

鄂尔多斯盆地南部三叠系延长组沟谷体系构造成因

何发岐,齐荣,王付斌,邓杰,成立,胡天乐

(中国石化华北油气分公司,河南郑州450006)

摘要:鄂尔多斯盆地南部镇泾地区延长组顶部广泛发育沟谷体系,前人多认为是风化剥蚀和河流侵蚀所致。为了进一步厘清沟谷体系的发育特征、分布规律及其与区域构造的联系,基于三维地震资料对断裂的解释和前侏罗纪古地貌的恢复,刻画了延长组沟谷体系,探讨了其构造成因。结论显示,在延长组沉积晚期,受SW向区域构造挤压作用,玉都断裂发生左旋走滑,使延长组未成岩地层发生塑性变形,形成了一系列NW-SE向展布的挤压隆起与谷地;同时NW-SE向的拉张作用形成了NE-SW向的伸展谷地,最终形成了延长组晚期广泛分布的沟谷体系格局。该认识对于鄂尔多斯盆地南部延长组及其上覆的延安组的油气勘探都具有一定的指导意义。

关键词:左旋走滑;塑性变形;沟谷体系;构造成因;延长组;鄂尔多斯盆地

中图分类号:TE121.2

文献标识码:A

Tectonic genesis of Triassic Yanchang Formation valley systems, southern Ordos Basin

He Faqi, Qi Rong, Wang Fubin, Deng Jie, Cheng Li, Hu Tianle

(North China E & P Company, SINOPEC, Zhengzhou, Henan 450006, China)

Abstract: The valley systems widely developed at the top of Yanchang Formation in the Zhenjing area, southern Ordos Basin, is previously considered to be a product of long denudation and river erosion. However, deeper investigation indicates otherwise. In order to gain clearer insights into the connection between the development characteristics and occurrence of the systems with regional tectonics, this study characterizes the systems and discusses their tectonic genesis through analyses of fault interpretation and pre-Jurassic paleogeomorphology restoration based on 3D seismic data. It shows that the main fault (Yudu) experiences a sinistral strike-slip due to a NE-SW oblique compression during the late deposition stage of the Yanchang Formation, causing some layers of the formation that are still in the process of diagenesis to be plastically deformed to form a series of NW-SW trending compressional uplifts and valleys. An almost synchronously occurring NW-SE extension eventually results in the formation of this broadly distributed valley systems. The understanding can be used to guide the exploration of reservoirs in both the Yanchang Formation and overlying Yan'an Formation in the area.

Key words: sinistral strike-slip, plastic deformation, valley system, tectonic genesis, Yanchang Formation, Ordos Basin

鄂尔多斯盆地是中国大型多层系叠合含油气盆地,其天环坳陷南段的镇泾地区有侏罗系延安组和三叠系延长组等多个含油层系,建成了红河油田。受印支运动影响,延长组顶部被剥蚀,形成了广泛分布的大型沟谷体系。长期以来,延长组沟谷体系被认为是风化剥蚀和河流侵蚀作用所致^[1-5]。在延长组剥蚀面之上,沉积了具有河道充填特征的延10油层组和广覆型补偿沉积的

延9油层组,是延安组的主力油层组^[6-10]。沟谷体系是碎屑物搬运的重要通道,也是砂体优先沉积的地方,控制着砂体的展布形态和沉积厚度,因此对油气勘探具有重要意义^[11-12]。基于三维地震资料解释及岩心观察,对延长组顶部广泛发育的沟谷体系进行了描述和刻画,认为其主要成因为走滑构造运动背景下的挤压和伸展的联合作用,而非河流的侵蚀作用。

收稿日期:2021-03-05;修订日期:2021-09-22。

第一作者简介:何发岐(1967—),男,博士、教授级高级工程师,石油天然气勘探开发及管理。E-mail:hefq@sinopec.com。

基金项目:中石化科技部项目(2016ZX05048)。

1 地质背景

鄂尔多斯盆地是发育在华北克拉通西部的多旋回叠合型盆地。镇泾地区位于鄂尔多斯盆地天环坳陷南段,地处东侧陕北斜坡、西侧冲断构造带与南侧渭北隆起所夹汇的构造转折区,构造活动较盆地内部强烈,总体为西北低、东南高的平缓单斜。中三叠世,华北板块与扬子板块发生拼接,并于晚三叠世开始碰撞造山^[13-16],导致鄂尔多斯盆地西南缘的强烈抬升变形,形成众多褶皱及断裂(图1)。印支运动使得盆地由晚古生代一中三叠世的华北克拉通坳陷盆地逐渐向内陆湖盆转化^[17]。上三叠统延长组主要为一套灰绿色、灰色中厚层块状细砂岩、粉砂岩和深灰色、灰黑色泥岩组成的旋回性沉积,广泛发育河流、三角洲、湖泊和重力流沉积,按岩性和电性特征可划分为10个油层组^[18](图2),其中长7油层组发育的深湖相泥岩和油页岩是中生界含油气系统的主要烃源岩。印支期的区域性抬升剥蚀致镇泾地区长3油层组至富县组普遍缺失,

