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准噶尔盆地吉木萨尔凹陷井井子沟组微裂缝微观特征及成因

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内容提要:笔者等利用岩芯、薄片、扫描电镜和分析化验等资料,开展了吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝特征分析,并揭示了微裂缝成因。研究表明:①基于裂缝与颗粒之间的分布关系,将井井子沟组致密砂岩储层微裂缝分为粒内缝、粒缘缝和穿粒缝3种类型,其中粒内缝最发育,穿粒缝次之,粒缘缝最不发育;利用延伸长度、面密度和开度等参数评价了3种类型微裂缝分布,研究区开启性裂缝占60%以上,以穿粒缝开启性最好。②微裂缝发育控制的因素主要有构造作用、岩石成分和结构等,微裂缝主要发育在中砂岩、细砂岩中,颗粒粒度越粗、分选越好,微裂缝越发育;储层抗压能力较弱,致使粒内缝和穿粒缝的成为主要微裂缝类型;点—线接触使得颗粒间的接触面积较小,有利于微裂缝发育。③研究区微裂缝成因主要为原生、成岩和构造成因,粒内缝为原生成因和成岩成因,粒缘缝为成岩成因和构造成因,穿粒缝为构造成因,穿粒缝有助于储层渗流能力的发育,是优质储层发育的有利因素之一。研究成果对于准噶尔盆地致密砂岩储层微裂缝的成因及优质储层评价具有指导意义,并对类似地质条件的致密储层油气勘探可以起到一定的借鉴作用。

关键词:微裂缝;成因类型;致密砂岩储层;井井子沟组;吉木萨尔凹陷

吉木萨尔凹陷位于准噶尔盆地东部,早期勘探主要集中在东南斜坡的二叠系梧桐沟组砂砾岩和芦草沟组油页岩(陈建平等,2016;郭佳等,2018;许琳等,2019;陈磊等,2020)。近年来,准噶尔盆地吉木萨尔凹陷二叠系井井子沟组致密砂岩储层规模领域相继获得突破(支东明等,2022),吉南4井区落实油藏规模615万吨,双吉构造带吉新2井落实探明地质储量11.58 Mt,2023年10月,新钻评价井吉451井在井井子沟组钻遇含油砂体,取心16.0 m均见油浸、油迹良好油气显示,表明吉木萨尔凹陷二叠系井井子沟勘探潜力大。目前,研究区致密砂岩储层勘探程度低,储层评价主要以宏观认识为主,缺少微观储层研究,特别是研究区微裂缝尚未开展研究。

前人在发育规模、成因类型、成岩特征等方面对微裂缝进行了定义和总结(王瑞飞等,2008;丁文龙等,2012;何伶等,2014;汪吉林等,2015;Hooker et al., 2018)。根据前期文献调研,微裂缝分类方法较多,根据成因可将微裂缝分为构造微裂缝、成岩微裂缝和与异常流体压力相关的微裂缝(王瑞飞等,2009;Zeng Lianbo et al., 2010;李长海等,2020);根据微裂缝与周围颗粒间的相对关系,可将微裂缝分为粒内缝、穿粒缝和粒缘缝(曾联波等, 2007;吕文雅等,2020)。成因分类方法是目前应用最广泛且使用最普遍的方法,微裂缝与颗粒的相对位置关系的分类方法因其简便性和极强的实用性,也得到了较广泛应用,因此本文亦采用微裂缝成因、微裂缝与周围颗粒间的相对关系进行微裂缝的分类。当前,微裂缝直接识别手段为薄片鉴定和扫描电镜,间接手段有纵横超声波测试、微米CT成像技术和渗透率差异值法(Sarout et al., 2008;白斌等,2013;

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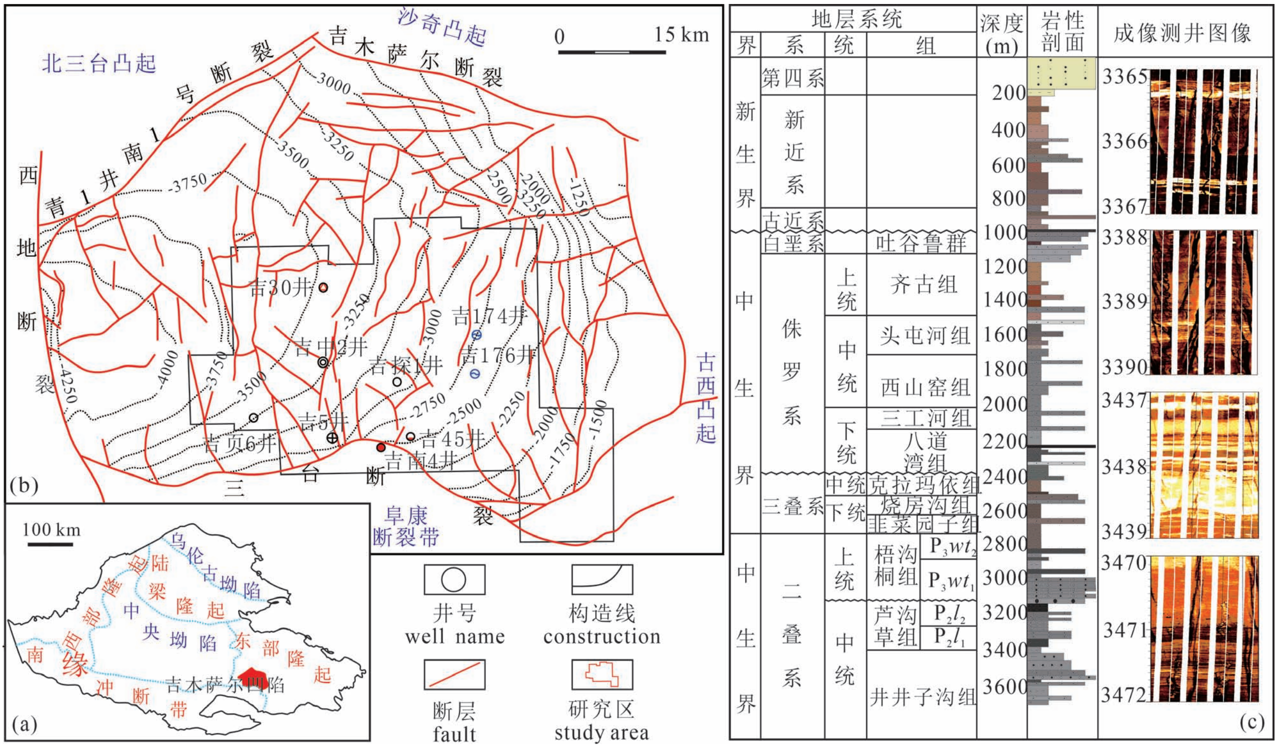

