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四川盆地川西北地区侏罗系自流井组大安寨段页岩气聚集条件

柳 妮[1] 林良彪[1] 陈洪德[1] 张宗斌[2] 赵梦莹[1]

(1. 成都理工大学"油气藏地质及开发工程"国家重点实验室,四川 成都 610059;
2.中国石油新疆油田分公司勘探开发研究院,新疆 克拉玛依 834000)

提要:通过采用岩心观察、扫描电镜、地化参数分析等实验方法,研究了四川盆地川西北地区页岩的沉积相、厚度及分布、有机质类型及含量、成熟度、生烃史等页岩气成藏条件。川西北地区侏罗系自流井组大安寨段发育潮坪、沼泽及泻湖相,富有机质黑色泥页岩为主、单层厚度大,有机碳平均质量分数为2.0%,有机质类型以Ⅱ$_1$、Ⅱ$_2$、型为主的混合型,生烃潜力较大,热演化程度高,具备页岩气藏发育的良好地质条件。根据页岩气富集的多种因素分析,认为元坝—仪龙南部、达州—宣汉地区页岩气聚集条件较优越,是四川盆地川西北地区自流井组大安寨段页岩气勘探开发的有利区域。

关 键 词:自流井组大安寨段;页岩气;聚集条件;川西北地区;四川盆地
中图分类号:P536;P618.1 **文献标志码**:A **文章编号**:1000−3657(2014)05−1664−09

1 引 言

页岩气作为非常规天然气资源的重要类型之一,近年来,在受美国和加拿大页岩气成功开发的启示下[1-2],针对中国页岩气的形成机理和分布规律均形成了一定的认识[3],初步展示了中国页岩油气勘探的巨大资源潜力[4-5]。研究表明:四川盆地页岩气成藏地质条件优越[6-9],2012 年 3 月国土资源部公布的四川省境内页岩气地质资源 27.50×10^{12} m^3,占全国总量 20.46%[10],且中石化南方勘探公司在四川省元坝探区一重点探井自流井组大安寨段钻获高产页岩气流,日产 50.7×10^4 m^3 页岩气,可见四川盆地陆相页岩气在下侏罗统湖相泥页岩中的勘探获得良好的天然气显示和工业气流,成为中国陆相页岩气勘探开发的重要区域。本文采用岩心观察、扫描电镜、有机碳测试等实验方法,初步探讨了川西北地区自流井组大安寨段沉积相及其展布、有机质类型及含量、成熟度等页岩气聚集条件,并预测页岩气藏发育有利区。

2 地质背景

研究区位于四川盆地西部和北部,即龙门山、米仓山和大巴山前缘,构造区划上位于川北平缓褶皱带、川西低缓褶皱带和部分川东褶皱带。四川盆

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作者简介:柳妮,女,1985 年生,博士生,沉积学专业; E−mail: liuni_smile@aliyun.com。
通讯作者:林良彪,男,1979 年生,副教授,主要从事沉积学的教学与科研工作,E−mail: linliangbiao08@cdut.cn。

地为东亚典型的红色盆地,侏罗纪地层广泛发育,厚1500~3500 m,层序完整[11,12],大安寨段位于下侏罗统自流井组上部。早、中侏罗世,北部地区的秦岭造山带由北东向南西逐渐推进,导致米仓山、大巴山进入了逐渐增强的逆冲推覆的构造演化阶段[13]。盆地内早侏罗世沉积厚度较薄,以发育岩性,岩相和厚度均较稳定的湖泊相沉积为主,尤以自流井组上部的大安寨段最稳定。大安寨段早期构造沉降速率较大,后期构造运动转为平静[14],整体上为湖泊沉积环境,局部发育三角前缘沉积,最显著的特点是由淡水双壳类化石的连续沉积形成厚层块状的、呈大面积环带状分布的介壳滩相沉积,介壳滩向陆一侧以发育滨浅湖相杂色泥质沉积为主[15-17];向盆内一侧的达川、南充等地,则以发育深—半深湖相黑色页岩沉积为主,厚度亦相应加大(图1)。

