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物源与沉积相对鄂尔多斯盆地东南部上古生界砂体展布的控制①

屈红军[1] 马 强[2] 高胜利[1,3] 梅志超[1] 苗建宇[1]

(1. 西北大学大陆动力学国家重点实验室/地质学系 西安 710069; 2. 中国石油吐哈油田勘探开发研究院 新疆哈密 839000;
3. 陕西延长石油(集团)有限公司研究院 西安 710000)

摘 要 近几年鄂尔多斯盆地东南部上古生界陆续发现新的天然气区带,显示出巨大的勘探潜力,因此在盆地东南部上古生界进行物源、沉积相、砂体展布规律的研究具有重要价值。以钻测井、岩芯及周边露头资料为基础,通过露头剖面古流向测定、重矿物分析及相带分析的方法,确定了研究区二叠系的物源方向;分析了上古生界沉积相类型,揭示了骨架砂体平面展布特征。研究认为:山西组与石盒子组物源可分为北北东、北北西及南部三个方向;本溪组主要发育障壁岛—潟湖及潮坪沉积,海侵方向来自东部,由沉积相控制的本溪组障壁岛砂体呈北北东向展布;山 2、山 1、盒 8 段主体发育不同来源方向的三角洲前缘沉积,受物源方向及沉积相控制,以延安为中心区域主体属于汇水区,骨架砂体分别由四个向延安区域汇聚的北北西、北北东、南南东向及南部三角洲前缘水下分流河道朵体组成,在汇水区不同方向来源砂体在不同层段具有相互叠置特征;山 2 段南部物源砂体较发育,盒 8 段北部物源砂体较发育,反映研究区古构造从南高北低转换为北高南低,指示鄂尔多斯盆地在山西组与石盒子组之间发生了南北向构造反转。

关键词 鄂尔多斯盆地 上古生界 古流向 物源 沉积相 砂体

第一作者简介 屈红军 男 1967 年出生 博士 教授 沉积学与盆地分析 E-mail: hongjun@nwu.edu.cn

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0 引言

鄂尔多斯盆地已发现的上古生界气藏主要位于盆地中北部,因而盆地中北部上古生界物源、沉积、储层、成藏规律研究程度比较高[1~11];近 10 年来加大了盆地东部研究力度[12~15];盆地西南部也得到了地质工作者的一定重视与研究[16~19],相对而言盆地东南部研究程度比较低,但近几年在盆地东南部有新的天然气区带发现[20,21],显示出巨大的勘探潜力,但研究仅是初步阶段[22~24]。

前人研究认为鄂尔多斯上古生界受多物源控制影响,但以北部物源为主[25~29]。对于是否存在南部物源,以及南部物源的影响范围、影响程度还不清楚,这在很大程度上影响了研究区的天然气勘探战略。由于鄂尔多斯盆地主体为岩性气藏[2],因此研究物源及沉积相对上古生界储集砂体展布的控制作用具有重要价值。

研究区位于盆地东南部的陕北地区,构造单元上位于伊陕斜坡中南部(图 1)。本次研究通过 35 口探

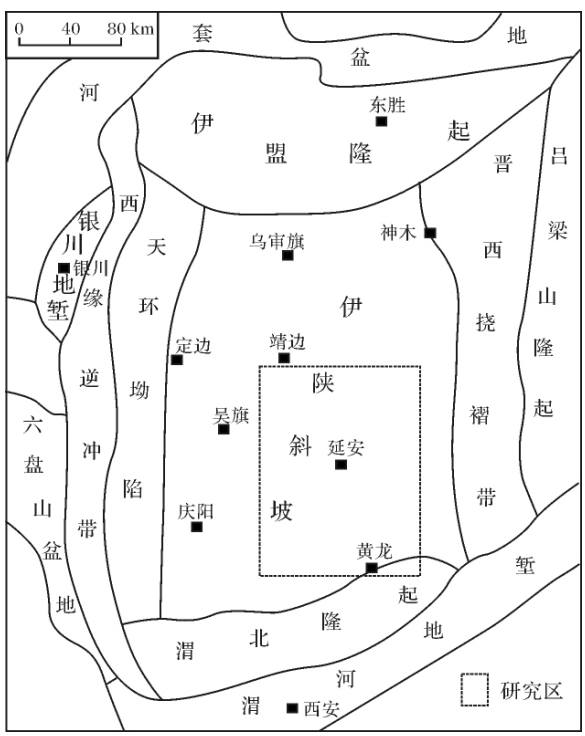

图 1 研究区区域位置图

Fig. 1 Tectonic location map of the study area

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井详细岩芯观察及钻测井资料综合分析，结合 5 条野外剖面实测及古流向测定，应用重矿物分析进行物源研究，沉积相分析方法确定沉积相类型及平面展布。以物源及沉积相分析为基础，确定研究区上古生界主力储集段本溪组、山 2 段、山 1 段、盒 8 段砂体展布规律。