图 1 准噶尔盆地吉木萨尔凹陷井井子沟组综合地质图:(a)准噶尔盆地构造区域图;(b)吉木萨尔凹陷研究区位置图;(c)井井子沟组综合柱状图

Fig. 1 Comprehensive geological map of the Jinjinzigou Formation (P_2jj) in the Jimsar Sag, Junggar Basin: (a) structural regional map; (b) location map of the study area; (c) comprehensive histogram of the P_2jj

Ougier et al., 2016; 苟启洋等, 2019; 赵华伟等, 2019; Zeng Lianbo et al., 2023)。针对致密砂岩储层,微裂缝的存在极大的改善了储层的结构,提高了储层的渗透能力并为油气的运移和存储提供了通道(南珺祥等, 2007; 巩磊等, 2016, 2023; 刘卫彬等, 2018; 张世华等, 2019; Nian Tao et al., 2020; Guo Zhiqi et al., 2023; 邵国勇等, 2023)。因此开展微裂缝发育特征、成因类型及控制因素的研究对致密砂岩储层评价以及指导致密油气勘探开发具有重要的意义。近年来,吉木萨尔凹陷二叠系井井子沟组致密砂层规模领域相继获得突破,目前吉木萨尔凹陷及周缘钻遇井井子沟组井 50 余口,展现出良好的勘探前景。笔者等通过对吉木萨尔凹陷的井井子沟组储层铸体薄片和扫描电镜观察,结合岩芯、测井、物性等资料,对研究区微裂缝的发育特征、控制因素及成因进行了研究,在系统研究井井子沟组致密砂岩储层微裂缝微观特征基础上,划分微裂缝的成因类型,讨论了微裂缝的发育因素和形成时期,研究认识对准噶尔盆地类似地质条件的致密储层油气勘探可以起到一定的借鉴作用。

1 地质背景

吉木萨尔凹陷位于准噶尔盆地东部(图 1a),占地面积约 1300 km^2,为三面断层控制的箕状凹陷,凹陷西高东低,发育受断裂控制的多个低幅度鼻隆(图 1b)。受 NE—SW 向和近 NS 向断裂控制,井井子沟组自西向东发育吉新 1、双吉和吉东三大低幅度鼻凸发育带,吉东断控鼻凸排带发育 4 大低幅度鼻凸,延伸至生烃凹陷(吴孔友等, 2007)。井井子沟组成藏主要受断层、低凸、砂体控制,具有断裂输导、低凸控聚的特征(支东明等, 2022)。井井子沟组是芦草沟组优质湖相源岩层之下的第一套层系,以三角洲沉积为主,受沉积沟槽控制发育古西、吉南、三台和沙奇 4 大物源。井井子沟组主要发育两套砂体(图 1c),由下到上划分为两段:井一段、井二段。其中井一段(P_2jj_1)岩性以褐色厚层状泥岩夹粉细砂岩、泥质粉砂岩为主,下层砂体厚度 15~30 m,连续性差,局部发育;井二段(P_2jj_2)以灰色、深灰色砂岩为主,发育薄泥岩,上层砂体厚度 50 m 左右,砂岩连续性好。井一段和井二段分布稳定、砂体规模

