

涠西南凹陷流沙港组二段优质烃源岩判别及其控油作用

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摘要:针对北部湾盆地涠西南凹陷流沙港组湖相优质烃源岩发育特征及其控油作用不清的实际,基于烃源岩生、排烃基本原理,利用有机地化方法建立判别优质烃源岩的方法,并确定了其分布和对油气分布的控制作用。流沙港组泥岩是涠西南凹陷的主要烃源岩,从下到上分为流三段、流二段和流一段,流二段为主力烃源岩。依据生、排烃基本原理,利用烃源岩 *TOC* 含量与热解 *S₁*、氯仿沥青“A”含量的关系确定的流沙港组湖相优质烃源岩的 *TOC* 含量界限值为 2% 左右。流二段底部黑色页岩 *TOC* 含量均大于 2%,母质类型好,生烃潜力高,均属于优质烃源岩;部分暗色泥岩属于优质烃源岩。与流二段底部黑色页岩有亲缘关系的原油既可在黑色页岩层段之下近源运移、聚集,也可沿流二段之下的流三段砂体长距离侧向运移而在构造高部位聚集;与暗色泥岩有亲缘关系的原油主要在凹陷内部优质烃源岩层之上的流一段—涠洲组聚集,断裂为近距离垂向运移通道,源控特征显著。

关键词:烃源岩;黑色页岩;暗色泥岩;流沙港组;涠西南凹陷;北部湾盆地

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Organic geochemistry identification of high-quality source rocks in the 2nd member of Liushagang Fm and its controls on petroleum occurrence in the Weixi'nan Sag, Beibuwan Basin

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Abstract: In the Weixi'nan Sag of the Beibuwan Basin, the high-quality lacustrine source rock in the Liushagang Fm has been poorly understood in terms of its characteristics and its controls on hydrocarbon distribution. To this end, we establish an organic geochemical method to identify quality source rocks, and reveal the source rock distribution pattern and its controls on hydrocarbon distribution, based on the fundamental mechanisms of hydrocarbon generation and expulsion for source rocks. Among others, the major source rocks for the Weixi'nan Sag are the Liushagang Fm shale, which can be divided into three intervals, namely the Liu 3, Liu 2 and Liu 1 members downwardly, with the Liu 2 member as the major zone. Based on the principle of hydrocarbon generation and expulsion for source rocks as well as relations between the *TOC* content, and the pyrolysis *S₁* and chloroform bitumen “A” content of mature source rocks, we identify the lower limit value of *TOC* content of the high-quality lacustrine source rocks in the Liushagang Fm is about 2%. The black shale at the bottom of the Liu 2 member (*El₂*) with a *TOC* content higher than 2%, contains oil-prone organic matters with high hydrocarbon-generating potential, and is high-quality source rocks. Part of the dark mudstone is also high-quality source rocks. The crude oil expelled from the black shale at the bottom of Liu 2 member could migrate in short distance and accumulate under the black shale interval, or could migrate laterally in long distance along the sand bodies in the Liu 3 member and accumulate at higher structures. However, the crude oil expelled from the dark mudstone mainly accumulates in the Liu 1 member and Weizhou Fm, which are vertically above the quality source rocks inside the sag, with faults as the vertical pathway for migration and thus the accumulation is directly characterized by source rock distribution.

Key words: source rock, black shale, dark mudstone, Liushagang Fm, Weixi'nan Sag, Beibuwan Basin

