第48卷 第6期
2023 年 6 月

地球科学 Earth Science
http://www.earth-science.net

Vol. 48 No. 6
Jun. 2023

https://doi.org/10.3799/dqkx.2023.094

我国大型克拉通叠合盆地的走滑构造与油气聚集研究进展

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摘　要：在系统回顾走滑断裂研究历史、形成机制和基本构造特征的基础上，重点讨论了我国大型克拉通叠合盆地走滑构造与油气聚集方面的最新研究进展．概括起来包括：(1)走滑断裂应力和生长机制决定了走滑断裂体系和构造样式具有“平面分区、走向分段、侧向分带、垂向分层、层内分异”特征；(2)板内走滑断裂与油气富集关系表明走滑断裂带具有“控源、控输、控储、控圈、控藏和控富”作用；(3)这种断控孔缝洞型储集体的表征可以从露头测量→测井资料刻画→三维地震雕刻3个方面进行，其核心是裂缝密度的分布与预测；(4)板内走滑断裂带断控油气藏通源性、充注过程和年代学研究为克拉通盆地深层－超深油气勘探提供了新的工具．另外，对本专辑发表的论文进行了评述．以期对推动我国克拉通盆地深层－超深层油气勘探起到抛砖引玉之功效．

关键词：板块走滑断裂；克拉通叠合盆地；深层－超深层；断控油气藏；塔里木盆地；四川盆地；鄂尔多斯盆地；石油地质．

中图分类号：P618　　**文章编号：**1000－2383(2023)06－2039－28　　**收稿日期：**2022－11－30

Advances on Relationship between Strike-Slip Structures and Hydrocarbon Accumulations in Large Superimposed Craton Basins, China

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Abstract: On the basis of review of strike-slip fault research history, formation mechanism and principal structural characteristics, the relationship between strike-slip fault in intraplate cratonic basins and hydrocarbon accumulation in China are emphatically discussed in this paper, which can be outlined as follows. (1) Strike-slip fault stress, growth mechanism and structural style determine the strike-slip fault belt having five features of “different systems in planar, segmentation in strike, zoning in lateral, layering in vertical, and differentiation within layers”. (2) The relationship between strike-slip faults within intraplate and hydrocarbon accumulation indicates that the strike-slip fault plays six roles of “controlling source, transmission, reservoir enhancement, trap-forming, reservoiring, and hydrocarbon enrichment”. (3) The delineation of this strike-slip-controlled reservoir bodies can be conducted from outcrop measurement to log data depiction to 3D seismic data characterization in steps, and the key is fracture distribution acquirement and fracture density prediction. And (4) the studies of hydrocarbon sourcing, charging and dating for the exploration of strike-slip-controlled reservoirs in intraplate provides a strong tool in the deep and ultra-deep cratonic basins in china. In addition, the comments of published papers in this special issue have been made. The expectation of this issue is serving as a modest spur to promote hydrocarbon exploration to come forward with the valuable contributions in China in future.

基金项目：国家科技部“973”课题(No.2012CB214800)；国家自然科学基金重点项目(No.41730421)；面上项目(Nos.42072176，42272169)；国家科技重大专项(No.2016ZX05004-001)．

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引用格式：陈红汉，2023.我国大型克拉通叠合盆地的走滑构造与油气聚集研究进展．地球科学，48(6)：2039－2066.

Citation: Chen Honghan, 2023. Advances on Relationship between Strike-Slip Structures and Hydrocarbon Accumulations in Large Superimposed Craton Basins, China. *Earth Science*, 48(6): 2039－2066.

Key words: intraplate strike-slip fault; superimposed craton basin; deep-superdeep; strike-slip fault-controlled reservoir; Tarim basin; Sichuan basin; Ordos basin; petroleum geology.

1 走滑断裂研究历史回顾

李四光(1962)从20世纪30年代以来一系列有关旋扭构造的研究,成为世界走滑构造研究的重要部分.张文佑(1992)的X型剪切破裂及黄汲清(1984)的剪切型深断裂均将平移断层提到重要高度.20世纪60年代以来,我国一些著名的平移断层被查明并开展了研究,如东部的郯庐断裂带(陈丕基,1988;徐嘉炜,1995;Qi *et al.*,2013)、阿尔金断层(张治洮,1985);红河－哀牢山断层(吴海威等,1989)、地震活动的鲜水河断层(罗灼礼,1987)及富蕴断层(林传勇和范福田,1984).走滑盆地研究有富火山岩的宁芜盆地(姜波和徐嘉炜,1989)、活动的海原盆地(邓起东等,1989)与含油气的百色盆地(侯建军等,1993);王燮培和谢德宜(1989)研究含油区的花状构造,提出了走滑构造作用是大陆走滑造山带与走滑盆地形成的重要机制(刘和甫等,1999;刘池洋等,2015).钟嘉猷等(1982)和单家增(1996)较早地开展了走滑断层实验研究.

自1988年美国地质学会成立100周年之际全面详细评述走滑断裂在过去100年的研究历史和进展以来(Sylvester,1988),又过去了34年,走滑断裂研究在以下方面取得长足的进展:(1)走滑断裂的深部构造特征(Zhu,2000;Rostirolla *et al.*,2003;Yin and Taylor,2011;Cao and Neubauer,2016);(2)走滑断裂的应变承载及分解机制(张建新等,1998;Jones,2003;Aydin and Joussineau,2014);(3)走滑断裂与深部流(气)体的关系(Kennedy *et al.*,1997);(4)走滑断裂的活动特征与地震活动的关系(Liu *et al.*,2003;Liu *et al.*,2004);(5)走滑断裂与其两侧的(古)地形地貌(Spotila *et al.*,1998;Yule and Sieh,2003)以及沉积环境(丘滩体)(Wen *et al.*,2022)的关系;(6)板内走滑断裂与油气聚集(许志琴等,2004;焦方正,2017;潘杰等,2017;焦方正等,2021;郑和荣等,2022).

文献调研结果表明,20世纪90年代开始,有关走滑断裂研究中、英文论文发表数量开始稳步增加,至21世纪20年代英文论文数量达到900余篇/年;中文论文数量达60余篇/年.同期,走滑断裂与油气方面的研究英文论文数量从低于10篇/年,增加到60多篇/年;中文论文数量达30余篇/年(图1).由此可见,走滑断裂与油气聚集研究成为相关进展的重要推动力.

2 板内走滑断裂形成机制及特征

早古生代早期,塔里木板块、华北板块和扬子板块隶属东亚微陆块,南北分别为早期原特提斯洋和古亚洲洋;早古生代末－晚古生代古特提斯洋也开始打开(李三忠等,2016).3个洋盆分阶段先后作用于这些微陆块,随着埃迪卡拉生物大爆发(Craig *et al.*,2009),在板缘/板内裂谷系广泛发育了早古生代优质烃源岩(李江海等,2013;管树巍等,2017;Zhu *et al.*,2017),为板内深层－超深层油气富集奠定了坚实的物质基础(Lottaroli *et al.*,2009).

根据板块构造理论,经历了Rodinian超级古陆解体之后,于加里东中期I幕开始了新一轮的板块聚合旋回.随着Gondwana大陆拼合进程不断推进,塔里木、华北和扬子以及中间的微陆块在早古生代就完成了古中国联合陆块的聚集和造山(董顺利等,2013).大量年代学资料表明,阿尔金－祁连－昆仑地区洋盆在晚新元古代开启,寒武纪发育成熟,于中－晚奥陶世开始发生俯冲消减作用,晚志留世－早泥盆世陆块或岛弧发生碰撞(李三忠等,2016).正是由于这种由离散转换成聚敛的盆－山耦合机制形成的压扭性区域应力场背景(许志琴等,2004),在板内形成了一种独特的构造响应之一——通过平面应变分解作用(strain partitioning)来实现应力场转换,形成与盆缘或一级构造带呈大角度或近垂直角度突变式交切且终止的(张建新等,1998;徐怀民等,2008;吕海涛等,2017;潘杰等,2017;马德波等,2018;黄雷等,2022)、具有似"均匀间隔(even space)"特征并俗称"虎斑"(tiger-strip)的(Yin *et al.*,2016;Zuza *et al.*,2017)、板内"小位移、长"走滑断裂(Harding, 1974;Deng *et al.*,2019;邬光辉等,2021;王清华等,2021;管树巍等,2022).

板内走滑断裂由于远离活动板块边界,与滑移距通常在数百米至数千米尺度的板块边界型、嵌入碰撞型走滑断裂等存在显著差异.它是板内先存构造(例如,薄弱带、破裂或断层)在应力集中下再活

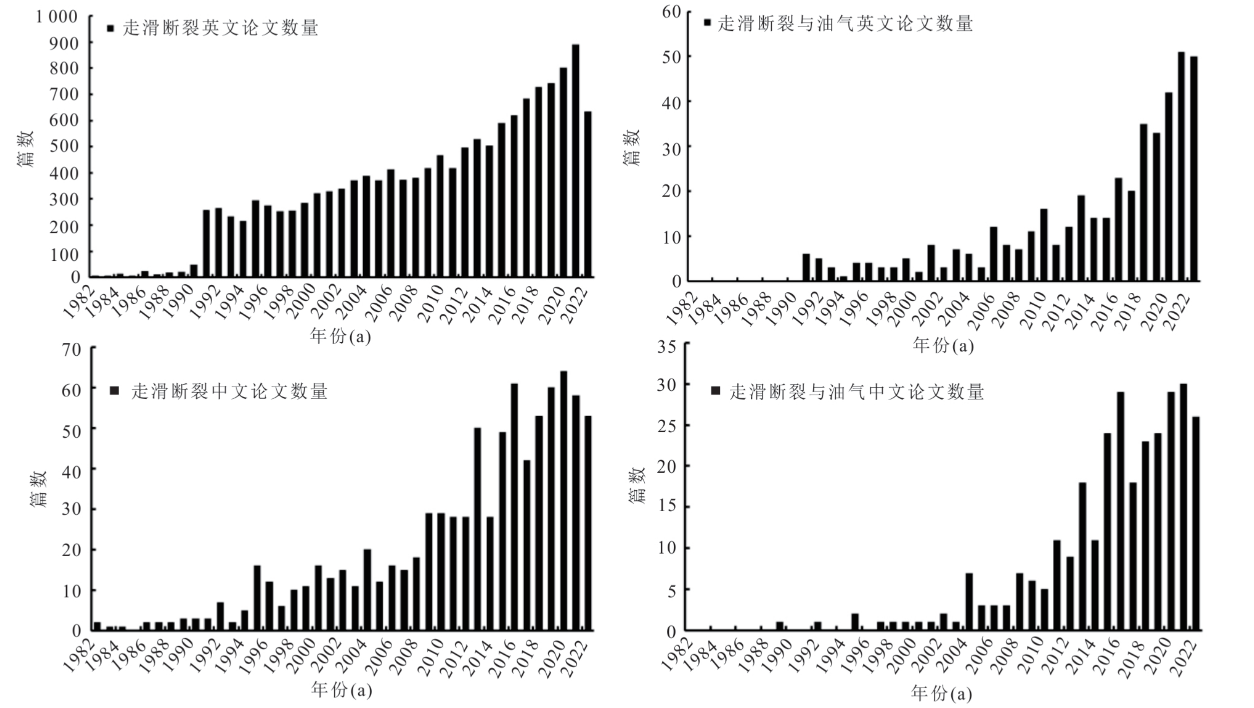


图1　走滑断裂及其与油气聚集相关研究发表的论文统计直方图

Fig. 1　Statistical histograms of globally published articles with the topics of strike-slip fault and its related hydrocarbon accumulation

统计时间为1982年1月1日至2022年10月30日；中文文献来自于中国知网CNKI；英文文献来自于Web of Science

动而形成的，滑移距多在数百米尺度，活动弱且产状高陡(Mann，2007；Aydin and Berryman，2010)．由于板内"小位移"走滑断裂在二维地震资料中难以被识别，长期以来被人们所忽视(Gogonenkov and Timurziev，2010；Timurziev and Gogonenkov，2015)，而三维地震资料为这种板内地下小位移走滑断裂的正确识别提供了一种有效的工具．

在构造地质学中，走滑断裂基本特征可概括为以下几个方面．

(1)走滑断层应力机制：由扭应力或剪切应力引起地壳或岩石圈沿着某些构造边界或特定的构造带发生走滑变形的构造作用称为走滑作用．走滑作用产生的各种构造变形组合称为走滑构造(朱志澄和宋鸿林，1990)．走滑断层是走滑构造中最重要的构造要素．走滑断层是指沿断面走向一盘相对于另一盘作水平运动．Anderson(1951)认为这种断层的应力状态是最大主应力轴(σ_1)和最小主应力轴(σ_3)都是水平的，中间应力轴(σ_2)是直立的，断面近直立．走滑断层有不同尺度，产生于板块构造的不同构造部位．

(2)走滑断层生长机制：刻画走滑断层生长的参数包括断段长度($l_1, l_2, \cdots, l_n$)、阶步宽度(或离距)($w_1, w_2, \cdots, w_{n-1}$)、阶步数($s_1, s_2, \cdots, s_{n-1}$)和阶步长度($o_1, o_2, \cdots, o_{n-1}$)，以及描述走滑断层内部构型的参数：断岩厚度和宽度、围岩、损伤带和断核(图2)．断层通过链接(linkage)和合并(coalescence)相邻断层段或断层串以便适应更大的滑距而变长，通过碎裂变形向高度破裂的内部破碎带演化而得到加宽．断层链接和合并会导致一个重要结果是，合并的断段会发生更大规模的滑动，对于先期的分段状或不连续痕迹而言，这会拉直整个断层呈穿透式的痕迹．这一过程是二次剪切定位现象，在断带实现下一个合并构型后立刻发生，被称为断层贯穿作用(也称作断层矫直或断带简化作用)．同时，随着滑距的增加，沿走滑断层每千米的阶步数会而减少，平均断段长度、断岩宽度和损伤带宽度都会增加(Aydin and Berryman，2010)．

Watterson(1986)给出了走滑断层长度(L)与最大滑距或位移(D)存在以下关系：

$$L=D^n, \tag{1}$$

式(1)中，n在1～2之间取值．而不同尺度测量结果表明，走滑断层的长度与位移呈双对数线性正相关

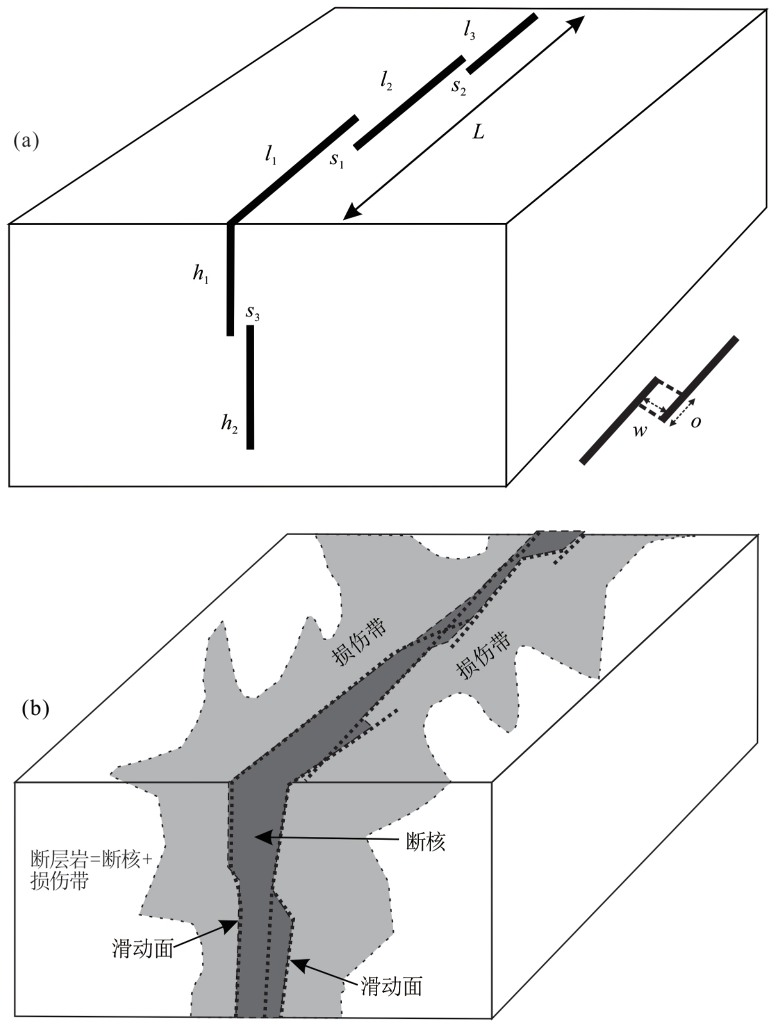


图2　走滑断层基本几何属性图(据Aydin and Berryman,2010)

Fig.2　The basic geometric attribution of strike-slip fault (after Aydin and Berryman,2010)

a.沿走滑断层分段以及各段的长度(l_1、l_2、l_3)、高度(h_1、h_2)、阶步数(s_1、s_2、s_3).阶步长度(o)和阶步宽度(或断层离距w);b.走滑断层的内部构型包括断岩、断面和由损伤带所围的断核

关系,二者之比为3.2(图3).走滑断层的厚度与位移(图4)也是呈双对数线性正相关关系.

平面上,断岩区域通过碎裂变形向高度破裂的内部破碎带演化而得到加宽,即破碎带宽度随着走滑断裂位移的增大而增大,当断层位移量达到一定值后,破碎带宽度逐渐趋于稳定(Aydin and Berryman,2010).垂向上,随着盖层厚度增加,张剪性破裂带宽度而增加,张扭性断裂与基底走滑断裂夹角也增大(<45°).简言之,地层厚度与破裂分布及最大剪切应变关系表现为:地层薄,易贯穿,破裂带窄;反之,地层厚,难贯穿,破裂带宽(代树红等,2006).

(3)走滑断层构造样式:在了解走滑断裂构造样式之前,需要明确以下4个基本概念.

①纯剪切:是一种岩石体积保持不变的、在X或Y方向上的缩短或拉伸共轴变形,不存在内部旋转分量(Fossen,2010).

②简单剪切:是一种岩石体积保持不变、在X-Y面上具有旋转分量的面应变变形,在Z方向上没有线的拉伸或缩短,也没有质点运动.许多地质学家认为这种二维简单剪切和其他非共轴变形都是旋转变形(Fossen,2010).因此,简单剪切可看作"纯剪切+旋转"(罗贤光,1994).

