

引用格式: 王千军, 周健, 张发强, 等. 2025. 准噶尔盆地西北缘哈山地区超浅层油气成藏期次研究[J]. 地质力学学报, 31(3): 491–505. DOI: [10.12090/j.issn.1006-6616.2024075](https://doi.org/10.12090/j.issn.1006-6616.2024075)

Citation: WANG Q J, ZHOU J, ZHANG F Q, et al., 2025. Research on the charging periods of the ultra-shallow play in front of the Hashan area, northwestern margin of the Junggar Basin[J]. Journal of Geomechanics, 31(3): 491–505. DOI: [10.12090/j.issn.1006-6616.2024075](https://doi.org/10.12090/j.issn.1006-6616.2024075)

准噶尔盆地西北缘哈山地区超浅层油气成藏期次研究

王千军¹, 周 健¹, 张发强², 于洪洲¹, 吴倩倩¹, 鲁红利¹, 刘庆新², 周 瑜³,
程 明², 闫建钊², 吕延防³

WANG Qianjun¹, ZHOU Jian¹, ZHANG Faqiang², YU Hongzhou¹, WU Qianqian¹, LU Hongli¹, LIU Qingxin²,
ZHOU Yu³, CHENG Ming², YAN Jianzhao², LYU Yanfang³

1. 中国石油化工股份有限公司胜利油田分公司勘探开发研究院, 山东 东营 257000;

2. 东北石油大学环渤海能源研究院, 河北 秦皇岛 066004;

3. 东北石油大学地球科学学院, 黑龙江 大庆 163318

1. *Exploration and Development Research Institute, Shengli Oilfield, Sinopec, Dongying 257000, Shandong, China;*

2. *Huanbohai Energy Research Institute, Northeast Petroleum University, Qinhuaungdao 066004, Hebei, China;*

3. *School of Earth Sciences, Northeast Petroleum University, Daqing 163318, Heilongjiang, China*

Research on the charging periods of the ultra-shallow play in front of the Hashan area, northwestern margin of the Junggar Basin

Abstract: [Objective] The Hala'alat Mountain front-overthrust belt, renowned for its abundant hydrocarbon resources, is characterized by multi-layer oil-bearing systems and intricate source-reservoir relationships. Ultra-shallow strata have emerged as an important domain for resource evaluation and exploration in this region. However, the timing of hydrocarbon charging and adjustment processes and the complex accumulation mechanisms of ultra-shallow reservoirs remain inadequately understood, posing significant challenges for exploration planning and appraisal programs. This study endeavors to unravel the genetic characteristics, accumulation stages, and dynamic mechanisms of ultra-shallow reservoirs in the Hala'alat Mountain front, with the goals of enhancing the theoretical framework for hydrocarbon enrichment patterns in structurally complex zones and providing actionable insights for future exploration endeavors. [Methods] To achieve this objective, an integrated suite of analytical techniques was meticulously employed. Homogenization temperature measurements and salinity analysis of fluid inclusions were conducted to decipher thermal histories and fluid evolution. Quantitative grain fluorescence (QGF) analysis was utilized to track hydrocarbon migration pathways and accumulation dynamics. Calcite U–Pb geochronology provided precise temporal constraints for thermal events and hydrocarbon charging episodes. These methods were systematically applied to reservoir rock samples, enabling a comprehensive investigation of fluid inclusion characteristics, paleo-temperature evolution, and paleo-fluid interfaces. By constraining the thermal event chronology, we aimed to reconstruct the intricate hydrocarbon charging and adjustment processes that have shaped the current reservoir configuration. [Results] (1) The analysis revealed a diverse array of fluid inclusion types, with variations in fluorescence color and intensity indicative of multiple stages of hydrocarbon charging, each with a distinct maturity levels. The homogenization temperatures of aqueous inclusions exhibited two predominant intervals: 70–90°C and 100–130°C. These temperature ranges correspond to distinct thermal episodes, reflecting varying paleo-thermal regimes

基金项目: 中国石油化工股份有限公司科技重大攻关项目 (P22078); 国家自然科学基金项目 (42172155, 42272166)

This research is financially supported by the Major Scientific Research Project of China Petroleum & Chemical Corporation (Grant No. P22078) and the National Natural Science Foundation of China (Grant Nos 42172155 and 42272166).

第一作者: 王千军 (1973—), 男, 博士, 研究员, 从事油气地质综合研究工作。Email: wangqianjun3650@163.com

通信作者: 张发强 (1973—), 男, 博士, 副教授, 从事油气成藏研究和教学工作。Email: faqiang.zhang@nepu.edu.cn

收稿日期: 2024-06-30; 修回日期: 2025-04-14; 录用日期: 2025-04-21; 网络出版日期: 2025-05-16; 责任编辑: 范二平

that influenced hydrocarbon maturation and migration. (2) The QGF profiles provided compelling evidence of dynamic hydrocarbon migration processes, showcasing multiple northward adjustments and accumulations over geological time scales. Notably, Jurassic strata displayed continuous charging characteristics, suggesting prolonged hydrocarbon influx, while Cretaceous reservoirs exhibited late-stage charging patterns, reflecting differential hydrocarbon charging histories across stratigraphic units. This stratigraphic variation in charging behavior offers crucial insights into the temporal and spatial distribution of hydrocarbons within the study area. (3) Calcite U–Pb dating identified two major thermal events at approximately 133 Ma (Early Cretaceous) and 73 Ma (Late Cretaceous). These events are temporally correlated with significant tectonic activities in the study area, including regional compression and fault reactivation. (4) The integration of homogenization temperatures, QGF data, and U–Pb ages revealed a two-phase hydrocarbon charging history. The first phase occurred during the Early Cretaceous (133 Ma), characterized by initial hydrocarbon accumulation driven by regional tectonic compression. The second phase took place during the Late Cretaceous (73 Ma), marked by structural adjustment and hydrocarbon redistribution. These phases were primarily driven by tectonic forces that facilitated vertical migration and redistribution of hydrocarbons into ultra-shallow traps, highlighting the interplay between tectonic events and hydrocarbon accumulation. [Conclusions] The ultra-shallow reservoirs in the Hala’alat front have undergone two critical accumulation phases: the Early Cretaceous initial charging phase and the Late Cretaceous structural adjustment phase. Hydrocarbon migration pathways were predominantly controlled by fault systems, which acted as migration carriers. The northward adjustments were facilitated by differential uplift and the caprock integrity, ensuring the preservation of hydrocarbons within the reservoirs. The coupling of fluid inclusion thermometry, QGF, and U–Pb dating has proven to be a robust and innovative toolkit for resolving multi-stage accumulation processes in complex thrust belts. This methodological integration not only enhances our understanding of hydrocarbon accumulation mechanisms but also provides a precise framework for identifying and dating these events. This study establishes a novel and comprehensive methodology for deciphering multi-phase hydrocarbon accumulation in tectonically active regions. [Significance] By offering critical insights into the timing, pathways, and driving mechanisms of hydrocarbon charging, this study provides a solid foundation for predicting ultra-shallow reservoir distributions in similar geological settings. The integration of chronostratigraphic and fluid dynamic analyses advances the theoretical understanding of hydrocarbon enrichment mechanisms in foreland thrust belts, with direct implications for exploration strategies and resource evaluation in analogous basins. Furthermore, the methodological framework developed in this study can be adapted and applied to other complex structural zones, potentially revolutionizing our approach of hydrocarbon exploration in challenging geological environments.

Keywords: Hashan ultra-shallow play; fluid inclusions; particle fluorescence; calcite U–Pb dating; oil and gas migration; oil charging period

摘 要: 准噶尔盆地西北缘哈山山前超剥带油气资源丰富,具有多层系含油、源–藏关系复杂的特点。超浅层是目前哈山地区油气勘探的重点层系,明确其油气藏充注时期和调整过程等成藏机理问题,对于研究哈山油藏富集规律具有重要的理论和实际意义。通过对哈山山前地区油气藏样品进行流体包裹体均一温度、盐水包裹体盐度特征以及定量颗粒荧光、方解石 U–Pb 定年等分析,开展油气包裹体特征、地层古温度和古油藏流体界面的研究,标定热事件时间,探讨该区超浅层油藏成藏机制、特征及成藏期次和聚集规律。研究表明,流体包裹体类型多样,其荧光颜色和强度变化表明发育多期不同成熟度的烃类流体,且流体包裹体均一温度主要集中在 70~90 ℃ 和 100~130 ℃ 区间。定量颗粒荧光技术显示,油气运移具有明显的动态过程,主要表现为从南向北的多次调整和聚集,侏罗系和白垩系分别以持续充注型和晚期充注型颗粒荧光特征为主,反映了不同地层的油气充注特征。方解石的 U–Pb 同位素测年结果表明,在研究区分别于 133 Ma 和 73 Ma 发生过至少 2 次热事件。结合流体包裹体盐水均一温度测量和定量颗粒荧光分析,揭示研究区经历了 2 期油气充注和调整过程,油气成藏时间为早白垩世和晚白垩世。应用流体包裹体、定量颗粒荧光和方解石 U–Pb 定年耦合技术为复杂构造带油气成藏提供了重要的方法手段,为厘定成藏期次提供了精确方法。

关键词: 哈山超剥带; 流体包裹体; 颗粒荧光技术; 方解石 U–Pb 定年; 油气运移; 成藏期次

中图分类号: TE122.3

文献标识码: A

文章编号: 1006-6616(2025)03-0491-15

DOI: 10.12090/j.issn.1006-6616.2024075

哈山地区位于中国西部哈拉阿特山前,地处准噶尔盆地北缘的复杂逆冲构造带,其油气勘探始于20世纪50年代。2011年中国石化新疆新春石油开发有限责任公司在哈山地区部署了哈浅1井,于侏罗系八道湾组钻遇良好油气显示,从而发现了春晖油田。在哈浅2井区,侏罗系八道湾组稠油油藏预测地质储量可达 2071.5×10^4 t。2012年继续向东部部署钻探哈浅20井、哈浅21井和哈浅22井,均获成功,并发现了阿拉德侏罗系油田。春晖油田和阿拉德油田控制及预测石油地质储量达 6992×10^4 t。靠近哈山山前的哈浅23井区内有16口井在白垩系见良好油气显示,其中呼图壁二段和呼图壁三段为主力含油层(王圣柱等,2012)。

