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陆相页岩地层地质-工程一体化水平井精确钻探技术——以松辽盆地吉页油1HF井为例

刘卫彬[1,2],徐兴友[1,2],张君峰[1,2],陈珊[1,2],白静[1,2],刘畅[1,2],李耀华[1,2]

(1.中国地质调查局油气资源调查中心,北京100083;2.中国地质调查局非常规油气重点实验室,北京100083)

提要:【**研究目的**】陆相页岩油是中国能源重要的接替领域,长水平井精确钻探是实现页岩油商业开发的关键技术。但由于陆相页岩具有黏土矿物含量高、非均质性强、层理发育等特点,导致水平井井壁失稳严重、薄目标靶层精确导向困难等钻探技术难题。【**研究方法**】以松辽盆地南部青一段页岩为研究对象,综合利用地球化学、地球物理、岩石力学、地应力分析等手段,开展地质工程一体化研究。【**研究结果**】青一段上部页岩为层理型页岩不适合作为水平井穿行层段,青一段中下部纹层状页岩中的含油薄砂条兼具含油性、可钻性、可压性,可作为穿行目标层;页岩地层需选择强抑制KCL聚胺钻井液体系和油基钻井液体系实施水平井钻探,泥浆密度窗口随水平应力差和井轨迹倾角的增大而增高;测井GR和录井总烃可以精确反映目标靶层岩性非均质变化,结合高精度地球物理,可实时精确调控钻井轨迹。【**结论**】经应用实践,吉页油1HF井沿1.94 m超薄目标靶层安全钻进1252 m,钻遇率100%,实现了陆相页岩油长水平段精确钻探的技术突破,为吉页油1HF井获得高产工业油流奠定了基础,对中国同类型陆相页岩油长水平段精确钻探具有引领和借鉴意义。

关 键 词:陆相页岩地层;地质工程一体化;长水平段;精确钻探;油气勘查工程;吉页油1HF井;松辽盆地

创 新 点:(1)创新地质-工程一体化甜点评价方法,设计出水平井最优钻探轨迹;(2)构建地质-地球物理一体化精确导向模型,实现超薄目标靶层长距离钻探。

中图分类号:P618.13;P634 **文献标志码:**A **文章编号:**1000−3657(2022)06−1808−15

Accurate drilling technology for horizontal wells in continental shale formation geology−engineering integration—Taking Jiyeyou 1HF well in Songliao Basin as an example

LIU Weibin[1,2], XU Xingyou[1,2], ZHANG Junfeng[1,2], CHEN Shan[1,2], BAI Jing[1,2], LIU Chang[1,2], LI Yaohua[1,2]

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作者简介:刘卫彬,男,1991年生,工程师,主要从事页岩油气调查评价与地质-工程一体化综合研究工作;E−mail:ogslwb@126.com。

通讯作者:徐兴友,男,1968年生,教授级高级工程师,主要从事页岩油气调查评价与地球化学综合研究工作;E−mail:xuxingyou@mail.cgs.gov.cn。

(1. *Oil and Gas Survey, China Geological Survey, Beijing* 100083*, China;* 2. *Key Laboratory of Unconvential Oil and Gas, China Geological Survey, Beijing* 100083*, China*)

Abstract: This paper is the result of oil and gas exploration engineering.

[Objective] Continental shale oil is an important replacement field of energy in China, and precise drilling of long horizontal wells is a key technology to achieve commercial development of shale oil. However, due to the characteristics of continental shale such as high clay mineral content, strong heterogeneity and bedding development, serious instability of horizontal well wall and difficulties in precise steering of thin target layer are caused. **[Methods]** Taking the shale of the first member of Qinghe Formation in the south of Songliao Basin as the research object, the integrated research of geological engineering is carried out by comprehensively using geochemical, geophysical, rock mechanics, geostress analysis and other means. **[Results]** The shale in the upper part of Qing−1 Member is bedding shale, which is not suitable for horizontal wells to pass through. The thin oil−bearing sand bars in the lamellar shale in the middle and lower part of Qing−1 Member are both oil−bearing, drillable and compressible, which can be used as the crossing target layer; For shale formation, strong inhibition KCL polyamine drilling fluid system and oil−based drilling fluid system should be selected for horizontal well drilling. The mud density window increases with the increase of horizontal stress difference and well trajectory inclination angle; Logging GR and logging total hydrocarbon can accurately reflect the lithological heterogeneity change of target layer, and combined with high− precision geophysics, it can accurately control the drilling trajectory in real time. **[Conclusions]** Through application and practice, Jiye 1HF well has safely drilled 1252 m along 1.94 m ultra−thin target bed, with a penetration rate of 100%, which has achieved a technical breakthrough in accurate drilling of long horizontal section of continental shale oil, laid a foundation for Jiye 1HF well to obtain high−yield industrial oil flow, and has guiding and reference significance for accurate drilling of long horizontal section of continental shale oil of the same type in China.

Key words: continental shale formation; integration of geology and engineering; long horizontal well; precision drilling; oil and gas exploration engineering; Jiyeyou 1HF well; Songliao Basin

Highlights:(1) Innovate the geological engineering integration dessert evaluation method and design the optimal drilling trajectory of horizontal wells; (2) Build the geological geophysical integration precise guidance model to achieve long−distance drilling of ultra−thin target layers.

About the first author: LIU Weibin, male, born in 1991, engineer, mainly engaged in comprehensive research on shale oil and gas survey and evaluation and integration of geology and engineering; E−mail: ogslwb@126.com.

About the corresponding author: XU Xingyou, born in 1968, senior engineer, mainly engaged in shale oil and gas geochemical investigation, evaluation and research; E−mail: xuxingyou@mail.cgs.gov.cn.

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1 引 言

中国陆相盆地发育多套富有机质页岩,存在松辽盆地白垩系、准噶尔盆地及三塘湖盆地二叠系、鄂尔多斯盆地三叠系、四川盆地侏罗系及渤海湾、江汉等东部断陷盆地古近系5大页岩发育区别(贾承造等,2012;马永生等,2012;邹才能等,2015;周志等,2017;赵贤正等,2018;刘忠宝等,2019;王小军等,2019;王民等,2019;付金华等,2019;张宇等,2022),其中深湖相纯页岩地层沉积厚度大,有机质丰度高、热演化程度适中、生烃强度大,页岩油资源潜力巨大(张金川等,2012;杜金虎等,2019)。受美国页岩油革命启发,近年来,中国开始逐步探索陆相页岩油的开发利用。最新勘探进展表明,由于中国陆相页岩油黏土矿物含量高、地层非均质性强(聂海宽等,2016;胡素云等,2020;赵文智等,2020;黄振凯等,2020),缺乏有效的陆相页岩油高效开发技术,很难实现商业动用,尚未实现工业突破。