1 物源分析

物源研究方法已经比较成熟，古流向测定、重矿物分析等是分析物源区的有效方法[30~33]，常量或微量地球化学研究方法也应用于物源研究[34,35]。本次研究应用古流向测定、重矿物分析进行物源研究。

1.1 古水流分析

古流向分析不仅可以确定骨架沉积体的走向、圈定古斜坡、推测古岸线走向，还可以按沉积物散布的样式探索盆地的结构及几何形态。本次研究依据各种交错层理倾向，砾石的定向排列分析以及平行层理中的剥离线理等原生沉积构造，经过吴氏网校正后做出流向玫瑰图，从而指示物源方向。

1) 山西组

从韩城沮水河、澄城三元桥、柳林北成家庄及柳林南三川河剖面玫瑰图可见(图 2a)，南部韩城沮水河及澄城三元桥古水流显示，主要指向从东南向西北，反映来自为南物源；而山西柳林成家庄剖面水流方向从北向南，反映来自为北物源。总的来说，古水流方向显示研究区中部在山西组时期整体为汇水区，说明研究区在山西期可能存在南北不同方向的物源。

2) 石盒子组

从韩城沮水河、澄城三元桥、柳林北成家庄、淳化口镇等剖面玫瑰图可见(图 2b)，南部韩城沮水河、澄城三元桥、淳化口镇剖面古水流方向主要指向从自南向北，反映来自为南物源；而山西柳林成家庄剖面水流方向还是自北向南，反映来自为北物源。总的来说，古水流方向显示研究区在石盒子组时期与山西组时期略有所差别，但是研究区主体依然为汇水区说明研究区在石盒子组时期可能存在南北不同的物源。

1.2 重矿物分析

对山西组与石盒子组 50 个砂岩样品的重矿物分析可以看出，各组砂岩中主体共有 8 种陆源重矿物，分别是锆石、金红石、电气石、石榴子石、磁铁矿、板钛矿、白钛矿及绿帘石，其中以锆石、石榴子石和白钛矿含量最高，也较稳定，三者之和平均含量可达 88%，从而成为主要重矿物(只有 2 个样品例外，电气石和磁铁矿含量大于 10%)。

根据重矿物分析数据，结合前人区域研究资料，可以把研究区山西组与石盒子组物源分为北北东方向、北北西方向和南方三个物源区(图 3a，b)：A 区为富锆石区，即锆石含量较高，石榴子石与白钛矿含量较低；B 区为锆石 + 白钛矿 + 石榴子石区，即锆石含量低于 A 区，但石榴子石与白钛矿含量相对较高；C 区为富白钛矿区，白钛矿含量较高，锆石含量低于 A 区和 B 区。

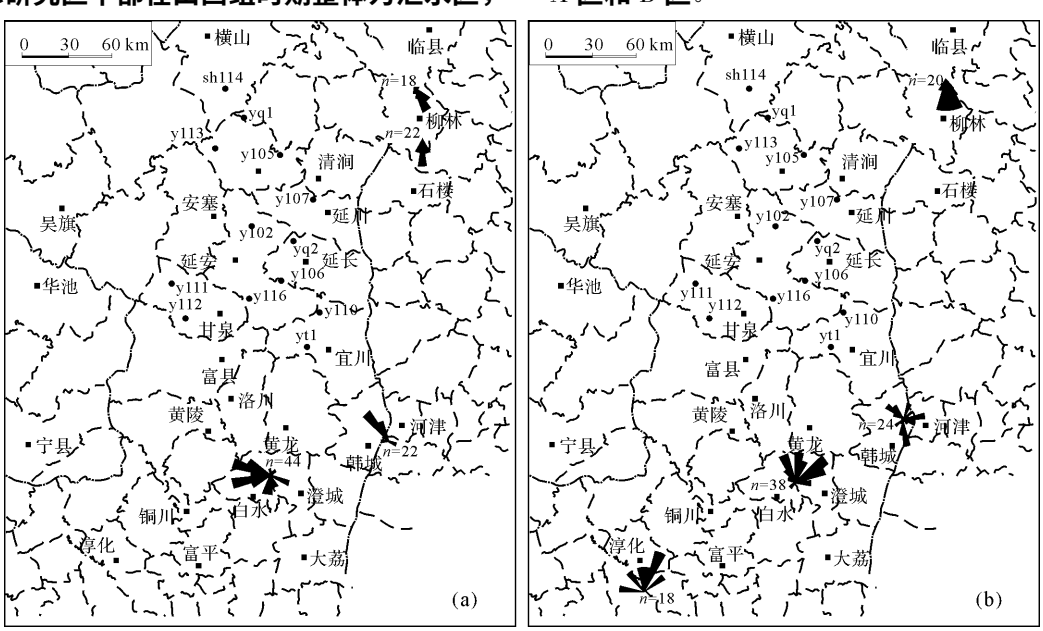

图 2 研究区周边山西组(a)及石盒子组(b)古流向玫瑰图

Fig. 2 Paleo-current rose diagrams of Shanxi Formation in (a) and Shehezi Formation in (b) in surrendering areas of the study area

