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Article

Regional geology and hydrogeology of the Yellow River basin

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Zhang Eryong, Shi Yingchun, Gao Cunrong, Hou Xinwei, Han Zhantao, Zhao Hongmei, Ding Jianqing, Liu Xingchun, Li Baogui, Zhao Runlian, Jiao Xili, Shan Lijun, Zhu Zhongdao and Wang Ning (2009) Regional geology and hydrogeology of the Yellow River basin. *Bull. Geol. Surv. Japan*, vol. 60 (1/2), p. 19-32, 6 figs, 2 table.

Abstract: The paper reviews regional geology in the Yellow River basin from viewpoints of stratigraphy and structure. Based on the geologic features, water-bearing formations are classified into following 5 types: Loose sediment type pore water-bearing formation, Clastic rock type fissure-pore water bearing formation, Carbonate rock type formation, Magmatic and metamorphic rock type formation, and Frozen layer type formation. Groundwater in the Yellow river basin is classified into 12 systems on the basis of hydrogeological conditions and characteristics of recharge, runoff and discharge of groundwater. Each system is described in detail, and distribution map for classified systems are shown in the map. Three cross sections are illustrated as representative examples for upper, middle and lower reaches respectively.

Keywords: Yellow River, regional geology, stratigraphy, fault, hydrogeology, groundwater, classification of groundwater system

1. Regional geology

1.1 Stratigraphy

The Yellow River basin is large in area, with relatively complete set of strata from Archean to Cenozoic being developed showing complex lithology, intensive structural complexity, and a variety of landform types.

The Archean strata are dominated by gneiss and migmatite, mainly distributed in Lüliang Mountains, North Qinling, Wula Mountains, Songshan Mountains, Luzhong (Central-Shandong) mountainous land, Taiyue mountainous land and Xiong'er Mountains in the middle-lower reaches.

The Proterozoic strata are composed mainly of schist, phyllite, gneiss and conglomerate, mainly distributed in Dingxi of Gansu, Haiyan and Huangyuan in eastern Qinghai, and mountain areas in western Henan, Lüliang Mountains, Zhongtiao Mountains, Wula Mountains and the Daqing Mountains.

The Paleozoic strata exposed in the region mainly include those of Permian, Carboniferous, Silurian, Ordovician and Cambrian. The Permo-Carboniferous systems consist of paralic facies limestone and detrital deposits, spread in Daqing Mountains, Wula Mountains, Helan Mountains, Qinling Mountains and

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eastern Ordos Basin. The Silurian System is composed of paralic facies detrital rocks and volcanic deposits, distributed in the Qinling Mountains, mainly consisting of metamorphosed sandstone, slate, phyllite, and tuff, with a thickness exceeding 3,600 m. The Cambrian and Ordovician are dominated by carbonate rocks, several thousands of meters to ten thousand meters thick. They are widely distributed and karst is well developed, mainly distributed in Lüliang Mountains, Liupan Mountains, as well as in regions such as Ningnan and Gansu.

The Mesozoic strata are dominated by continental deposits. The Triassic strata exposed in the Shaanxi-Gansu-Ningxia-Inner Mongolia-Shanxi regions are mainly composed of red clastic deposits in the lower part and clastic coal-bearing formations in the upper part, all of which are widely exposed with the total thickness reaching 1,500-4,500 m; those exposed in Qinghai and Gansu west of Liupan Mountains consist of clastic rocks and limestone, 200-1,000 m thick, locally mixed with tuff. The Jurassic and Cretaceous strata crop out widely in the region. The Jurassic System in the Shaanxi-Gansu-Ningxia-Inner Mongolia-Shanxi region is the main coal-bearing sequence in China consisting of clastic coal-bearing formations. The Cretaceous System is composed of lake and river facies deposits totaling 500-1,000 m in thickness, lithologically sandy mudstone, generally 100-200 m thick, with a maximum over 1,000 m. The Jurassic and Cretaceous systems in Qinghai and Gansu west of Liupan Mountains are basically same type of rocks dominated by clastic rocks, shale and marl.

The Neogene strata are widespread in Qinghai, Gansu and the Qinling region of Shaanxi, consisting of clastic and volcanic rocks, and are especially well developed in Qinghai and Gansu. They are dominated by deposits of river and lake facies about 500 m thick, forming the basement of a series of intermontane basins in the region. The Quaternary System is widely distributed, mainly in the major plains and basins as well as in alluvial-pluvial plains and littoral areas in the lower Yellow River. Except for the marine deposits in the littoral areas, all the Quaternary strata are composed of fluviolacustrine alluvial-pluvial deposits and lacustrine deposits dominated by sand, gravel and silty sediments. Their thickness varies from several tens of meters to some hundreds of meters, and may reach a thousand meters in the large fault basins in the middle Yellow River. The Lower Pleistocene in the Feng-Wei Basin consists of lake deposits of the Sanmen Formation, and above the Middle Pleistocene is the loess section. In the Yinchuan-Hetao Basin, the Pleistocene is totally composed of very thick lacustrine deposits. In the Ordos Plateau region, the Pleistocene Salawusu Formation is important, which is composed of alluvial sand with a thickness over 70 m. In the downstream alluvial plains, the Quaternary System is several hundreds meters thick, dominated by alluvial sandy loam and loam. Around the Yellow River delta, fluviomarine deposits are well developed, where the Lower Pleistocene is composed of alluvial deposits, while all the overlying strata are alluvial-fluvial.

In the Yellow River basin, magmatic rocks are widely distributed, especially in the Qinling and Daqingshan (Mountain) areas, characterized by complex types of rocks and multiple stages of intrusion.

1.2 Regional faults and neotectonism

According to data only for insiders, the major faults in the Yellow River basin are as follows (Fig. 1):

The North Qilian-North Qinling fault zone: Extending along the North Qilian-North Qinling fold zone, it is a deep fault zone active since Proterozoic.

The Taibai Mountains-Qinghai Lake fault zone: Going eastward from the south margin of Qinghai Lake, via Niaoshu Mountains and Tianshui to Taibai Mountains, it is the second largest deep fault system traversing the basin, formed by several multi-stage active fault belts. Magmatism is frequently observed along the faults.

The Songpan-Garzê fault system: All the large and deep faults in the system extend several hundred kilometers, with magmatic rocks distributed along the faults. The faults are characterized by multi-stage activity, some still active in recent times.

The Daqingshan piedmont fault system: It consists of several disconnected faults, which form the boundary of the Daqing Mountains and the Hetao Plain. The faults are featured by multi-stage activity, especially active in the Meso-Cenozoic, and some still active in recent times.