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涠西南凹陷是北部湾盆地北部的一个二级构造单元,面积约为3 800 km²(图1),属于断陷湖盆,经历了古近纪断陷和新近纪拗陷两个构造-沉积演化阶段^[1-4]。凹陷沉积地层自下而上依次为古近系长流组(Ech)、流沙港组(EI)、涠洲组(Ew)陆相沉积、新近系下洋组(Nx)、角尾组(Nj)、灯楼角组(Nd)和望楼港组(Nw)海相沉积以及第四系(Q)海相灰黄色砂层和灰色粘土^[5-6]。其中,流沙港组从下到上依次分为流三段(EI³)、流二段(EI²)与流一段(EI¹),流一段和流三段主要为页岩、流二段底部有一套黑色页岩,中上部主要为暗色泥岩^[7-9]。有关流沙港组烃源岩已有多位学者针对烃源岩有机相^[8]、热演化特征^[10-13]和烃源岩基本有机地化与分布特征^[9,14-16]等进行过研究,但对于凹陷中流沙港组优质烃源岩特征以及如何控制油气分布尚无报道。许多研究者都对优质烃源岩进行过探讨和分析^[17-22],但更多学者倾向于认为优质烃源岩主要是厚度较大、有机质丰度高和进入大量生烃阶段的烃源岩^[23-24]。目前主要由有机碳含量来界定优质烃源岩,但不同研究者所给出的有机碳含量下限值变化较大,并且普遍未提及确定有机碳含量下限值的依据^[19-21,25-26]。优质烃源岩首先应是排烃源岩。研究表明,涠西南凹陷流沙港组二段湖相暗色泥岩和黑色页岩发育,是凹陷主力烃源岩。其富有机质的黑色页岩厚度较小,主要发育在流二段底部,而黑色页岩之上的有机质含量相对低的暗色泥岩厚度大^[27](图2)。本文将依据生排烃基本原理,结合钻井地质数据、分析测试数据等,确定涠西南凹陷流沙港组二段的优质烃源岩分布及其对油气分布的控制作用。

1 优质烃源岩的判别方法

烃源岩已生成的烃包括残留烃和排出烃两部分。一般有两种方法可以得到烃源岩的残留烃量。一种是热解(Rock ~ Eval)方法获得的 S_1 一般代表烃源岩中的残留烃量,若烃源岩未发生排烃,则 S_1 可以近似代表已生烃量;另一种是有机溶剂氯仿抽提得到的氯仿沥青“A”含量可以直接代表烃源岩中的残留烃,在未发生排烃时也代表已生烃量^[28]。作为排烃烃源岩,关键在于不但要有烃类生成,更重要的是要有烃类排出。烃源岩对烃类都有吸附性,所以,烃源岩生成的烃必须要首先满足岩石吸附之后才能排出^[29-30]。在烃源岩母质特征、热演化程度相近的情况下,有机质丰度越低,生烃量越小,有机质丰度越高,生烃量越大。所以,在母质类型与成熟度接近的情况下,只有在有机质丰度达到一定值后,烃源岩中的烃类才能达到饱和而排烃成为优质烃源岩。在此,将烃源岩开始排烃时对应的有机质丰度作为优质烃源岩的有机质丰度界限值。

将热解 S_1 、氯仿沥青“A”含量转化为相对参数,即烃指数($HCI = S_1/TOC$)和 A/TOC 值。图3显示,随 TOC 含量增加,不同烃源岩样品的 TOC 值对应的 HCI 与 A/TOC 值均有一定的变化范围,但观察不同 TOC 含量对应的 HCI 与 A/TOC 最大值(最大包络线)可以发现,其均具有随 TOC 含量先增后降的特点。之所以发生这种变化主要是由于较高的 TOC 含量生成的烃相对较多,达到了烃源岩的饱和吸附量,多余的烃排出了烃源岩,从而导致较高 TOC 含量对应的 HCI 与

