Vol. 90 No. 4 pp. 1284–1297 ACTA GEOLOGICA SINICA (English Edition) Aug. 2016

Current Status of the Research on Coal Geology in China

WANG Tong[1, *], WANG Qingwei[2], SHAO Longyi[3], XIA Yucheng[4], FU Xuehai[5], NING Shuzheng[1], XIE Zhiqing[1] and JIANG Tao[1]

1 *China National Administration of Coal Geology, Beijing 100039, China*

2 *College of Resources and Environment, North China University of Water Resources and Electric Power, Zhengzhou 450046, China*

3 *College of Geoscience and Surveying Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China*

4 *Xi'an University of Science and Technology, Xi'an 710054, China*

5 *China University of Mining and Technology, Xuzhou 221008, China*

Abstract: Coal is the main energy in China, which has already played and will continue to play an important role in the national economy. Coal geology, as a practical science, has an access to gradual development with the growth and prosperity of China. From the meaning of the coalfield geology, this paper introduces the research progress and status of coalfield geology, including the research on coal basin, stratigraphy of coal-bearing stratigraphic sequences, coal-forming process, structural geology of coalfields, and exploration and development status of coal resources. The paper specially focuses on coal-forming process, including coal formation in terrestrial facies and transgressive / regression events, and introduces new technology which has been applied to research progress in structural geology of coalfield. This paper puts forward a new comprehensive exploration system for coal exploration and reviews regional coal geological exploration results in recent years, such as coal-poor regions of seven provinces in southern China and the coal resources area in northwest China, which will be an important coal-producing area in the future.

Key words: coal, resource distribution, exploration and exploitation, new thought

Coal is the earliest used (Peng, 2009), the richest and most inexpensive fossil fuel in the world (Tian, 2015; ChinaIRN.com, 2014). China is rich in coal resources, and the total amount of resources is about 5.9 trillion tons, and also has abundant coalbed methane resources about 36.8 trillion m^3 within 2000 m in depth (Wang, 2009). In recent years, China's energy demand continues to increase with rapid development of economy, and the rapid growth of coal production ensures the energy supply and makes tremendous contributions to the development of national economy and the social functioning. The real economy is the main part of the national construction, and mineral resources are the foundation of national development. China's energy security must be based on safety coal energy in the future (Peng et al., 2013). As one of the most important subjects of geosciences and geological practice, coal geology has made fruitful development both in China and in many other countries. With the development of modern geosciences, the research area of coal geology is gradually increasing. It has practical significance to analyze some new progress of coal geology made in recent years in China and summarize the theoretical and technological achievements of coalfield geology.

1 Coal Geology Research Develops into Coal Geology

The human gains knowledge about anything by stages and deepens the knowledge with social development and broadening of human vision. The concept of coal geology is no exception. In the tide of China's economic construction, the meaning of coal geology is changing and developing in the process of exploration and utilization of coal resources (Han, 1986; Yang, 1987; Xiao, 1998). Coal geology has become a subject of resource-economy-environment-society type from a subject of a single-resource type. The relationship between coal geology and technical economy, coal development, mine safety, ecological environment has become closer and closer

* Corresponding author. E-mail: wangtong517@126.com

(Zhang et al., 2003; Xie, 2007). From the discrimination of terminology in coal geology, Cao Daiyong and Wang Tong et al. (2010) summarized and compared different definitions of coal geology in production and scientific research. For instance, the definition of coal geology in *China Coal Industry Encyclopedia (Geology and Survey Volume)* (1996) is coalfield geology, also called coal geology, is a subject to research the genesis, composition, properties and distribution rules of coal, coal seams, coal-bearing rock series with geology theory and method. The research contents include researches of coal petrology, coal chemistry, coal-forming process, coal seams, coal-bearing rock series, coal basin analysis, coal-accumulating pattern, genetic relationship of coal, oil and gas (Yang and Zhou, 1996). In *Dictionary of Earth Sciences* (2006), coal geology, also called coalfield geology, is a branch of geology and a subject to research geologic characteristics, genesis, distribution laws and industrial value of coal, coal seams, and coal-bearing rock series. The main contents include: (1) composition, properties and genesis of coal; (2) characteristics and formation conditions of petrographic compositions and sedimentary facies of coal and coal measures; (3) genesis and distribution rules of coal-accumulating process, coal-accumulation basin and coal-rich zone, coal resources exploration, etc. The use of term "Coal Geology" in western countries and the description of *The International Journal of Coal Geology* on its title page about the scope of this journal, to some extent, reflect the understanding of international academia for the term "Coal Geology". *The International Journal of Coal Geology* is committed to treating the basic and applied aspects of the geology and petrology of coal in a scholarly manner. Its scope encompasses: the genesis of coal and coal seams, including studies of modern coal-forming process and environments. The metamorphosis of coal materials in coal seams is dispersed in other rock types. Geology of coal measures includes stratigraphic, structural, geomorphic, paleogeographic, paleoecologic, hydrogeologic, Paleontologic, paleozoologic and paleobotanic facets of the subject. Petrology and petrography of coal and coal seams include coal mineralogy, geochemistry and chemical and physical constitution of coal. Coalbed gases, including coalbed methane and CO_2 sequestration. In consideration of related research fields of the current coalfield geological research, including coalfield geology, mining geology, hydrogeology, engineering geology and environmental geology, geophysical prospecting, mineral comprehensive evaluation, exploration engineering, laboratory test, remote sensing geology, mathematical geology, coalbed methane, geological economy and managing forum, etc., the concept of coalfield geology has even broader research content and more complex research system (Fig. 1), which has been extended to the research of the whole process, including formation, exploration, exploitation and utilization of coal resources. Therefore, the preliminary scientific definition is that "coal geology" is a comprehensive discipline to study the genesis, properties,

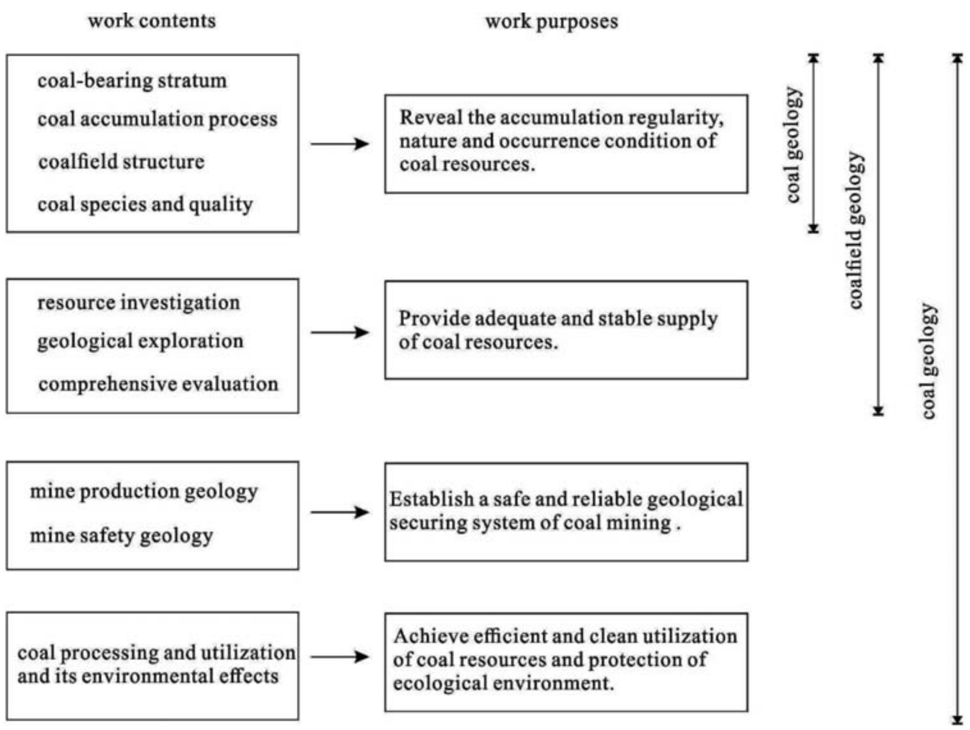

Fig. 1. Evolution of nomenclature in coal geology (after Cao et al., 2010).

occurrence regularity, exploitation and utilization and environmental effect of coal resources, including coal, coalbed methane and other associated minerals, with geology theory and methods; the content of coal geology includes not only basic theory research, but also resource evaluation and exploration, coal processing and utilization and environmental protection, etc. (Cao et al., 2010).