The Ordos West Margin fault system: It begins from the east side of Zhuozi Mountains, via Taole, Tianshui and Maojing southward to Longxian County, extending several hundred kilometers long with west side upthrown. It has controlling role on the strata, structure and geomorphology of both sides. Multiple activities occurred in the Proterozoic, and continued to the Cenozoic.

In addition, there are some buried pre-Quaternary active fault structures in the lower plains.

The important active faults in the region include the Qingtongxia-Liupanshan-Baoji-Xi’an and the Maqên-Maqu active deep faults, some of which are lithospheric faults in nature.

Besides, major active faults such as the Yinchuan-Tongwei fault, the Longxian-Tiansui fault, the Jingtai-liupanshan deep active fault, the faults at the northwest and southeast margins of the Feng-Wei graben, the N-S-trending Longyangxia fault etc. are distributed.

The neotectonic uplift-subsidence movements vary remarkably in the region, as shown by uplift in the west,

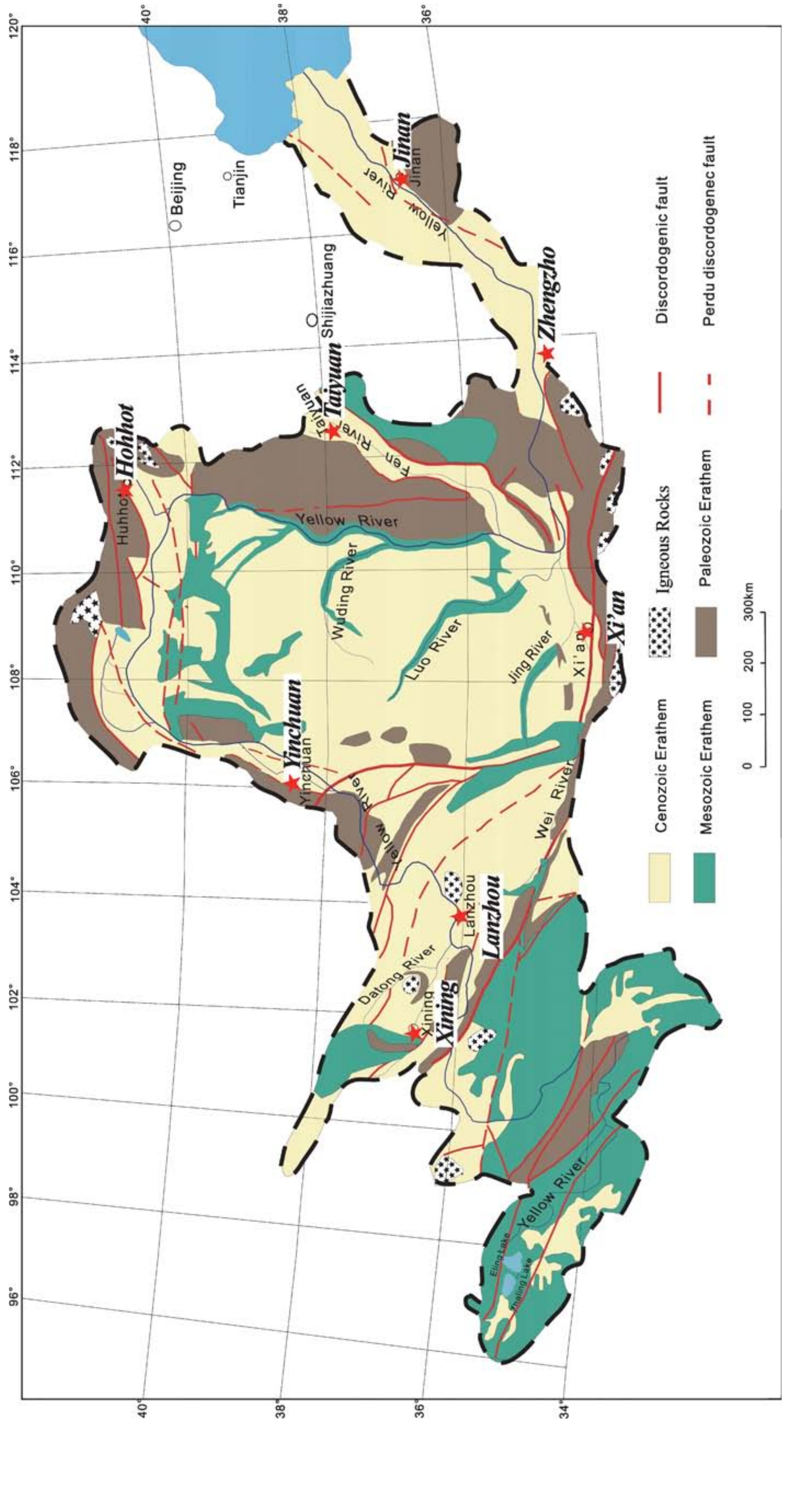

Fig. 1 Geological sketch map of the Yellow River basin

subsidence in the east, and mixed uplift-subsidence in the middle, which is basically consistent with the three large topographic steps. In the western areas, the Bayan Har Mountains, Jishi Mountains and Qilian Mountains have risen 2,000-5,000 m since early Quaternary, at a rate of 1-2.5 mm/a; the middle and eastern mountain areas 500-2,000 m during Quaternary, at 0.2-1 mm/a. The Yinchuan, Hetao, Feng-Wei and Taiyuan basins are where the maximum uplift/subsidence and rate of subsidence are observed, with the subsidence reaching a thousand meters in the Quaternary. The downstream basins east of the Taihang Mountains are dominated by large subsidence, with subsidence up to 50-400 m.

2. Regional hydrogeology

2.1 Water carrier

According to the data on water carrier, occurrence, and hydrographic properties of groundwater in the basin, the water-bearing formations can be classified into five types, each of which can be subdivided into several subformations, as shown in Table 1 and Fig. 2.

The loose sediment type pore water-bearing formation is the main one in the region consisting mainly of Quaternary aquifers lithologically comprising sand and gravel. It is divided into 4 water-bearing subformations depending on their origin and water storage structure, namely, the alluvial-lacustrine-pluvial subformation, the loess soil subformation, the eolian sand subformation and the alluvial-marine subformation. The alluvial-pluvial-lacustrine beds are multi-layered with great thickness, and important for water supply. They are grouped together into the same subformation. The loess soil, although different in origin, has similar hydrogeologic characters. It has low and uneven water contents, but is widely distributed, so that it is of some value for water supply in arid areas, and is shown as one subformation. The eolian sand bed and alluvial-marine bed show limited distribution.

The clastic rock type pore water-bearing formation comprises mainly Paleozoic and Mesozoic unmetamorphosed clastic sedimentary rocks. It is characterized by water contained in fissures. In some Mesozoic formations, the rock is incompletely cemented, with water contained in fissures and pores. They often form artesian basins under suitable structural conditions.