延长组顶部起伏不平、沟壑纵横。镇泾地区中生界油藏主要分布在延长组和延安组碎屑岩,其中延长组油藏主要分布在长8油层组和长6油层组,储层普遍含油,大面积成藏,为典型的致密砂岩岩性油藏。延安组油藏主要分布在延9油层组和延10油层组。

2 延长组沟谷体系分布特征

2.1 剖面地质特征

鄂尔多斯盆地南部延长组晚期沟谷体系非常发育,在垂直于沟谷体系的典型地震剖面上显示为明显的下凹现象(图3),沟谷多以宽缓U型和V型为主,其中最宽的沟谷宽约为7 km,最窄的沟谷宽约3.25 km。这些沟谷的底部都发育了断裂,形成了断折点,围限沟谷的高点区普遍发生了上拱,部分刺穿到了上覆的延安组,而且其内部反射较杂乱,表明地层发生了挤压变形;另外这些沟谷无论规模大小,底部都为连续反射界面,且沟谷的充填特征不明显,与侵蚀成因型沟谷的外形、规模和充填特征都有明显差异^[19-21],属

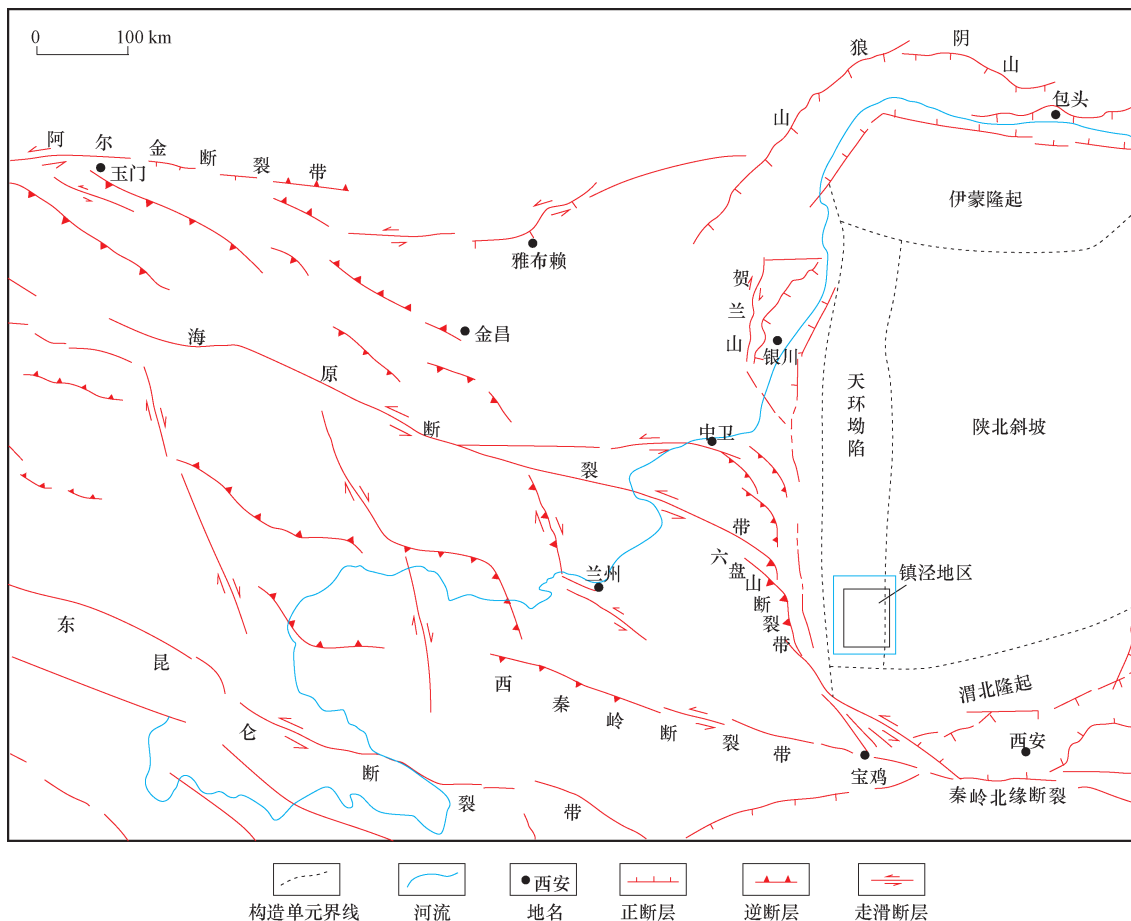


图1 鄂尔多斯盆地南部镇泾地区位置及周缘断裂发育特征

Fig. 1 Locations of the study area and surrounding faults, Zhenjing, southern Ordos Basin