水平井精确钻探是国内外页岩油气实现商业开发的关键核心技术之一(蒲秀刚等,2019;张瀚之等,2019;刘合等,2020;周立宏等,2020;高阳等,2020),研究表明,水平井甜点层的优选的准确度、水平段安全钻探的长度、目标靶层的钻遇率是影响页岩油单井产能的关键因素(郭艳东等,2018;张本健等,2019;李浩等,2020)。由于中国陆相页岩地质条件特殊,尤其是松辽盆地南部长岭凹陷青一段

页岩与北美海相页岩、中国其他盆地陆相页岩具有显著差异(高有峰等,2009;柳波等,2014,2018)。该页岩沉积于半深湖—深湖相,黏土矿物含量高,一般为40%~50%,平均值为46.7%,远高于国内外其他盆地页岩,并且页岩中层理和裂缝比较发育,在水平井钻井过程中,高黏土含量高、裂缝发育的页岩地层容易发生吸水膨胀、垮塌、掉块等事故,影响井壁稳定性,从而导致水平井钻探难度大、水平段长度短、优质储层钻遇率低等问题,因此难以实现页岩油工业突破,严重制约中国陆相页岩油的勘探和开发。

针对制约陆相页岩油长水平段精确钻探的关键科学难题,以松辽盆地南部长岭凹陷吉页油1HF井为研究对象,展开了针对性的地质-工程一体化研究攻关,探索形成了一套适合中国陆相页岩油水平井钻探的工程技术体系,并且取得显著效果,对中国同类型页岩油的效益开发具有借鉴意义。

2 松辽盆地陆相页岩地层特征及钻探难点

2.1 松辽盆地青一段地层特征

松辽盆地南部整体划分为中央坳陷、西部斜坡、东南隆起和西南隆起4个一级构造单元,中央坳陷是页岩油形成和富集的最主要区域,面积约6500 km^2,页岩油主要分布在下白垩统青山口组一段地层中(黄文彪等,2014;薛海涛等,2015;李士超等,2017;李微等,2018)。本文研究对象吉页油1HF井部署在松辽盆地南部中央坳陷长岭凹陷的乾安有利区内,该井导眼井在青一段页岩地层中钻遇了良好的页岩油显示,青一段厚度一般为90 m,岩性主要为深灰色、灰色页岩,夹少量灰色、灰白色泥质粉砂岩、粉砂岩,累计砂地比10%左右(图1)。

青一段暗色页岩有机质丰度高、类型好,TOC值为0.5%~4.5%,均值为2.15%,有机质类型基本以Ⅰ型和Ⅱ1型为主,生油潜力巨大,Ro值为0.5%~1.0%,处于成熟演化阶段,热解参数S_1值普遍大于1.0 mg/g,最高可达4 mg/g,平均值为1.5 mg/g,页岩孔隙度平均值为4.5%;渗透率均值为0.07×10^{-3} μm^2,是页岩油形成和富集的有利层段,也是吉页油1HF井水平井钻探的主要目标甜点层。青一段在长岭凹陷乾安有利区埋深在2400~25500 m,地层压力在22~25 MPa,平均压力系数1.0,地温梯度3.98℃/100 m,平均地层温度101℃,属于常压高温地层。

2.2 吉页油1HF井水平井钻探难点分析

根据X射线衍射实验分析结果,青一段页岩主要由黏土矿物和石英、长石等组成,含有少量的方解石、白云石。其中黏土矿物含量40%~60%,均值为47%,以伊利石和伊蒙混层为主(图2),远高于海相页岩和国内外其他陆相页岩(表1)。黏土矿物含量高导致青一段页岩在钻探过程中存在易水化、易膨胀、易分散等风险,易发生井壁坍塌(康毅力等,2017)。

通过岩心、薄片、扫描电镜、成像测井等分析发现,青一段页岩裂缝较为发育(图3a),主要裂缝类型为层理缝和构造缝,其中层理缝发育密度较大,切割页岩成薄片状,裂缝间距为0.1~1.5 cm,层理缝宽2~5 μm(图3b、c)。构造裂缝主要为高角度裂缝,裂缝倾角达到了60°~80°(图3d),裂缝长度为10~100 cm,裂缝密度0.5~1条/m,成像测井解释裂缝宽度0.2~1.5 cm。构造裂缝和层理缝的密集发育,容易引起泥岩掉块、井壁坍塌的风险,严重影响井筒安全性(陈平等,2014;马天寿和陈平,2014;邓媛等,2020)。

为保证水平井沿高黏土矿物含量裂缝发育的纯页岩地层穿行长度,水平井目标靶层需要优选为可钻性、可压性较好的砂层。由于青一段页岩层系中砂层发育较差,厚度较薄,薄砂条单层厚度一般小于2 m,造成水平井精确导向困难、目标靶层钻遇率低、井筒规则性差等难题,影响页岩油水平井产能。目前世界最先进的导向技术为斯伦贝谢旋转导向技术,但由于其施工价格十分高昂,存在较大经济成本和风险成本(马鸿彦等,2019)。为保证陆相页岩油能够效益开发,亟需建立一套低成本的陆相页岩油水平井精确导向技术。

3 水平井甜点靶层优选及轨迹设计

3.1 地质-工程双甜点靶层优选

根据青山口组一段岩心、岩相、含油性、物性、可动油占比、岩石力学性质、可钻性、可压性、裂缝发育程度等特征,对有利目标层和目标靶层进行了优选确定。自上而下共划分为3个层组(图4)。

