

引用格式:郑华,宋新飞,柴秋会,等.渤海深层变质岩覆盖型潜山储层特征及发育模式:以渤中A油田区为例[J].油气藏评价与开发,2026,16(1):216-224.

ZHENG Hua, SONG Xinfei, CHAI Qihui, et al. Characteristics and development model of buried hill reservoirs covered by deep metamorphic rocks in Bohai Sea: A case study of Bozhong A oilfield[J]. Petroleum Reservoir Evaluation and Development, 2026, 16(1): 216-224.

DOI: 10.13809/j.cnki.cn32-1825/te.2024472

# 渤海深层变质岩覆盖型潜山储层特征及发育模式

## ——以渤中A油田区为例

郑华,宋新飞,柴秋会,姜永,赵雨佳,龚敏,刘庆顺  
(中海石油(中国)有限公司天津分公司,天津 300459)

**摘要:**渤中A油田区是渤海海域首个中生界覆盖下深层变质岩潜山区域,受多期构造运动影响,裂缝储层分布规律复杂,如何刻画裂缝储层展布特征、规避区域整体开发风险,是亟待解决的问题。针对裂缝储层分布复杂、发育模式认识不清等难点,通过结合测井、地震等资料,综合考虑风化作用、古地貌等控制因素,将潜山储层纵向上划分为强风化带、次风化带和内幕带,进一步揭示了研究区潜山储层分布特征及发育模式。研究表明:平面上长期活动的断层附近发育优势储层,纵向上裂缝呈分带发育特征,上部强风化带发育网状缝,为古地貌主控的“似层状”分布模式,储层侧向连通性较好;中部次风化带发育网状缝和构造缝,为褶皱构造核部、断裂和古地貌主控的“似层状”分布模式,储层侧向连通性好于强风化带;下部内幕带发育构造缝,为褶皱构造核部和断裂主控的“漏斗状”分布模式,储层侧向连通性差。为提高驱油效率及纵向波及程度,通过分析潜山地质模式及裂缝储层分布规律,按照“优先动用次风化带,兼顾动用强风化带和内幕带有利区”的原则,将注气井部署在潜山上部,采油井部署在潜山中下部,为该地区潜山开发提供坚实支撑。通过推进评建一体化,探索形成了深层潜山勘探评价与开发试采同步的工作做法及模式,助推新发现储量高效建产,高部位3口试采井平均日产油气当量达300 t,为落实区域风险、实现储产快速转化奠定了基础,研究成果及实践经验对类似油田开发具有重要的指导和借鉴意义。

**关键词:**渤海;深层;变质岩;覆盖型潜山;裂缝储层;发育模式;评建一体化

**中图分类号:**TE51

**文献标识码:**A

## Characteristics and development model of buried hill reservoirs covered by deep metamorphic rocks in Bohai Sea: A case study of Bozhong A oilfield

ZHENG Hua, SONG Xinfei, CHAI Qihui, JIANG Yong, ZHAO Yujia, GONG Min, LIU Qingshun

(CNOOC (China) Limited, Tianjin Company, Tianjin, 300459, China)

**Abstract:** Bozhong A oilfield is the first region in the Bohai Sea where deep metamorphic buried hills are covered by Mesozoic strata. Affected by multiple tectonic movements, the distribution of fractured reservoirs is complex. Accurately characterizing the fractured reservoir distribution and mitigating overall development risks are urgent issues. To address these challenges such as the complex distribution and unclear development models of fractured reservoirs, this study integrated logging and seismic data and incorporated key controlling factors such as weathering and paleogeomorphology. The buried hill reservoirs were vertically divided into three zones: a strongly weathered zone, a moderately weathered zone, and an inner zone, further revealing the distribution characteristics and development model of the buried hill reservoirs in the study area. The results showed that favorable reservoirs developed near long-active faults on the plane. Vertically, fractures exhibited zonal development. The upper strongly weathered zone developed network fractures and had relatively good lateral connectivity, forming a “quasi-layered” distribution pattern controlled by paleogeomorphology. The central moderately weathered zone, which had better lateral connectivity than the strongly weathered zone, developed both network and structural fractures. This zone was controlled by fold cores, faults, and paleogeomorphology, also showing a “quasi-layered” distribution pattern. The lower inner zone, which had poor lateral connectivity, developed structural fractures, forming a “funnel-shaped” distribution pattern controlled by fold cores and faults. To improve oil displacement efficiency and vertical sweep, this study analyzed the geological model of the buried hill and the distribution pattern of fractured reservoirs. Gas injection wells were deployed in the upper part of the hill, and oil production wells were placed in the middle and lower parts, following the principle of “prioritizing the moderately weathered zone, with supplementary development of favorable areas in the

收稿日期:2024-10-22。

第一作者简介:郑华(1986—),男,硕士研究生,高级工程师,主要从事海上油气田开发地质研究工作。地址:天津市滨海新区海川路2121号,邮政编码:300459。E-mail:zhenghua@cnooc.com.cn

基金项目:中海石油(中国)有限公司重大专项“渤海中深层复杂油气藏高效开发技术”(CNOOC-KJ135ZDXM36TJ03TJ)。

strongly weathered and inner zones". This method provides a solid foundation for the development of the buried hill reservoirs in the region. By promoting integrated evaluation and construction, a synchronized model and workflow for deep buried hill exploration, evaluation, and pilot production were established. It facilitated the efficient development of newly discovered reserves, with three trial production wells near a high position producing an average of 300 tons of oil and gas equivalent per day. This achievement lays a foundation for mitigating regional risks and realizing rapid conversion of reserves to production. The research findings and practical experience provide valuable guidance and reference for the development of similar oilfields.