③共轭剪切:是指在同一应力场作用下产生的两组交叉纯剪破裂,二者剪切旋向相反.亦称为X型共轭剪切.形成共轭剪切的边界条件相对来说是比较苛刻的.除了纯剪切条件之外,还需要变形岩石比较均质,两侧的主应力(σ_1)对等(Hafner,1951;

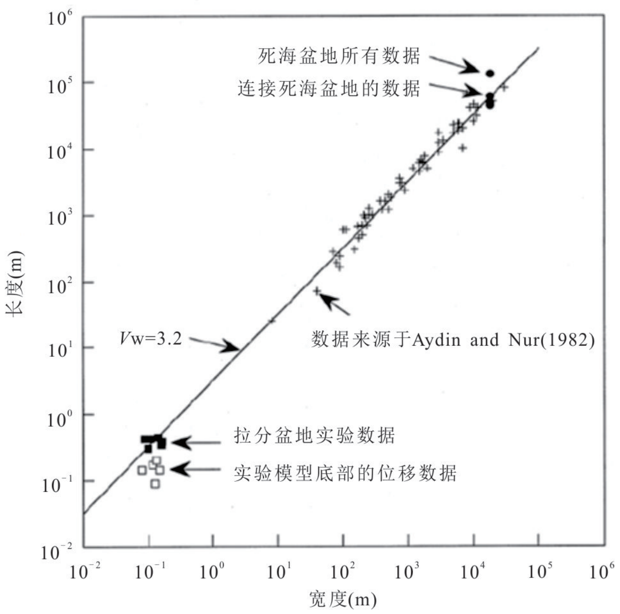


图 3　走滑断层宽度与位移关系

Fig.3　Plot of width of strike-slip fault vs. displacement

据 Aydin and Nur(1982);斜率显示长/宽比为 $l/w=3.2$

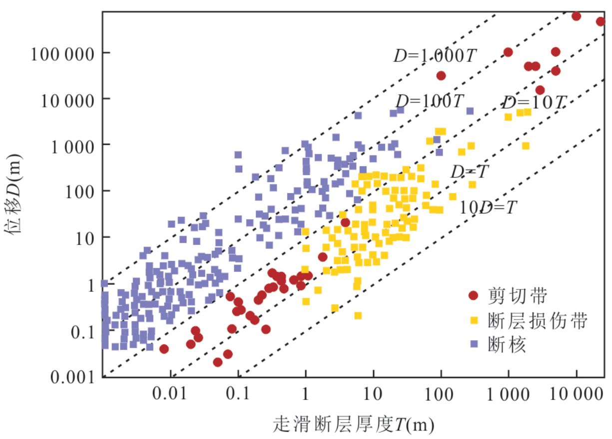


图 4　走滑断层厚度(T)与位移(D)关系(据 Fossen,2010)

Fig.4　Plot of thickness of strike-slip fault vs. displacement (Fossen,2010)

González *et al.*,2008);还可能受到中间主应力(σ_2)的影响,因为对于走滑断裂来说σ_2是垂直的(Anderson,1951),这种影响是通过地层厚度的变化可以改变岩石的内摩擦角和凝聚力强度参数来体现的(周小平等,2005);另外,还可以改变 Riedel 剪切拖曳点(起始点)的深度(代树红,2006).

④应变分解:在与区域主压应力轴斜交的构造变形带,包括板块边缘或者板内变形带,存在两种可能的平面应变方式.(a)斜向运动解耦,形成以单剪应变为主的走滑断裂系统和以纯剪应变为主的挤压构造系统(形成包括褶皱、逆断层在内的构造型式)(Fitch,1972;Wittlinger *et al.*,1998;张建新等,1998),这就是所谓的变形分解;(b)并不发生分解,而是形成以单剪和纯剪分量强烈耦合的扭压和扭张构造系统(Harland,1971).变形分解在扭压带中是较为普遍的构造现象,特别是在盆－山耦合过程中,克拉通内部变形带为适应造山所施加的外加边界条件而产生的运动学响应(Tikoff and Teyssier,1994).另外,同一条走滑断裂在穿过不同构造层时由于能干层和非能干层内摩擦角和凝聚力的差异,也会导致垂向上的应变分解,并体现在走滑断裂系统的垂向分层性(Carlini *et al.*,2019).

在地壳深部主走滑位移带往往是一条走向稳定、线性延伸的走滑主干断层,称作主走滑位移带 PDZ(principal displacement zone),向上发散可能与浅层的破裂面连接在一起构成网状的破裂带.走滑构造带内和主要走滑位移带附近区域,由走滑位移引起的各种相关构造,称为伴生构造(associated structures).如:①同向走滑断层(synthetic strike-slip fault)或里德尔(R)剪切破裂,与 PDZ 带呈小角度(通常小于15°),剪切方向与主位移带一致的次级走滑断层,角顶指向本盘断块位移方向(以 PDZ 为标准);②反向走滑断层(antithetic strike-slip fault)或共轭里德尔(R')剪切破裂,与 PDZ 呈大角度相交(60°～70°)且剪切位移方向与 PDZ 相反的次级走滑断层;③同向剪切破裂(P):次级同向断层(secondary synthetic fault).与 PDZ 呈小角度(一般<10°)相交,剪切位移方向与 PDZ 一致,角顶指向本盘断块位移方向;④局部张性破裂(T):与 PDZ 呈大角度相交且延伸不长的断层组,断层走向与应变椭圆中的局部伸展方向垂直;⑤Y 剪切:与 PDZ 平行的断层;⑥局部收缩变形:雁列式褶皱(en echelon folds)、缝合岩面和逆断层组,其走向基本与褶皱轴一致,与应变椭圆中的局部收缩方向垂直,且仅在构造带内发育且延伸不长(图 5).其中,①、③和⑤的剪切方向一致,在走滑构造递进变形过程中可相互沟通连接,组成交织的辫状或豆荚状走滑断层带.R'剪切在剪切旋转中可以不发育(Fossen,2010).

理想的走滑断层是一条非常平直的直线.然而,即使最简单的实验模型也会产生次生断层或断层分段;而这些次生断层或断段与断层总体趋势呈斜交.这种异常现象通常用断层链接(fault linkage)加以解释.当单个断层段在平面图上叠置或链接

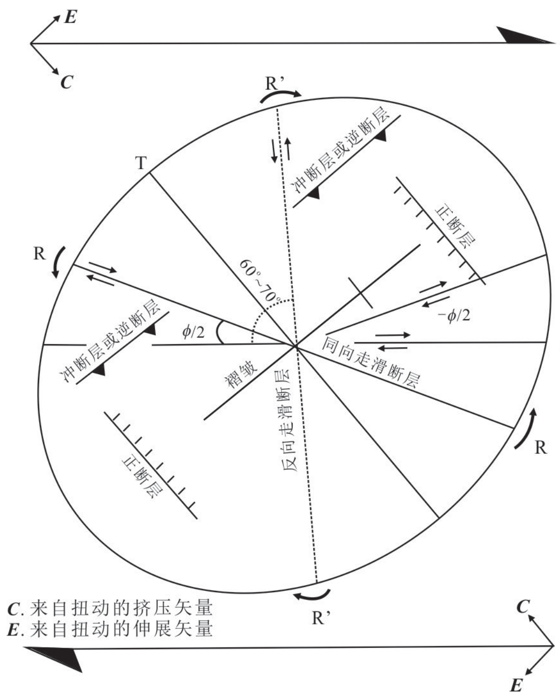


图5 运用应变椭圆图示右行力偶产生的各种走滑构造

Fig.5 Using strain ellipse produced by dextral couple schematically to exhibit composite structures in strike-slip fault belt

据Harding(1974);PDZ为主位移带;P为同向剪切断层;T为张断层;R和R'分别为同向剪切和反向断层;ϕ为内摩擦角

时,就形成了断阶或断弯(fault bend).断弯中形成压扭构造还是张扭构造取决于阶步(stepover)与断层滑动之间的关系.李四光(1962)首先提出走滑断层这种双重力学性质(Woodcock and Fischer, 1986).Harland(1971)应用到板块构造中去,称为走滑—挤压(transpression)和走滑—伸展(transtension)(Holdsworth *et al.*,1998;刘和甫等,2004;Cunningham and Mann,2007).

譬如,形成于左旋走滑断层左侧(或右旋走滑断层右侧的断阶区)的伸展弯曲带发育正断层和张性裂缝.在中等尺度弯曲带,张性裂缝非常普遍,而较大尺度下的断层具有十分显著正向滑动分量.被两条走滑断层所限的一系列平行伸展断层即称之为伸展—走滑双重构造(extensional strike-slip duplexes).正断层产生负向构造,也称作拉分地堑(图6).

形成于左旋走滑断层右侧断阶区(或右旋走滑断层的左侧断阶区)的挤压弯曲带发育的挤压构造包括缝合岩面、节理、褶皱和逆断层.在两条走滑段所限定的区域形成亚平行逆断层或斜向滑动挤压断层.这就是所谓的挤压—走滑双重构造(contractional strike-slip duplexes).大尺度挤压弯曲带呈现出正地形(造山)(图6).在递进变形过程中挤压构造可被一组新的、平直断层带所切割.尽管在挤压弯曲带内部的应变硬化作用(strain hardening)会因此而减少或消失,但还会有一些不规则的构造会保留下来.挤压带还可能发育一些新的断层,譬如P剪切断裂.

在地壳表层见到的走滑断层常常具有分段性(segmentation),即一个宏观的走滑断层,常由许多近于平行的次级断层斜列而成.无论在上百公里级的大断层上(如圣安德烈斯断层)(Fossen,2010),还

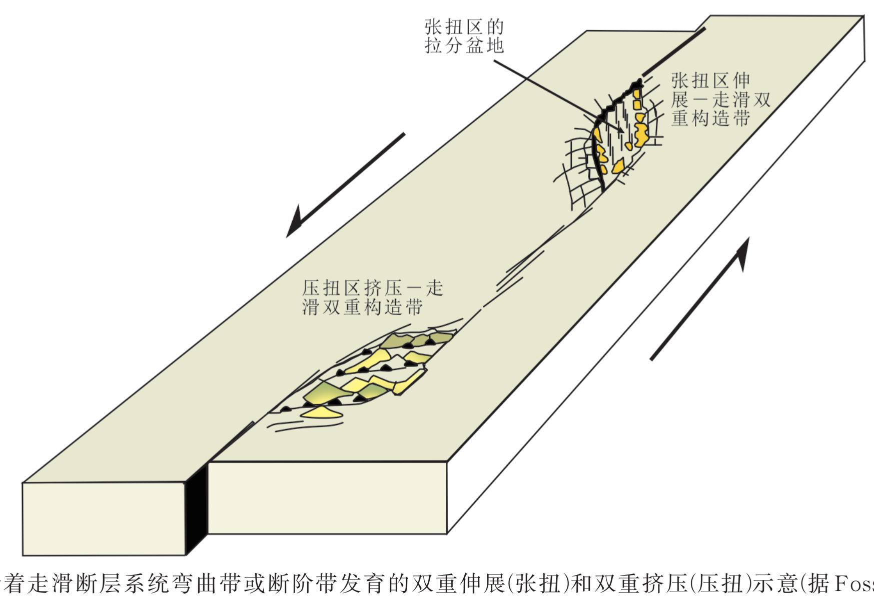


图6 沿着走滑断层系统弯曲带或断阶带发育的双重伸展(张扭)和双重挤压(压扭)示意(据Fossen,2010)

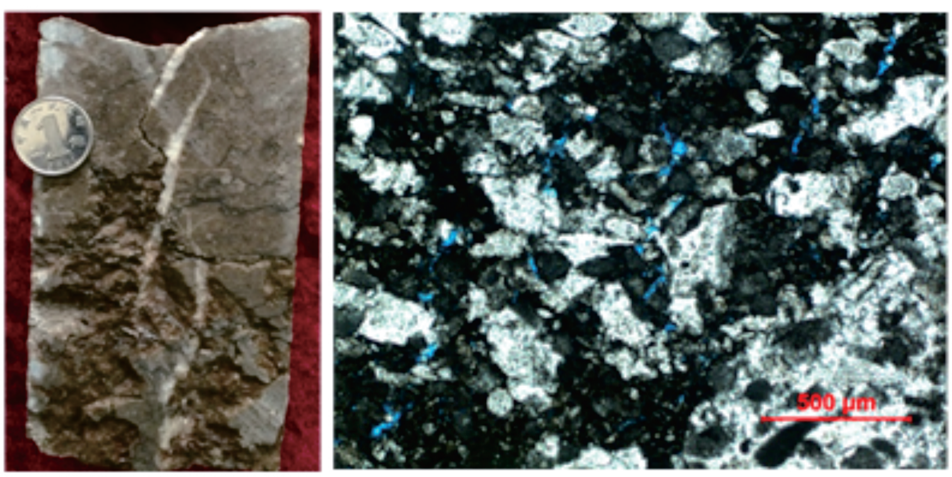
Fig.6 Schematic diagram showing contractional extensional strike-slip duplexes (transtensional deformation) and strike-slip duplexes (transpressional deformation) at bends or stepover along strike-slip fault system (Fossen, 2010)

是走滑断裂带内部手标本（图7a）和显微尺度（图7b）上都可见到发育这种剪切构造．即使在走滑断裂物理模拟实验这样的“均质”条件下同样出现分段性（McClay and Bonora，2001；Dooley and Schreurs，2012）．走滑断裂分段性的根本原因是在剪应力作用下，岩石沿潜在的主滑动带的各个初始破裂点的破裂方向与主断裂方向的斜交所致（宋鸿林，1996），也是走滑断裂的一种链接方式（Aydin and Berryman，2010）．各分段断层头尾互相重叠的地段，称为叠接带（stepover zone）（图2）（Swanson，2005）．由于要满足应变的协调性及体积平衡的原则，在水平面上的体积缩小，必将引起垂向上的地壳加厚和挤起，从而形成推起型构造（push-up）或推闭型构造（push-close）．反之，将形成垂向上的地壳变薄和下陷，形成拉分地堑/盆地．

叠接带按两条断层排列方式可分为左阶式和右阶式：沿分段断层向前时，下一个断层出现于左侧称为左阶，出现于右侧的称右阶．一般认为，按其排列方向和两盘相对运动方式，相当于走滑断层的Riedel单剪模式中的R和P破裂面，二者分别与主滑动面成$\pm\phi/2$角度（ϕ为岩石的内摩擦角）（图5）．故右行右阶或左行左阶式破裂为P型破裂，右行左阶或左行右阶式破裂为R型破裂（宋鸿林，1996）．这就从理论上解释了为什么在简单剪切模拟实验和自然界走滑断裂带中常见的是R型破裂．

需要说明的是，前人还总结了导致走滑断裂带分段性的其他因素．诸如：①地质体非均质性（先存软弱带或破裂带）（Fossen，2010；Dooley and Schreurs，2012）；②扭动应力场下，压应力衰减所致，即应力－遮蔽作用（stress shadow）（Yin *et al.*，2016）．但这些不同因素造成走滑断裂带分段性之间的差异性至今仍不清楚．

块体之间的斜向作用（斜向拉张或斜向挤压）是普遍存在的（Woodcock，1986；王燮培和谢德宜，1989），从而在深部形成较为平直的走滑断裂、在浅层拖曳点处开始形成由多条断裂组成撒开的、形似花状的扭断裂带（wrench fault belt），称为花状构造（Wilcox，1973；Harding，1974；王燮培和谢德宜，1989；宋鸿林，1996；刘和甫等，1999；漆家福等，2006）．随着3D地震（属性）成像分辨率的不断提高，能够识别出地下（半）正花状、（半）负花状和花上花（多期走滑运动形成的反转构造：正花上叠负花构造）等各种花状构造．花状构造不仅常常被用作判断深部存在走滑断裂的重要依据，而且还反映了走滑断裂构造的垂向分层性．对塔里木盆地顺托果勒地区F_I17走滑断裂带（中石化西北油田分公司命名为SB4号）的解释，认为发育6期构造活动，不同构造层走滑断裂发育特征差异显著：深部走滑断裂较为平直，但自加里东中期Ⅲ开始发育压扭正花状构造，在加里东晚期－海西晚期反转成张扭的负花状



(a)　(b)

图7　走滑断裂带中不同尺度下雁列方解石脉显示的剪切构造照片

Fig.7　Photos of the en echelon calcite veins showing shearing structures in the strike-slip fault belts

a.塔里木盆地跃进3-3井奥陶系一间房组(7 187.35 m)走滑断裂带内垂直雁列方解石脉岩心照片；b.塔里木盆地富满油田满深5井奥陶系(7 608.12 m)走滑断裂带内亮晶砂屑灰岩中雁列状微裂缝(蓝色铸体薄片所示)显微照片(张秋艳提供)

构造(图 8).尽管前人总结出“盐下断裂控源、穿盐断裂控运、花状构造控储、晚期雁列控聚”的认识(Shen *et al.*,2022;能源,2021,内部材料),但对于各构造层走滑断裂带之间的流体连通性至今仍了解得还远远不够.

另外,在走滑断层面倾斜方向相同的情况下,在一个横切剖面上显示为正断层,而在另一个剖面上显示为逆断层.即相邻剖面的相对升降盘、滑距类型和方向不同.这种现象称为海豚效应(dolphin effect).

走滑断层总体来看是近于直立的,但沿其倾向有变化,造成有正断层和逆断层的表现.这种现象称为丝带效应(ribbon effect).

