Chapter II.13

GYPSUM KARST IN CHINA

Lu Yaoru & Anthony H.Cooper

Abstract

The People's Republic of China has the largest gypsum resources in the world and a long history of their exploitation. The gypsum deposits range in age from Pre-Cambrian to Quaternary and their genesis includes marine, lacustrine, thermal (volcanic and metasomatic), metamorphic and secondary deposits. The gypsum is commonly associated with other soluble rocks such as carbonates and salt. These geological conditions, regional climate differences and tectonic setting strongly influence the karstification process resulting in several karst types in China. Well developed gypsum palaeokarst and some modern gypsum karst is present in the Fengfeng Formation (Ordovician) gypsum of the Shanxi and Hebei Provinces. Collapse columns filled with breccia emanate upwards from this karst and affect the overlying coalfields causing difficult and hazardous mining conditions. Gypsum karst is also recorded in the middle Cambrian strata of Guizhou Province and the Triassic strata of Guizhou and Sichuan Provinces. Gypsum-salt lake karst has developed in the Pleistocent to Recent enclosed basin deposits within the Qinghai-Xizang (Tibet) Plateau.

Introduction

Gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$) are important industrial minerals in The People's Republic of China which has the world's largest reserves and second largest annual production (Chinese Institute of Geology and Mineral Resources, 1993). The rapid dissolution of gypsum causes karst to develop quickly (Lu Yaoru et al., 1966) and commonly results in geological hazards such as collapse, land subsidence and degraded and polluted water (Lu Yaoru, 1966). These hazards are economically important and cause difficult mining conditions, difficult construction and urban development. Anthropogenic activity, construction and development may enhance gypsum dissolution and karst formation aggravating the geohazards. Therefore, the study of gypsum karst is of practical significance.

The distribution and nature of the gypsum karst types in China is dependent on the distribution and genesis of the original gypsum deposits, their associated rocks and the local hydrological regime. Gypsum karst is particularly well-developed in the Ordovician gypsum of Shanxi and Hebei provinces where geological hazards associated with it have important consequences for coal mining. Gypsum karst is also developed in the Cambrian strata of Guizhou Province and the Triassic strata of Guizhou and Sichuan provinces. Enclosed drainage basins in the Qinghai-Xizang (Tibet) Plateau have extensive deposits of gypsum and other more soluble sulphates in which small-scale karst features have developed. Elsewhere in China, although gypsum is known to exist,

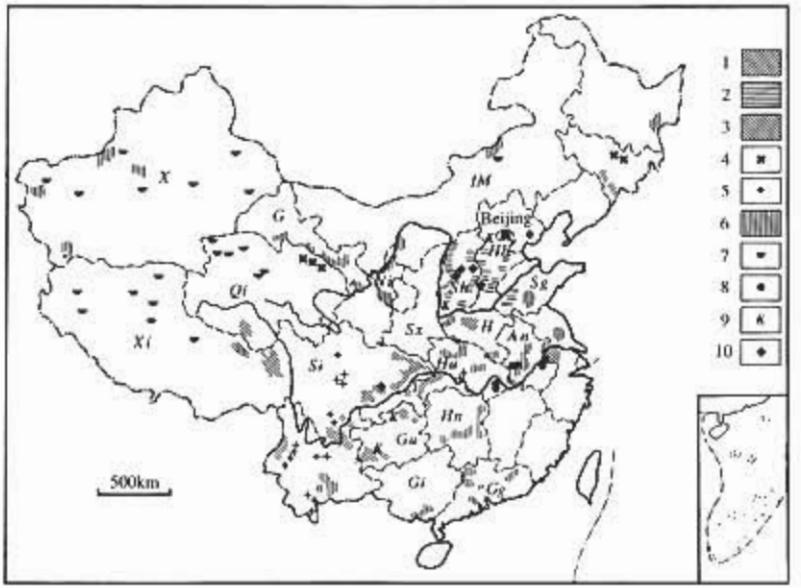

Fig. 1. Map showing the age and distribution of the main genetic types of gypsum in China. 1. Cambrian marine gypsum; 2. Ordovician marine gypsum; 3. Triassic marine gypsum; 4. Carboniferous marine gypsum; 5. Cretaceous lacustrine gypsum; 6. Tertiary lacustrine gypsum; 7. Late Tertiary-Quaternary lacustrine gypsum; 8. Thermal and metamorphic gypsum (typical localities); 9.Secondary deposits of gypsum produced by karstification (typical localities); 10. Coal mining areas affected by collapse columns caused by gypsum dissolution. Abbreviations for province names: An-Anhui, G-Gansu, Gg-Guangdong, Gi-Guangxi, Gu-Guizhou, H-Henan, Hb-Hebei, Hn-Hunan, Hu-Hubei, IM-Inner Mongolia, Ni-Ningxia, Qi-Qinghai, Sg-Shandong, Sh-Shanxi, Sx-Shaanxi, X-Xinjiang, Xi-Xizang (Tibet).

the gypsum karst features are not widely described and constitute an interesting area for future research. This paper seeks to document and review briefly the main developments of gypsum karst in China.