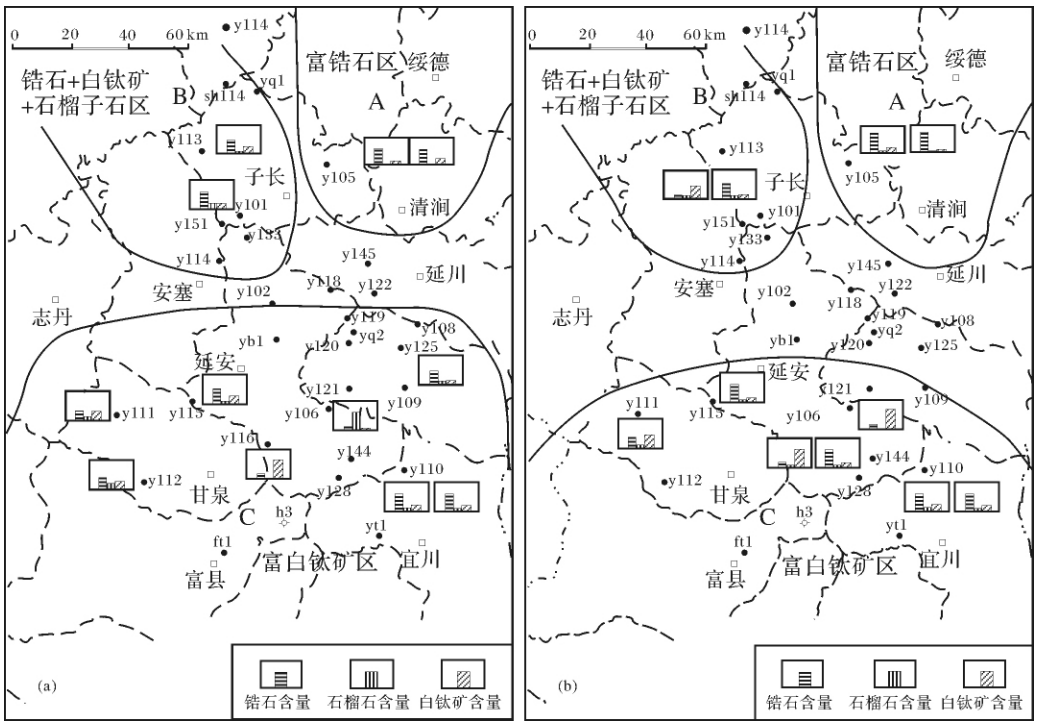

图 3　研究区山西组(a) 及石盒子组(b) 重矿物物源分区图

Fig. 3　Provenance zoning diagrams of heavy mineral in Shanxi and Shehezi Formation in the study area

2　沉积基地底形及沉积相带控制本溪组砂体展布

通过岩芯详细观察,确定本溪组沉积相主要为海岸沉积的障壁岛—潟湖及潮坪沉积; 其中本 2 段以发育障壁岛—潟湖沉积为主,本 1 段以发育潮坪沉积为主。由沉积相控制的本溪组主要储层砂体为本 2 段障壁岛砂体。通常障壁岛砂体基本平行于海岸线或沉积相带方向,因而确定海岸线或沉积相带方向是海岸沉积研究的重点。

2.1　地层厚度与灰岩厚度反映海岸线及沉积基地底形

通过本溪组地层厚度等值线图(图 4a) 及灰岩厚度(图 4b) 等值线图可以看出,地层厚度等值线与灰岩厚度等值线都具有北北东向展布的特征,指示本溪组沉积时海岸线、沉积基地底形及沉积相带方向为北北东向,研究区此时可能为伸向南南西方向的一个海湾,地层厚度及灰岩厚度受沉积基地底形影响是显而易见的(图 5) 。

从本溪组地层厚度与灰岩厚度从东向西逐渐变薄(图 5) ,而南北向变化不大(图 6) ,说明本溪组沉积时沉积基地底形为东低西高,鄂尔多斯本部地区本溪组时期海侵来自东部,这一认识与前人认识一致[36~38]。

2.2　沉积基地底形及沉积相带方向指示障壁岛及潮道砂体展布

本溪组骨架砂体主要沉积微相为障壁岛及潮道,从理论上讲二者在空间展布方向是有所区别的。但由于研究区此时为伸向南南西方向的一个海湾,二者都是平行于海湾延伸分布,因此二者在方向上难以区分。由相分析及砂地比等值线图确定的沉积相平面图反映的沉积相带方向为北北东向(图 7a) ,通过砂岩厚度等值线图也反映了同样的方向(图 7b) ,因此由沉积相控制的本溪组障壁岛及潮道砂体呈北北东向展布。

3　物源决定了不同方向三角洲前缘朵状砂体展布

3.1　物源方向决定了山西组与石盒子组沉积相带

以 35 口井详细的岩芯观察为基础,通过岩石相、测井相的综合分析,确定研究区二叠系山西组及石盒子组沉积相类型主体为三角洲相三角洲前缘亚相,其骨架砂体微相为水下分流河道。

