南堡凹陷老爷庙地区构造—沉积分析

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摘要: 利用构造—沉积分析方法, 探讨南堡凹陷老爷庙横向背斜对东营组扇三角洲沉积体系的控制作用. 通过对西南庄边界断层和老爷庙背斜的几何学解剖, 确定老爷庙背斜为西南庄断层断面弯曲控制的横向背斜. 该背斜从沙河街组一段沉积期开始发育, 馆陶组沉积期叠加了NE向的走滑断层. 含砾率统计发现, 含砾率高值均分布在横向背斜转折端、横向背斜和边界断层交汇控制了主水系的入口, 提供长距离输沙路径. 从井—震结合剖面和古地貌图识别出横向背斜发育时期的上、下坡折位置. 扇三角洲平原受上坡折控制, 发育在背斜转折端; 下坡折控制扇三角洲前缘和前扇三角洲的分界. 边界断层控制的横向背斜在沉积盆地内普遍发育. 横向背斜控制长距离输沙和相分配模式对砂体预测具有重要的意义.

关键词: 横向背斜; 构造—沉积分析; 老爷庙地区; 南堡凹陷.
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Tectono-Sedimentary Analysis of Laoyemiao Region in Nanpu Depression

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Abstract: The aim of this paper is to test a new approach-tectono-sedimention analysis to gain insights into the controls of Laoyemiao transverse fold on the fan delta of Dongying Formation. By investigating the features of basin-bounding master fault (Xi' nanzhuang fault) and fold geometry in Laoyemiao region, we have determined that Laoyemiao fold is essentially a transverse fold produced by Xi' nanzhuang fault flexural. The fold with axes trending NW-SE was developed in sedimentary period of the 1st Member of Shahejie Fm., and superimposed by Miocene NE trending strike-slip faults. Calculation of gravel content shows that the high values zone basically coincides with the hinge, which in turn reveals that the joint of the transverse fold and Xi' nanzhuang fault is the main drainage entry, and fold hinge provides major sediment long distance transportation pathway. From logging, seismic data and paleogeomorphology, the upper and lower slope break of transverse fold are identified. The sedimentary facies interpretation shows that they are consistent with the delimits of fan-delta plain and front, fan-delta front and pro-fan delta respectively. It can be proved that transverse fold constrains the facies distribution. Transverse folds caused by basin-bounding master fault are widely developed in sedimentary basins. The established model of sediment transportation for long distance and facies distribution of transverse fold is significant for favorable sandbodies prediction.

Key words: transverse fold; tectono-sedimention analysis; Laoyemiao region; Nanpu Depression.

南堡凹陷地处黄骅坳陷的东北端, 为中、新生代发育起来的小型生油凹陷. 北部西南庄和柏各庄断层交汇构成了盆地的边界. 老爷庙地区位于凹陷北部西南庄下降盘, 勘探面积约150 km^2. 老爷庙油田钻遇地层自下而上依次为古近系的沙河街组和东营组以及新近系的馆陶组和明化镇组. 老爷庙构造是沙河街组时期开始发育的同沉积背斜, 以往研究将其定性为受西南庄边界断层控制继承性发育的滚动背斜.

在大陆裂谷盆地, 边界断层是最重要的构造因

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素,因为它控制了盆地的形态和沉降史(Magnavita and da Silva, 1995). 扇体发育的规模除受气候、沉积物源和构造活动等因素的影响外,还受入盆水系面积、地貌起伏的制约(Heward, 1978; Galloway and Hobday, 1983; Blair and McPherson, 1994). 老爷庙地区受边界断层和背斜双重控制,在下降盘平行断层方向上具有相变快、相带分布窄的沉积特点,运用原有的滚动背斜模式不能对该区沉积展布特征予以合理解释.

构造—地层学在研究盆地构造与古地貌、沉积物分散体系以及沉积层序或旋回的成因分析方面是行之有效的工具(冯有良等, 2004). 随着地震资料品质的提高,特别是高精度三维地震资料的广泛应用,使得人们可以精细刻画和分析断层系统几何形态和运动特征,为进一步研究盆地内构造对沉积体系和骨架砂体的控制提供了可能(赵博等, 2007). 因此,构造—沉积分析便引起了广泛关注. 构造—沉积分析更强调了构造作用与沉积要素(如可容空间变化、构造古地貌、水系网络、沉积物输送路径、沉积物分配、沉积物堆积样式和沉积体改造等)的结合分析,通过三维地震成像技术和地震属性技术对构造运动及演化规律的刻画,探讨幕式构造作用及构造演化各阶段沉积要素的响应. 本文以东营组一、二段的扇三角洲沉积体系为研究对象,运用构造—沉积分析的思路,对三维地震资料的地震—地质解释,综合地震、录井和测井信息,探索老爷庙构造对水系入口、输沙路径和沉积相配置的控制作用,为这种典型模式下的有利砂体预测提供帮助.