1号层组发育层理型页岩岩相,有效储集空间

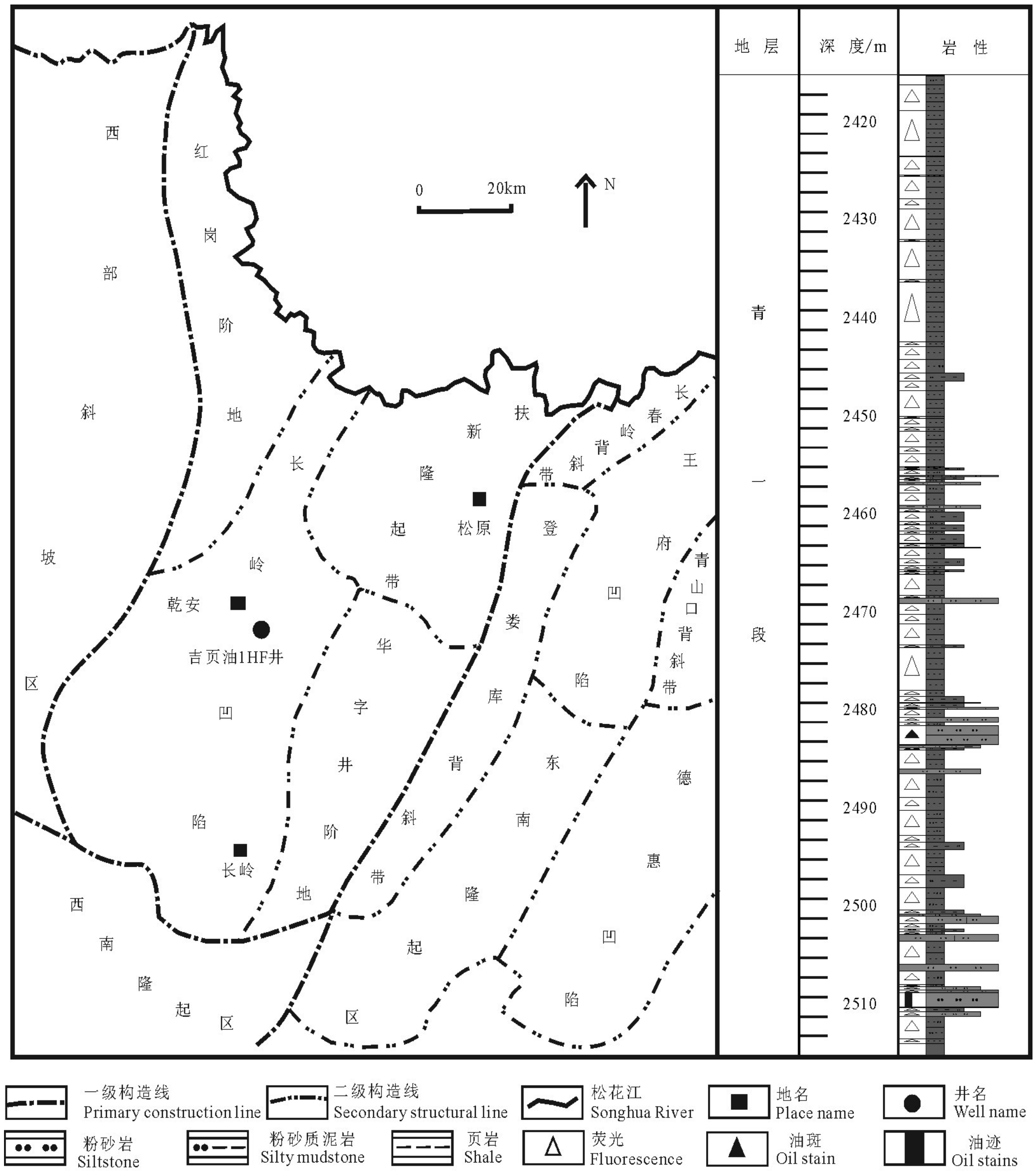

图1 松辽盆地南部构造单元及地层柱状图
Fig.1 Structural map and stratigraphic histogram of southern Songliao Basin

以层理缝、基质微裂缝及局部发育的高角度缝为主,含油性好,孔隙度高,泊松比高、杨氏模量低,易于压裂,但由于黏土矿物含量高、层理和裂缝发育,可钻性较差,不宜作为水平井的主要穿行目标层。

2号层组发育纹层型页岩相,有效储集空间以粒间孔为主,可动烃含量高,约为55%,大孔径粒间孔占比高,为20%~30%,脆性矿物含量相对较高,约为60%,黏土矿物含量相对较低,约为40%,裂缝发育强度弱,地层完整性好,兼具良好的含油性、可动性、物性、可压性、可钻性等条件,属于地质+工程双甜点有利目标层,适合作为水平井穿行主要目标层。

3号层组发育互层型页岩相,有效储集空间为砂质纹层,与1、2号层组对比,其含油性、储层物性、可动油占比等参数比较差,砂条发育,储层非均质性强,且位于青一段的下部,水平井压裂很难实现纵向拓展,改造效果差。因此,不宜作为水平井的主要穿行目标层。

根据青一段岩石力学性质和地应力解释结果发现,青一段地应力、杨氏模量自上而下逐渐变大,人造裂缝主要向上拓展,因此为了充分改造含油气性最好1、2号层组,目标靶层应尽量选择在2号层底部,同时必须保证水平井的可钻性和可压性,通

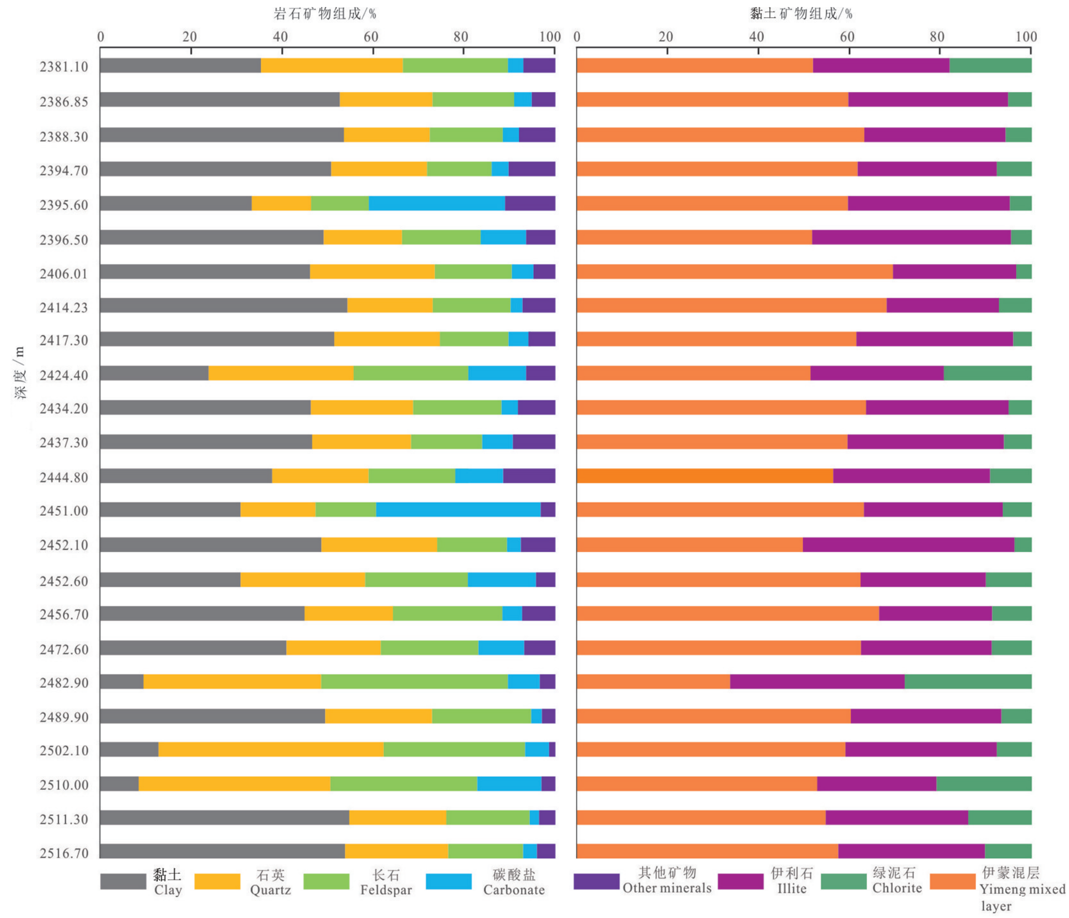

图2 吉页油1井青一段页岩全岩矿物及黏土矿物组成

Fig.2 The composition of whole-rock minerals and clay minerals of the shale in the Qing 1st of Jiyeyou 1 well