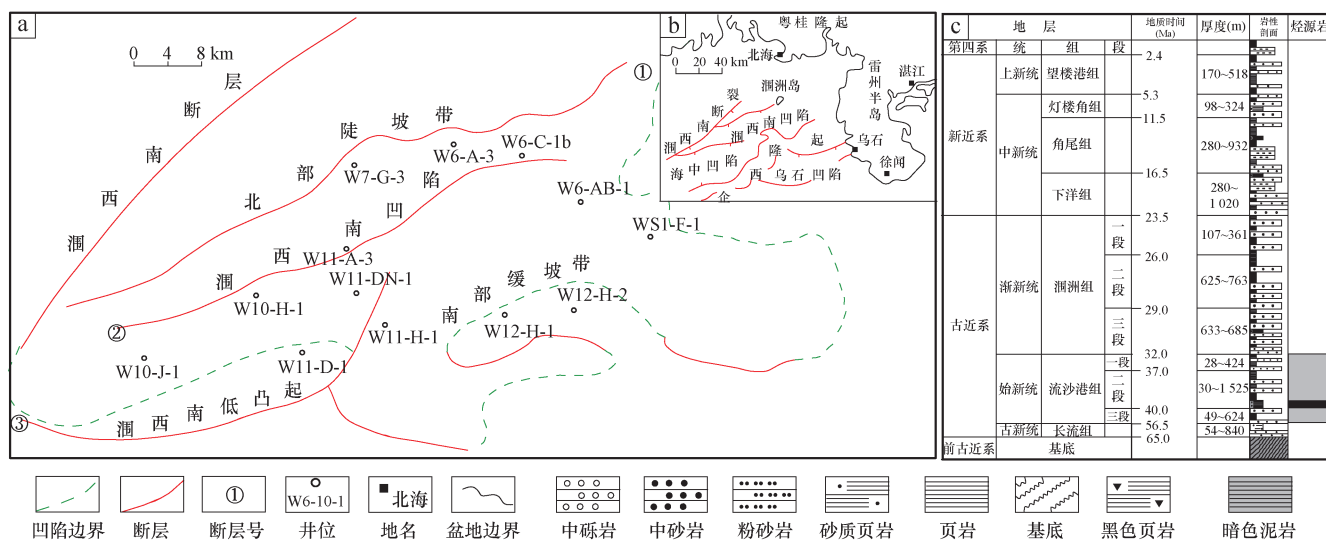


图1 北部湾盆地涠西南凹陷基本地质单元(a,b)与地层柱状图(c)

Fig. 1 The map of the geological units (a,b), and the composite stratigraphic column (c) of Weixi'nan Sag, Beibuwan Basin