2 Geological Research and Classification of Coal Basins

Predecessors have conducted relevant researches about the classification of coal-bearing basins. Scholars of the former Soviet Union have done a lot of very useful work for the classification of coal basins. Their classification was based on stable regions (platforms) and active zones (geosynclines) with a view to tectonic genesis of coal-accumulation basins and coal-bearing formation (Huang et al., 2006). From the perspective of the geodepression theory, Tong Yuming et al. (1984) further divided the genetic types of geodepression coal basins. Based on geodynamic conditions, location and crustal nature of the basin when it formed, Ren Wenzhong (1992) divided Chinese coal-bearing basins into seven types. According to the stability of basins during coal-forming period and tectonic reworking characteristics of coal measures after basins are formed, Mang Donghong et al. (1994) established dual classification of structural types of coal basins. From the view of plate tectonics, Wang Rennong et al. (1995) divided Chinese coal-bearing basins into the following types: internal depression of craton, continental accretion belt, rift valley within continents after collision and basin in active rim zones, etc. Cheng Aiguo et al. (2000) divided Chinese coal-accumulation basin types by the index of plate location, type of earth crust, type of basin, thickness of coal seam, stability of tectonics and coal seam and coal accumulating quantity etc. Sun Wanlu et al. took a comprehensive analysis of tectonic epochs when sedimentary basins were formed and characteristics of sedimentary characteristics in basins, then divided the distribution of Chinese coal-bearing basin into five tectonic domains according to the tectonic location. Song Lijun et al. (2009) proposed a dual-level classification and naming scheme for coalbed methane basins, which is a prototype type of coal-accumulation basins and a type of reform action (tectonic style). Cao Daiyong et al. (2016) established a comprehensive classification scheme of basins from seven aspects including structure type, basemental attribute, morphostructure, scale, dynamic environment, paleogeography and coal-accmnulation process, which is shown in Table 1.

3 Important Progress in Sequence Stratigraphy of Coal-bearing Strata

3.1 Research on coal-bearing strata

Sequence stratigraphy was initially applied as seismic stratigraphy sequentially and has subsequently applied to petroleum and coal. So far, the stratigraphic resolution becomes higher (Chen, 1994, 1995; Li, 1993), and its inversion interpretation software tends to be more realistic and humanized, especially the research of high-resolution sequence stratigraphy on the outcrop scale was successfully utilized in the prediction of underground phase and mineral resources, which has been greatly improved the accuracy of people’s understanding of lithofacies geometry and reservoir distribution frame (Li, 1999). These new sedimentological research methods have been extensively used in the research of coal-bearing rock series, and pushed forward rapid development of coal-

Table 1 the type of coal-bearing basins in China

Intraplate position	Crustal type	Basin type	Seam thickness	Coal bed and tectonic stability	Coal accumulation amount	Typical basin
Intraplate	Craton	Cratonic basins	Medium-thick	Extremely stable	0.1×10^{12} – 1×10^{12} tons	North China Basin (C-P), Yangtze Basin (C-P)
	Continental crust	Extensional fault basin	Changing greatly with very thick coal seams	Unstable - relatively stable	10×10^{9} tons	NE China basin group （K）
Collision margin	Continental crust -transition crust	Foreland basin	Changing greatly	Relatively stable	100×10^{9} tons	Sichuan-Yunnan Basin (T-J), Ordos Basin (T-J)
		Superposed basin or intramontane basin	Changing greatly	Unstable	1×10^{9} – 10×10^{9} tons	Tuha Basin (J)
Transform margin	Continental crust -transition crust	Strike-slip pull -apart basin	Changing greatly with very thick coal seams	Unstable - stable	10×10^{9} tons	Tuoyun-Hetian (J), NE China Basin group (E)
Passive continental margin	Continental crust -transition crust	Continental rifted basin	Thin-medium	Unstable	10^{9} tons	Jiangxi-Hunan-Guangxi province (C-P)
		aulacogen	Thin-medium	Unstable	10^{9} tons	Helanshan aulacogen (C-P)
Active continental margin	Transition crust	Active continental margin basin	Thin	Unstable	10×10^{3} – 100×10^{6} tons	Tangshan-Changdu Basin (C-P), Taiwan Basin (N)

bearing rock series sedimentology forward. A large number of research results have been achieved in the past 20 years or so, especially the sequence stratigraphic model in the coal-accumulation basin in epicontinental sea has been basically mature, and the theory and model of sequence stratigraphy of continental coal accumulation basin have been basically formed. These results not only fully and flexibly used the key ideas of classic sequence stratigraphy, but also adhered to the basic principles of classic sequence stratigraphy, thus receiving significant attention and recognition of domestic and foreign counterparts (Chen, 1994; Li, 1999; Shao et al., 1999; Li et al., 2001). Based on the achievements of sequence stratigraphic analysis for coal-bearing strata, the characteristics of sequence stratigraphic analysis of coal-bearing strata can be summarized as follows:

The main control factors of continental coal accumulation basin are tectonic movement and climate condition, and the secondary factor is the change of basin's water level and supply of sediments, among which the tectonic movement is the most important control factor on the continental basin.

(2) Coal-bearing strata sequence stratigraphic models have diversity, which may have double-layer structure (the lower part for transgressive system tract, while the upper part of highstand system tract), and can also be divided into three structures (lowstand system tract, transgressive system tract and highstand system tract), and even four element structures or multi-layer structures. Moreover, a sequence stratigraphic model of a certain basin cannot be used in another basin arbitrarily.

(3) As for the coal formation process, there are the regression model and the transgression model, and coal seams may be isochronous or diachronous. Coal formation system tract types are also diversified, namely coal formation mechanism is characterized by diversity: coal could be formed through lowstand system tracts, highstand system tracts or transgressive system tracts. This research has enriched the theory of coal formation.

(4) In some coal-bearing strata, marine sediments appear alternatively with coal seams, pelite and clastic rock, which is the important basis of high resolution sequence and high frequency sequence division. However, the high resolution sequence and high frequency sequence are two different sequences. In an epicontinental sea basin, the high frequency sequence may be high resolution sequence, but in other types of coal accumulation basins, the "high resolution rate" and "high frequency" should not be confused.

(5) Taking the system tract or high resolution sequence as the mapping unit for lithofacies paleogeography of coal-bearing basins has become the basis of high-precision lithofacies paleogeography mapping, and a good guidance for accurate prediction of coal and associated minerals. At present, there is a kind of abnormal phenomenon, that is, some research applies the theory and method of sequence stratigraphy in the analysis of basin filling, while uses traditional methods in paleogeographic analysis.

3.2 Research of sequence stratigraphy and coal accumulation

Coal accumulation of marine-terrigenous facies coal basins is closely related to the change of sea level because the change of sea level controls the formation of coal-rich units and the migration of coal-rich zones (Li et al., 2001). Peat swamp system or peat swamp facies is a building block of sequence stratigraphy. In space, it interrelates and is mutually adjacent to other sedimentary systems or sedimentary facies; in time, the thickness of a coal bed is a function of tectonic movement, sea level change and sediment supply (Li et al., 2003). During the transformation period of the lowstand system tract and the transgressive system tract, clastic activity is weakened, continental scale exposed, sea level decline rate slowed down and gradually begin to rise, peat swamp begins to develop in low-lying areas and rapidly expand into the whole region. In the process of peat accumulation, the sea level is rising gradually, and the diving surface is improved, which provides a sufficient source of water for the development of peat swamp. The sedimentation rate, the sea level fluctuation rate and the peat accumulation rate are balanced, and therefore the coal seam is formed, which is widely distributed and has a large thickness. In the late stage of peat swamp development, the sea level rises rapidly, and the peat swamp is terminated (Li et al., 2000, 2001 and 2003). The coal seam is formed during transgression and sometimes the coal seam bottom could be the initial flooding surface (Kang, 1998). During the transformation period of the transgressive system tract and highstand system tract, the sea level rise rate is significantly slowed down, the basin sedimentation rate, the sea level rise rate and the material accumulation rate achieve balance, accommodation space is significantly reduced and gradually close to zero. This period is favorable to form thick coal seams, but the distribution is generally smaller than that which formed in the transformation period of the low system tract and the high system tract.