3　大安寨段页岩沉积特征

3.1 岩性特征

研究区自流井组大安寨段地层岩性和厚度变化较大,以黑色、黄绿色页岩与生物介壳灰岩不等厚互层为主,上部夹紫红色泥岩,偶夹薄层泥灰岩及灰质细砾岩透镜体,厚50~240 m。该岩性段顶部于区域上稳定地发育有一套厚2~8 m的紫红与灰绿相间的杂色钙质泥岩夹薄层粉、细砂岩组合(图2),并以杂色钙质泥岩沿层面介壳富集产出特征成为区域地层划分和追踪对比的重要标志层。所含的淡水双壳类和介形类化石于自流井组中最为丰富,分布范围亦最广(图3)。

3.2 页岩厚度分布

不同的沉积环境,页岩的厚度是不一样的[18]。侏罗系自流井组大安寨段沉积水体较深、水动力条件弱,沉积的泥岩质纯,分布面积广。从对比图和平面图上可以看到(图4~5),在仪陇地区页岩厚度可达30~70 m,其中龙岗1井,其埋藏为3200 m、页岩累计厚55 m。在川东部,沉积背景为介屑滩的达州地区,包括坡1、普光1、七里21、雷2井,从北到南,页岩的厚度30~60 m。都江堰地区附近的川鸭91、川鸭92井,其埋藏深度2000 m,没有沉积页岩。对比四川盆地下侏罗统大安寨段岩相古地理图,可以看出,盆地边缘地区(沉积相为三角洲前缘的部

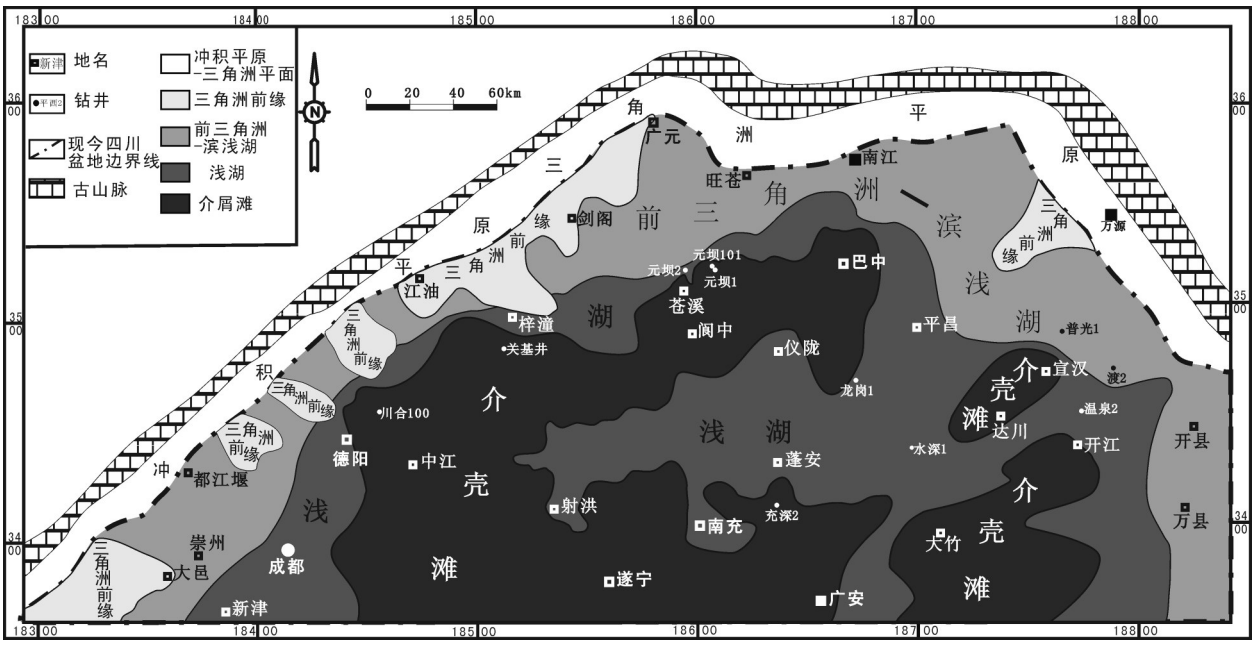

图1 川西北地区下侏罗统自流井组大安寨段岩相古地理图

Fig.1 Lithofacies-paleogeographical map of Daanzhai Member of lower Jurassic Ziliujing Formation in the northwest of Sichuan Basin

