2009 Asia Pacific
Coalbed Methane Symposium
2009 China

2009 Asia Pacific Coalbed Methane Symposium and 2009 China Coalbed Methane Symposium (Vol.1)

2009亚洲太平洋国际煤层气会议暨2009年全国煤层气学术研讨会论文集

煤层气储层与开发工程研究进展 上

主编 傅雪海 秦 勇 Geoff G.X. Wang 韦重韬 Victor Rudolph 赵庆波 叶建平

Editors in chief Fu Xuehai Qin Yong Geoff G.X. Wang Wei Zhongtao Victor Rudolph Zhao Qingbo Ye Jianping

Advances on CBM Reservoir and Developing Engineering

中国矿业大学出版社

China University of Mining and Technology Press

内容提要

本书介绍了亚洲太平洋地区煤层气储层与开发工程研究进展，主要内容包括：煤层气地质与储层工程、煤层气勘探、钻井、完井、增产改造与排采工程、煤层气地面集输、利用工程、煤层 CO_2 注入与地质储存工程、煤层气政策、经济、市场与信息技术、煤矿瓦斯赋存、运移、抽采及安全工程。

本书可作为煤层气勘探开发及瓦斯抽采等相关科技人员参考、使用。

图书在版编目(CIP)数据

煤层气储层与开发工程研究进展/傅雪海等主编. —徐州：中国矿业大学出版社，2009.9

ISBN 978-7-81107-003-3

Ⅰ.煤…　Ⅱ.傅…　Ⅲ.煤层—地下气化煤气—储集层—气田开发—研究—亚太地区　Ⅳ.TE37

中国版本图书馆 CIP 数据核字(2009)第 169879 号

书　　名　煤层气储层与开发工程研究进展

主　　编　傅雪海　秦勇　Geoff G. X. Wang　韦重韬　Victor Rudolph　赵庆波　叶建平

责任编辑　潘俊成

责任校对　王美柱　杨　洋

出版发行　中国矿业大学出版社(江苏省徐州市中国矿业大学内　邮政编码 221008)

营销热线　(0516) 83885307　83884995

网　　址　http://www.cumtp.com　**E-mail**:cumtpvip@cumtp.com

排　　版　中国矿业大学出版社排版中心

印　　刷　徐州中矿大印发科技有限公司

经　　销　新华书店

开　　本　880×1230　1/16　**印张** 52.75　**字数** 1709 千字

版次印次　2009 年 9 月第 1 版　2009 年 9 月第 1 次印刷

总 定 价　300.00 元(共二册)

2009亚太地区国际煤层气会议暨2009年全国煤层气学术研讨会论文集

2009 Asia Pacific Coalbed Methane Symposium and 2009 China Coalbed Methane Symposium September 24-26, 2009

编辑委员会(Editorial Committee)

主　任(Director):秦　勇(Qin Yong)

副主任(Associate Directors):Victor Rudolph 赵文智(Zhao Wenzhi) 冯三利(Feng Sanli)

委　员(Committee in the order of the number of strokes in the surnames):

Geoff G. X. Wang	Paul Massarotto	Sue Golding
王　霞(Wang Xia)	韦重韬(Wei Chongtao)	叶建平(Ye Jianping)
张　群(Zhang Qun)	张遂安(Zhang Suian)	李五忠(Li Wuzhong)
汤达祯(Tang Dazhen)	朱炎铭(Zhu Yanming)	姜　波(Jiang Bo)
杨永国(Yang Yongguo)	赵庆波(Zhao Qingbo)	郭英海(Guo Yinghai)
唐书恒(Tang Shuheng)	鲜保安(Xian Baoan)	傅雪海(Fu Xuehai)

主　编:傅雪海(Fu Xuehai)　秦　勇(Qin Yong)　Geoff G. X. Wang　韦重韬(Wei Chongtao)　Victor Rudolph　赵庆波(Zhao Qingbo)　叶建平(Ye Jianping)

主办单位(Hosted by)

中国矿业大学 (China University of Mining & Technology)

澳大利亚昆士兰大学 (The University of Queensland, Australia)