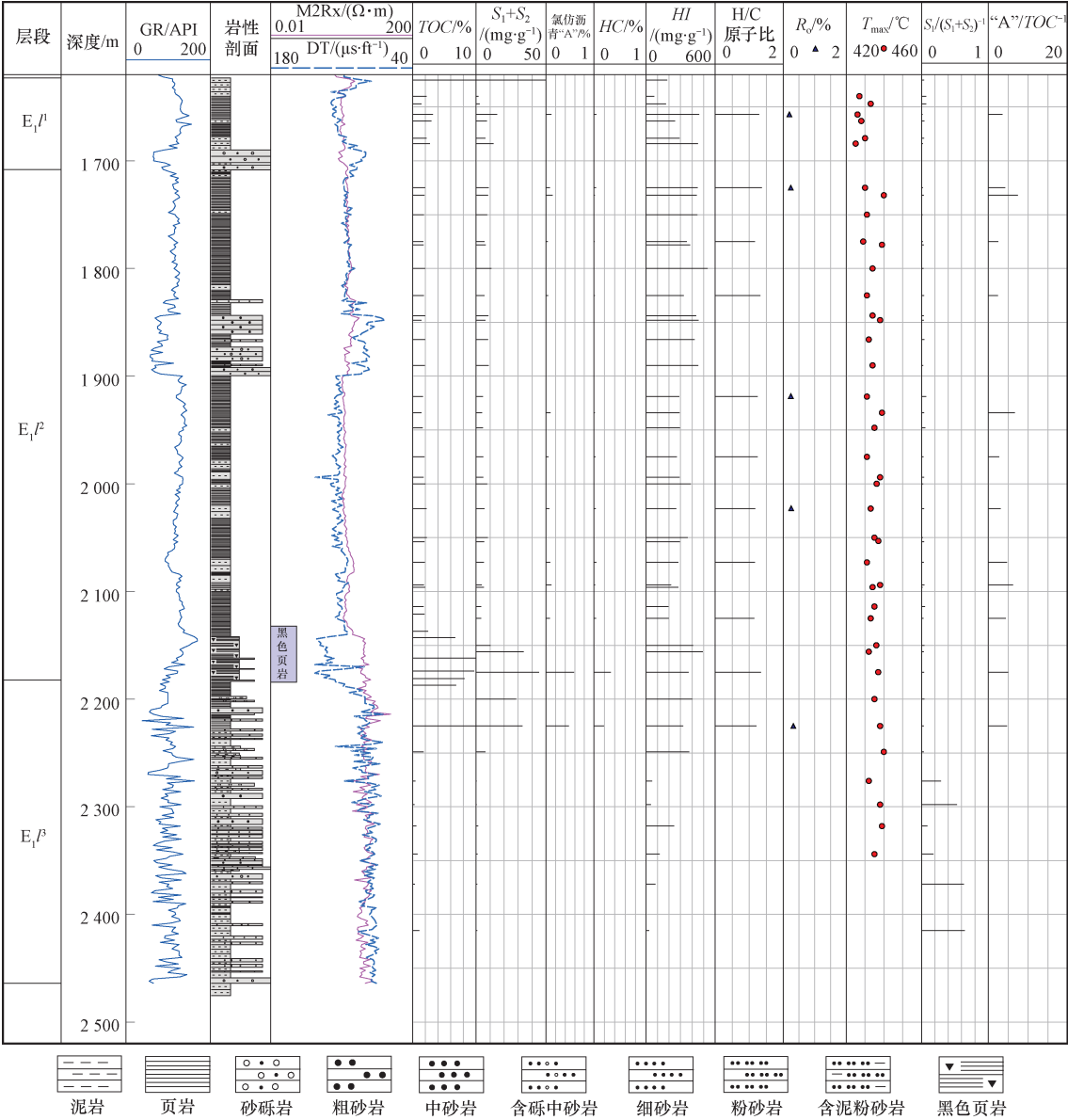


图 2 北部湾盆地涪西南凹陷 W10 - C - 30 井有机地化综合柱状图

Fig.2 The composite column of organic geochemistry for Well W10 - C - 30 in the Weixi'nan Sag, Beibuwan Basin

A/TOC 值降低了。根据较高 HCI 与 A/TOC 值随 TOC 含量的变化趋势来看,最高的 HCI 与 A/TOC 趋势值大致为 2%(图 3)。该值的石油地质意义在于,当 TOC 低于该值时,烃源岩生成的烃量相对较低,难以满足烃源岩的饱和和吸附,烃源岩难以排烃而不能作为优质烃源岩;但 TOC 高于该值后,烃源岩生成的烃量将超过饱和吸附量而有部分烃类从烃源岩中排出,这样的烃源岩才满足优质烃源岩的基本条件。所以,2%即相当于优质烃源岩的最低 TOC 含量值,其中流二段底部黑色页岩的有机质丰度基本高于 2%,并表明其已经普遍发生了排烃,故这段黑色页岩可以表示优质的烃源岩,部分暗色泥岩也达到优质烃源岩标准。

2 优质烃源岩的识别及其分布特征

涪西南凹陷虽有较多的烃源岩分析测试数据,但多数钻井的分析数据离散型强,连续性差,难以在单井上进行不同有机质丰度烃源岩段的划分。为此,利用测井 ΔIgR 法估算了不钻井的烃源岩 TOC 含量^[31-33]。黑色页岩在单井上表现为声波时差高、自然伽马高、电阻率高等特点。实测与预测的 TOC 含量数据综合识别单井暗色泥岩中的优质烃源岩和黑色页岩,并确定统计其厚度(图 4)。对全区主要钻井的流沙港组黑色页岩与优质烃源岩进行了识别,依据单井黑色页岩厚度、优质烃源岩厚度统计结果,结合地层厚度与沉积相