作为准噶尔盆地油气勘探的重点领域,哈山地区浅层—超浅层侏罗系—白垩系储层的勘探前景以及稠油成藏机制一直是地质学界关注的热点问题。依据行业分类标准,浅层稠油油藏的埋深通常不大于600 m(国家能源局,2021),而超浅层稠油油藏则指埋深小于300 m的油气藏。哈山地区春风油田和阿拉德油田埋深在200 m到660 m之间,属于浅层—超浅层稠油油藏。近年来,众多学者在该区的构造与沉积领域开展了大量基础性研究工作(王圣柱,2015;薛雁等,2017;梁媛媛,2020)。研究表明,推覆叠加构造、逆冲断裂以及走滑断裂等对该地区的沉积源—汇体系和油气成藏过程起到了重要的控制作用(张奎华,2014;周健,2016;杨蕴泽等,2023;张奎华等,2023)。哈山地区原油具有多套烃源供烃、断—毯格架体系输导运移的成藏特征(林会喜等,2017)。超剥带与推覆冲断带的油气输导系统差异大,油气以混源为主,主要来源于玛湖凹陷和哈山地区,原油后期经历了生物降解作用而不断稠化(王圣柱等,2015;韩祥磊等,2016)。目前该区域的成藏期次判别以定性研究为主(王圣柱等,2015),曾有学者使用颗粒荧光定量分析技术和流体包裹体等方法在该地区开展成藏期次的研究,取得了初步定性认识(于春勇等,2022;杨蕴泽等,2023)。但研究发现,现今盐水包裹体均一温度往往偏高,与正常埋深热史模拟不匹配(徐国盛等,2014;张阳,2018;Hestnes et al., 2023),造成流体包裹体分析在某些情况下可能无法准确确定成藏时间。

尽管流体包裹体分析和颗粒荧光技术具有记录地质流体充注条件的能力,但在复杂热演化环境条件下,还存在不确定和多解性问题。方解石U-

Pb定年技术可为油气成藏问题的研究提供年代学约束,提升定年精度(张阳,2018)。文章综合应用流体包裹体分析、颗粒荧光定量技术以及方解石U-Pb定年技术,对哈山地区开展浅层油气成藏期次及过程分析,为该区油气成藏机理提供重要的定量依据,对于下一步的油气勘探部署和评价具有重要意义。

1 区域地质背景

哈山地区位于准噶尔盆地北缘,为哈拉阿拉特山逆冲推覆构造带的一部分,北部通过达尔布特断裂与和什托洛盖盆地相接,南部为逆冲推覆带的前缘——乌夏断裂带,再向南为玛湖凹陷(图1a)。该地区自晚石炭世以来,经历了石炭纪伸展裂陷、二叠纪拗陷、三叠纪前陆逆冲、侏罗纪—白垩纪压扭作用等一系列构造活动,形成了由石炭系—二叠系组成的大型逆冲推覆构造和侏罗系—白垩系超覆斜坡构造。这些构造活动导致了地层的强烈变形、剥蚀和热流活动,形成了油气聚集和分布的复杂地质背景(王圣柱等,2012, 2018;胡杨和夏斌,2012;白国娟,2009)。

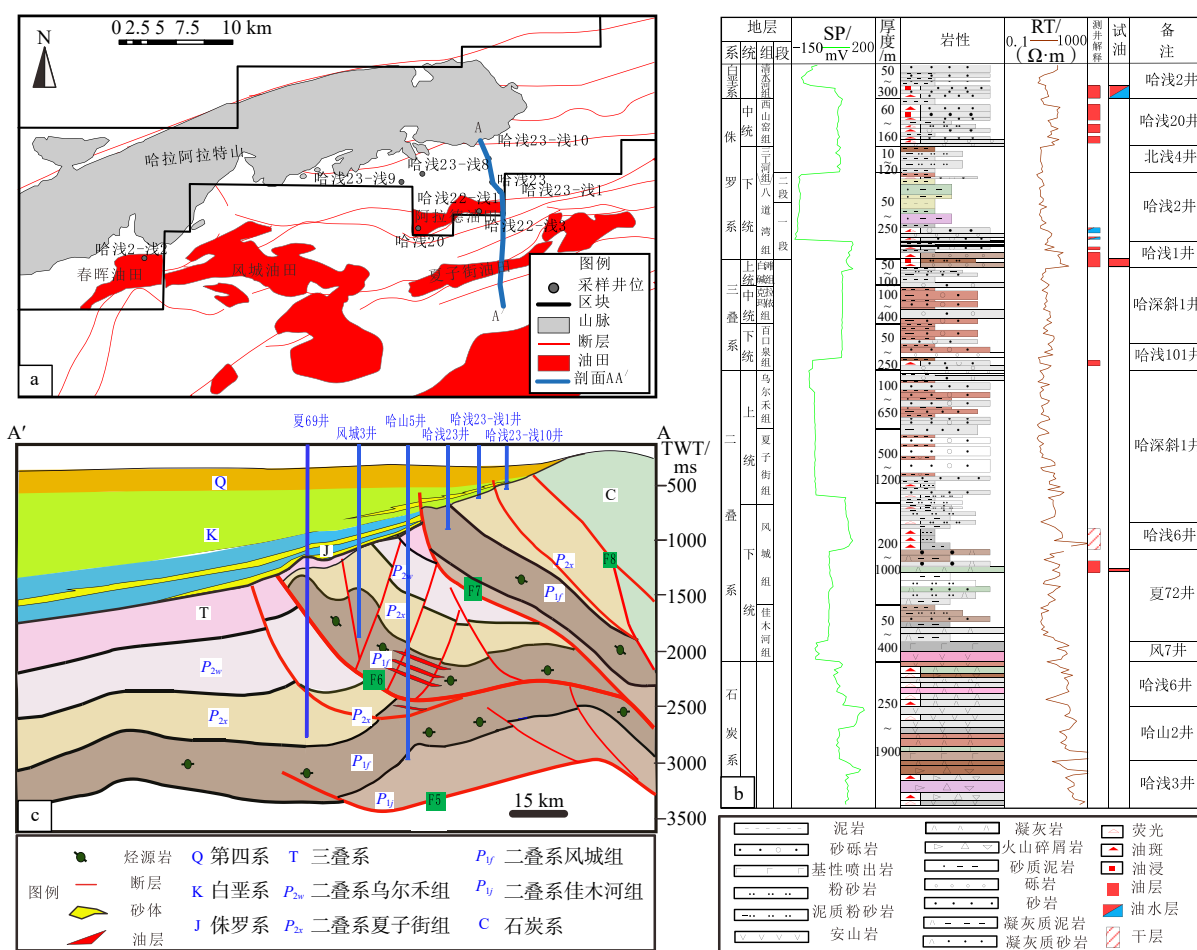
根据该区钻井和地震解释成果,哈山地区由5套沉积地层组成,底部逆冲推覆体由石炭系、二叠系和三叠系组成,上部为侏罗系和白垩系,发育有利的油气生—储—盖组合(图1b)。其中,二叠系风城组和乌尔禾组暗色泥岩为主要烃源岩(王圣柱等,2017),侏罗系和白垩系砂岩为主要储层,断层、砂体和不整合面组成油气的复合输导格架(图1c)。哈山地区侏罗系八道湾组和西山窑组、白垩系清水河组为哈山浅层系的主力产油层(图1b),原油物性具有高密度、高黏度、低含蜡量和低含硫量特点。

2 流体包裹体特征

实验样品主要取自哈山地区阿拉德油田11口井的岩心。镜下观察发现,侏罗系和白垩系储层样品均处于早期成岩阶段,其中白垩系样品固结程度较低,原生粒间孔隙发育,以杂基充填为主,石英次生加大边不常见,长石溶解作用相对较少;侏罗系样品以钙质胶结和杂基充填压实为主,其成岩作用强度明显高于白垩系。

2.1 流体包裹体产状及荧光特征

包裹体显微岩相特征显示,哈山地区侏罗系和白垩系中油气显示丰富,发育多种类型的烃类包裹



a—准噶尔盆地北缘哈山地区勘探形势图; b—哈山地区综合柱状图; c—哈山地区地质构造剖面图(剖面位置见图1a)

图1 哈山地区油田分布及底层综合柱状图

Fig. 1 Distribution of oil fields and comprehensive stratigraphic chart for the Hashan Area

(a) Exploration status of the Hasan Area at the northern margin of the Junggar Basin; (b) Comprehensive stratigraphic chart of the Hashan Area; (c) Geological cross-section of the Hashan Area

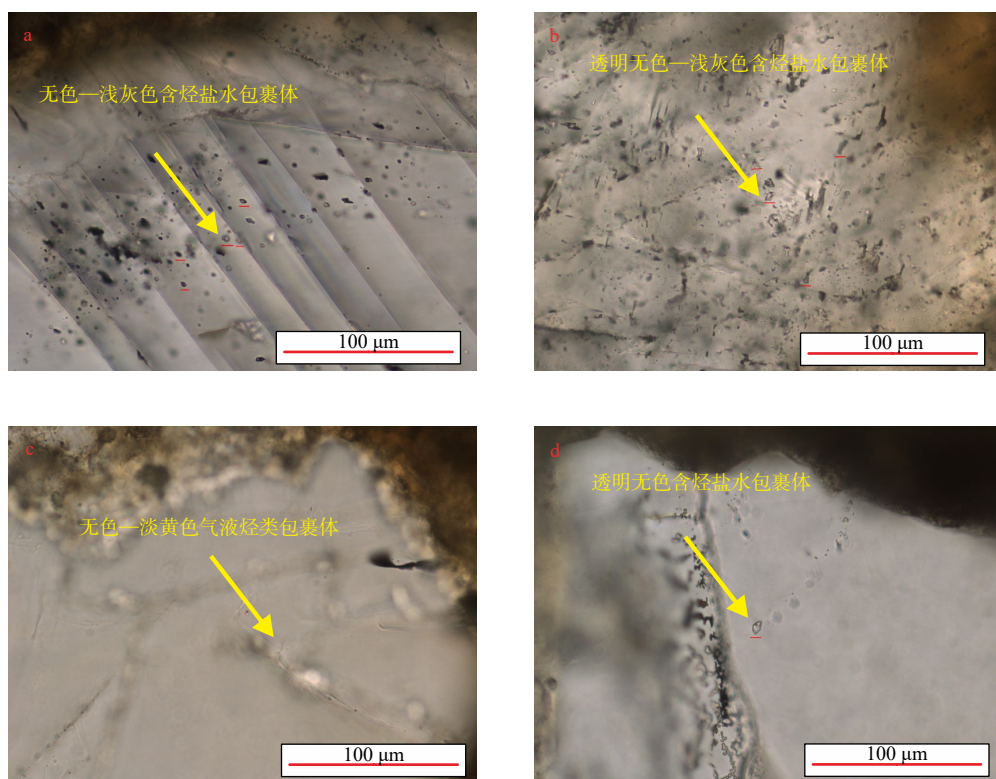
体。包裹体主要存在于方解石矿物的缝洞、微裂隙和石英颗粒(包括岩屑中石英颗粒)的微裂隙内。在侏罗系储层中,包裹体多位于石英颗粒微裂隙内,也有少量包裹体分布在方解石缝洞裂隙内,这表明油气充注发生在成岩过程中的溶蚀作用之后。侏罗系储层中气液烃包裹体较为常见,白垩系包裹体宿主结构与侏罗系相似,但在油层埋藏浅的地区,如哈浅23井区,成岩作用弱,捕获的烃类包裹体相对较少(图2)。