1 老爷庙构造性质厘定

西南庄断层倾角变化表明,从 SW 至 NE 向断层中间缓两侧陡. 统计东营组地层段的倾角得出,西南庄断层倾角大致可分为 3 段,中段倾角最缓,约 30°~40°,两侧不对称,西段为陡坡,约 60°~70°,东段为 40°~60°陡坡(图 1a). 通过对西南庄边界断层断面(图 1b)解剖发现,断面在 3 500~7 800 m 的深度中间隆起,SW 和 NE 下凹. 正是因为这种断面的隆起与下凹导致了上覆沉积地层的褶皱弯曲,褶皱的枢纽呈 SE 向,垂直于西南庄断层.

垂直西南庄边界断层 *A*-*A*′剖面显示老爷庙地区地层整体向南倾斜(图 1c),不具有滚动的特点;平行于边界断层的剖面西南庄断层断面发生弯曲,上覆地层发生弯曲响应而形成褶皱. Wheeler (1939)首次将这类成因的褶皱称为断层线偏移褶

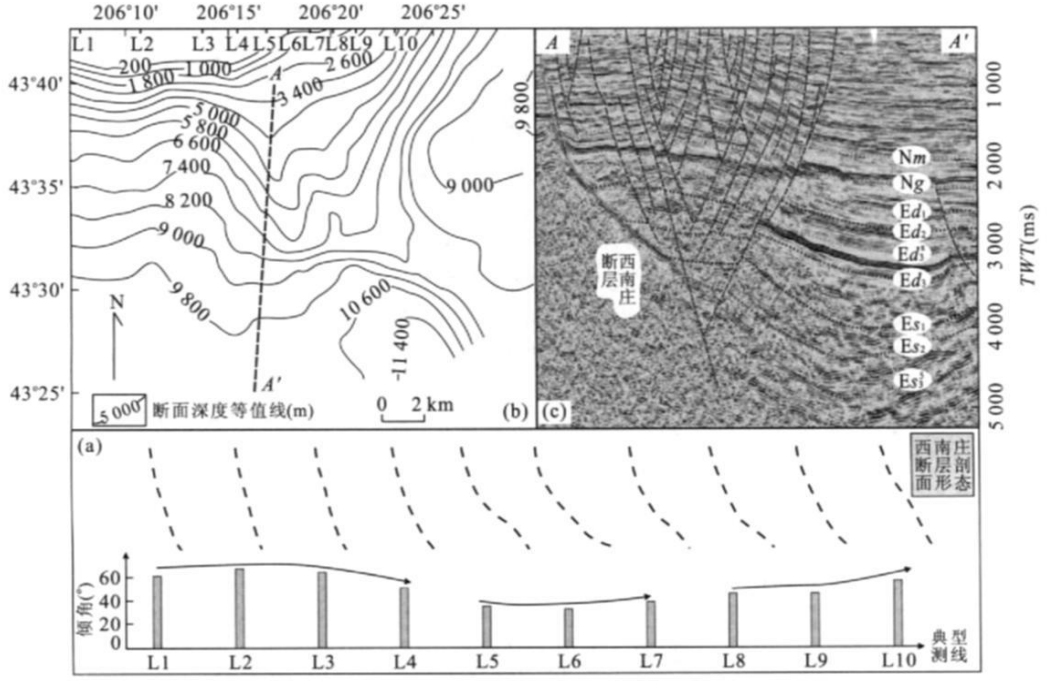

图 1 南堡凹陷老爷庙背斜性质解剖

Fig. 1 Structural characteristics of Laoyemiao anticline in Nanpu depression

a. 老爷庙地区西南庄断层倾角变化; b. 老爷庙地区西南庄断层断面形态; c. *A*-*A*′剖面褶皱形态

皱, Schliche(1995)将其划分为横向褶皱一类, 并进一步指出横向向斜形成于断面凹部(向下盘凸出)的上盘一侧, 背斜形成于断层面凸部(向上盘凸出)的上盘一侧; 褶皱幅度向离开断层线偏转点方向减小. 它与滚动背斜的本质区别就是这类褶皱的枢纽垂直于断层, 而后者平行于断层.