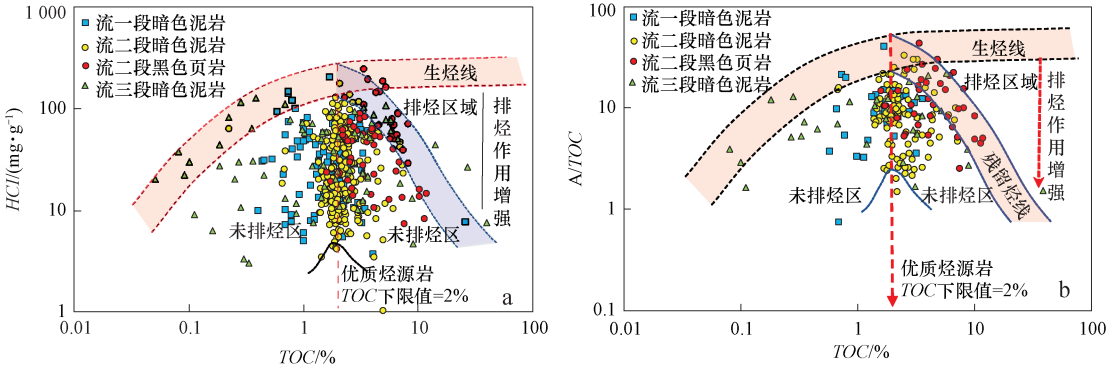


图 3 涪西南凹陷流沙港组烃源岩 $HCl-TOC$ (a) 和 $A/TOC-TOC$ (b) 含量关系

Fig. 3 The cross-plot of $HCl-TOC$ (a) and $A/TOC-TOC$ (b) of the Liushagang Fm source rocks in the Weixi'nan Sag

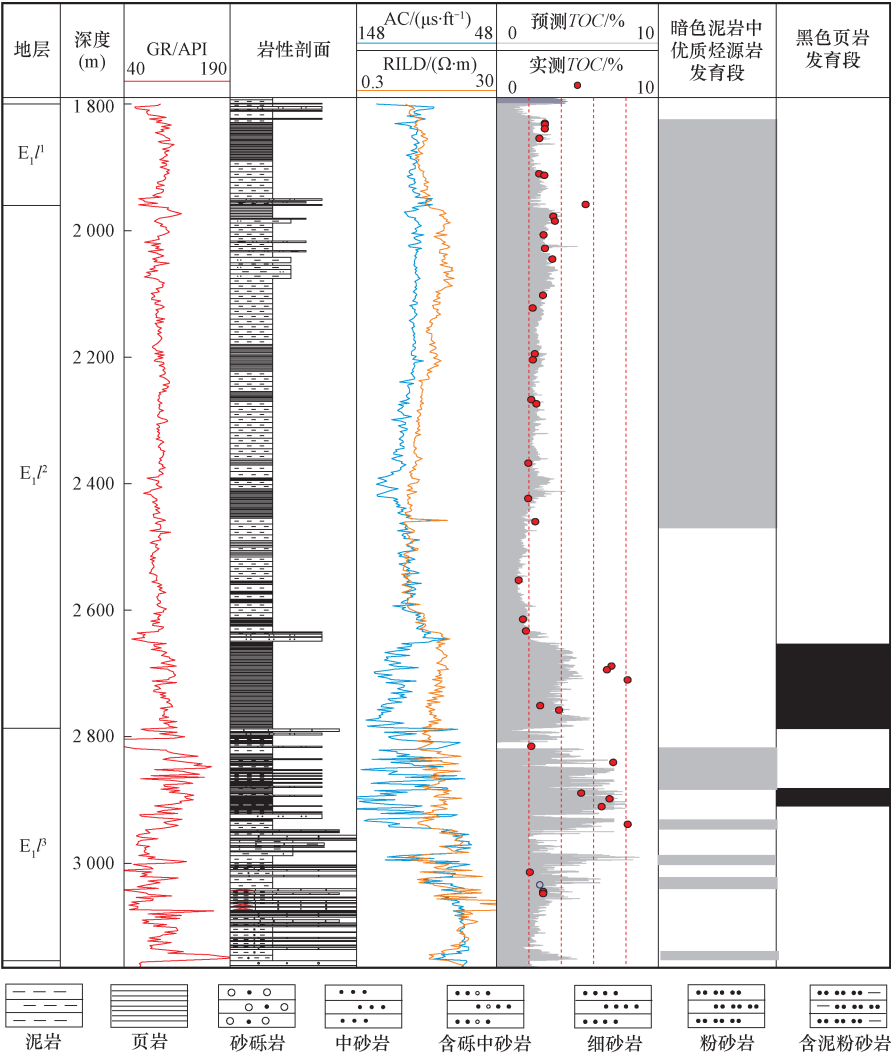


图 4 涪西南凹陷 W6 - C - 1 井流沙港组暗色泥岩中优质烃源岩与黑色页岩段分布

Fig. 4 The stratigraphic distribution of high-quality source rocks in dark mudstone and black shale intervals in the Liushagang Fm in Well W6 - C - 1, Weixi'nan Sag