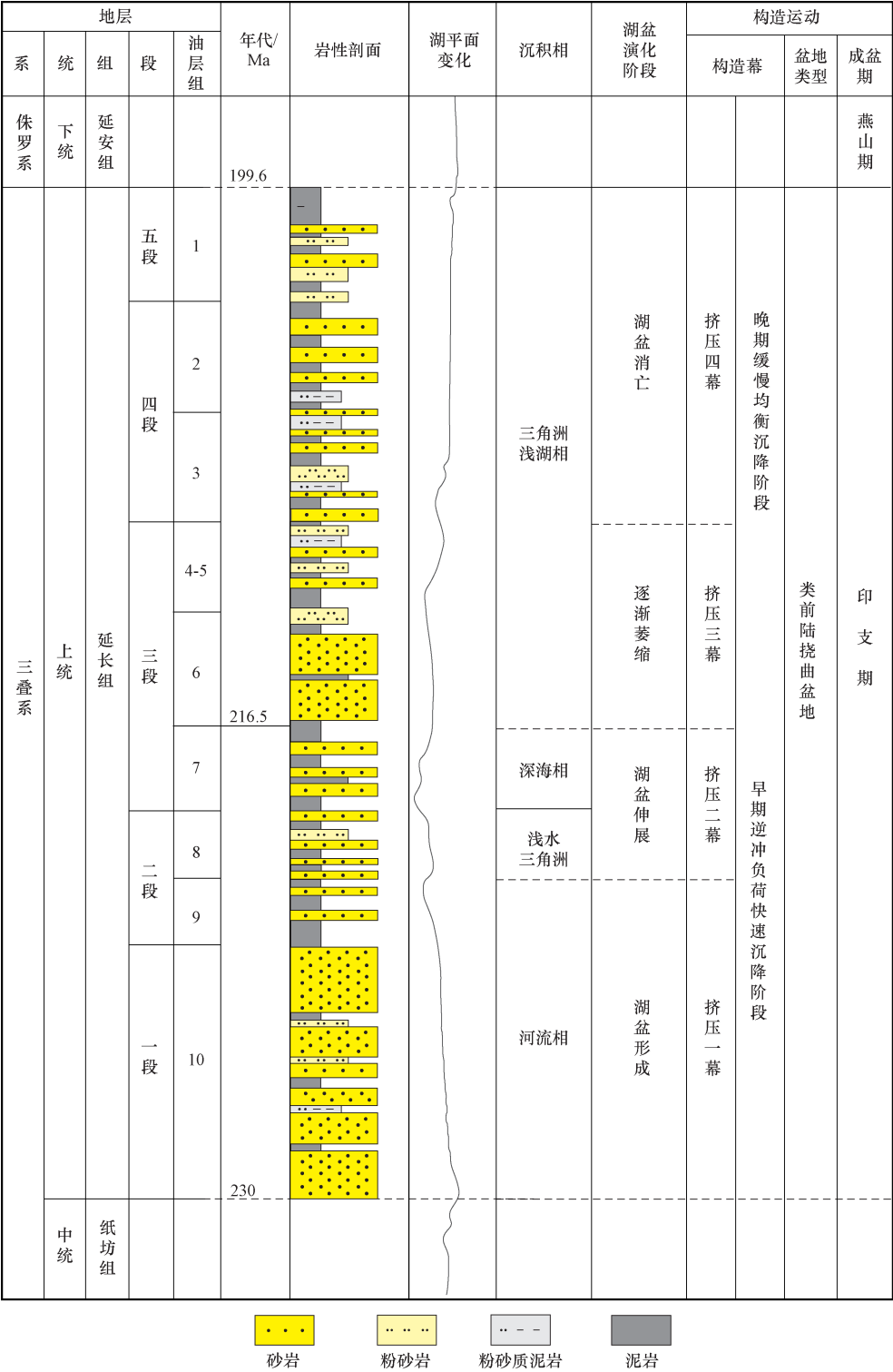


图 2 鄂尔多斯盆地南部延长组综合柱状图

Fig.2 Composite stratigraphy column showing the Yanchang Formation, southern Ordos Basin

非侵蚀成因沟谷。

在 NW - SE 向地震剖面上可以观察到一宽缓沟谷,在该沟谷中未见侵蚀充填特征,但沟谷的厚度明显小于两侧地层厚度,表明其由地层的拉伸减薄所形成(图 3),也属于构造成因。

