

Reaping Potential Reserves in Mature Channel Sand Field Using Boundary Mapping Technology*

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Abstract

BZ25-1 is the largest development field of CCLT (CNOOC CHINA LTD- TIANJIN) in Bohai Bay. Its main depositional environment was shallow delta, fluvial channels combined with multiple post-diagenesis tectonic movements. After 10 years' production, the water-cut ratio has increased to 58%. Thus, production optimization becomes a major challenge for the operator. Supported by detailed seismic research and production data analysis, large potential hydrocarbon reserves are still recoverable. However, to tap these reserves, well trajectory has to be paced preciously and consistently in a suitable position in this mature field. After considerable data assessment and study in measurement feasibility, boundary-mapping technology based on resistivity contrast and rotary steerable system was selected as the integrated solution. By employing this advanced technology, detailed reservoir profile is obtained and provides significant information for proactive geo-steering beneath the reservoir cap rock. With rotary steerable system, the trajectory is optimized to satisfy the reservoir's requirement for precise well path control, and substantially reduce construction risk in a complex environment. Total recovery factor has been improved 37% in this drilling campaign. Optimizing remote data transmission system, a multi-disciplinary team's real time execution delivered in best class results of a net-to-gross (NTG) increase to 94% with a reduction in water production for first time.

Introduction

BZ25-1S is the largest development field in Bohai Bay in the eastern part of North China ([Figure 1](#)). The depositional system in this field is a typical fluvial environment, stacked with a multistage meandering river and modified by tectonic movements in the post-diagenesis phase. In 1998, hydrocarbon resources were first found in this area and the development plan was approved in 2003. In August 2004, wells in the first phase were put into production. During production, a steep pressure drop was shown and the production declined (Xin et al. 2009). After 10 years, the aquifer's extension became a big challenge for hydrocarbon yield. The average water-cut ratio increased to 58% in 2014. Exploration of potential reservoirs and optimization of production were the priority task for this project's operators. In this paper, we introduce an integrated approach combining geological, petrophysical, and seismic and dynamic production data with real-time boundary mapping technology and a RSS to place horizontal wells precisely in the required position to reap the potential resources and optimize production.

Background

General Geology

Bohai Bay Basin formed at the end of the Tertiary on a crystalline basement solidified from Archeozoic to Early-Middle Proterozoic, covering an area around 200,000 km² (about 74,000 km² offshore). After deposition in Middle-to-Late Proterozoic, Paleozoic, Mesozoic and Cenozoic, a complex fluvial channel system was generated with variant features: disconnected and isolated sand bodies, mingling structure between the hydrocarbon reservoir and aquifer, inconsistent property both vertically and laterally, fully developed heterogeneity, and so on (Figure 2). Until 1994, the Bohai Bay Basin was composed of 47 faulted depressions, in which 170 oil and gas fields have been found (Jianyi et. al., 1994).

As the typical representative of Bohai Bay Basin, BZ25-1S field inherited all the above features. The main burial depth for its target reservoir—the lower part of Ming—is 1500~1800 m in true vertical depth (TVD). Since this field is located on the external edge of the current Yellow River delta, these channel sand bodies are considered the ancient distributary parts of the river existing in the Middle to Late Miocene. Affected by the Tan-Lu crustal fault, extensive faults developed in this field, which further complicated reservoir formation.

Development and Production History

At the initial stage of development, conventional vertical wells were the main production well type. Horizontal wells are dedicated to large single-sand channels (Xin et al. 2009). By October 2012, 116 wells were put into production with daily oil yield of 3505 m³ and total production volume of 1069.04*104 m³. The recovery rate of reserves is 8.69%, unfortunately only with the assistance of seismic data and offset well correlations. The trajectories' net-to-gross (NTG) in the pay zone is significantly limited by scattering channel sand deployment and the reservoir's lateral inconsistency. The estimated net-to-gross (NTG) in the planning stage is 15 ~ 35% and the actual average value is approximately 20% (Xin et al. 2009).

Since field development has proceeded to a further stage, this field has matured. For the main reservoir layer, the density and viscosity have increased to 0.87 g/cm³ and 17.58 mPa*s. Porosity has a wide range (18~40 pu) with an average of 33%. Very impressively, porosity in more than 75% of 459 core samples is higher than 32 pu, associated with a good permeability in this pay zone, but also a quick water sweep (Figure 3). Based on the statistics study for 420 core samples from exploration and evaluation wells, the permeability is scattered from 1 to 7,000 mD, but more than 78% of the samples' permeability is higher than 500 mD and the average value is 1,962 mD.