研究成果,绘制相应的烃源岩厚度图。

由于涪西南凹陷流二段烃源岩最发育,并且稳定分布,钻遇井多,而流一段和流三段烃源岩分布范围相对较小,流一段成熟度总体较低。同时,油源对比分析

表明^[15-16],流二段暗色泥岩和黑色页岩为主力烃源岩,流一段和流三段贡献相对较小。所以,主要分析流二段底部黑色页岩和暗色泥岩中优质烃源岩的分布特征及其对油气分布的控制作用。流二段底部黑色

页岩发育中心主要在凹陷内的中东部,厚度最大可达 140 m,分布范围广,连续性好,陷中西部有一个次厚度中心,最大沉积厚度为 60 m(图 5a)。流二段暗色泥岩中的优质烃源岩分布范围广,总体分布趋势与黑色页岩相似,同样有中东部与中西部 2 个次中心,但厚度最大都超过了 500 m,东部的厚度次中心范围更大(图 5b)。

3 优质烃源岩对油气分布的控制作用

涪西南凹陷的原油总体可以分为 I 和 II 两大类^[34],通过油源对比, I 类原油具有较高的 4-甲基萘烷,主要与黑色页岩有关(图 6), II 类主要与暗色泥岩

有关(图 7)。流二段底部黑色页岩与 I 类原油的叠合图(图 8a)显示, I 类原油主要围绕底部黑色页岩厚度中心分布,但也有的远离厚度中心,甚至在没有黑色页岩分布的部位也有分布,表明 I 类原油既有近距离运移、聚集、也有远距离运移、聚集。流二段暗色泥岩中的优质烃源岩厚度与 II 类原油的叠合图(图 8b)显示, II 类原油主要分布在涪西南凹陷中部,围绕优质烃源岩厚度中心分布,表明 II 类原油运移距离总体较短,源控特征显著。

在过凹陷的剖面(图 9)上, I 和 II 类原油的分布与相应烃源岩有密切关系, I 类原油主要在流二段底部黑色页岩层段之下的流三段、长流组与基底中分布,紧邻流二段底部黑色页岩的 I 类原油以近源运移为特