(4)板内走滑断裂体系:在盆－山耦合过程中,板内变形在平面上往往受到多边界不均衡挤压应力体制作用,在垂向上还可能受到基底先存断裂的影响(黄少英等,2021;邬光辉等,2021).在这种聚敛型应力场下,为了满足应变的协调性和体积平衡,除了掀斜、褶皱隆升和走滑拉分下陷等变形之外,走滑断裂本身就是板内一种“调节型”变形.走滑断裂的发育可能会出现3种情况:继承和新生的走滑断裂以及先存走滑断裂停止活动.但在多边界挤压应力体制和不同应力场多期走滑活动下,走滑断裂总体特征受到其最靠近的边界条件控制更加明显一些.如此,会相应地形成多种走滑断裂体系,且不同走滑断裂体系之间主要靠调节型走滑断裂来均衡(McClay and Bonora, 2001; Mann, 2007; Neng *et al.*,2022).由此会导致不同走滑断裂带差异变形以及油气成藏和富集的差异性(周新源等,2013;邓尚等,2018;云露和邓尚,2022)

以塔里木盆地为例,自加里东中期Ⅰ幕(中奥陶世末期)开始台盆区从伸展体制转变成西南、东南和北部3面挤压应力的“三面挤压、北弱南强”的动力学环境,形成了统一的大型走滑断裂系统.其中,F_I5走滑断裂受到西南方向的挤压应力场影响最大,呈弧形,调节了东、西两侧地块的运动差异,是台盆区东、西部走滑断裂系统的分界线,而F_I10、F_I17等调节型走滑断裂则分解了南北向地层缩减,构成了走滑断裂体系的边界,控制了不同走滑断裂体系中走滑断裂的构造样式、发育范围和程度.据此可划分为4个走滑断裂体系:①塔北隆起纯剪X型断裂体系;②塔中隆起NE向左行“均匀间隔”断裂体系;③巴楚隆起NW向右行断裂体系;④阿满过渡带调节型断裂体系(吕海涛等,2017;李国会等,2021;Deng *et al.*,2022;刘雨晴和邓尚,2022)(图9).在这些调节型走滑断裂中,与主应力方向直

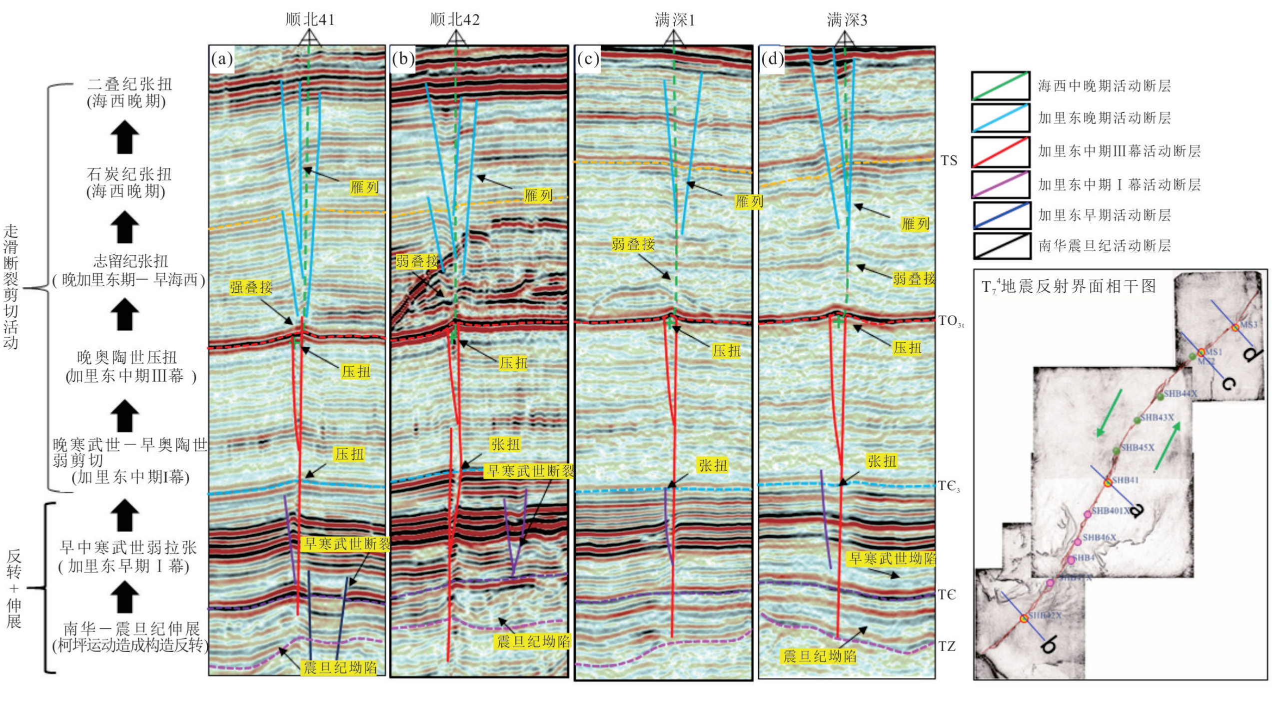


图8　塔里木盆地顺托果勒地区F_I17号走滑断裂带复式花状构造(引自能源,2021,内部材料)

Fig.8　3D seismic profile showing composite flower structures in No. F_I17 strike-slip fault in Shuntuoguole area, Tarim basin (after Neng, 2021)

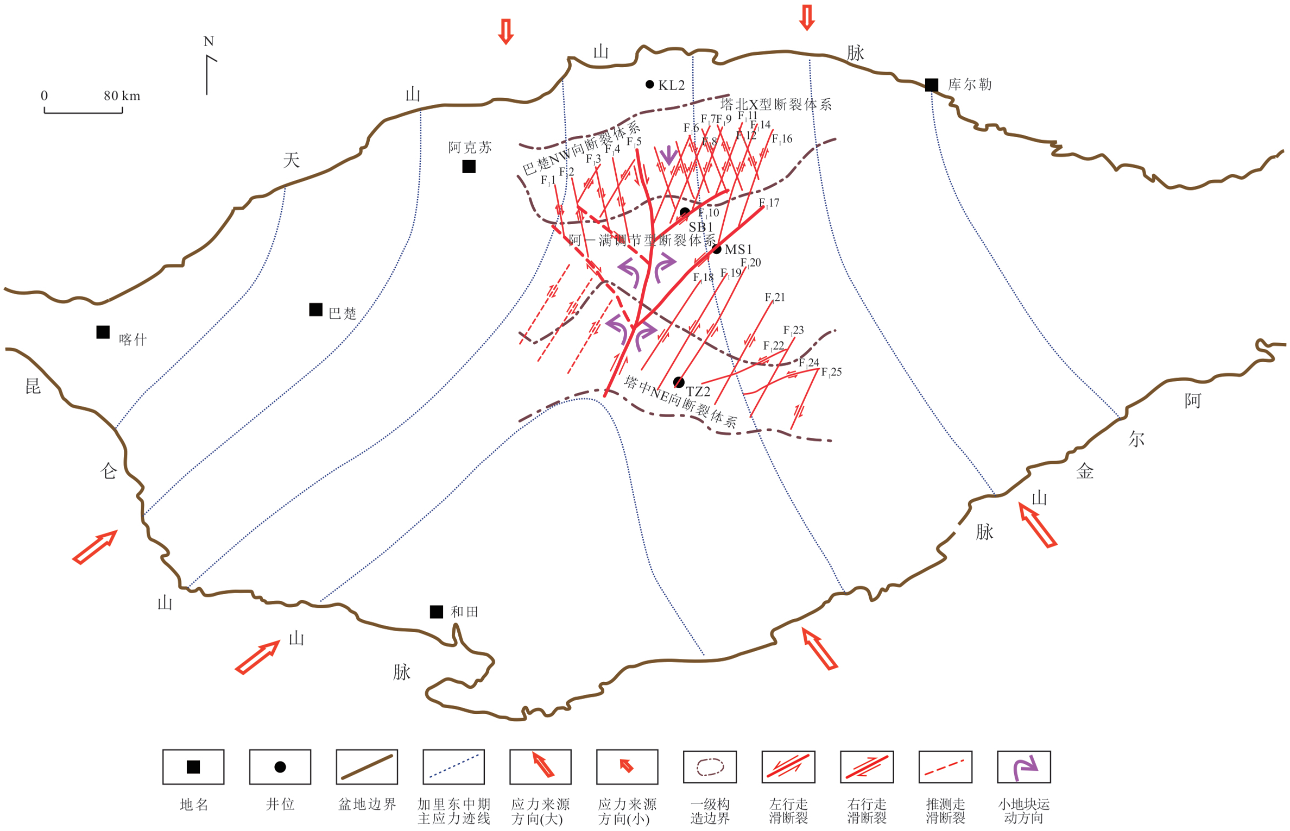


图 9　塔里木盆地台盆区加里东中期Ⅲ幕应力场与走滑断裂带体系划分叠合(据李国会等,2021 修改)

Fig.9　Map showing the strike-slip fault system division in the cratonic Tarim basin (modified from Li *et al.*, 2021)

交的以压扭型为主(例如,F$_{I}$5),而与主应力平行的则以张扭为主(例如,F$_{I}$10、F$_{I}$17).由此影响到走滑断裂带中裂缝的张开度,进而影响到油气的充注、储集体的发育和规模以及产能.显然,张扭为主的走滑断裂带,沿着走向发育更多的拉分地堑段,产能也是最高的(邓尚等,2018).

(5)走滑断层内部构型:断层属性包括长度、宽度、倾向/倾角、位移、断岩厚度和内部构型等.一般情况下,走滑断裂内部构型具有二元结构(Schröckenfuchs *et al.*,2015),包含断核(fault core)(剪切带中的滑动面和擦痕、断层泥、糜棱岩、碎裂岩和角砾岩等)和围绕断核的损伤带(fault damage zone)(裂缝化围岩中的低序次断层、裂缝、脉体和与走滑断层相关的褶皱等)(图 10).因此,断层的宽度实质上就是断核与损伤带的宽度之和.

de Joussineau and Aydin(2007)根据野外观察结果,认为走滑断裂损伤带的宽度是随着滑动距离的增加而增加(图 11),并且在总结前人认识的基础上给出了不同因素条件下的损伤带构造样式概念模型(图 12).

大量多尺度测量研究建立起了走滑断层宽度(损伤带+断核的宽度)与位移呈双对数线性正相关关系,即损伤带+断核的宽度是随着滑动距离的增加而增加(Evans, 1990; Aydin and Berryman, 2010),但数据点比较分散,达不到定量预测的精度(Choi *et al.*,2016).若损伤带的宽度可由诸如裂缝、低序次断裂和变形带等损伤性构造的频率分布来定义.一般情况下,这些损伤性构造发育的频率自断核→损伤带→围岩会逐渐降低(Goddard and Evans,1995).为此,可用裂缝密度累计频率分布曲线的折点来定量确定断核与损伤带、损伤带与围岩的界线,从而对走滑断裂带侧向分带性进行划分并获得断核、损伤带和断层宽度(Choi *et al.*,2016).

由于断层损伤带对于与流体渗流相关的成藏—成矿、地下水、水库大坝和地下核污染处置以及地震波传播等众多领域均具有重要影响,Peacock *et al.*(2017)在总结前人工作的基础上,给出了一个更为广泛的"平面形态"分类(图 13).

3　板内走滑断裂带断控油气成藏系统

与走滑断裂相关的油气聚集研究最早可追溯

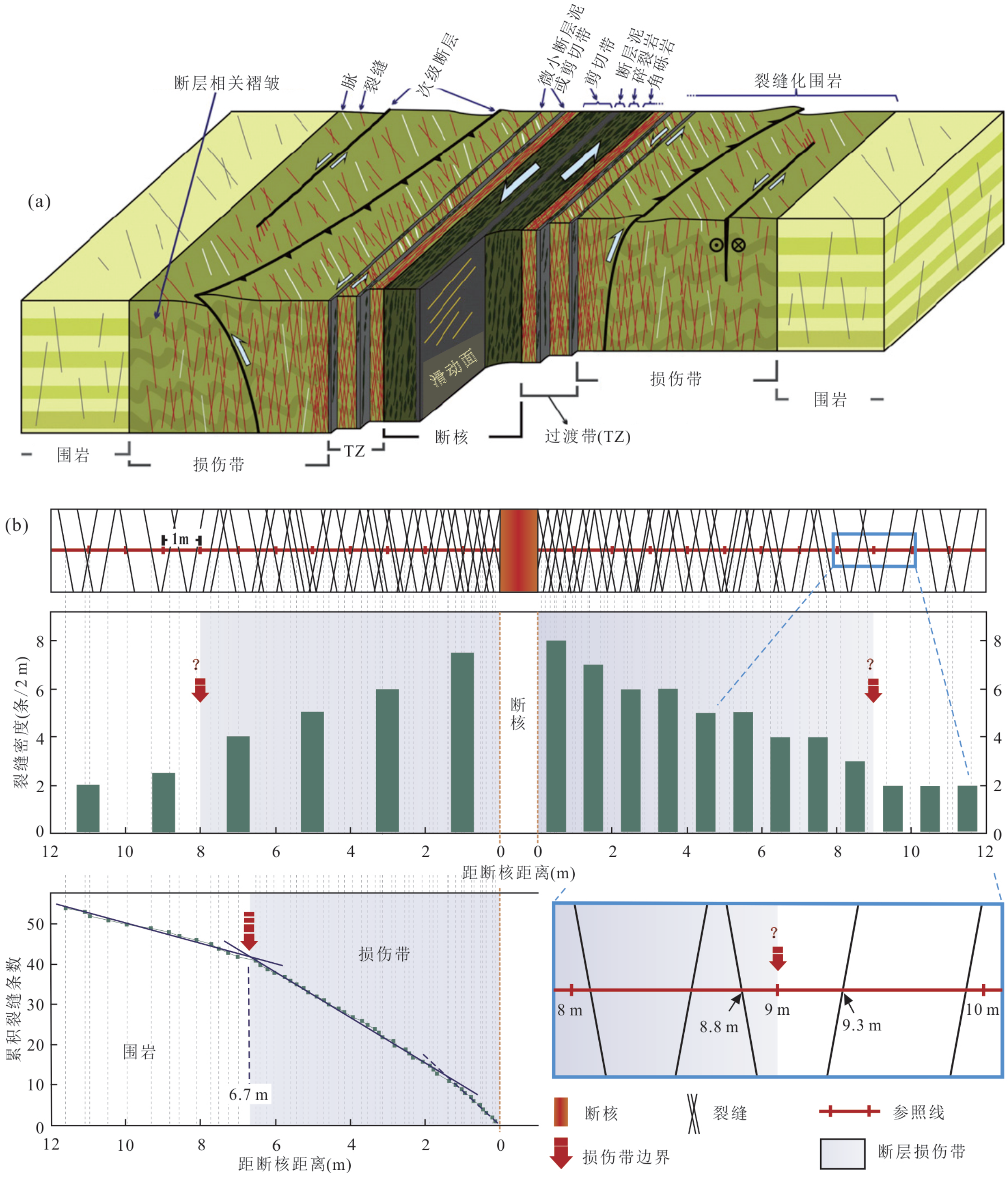


图10 走滑断层损伤带立体概念模型图(a)和确定断层损伤带及断核宽度示意(b)(据Choi *et al.*,2016修改)

Fig.10 Conceptual block diagram of strike-slip fault damage zone (a) and schematic diagram of determining the fault damage zone width (b) (after Choi *et al.*, 2016)

到20世纪走滑构造(李四光,1962;Sylvester,1988)、走滑拉分盆地以及与走滑构造相关的圈闭(Wilcox *et al.*,1973;Harding,1985;王燮培和谢德宜,1989;刘和甫等,1999;Aydin,2000)、对烃源岩和储层发育以及油气成藏的控制作用等(汤良杰,1992;范秋海等,2008;张承泽等,2008;邬光辉等,2011).而将走滑断裂带作为一个"地质体"的概念来理解和油气圈闭的勘探目标,则经历了一个相当长的过程(罗群等,2004;夏义平等,2007).长期以来,西方将之统称为与走滑断裂相关的油气藏(Harding,1974;Sylvester,1988;Caine *et al.*,1996;Alaei and Torabi,2017;Peacock *et al.*,2017).

前苏联学者首次把这种与走滑断裂带相关的圈闭称为"脉型油气圈闭",并强调其形成于地震应

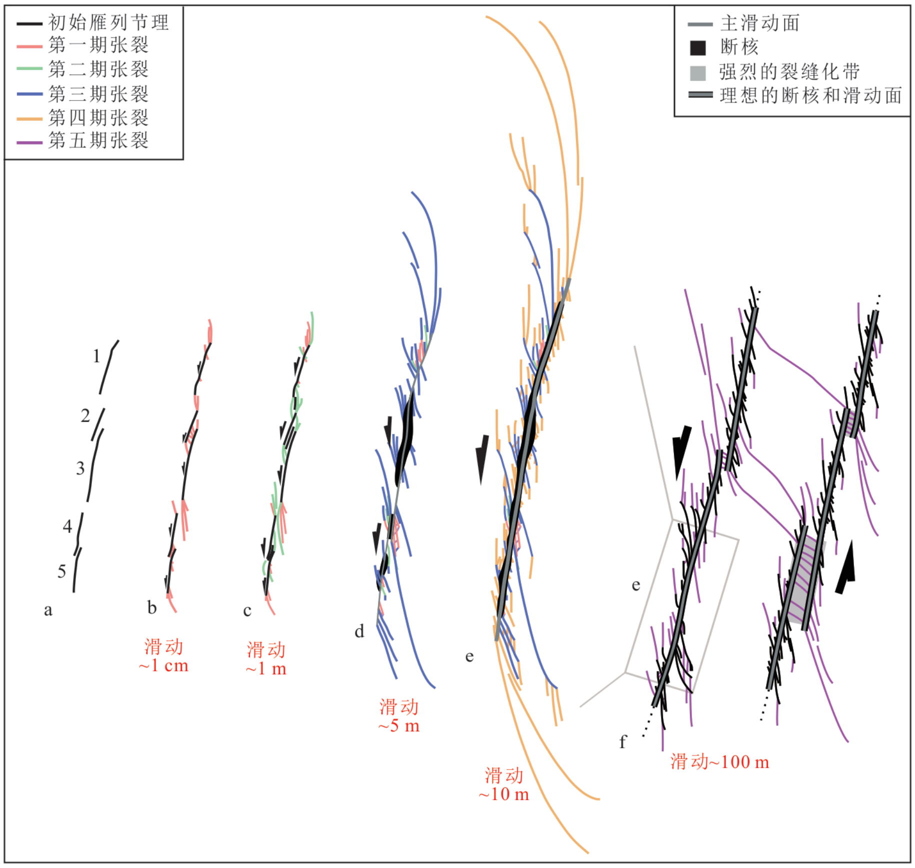


图 11　走滑断层不同生长阶段损伤带演化概念模型(de Joussineau and Aydin，2007)

Fig.11　Conceptual model of damage zone of strike-slip fault during different growth stages (de Joussineau and Aydin，2007)

力带上，通过膨胀与破裂和热液改造，极大地提高原先基本不渗透岩石的储集性能，其孔隙度可达20%，形成具备油气储集能力的圈闭．若地震应力带分布很接近，因热液活动性在有利层位的扩展，可以使两个或多个独立脉型圈闭合并成一个层状圈闭(Белкин and Медведский，1989)．

2007年俄罗斯资源委员会“西西伯利亚中部走滑形变及其在普查、勘探和开发油气田中的作用”的报告中不仅明确表明只有三维地震资料才能发现基底走滑断层构造，而且在2005年按照走滑断层构造理论提出的西西伯利亚叶特—普罗夫油田的侏罗系7口探井全部获得工业性油流，2007—2008年钻探30口井又都获得工业性油气流．即在走滑断层构造区部署的探井钻探成功率达到100%，并总结出如下几点重要认识：(1)走滑断层区存在一种新的油藏类型——层状—带状型油藏；(2)提出了这种走滑断裂带非传统的层状—带状油气聚集带储量计算和远景圈闭等级分类方法；(3)强调了天然裂缝描述和预测对这种油气藏开发的重要性(Gogonenkov and Timurziev，2012；齐穆尔基耶夫和戈戈宁科夫，2015)．

在四川盆地海相油气勘探过程中，就有许多学者提出与背科圈闭和断层圈闭不同的“储渗体圈闭”的概念(唐泽尧，1989；黄继祥等，1996；王兴志等，1998；谷溪，1999)，但没有与走滑断裂关联起来．塔河南走滑断裂带“断溶体”油气藏(鲁新便等，2015)、四川盆地致密砂岩“断缝体”气藏(王威和凡睿，2019；刘振峰等，2021)和鄂尔多斯盆地鄂南地区与走滑断裂相关的延长组致密砂岩“断缝体”油藏(何发岐等，2020)勘探开发，开启了对这种断控油气藏的新认识(漆立新，2016；焦方正，2017；李培军等，2017；潘杰等，2017；马永生等，2019；贾承造等，2021；焦方正等，2021；郑和荣等，2022)．

