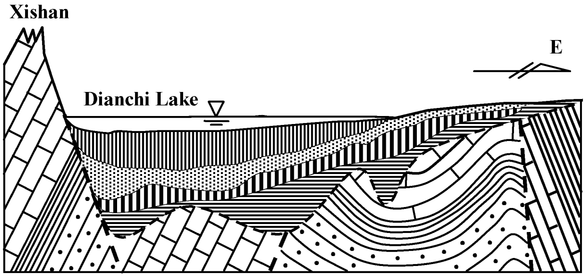

Figure 4. Sketch map of Dianchi basin ground structure

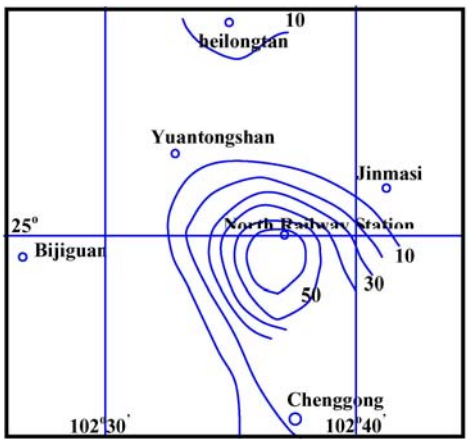

Figure 5. The contour of Kunming subsidence deformation (1979~1986) (C. S. Jiang, *et al*., 2001)

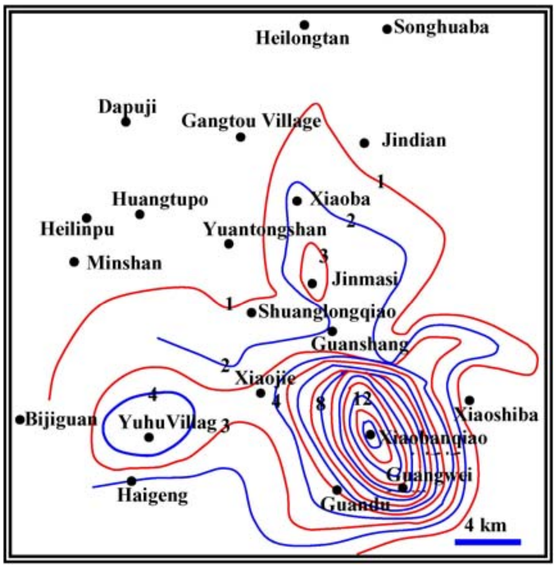

Figure 6. The contour of Kunming subsidence rate (mm/a) (1986~1993) (C. S. Jiang, *et al*., 2001)

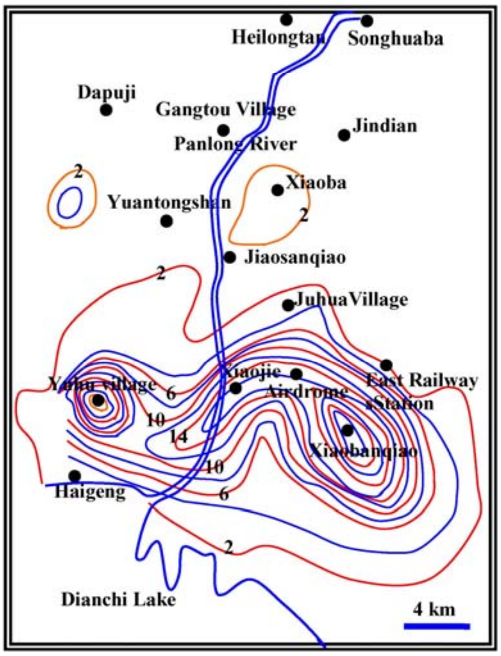

Figure 7. The contour of Kunming subsidence rate (mm/a) (1993~1998)(C. S. Jiang, *et al*., 2001)

In order to inhibit fast fall of groundwater and ground subsidence Songhuaba Reservoir in the north Kunming was rebuilt on a large scale in late 1980's. Then gross water supply was 45×10^4 cubic meters that could satisfy 75% of water requirement, and thus excessive exploitation of groundwater resources was controlled to some degree. However because of management factors ground water was still exploited, and the trend of ground subsidence wasn't completely suppressed. From 1986 to 1993 ground subsidence area of East Kunming was extended to Weicun, Guandu, Xiaojie and so on. The center of the subsidence was located at East Railway Station and nearby Xiaobanqiao. The maximum subsidence was 106.2 mm during seven years, and rate of subsidence added up to 15.2 mm/a. Distinct subsidence had happened in the southwest Kunming and the north Haigeng. Accumulative total of ground subsidence was 5.7 mm/a in Yuhu Village for 7 years. Moreover, subsidence center was found in the eastern Jinmasi (Fig. 6) (C. S. Jiang, *et al*., 2001; C. D. Xue *et al*., 2004).

From 1993 to 1998 ground in Kunming continued to subside. The rate of subsidence at the center in the East increased to 30.3 mm/a. Cumulative total of subsidence in the west subsidence region was 100.4 mm from 1993 to 1997 and mean rate reached 25.1 mm/a. Ground subsidence area increasingly enlarged, and former east subsidence region had jointed with the west subsidence one. Offshore subsidence zone of about 250 km^2 was formed in the south of second-ring road and the north Dianchi (Fig. 7) (C. S. Jiang, *et al*., 2001; C. D. Xue *et al*., 2004).

Water Diversion Engineering of the Zhangjiu River valley that began construction in Dec 1999 with investment of 3900 million Yuan will be running by the end of 2006 when water supply ability of Songhuaba Dam will be 70×10^4 m^3/d. This will radically relieve supply shortage in Kunming, and inhibit excessive exploitation of groundwater and corresponding ground subsidence.

Stability issues of soft foundation

As discussed above, foundation soil in Kunming is mainly composed of organic clay, muddy silt and fine silt with lake facies and marsh sediment. The kind of soil foundation with high natural water content and high compression coefficient belongs to a typical soft soil foundation (C. D. Xue *et al*., 2004; X. Q. Xu, 1996).