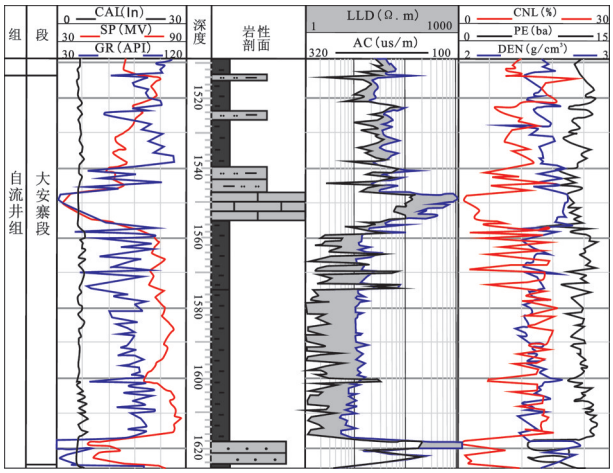

图2 充深2井大安寨段富有机质页岩地质综合剖面

Fig.2 Composite geological section of shale with rich organic matter in Chongshen well 2

分),其页岩厚度范围在10 m左右。除以上描述外,研究区其余部分页岩有效厚度都基本一致,分布均匀,范围在10~30 m。在仪龙—南部、达州—宣汉、开县等构造厚度相对更大,平均厚度在30~70 m。

4 大安寨段页岩地质特征

4.1 矿物组分

岩石矿物组成对页岩气后期开发至关重要,具备商业性开发条件的页岩,一般其脆性矿物含量要高于40%,粘土矿物含量小于30%[19]。根据粘土矿物及全岩X射线衍射分析,侏罗系自流井组大安寨段岩石的粘土矿物含量平均为18%(10%~28%);石英、长石和黄铁矿平均含量分别为55%(43%~65%)、4.3%(1.55%~20.74%)、2.08%;碳酸盐含量平均为21%(5%~42%)(表1),可见大安寨段有利于页岩气开采。

4.2 有机质类型

四川盆地侏罗系自流井组大安寨段干酪根类型包括Ⅲ型、$Ⅱ_2$型和$Ⅱ_1$型。根据显微组分特征湖盆中心大安寨段页岩有机质主要为$Ⅱ_1$—$Ⅱ_2$型[20-21]。腐泥组含量0~53%,平均30.28%;壳质组含量63%~86%,平均45.28%;镜质组含量1~30%,平均15%;惰质组含量2%~20%,平均9.14%。

4.3 有机碳含量分布

根据研究需要,川西北地化参数分布研究受实测数据点的限制,分布图的编制缺少响应资料点的控制,因此本次研究通过对有机地化参数与测井响应信号之间关系进行了分析。TOC与各种测井响应的关系表明:与声波时差具有一定的线性正相关关系,呈较好的指数关系,相关系数达到0.8678(图6)。因此针对大安寨组建立解释模型如下:

$$TOC_{大安寨组}=0.3362\times e^{0.201\times AC} \quad (1)$$

利用川西北地化参数实测数据和测井解释结果对研究层段编制了富有机质页岩的TOC平面分布图(图7),可见TOC含量为0.75%~2.7%,高值分布区很局限,主要分布在苍溪以北的旺苍地区以及渠县至达州地区,但平均值也仅在2%左右。总体上该层富有机质泥页岩有机碳含量在1.8%以下,含

图3 川西北地区自流井组大安寨段组沉积构造照片

a—介壳灰岩,大安寨段,渠县三汇;b—泥岩夹介壳灰岩,大安寨段,渠县三汇;c—粉砂质泥岩中的介壳,大安寨段,达州铁山

Fig.3 Photos of sedimentary structures in Daanzhai Member of lower Jurassic Ziliujing Formation in the northwest of Sichuan Basin

a−Shell limestone of Daanzhai Member in Sanhui of Quxian County; b−Shell mudstone intercalated with limestone of Daanzhai Member of lower Jurassic Ziliujing Formation in Sanhui of Quxian County; c−Shell within silty mudstone of Daanzhai Member in Tieshan of Dazhou

