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Abstract: Hydrogeological map is one of the important carriers of groundwater related information. It directly reflects the hydrogeological conditions and previous investigation and research results of a mapping area. The hydrogeological map of China is a map reflecting the characteristics of hydrogeology and groundwater dynamics on a national scale. On the basis of the hydrogeological map of China (1: 4 000 000) compiled in 1988, this map compilation attempted to update and enhance the existing map, with the latest survey results from the project of National Investigation and Evaluation of Groundwater Resources and Environmental Problems led by China Geological Survey. Task of the mapping program included redefining groundwater types, quantifying the classification standard of the groundwater and adding the pore-fissure water in laterite layer of hilly basin. The multilayer structures for porous, karst and porous-fractured groundwater and their water-rich grades are reflected on the map. Based on the comprehensive summary of the latest hydrogeological data of China, this research conducts an in-depth analysis of the regional distribution characteristics of groundwater in China, utilizes a digital mapping process and establishes a cartographic database for the purpose of further use. With the enrichment of the content and the continuous improvement of cognitive level, mapping content can be updated quickly, which has practical significance for the concept of surveying and mapping and scientific popularization.

Keywords: Hydrogeology map; Mapping methods; Groundwater types; Water-bearing degree; Groundwater regional distribution characteristics

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Introduction

Hydrogeological map is one of the important carriers that can directly reflect the research results of hydrogeology. China has always attached great importance to hydrogeological mapping. The exploitation of groundwater has a long history. Since the mid-1950s, regional hydrogeological surveys have been carried out in China in a planned way. China has collectively made great efforts to the comprehensive study of the distribution and occurrence conditions of groundwater; and as a result the compilation of hydrogeological maps on various scales has been achieved.

In the late 1950s, the Bureau of Hydrology and Engineering Geology and the Institute of Hydrology and Engineering Geology of Ministry of Geology firstly completed the compilation of the Geological Division Map of China with the scale of 1: 3 000 000 (CHEN Meng-xiong, 2007). In the 1960s, they completed the compilation of hydrogeological maps of some large plain basins units, such as the North China Plain and Songliao Plain and the complication of national map with a small scale. At the end of the 1970s, with the completion of the hydrogeological surveys on a scale of 1: 200 000 in most parts of the country, except for Qinghai-Xizang Plateau, desert hinterland and forest land, the hydrogeological work was flourishing, from which the cartographic methods and map contents map also became mature (CHEN Meng-xiong and MA Feng-shan,

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2002). In 1979, the hydrogeological professionals and the related governmental departments worked together to compile and publish the hydrogeological atlas of the People's Republic of China. In 1988, the Institute of Hydrogeology and Engineering Geology of Chinese Academy of Geological Sciences completed and published the hydrogeological map of China (1: 4 000 000) (JIAO Shu-qin *et al*. 1988). In the late 1990s, China Geological Survey of the Ministry of Land and Resources (now renamed as Ministry of Natural Resources) initiated to conduct the "survey and assessment of national groundwater resources and environment problems", and completed the compilation of a series of maps.

After more than 30 years, the hydrogeological map of China (1: 4 000 000) can no longer represent the current status of hydrogeological research in China. It is hence imperative to revise or recompile the maps. In 2014, in the compilation of national hydrogeological maps project organized and implemented by China Geological Survey, Ministry of Natural Resources, a competent titled digitization of hydrogeological map of China on a scale of 1: 5 000 000 was specially established, which was undertaken by China Geological Environment Monitoring Institute and the Institute of Hydrogeology and Environment Geology, Chinese Academy of Geological Sciences.

The mapping program was undertaken on the basis of existing hydrogeological map of China (1: 4 000 000) and the results of the project "Survey and Assessment of National Groundwater Resources and Environment Problems" (conducted in 1999-2005. During the mapping process, the groundwater type and water-bearing degrees of aquifer and rock formations were redefined (CHENG Xue-xu *et al*. 2008; HAN Ying *et al*. 2008; LIU Bin *et al*. 2008; WU Xue-hua *et al*. 2009; YANG Xiang-kui *et al*. 2008; LIU Zhi *et al*. 2009; SHEN Tian-de *et al*. 2009; ZHAO Hai-qing *et al*. 2009, LI Rui-min *et al*. 2018). Furthermore, other existing maps, including groundwater resources map of China (1: 4 000 000) (ZHANG Zong-hu *et al*. 2006), hydrogeological map of karst in China (1: 4 000 000) (LI Guo-fen *et al*. 1992) and Hydrogeological hydrogeological map of Asia (1: 8 000 000) (ZHANG Fa-wang *et al*. 2012), were also referred to enhance the map contents and mapping methods.

Based on previous studies and current systematic analyses, the hydrogeological mapping of China facilitates an intensive research into the types, distribution and characteristics of groundwater occurrence in water-bearing rock formations in China. Results of this mapping program will provide fundamental data for further research and application purposes, particularly in the areas of groundwater dynamics, groundwater exploration and exploitation for the demands in social and economic activities. It will also provide a basis for groundwater resources development, resource management and environmental protection across the country. Moreover, the map and associated materials will serve as an important reference for capacity building of college and university students.

1 Methods and technical route of map compilation

The hydrogeological map of China principally reflects regional and fundamental features in relation to the formation and distribution of groundwater in the major aquifer units; it roughly summarizes the groundwater occurrence, spatial distributions and structure features of water-bearing formations, as well as distinguishes the hydrogeological settings across different regions of the country.