In the classification of carbonate rocks type water-bearing formation and subformations, the water storage characters are considered in addition to the proportion of carbonate rocks. If karst water exists, it is classified according to the proportion of carbonate rocks. Generally, those with the proportion of carbonate rocks exceeding 90 % are grouped into the carbonate rocks type subformation, while those with proportions of 30-90 % are ascribed into the Carbonate rocks-clastic rocks subformation.

The magmatic and metamorphic rocks type formation comprises magmatic rocks and metamorphic rocks of all ages, of which Archean and Proterozoic metamorphic rocks are major constituents with partial metamorphic rocks of the Paleozoic and Triassic.

The frozen layer type water-bearing formation is a special type. Various water-bearing formations are separated by perpetually frozen soil layer into the suprapermafrost water and the subpermafrost water. The frozen layer serves as a watertight stratum, beneath which is liquid water while above which is seasonal thawed water. According to the basic properties of the water-bearing formation, two subformations are defined, the loose sediment frozen layer type and the bedrock frozen layer type, respectively. This formation mainly occurs in the plateaus and mountain areas in the upper Yellow River.

2.2. Groundwater distribution

According to the above-mentioned water-bearing media classification, the groundwater in the basin can

Table 1 Classification of main water-bearing formations in the Yellow River basin

Water-bearing formation	Subformation
Loose sediment type pore water-bearing formation	Alluvial, lacustrine and pluvial subformation, Loess soil subformation, Eolian sand subformation, Alluvial-marine subformation
Clastic rock type fissure-pore water-bearing formation	
Carbonate rock type formation	Carbonate rock type subformation Carbonate rock- clastic rock subformation
Magmatic and metamorphic rock type formation	Magmatic rock type subformation Metamorphic rock type subformation
Frozen layer type formation	Loose sediment frozen layer type subformation Bedrock frozen layer type subformation

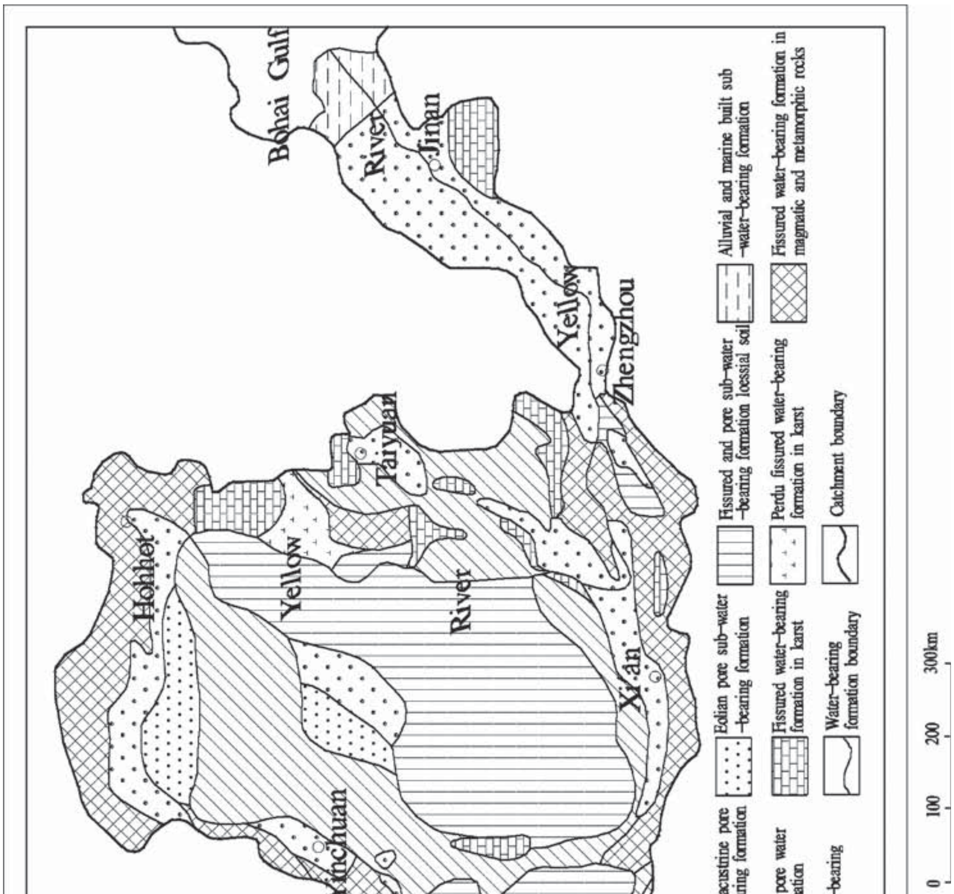

Fig. 2 Aquifer lithology map of the Yellow River basin
(Modified from "unpublished" *Map Series of Environmental Geology in the Yellow River Basin*)

be divided into loose sediment type pore water, clastic rock type fissure and pore water, carbonate rocks type pore and fissure water, magmatic and metamorphic rock type water and the frozen-layer water. The loose sediment type pore water is the most widely distributed, concentrated mostly in basins and plains of the subsidence zones and in river valleys. The clastic rock type fissure and pore water is distributed in mountain areas and Meso-Cenozoic basins. In the former area, the water is characterized by layered distribution, mostly occurring as fissure-fill; in the latter, it is mainly distributed as pore and fissure water and occurs in the eastern fold-fault mountain areas and hills, e.g., the Taihang, Lüliang and Taishan mountains as well as the eastern section of the Qinling Mountains. In contrast, in the western section as well as in the Qilian and Helan mountains, it is only found scattered. The magmatic and metamorphic rock type water is distributed in various elevated mountains and hills; particularly in the western Qinling Mountains, the metamorphic fissure water occurs in large areas. The frozen-bed water is concentrated in the mountain areas of the Qinghai Plateau.

The groundwater, especially that of utility value, occurs mainly in water-storage structures of several large basins followed by in carbonate rocks in the eastern mountain areas. These areas all have good recharge conditions, and thus exploitable. The aquifers in large basins and alluvial plains in the lower reaches are characterized by great thickness and multiple layers. The groundwater occurs in sands and gravels with different origins and in layers as pore water and confined water. The karst water occurs in fissures and pores of carbonate rocks, and unevenly distributed. Also, small intermontane basins and alluvial-pluvial beds in river valleys often host abundant groundwater.

Groundwater in Meso-Cenozoic basins occurs mostly as confined water in pores and fissures of layered sandstone and granule-sized gravels, generally at depths, with altered and complex water quality, high water head and low water volume. This type of groundwater is mainly distributed in arid and semiarid regions, and brackish or semi-brackish. However, this type of water is still of some value as water source.