**Keywords:** Bohai Sea; deep layer; metamorphic rock; covered buried hill; fractured reservoir; development model; integrated evaluation and construction

近年来,随着渤海深层大型潜山凝析气藏的勘探发现,部分学者对于变质岩潜山成藏规律及地质理论认识方面取得了一定的进展<sup>[1-6]</sup>,针对规律性的认识也一直在不断深化,实现了深层天然气勘探的领域性突破。基于此,在区域以北地区继续进行滚动评价,先后钻探了2口探井(BZA-2井、BZA-4井)且获工业油气流,进一步揭示了新生界覆盖下的新太古界潜山(暴露型潜山)具有成藏潜力。渤中A油田区构造位于暴露型潜山油藏的东部,构造高点区域于2020年完钻1口探井(BZA-5井),测试获工业油气流,证实了BZA-5井区覆盖型潜山具有成藏潜力,以渤中A油田区新太古界潜山为目标区,梳理周边覆盖型潜山整体原油资源量约 $3\ 000\times 10^4$  t,潜力储量规模较大。然而,中生界覆盖下的新太古界潜山储层净毛比低,且受多期构造运动影响,裂缝储层分布十分复杂<sup>[7-9]</sup>,如何落实储层分布规律、刻画地质模式、有效储层潜力评价、实现区域整体把控,是亟待解决的问题。

渤中A油田区生产层位沙一段的日产油不足200 t,亟待寻找油田潜力储层,实现产能接替,为后续整体方案部署提供指导。近年来,中国海上一体化工作不断深入<sup>[10]</sup>,渤中A油田区作为渤海首个深埋潜山复杂裂缝油藏,针对深埋裂缝储层分布规律复杂、地质模式不确定等困难,为规避整体开发风险,加快落实潜力并实现储量高效转化,通过推进评建一体化,能够立足全局、整体规划,在裂缝储层“甜点”预测基础上统筹考虑,充分利用现有设施实现潜山勘探评价与开发试采同步,为落实区域风险,指导后续井位部署和实现储产快速转化奠定基础。

## 1 区域地质条件

渤中A油田区位于渤中凹陷西南部(图1),北邻沙垒田凸起,东西受渤中主洼和渤中西南次洼夹持<sup>[11]</sup>,具有“洼中隆”特征,整体上表现为被一系列断层复杂化的半背斜构造,地层向北西方向倾斜。油田区范围内发育新生界、中生界和新太古界潜山地层,目的层位于新太古界潜山地层,其中,BZA-5井区新太古界潜山位于该半背斜构造的核部区域。

2020年1月,渤中A油田区及周边围区共钻探3口井,其中,西侧暴露型潜山2口(BZA-2井钻遇油层346 m,

BZA-4井钻遇油层224.1 m,储层净毛比介于48.4%~61.8%),东侧覆盖型潜山1口(BZA-5井钻遇油层121.9 m,储层净毛比为26.3%)。渤中A油田区属于覆盖型潜山,其目的层位新太古界潜山的主要岩性为花岗片麻岩,储集空间为双孔介质,类型以孔隙-裂缝型为主,储层非均质性强。BZA-5井区测井解释孔隙度介于0.6%~8.9%,平均为3.1%;渗透率介于 $(0.10\sim 47.30)\times 10^{-3}\ \mu\text{m}^2$ ,平均为 $18.86\times 10^{-3}\ \mu\text{m}^2$ ,以低孔、低渗储集层为主。油田区范围内新太古界潜山整体为以裂缝体系为主的块状强挥发性裂缝型油藏,油藏埋深介于4 200~5 056 m,地面原油密度为 $0.811\ \text{t}/\text{m}^3$ ,地层原油黏度为 $0.27\ \text{mPa}\cdot\text{s}$ ,溶解气油比为 $510\ \text{m}^3/\text{m}^3$ ,原油体积系数为2.638,具有地面原油密度低、地层原油黏度低、气油比高、体积系数大的特征。