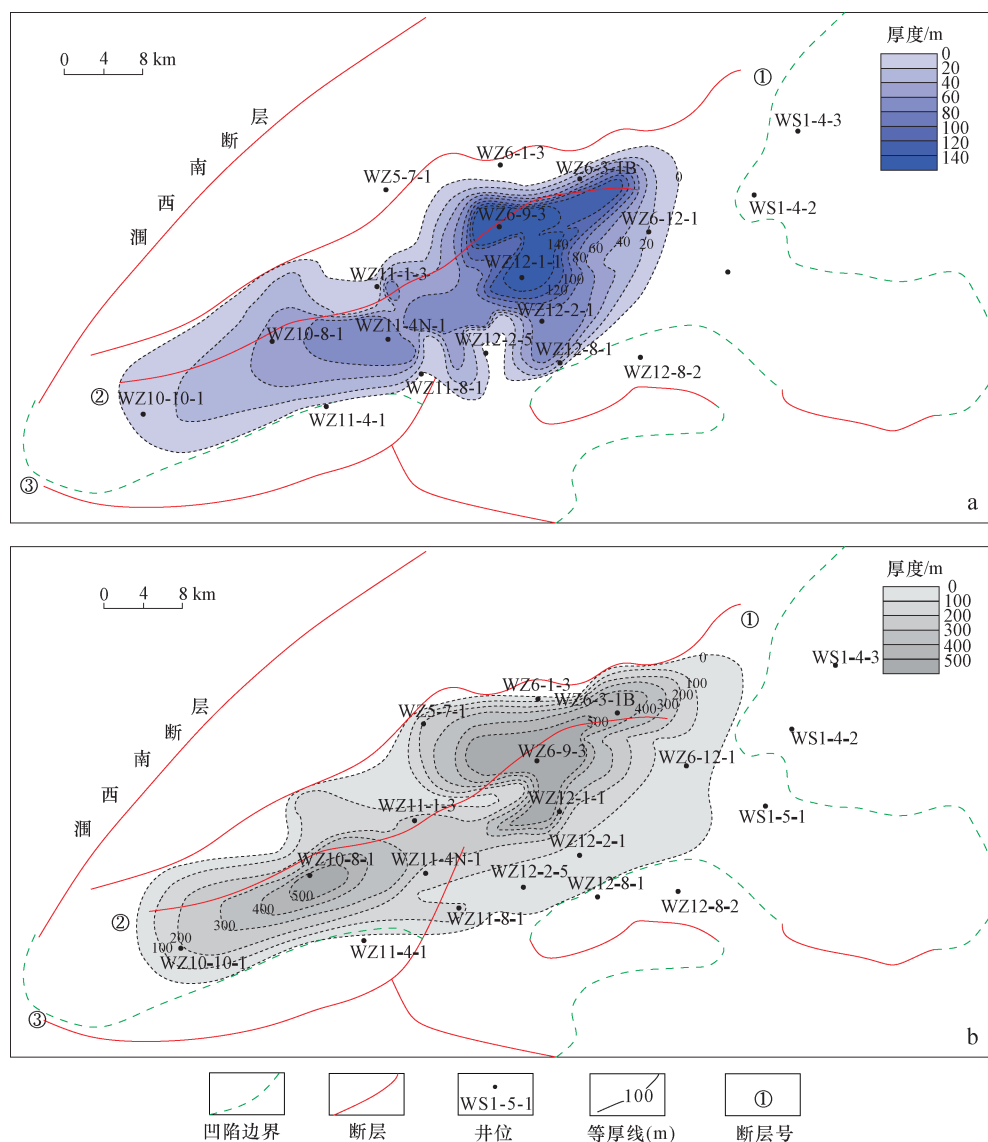


图 5 涪西南凹陷流二段优质烃源岩厚度分布平面图

Fig. 5 The isopach map of high-quality source rocks in the Liu 2 member, Weixi'nan Sag