1. The genetic types and distribution of gypsum in China

Gypsum occurs in most of the provinces and autonomous regions of China. It is an important mineral resource that is widely mined and 90 percent of Chinese production comes from Shandong, Inner Mongolia, Qinghai, Hunan, Ningxia, Xizang, Anhui and Sichuan. The gypsum was formed in many different geological conditions which include: marine, lacustrine, thermal (volcanic and metasomatic), metamorphic, karst and other secondary processes (Lu Zhicheng, 1981; Tao Weiping, 1981). The simplified distribution, age and genesis of the main gypsum types in China are shown in Fig. 1 (Lu Yaoru, 1986, 1993; Chinese Institute of Geology and Mineral Resources, 1993).

Stratigraphical sequence of the karst aquifers of Shanxi Province (based on Zhang Shouquan, 1989, and Sha Qingan *et al.*, 1989)

Age	Formation	Lithology	Thickness (m)	Hydrological properties
Middle Ordovician	Fengfeng	Thick limestones and marls	20-70	aquifer
		Dolomite and marly limestone with gypsum and breccia	36-152	moderate aquifer
	Shang Majiagou	Limestone, marl and dolomite	150-200	main aquifer
		Dolomite, marl, brecciated limestone and gypsum	30-50	confinin g bed
	Xia Majiagou	Thick limestones and dolomites	90-130	aquifer
		Dolomitic mudstone and marl, sandy near base	30-50	confining bed
Lower Ordovician	Liangjiashan	Dolomite and marl	75-150	weak aquifer
	Yeli	Marly dolomite and limestone	30-60	confining bed

2. Gypsum karst in Shanxi Province and surrounding areas

In Shanxi Province gypsum is present mainly in the Ordovician Fengfeng Formation, but also to a lesser extent in the underlying Shang Majiagou Formation; below this lie the dolomites and marls of the Xia Majiagou, Liangjiashan and Yeli Formations (Table). The Fengfeng, Shang Majiagou and Xia Majiagou formations are the main aquifers in the region. The Fengfeng Formation contains up to about 60 percent of secondary gypsum, present as thick massive beds, nodular gypsum and gypsum interbedded with mudstone and dolomite (Sha Qingan et al., 1989). The Shang Majiagou Formation also contains some gypsum and is the major regional aquifer. In the Tiejingou deposit near Yangquan the Fengfeng Formation ranges in thickness from several tens to more than one hundred metres.

The current tectonic setting of the Fengfeng Formation has largely resulted from regional uplift and subsidence. Four belts can be recognised: an eastern plain at less than 50m above sea level, the Huabei Pinguan, extending into Hebei Province; the Taihang Shan mountains rising to 2000m; the main basin of the Shanxi Coalfield at 500-1200m above sea level; the Lüliang Shan mountains to the west of the coalfield rising to about 2800m above sea level. Within this part of China the rainfall is about 460mm per year with very high evaporation (Wei Keqin et al., 1989) so most of the active gypsum dissolution here comes from river seepage and groundwater flow (Zhang Shouquan, 1989; Pan Shulan, 1989). Some active gypsum dissolution is evidenced by the presence of sulphate in groundwater from springs, such as the Jinci Spring, situated along the faulted western margin of the Shanxi basin (Fig. 2). However, most of the gypsum karst is palaeokarst that has been uplifted or has subsided to its present hydrological position. The most impressive karst features are the collapse columns or breccia pipes that have developed in the Fengfeng Formation after the dissolution of massive gypsum and the collapse of the associated