Groundwater is very scarce in the widespread loess, and occurs only in some specific landforms. In regions where precipitation is greater than 400 mm, small volumes of groundwater may occur in the high lands and ravines; in regions with precipitation of 300-400 mm, water content in loess is low with high salinity, and only minor amounts of fresh or brackish water occur in special landforms controlled by microgeomorphology.

The fissure water is mostly unconfined, unevenly distributed, and generally shallow. The volume is not large and changeable. Faults and other structural fracture zone may cross different aquifers, and considerable amount of groundwater may be stored provided they develop at depths under good recharge and storage conditions.

The frozen-layer water develops under special conditions. The permanently frozen layer forms a regional watertight stratum: above it is unconfined water alternated by liquid and solid phases, whereas beneath it is liquid water, mostly unconfined, and occurring in different media as free water.

2.3 Groundwater recharge, runoff and discharge

Precipitation is the fundamental recharge for groundwater. Infiltration of surface water and irrigation water of farmland are also important sources of replenishment. Some local sections may be recharged by condensate water, but it is of minor importance.

The recharge of fissure water in hilly regions is simple, derived from precipitation or snow-ice melting water. As the landform is strongly incised, where drainage is smooth, most of the fissure water is discharged quickly as springs. Karst fissure water is recharged by precipitation and surface water. The karst groundwater circulates deeply along the fissure channels, and it often forms groundwater drainage areas not coincident with those above the ground, and discharged concentrated as large karst springs, e.g., the Tianqiao spring and Liulin spring on the west foot of the Lüliang Mountains.

The recharge and migration of groundwater in basins and alluvial plains are more complicated. The recharge of Quaternary pore water in basins includes precipitation infiltration, surface water infiltration, and lateral recharge of bedrock fissure water and fissure karst water. Proportions of the ways of recharge vary from basin to basin; surface water recharge has a greater proportion in arid regions. The discharge areas are mostly located in the middle and lower reaches. Mining activity may be the main source of drainage in some basins. The fissure and pore water in Meso-Cenozoic basins is mostly artesian water in a broad sense, in which the Cretaceous artesian water in the Ordos Basin is typical. The recharge areas in smaller Mesozoic and Neogene basins are mostly located on edges of the basins, and the discharge areas coincide with the outlets of surface water.

Groundwater in the loess is recharged only by precipitation, locally with infiltration of irrigation water. Stable aquifers may often form in a large loess tableland, where infiltration conditions are favorable. There is a complete recharge-runoff-discharge process of groundwater; precipitation infiltration and recharge are even, and discharged from surrounding areas of the tableland.

3. Groundwater systems

3.1 Classification of groundwater systems

A systematic classification of groundwater in the Yellow River basin is made on the basis of hydrogeological conditions and characteristics of recharge, runoff and discharge of groundwater.

With reference to Qin (1998) and Lin *et al*. (2006), the present study classifies the groundwater in the basin into 12 systems and 27 subsystems. The first-order systems are based on hydrographic distributions and time-space evolution process, whereas the geomorphological characters, types of water-bearing media and hydrodynamic features are considered in defining the second-order systems (subsystems). List of systems is given in Table 2, and the distribution is shown in Fig. 3.

Compared with the work by our predecessors, the present classification is different in the following points:

(1) It separates the Yinchuan Plain from the Longzhong and Longxi Loess Plateau and the Liupan mountainous region. The Yinchuan is completely different from the latters for the water circulation and time-space evolution process. Its separation will help us to understand more clearly the process of the formation of rich sources by the piedmont recharge in the Yinchuan Plain together with the recharge from the Yellow River diversion irrigation.

(2) It divides the Weining Plain and the Qingshuihe Plain into two subsystems based on the fact that the groundwater recharge source for the former is mainly the Yellow River diversion irrigation, whereas the latter mainly from the Liupan mountainous area.

(3) It defines the Qinshui and Dawen river basins as individual systems, because the two have no hydrographic relations with adjacent systems, and their water-bearing media are different.

3.2 Characteristics of groundwater systems

3.2.1 The Qilian-Qingnan Plateau groundwater system (I)

The system is located in the upper Yellow River, in the northeast of the Qinghai-Tibet Plateau. The west is bounded by Qilian watershed; its northern boundary consists of a number of mountains and hills that act as the Yellow River watershed, including the watershed of the Qilian Nanshan, Shazhuyu River and Caka Salt Lake, and Ela Mountains; the south is bordered by watershed of Bayan Har and Minshan Mountains; the eastern boundary is Taohe watershed, Weihe, Datong and Zuli rivers.

Geomorphologically, the north is characterized by a series of folded mountains, the center a zone of basins (including the Xining, Gonghe, Guide, Tongren and Tongde-Xinghai basins), and the eastern and southern parts are deep-cut river valleys and the undulating Qingnan Plateau (including mountains such as Jishi Mountains, A'nyêmaqên and Bayan Har).

The system is controlled by topographic structure, and the landform is intensively eroded. A typical profile is shown in Fig. 4. The watershed of surface water is basically the same as that of groundwater, except in the Gonghe Basin. This is a region with intensive recharge of groundwater to surface water.

The system is divided into 5 subsystems, namely, the Bayan Har Mountains subsystem (I_1), the A'nyêmaqên Mountains subsystem (I_2), the Longyangxia-Liujiaxia subsystem (I_3), the Huangshui River subsystem (I_4), and the Taohe River subsystem (I_5). It is located in the northeastern part of the Qinghai-Tibet Plateau, with high relief and strongly eroded landform. The Yellow River and its tributaries form the groundwater drainage datum level within the system, and groundwater strongly recharges surface water, so that it is the main water-feeding region of the river. The water volume of the system accounts for 40 % or more of the whole volume of the Yellow River basin.

The system is located in the frigid zone, where large areas of permanently frozen soil and seasonally frozen soil are distributed at elevations above 4,000 m. The presence of frozen soil has changed the conditions of regional groundwater circulation, separating the shallow groundwater into the suprapermafrost water and the subpermafrost water. The former, shallowly buried with rapid changes of circulation, is the water source for the frigid grasslands and meadows, and also the main recharge source for surface water in the region.

In the last decades, temperature rose, precipitation reduced, and evaporation increased, so that water production dropped gradually, thereby intensifying the crisis of water resources in the basin.

3.2.2 The Zuli-Qingshui River groundwater system (II)

The system is located in the middle section of the upper Yellow River, i.e., along the banks of the mainstream from Lanzhou to Qingtong Gorge, including three first-order tributaries, the Zhuanglang, Zuli and Qingshui Rivers, crossing Gansu and Ningxia. Its southwestern boundary coincides with the watershed of the Zuli, Qingshui and Weihe Rivers, being the westernmost basement structure uplift zone of the Loess Plateau. Clastic, igneous, and metamorphic rocks crop out intermittently. Controlled by structure, mountains, plains and loess hills are distributed.

