CHAPTER 6

DEEP GEOLOGICAL DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE IN CHINA

Guoqing Xu[1], Ju Wang[1], Hualing Zheng[2], and Donghui Sun[3]

1. Beijing Research Institute of Geology, China National Nuclear Corporation, P.O. Box 9818, Beijing 100029
2. Bureau of Science and Technology, China National Nuclear Corporation
3. Everclean Environment Engineering Company, China National Nuclear Corporation

6.1 INTRODUCTION

China is now facing the challenge of how to safely dispose of nuclear waste. China's nuclear industry was first established in 1955, five years after the birth of the People's Republic of China. With the development of nuclear facilities, more and more radioactive waste has been generated. Much of liquid high level waste has been accumulated to date (Luo et al, 1995), and it is stored in stainless steel casks, waiting for vitrification.

On the Chinese mainland, there are two nuclear power plants (NPPs) in operation: the Qinshan NPP in east China's Zhejiang province and the Daya Bay NPP in south China's Guangdong province (Fig. 6.1). In the next five years, four more NPPs (8 units) will be built (Fig. 6.1); their estimated capacities are listed in Table 6.1. China has plans for a significant nuclear energy development. The total electrical capacity produced by the NPPs is planned to reach 20,000 MW by 2010. In the near future, China is also facing the problem of disposing of the spent nuclear fuel from the NPPS. At present, the national policy is that the spent fuel should be reprocessed before final disposal.

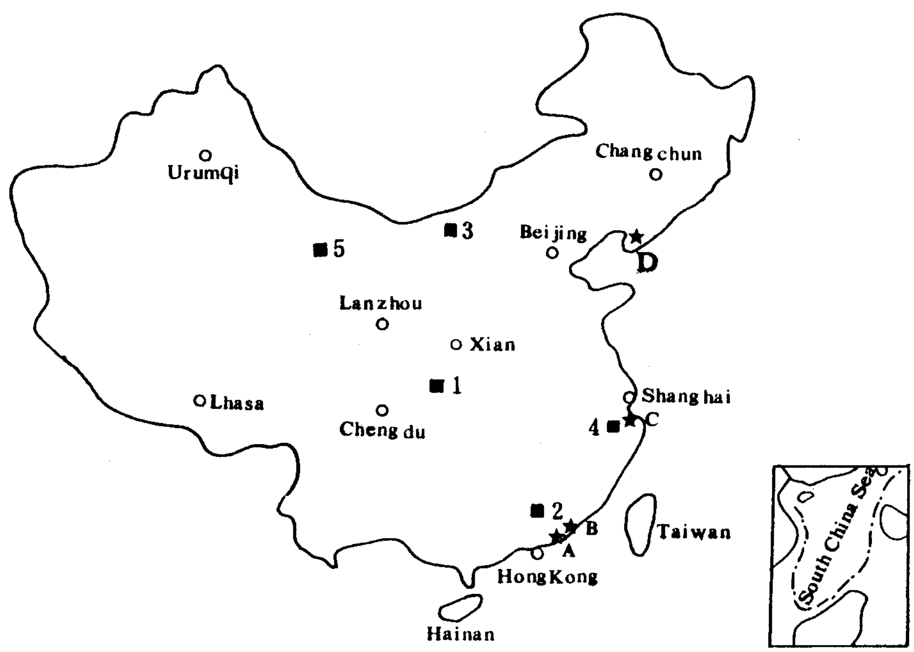

Figure 6.1. Map showing distribution of nuclear power plants (NPPs) on Chinese mainland. Legend: A - Daya Bay NPP; B - Lin'ao NPP; C - Qinshan NPPs (Phases 1, 2, and 3); and D - Liaoning NPP. Preselected regions for development of HLW repository: 1 - southwest China (granite, shale): 2 - Guandong area (granite); 3 - Inner Mongolia (granite); 4 - east China (granite, tuff); and 5 - northwest China (mudstone, shale, granite).

Table 6.1. Nuclear power plants of China.

	Name of NPP	Province	Capacity (MW)	Remarks
1	Qinshan	Zhejiang	300 x 2	in operation
2	Qinshan (2nd phase)	Zhejiang	600 x 2	under construction
3	Qinshan (3rd phase)	Zhejiang	700 x 2	to be built
4	Daya Bay	Guangdong	900 x 2	in operation
5	Lin'ao	Guangdong	1,000 x 2	under construction
6	Liaoning	Liaoning	1,000 x 2	to be built

6.2 ORGANIZATION

In China, work related to radioactive waste disposal is managed by the China National Nuclear Corporation (CNNC). The organizational structure for the disposal of high level radioactive waste is shown in Figure 6.2.