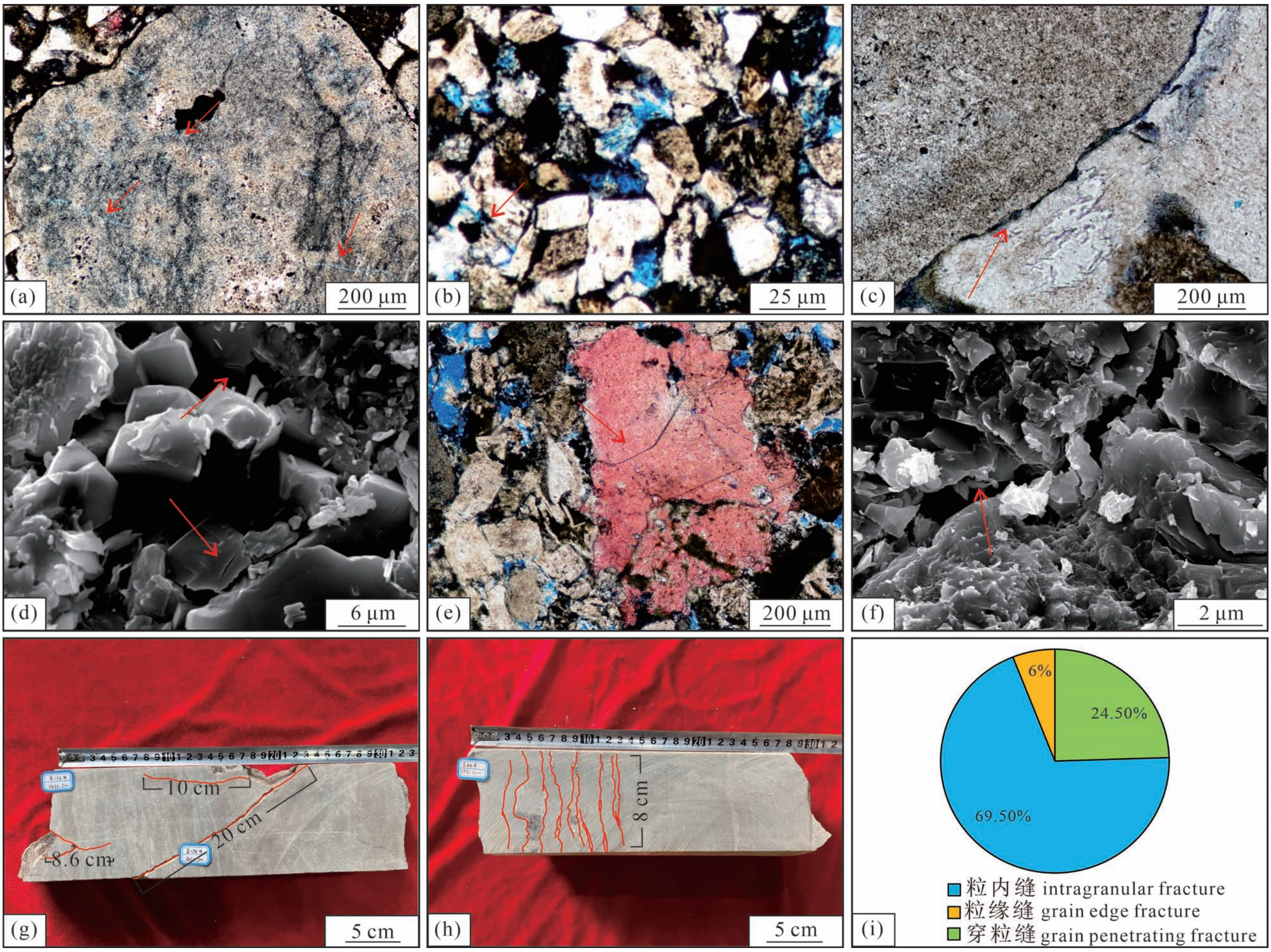

图 2 准噶尔盆地吉木萨尔凹陷研究区裂缝类型和分布特征

Fig. 2 Fracture types and distribution characteristics in the study area of Jimsar sag, Junggar Basin

(a)吉 451 井,3773 m,粒内缝;(b)吉 451 井,3769. 1 m,穿粒缝;(c)吉 451 井,3767. 5 m,粒缘缝;(d)吉 174 井,3434. 72 m,粒内缝;(e)吉 174 井,3428 m,交代作用致使矿物裂开;(f)吉 174 井,3422. 36 m,成岩收缩缝;(g)吉 174 井,3432. 5～3432. 7 m,构造成因缝;(h)吉 451 井,3781. 35 m,顺层缝;(i)吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝类型饼状图

(a) The Well Ji 451, 3773 m, intragranular fracture; (b) the Well Ji 451, 3769. 1 m, grain penetrating fracture; (c) the Well Ji 451, 3767. 5 m, grain edge fracture; (d) the Well Ji 174, 3434. 72 m, intragranular fracture; (e) the Well Ji 174, 3428 m, metasomatism causing mineral cracking; (f) the Well Ji 174, 3422. 36 m, diagenetic shrinkage joint; (g) the Well Ji 174, 3432. 5～3432. 7 m, structural fracture; (h) the Well Ji 451, 3781. 35 m, bedding fracture; (i) pie chart of microfracture types in tight sandstone reservoir of the P_2jj in the Jimsar sag

大、油气显示活跃。岩性以细砂岩、粉砂岩为主,井井子沟组储层普遍致密,孔隙度主要分布在 1. 1%～12%,渗透率分布在(0. 01～0. 253)×10^{-3} μm^2,为典型的致密砂岩储层,在成岩和构造的共同作用下,裂缝较发育(曾联波等,2007;何江林等,2009;郭小文等,2011;李新宁等,2023)。

2　微裂缝发育特征

2. 1　微裂缝类型

通过对吉木萨尔凹陷井井子沟组取心井的 226 张铸体薄片和扫描电镜照片的观察,结合岩芯资料,发现微裂缝发育的样品共 138 张,占 61%。通过对镜下微裂缝的观察、测量和计算,并结合岩芯、测井、物性等资料,定性、定量地表征了微裂缝的类型、规模。根据微裂缝与颗粒之间的接触关系可以将吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝分为粒内缝、粒缘缝和穿粒缝。粒内缝是井井子沟组发育最多的微裂缝类型,分布在颗粒的内部,延伸较短,不会切穿颗粒,常常被方解石和泥质所充填(图 2a、d),含量达到 50%之上(图 2i);穿粒缝发育数目仅次于粒内缝,其发育规模较大,延伸较长,常常切穿颗粒延伸,被原油、方解石所充填(图 2b);粒缘缝发

育数目较少，主要表现为分布在矿物颗粒之间，沿着矿物颗粒边缘发育，规模中等，与穿粒缝交织呈网状分布（图 2c）。另外在扫描电镜中可观察到成岩收缩缝（图 2f），属于非构造缝，在岩芯中亦可观察到厘米级规模的裂缝，主要是构造裂缝（图 2g）和顺层缝（图 2h），构造裂缝较陡，倾角较大。