2.2 平面地质特征

基于三维地震资料的精细解释,利用厚度印模法恢复了研究区前侏罗系古地貌(图 4)。从图 4 中可以看出有两组沟谷体系:1 条 NE - SW 向沟谷体系;6 条

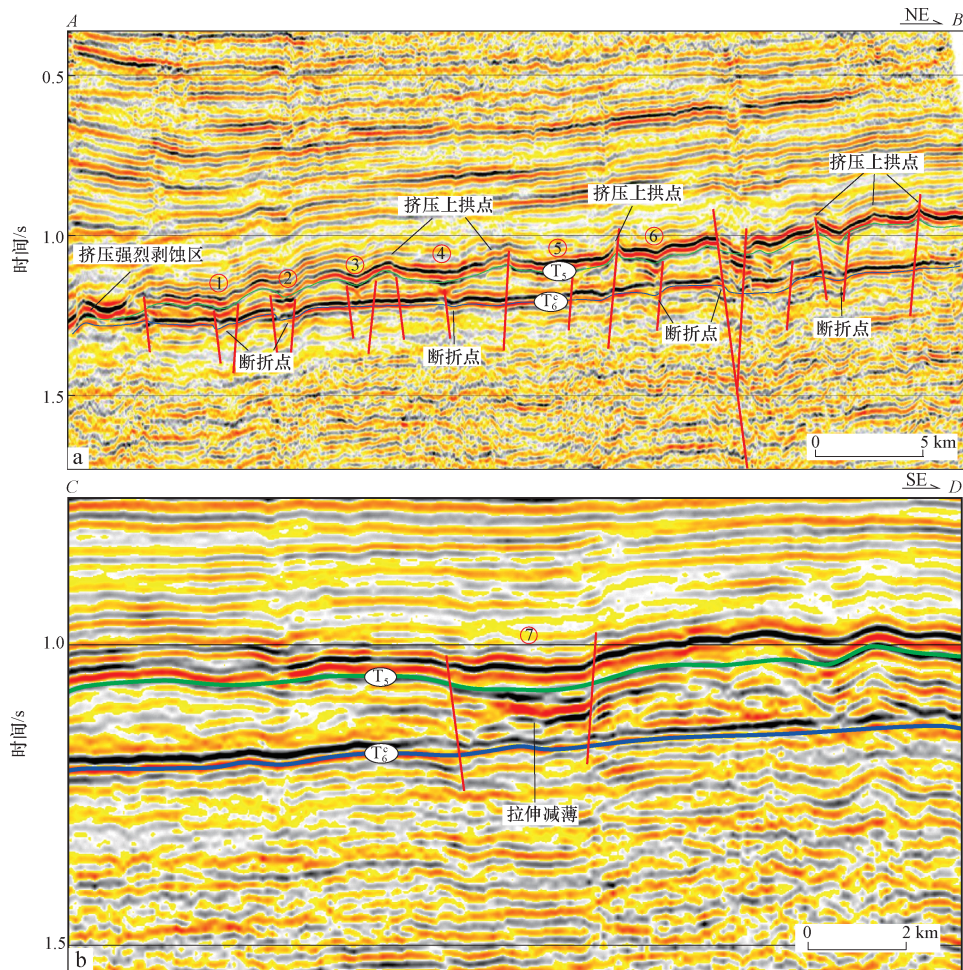


图 3 鄂尔多斯盆地南部延长组沟谷体系地震剖面特征(剖面位置见图 4a)

Fig.3 Seismic section showing the valley systems in the Yanchang Formation, southern Ordos Basin (section location shown in Fig. 4a)

(图中带圆圈数字为沟谷体系序号,沟谷平面位置见图 3a)

a. 剖面 A—B; b. 剖面 C—D;

T₅. 延长组顶界面; T₆. 长 7 油层组底部

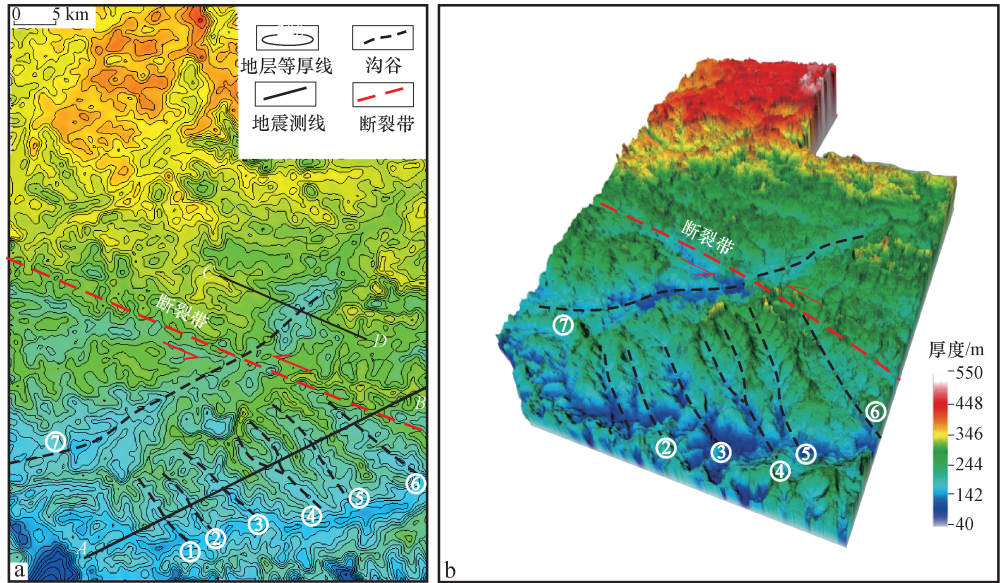


图 4 鄂尔多斯盆地南部前侏罗纪古地貌平面图(a)和立体图(b)