The China Environmental Protection Agencyis responsible for the issuance of related regulations, the final review of environmental impact statements, and the licensing for the construction and operation of a repository. The China National Nuclear Safety Administration is responsible for the safety issues related to the dispos-

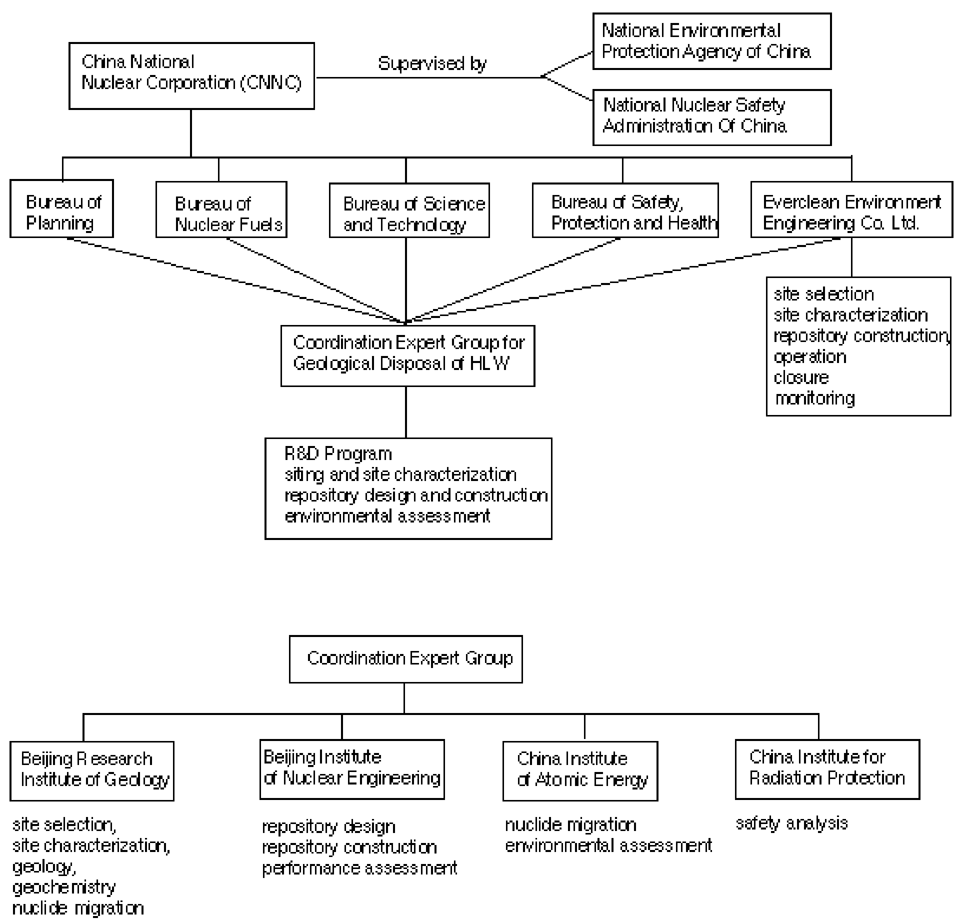

Figure 6.2. China's organizational structure for the disposal of high level radioactive waste.

al of high level waste.

The CNNC is responsible for the transportation of HLW and spent fuels, reprocessing of spent fuels, vitrification of liquid HLW, and final geological disposal of HLW. Under CNNC, four bureaus are involved in the disposal process: Bureau of Planning, Bureau of Nuclear Fuels, Bureau of Science and Technology and Bureau of Safety, Protection and Health.

The Everclean Environment Engineering Corporation, attached to CNNC, is responsible for site selection, site charactererisation, construction, operation, closure and monitoring of repositories of low and intermediate level, and high level radioactive waste.

A Coordination Expert Group was organized for the geological disposal of HLW in 1986. The group is composed of experts from the Beijing Research Institute of Geology, Beijing Institute of Nuclear Engineering China Institute of Atomic Energy, and China Institute for Radiation Protection. The group is responsible for R & D programs, site selection, research work related to site characterization, repository design, environmental assessment, safety analysis and performance assessment.

6.3 DEEP GEOLOGICAL DISPOSAL PROGRAM

In 1985, CNNC worked out an R & D program which has been called the Deep Geological Disposal (DGD) of HLW (Yang, 1992). The program is divided into 4 phases:

Phase 1: 1985-2025 Site Selection and Site Characterization

1. 1985-1986, Nationwide screening;
2. 1986-1988, Regional screening;
3. 1989-2010, District screening and preliminary site characterization;
4. 2011-2015, Pre-feasibility study of the pre-selected district;
5. 2015-2017, Licensing for site characterization;
6. 2017-2023, Site characterization and suitability study; and
7. 2023-2025, Licensing for the site.

Phase 2: 2025 - 2029, Repository Design

Phase 3: 2041-2050, Repository Construction

Phase 4: 2051- , Repository Operation.

Between Phase 2 and Phase 3, there is a 10-Year interval, during which an underground research laboratory will be built near the selected site between 2028 and 2033. Afull-scale *insitu* test and disposal demonstration will be conducted in the laboratory between 2034 and 2040. The final repository design will be revised after the work in the underground research laboratory is finished.