In terms of system tracts, at the stage of transgressive system tract deposition, sea level rises on the whole, basins expand rapidly, parasequence rise over coast onlap and the diving surface rises at the same time, clastic thickness weakens relatively, peat swamp is well developed compared with highstand system tracts. Highstand system tracts are formed at a high sea level and in a quickly declined period of sea level. The early highstand system tract is formed in high water-level period, and coal strata are well developed, but distributed in a limited area. For the lowstand system tract and late highstand system tract, the sea level is declined quickly, and clastic movement is stronger, which is not conducive to the development of peat swamp, and therefore coal strata are normally thin.

It needs to be emphasized that for continental fault basins and large down-warped basins, there are still some differences between sequence stratigraphy and coal accumulation. The research about continental sequence stratigraphy will be discussed specially in research progress of coal geological exploration in Northwest China, but it should be emphasized that the foundation and transformation of continental coal-bearing basins are more complicated. Fault basins have strong tectonism and the basin area is normally small. And because of the difference of tectonic part and tectonic activity, some basins may lack the upper coal formation or lower coal formation, and coal accumulation may not happen in the basin expansion stage. Large depression basins developed in cratons or large land blocks have no obvious two stages of coal accumulation due to stable tectonic activity. Coal accumulation bears a close relationship with the subsequence and there are no clear differences between systems as regards coal accumulation.

3.3 Sequence stratigraphic division of coal-bearing strata in epicontinental basins

The late Paleozoic (C2-P3) sedimentary basins in North China are actually large composite basins (Shang et al., 1997). According to the filling characteristics of composite basins in the late Paleozoic, they can be divided into three structural sequences, and the interface is a transform face of the regional unconformity of the basin (at the top and bottom of basins filling sequences) and the tectonic stress field (Li, 1998). The transform face of the tectonic stress field is a structural interface formed due to the change of tectonic movement nature or type, which leads to transform of tectonic stress field (often shown as unconformities interface or large area erosion interface), and the transform of the stress field changes the basin system, which is shown as the transform of system tracts in depositions, and the sedimentary characteristics of interface are completely different. In the late Middle Permian to the early Late Permian (Shangshihezi deposition period), because the south China plate was pushed towards the north, significant change in the tectonic stress field and overall uplift of the North China platform took place and there was significant terrain elevation difference, meanwhile extensive scouring was shown. The unconformity between the Shangshihezi Formation and the Shiqianfeng Formation formed due to the transform of tectonic stress field is a dividing interface of tectonic sequences. Grade III sequence interface of coal-bearing strata in epicontinental basins can be identified and continuously traced with drilling cores, logging curves and outcrops. Besides, based on the biostratigraphy method the interface comparison problem can be correctly resolved, and the common long-term disputes about stratigraphic ages and boundaries in the history of geology could be avoid (Diessel, 1992). The following three interfaces are typical divisions of Grade III sequence interface of coal-bearing strata in epicontinental basins.

(1) Interfaces of basin regional unconformities

In the vast area of North China, between the Carboniferous-Permian and the Ordovician, disconformity interfaces are prevalent, which are long-term discontinuities in the history of geology, so they became typical interfaces dividing structural sequences and third-order sequences in this area. In the Luxi and Jiyang depressions, such interfaces are also very clear.

(2) Interfaces of regional regression events

Due to sea-level changes in the late Paleozoic in North China and tectonic movement which led to significant drop of the relative sea level in a short time interval, the north-south lifting differences in the North China coal-bearing basins were increased, seawater retreated to the south and finally exited out of the basin (thereafter there was no more long-term and full-basin transgression event), eventually changed the coal-bearing basin environment and the ancient geographic landscape and the coal-bearing district moved southwards to the southern margin of North China (such as South Anhui and South Henan). The regional regression event interface is essentially deposition discontinuities in coal-accumulation basins in northern China, continental sedimentary assemblages appear mainly in the upper part, and sea-level change is no longer a direct control and influence over the sedimentation of the North China basin.

(3) Interface of the greatest regressive event

The greatest regressive event interface was identified through the comparison of the temporal and spatial scales of marine transgression and regression (recognition of sea-level change grades), and observation of the changes of regional sedimentary system and system tracts configuration relationship. Transgression of sudden, large-scale events and the greatest regressive events are the main events in third-order sea-level changes in the epicontinental basin. In epicontinental basin filling sequence of alternating land and sea coal-bearing party we identified a regional unconformity interface which is located at the bottom of the basin filling sequence, a regional recession the event interface is located at the top of the basin filling sequence and two greatest regressive events interfaces are inside the basin filling sequence.

Based on the above characteristics of sequence boundary and comparison, the sequence stratigraphic framework of the upper Paleozoic in North China was established, and each sequence is a binary structure, namely "transgressive system tract-highstand system tract", which is significantly different from some three-segment sequence that were found in some foreign countries (Li, 1996).

4 Great Progress of Coalfield Structure Research in Eastern China

4.1 Basin dynamics and structural coal-control in Eastern China attracted more attention

Basin tectonic dynamics directly controls the occurrence of various geological processes, the basin types and their evolution (Wang et al., 1992; Li, 1988), and further restricts the occurrence of coal beds. Coal basins in China have experienced complicated tectonic-thermal history, especially in Eastern China in the late Paleozoic, which experienced different periods of tectonic movement and deep process, such as Indosinian, Yanshanian and Himalayan, etc. Within the coal basin, non-isostatic uplifting, tilting, deeply buried, tectonic deformation, compound modification in different degrees took place. Intensive study has been done on coal field structure in Eastern China. Owing to the research of nappes and extension structures conducted since the 1980s, massive coal resources and new directions of coal prospecting have been found in China, and great progress has been made in the understanding of coalfield structure theory. Based on the research of the transform of two tectonic regimes and the mechanism of lithospheric thinning, the discussion on structural control over coal beds in different periods and different tectonic regimes has attracted much attention. Coal basins in North China in the late Paleozoic experienced the collision and amalgamation between the south and north plates in the Indo-Sinian and structural superposition in the Yanshanian, which made the tectonic regime transfer from extrusion to extension, and had an important effect on the model reform of coal deposits and emplacement along with multi-period and multi-type magmatic activity.

4.2 Research of coal-control structural style and coal exploration model

Structural style was used to describe folds, but it was widely used in oil and gas basins structure analyses. We adopt the mainstream division of coal-control structural styles, namely the geodynamic classification, which divides the coal-control structural style into the extending tectonic style, compression tectonic style, shear and rotation tectonic style, and inverse tectonic style characterized by structural superposition and composition. Based on this, we care about the structural feature of coalfields. For example, sliding structure is common in coalfields, which can form different stress environments. Thus, we define the sliding structure style separately from other coalfield structure styles. The CNACG, based on the project of coal-poor regions in South China, summarized the occurrence regularity of coal resources, built the coal accumulation model in different coalfields and 8 types of coal-control structural styles (intraplate stable region paleostructure coal-control style, mobile belt of continental margin paleostructure coal-control style, synsedimentary fold coal-control style, synsedimentary faulting coal-control style, fold coal-control style, faulting coal-control style, sliding structure coal-control style and rheological structure coal-control style) (Wang, 2003). It provided a sufficient geological foundation for coal resource forecasting. The CNACG carried out coal resource grade assessment for 281 coal-poor units in South China, totally 3.749 billion tons, including 25 favorable coal units with the first utilized resources of 1.061 billion tons in total, 120 near-favorable coal units with recently available resources of 2.013 billion tons in total, and 136 coal-poor units with forward available resources of 6.675 billion tons in total. The establishment of coal-control tectonic style is the continuation and development of the research on the coalfield sliding structure. And it is of great importance to understand coalfield structure, direct coal resource assessment and coal resource prospecting.