从山西组—盒 8 段南北向沉积相对比剖面图(图 6) 可以看出,不同层段南北区域之间存在砂岩不

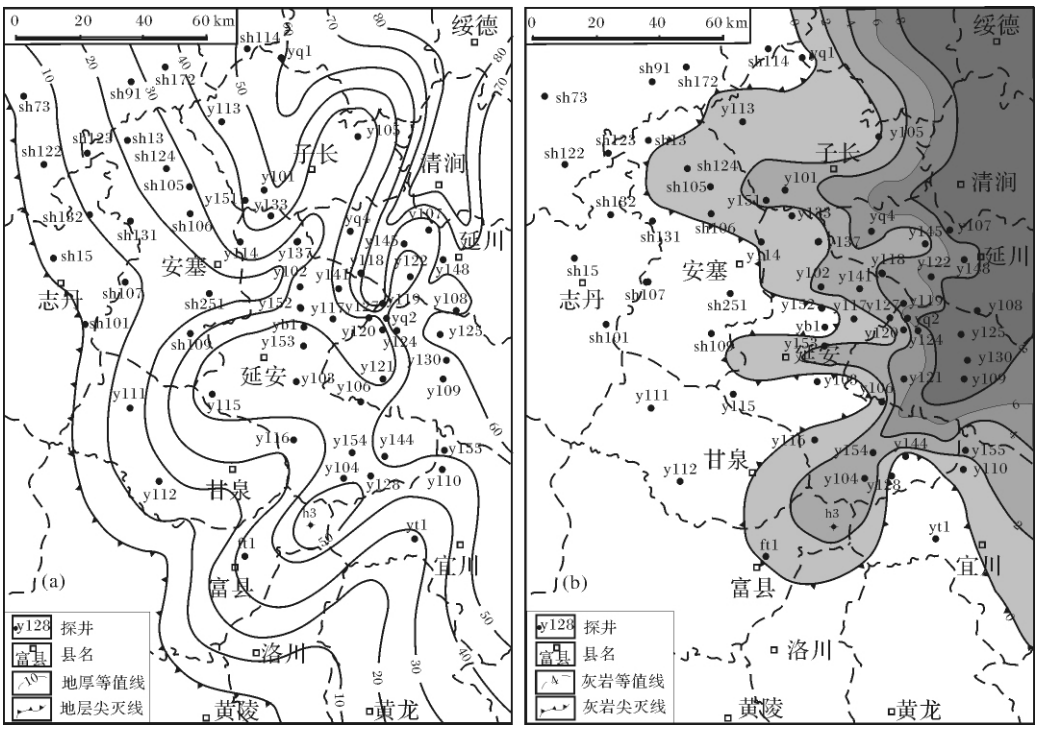

图 4 盆地东南部本溪组地层厚度(a) 及灰岩厚度(b) 等值线图

Fig. 4 Contour maps of stratum thickness and limestone rock thickness in Benxi Formation in southeast Orodos basin

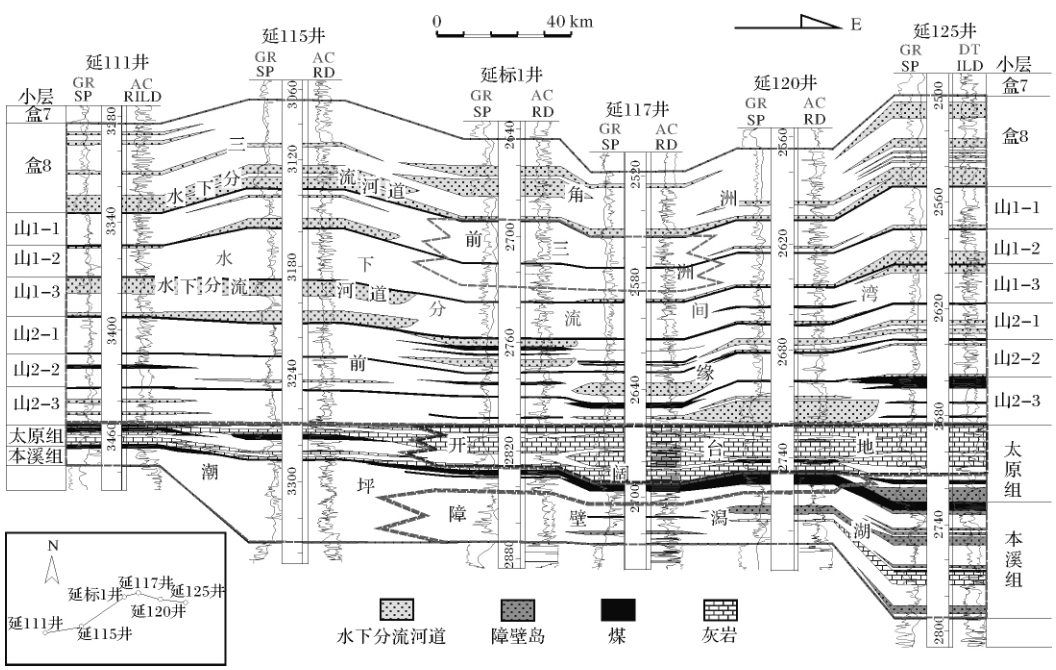

图 5 延 111 井—延 125 井本溪组—山西组东西向沉积相对比剖面图

Fig. 5 WE direction depositional facies cross section from Well Yan-111 to Well Yan-125 well of Benxi Formation to He 8 member