哈山地区既发育有盐水包裹体,也有烃类包裹体,其中烃类包裹体包括不同成熟度的单相液态烃包裹体、两相油气包裹体和单相气态烃包裹体。从烃类包裹体的产状上看,其主要存在于矿物缝洞充填脉或颗粒间的胶结物中,成群成带分布,或分布于切穿石英颗粒的微裂隙内,呈带状或串珠状分

布;烃类包裹体大小不一,直径一般为8~50 μm,形状为水滴形、长椭圆形和不规则状等(图2);气液比介于3%~50%。

在显微镜下,对岩石薄片石英颗粒总数和含油包裹体的石英颗粒总数进行计数,计算出每个样品中含油包裹体的石英颗粒的百分比,由此来定量分析油气包裹体丰度(Grains containing Oil Inclusion, GOI),定量评价古油层。GOI>5%说明古油层已经形成,GOI<1%则表明油气只发生了运移而没有聚集(Lisk et al., 2002)。哈山地区多数样品的GOI在1%~3%之间,其中哈浅21-浅8井样品中的GOI最高,达30%,表明油气曾发生过大规模的运移和聚集。

在透射光下烃类包裹体可呈浅褐色、黄色、无色、蓝绿色和蓝色等,此次发现的气液包裹体以浅黄色和黄色为主,另外也有一部分偏蓝色荧光的包



a—透明无色—浅灰色的含烃盐水包裹体,分布于方解石矿物缝洞内,侏罗系,哈浅21-浅8井440.5 m,单偏光;b—透明无色—浅灰色含烃盐水包裹体,沿方解石矿物微裂隙面分布,白垩系,哈浅23-浅8井183.5 m,单偏光;c—无色、淡黄色气液烃类包裹体,分布于石英颗粒微裂隙内,侏罗系,哈浅22-浅3井803 m,单偏光;d—透明无色含烃盐水包裹体,分布于石英颗粒的微裂隙内,成带状,白垩系,哈浅23-浅10井224.1 m,单偏光

图2 哈山地区中部典型钻井中流体包裹体岩相学特征

Fig. 2 Petrographic characteristics of fluid inclusions in key wells in the central Hashan Area

(a) HQ21-Q8, 440.5 m, J, transparent colorless to light gray hydrocarbon-bearing saline inclusions in calcite mineral fractures and vugs (PPL); (b) HQ 23-Q8, 183.5 m, K, transparent colorless to light gray hydrocarbon-bearing saline inclusions in micro-fracture surfaces of calcite (PPL); (c) HQ22-Q3, 803 m, J, visible colorless and light yellow gas-liquid hydrocarbon inclusions in micro-fractures of quartz grains (PPL); (d) HQ23-Q10, 224.1 m, K, transparent hydrocarbon-bearing saline inclusions in micro-fractures of quartz grains (PPL)

裹体,指示存在多期不同成熟度的烃类流体(图3)。在哈浅21-浅8井白垩系清水河组的石英颗粒裂隙中,可观察到黄色和蓝色的烃类包裹体和气相包裹体,呈带状分布,这表明可能经历了至少2期不同成熟度的油气充注。在侏罗系储层中发现的包裹体相对较小,以淡黄色和蓝绿色烃类包裹体为主(图4)。

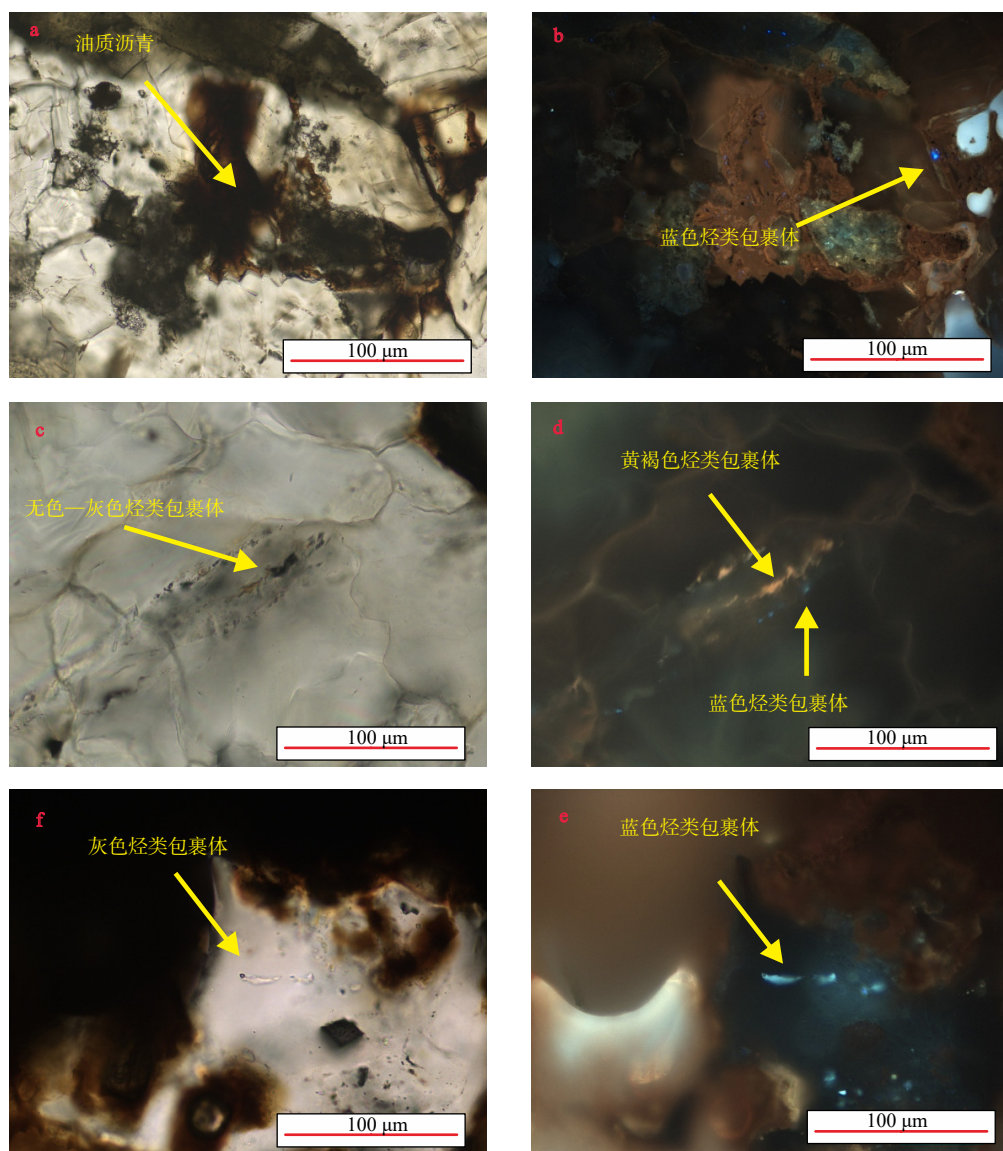
2.2 盐水包裹体均一温度及盐度特征分析

通过对与油气包裹体共生的盐水包裹体显微测温,结果显示(图5)其均一温度区间分布范围为60~150℃,且主要分布于70~90℃和100~130℃这2个区间内。侏罗系盐水包裹体的均一温度在这2个区间内均有分布,白垩系盐水包裹体的均一温度主要分布在第2个主峰内。这一分布特征表明,不同地质时期的油气充注期次以及油气藏所在的层位具有显著差异。

由盐水包裹体的盐度与均一温度的交汇图(图6)可以看出,该区经历了2个不同盐度环境的流体充注,盐水包裹体的盐度的峰值集中在0.1%~8.0%和11.2%~14.3%范围内。第1个盐度区间为原始地层水,对应于燕山期的构造运动,由此引起热流事件和地表水侵入;第2个区间为完全稀释的地层水,对应于构造强烈抬升,地表水进一步侵入地层水中,导致地层水变淡。

3 颗粒荧光特征

颗粒荧光技术分析中,定量颗粒荧光指数(Quantitative Grain Fluorescence Index, QGF-Index)和萃取液定量荧光强度(Quantitative Grain Fluorescence on Extract, QGF-E)这2个参数的变化反映了油气充



a—砂砾岩缝洞中充填的油质沥青, 侏罗系, 哈浅 22-浅 1 井 634.1 m, 单偏光; b—砂砾岩缝洞中的蓝色荧光包裹体, 侏罗系, 哈浅 22-浅 1 井 634.1 m, 荧光; c—缝洞中充填方解石气液包裹体, 侏罗系, 哈浅 22-浅 3 井 805.1 m, 单偏光; d—方解石中蓝色、黄色、黄褐色荧光气液烃包裹体, 侏罗系, 哈浅 22-浅 3 井 805.1 m, 荧光; e—石英微裂隙中透明无色的液烃和浅灰色气液烃包裹体, 白垩系, 哈浅 2-浅 2 井 156.7 m, 单偏光; f—蓝色、蓝绿色荧光包裹体, 白垩系, 哈浅 2-浅 2 井 156.7 m, 荧光