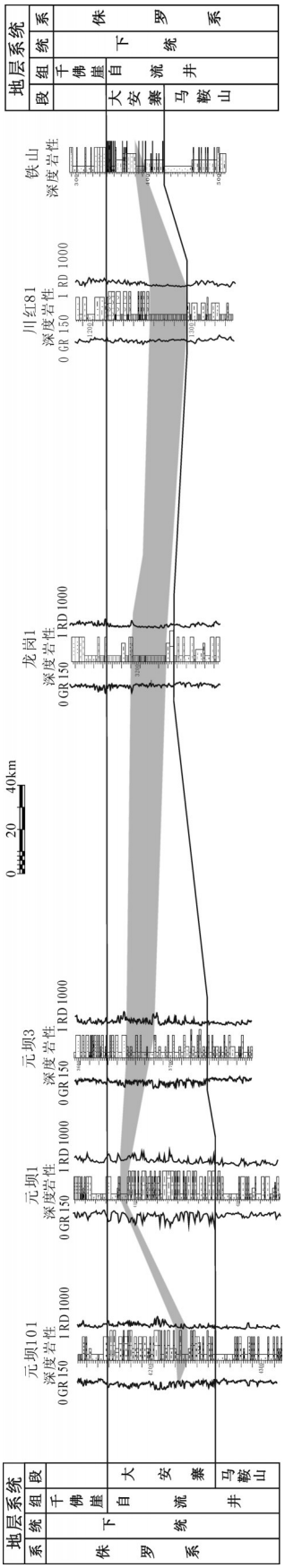

图4 川西北地区大安寨段富有机质泥页岩厚度平面分布图

Fig.4 The thickness plan view of shale with rich organic matter in Daanzhai Member in the northwest of Sichuan Basin

表1 川西北地区大安寨段页岩(黑色页岩)矿物含量

Table1 Values of minerals in shale from Daanzhai Member in the northwest of Sichuan Basin

井名	深度 /m	石英 /%	斜长石 /%	方解石 /%	黄铁矿 /%	白云石 /%	粘土 /%
兴隆 1	2403	55.94	0	33.29	0	0	10.77
	2409	55.51	6.66	18.55	0	0	18
	2416	48.74	0	31.22	0	0	20.04
	2419	53.76	0	26.41	2.08	0	17.75
元坝 2	3590	56.95	20.74	5.32	0	0	16.99
	3661	62.27	7.71	1.33	0	0	28.69
	3700	65.46	0	15.15	0	0	19.39
元坝 12	3674	43.77	1.55	42.3	0	1.55	10.83
	3720	58.56	2.33	18.68	0	0	20.43

表 2 湖盆中心大安寨段页岩干酪根显微组分(30件样品)(据文献[20])

Table 2 The kerogen maceral table of 30 samples in Daanzhai Member of lake center (after reference [20])

取样位置	腐泥组 /%	壳质组 /%	镜质组 /%	惰质组 /%	氢指数 /mg×g^{-1}	干酪根类型
仪陇	0	86	11	3	31.75	II_2
	10	81	6	3	43	II_1
	10	87	1	2	50.75	II_1
平昌	30	63	4	3	55.5	II_1
西充	56	0	30	14	19.5	II_2
龙岗	53	0	28	19	13	II_2
渠县	53	0	25	20	16.25	II_2

量相对偏低。

4.4 有机质成熟度

川西北地区侏罗系大安寨组富有机质泥页岩的演化程度南部相对偏低[22-23],一般在0.6%以下,而北部从梓潼至苍溪、仪陇是该套泥页岩演化程度相对较高的区域,*R*o达到1.2%以上,东部的宣汉地区*R*o也达到1.0%以上;北部盆地边缘演化程度逐渐降低,至广元、南江、万源等地都已在0.8%以下(图8)。富集有利区为仪龙—南部和达州—宣汉2个区域。页岩气聚集地质地球化学条件和泥页岩厚度较优越,是川西北地区侏罗系自流井组大安寨段页岩气勘探的有利区域。