在3D地震属性融合技术大力支撑下，能够对深层—超深层走滑断裂和串珠开展有效识别．中石化西北油田分公司相继在塔里木盆地顺南、顺托和顺北地区深层—超深层走滑断裂带奥陶系碳酸盐岩断控油气藏获得重大突破(焦方正，2017)；顺北油气田18条主干走滑断裂带，落实地质资源量17.00×10^8 t油当量(漆立新等，2021)．同期，中石油

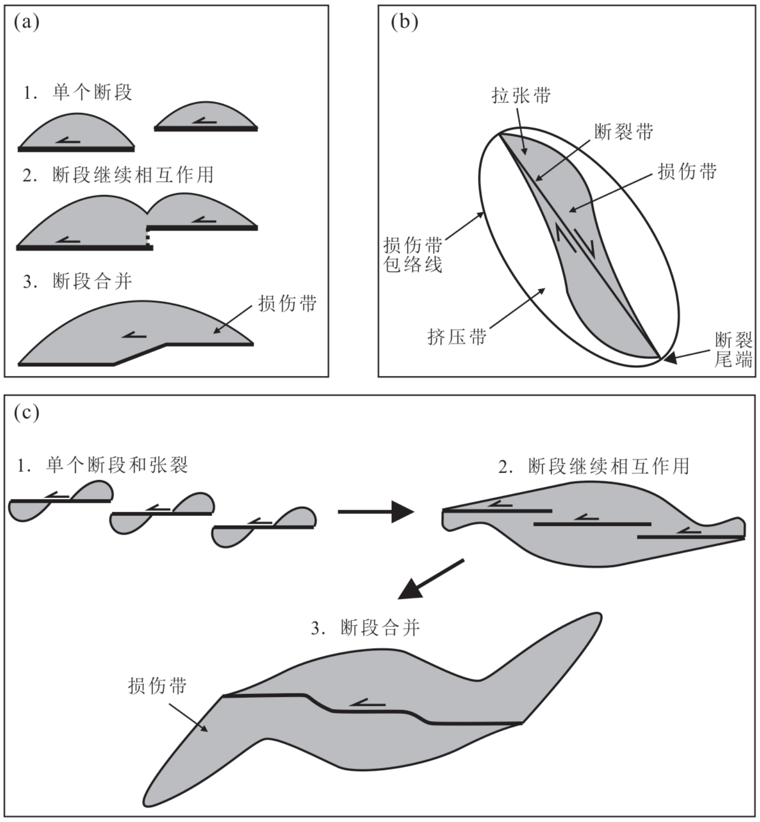


图12　考虑不同因素的损伤带构造样式概念模型(de Joussineau and Aydin,2007)

Fig.12　Conceptual models of structural pattern of damage zone under the considering of different factors (de Joussineau and Aydin, 2007)

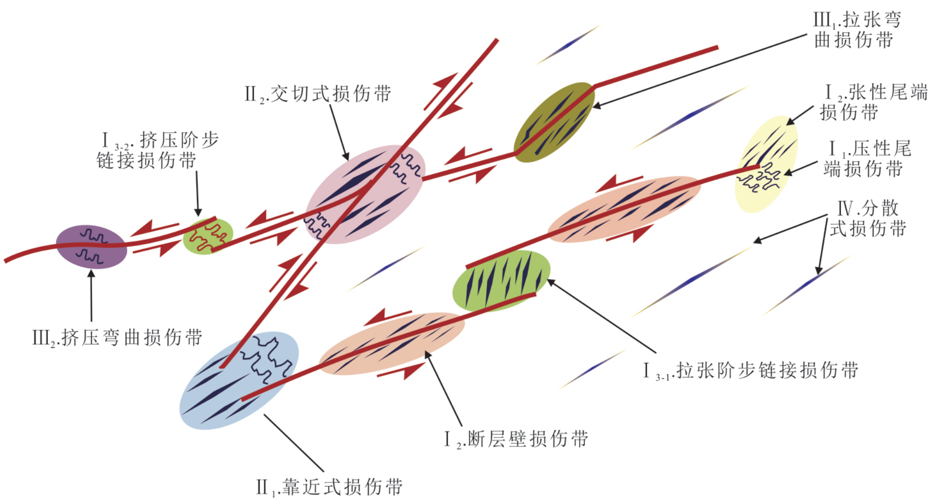


图13　走滑断层损伤带类型划分图(据Peacock *et al.*,2017修改)

Fig.13　Diagram showing classification of different types of strike-slip fault damage zones (modified from Peacock *et al.*, 2017)

塔里木油田分公司在富满油田走滑断裂带落实地质资源量10.00×10^8 t油当量(王清华等,2021;Zhu *et al.*,2022).

3.1　断控储集体雕刻技术与方法

勘探实践表明,影响断控油气藏产能的因素包括:(1)走滑断裂带分段性(邓尚等,2018);(2)走滑断裂带通源性(供烃能力)(马庆佑等,2020);(3)走滑断裂带断穿地层沉积相(例如,台洼泥晶灰岩相和台内/台缘礁滩相)(陈红汉等,2016a;焦存礼等,2018;王玉伟,2019);(4)走滑断裂走向与现今主应

力夹角(影响裂缝的开启程度)(林波等,2021;云露等,2022);(5)油气充注的差异性(Lu *et al.*,2017;王玉伟等,2019)等.其核心因素之一是走滑断裂带储集体类型及其规模.另外,工程因素,譬如斜井/水平井和酸化压裂技术提高产能不在本文讨论之列.

顺北油田勘探开发成果表明,走滑断裂带拉分段油气产量往往是最高的,其次是纯走滑段,产量最低的是压隆段(邓尚等,2018).前人将之归结为与其成储结构相关的流体流动性能(Peacock and Anderson,2012;Gomila *et al.*,2016;Tondi *et al.*,2016).尽管 Tveranger *et al.*(2005)提出了断裂相概念,并指出断裂带是具有特定断裂相组合序列和内部结构的三维地质体,但走滑断裂带本身内部构型的复杂性、变形地层的层内分异性(平面上的相变和垂向上能干与非能干层之间的力学性质方面的差异性)(Chen *et al.*,2022)以及叠加的(表生或深成)岩溶作用(陈红汉等,2016b;朱秀等,2016;Zhu *et al.*,2017;Yu *et al.*,2022),为建立能够满足开发条件的走滑断裂带储层地质模型增加了很大的难度.

迄今,对这种断控油气藏的储层成因仍存在争议.马永生等(2019)针对深层－超深层碳酸盐岩储层形成机理,提出了沉积－成岩环境控制早期孔隙发育、构造－压力耦合控制裂缝与溶蚀、流体－岩石相互作用控制深部溶蚀与孔隙保存的“三元控储”成因模式.运用试井压力恢复双对数曲线响应类型,虽然能够粗略地区分地下裂缝型、洞穴型和裂缝－洞穴等3种不同类型的储集体(赵锐等,2019;邓兴梁等,2021;Zhang *et al.*,2021;王清华等,2022),既远远达不到对断控储集体雕刻的要求,又对其中的断控洞穴成因存在两种不同的认识:一是断裂带内岩体错动、破碎体积调整形成空腔的“构造增容”观点,并以洞穴取心肉眼观察到角砾没有发生溶蚀现象作为辅助依据(黄诚等,2022);按照“构造增容”的观点,在压隆段和纯走滑段是不会出现所谓的“空腔”洞穴.二是断裂带内裂缝化作用导致储集岩碎裂岩化和/或糜棱岩化并叠加溶蚀作用,溶质的迁移尤其在断核部位会导致垮塌,从而形成洞穴的观点(Белкин and Медведский,1989;陈红汉等,2016b;Yu *et al.*,2022;王清华等,2022).

正如前文所述,与正断层和逆断层系统发育机制不同的是,聚敛环境的板内走滑断裂系统属于简单剪切或纯剪切变形,总体上具有体积基本守恒的特点.只是在压隆或推起构造会稍许带来其他变形位置体积的增加(构造增容),并被拉分下陷体积所均衡(宋鸿林,1996;Fossen,2010).至如洞穴中具有棱角状垮塌角砾属于机械垮塌,并不能否认溶蚀现象的存在.大量薄片观察结果表明,洞穴垮塌角砾发育多期埋藏溶蚀孔隙和胶结物充填(王玉伟,2019).

裂缝化作用对储层的改造具有两面性:它可以使致密化岩石提高孔渗性;也可以使高孔渗性岩石物性降低.在断核部位的密集的裂缝化不仅会造成岩石破碎,甚至糜棱岩化,还会导致岩石力学性能极大地下降,尤其在溶蚀流体作用下易引起垮塌,进而形成断核控洞穴.

由于埋藏阶段成岩胶结作用,大多数颗粒碳酸盐岩储层残留孔隙度仅为2%左右(小径岩栓)(陈红汉等,2016b).无论是溶孔(直径<5 mm)、溶洞(直径介于5~1 000 mm)还是洞穴(直径>1 000 mm)的形成,裂缝在其中扮演的作用是至关重要的(Gogonenkov and Timurziev,2012),即使是走滑断裂带中致密砂岩断控储集体也是如此(图14).为此,需要发展多技术、多尺度断控储集体雕刻技术与方法.

3.1.1　野外露头测量　理想的露头测量优势在于能够观测整个走滑断裂带的横截面.譬如,陕西省泾阳县口镇石盒子组碎屑岩剖面发育的不对称性压

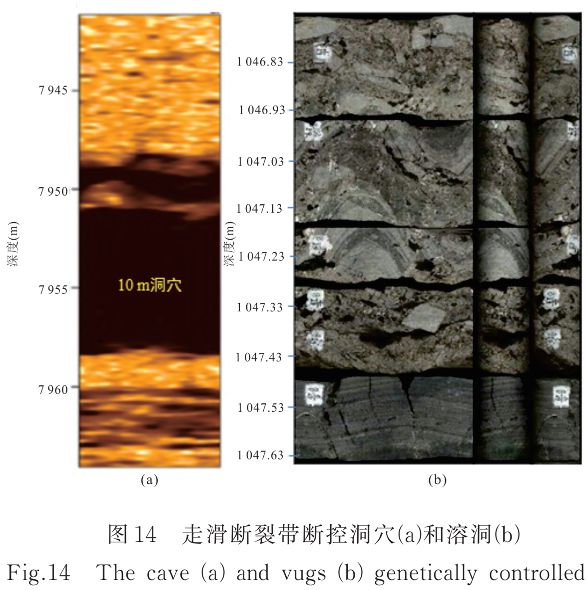


图14　走滑断裂带断控洞穴(a)和溶洞(b)

Fig.14　The cave (a) and vugs (b) genetically controlled by strike-slip faults

a.塔里木盆地富满油田满深4井(F_I17走滑断裂带上)FMI成像测井显示的近10 m的洞穴(据王清华等,2022中图2);b.鄂尔多斯盆地南缘泾河油田永和走滑断裂带上JH9井长8_1^1砂岩中发育的溶蚀孔洞

扭性走滑断裂带（骆杨等，待刊）.野外不仅观察到断面、断核、断核中的次级断面和两侧的损伤带，而且还可以测量损伤带中簇状分布的裂缝产状和密度（左侧上盘损伤带平均密度 3.1 条/m；右侧下盘损伤带平均密度 2.1 条/m）.所获裂缝密度和产状参数可作为类似地区地下测井和地震资料预测裂缝分布的约束.

3.1.2　测井资料综合裂缝指数（*CFI*）计算　钻穿走滑断裂带的水平井/斜井的FMI成像测井能够直观显示其发育的裂缝和溶洞（漆立新，2021；黄诚等，2022；王清华等，2022；云露和邓尚，2022）.选择对裂缝比较敏感性的常规测井资料，如孔隙度测井的声波（*AC*）、中子（*CNL*）、密度（*DEN*）和电阻率测井的中感应（*ILM*）、深感应（*ILD*）、8侧向（*LL*8）等，按照图 15 和式（2）获得综合裂缝指数（*CFI*）（Lü *et al.*，2017）：

$$CFI=\begin{cases}0,\ CI_i<CI_u\\ CFI_i,\ CI_i\geqslant CI_u\end{cases},\tag{2}$$

式（2）中，CFI_i为某一深度的*CFI*值，CI_u为储层综合指数基本值.其中，

$$CI_i=\sum\nolimits_{i=1}^{m}w_i\times CV_i,\tag{3}$$

式（3）中，CI_i为某一深度的置信区间值，CV_i为某一深度的裂缝特征测井值，w_i为裂缝特征测井的权重系数.

计算的单井综合裂缝指数（*CFI*）还可以与FMI成像测井和裂缝敏感测井曲线进行对比，以检验*CFI*在走滑断层裂缝簇、断核、损伤带和围岩识别方面的吻合程度（孟玉净等，2023中图8）.由此可见，走滑断裂带裂缝簇分布具有显著的侧向分带性.

若在FMI成像图片上以1 m的窗口滑动读取

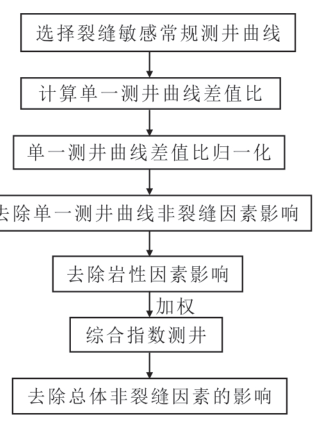


图 15　运用常规测井曲线预测裂缝带流程图

Fig.15　The flow chart of using traditional log curves to predict fracture zones

裂缝条数，这样就可以建立*CFI*与裂缝密度（*FD*）（条/m）的关系（孟玉净等，2023中图10），从而达到运用*CFI*直接预测裂缝密度的目的，并结合野外裂缝密度测量阈值，划分断核、损伤带和与围岩的边界.

3.1.3　三维地震属性雕刻　在塔里木盆地顺北和富满走滑断裂带断控油气藏勘探过程中，三维地震多属性融合技术已成为圈闭落实、钻井部署、储集体刻画和地质储量计算的重要手段.形成了"增强相干属性定带、振幅属性定边界、梯度结构张量定轮廓、波阻抗反演定洞穴、融合雕刻定体积"的技术流程（李树珍等，2016；刘军等，2017；李海英等，2020；李宗杰等，2020；廖茂辉等，2020；邓兴梁等，2021）.

然而，对于小断距的走滑断裂带，在运用三维地震数据体相干和曲率属性进行分析时，不仅存在对小断距断裂识别能力差、断点识别位置有偏差等问题，而且曲率属性不能同时反映上、下两盘的信息.而通过对小断层正断距的膝折状挠曲极大曲率（K_1）和极小曲率（K_2）构造的、反映地震同相轴挠曲形态的断层形态指数（shape index，*SI*）能够较精确地落实断点位置（公式 4）（杨珂等，2020）：

$$SI=\frac{2}{\pi}\times\tan^{-1}\left[\frac{K_1+K_2}{K_1-K_2}\right].\tag{4}$$

标准的脊状挠曲的形态指数值为1，谷状挠曲的形态指数为－1，断点位置为0；而膝折状挠曲的形态指数为正值→负值（或负值→正值）转换.这样，断层形态指数就为地震曲率属性和断层形态之间架设了一道桥梁，且能同时显示断层上、下两盘曲率属性的变化.

若沿着水平井FMI成像测井（例如，JH17P23井）井轨迹提取*SI*值（分导系数为0.5），并将沿井的*SI*绝对值与粗化后（由于测井与地震资料之间存在巨大尺度差异，需要对测井数据进行粗化处理）的裂缝密度（*FD*）进行回归分析，获得二者线性正相关关系（孟玉净等，2023中图12）.这样，就可以利用形态指数属性指示裂缝密度的变化，并根据形态指数属性值（*SI*）累积曲线梯度的变化（折点），确定地震尺度下的断核与损伤带、损伤带与围岩边界（图16）.这就为利用三维地震数据体雕刻断控储集体积和储量计算奠定了基础.

3.2　断控油气藏通源性评价

前人大量研究表明，走滑断裂带断控油气成藏以下生上储的垂向运移为特征（Gogonenkov and

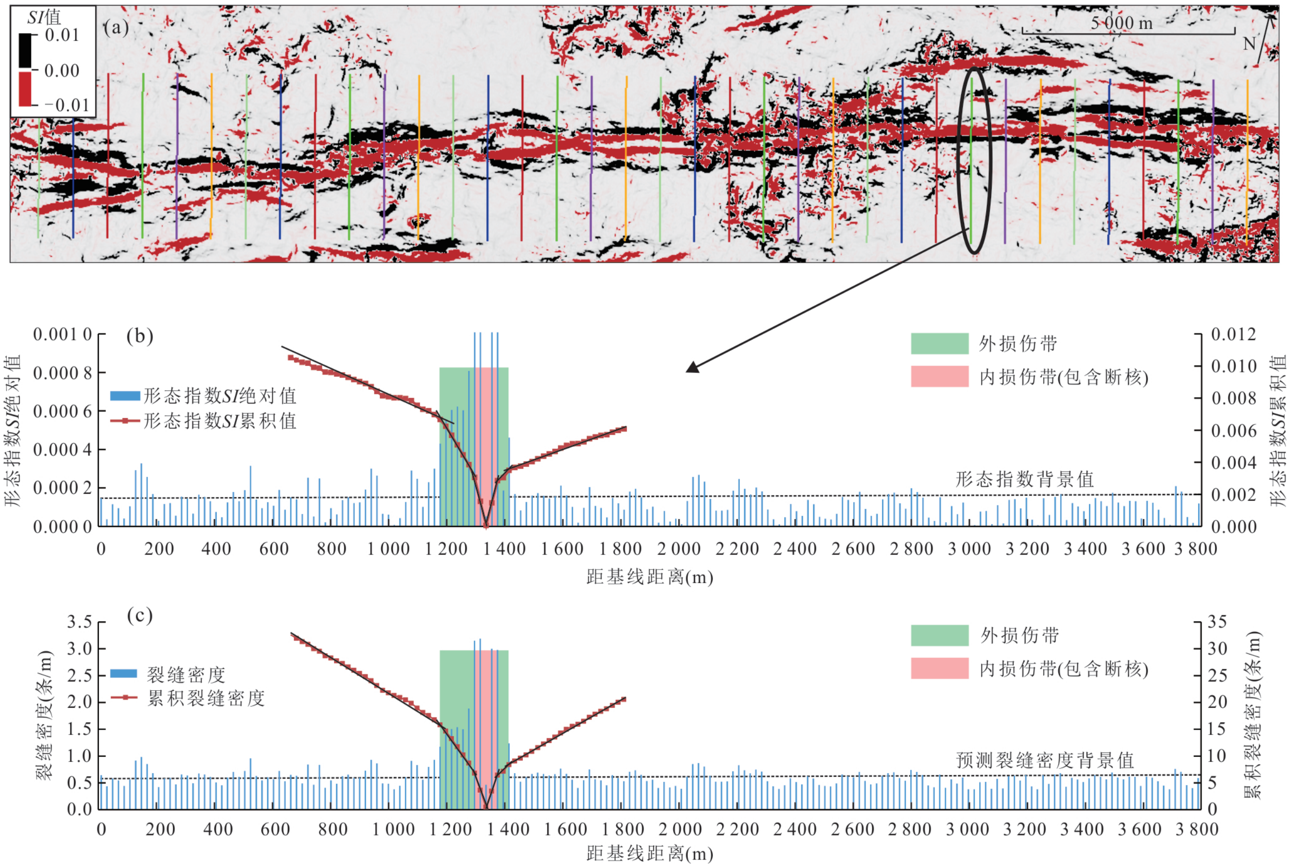


图 16　泾河油田榆林子走滑断裂带 T_6^c 形态指数(*SI*)平面图

Fig.16　Planar map of T_6^c shape index (*SI*) of Yulinzi strike-slip fault belt in Jinghe oilfield

a.红色为负值，代表下降盘；黑色为正值，代表上升盘，白色代表断核；b.横切榆林子走滑断裂带的一条 *SI* 分布剖面；c.根据 *SI* 预测的该剖面裂缝密度分布

Timurziev，2012；鲁新便等，2015；吴梅莲等，2021；冯保周等，2022）.为此，马庆佑等（2020）依据塔里木盆地走滑断裂与现今的烃源层接触关系、断裂的构造样式和活动强度等参数，定性地评价走滑断裂带的通源性，并将塔河—顺北地区的走滑断裂带划分为“上下多层贯通”强通源型、“下贯通上隐伏”中等通源型、“上下均未贯通”弱通源型等 3 种通源性结构模式；结合产能讨论了其与油气富集的相关性：“上下多层贯通”强通源型油气往往最富集，产能较好；“下贯通上隐伏”中等通源型油气富集程度减弱，产能差—中等；而“上下均未贯通”弱通源型油气产能通常很低甚至失利.这里，走滑断裂带具有输导、储集体和圈闭 3 种功能.换句话说，走滑断裂向下延伸到那里就会将那里的油气排出烃源灶；走滑断裂向上贯穿到那里就会将油气输送到那里的圈闭中成藏.因此，板内走滑断裂向下延伸的“根”不仅是天然地震研究的热点（震源深度）（Ampuero and Mao，2017），也是油气来源研究的课题.