过矿物组分、岩石力学性质等的对比分析,优选出2号层底部可钻性较好、厚1.94 m的薄砂层作为水平井穿行的目标靶层(表2)。

3.2 阶梯式水平井井身结构与井眼轨道设计

在确定了水平井的主要目标甜点层和穿行靶层的基础上,对水平井沿青一段穿行的井轨迹进行了优化设计,思路主要为:(1)井轨迹以穿行2号层组为主,尽量兼顾整个青一段1号、3号层组,以获取3个层组的产能数据,为后期资源评价提供依据。(2)水平井主体部分要在选定的2号层组底部1.94 m厚的薄砂层中穿行,既有利于后期压裂效果最大化,又能确保安全高效钻进。按照地质-工程一体化评价思路,吉页油1HF井井轨迹设计方案如下:整井采用三开井身结构,二开技术套管下至青一段顶部,固封上部松散地层;青一段全部采用三开钻进,油层套管完井。水平段采用阶梯式轨迹设计,

表1 松辽盆地与国内其他含陆相页岩矿物成分对比数据

Table 1 Comparison data table of mineral composition of domestic continental shale between Songliao Basin and other Basins

盆地	层位	TOC/%	黏土矿物含量/%	数据来源
松辽盆地长岭凹陷	青山口组一段	4.1	47	本次研究
鄂尔多斯盆地	延长组7段	3.8	28	付金华等, 2019
渤海湾盆地沧东凹陷	孔店组二段	5.2	16	赵贤正等, 2018
准噶尔盆地吉木萨尔	芦草沟组	3.6	13	王小军等, 2019
江汉盆地	潜江组	4.3	10	蔡媛等, 2022

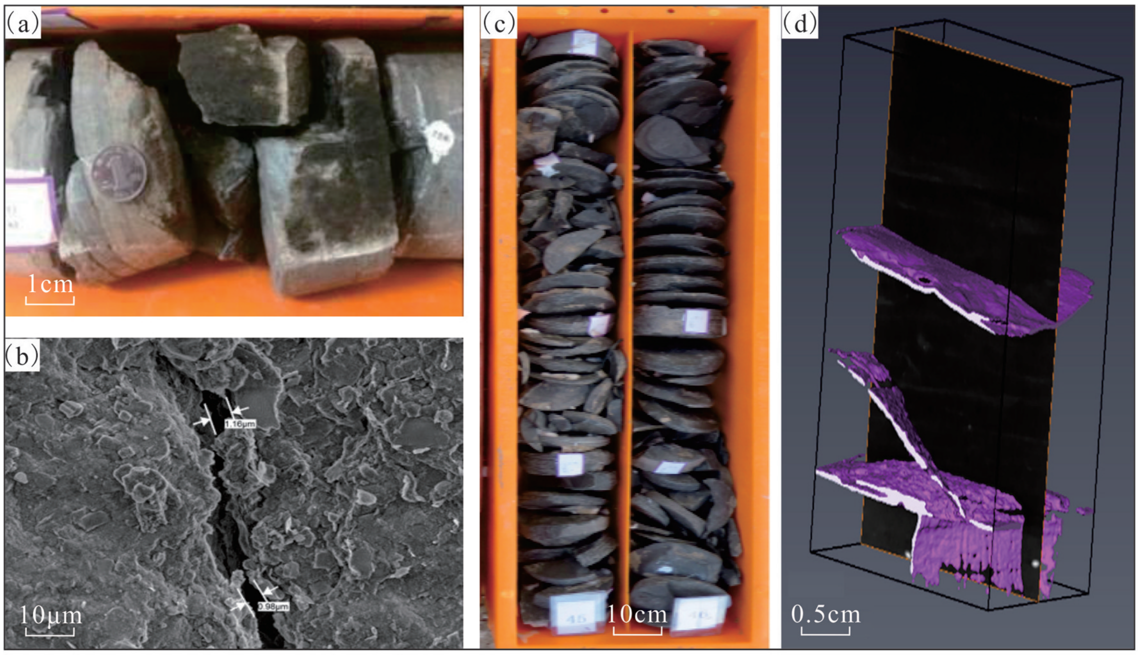

图3 吉页油1HF井青一段页岩裂缝发育特征图
a—高角度构造裂缝,岩心;b—页岩储层微裂缝,扫描电镜;c—水平层理缝,岩心;
d—构造裂缝与层理缝形成的交错缝网,CT扫描

Fig.3 Fracture development characteristics of shale in the Qing 1st of Jiyeyou 1 well
a−High−angle structural fractures, cores; b−Micro fractures in shale reservoirs, scanning electron microscope; c−Horizontal bedding fractures, cores; d−The staggered fracture network formed by structural fractures and bedding fractures, CT scan