图 3 哈山地区侏罗系、白垩系烃类包裹体荧光特征

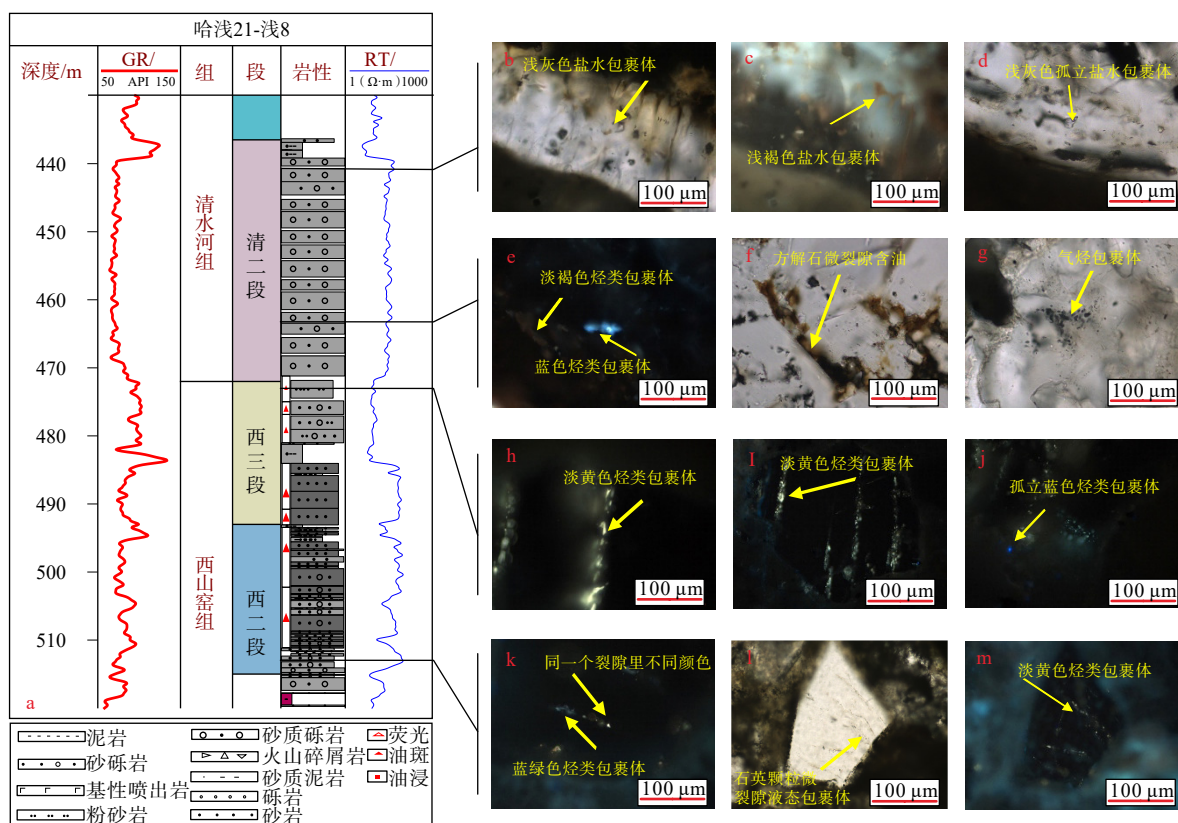
Fig. 3 Fluorescence characteristics of hydrocarbon inclusions in the Jurassic–Cretaceous strata of the Hashan Area

(a) Bitumen in conglomerate fractures and vugs (PPL), HQ22-Q1, 634.1 m, J; (b) Blue fluorescence in the conglomerate fractures and vugs (PVL), HQ22-Q1, 634.1 m, K; (c) Gas-liquid inclusions in calcite fractures and vugs (PPL), HQ22-Q3, 805.1 m, J; (d) Blue, yellow, and yellow-brown fluorescent gas-liquid hydrocarbon inclusions in calcite (PVL), HQ22-Q3, 805.1 m, K; (e) Transparent colorless liquid hydrocarbons and light gray gas-liquid hydrocarbon inclusions in quartz fractures (PPL), HQ2-Q2, 156.7 m, J; (f) Blue and blue-green fluorescent inclusions (PVL), HQ2-Q2, 156.7 m, K.

注的时间和程度(刘可禹等, 2016)。由于含油储层的矿物、润湿性等条件的差异, 目前学术界对 QGF-Index 和 QGF-E 参数没有形成统一标准。一般认为, 在古油藏油水界面以上, QGF-Index 大于 4, 同时 QGF-E 大于 40 pc, 表明现今含油性高, 为含油气

层。通过对含油气井段进行密集取样分析, 可以进一步揭示油气运移的动态过程(高剑波等, 2011; 刘可禹等, 2016)。

基于 QGF-Index 和 QGF-E 的油气地质含义, 结合哈山地区油气藏分析, 文中建立了 7 种定量颗粒



a—哈浅21-浅8井地层综合柱状图; b—d—清水河组浅灰色、浅褐色盐水包裹体, 440.5 m, 单偏光; e—g—清水河组淡褐色烃类包裹体、蓝色烃类包裹体、褐色含油荧光和深灰色的气包包裹体, 465.5 m, 荧光; h—j—西山窑组淡黄色和蓝色包裹体, 471.5 m, 荧光; k—m—西山窑组二段蓝绿色、淡蓝色烃类包裹体, 516.75 m, 荧光

图4 哈浅21-浅8井不同荧光颜色的烃类包裹体

Fig. 4 Fluid inclusions with different fluorescence colors in the Well HQ21-Q8

(a) The comprehensive column graph of HQ21-Q8; (b-d) Shallow gray and light brown saline inclusions, 440.5 m (PPL); (e-g) Light brown and blue hydrocarbon inclusions, brown oily fluorescence and dark gray gaseous inclusions, 465.5 m (PVL); (h-j) Light yellow and blue inclusions, 471.5 m (PVL); (k-m) Blue-green and light blue hydrocarbon inclusions, 516.75 m (PVL)

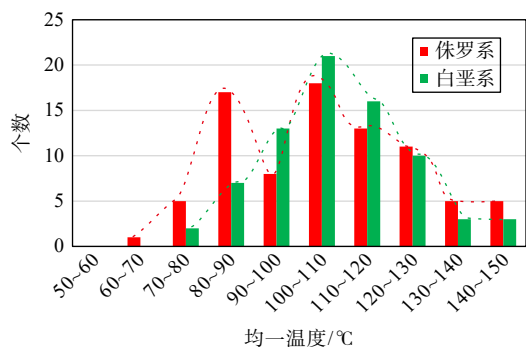


图5 哈山地区侏罗系—白垩系与烃类共生的盐水包裹体均一温度直方图

Fig. 5 Histogram of homogenization temperatures of brine water and hydrocarbon fluid inclusions in the Hashan Area

荧光矩阵组合模式(图7; X轴为 QGF-E 强度变化趋势, 从低到高, 代表晚期未发生充注到晚期发生显著充注; Y轴为 QGF-Index 强度变化趋势, 从低到

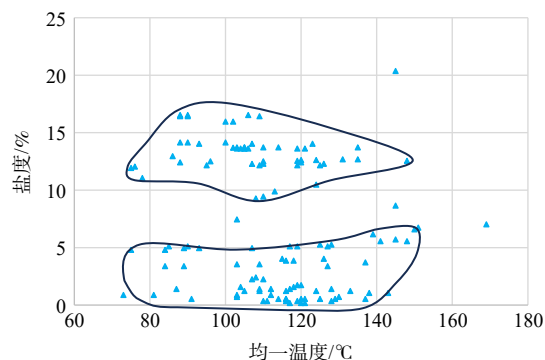


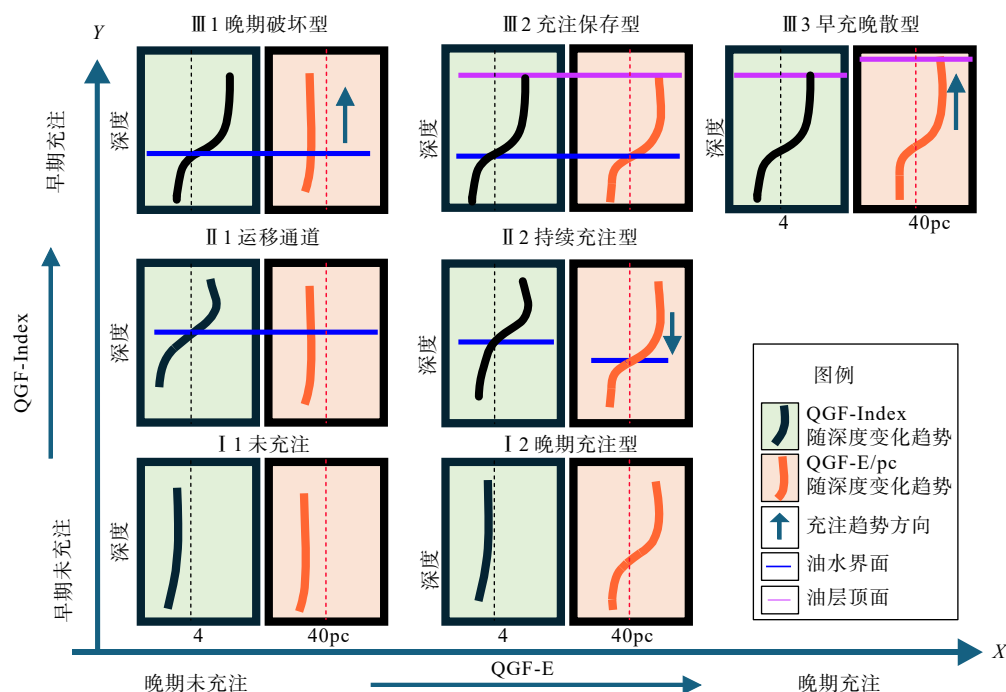
图6 哈山地区超浅层烃类共生盐水包裹体均一温度与盐度交汇图

Fig. 6 Cross plot of homogenization temperatures and salinities of hydrocarbon-associated brine inclusions in the Hashan Area

高, 代表早期未发生充注到早期发生显著充注)。其中, I 1 未充注型, QGF-Index 一般低于 4, 而 QGF-

E 一般低于 40 pc, 该类型属于无充注地层。晚期充注型, QGF-Index 低、QGF-E 高, 表现为晚期石油充注特征, 烃类包裹体缺失。II 1 运移通道型、III 1 晚期破坏型, 这 2 种类型整体上表现为 QGF-Index 高、QGF-E 低, II 1 运移通道型的 QGF-Index 曲线为钟形, III 1 晚期破坏型的 QGF-Index 曲线为箱型; II 1 运移通道型的储层为油气充注通道, 其历史上没有形成油气规模聚集, III 1 晚期破坏型则表明储层早期捕获了大量烃类包裹体, 形成了古油藏, 但由于后期调整, 油气发生了散失(高剑波等, 2011)。