中国石油学会石油地质专业委员会 (Oil Geology Specialized Committee, Chinese Petroleum Society)

中国煤炭学会煤层气专业委员会 (Coalbed Methane Specialized Committee, China Coal Society)

承办单位(Organized by)

中国矿业大学 (China University of Mining & Technology)

澳大利亚昆士兰大学 (The University of Queensland, Australia)

资助单位(Sponsored by)

中国国家自然科学基金委员会(National Natural Science Foundation of China)

中国石油煤层气有限责任公司(Coalbed Methane Co., Ltd, PetroChina)

晋煤集团蓝焰煤层气有限责任公司(Lanyan Coalbed Methane, Jincheng Coal Group)

山西煤炭地质114勘查院(The No. 114 Exploration Institute, Shanxi Coal Geologic Bureau)

奥瑞安能源国际有限公司(Orion Energy International)

河南省煤层气开发利用有限责任公司(Henan coalbed Methane development and utilization Co., Ltd)

亚美大陆煤层气有限公司(Asian American Gas Inc)

美国雪姆公司(Schramm Inc.)

山西省煤炭地质勘查研究院(Survey Institute, Shanxi Coal Geologic Bureau)

北京中煤大地技术开发公司(Beijing China Coal Dadi Technology Development Company)

中国石化南京石油物探研究所(Nanjing Institute of Geophysical Prospecting; SINOPEC)

前 言

亚洲太平洋地区煤层气资源十分丰富，也是世界上重要的煤炭生产基地，在合理利用这些资源的同时，相关国家有义务共同担负煤矿甲烷减排的重任。为此，中国矿业大学和澳大利亚昆士兰大学联合有关机构，定期举行亚洲太平洋地区国际煤层气学术会议。2008年9月22日至24日，"2008亚洲太平洋地区煤层气学术会议"在澳大利亚昆士兰州布里斯班市成功举行。举办者和与会者同意，乘中国矿业大学百年校庆东风，2009年9月在中国举行"2009亚洲太平洋地区煤层气学术会议"。经与中国石油学会石油地质专业委员会和中国煤炭学会煤层气专业委员会商定，"2009年亚洲太平洋地区煤层气学术会议"与原由中国石油学会石油地质专业委员会和中国煤炭学会煤层气专业委员会承办的"2009年全国煤层气学术研讨会"合并召开。

中国煤层气资源勘探开发近年来取得了快速的发展。截止2009年5月底，全国共钻煤层气井2 818口，包括参数井540口，水平井65口，开发井2 213口，其中1 419口投入生产或正在排采；探明煤层气储量1 790×10^8 m^3，占总资源量的0.5%。目前，地面煤层气井产能已达每年15×10^8 m^3左右，2008年煤层气地面井产量约7.5×10^8 m^3；全国共建有压缩气(CNG)站7座，总设计生产能力130万m^3/日；煤层气汽车加气站7座，日加气能力20万m^3；煤层气液化气(LNG)站3座，总设计用气规模155万m^3/日；已建成长输管道2条，总长100 km，总设计年输气能力20亿m^3；正在施工建设的长输管道2条，总长140 km，总设计年输气能力50亿m^3。煤层气用户主要分布在产气区及周边地区，用途主要有发电、城市居民生活、煤层气汽车(油气双燃料)、小型工业企业用气等。此外，2008年，中国煤矿抽采瓦斯58亿m^3，利用量达20亿m^3；民用已达90万户，发电总装机容量92万kW，世界上规模最大的12万kW瓦斯发电厂已在晋城煤业集团建成发电。

本次会议得到了国内外同行和有关机构的高度关注。本论文集收录论文117篇，其中英文65篇，中文(带英文摘要)52篇，作者来自中国、澳大利亚、美国、日本、德国、荷兰、印度尼西亚7个国家的高等学校、研究机构和企业单位。其中：涉及煤层气地质与储层工程论文57篇；煤层气勘探、钻井、完井、增产改造与排采工程论文29篇；煤层气地面集输、利用工程论文7篇；煤层CO_2注入与地质储存工程论文9篇；煤层气政策、经济、市场与信息技术论文7篇；煤矿瓦斯赋存、运移、抽采及安全工程论文7篇。