2.2　微裂缝分布特征

致密砂岩储层微裂缝特征参数包括：延伸长度、充填成分、充填程度、裂缝连通性、裂缝密度等（丁文龙等，2015；董少群等，2023；曾联波等，2024）。根据 78 块薄片资料统计分析，从延伸长度、面密度和开度等 3 个方面进行微裂缝的分布特征评价。吉木萨尔凹陷井井子沟组致密砂岩储层中微裂缝的面密度普遍小于 1.2 mm/mm^2。粒内缝的面密度主要集中在 0.2～0.6 mm/mm^2，一般小于 1.2 mm/mm^2（图 3a）。穿粒缝的面密度主要分布在 0～0.2 mm/mm^2，

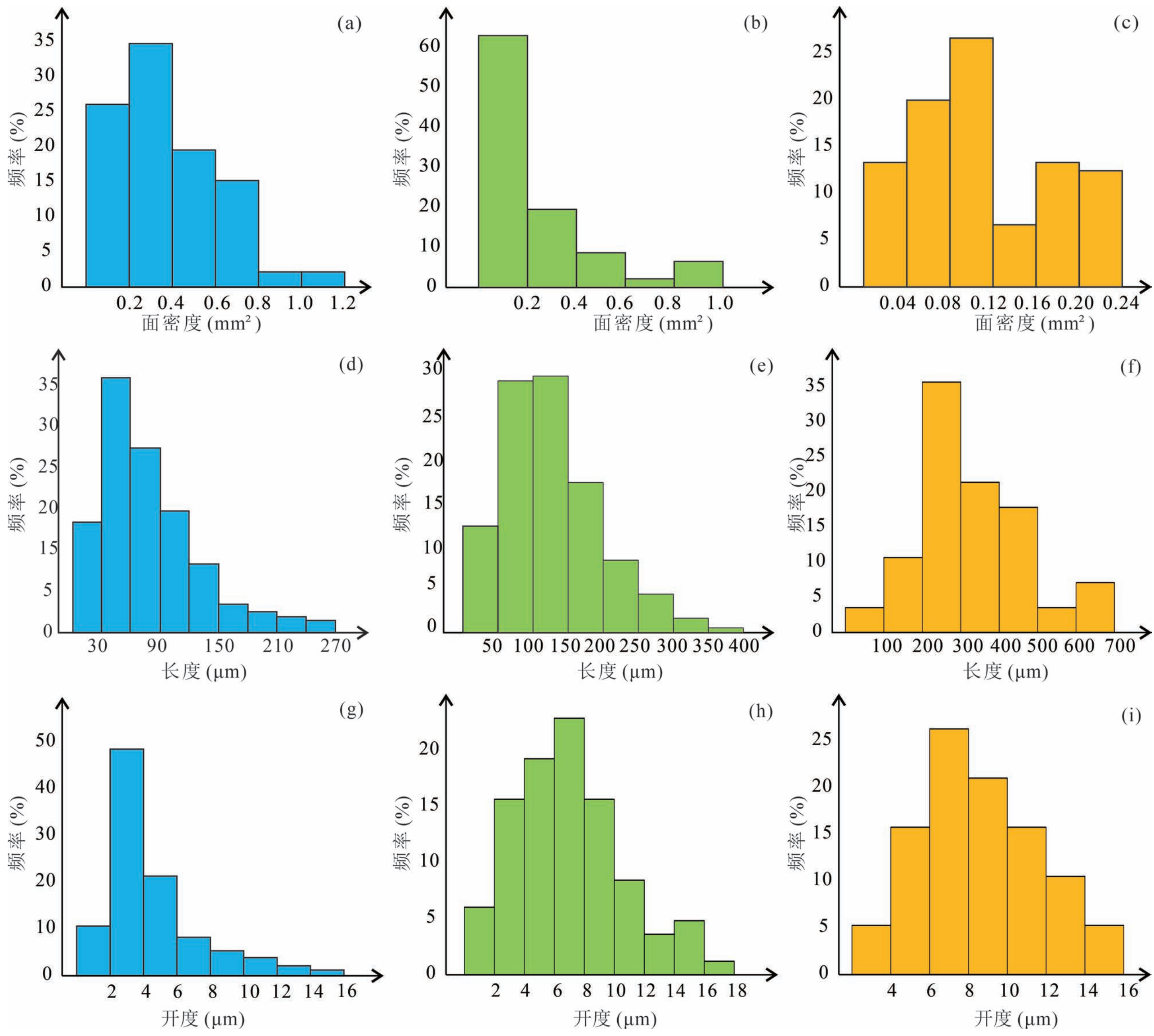

图 3 准噶尔盆地吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝分布特征

Fig. 3 Distribution characteristics of micro-fractures in tight sandstone reservoirs of the Jinjinzigou Formation（P_2jj） in the Jimsar Sag, Junggar Basin

（a）粒内缝面密度频率分布图；（b）穿粒缝面密度频率分布图；（c）粒缘缝面密度频率分布图；（d）粒内缝长度频率分布图；（e）穿粒缝长度频率分布图；（f）粒缘缝长度频率分布图；（g）粒内缝开度频率分布图；（h）穿粒缝开度频率分布图；（i）粒缘缝开度频率分布图

（a） The density frequency distribution of intragranular fracture；（b） the density frequency distribution map of grain penetrating fracture；（c） the density frequency distribution map of grain edge fracture；（d） frequency distribution of intragranular fracture length；（e） frequency distribution of grain penetrating fracture length；（f） frequency distribution of grain edge fracture；（g） the frequency distribution of intragranular fracture seam opening；（h） the frequency distribution of grain penetrating fracture seam opening；（i） the frequency distribution of grain edge fracture seam opening

表 1 准噶尔盆地吉木萨尔凹陷井井子沟组微裂缝类型和特征

Table 1 Types and characteristics of microfractures in the Jinjinzigou Formation (P_2jj) in the Jimsar Sag, Junggar Basin