1.1 Mapping principles

The mapping was conducted on the basis of the following principles:

(1) Scientific, inheritance and innovation

Each content displayed on the map should have corresponding scientific basis. The new map must adopt the achievements of previous studies and the data derived from latest surveys should be incorporated into the new map.

(2) Coordination

It is necessary to clarify the water-bearing degrees of different water-bearing formations according to updated materials which are marked on the map under same standards.

(3) Clear distinction

It is prioritized to present groundwater occurrence types and the water-bearing degree of water-bearing formations; and to show the features of groundwater quality and hydrogeological characteristics on the map should be done in an orderly way.

1.2 Mapping methods

In terms of groundwater occurrence type classification, this mapping process takes into account not only the features of regional groundwater units, but also the water-bearing rock formations and rock fractures, which is in line with water-bearing degrees. Combining these factors with the characteristics of regional geomorphology and geological structures, the distribution of various types of water-bearing formations and aquifer units is then scoped and marked on the map.

With respect to groundwater quality classification, this mapping process started with assessment of the suitability of drinking, agricultural, industrial and eco-environmental water on a large scale, in which the concentration of total dissolved solids (TDS) in the water was used as a major component. For the other content, this map mainly focuses on groundwater burial characteristics for key areas with extensive groundwater studies and highly economic development, with the intension of groundwater resources development perspective. In order to display the natural groundwater occurrence on the map and to reveal the regional recharge, groundwater runoff as well as the interaction between groundwater and surface water, the map principally presents some large and famous springs, thermal springs and subterranean streams.

1.3 Technical route

Technical route of this mapping process is highlighted in Fig. 1.

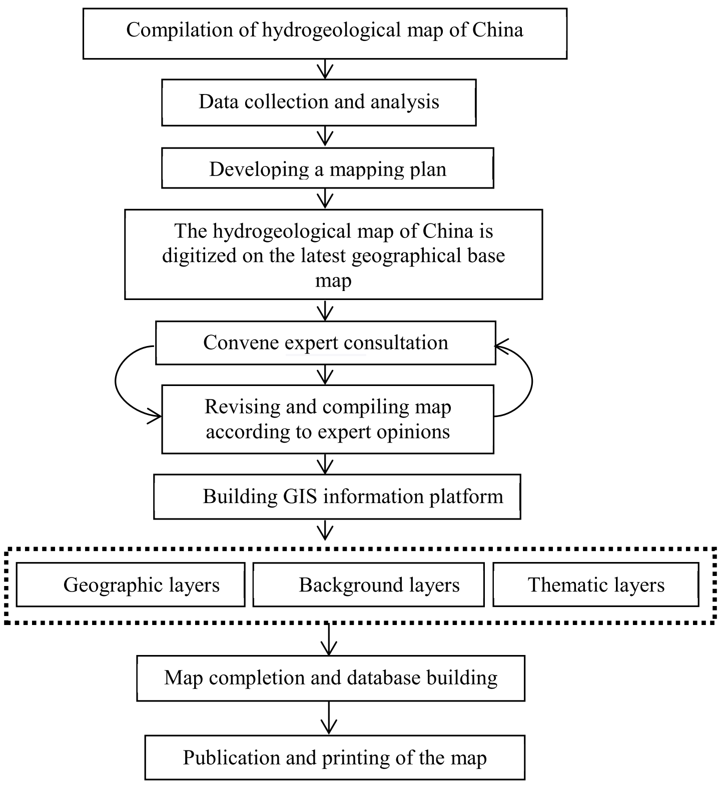

Fig. 1 Map of technical route

2 Main contents and cartographic methods

2.1 Main content

The hydrogeological map of China (1: 5 000 000) mainly reflects the types of groundwater and the level of groundwater richness in the country. It also reflects the quality of groundwater, the characteristics of deep groundwater burial in important plains, the main representative water points and other related contents, which is specifically divided into the following aspects.

(1) Highlighting the spatial distribution of different groundwater types and the water richness of aquifer groups

According to the different properties of water-bearing media, groundwater is divided into five basic types: Pore water in unconsolidated sediments, fissure-cavity water in carbonate rocks, pore-fissure water in clastic rocks, fissure water in magmatic and metamorphic rocks as well as water in frozen layer (Fig. 2). Taking into account the differences in climate, geomorphology and precipitation in different regions, as well as the differences in hydrogeological conditions, aquifer systems and structures, and groundwater infiltration conditions, each basic type is further divided into a number of sub-categories on the basis of the differences in the distribution and burial of aquifer groups and their geomorphological conditions. The porous-fractured water of red beds in the hilly basins is firstly included in this map compilation. The characteristics of each type of aquifer group is expressed by water richness; and the classification of water richness is divided according to the specific conditions of each type. The yield of a single well (or underground river or spring flow) is divided into different levels, with a maximum of 5 levels. The grading standard for groundwater richness is quantified; and the difference of different rock aquifer groups is taken into account in the selection of the numerical interval value of the water richness. The five levels of pore water of loose deposits are: Strong, moderately strong, medium, weak, very weak. Three levels of carbonate rock fissure water and clastic rock pore fissure water are strong-medium-weak, respectively. Igneous and metamorphic rock fissure water can be divided into two levels, namely medium and weak ones, while frozen layer water is represented by only one weak level (Fig. 2).