Fig.4 Plan (a) and stereogram map (b) of the pre-Jurassic paleogeomorphology, southern Ordos Basin

(图中带圆圈数字为沟谷体系序号。)

NW-SE向沟谷体系。NW-SE向沟谷体系①—⑥在平面上多呈NW-SE向展布,位于玉都走滑断裂的南部,沟谷体系规模大,分布范围广,但是延伸距离有限,为挤压构造形成的沟槽;NE-SW向沟谷⑦延伸较长,主沟谷宽度较大,在玉都断裂的两盘都有发育,为伸展作用下形成(图4)。这两组沟谷体系呈现垂直分布的特征,但相互并不连通,与侵蚀成因型沟谷分布特征明显不同。

长7段底界面(T_6^c)—延安组顶界面(T_5)残留厚度图显示(图4a):玉都断裂的北侧残留厚度大,南侧残留厚度小,表明玉都断裂对该区的地层有明显的控制作用;另外,向西南方向地层残留厚度逐渐变薄,表明抬升剥蚀作用越来越强,构造挤压作用也越来越强。研究区在延长组沉积晚期整体处于西南方向的挤压作用下,沟谷体系形成与构造作用密不可分。

3 沟谷体系成因

前人研究认为古沟谷是基准面下降到坡折点以下地表遭受侵蚀形成的残留可容纳空间,一般沿层序界面发育,属于沉积侵蚀成因^[22]。鄂尔多斯盆地南部延长组晚期发育的沟谷体系,无论其剖面特征还是平面分布特征都表明其为构造成因,而非侵蚀成因。

3.1 构造活动特征

由于受到古太平洋板块与欧亚板块斜向碰撞所产生的区域构造效应和特提斯构造动力体系的远程构造效应的联合作用,鄂尔多斯盆地西南缘最大主压应力呈NE-SW向^[23-29],使得祁连地块和阿拉善地块向东挤出,鄂尔多斯盆地周缘主要断裂在中生代以左旋走滑运动为主(图1)。图1显示的海原断裂带为通过填图识别出的区域左旋走滑断裂,该走滑断裂带恰好能够延展到镇泾地区。

在地震资料的精细解释下,编制了长7段底界面断裂分布图(图5a),可以看出NW向玉都断裂的北侧断裂呈现NEE走向,这些断裂基本都为正断裂,与玉都断裂呈近45°角,属于玉都断裂左旋走滑运动的派生断裂;玉都断裂南侧断裂呈马尾状和雁列式分布特征,指示为走滑作用下形成。据此可以判定在SW-NE向区域构造挤压作用下,形成了垂直于应力方向的NW-SE向展布的挤压沟谷;由于玉都断裂的左旋走滑作用,NW-SE发生伸展作用,形成了NE-SW向的伸展沟谷(图5b)。

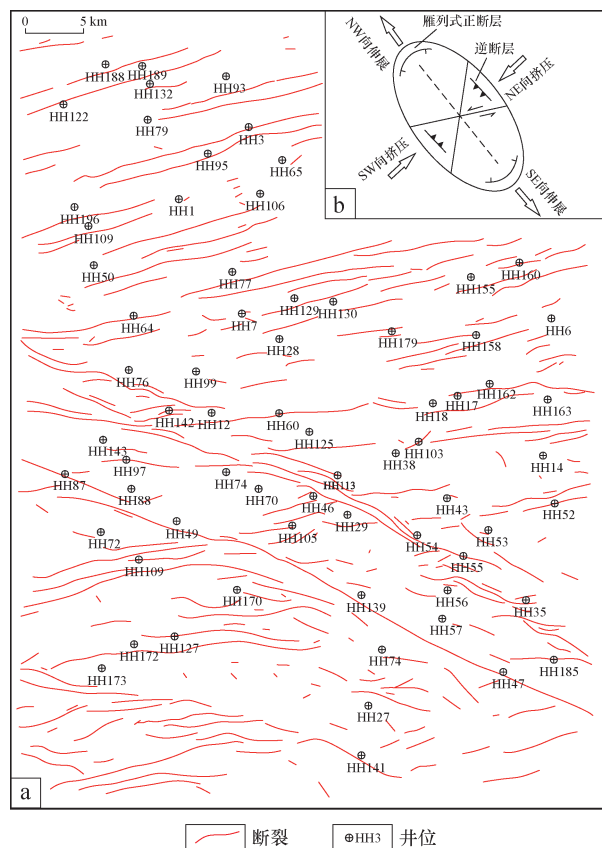


图5 鄂尔多斯盆地南部长7油层组底界面断裂分布(a)及应力分布模型(b)

Fig. 5 Faults (a) and model of stress (b) at the bottom of Chang 7 Member, southern Ordos Basin