III 2 充注保存型, QGF-Index 和 QGF-E 均较高, 为典型生烃高峰期发生油气充注、后期得到有效保存的油气藏。II 2 持续充注型, QGF-Index 和 QGF-E 较高, 但大于阈值的古油水界面和现今油水界面不一致, 表明油气在成藏高峰期充注没有充满而发生停滞, 后期发生了二次充注, 油水界面发生向下调整。III 3 早期充注晚期逸散型, QGF-Index 和 QGF-E 均较高, 且往往 QGF-E 顶部异常高值大于 QGF-Index 顶面值, 表明晚期油气突破盖层, 向上发生了动态扩散。



X轴为 QGF-E 强度趋势, 从低到高代表晚期未发生充注到晚期发生显著充注; Y轴为 QGF-Index 强度趋势, 从低到高代表早期未发生充注到早期发生显著充注

图 7 颗粒荧光显示组合模式分类图

Fig. 7 Classification of combined fluorescence display patterns of particles

X-axis: QGF-E trend (low to high: insufficient to significant charge at the late stage); Y-axis: QGF-Index trend (low to high: insufficient to significant charge at the early stage)

利用文中建立的定量颗粒荧光模型, 描述哈山地区主要油气层和输导格架的定量颗粒荧光特征, 可以从时空角度观察油气成藏充注的活动。从南北向连井剖面(图 8)分析发现, 油气经历了从南向北聚集的过程, 且侏罗系以 III 3 早充晚散型为主, 白垩系则主要发育 I 2 晚期充注型。在哈浅 22-浅 3 井顶部和哈浅 23-浅 10 井古油水界面以下, 仍能检测出较强的 QGF-E 荧光强度, 表明后期油气活动依然比较活跃。根据哈浅 22-浅 3 井定量颗粒荧光分析结果, 认为油气通过断层和不整合面持续稳定

充注, 油气藏规模扩大, 后期油气逐渐向上调整和扩散。在哈浅 23-浅 1 井的呼三段底部和呼二段底部发育 2 套 QGF-Index 小于 4 的荧光剖面, 古油水界面发育在 178 m 和 209 m 附近, 在古油水界面之下仍能检测出较强的 QGF-E 荧光反应, QGF-E 多数处于几百到几万 pc 区间内, 说明油气持续稳定充注, 已经形成的古油水界面逐渐向下调整, 充满度增加。但在下倾方向的哈浅 23 井中, 没有检测到明显的颗粒荧光强度, 表明油气没有过路和充注。因此, 哈浅 23-浅 1 井的油气可能来自于临近的断层,

而不是横向砂体输导层(图8)。从哈浅22井的荧光光谱图上可以看出,侏罗系和白垩系均获得有不同程度的油气充注,西山窑组底部荧光波长比上部长,表明发生了不同期次的原油充注(图9)。侏罗

系整体上以Ⅱ2持续充注型为主,充注高峰期成藏并后期调整,白垩系以Ⅰ1未充注型、Ⅱ2晚期充注型/Ⅱ2持续充注型为主,油气充注达到高峰后成藏,局部有调整。

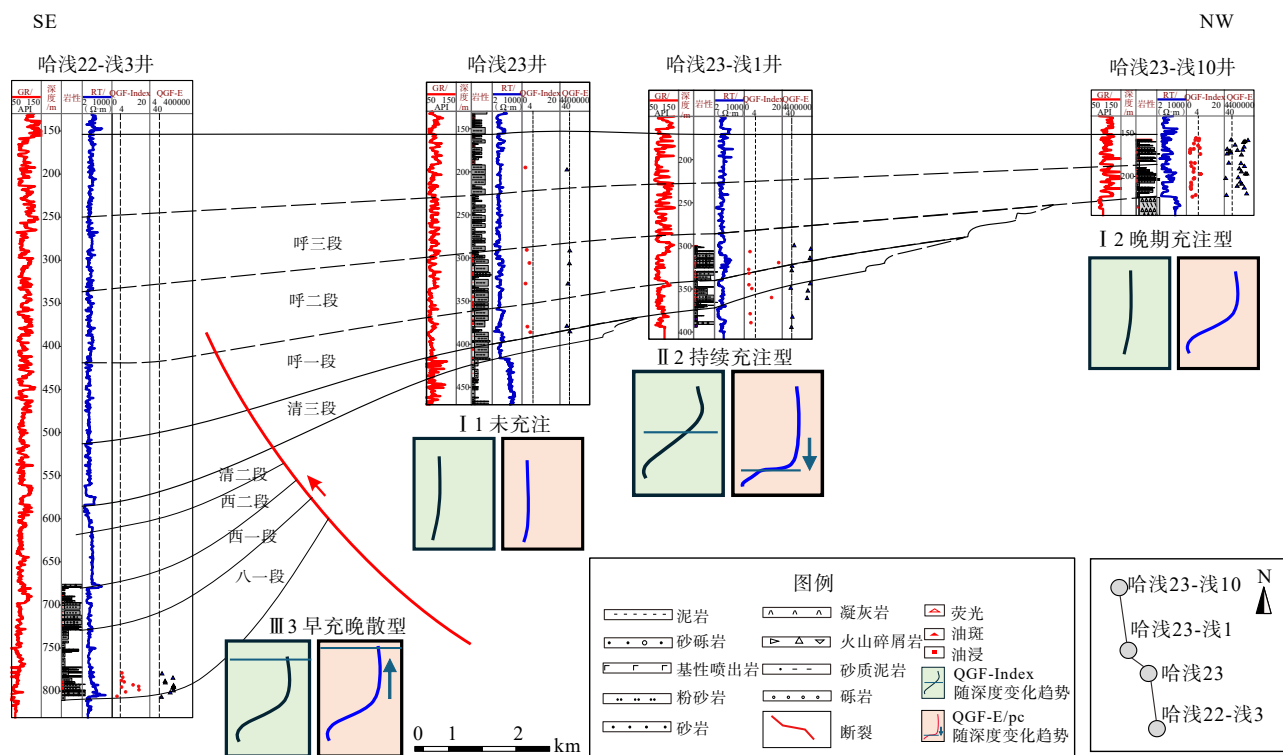


图8 哈浅22-浅3井—哈浅23井—哈浅23-浅1井—哈浅23-浅10井定量颗粒荧光连井剖面图

Fig. 8 Quantitative particle fluorescence profiles of Wells HQ 22-Q3, HQ23, HQ23-Q1, and HQ23-Q10

4 方解石 U-Pb 定年

研究采用激光剥蚀电感耦合等离子体质谱仪(LA-ICP-MS),对侏罗系西山窑组和白垩系清水河组中的2期方解石进行了U-Pb绝对年龄测定(图10)。鉴于样品中方解石的分布相对有限,研究中采取了选择性筛选与定位相结合的方法,通过挑选具有较高铀(U)含量和较低普通铅(Pb)含量的样本点,有效地提升目标点位筛选的精确度,并优化了样本采集点的布局效率。

针对哈浅20井早期形成的方解石脉样品定年分析中,使用了120 μm的激光光斑对306个单点进行了测定。研究结果显示,铀的含量范围在0.047~0.721 μg/g,平均含量为0.262 μg/g。铀铅同位素比值 $^{238}\text{U}/^{206}\text{Pb}$ 介于26.87~46.77,而铅同位素比值 $^{207}\text{Pb}/^{206}\text{Pb}$ 的范围是0.048~0.292。基于这些数据所计算得出的下交点年龄为133.6 Ma,误差范围为±2.7 Ma,初始铅同位素比值 $^{207}\text{Pb}/^{206}\text{Pb}$ 为0.254,平均标准权重偏差

(MSWD)为3.6。

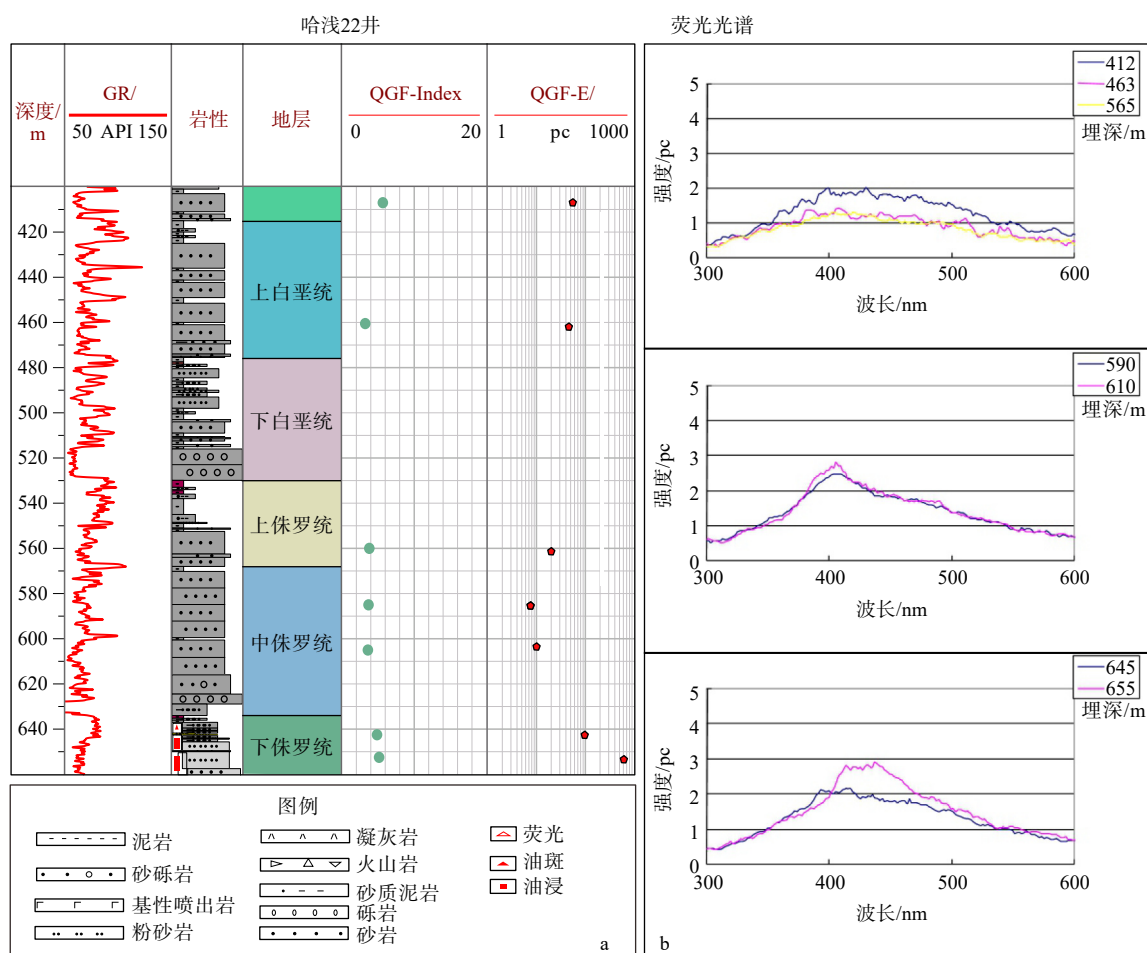
对于哈浅20井中切割前期脉体的晚期方解石样品,同样采用了120 μm的激光光斑,对196个单点进行了深入分析。经测定发现,铀含量介于0.0127~0.8240 μg/g,平均值为0.4840 μg/g。铀铅同位素比值 $^{238}\text{U}/^{206}\text{Pb}$ 的范围是62~89,而铅同位素比值 $^{207}\text{Pb}/^{206}\text{Pb}$ 从0.103~0.272。根据这些数据计算得到的下交点年龄为72.8 Ma,误差范围为±0.48 Ma,初始铅同位素比值 $^{207}\text{Pb}/^{206}\text{Pb}$ 为0.273,平均标准权重偏差(MSWD)为1.3。