5 Research Status of Coal-poor Areas in Southern China

Coal prospecting in coal-poor areas in South China started in the late 1800s with a history of over 100 years. After the founding of New China, South China attaches great importance to coal prospecting and development, and thus many technical coal geological exploration teams were established. In dozens of years, great progress was made in coal geological exploration. Since 2008, the CNACG carried out the "research on coal resource occurrence regularity and exploration and utilization in South China coal-poor area" (Wang, 2011). According to incomplete statistics, by the end of December 2007, South China coal-poor areas have submitted 1671 coal geological prospecting reports, involving totally 117.93

billion tons of coal. It lays a foundation for coal resource exploration and utilization in South China. Coal-bearing strata in South China are Lower Carboniferous, Lower Permian, Upper Permian, Upper Triassic, Lower Jurassic, Upper Jurassic, Paleocene and Neocene. The Upper Permian Longtan Formation, Wujiaping Formation, Xuanwei Formation are widely spread in South China, where minable coal seams are well developed, and coal-rich areas include Liupanshui, Guizhou province, Junlian, Sichuan, central Jiangxi, south-central Hunan and northern Hubei provinces. South China coal-bearing regions are located in the junction of the Tethyan tectonic domain and the Circum-Pacific Ocean tectonic field, which crosses the Yangtze platform and South China fold system. The coal-bearing deformation in the Yangtze platform is characterized by approximately concentric ring structure. Almost all types of coal are discovered in South China coal-bearing regions. Non-coking coal takes up a large proportion and coking coal is distributed in Yunan and Guizhou provinces. The major coal-forming period in South China coal-bearing regions is the Permian. The Lower Permian Liangshan Formation coal-bearing strata are distributed in the junction of Hunan, Hubei and Sichuan provinces, whose coal-bearing property is poor with only local minable seams. The coal-bearing property in the Middle Permian Tongziyan Formation and Shangrao Formation coal-bearing strata in Southwest Fujian and central Guangdong provinces is good and the coal seams are minable or partially minable.

The South China coal-bearing regions cross the Yangtze platform and South China fold system and are mainly Late Permian coal-accumulation basins. During the Late Triassic the South China coal-bearing regions experienced intense transformation that lead to well-developed uplifts and folds in the caprock in the middle and eastern parts. A bundle of fold appear in parallel with the margins of the coal-bearing regions, WNW- and nearly E-W-striking from the northern margin to eastern Hubei, and N-S and NW-striking on the southwest margin and in southwest Guangxi. In the central party, the coal-bearing regions in West Hubei province are characterized by complete continuing gentle fold belts. Southeast Hubei, Hunan, Jiangxi and north Guangdong provinces are located in the South China and southeast coast fold systems, which are characterized by intensive deformation, development of folds, concentrated faults and nappe structure. The Tertiary coal-bearing basins appear mostly as down-faulted basins with weak magmatism. After reformation, the basin morphology is concordant with regional tectonic directions. The South China coal-bearing regions cross the Yangtze platform and South China fold system, and are mainly Late Permian coal-accumulation basins. During the Late Triassic, the South China coal-bearing regions experienced intense transformation. In the Longmen Mountains on the western margin, intense folds and overthrusts are developed. A bundle of fold appear in parallel with the margins of the coal-bearing regions, N-S- and NW-striking in the Kangdian area and South Yunnan. In the central part, East and South Sichuan, and North and East Guizhou provinces are characterized by complete continues barrier-like and trough-like folds. During the Late Permian, the geological structural was complicated with faults and folds well developed, causing serious damage to coal seams. In the Late Triassic the structure of coal seams was still moderately or very complex. Tertiary coal-bearing basins are mainly distributed in basins of eastern Yunnan province, occurring as down-faulted basins with weak deformation and magmatism. The basin morphology is concordant with the regional tectonics directions. Totally 56 million tons of coal resources were ascertained by applying the sliding structure theory to coal prospecting under nappe and laterite beds in poor-coal provinces, such as Fujian, Jiangxi and Hunan provinces.

6 Research Status and Achievements in Northwest China

Since the 1950s the coal geological exploration teams of Qinghai, Gansu, Xinjiang and other provinces or autonomous regions have carried out coalfield geological exploration in Northwest China, and accumulated a large number of coalfield geological data. At the same time, with the implementation of the western development strategy of China, the geological, mineral and petroleum sectors also carried out prospecting work aiming at Jurassic strata in large basins. On the basis of these data, Wang Tong, Shao Longyi, etc. (Wang, 2012, 2013) made further research on the relation of basin structure, basin-range coupling, sedimentary facies palaeogeography, coal accumulation, and petroleum system in Jurassic basins in northeastern parts of China. They conducted research on the accumulation law of Jurassic coal resources, established a continental sequence stratigraphic framework, made unified comparison for the Jurassic coal system strata, so as to reach unified understanding about the geological environment of northwest China. Wang Tong made assessment for 126 mining areas in 80 coalfields, whose area is 37622.55 km^2 and gave total coal resources of 18.2441 billion tons (Wang, 2013). Based on the geological backgrounds, filling characteristics of different coal accumulation basins and by means of the latest basic data from analysis of outcrops, drill cores, seismic profiles and logging curves, the boundary types and identification features of of Jurassic sequences in

Northwest China were summarized and fifteen system tract in five third-order sequences were defined. A sequence stratigraphic framework of the coal and rock series in the area was established and it was confirmed that the late stage of the lake transgressive systems of SQ1 and SQ3 is the time when thick coal seams were accumulated. It was proposed that the overall structure of the coalfields in the Xinjiang area is complicated on the margins of coal-bearing basins, mainly high-angle faults, and tends to be relatively simple inwards. The Xinjiang Uyghur Coalfield Geology Bureau discovered the large Santanghu coalfield, Naomaohu coalfield, etc. during coal resources survey in Kamusite Mining district, Kubai, south Anhui, Barkol-Santanghu and Tuha coalfields with total coal resources of 159.78 billion tons, so as to guarantee the needs in mineral resource for establishing the large Xinjiang energy base.

7 Octothorpe(#) Distribution and Sudoku-pattern Distribution of Resources

China's coal resources are hosted in different types of coal basins in different geological periods, and China is well known for its huge amount of resources (Wang et al., 1995; Jia et al., 2009). According to statistics, the number of coal-bearing basins in China has reached 300 or more. In addition to large well-known large basins include the Ordos, Junggar, Tarim, Sichuan, Qaidam,Songliao Basins, etc., China also has some middle- and small-scale coal basins such as the Tuha, Yanqi, Datong, Qinshui, Mohe, Chuxiong, Shiwandashan Basins. With respect to the distribution, number, scale and type of coal basins and the macro structural deformation of coal measures, one can see obvious differentiation characteristics.

Carboniferous-Permian coal basins are mainly distributed in eastern China, while the North China Basin of Late Carboniferous and Early Permian and the Southern China Basin of Late Permian are the most important giant coal basins in China during the late Paleozoic. Coal basins of the Late Triassic are mostly distributed in southern China, namely Sichuan, Yunnan, Jiangxi, Hunan, Guangdong, etc. Secondly, the northeast of Ordos, Qamdo and Qingtang in Tibet and the northern margin of the Tarim Basin in Xinjiang are also coal basins in the Late Triassic. The area of coal basins of Early-Middle Jurassic is second only to the North China basin and Southern China basin. In addition to the Junggar Basin and Ordos Basin, the basins' areas are not large and they are sporadically distributed. However, they have abundant coal resources. For example, the Turpan-Hami Basin and the northern margin of the Tarim Basin are very famous. Besides, there are coal resources in the northern and northeast parts of North China, such as Datong, West Beijing, Liaoning, Daqingshan, Da Hinggan Mountains, high poplar and Western Hexi Corridor. The total amount of coal resources reached 3 trillion tons, and about half of the resources are from the Ordos Basin. The coal basins of Early Cretaceous are small, dispersed, and they often appear in groups. Among them, the Hailar-Erlian basin group is the largest one, and its total amount of coal resources is more than 200 billion tons.

What's more, there are also sporadic coal basins from the Jixi-Hegang to West Beishan area. The distribution area of this kind of basin is very large, about 450 thousand km^2, and it contains hundreds of basins of different sizes. Among the whole basin, coal-bearing property shows obvious difference. Even a single basin can have coal resources more than 10 billion tons. The coal basins of Tertiary are mainly distributed in the eastern coast of China, and a few of them hide in the East China Sea and the South China Sea. Besides, some of them are found in the south of the Hengduan Mountains. As for the basins' distribution characteristics, part of them are small, dispersed, and they also appear in groups, such as basins of Neogene in Western and Eastern Yunnan, which have better coal formation during Miocene. The northern (mainly northeast) region is characterized by coal basins of Paleogene. Its total amount of coal resources is more than 20 billion tons. Generally, lignite is the most abundant one among all kinds of coal.