3.2 未成岩地层塑性变形

地层受构造挤压发生塑性变形的前提是地层未成岩。依据地震及钻井资料估算,在延长组晚期发生构造挤压时,长8油层组及以上地层埋深不超过800 m,还未完全固结成岩,因此在构造挤压及伸展作用下才能形成沟谷。长8油层组岩心观察可见典型的火焰状构造、砂岩侵入构造和揉皱变形层理等软沉积变形构造(图6),表明延长组在未成岩阶段受到挤压作用产生了普遍的塑性变形。而下伏更老的成岩地层未发生塑性变形,通过产生破裂以释放应力,地震剖面上显示的断折点就是最直接的证据(图3)。

4 结论

1) NW-NE向沟谷规模大、分布范围广,但是延伸距离有限,为挤压成因沟槽;NE-SW向沟槽沟谷体系延伸较长,主沟谷宽度较大,但范围局限,为伸展作用下形成。



图6 鄂尔多斯盆地南部延长组软沉积变形岩心照片特征

Fig. 6 Core images showing soft sediment deformation, Yanchang Formation, southern Ordos Basin

a. HH87 井,埋深 2 475.87 ~ 2 476.15 m,泥岩;b:HH87 井,埋深 2 457.07 ~ 2 457.29 m,粉砂质泥岩;c:HH91 井,埋深 1 744.38 ~ 1 744.61 m,砂岩;d:HH91 井,埋深 1 744.38 ~ 1 744.61 m,细砂岩;e:HH91 井,埋深 1 746.66 ~ 1 746.85 m,细砂岩;f:HH91 井,埋深 1 747.93 ~ 1 748.10 m,粉砂质泥岩

2) 延长组沉积晚期地层尚未完全固结成岩,在 SW-NE 向区域构造挤压作用下,形成了垂直于应力方向的 NW-SE 向展布的挤压沟谷;由于玉都断裂的左旋走滑作用,NW-SE 发生伸展作用,形成了 NE-SW 向的伸展沟谷。

参 考 文 献

- [1] 时志强,韩永林,赵俊兴,等.鄂尔多斯盆地中南部中侏罗世延安期沉积体系及岩相古地理演化[J].地球学报,2003,24(1):49-54.
Shi Zhiqiang, Han Yonglin, Zhao Junxin, et al. Depositional system and paleogeographic evolution of the Middle Jurassic Yan'an stage in the central and southern Ordos Basin[J]. Acta Geoscientica Sinica, 2003, 24(1): 49-54.
- [2] 郭正权,张立荣,楚美娟,等.鄂尔多斯盆地南部前侏罗纪古地貌对延安组下部油藏的控制作用[J].古地理学报,2008,10(1):63-71.
Guo Zhengquan, Zhang Lirong, Chu Meijuan, et al. Pre-Jurassic palaeogeomorphic control on the hydrocarbon accumulation in the Lower Yan'an Formation in southern Ordos Basin[J]. Journal of Palaeogeography, 2008, 10(1): 63-71.
- [3] 朱静,李文厚,韩永林,等.陇东地区前侏罗纪古地貌及油藏成藏规律研究[J].沉积学报,2010,28(6):1229-1237.
Zhu Jing, Li Wenhong, Han Yonglin, et al. Research on palaeogeomorphic features of pre-Jurassic and accumulation regularity of oil reservoir in the area of eastern Gansu, Ordos Basin[J]. Acta Sedimentologica Sinica, 2010, 28(6): 1229-1237.
- [4] 李凤杰,李磊,林洪,等.鄂尔多斯盆地吴起地区侏罗系侵蚀古河油藏分布及控制因素[J].天然气地球科学,2013,24(6):1109-1117.
Li Fengjie, Li Lei, Lin Hong, et al. Distribution characteristics and controlling factors analyses on incised paleochannel reservoir of valley filling in Jurassic of Wuqi area, Ordos Basin[J]. Natural Gas Geoscience, 2013, 24(6): 1109-1117.
- [5] 李永锋,代波,怀海宁,等.安塞油田南部侏罗系古地貌与延安组油气成藏关系[J].桂林理工大学学报,2020,40(3):486-493.
Li Yongfeng, Dai Bo, Huai Haining, et al. Paleomorphology of Jurassic in the southern area of Ansai Oilfield and its relationship with oil and gas accumulation in Yan'an Formation[J]. Journal of Guilin University of Technology, 2020, 40(3): 486-493.
- [6] 赵虹,党奔,党永潮,等.鄂尔多斯盆地安塞志丹地区侏罗系延安组下部组合沉积演化及其对油气的控制[J].西北大学学报(自然科学版),2020,50(3):490-500.
Zhao Hong, Dang Ben, Dang Yongchao, et al. Depositional system and its evolution of the Lower Yan'an Formation Jurassic in Ansai district, Ordos Basin[J]. Journal of Northwest University (Natural Science Edition), 2020, 50(3): 490-500.
- [7] 袁珍,李文厚,朱静,等.鄂尔多斯盆地陇东地区侏罗系古地貌恢复及其对石油聚集的影响[J].地质通报,2013,32(11):1806-1814.
Yuan Zhen, Li Wenhong, Zhu Jing, et al. The restoration of Pre-Jurassic paleogeomorphology and its influence on oil accumulation in Longdong area[J]. Geological Bulletin of China, 2013, 32(11): 1806-1814.
- [8] 于雷,王维斌,车飞,等.鄂尔多斯盆地吴旗油区下侏罗统古地貌特征与油气富集关系[J].断块油气田,2014,21(2):147-151.
Yu Lei, Wang Weibin, Che Fei, et al. Lower Jurassic paleogeomorphology characteristics and relationship between oil and gas accumulation in Wuqi oil area of Ordos Basin[J]. Fault-Block Oil & Gas Field, 2014, 21(2): 147-151.
- [9] 蒋代琴,文志刚,汤仁文,等.鄂尔多斯盆地吴起地区古地貌对侏罗系下部油藏形成和富集控制机制分析[J].地质力学学报,2019,24(5):627-634.
Jiang Daiqin, Wang Zhigang, Tang Renwen, et al. Analysis on the formation and enrichment control mechanism of the lower Jurassic reservoirs by paleo-geomorphology of Wuqi area in the Ordos Basin[J]. Journal of Geomechanics, 2019, 24(5): 627-634.
- [10] 王霞,刘凤林,范柏江,等.鄂尔多斯盆地吴起曾岔地区前侏罗纪古地貌与油藏成藏规律[J].兰州大学学报(自然科学版),2020,56(1):8-15.
Wang Xia, Liu Fenglin, Fan Baijiang, et al. Palaeogeomorphic features of pre-Jurassic and accumulation regularity of oil reservoir of Zengcha area in Wuqi County, Ordos Basin[J]. Journal of Lanzhou University