通过方解石U-Pb定年,确定了该区热液作用活动的时间点分别在133 Ma和74 Ma左右,有效地界定了流体活动的2个关键时期。

5 讨论

5.1 埋藏史恢复

哈山地区逆冲推覆构造的形成始于石炭纪晚



a—哈浅22井综合地层及颗粒荧光指数柱状图; b—不同深度段的荧光光谱图

图9 哈浅22井侏罗系—白垩系储层 QGF-Index、QGF-E 参数及荧光光谱

Fig. 9 QGF Index, QGF E, and fluorescence spectra of Well HQ 22

(a) Comprehensive column chart with QGF Index and QGF E of Well Haqian 22; (b) Fluorescence spectra chart at different depths

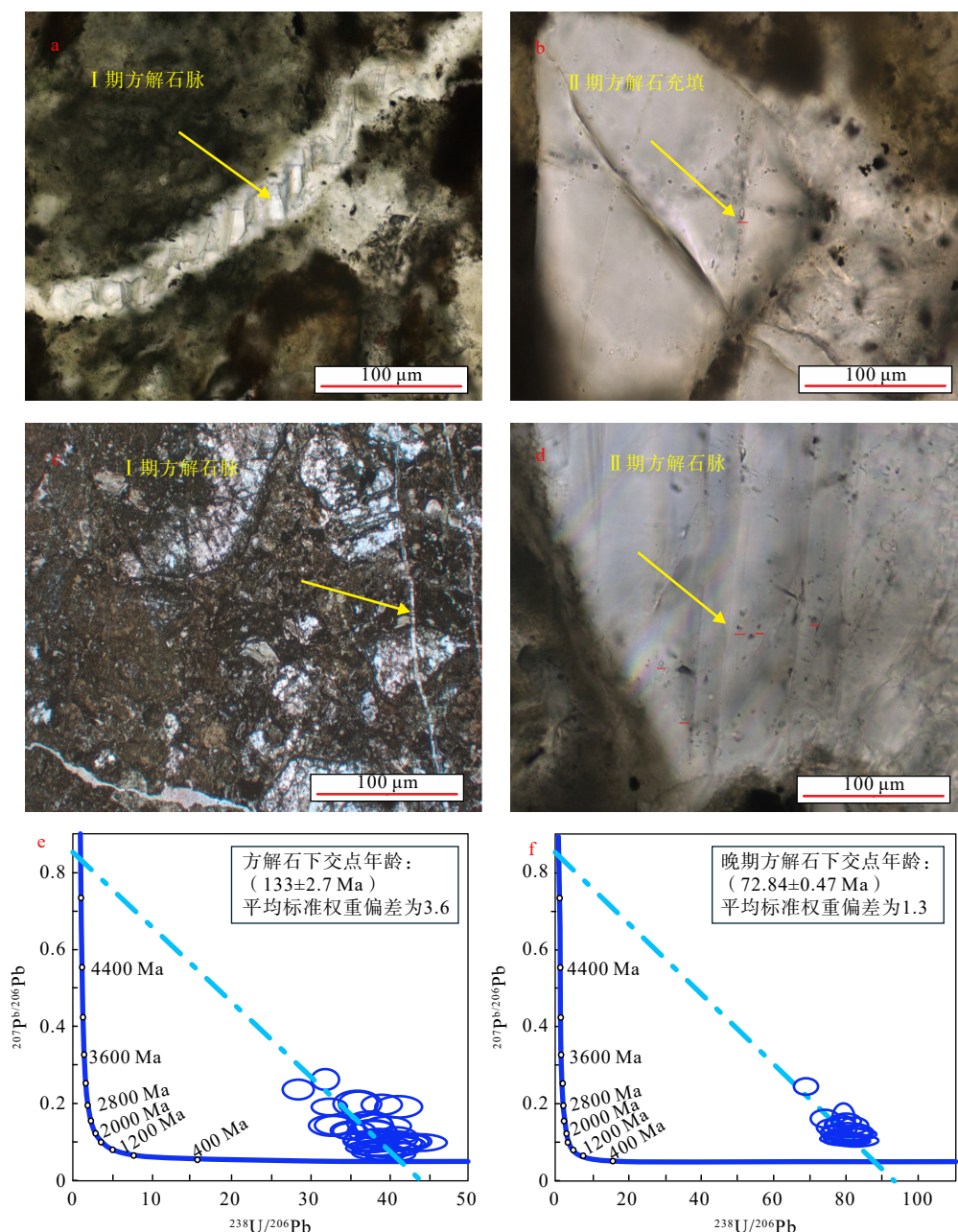
期,并在经历了海西、印支、燕山构造运动的继承性发展后,最终定型于燕山期早期(何登发等,2006)。为分析哈山地区浅层在印支和燕山构造运动中的油气充注问题,选取典型的哈浅20井,采用盆地模拟软件进行了埋藏史模拟(图11)。根据以往大地热史、地层剥蚀量以及有机质成熟度的研究成果(白国娟,2009;李振华,2011;黄少华等,2018;饶松等,2018)可知,三叠纪末期强烈的构造挤压,使得该区地层褶皱变形、风城组烃源岩生烃停滞;侏罗纪—白垩纪该区再次接受超覆沉积,并在中侏罗世、早白垩世和晚白垩世发生了3次抬升剥蚀,其剥蚀量为150~500 m(冯建伟,2008)。在早白垩世发生的区域抬升作用,使得古油藏发生调整,油气由深层沿断层和输导层向储层运移充注;在白垩系沉积后,风城组烃源岩再次生烃(王圣柱,2015),

随着烃源岩埋深增大,其热演化程度进一步增高,进入成熟—高成熟演化阶段。

盆地模拟结果表明,利用正常热流参数(饶松等,2018)测算,该区侏罗系最高古埋藏温度不超过65℃。然而,测得的盐水包裹体均一温度却多数都超过了80℃,明显偏高。对于这2种温度数据存在矛盾的情况,用投影法难以准确判断油气成藏的时期,因此,在热流值逐渐降低的地质背景下,判别古热流异常是厘定该区油气成藏期次的关键因素。

5.2 成藏期次

许多学者通过磷灰石裂变径迹、Re-Os 同位素定年、自生伊利石 K-Ar 年龄等年代学技术分析了准噶尔盆地北缘的古热流机制,多种古温标参数显示早—中侏罗世时期准噶尔盆地的地温梯度较低,大致接近2.6℃/100 m(王志维,2009),在140~130



a—白垩系砂砾岩 I 期方解石脉充填, 哈浅 23-浅 10 井 224 m, 显微照片; b—白垩系砂砾岩 II 期方解石脉充填, 哈浅 23-浅 10 井 225 m, 显微照片; c—侏罗系砂岩 I 期方解石脉充填, 哈浅 20 井 514 m, 显微照片; d—白垩系砂岩 II 期方解石充填, 哈浅 20 井 454 m, 显微照片; e—第 I 期方解石原位 U-Pb 定年结果; f—第 II 期方解石原位 U-Pb 定年结果

图 10 哈山地区哈浅 20 井清水河组方解石 U-Pb 定年结果

Fig. 10 U-Pb dating of calcite from the Qingshuihe Formation of Wells Haqian 23-Q10 and HQ 20 in the Hashan Area

(a) Cretaceous sandstone: Stage I calcite vein filling, Well Haqian 23-Q10, 224 meters, photomicrograph; (b) Cretaceous sandstone: Stage II calcite vein filling, Well Haqian 23-Q10, 225 meters, photomicrograph; (c) Jurassic sandstone: Stage I calcite vein filling, Well Haqian 20, 514 meters, photomicrograph; (d) Cretaceous sandstone: Stage II calcite vein filling, Well Haqian HQ20, 454 m, K, photomicrograph; (e) In-situ U-Pb dating results of the first-stage calcite; (f) In-situ U-Pb dating results of the second-stage calcite.