According to China's policy, the final form of the disposed waste will be vitrified radiowastes after reprocessing. The conceptual design for the HLW repository will be a shaft-tunnel model, which will be located in the saturated zone in granite.

6.4 PROGRESS IN SITE SELECTION

According to the DGD Program, the site selection for China's HLW repository is in progress, and granite is considered as the candidate host rock for the repository. The site selection process, started in 1985, is composed of 4 stages: nationwide screening, regional screening, district screening and site screening. At present, the third stage has been reached, and the screening efforts are focused on the Beishan area, Gansu province in northwest China.

6.4.1 Siting Criteria

Because of the high radiotoxicity and long half-life of radionuclides in high level waste, sites for HLW repositories should be selected very carefully. Siting guidelines, or siting criteria, have been issued by many countries or international organizations, such as USA, Sweden, EC, IAEA, etc. Taking China's situation into account, as well as experience in other countries, we proposed preliminary siting guidelines that have been followed during our work (Xu, 1992).

The general siting principle is that, under the effects of natural and human activities, the long term (100,000 year) safety of the repository can be obtained, and the disposed radioactive wastes can be prevented from entering the biosphere and harming human beings. Furthermore, the following factors are considered in the siting process. However, detailed and exact technical requirements and limits for these natural factors have not been worked out.

Social Factors

- the distribution of nuclear industry in China;
- the animal and plant resources, the potential mineral

resources;
- the attitude of the public and the local government;
- the requirement of national environmental protection laws; and
- the feasibility for construction and operation of the repository.

Natural Factors

- natural geography, including topography, climate, hydrology etc.;
- geology, including crustal stability (earthquakes, active faults, etc.); and
- crustal stress, crustal thermal flow, host rock type, hydrogeology and engineering geology.

6.4.2 Progress in Site Selection

Since 1985, the site selection for China's HLW repository has progressed through three stages: (1) nationwide screening (1985-1986); (2) regional screening (1986-1988); and (3) district screening (1989-present).

Nationwide Screening (1985-1986)

During this stage, the first work was the investigation of the site selection process conducted in other countries. Then, based on these experiences, and considering the distribution of China's nuclear industry, the problems of crustal stability and social economic conditions, the following five regions were selected for the repository (Fig. 6.1): southwest China, Guangdong Area, Inner Mon-golia, east China, and northwest China. In this stage, granite, tuff, mudstone and shale were considered as candidate host rocks.

Regional Screening (1986-1988)

Based on the work of Stage 1, twenty-one districts were selected for further investigation within the five above mentioned areas:

1. *Southwest China.* Three districts were selected: Hanwangshan district, Zhongba district, and Hannan district. The potential host rocks are shale, biotite granite, and plagioclase granite, respectively.
2. *Guangdong Area.* Since the Daya Bay NPP is located in this area and more NPPs are planned to be built, it was considered a potential area for the HLWrepository. The candidate geological formations are the Fuogang granite body and the Jiufeng granite body. However, because of the rapid development in the Guanadong province, this area may not be considered for further investigation.
3. *Inner Mongolia.* The selected districts, including Parjiang Haizhi and Dabaolitu districts, are located in central Inner Mongolia. The host rock is Hercynian granite.
4. *East China.* In east China's Zhejiang and Anhui provinces, six districts have been selected: Lin'an, Gaoyu, Chenshi, Jiangshan, Guangde and Yixian. The host rocks include granite and tuff. The Chenshi district is located on a small island composed of granite.
5. *Northwest China.* The selected area is located in northwest China's Gansu Province It is the most promising area for the construction of a HLW repository. It is an arid gobi area with very low population density and without an economic potential. Atotal of five districts have been selected for investigation:

   - Toudaohe-Xiatianjinwei, biotite monzonitic granite;
   - Kuangqu, mudstone;
   - Baiyuantoushan, quartz diorite;
   - Qianhongquan, K-feldspar granite and plagioclase granite; and
   - Jiujin, plagioclase granite.

District Screening (1989-present)

Since 1989, our work has been focused on northwest China, with granite considered as the candidate host rock. The following aspects of the area have been studied: earthquakes, structural framework, active faults, crustal stability, lithology, hydrogeology, and engineering geology. According to the crustal stability, we consider the Qianhongquan and Jiujin districts, located in the southern part of the Beishan Folded Belt, as the most promising districts, and further work will be conducted in those areas.