- (Natural Sciences), 2019, 24(5): 627–634.
- [11] 董桂玉, 何幼斌. 陆相断陷盆地基准面调控下的古地貌要素耦合控砂机制[J]. 石油勘探与开发, 2016, 43(4): 529–539.
Dong Guiyu, He Youbin. Mechanism of sand body prediction in a continental rift basin by coupling paleogeomorphic elements under the control of base level[J]. Petroleum Exploration and Development, 2016, 43(4): 529–539.
- [12] 蒙启安, 李跃, 李军辉. 复杂断陷盆地源-汇时空耦合控砂机制分析——以海拉尔盆地贝尔凹陷为例[J]. 中国矿业大学学报, 2019, 48(2): 344–352.
Meng Qian, Li Yue, Li Junhui, et al. Analysis of source and convergence coupling control sand mechanism in complicated faulted basin: An example of Beier depression in Hailar basin[J]. Journal of China University of Mining & Technology, 2019, 48(2): 344–352.
- [13] 刘池洋, 赵红格, 桂小军, 等. 鄂尔多斯盆地演化-改造的时空坐标及其成藏(矿)响应[J]. 地质学报, 2006, 80(5): 617–638.
Liu Chiyang, Zhao Hongge, Gui Xiaojun, et al. Space-time coordinate of the evolution and reformation and mineralization response in Ordos Basin[J]. Acta Geologica Sinica, 2006, 80(5): 617–638.
- [14] Chen G, Sun J B, Zhou L F, et al. Fission-track-age records of the Mesozoic tectonic-events in the southwest margin of the Ordos Basin, China[J]. Science in China (Series D), 2007, 50(2): 133–143.
- [15] 张园园, 任战利, 何发岐, 等. 克拉通盆地构造转折区中-新生界构造特征及其控藏意义——以鄂尔多斯盆地西南部镇泾地区延长组为例[J]. 岩石学报, 2020, 36(11): 3537–3549.
Zhang Yuanyuan, Ren Zhanli, He Faqi, et al. Meso-Cenozoic structural characteristics and their reservoir controls of structural transition area in China Craton: A case study of Yanchang Formation in Zhenjing area of southwestern Ordos Basin[J]. Acta Petrologica Sinica, 2020, 36(11): 3537–3549.
- [16] Dong Y P, Yang Z, Liu X M, et al. Mesozoic intracontinental orogeny in the Qinling, Mountains, Central China[J]. Gondwana Research, 2016, 30: 144–158.
- [17] 丁熊, 田景春, 姚泾利, 等. 鄂尔多斯盆地延长组长 10₁ 期沉积特征[J]. 岩性油气藏, 2015, 27(4): 26–30.
Ding Xiong, Tian Jingchun, Yao Jingli, et al. Sedimentary characteristics of sandstone in Chang 10₁ stage of Yanchang Formation in Ordos Basin[J]. Lithologic Reservoirs, 2015, 27(4): 26–30.
- [18] 李元昊, 杨桂茹, 彭建, 等. 鄂尔多斯盆地前侏罗纪古地貌形成演化及沉积充填特征[J]. 世界地质, 2020, 39(1): 56–71.
Li Yuanhao, Yang Guiru, Peng Jian, et al. Formation and evolution of pre-Jurassic palaeogeomorphology and characteristics of sedimentary filling in Ordos Basin[J]. Global Geology, 2020, 39(1): 56–71.
- [19] 刘强虎, 朱筱敏, 李顺利, 等. 沙垒田凸起西部断裂陡坡型源-汇系统[J]. 地球科学, 2017, 42(11): 1883–1896.
Liu Qianghu, Zhu Xiaomin, Li Shunli, et al. Source-to-sink system of the steep slope fault in the western Shaleitian Uplift[J]. Earth Science, 2017, 42(11): 1883–1896.
- [20] 谈明轩, 朱筱敏, 张自力, 等. 古“源-汇”系统沉积学问题及基本研究方法简述[J]. 石油与天然气地质, 2020, 41(5): 1107–1118.