发育区域,分割南北物源区,说明研究区存在北部及南部物源,且在不同层段南北物源影响范围不同,不同来源方向水下分流河道朵状砂体在不同层段具有相互叠置特征(图 6) 。

通过单井岩石相、测井相、联井沉积相对比剖面、砂地比等值线分析,绘制了研究区二叠系山 2 段、山

1 段、盒 8 段沉积相平面图(图 8a,9a,10a) 。从山 2 段、山 1 段、盒 8 段沉积相平面图可以看出二叠系山西组与石盒子组物源可分为北北东、北北西及南部三个方向,以延安为中心区域属于汇水区; 山 2 段南部物源范围较大,影响到了延安以北区域; 盒 8 段北部物源范围较大,越过了延安一带,相应的南部物源范围后撤。

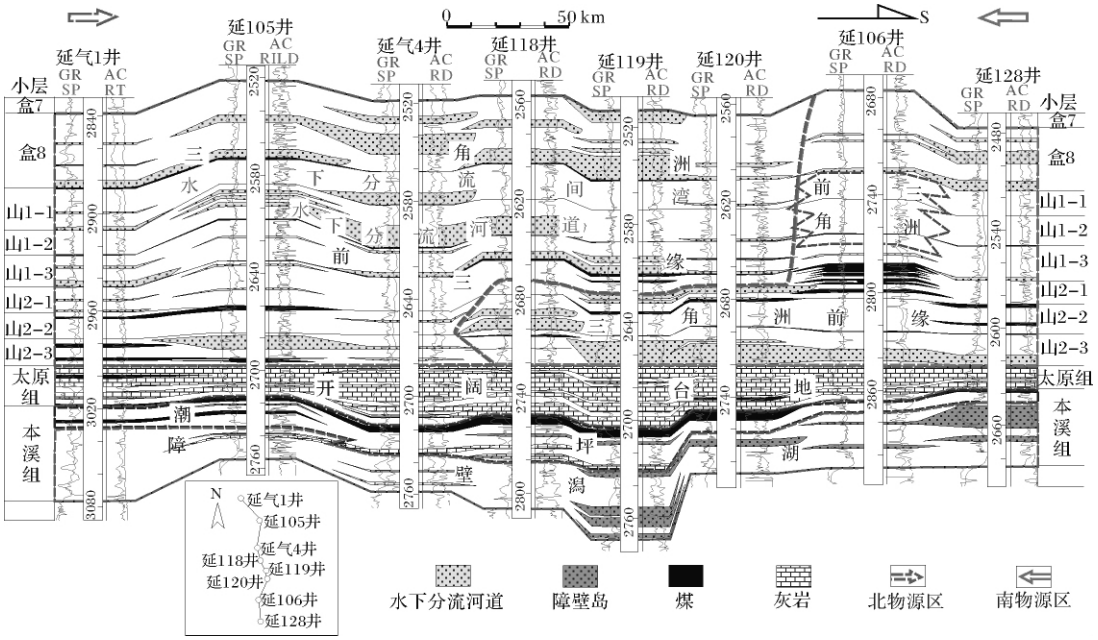

图 6　延气 1 井—延 128 井本溪组—盒$_8$段南北向沉积相对比剖面图

Fig. 6　NS direction depositional facies cross-section from Well Yanqi-1 to Well Yan-128 of Benxi Formation to He 8 member