Pile foundations are widely used for industrial and civilian constructions in Kunming region due to soft foundation, for instance gravel piles with high diameter (commonly from 90 cm to 140 cm, maximum diameter is 160 cm) (L. X. You *et al*., 1995; M. J. Gong, 1999), bored piles, manual excavation piles, deep-mixing piles (X. L. Yang, 1992) and static pressure piles etc. Compared with natural foundations and shallow foundations, pile foundations increase construction cost, and some types may not work well in soft soils. No. 53rd Building was disposed by deep-mixing piles in Yongchang Village, Kunming, and maximum settlement was 572.2 mm. Its use was affected. During construction of thirteen-floor Business Edifice of agriculture hall of Yunnan Province silt clay was treated by vibroflotation method. Settlement observation started on Aug 1 1987 when crown plates of the box foundation are poured. When the major structure was finished on June 6 1988 the mean subsidence was 256 mm with subsidence rate of 0.611 mm/d (Y. F. Ruan *et al*., 2003).

Soil nails have become one of the main ways of urban foundation reinforcements. However in Kunming grouted nail retaining wall is seldom used, whereas jet-grouted nailed retaining wall is widely done, unlike in other cities. This soil nail is a steel tube 30 cm to 40 cm in diameter. Steel tubes with prefabricated holes and close bottoms are installed by vibration or hammering and then grout is injected through the holes. However, imperfect bonding between the soil nail and the soil body may result. Foundation failure has become a key problem in the Kunming region that needs to be resolved.

Figure 8. Slope failure of foundation pit A in Kunming city

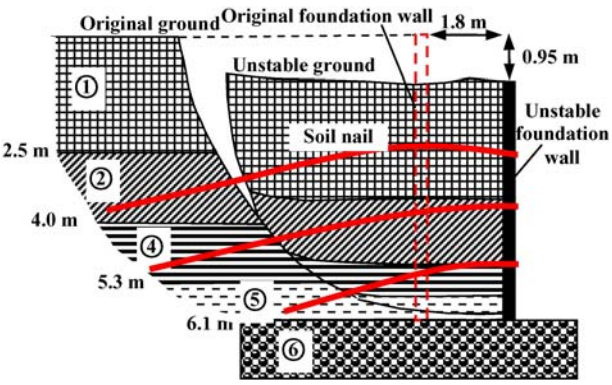

Figure 9. Slope failure section of foundation pit B in Kunming (G. M. Xu *et al*., 2003)

A residential building was under construction in the center of Kunming city. Its foundation excavation was 12 meters deep into variegated clay with lake facies. Steel tube nail retaining wall, of length 5 to 12 meters, was used to support the excavation. In early morning of Sep 26 2004 a collapse occurred on one side of the excavation (Fig. 8). The collapse undermined two neighboring buildings, whose bases were left hanging in the air, and led to the evacuation of 72 households (about 200 persons). With the sliding mass of 2000 cubic meters the front displacement of the slide body was from 10 meters to 15 meters. Part soil nails were still kept in the original ground, a majority of soil nails were pulled out. After the landslide sandy soil backfill was used to prevent the foundation from continuing deformation. However due to excessive deformation the two buildings were completely removed, consequently high economic losses were suffered.

The net excavation depth of a foundation in a Training Base was 6.3 meters. Soil layers from the top down are separately mixed fill (①), brown-gray silt clay (②), gray-black clay (④), bice silt clay (⑤) and close-gray round gravel (⑥). A steel tube nail retaining wall was utilized, the density of which was a line of 1.2 meters and an array of 1.5 meters. From the top down lengths of the soil nails were 9, 9, 6 and 2 meters. Steel tube wall thickness was 3 mm, and with external diameter 48 mm. There was no injected holes and triangle angle iron with guard aperture barb. Pouring after down-the-hole hammer blow was used during the construction. Shotcrete-bolting-mesh support was used with the concrete layer thickness of 10 cm, and staged excavating and reinforcing according to the line range interval of soil nails. On Jan 29th 2002 a one-side foundation wall failure happened, with level displacement towards the inner of the foundation caused (Fig. 9). Maximum displacement was about 2 meters, and width of maximum tension crack in the surface was 1.3 meters. Back-wall was 5 meters from the original foundation. The vertical height between destabilized block and original foundation was 0.95 meters (G. M. Xu *et al*., 2003). Although destabilization maybe be result from over-short length of the soil nails and unreasonable construction methods and so on uppermost factor is related with soft engineering geological properties of reinforcement soil layers (②,④ and ⑤). Because the soil layers presented saturated, plastic behavior and possessed high compression the steel tubes was difficult to supply enough jogged force for the composite body after being poured.

There have been other problems besides the projects stated above. Severe deformation and damage of foundation slope at the in In-patient Department Building of Kunming Red Cross Society, a slope of brick workshop in Bailongsi, a foundation slope of a house building. Foundation slope destabilization has become a common problem of civil engineering construction in Kunming region.

To sum up, Kunming, a highland lake city is located at the north of Dianchi fault basin. In its periphery there are active faults. It is zoned as high earthquake intensity (8 degree). Dianchi is underlain by Upper Paleozoic and Quaternary soils, and the latter is involved in civil engineering construction. Quaternary strata are mainly made up of sediments, with Dianchi lake facies, partial marsh and river facies. Their lithology mainly includes organic clay, silt fine-grained sediments. This kind of soil possesses bad water storage capacity, with limited groundwater resource. Formerly excessive extraction of ground water caused extensive ground subsidence. Henceforward groundwater extraction should be strictly controlled. Since clay, silt and so on in the stratum of the Quaternary are usually under wet saturated conditions, and possess high compression and low shear strength, pile foundations are used for most construction engineering. This increases the cost of urban construction. In the meantime foundation excavation and slope failures often occur. Excavation support, especially the interaction between soil nail and soft soil, and reinforcement effect of soil nail on the soil body, are important problems that require in-depth research.