裂缝类型	开度（μm）	面密度（mm/mm^2）	发育部位	发育特征	含油性
粒内缝	2~6	0.2~0.6	颗粒内部	分布在颗粒内部，延伸较短	较差
穿粒缝	2~10	0~0.2	切穿岩石颗粒和基质	发育规模较大，延伸较长，常常切穿颗粒，可与粒缘缝交织呈网状分布	较好
粒缘缝	8~12	0.04~0.12	颗粒边缘	沿着矿物颗粒边缘发育，规模中等	一般

通常小于 1.0 mm/mm^2（图 3b）。粒缘缝的面密度在 0.04～0.12 mm/mm^2，一般少于 0.24 mm/mm^2（图 3c）。研究区致密砂岩储层中粒内缝、穿粒缝比粒缘缝更发育，井井子沟组致密砂岩储层微裂缝发育程度较差，虽然微裂缝发育样品占总样品数较高，但单个样品下微裂缝发育数目较少。通过测量吉木萨尔凹陷井井子沟组储层粒内缝长度主要集中在 30～120 μm（图 3d），穿粒缝长度集中在 50～150 μm（图 3e），粒缘缝长度集中在 200～400 μm 范围内（图 3f），粒内缝发育规模较小，穿粒缝发育规模中等，粒缘缝的发育规模最大。一般用面密度来表示微裂缝的发育程度（童亨茂等，1994），通过统计吉木萨尔凹陷井井子沟组致密砂岩储层粒内缝开度主要集中在 2～6 μm（图 3g），穿粒缝主要集中在 2～10 μm（图 3h），粒缘缝主要集中在 8～12 μm（图 3i），粒内缝和粒缘缝的开度一般小于穿粒缝的开度，以穿粒缝开启性最好，含油性较好，而粒缘缝和粒内缝开启性一般，改善储层效果一般（表 1）。吉木萨尔凹陷井井子沟组储层微裂缝有效性较好，开启性裂缝占 60% 以上，以穿裂缝为主，开启性裂缝被有机质、原油等充填，封闭性裂缝被方解石、黄铁矿等充填。

3　微裂缝发育控制因素及形成期次讨论

3.1　控制因素

吉木萨尔凹陷井井子沟组断层比较发育，在强烈的构造应力作用下，不同位置、不同深度的地层中均可以见到裂缝发育。裂缝的形成不仅与构造作用相关，还受岩石的成分和结构影响。不同的砂岩粒度、岩石碎屑成分、填隙物含量和颗粒之间的接触关系都会对微裂缝的发育产生不同程度的影响（丁文龙等，2012；王维斌等，2017；赵兰，2022）。粒度较粗的砂岩颗粒相互间的接触面积小，单位面积上所受的压力较大，有利于微裂缝发育（南珺祥等，2007；万永平等，2010；赵兰，2022；巩磊等，2023），吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝主要发育在中砂岩、细砂岩中，含砾砂岩次之，粉砂岩最不发育（图 4）。粒径主要分布在 0.34～1.08 mm，且砂岩粒度越粗、分选越好，微裂缝越发育；硬度较高的石英、长石和软性岩屑、填隙物在各个方向压力的作用下，容易在石英和长石周围发生位移和错动，当储层中砂岩塑性填隙物含量较低时，越容易产生微裂缝，井井子沟组致密砂岩储层碎屑成分主要以石英、长石和岩屑为主，填隙物主要为黄铁矿，喷出岩岩屑中填隙物主要为绿泥石和磁铁矿，总的来说，塑性填隙物含量较低，无法在石英颗粒、长石颗粒和岩屑周围承受外力作用的抗压，致使粒内缝和穿粒缝的成为研究区主要微裂缝类型；井井子沟组致密砂岩储层主要以点—线接触为主，偶见点接触，点线接触和点接触的砂岩颗粒间的接触面积小，在单位面积上所受压力较大，有利于微裂缝的发育。宏观上，吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝发育主要受成岩作用和构造作用影响。通过镜下薄片观察，井井子沟组致密砂岩储层普遍发育强压实，可见长石溶蚀现象，随着压实作用的增强，微裂缝发育程度也逐渐增大（图 5b、c）。另外受构造应力的影响下，岩石可能发生剪切破裂，或沿着应力方向扩展形成构造

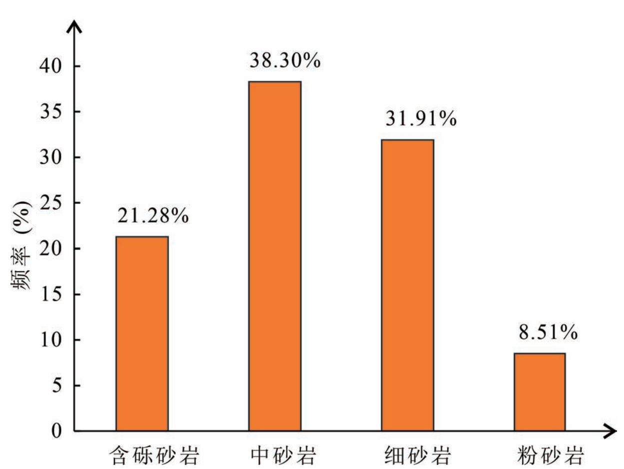

图 4 准噶尔盆地吉木萨尔凹陷井井子沟组不同砂岩粒度微裂缝发育直方图

Fig. 4 Micro-fracture development histogram of different sandstone grain size in the P_2jj in the Jimsar sag, Junggar Basin