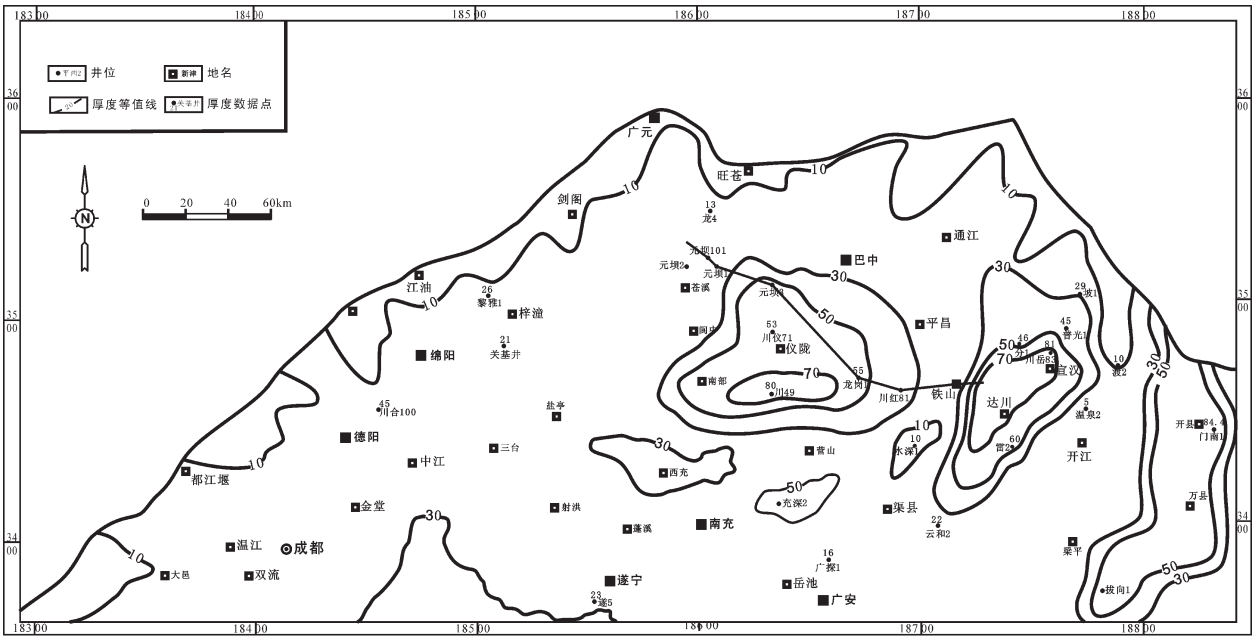

图5 川西北地区大安寨段富有机质泥页岩厚度对比图

Fig.5 The thickness contrast diagram of shale with rich organic matter in Daanzhai Member in the northwest of Sichuan Basin

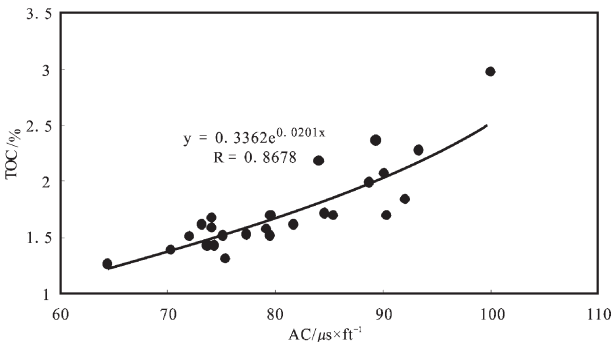

图6 川西北地区大安寨段富有机质泥页岩有机碳含量与声波时差关系

Fig.6 The relationship between TOC and interval transit time of mud shale with rich organic matter in Jurassic Daanzhai Member

表3 四川盆地侏罗系有利区优选参数

Table 3 Optimum parameter list of favorable zones

主要参数	取值标准
面积/km^2	大于100
厚度/m	单10层泥页岩厚度≥10；或泥地比>60%，单层泥岩厚度>6，且连续厚度≥30
埋深/m	300~4500
TOC/%	平均不小于1.5
Ro/%	Ⅰ型干酪根≥1.2；Ⅱ型干酪根≥0.7；Ⅲ型干酪根≥0.5
地表条件	地形高差较小