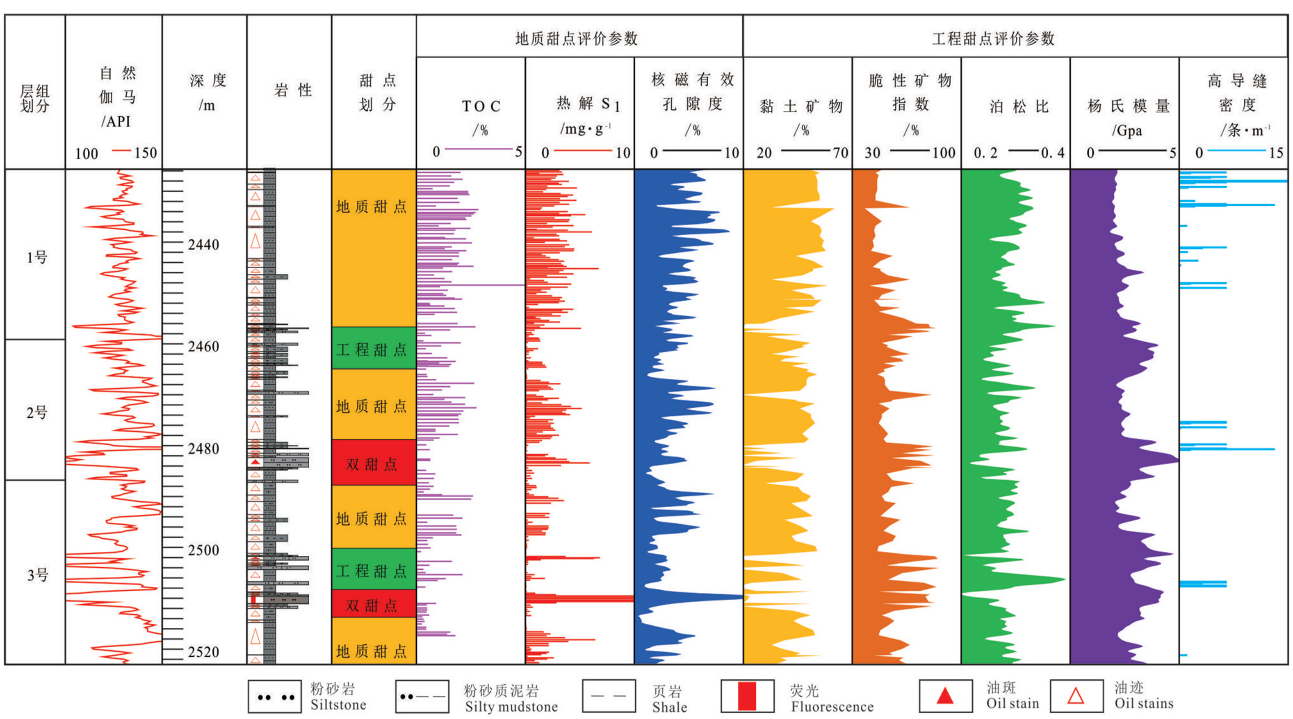

图4 吉页油1HF井青一段页岩油甜点综合评价图
Fig. 4 Comprehensive evaluation map of shale oil sweet spots in the Qing 1st of Jiyeyou 1 well

表2 吉页油1井青一段各层组级目标靶层参数对比

Table 2 Comparison table of target layer parameters of each layer in the Qing 1st of Jiyeyou 1 well

分层	S_1/(mg/g)	可动油占比/%	核磁有效孔隙度/%	大孔径占比/%	黏土矿物含量/%	脆性矿物含量/%	泊松比	杨氏模量/GPa	脆性指数	裂缝
1层组	2.87	40	4.9	15~25	47.44	52.56	0.3	2.3	30.16	发育
2层组	2.37	55	4.28	20~30	39.62	60.36	0.28	3.13	40.38	欠发育
目标靶层	4.3	60	5.0	40	15	85	0.2	5	60	欠发育
3层组	2.02	46	4.1	15~20	38.7	62.59	0.24	3.97	45.38	欠发育

首先利用部分造斜段在1号层组中穿行200 m，专探1号层组页岩油潜力；水平段主要穿行2号层组，以其底部1.94 m厚的薄砂层为目标靶层，钻进1000 m，通过压裂改造向上探索1、2号层组的页岩油资源潜力；最后，设计下倾段在3号层组中钻进200 m，专探3号层组页岩油潜力(图5)。

4 钻井液配方优选及性能优化

4.1 防塌、防漏钻井液体系优选技术

根据水平段地层特点及钻井技术难点，钻井液要保持强抑制、强封堵、较低的滤失量、薄而韧的泥饼、优良的造壁性和润滑性，以及良好的流变性和储层保护效果，保证安全快速钻进(尹增苇等，2013；孟英峰等，2019；王波等，2020；田璐等，2020)。通过钻屑回收率实验对水平井各开次的钻井液配方进行优选。二开选用强抑制KCL聚胺钻井液体系，三开采用油基钻井液体系，岩屑回收率试验表明，KCL聚胺钻井液钻屑滚动后回收率可达99.1%，油基钻井液钻屑滚动后回收率可达99.8%(表3)。

4.2 基于地应力预测的钻井液性能优化技术

井眼稳定性是地应力、地层压力、岩石力学性质和泥浆密度等参数综合作用的结果。对于水平井而言，随着水平井方位和井斜角的不同，孔周应力环境变得更加复杂(闫传梁等，2013；崔云海等，2016；孙东生等，2020)。根据偶极子声波、地层岩石力学、地层压力等参数，建立了基于流变模型的地应力剖面(图6a)，目的层最小水平主应力分布在42 ~ 53 MPa，最大水平主应力分布在56 ~ 63 MPa，最大水平主应力方向为近东西向，根据水平井走向尽量垂直于最大主应力方向原则，确定吉页油1HF井钻探方位为180°，同时，预测了水平井周向应力分布及对应的泥浆密度，获取了水平井不同位置、方位和井斜角条件下的泥浆密度窗口。根据预测

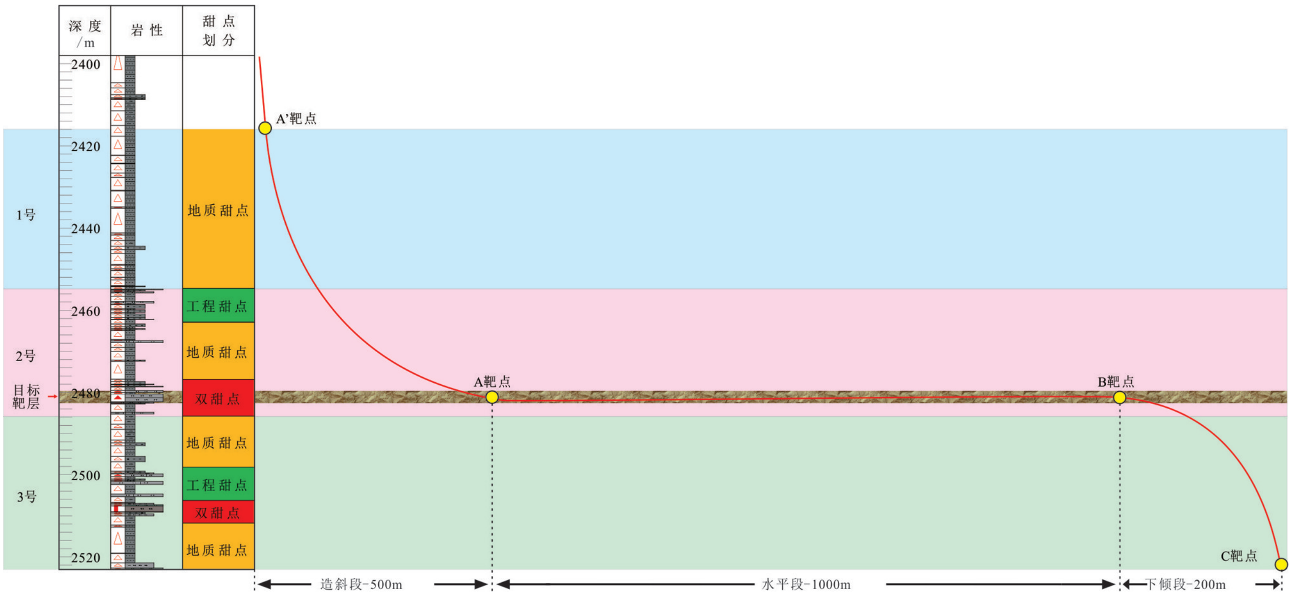

图5 吉页油1HF井三开阶梯式水平段轨迹示意图

Fig.5 Schematic diagram of the three-open stepped horizontal section trajectory of Jiyeyou 1HF well

表3 吉页油1HF井钻井液配方及钻屑回收率试验结果对比

Table 3 Comparison table of drilling fluid formulation and cuttings recovery test results of Jiyeyou 1HF well