Tan Mingxuan, Zhu Xiaomin, Zhang Zili, et al. Liu Wei, Zhao Hongchao, Su Bin. Summary of sedimentological issues and fundamental approaches in terms of ancient “Source-to-Sink” systems[J]. Oil & Gas Geology, 2020, 41(5): 1107–1118.
- [21] 杜晓峰, 王清斌, 庞小军, 等. 渤中凹陷石南陡坡带东三段源汇体系定量表征[J]. 岩性油气藏, 2018, 30(5): 1–10.
Du Xiaofeng, Wang Qinbin, Pang Xiaojun, et al. Quantitative characterization of source-sink system of Ed₃ in Shinan steep slope zone, Bozhong Depression[J]. Lithologic Reservoirs, 2018, 30(5): 1–10.
- [22] 万志云. 珠江口盆地恩平凹陷文昌组古沟谷体系与砂体展布分析[D]. 湖北 武汉: 中国地质大学(武汉), 2012.
Wang Zhiyun. Analysis of ancient valley system and sand body distribution of Wenchang Formation in Enping Sag, Pearl River Mouth Basin[D]. Wuhan: China University of Geoscience (Wuhan), 2012.
- [23] 王建强, 刘池洋, 赵红格, 等. 鄂尔多斯盆地西南部三叠纪末抬升剥蚀事件及热年代学记录[J]. 岩石学报, 2020, 36(4): 1199–1212.
Wang Jianqiang, Liu Chiyang, Zhao Hongge, et al. Uplift and exhumation events and thermochronological constraints at the end of Triassic in southwestern Ordos Basin[J]. Acta Petrologica Sinica, 2020, 36(4): 1199–1212.
- [24] Xia Dongling, Wu Yue, Zou Min, et al. Quality characterization of tight sandstone reservoirs in the Yanchang Formation of the Honghe oilfield, Ordos Basin, central China[J]. Energy Geoscience, <https://doi.org/10.1016/j.engeos.2021.07.001>.
- [25] 徐兴雨, 王伟锋, 陈谋. 鄂尔多斯盆地断裂特征及其石油地质意义[J]. 中国矿业大学学报, 2019, 48(4): 830–841.
Xu Xingyu, Wang Weifeng, Chenmou. Characteristics of faults and their significance in hydrocarbon accumulation in Ordos Basin[J]. Journal of China University of Mining & Technology, 2019, 48(4): 830–841.
- [26] Yuan Hui, Yin Shuai, Dong Li, et al. Restoration of the pre-Jurassic paleogeomorphology and its control on hydrocarbon distribution in western Ordos Basin[J]. Energy Geoscience, <https://doi.org/10.1016/j.engeos.2021.06.007>.
- [27] 王猛. 鄂尔多斯盆地镇原-泾川地区中生界断裂发育[J]. 断块油气田, 2019, 26(02): 142–146.
Wang Meng. Mesozoic fracture development characteristics of Zhenyuan-Jingchuan area, Ordos Basin[J]. Fault-Block Oil and Gas Field, 2019, 26(02): 142–146.
- [28] 石文龙, 杨波, 李慧勇, 等. 沙垒田凸起围区古近系源-汇体系[J]. 断块油气田, 2019, 26(03): 279–284.
Shi Wenlong, Yang Bo, Li Huiyong, et al. Paleogene source-to-sink system of surrounding slope area of Shaleitian Uplift[J]. Fault-Block Oil and Gas Field, 2019, 26(03): 279–284.
- [29] 屈红军, 蒲仁海, 陈硕, 等. 相-势耦合控制鄂尔多斯盆地中生界石油聚集[J]. 石油与天然气地质, 2019, 40(4): 752–762.
Qu Hongjun, Pu Renhai, Chen Shuo, et al. Controls of facies potential coupling on oil accumulation in the Mesozoic Ordos Basin[J]. Oil & Gas Geology, 2019, 40(4): 752–762.