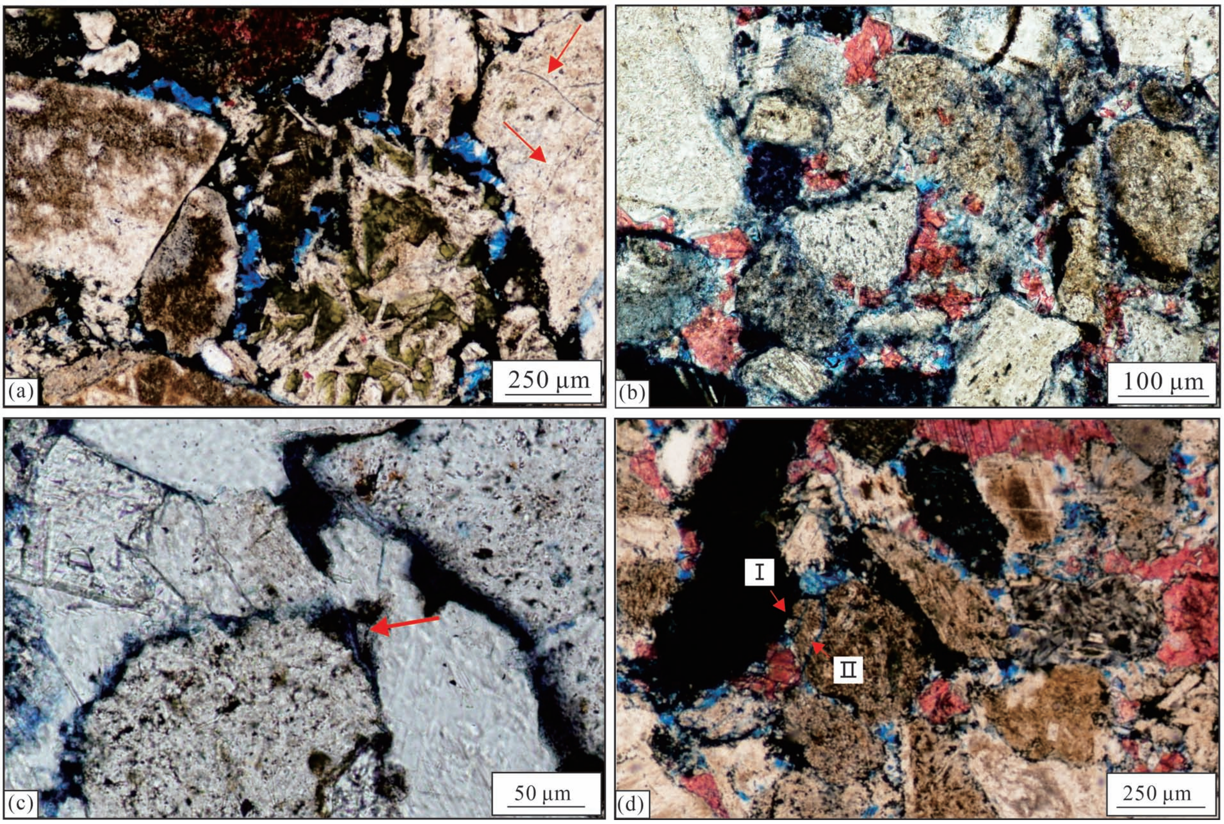

图 5 准噶尔盆地吉木萨尔凹陷井井子沟组微裂缝形成期次

Fig. 5 Formation period of micro-fracture in the P_2jj in the Jimsar sag, Junggar Basin

(a)吉 174 井,3430.9 m,泥质充填原生缝;(b)吉 451 井,3781.65 m,方解石溶蚀沟通粒缘缝;(c)吉 451 井,3767.53 m,早期充填又重新裂开;(d)吉 174 井,3435.8 m,晚期裂缝切割早期裂缝

(a) The Well Ji 174,3430.9 m, muddy filling primary fracture; (b) the Well Ji 451,3781.65 m, calcite dissolution communicates grain edge fractures; (c) the Well Ji 451,3767.53 m, early filling and re-cracking; (d) the Well Ji 174, 3435.8 m, late fractures cut early fractures

成因的微裂缝,或者与成岩作用结合,形成构造—成岩微裂缝(蔡正旗等,2001;Ezati et al., 2018;吕文雅等,2020)。

3.2 形成期次讨论

通过镜下观察发现,薄片中存在微裂缝的充填和切割的现象,既有原生裂缝充填又有成岩裂缝充填,既有早期充填又再次裂开形成的裂缝又有一组裂缝切割另一组裂缝的现象(图 5d)。微裂缝的形成期次和时间可以通过裂缝的充填顺序和裂缝间的切割关系来判断(李学万等,2005;白斌等,2012)。结合研究区的构造演化和镜下薄片,研究区主要发育三期微裂缝(表 2),分别为第一期的泥质充填的原生缝(图 5a)、第二期的溶蚀成岩缝(图 5b)和第三期的构造作用形成的构造缝(图 5c)。其中构造缝根据裂缝切割关系和发育程度可进一步细分为三小期(表 2)。吉木萨尔凹陷井井子沟组沉积后,主要经历了 3 次大的构造运动(刘卫彬等,2018;夏世威等,2023),在晚二叠世—三叠纪,吉木萨尔凹陷处于周缘前陆盆地坳陷阶段,在挤压应力的作用下使得地层抬升,造成最小主应力降低,产生第一期构造微裂缝,以穿裂缝为主,由于该期构造应力较小,仅切开颗粒边缘;在侏罗系沉积时期,吉木萨尔凹陷处于陆内坳陷阶段,盆地边缘收到挤压而坳陷内部在伸展应力的作用下发生隆升,吉木萨尔吉周缘处于南高北低的局势,产生第二期构造微裂缝,该期构造微裂缝以粒缘缝、穿粒缝为主,该期构造应力增强,表现为切穿颗粒、后期构造裂缝切割早期裂缝等特征;在上白垩统沉积时期,断层活动相对薄弱,在挤压应力下隆升,产生大规模的抬升剥蚀;古近系、新近系沉积时期,博格达山持续隆升,新近系之后,喜马拉雅运动使得博格达山强烈隆升并向南俯冲,构造应力增强产生第三期构造微裂缝,发育粒缘缝和穿粒缝,该期构造应力最强,表现为后期构造裂缝切割早期裂缝、早期沥青充填裂缝重新裂开的特征。