Donzé *et al.*（2021）根据 Riedel 剪切的离散元模型（DEM），提出了估算走滑断裂深度的解析式：

$$\frac{S}{h}=1.2\times\tan^{-1}\left[\left(\frac{5}{2}\omega-1\right)\pi\right]+\frac{\pi}{2},\qquad(5)$$

式（5）中，ω 为雁列构造扭转角（°）（雁列断裂与 PDZ 的夹角），S 为雁列断层间隔（m），h 是要预测的走滑断裂的深度（m）.

运用（5）式对土卫二号均匀间隔走滑断裂（俗称虎斑断裂）预测的脆性层最小厚度 h_1=11～14 km；并与 Thomas *et al.*（2016）“热+旋转”模型预测的脆性层最小厚度 h_2=13 km 和 Yin *et al.*（2016）“应力—遮蔽”模型预测的脆性层最小厚度 h_3=10 km进行了对比.

应力—隐蔽概念是指在区域拉张中一岩石层中某一张性断裂的形成施加了一局部应力边界条件，导致相邻断裂处的应力幅度下降.这个过程通常被称作应力—隐蔽效应（stress-shadow effect）（Lachenbruch，1961），它会产生比相邻断裂处的完

整岩石抗张强度更低应力幅度的区域.由于这种效应,在这个相邻的早期形成断裂且具有较低应力幅度区域内不会产生新的断裂;定义较低应力带宽度的临界距离作为应力隐蔽长度的丈量.由于新的张性断裂只能在相邻应力隐蔽之外的区域产生,应力隐蔽长度应等于断裂间隔.于是,将这种简单的概念应用于地球张性节理均匀间隔的定量化研究(Pollard and Segall,1987).

正断裂与走滑断裂之间一个关键不同之处在于后者的剪切应力不为0,而是等于走滑断裂面摩擦强度(Roy and Royden,2000).只要区域应力幅度大于断层摩擦强度和岩石的剪切破裂强度,应力-隐蔽机制就会产生.假如所有的走滑断层都具有相同摩擦强度,即发育断层的地层具有相同的剪切破裂强度,走滑断层均匀间隔(S)就会形成.相反,断层强度和/或断层为边界的地壳域内剪切破裂强度空间变化性将导致形成不均匀的平行走滑断层间隔.于是,Yin *et al.*(2016)和Zuza *et al.*(2017)建立起走滑断层线性应力-隐蔽模型,将走滑断层间隔(S)与走滑断层深度(h)和脆性层强度以及遥远的区域应力关联起来:

$$S=\frac{(C_0-C_1)+\frac{1}{2}\rho gh\left(\mu_\varphi-\mu_f\right)h}{\frac{1}{2}\rho gh\mu_\varphi(\alpha-1)},\qquad(6)$$

式(6)中,ρ是断域内介质密度,g是重力加速度,C_0是脆性层粘性强度,C_1是断层粘性强度,μ_φ是断域内摩擦系数,μ_f是断面摩擦系数,α是区域应力幅度所定义$\alpha=H/h>1$的替代参数(H是边界区域脆性层厚度).

通过编制走滑断裂带深度(h)与烃源岩厚度等值线或成熟度等值线叠加图,就可以定量评价断控油气藏的通源性.

3.3 断控油气藏成藏过程

塔里木盆地顺托果勒鞍部构造带顺北和富满走滑断裂带断控油气田的成功勘探和开发,不仅突破了传统的古隆起-斜坡控藏理论的束缚,而且对于聚敛环境中的克拉通盆地深层-超深层断控油气富集,甚至可能的"立体成藏效应",都具有普遍性的意义.

然而,无论是Anderson(1951)模式还是Hafner(1951)模式,都是以均匀介质为前提来分析断层与主应力轴位置关系,但实际上地层往往是非均质的,还有先存的力学上弱面(层面、老断层、不整合面等),而这些薄弱面的取向与上述两种模式给出的断裂面方位并无固定关系.因此,若是沿薄弱面发展而成的断层,其方位与σ_1的夹角并不规则,断层面σ_2都与不一定平行.正是由于走滑断裂带内部构造的这种复杂性决定了其油气成藏过程和产能的差异性.于是,有人在顺托果勒地区油气勘探开发实践中,发出了这样的感叹:(1)主干走滑断裂带具有"一带一世界"的特点;(2)同一条走滑断裂带具有"一段一油藏"的特征;(3)同一断面不同深度靶点钻遇储集体的规模具有"一点一规模"的特色(云露和邓尚,2022).

运用流体包裹体系统分析的技术和方法(陈红汉,2007;平宏伟等,2012;王玉伟等,2019),对顺北地区不同走滑断裂带检测结果表明,这种断控油气藏总体上发育4期成藏:第一期发生在加里东中-晚期-海西早期(438.2~405.8 Ma),第二期发生在海西晚期-印支早期(297.8~219.5 Ma),第三期发生于燕山期(139.9~106.1 Ma),第四期发生于喜山中-晚期(29.0~3.0 Ma)(张钰等,2023中图6).也就是说,板内第一期走滑断裂开始发育(加里东中期,即盆地由伸展向挤压转折期),就启动了这种断控油气藏的第一期油气充注.

油气充注期次和各期次充注贡献度平面特征表明,顺北地区走滑断裂带断控油气藏存在东西和南北差异:(1)以顺北7号走滑断裂带为界,西侧以阿瓦提凹陷供烃为主,发育第一至第三期成藏;(2)东侧以满加尔坳陷供烃为主,发育第一至第四期成藏;(3)顺北7号断裂带仅发育第一至第二期成藏,且以第一期贡献为主.同一条走滑断裂带自北向南存在期次减少和成熟度增加的趋势(张钰等,2023中图10).再将油气充注期次和各期次充注贡献度与各井产能数据进行比较(张钰等,2023中图10)发现,油气充注期次和贡献度极大地影响到这种断控油气藏的原油物化性质(密度、粘度、气/油比和成熟度)(张钰等,2023中图8):早期充注且贡献度大的原油密度和粘度大,气/油比和成熟度低;晚期充注的原油密度和粘度小,气/油比和成熟度高.

为了更加准确厘定走滑断裂活动与油气成藏的时间关系,需要开展走滑断裂带捕获原生油气包裹体宿主矿物(方解石、白云石或石英等)和断裂带镜面擦痕(譬如,纤维状方解石镜岩)LA-ICP-MS U-Pb定年分析(Müller,2003).这样可以比较走滑断裂活动时间与油气充注时间的吻合性.但是,顺

北4号走滑断裂带奥陶系两个方解石脉U-Pb年龄433±17 Ma和449±15 Ma（宋刚等，2022），以及塔中2井和热普4井走滑断裂带奥陶系裂缝充填方解石脉U-Pb年龄（分别为460±12 Ma和460.6±6.8 Ma）只能约束其方解石脉的形成时间（邬光辉等，2021）．实际上，这些方解石脉U-Pb年龄可能要比其走滑断裂活动时间稍晚一些．而捕获次生油气包裹体的宿主矿物方解石U-Pb年龄也是早于油气充注年龄的，只有捕获原生油气包裹体的宿主方解石U-Pb年龄才是代表油气成藏年龄．

4　本专辑论文简评

本专辑收录的20篇论文，主要反映了近年来我国中西部克拉通盆地小位移走滑断裂构造特征及其与油气聚集关系方面的研究成果．

唐大卿等《板内小位移走滑断裂特征解析：以塔里木、四川及鄂尔多斯盆地为例》一文较为系统地总结了塔里木、四川和鄂尔多斯盆地板内小位移走滑断裂构造特征，并比较了它们之间几何学和演化过程的异同．

耿锋等《塔里木盆地麦盖提斜坡罗西断裂发育特征、演化及形成机制》一文运用砂箱物理模拟和应变分析相结合的技术，分析了塔里木盆地塔西南地区多边界——多期应力作用形成的罗西逆冲—走滑断裂带规模成储机制．

付晓飞等《走滑断裂“分期—异向”变形过程砂箱物理模拟：以塔里木盆地顺北5号断层北段为例》一文也是运用砂箱物理模拟并结合断层几何学和运动学解析，分析了塔里木盆地顺北5号走滑断裂带走向分段和垂向多期叠加生长机制．

田方磊等《塔里木盆地顺北5号走滑断裂带北—中段构造特征与多期构造叠加演化时—空序列》一文通过剖面、层面构造解析与剖面构造回剥反演，重塑了塔里木盆地顺北5号走滑断裂带构造叠加演化历史．

何松高等《克拉通内走滑断裂空间结构及派生构造新样式：以塔里木盆地顺北12号断裂为例》一文是运用高精度三维地震资料，刻画了塔里木盆地顺南地区12号走滑断裂带内部结构，并分层、分期总结了其构造样式．

毛丹凤等《塔里木盆地顺南地区18号走滑断裂带的构造几何学特征及成因机制》一文也是运用高精度三维地震资料解析了塔里木盆地顺南地区18号走滑断裂带构造样式、运动学特征及其影响因素．

张钰等《顺北地区不同走滑断裂带奥陶系油气成藏期次及其贡献度差异性》一文运用储层“宏观油”和包裹体“微观油”对比分析的方法，厘定了塔里木盆地顺北油田1、3、5和7号走滑断裂带油气成藏期次和时期，并定量评价了各成藏期次的贡献度，据此，探讨了不同走滑断裂带油气成藏的差异性．

刘建章等《柯坪地区中下寒武统走滑断裂带方解石脉期次、古流体演化与油气充注历史》一文是根据新疆柯坪地区露头中下寒武统走滑断裂带脉体岩石学、原位微区稀土元素和O-C同位素及流体包裹体等多项测试结果，综合分析与走滑断裂相关圈闭的油气成藏条件．

马峰等《川中海相碳酸盐岩层系小型走滑断裂地震识别》一文运用三维地震多属性融合技术，并结合成像测井信息，刻画了四川盆地川中震旦系—古生界二叠系海相碳酸盐岩层系小型走滑断裂体系，并总结出川中高磨区6种走滑断裂构造样式．

付小东等《四川盆地中西部走滑断裂及其对油气成藏控制作用》一文基于三维地震断裂解释，缝洞充填物定年和已发现气藏解剖，揭示了四川盆地中西部走滑断裂活动期次与油气成藏的耦合关系，总结了走滑断裂4种差异化立体成藏模式，并优选出7个有利勘探区带．

鲁国等《四川盆地中部高石梯—磨溪地区F_I9走滑断裂带构造特征与演化》一文基于深钻井及高精度三维地震资料，刻画四川盆地高石梯—磨溪地区F_I9走滑断裂带构造几何学特征；通过构造回剥反演重建其形成演化过程．

李纯泉等《四川盆地高石梯—磨溪地区走滑断裂控制下的“层楼式”油气成藏模式：以震旦系—寒武系为例》一文根据走滑断裂解释和流体包裹体分析成果，总结了四川盆地高石梯—磨溪地区震旦系—寒武系走滑断裂控制下的“层楼式”油气成藏模式和立体勘探的意义．

张威等《鄂尔多斯盆地大牛地区块板内走滑断裂构造特征及演化》一文运用三维地震资料和构造解析理论，对鄂尔多斯盆地伊陕斜坡北部大牛地区块碳酸盐岩层系走滑断裂进行了精细解释，并讨论了其形成过程与区域应力演变的关系．

孟玉净等《鄂尔多斯盆地南部泾河油田延长组板内走滑断裂内部结构刻画》一文主要是根据岩心、测井和三维地震资料，建立起断缝体内部构型定量

雕刻技术和方法，对鄂尔多斯盆地南部泾河油田走滑断裂带长6－长8段断缝体损伤带进行精细刻画，从而为断缝体圈闭和储量定量评价奠定了基础.

叶慧等《鄂尔多斯盆地南部玉都走滑断裂带构造特征及其对油气成藏的控制》一文主要是通过相干切片技术和三维地震资料精细解释，对鄂尔多斯盆地南部镇泾－彬长地区玉都走滑断裂带进行了刻画；结合流体包裹体定年，探讨了玉都走滑断裂带形成演化过程及其与油气成藏的关系.

苏鹏等《走滑断裂对原油性质的控制作用：以鄂尔多斯盆地南部泾河油田为例》一文是根据原油有机地球化学分析结果，讨论了鄂尔多斯盆地南部泾河油田不同走滑断裂带对油气富集和改造（稠化、散失）过程.

杨鑫等《鄂尔多斯盆地泾河油田走滑断裂带油气成藏特征及控藏机制》一文主要是运用流体包裹体系统分析和原位微区方解石胶结物超低浓度U-Pb定年技术和方法，厘定了鄂尔多斯盆地泾河油田走滑断裂带长6－长8段油气成藏期次和时期，并探讨了走滑断裂带对不同期次油气运聚的控制作用.

罗群等《走滑断裂内部结构渗透差异特征及其输导控藏模式》一文以准噶尔盆地西北缘碎屑岩层系露头NW向走滑断裂带观测和样品分析为基础，分析了走滑断裂内部结构渗透性差异；结合物理模拟实验，讨论了走滑断裂带输导－控藏机制.

彭光荣等《珠江口盆地西江主洼烃源岩属性、原油分类及成藏主控因素》一文基于原油地化分析和三维地震断裂解释结果，总结了张扭性断裂控制烃源岩发育与分布，以及油气富集成藏机理.

5 结束语

随着埃迪卡拉动物群到早寒武世全球生物大爆发，在板内克拉通盆地深层－超深层新元古界－下古生界发育了极为丰富的优质烃源岩.在后续的盆－山耦合过程中不仅经历了多旋回叠合，而且还发育了具有"平面分区、走向分段、侧向分带、垂向分层、层内分异"五大基本特征的走滑断裂系统.这种走滑断裂系统具有"控源、控输、控储、控圈、控藏和控富"作用，在盆地深层－超深层形成的断控油气藏已为塔里木盆地顺北和富满油气田的勘探开发实践所证实.

本专辑所收录的论文涉及塔里木盆地、四川盆地、鄂尔多斯盆地、渤海湾盆地和准噶尔盆地.围绕"板内走滑断裂与油气聚集"这个主题，展现出它们之间的共性和个性.期望对推动我国克拉通盆地深层－超深层油气勘探开发起到抛砖引玉之功效.未来正如贾承造院士（2021）所说："相信随着越来越多研究力量投入到对中国三大克拉通盆地走滑断裂的研究，不久的将来必将形成适应于中国小陆块、多旋回盆地的克拉通内走滑断裂理论认识".

致谢：感谢中石化西北油田分公司、中石化石油勘探开发研究院和中石油塔里木油田分公司长期以来对塔里木盆地相关研究的支持；感谢中石油勘探开发研究院对四川盆地相关研究的支持；感谢中石化华北油气分公司对鄂尔多斯盆地相关研究的支持.参加本文研究工作的还有团队成员赵彦超教授、平宏伟教授、胡守志教授、骆杨副教授、李纯泉副教授、唐大卿副教授、苏奥副教授，博士研究生李培军、鲁子野、王玉伟、吴悠、孟玉净、周铂文、孔令涛、张辉、尚培、肖雪薇、吴维、苏丹梅等，在此一并致谢.对为本专辑撰稿、评审和编辑发表付出辛勤劳动和智慧的所有人表示诚挚的谢意！

References

Alaei, B., Torabi, A., 2017. Seismic Imaging of Fault Damaged Zone and Its Scaling Relation with Displacement. *Interpretation*, 5(4): 83－93. https://doi.org/10.1190/int-2016-0230.1

Ampuero, J. P., Mao, X. L., 2017. Upper Limit on Damage Zone Thickness Controlled by Seismogenic Depth. In: Marion, Y.T., Thomas, M.M., Harsha, S.B., eds., *Fault Zone Dynamic Processes: Evolution of Fault Properties during Seismic Rupture, Geophysical Monograph*, 227: 243－253.

Anderson, E.M., 1951. The Dynamics of Faulting and Dyke Formation with Applications to Britain. Oliver and Boyd, Edinburgh.

Aydin, A., 2000. Fractures, Faults, and Hydrocarbon Entrapment, Migration and Flow. *Marine and Petroleum Geology*, 17(7):797－814. https://doi.org/10.1016/s0264-8172(00)00020-9

Aydin, A., Berryman, J.G., 2010. Analysis of the Growth of Strike-Slip Faults Using Effective Medium Theory. *Journal of Structural Geology*, 32(11): 1629－1642. https://doi.org/10.1016/j.jsg.2009.11.007

Aydin, A., de Joussineau, G., 2014. The Relationship between Normal and Strike-Slip Faults in Valley of Fire State Park, Nevada, and Its Implications for Stress Rotation and Partitioning of Deformation in the East-Central Basin and Range. *Journal of Structural Geology*, 63:12—26. https://doi.org/10.1016/j.jsg.2014.02.006

Aydin, A., Nur, A., 1982. Evolution of Pull-apart Basins and Their Scale Independence. *Tectonics*, 1(1): 91—105. https://doi.org/10.1029/tc001i001p00091

Белкин, В.И., Медведский, Р.И., 1989. Translated by Zhu, Q.H.. Vein-Shaped Hydrocarbon Trap. *Geological Science and Technology Information*, 8(2): 83—88(in Chinese).