6.5 BEISHAN AREA, GANSU PROVINCE, NORTHWEST CHINA

6.5.1 Regional Geology

Regional Tectonics

The Beishan area in Gansu Province, is the preselected area for a HLW repository in China. Geographically, the Beishan area is located north of the town of Yumen in northwest Gansu province, China. Tectonically, it is located in the Erdaojin-Hongqishan compound anticline of the Tianshan-Beishan folded belt (Fig. 6.3). The anticline strikes nearly east-west, with its core composed of schist, laminated migmatite of the Laojunmiao Group and Dakouzhi Group of pre-Changchengian age, and its limbs are composed of schist, marble, quartzite and migmatite of the Yujishan and Huayaoshan Groups of pre-Changchengian age. In addition, along the limbs, there are Jiujin Caledonian magmatite (plagioclase granite), Baiyuantoushan Caledonian magmatite (quartz diorite) and Qianhongquan Hercynian magmatite (monzonitic and orthoclase granites). These magmatite rocks are the main candidate host rocks for the repository.

The border between the Beishan area and the Hexi Corridor Transitional zone is the blind Sulehe fault. Within the Beishan area there are three east-west-striking large scale ductile shear zones (DSZ), namely: South Erduanjin, Zhongqiujin-Jinmiaogou, and Erdojin-

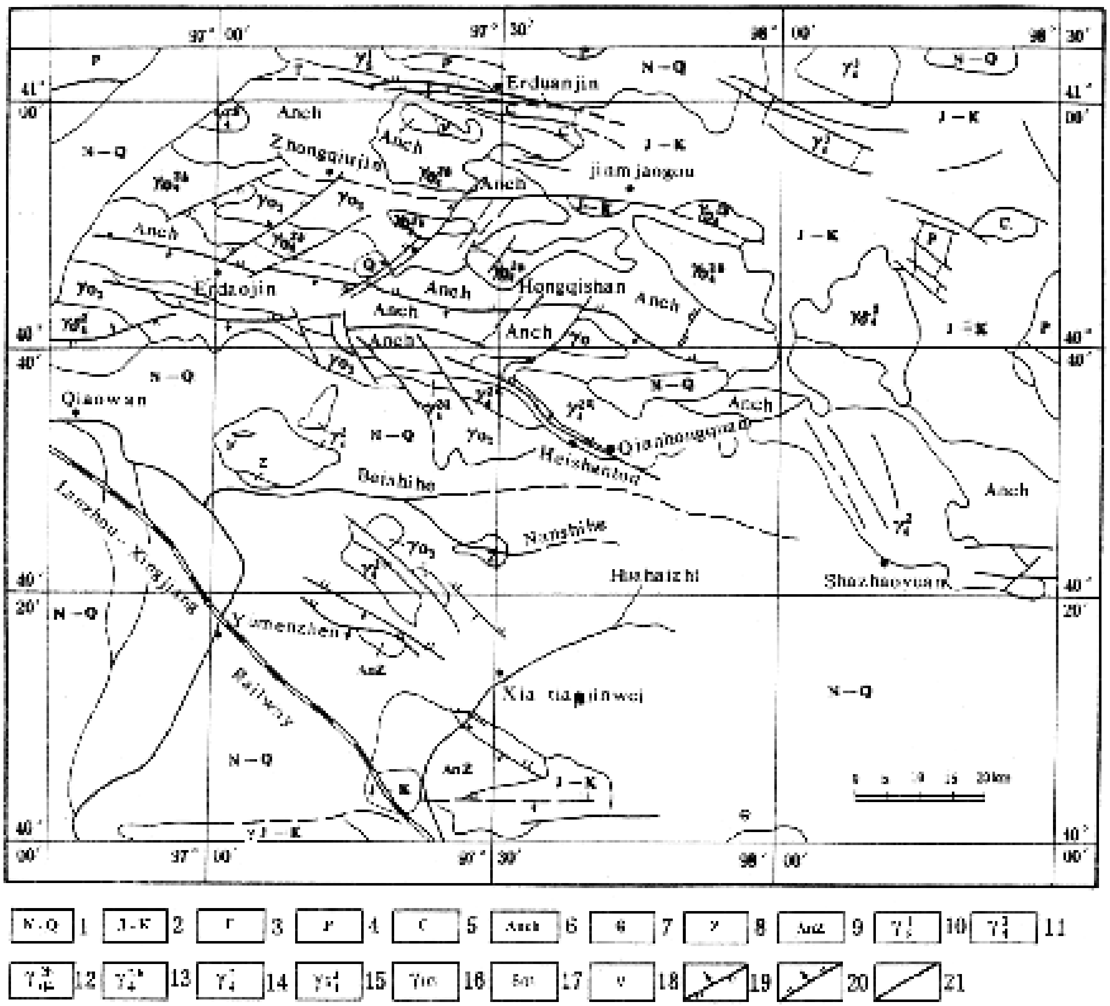

Figure 6.3. Geological sketch map of the Beishan area, Gansu Province, northwest China containing the pre-selected area for China's high level radioactive waste repository. Legend: 1 - Tertiary and Quaternary sediment; 2 - Cretaceous and Jurassic sandstone, shale and sandstone; 3 - Triassic conglomerate and pebbly sandstone; 4 - Permian System; 5 - Carboniferous system; 6 - Pre-Changchengian schist, gneiss, marble and migmatite; 7 - Cambrian System; 8 - Sinian System; 9 - Pre-Sinian System; 10 - Yanshanian granite; 11 - Heicynian granite; 12 - Heicynian plagioclse granite; 13 - Heicynian orthoclase granite; 14 - Heicynian Plagiolcase granite and two-mica granite; 15 - Heicynian granite diorite; 16 - Caledonian plagioclase granite; 17 - Caledonian quartz diorite; 18 - gabbro vein; 19 - normal fault; 20 - reverse fault; and 21 - fault.