Chongqing's geological setting and environmental geological issues

Geological setting in Chongqing

Chongqing, where Yangtze River and Jialing River meet, is located in the southeastern part of the Sichuan Basin. Average temperature in summer is 27°C to 29°C and annual average rainfall is from about 1000 mm to 1400 mm, with annual relative humidity of 81%. It is situated at the southeastern part of Sichuan depression in Yangtze Platform, and at the southwestern end of N-E-trending huge brush detachment folds constituted by Red Bed of the Mesozoic (Fig. 10).

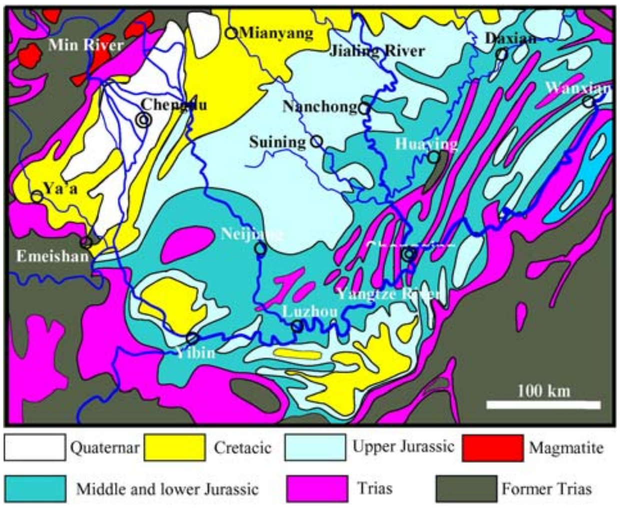

Figure 10. Geological sketch for Sichuan basin

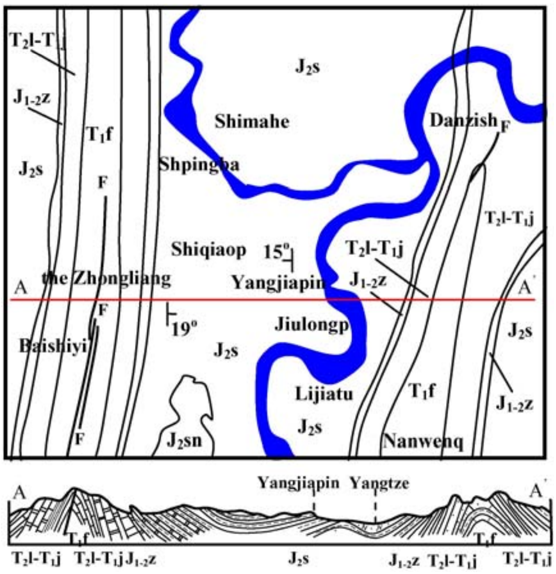

Figure 11. Geological sketch for Chongqing City

Chongqing City lies at 160-280m above sea level on the Jiangbei syncline, with bedding dipping 10 ^{o} to 20 ^{o}, between N-S-trending low mountains formed by the Zhongliangshan and Nanwenquan anticlines. At outcrop the strata mainly include mauve mudstones, mauve sandy mudstones and lark arkosic sandstones of Shaximiao Group of Middle Jurassic (J2sn). In its periphery felspar quartz sandstones, mauve mudstones of Suining Group of Middle Jurassic (J_2sn), shale, silt sandstone and sandstone of Ziliujing Group of Middle and Lower Jurassic (J_{1-2}z), carbonatite, marlite of Leikoupo Group of Middle Triassic and Jialingjiang Group of Lower Triassic (T_2l-T_1j), red shale and limestone of Feixianguan Group of Lower Triassic (T_1f) and so on cropped out. Faults developed at the anticline axis, but not in the syncline region (Fig. 11).

Slope hazard issues in Chongqing

Due to long-term encroachment of the Yangtze River, the Jialing River and its branch, Chongqing City shows undulating landforms with marked differences in height. Ramps with different shapes are its main landform element. Chongqing is considered as a typical mountain river city (there are other such cities in Sichuan Province - Wanxian and Luzhou). Slope planation and landform remodeling are a necessary process of Earth surface evolution and give rise to slope hazards (landslide and collapse). Civil engineering in Chongqing is largely carried out in sandstone and mudstone interbedded strata of the Shaximiao Group. Owing to 10 to 20^o dip angle of the strata it is easy to slip and slope hazards are commonplace in the Chongqing region. The sliding surfaces of landslides are commonly within the mudstone below the sandstone and at the contact zone between the two rocks. Brush detachment folds in the eastern Sichuan basin were formed in Middle Mesozoic Era. In Late Eocene Epoch indentation of the Eurasia Plate by India activated the thrust fault zone of Longmenshan, with continuing deformation in the Sichuan basin. Two large-scale deformations occurred in the Red Bed with mesoscale structural traces, represented by interlaminar collapses and structural fractures. These structural traces allow rainfall infiltration into the rock body, mudstone softening and (potential) slide surface formation and evolution. High temperature and humidity, heavy rainfall and rain concentration are key characteristics of Chongqing climate. Plentiful rainfall is a main factor in slope evolution and a common excitation condition of slope hazards (Van Asch Th.W.J. *et al.*, 1996; El-Kadi A. I., 2001). In the rocks of the Chongqing urban area there has been chemical and physical weathering and the gradual planation of rock slopes. The bedrock is usually covered with thick saprolite, intensively weathered or residual layers, which is the seat of landsliding. Furthermore, steep slopes can be formed in sediments with gently inclined bedding. In Chongqing's urban region a low dip angle has allowed steep slopes to be formed. The mudstone in the interbed of sandstone and mudstone shows intensive weathering and cracking, due to the high temperature and humid climate. By contrast weathering process of the sandstone is very slow. Thus it is easy to form the concave cavities between the sandstone layers. Owing to structural fractures in the sandstone, especially X shear joint developing, sandstone blocks are liable to collapse. These conditions make Chongqing a city with a frail geological setting and frequent slope hazards. As urban construction scale continuously increases and relevant geological setting is increasingly disturbed these problems will be very evident.