钻井液类型	基本配方	密度/(g/cm³)	黏度/s	失水/mL	滚动前重量/g	滚动后重量/g	回收率/%
清水	清水	1.0	—	—	10.03	9.65	96.2
KCL聚胺	清水+4%膨润土+0.2%Na_2CO_3+0.2%NaOH+0.3%包被剂HP+0.5%乳液聚合物PL+0.5%LV-CMC+0.3%聚胺+0.5%~1.0%防塌剂PZ-7+0.5%~0.8%聚合物降滤失剂COP-HFL+0.5%~1%NH4-HPAN+5%~7%KCL+1%~2%超细碳酸钙QS-2+1%~2%磺化沥青FT-1+1%~3%液体润滑剂	1.2~1.5	50~75	≤1.5	10.16	10.07	99.1
油基钻井液	基液(油水比80∶20)+2%有机土+3%生石灰粉+5%油包水主乳化剂+5%油包水辅乳化剂+5%油基降滤失剂(FT)+3%油基封堵剂(树脂类)+3%超细凝胶封堵剂+2%QS-1+2%QS-2+2%QS-3+重晶石	1.4~1.6	70~95	≤1.0	10.14	10.12	99.8

结果显示,随着井斜角增大,防止井壁发生坍塌的临界钻井液密度逐渐增大。造斜段垂深2000~2416 m,井斜角在0~60°,以垂深2399.4 m的位置为例,沿180°方位角,井斜角在0~60°时,保证井筒安全的泥浆窗口密度在1.20~1.55 g/cm³(图6b);水平段垂深2416~2530 m,井斜角60~90°,所需泥浆密度较大,泥浆密度窗口为1.35~1.60 g/cm³(图6c),为水平井施工提供了有效的参考指导。

5 薄目标靶层精确导向技术

地质导向技术是水平井钻井的重要组成部分,是提高优质页岩储层钻遇率的主要手段,随着国内页岩油气资源勘探开发进程的加快,水平井精确导向技术在页岩油气勘探开发中的作用尤为重要(刘乃震和王国勇,2016;郑述权等,2019;柳伟荣等,2020)。吉页油1HF井设计目标靶层较薄,为保障

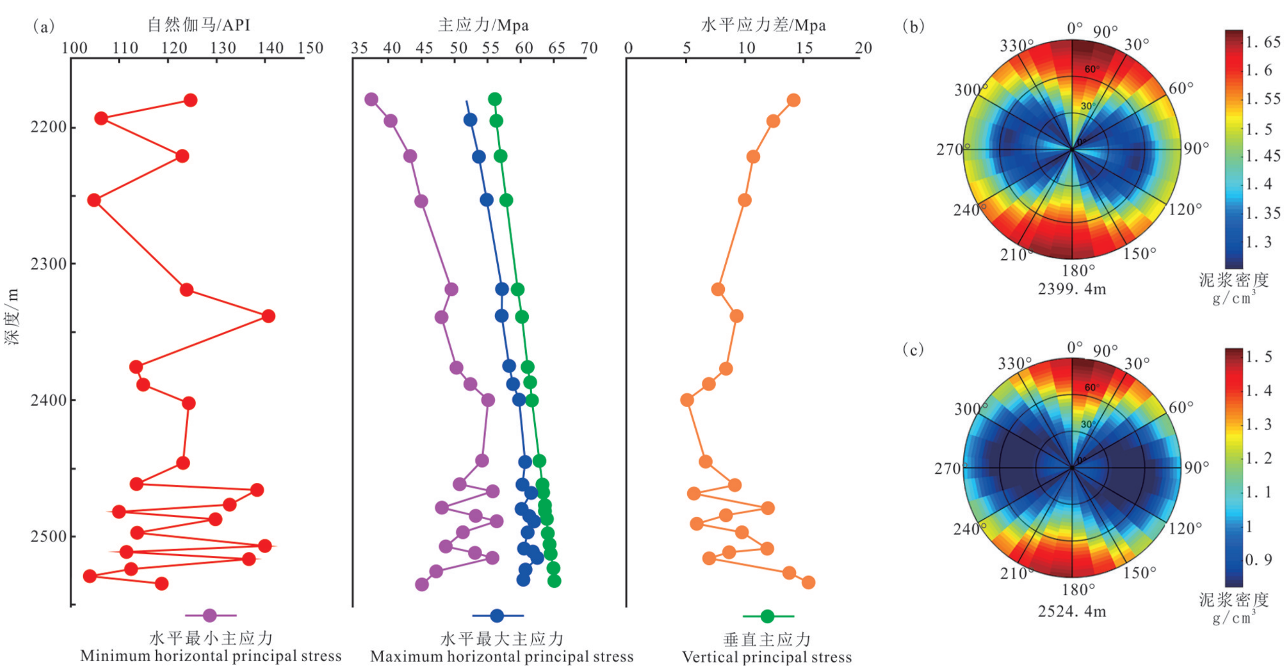

图6 吉页油1井岩石流变模型地应力剖面和井二开、三开泥浆密度窗口预测

Fig.6 Rock rheological model in-situ stress profile of Jiyeyou 1 well and prediction of mud density window for the second and third wells

钻井井筒的安全和后期压裂效果,要求薄目标靶层钻遇率在90%以上,针对导向难点,创新地质−地球物理一体化导向方法,采用地质−地球物理综合建模、多参数精确实时导向技术等技术,成功实现薄目标靶层钻遇率100%的目标。

5.1 三维地球物理构造模型

水平井目标靶层平面展布、纵向起伏、沿井轨迹方向地层倾角的变化等参数的描述和预测,是精准导向的前提,需要获取高精度深度数据。本次研究充分利用三维地震解释的水平切片技术、相干体技术对小幅度构造的分布进行了精细刻画,在精细合成地震记录标定基础上,通过精细井震联合统层、时深转换方法优选、速度场建立精度控制等技术,提高目标靶层构造图的精度,通过增加测网解释密度,完成等值线间距为1 m高精度构造成图(图7),对目标靶层在水平井轨迹方向的起伏变化及地层倾角进行了精细预测,实现由点到线、由线到面的空间立体综合解释,为水平井导向、定向提供了可靠的依据。

5.2 地质综合导向模型

由于水平井目标靶层较薄,厚度仅有1.94 m,导向难度大,难以保证水平井沿目标靶层连续钻进1000 m不出层,为了提高储层钻遇率,对目标靶层岩性、电性、含油气性等地层性质进行大比例尺精细描述,构建精细地质模型,将目标靶层在纵向上自上而下划分出3个小层,它们在岩性、气测总烃、电测伽马曲线上均呈现明显差别(图8),可以作为精确导向的地质依据。此3小层具体岩电特征如下:1号小层:岩性为粉砂岩,厚约0.8 m,低伽马值80~90,气测总烃0.8%~1.5%;2号小层:岩性为泥质粉砂岩,厚约0.2 m,高伽马100~110,气测总烃0.5%~1%;3号小层:岩性为粉细砂岩,厚约1 m,低伽马