a. 涪西南凹陷流二段底部黑色页岩; b. 涪西南凹陷流二段暗色泥岩优质烃源岩

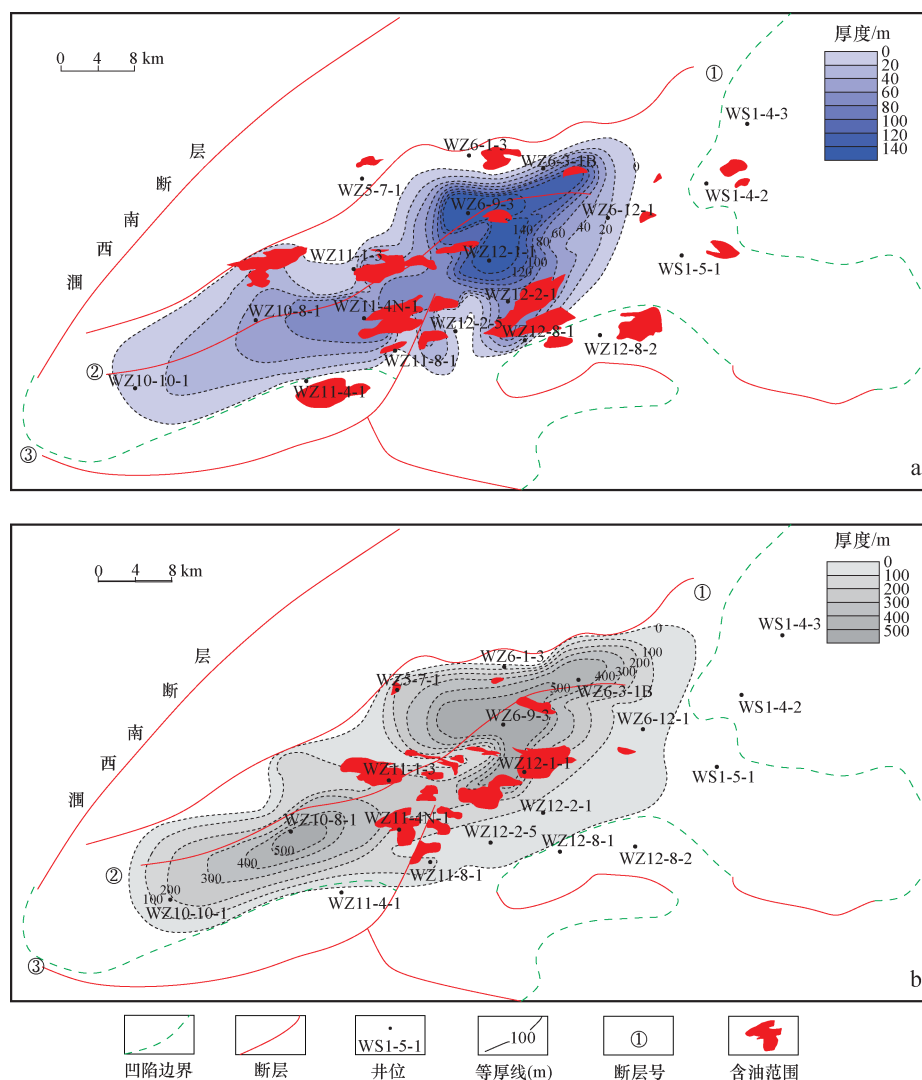


图 8 涪西南凹陷流二段优质烃源岩厚度与原油分布叠合图

Fig. 8 Superimposition of high-quality source rock thickness and crude oil accumulation in the Liu 2 member, Weixi'nan Sag

a. 流二段底部黑色页岩厚度 - I 类原油分布叠合图; b. 流二段暗色泥岩优质烃源岩厚度 - II 类原油分布叠合图

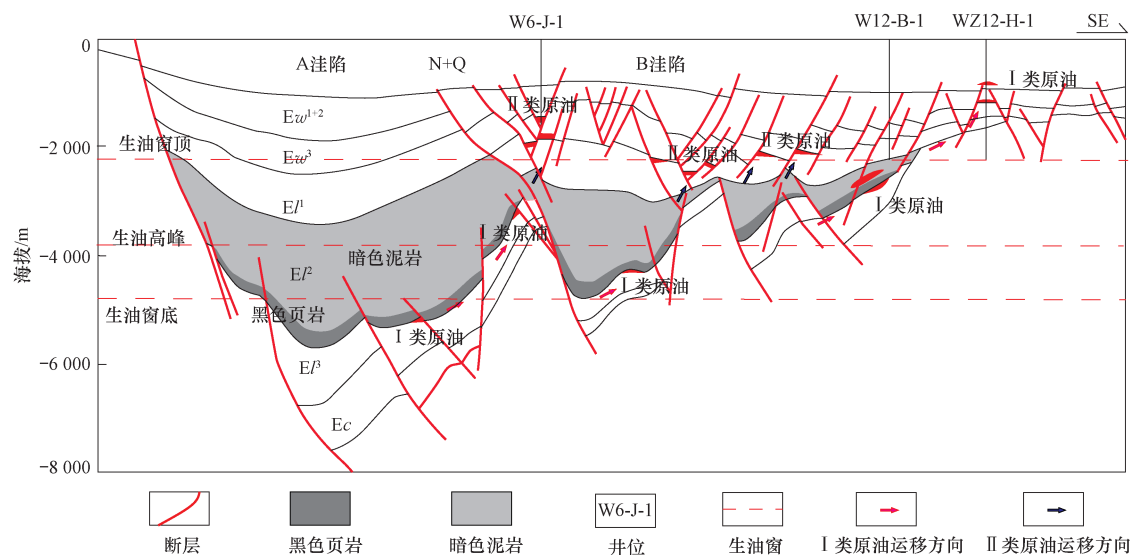


图9 过涪西南凹陷的南北向原油类型剖面

Fig. 9 The SN-trending cross section showing the crude oil types across the Weixi'nan Sag

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