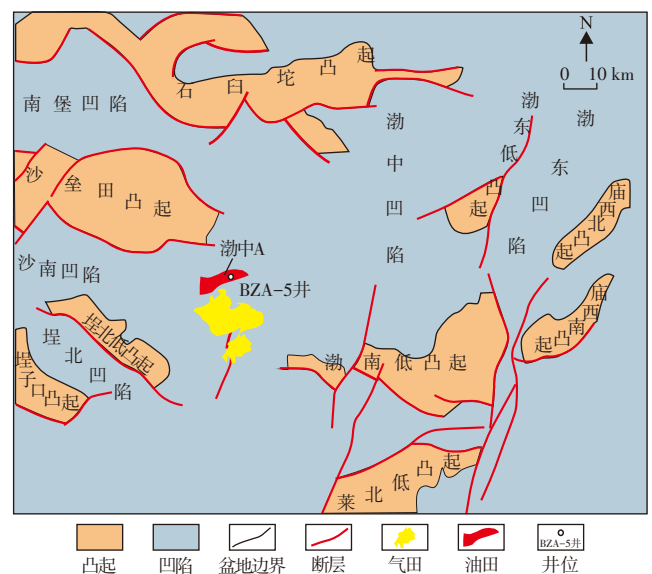


图1 渤中A油田区域构造位置

Fig. 1 Structural location of Bozhong A oilfield

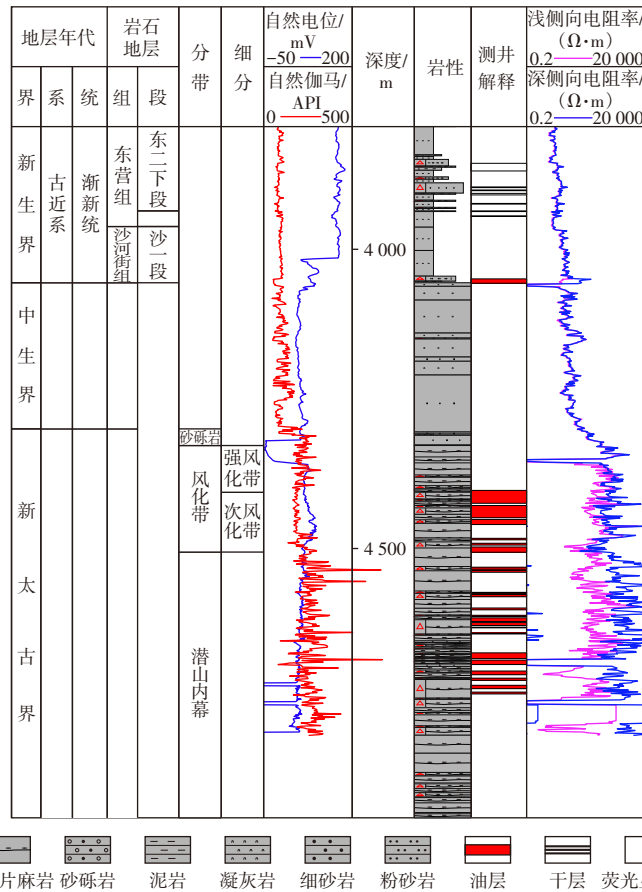
## 2 研究区储层发育模式

### 2.1 区域分带特征

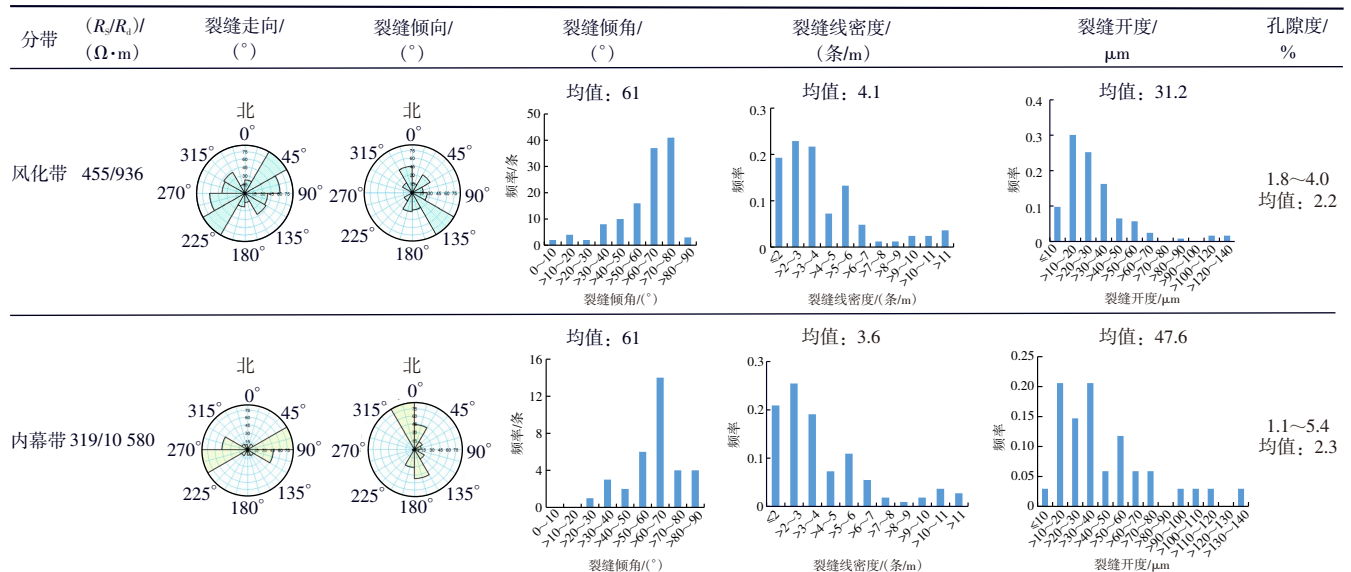
渤中A油田区已钻井揭示潜山顶部之上披覆一套具有风化特征的薄层细砂岩或砂砾岩,中间不发育泥岩,受构造、风化淋滤作用影响,与下部风化带一起形成,风化带裂缝呈网状发育,部分井段被黏土矿物充填导致欠发

育,从而出现“空白带”<sup>[11]</sup>,电阻率一般介于170~936 Ω·m,受中生界地层覆盖影响(地层厚度介于256~663 m),BZA-5井覆盖型潜山净毛比(26.3%)较西侧暴露型潜山BZA-4井(48.4%)偏低,且披覆厚度大的区域风化淋滤作用相对较弱,因此,BZA-5井区整体风化带厚度较薄(钻遇油层121.9 m)。随着深度的增加,受风化淋滤作用

影响较小,构造运动控制影响加剧<sup>[12-14]</sup>,远离断层区域致密层较为发育,纵向上逐渐由风化带转为内幕带,电阻率一般介于500~15 580 Ω·m,明显高于风化带。风化带和内幕带成像测井结果显示以中高角度裂缝为主(裂缝倾角介于30°~80°),裂缝走向一般介于60°~105°,与断裂系统北东走向基本一致(图2)。



a. 储层分带综合柱状图



b. 井点裂缝特征

注:  $R_s/R_d$ 为浅侧向电阻率/深侧向电阻率。

图2 渤中A油田区BZA-5井潜山分带及裂缝特征

Fig. 2 Zoning and fracture characteristics of buried hill in well BZA-5, Bozhong A oilfield

## 2.2 裂缝储层分布特征

渤中A油田区太古界潜山受中生界地层覆盖及古地貌控制,风化带厚度在200 m以内,受构造和风化淋滤双重作用控制,整体储层比较发育,空间连续性好,呈“似层状”分布。受局部断层、沟-脊、坡度等因素的调节作用,局部风化带储层厚度有所变化<sup>[15-17]</sup>,如何寻求有效的方法刻画风化带裂缝储层展布特征成为亟待解决的问题。

由于受到埋深大以及上覆中生界地层屏蔽作用,潜山内幕带断裂响应不清、信噪比低,常规地震刻画方法难以有效预测内幕带储层展布规律,研究区中生界覆盖区下潜山内幕储层预测整体难度大。基于此,为了降低单一属性预测多解性,提出利用融合属性方法(即结构张量与绕射波耦合属性)对该区风化带、内幕带储层平面分布进行裂缝密度预测<sup>[11]</sup>。

根据地震融合属性,按照太古界潜山顶层拉平提取时窗介于0~60 ms(相当于风化带地层厚度),再结合距边界活动断层距离、储层净毛比等因素,实现风化带裂缝密度预测,将风化带储层划分为4类:Ⅰ类储层最好,主要位于长期活动大断层附近的构造高部位,地震融合属性特征最好,净毛比大于等于25%;Ⅱ类储层较好,主要位于构造腰部位置,地震融合属性特征较好,净毛比大于15%且小于25%;Ⅲ类储层较差,主要位于构造翼部,地震融合属性特征较差,净毛比大于等于5%且小于等于15%;Ⅳ类储层最差,主要位于距离大断层较远处,地震融合属性特征最差,净毛比小于5%<sup>[11]</sup>。Ⅰ、Ⅱ类储层均为“甜点”区域,是储层分布相对好的区域,也是后续待评价和开发的重点区域。通过综合考虑边界大断层等裂缝控制因素<sup>[18-20]</sup>,开展“甜点”预测研究,研究发现长期活动

的断层附近属于风化带储层发育最好的区域,而距离大断层相对略远的“甜点”区域储层发育程度次之(图3)。利用裂缝储层“甜点”预测方法对储层进行预测,预测结果可对储层进行平面分类划分,研究成果可进一步指导开发方案井位部署。