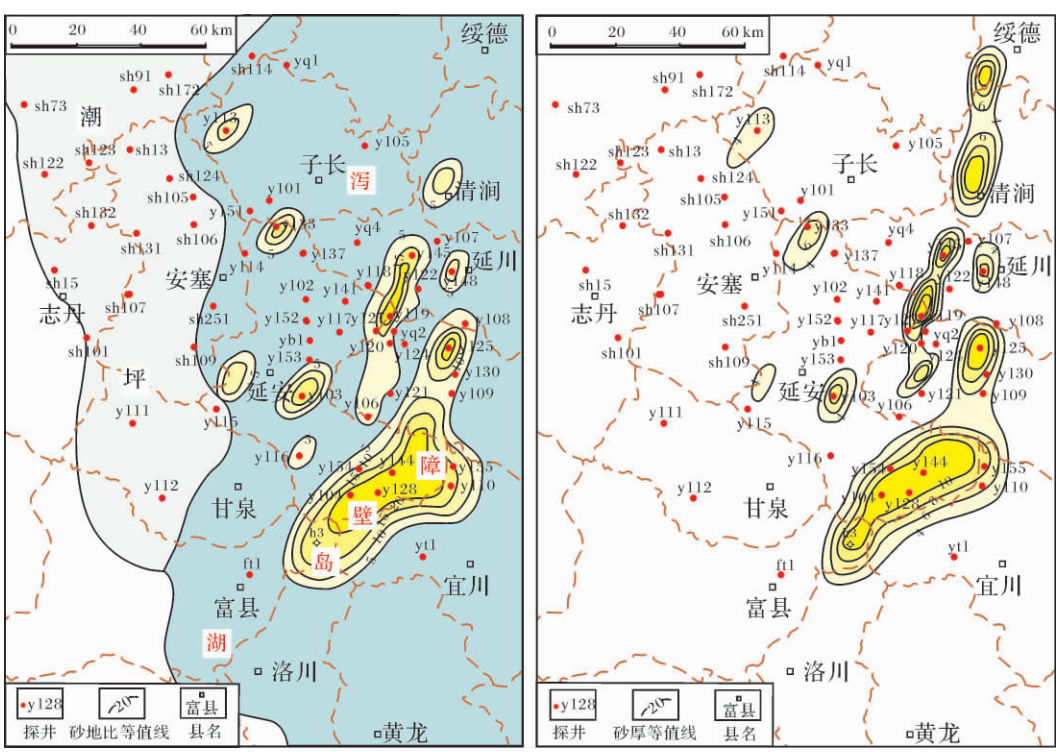

图 7　鄂尔多斯盆地东南部本溪组沉积相及砂体展布平面图

Fig. 7　Depositional facies and sandbody distribution of Benxi Formation in southeast Orodos basin

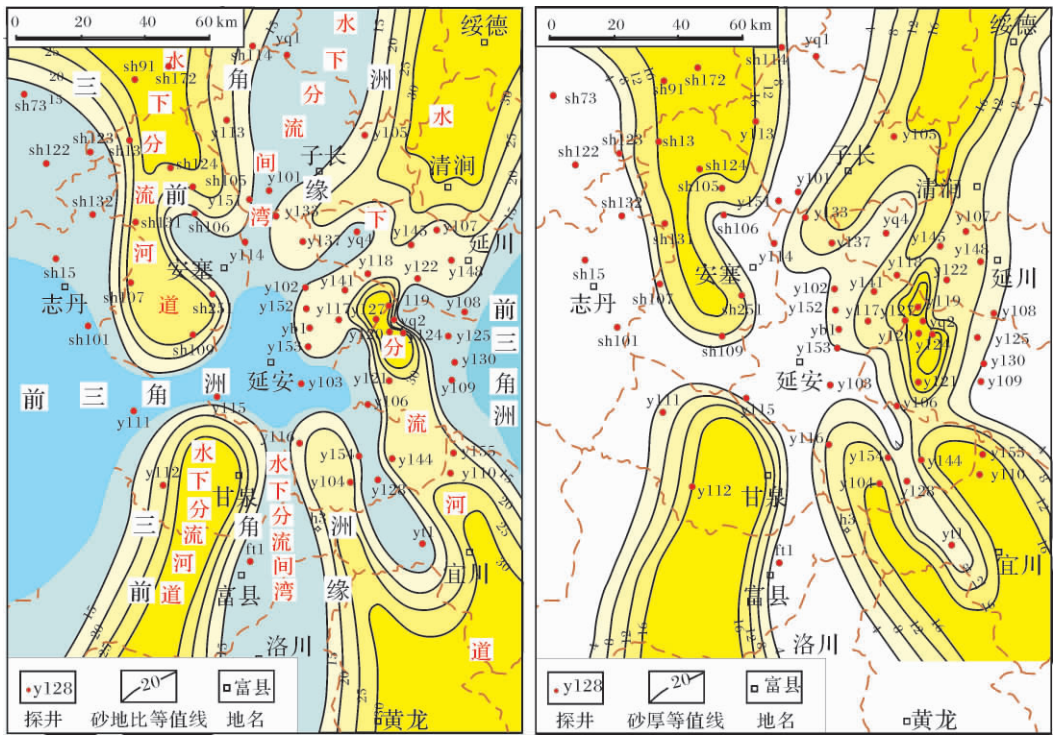

图 8 鄂尔多斯盆地东南部山 2 段沉积相及砂体展布平面图

Fig. 8 Depositional facies and sandbody distribution plans of Shan-2 member in southeast Ordos basin