5 页岩气富集有利区

5.1 选区标准

本次有利区的优选参照标准❶，根据四川盆地地质条件对侏罗系制定有利区的优选标准（表3）。主要选取了面积、厚度、埋深、有机碳含量、有机质演化程度及地表条件6项指标[24-26]。其中大安寨段厚度按照连续厚度≥30 m，TOC按照1.5%，*Ro*根据干酪根类型对应Ⅰ型干酪根大于1.2%、Ⅱ型干酪根大于0.7%、Ⅲ型干酪根大于0.5%来作为有利区优选标准[27]。

5.2 有利区分布

按照上述有利区优选标准，对侏罗系自流井组大安寨段泥页岩评价层系进行了有利区优选仪龙—南部、达州—宣汉2个区块（图9）。这2个页岩气区块均具有泥页岩厚度大，TOC值较高，埋深适中，以及泥页岩中已见大量油气显示等有利条件。但是川西北地区的泥页岩气勘探还尚未起步，因此，随着勘探技术的不断进步，侏罗系自流井组组的泥

❶国土资源部油气中心. 全国页岩气潜力调查及有利区优选标准. 2013.

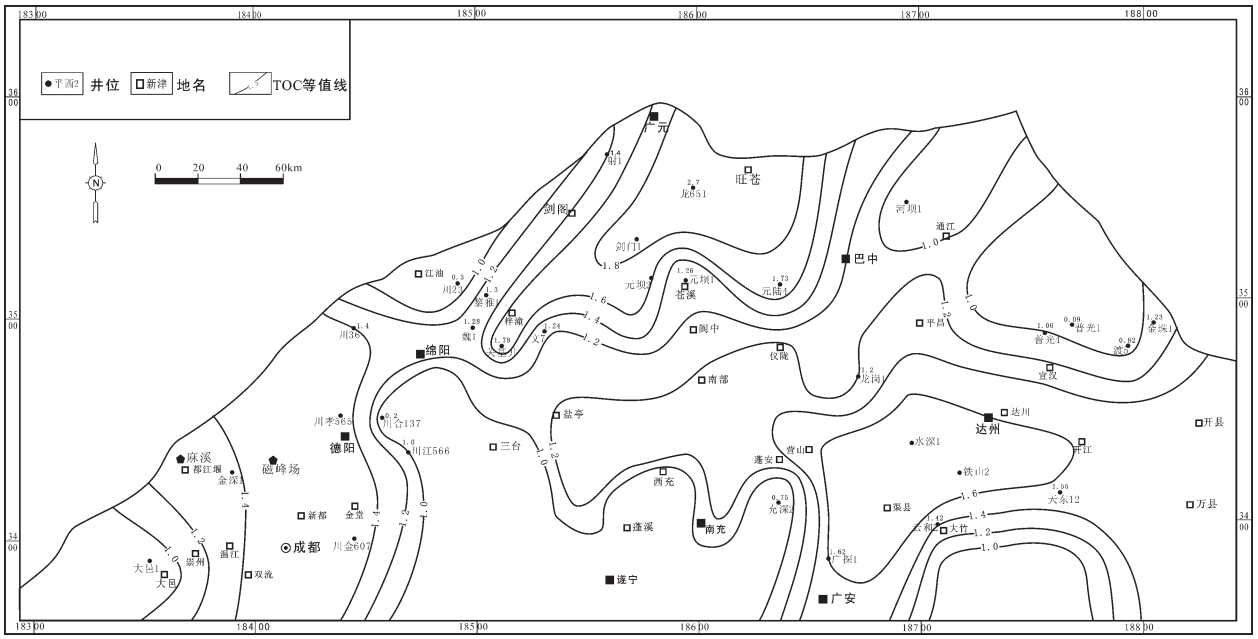

图7 川西北地区大安寨段富有机质泥页岩有机碳含量分布图

Fig.7 TOC distribution maps of mud shale with rich organic matter in Daanzhai Member in the northwest of Sichuan Basin