相比潜山风化带,内幕带储层主要受构造及深部断层控制,随着深度的增加,内幕带储层相对较差,整体基质相对致密,储层净毛比偏低,另外,内幕带储层沿褶皱核部和断层附近仍有优势裂缝发育,整体分布呈现零散、平面不连续的特征,在褶皱核部和断层附近自上而下发育优势裂缝带,呈“漏斗状”分布,因此,基本不受风化作用的影响。

## 2.3 储层发育模式

渤中A油田BZA-5井区内部中生界残余厚度整体由南向北呈现变薄的趋势,整体表现“似层状”鲤鱼背模式。分析和研究认为:古地貌越高处接受中生界沉积越晚、遭受风化剥蚀时间越久,风化淋滤作用强,对应的风化带储层净毛比越高。在此基础上,建立中生界残余厚度与古地貌之间的关系,通过中生界残余厚度法来间接反映古地貌特征,即中生界残余厚度越厚,反映古地貌越低,风化淋滤时间短,裂缝发育相对较差,总体上中生界残余厚度与风化带储层净毛比呈负相关<sup>[11]</sup>,因此,对应中生界残余厚度大的地区古地貌较低,风化带储层较薄,反之,中生界残余厚度薄的地区古地貌较高,风化带储层较厚。近年来,随着认识的不断深入,通过结合风化作用强弱、古地貌等控制因素<sup>[21-23]</sup>,依据电测特征,纵向上将风化带进一步划分为强、次风化带,其中,强风化带电阻率一般小于200 Ω·m,次风化带电阻率一般介于200~1 000 Ω·m。在井震结合的基础上开展了潜山储层分布模式研究(图4、图5),

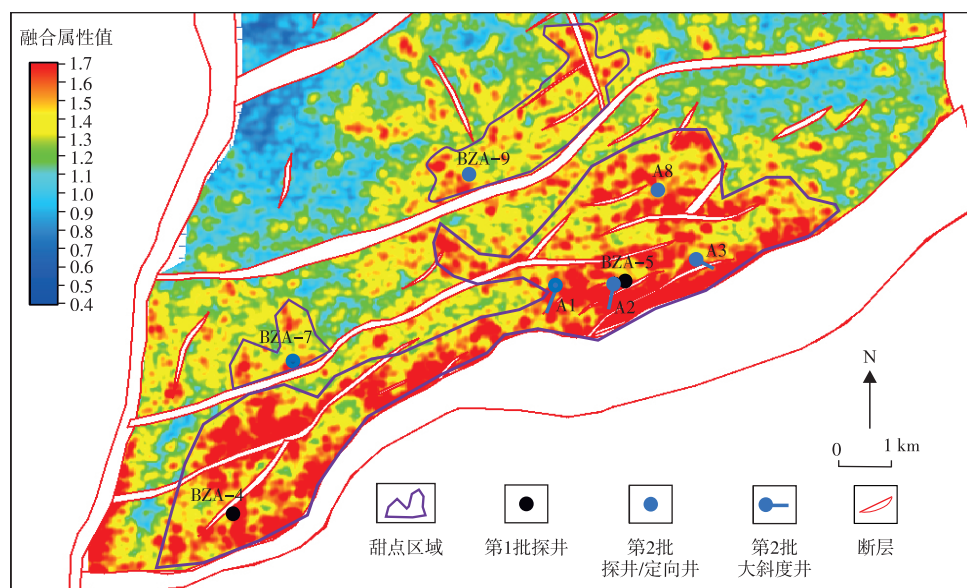


图3 渤中A油田区基于地震融合属性下风化带裂缝“甜点”预测( $T_g^8$ 以下提取时窗介于0~60 ms)

Fig. 3 Prediction of fracture sweet spots in weathered zone based on seismic fusion attributes in Bozhong A oilfield (extraction window of 0~60 ms below  $T_g^8$ )