Since the Chinese Academy of Engineering carried out the major consulting project of "Strategic studies of the clean, efficient, sustainable development and utilization of China's coal" in 2010, Peng Suping, Wang Tong et al. (2014) have done related research and came up with significant innovation results: The #-shaped structure pattern composed of two zonal orogenic belts, named the Tianshan-Yinshan-Yanshan zone and the Kunlun-Qinling-Dabie Mountains zone, and two longitudinal orogenic belts, called the Xingmeng-Taihang-Xuefeng Mountain belt and the Helan-Liupan-Longmen Mountain belts, control China's basic characteristics of coal geology and resource distribution obviously (Fig. 2). Combining this study and #-shaped coal basins' scale, they finally proposed the Sudoku-pattern distribution of resources.

From north to south, and from east to west, the Sudoku -pattern distribution of coal resources can be divided into the following three areas: Eastern region: the coal-bearing area of northeast-coal reserve partition of Liaoning, Jilin, Heilongjiang Province, the coal-bearing area of North China-coal reserve partition of the Yellow River and Huaihai (Hebei, Shandong, Henan, Beijing, Tianjin, North Jiangsu and North Anhui), the coal-bearing area of South China-coal reserve partition of the South China coal-poor regions (Fujian, Zhejiang, Jiangxi, South of Jiangsu,

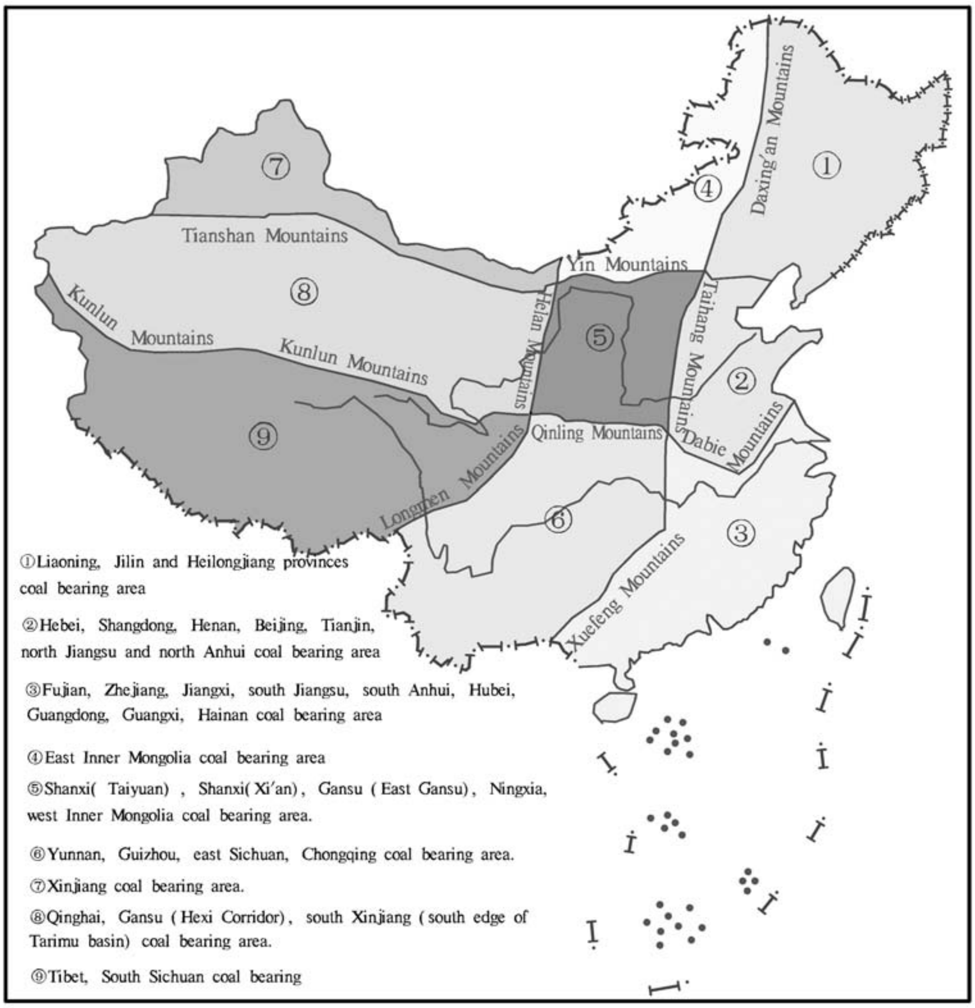

Fig. 2. Sketch map of coal resources distribution (after Wang et al., 2014).

Anhui, Hubei, Hunan, Guangdong, Guangxi and Hainan); Central area: the coal-bearing area of northeast-coal reserve partition of eastern Inner Mongolia, the coal-bearing area of North China-coal reserve partition of Shanxi, Shaanxi, Gansu, East Ningxia, West Inner Mongolia, the coal-bearing area of South China-coal reserve partition of southwest region (Yunnan, Guizhou, Sichuan, Chongqing City); Western area: the coal-bearing area of northwest-coal reserve partition of North Xinjiang and South Xinjiang (Qinghai, Gansu, Longxi, Hexi and the south of Xinjiang), the coal-bearing area of Dianzang (Tibet, West Yunnan and West Sichuan). The Sudoku - pattern distribution of coal resources show differences on sedimentary characteristics of coal-bearing series, resource accumulation and reserve, coal quality, etc. Besides, different partitions have distinct geographical conditions, climate, water resources, ecological characteristics, etc. Furthermore, the distribution of coal resources is consistent with different areas' economic and social development situation in China.

8 A New System about China's Comprehensive Exploration of Coal Geology

8.1 Main framework of the stereoscopic and informationized exploration system

Because of the complexity of coal geological conditions and the differences of natural and geographical conditions in China, it is difficult to apply a single exploration technology to solve the problem of exploration targets under complex geological conditions. Exploration work at different stages in different regions should be aimed at obtaining the best prospecting results. We should consider specific geographical, geological and geophysical conditions of the exploration area and select the most appropriate exploration technology and combination. According to the geological characteristics of the West Henan coalfield, Wang Tong (1992) put forward the basic thinking of the classification principle and method of exploration type in the West Henan coalfield.

In recent years, through continuous summary of coal geological exploration experience, a new basic framework of coal geological prospecting technical system was formed. Based on systematic analysis of the regular occurrence pattern of coal resources in China, Wang Tong, Cao Daiyong, Li Zengxue et al. reestablished the basic principles of coal geological prospecting according to the characteristics of coal geological exploration in China. They developed "Coal geological prospecting" to "Comprehensive exploration of coal resources" that covers coal exploration, mine construction, production safety, environmental protection, etc., and they put forward a new system of comprehensive exploration technology for coal resources, which is suitable for the contemporary needs (Wang et al., 1992).

According to the distribution characteristics of the coal resources in China, under the support of the new development of coal geological theory in China, based on the coal geological exploration standard under the new situation, on the basis of the systematic analysis of the regular occurrence pattern of coal resources and the characteristics of coal geological exploration in China, they reestablished the basic principles of coal geological prospecting and developed "coalfield geological exploration" into "the comprehensive exploration of coal geology", which cover the whole process of geological work including the resources survey, geological survey, mine construction, production safety, environmental protection etc. Under the support of the new development of coal geological theory in China, based on the coal geological exploration standard under the new situation, the theory and technology system of modern coal geological exploration was established, which include coal geological remote sensing technology, high precision geophysical exploration technology, fast and accurate geological drilling technology, coal geological survey information technology, coal mining area environmental monitoring technology and other core technologies (Fig. 3). "The new theory and technology system of comprehensive exploration of China's coal resources" consists of "an innovative thinking, two major support theory, five key technologies, a set of standards and norms".