本论文集分上、下两卷出版。上卷收录了关于煤层气地质与储层工程的57篇论文(包括37篇英文)，下卷收录了本次会议其他五个主题的60篇论文(包括28篇英文)。

论文集涉及的论文数量多，内容广，编审时间短，没有时间与作者逐一校核，不足之处在所难免，恳请广大作者与读者谅解。

最后，衷心感谢资助单位、论文作者/全体与会代表及相关的煤层气企业家对本次会议的帮助与支持！

主编谨识

2009年8月31日

Preface

The Asia and Pacific region, where there is one of an important production coal base in the world, is very abundant in coalbed methane (CBM) resources. The countries in the region are bound in decreasing together emissions of coal mine methane (CMM) to aerosphere. To promote the technical exchange and regional collaboration in the CBM/CMM development and utilization, China University of Mining & Technology (CUMT) and the University of Queensland (UQ), Australia, jointed with relative organizations have initiated to convene periodically the Asia & Pacific CBM Symposium. The "2008 Asia & Pacific CBM Symposium" (2008 APCBM) was successfully held in Brisbane, Australia, on 22-24 September, 2008. The hosting institutes and delegates agreed that the 2009 Asia & Pacific CBM Symposium (2009 APCBM) is held in China in connection with the 100th anniversary activities of CUMT. The China CBM Symposium (CCBM) is usually hosted jointly by Coalbed Methane Specialized Committee, China Coal Society (CCS) and Oil Geology Specialized Committee, Chinese Petroleum Society (CPS) for every year. After a satisfying negotiation, it was decided to host a joint 2009 APCBM/2009 CCBM symposium co-organized by CUMT, UQ, CCS and CPS in Xuzhou, China on 24-26 September, 2009.

CBM exploration and development of China have achieved a rapid progress in recent years. Until May of 2009, there were 2 818 CBM wells drilled in China, including 540 parameter wells, 65 horizontal wells and 2 213 production wells. Currently 1 419 production wells are commercially operating. Confirmed CBM reserve in China is about $1\ 790\times10^8\ m^3$, accounting for 0.5% of the total CBM resource of China. In 2008, the CBM production was approximately $7.5\times10^8\ m^3$. At present, the CBM producing capacity with surface well has reached about $15\times10^8\ m^3$ per year. Seven CBM compression stations with compressed capability of $1.3\times10^6\ m^3/d$ and seven CBM filling stations with gas-filling capacity of $200\ 000\ m^3$ have be constructed, and three liquefied CBM plants with design capacity of $1.55\times10^6\ m^3/d$ have put into production. In addition, two CBM-send-out pipelines with total length of 100 km are operating, with CBM transportation capacity of $20\times10^8\ m^3$ per year. Another two pipelines are building, with total length of 140 km and CBM transportation capacity of $50\times10^8\ m^3$ per year.

Consumers of CBM are mainly distributed in gas production and neighboring areas. CBM is mainly used as the electric power generation, gas supply for urban residents, CBM vehicles (gas and oil bi-used vehicle), small-scale industrial enterprises and so on. Also, the coal mine methane (CMM) of $58\times10^8\ m^3$ were extracted from underground mines of China in 2008, of which about $20\times10^8\ m^3$ were utilized. Now, consumers form urban residents have reached 900 000 families, and the installed gross capacity of the CBM power plants is 920 000 kW. A CBM power plant with the power generation capacity of 120 000 kW, a largest CBM power plant in the world, had been completely constructed and began to generate electricity in Jincheng Coal Group in 2009.

CBM experts, scholars and organizations form China and other countries pay close attention to the symposium. More than 180 authors responded to the Call for Abstracts, addressing the key themes of CBM/CMM and CO_2-ECBM geosequestration. Total of 117 papers, including 65 papers in English and the others in Chinese with English abstracts, were collected in the publication. Authors in the papers come respectively from China, Australia, America, Japan, Germany, Netherlands and Indonesia.