Caine, J.S., Evans, J.P., Forster, C.B., 1996. Fault Zone Architecture and Permeability Structure. *Geology*, 24(11): 1025—1028.

Cao, S.Y., Neubauer, F., 2016. Deep Crustal Expressions of Exhumed Strike-Slip Fault Systems: Shear Zone Initiation on Rheological Boundaries. *Earth-Science Reviews*, 162: 155—176. https://doi.org/10.1016/j.earscirev.2016.09.010

Carlini, M., Viola, G., Mattila, J., et al., 2019. The Role of Mechanical Stratigraphy on the Refraction of Strike-Slip Faults. *Solid Earth*, 10(1): 343—356. https://doi.org/10.5194/se-10-343-2019

Chen, H.H., 2007. Advances in Geochronology of Hydrocarbon Accumulation. *Oil & Gas Geology*, 28(2): 143—150 (in Chinese with English abstract).

Chen, H.H., Lu, Z.Y., Cao, Z.C., et al., 2016a. Hydrothermal Alteration of Ordovician Reservoir in Northeastern Slope of Tazhong Uplift, Tarim Basin. *Acta Petrolei Sinica*, 37(1):43—63(in Chinese with English abstract).

Chen, H.H., Wu, Y., Zhu, H.T., et al., 2016b. Eogenetic Karstification and Reservoir Formation Model of the Middle-Lower Ordovician in the Northeast Slope of Tazhong Uplift, Tarim Basin. *Acta Petrolei Sinica*, 37(10): 1231—1246(in Chinese with English abstract).

Chen, J.J., He, D.F., Tian, F.L., et al., 2022. Control of Mechanical Stratigraphy on the Stratified Style of Strike-Slip Faults in the Central Tarim Craton, NW China. *Tectonophysics*, 830: 229307. https://doi.org/10.1016/j.tecto.2022.229307

Chen, P.J., 1988. Age and Pattern of Huge Translation of Tanlu Fault. *Chinese Science Bulletin*, 33(4):289—293(in Chinese).

Choi, J.H., Edwards, P., Ko, K., et al., 2016. Definition and Classification of Fault Damage Zones: A Review and a New Methodological Approach. *Earth-Science Reviews*, 152: 70—87. https://doi.org/10.1016/j.earscirev.2015.11.006

Craig, J., Thurow, J., Thusu, B., et al., 2009. Global Neoproterozoic Petroleum Systems: The Emerging Potential in North Africa. *Geological Society, London, Special Publications*, 326(1):1—25. https://doi.org/10.1144/sp326.1

Cunningham, W.D., Mann, P., 2007. Tectonics of Strike-Slip Restraining and Releasing Bends. *Geological Society, London, Special Publications*, 290(1):1—12. https://doi.org/10.1144/sp290.1

Dai, S.H., Ma, S.L., Pan, Y.S., et al., 2006. Experimental Study on Rupture Propagation along Buried Strike-Slip Fault. *Seismology and Geology*, 28(4): 635—645(in Chinese with English abstract).

de Joussineau, G., Aydin, A., 2007. The Evolution of the Damage Zone with Fault Growth in Sandstone and Its Multiscale Characteristics. *Journal of Geophysical Research: Solid Earth*, 112(B12):B12401. https://doi.org/10.1029/2006jb004711

Deng, Q.D., Zhang, W.Q., Zhang, P.Z., et al., 1989. Haiyuan Strike-Slip Fault Zone and Its Compressional Structures of the End. *Seismology and Geology*, 11(1):1—14(in Chinese with English abstract).

Deng, S., Li, H.L., Zhang, Z.P., et al., 2018. Characteristics of Differential Activities in Major Strike-Slip Fault Zones and Their Control on Hydrocarbon Enrichment in Shunbei Area and Its Surroundings, Tarim Basin. *Oil & Gas Geology*, 39(5): 878—888(in Chinese with English abstract).

Deng, S., Li, H.L., Zhang, Z.P., et al., 2019. Structural Characterization of Intracratonic Strike-Slip Faults in the Central Tarim Basin. *AAPG Bulletin*, 103(1): 109—137. https://doi.org/10.1306/06071817354

Deng, S., Zhao, R., Kong, Q.F., et al., 2022. Two Distinct Strike-Slip Fault Networks in the Shunbei Area and Its Surroundings, Tarim Basin: Hydrocarbon Accumulation, Distribution, and Controlling Factors. *AAPG Bulletin*, 106(1):77—102. https://doi.org/10.1306/07202119113

Deng, X.L., Yan, T., Zhang, Y.T., et al., 2021. Characteristics and Well Location Deployment Ideas of Strike-Slip Fault Controlled Carbonate Oil and Gas Reservoirs: A Case Study of the Tarim Basin. *Natural Gas Industry*, 41 (3):21—29(in Chinese with English abstract).

Dong, S.L., Li, Z., Gao, J., et al., 2013. Progress of Studies on Early Paleozoic Tectonic Framework and Crystalline Rock Geochronology in Altun-Qilian-Kunlun Orogen. *Geological Review*, 59(4): 731—746(in Chinese with English abstract).

Donzé, F.V., Klinger, Y., Bonilla-Sierra, V., et al., 2021. Assessing the Brittle Crust Thickness from Strike-Slip Fault Segments on Earth, Mars and Icy Moons. *Tectonophysics*, 805: 228779. https://doi.org/10.1016/j.tecto.2021.228779

Dooley, T. P., Schreurs, G., 2012. Analogue Modelling of Intraplate Strike-Slip Tectonics: A Review and New Experimental Results. *Tectonophysics*, 574—575: 1—71. https://doi.org/10.1016/j.tecto.2012.05.030

Evans, J. P., 1990. Thickness-Displacement Relationships for Fault Zones. *Journal of Structural Geology*, 12(8): 1061—1065. https://doi.org/10.1016/0191-8141(90)90101-4

Fan, Q. H., Lü, X. X., Li, B. H., 2008. Strike-Slip Fault and the Hydrocarbon Reservoir Formation. *Journal of Southwest Petroleum University (Science & Technology Edition)*, 30(6): 76—80, 209(in Chinese with English abstract).

Feng, B. Z., Yu, C. L., He, T. H., et al., 2022. Discovery of Fault System in the North of Yishan Slope in Ordos Basin and Its Geological Significance. *Journal of Xi'an Shiyou University (Natural Science Edition)*, 37(2): 1—8(in Chinese with English abstract).

Fitch, T. J., 1972. Plate Convergence, Transcurrent Faults, and Internal Deformation Adjacent to Southeast Asia and the Western Pacific. *Journal of Geophysical Research*, 77(23): 4432—4460. https://doi.org/10.1029/jb077i023p04432

Fossen, H., 2010. Structural Geology. Cambridge University Press, Cambridge, London.

Goddard, J. V., Evans, J. P., 1995. Chemical Changes and Fluid-Rock Interaction in Faults of Crystalline Thrust Sheets, Northwestern Wyoming, U. S. A.. *Journal of Structural Geology*, 17(4): 533—547.

Gogonenkov, G. N., Timurziev, A. I., 2010. Strike-Slip Faults in the West Siberian Basin: Implications for Petroleum Exploration and Development. *Russian Geology and Geophysics*, 51(3): 304—316. https://doi. org/10.1016/j.rgg.2010.02.007

Gogonenkov, G. N., Timurziev, A. I., 2012. Strike-Slip Faulting in the West Siberian Platform: Insights from 3D Seismic Imagery. *Comptes Rendus Geoscience*, 344(3—4): 214—226. https://doi.org/10.1016/j.crte.2011.09.010

Gomila, R., Arancibia, G., Mitchell, T. M., et al., 2016. Palaeopermeability Structure within Fault-Damage Zones: A Snap-Shot from Microfracture Analyses in a Strike-Slip System. *Journal of Structural Geology*, 83: 103—120.

González, G., Gerbault, M., Martinod, J., et al., 2008. Crack Formation on Top of Propagating Reverse Faults of the Chuculay Fault System, Northern Chile: Insights from Field Data and Numerical Modelling. *Journal of Structural Geology*, 30(6): 791—808. https://doi. org/10.1016/j.jsg.2008.02.008

Gu, X., 1999. Reservoir-Permeability Trap Different from Anticline Trap and Fault Trap. *Marine Origin Petroleum Geology*, 4(1): 7(in Chinese).

Guan, S. W., Liang, H., Jiang, H., et al., 2022. Characteristics and Evolution of the Main Strike-Slip Fault Belts of the Central Sichuan Basin, Southwestern China, and Associated Structures. *Earth Science Frontiers*, 29(6): 252—264 (in Chinese with English abstract).

Guan, S. W., Wu, L., Ren, R., et al., 2017. Distribution and Petroleum Prospect of Precambrian Rifts in the Main Cratons, China. *Acta Petrolei Sinica*, 38(1): 9—22(in Chinese with English abstract).

Hafner, W., 1951. Stress Distributions and Faulting. *Geological Society of America Bulletin*, 62(4): 373. https://doi. org/10.1130/0016-7606(1951)62[373:sdaf]2.0.co;2

Harding, T. P., 1974. Petroleum Traps Associated with Wrench Faults. *AAPG Bulletin*, 58(7): 1290—1304. https://doi. org/10.1306/83d91669-16c7-11d7-8645000102c1865d

Harding, T. P., 1985. Seismic Characteristics and Identification of Negative Flower Structures, Positive Flower Structures, and Positive Structural Inversion. *AAPG Bulletin*, 69(4): 1016—1058. https://doi. org/10.1306/ad462538-16f7-11d7-8645000102c1865d

Harland, W. B., Francis, E. H., 1971. Phanerozoic Time-Scale: A Supplement. Geological Society, London, Special Publications, No.5. The Geological Society, London.

Harland, W. B., 1971. Tectonic Transpression in Caledonian Spitsbergen. *Geological Magazine*, 108(1): 27—41. https://doi.org/10.1017/s0016756800050937

He, F. Q., Liang, C. C., Lu, C., et al., 2020. Identification and Description of Fault-Fracture Bodies in Tight and Low Permeability Reservoirs in Transitional Zone at the South Margin of Ordos Basin. *Oil & Gas Geology*, 41(4): 710—718(in Chinese with English abstract).

Holdsworth, R. A., Strachan, R. A., Dewey, J. F., 1998. Continental Transpressional and Transtensional Tectonics. Geological Society, London, Special Publication, No.135. The Geological Society, London.

Hou, J. J., Liu, X. D., You, X. Z., et al., 1993. Characteristics of Surface Deformation Combination of Active Strike-Slip Fault System in Western Guangxi and Its Relationship with Seismic Activity. *Acta Seismologica Sinica*, 15(1): 119—122, 131(in Chinese with English abstract).

Huang, C., Yun, L., Cao, Z. C., et al., 2022. Division and Formation Mechanism of Fault-Controlled Fracture-Vug System of the Middle-to-Lower Ordovician, Shunbei Area, Tarim Basin. *Oil & Gas Geology*, 43(1): 54—68(in Chinese with English abstract).

Huang, J. Q., 1984. New Researches on the Tectonic Characteristics of China. *Acta Geosicientia Sinica*, 5(2): 5—18, 268(in Chinese with English abstract).

Huang, J. X., Zhu, S. J., Zeng, W., et al., 1996. Reservoir-Permeation System Trap Models for Gas Accumulation of the Upper Triassic in the Intermediate Zone between the Centre and South of Sichuan Basin. *Natural Gas Industry*, 16(3):5－8, 11(in Chinese with English abstract).

Huang, L., Liu, C.Y., He, F.Q., et al., 2022. Strike-Slip Deformation Characteristics of Fault in Craton Basin. *Journal of Northwest University* (*Natural Science Edition*), 52(6):930－942(in Chinese with English abstract).

Huang, S.Y., Song, X.G., Luo, C.M., et al., 2021. Formation Mechanism of the Conjugate Strike-Slip Faults in Tabei Uplift. *Geoscience*, 35(6): 1797－1808, 1829(in Chinese with English abstract).

Jia, C.Z., Ma, D.B., Yuan, J.Y., et al., 2021. Structural Characteristics, Formation & Evolution and Genetic Mechanisms of Strike-Slip Faults in the Tarim Basin. *Natural Gas Industry*, 41(8): 81－91(in Chinese with English abstract).

Jiang, B., Xu, J. W., 1989. Formation and Evolution of the Ningwu Basin as a Mesozoic Pull-apart Basin. *Chinese Journal of Geology*, 24(4): 314－322(in Chinese with English abstract).

Jiao, C. L., He, B. Z., Wang, T. Y., et al., 2018. Types and Quantitative Characterization of Reservoir Spaces of the Ultra-Deep Limestone Reservoirs in the Yijianfang Formation during the Middle Ordovician, Shuntuoguole Area, Tarim Basin. *Acta Petrologica Sinica*, 34(6): 1835－1846(in Chinese with English abstract).

Jiao, F. Z., 2017. Significance of Oil and Gas Exploration in NE Strike-Slip Fault Belts in Shuntuoguole Area of Tarim Basin. *Oil & Gas Geology*, 38(5):831－839(in Chinese with English abstract).

Jiao, F. Z., Yang, Y., Ran, Q., et al., 2021. Distribution and Gas Exploration of the Strike-Slip Faults in the Central Sichuan Basin. *Natural Gas Industry*, 41(8): 92－101(in Chinese with English abstract).

Jones, C.H., 2003. How Faults Accommodate Plate Motion. *Science*, 300(5622): 1105－1106. https://doi.org/10.1126/science.1084028

Kennedy, B. M., Kharaka, Y. K., Evans, W. C., et al., 1997. Mantle Fluids in the San Andreas Fault System, California. *Science*, 278(5341): 1278－1281. https://doi.org/10.1126/science.278.5341.1278

Lachenbruch, A. H., 1961. Depth and Spacing of Tension Cracks. *Journal of Geophysical Research*, 66(12): 4273－4292. https://doi.org/10.1029/JZ066i012p04273

Li, G.H., Li, S.Y., Li, H.Y., et al., 2021. Distribution Pattern and Formation Mechanism of the Strike-Slip Fault System in the Central Tarim Basin. *Natural Gas Industry*, 41(3):30－37(in Chinese with English abstract).

Li, H. Y., Liu, J., Gong, W., et al., 2020. Identification and Characterization of Strike-Slip Faults and Traps of Fault-Karst Reservoir in Shunbei Area. *China Petroleum Exploration*, 25(3): 107－120(in Chinese with English abstract).

Li, J.H., Li, W.B., Wang, H.H., et al., 2013. Kinematic Analysis of Plate Collision during the Assembly of Pangea in Late Paleozoic. *Geological Review*, 59(6): 1047－1059(in Chinese with English abstract).

Li, P.J., Chen, H.H., Tang, D.Q., et al., 2017. Coupling Relationship between NE Strike-Slip Faults and Hypogenic Karstification in Middle-Lower Ordovician of Shunnan Area, Tarim Basin, Northwest China. *Earth Science*, 42(1):93－104(in Chinese with English abstract).

Li, S.G., 1962. Introduction to Geomechanics. Science Press, Beijing (in Chinese).

Li, S. Z., Li, X. W., Zhang, J. W., et al., 2016. Application of GeoEast Software Volume Curvature Attribute Technology in Carbonate Rock Fracture Research. *Petroleum Geology and Engineering*, 30(2): 53－55, 79(in Chinese with English abstract).

Li, S.Z., Yang, Z., Zhao, S.J., et al., 2016. Global Early Paleozoic Orogens (Ⅳ): Plate Reconstruction and Supercontinent Carolina. *Journal of Jilin University* (*Earth Science Edition*), 46(4): 1026－1041(in Chinese with English abstract).

Li, Z.J., Yang, Z.C., Li, H.Y., et al., 2020. Three-Dimensional Seismic Exploration Method for Ultra-Deep Fault-Related Dissolution Reservoirs in the Shunbei Desert Area. *Geophysical Prospecting for Petroleum*, 59(2): 283－294 (in Chinese with English abstract).

Liao, M.H., Liu, J., Gong, W., et al., 2020. Discussion on Reflection Characteristics and Prediction Technology of Fault-Controlling Fractured-Vuggy Reservoir in Shunbei Area. *Chinese Journal of Engineering Geophysics*, 17(6): 703－710(in Chinese with English abstract).

Lin, B., Zhang, X., Kuang, A.P., et al., 2021. Structural Deformation Characteristics of Strike-Slip Faults in Tarim Basin and Their Hydrocarbon Significance: A Case Study of No.1 Fault and No.5 Fault in Shunbei Area. *Acta Petrolei Sinica*, 42(7): 906－923(in Chinese with English abstract).

Lin, C.Y., Fan, F.T., 1984. Microstructure Analysis of Fuyun Fault Zone in Xinjiang. *Journal of Disaster Prevention and Mitigation Engineering*, 4(2): 1－8, 87(in Chinese with English abstract).

Liu, C.Y., Wang, J.Q., Zhao, H.G., et al., 2015. The Classification of Sedimentary Basins and Discussion on Relevant Issues. *Earth Science Frontiers*, 22(3): 1－26(in Chinese with English abstract).

Liu, H.F., Li, X.Q., Liu, L.Q., et al., 2004. Petroleum Play Analysis and Strike Slip System Basin-Mountain Coupling. *Geoscience*, 18(2): 139－150(in Chinese with English abstract).

Liu, H.F., Xia, Y.P., Yin, J.Y., 1999. Coupling Mechanism of Strike-Slip Orogen and Basin. *Earth Science Frontiers*, 6(3): 121－132(in Chinese with English abstract).

Liu, J., Klinger, Y., Sieh, K., et al., 2004. Six Similar Sequential Ruptures of the San Andreas Fault, Carrizo Plain, California. *Geology*, 32(8): 649. https://doi.org/10.1130/g20478.1

Liu, J., Ren, L.D., Li, Z.J., et al., 2017. Seismic Identification and Evaluation of Deep Carbonate Faults and Fractures in Shunnan Area, Tarim Basin. *Oil & Gas Geology*, 38(4): 703－710(in Chinese with English abstract).

Liu, J., Sieh, K., Hauksson, E., 2003. A Structural Interpretation of the Aftershock "Cloud" of the 1992 *M*w 7.3 Landers Earthquake. *Bulletin of the Seismological Society of America*, 93(3): 1333－1344. https://doi.org/10.1785/0120020060

Liu, Y.Q., Deng, S., 2022. Structural Analysis of Intraplate Strike-Slip Faults with Small to Medium Displacement: A Case Study of the Shunbei 4 Fault, Tarim Basin. *Journal of China University of Mining & Technology*, 51(1): 124－136(in Chinese with English abstract).

Liu, Z.F., Liu Z.Q., Guo, Y.L., et al., 2021. Concept and Geological Model of Fault-Fracture Reservoir and Their Application in Seismic Fracture Prediction: A Case Study on the Xu 2 Member Tight Sandstone Gas Pool in Xinchang Area, Western Sichuan Depression in Sichuan Basin. *Oil & Gas Geology*, 42(4): 973－980(in Chinese with English abstract).