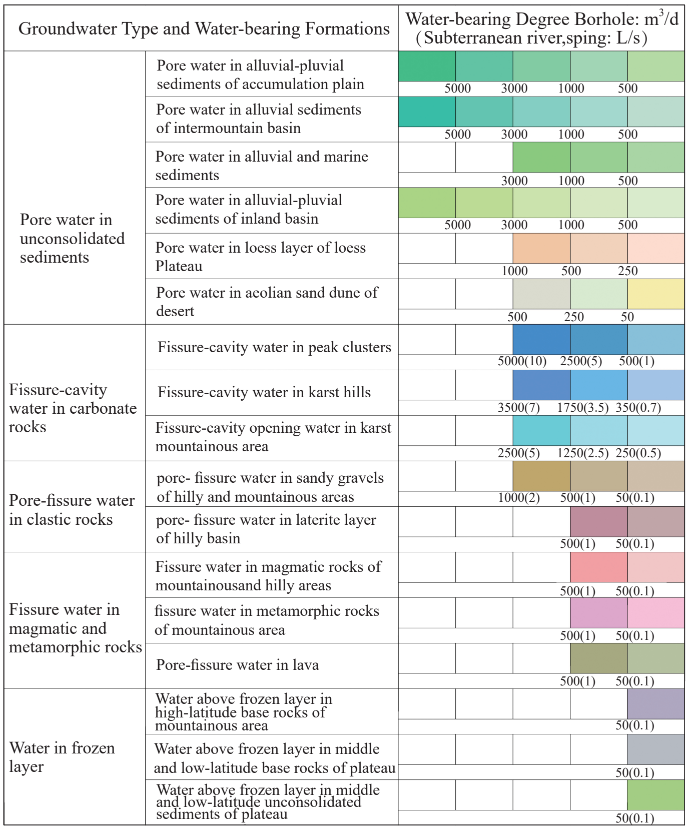

Fig. 2 Cartographic standard for groundwater type and water-bearing degree

(2) Multi-layered porous sediments with underlying confined aquifers in plain areas

In this case, particularly with underlying karstic and fractured rock aquifers, the map areas will be represented by dual-layered structures with groundwater richness levels (Fig. 3).

(3) Water quality

To present groundwater quality, TDS was used as a key grading directive in line with the requirement of domestic water supply. In addition to fresh water with wide distribution, this map stresses 4 types of saline water regions, including

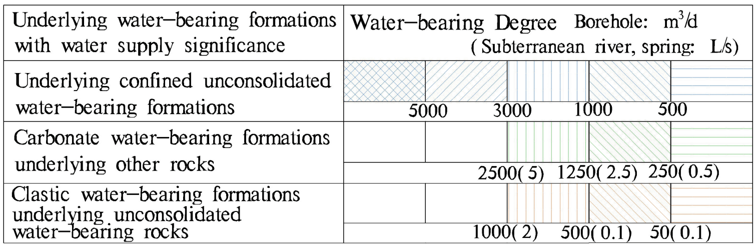

Fig. 3 Cartographic method of underlying water-bearing formations with water supply significance and associated groundwater yield levels

brackish water with the TDS of 1~3 g/L, semi-saline water (for TDS of 3~5 g/L), saline water (for of TDS >5 g/L) and poor fresh water area within groundwater extraction depth in coastal plains (AN Le-sheng *et al*. 2012; WEN Dong-guang *et al*. 2012).

(4) Groundwater depth

For the groundwater burial characteristics, the map mainly presents burial depth of confined aquifer roof, burial depth of deep freshwater aquifer roof in sedimentary plains, groundwater beneath frozen layer in the middle- to low-latitude plateaus, and areas with sparse unconfined aquifers.

(5) The map only displays typical groundwater outcrop points such as large or famous springs and spring groups, thermal springs and subterranean rivers.

(6) Other features displayed on the map include hydrogeological boundaries for groundwater types, boundary conditions of underlying water-bearing formations with water supply significance, thickness isoline of permafrost, upper and low limits of permafrost thickness, catchment divides, major fault lines, glacier and snow cover as well.

2.2 Display method

The cartographic process of this map is to make the best effort to display the logical relationship between graphic language and the contents on the map, which also aims to elevate the level of hydrogeological mapping. For the matching of hues, different colors are chosen based on the water-bearing type. More importantly, the universality and particularity of color matching are combined so that the graphic contents and colors get abundant and coordinated.

The map projection system adopts plane rectangular coordinates and Lambert equiangular conic projection. The projection parameters are Beijing 54/Krasovsky (1940) ellipsoid, with the first normal latitude of 25°00′00″, the second normal latitude of 47°00′00″, the central meridian of 105°00′00″ and projecting original latitude of 18°00′00″.

Different colors are used to represent different types of groundwater, considering different conditions of regional geology, topography, geomorphology and climate. In the mapping process, daily discharge of a single well or spring is used to represent and distinguish the groundwater richness levels in a region, for which the same color hue but different color scales are used to indicate the differences in the richness levels for the same type of groundwater. Accordingly, this map uses color matching technique to represent the dual-layer aquifers and associated groundwater burial conditions. For groundwater quality, areal symbols are used to represent the distribution of saline water. Moreover, line and dot symbols are used to represent controlling water points such as well, spring, subterranean river and other groundwater related points (JIAO Shu-qin *et al*. 1988; ZHANG Zong-hu *et al*. 2006; ZHANG Fa-wang *et al*. 2012).

3 Updated contents

3.1 Major items updated in current map

In the late 1990s, the work of “Survey and Assessment of National Groundwater Resources and Environment Problems” was carried out by the Ministry of Land and Resources (now the Department of Natural Resources), China Geological Survey (1999-2005); a series of research results with valuable data were obtained. The following contents derived from current mapping campaign are supplemented to and updated on the hydrogeological map of China (1: 4 000 000).