Thereinto, 57 papers are focused on CBM geology and reservoir engineering, 29 papers on CBM exploration, drilling, well completion and reservoir enhance and recovery engineering, 8 papers on the CBM ground collection, transportation and utilization engineering, 9 papers on CO_2 coal seam sequestration (CO_2-ECBM) and geological storage, 7 papers on CBM policy, economics, marketing and information technology, and 7 papers on CMM occurrence, migration, extraction and safety engineering.

The publication was printed in two volumes, in which the papers on CBM geology and reservoir engineering are arranged in Volume Ⅰ and those on other five subjects of the symposium in Volume Ⅱ.

We wish to extend our sincere gratitude to the National Natural Science Foundation of China and other sponsors for the financial support. We are very grateful to all authors, all attendee and other CBM enterprisers for their help and support to this symposium.

Chief-Editors
August 31, 2009

目　录(Content)

第一编　地质与储层工程
(CBM geology and reservoir engineering)

第二编 钻井、完井、增产改造与排采工程

(CBM exploration, drilling, completion and reservoir enhance and recovery engineering)

第三编　地面集输、利用工程
(CBM ground collection, transportation and utilization engineering)

第四编　煤层 CO_2 注入与地质储存工程
(CO_2 sequestration into coal seam (CO_2-ECBM) and geological storage engineering)

第五编　政策、经济、市场与信息技术
(CBM policy, economics, market and information technology)

第六编　煤矿瓦斯赋存、运移、抽采及安全工程
(CMM occurrence, migration, extraction and safety engineering)

第一编

地质与储层工程

Geological controls on the formation of coalbed methane reservoirs and prediction of target areas of Turpan-Hami basin, Northwest China

Y. D. Cai D. M. Liu Y. B. Yao B. L. Hu Y. Che
(School of Energy Resources, China University of Geosciences, Beijing, 100083, China)

【Abstract】 To better understand the controls on coalbed methane (CBM), a lot of surveys and experiments (including coal petrology analysis, mercury porosimetry, Brunauer-Emett-Teller (BET) nitrogen adsorption at low temperature and methane adsorption/desorption) are conducted. The structures, coal-bearing strata and coal facies are revealed by geological research and the laboratory tests showed the coal petrologic characteristics, coal types, macerals, vitrinite reflectance (R_o), permeability, pore and cleats characteristics and coal adsorption/desorption ability. Finally, based on above analysis, analytic multi-hierarchy process-fuzzy mathematics (AMP-FM) method is introduced into appraising the CBM resources. The results show that Turpan-Hami basin was divided into five levels for CBM resources, in which Aiweiergou and Yilahu mines are the most favorable CBM development districts. Total CBM resources less than 1 500 m in Turpan-Hami basin are $2.058\,7 \times 10^{12}$ m^3 calculated using cubage method, and the average abundance of CBM resources for Turpan-Hami basin is 1.56×10^8 m^3/km^2.

【Key words】 geological controls; coalbed methane reservoir; prediction; Turpan-Hami basin

1 Introduction

Coalbed methane (CBM) resources are very abundant in the Turpan-Hami Basin, which is the basin with low rank coal. Although many CBM exploration and basic research projects have been initiated, nowadays most are concentrated on limited districts of the basin (Yang et al., 1996; Li et al., 2003; Yang et al., 2005). Only some preliminary studies on reservoirs and gas content (Hu et al., 2002; Li, 2002; Ning et al., 2003; Liu et al., 2006; Yang,Li, 2008) have been conducted in the Aiweiergou and Shaerhu coalfields in the Turpan-Hami Basin.

Some studies related to the geological features of the basin and some primary evaluation of CBM reservoirs (including the Aiweiergou and Hami Coalfields) have been conducted (Hu et al., 2003; Yang et al., 2005), but these data are insufficient for evaluating the CBM potential and determining the target area. In this paper, we will report the data from the field and laboratory study on the geological controls of CBM, and the reservoirs, the resources and the production potential. With the available data and analytic multi-hierarchy process-fuzzy mathematic (AMP-FM) model (Sun et al., 2000; Yang 2000; Yao et al., 2008; Liu et al., 2008), we attempt to generalize the most favorable conditions for CBM production and to predict the target areas with good CBM production potential.