Until 1998 there had been 777 places where various slope hazards happened. There were 503 slides, 89 collapses and 185 unstable rock masses. Hazard density of the main city zone along the Yangtze River is one dot per square kilometers, however hazard density of Yuzhong District eroded by the two Rivers is five dots per square kilometers (G. Xu, 1990; H. Q. Rao *et al.*, 1995; Y. S. Li. 1995; K. D. Hu, 1995; K. Liu *et al.,* 2002;W. N. Shu, S. Q *et al*., 1998). The slopes are mainly distributed from 160 meters to 300 meters in altitude. Zhongnutuo, Liziba and Zhengjiangsi along the Jialing River and Steel Mill of Chongqing, Caiyuanba and Hantanxi along the Yangtze River are all the regions with high occurrence rate of landslides. 'Medium type landsides' are divided into bedrock and bedrock-unconsolidated types. Although number of the bedrock slips is small they are large in size and their volume makes up 76% of the total volume of all slips. Slip surfaces of bedrock landslides currently develop near the interfaces of sandstone and mudstone. Dip angle of the basal sliding surface generally varies from 10^o to 40^o, but the slip plane in partial landslides may be at 5^o dip angle and even horizontal. The kind of slips with low dip angle is mostly correlated with strong lubricative action that is created when the mudstones meet water. There are large numbers of small scales unconsolidated landslides. On the basis of material comprising the slips the landslides are separated into residual (including intensively weathered layers) and collapsing talus slides and so on. The fluctuation of the river water level and rainfall are a main excitation factor. The collapses in the region are mainly distributed at Futuguan, Cangbailu along the Jialing River and Jiudukou, Yanziya and Leijiapo along the Yangtze River. Where collapses usually happen steep slopes have been shaped by the interbedded mudstone and sandstone in the region. Dense joints in the sandstones and the cavities formed by mudstone abrasion create conditions for occurrence of the collapses.

The volume of a collapse or landslide in Chongqing's urban area is about 10×10^4 cubic meters, most of which are small-scale slope hazards with less than 1×10^4 cubic meters. Its characteristic is high density and frequent occurrence rate. Therefore the risk of the geological hazards is huge. It can be seen from the data that in the urban region from 1985 to 1990 there occurred hundreds of collapse accidents that ruined more than 100 buildings and lead to death of 65 persons, and 37 railway intermissions and traffic stoppage of 200 hours. The volume of soils and rocks silting city roads reached 88×10^4 cubic meters with more than 100 million yuan direct losses (Z. Q. Du, 1994). In addition, latent economic social losses caused by collapsing rock and soil masses in Chongqing's urban region further exceed common collapse hazards themselves. It is a trend that any slope in the land gradually becomes low and is even leveled. This trend is an important and indispensable segment in the natural cycle of formation and evolution of the sedimentary rock and even lithosphere. Collapses and landslides are special manners of the slope planation. They are essentially natural processes, and when they affect and threaten human life and production activities they become geohazards. The landslides with huge volume, which happen in the uninhabited or undeveloped regions may be considered as natural processes, and not hazards. Thus not only single slide volume and hazard but also corresponding economic and social loss scales should be considered when damage grade of the slope hazard is evaluated. On May 1st 2001 road bed slope of national highway in Wulong, Chongqing a slip occurred, the volume of which was 1.2×10^4 cubic meters. The slip body completely ruined a residential building with 9 floors, which lead to death of 79 persons and interruption of the national highway for four days and nights (Y. P. Yin, 2001). In 2003 there were already 6.18 million people in Chongqing's urban region with high population density and limited city land for building. At the same time in its urban area there occur dense industrial and mining factories and enterprises, and great social economic load capacity per unit area (Z. Q. Du, 1994). Once slope hazards are encountered the losses will be disastrous.

In summary, Chongqing, where the Yangtze River and Jialing River meet, is located in the southeastern part of the Sichuan Basin. Due to long-term encroachment of the two Rivers the region shows remarkably undulating landforms. Thus Chongqing is typical mountain river city. The urban region is situated at the southwestern part of N-E-trending huge brush detachment folds constituted by Red Bed in Middle Mesozoic Era, which lie on the gentle syncline between the Zhongliangshan and Nanwenquan anticlines. Dip angle of interbedded strata of sandstone and mudstone of Shaximiao Group of the Jurassic, which constitutes the syncline, is 10^{o} to 20^{o}. Rainfall, prevalent slope relief, the Red Bed with soft and hard interphase layers and the dip angle of 10^{o} to 20^{o} determine high occurrence rate of slope hazards in Chongqing's urban region. Through two large-scale tectonic movements in Late Mesozoic Period and Late Eocene Epoch, development of interlaminar collapses and structural fractures in the stratum in the Red Bed of Shaximiao Group provides favorable conditions for rainfall infiltration and slope evolution and failure. Temperate and humid climate and concentrated heavy rainfalls accelerate slope evolution, and make occurrence of the slope hazards possible. Combination of these conditions makes Chongqing a city with a frail geological setting and frequent slope hazards. In the urban area hazard density is one dot per square kilometers, and the landslides are distributed on the slope region along the Rivers with 160 to 300 meters in altitude, and the collapses are mainly distributed at Futuguan, Chuangbailu along the Jialing River and Jiudukou and Leijiapo along the Yangtze River. Even without large-scale collapses and landslides in Chongqing City region slope hazards would still be disastrous due to high population density, high incidence rate, dense industrial and mining factories and enterprises and great social economic load capacity per unit area. These are key problems restricting sustainable development of Chongqing's urban region.