An innovative idea is to put forward a new idea composed of coal exploration, mine construction, safety production, environmental protection as one of the "comprehensive exploration of coal resources". Based on the system analysis of the occurrence regularity of China's coal resources and characteristics of coal resources

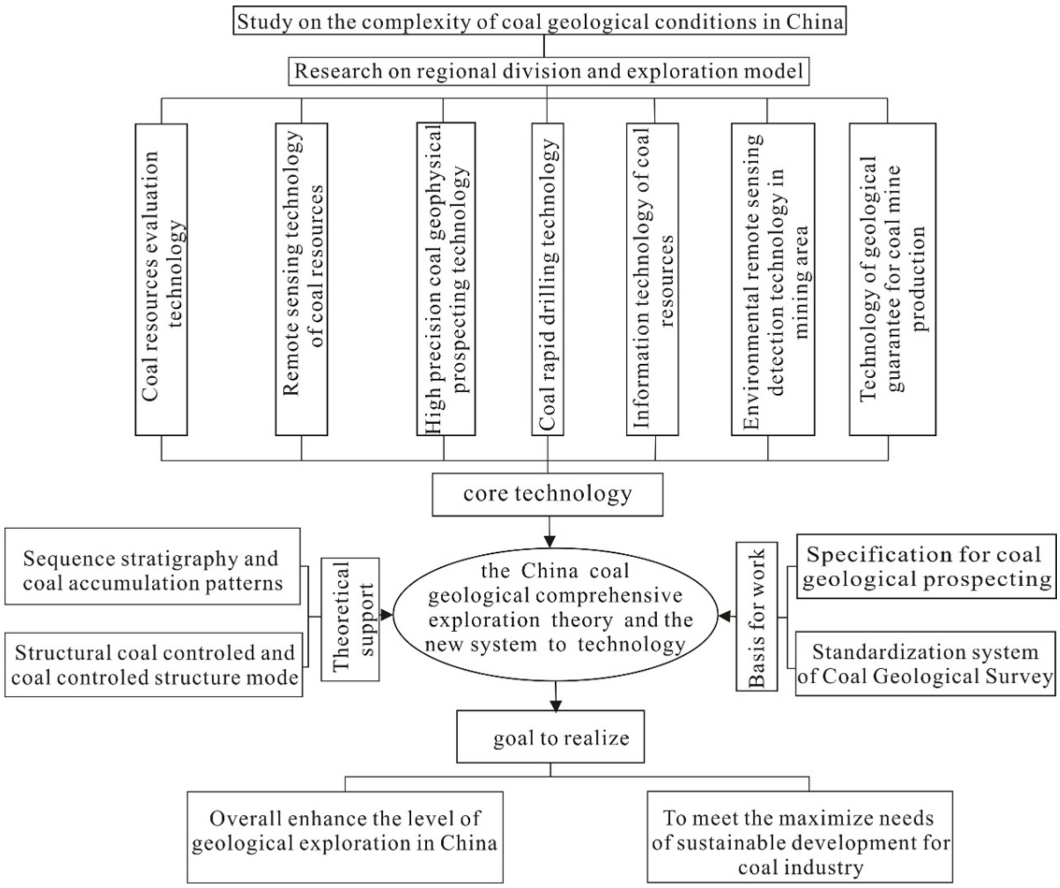

Fig. 3. Composition of the new system of comprehensive exploration technology of Chinese coal resources (after Wang et al., 2014).

prospecting, they developed "Coal geological prospecting" into "Comprehensive exploration of coal resources" that includes coal exploration, mine construction, production safety, environmental protection etc. Under the support of the new development of coal geological theory in China, based on the coal geological exploration standard under the new situation, the theory and technology system of modern coal geological exploration was established, which includes remote sensing technology of coal resources, high precision geophysical exploration technology, fast and accurate geological drilling technology, informationized technology of coal resource exploration, environmental remote sensing monitoring technology in coal mining area and other core technologies.

Two major supporting theories, i.e., research of coal accumulation regularity and structural coal-control action, has made outstanding progress, which provides a strong theoretical support for the comprehensive exploration technology system of coal resources. Coal resources comprehensive exploration technology system is based on coalfield geological theory. In recent years, the research of coal accumulation regularity and structural coal-control action has made outstanding progress; the new ideas of high resolution sequence stratigraphic model of coal measures, model of terrestrial facies of coal, marine coal forming model, episodic coal formation, etc. deepened people's understanding of the regularity of coal accumulation; some new results including the analysis of basin dynamics, study of the slip structure of coal field, division of coal-control structure etc., promoted the structural coal-control action more and more in-depth and practical, so as to provide a strong theoretical support for the establishment of comprehensive exploration technology system of coal resources.

Five key technologies, namely remote sensing technology of coal resources, high precision geophysical exploration technology, fast and accurate geological drilling technology, informationized technology of coal resource exploration and environmental remote sensing monitoring technology, have formed the main body of the new comprehensive theory and technology system for the exploration of coal resources in China.

The establishment of the new comprehensive theory and technology system for the exploration of coal resources in China is the actual demand of China's coal geological workers in complicated geological conditions of the country and is an integrated achievement based on long-term scientific research and engineering practice, which covers multiple aspects including coal resources exploration, before-mining construction, mining, and post-harvest treatment, widely uses the most advanced technology and methods in China and overseas, and realized the developments of coal geological exploration theory and technology by leaps and bounds, and greatly promoted Chinese coal geological exploration, and has made many breakthroughs on comprehensive exploration of coal resources in practice.

8.2 High-precision safeguard technique of coal geology represented by 3D seismic technology

The improvement of the overall level of discipline must be based on modernization of research methods and technical means (Peng, 2008, 2011). By the end of the 1980s, the exploration level of coal fields has been greatly improved by introducing the technology of rope drill and high resolution digital seismic exploration. The exploration industrial test with 3D seismic first found out a fault throw over 5 m in the Huainan Xieqiao Coal Mine in 1993, and realized to identify fault throws by equal to or more than 3 m fault in a depth of 700 m in the Huainan Pansan Mine in 1997. In recent years, the interpretation of faults and subsided columns in coal-bearing beds has an accuracy of higher than 95%. By increasing the sampling density and the number of coverage, studying the excitation parameters, and using image processing and other comprehensive interpretation technologies, the ability of seismic recognition fault can be improved to 2 m. Since the beginning of the 21 century, by studying 3-D three component seismic exploration technique and AVO inversion technology, we promoted the application of 3D seismic exploration technology in the whole country, established the geological structure detection system of coalmine district 3D seismic exploration with Chinese characteristics, found an effective way of small geological structure which affects the application of comprehensive mechanized mining technology in coal mines.

9 Accumulation Pattern and Coordinated Survey on Multiple Coal Resources and Associated Minerals

9.1 Comprehensive evaluation of multiple resources of coal measures

The natural gas content is generally 1-45 m^3/t in coal (Dai, 1979; Sun, 1989; Ермиеков and Скоробогатов, 1984). According to A.K. Matveev, a geologist from the former Soviet Union, the total amount of methane produced from coal seams in all coal-bearing basins in this country, theoretically, was about 2650 trillion m^3. Actually, however, there was only 240-250 trillion m^3 (10%), which means 2400 trillion m^3 methane has been lost (other 240 trillion m^3 from thin seams are not included here) (Li, 2009). Therefore，coal-measure gas during the whole process of coal-forming period is far more than the natural gas conserved in coal seams. Meanwhile, contributions made by other gas source rock outside coal seams, such as carbonaceous argillaceous shale and mudstone, have been confirmed, too. (Dai, 1981; Ju, 2012; Law, 2002). In resent years, great progress has been made in exploration and assessment on coal bed methane, shale gas, and tight sandstone gas. 45 coal accumulation basins have coal gas of 41.5×10^4 km^2 and geological resources of 36.8×10^{12} m^3 at a depth of 2000 m. In the past 5 years, the annual explored tight sandstone gas reserves of China accounted for over 50% of the explored reserves of natural gas.

Experiment on simultaneous extraction pilot for coal bed methane and low permeability sandstone gas was taken in the United States from 2001-2002. It was found that the daily production of 65 wells stays at 10890 m^3, up to 14375 m^3, among which 60% was from coal seams, foretelling bright exploitation prospects of coal-bed methane and tight gas.

Based on Wang Tong's research (2012) on coal bed methane, shale gas and natural gas hydrate, starting from coal bearing source rock, the exploration has the possibility of conducting, unconventional gas of coal resource as a system. Nowadays, the Xinjiang Coal Geology Bureau has explored and controlled coal bed methane of 500 billion m^3 in east Xinjiang, which is an significant breakthrough of low rank coal seam gas development with assessment coal of 1785 billion ton, coal bed methane of 7.86 trillion ton, and assessment shale gas of 10.2 trillion m^3. Combining mining of coal bed methane gas in these large scale basins will greatly promote the safe and green development of energy on the one hand, and improve out energy structure on the other hand.

9.2 Research on "3 Rarities" in coal associated minerals

China is rich in coal-measure associated minerals with a complete set of varieties, wide distribution, and potential high economic value. The major minerals include kaolin, bentonite, refractory clay, pyrite, gypsum, limestone, oil shale, diatomite, graphite, natural coke, etc. (Dai, 2003, 2006). The rare minerals, largely contained in coal, were wasted in exploration in the past due to poor testing technology. However, reasonable development and utilization of these resources are important to the sustainable and stable development of the national economy.