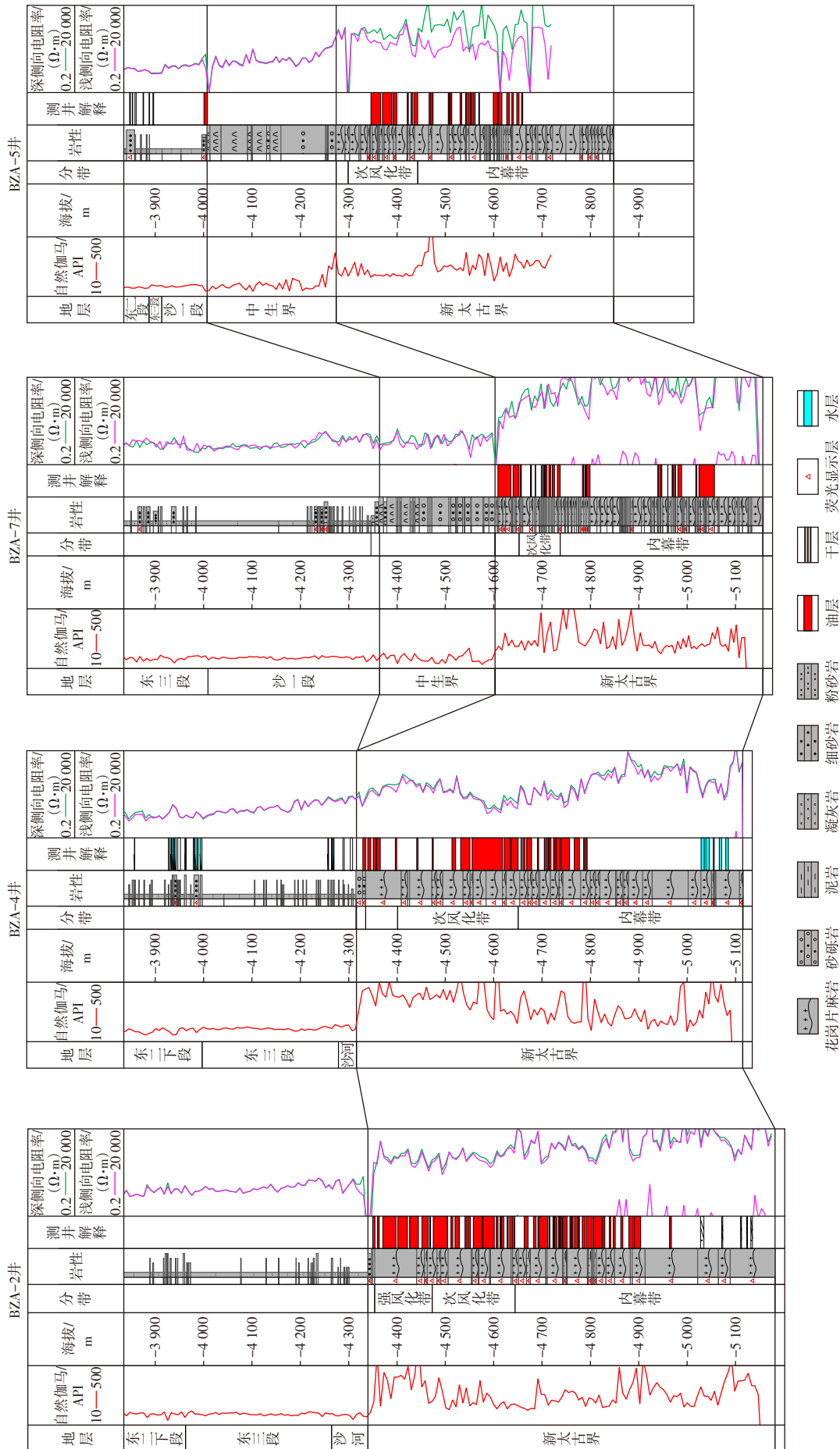


图 4 渤中A油田区深层潜山过BZA-2井—BZA-4井—BZA-7井—BZA-5井剖面  
Fig. 4 Profiles of deep buried hill across wells BZA-2, BZA-4, BZA-7, and BZA-5 in Bozhong A oilfield

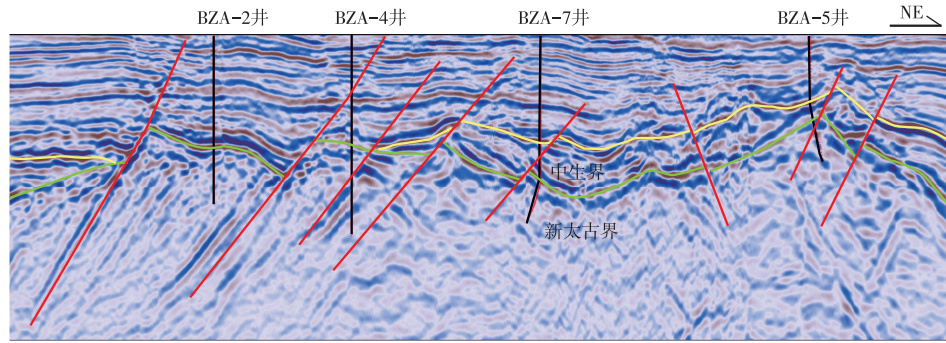


图5 渤中A油田区深层潜山地震剖面

Fig. 5 Seismic profile of deep buried hill in Bozhong A oilfield

认为强风化带发育网状缝,为古地貌和风化作用主控的“似层状”模式,储层平面分布相对稳定,侧向连通性较好;次风化带发育网状缝和构造缝,为褶皱构造核部、断裂和风化作用主控的“似层状”模式,储层平面分布稳定,侧向连通性好于强风化带;内幕带发育构造缝,为褶皱构造核部和断裂主控的“漏斗状”模式,储层平面变化大,储层侧向连通性差(图6)。区域实钻井结果进一步揭示风化带储层分布稳定,是重要的生产层段<sup>[24-28]</sup>,利于开发方案纵向井位部署。基于研究区潜山地质模式及裂缝储层分布规律,为提高驱油效率及纵向波及程度,将注气井部署在潜山上部,钻穿强风化带,采油井部署在潜山中下部,钻穿次风化带,按照“优先动用次风化带,兼顾动用强风化带和内幕带有利区”的原则,为该地区潜山开发奠定了模式基础,也对类似潜山储层研究具有重要的指导意义。

### 3 评建一体化实践及成效

#### 3.1 评建一体化工作做法

在裂缝储层模式指导井位部署基础上结合区域统筹

考虑,按照“整体规划、统一部署、充分依托、试采先行”原则<sup>[29]</sup>,在BZA-5井区西部和北部构造圈闭区域分别部署探井进行评价,依托现有平台设施,通过全区覆盖、落实储量潜力,在BZA-5井区构造高、低部位分别部署开发试采井、一体化井,进行优势储层“甜点”预测及开发,快速实现建产,该“甜点”分布认识也为BZA-5井区开发试采方案的编制及平面井位部署提供了有利指导。

基于“甜点”预测分析研究成果,进行勘探开发一体化统筹,第1批部署实施了2口探井(BZA-2井、BZA-4井),钻后证实了深层暴露型潜山裂缝油藏成藏的可行性,进一步加深了对储层模式的认识,整体风化带由“似层状”鲤鱼背模式转变为强、次风化带划分模式;第2批新增部署2口探井(BZA-5井、BZA-7井)滚动评价周边潜力,利用现有设施推动BZA-5井区快速试采,部署了3口试采井和1口一体化井,通过逐步认识储层发育特征,明确了风化带是主要贡献层段,同时,考虑重力分异和气体膨胀作用影响,在高部位部署注气井,低部位部署采油井,有利于平面及纵向剩余油驱替动用,提高区块采收率,最终确定将注气井部署在潜山上部,以钻穿强风化

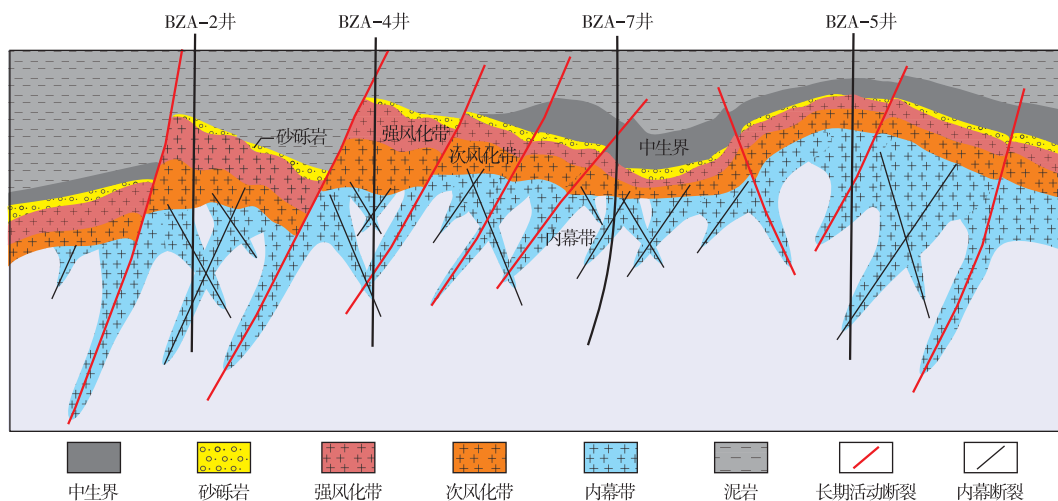


图6 渤中A油田区深层潜山裂缝纵向储层发育模式

Fig. 6 Vertical reservoir development model of fractures in deep buried hill of Bozhong A oilfield