(1) The red-bed porous-fractured water in hilly basin was added in the groundwater occurrence categories. The red-bed rocks normally refer to the detritus sedimentary strata formed in the Cretaceous to the Pleistocene (ZHANG Zong-hu *et al*. 2004), under hot and arid paleoclimate environments. In recent years, increasing number of researches have been made on the formation age and tectonic background of the red horizon and on the chemical characteristics and genesis of red-bed porous-fractured water (CHEN Shu-hua *et al*. 2020; CHEN Qian *et al*. 2013; FENG Wen-kai *et al*. 2020).

(2) Groundwater richness grade

In this mapping process, the groundwater richness levels were defined in a quantitative manner. By using the yield of single well or spring (ZHANG Zhao-ji *et al*. 2009), and taking into account the differences in climate, geomorphology and precipitation, hydrogeological conditions of aquifer systems and groundwater recharge conditions in different regions, the richness level was subdivided up to 5 levels.

(3) The porous aquifer with multi-layered structure, underlying karstic and porous-fracture groundwater basin and their water richness levels are reflected on the map by using dual-layered areal symbols.

3.2 Major data updated in current mapping campaign

(1) Pore water of unconsolidated sediments

In many areas, hydrogeological data of groundwater in porous sediments are available, especially those of aquifer lithology and aquifer thickness and associated groundwater abundance reflected by single-well yield. The areas with full data availability include Songnen Plain (ZHAO Hai-qing *et al*. 2009), the intersection of Kailu County and Horqin district in the west Liaohe Plain (LI Zhi *et al*. 2009), wondersun piedmont of Sanjiang Plain platform (YANG Xiang-kui *et al*. 2008), the throat of the Yellow River alluvial fan in the Yinchuan Plain (WU Xue-hua *et al*. 2009), Shanxi Taiyuan basin (HAN Ying *et al*. 2008), north Tianshan piedmont area in Junggar basin (SHEN Tian-de *et al*. 2009), Aksu River Alluvial Plain (LIU Bin *et al*. 2008), a figure attash-kashgar west geermu (WANG Yong-gui *et al*. 2008); the Yumen-Renren basin of Shule River basin, Anxi-Dunhuang basin, Huhai basin (CHENG Xu-xue *et al*. 2008) and other regions.

Among them, Songnen Plain is a water storage and convergence basin with abundant groundwater resources, where groundwater converges from all the sides. The sediments formed in the Mesozoic period have a thickness of about 80~150 m. The aquifers in the Songnen sedimentary basin can be classified as single-, dual- and multi-layered ones. Aquifers with dual-layered structure mainly distribute in eastern high plains. Major content of confined basins in areas including Yushu, Shuangcheng and Suihua is sand gravel of Miocene and Pleistocene. Water-bearing formations of these areas are characterized by coarser grained sandy gravels. In the central area of the basin, the aquifers generally reach 10~30 m in thickness and are highly groundwater abundant with higher water-bearing degree and outflow of per well is 1 000 m^3/d to 3 000 m^3/d. The upper part of the water-bearing formations in the high lands is mainly mild clay and the lower part is disjunctive distribution of sand and sandy gravel with different thicknesses, so that the supply capability of aquifers is low. In the sedimentary plain, water-bearing degrees of sand and sandy gravel are at a medium level with outflow of 300~1 000 m^3/d per well, while that of loess soils is normally low indicated by well yield of below 100 m^3/d.

The alluvial sand and sandy gravel deposits, along the river valleys of Second Songhua River, Lalin River, Tongken River, Hulan River, Wuyuer River and Namoer River, mainly comprise alluvial sand and sad gravel with high water-bearing degree and outflow of per well is usually 3 000 m^3/d to 5 000 m^3/d. The middle of the plain is characterized by flat terrain with strong evaporation and slow groundwater flow. This leads to high salinity and low yield of the upper phreatic groundwater. However, underlying confined aquifers consisting of sands and sandy gravels produce groundwater of good quality and high yield. These aquifers are generally 10 m to 30 m in thickness with a piezometric level of 2 m to 5 m and a well yield of 1 000~3 000 m^3/d. Beneath the unconsolidated sediments in the middle of the plain are clastic rocks of the Neogene period, Paleogene period and the Cretaceous period. These fractured rock aquifers produce groundwater of good quality as indicated by TDS of less than 1 g/L, but low borehole yield of less than 100 m^3/d (ZHAO Hai-qing *et al*. 2009).

West Liaohe Plain is located at the junction of Kailu County and Horqin district. The maximum aquifer thickness is 196.8 m which is thinning toward the plain border. The aquifers in Baiyintala-Baxiantong-Kailu-Dongfeng area of central plains mainly consist of sand gravel, argillaceous pebble, medium to coarse-grained sands and medium- to fine-grained sands with the thickness of 100~180 m and high water-bearing degree. Daily outflow of per well is over 3 600 m^3/d. Water-bearing degree will decrease from high to medium and low as the aquifers extend to the plain boundary. The aeolian loess-like soil, over the loess hilly areas in the southern part of the Daxinganling Mountains, has a thickness of 10~30 m, where the single-well yield is generally less than 120 m^3/d (LI Zhi *et al*. 2009).

In the piedmont terrace lands of Wandashan Mountain, the aquifer lithology is of lightly cemented medium- to fine-grained sandstones, sandy conglomerate and gravelly sandstone from Fujin River Paleogene Period to Neogene Period. Due to the well-developed pore spaces and fracture networks, these aquifers have a good condition for developing groundwater flow paths and have a medium groundwater richness level with the single well yield of 100~1 000 m^3/d. Especially in Qixing township, Baoqing County, the outflow of per well is in the range of 1 000~3 000 m^3/d (YANG Xiang-kui *et al*. 2008).