Chengdu's geological setting and environmental geological issues

Chengdu's geological setting

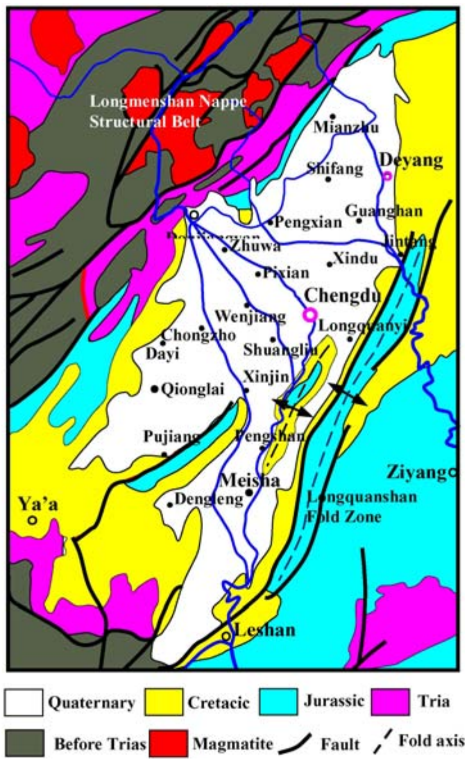

Figure 12. Geological sketch for Chengdu city and its periphery

Like Chongqing, Chengdu is a big city in the Sichuan Basin. However it possesses completely different geological and geographical settings (Fig. 10 and Fig. 12). Chengdu is located at the west of Sichuan Basin and the eastern part of the West Sichuan Plain, and is bordered by Longquanshan to the east. Therefore it belongs to plain city (nearby there are similar cities such as Doujiangyan and Deyang). The urban region, through which a branch of the Min River flows, is on level terrain with higher ground to the West (Fig 13). The average altitude is 506 meters. Annual rainfall in Chengdu was 920 millimeters from 1961 to 1990 and the average annual temperature is 16 ^{o}C with the highest temperate of 30 ^{o}C. Rainfall is mainly concentrated from Jun to Sep with annual relative humidity of 80%. In Middle Mesozoic Era N-E-trending gentle syncline developed, involving strata of the Cretaceous (K), the Jurassic (J) and the Triassic (T), between Longmenshan nappe structural belt and Longquanshan fault zone. Since Quaternary Period the syncline has been covered with Min River alluvial-proluvial fan with varying thickness and broad extent. Chengdu lies at the end of the fan (Fig. 13). In its periphery Longmenshan, Pujiang, Xinjin and Longquanshan active fault belts crop out and the earthquake intensity of which is VI degree. In the urban region the stratigraphy is simple, and there is no marked spatial change. The upper 1-3 m surface layer is occupied by yellow-gray silt clay and fill. The middle is brown- yellow gravels 10 to 20 meters thick, containing a few clay, silt clay and silt lenses. The bottom is lilac-red medial and thick-bedded mudstones of the Guankou Group of the Cretaceous. Due to high bearing capacity of the gravels (allowable bearing pressure is commonly from 700 to 1200 kPa) in Chengdu the layer supports most buildings. As a whole Chengdu's geological and geographical settings are advantage. However with city development, latent environmental geological issues will emerge, the most important of which is water resources.

Issues of groundwater resources

Chengdu City's groundwater comes from the gravel boulder bed of the Middle and Late Pleistocene Epoch to Holocene Epoch. It is a part of groundwater system of Min River's alluvial-proluvial fan on the West Sichuan Plain (Fig. 13). The thickness of this aquifer is commonly 15 meters but it reaches 35 meters. To the West the depth of the top of the aquifer is 10 meters, though in the urban area from 3 to 5 meters: water level fluctuates seasonally 1 to 3 metres. Ample groundwater supply originates from N-W-trending lateral runoff of groundwater of Min River, leakage of agricultural irrigation trenches and partial rainfalls. Bank discharge of groundwater into the rivers occurs. There is high infiltration to the aquifer in the urban region with the permeability coefficient of 15 to 40 m/d (M. L. Wu, 1999; Z. M. Xu *et al*., 2002).

Groundwater resources of the aquifer of the Quaternary in the West Sichuan Plain are 34.73×10^{8} m^3/a, with workable resources 25.90×10^{8} m^3/a, and with storage capacity 96.91×10^{8} m^3/a, which is a huge unexploited natural groundwater reservoir (Y. F. Liang, 1989; D. F. Zhen *et al*., 2004; X. J. Wang *et al*., 2004). Exploitation should not cause settlement problems, but would still be quite costly (W. S. Jing *et al*., 1989; X. C. Chen *et al*., 1999). Its exploitation would be very importance if the ecological environment at upper reach of Doujiangyan in Min River valley should gradually worsen. Frequent drought and severe water depletion occur at the hilly area of Red bed of middle Sichuan to the eastern Longquanshan (Fig. 10 and 14). It is suggested that river water of Doujiangyan be eastwardly diverted into the central section of Sichuan. Although the Project of West-to-East water diversion, which is an important part of groundwater exploitation in West Sichuan Plain, isn't yet executed it possesses good technical feasibility, especially under increasingly scarce water resources (M. L. Wu, 1999; Z. M. Xu *et al*., 2002). Groundwater in the middle part of Sichuan is crucial for water cycle of the West Sichuan Plain.

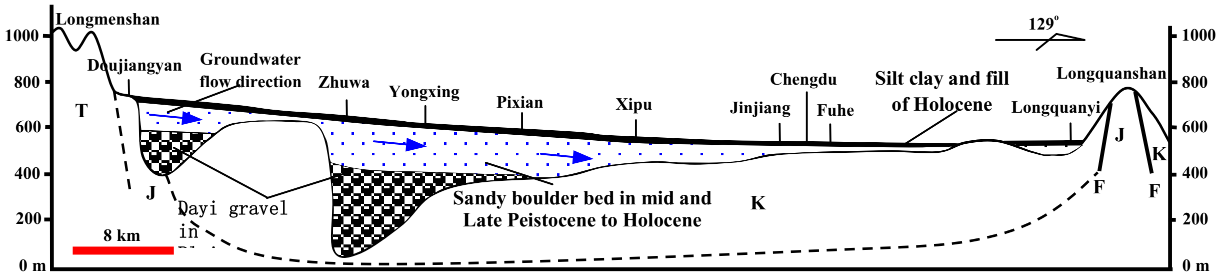

Figure 13. Geological section for giant Min river fluvial-Alluvial fan (Y. W. He, 1992)

The West Sichuan Plain has long been inhabited due to its geological and geographical setting. Since the 1980's all cities in the plain have rapidly developed and there are ambitious expansion plans towards 2020. Water resources are becoming scarce in the West Sichuan Plain, especially for Chengdu—a super city.