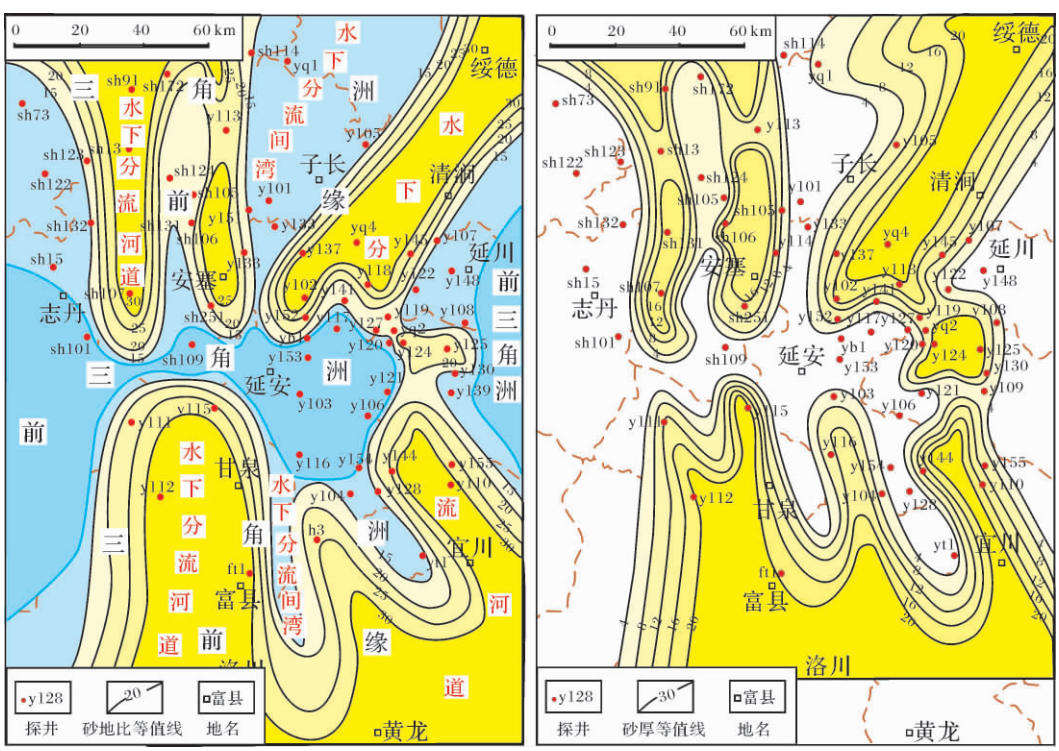

图 9 鄂尔多斯盆地东南部山 1 段沉积相及砂体展布平面图

Fig. 9 Depositional facies and sandbody distribution of Shan-1 member in southeast Orodos basin

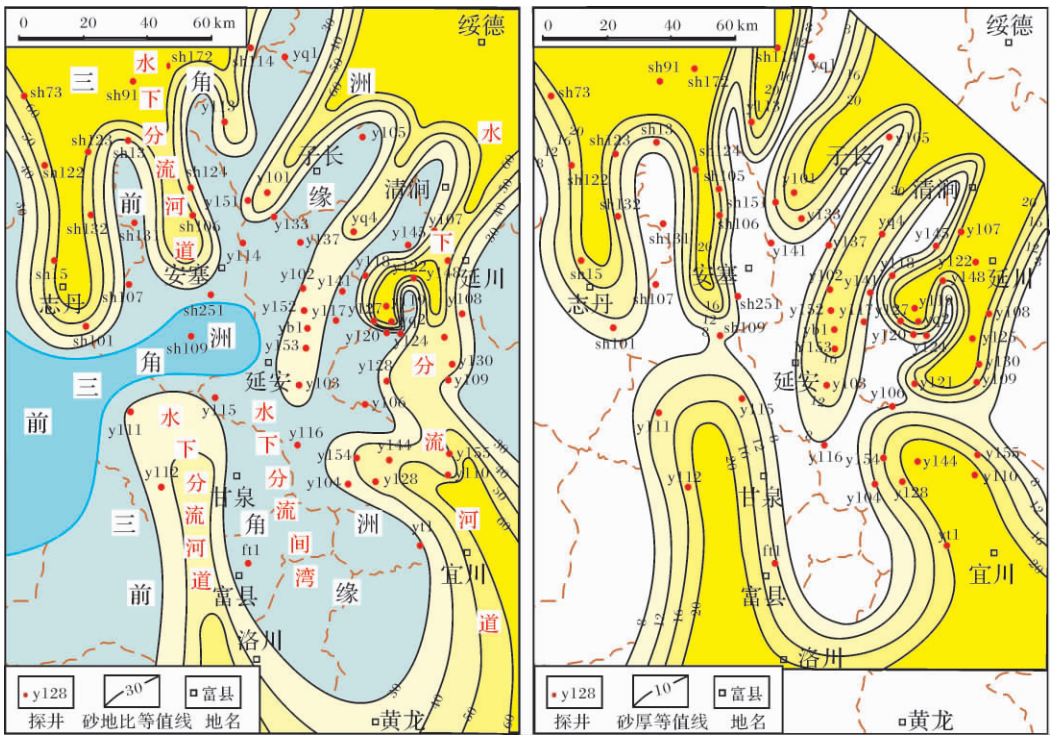

图 10　鄂尔多斯盆地东南部盒 8 段沉积相及砂体展布平面图

Fig. 10　Depositional facies and sandbody distribution of He-8 member in southeast Orodos basin