The Yellow River gorge alluvial fan, located at the southmost Yinchuan Plain, makes up a comparatively unconfined aquifer with a thickness of 20 m to 60 m, groundwater level of 0.5 m to 4 m below surface and a single-well yield of 2 000 m^3/d. Moreover, the upper part of the alluvial fan qualifies an outflow of 5 000 m^3/d per well, which decreases towards the fan edge. These multi-layered water-bearing formations mainly consist of fine sand, partially silty sand and sandy gravel. The water-bearing degree of underlying and confined aquifer is lower than 1 000 m^3/d. Some of the confined aquifers usually have a yield of 1 000~2 000 m^3/d (WU Xue-hua *et al*. 2009).

The aquifer yield in large pluvial fan of the Fenhe and Wenyu rivers, Taiyuan basin, can generally reach 1 500 m^3/d, while the value decrease to less than 500 m^3/d at the areas in between pluvial fans, 100~250 m^3/d in the alluvial layer of the north of the Fenhe River and 25~500 m^3/d in the south. The alluvial aquifers in north of Fenhe River are characterized by high groundwater richness with a single-well discharge of 1 500~5 000 m^3/d, whereas the well production is low in other aquifers with an average well yield of 50~130 m^3/d. In the sedimentary basins in the alluvial/pluvial fans in the south of Fenhe River, that value is basically less than 10 m^3/d (HAN Ying *et al*. 2008).

Along the piedmont area of Tianshan Mountain, north of Junggar basin, the groundwater yield of aquifers with loose sediments shows a horizontal tendency, namely changes from low yield zone to the high and then low once again from the south to the north. For example, the piemount areas around Chaiwopu basin in southern Urumqi show obvious zoning of aquifer production. Per well outflow in the stripped areas can reach 2 100 m^3/d, while in the south the value slowly decreases to less than 24 m^3/d (SHEN Tian-de *et al*. 2009).

In the southwest of Xinjiang, the alluvial/pluvial plain along Aksu River reveals a characteristics of high hydraulic conductivity (as 600~1 000 m/d) and a high aquifer production (as 1 000~3 000 m^3/d). Moreover in the west of Atushi-Kashgar delta ares, groundwater is extremely abundant with the per-well outflow of 3 000~5 000 m^3/d. However, in the south of Yecheng County along Yarkant River and south of Zepu as well as Shache counties, aquifers of the alluvial-pluvial fans mainly comprise thick sandy pebble. The sandy gravel deposit occurs on the fan edges with high water-bearing degree and the outflow of per well in this portions of area is more than 5 000 m^3/d (LIU Bin *et al*. 2008).

In Qinghai Province, the water supply of Golmud City is highly dependent on the Nuomu alluvial/pluvial fan, where the aquifer yield is more than 4 000 m^3/d, but the value is slighty low as 100~1 000 m^3/d around the edge of the sedimentary fan (WANG Yong-gui *et al*. 2008).

According to surveys of Shule River Basin since 2000, for water-abundant area in piemount alluvial-proluvial fan, the outflow of per well in Yumen-Tashi Basin is 5 000 m^3/d, 3 000~5 000 m^3/d in water-abundant area in alluvial-proluvial fan of Anxi-Dunhuang basin and 1 000~3 000 m^3/d for fan edge as well as area south of the fan, 1 000 m^3/d for Huahai Basin along with generally lower than 1 000 m^3/d in other areas (CHENG Xu-xue *et al*. 2008).

(2) Fissure-cavity water in carbonate rock

In the eastern and southern parts of Sichuan Province, the carbonate strata are about 1 000 m thick, the maximum diameter of cavity can reach dozens of meters, and the underground rivers can even be several thousand meters long and have the flow of more than 4 000 m^3/h with the maximum flow of springs of more than 4 000 m^3/h. However, the flow of underground river system is unevenly distributed. For example, some Changxing limestone during the Permian Period is usually rather dry. In Henan Province, the carbonate strata are over 1 000 m thick, and there are more than 100 large springs and underground rivers with the flow of over 180 m^3/h per hour, and mostly with the flow of 700~1 000 m^3/h.

(3) Pore-fissure water in clastic rocks

(a) Groundwater in porous-fractured sandstone and conglomerate over hilly and mountainous areas

The Ordos sedimentary basin, located in the north of Shaanxi Plateau, is a tectonic basin formed in the period from the Mosozoic to the Cenozoic. The Cambrian-Ordovician carbonate formations comprise an important aquifer system with favorable recharge conditions and high water-bearing capacity in the area. For example, in the areas including Zhuozi Mountain in Inner Mongolia, Pengyang in Ningxia and Pingliang in Gansu provinces, the yield of the karst aquifer is in the range of 1 000~5 000 m^3/d with high water quality. On the other hand, the porous-fractured rock aquifers in the Cretaceous phreatic basin are characterized by huge variation in aquifer thickness, which is thin in the east and thick in the west. For example, the thickness in the east of Shangzhenzi (Ziwuling Mountain)-Jiangbian, is less than 400 m, but it is 400~800 m in the west of Qingyang-Heshui and 800~1 000 m in Huanxian-Tianchi. Lacustrine clastic rocks with the thickness of 60~391 m largely occur in the west of Huanxian County and Xifeng, and the main aquifers are composed of sandstones. According to borehole testing at Borehole B5, the porosity is 8.54% to 11.85% and the rate of water content is 27.72%~128%. The southern area of the basin is covered by loess on the top; and the aquifer system here comprises the Holocene alluvial deposits and its underlying Cretaceous Baoan Group with a groundwater yield of less than 100 m^3/d (HOU Guang-cai *et al*. 2004).