带,采油井部署在潜山中下部,以钻穿次风化带,尽可能保证钻遇更长的风化带井段。渤中A油田区共完钻7口井,其中3口探井、3口试采井和1口一体化井。基于一体化井的实施,对储层认识不断深化,为研究区储量高效转化为产量及后续整体方案部署奠定了基础。

### 3.2 评建一体化模式与成效

在整体部署勘探评价的同时统筹潜力资源及开发设施,多专业结合制定一体化实施策略,降低滚动评价风险,同时在裂缝储层“甜点”预测基础上统筹考虑、充分依托、全局规划部署,为落实区域风险、实现储产快速转化奠定基础,探索形成了勘探开发一体化评价工作模式(图7),在优势储层分布预测及实践方面取得了良好成效。

在评建一体化的工作思路下,充分利用现有设施实现潜山勘探评价与开发试采同步,在成功评价储量的同时助推当年新发现储量高效建产。研究区已实施的3口试采井和1口一体化井动态认识与现有储层模式相匹配,其中,活动性大断层附近高部位的3口试采井次风化带储层发育最好,强风化带储层发育次之,内幕带储层发

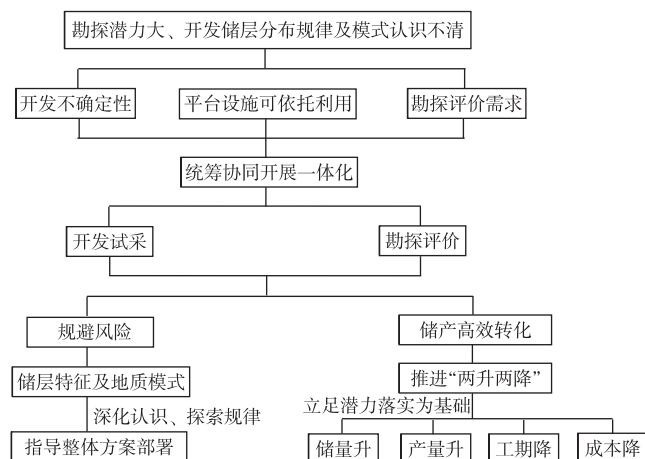


图7 深埋潜山裂缝油藏勘探开发一体化评价工作模式  
Fig. 7 Integrated exploration and development workflow for deep buried hill fractured reservoirs

育最差,开发阶段取得了较好的试采效果,平均日产油为200 t,日产气为 $14 \times 10^4 \text{ m}^3$ ,折合日产油气当量约300 t,生产产量稳定,实施结果验证了大断裂区带周边储层发育、主力层(次风化带)侧向连通性好的成果认识(图3、图8),在满足勘探评价的基础上进一步快速实现了储量向产量的转化。

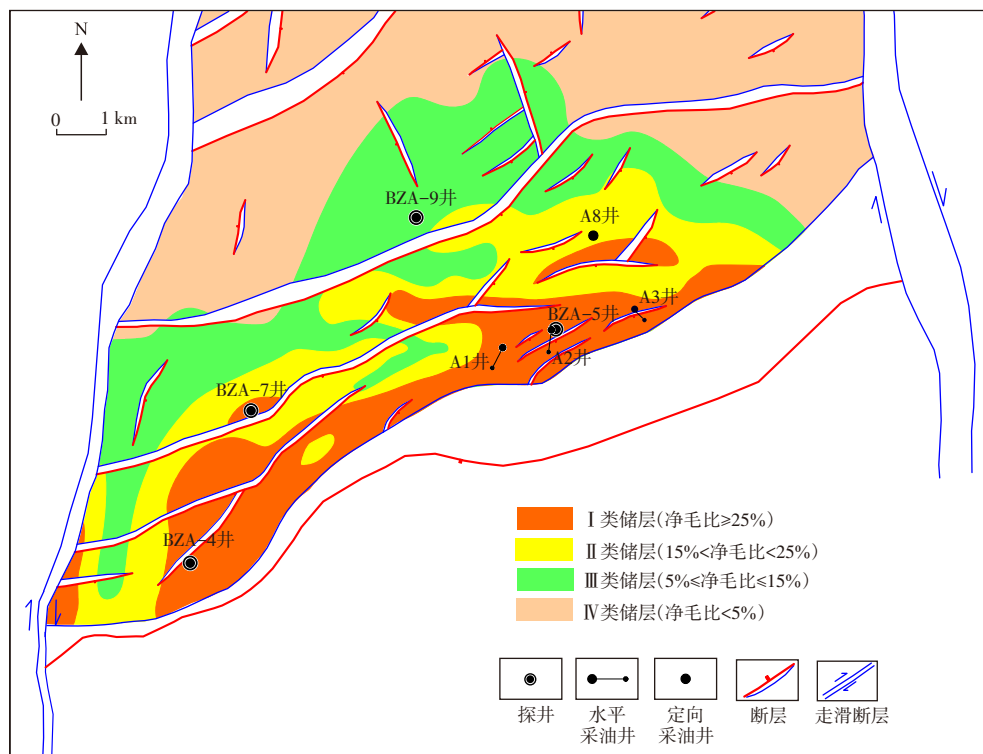


图8 渤中A油田区风化带综合评价

Fig. 8 Comprehensive evaluation of weathered zone in Bozhong A oilfield

## 4 结论

1) 通过结合风化作用、古地貌等控制因素,进一步

明确了研究区潜山储层发育模式,研究发现:强风化带发育网状缝,为古地貌主控的“似层状”分布模式,储层侧向连通性较好;次风化带发育网状缝和构造缝,为褶皱构造核部、断裂和古地貌主控的“似层状”分布模式,储层侧向

连通性好于强风化带;内幕带发育构造缝,为褶皱构造核部和断裂主控的“漏斗状”分布模式,储层侧向连通性差。

2) 基于研究区潜山地质模式及裂缝储层分布规律,为提高驱油效率及纵向波及程度,按照“优先动用次风化带,兼顾动用强风化带和内幕带有利区”的原则,将注气井部署在潜山上部,采油井部署在潜山中下部。为该地区潜山开发提供支撑。