除横向褶皱的特点之外, 本区走滑断层很发育, 有的甚至切穿边界大断裂, 形成负花状构造, 在顶部形成走滑—背斜(图 1c), 但不控制东营组地层沉积, 为馆陶组时期在区域性右旋走滑应力场作用下发育的产物.

2　横向背斜控制沙输送

前人曾在裂谷盆地中水系入口和沉积物输送路径方面做过大量研究工作, 总体可概括为以下 4 种模式: 转换断层(Leeder and Gawthorpe, 1987; Gawthorpe and Colella, 1990; Roberts and Jackson, 1991; Gawthorpe and Hurst, 1993)、调节带(Morley *et al*., 1990; 陈昭年等, 2005)、断层下降盘轴向运移(Ravnas and Steel, 1998)和上升盘在断崖处的短距离沉积(Surlyk, 1978, 1984; Turner *et al*., 1987; Cherry, 1993; Surlyk *et al*., 1993). 断层线偏移引起的横向褶皱在断陷盆地中普遍发育, 尤其由大的边界断层所形成, 如歧口凹陷的沧东断层. 但对于横向褶皱的研究远不如调节带等研究的成熟和系统, 其对沉积作用的控制如水系活动及形成的砂分散体系也尚未引起重视.

通常情况, 含砾率高的部位可被认为是主河道发育部位. 现今地貌基本能够反映地层沉积时期的相对起伏, 对东二段和东一段分别进行含砾率统计, 两者叠合(图 2)显示含砾率最高值位于边界断层与横向背斜交汇部位, 沿背斜转折端向盆地中心逐渐降低, 背斜两侧含砾率值骤减. 说明老爷庙背斜与盆地边缘物源区沟通, 横向背斜和边界断层交汇控制了主水系入口, 主河道沿背斜轴向展布, 长距离输沙进入盆地.

分析其长距离输沙机制主要有以下两点: 一是当河流携带沉积物注入湖盆时, 由于其密度大于蓄水体密度, 它将沿盆地底部流动并与湖水混合. 参与影响和控制注入水体变化和扩散型式的有 3 种力: 惯性力、摩擦力和浮力(王良忱和张金亮, 1996). 首先由于背斜为隆起带, 坡降比两侧小, 床底沉积物与水体摩擦力较小, 有利于水体惯性的保持, 从而有利于沉积物搬运至较远处沉积, 在末端形成向外辐射状砂体; 而两侧向斜水体深, 底部摩擦力大, 水动力减弱快, 沉积物卸载迅速, 不利于远距离输沙. 二是背斜转折端的高部可形成平行背斜轴向的张性节理—断裂—地堑构造序列, 构成水下水道发育的理想地区, 为输沙提供了高效的路径.

3　横向背斜坡折控制沉积相分配

坡折带原是地貌学概念, 指地形坡度突变的地

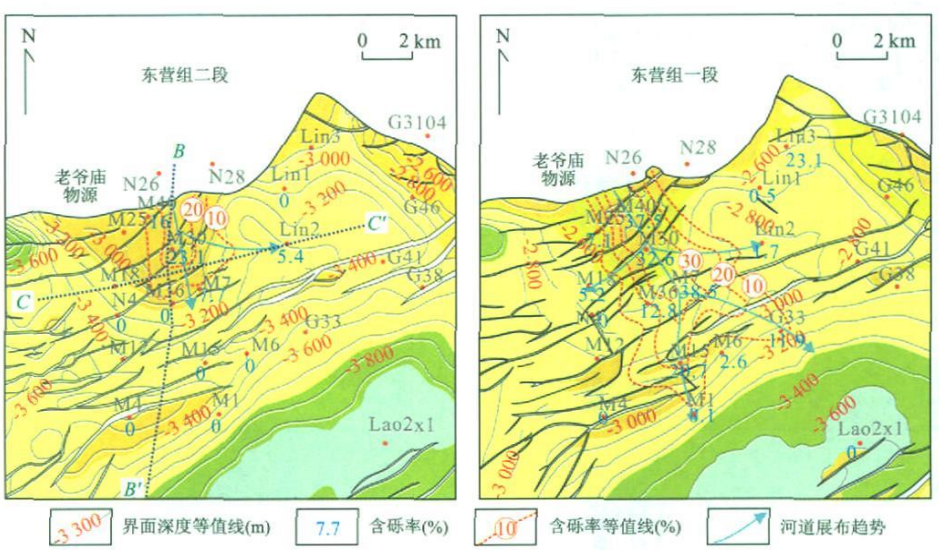

图 2　老爷庙地区含砾率分布

Fig. 2　Variation of calculated gravel content in Laoyemiao region

带(Vail *et al*., 1977).林畅松等(2000)通过对渤海湾等第三纪湖盆的研究发现,长期活动的同沉积断裂形成的"构造坡折带"制约着盆地充填可容纳空间,控制着低水位体系域和高水位域三角洲—岸线体系的发育部位,对沉积体系的发育和砂体分布起重要的控制作用.王英民等(2002)通过对准噶尔盆地侏罗纪湖盆坡折带的深入研究,将坡折带按成因机制划分构造坡折带、沉积坡折带和侵蚀坡折带 3 种类型,其中构造坡折带可划分为断裂坡折带和挠曲坡折带.老爷庙地区背斜坡折带从成因上应属于挠曲坡折带.