Wang Tong (2009) promoted comprehensive exploration from coal bed rock systematically, explained it later with Li Zengxue (2011) and discussed the connotation of collaborative survey and the idea of coexistence and enrichment of various energy resources in the same basin collaborative exploration. In their opinion, collaborative survey shall cover mineral exploration in the physical infrastructure, deployment guidance, technical methods, the maximum benefit and mineral exploitation and cooperation, joint, support and usage of other areas. They also promoted that the collaborative survey of coal and other mineral resources shall obey the principle of "coordinated with order, economic with logic, complement the advantages and disadvantages, scientific deployment for maximum benefit".

Recently, more attention has been attached to mineral resources generating from rare metals, rare earth elements and rare scattered elements contained in coal beds. For example, investigation and evaluation of germanium resources in coal has found a series of germanium-bearing coal deposits. The Special Technical Exploration Center of the Coal Geological Bureau carried out investigation and assessment of lithium and gallium contained in coal in the Shanxi Pingshuo Mine in 2012, and estimated that there are 1.2966 million tons of lithium and 423,100 tons of gallium in the Antaibao mining area.

10 Conclusions

Coal is an important mineral resource of our country and also the major energy source. In the future, traditional energy will remain the main energy and coal's important strategic position will not be fundamentally shaken in China's energy security and economic and social development. Changing the extensive mode of coal development and utilizing clean and efficient energy is not only the core task of China's energy development, but also an important symbol of the success of China's energy revolution. In the next few years, the high-class design of coal resources development in China shall reflect the will of the nation. In accordance with innovation, green, open, coordinated and shared ideas, standing at nation's point of view, we should commit to exploration, development and utilization of coal resources, improve clean coal utilization, and realize a leap of coal resources from the fuel to the raw material. All above shall the main task of our work.

Acknowledgements

Funding program: 973 National Basic Research Program (No. 2013CB227901).

Manuscript received June 20, 2016
accepted July 10, 2016
edited by Liu Lian and Liu Xinzhu

References

Cao Daiyong, Guo Aijun and Chen Limin, 2016. The new insights of coalfield structure evolution—from the coal into coal basin to the tectonic units. *Coalfield Geol. Exploration*, 44(1): 1-8, 16 (in Chinese).

Cao Daiyong, Li Xiaoming and Deng Juemei, 2009. The coupling effect research of tectonic thermal event and Coalification—the geologic record in the process of basin dynamics. *Study Leading Edge* (China University of Geosciences (Beijing); Peking University), 16(4): 52-60 (in Chinese).

Cao Daiyong, Wang Tong and WangDan, 2010.Coal geology-Meaning and development trend. *J. China Coal Soc.*, 35(5): 765-769 (in Chinese).

Cao, D.Y., Li, X.M., and Zhan, W.F., 2006. Influence of tectonic thermal process on coal if ication. *Abstracts of the 23rd Annual Meeting of the Society for Organic Petrology. TSOP*, 23: 40-43 (in Chinese).

Chen Shiyue and Liu Huanjie, 1994. The research characteristic of North China Permo-carboniferous sequence stratigraphy. *Lithofacies Paleogeogr*., 14(5): 11-20 (in Chinese).

Chen Shiyue and Liu Huanjie, 1995. The late Paleozoic sequence stratigraphic pattern and its evolution in North China. *Coalfield Geol. Exploration*, 23(5): 1-5 (in Chinese).

Chen Zhonghui, 1988. *Coal and Coal-bearing Rock Series of Sedimentary Environment.* Wuhan: China University of Geosciences Press, 62-63 (in Chinese).

Chen Zhonghui, Wu Fadong and Zhang Shouliang, 1993. *The Depositional Environment and Coal Accumulating Law of North China Late Paleozoic Coal-bearing Rock Series*. Wuhan: China University of Geosciences Press, 75-77 (in Chinese).

Cheng Aiguo, 2000. The type and evolution of the Chinese coal accumulation basin. *The Memoir of Important Achievements from the National Geological Science and Technology of "95"*, 594-598 (in Chinese).

ChinaIRN.com. *Coal is still the one of the most important basic energy in the world*. On August 18, 2014: http:// www.chinairn.com/news/20140818/161116583.shtml (in Chinese).

Dai Jinxing and QI Houfa, 1981. About the calculation of coal generates gas. *Natural Gas Industry*, 1(3): 49−54 (in Chinese).

Dai Jinxing, 1979. *A Preliminary Study of Coal-series Hydrocarbon Showings*. Beijing: The oil industry publishing Clubs, 29-31 (in Chinese).

Dai Shifeng, Ren Deyi and Li Shengsheng, 2003. North China platform late Paleozoic coals in the distribution of trace elements and As. J. China Univ. *Mining Tech*., 32(2): 111-114 (in Chinese).

Dai Shifeng, Ren Deyi and Li Shengsheng, 2006. The discovery of super-large gallium ore deposition in the Junggar Basin, Inner Mongolia. *Chinese Sci. Bull.*, 51(2): 177-185 (in Chinese).

Diessel, C.F.K., 1992. *Coal-bearing Depositional Systems-coal Facies and Depositional Environments*. Springer-Verlag, 461-514.

Ермиеков, В.И., and Скоробогатов, В.А., 1984. *Образоавание Углеводороднщх Гаэов в. УглеЕоснщх Суббугиеносвщх оорщайаа. Г. Неддра*, 31(35): 197−198 (in Russian).

Han Deqing, 1986. *The history of coalfield geology research and development of China*. *History of Geological Sciences* (A). Beijing: Geological Publishing House, 2-8 (in Chinese).

He Qixiang, Ye Zhizheng and Zhang Mingshu, 1991. The transgression mode of restricted epicontinental sea. *J. Sedimentary*, 9(1): 1-10 (in Chinese).

Huang Zongli and Zhang Liangbi, 2006. *Earth Science Dictionary* (Basic Subjects Volume). Beijing: Geological publishing house, 114 (in Chinese).

Jia Jiancheng, Zhang Miaofeng and Long Yaping, 2009. Geological background of Coal-bearing area and tectonic deformation characteristics in china. J. *Anhui Univ. Sci. Tech*., 29(4): 1-8 (in Chinese).

Ju Yiwen Yan Zhifeng and Li Chaofeng, 2012.The coal bed methane and shale gas enrichment characteristics and the open mining technology commonalities and differences in our country. *Natural Gas Geosci.*, (1): 1−8 (in Chinese).

Law, B.E., 2002. Basin-centered gas systems. *AAPG Bull.*, 86 (11): 1891−1919.

Li Baofang, Wen Xianduan and Li Guidong, 1999. North China carboniferous, Permian high resolution sequence stratigraphy analysis. *Study Leading Edge*, 6(Supp.): 81-94 (in Chinese).

Li Jianzhong, Dong Dazhong and Chen Gengsheng, 2009. China's shale gas resources prospect and strategy. *Natural Gas Industry*, 29(5): 11−16 (in Chinese).

Li Sitian, 1988. *Fault Basin Analysis and Law of Coal Accumulation*. Beijing: Geological Publishing House, 32-35 (in Chinese).

Li Sitian, Li Zhen and Lin Changsong, 1993. The several basic questions of the coal bearing basin sequence stratigraphy. *Coalfield Geol. Exploration*, 1(4): 1-8 (in Chinese).

Li Xiaoming, 2007. The deformation and metamorphism of high-rank coal and its response to geological environment conditions. J. *China Univ. Mining Tech. (Beijing)*, 79-82 (in Chinese).

Li Zengxue, Wei Jiuchuan and Han Meilian, 2001. Transgressive events into coal—A new kind of coal accumulating mode. *Earth Science Progress*, 16(1): 120-124 (in Chinese).

Li Zengxue, Wang Tong and Wang HuaiHong, 2011. Theory and Technical System Study on Multiple Energy Mineral Resources Exploration in Coordination. *Coal Geol. China*, (4): 68-72 (in Chinese).

Li Zengxue, Wei Jiuchuan and Wang Mingzhen, 1996. North south of the epicontinental sea basin in the late Paleozoic stratigraphic sequence stratigraphic framework and sea level changes. *Lithofacies Paleogeogr.,* 16(5): 1-11 (in Chinese).