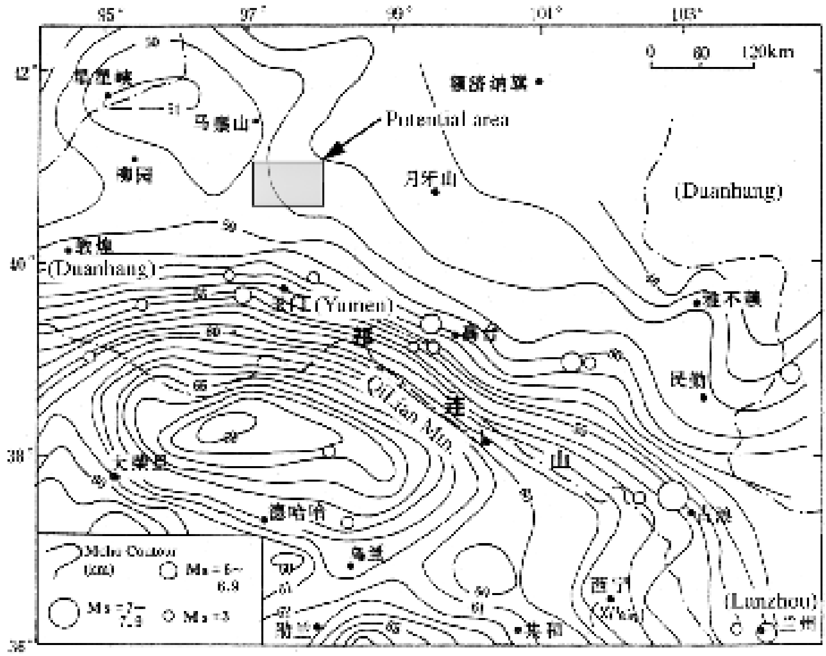

Figure 6.4. Moho discontinuity iso-depth contour map of northwest Gansu, China.

Hongqishan. The activity of brittle faults developed within the shear zones is a key factor affecting the crustal stability of the area.

The Zhongqiujin-Jinmiaogou DSZ is east-west striking with a length of 90 km and a width ranging between 50 and 2000 m. It was developed in monolithic gneiss, granite and sericite slate during the Hercynian period. The maximum depth of the shear zone is about 10 km. Several east-west striking brittle faults are developed in the shear zone. However, these faults do not cut the Quaternary sediments, and no earthquakes with Ms > $4^3/4$ have been recorded along them, which indicates that they are not active faults.

The Erdaojin-Hongqishan DSZ is about 130 km long and has a maximum width of 7 km. The southern and northern borders of the shear zone are two east-west striking brittle faults which are not active faults, either.

Crustal Structure

According to the main tectonic units, deep geophysical features and the crustal thickness, the crustal structure of the western Gansu province can be divided into the areas of Beishan-Alashan, North Qilian Mt., Hexi corridor, and Qilian. The selected area for the HLW repository is located within the Beishan-Alashan area. The depth contour of the crust in the area strikes NWW-EW. The thickness of the crust is 47-50 km (Fig. 6.4), and it gradually increases from north to south with very little variation. The gravity anomaly is -150 to -225x10^{-5} m/s^2 (Fig. 6.5) with a gradient that is less than 0.6 mGal/km. On the gravity anomaly map, the contours are very sparse without obvious step zones, indicating that there are no large faults extending to the depth of the crust. Based on these characteristics, the crust in the Beishan area possesses a block structure with good integrity.

Earthquake Activity

Earthquakes are a demonstration of modern crustal movement, and have a close relationship with tectonic movement, especially with the intensive activityof large deep-rooted faults. The Beishan area is located north of the Hexi Corridor earthquake zone. In this area, there is a lack of large active deep-rooted faults and strong earthquakes. According to data provided by the National Seismological Bureau of China, no earthquakes with Ms > $4^3/4$ have been recorded in the Beishan area. On the "Seismic Intensity Regionalization Map of China (1:4,000,000)", the Beishan area is within a VI seismic intensity region (Fig. 6.6).