City structure of Chengdu exerts an influence on groundwater mainly through the replenishment of the aquifer. As stated above, the groundwater of the West Sichuan Plain is from ditch leakage, irrigation water and rainfall. After city constructions are built on the aquifer irrigation water and ditch supply vanish and rainfall replenishment is cut off by the impermeable covering of the infrastructure (X. C. Chen *et al*., 1999; J. P. Quan, 1997). In recent years partial pavement road slabs with vesicular texture are used instead and urban green area has increased. However these have a limited effect on infiltration to the aquifer. In principle when vertical supply is cut off the groundwater can get remote replenishment through lateral radial flow. If the city covers an extensive area of the aquifer this kind of supply is feeble (In natural conditions lateral supply of the aquifer only occupies 0.28% (Z. P. Wang, 1995)). In early days of the liberation the urban area of Chengdu was only 16 square kilometers (J. Jiang, 2002); then the effect of the city on groundwater is basically negligible. By 2004 the urban area had increased to 283 square kilometers (Plan and Design Institute in Chengdu, 2004). Adjusting and storage functions of groundwater in the urban region have been lost on the whole because it is far from the lateral supply boundary.

After urban structure cuts off vertical supply groundwater may be slowly replenished through lateral runoff, and at least maintain the existence of the aquifer. However the basements of tall buildings can severely impair the functioning of the aquifer. Before construction large-scale pumping of the ground is carried out, to dewater the excavation, and then the topsoil and sandy boulder bed of storage media are excavated. Finally the basement is constructed.

Construction of building basements results in a decrease in volume of the aquifer, damming of flows and reduced infiltration (Fig. 14).

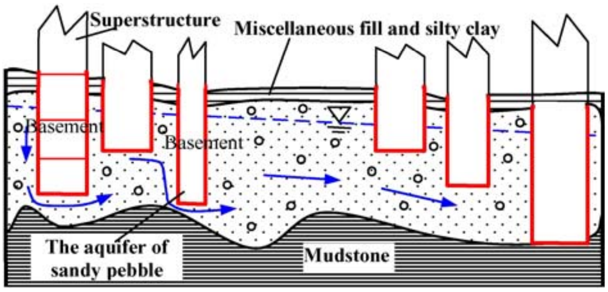

Figure 14. Sketch map for building foundations invading aquifer in Chengdu city

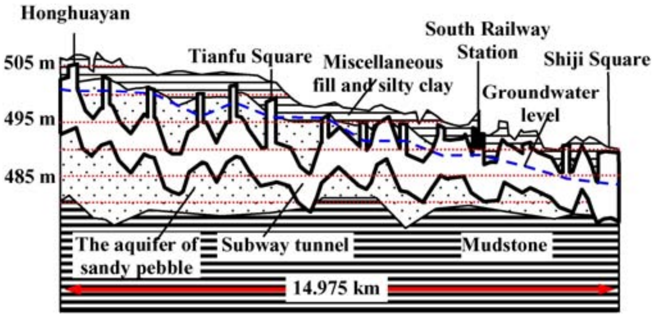

Figure 15. Simplified section of Chengdu subway

Since 1990's with fast development of Chengdu City and gradual extension of construction land more than ten-floor tall buildings with the height of over 24 meters have already become common (T. Lu et al., 2002). These buildings mostly use box foundations for basements. Embedment depth of the basement is currently over 7 meters. Some exceed 10 meters, and even break through the strata of the Quaternary and sit in the mudstone of the Cretaceous (X. B. Liao et al., 1998). Oversea Communion Center Edifice, located at Yanshikou, is composed of two towers with 37 floors and the podium. There are three floors in its basements. Embedment depth of its basement is 15.1 meters, and penetrating the aquifer by 11 metres, for 73% of its depth (J. B. Shao, 1996). The superstructure of Tongjin Edifice, situated at the crossing of Tongjin Road, is 15 floors, and there are two floors in its basement. Maximum embedment depth of the basement is 11.76 meters, and it intrudes into the aquifer by 8 meters (G. S. Huang, 1999). Chengdu Science and Technology Center Building is located near the Sports Center. Its superstructure is 32 floors, and there are two floors in its basement with local part of 3 floors. Embedment depth of the basement is 13.5 meters. Soil layer and aquifer are separately 5.5 and 17.5 meters in thickness, and the basement intrudes into the aquifer for 8 meters, which accounts for 46% of its total depth (Y. P. Cheng, 1997). Wangfujing Trade Building is made up of three main buildings from 23 to 46 floors and a podium with 7 floors. Maximum height of the buildings is 163 meters. Its superstructure is 43 floors, and there are 3 floors in its basement with foundation excavation depth of 18 meters. The aquifer is penetrated for 8 meters (D. Y. Fei, 1999). Compared with the superficial encroachment of common industrial and civilian construction basment on the aquifer, civil defense underground engineering has a more destructive effect by linear invasion of the aquifer. Civil defense engineering in Shuncheng Street was constructed with the length of 1269 meters and the width of 19 to 31 meters. Its embedment depth was from 7.3 meters to 12.5 meters, and water table was intruded by 5 to 10 meters. It forms a dam perpendicular to the flow, narrowing the water-carrying section and locally completely cutting off the flow (J. P. Quan, 1997; Y. D. Fu, 1995). As a result, groundwater natural flow is severely affected. Construction of the first-stage of the Chengdu subway is planned to begin at Honghuayan in the north, go through Tianfu Square and South Railway Station, and arrive at Shiji Square. There are 14 subway stations planned with the total system length of 14.975 km. N-S-aligned railway tunnel is mostly perpendicular to groundwater flow direction in the urban region. Because a principal part of the structure is basically embedded in the aquifer most of the railway tunnel breaks into the aquifer (Fig. 15) and underground flows will be markedly affected.