Ma 和 80~60 Ma 期间, 存在 2 次重要的热异常事件 (白国娟, 2009; 李振华, 2011; 黄少华, 2018)。在此期间, 随着该区构造活动的加强, 高温热液在盆地

的输导层内发生流动, 促进了成熟油气的运移, 而且在油气尚未降低至地层温度时, 便被宿主矿物捕获 (徐佑德等, 2020)。由此, 盐水包裹体的均一温

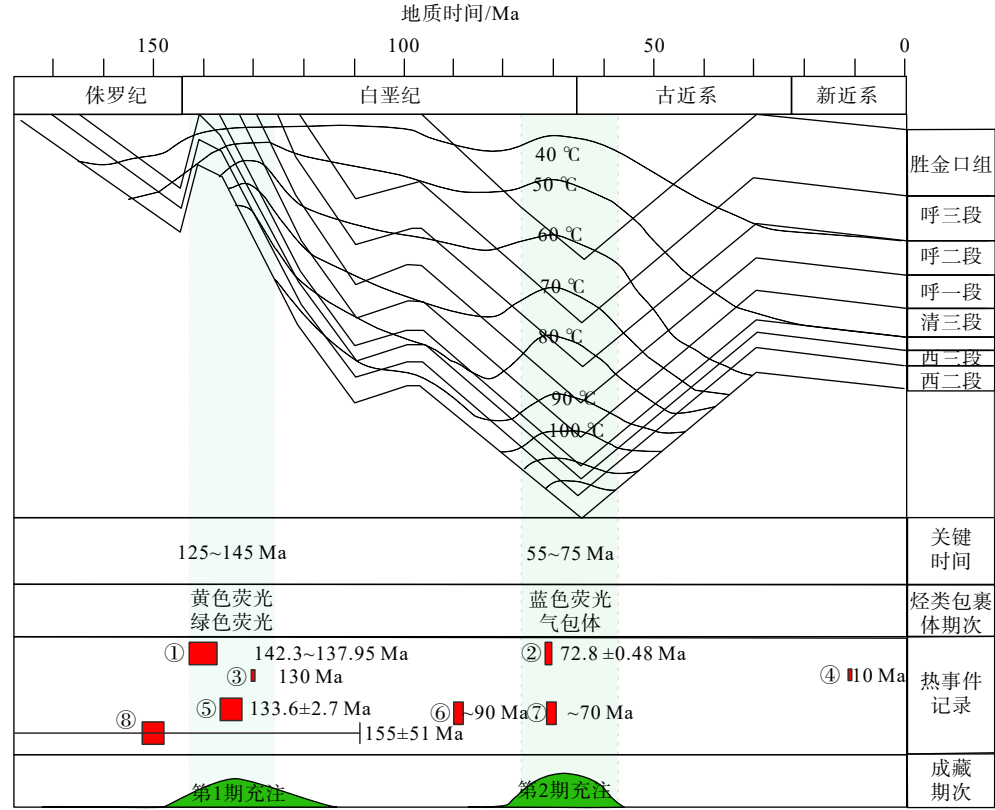
度呈现出显著偏高的现象。

利用流体包裹体的荧光颜色可定性判识出流体的充注次数(刘可禹等, 2016; 徐佑德等, 2020)。哈山地区共辨识出3种类型的油气包裹体: 黄色荧光油气包裹体、蓝色荧光油气包裹体以及气态烃类包裹体。其中, 黄色荧光油气包裹体相对较多, 成群成带分布, 指示早期油气成熟度较低, 岩石薄片中所见的沥青质可作为这一早期油气充注阶段的直接证据。在晚期方解石脉/缝隙和石英裂隙中, 可发现蓝色的荧光油气包裹体, 标志着较晚期的油气充注事件, 相较于黄色荧光包裹体, 其分布比较分散, 成熟度更高。此外, 储层中还发现了气态烃类包裹体, 这揭示出天然气在晚期的充注活动。

盐水包裹体的盐度和均一温度统计数据表明, 盐度分化为2个明显的组群, 均一温度至少有2个峰值区。另外, 定量颗粒荧光分析也证实该区存在早期充注、调整和再充注的过程。总体分析认为, 哈山地区至少发生2期的流体充注活动。

5.3 成藏演化

燕山运动中期, 二叠系、三叠系古油藏受到破坏, 逆冲断层活动导致区域抬升剥蚀, 深层盐度高的地层水注入储层, 盐水包裹体的盐度大于10%, 均一温度峰值为70~90 ℃(图5), 这一时期伴随着沥青质的充填、淡黄色荧光包裹体的形成以及低成熟油气的注入。方解石 U-Pb 测年约为133 Ma, 这与自生伊利石 K-Ar 年龄(137.95~142.30 Ma; 白国娟,



①哈山白垩系测得自生伊利石 K-Ar 年龄(白国娟, 2009); ②方解石 U-Pb 定年年龄; ③准噶尔北缘磷灰石裂变径迹热史模拟第2次热事件时间(李振华, 2011); ④磷灰石裂变径迹热史模拟第3次弱热事件时间(李振华, 2011); ⑤方解石 U-Pb 定年年龄; ⑥准噶尔北缘东段磷灰石裂变径迹(AFT)峰值年龄(王志维, 2009); ⑦准噶尔北缘东段 AFT 峰值年龄(王志维, 2009); ⑧准噶尔北缘侏罗系油砂 Re-Os 等时线年龄(黄少华等, 2018)

图 11 哈山山前构造浅层含油气系统埋藏史、热史和成藏史综合图

Fig. 11 Petroleum system chart of shallow oil- and gas-bearing systems in the Hashan area

① The K-Ar age of authigenic illite measured for the Cretaceous strata of the Hasanshan area (Bai, 2009); ② The U-Pb age of calcite of this study, 72.8 ± 0.48 Ma; ③ The timing of the second thermal event obtained by apatite fission track dating (Li, 2011); ④ The timing of the third weak thermal event determined with the apatite fission track method (Li, 2011); ⑤ The U-Pb age of calcite of this study, 133.6 ± 2.7 Ma; ⑥ The AFT peak age of 90 Ma (Wang, 2009); ⑦ The AFT peak age of 70 Ma (Wang, 2009); ⑧ The Re-Os isochron age of Jurassic oil sands, 155 ± 2.7 Ma (Huang et al., 2018).

2009))相似,印证了该区在早白垩世发生的第1期油气充注事件(图11)。

在晚白垩世,哈山地区处于火山活跃期(王志维,2009)。这一时期,早期形成的大型断层重新活动,深部热液通过断层向浅层流动,导致该时期形成的流体包裹体均一温度高,介于100~130℃之间(图5)。与此同时,地表水的侵入导致地层水盐度降低,盐水包裹体的盐度介于0.1%~8.0%,此期方解石U-Pb测年结果约为73 Ma。随着埋深增大,烃源岩进入成熟—高成熟阶段,油气通过高角度逆断层和走滑调节断层向超浅层运移,发生第2期充注,并在圈闭中聚集成藏。在哈浅21-浅8井的缝洞充填方解石矿物中,发现了成群分布的深灰色气态烃类包裹体,为该期发生充注作用提供了有力的证据(图4)。

6 结论

(1)哈山地区侏罗系和白垩系储层中发育类型多样的流体包裹体,包裹体的荧光颜色和强度变化表明其发育多期不同成熟度的烃类流体。流体包裹体均一温度主要分布于70~90℃和100~130℃区间内。

(2)借助定量颗粒荧光技术揭示了油气运移的动态过程,哈山地区浅层油气经历了多次调整并由南向北聚集。其中侏罗系油气以Ⅱ2持续充注型为主,白垩系则以Ⅰ2晚期充注型油气为主,显示出不同地层的油气充注特征。

(3)方解石U-Pb同位素测年确定了热液作用发生的时间分别为133 Ma和73 Ma,有效框定了流体活动的关键时期。结合盐水包裹体均一温度测量和定量颗粒荧光技术,该方法为油气成藏期次提供了精确的厘定手段,清晰确定了油气流体活动的2个关键时期,即早白垩世和晚白垩纪世,进而提升了盆地热史研究的准确性。

(4)在早白垩世,构造抬升导致古油藏破坏,初期油气充注其中,表现为沥青质充填、淡黄色荧光包裹体形成和低成熟油气的注入;到晚白垩世,第2次强烈热事件促使方解石脉充填,成熟油气(蓝色荧光烃类包裹体)开始充注,同时伴有大量气态烃类包裹体,且后期有天然气充注。这一发现对于理解复杂山前带油藏的形成机制以及指导未来的勘探活动具有重要的理论和实际意义。

致谢:本文在写作过程中得到了胜利油田春风采油厂和胜利油田勘探开发研究院西部分院的大力支持,在此致以衷心感谢!

References

- BAI G J, 2009. The tectonic feature and hydrocarbon accumulation in the northwest part of Junggar Basin[D]. Xi'an: Northwest University. (in Chinese with English abstract)
- FENG J W, 2008. The tectonic evolution and its controlling on hydrocarbon in Wuxia fault belt of Junggar Basin[D]. Qingdao: China University of Petroleum (East China). (in Chinese with English abstract)
- GAO J B, ZHANG H H, PANG X Q, et al., 2011. Application of quantitative grain fluorescence (QGF) analysis in low permeability sandstone reservoirs: a case study of Chang4+ 5 oil formation in Ordos Basin[J]. Journal of Oil and Gas Technology, 33(10): 1-5. (in Chinese with English abstract)
- HAN X L, WU Q Q, LIN H X, et al., 2016. Types of carrier system and models of hydrocarbon migration and accumulation of Hala'alat Mountain structural belt in the northern margin of Junggar Basin[J]. Natural Gas Geoscience, 27(4): 609-618. (in Chinese with English abstract)
- HE D F, GUAN S W, ZHANG N F, et al., 2006. Thrust belt structure and significance for petroleum exploration in Hala'alat mountain in northwestern margin of Junggar Basin[J]. Xinjiang Petroleum Geology, 27(3): 267-269, 298. (in Chinese with English abstract)
- HESTNES Å, DROST K, SØMME T O, et al., 2023. Constraining the tectonic evolution of rifted continental margins by u-pb calcite dating[J]. Scientific Reports, 13(1): 7876.
- HU Y, XIA B, 2012. An approach to the tectonic evolution and hydrocarbon accumulation in the Hala'alat Mountain area, northern Xinjiang[J]. Sedimentary Geology and Tethyan Geology, 32(2): 52-58. (in Chinese with English abstract)
- HUANG S H, QIN M K, SELBY D, et al., 2018. Geochemistry characteristics and Re-Os isotopic dating of Jurassic oil sands in the northwestern margin of the Junggar Basin[J]. Earth Science Frontiers, 25(2): 254-266. (in Chinese with English abstract)
- LI Z H, 2011. Analysis on the tectonic event and paleo-geothermal feature of Yanshanian in the Northern Junggar Basin[D]. Xi'an: Northwest University. (in Chinese with English abstract)
- LIANG Y Y, 2020. Strike-slip fault system at the northwestern margin of Junggar Basin and its relationship with hydrocarbon accumulation[D]. Beijing: China University of Petroleum (Beijing). (in Chinese with English abstract)
- LIN H X, GUO R C, GONG Y J, et al., 2017. Geochemical characteristics of crude oil and cogenetic-bidirectional charging effect in Hashan Area[J]. Special Oil and Gas Reservoirs, 24(2): 35-39. (in Chinese with English abstract)
- LISK M, O'BRIEN G W, EADINGTON P J, 2002. Quantitative evaluation of the oil-leg potential in the Oliver gas field, Timor sea, Australia[J]. AAPG Bulletin, 86(9): 1531-1542.
- LIU K Y, LU X S, GUI L L, et al., 2016. Quantitative fluorescence tech-