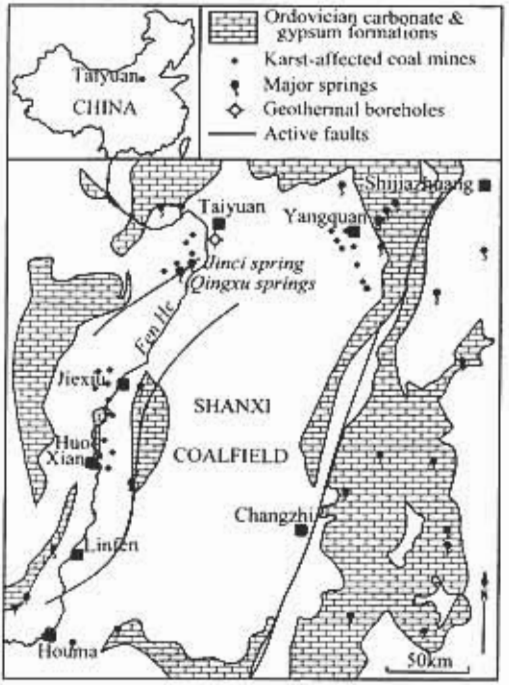

Fig. 2. The Shanxi coalfield and the locations of the main karst-affected coal mines and some important springs. The distribution of the Ordovician gypsiferous and carbonate sequences are shown surrounding the coalfield.

caves (Zhang Zhigan, 1982). The resultant collapse columns can be large, reaching many tens of metres in diameter and penetrating upwards through 50-500m of overlying strata (Fig.s 4 and 6) (Qian Xuepu, 1988). In addition to the massive collapse columns, the dissolution of gypsum and collapse of interbedded gypsum and carbonate strata has resulted in the formation of breccia layers that are commonly re-cemented with carbonate (Zhang Fenqi and Han Zingrui, 1983).

Boreholes in the Shanxi Coalfield basin show that anhydrite is generally present at depths of more than 800-1000m; it passes laterally up-dip into strata with gypsum. This in turn passes up-dip into gypsum karst breccias and collapse columns that, depending on the hydrological regime, are present from depths of about 300-600m to surface (Han Xingrui, 1991). The control of the gypsum karst by depth is responsible for the concentration of the coal mines with gypsum collapse columns around the margins of the coalfield in the Taiyuan, Huoxian and Yangquan mining areas (Fig. 2).

Several intervals of karstification have affected the gypsum of the Fengfeng Formation. In the Taihang Shan mountains, along the eastern side of the Shanxi Plateau, inclined collapse columns are present, but they have a perpendicular relationship with the associated strata. The inclination is assigned to the Yanshanian-Himalayan earth movements during the early Mesozoic, implying that much of the karstification predated that interval (Zhang Zhigan, 1980; Han Xingrui, 1991). These earth movements have been largely responsible for the uplift and subsidence of the gypsum karst so that collapse columns are now found at elevations of 700m above sea level in the Shanxi Plateau and depths of 700m below sea level in the Hebei Plane (Fig. 3). Subsequent karstification of the Shanxi Plateau and areas to the west was developed in the early Pleistocene when

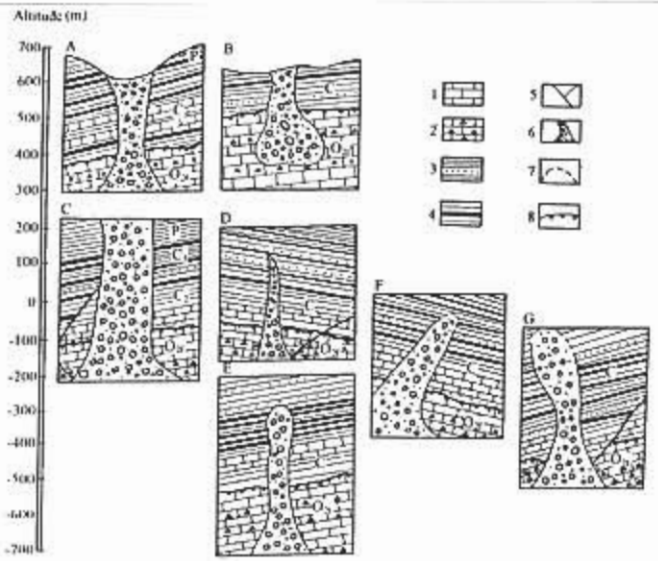

Fig. 3. Variations in the morphology and situation of collapse columns formed by the dissolution of Ordovician gypsum in the coalfields of northern China. The altitude variation of the different localities shows the effect of later tectonic activity. Collapse columns that reach the surface: A. Yangquan, Shanxi; B. Nianzhiguan, Shanxi; C. Jingjing No 5 Pit, Hebei. Collapse columns that only occur in the subsurface: D. Jingjing No 1 Pit, Hebei; E. Fengfeng No 9 Pit, Henan; G. Jingjing No 1 Pit, Hebei. Geological explanations: 1. carbonate rock; 2. breccia in carbonate rock; 3. shale and sandstone; 4. coal and clastic rock; 5. faults; 6. collapsed column; 7. conjectural boundary of collapsed column; 8. palaeokarst surface between the Ordovician Fengfeng Formation (O2f) and the Carboniferous (C2).