表 2 准噶尔盆地吉木萨尔凹陷井井子沟组三期微裂缝特征统计表

Table 2 Statistics of three stages micro-fracture characteristics in the P_2jj in the Jimsar sag, Junggar Basin

微裂缝期次	主要成因	主要裂缝类型	发育特征
第一期	原生	粒内缝	颗粒内部裂缝,常常被方解石和泥质所充填
第二期	成岩	粒内缝、粒缘缝	交代作用致使矿物裂开、部分微裂缝进一步溶蚀形成微裂缝
第三期	构造	穿粒缝	切开颗粒边缘
		粒缘缝、穿粒缝	切穿颗粒、后期构造裂缝切割早期裂缝
		粒缘缝、穿粒缝	后期构造裂缝切割早期裂缝、早期沥青充填裂缝重新裂开

4 微裂缝成因

岩芯、铸体薄片和扫描电镜分析结果显示了吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝的分布特征,在成因上可分为原生、构造和成岩成因。原生成因微裂缝为储层沉积形成之前在母岩中已经存在的裂缝。吉木萨尔凹陷井井子沟组原生裂缝绝大部分被矿物以及泥质完全充填(图 6a),属于无效裂缝,粒内缝主要为原生成因。构造成因的微裂缝主要表现为切穿石英长石等矿物颗粒,发育较平直,不受矿物颗粒的限制,规模较大、延伸较长,开度变化较大,多为有效裂缝,主要发育在细砂岩和粉砂岩等岩性中。构造成因是井井子沟组致密砂岩储层穿粒缝形成的关键因素,构造应力作用于岩体上产生了一系列分布相对均匀的细小微裂缝,然后随着周围地层压力的增大,岩石开始发生破裂,形成了大量的微裂缝。成岩成因的微裂缝主要表现为顺着层面发育,多发生在岩性界面上,呈树枝状,具有弯曲、断裂等特征。穿粒缝有助于储层渗流能力的发育,是优质储层发育的有利因素之一(Yin Shuai et al., 2018; 吕文雅等,2020)。另一方面构造作用与成岩作用共同控制着构造—成岩微裂缝的发育(图 6b、c),吉木萨尔凹陷井井子沟组储层成岩作用以压实作用与溶蚀作用为主,交代作用次之。成岩序次为Ⅰ期方解石交代→Ⅰ期绿泥石化→Ⅰ期长石溶蚀(图 6d)。由于重结晶、压实、矿物交代等作用,储层中的岩石发生收缩、膨胀和矿物间的重新组合,发育了一系列的成岩收缩缝(图 6e),主要包括粒缘缝和粒内缝,之后部分收缩缝还会进一步发生溶蚀形成溶蚀缝(图 6f),溶蚀缝使储层内的孔隙得以连通,改善储层物性。

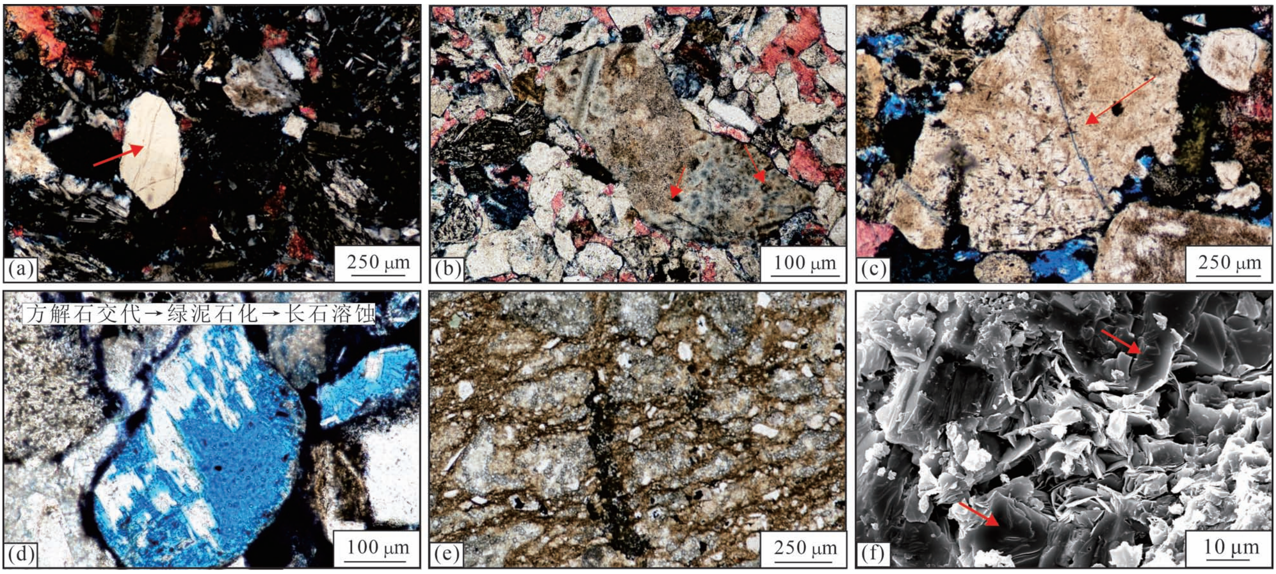

图 6 准噶尔盆地吉木萨尔凹陷井井子沟组 3 种成因微裂缝

Fig. 6 Three genetic kinds of micro-fractures in the P_2jj in the Jimsar Sag, Junggar Basin