The system can be divided into 3 subsystems, the Zuli River-Zhuanglang River subsystem (II_1), the Qingshui River subsystem (II_2), and the Weining Plain subsystem (II_3).

Table 2 Classification of the groundwater systems in the Yellow River basin

No.	First-order groundwater system			Second-order groundwater system (subsystem)		
	Name	Code	Area (km^2)	Name	Code	Area (km^2)
1	Qilian-Qingnan Plateau	I	224617.84	Bayan Har Mountains	I_1	34705.91
				A'nyêmaqên	I_2	82035.82
				Longyangxia-Liujiaxia	I_3	47597.16
				Huangshui River	I_4	32391.82
				Taohe River	I_5	27887.13
2	Zuli-Qingshui River	II	62546.78	Zuli River	II_1	37165.14
				Qingshui River	II_2	24587.51
				Weining Plain	II_3	794.13
3	Helan Mountains -Yinchuan Plain	III	13748.51	Helan Mountains	III_1	6218.26
				Yinchuan Plain	III_2	7530.25
4	Daqing Mountains -Hetao Plain	IV	58155.35	Daqing Mountains South Foot	IV_1	37382.55
				Hetao Plain	IV_2	20772.8
5	Ordos Plateau North Region	V	161814.7	Eastern subsystem	V_1	120897.56
				western subsystem	V_2	40509.52
6	Lüliang Mountains West Foot	VI	39070.91	Tianqiao Spring Area	VI_1	18862.77
				Liulin Spring Area	VI_2	20207.42
7	Fenhe Reaches -Yuncheng Basin	VII	44708.66	Taiyuan Basin	VII_1	23089.35
				Linfen Basin	VII_2	15461.38
				Yuncheng Basin	VII_3	6157.93
8	Weihe Catchment	VIII	136145.58	Longxi Loess Plateau	$VIII_1$	28778.59
				Guanzhong Basin	$VIII_2$	19063.11
				Qinling North Foot	$VIII_3$	8819.14
				Weibei Karst	$VIII_4$	3168.67
				Weibei Loess Plateau	$VIII_5$	76316.07
9	Sanmenxia-Yiluo Basin	IX	32801.86	Sanmenxia-Taohuayu	IX_1	13808.81
				Yiluo River	IX_2	18993.05
10	Qinhe Catchment	X	15710.23			
11	Yellow River Lower	XI	29288.26			
12	Dawen River Catchment	XII	10132.04			
Total (including unconfined artesian zones)			828740	Total (excluding unconfined artesian zones)		796369.45