2 Geological setting

2.1 Tectonic settings

Main structural lines of coal-bearing strata in Turpan-Hami basin are NE-NW-NE-NW from west to east, which performs as "W". NE structural line developed from western Tuokexun and Taibei sub-depressions to eastern Liaodun uplift, NW structural line developed in Aidinghu slope, western Taibei and Hami sub-depressions. This "W" type structural line is controlled by base background and surrounded with mountains. Kalawucheng, Bogeda and Haerlike mountains form the north boundary of the basin. The formation of main structural lines was controlled by the activity of these mountains at different stages and scales (Zhao et al., 1992; Tong, 1999; Lu, 2001; Zhang, 2000; Tang et al., 2003; Dai et al., 2005; Zhou, Yao, 2006). At the Indonisian movement stage, a series of NW structures are created by the activity of mountain Haerlike. At the Yanshanian movement stage, a series of NE structures are formed by the activity of mountain Kalawuchen due to two structures interspersed each other. At last, the netlike structures performed in the basin at the Yanshanian stage. At the Himalaya movement stage, the uplift of mountain Bogda resulted in nearly N-S compressive stress. The original lines are composited, adjusted, which due to a number of recent east-west extensional structures and near-vertical N-S faults formed. By the multi-phase structural changes, the north-south zonation is the basic characteristics of Turpan-Hami basin, which (mainly the northern part of the Turpan Depression zone) appeared with the distribution of different structural features.

Turpan-Hami basin is made up of composite sedimentary basins formed at different periods. The basin exists among the confluence spot of three major plates of the Northwest China, and the boundary of the basin is very complex. Based on structural characteristics of different structural stratum, Zhang et al. (1997) recognized that the tectonic stress of the basin at early Permian is NE-SW stretch region stress field, and at the late Permian is S-N extrusion region stress field, while at the Indonisian stage it's NW-SE extrusion dextrorotation sub-class stress field, at the Yanshanian stage it's NE-SW extrusion stress field which levorotation sub-class stress field derived from, and at the Himalayan stage NE-SW extrusion stress field (Ji, Qin, 2005).

2.2 Coal-bearing strata

The clastic rocks deposited in fluvial, lacustrine and swamp facies in the Turpan-Hami Basin, in which Jurassic coal-bearing strata mainly occur. The total thickness of the strata is close to 4 000 m, which are divided into the Lower Jurassic Badaowan and Sangonghe Formations, Middle Jurassic Xishanyao, Sanjianfang and Qiketai Formations, and Upper Jurassic Qigu and Kalazha Formations. Coal seams mainly occurred in the Lower Jurassic Badaowan and middle Jurassic Xishanyao Formations.

3 Experimentals

Vitrinite reflectance (R_o) and coal lithotype tests are conducted on microscope photometer (MPV-III, Leitz) following the GB/T 6948—1998. standard procedure at laboratory of coal geology, China University of Mining and Technology in Beijing, average vitrinite reflectance ($R_{o,max}$) (immersion in oil) is acquired. Coal macerals are counted by the scheme of International Committee of Coal and Organic Petrology (ICCP, 1998).

Mercury porosimetry parameters (pressure, pore diameter and mercury volume) are automatically recorded by Autopore 9410 analyzer (micrometrics, US) following SY/T 5346—1994 (Chinese Oil and Gas Industry) and permeability parameters are acquired following the SY/T 5336—1996. At the same time, the tests of specific surface area, pore diameter and isothermal adsorption/desorptiom experiments are conducted at the Gas Research Center, Langfang Branch of Research Institute of Petroleum Exploration and Development, China National Pe-troleum Corporation. The isothermal equipment conditions are as follows: high-pressure CH_4 gas, the purity 0.999, and the initial pressure 14 MPa, average experimental temperature of 35 ℃ (Calculated from Turpan-Hami Basin geothermal gradient) in depth of 1 000 m of Turpan-Hami basin, and the water equilibrium method for testing.