3.2　沉积相带决定了水下分流河道朵状砂体展布

骨架砂体展布受控于物源方向及沉积相。在研究区山西组与石盒子组沉积期为不同方向的三角洲前缘沉积特征的认识基础上，以物源方向及沉积相带展布为框架，以山 2 段、山 1 段、盒 8 段砂岩厚度数据为依据，分别绘制不同主力储集段砂岩厚度等值线图(图 8b，9b，10b)。从图可以看出，山 2 段、山 1 段、盒 8 段骨架砂体分别由四个向延安区域汇聚的北北西、北北东、南部、南南东向三角洲前缘水下分流河道朵体组成; 山 2 段南部物源砂体较发育(图 6，图 8b)，盒 8 段北部物源砂体较发育(图 6，图 10b)。

4　结论

(1) 研究区本溪组主要发育障壁岛—潟湖及潮坪沉积，海侵方向来自东部，由沉积相控制的本溪组障壁岛砂体呈北北东向展布; 山西组与石盒子组物源可分为北北东、北北西及南部三个方向;

(2) 山 2 段、山 1 段、盒 8 段主体发育不同来源方向的三角洲前缘沉积，受物源及沉积相控制，以延安为中心区域属于汇水区，骨架砂体分别由四个向延安区域汇聚的北北西、北北东、南部、南南东向三角洲前缘水下分流河道朵体组成，在汇水区不同来源方向砂体在不同层段具有相互叠置特征;

(3) 山 2 段南部物源砂体较发育，盒 8 段北部物源砂体较发育，反映研究区古构造从南高北低转换为北高南低，指示鄂尔多斯盆地在山西组与石盒子组之间发生了南北向构造反转。

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Controls of Provenance and Depositional Facies on Sandbody Distributions of the Upper Paleozoic in Southeast Ordos Basin

QU Hong-jun[1]　MA Qiang[2]　GAO Sheng-li[1,3]　MEI Zhi-chao[1]　MIAO Jian-yu[1]

(1. State Key Laboratory of Continental Dynamics, Northwest University, Xi'an 710069;
2. Institute of Petroleum Exploration and Development, Tuha Oil Corporation, CNPC, Hami, Xinjiang 839000;
3. Research Institute of Shaanxi Yanchang Petroleum Corporation, Xi'an 710000)

Abstract　In recent years, lots of new gas plays are found continuously in the Upper Paleozoic in southeast Ordos basin, which displays great exploration prospects. The Upper Paleozoic was influenced by multisource in the former

study, while the main provenance was from north. It is not clear that whether there was sourthern provenance, how much the influenced area was, and what degree the influence was, which greatly influenced gas exploration strategy in the study area. Since lithologic play is the main reservoir in Ordos basin, the study on source and the rule of depositional facies on Upper Paleozoic sandbody distribution is of great importance in southeast Ordos basin. Based on data of well drilling, logging and core as long with outcrop sections of surroundings, by means of paleocurrent direction measuring in outcrop sections, heavy mineral analyzing as well as facies belt diagnosing, the provenance directions of the Permian are confined, the depositional facies styles of the Upper Paleozoic are analyzed, the rule of source, geography of depositional basement and depositional facies on sandbody distributions in the study area are studied, and also the distribution feature of skeleton sandbody are disclosured. Based on the above studies the following conclusion can be obtained. Paleocurrent direction revealed the whole middle part of the study area was catchment area in periods of Shanxi and Shehezi Formation, which suggests the possible existence of north and south of two different sources in the very time. Heavy mineral analyzing indicated that the NNE region of the studied area is rich in zircon, the NNW region of the studied area is mixed area of zircon, leucoxene and garnet, while the south region is rich in leucoxene, which disclosures that the provenance of Shanxi and Shehezi Formation can be divided into three directions which are NNE, NNW, and south. The coast line and geography of deposit basement reflected by thickness of strata and limestones indicated transgression direction being from east. Benxi Formation mainly developed barrier island & lagoon and tidal flat facies, the distribution of barrier island and tidal channel sandbodies were controlled by geography of deposit basement and depositional facies belts with the barrier sandbody being distributed along NNE direction. Depositional facies belts of Shanxi and Shehezi Formation were controlled by the orientation of provenance, which controlled the distribution of under water lobate distributary channels. Shan 2, Shan 1 and He 8 Member mainly developed delta front depositional facies sourced from different directions which were controlled by provenance directions and depositional facies belts, while Yan'an region being the center of water catchment. The skeleton sandbodies are composed of four under water lobate distributary channels converging to Yan'an region coming from NNE, NNE, and SSE as well as south direction, different sourced sandbodies in different layers display the style of overriding in water catchment area. The skeleton sandbodies sourced from south developed well in Shan-2 member, which influenced areas of north of Yanan, while the skeleton sandbodies sourced from north developed well in He 8 member, which overreached areas of south of Yanan while the southern provenance receded simultaneously, reflecting that palaeo-terrain in the studied area conversed from south being higher than north to north being higher than south, and also indicating that constitution reversed along NS direction in Ordos basin between periods of Shanxi and Shehezi Formation.

Key words Ordos basin; the Upper Paleozoic; paleo-current directions; Provenance; depositional facies; sandbody