In summary, Chengdu, located at the eastern part of the West Sichuan Plain, is a typical plains city with the earthquake intensity zonation of VI. Located on the alluvial-proluvial fan of the Min River the geology of Chengdu is composed of miscellaneous fill and silty clay overlying Quaternary gravels with some silt and clay lenses and Cretaceous mudstone. Due to its high bearing capacity the gravel bed supports most construction. However fast urbanisation has damaged the groundwater environment of Chengdu. Ample groundwater resources in the fan are of importance for adjusting and storage of water resources in West Sichuan Plain, and possess key potential for relieving the scarcity of water resources in middle Sichuan. Groundwater in West Sichuan Plain mainly originates from ditch leakage, irrigation water and rainfall. Infrastructure can cut off the water supply source. On the whole adjusting and storage functions of groundwater in the urban region have been lost because the groundwater abstraction is far from the lateral recharge boundary. Construction of tall building basements and underground engineering in Chengdu leads not only to decrease of the aquifer space but also to severe destruction of the groundwater system and its recharge. In the future the planning and development of Chengdu will need to learn important lessons from the past damage to the groundwater resource.

ISSUES OF ENVIRONMENTAL HYDROLOGICAL GEOLOGY AND URBAN PLANNING

When planning cities the future need for urban development should be considered. Lessons should be learnt from the problems that have occurred in the past if sustainable development is to be achieved. Since 1980's like other cities Kunming, Chongqing and Chengdu have rapidly developed. Many issues have emerged confining urban development, the most important and basic of which are environmental geological issues. The problems, which are more distinct in Kunming and Chengdu, couldn't be adequately treated when urban expansion planning towards 2020 was constituted at the beginning of this century.

1) Excessively fast development and great geographical expansion are common characteristics of the two cities. This worsens their geological environment, and accelerates the occurrence of latent environmental geological issues.

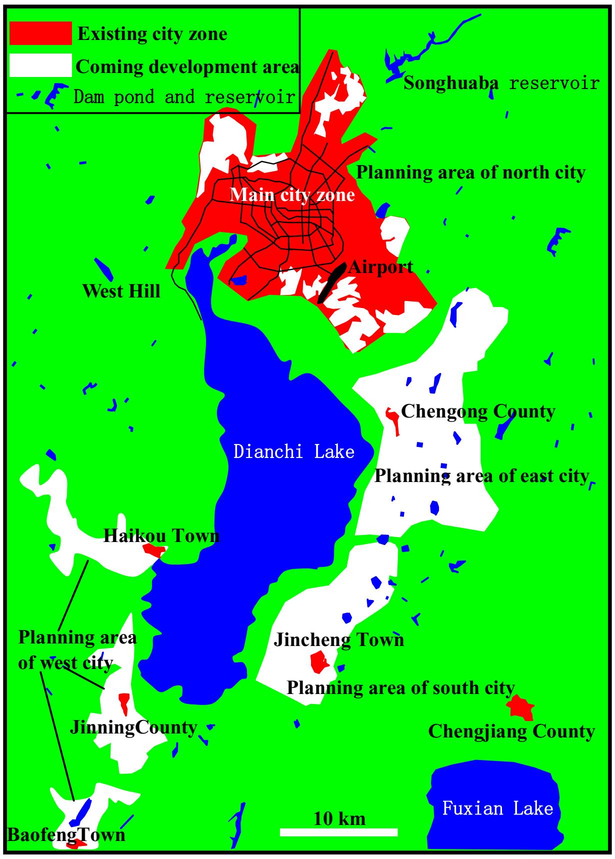

Figure 16. Kunming city planning sketch map from 2002 to 2020 (Suevey and Mapping Institute in Kunming, 2003)

Until 2003 Kunming's main city zone occupied an area of 180 square kilometers. According to developmental planning from 2002 to 2020 (Survey and Mapping Institute in Kunming, 2003) the main city zone will increase to 220 square kilometers. In addition, the east city (nowadays Chenggong County), the south city (nowadays Jincheng County, Xinjie and Jinmapu Village) and the west city (nowadays Haikou and Gucheng town and Jinning County) (Fig. 16) will be built. The future Kunming will cover an area of 460 square kilometers. The population of 1.87 million will be increased to 4.5 million. It can be seen from Fig. 1 and Fig. 16 that almost the entire flat ground underlain by Quaternary lake-facies sediments in Dianchi Lake's periphery will be occupied by the city in 10 years time according to development plan. Furthermore, large area of the upland ramps will be brought into the developed region. The enclosure-type development strategy around the Lake will be quite disadvantageous to sustainable development of Kunming. Groundwater of the Quaternary in Dianchi Lake's periphery is mainly from rainfall supply. After construction in the development areas the groundwater recharge will be cut off by the impermeable surface cover and groundwater level will fall. With increase of urban population it is impractical to completely forbid the exploitation of groundwater. However past exploitation caused an extension of the subsidence region, and even induced new sedimentation in the lake. The execution of new planning will further deteriorate replenishment conditions of Dianchi Lake and result in further decline of groundwater cycles and self-purification capacity.

Under natural conditions Dianchi Lake receives its water supply from the rivers rising in the surrounding mountains, the lateral supply of groundwater in the Quaternary aquifers around the Lake and rainfall incident on the lake. Since 1980's due to ceaseless increase of the population in Dianchi valley water has become increasingly scarce. Until 2003 one large-size reservoir, seven middle-sized ones, 34 small I-type and 80 small II-type ones in the valley had been constructed with 733 dam ponds (Z. S. Yan *et al*., 1993; Z. W. Duan *et al*., 2002). There are big or small dotted water bodies in the hilly region in Dianchi Lake's periphery (Fig. 16), which effectively hold up the surface runoff. Groundwater of the Quaternary around Dianchi Lake receives rainfall supply in rainy season, and is drained into the lakes, exerting a key influence on the cycle of the Lake water. Constructions of new urban region will severely threaten and even cut off the valuable supply resources of Dianchi Lake. It is predicted that with time the Dianchi Lake will only receive the rainfall in the range of the Lake itself and there will no drainage at its discharge port—Haikou Town (Fig. 16), and that it is fully possible to become a genuine sewage reservoir due to lower and lower water level and worse and worse water quality.