the water table was locally much higher. However, the area has now been uplifted further and the gypsum karst exists in the current vadose zone (Fig. 4). Within the Fengfeng Formation large palaeokarst caves, situated in the present vadose zone, have collapsed and are filled with breccia. Some of the collapse columns, such as those in the Nanyuan Mine of the Huo Xian area, are of Quaternary age (Qian Xuepu, 1988), and karst fissures are still undergoing dissolution and enlargement where there is active water flow.

3. Gypsum karst in Hebei Province

The gypsum karst of the Hebei Province forms an eastwards continuation of that seen in Shanxi Province. Collapse columns are present in the southern part of the Yan Shan mountains and in the coal mining area of the low-lying coastal plane where they cause mining difficulties (Fig. 3). At the Fangezhuang Coal Mine, 25 km ENE of Tangshan (150km ESE of Beijing) a breccia pipe filled with water-bearing collapse deposits was proved. It penetrated more than 300m upwards into the coal sequences from the underlying Ordovician carbonates and gypsum and had an open cavity at the top (Fig. 5). This palaeokarst structure allowed up to 12m^3/s of water to

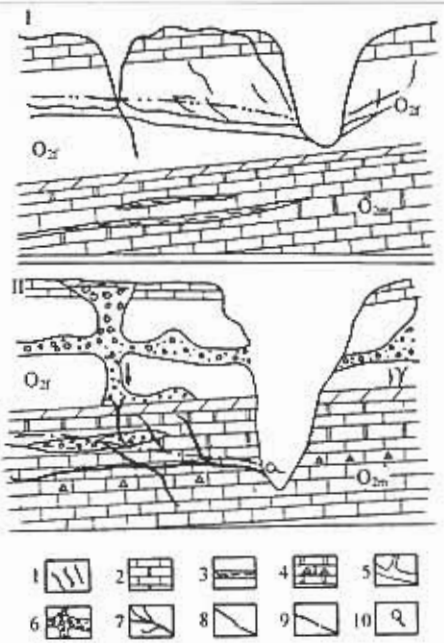

Fig. 4. The evolution of the gypsum karst in the Fengfeng Formation (Ordovician) gypsum of Shanxi Province. I. The early karstification stage (early Pleistocene); II The recent karstification stage (post middle Pleistocene); 1. gypsum in the Ordovician Fengfeng Formation; 2. carbonate rocks; 3. gypsum interbedded with the carbonate rocks; 4. breccia in the carbonate rocks; 5. early karst cave passage in gypsum; 6. karst collapse column and breccia; later karstified cave-passage system in carbonate rocks; 8. early groundwater table in gypsum; 9. recent karst groundwater table in carbonate rocks; 10. karst spring; O2f Fengfeng Formation; O2m Majiagou Formation.

flood the mine. The total amount of karst water that entered the mine over three months was about 46 million cubic metres (Qian Xuepu, 1988) and surface collapses were associated with the dewatering. The Jingjing mine of west Hebei has also suffered serious water inrushes from encountering karst collapse columns.

4. Gypsum karst in Sichuan Province

Within the south-eastern part of Sichuan Province a thick collapse breccia after gypsum dissolution is present in the Jialingjiang "Series" of Triassic age. Breccia-filled collapse columns ranging from several to 60m in diameter have developed and migrated upwards into the overlying Jurassic coal measures. These collapse columns have penetrated several coal seams and cause difficult mining conditions in Hechuan County (Qian Xuepu, 1988).

5. Gypsum karst in other areas of northern China

In addition to the gypsum karst documented in Shanxi, Hebei and Sichuan Provinces, karst collapse columns are also developed in Shangdong, Inner Mongolia, Shaanxi, Henan and Jiangsu (Xiang Shijun, 1993: Liu Qiren et al., 1996). Like those in Shanxi Province, the collapse columns range from tens to several hundreds of metres across, and can be tens to hundreds of metres high. Stratigraphically they have been caused by the dissolution of Cambrian, Ordovician, and Triassic gypsum. The collapse columns penetrate the overlying strata of Cambrian, Ordovician, Carboniferous, Permian and Triassic age and locally cause hazardous mining conditions (Wang Rui, 1982; Li Jinkai and Zhou Wangang, 1988).