- niques and their applications in hydrocarbon accumulation studies[J]. Earth Science, 41(3): 373-384. (in Chinese with English abstract)
- National Energy Administration, 2021. Classification of oil reservoir: SY/T 6169-2021[S]. Beijing: Petroleum Industry Press. (in Chinese)
- RAO S, ZHU Y K, HU D, et al., 2018. The thermal history of Junggar Basin: constraints on the Tectonic attribute of the Early-Middle Permian basin[J]. Acta Geologica Sinica, 92(6): 1176-1195. (in Chinese with English abstract)
- WANG S Z, ZHANG K H, XIAO X F, et al., 2012. Study on meshwork-carpet hydrocarbon pool-forming features in Hashan area, the sloping zone, the northern border of Junggar Basin[J]. Journal of Xi'an Shiyu University (Natural Science Edition), 27(6): 19-24. (in Chinese with English abstract)
- WANG S Z, 2015. The formation and evolution of Hashan structural belt and its controlling on hydrocarbon in the Northern of Junggar Basin[D]. Qingdao: China University of Petroleum (East China). (in Chinese with English abstract)
- WANG S Z, LIN H X, ZHANG K H, et al., 2015. Formation mechanism and hydrocarbon charging of Jurassic reservoirs in Hashan area northern sloping zone of Junggar Basin[J]. Natural Gas Geoscience, 26(3): 477-485. (in Chinese with English abstract)
- WANG S Z, WU Q Q, CHENG S W, et al., 2017. Hydrocarbon transmission system and accumulation in Hala'alat mountain structural belt in the northern margin of Junggar Basin[J]. Acta Sedimentologica Sinica, 35(2): 405-412. (in Chinese with English abstract)
- WANG S Z, WU Q Q, SONG M Y, et al., 2018. Quantitative evaluation of the transportation of fault zone and its controlling effect on hydrocarbon migration and accumulation: case study of Hala'alat Mountain tectonic belt in the north margin of Junggar Basin[J]. Natural Gas Geoscience, 29(11): 1559-1567. (in Chinese with English abstract)
- WANG Z W, 2009. Research on the tectonic event and thermal evolution history of piedmont zone in northern margin of Junggar Basin[D]. Xi'an: Northwest University. (in Chinese with English abstract)
- XU G S, DING S B, LIU W J, et al., 2014. Geochemical characteristics and correlation of oil with source correlation of hydrocarbon source rock in Hassan area of Xinjiang, China[J]. Journal of Chengdu University of Technology (Science & Technology Edition), 41(6): 752-759. (in Chinese with English abstract)
- XU Y D, WANG L, LIU Z C, et al., 2020. Characteristics of fluid inclusions and time frame of hydrocarbon accumulation for volcanic reservoirs in Chepaizi Uplift[J]. Fault-Block Oil & Gas Field, 27(5): 545-550. (in Chinese with English abstract)
- XUE Y, LIN H X, ZHANG K H, et al., 2017. Tectonic characteristics and genetic simulation of Hala' alate mountain area[J]. Geotectonica et Metallogenia, 41(5): 843-852. (in Chinese with English abstract)
- YANG Y Z, LIU Q X, ZHANG F Q, et al., 2023. Study on quantitative grain fluorescence analysis technique applied to shallow reservoirs in Hashan area, Junggar Basin[J]. Mud Logging Engineering, 34(3): 22-31. (in Chinese with English abstract)
- YU C Y, JIA Y M, LI X X, et al., 2022. Determination of Carboniferous-Permian hydrocarbon accumulation period and time in Hala'alate Mountain area, Junggar Basin[J]. Mud Logging Engineering, 33(3): 110-116. (in Chinese with English abstract)
- ZHANG K H, 2014. Study on depositional features and hydrocarbon accumulation control factors of Jurassic in Hashan slope belt of Junggar Basin[D]. Qingdao: China University of Petroleum (East China). (in Chinese with English abstract)
- ZHANG K H, SUN Z L, ZHANG G L, et al., 2023. Shale dominant lithofacies and shale oil enrichment model of Lower Permian Fengcheng Formation in Hashan area, Junggar Basin[J]. Petroleum Geology & Experiment, 45(4): 593-605. (in Chinese with English abstract)
- ZHANG Y, 2018. Research on geochemical characteristics and accumulation process of upper Paleozoic reservoir in Hashan Area[D]. Beijing: China University of Petroleum (Beijing). (in Chinese with English abstract)
- ZHOU J, 2016. Research on the role of the basin-marginal sequence architectural model in controlling the development of sand-bodies and traps: a case study of the Jurassic system in Hashan Area[J]. Science Technology and Engineering, 16(21): 177-185. (in Chinese with English abstract)

附中文参考文献

- 白国娟, 2009. 准噶尔盆地西北部构造特征与油气成藏关系研究[D]. 西安: 西北大学.
- 冯建伟, 2008. 准噶尔盆地乌夏断裂带构造演化及控油作用研究[D]. 青岛: 中国石油大学(华东).
- 高剑波, 张厚和, 庞雄奇, 等, 2011. 定量颗粒荧光技术在低渗透致密砂岩油藏研究中的应用: 以鄂尔多斯盆地姬塬地区长4+5油层组为例[J]. 石油天然气学报, 33(10): 1-5.
- 国家能源局, 2021. 油藏分类: SY/T 6169-2021[S]. 北京: 石油工业出版社.
- 韩祥磊, 吴倩倩, 林会喜, 等, 2016. 准噶尔盆地北缘哈拉阿拉特山构造带油气输导系统类型及运聚模式[J]. 天然气地球科学, 27(4): 609-618.
- 何登发, 管树巍, 张年富, 等, 2006. 准噶尔盆地哈拉阿拉特山冲断带构造及找油意义[J]. 新疆石油地质, 27(3): 267-269, 298.
- 胡杨, 夏斌, 2012. 新疆北部哈山地区构造演化特征及油气成藏条件初步分析[J]. 沉积与特提斯地质, 32(2): 52-58.
- 黄少华, 秦明宽, SELBY D, 等, 2018. 准噶尔盆地西北缘超覆带侏罗系油砂地球化学特征及 Re-Os 同位素定年[J]. 地学前缘, 25(2): 254-266.
- 李振华, 2011. 准噶尔盆地北部燕山期构造事件及其古地温特征分析[D]. 西安: 西北大学.
- 梁媛媛, 2020. 准噶尔盆地西北缘走滑构造特征及其控藏作用研究[D]. 北京: 中国石油大学(北京).
- 林会喜, 郭瑞超, 宫亚军, 等, 2017. 哈山地区原油地化特征及同源双向充注效应[J]. 特种油气藏, 24(2): 35-39.
- 刘可禹, 鲁雪松, 桂丽黎, 等, 2016. 储层定量荧光技术及其在油气成藏研究中的应用[J]. 地球科学, 41(3): 373-384.
- 饶松, 朱亚珂, 胡迪, 等, 2018. 准噶尔盆地地史恢复及其对早—中二叠世时期盆地构造属性的约束[J]. 地质学报, 92(6): 1176-1195.
- 王圣柱, 张奎华, 肖雄飞, 等, 2012. 准北缘哈山地区斜坡带网毯式油气成藏规律[J]. 西安石油大学学报(自然科学版), 27(6): 19-24.

- 王圣柱, 2015. 哈山复杂构造带形成演化对油气成藏的控制作用[D]. 青岛: 中国石油大学(华东).
- 王圣柱, 林会喜, 张奎华, 等, 2015. 准北缘哈山斜坡带侏罗系原油稠化机理及充注特征[J]. 天然气地球科学, 26(3): 477-485.
- 王圣柱, 吴倩倩, 程世伟, 等, 2017. 准噶尔盆地北缘哈山构造带油气输导系统与运聚规律[J]. 沉积学报, 35(2): 405-412.
- 王圣柱, 吴倩倩, 宋梅远, 等, 2018. 断裂带内部结构及其对油气运聚的控制作用: 以准噶尔盆地北缘哈山构造带为例[J]. 天然气地球科学, 29(11): 1559-1567.
- 王志维, 2009. 准噶尔盆地北缘山前带构造事件与热演化史研究[D]. 西安: 西北大学.
- 徐国盛, 丁圣斌, 刘文俊, 等, 2014. 哈山地区烃源岩地球化学特征及油源对比[J]. 成都理工大学学报(自然科学版), 41(6): 752-759.
- 徐佑德, 王林, 刘子超, 等, 2020. 车排子地区火山岩油藏流体包裹体特征与成藏期次[J]. 断块油气田, 27(5): 545-550.
- 薛雁, 林会喜, 张奎华, 等, 2017. 哈拉阿拉特山地区构造特征及成因机制模拟[J]. 大地构造与成矿学, 41(5): 843-852.
- 杨蕴泽, 刘庆新, 张发强, 等, 2023. 定量颗粒荧光分析技术在准噶尔盆地哈山地区浅部储层中的应用研究[J]. 录井工程, 34(3): 22-31.
- 于春勇, 贾雨萌, 李晓祥, 等, 2022. 准噶尔盆地哈山地区石炭-二叠系油气成藏期次及时间厘定[J]. 录井工程, 33(3): 110-116.
- 张奎华, 2014. 准噶尔盆地哈山斜坡带侏罗系沉积特征及成藏控制因素研究[D]. 青岛: 中国石油大学(华东).
- 张奎华, 孙中良, 张关龙, 等, 2023. 准噶尔盆地哈山地区下二叠统风城组泥页岩优势岩相与页岩油富集模式[J]. 石油实验地质, 45(4): 593-605.
- 张阳, 2018. 哈山地区上古生界油藏地球化学特征及成藏过程分析[D]. 北京: 中国石油大学(北京).
- 周健, 2016. 盆缘层序构成模式下的控砂控圈作用研究: 以哈山地区侏罗系为例[J]. 科学技术与工程, 16(21): 177-185.