4 Results and discussions

4.1 Potential of CBM generation

4.1.1 Coal facies

The Jurassic coal seams of Turpan-Hami basin mainly developed in dry peat swamp, forest peat swamp, peat swamp with flowing water and fresh water marsh facies. During the Badaowan period, the forest peat swamp facies developed in Tuokexun-Turpan, while in Sandaoling, Aiweiergou and near the well Hacan 2 dry peat swamp developed. Dry peat swamp and forest peat swamp developed extensively with the obviously eastward shift, fresh water peat swamp and fresh water marsh developed with local distribution during the Xishanyao period. From the plane distribution of coal facies, the thick coal seam occurs stably in the forest peat swamp zone, in which large amount of CBM generated. The properties of coal reservoirs are also well-developed, which is favorable for CBM accumulation.

4.1.2 Coal petrography

The generation and concentration of CBM during coalification are revealed by the controls on the adsorption capacity and reservoir properties. High coal ranks in the Yemaquan and Aiweiergou mining areas are related with magma intrusion resulted from the activity of Boluokenu-Aqikekuduke deep fault (Yang et al., 1996). According to former studies (Yang et al., 2000), the results showed that magmatic metamorphism of coals can improve the porosity and permeability and promote CBM production, which is beneficial to CBM exploration and development.

Coal petrology of Turpan-Hami basin is very special and characteristics of coal macrostructures are different as well. The bright coal for Aiweiergou and Kekeya coal mines are very thick, the structures of conchoids and eyeball-like are very obvious (Figure 1). Fusain occurs more frequently, single-layer is normally thick, the thickness of fusain-rich coal can be as large as 2 m, such as No. 4 coal seam in Sandaoling (Figure 2). The characteristics of sapropel coal show that it is pure and light, and characterized with conchoidal fracture, homogeneous structure and massive structure. The thickness is always larger than 0.5 m, as in the Kekeya coal mine (Figure 1). As for a small number of coals, the macrolithotypes vary from bright to semi-bright. Microlithotypes of Turpan-Hami basin for Jurassic coal are characterized by more durite and less vitrite. While in the Aiweiergou coal mine, vitrite is the major coal microlithotype.

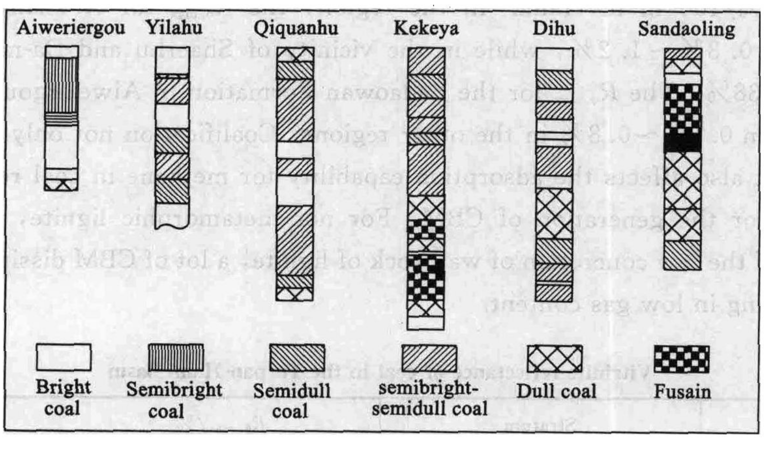

Figure 1 Lithotypes of main coal seams in Turpan-Hami basin

Vitrinite gives its priority to coal macerals of Xishanyao and Badaowan Formations in Turpan-Hami Basin, which up to 40%～95%. Inertinite contents vary from 2% to 67%, with an average of 20%. Liptinite content is less than 10%. According to the thermal simulation experiments (Zhao et al.,