In sharp contrast to the Beishan area, the Hexi Corridor earthquake zone has several active NWW deep-rooted faults. Along the North Hexi Corridor Great Fault, several intensive earthquakes took place, e.g., the M=7 1/4

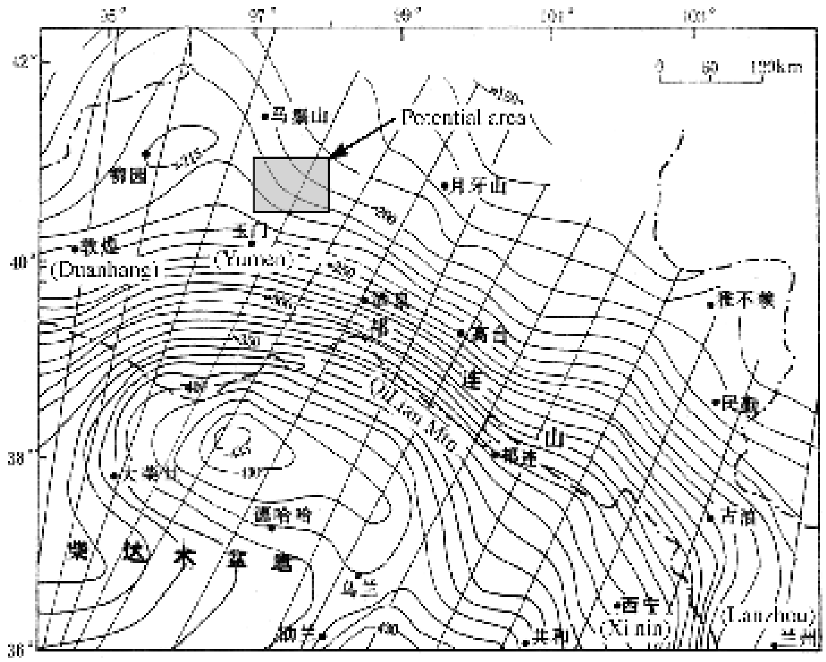

Figure 6.5. Regional magnetic anomaly map of northwest Gansu, China.

earthquake in Mingle County in 1790; the M=7 1/2 earthquake in Shandan County in 1954; and the M=6 earthquake in Gaotai County in 756.

Neotectonism and Tectonic Stress Field

Neotectonism refers to the crust tectonic movements since the Tertiary, including the horizontal and vertical movement of the crust, volcanism, earthquakes and slides, etc. According to the neotectonic characteristics, the western Gansu Province can be divided into three parts, namely: the Qilianshan blocking and intensive uplifting region; the Corridor depression region; and the Beishan weakly uplifting region (Fig. 6.7). The selected area for the HLW repository is located within the Beishan weakly uplifting region. The land form of the area is characterized by a flatter gobi and small hills with elevations above sea level, ranging between 1000 and 2000 m. The height deviation is usually several tens of meters. Since Tertiary time, it is a slowly uplifting area without obvious differential movements. The rate of uplift for the crust in the area is about 0.6 - 0.8 mm/a, much lower than that of the Qilian region (1.5-1.8 mm/a).

Comprehensive analysis of the structural deformation of the Cenozic faults and folds indicates that the area is undergoing horizontal compression at present, and the principal compressive stress is between 30 and 60 degrees. The data provided by the mechanism at the source of earthquakes show that the direction of the principal compressive stress is about 40 degrees.

The strike of the main faults in the Beishan area is between 95 and 120 degrees. The angle between the direction of the principal compressive stress and the strike of the main faults, which is also called the superimposed fault angle, ranges between 55 and 80 degrees. These are within the range of stable superimposed fault angles, suggesting that the main faults are stable and will not undergo strike-slip displacement.

6.5.2 Regionalization and Evaluation ofCrustal Stability

There are nine indices to evaluate the crustal stability of an area, namely: (1) crustal structure and deep-rooted faults; (2) Cenozoic crustal deformation; (3) Quaternary block and faults; (4) Quaternary and modern tectonic stress field; (5) Quaternary volcanoes and geothermal fields; (6) ground deformation and displacement; (7) gravity field; (8) earthquake strain energy; and (9) earthquakes. According to these indices, crustal stability can be divided into four classes: (1) stable region; (2) basically stable region; (3) sub-stable region; and (4) unstable region.