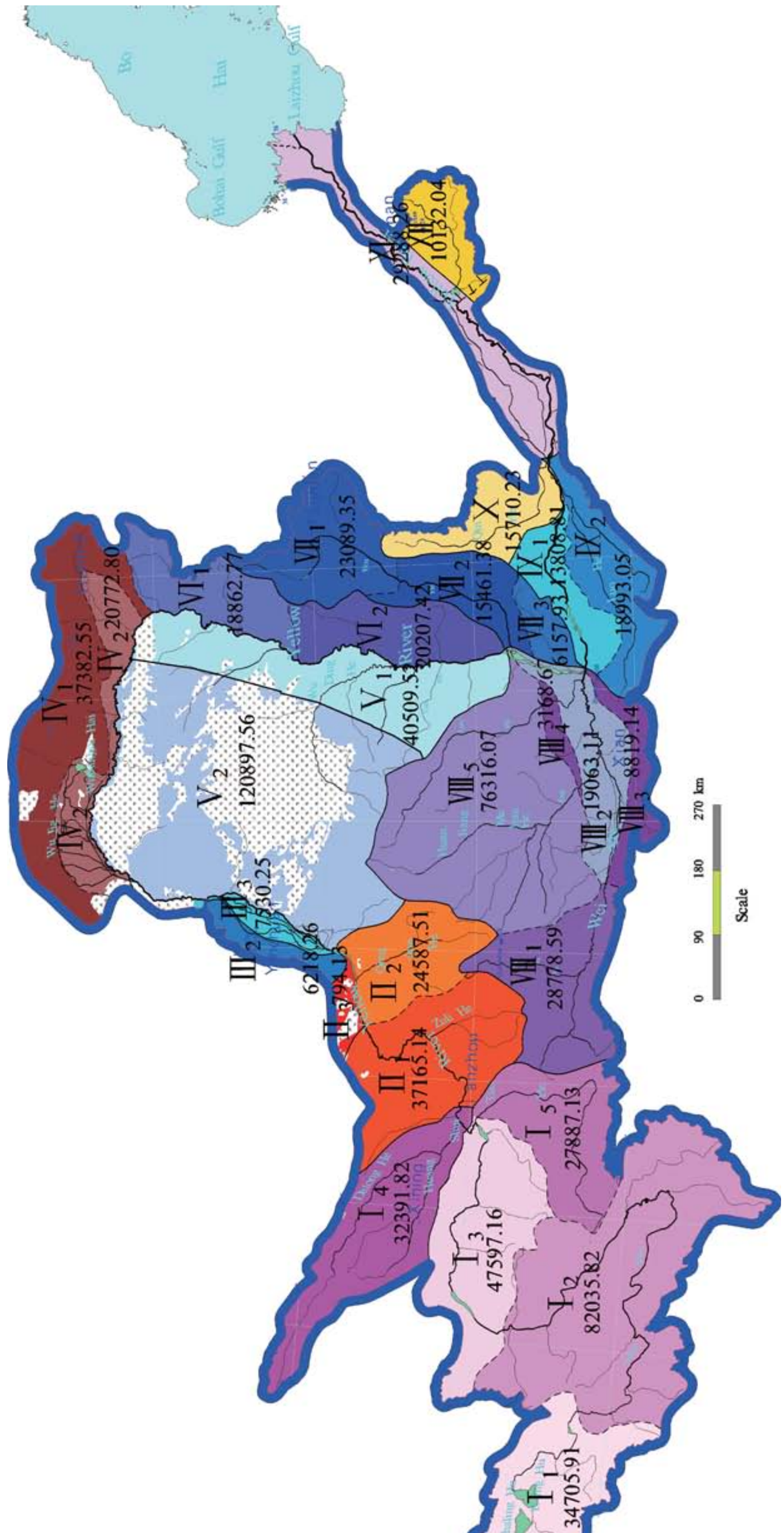

Fig. 3 Groundwater systems in the Yellow River basin

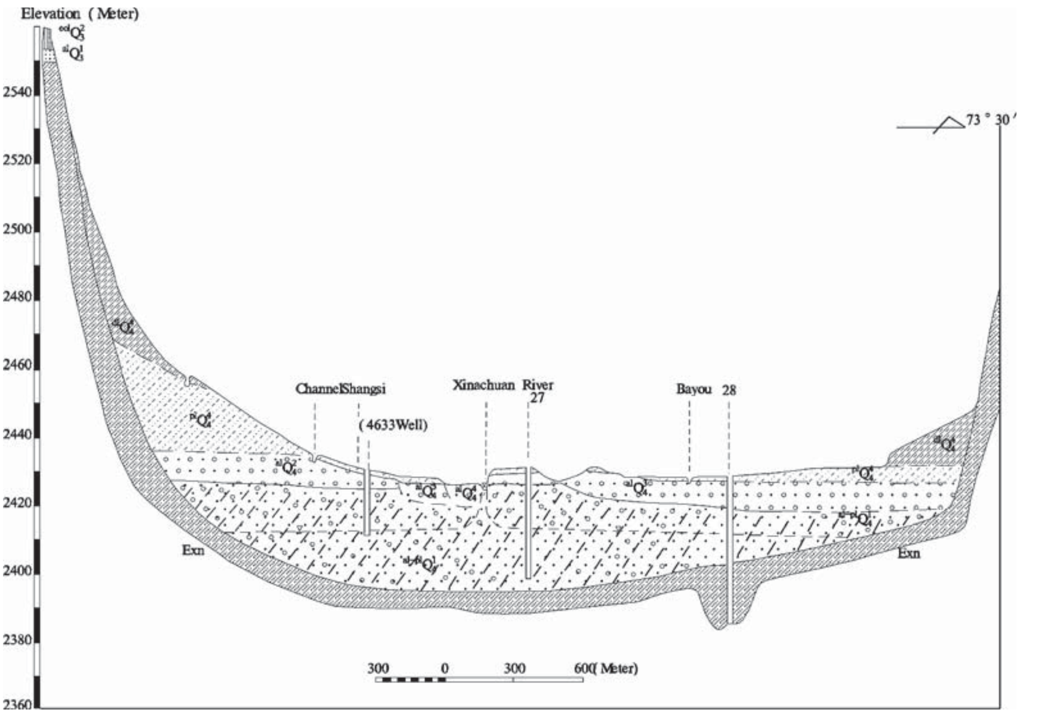

Fig. 4 Hydrogeologic profile through Xinachuan River

The average annual precipitation is below 400 mm for years. As the land is largely forming mountain foot, most surface water from precipitation flows away as floods. The Quaternary strata are mostly permeable and water-free loess layers, while the Tertiary strata at the base of the Quaternary are in-land river and lake facies clastic rocks, which are low in water-retaining quality, and rich in gypsum and soluble salts; therefore the groundwater in this system is commonly of poor quality, with mineral components mostly over 3 g/L. The shortage in surface water and the poor quality of groundwater make the system the most freshwater-deficient region in the basin.

3.2.3 The Helan Mountains-Yinchuan Plain groundwater system (III)

This system is bordered by Helan Mountains in the west, east by the Yellow River, south by the Qingtong Gorge mouth and the north by Shizui Mountains. It comprises two subsystems, the Helan Mountains subsystem (III_1) and the Yinchuan Plain subsystem (III_2). The two subsystems form a complete recharge-runoff-discharge system (Fig. 5).

The Yinchuan Plain is a Cenozoic fault basin, with Cenozoic beds exceeding 7,000 m thick in which Quaternary reaching 2,400 m. The very thick Quaternary loose sediments form huge water-storage space, which can be divided into three aquifers. Groundwater of the plain is mainly recharged by infiltration from the Yellow River diversion, and it also receives lateral recharge of groundwater and surface water from Helan Mountains. Thus the plain is rich in water resources. The groundwater discharges mainly through evaporation and transpiration besides into the Yellow River.

3.2.4 The Daqing Mountains-Hetao Plain groundwater system (IV)

The system is bordered by Langshan Mountains and the Ulan Buh Desert in the west, the east by the watershed between the Dahei River and the Hunhe River, the south by the Yellow River, and the north by the Daqing Mountains. It consists of the Daqing Mountains and the Hetao Plain, and divided into the Daqing Mountains South Foot subsystem (IV_1) and the Hetao Plain subsystem (IV_2).

The Hetao Plain is a Mesozoic fault basin, which is divided into the Houtao, Sanhuhe and Hubao plains. Very thick Quaternary loose sediments containing rich pore water are deposited in the basin. The bedrock region has well-developed fissures with favorable runoff conditions, and receives recharge from precipitation. The plain is discharge zone of groundwater runoff, receiving lateral recharge from the bedrock region and infiltration recharge from the Yellow River diversion irrigation in addition to precipitation. The general flow direction of groundwater is from southwest to northeast in the Houtao Plain, and opposite in the Hubao Plain. In the plain, groundwater is shallow, discharged mainly from evaporation and mining followed by runoff.

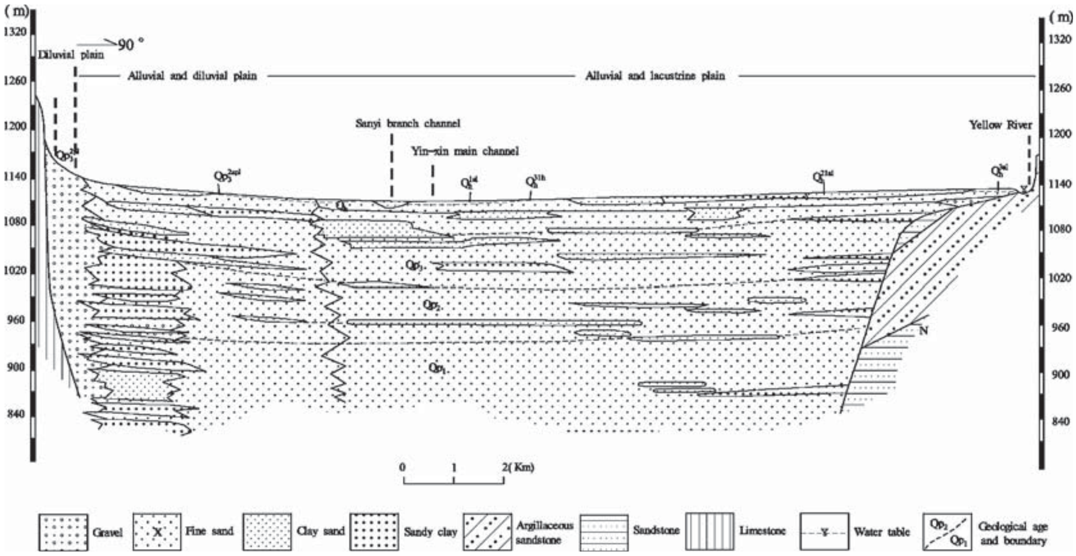

Fig. 5 Hydrogeologic profile through the middle part of the Yinchuan Plain

This system has a small water production, and the groundwater resources mainly depend on irrigation recharge from the Yellow River. In the Hetao Plain, salinization of soil is serious because of the shallow depth of groundwater and poor drainage.