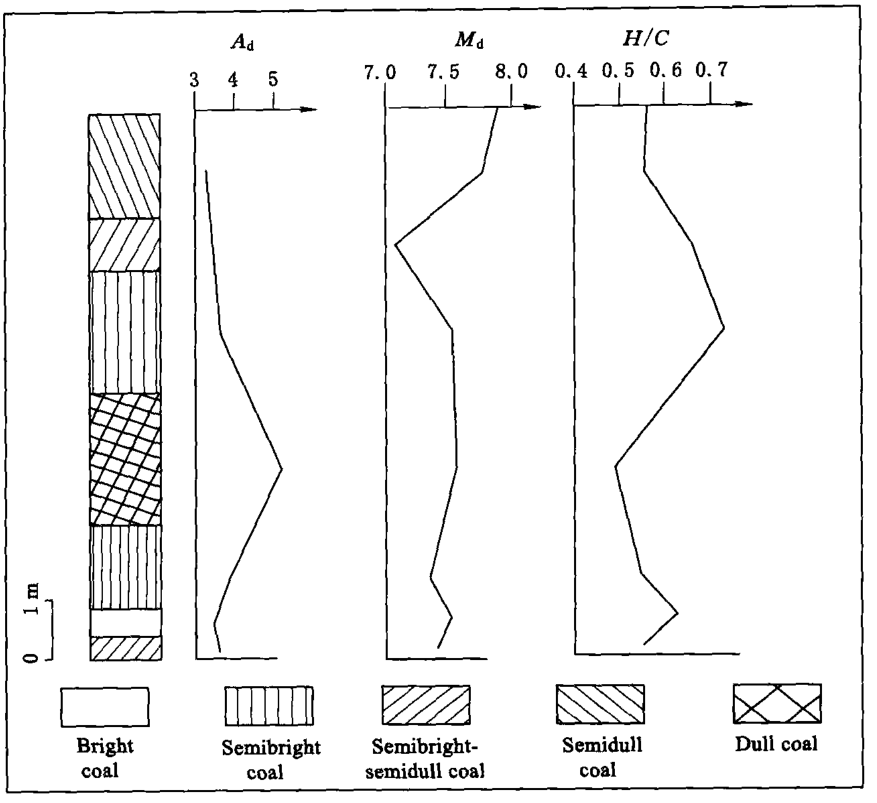

Figure 2 Coal petrological and coal quality of No. 4 coal seam in the Sandaoling coal mine

1997), the liptinite is the most favorable type for CBM production, followed by vitrinite and inertinite. The total gas production is different due to the different content of macerals.

Coal types in the Turpan-Hami Basin are very complete, which ranges from lignite to the lean coal, while kennel coal and non-caking or weakly caking coals are the main types.

4.1.3 Coal rank

Coal vitrinite reflectance for Turpan-Hami Basin largely changes from 0.38% to 1.9% (Table 1). In general, $R_{o,max}$ values increase from 0.38% to 1.2% with increasing the depth of coal seam (Figure 3). In the Taipei district, the vitrinite reflectivity gradient is 0.035%/100 m, 0.22%/100 m in Tuokexun and 0.05%/100 m in Hami. In the region, the $R_{o,max}$ for Xi-shanyao seam around the Wutongwozi is up to 0.8%~1.2%, while in the vicinity of Shaerhu and Da-nanhu mines it is at a minimum of about 0.38%. The $R_{o,max}$ for the Badaowan Formation in Aiweiergou is up to 1.9% more than that ranging from 0.5%~0.8% in the other regions. Coalification not only influences on the gas generation of coal but also affects the adsorption capability for methane in coal reservoirs. Lower coal rank is unfavorable for the generation of CBM. For non-metamorphic lignite, only biochemical gas generated. Because of the low concretion of wall rock of lignite, a lot of CBM dissipates from the coal reservoir, which resulting in low gas content.

Table 1 Vitrinite reflectance of coal in the Turpan-Hami basin

Sampling spot	Stratum	$R_{o,max}$/%	Coal rank
Hami	J_2x	0.38~0.58	Lignite-Kennel coal
Sandaoling	J_2x	0.52	Kennel coal
Hacan 1	J_2x	0.57	Kennel coal
Well Fang 1	J_2x	0.6~0.7	Kennel coal