前人对挠曲坡折带的研究常常局限在断层引起的断块掀斜构造、逆牵引背斜和潜山披覆背斜等同沉积构造弯曲、倾斜形成的坡折带,对横向背斜的坡折及其控制的沉积相分配研究较少.

图 3 分别为平行和垂直背斜枢纽的连井剖面,B-B'剖面显示背斜存在明显的上坡折和下坡折,上坡折控制冲积扇扇根或扇三角洲平原沉积,下坡折之上为扇三角洲前缘,之下坡度突变,可容空间突然增加,为浊积扇发育提供有利条件.因此,平行背斜枢纽方向上,可以呈现出扇三角洲平原—扇三角洲前缘—浊积扇较完整的沉积序列.东二段时期湖盆整体加深,粗碎屑搬运距离较短,但总体也存在这个特点.C-C'剖面背斜大致呈箱状,上坡折主要位于转折端附近,下坡折位于翼部拐点附近,分别构成了凸起—缓坡和缓坡—凹陷的分界.上坡折主要为粗粒沉积,砂体较厚,规模较大,发育下切谷,之下与下坡折间发育扇三角洲前缘河口坝、席状砂等,沉积物从背斜转折端向两侧深凹进积.下坡折点之下可容纳空间突然加大,过渡为前扇三角洲,沉积深湖相泥岩、油页岩,并发育浊积砂体,可形成有利的岩性圈闭.由于深部沉积物的供给匮乏,下坡折出现明显的地层上超尖灭现象.

可见坡折客观上控制了沉积相的前端和侧向配置.由于沉积物主要沿背斜轴向展布,沉积相侧向分配具有相带较窄,相变迅速的特点.这种展布特征对该区岩性—构造圈闭和浊积砂体圈闭预测十分有利.

古地貌是古构造和沉积充填的结果,它代表了一个时期沉积盆地原型的地表形态.通过恢复东营组各沉积时期的古地貌,叠合沉积相平面展布从平面上揭示背斜坡折的沉积响应.