3) 在储层发育模式认识指导下,通过推进评建一体化,探索形成了深层潜山勘探评价与开发试采同步的工作做法及模式,助推新发现储量高效建产,为落实区域风险、实现储产快速转化奠定了基础。

### 参考文献

- [1] 薛永安. 渤海海域深层天然气勘探的突破与启示[J]. 天然气工业, 2019, 39(1): 11-20.  
XUE Yong'an. The breakthrough of the deep-buried gas exploration in the Bohai Sea area and its enlightenment[J]. Natural Gas Industry, 2019, 39(1): 11-20.
- [2] 薛永安, 李慧勇. 渤海海域深层太古界变质岩潜山大型凝析气田的发现及其地质意义[J]. 中国海上油气, 2018, 30(3): 1-9.  
XUE Yong'an, LI Huiyong. Large condensate gas field in deep Archean metamorphic buried hill in Bohai Sea: Discovery and geological significance[J]. China Offshore Oil and Gas, 2018, 30(3): 1-9.
- [3] 徐长贵, 于海波, 王军, 等. 渤海海域渤中19-6大型凝析气田形成条件与成藏特征[J]. 石油勘探与开发, 2019, 46(1): 25-38.  
XU Changgui, YU Haibo, WANG Jun, et al. Formation conditions and accumulation characteristics of Bozhong 19-6 large condensate gas field in offshore Bohai Bay Basin[J]. Petroleum Exploration and Development, 2019, 46(1): 25-38.
- [4] 施和生, 王清斌, 王军, 等. 渤中凹陷深层渤中19-6构造大型凝析气田的发现及勘探意义[J]. 中国石油勘探, 2019, 24(1): 36-45.  
SHI Hesheng, WANG Qingbin, WANG Jun, et al. Discovery and exploration significance of large condensate gas fields in BZ19-6 structure in deep Bozhong sag[J]. China Petroleum Exploration, 2019, 24(1): 36-45.
- [5] 徐长贵. 渤海湾盆地天然气勘探新进展、未来方向与挑战[J]. 天然气工业, 2024, 44(1): 72-85.  
XU Changgui. Progress, future direction, and challenges of natural gas exploration in the Bohai Bay Basin[J]. Natural Gas Industry, 2024, 44(1): 72-85.
- [6] 闫建丽, 李超, 马栋, 等. 渤海复杂潜山油藏动态特征识别方法及应用[J]. 油气藏评价与开发, 2024, 14(2): 308-316.  
YAN Jianli, LI Chao, MA Dong, et al. Dynamic and static feature identification method of complex buried hill reservoirs in Bohai and its application[J]. Petroleum Reservoir Evaluation and Development, 2024, 14(2): 308-316.
- [7] 李洪革, 杜旭东, 陆克政, 等. 渤海湾地区中西部中生代构造特征及演化[J]. 石油大学学报(自然科学版), 1999, 23(3): 1-5.  
LI Hongge, DU Xudong, LU Kezheng, et al. Evolution and structural characteristics of the Mesozoic era in the central[J]. Journal of the University of Petroleum, China, 1999, 23(3): 1-5.
- [8] 李三忠, 索艳慧, 戴黎明, 等. 渤海湾盆地形成与华北克拉通破坏[J]. 地学前缘, 2010, 17(4): 64-89.  
LI Sanzhong, SUO Yanhui, DAI Liming, et al. Development of the Bohai Bay basin and destruction of the North China Craton[J]. Earth Science Frontiers, 2010, 17(4): 64-89.
- [9] 侯贵廷, 钱祥麟, 蔡东升. 渤海湾盆地中、新生代构造演化研究[J]. 北京大学学报(自然科学版), 2001, 37(6): 845-851.  
HOU Guiting, QIAN Xianglin, CAI Dongsheng. The tectonic evolution of Bohai basin in Mesozoic and Cenozoic time[J]. Acta Scientiarum Naturalium Universitatis Pekinesis, 2001, 37(6): 845-851.
- [10] 张健, 李保振, 周文胜, 等. 中国海上气田开发与提高采收率技术[J]. 天然气工业, 2023, 43(1): 132-140.  
ZHANG Jian, LI Baozhen, ZHOU Wensheng, et al. Development and EGR technologies of offshore gas fields in China[J]. Natural Gas Industry, 2023, 43(1): 132-140.
- [11] 郑华, 康凯, 刘卫林, 等. 渤海深层变质岩潜山油藏裂缝主控因素及预测[J]. 岩性油气藏, 2022, 34(3): 29-38.  
ZHENG Hua, KANG Kai, LIU Weilin, et al. Main controlling factors and prediction of fractures in deep metamorphic buried hill reservoirs in Bohai Sea[J]. Lithologic Reservoirs, 2022, 34(3): 29-38.
- [12] 于福生, 漆家福, 王春英. 华北东部印支期构造变形研究[J]. 中国矿业大学学报, 2002, 31(4): 402-406.  
YU Fusheng, QI Jiafu, WANG Chunying. Tectonic deformation of Indosinian Period in eastern part of North China[J]. Journal of China University of Mining & Technology, 2002, 31(4): 402-406.
- [13] 赵越, 徐刚, 张拴宏, 等. 燕山运动与东亚构造体制的转变[J]. 地学前缘, 2004, 11(3): 319-328.  
ZHAO Yue, XU Gang, ZHANG Shuanhong, et al. Yanshanian movement and conversion of tectonic regimes in East Asia[J]. Earth Science Frontiers, 2004, 11(3): 319-328.
- [14] 周立宏, 李三忠, 刘建忠, 等. 渤海湾盆地燕山期构造特征与原型盆地[J]. 地球物理学进展, 2003, 18(4): 692-699.  
ZHOU Lihong, LI Sanzhong, LIU Jianzhong, et al. The Yanshanian structural style and basin prototypes of the Mesozoic Bohai Bay Basin[J]. Progress in Geophysics, 2003, 18(4): 692-699.
- [15] 侯明才, 曹海洋, 李慧勇, 等. 渤海海域渤中19-6构造带深层潜山储层特征及其控制因素[J]. 天然气工业, 2019, 39(1): 33-44.  
HOU Mingcai, CAO Haiyang, LI Huiyong, et al. Characteristics and controlling factors of deep buried-hill reservoirs in the BZ19-6 structural belt, Bohai Sea area[J]. Natural Gas Industry, 2019, 39(1): 33-44.
- [16] 邓运华. 渤海大中型潜山油气田形成机理与勘探实践[J]. 石油学报, 2015, 36(3): 253-261.  
DENG Yunhua. Formation mechanism and exploration practice of large-medium buried-hill oil fields in Bohai Sea[J]. Acta Petrolei Sinica, 2015, 36(3): 253-261.
- [17] 施宁, 刘敬寿, 张冠杰, 等. 基底变质岩深部潜山储层构造裂缝发育特征及主控因素: 以渤海湾盆地渤中B区块为例[J]. 石油实验地质, 2024, 46(4): 799-811.  
SHI Ning, LIU Jingshou, ZHANG Guanjie, et al. Characteristics and main controlling factors of structural fracture development in deep buried hill reservoirs of basement metamorphic rocks: A case study of B block, Bohai Bay Basin[J]. Petroleum Geology & Experiment, 2024, 46(4): 799-811.