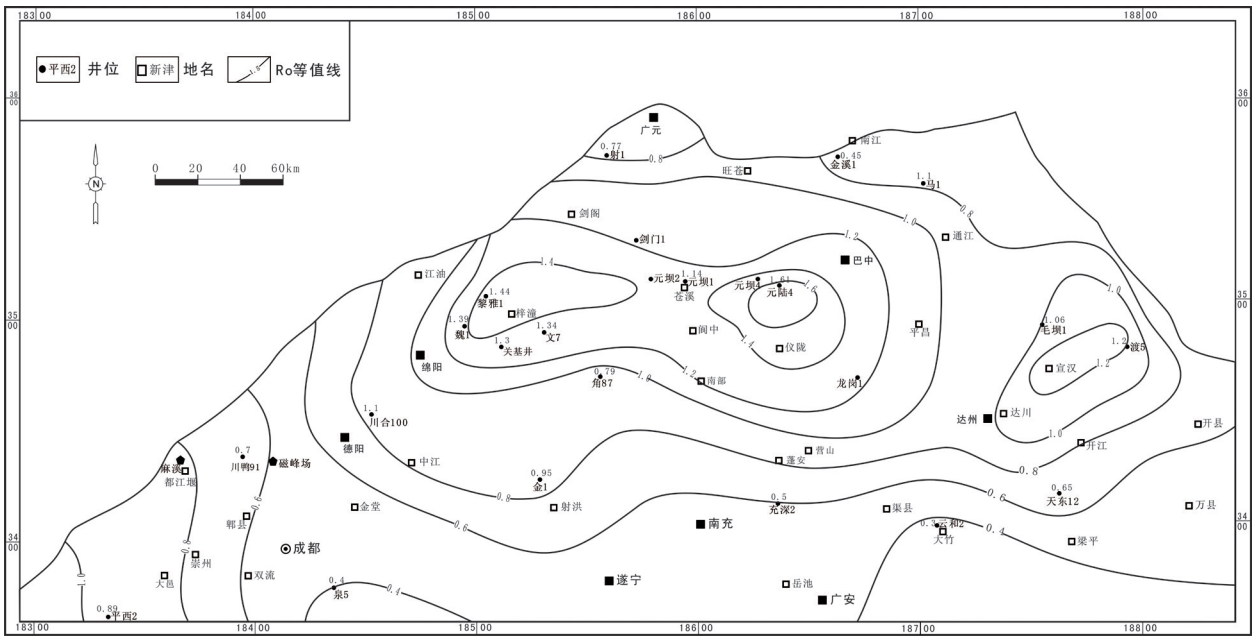

图8 川西北地区大安寨段富有机质泥页岩*Ro*分布图

Fig.8 Ro distribution maps of mud shale with rich organic matter in Daanzhai Member in the northwest of Sichuan Basin