(b) Pore-fissure water in laterite layer of hilly basin

Laterite layers in the southwestern region. The red beds typically refer to the Mesozoic sedimentary rock formations across Sichuan, Yunnan, Chongqing, Guizhou and Guangxi provinces, the southwest of China. In addition, the red beds, which occur in the northwest of China including the areas across Shaanxi-Gansu-Ningxia basin, the Tarim basin and the Qaidam basin are characterized by the sedimentary rocks of the Triassic and Paleogene-Neogene period. Moreover, the porous-fractured aquifers with clastic rocks of the Cretaceous period are found in the deeper portion of the Ordos Basin (as deep as 1 200~1 800 m blg) and porous-fractured aquifers with clastic rocks of the Carboniferous and the Jurassic are found in the shallower part of the basin (mostly less than 300 m). The red beds in the mid-southern and southeastern regions of the country are referred to as the sedimentary formations formed from the Cretaceous period to the Paleogene one. In many regions, such as Changsha, Guangzhou, Hefei and Nanjing, these red beds are covered by the strata of the Quaternary deposits (CHENG Qiang *et al*. 2004; GUO Yong-chun *et al*. 2007).

(4) Fissure water in magmatic and metaphoric rocks

A typical case is that groundwater flow in the fractured aquifer of the Quaternary basalt in Datong Basin generally reaches 1 L/s and the yield of exploitation well can reach 500~1 000 m^3/d. Around Huanghualiang area in the centre of the basin, groundwater level is shallow and the outflow of per well is 500 m^3/d. In terms of water quality, groundwater of the basalt is of HCO_3-Ca·Mg type with the TDS of lower than 0.5 g/L (HAN Ying *et al*. 2008).

The above examples are typical areas with updated data. In this mapping process, more contents and updated information need to be addressed. However, due to space limitation of the paper, we will not go into details of many other cases here.

4 Layer structure

GIS layer layout of this hydrogeological map consists of geographic layers, background layers and thematic layers, which are listed in Table 1.

Table 1 GIS layers and associated layout for hydrogeological map

Serial No.	Classification	Name	Contents	Graphic object
1	Geographic layer	Geographic elements	Rivers (tertiary tributaries), main lakes, important summits, deserts and their name labels; boundaries at the level of provincial administrative division and above; the place of residence at the prefecture level and above and the professional contents required	Line graphic object
2	Background layer	Others	Boundary of groundwater type	Line graphic object
			Boundary of underlying aquifer with water supply significance	Line graphic object
			Thickness isoline of permafrost (m)	Line graphic object
			Upper and low limits of permafrost thickness (m)	Line graphic object
			Catchment divide	Line graphic object
			Major fault lines	Line graphic object
			Glacier and snow cover	Zone graphic object
			Crater	Dot graphic object
3	Thematic layer	Groundwater type and water richness level of water-bearing formations	Pore water in unconsolidated sediments, fissure-cavity water in carbonate rocks, pore-fissure water in clastic rocks, fissure water in magmatic and metamorphic rocks as well as water in frozen layer	Zone graphic object
4		Underlying water-bearing formations with water supply significance	Underlying confined unconsolidated water-bearing formations, carbonate water-bearing formations underlying other rocks, clastic water-bearing formations underlying unconsolidated water-bearing rocks	Zone graphic object
5		Distribution area of saline water	Brackish water, semi-saline water, saline water and no fresh water area within groundwater extraction depth in coastal plain	Zone graphic object
6		Groundwater burial characteristics	Burial depth isoline of confined water- bearing formation roof, burial depth isoline of deep freshwater aquifer roof in accumulation plain, water beneath frozen layer in middle and low-altitude base rocks of plateau, areas with sparse phreatic aquifers or with local absence of aquifer	Zone graphic object Line graphic object
7		Controlling water points	Large and famous springs, outflow spring group, thermal spring, and outlet of underground rivers	Dot graphic object
			Subterranean River	Line graphic object