3.2.5 The Ordos Plateau North region groundwater system (V)

The system, comprising two large natural units, covers Ningxia, Inner Mongolia and part of Shaanxi, the Ordos Desert, and the Loess Plateau. It is centered by surface water in the closed Ordos catchment and unconfined water artesian zone. In the region the relatively large tributaries of the Yellow River mainly develops on both banks of the Jinshan Gorge in the eastern part of the system, along the Kuye, Tuowei and Wuding Rivers. According to the latest investigation, deep in the surface water in the closed catchment area and unconfined water artesian zone there is a Cretaceous groundwater system. Bordered by the surface watershed along the Sishililiang-Baiyu Mountains area, it flows toward southeast and northwest to recharge the surface water. Accordingly, the Ordos Plateau North Region groundwater system is divided into the Eastern subsystem (V_1) and the Western subsystem (V_2).

This system represents the region with the lowest precipitation in the Yellow River basin, where the Mu Us and Kubuqi deserts are developed, and the land is relatively flat. The roughly NE-SW-trending Sishililiang-Baiyu Mountains area is the watershed of surface water and groundwater. The main aquifer consists of Quaternary eolian sand of the Salawusu Formation and Cretaceous sandstones. Groundwater, after recharged by precipitation, runs down within the Quaternary System, or infiltrates into deeper Cretaceous sandstones, and then recharges the shallow groundwater or surface water in the drainage zone after undergoing deep circulation. The groundwater flows from the central watershed to the northwest and southeast, recharging the lakes in the northern surface water in the closed catchment area, and the Dusitu, Kushui, Wuding and Kuye Rivers as well as main stream of the Yellow River in the northwest and southeast.

3.2.6 The Lüliang Mountains West foot groundwater system (VI)

The system is bordered by the Yellow River in the west, and the Lüliang Mountains surface watershed in the east. The groundwater types are dominated by fissure karst water, followed by bedrock fissure water. The former occurs mainly in Cambrian and Ordovician limestones and dolomites. The groundwater, running from the Lüliang Mountains watershed to the Yellow River, finally discharging into the river valley, is in the form of a large spring. It is a key component of the river's basal flow, and one of the important recharge sources of the Yellow River. Based on the distribution and concentration of spring areas, the groundwater system can be further divided into the Tianqiao subsystem (VI_1) and the Liulin Spring Area subsystem (VI_2).

3.2.7 The Fenhe Reaches-Yuncheng basin groundwater system (VII)

The system lies in the Fenhe River and the Shushui River catchments on the east wing of the Є–type Qilian-Lüliang-Helan (mountains) structural system. It corresponds mainly to the N-S-arranged in en echelon

Taiyuan, Linfen and Yuncheng fault basins, with the east and west parts being bordered by the Taihang and Lüliang mountains' surface watersheds respectively, and the south by Zhongtiao Mountains. It can be divided into 3 subsystems, the Taiyuan Basin subsystem (VII_1), the Linfen Basin subsystem (VII_2) and the Yuncheng Basin subsystem (VII_3).

In the various basins of this system, Quaternary pore water resources are abundant, receiving recharge from the mountains and from precipitation. Drainage is to river valleys or through artificial mining. The groundwater level has been dropping continuously owing to over-extraction for many years. Cambrian and Ordovician karst water resources are also rich in the system. Karst water generally receives direct recharge from precipitation in uncovered mountain areas, and drains into the river valleys, or in large karst springs, or directly feeds the Quaternary pore water-bearing formations.

3.2.8 The Weihe Catchment groundwater system (VIII)

The system is identical in extent with the Weihe River catchment, including areas west of Liupan Mountains, the hilly loess areas south of Huining, the Guanzhong Basin and surrounding mountain areas. In consideration of the contact relationship between the Quaternary System and the bedrock in the mountains, it is divided into 5 subsystems, namely, the Longxi Loess Plateau subsystem ($VIII_1$), the Guanzhong Basin subsystem ($VIII_2$), the Qinling North Foot subsystem ($VIII_3$), the Weibei Karst subsystem ($VIII_4$) and the Weibei Loess Plateau subsystem ($VIII_5$).

In this system the landform are complex including Longxi and Longdong loess plateaus, the Qiling Mountains and the Guanzhong Basin. In the Longxi and Longdong loess plateaus, the land is intensively incised, and groundwater is of small volume in the loess layers. Only in some large tableland, e.g., the Dongzhi tableland, groundwater resources are relatively rich. Tertiary strata which form the base of Quaternary are mostly composed of mudstone, which is poor in water. The Cretaceous sandstone bed is thick, and forms main aquifer of the system. However, as it is deeply buried, the circulation is slow. The groundwater in loess layers and Cretaceous aquifers generally discharges into the ditches and valleys on both sides along the basement, to feed the surface water. Precipitation is relatively large in the Qinling Mountains, where the bedrock fissure water and surface water formed by precipitation discharges into the Guanzhong Basin. Topographically, the elevation of Guanzhong Basin goes down in steps from the foreland to the Weihe River, i.e., the piedmont pluvial fan, the loess tableland and the Weihe alluvial-pluvial plain in decreasing elevations. Among them, the Weihe alluvial-pluvial plain and the piedmont pluvial fan have rich groundwater resources of good quality, and they are the main mining layers in large cities such as Xi'an and Xianyang.

3.2.9 The Sanmen Gorge-Yiluo basin groundwater system (IX)

The system lies in the lower reaches of the Yellow River, consisting mainly of the mountain areas on both banks and the Yiluo River catchment. It is bordered in the north by the west end of Sanmen Gorge, and Funiu Mountains in the southeast. Based on the large geomorphological units in the region and the water-bearing media, this system is divided into the Sanmen Gorge-Taohuayu subsystem (IX_1) and the Yiluo Basin subsystem (IX_2). The former lies in the canyon zone of the Yellow River mainstream, bordered by the Yilo and Qinshui basins in the south, and by the Yuncheng basin in the north. As the watershed of Xiaoshan Mountains and Zhongtiao Mountains on the north and south sides of the Yellow River is very close to the river, the groundwater recharge is limited. The Yiluo Basin subsystem is located in the east end of the Qinling fold belt, and its extent coincides with the Yiluo River catchment, which includes the Yiluo fault basin and surrounding mountain areas.