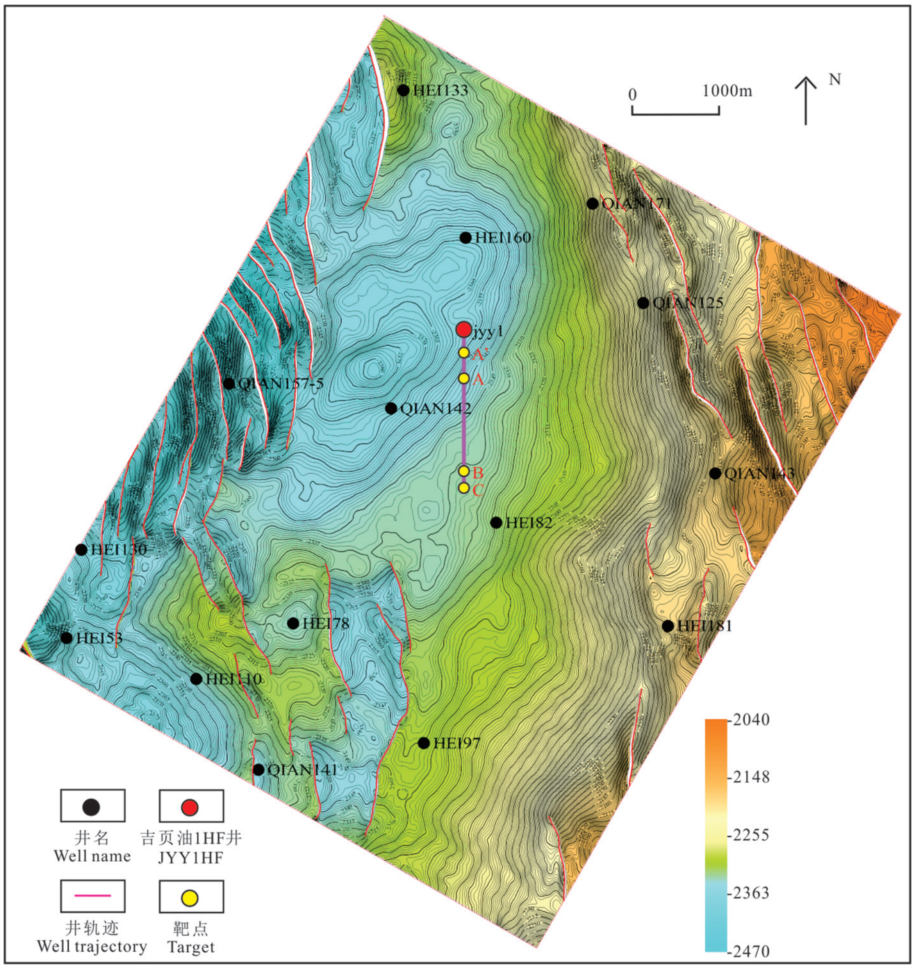

图7 吉页油1HF井目标靶层顶面深度三维构造图

Fig.7 Three−dimensional structure diagram of the top surface depth of the target layer of Jiyeyou 1HF well

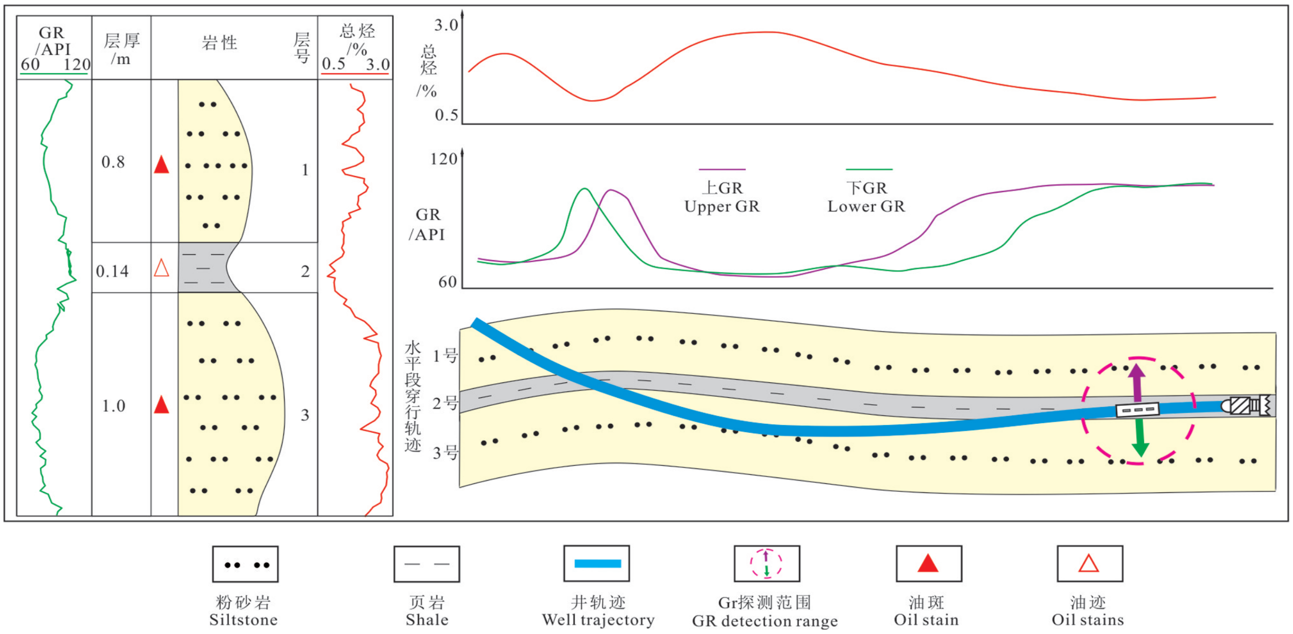

图8 吉页油1HF井目标靶层小层精细划分及水平井导向综合模型
Fig. 8 The fine division of target layer and the comprehensive model of horizontal well steering in Jiyeyou 1HF well

70~80,气测总烃1%~2.5%。基于以上差异,优选岩性录井、气测录井、伽马随钻测井3种随钻地质导向手段,结合地层倾角预测技术,构建基于实钻岩性、气测总烃、随钻伽马、地层倾角等参数为核心的导向地质模型(图8),为水平井地质导向提供精细可靠的地质依据。

5.3 多参数精确实时导向技术

本次导向工具选择兼顾考虑了导向工具的精确性,地层适应性和经济实用性,选择了Schlumberger公司Path Finder近钻头自然伽马测量工具进行随钻测量。该工具可以提供钻头处实时的井斜、伽马和转速,且伽马和井斜的零长较短,距钻头只有0.6 m,分为上下两个短节,通过无线通讯,传输数据,实时测得钻头处的井斜、伽马数据,使工程人员可根据地层变化及时调整轨迹。