The western Gansu Province can be divided into three

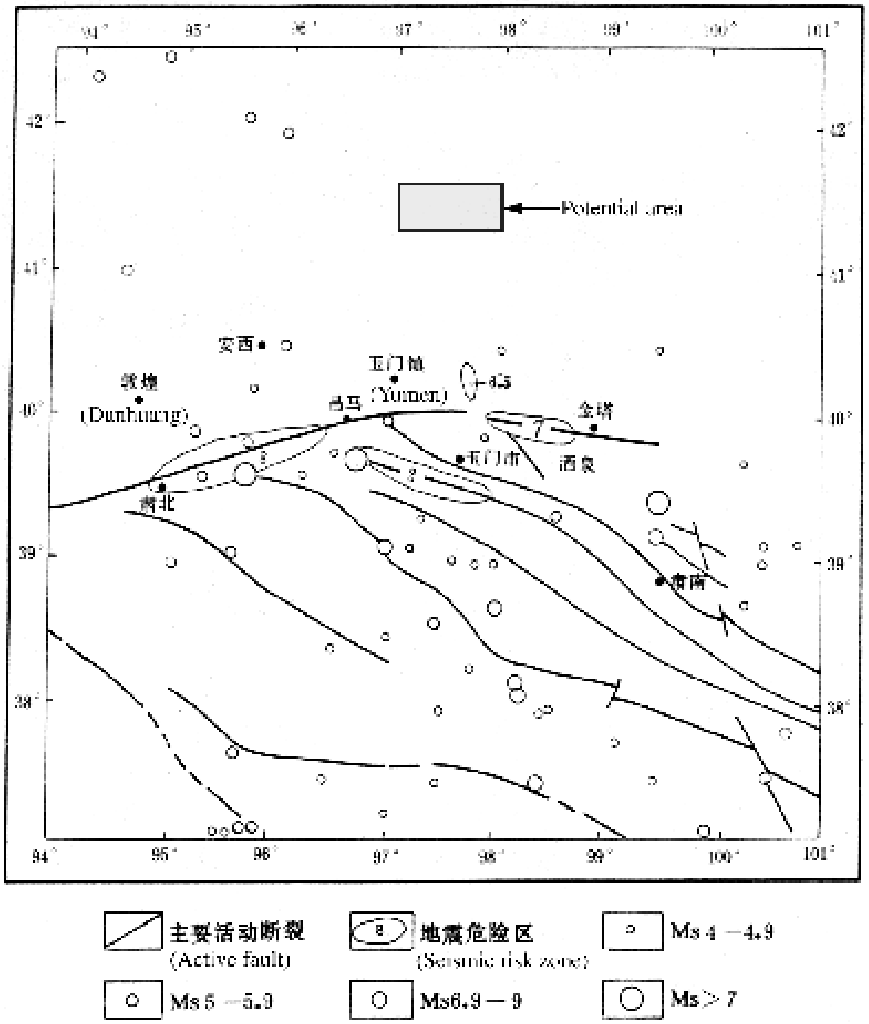

Figure 6.6. Seismic risk zoning of northwest Gansu, China.

regions (Fig.6.8): (1) Beishan stable region; (2) Yumenzhen-Huahai sub-stable region; and (3) Hexi Corridor unstable region. The characteristics of these regions are summarized in Table 6.2. From the table we can see that the Beishan region has a block crustal structure with good integrity and without regional active faults, and it is a slowly uplifting region. The direction of the principal compressive stress in the area is about 40 degrees, and the superimposed fault angles indicate that the main faults will not have strike-slip displacement. There are no gravity steps in the area, and no records of intensive earthquakes either. The earthquake intensity of the area is less than 6. These features show that the crust in Beishan area is more stable than in the southern regions, and is a suitable candidate region for a HLW repository. On this basis, smaller districts can be further selected for detailed site characterization.

Geological work in the Beishan area is at the very beginning stage, and the above data are only preliminary results. In the future, systematic site characterization work will be conducted year-by-year, to determine the suitability of the Beishan area and to select the final site for a HLW repository.

6.6 OTHER STUDIES

The geological disposal of HLW is a long-term comprehensive task. In addition to site selection and site characterization, other studies are also being conducted on:

- Site preselection for an underground research laboratory;
- Experiments on radionuclide migration (laboratory and field);

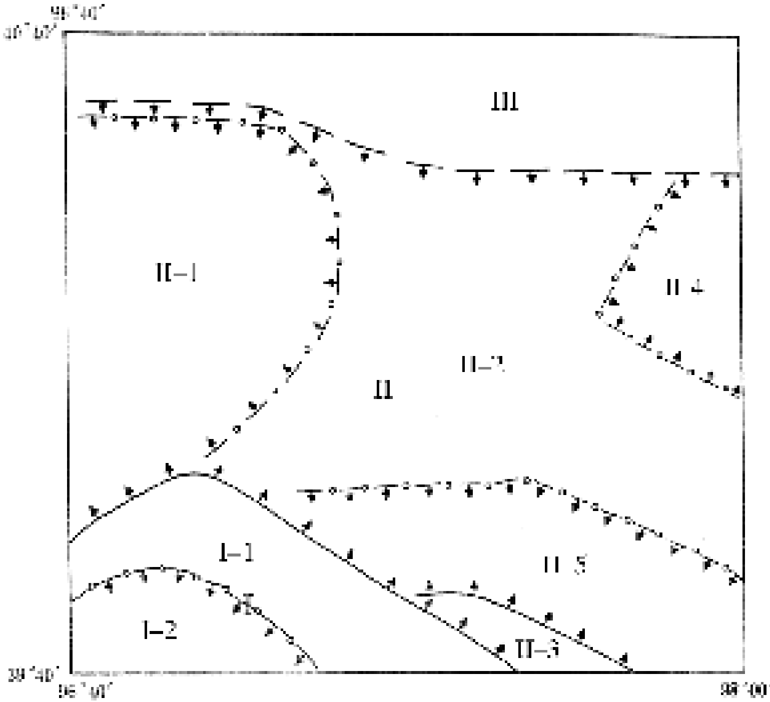

Figure 6.7. Map showing the regions of neotectonics. 1 - Qilian Mt. intensive uplifting region; II - Corridor depression region, and III - Beishan slight uplifting region.