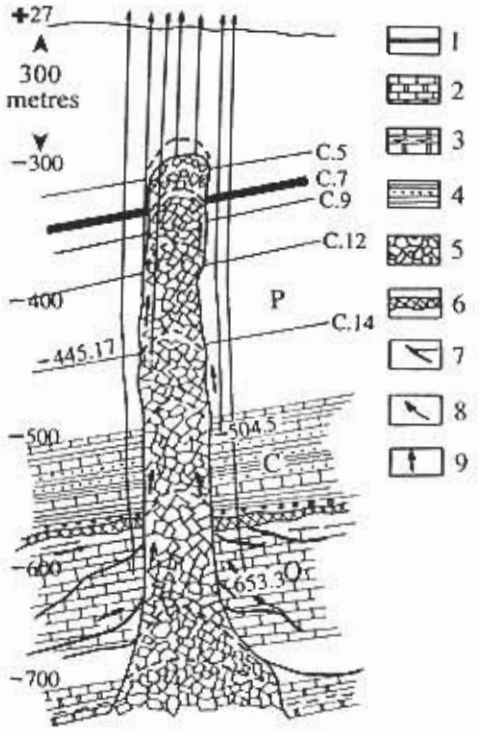

Fig. 5 Cross-section through a large collapse column filled with breccia at the Fangezhuan Mine near Tangshan.
1- Permian Shanxi Formation;
2- carbonate rocks;
3- carbonate rocks with gypsum;
4- sandstone and shale;
5-collapse column showing various stages of its upward progression;
6-palaeokarst horizon between the Ordovician and Carboniferous sequences;
8- direction of water flow;
9- boreholes.
Compiled from borehole data of the Bureau of Kailuan Mine (Xiang Shijun et al., 1993; Liu Qiren et al., 1996).

6. Gypsum karst in Guizhou Province

In South China sub-tropical climatic conditions have existed for a long time. Within the Suiyang area, situated to the north of Guizhou Province, there is a mixed limestone and gypsum karst developed in the Middle Cambrian Shilengshui Formation of the Luoshanguan Group. In the Shilengshui Formation, thick and medium beds of gypsum total more that 10m in thickness. Both the gypsum and the carbonates have been karstified for a prolonged period, and gypsum within an area of 5 km by 3 km has largely dissolved. Some of the gypsum has subsequently been redeposited as secondary gypsum in the vadose zone of the Shigao Dong Cave developed in the carbonates of the Luoshanguan Group. Shigao means gypsum in Chinese, and the secondary gypsum deposits here have been exploited by the local people for more than one hundred years.

Guizhou Province has well-developed Fenglin (cone) karst in the Triassic limestone sequences, but gypsum is also present. Near to Puding (about 90km SW of Guiyang and 20km west-north-west of Anshun) there is a mixed gypsum and limestone karst developed in the Middle Triassic Guanling and Yingling Formations. The Yingling Formation is the lowest, and contains up to 10m of gypsum and breccia beds in units up to 1.5m thick. The overlying Guanling Formation includes some gypsum, but also breccia after gypsum dissolution. The Huoshipo Dam here has suffered serious leakage through the gypsum karst beneath it (Hu Wuzhou, 1988; Lu Yaoru and

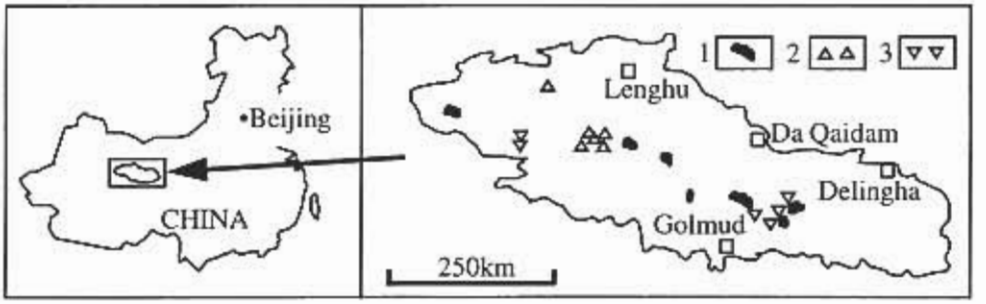

Fig. 6. Gypsum deposited in the Chaidamu Basin of Qinghai: 1 - recent salt water lake; 2 -Early Pleistocene gypsum deposits; 3- Late Pleistocene gypsum deposits.