沉积相叠合古地貌图(图 4)反映出沉积相带界限受坡折带控制,扇三角洲平原主要发育于背斜转折端,其下发育扇三角洲前缘,下坡折之下发育浊积

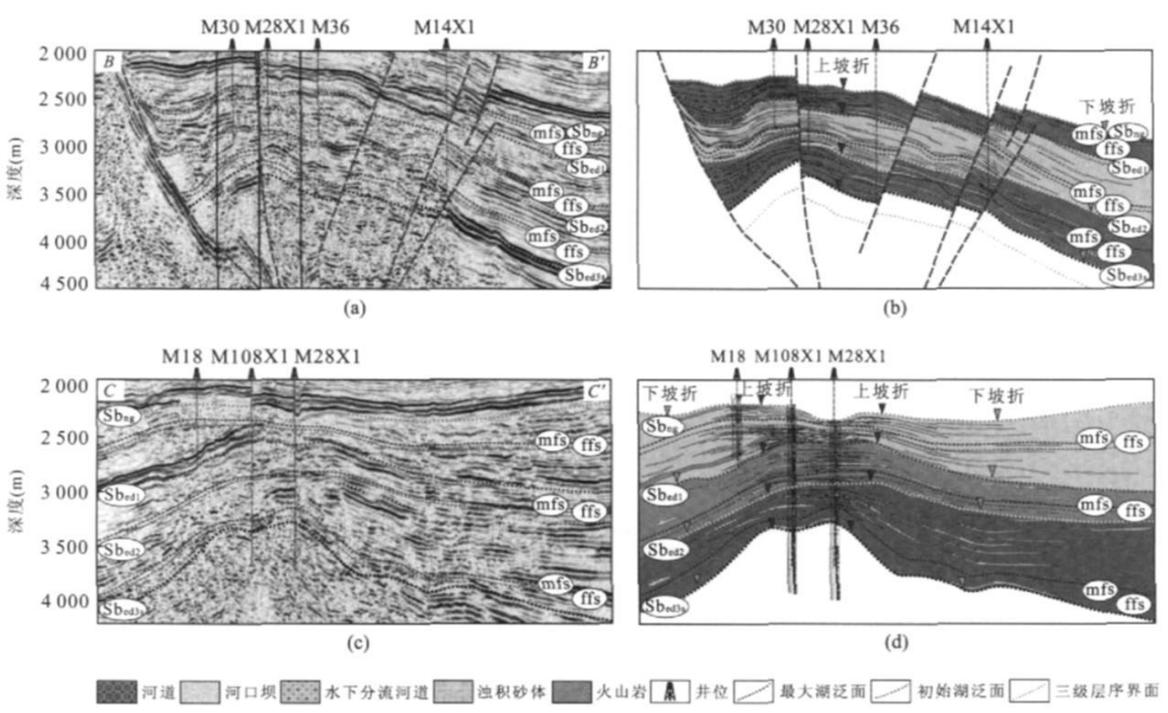

图 3 横向背斜坡折对沉积相的分配(剖面位置见图 2)

Fig. 3 Seismic profiles (B-B', C-C') and our interpretation in the Laoyemiao region showing the significant controls of the upper and lower slope breaks on the sedimentary facies distribution

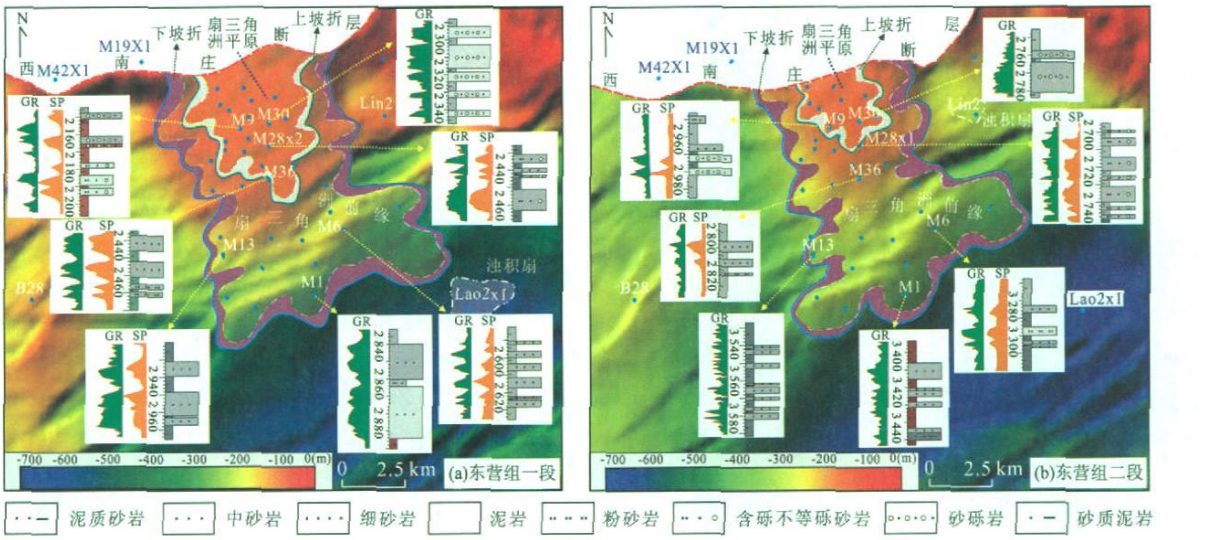

图 4　东营组一、二段底界面构造古地貌及其对沉积体的控制作用

Fig. 4　Palaeogeomorphology and their controls on sedimentary system of 1st and 2nd members of Dongying Fm.

砂体, 如东一段深凹 Lao2x1 井. 背斜翼部的下坡折也控制浊积体的形成, 如东二段的 Lin2 井.

4　结论

通过西南庄断层的解剖, 确定老爷庙背斜为断层线偏移引起的横向背斜, 背斜左翼陡, 右翼缓, 并被后期发育的走滑断层切割. 老爷庙构造对沉积的控制表现在以下两方面: 一是横向背斜和边界断裂交汇控制水系入口, 背斜转折端提供入盆水系长距离输送路径; 二是横向背斜存在上坡折和下坡折, 它们共同控制了沉积相的前端配置和侧向配置. 上坡折控制扇三角洲平原发育在背斜转折端, 下坡折是扇三角洲前缘和前扇三角洲的分界. 横向背斜长距离输沙模式和控相模式的提出可用于准确预测有利储集砂体, 尤其是前扇三角洲的浊积砂体.

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