随钻方位伽马测量仪将伽马传感器对称安装于钻铤表面,用以记录来自其对应地层的伽马射线(刘旭礼,2016;熊方明等,2016;郑奕挺等,2019)。通过方位伽马实时数据可以对钻头距离目标靶层上、下界面距离做出判断,而进行实时调整。原理如下,当钻头从目标靶层顶部进层时,下伽马值首先降低,然后上伽马值降低;从顶部出层时,上伽马值首先抬起,然后下伽马值抬起;从底部进层时,上伽马值首先降低,然后下伽马值降低;从底部出层时,下伽马值首先抬起,然后上伽马值抬起;完全进层或出层后,上、下伽马值基本一致(图8)。

为更好地进行实时导向,采用了随钻方位伽马数据实时成像技术,首先将测量的伽马值进行插值处理,根据不同的色度标定方法预定义成像色谱,再将伽马值按照一定的规则刻度成对应颜色的色标数据(一般亮色代表低伽马值,暗色代表高伽马值),最后把伽马颜色数据按坐标位置显示出来,即可生成随钻伽马测井图像。利用随钻方位伽马以及伽马成像仪器,可以确定进入储层的最佳时机,提高油层穿透率和对井眼轨迹的控制能力(图9)。

6 应用效果

吉页油1HF井是松辽盆地南部页岩油勘查的第一口水平井,对松辽盆地陆相页岩油勘探具有重要引领意义。通过创新应用陆相页岩油地质工程一体化水平井精确钻探系列技术,吉页油1HF井实现水平段长度1252 m的超长钻探目标,实钻轨迹与设计轨迹高度吻合,1.94 m目标靶层钻遇率100%,目的层井径扩大率<6%,井身质量优质,并且水平段钻获888 m油斑显示(图9),为后期地层含油气性测试奠定了良好的基础。吉页油1HF井经过大规模体积改造,获得最高日产油量为36 m^3,日稳产油16.4 m^3的高产工业油流,取得中国陆相常压高黏土

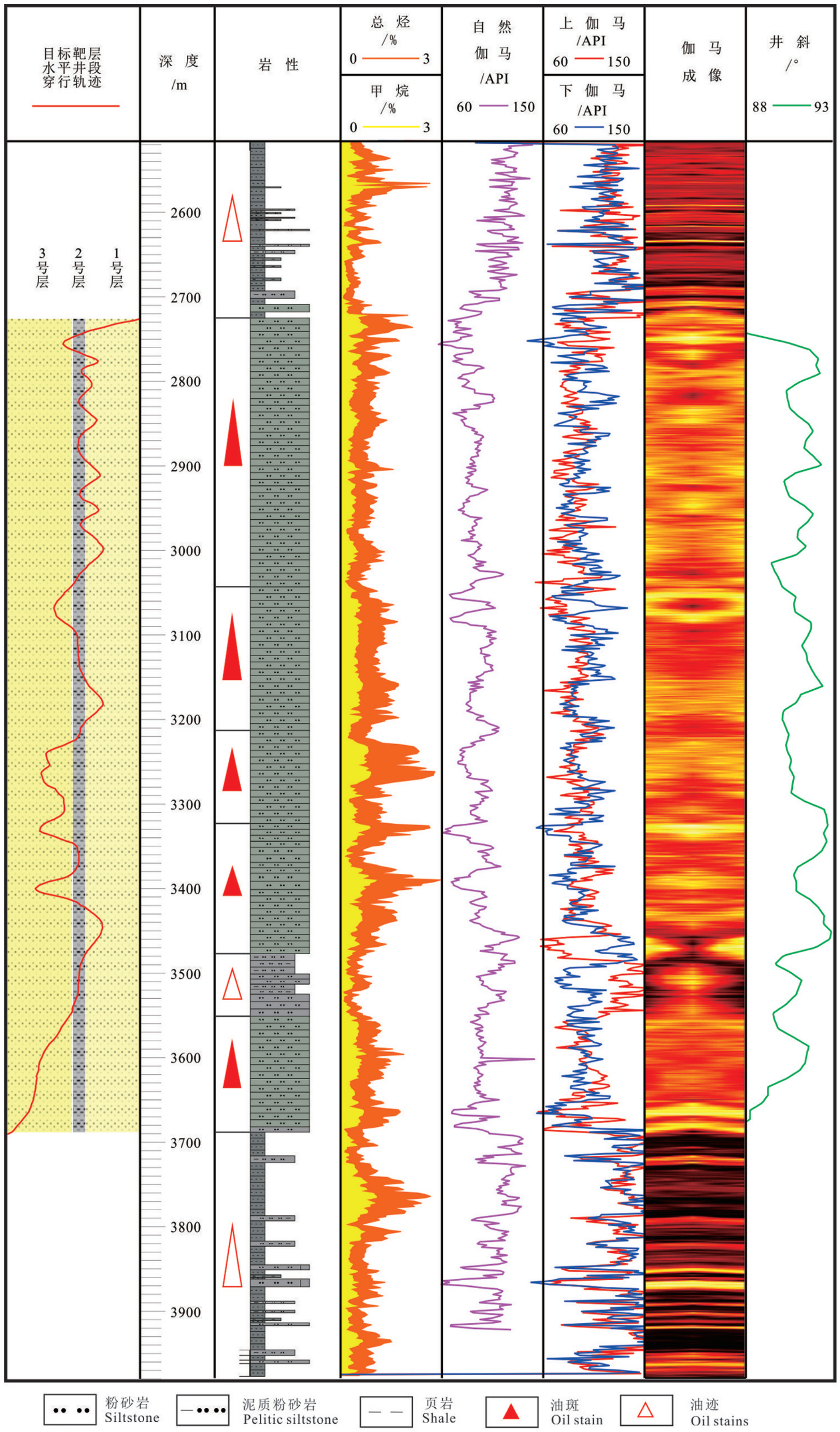

图9 吉页油1井水平段多技术综合精确导向图

Fig.9 Multi−technology comprehensive accurate steering map of the horizontal section of Jiyeyou 1HF well

矿物含量页岩地层最高页岩油产量,实现了陆相页岩油战略调查重大突破。

7 结 论

中国陆相页岩油资源潜力巨大,水平井精确钻探技术是页岩油实现效益动用的关键。瞄准陆相页岩油资源勘探开发的迫切需求,针对陆相页岩长水平段精确钻探技术难题,基于地质工程一体化设计思路,创新形成目标甜点层和靶层优选、钻井液配方及性能优化、地质+地球物理建模精确导向等系列关键技术,克服松辽盆地南部陆相页岩黏土矿物含量高、层理裂缝系统发育、目标靶层厚度薄等诸多不利因素,成功实施了水平段长度为1252 m的吉页油1HF井,并获得日稳产油16.4 m^3/d的高产工业油流,为中国陆相页岩油水平井钻探提供了系列创新技术和实践经验,具有重要的创新和借鉴意义。

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