Cooper, in press). The Yangmazhai Reservoir near Langdai and the Mahuangtian Reservoir near Guanling also have similar leakage problems (Hu Wuzhou, 1988).

7. The gypsum-salt lake karst of the Qinghai-Xizang Plateau

In the Qinghai-Xizang (Tibet) Plateau and in Northwest China there are a number of enclosed saline basins with salt lakes containing sulphate-rich water. Analyses of the lake waters (Lu Yaoru 1986, 1996; Zhang Xiyu, 1988) shows that they have concentrations of sulphate between 2,332-90,610 ppm in the Xizang Plateau lakes and 20-37,440 ppm in the Chaidamu Basin of Qinghai. Within these lake basins deposits of gypsum are associated with complex soluble sulphate salts of Na, Mg, K, and Ca including thenardite, mirabilite, epsomite, syngenite and hydroglauberite. During the wet season small-scale karst phenomena form rapidly in the gypsum and other salts which as they are dissolved; these salts get redeposited later during the dry evaporitic season. In addition to the annual climatic variation, uplift of the Qinghai-Xizang Plateau since the Quaternary has affected the climate and reduced the precipitation. This has caused the initially large salt lakes, such as the Chaidamu Basin, to dry out considerably so that only small salt lakes now exist (Fig. 6). Within this basin extensive layered gypsum deposits of Pleistocene age are present and these have developed gypsum karst features which include corroded flutes, fissures with a few small caves and passages which readily collapse.

8. Thermal and biogenetic-chemical gypsum karst

Thermal (volcanic and metasomatic) and biogenetic-chemical gypsum are minor components of the Chinese gypsum karst. Gypsum of thermal origin occurs as replacement deposits, an example being the Daye gypsum deposit in Hubei Province. Gypsum of volcanic origin occurs in the Ma'an Shan gypsum deposit in Anhui Province. In areas of hydrothermal activity, hot deeply circulating groundwater can corrode the gypsum deposits and develop thermal karst features. There are many sulphate-rich geothermal springs, such as the Chongqing spring, (50km west of Chengdu, Sichuan Province) emanating from the Triassic carbonate and gypsum rocks. In the

south of Sichuan Province there are Tertiary deposits of native sulphur associated with carbonates and gypsum. These deposits were formed by biogenic processes acting on gypsum and have karst holes, small caves and passages associated with them.

Acknowledgements

This study is one result of a wider project that has been funded by the British Government Overseas Development Administration (ODA), under Technology Development and Research (TDR) contract R6490: Gypsum Geohazards and their impact on development. We are very thankful to Dr Tony Waltham for introducing us as co-workers. Our thanks for help with this research go to Chief Engineer Wang Guixi, Senior Hydrologist Guo Wenbing, Professor Han Zi Jun, Senior Hydrogeologist Sun Yunzhong, and Senior Engineer Ma Hong Hai, Engineer Xue Zhi Weng, Engineer Tien Jia, Jiang Defu, Associate Professor Xin Fangming and all his staff at the Puding Karst Research Station and Professor Yang Mingde. Our thanks also go to the many other people in the following Chinese and British institutes that helped with our study: Ministry of Geology and Mineral Resources; Institute of Hydrogeology and Engineering Geology; Shanxi Bureau of Geology; Bureau of Geology and Mineral Resources of Yangquan City; Shanxi Geological Engineering and Exploration Institute; Sichuan Bureau of Geology and Mineral Resources; Guizhou Bureau of Geology and Mineral Resources; Guizhou Normal University; Guangxi Bureau of Geology and Mineral Resources and the British Geological Survey. Dr John Bennett and Mr Tim Charsley are thanked for commenting on this and earlier versions of the manuscript. A.H.Cooper publishes with permission of the Director, British Geological Survey (N.E.R.C.).

Place names

The translation of Chinese place names to Pinyin (western script) can be variable. The main spellings used in this paper have been taken from the Chinese Atlas: Zhonghua Renmin Gongheguo Fen Sheng Dituji (Hanyu Pinyinban) Ditu Chubanshe, Zhongguo Beijing, 1977. Where the places mentioned are not in the atlas they have been located relative to a larger named place.

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