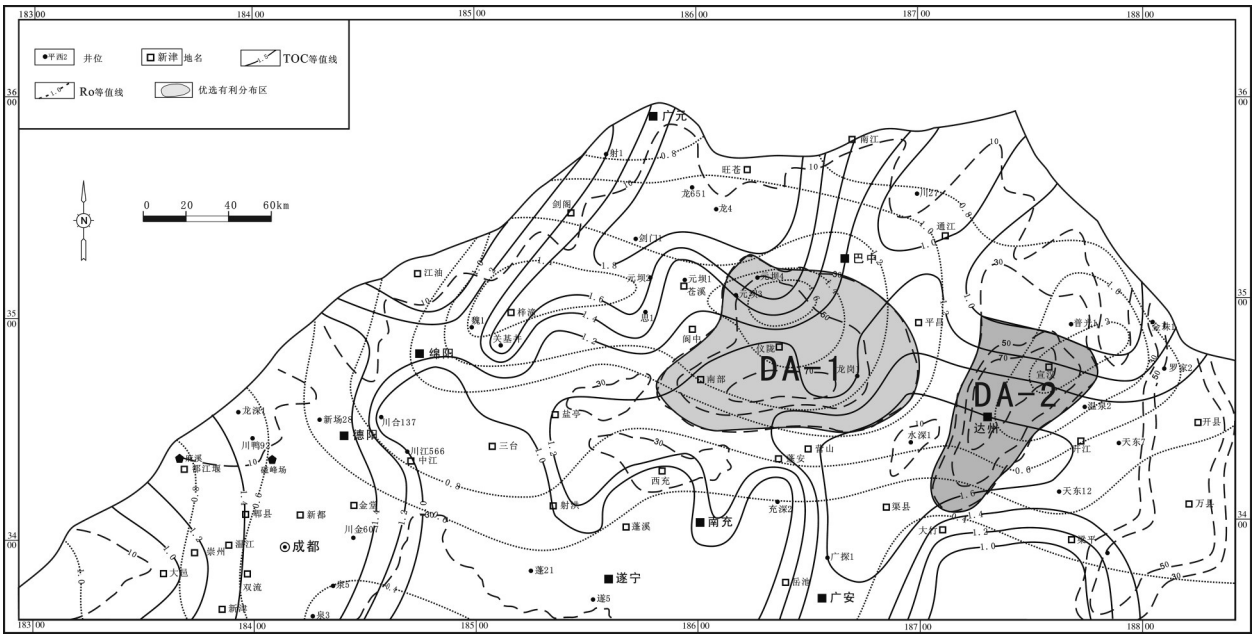

图9 川西北侏罗系自流井组大安寨段页岩气有利区优选分布图

Fig.9 Favorable zone optimization map of shale gas in Daanzhai Member of Jurassic Ziliujing Formation in the northwest of Sichuan Basin

页岩气有可能成为未来天然气储产量增长的新类型,逐步发展成为四川盆地一个重要的天然气勘探区带。

6 结 论

(1)自流井组大安寨段沉积期,相对较稳定,整体上为湖泊沉积环境,局部发育三角前缘沉积。大安寨段富有机质页岩厚度分布图显示,该套页岩具有一定的厚度,且分布稳定,埋藏相对较浅。在仪龙—南部、达州—宣汉、开县等构造页岩厚度相对更大,平均厚度在30~70 m。

(2)本次研究的页岩层系有机质类型主要为Ⅲ型和$Ⅱ_2$型,湖盆中心为$Ⅱ_1$型干酪根分布;TOC含量为0.75%~2.7%,高值分布区很局限;有机碳含量在1.8%以下,含量相对偏低;*Ro*达到1.2%以上,演化程度适中,符合前人总结的页岩气成藏有利条件。

(3)在综合考虑研究工区地质条件和背景的基础上,参考了国土资源部油气中心2013年页岩气评价标准,根据富有机质泥页岩厚度、沉积相、有机碳含量、有机质成熟度预测自流井组大安寨段页岩气富集有利区为仪龙—南部和达州—宣汉两个区域。页岩气聚集地质地球化学条件和泥页岩厚度较优越,是川西北地区侏罗系自流井组大安寨段页岩气勘探的有利区域。

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Shale gas accumulation conditions in Daanzhai Member of lower Jurassic Ziliujing Foramtion in the northwest of Sichuan Basin

LIU Ni [1], LIN Liang−biao[1], CHEN Hong−de[1], ZHANG Zong−bin[2], ZHAO Meng−ying[1]

(1. *State Key Laboratory of Oil & Gas Reservoir Geology and Exploitation, Chengdu University of Technology, Chengdu* 610059*, Sichuan, China;* 2. *Research Institute of Exploration and Development, Xinjiang Oilfield Company, PetroChina, Karamay* 834000*, Xinjiang, China*)

Abstract: Based on core observation, scanning electron microscope and analysis of geochemical parameters, the authors studied the reservoir− forming conditions such as sedimentary faces, thickness and distribution, organic types and content, maturity and hydrocarbon generation history of the shale in the northwest of Sichuan Basin. Compared with the gas−producing shale in the USA, the study area has developed tidal flat, swamp and lagoon facies, lithology is mainly characterized by shale mud with rich organic matter and large thickness in a single formation, TOC is 2.0% and organic matter is mainly of Ⅲ type with great hydrocarbon generation potential and high thermal evolution. All these factors are favorable for the formation of shale gas reservoir. An analysis of many factors of shale gas accumulation show that Yuanba− southern Yilong and Dazhou−Xuanhan areas have good accumulation conditions for shale gas, and hence are favorable areas for shale gas exploration and development in Daanzhai Member of Jurassic Ziliujing Formation in the northwest of Sichuan Basin.

Key words: Daanzhai Member of Ziliujing Formation; shale gas; accumulation condition; northwest Sichuan; Sichuan Basin

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About the first author: LIU Ni, female, born in 1985, doctor, mainly engages in the study of sedimentology; E− mail: liuni_smile@aliyun.com.

About the corresponding author: LIN Liang−biao, male, born in 1979, associate professor, mainly engages in teaching and study of sedimentology, E−mail: linliangbiao08@cdut.cn.