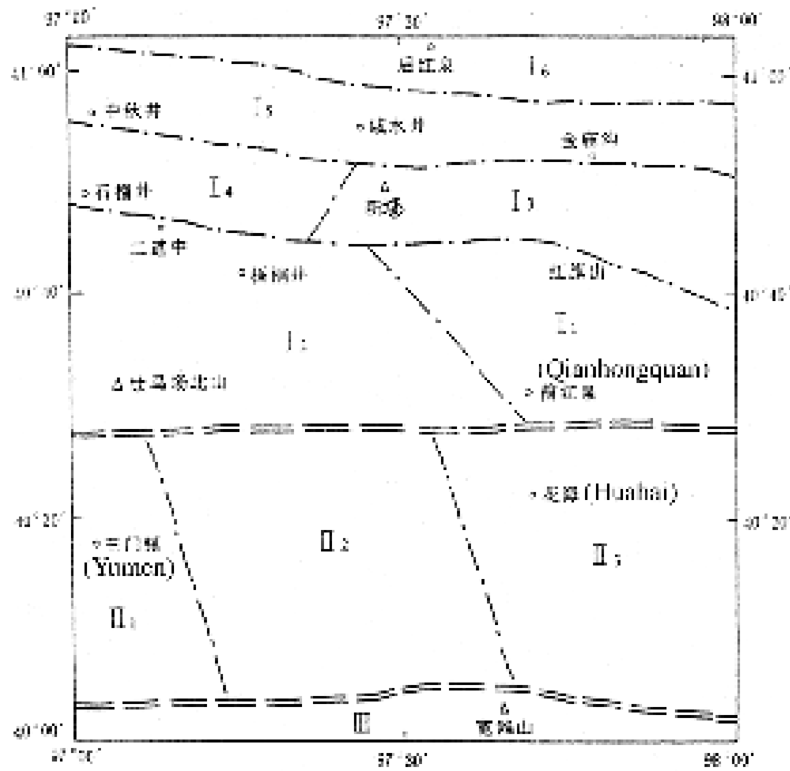

Figure 6.8. Map showing the classification of crustal stability of northwest Gansu Province. I - Beishan stable region; II - Yumenzhen-Huahai sub-stable region; and III - Hexi Corridor unstable region.

Table 6.2 Crustal characteristics in western Gansu Province, China.

Characteristics		Beishan Stable Region	Yumenzhen-Huahai Sub-stable Region	Hexi Corridor Unstable Region
Crust structure and deep fault		Crust is block structure with good integrity, NW-striking basement faults are distributed.	Crust is mosaic structure, with NE- and NW-striking basement faults.	Crust is crushed structure controlled by the north Qilian deep fault and Aljin active fault.
Active fault and Quaternary crustal movement		With few active faults, crustal movements of slowly uplift-ing region with less than 0.1 mm/a.	With Sanweishan and Aljin active faults, crustal movement is between 0.1 - 3.5 mm/a.	With Aljin active fault, largest crustal movement is 4.7 mm/a.
Superimposed fault angle		55° - 80°	45° - 70°	80°
Gravity field		Gravity anomaly is smooth, gradient is less than 0.5 mGal/km	With regional positive negative gravity anomalies, the gradient is 1 to 2 mGal/km	Located in gravity anomaly step zones with negative gravity anomaly
Seismicity	Largest earthquake (Ms)	3.0	5	6.0
	Energy $\sqrt{E}$ ($10\sqrt{erg}$)	0.14	10.59	25.54
	Frequency (Ms >3.0)	1	4	2
Possibility for construction of HLW repository		Possible	Not possible	Not possible

- Natural analogues;
- Buffer/backfill materials and their geotechnics;
- Speciation of transuranic elements in solutions;
- Heater test; and
- Models for safety and environmental assessments.

The safe disposal of high level radioactive waste is a worldwide challenging task. Although China has made much progress in this field, there is still a long way to go. For example, a policy act related to nuclear waste disposal should be established, a more effective organization should be formed to promote the required work, and a way should be explored to raise enough money for the safe disposal of nuclear waste.

Information exchange is very important for the disposal of radwaste. China is willing to learn of the successful experiences in other countries and to strengthen international cooperation. China is also willing to share its own experiences and achievements with other countries, for the purpose of protecting the living environment of human beings and protecting the Earth

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