Lottaroli, F., Craig, J., Thusu, B., 2009. Neoproterozoic-Early Cambrian (Infracambrian) Hydrocarbon Prospectivity of North Africa: A Synthesis. *Geological Society, London, Special Publications*, 326(1): 137－156. https://doi.org/10.1144/sp326.7

Lü, H.T., Zhang, S.N., Ma, Q.Y., 2017. Classification and Formation Mechanism of Fault Systems in the Central and Northern Tarim Basin. *Petroleum Geology and Experiment*, 39(4): 444－452(in Chinese with English abstract).

Lü, W.Y., Zeng, L.B., Liao, Z.H., et al., 2017. Fault Damage Zone Characterization in Tight-Oil Sandstones of the Upper Triassic Yanchang Formation in the Southwest Ordos Basin, China: Integrating Cores, Image Logs, and Conventional Logs. *Interpretation*, 5(4): SP27－SP39. https://doi.org/10.1190/int-2016-0231.1

Lu, X.B., Hu, W.G., Wang, Y., et al., 2015. Characteristics and Development Practice of Fault-Karst Carbonate Reservoirs in Tahe Area, Tarim Basin. *Oil & Gas Geology*, 36(3): 347－355(in Chinese with English abstract).

Lu, Z.Y., Chen, H.H., Qing, H.R., et al., 2017. Petrography, Fluid Inclusion and Isotope Studies in Ordovician Carbonate Reservoirs in the Shunnan Area, Tarim Basin, NW China: Implications for the Nature and Timing of Silicification. *Sedimentary Geology*, 359: 29－43. https://doi.org/10.1016/j.sedgeo.2017.08.002

Luo, Q., Huang, H.D., Pang, X.Q., et al., 2004. A Kind of Possible Natural Fault Petroleum Trap. *Petroleum Exploration and Development*, 31(3): 148－150(in Chinese with English abstract).

Luo, X.G., 1994. The Relation between Simple Shear and Pure Shear in Rubber. *Acta Polymerica Sinica*, (4): 385－391(in Chinese with English abstract).

Luo, Z.L., Qian, H., Wen, X.Z., 1987. Comparative Study on Seismic Geology of Xianshuihe Fault and San Andreas Fault. *Earthquake Research in Sichuan*, (4): 1－10, 20(in Chinese).

Ma, D.B., Wang, Z.C., Duan, S.F., et al., 2018. Strike-Slip Faults and Their Significance for Hydrocarbon Accumulation in Gaoshiti-Moxi Area, Sichuan Basin, SW China. *Petroleum Exploration and Development*, 45(5): 795－805(in Chinese with English abstract).

Ma, Q.Y., Cao, Z.C., Jiang, H.S., et al., 2020. Source-Connectivity of Strike Slip Fault Zone and Its Relationship with Oil and Gas Accumulation in Tahe-Shunbei Area, Tarim Basin. *Marine Origin Petroleum Geology*, 25(4): 327－334(in Chinese with English abstract).

Ma, Y.S., He, Z.L., Zhao, P.R., et al., 2019. A New Progress in Formation Mechanism of Deep and Ultra-Deep Carbonate Reservoir. *Acta Petrolei Sinica*, 40(12): 1415－1425(in Chinese with English abstract).

Mann, P., 2007. Global Catalogue, Classification and Tectonic Origins of Restraining- and Releasing Bends on Active and Ancient Strike-Slip Fault Systems. *Geological Society, London, Special Publications*, 290(1): 13－142. https://doi.org/10.1144/sp290.2

McClay, K., Bonora, M., 2001. Analog Models of Restraining Stepovers in Strike-Slip Fault Systems. *AAPG Bulletin*, 85(2): 233－260. https://doi.org/10.1306/8626c7ad-

173b-11d7-8645000102c1865d

Meng, Y.J.,, Chen, H.H., Zhao, Y.C., et al., 2023. Characterization of Architecture of Intraplate Strike-Slip Faults in Yanchang Formation of the Jinghe Oilfield in Southern Ordos Basin. *Earth Science*, 48(6): 2281—2293(in Chinese with English abstract).

Müller, W., 2003. Strengthening the Link between Geochronology, Textures and Petrology. *Earth and Planetary Science Letters*, 206(3—4): 237—251. https://doi. org/10.1016/s0012-821x(02)01007-5

Neng, Y.A., Li, Y., Qi, J.F., et al., 2022. Deformation Styles and Multi-Stage Evolution History of a Large Intraplate Strike-Slip Fault System in a Paleozoic Superimposed Basin: A Case Study from the Tarim Basin, NW China. *Frontiers in Earth Science*, 10: 837354. https://doi.org/10.3389/feart.2022.837354

Pan, J., Liu, Z.Q., Pu, R.H., et al., 2017. Fault Characteristics and Oil-Controlling Effects in Zhenyuan-Jingchuan District, Southwestern Ordos Basin. *Oil Geophysical Prospecting*, 52(2): 360—370, 196(in Chinese with English abstract).

Peacock, D.C.P., Anderson, M.W., 2012. The Scaling of Pull-aparts and Implications for Fluid Flow in Areas with Strike-Slip Faults. *Journal of Petroleum Geology*, 35(4): 389—399. https://doi. org/10.1111/j. 1747 - 5457.2012.00537.x

Peacock, D.C.P., Dimmen, V., Rotevatn, A., et al., 2017. A Broader Classification of Damage Zones. *Journal of Structural Geology*, 102: 179—192. https://doi. org/10.1016/j.jsg.2017.08.004

Ping, H.W., Chen, H.H., Song, G.Q., et al., 2012. Contributions Degree of Petroleum Charging to Oil and Gas Accumulation and Its Significance. *Earth Science*, 37(1): 163—170(in Chinese with English abstract).

Pollard, D.D., Segall, P., 1987. Theoretical Displacements and Stresses near Fractures in Rock: With Applications to Faults, Joints, Veins, Dikes, and Solution Surfaces. Fracture Mechanics of Rock. Elsevier, Amsterdam, 277—349. https://doi.org/10.1016/b978-0-12-066266-1.50013-2

Qi, J.F., Li, X.G., Yu, F.S., et al., 2013. Cenozoic Structural Deformation and Expression of the "Tan - Lu Fault Zone" in the West Sag of Liaohe Depression, Bohaiwan Basin Province, China. *Science China Earth Sciences*, 56(10): 1707—1721. https://doi. org/10.1007/s11430-013-4617-2

Qi, J.F., Xia, Y.P., Yang, Q., 2006. Structural Analysis of Oil Region. Petroleum Industry Press, Beijing(in Chinese).

Qi, L.X., 2016. Oil and Gas Breakthrough in Ultra-Deep Ordovician Carbonate Formations in Shuntuoguole Uplift, Tarim Basin. *China Petroleum Exploration*, 21(3): 38—51(in Chinese with English abstract).

Qi, L.X., Yun, L., Cao, Z.C., et al., 2021. Geological Reserves Assessment and Petroleum Exploration Targets in Shunbei Oil & Gas Field. *Xinjiang Petroleum Geology*, 42(2): 127—135(in Chinese with English abstract).

Rostirolla, S.P., Mancini, F., Rigoti, A., et al., 2003. Structural Styles of the Intracratonic Reactivation of the Perimbó Fault Zone, Paraná Basin, Brazil. *Journal of South American Earth Sciences*, 16(4): 287—300. https://doi. org/10.1016/s0895-9811(03)00065-8

Roy, M., Royden, L.H., 2000. Crustal Rheology and Faulting at Strike-Slip Plate Boundaries: 2. Effects of Lower Crustal Flow. *Journal of Geophysical Research: Solid Earth*, 105(B3): 5599—5613. https://doi. org/10.1029/1999JB900340

Schröckenfuchs, T., Bauer, H., Grasemann, B., et al., 2015. Rock Pulverization and Localization of a Strike - Slip Fault Zone in Dolomite Rocks (Salzach - Ennstal - Mariazell-Puchberg Fault, Austria). *Journal of Structural Geology*, 78: 67—85. https://doi. org/10.1016/j.jsg.2015.06.009

Shan, J.Z., 1996. Application of Structural Simulation to Petroleum Geology. Petroleum Industry Press, Beijing(in Chinese).

Shen, Z.Y., Neng, Y., Han, J., et al., 2022. Structural Styles and Linkage Evolution in the Middle Segment of a Strike-Slip Fault: A Case from the Tarim Basin, NW China. *Journal of Structural Geology*, 157: 104558. https://doi.org/10.1016/j.jsg.2022.104558

Song, G., Li, H.Y., Ye, N., et al., 2022. Types and Features of Diagenetic Fluids in Shunbei No. 4 Strike - Slip Fault Zone in Shuntuoguole Low Uplift, Tarim Basin. *Petroleum Geology & Experiment*, 44(4): 603—612(in Chinese with English abstract).

Song, H.L., 1996. Oblique Sliding and Strike-Slip Transform Structures. *Geological Science and Technology Information*, 15(4): 33—38(in Chinese with English abstract).

Spotila, J.A., Farley, K.A., Sieh, K., 1998. Uplift and Erosion of the San Bernardino Mountains Associated with Transpression along the San Andreas Fault, California, as Constrained by Radiogenic Helium Thermochronometry. *Tectonics*, 17(3): 360—378. https://doi. org/10.1029/98TC00378

Swanson, M.T., 2005. Geometry and Kinematics of Adhesive Wear in Brittle Strike-Slip Fault Zones. *Journal of Structural Geology*, 27(5): 871—887. https://doi.org/10.1016/

j.jsg.2004.11.009

Sylvester, A.G., 1988. Strike-Slip Faults. *Geological Society of America Bulletin*, 100(11): 1666−1703. https://doi.org/10.1130/0016-7606(1988)1001666:ssf>2.3.co;2

Tang, L. J., 1992. A Discussion on the Relation between Strike-Slip Fault Belts and Hydrocarbon Accumulation in Tarim Basin. *Earth Science*, 17(4): 403−410(in Chinese with English abstract).

Tang, Z.Y., 1989. Reservoirs of Carbonate Rock. In: Petroleum Geology Writing Group of Sichuan Hydrocarbon Province, ed., Petroleum Geology of China (Vol. 10). Petroleum Industry Press, Beijing, 151−205(in Chinese).

Thomas, P.C., Tajeddine, R., Tiscareno, M.S., et al., 2016. Enceladus' s Measured Physical Libration Requires a Global Subsurface Ocean. *Icarus*, 264: 37−47. https://doi.org/10.1016/j.icarus.2015.08.037

Tikoff, B., Teyssier, C., 1994. Strain Modeling of Displacement-Field Partitioning in Transpressional Orogens. *Journal of Structural Geology*, 16(11): 1575−1588. https://doi.org/10.1016/0191-8141(94)90034-5

Timurziev, A.I., Gogonenkov, G.N., 2015. Translated by Qiu, W. T., Lei, X. Z.. 100% Success Rate of Oil and Gas Well Drilling in Russia. *Leisure Reading* (*The World*), (2):157−161 (in Chinese).

Tondi, E., Rustichelli, A., Cilona, A., et al., 2016. Hydraulic Properties of Fault Zones in Porous Carbonates, Examples from Central and Southern Italy. *Italian Journal of Geosciences*, 135(1): 68−79. https://doi. org/10.3301/ijg.2015.08

Tveranger, J., Braathen, A., Skar, T., et al., 2005. Center for Integrated Petroleum Research-Research Activities with Emphasis on Fluid Flow in Fault Zones. *Norwegian Journal of Geology*, 85:63−72.

Wang, Q.H., Yang, H.J., Li, Y., et al., 2022. Control of Strike-Slip Fault on the Large Carbonate Reservoir in Fuman, Tarim Basin—A Reservoir Model. *Earth Science Frontiers*, 29(6):239−251(in Chinese with English abstract).

Wang, Q.H., Yang, H.J., Wang, R.J., et al., 2021. Discovery and Exploration Technology of Fault-Controlled Large Oil and Gas Fields of Ultra-Deep Formation in Strike Slip Fault Zone in Tarim Basin. *China Petroleum Exploration*, 26(4):58−71(in Chinese with English abstract).

Wang, W., Fan, R., 2019. Characteristics of Xujiahe Formation Fault-Fracture Reservoirs in the Northern Sichuan Basin and Its Exploration Significance. *Journal of Chengdu University of Technology* (*Science & Technology Edition*), 46(5): 541−548(in Chinese with English abstract).

Wang, X.P., Xie, D.Y., 1989. Finding Flower Structures in China's Oil and Gas Bearing Basins and Its Significance in Petroleum Geology. *Geological Science and Technology Information*, 8(2):59−66(in Chinese with English abstract).

Wang, X.Z., Mu, S.G., Huang, J.X., et al., 1998. The Traps of the Dengying Formation Reserviors in Ziyang of Sichuan. *China Offshore Oil and Gas*, 10(6):386−389(in Chinese with English abstract).

Wang, Y.W., 2019. Multiple Originanl Mechanisms of the Ordovician Reservoir and Their Control on Hydrocarbon Charging in Shuntuoguole Area, Tarim Basin (Dissertation). China University of Geosciences, Wuhan(in Chinese with English abstract).

Wang, Y.W., Chen, H.H., Guo, H.F., et al., 2019. Hydrocarbon Charging History of the Ultra-Deep Reservoir in Shun 1 Strike-Slip Fault Zone, Tarim Basin. *Oil & Gas Geology*, 40(5): 972−989(in Chinese with English abstract).

Watterson, J., 1986. Fault Dimensions, Displacements and Growth. *Pure and Applied Geophysics*, 124(1):365−373. https://doi.org/10.1007/bf00875732

Wen, L., Ran, Q., Tian, W.Z., et al., 2022. Strike-Slip Fault Effects on Diversity of the Ediacaran Mound-Shoal Distribution in the Central Sichuan Intracratonic Basin, China. *Energies*, 15(16): 5910. https://doi. org/10.3390/en15165910

Wilcox, R.E., Harding, T.P., Seely, D.R., 1973. Basic Wrench Tectonics. *AAPG Bulletin*, 57: 74−96. https://doi.org/10.1306/819a424a-16c5-11d7-8645000102c1865d

Wittlinger, G., Tapponnier, P., Poupinet, G., et al., 1998. Tomographic Evidence for Localized Lithospheric Shear along the Altyn Tagh Fault. *Science*, 282(5386): 74−76. https://doi.org/10.1126/science.282.5386.74

Woodcock, N.H., 1986. The Role of Strike-Slip Fault Systems at Plate Boundaries. *Philosophical Transactions of the Royal Society of London Series A, Mathematical and Physical Sciences*, 317(1539): 13−29. https://doi.org/10.1098/rsta.1986.0021

Woodcock, N.H., Fischer, M., 1986. Strike-Slip Duplexes. *Journal of Structural Geology*, 8(7): 725−735. https://doi.org/10.1016/0191-8141(86)90021-0

Wu, G.H., Cheng, L.F., Liu, Y.K., et al., 2011. Strike-Slip Fault System of the Cambrian-Ordovician and Its Oil-Controlling Effect in Tarim Basin. *Xinjiang Petroleum Geology*, 32(3): 239−243(in Chinese with English abstract).

Wu, G. H., Ma, B. S., Han, J. F., et al., 2021. Origin and Growth Mechanisms of Strike-Slip Faults in the Central Tarim Cratonic Basin, NW China. *Petroleum Explora-*

tion and Development, 48(3): 510－520(in Chinese with English abstract).

Wu, H. W., Zhang, L. S., Ji, S. C., 1989. The Red River-Ailaoshan Fault Zone: A Himalayan Large Sinistral Strike-Slip Intracontinental Shear Zone. *Chinese Journal of Geology*, 24(1): 1－8, 109(in Chinese with English abstract).

Wu, M.L., Liu, Y.F., Peng, P., et al., 2021. Characteristics of Strike-Slip Faults in Lunnan Buried Hill and Its Influence on Hydrocarbon Accumulation. *Fault-Block Oil & Gas Field*, 28(4): 456－462(in Chinese with English abstract).

Xia, Y.P., Liu, W.H., Xu, L.G., et al., 2007. Identification of Strike-Slip Fault and Its Petroleum Geology Significance. *China Petroleum Exploration*, 12(1): 17－23, 48, 92(in Chinese with English abstract).

Xu, H.M., Xu, Z.H., Li, Z.H., et al., 2008. Characteristics of Strike-Slip Faults in the Northwestern Margin of Junggar Basin and Their Geological Significance for Petroleum. *Geological Journal of China Universities*, 14(2): 217－222(in Chinese with English abstract).

Xu, J.W., 1995. Some Major Problems on Strike-Slip Faulting. *Earth Science Frontiers*, 2(2): 125－136(in Chinese with English abstract).

Xu, Z.Q., Zeng, L.S., Yang, J.S., et al., 2004. Role of Large-Scale Strike-Slip Faults in the Formation of Petroleum-Bearing Compressional Basin-Mountain Range Systems. *Earth Science*, 29(6): 631－643(in Chinese with English abstract).

Yang, K., Sun, T.J., Wang, T.Y., et al., 2020. Application of Fault Shape Index Attribution to the Identification of Sub-Seismic Faults. In: The Album of International Geophysical Conference Sponsored by SPG/SEG in 2020, Nanjing, 746－949(in Chinese).

Yin, A., Taylor, M.H., 2011. Mechanics of V-Shaped Conjugate Strike-Slip Faults and the Corresponding Continuum Mode of Continental Deformation. *Geological Society of America Bulletin*, 123(9－10): 1798－1821. https://doi.org/10.1130/b30159.1

Yin, A., Zuza, A. V., Pappalardo, R. T., 2016. Mechanics of Evenly Spaced Strike-Slip Faults and Its Implications for the Formation of Tiger-Stripe Fractures on Saturn's Moon Enceladus. *Icarus*, 266: 204－216. https://doi.org/10.1016/j.icarus.2015.10.027

Yu, J.X., Shi, K.B., Wang, Q.Q., et al., 2022. Structural Diagenesis of Deep Carbonate Rocks Controlled by Intra-Cratonic Strike-Slip Faulting: An Example in the Shunbei Area of the Tarim Basin, NW China. *Basin Research*, 34(5): 1601－1631. https://doi. org/10.1111/bre.12672

Yule, D., Sieh, K., 2003. Complexities of the San Andreas Fault near San Gorgonio Pass: Implications for Large Earthquakes. *Journal of Geophysical Research: Solid Earth*, 108(B11): 2548. https://doi. org/10.1029/2001jb000451

Yun, L., Deng, S., 2022. Structural Styles of Deep Strike-Slip Faults in Tarim Basin and the Characteristics of Their Control on Reservoir Formation and Hydrocarbon Accumulation: A Case Study of Shunbei Oil and Gas Field. *Acta Petrolei Sinica*, 43(6): 770－787(in Chinese with English abstract).