- [18] 胡安文,牛成民,王德英,等.渤海湾盆地渤中凹陷渤中19-6构造凝析油气特征与形成机制[J].石油学报,2020,41(4):403-411.  
HU Anwen, NIU Chengmin, WANG Deying, et al. The characteristics and formation mechanism of condensate oil and gas in Bozhong19-6 structure, Bozhong sag, Bohai Bay Basin[J]. Acta Petrolei Sinica, 2020, 41(4): 403-411.
- [19] 徐长贵,杜晓峰,刘晓健,等.渤海海域太古界深埋变质岩潜山优质储集层形成机制与油气勘探意义[J].石油与天然气地质,2020,41(2):235-247.  
XU Changgui, DU Xiaofeng, LIU Xiaojian, et al. Formation mechanism of high-quality deep buried-hill reservoir of Archean metamorphic rocks and its significance in petroleum exploration in Bohai Sea area[J]. Oil & Gas Geology, 2020, 41(2): 235-247.
- [20] 孟卫工,陈振岩,李湃,等.潜山油气藏勘探理论与实践:以辽河拗陷为例[J].石油勘探与开发,2009,36(2):136-143.  
MENG Weigong, CHEN Zhenyan, LI Pai, et al. Exploration theories and practices of buried-hill reservoirs: A case from Liaohé Depressions[J]. Petroleum Exploration and Development, 2009, 36(2): 136-143.
- [21] 朱博远,张超谟,张占松,等.渤中19-6太古界潜山复杂岩性储层矿物组分反演[J].岩性油气藏,2020,32(4):107-114.  
ZHU Boyuan, ZHANG Chaomo, ZHANG Zhansong, et al. Mineral component inversion of complex lithologic reservoirs in Bozhong 19-6 Archean buried hill[J]. Lithologic Reservoirs, 2020, 32(4): 107-114.
- [22] 官大勇,王昕,刘朋波,等.渤海南部碳酸盐岩潜山储层特征及发育模式:以渤中28-29区为例[J].东北石油大学学报,2024,48(3):1-13.  
GUAN Dayong, WANG Xin, LIU Pengbo, et al. The characteristics and development pattern of carbonate buried hill reservoirs in the Southern Bohai Sea: A case study of Bozhong 28-29 Area[J]. Journal of Northeast Petroleum University, 2024, 48(3): 1-13.
- [23] 曹东升,曾联波,黄诚,等.多尺度岩石力学层对断层和裂缝发育的控制作用[J].地球科学,2023,48(7):2535-2556.  
CAO Dongsheng, ZENG Lianbo, HUANG Cheng, et al. Control of multi-scale mechanical stratigraphy on development of faults and fractures[J]. Earth Science, 2023, 48(7): 2535-2556.
- [24] 廖新武,谢润成,周文,等.古地貌对渤海湾盆地B区块太古宇暴露型潜山变质岩风化带储层裂缝发育的影响[J].石油与天然气地质,2023,44(2):406-417.  
LIAO Xinwu, XIE Runcheng, ZHOU Wen, et al. The effects of paleogeomorphology on the development of fractures in reservoirs of weathering metamorphic zone in an exposed Archean burial hill, Block B, Bohai Bay Basin[J]. Oil & Gas Geology, 2023, 44(2): 406-417.
- [25] 许鹏,牛成民,李慧勇,等.渤海湾盆地渤中凹陷西南部变质岩潜山裂缝型储层特征及主控因素[J].矿产勘查,2022,13(4):418-427.  
XU Peng, NIU Chengmin, LI Huiyong, et al. Characteristics and main controlling factors of natural gas fracture-related reservoir in Archean metamorphic rocks in southwest Bozhong Sag, Bohai Bay Basin[J]. Mineral Exploration, 2022, 13(4): 418-427.
- [26] 胡志伟,吕丁友,王德英,等.渤海海域前新生代关键构造期变形特征与潜山油气成藏意义[J].中国海上油气,2023,35(1):50-62.  
HU Zhiwei, LYU Dingyou, WANG Deying, et al. Deformation characteristics of critical tectonic periods during pre-Cenozoic and significance of buried hill hydrocarbon accumulation in the Bohai sea area[J]. China Offshore Oil and Gas, 2023, 35(1): 50-62.
- [27] 任宪军,石云倩,靖伟.陆相湖盆水下喷发火山岩储层特征及发育模式:以松辽盆地长岭断陷查干花次凹为例[J].油气藏评价与开发,2024,14(2):176-189.  
REN Xianjun, SHI Yunqian, JING Wei. Characteristics and development model of underwater eruptive volcanic reservoirs in continental lacustrine basin: A case study of Chaganhua Subsag in Changling Fault Depression, Songliao Basin[J]. Petroleum Reservoir Evaluation and Development, 2024, 14(2): 176-189.
- [28] 童凯军,赵春明,吕坐彬,等.渤海变质岩潜山油藏储集层综合评价与裂缝表征[J].石油勘探与开发,2012,39(1):56-63.  
TONG Kaijun, ZHAO Chunming, LYU Zuobin, et al. Reservoir evaluation and fracture characterization of the metamorphic buried hill reservoir in Bohai Bay[J]. Petroleum Exploration and Development, 2012, 39(1): 56-63.
- [29] 刘维永.渤海A油田勘探开发一体化实践与认识[J].中国石油和化工标准与质量,2014,34(11):146-147.  
LIU Weiyong. Practice and understanding of integration of exploration and development in Bohai A oilfield[J]. China Petroleum and Chemical Standard and Quality, 2014, 34(11): 146-147.

(编辑 余聪)