5 Regional distribution characteristics of groundwater

Table 2 Regional distribution characteristics of groundwater in China

Groundwater type and water-bearing formations		Distribution area	Distribution characteristics
Pore water of unconsolidated sediments	Pore water in alluvial- pluvial sediments of accumulation plain	It is principally found in the large plains of the eastern part of China. There are large plains, flat terrains, and very thick unconsolidated sediments with the lithology of sand and sand gravels, which have loose layered structure.	Songnen Plain is a water storage and convergence basin with abundant groundwater resources, where groundwater converges from all the sides.
			The western part of the Liaohe River Plain features a very thick sand layer during the Quaternary period. With regard to lithology, sand particles from upstream to downstream get finer and clay interlayer increases in number and thickness. Further southwards lies the Lower Liaohe River Plain, where the terrain inclines from the north to the south. There is the dust-pan-shaped basin with its opening facing the sea. The sand layer during the Quaternary Period is well developed and the thickness is considerably changeable (almost 40~300 m). The shallow groundwater, mostly saline water, is of poor quality, but the deep confined water has abundant water resources and satisfactory water quality (ZHANG Zong-hu *et al*. 2004).
			The hydrogeological conditions in different areas of Huang-Huai-Hai Plain are quite different. In the north to the Yellow River, the alluvial fan of sand gravels during the Quaternary Period is highly developed with the thickness of 40~60 m. This alluvial fan gently unfolds along the piedmont and assumes the multi-layer superimposed sediments. The front edges of some alluvial-pluvial fans extend rather far. With the depth of more than 120~200 m under the ground, the aquifer is featured by rough particles, strong permeability, smooth runoff, high water-bearing degree and good water quality. Eastward from the front edge of alluvial-pluvial fan is the central plain. With the depth of 60~80 m underground is principally phreatic water or slightly confined water with low water-bearing degree and complex change to water quality. Brackish water plays a major role, and freshwater is found available in the form of belt only within some areas. The confined water is widely distributed below the depth of 80 m, and shows the burial features of being shallow in the west and deep in the east (ZHANG Zhao-ji *et al*. 2009).
			The aquifers in Sanjiang Plain are composed of thick pebble gravels and sand gravels. These water-bearing formations gradually thicken from the peripheral parts to the center, and can be over 200 m thick in the center.
			The Hetao Plain is made up of several enclosed basins. In this plain, the unconsolidated sediments during the Quaternary Period are 600 m thick and aquifer has the lithology of sand and sand gravels, where phreatic and confined water is available. Specifically, phreatic water is widespread and steady, and confined water, which is widely distributed as well, shows different depths as the distribution of silt layers varies. Some confined water even bursts out of ground surface.

Table 2 (Continued)

Groundwater type and water-bearing formations		Distribution area	Distribution characteristics
Pore water of unconsolidated sediments	Pore water in alluvial-pluvial sediments of accumulation plain	It is principally found in the large plains of the eastern part of China. There are large plains, flat terrains, and very thick unconsolidated sediments with the lithology of sand and sand gravels, which have loose layered structure.	The Jianghan Plain to the south of the Qinling Mountains is a small plain with a total area of over 60 000 km^2. With broad and flat terrain, this plain enjoys sufficient precipitation, well-developed water system and dense network of rivers. The unconsolidated sediments during the Quaternary Period are about 170 m thick. The phreatic aquifers are less developed and the confined water plays a dominant role across the whole region. The water-bearing degree of confined water in aquifers proves quite strong in the center of the plain, but gradually gets weaker toward the edge. The confined water has the depth of 0.4~3.0 m.
			The shallow aquifers of the Chengdu Plain mainly consists of gravel and pebble layer with the thickness of 20~50 m, strong water-bearing degree (ZHANG Zong-hu *et al*. 2004).
	Pore water in alluvial sediments of inter-mountain basin	Widely distributed throughout the country. The faulted basin is generated after the part of mountainous region is subject to structural control. With the washing by rivers and the gradual accumulation of unconsolidated sediments, there are some small-scale inter-mountain basins (valleys) of different thicknesses.	The pore water of these unconsolidated sediments are widely distributed and of considerable quantity. In the bedrock-based mountains of southern China, the inter-mountain basins are widely distributed. The groundwater of this type has the features that distribution of aquifers is closely related to tectonic causes. In most cases, their respective independent hydrogeological systems are created, and the enclosed and semi-enclosed confined artesian basins show their characteristics to develop their independent water convergence centers. Yet, the depth of groundwater varies from one place to another (CHEN Meng-xiong and MA Feng-shan, 2002).
	Pore water in alluvial and marine sediments	Mainly located along the eastern coastal zone of China.	To the north of the Hangzhou Bay are primarily the interactive sedimentations of alluvial and marine sediments as a result of seaward movement of great plains or piedmont rivers, so there emerges the pore aquifers of unconsolidated sediments in the coastal plain or delta. Groundwater has the deferred runoff. For instance, the phreatic aquifers in the costal zones along the Bohai Sea and the Yellow River are mostly composed of marine mucky clay together with silty sand. With shallow groundwater, the aquifers have weak water yield quality and poor water quality, but the confined water is usually available in the deep water-bearing formation. With varied depth and in most cases, the depth of 80~200 m or even more, the confined water boasts satisfactory quality and sufficient supply. Leiqiong area alone can be categorized as the east-west down-faulted zone during the Cenozoic Era. The unconsolidated sediments are more than 3 000 m thick and the confined groundwater is stored in large quantities.

Table 2 (Continued)

Groundwater type and water-bearing formations		Distribution area	Distribution characteristics
Pore water of unconsolidated sediments	Pore water in alluvial-plubial sediments of inland basin	Distributed in the northwestern part of China	The Junggar basin, the Tarim basin, the Qaidam basin are distributed in the northwestern part of China. The marginal areas of these basins are extensive, and the alluvial-pluvial sediments are hugely thick. On the top of the widely available piedmont sloping plains is the Gobi gravel layer. All the basins are surrounded by high snow-capped mountains, which serve as favorable sources to recharge the basin groundwater.
	Pore water in loess layer of loess plateau	Widely distributed in China, but mainly in the midstream and downstream areas along the Yellow River	The loess layers are characterized by thick and continued sediments. The distribution of pore water in loess layer is related to precipitation, and restricted by the loess landform.
	Pore water in aeolian sand dune of desert	Deserts constitute about 1/9 of the total land area in China. Most of deserts are located in the middle of landlocked basins across the northern and north-western parts of China.	The main deserts include the Taklamakan Desert, the Gurbantunggut Desert, the Kumtagh Desert, the Badain Jaran Desert, the Tengger Desert, the Ulanbuh Desert and the Mu Us Desert. Climatically, deserts are featured by huge droughts, strong evaporation and insufficient surface water. Groundwater is mainly found in phreatic water of sand dunes or porous water beneath sand dunes.
Fissure-cavity water in carbonate rock	The fissure-cavity water in peak clusters	Primarily distributed in the Pearl River Basin in the southernmost part of China.	Carbonate rocks are found in many parts of China. The fissure-cavity water that is available in huge quantity shows the features like abundant resources, uneven distribution in terms of geological distribution and noticeable changes to water level and quantity over time. However, the fissure-cavity water within large areas has a limited change to water quality and the low salinity (JIAO Shu-qing and DAI Xi-sheng, 1988).
	Fissure-cavity water in karst hills	Mainly distributed in the northern part of China.	
	Fissure-cavity-opening water in karst mountainous area		