(a)吉 174 井,3435.8 m,原生微裂缝;(b)吉 451 井,3772.37 m,构造成因充填缝和未充填缝;(c)吉 174 井,3430.9 m,构造成因未充填缝;(d)吉 451 井,3767.53 m,吉木萨尔凹陷井井子沟组储层成岩序次图;(e)吉 174 井,3426.1 m,成岩收缩缝;(f)吉 174 井,3436.68 m,成岩溶蚀缝

(a) The Well Ji 174, 3435.8 m, primary micro-fracture; (b) the Well Ji 451, 3430 m, structural origin filling fracture and unfilled fracture; (c) the Well Ji 174, 3430.9 m, tectonic origin unfilled fracture; (d) diagenetic sequence diagram of the Jinjinzigou Formation (P_2jj) reservoir in the Jimsar sag, the Well Ji 451, 3767.53 m; (e) the Well Ji 174, 3426.1 m, diagenetic shrinkage joint; (f) the Well Ji 174, 3436.68 m, diagenetic dissolution fracture

5 结论

(1)吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝主要有粒内缝、穿粒缝和粒缘缝 3 种类型。穿粒缝开启性最好,含油性较好,而粒缘缝和粒内缝开启性一般,开启性裂缝占 60%以上,开启性裂缝被有机质、原油等充填。

(2)吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝的发育程度受构造作用、岩石成分和结构等控制,并至少存在 3 期微裂缝,分别为原生缝、溶蚀缝、早期充填裂缝重新开启和因交代作用矿物裂开所形成的裂缝,微裂缝的形成时间与构造作用相对应。

(3)吉木萨尔凹陷井井子沟组致密砂岩储层微裂缝主要为原生、构造和成岩成因。原生成因是井井子沟组致密砂岩储层粒内缝的主要成因,大部分为无效裂缝,构造成因是井井子沟组致密砂岩储层穿粒缝形成的关键因素,穿粒缝是优质储层发育的有利因素之一,成岩作用主要形成成岩收缩缝,主要包括粒缘缝和粒内缝,部分成岩收缩缝发生溶解形成溶蚀缝,溶蚀缝改善储层物性。

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Microscopic characteristics and causes of micro-fractures in the Jinjinzigou Formation in Jimsar Sag, Junggar Basin

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Objective: It is generally believed that the tight sandstone reservoir has strong heterogeneity and poor physical properties, but the tight sandstone reservoir in the Jimsar Sag, Junggar Basin, has good oil and gas production. Through the core data photos, it is found that the reservoir fractures of the Jinjinzigou Formation (P_2jj) in the study area are developed, most of which are filled with crude oil and calcite. Based on the microscopic thin sections and scanning electron microscope photos, it is found that most samples develop micro-fractures. Through the observation, measurement and calculation of micro-fractures under the microscope, combined with the core and regional tectonic background, the development characteristics, main controlling factors and genetic mechanism of micro-fractures were systematically analyzed, and the formation stages of micro-fractures were discussed. The research results have guiding significance for the genesis of micro-fractures in tight sandstone reservoirs and the evaluation of high-quality reservoirs in the Junggar Basin, and can be used as a reference for oil and gas exploration in tight reservoirs with similar geological conditions.

Methods: In order to study the distribution characteristics and genesis of micro-fractures in tight sandstone reservoirs of the Jinjinzigou Formation (P_2jj), cast thin sections, scanning electron microscopy (SEM) and Nano Measure software were used to observe and measure the reservoirs of the Jinjinzigou Formation (P_2jj) in PetroChina Xinjiang Oilfield Company. Through the observation of 226 cast thin sections and SEM images, the characteristics and causes of micro-fractures were analyzed. Through the cutting relationship, development characteristics and regional tectonic background between micro-fractures, the formation stages of micro-fractures were discussed.

Results: The results show that the micro-fractures in tight sandstone reservoirs of the P_2jj in the Jimsar sag can be divided into three genetic types: tectonic origin, diagenetic origin and abnormal high-pressure origin. Based on the scale of micro-fractures and the relationship between micro-fractures and particles, the micro-fractures in the study area are divided into three basic types: intra-granular fractures, grain-edge fractures and penetrating fractures. Among them, intra-granular fractures are the most developed and the most important micro-fracture type in the reservoir. The second is the most developed grain-penetrating fracture. The development scale of grain-penetrating fracture in the study area is large, cutting through particles, and most of them are effective fractures. The grain boundary seam is less developed, which is mainly developed between the particles, and the connectivity is better. According to the microscopic analysis, the reservoir micro-fractures in the study area are effective, and the open micro-fractures account for more than 60%. Most of the filled fractures are filled with organic matter and crude oil.

Conclusions: Based on the analysis, the micro-fractures in the reservoir of Jinjinzigou Formation (P_2jj) are mainly affected by diagenesis and tectonism, and their development degree is mainly controlled by internal factors (sandstone grain size, rock debris composition, interstitial content and contact relationship between particles and particles) and external factors (tectonism). Based on the analysis of tectonic stages, there are at least 3 stages of micro-fractures in the study area, which are primary fractures, dissolution fractures, early filling fractures re-split fractures and late cutting fractures. In general, micro-fractures are not developed in tight sandstone reservoirs in the study area. In medium-fine sandstone, micro-fractures are developed in siltstone, and micro-fractures are more developed. In argillaceous siltstone, the development of micro-fractures is weak, and in mudstone, micro-fractures are basically not developed.

Keywords: micro-fracture; genetic types; tight sandstone reservoir; Jinjinzigou Formation; Jimsar sag

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