The main aquifer in the system is the Quaternary sand and gravel layer in the Yellow River and Yiluo River valleys, and the recharge water is sourced from Xiaoshan Mountains, Zhongtiao Mountains, Qishan and Funiu Mountains on both sides of the valleys. Discharge is dominated by flowing into the valleys and by artificial drainage. Both valleys are quite narrow, so that groundwater resources are limited. In the Lohe Basin, groundwater level shows a lowering trend in recent years owing to large-scale extraction in Loyang City and adjacent areas.

3.2.10 The Qinhe catchment groundwater system (X)

The system lies in the south end of the Qinshui depression, bordered in the west by the surface watershed (Taiyue Mountains) of the Qinhe and Fenhe Rivers, in the east by the Taihang Mountains (boundary of the Yellow River basin), and in the south by the Yellow River. It is formed by continental clastic deposits in Carboniferous and Permian synclinal basins, and the deposits are overlain by thin-bedded loess. The river valley is covered by alluvial loose sediments of the Quaternary.

In the valley the Quaternary loose layer is thin, and groundwater resources are poor. Cambrian and Ordovician karst fissure water resources are rich, which are mainly discharged in the form of springs.

3.2.11 The Yellow River lower reaches plain groundwater system (XI)

The system is located in the lower reaches of

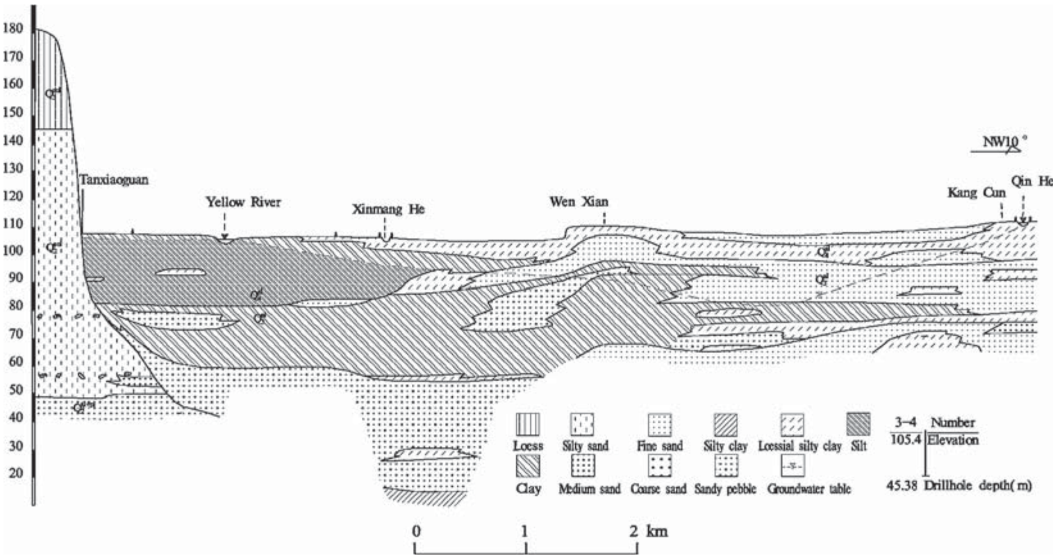

Fig. 6 Geologic profile in the downstream zone of the Yellow River

the Yellow River, covering the Jindi River, the Tuhai River at the downstream of Taohuayu and the Yellow River shoal plain, including the Yellow River alluvial plain within the extent of 10-20 km along the river. It is classified on the basis that downstream from Taohuayu of Zhengzhou, where the river enters the North China Plain, forming the raised bed river. There is no surface water drainage area, but the river water is higher than the surrounding ground, then it plays an important recharge role for both banks of the river. Therefore, the groundwater system related to the Yellow River water is still present. According to observations and researches for many years, the width of influence zone of recharge of the Yellow River water on the groundwater of the banks ranges 10-20 km (Zhao Yunzhang, 2003). Therefore, the influence zone is used to define the boundary of the system, the structure of which is shown in Fig. 6.

The groundwater in the influence zone receives lateral recharge of the Yellow River water besides precipitation recharge, and the volume of recharge differs with its distance from the river and the height of groundwater level.

3.2.12 The Dawen River catchment system (XII)

The system is located in the lower reaches of the Yellow River, belonging to the Dawen River catcment. In the system, Taishan and Lushan Mountains show high to moderately high mountain landform in the center, gradually decreasing height toward surrounding areas, finally reaching in the low hill topography of piedmont gentle plain and the fluviolacustrine plain with the elevation below 50 m. Among the mountains are Tailai, Feicheng, Liqu, Yiyuan and Yangzhuang basins.

This area of the system shows a landform of low hills, a piedmont gentle plain and a fluviolacustrine plain. The carbonate rock formation forming Quaternary basement is the main aquifer in the region. The area receives precipitation and direct surface water recharge in the mountain area, and receives recharge from Quaternary pore aquifers in the plain area. In the lower reach, recharge occurs to the Quaternary groundwater and surface water. Karst water resources are abundant in the dipping end of a monocline, the fault basin, the river valley, and the axial part of a syncline. Quaternary groundwater and pore water are distributed in the intermontane basins, plains and valleys, showing a banded pattern on both sides of the river. The aquifers are mainly sand and gravel layers, with rich water content. They also receive recharge from river water during the rainy season besides the recharge from precipitation. Locally there is also recharge from fissure water or karst water. Drainage is dominated by springs, artificial mining and flowing out into the river during the low-water season.

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黄河流域の地域地質と水文地質

チャンアルヨン・シインチュン・ガオスンロン・ホウシンウェイ・ハンチャンタオ・
チャオホンメイ・ディンジエンチン・リウシンチュン・リバオグイ・
チャオルンリエン・ジャオシーリ・シャンリジュン・
チュチョンダオ・ワンニン

要　旨

地質層序と地質構造の観点から，黄河流域の地域地質を述べ，ついで地質学的特徴から区分した水文地質の概要を報告する．この地域の帯水層は，軟弱堆積層の孔隙性帯水層，砕屑岩の割れ目空隙性帯水層，石灰岩の帯水層，変成岩の帯水層，凍土の帯水層の5タイプに分けられる．また，黄河流域の地下水系は，水理地質条件と地下水涵養，流動，流出の特徴から12系統に分類される．本報告ではそれぞれの地下水系統について詳述し，それらの分布図ならびに黄河上流，中流，下流の代表例として3つの地質断面図を示した．