Table 2 (Continued)

Groundwater type and water-bearing formations		Distribution area	Distribution characteristics
Pore-fissure water in clastic rocks	Pore-fissure water in sandy gravels of hilly and mountainous areas	(1) In the eastern part of Xizang, the western mountains of Sichuan and the Sichuan basin (2) In the western and northwestern parts of Guangxi Zhuang Auto-nomous Region and the northern mountains of Guizhou Province	In the eastern part of Xizang, the western mountains of Sichuan and the Sichuan Basin, there are lots of slightly metamorphic sandstones, sandy gravels, shale and sandstones during Mesozoic Era, where sandstones are abundant in water resources. In the western and northwestern parts of Guangxi Zhuang Autonomous Region and the northern mountains of Guizhou Province, sandy shale, sandstones, and mudstones mainly during Paleozoic Period and sometimes during Mesozoic Period. Fissures are developed to different degrees and water-bearing degree stays at low level. There are limited water contents and considerable water quantity in some areas.
	Pore-fissure water in laterite layer of hilly basin	The laterite layers can be found in southwestern region, northwestern region as well as mid-southern and southeastern regions in China.	In China, laterite layers mostly came into existence during the long geological history of Mesozoic-Cenozoic Era. Major sedimentation periods include Triassic Period, Jurassic Period, Cretaceous Period Paleogene Period and Neogene Period, and are widely distributed in the southwestern, northwestern, middle and southern parts of China.
Fissure water in magmatic and metaphoric rocks	Fissure water in magmatic rocks of mountainous and hilly areas	Mainly distributed in the bedrock outcrop area of mountainous area	In the areas with the fissure water of metamorphic rocks are mainly the mudstones, which have the poor water storage and conducting performance. Fissures are less developed, but in case of the strata with limestone, the abundant water-bearing strata will be available. In the granite area along the southeastern coast of China, the anti-weathering capability is rather low. The weathering process usually results in sand and mild clay with small water contents and weak permeability. So the water-bearing degree in the water-bearing strata is rather weak across the igneous rock area with considerable precipitation in the southeast of China.
	Fissure water in metamorphic rocks of mountains areas		
	Pore-fissure water in lava		
Water in frozen layer	Water above frozen layer in high-latitude base rocks of mountainous area	Mainly distributed in the nor-thernmost parts of Northeast China and Northwest China and in the Qinghai-Xizang Plateau	Tundra constitutes about 1/5 of the national total area in China. The groundwater in these areas is mainly frozen layer water. Tundra usually has the thickness of dozens of meters to over 100 m. The thickness may change as the terrain fluctuates, and especially horizontally. In the frozen soil areas as a whole, the water above tundra is generally found in the lowland or slopes, and gets recharged from atmospheric precipitation or the molten water of snow and ice. With good water quality but limited water quantity, the water above tundra cannot be exploited fully as the source of water. The water beneath tundra, as confined water, is usually affected by changes to tundra thickness and controlled by regional structure. Therefore, the fault valleys and basins are the perfect reservoir of water beneath trundra. Under the perennially frozen layer with the thickness of 10~50 m is confined water or artesian water.
	Water above frozen layer in middle and lowlatitude basse rocks of plateau		
	Water above frozen layer in middle and low latitude uncon-solidated sediments of plateau		

6 Conclusions

This map reflects the latest achievements of regional hydrogeology research in the past 30 years in China, and represents the highest level of mapping technology for small scale maps.

This map is compiled on the basis of the hydrogeological map of China (1: 4 000 000), together with the application of new research achievements from "The Survey and Evaluation of Groundwater Resources and Environmental Problems in China". Inheriting research results of predecessors, the new version map focuses on improving mapping content and cartographic methods to display as more and latest material and contemporary mapping features as possible. Moreover, through systematic analysis and data collation, the water-bearing degree of water-bearing formations are quantitatively measured in accordance with the same standards.

By using GIS technology, the geographical, background and thematic layers of the hydro-geological map are set up with a standardized layout. The layout of these layers attempts to form an entire picture while they have independent features, which is favorable to build a database and compiling related maps.

The result of the map compilation is the product of professionals in the areas of geosciences across the country. It is hence important scientific basis for the national government departments to conduct planning of national resources and the social and economic development, as well as the important guideline for the rational development of groundwater resources, environmental protection and building eco-civilization. This map can promote people's understanding of hydrogeological conditions, enhance their awareness of protecting groundwater environment and groundwater resources in order to better serve sustainable development in China. Hydrogeological characteristics are highly correlated with topography, landform, latitude and climatic conditions of the water-bearing system structure. In the future, the coupling mapping of underground water-bearing system and climatic geomorphologic data on the basis of hydrogeological mapping research is bound to become a new growth point of hydrogeological mapping.

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