Li Zengxue, Wei Jiuchuan and Wei Zhendai, 2000. *Coal bearing basin sequence stratigraphy*. Beijing: Geological Publishing House, 51-54 (in Chinese).

Li Zengxue, Wei Jiuchuan and Li Shouchun, 1995. Fluvial-dominated shallow water delta depositional system and the coal accumulation in Luxi. *Coalfield Geol. Exploration*, 23(2): 7-12 (in Chinese).

Li Zengxue, Wei Jiuchuan, Wang Mingzhen, Zhang Xilin and Fang Qinghua, 1998. *The Epicontinental Sea Basin Sequence Stratigraphy Analysis of North China*. Geological Publishing House, 19-21 (in Chinese).

Li Zengxue, Wei Jiuchuan, Wang Mingzhen, Zhang Xilin and Fang Qinghua, 1998. *The Epicontinental Sea Basin Sequence Stratigraphy Analysis in Southern North China*. Beijing: Geological Publishing House, 65-66 (in Chinese).

Li Zengxue, Yu Jifeng, Guo Jianbin and Han Meilian, 2003. The transgression of the epicontinental sea basin in the coal forming mechanism analysis. J. *Sedimentary*, 21(2): 288-297 (in Chinese).

Mang, D.H., Mang Donghong, Yang Bingzhong and Lin Zengpin, 1994. *Chinese Coal Basin Structure*. Beijing: Geological Publishing House, 53-54 (in Chinese).

Peng Suping and Yuan Liang, 2011. The 3D seismic exploration technology application and effect in Huainan coal mine. *Anhui Geol.*, 21(2): 95-99 (in Chinese).

Peng Suping, 2009. China's coal resources development and environmental protection. *Sci. Tech. Rev.*, 27(17): 5 (in Chinese).

Peng Suping, Du Wenfeng and Zhao Wei, 2008. Coalfield 3D seismic comprehensive interpretation is applied in the complex geological conditions. J. *Rock Mechanics Engineer*., 27(1): 2760-2765 (in Chinese).

Peng Suping, Zhang Bo and Wang Tong, 2013. *China Coal Clean and Efficient Strategy of Sustainable Development and Utilization Goes to the Coal Resources and Water Resources*. Beijing: Science Press, Vii-Viii: 7-8 (in Chinese).

Peng Suping, Zhang Bo and Wang Tong, 2014. *Coal Resources and Water Resources*. Beijing: Science Press, 6-9 (in Chinese).

Shang Guanxiong, 1997. *Coal Geology Research of the Late Paleozoic in North China Platform*. Taiyuan: Shanxi Science and Technology Press, 31-34 (in Chinese).

Shang Guanxiong, 1997. *The Late Paleozoic Coal Geology Research of the North China Platform*. Taiyuan: Shanxi Science and Technology Press, 53-55 (in Chinese).

Shao Longyi, Zhang Pengfei and Dou Jianwei, 1999. The new knowledge from the coal bearing strata and sequence stratigraphic analysis—Hebei late Paleozoic sequence stratigraphic framework. *J. China Univ. Mining*, 28(1): 20-24 (in Chinese).

Shao Longyi, Zhang Pengfei and Liu Qinpu, 1992. The measure water group of lower carboniferous sedimentary sequence and episodic coal accumulating effect in Hunan. *Geol. Rev.*, 38(1): 52-59 (in Chinese).

Sloss, L.L., 1962. *Stratigraphic models in exploration*. *Am. Assoc. Petrol. Geol. Bull.*, 46: 1050-1057.

Song Lijun and Zhao Jingzhou, 2009. The double level classification of Mainland coalbed methane basin. *Coal Sci. Tech.*, 37(10): 99–104 (in Chinese).

Sun Wanlu, 2005. *China's Coal Bed Methane Basin*. Beijing: Geological Publishing House, 68-70 (in Chinese).

Sun Yongxiang, 1989. There are a few questions, which contain the coal and the coal gas generation and accumulation. *Petrol. Exploration Development*, (4): 80−81 (in Chinese).

The Special Technology Exploration Center of China National Administration of Coal Geology, 2012. *Investigation and Evaluation on the Resources of Lithium and Gallium in Coal in Pingshuo Area Shanxi Province*, 22-24 (in Chinese).

Thomas, L., 1992. *Handbook of Practical Coal Geology*. New York: John Wiley&Sons Ltd., 51-55.

Tian Qianning, Wang Haihua and Zhang Wei, 2015. Overseas development and utilization of coalbed methane exploration technology and policy. *China's Geological Library Learning Intelligence Album,* 20: 1-2 (in Chinese).

Wang Guiliang, Cao Daiyong and Jiang Bo, 1992. *Thrust Nappe Stretch Slide and Gravity Sliding Structure in the Southern of North China*. Xuzhou: China Mining University Press, 32-33 (in Chinese).

Wang Libin, 2009. *China within 2000 meters of coalbed methane geology resources reached 36.8 trillion cubic meters*. Xinhua Online, on January 27, 2009: http:// news.xinhuanet.com/ newscenter/2009-01/27/ content_ 10724239.htm (in Chinese).

Wang Libin, 2014. *China's total coal resources reached 5.9 trillion tons*. Xinhua Online, on February 3, 2014: http:// news.xinhuanet.com/fortune/2014-02/ 03/ c_ 119206797.htm (in Chinese).

Wang Rennong and Li Guichun, 1995. Coal accumulating law of coal bearing basin in china. *Geol. Rev.*, (6): 487-498 (in Chinese).

Wang Rennong and Li Guichun, 1995. The law of the coal aggregation in Chinese coal basin. *Geol. Rev.*, (6): 487-498 (in Chinese).

Wang Rennong, 1997. *China's Coal Bearing Basin Evolution and Coal Accumulating Regularities*. Beijing: Coal Industry Publishing House, 19-20 (in Chinese).

Wang Tong, 1993. Linru coalfield in the tectonic characteristics and the new understanding to find the direction of the coal. J. *Xi'an Inst. Mining*, (3): 242-247 (in Chinese).

Wang Tong, 2011. *Meagre Coal Provinces in Southern China—the Occurrence Regularity of Coal Resources and the Development and Utilization of Countermeasures*. Beijing: Science Press, 33 (in Chinese).

Wang Tong, 2012. *Tectonic Development Law and Tectonic Coal-Controlling of Northwest China Coal Hosting Area*, 3-4 (in Chinese).

Wang Tong, 2013. China's northwest Jurassic coal resources accumulation and resource evaluation. *Res. Report*, 27 (in Chinese).

Wang Tong, 2014. *China's Coal Geological Exploration System*. Beijing: Science Press, 51-52 (in Chinese).

Wang Tong, Wang Qingwei and Fu Xuehai, 2014. Unconventional gas system research and its significance. *Coalfield Geol. Exploration*, 42(1): 24-27 (in Chinese).

Ward, C.R., 1984. *Coal Geology and Coal Technology*. London: Blackwell Scientific Publications, 53-54.

Xiao Jianxin, 1998. Coal geology in our country the current and future a period of several hot issues. *China Coal Field Geol.*, 10(4):24-28 (in Chinese).

Xie Jiarong, 2007. *Coal Geology.* Beijing: Geological Publishing House, 33-34 (in Chinese).

Xu ShuiShi, Wang Tong and Sun ShengLin, 2009. New Architecture of Integrated Coal Resource Exploration Technology in China. *Coal Geol. China*, 21(6): 1-3, 3-34 (in Chinese).

Xu Shuishi, Wang Tong and Sun Shenglin, 2009.China's coal resources comprehensive prospecting technology and new architecture. *China Coal Geol.*, 21(6):1-5 (in Chinese).

Yang Qi, 1987. *Coal Geology Progress*. Beijing: Science Press, 34 (in Chinese).

Yang Qi, 1996. *Coal Metamorphism Region in China*. Beijing: Coal Industry Press, 66-67 (in Chinese).

Yang Xilu and Zhou Guoquan, 1996. *China's Coal Industry Encyclopedia: Geology-Measuring Volume*. Beijing: Coal Industry Publishing House, 68-69 (in Chinese).

Zhang Pengfei, Shao Longyi and Cao Daiyong, 2003. In the development of China's coal field geology. *Coalfield Geol. Exploration*, 31(6): 1-5 (in Chinese).

About the first author

WANG Tong Male; born in 1959. Senior engineer, Ph.D. He is engaged in coal geological exploration.

E-mail: wangtong517@126.com.