According to general planning of Chengdu City from 2003 to 2020 central city land will increase to 400 square kilometers from 283 square kilometers, and city lands in Xindu, Qingbaijiang, Longquanyi, Huayang, Wenjiang and Pixian near Chengdu will increase from 177 square kilometers to 380 square kilometers (Plan and Design Institute in Chengdu, 2004). Expansion range, especially along the northwestern direction, is quite large. Year-by-year subsidence of the urban underground water level and the thought to develop towards the southeastern part are considered in the planning to some extent. If urbanization is fully achieved in the whole around-city expressway and expansion of Pixian etc, so-called united urban zone will be formed with the total area of 3681 square kilometers, which play a severely destructive role in groundwater system in the West Sichuan Plain. Even if there is a buffer area between the central city and satellite towns, groundwater system and runoff alternate capacity will be badly destroyed due to excessively small area of the buffer zone. Once the entirety of groundwater system is broken (particularly construction foundation breaking into the aquifer) it is very difficult to renew it.

2) No pertinent detailed rules of the planning are constituted against the environmental geological issues occurring in the city development.

At present in Kunming, Chongqing and Chengdu three cities bearing capacities of the foundations can't be enough used. In the main city zones there occur many buildings with less than ten-floors, there are even buildings with 3 to 4 floors. Effective utilization of comprehensive capacity in the old city should be considered in the city planning, but not just plain expansion. Reasonable development of tall buildings and ample utilization of the foundation bearing capacity inhibit the aquifer of Kungming and Chengdu etc. from being rapidly covered, and save rare land resources. Developing tall buildings and inhibiting low ones can increase city constructions and development cost. However these may prohibit population of big cities from rapidly expanding, and spur non-agricultural population to transfer in reason to small cities and towns. Currently urban construction lands in the southwest China are not as scarce as the eastern coastal regions and the Zhujiang River Delta area. However during the last 20 years fast expanding of the city populations has made Shenzhen etc. demolish the buildings with 15 floors, as should cause people's attentions.

In order to protect groundwater system in the West Sichuan Plain box bases used for basements should be confined or inhibited in Chengdu and the satellite towns. It is suggested that shallow foundation be used due to high bearing capacity of sandy gravel bed below the silty clay in Chengdu region, and that gravel piles be used for tall buildings. Under exceptional conditions concrete piles can be used. When natural foundations are reinforced, underground structures penetrating the aquifer should be avoided.

CONCLUSION

1) Kunming, Chongching and Chengdu in the southwest China are lakeside city in the Yungui Plateau, mountain city and plain city respectively, which can be widely representative of their regions with different geological settings. **Kunming** is located at the northern part of Dianchi taphrogenic lake. In its periphery active fractures develop, and it is the high-intensity city with the earthquake intensity of VIII. The foundation of Kunming is composed of dualistic structures that include the foundation base of the Proterozoic and cover stratum of the Quaternary. Engineering constructions are mainly in the stratum of the Quaternary with Dianchi lake facies. **Chongqing**, where the Yangtze River and Jialing River meet, is located in the southeastern part of the Sichuan Basin, and with undulating relief. The urban zone is situated at the southeastern part of huge brush detachment folds constituted by Red Bed of the Mesozoic and at the gentle synclinore composed of sandy mudstones of the Jurassic between Zhongliangshan and Nanwenquan anticlines. Its city construction mainly deals with the Red Bed of the Jurassic and the residual deposits. **Chengdu** is located the eastern part of the West Sichuan Plain, There is Quaternary foundation structure in Chengdu, which is composed of fill and silty clay, gravel with silt and clay lenses and Cretaceous mudstone. The gravel bed is the supporting course of most constructions.

2) Since 1980's with rapid development of three cities some environmental geological issues nearly correlated with sustainable development have occurred in the there cities. Foundation base of Kunming is composed of organic clay, silt fine-grained sediments with lake facies of the Quaternary. Due to bad storage capacity and limited groundwater resources excessive groundwater extraction leads to large-range ground subsidence in the past. Meanwhile its foundation base is a typical soft foundation with high water content, high compressibility and low shear strength and bearing capacity. Thus pile foundation is used in most construction engineering, and cost of urban construction and expansion is increased, and foundation slope failures frequently happen. Temperate and humid climate, concentrated heavy rainfalls, prevalent slope relief, middle-scale structural traces developed in the Red Bed and the dip angle of 10^{o} to 20^{o} make Chongqing a city with frail geological settings and frequent slope hazards. Although small-scale collapses and landslides in the city region of Chongqing happen, due to high population density, high incidence rate and dense industrial and mining factories and enterprises, landslide hazards create high risk, which is an important problem restricting the sustainable development of Chongqing. Alluvial-proluvial fan of the Min River is the carrier of Chengdu, where plentiful groundwater is vital to adjusting and storing water resources themselves in the West Sichuan Plain, and quite costly to relieve the scarcity of water resources in the middle Sichuan. Fast development of Chengdu has exerted a markedy destructive influence on the groundwater system. Construction in the cities cuts off main supply resources of the groundwater. As a result groundwater level in the urban zones gradually falls, and adjusting and storing functions of the aquifer are basically lost. Tall buildings' foundations and partial underground

engineering cause decrease of the aquifer space, and heavily destroy groundwater system and runoff alternate capacity.

3) Environmental geological issues should be the most important factors considered in city planning. However not enough emphasis is given to these issues in planning to the 2020 planning horizon for the three cities. The problems of Kunming and Chengdu are more marked. The same problems in the current planning are excessively fast and large scales that worsen its environmental geology, and that accelerate occurrence process of latent environmental geological issues.

4) Aimed at specific environmental geological issues the city planning normalizes city constructions by the regional rules, and inhibits geological environment from in-depth further worsening. With the foundation bearing capacity fully utilized, tall buildings can be reasonably developed so that the rate of expansion of the cities can be effectively controlled in order to protect the aquifer. Chengdu, located on the underground reservoir in West Sichuan Plain, can fully make use of high bearing capacity of sandy gravel bed, and use shallow foundation and gravel pile foundation. The box foundation should be inhibited to avoid underground structure breaking into the aquifer.

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