Zhang, C.Z., Yu, H.F., Zhang, H.Z., et al., 2008. Characteristic, Genesis and Geologic Meaning of Strike-Slip Fault System in Tazhong Area. *Journal of Southwest Petroleum University (Science & Technology Edition)*, 30(5): 22－26(in Chinese with English abstract).

Zhang, J.X., Xu, Z.Q., Cui, J.W., 1998. Deformation Partitioning of Ductile Transpressional Zones: An Example from the Eastern Segment of the Altun Fault Zone. *Geological Review*, 44(4): 348－356(in Chinese with English abstract).

Zhang, W. Y., 1992. Anthology of Zhang Wenyou. Science Press, Beijing(in Chinese).

Zhang, Y., Cao, Z.C., Chen, H.H., et al., 2023. The Difference of Hydrocarbon Charging Events and Their Contribution Percentages to the Ordovician Reservoirs among the Strike-Slip Fault Belts in Shunbei Area, Tarim Basin. *Earth Science*, 48(6): 2168－2188(in Chinese with English abstract).

Zhang, Z.P., Kang, Y., Lin, H.X., et al., 2021. A Study on the Reservoir Controlling Characteristics and Mechanism of the Strike Slip Faults in the Northern Slope of Tazhong Uplift, Tarim Basin, China. *Arabian Journal of Geosciences*, 14(8): 1－18. https://doi.org/10.1007/s12517-021-07076-5

Zhang, Z. T., 1985. Geological Characteristic of Altyn-Tagh Fault. *Journal of Xi'an Geology and Earth Resource Research Institute, Chinese Academy of Geological Sciences*, (9): 20－34(in Chinese).

Zhao, R., Zhao, T., Li, H. L., et al., 2019. Fault-Controlled Fracture-Cavity Reservoir Characterization and Main-Controlling Factors in the Shunbei Hydrocarbon Field of Tarim Basin. *Special Oil & Gas Reservoirs*, 26(5): 8－13 (in Chinese with English abstract).

Zheng, H. R., Hu, Z. Q., Yun, L., et al., 2022. Strike-Slip Faults in Marine Cratonic Basins in China: Development Characteristics and Controls on Hydrocarbon Accumulation. *Earth Science Frontiers*, 29(6): 224－238(in Chinese with English abstract).

Zhong, J.Y., Shan, J.Z., Wang, Z.Z., 1982. The Experimental Study of the Formation of Graben. *Chinese Journal of Geology*, 17(2): 171—178, 239(in Chinese with English abstract).

Zhou, X.P., Guo, Y.Z., Zhang, Y.X., 2005. Influence of Intermediate Principal Stress on Mutual Relation of Different-Order Stress Fields and Fault Structure Tracks in Conjugate Strike-Slip Faulting. *Chinese Journal of Geology*, 40(3): 319—327(in Chinese with English abstract).

Zhou, X.Y., Lü, X.X., Yang, H.J., et al., 2013. Effects of Strike-Slip Faults on the Differential Enrichment of Hydrocarbons in the Northern Slope of Tazhong Area. *Acta Petrolei Sinica*, 34(4): 628—637(in Chinese with English abstract).

Zhu, G.Y., Ren, R., Chen, F.R., et al., 2017. Neoproterozoic Rift Basins and Their Control on the Development of Hydrocarbon Source Rocks in the Tarim Basin, NW China. *Journal of Asian Earth Sciences*, 150: 63—72. https://doi.org/10.1016/j.jseaes.2017.09.018

Zhu, H.T., Zhu, X., Chen, H.H., 2017. Seismic Characterization of Hypogenic Karst Systems Associated with Deep Hydrothermal Fluids in the Middle-Lower Ordovician Yingshan Formation of the Shunnan Area, Tarim Basin, NW China. *Geofluids*, 2017: 1—13. https://doi.org/10.1155/2017/8094125

Zhu, L.P., 2000. Crustal Structure across the San Andreas Fault, Southern California from Teleseismic Converted Waves. *Earth and Planetary Science Letters*, 179(1): 183—190. https://doi.org/10.1016/s0012-821x(00)00101-1

Zhu, X., Zhu, H.T., Chen, H.H., et al., 2016. Characterization of Hypogenic Karst Systems in the Middle-Lower Ordovician of Shunnan Area, Tarim Basin. *Oil & Gas Geology*, 37(5): 653—662(in Chinese with English abstract).

Zhu, Y.F., Zhang, Y.T., Zhao, X.X., et al., 2022. The Fault Effects on the Oil Migration in the Ultra-Deep Fuman Oilfield of the Tarim Basin, NW China. *Energies*, 15(16): 5789. https://doi.org/10.3390/en15165789

Zhu, Z.C., Song, H.L., 1990. Geotectonics. China University of Geosciences Press, Wuhan(in Chinese).

Zuza, A.V., Yin, A., Lin, J., et al., 2017. Spacing and Strength of Active Continental Strike-Slip Faults. *Earth and Planetary Science Letters*, 457: 49—62. https://doi.org/10.1016/j.epsl.2016.09.041

附中文参考文献

A.И.齐穆尔基耶夫,Г.Г.戈戈宁科夫,2015,裘慰庭,雷学忠,译.俄罗斯油气井钻探成功率100%的案例.休闲读品(天下),(2):157—161.

Белкин,В.И.,Медведский,Р.И.,1989.朱起煌,译.脉型油气圈闭.地质科技情报,8(2):83—88.

陈红汉,2007.油气成藏年代学研究进展.石油与天然气地质,28(2):143—150.

陈红汉,鲁子野,曹自成,等,2016a.塔里木盆地塔中地区北坡奥陶系热液蚀变作用.石油学报,37(1):43—63.

陈红汉,吴悠,朱红涛,等,2016b.塔中地区北坡中—下奥陶统早成岩岩溶作用及储层形成模式.石油学报,37(10):1231—1246.

陈丕基,1988.郯庐断裂巨大平移的时代与格局.科学通报,33(4):289—293.

代树红,马胜利,潘一山,等,2006.隐伏走滑断层破裂扩展特征的实验研究.地震地质,28(4):635—645.

邓起东,张维岐,张培震,等,1989.海原走滑断裂带及其尾端挤压构造.地震地质,11(1):1—14.

邓尚,李慧莉,张仲培,等,2018.塔里木盆地顺北及邻区主干走滑断裂带差异活动特征及其与油气富集的关系.石油与天然气地质,39(5):878—888.

邓兴梁,闫婷,张银涛,等,2021.走滑断裂断控碳酸盐岩油气藏的特征与井位部署思路:以塔里木盆地为例.天然气工业,41(3):21—29.

董顺利,李忠,高剑,等,2013.阿尔金—祁连—昆仑造山带早古生代构造格架及结晶岩年代学研究进展.地质论评,59(4):731—746.

范秋海,吕修祥,李伯华,2008.走滑构造与油气成藏.西南石油大学学报(自然科学版),30(6):76—80,209.

冯保周,于长录,何太洪,等,2022.鄂尔多斯盆地伊陕斜坡北部断裂体系的发现及地质意义.西安石油大学学报(自然科学版),37(2):1—8.

谷溪,1999.与背斜圈闭和断层圈闭不同的储渗体圈闭.海相油气地质,4(1):7.

管树巍,梁瀚,姜华,等,2022.四川盆地中部主干走滑断裂带及伴生构造特征与演化.地学前缘,29(6):252—264.

管树巍,吴林,任荣,等,2017.中国主要克拉通前寒武纪裂谷分布与油气勘探前景.石油学报,38(1):9—22.

何发岐,梁承春,陆骋,等,2020.鄂尔多斯盆地南缘过渡带致密—低渗油藏断缝体的识别与描述.石油与天然气地质,41(4):710—718.

侯建军,刘锡大,游象照,等,1993.桂西活动走滑断裂系的地表变形组合特征及其与地震活动的关系.地震学报,15(1):119—122,131.

黄诚,云露,曹自成,等,2022.塔里木盆地顺北地区中—下奥陶统"断控"缝洞系统划分与形成机制.石油与天然气地质,43(1):54—68.

黄汲清,1984.中国大地构造特征的新研究.中国地质科学院院报,5(2):5—18,268.

黄继祥,朱仕军,曾伟,等,1996.川中—川南过渡带上三叠统

天然气聚集的储渗体圈闭模型.天然气工业,16(3):5－8,11.
黄雷,刘池洋,何发岐,等,2022.克拉通盆地内断裂走滑变形特征.西北大学学报(自然科学版),52(6):930－942.
黄少英,宋兴国,罗彩明,等,2021.塔北隆起X型走滑断裂成因机制的新解释.现代地质,35(6):1797－1808,1829.
贾承造,马德波,袁敬一,等,2021.塔里木盆地走滑断裂构造特征、形成演化与成因机制.天然气工业,41(8):81－91.
姜波,徐嘉炜,1989.一个中生代的拉分盆地:宁芜盆地的形成及演化.地质科学,24(4):314－322.
焦存礼,何碧竹,王天宇,等,2018.顺托果勒奥陶系一间房组超深层灰岩储层类型及储集空间定量表征.岩石学报,34(6):1835－1846.
焦方正,2017.塔里木盆地顺托果勒地区北东向走滑断裂带的油气勘探意义.石油与天然气地质,38(5):831－839.
焦方正,杨雨,冉崎,等,2021.四川盆地中部地区走滑断层的分布与天然气勘探.天然气工业,41(8):92－101.
李国会,李世银,李会元,等,2021.塔里木盆地中部走滑断裂系统分布格局及其成因.天然气工业,41(3):30－37.
李海英,刘军,龚伟,等,2020.顺北地区走滑断裂与断溶体圈闭识别描述技术.中国石油勘探,25(3):107－120.
李江海,李维波,王洪浩,等,2013.晚古生代泛大陆聚合过程中板块碰撞的运动学分析.地质论评,59(6):1047－1059.
李培军,陈红汉,唐大卿,等,2017.塔里木盆地顺南地区中—下奥陶统NE向走滑断裂及其与深成岩溶作用的耦合关系.地球科学,42(1):93－104.
李三忠,杨朝,赵淑娟,等,2016.全球早古生代造山带(Ⅳ):板块重建与Carolina超大陆.吉林大学学报(地球科学版),46(4):1026－1041.
李树珍,李相文,张建伟,等,2016.GeoEast软件体曲率属性技术在碳酸盐岩断裂研究中的应用.石油地质与工程,30(2):53－55,79.
李四光,1962.地质力学概论.北京:科学出版社.
李宗杰,杨子川,李海英,等,2020.顺北沙漠区超深断溶体油气藏三维地震勘探关键技术.石油物探,59(2):283－294.
廖茂辉,刘军,龚伟,等,2020.顺北地区断控缝洞型储层反射特征与预测技术探讨.工程地球物理学报,17(6):703－710.
林波,张旭,况安鹏,等,2021.塔里木盆地走滑断裂构造变形特征及油气意义:以顺北地区1号和5号断裂为例.石油学报,42(7):906－923.
林传勇,范福田,1984.新疆富蕴断裂带的显微构造分析.地震学刊,4(2):1－8,87.
刘池洋,王建强,赵红格,等,2015.沉积盆地类型划分及其相关问题讨论.地学前缘,22(3):1－26.
刘和甫,李晓清,刘立群,等,2004.走滑构造体系盆山耦合与区带分析.现代地质,18(2):139－150.
刘和甫,夏义平,殷进垠,1999.走滑造山带与盆地耦合机制.地学前缘,6(3):121－132.
刘军,任丽丹,李宗杰,等,2017.塔里木盆地顺南地区深层碳酸盐岩断裂和裂缝地震识别与评价.石油与天然气地质,38(4):703－710.
刘雨晴,邓尚,2022.板内中小滑移距走滑断裂发育演化特征精细解析:以塔里木盆地顺北4号走滑断裂为例.中国矿业大学学报,51(1):124－136.
刘振峰,刘忠群,郭元岭,等,2021."断缝体"概念、地质模式及其在裂缝预测中的应用:以四川盆地川西坳陷新场地区须家河组二段致密砂岩气藏为例.石油与天然气地质,42(4):973－980.
吕海涛,张哨楠,马庆佑,2017.塔里木盆地中北部断裂体系划分及形成机制探讨.石油实验地质,39(4):444－452.
鲁新便,胡文革,汪彦,等,2015.塔河地区碳酸盐岩断溶体油藏特征与开发实践.石油与天然气地质,36(3):347－355.
罗群,黄捍东,庞雄奇,等,2004.自然界可能存在的断层体圈闭.石油勘探与开发,31(3):148－150.
罗贤光,1994.橡胶中简单剪切与纯剪切的关系.高分子学报,(4):385－391.
罗灼礼,钱洪,闻学泽,1987.鲜水河断裂与圣安德列斯断层的地震地质对比研究.四川地震,(4):1－10,20.
马德波,汪泽成,段书府,等,2018.四川盆地高石梯—磨溪地区走滑断层构造特征与天然气成藏意义.石油勘探与开发,45(5):795－805.
马庆佑,曹自成,蒋华山,等,2020.塔河—顺北地区走滑断裂带的通源性及其与油气富集的关系.海相油气地质,25(4):327－334.
马永生,何治亮,赵培荣,等,2019.深层—超深层碳酸盐岩储层形成机理新进展.石油学报,40(12):1415－1425.
孟玉净,陈红汉,赵彦超,等,2023.鄂尔多斯盆地南部泾河油田延长组板内走滑断裂内部结构刻画.地球科学,48(6):2281－2293.
潘杰,刘忠群,蒲仁海,等,2017.鄂尔多斯盆地镇原—泾川地区断层特征及控油意义.石油地球物理勘探,52(2):360－370,196.
平宏伟,陈红汉,宋国奇,等,2012.油气充注成藏贡献度及其意义.地球科学,37(1):163－170.
漆家福,夏义平,杨桥,2006.油区构造解析.北京:石油工业出版社.
漆立新,2016.塔里木盆地顺托果勒隆起奥陶系碳酸盐岩超深层油气突破及其意义.中国石油勘探,21(3):38－51.
漆立新,云露,曹自成,等,2021.顺北油气田地质储量评估与油气勘探方向.新疆石油地质,42(2):127－135.
单家增,1996.构造模拟实验在石油地质学中的应用.北京:石油工业出版社.

宋刚,李海英,叶宁,等,2022.塔里木盆地顺托果勒低隆起顺北4号走滑断裂带成岩流体类型及活动特征.石油实验地质,44(4):603－612.
宋鸿林,1996.斜向滑动与走滑转换构造.地质科技情报,15(4):33－38.
汤良杰,1992.塔里木盆地走滑断裂带与油气聚集关系的探讨.地球科学,17(4):403－410.
唐泽尧.1989.碳酸盐岩储集层[M].见:四川油气区石油地质编写组.中国石油地质志(卷十).北京:石油工业出版社,151－205.
王清华,杨海军,李勇,等,2022.塔里木盆地富满大型碳酸盐岩油气聚集区走滑断裂控储模式.地学前缘,29(6):239－251.
王清华,杨海军,汪如军,等,2021.塔里木盆地超深层走滑断裂断控大油气田的勘探发现与技术创新.中国石油勘探,26(4):58－71.
王威,凡睿,2019.四川盆地北部须家河组"断缝体"气藏特征及勘探意义.成都理工大学学报(自然科学版),46(5):541－548.
王燮培,谢德宜,1989.中国含油气盆地中花状构造的发现及其石油地质意义.地质科技情报,8(2):59－66.
王兴志,穆曙光,黄继祥,等,1998.四川资阳地区灯影组气藏储渗体圈闭类型.中国海上油气地质,10(6):386－389.
王玉伟,2019.顺托果勒地区奥陶系储层多成因形成机制及对油气充注的控制作用(博士学位论文).武汉:中国地质大学.
王玉伟,陈红汉,郭会芳,等,2019.塔里木盆地顺1走滑断裂带超深储层油气充注历史.石油与天然气地质,40(5):972－989.
邬光辉,成丽芳,刘玉魁,等,2011.塔里木盆地寒武－奥陶系走滑断裂系统特征及其控油作用.新疆石油地质,32(3):239－243.
邬光辉,马兵山,韩剑发,等,2021.塔里木克拉通盆地中部走滑断裂形成与发育机制.石油勘探与开发,48(3):510－520.
吴海威,张连生,嵇少丞,1989.红河－哀牢山断裂带:喜山期陆内大型左行走滑剪切带.地质科学,24(1):1－8,109.
吴梅莲,刘永福,彭鹏,等,2021.轮南古潜山走滑断裂特征及其对油气成藏的影响.断块油气田,28(4):456－462.
夏义平,刘万辉,徐礼贵,等,2007.走滑断层的识别标志及其石油地质意义.中国石油勘探,12(1):17－23,48,92.
徐怀民,徐朝晖,李震华,等,2008.准噶尔盆地西北缘走滑断层特征及油气地质意义.高校地质学报,14(2):217－222.
徐嘉炜,1995.论走滑断层作用的几个主要问题.地学前缘,2(2):125－136.
许志琴,曾令森,杨经绥,等,2004.走滑断裂、"挤压性盆－山构造"与油气资源关系的探讨.地球科学,29(6):631－643.
杨珂,孙铁军,王田野,等,2020.断层形态指数属性在小断层识别中的应用.南京:SPG/SEG南京2020年国际地球物理会议,746－949.
云露,邓尚,2022.塔里木盆地深层走滑断裂差异变形与控储控藏特征:以顺北油气田为例.石油学报,43(6):770－787.
张承泽,于红枫,张海祖,等,2008.塔中地区走滑断裂特征、成因及地质意义.西南石油大学学报,30(5):22－26.
张建新,许志琴,崔军文,1998.一个韧性转换挤压带的变形分解作用:以阿尔金断裂带东段为例.地质论评,44(4):348－356.
张文佑,1992.张文佑文集.北京:科学出版社.
张钰,曹自成,陈红汉,等,2023.顺北地区不同走滑断裂带奥陶系油气成藏期次及其贡献度差异性.地球科学,48(6):2168－2188.
张治洮,1985.阿尔金断裂的地质特征.中国地质科学院西安地质矿产研究所所刊,(9):20－34.
赵锐,赵腾,李慧莉,等,2019.塔里木盆地顺北油气田断控缝洞型储层特征与主控因素.特种油气藏,26(5):8－13.
郑和荣,胡宗全,云露,等,2022.中国海相克拉通盆地内部走滑断裂发育特征及控藏作用.地学前缘,29(6):224－238.
钟嘉猷,单家增,王在中,1982.地堑成因的实验研究.地质科学,17(2):171－178,239.
周小平,郭映忠,张永兴,2005.中间主应力对共轭平移断层中各序次应力场和断裂等构造形迹相互关系的影响.地质科学,40(3):319－327.
周新源,吕修祥,杨海军,等,2013.塔中北斜坡走滑断裂对碳酸盐岩油气差异富集的影响.石油学报,34(4):628－637.
朱秀,朱红涛,陈红汉,等,2016.塔里木盆地顺南地区中－下奥陶统深成岩溶特征.石油与天然气地质,37(5):653－662.
朱志澄,宋鸿林,1990.构造地质学.武汉:中国地质大学出版社.