Challenges

In the initial part of the new drilling campaign, we realized some tough challenges needed to be solved before the next step.

1. With the complex geological settings and limited knowledge about channel sand deployment, understanding the regional geology and identifying the correlation among various individual sand bodies were the critical tasks for well planning. Figure 4 was a typical well

correlation for the pay zone. In some wells, the sand body was developed. In others, it pitched out or hardly to identified. Occasionally, the pay zone was separated to two or three small layers by shale.

2. Only relying on the conventional seismic data (Figure 6 is a compare between conventional seismic projection and the reprocessed projection), net-to-gross ratio (NTG) for the previous production wells had not been good (15~35%, Xin et al. 2009). Improving NTG in the new drilling campaign seemed to be the first option to increase production rate.
3. Dynamic surveillance showed that water had swept quickly after short-term production (Figure 3). In 5 years, the water cut increased from 30% to 60% and gas/oil ratio decreased from 100 to 40). However, without relogging data, the exact oil/water contact position was not clear. So to extend the production period and delay water swept, new well bores were required to hug the reservoir's top boundary.

Solution

Based on field structural map, well type and data quality, certain wells were selected as reference for target reservoir (Figure 5). Through feasibility studies in different scenarios, simulated log responses were used to assist tool selection), an integrated fit-for-purpose approach was proposed. Reprocessing the seismic data provided a high-resolution impedance map for the target pay zone (Figure 6). Boundary mapping technology provided the distance from the trajectory to the boundary in real time, leading to a precise well-path control and an azimuthal description of the reservoir profile. A RSS dramatically improved the drilling efficiency and avoided unnecessary execution risks.

The resolution for a conventional seismic profile is 20~30 m. However, after reprocessing, the resolution for the target reservoir in BZ25-1S field reached around 3 m, which significantly improved channel sand identification and reduced depth uncertainty while landing (Figure 6). Boundary detection technology based on resistivity contrast depicted the reservoir profile both in detail and in time. This method not only defined the contact relationship between different sand bodies but also provided the exact oil/water contact position. This showed that a trajectory could be hung under the top boundary within a certain distance range (1.5~2 m) and avoid aquifer zone (Figure 7). The post drilling analysis of the technique provided further understanding about the sedimentary pattern, potential reservoir distribution and deployment of the ancient fluvial system in this field.

The RSS was a striking advantage in this complex and fast drilling environment. By using near-bit measurement, the operator could control the trajectory more accurately, which was the cornerstone for geosteering the well path to follow the fluctuant top boundary. Besides, using the RSS's steering trajectory while the whole bottom hole assembly (BHA) keeps rotating substantially improves drilling efficiency and reduces relative construction risks. Before adopting this, the average sidetrack ratio is 31% meaning one third of horizontal wells were needed to re-drill in order to achieve the effective length in reservoir. It is a considerable consumption for time and variety resources comparing with no side track in this new drilling campaign.

Employing the remote data transmission system, a multidisciplinary analysis team delivered real-time geological support. Relying on the suggestions and instructions given by this team, a proactive strategy for the well path was taken in real-time drilling instead of passively following the initial plan. In Figure 7, instead to follow the plan trajectory, which was totally out of the reservoir, the trajectory was adjusted

during the entire drilling procedure by assistant of this reciprocal remote data transmission system and real time geological instructions. Finally, the well bore smoothly chased the top boundary as per operator's requirement.

A new drilling campaign was implemented according to the promising result given by this integrative solution. Eleven horizontal wells have been deployed in this field, focusing on the main potential channel sand—the lower part to the Ming layer. Most wells lie in the gap between the current production wells, which is usually the joint position between various sand bodies.

Result

For the initial stage, four wells have been drilled. The average NTG of these four wells reached 94%. Compared with 20% of previous wells (Xin et al. 2009), this result is truly beyond the operator's expectation. As expected, the advanced logging-while-drilling (LWD) tool provided clear and detailed reservoir profiles. For the first time, analysis and research staff directly saw the shape of the channel sands distribution (in [Figure 8](#), the boundary mapping result described the detailed profile of reservoir, showing a good consistency with high-resolution seismic projection).

Moreover, this campaign's implementation led to an innovative approach for multi-disciplinary collaboration ([Figure 9](#)). Instead of sitting in the backstage and doing the pre/post drilling study and analysis, the geological and seismic research staff was actively involved in the drilling procedure. Since the deposition environment was complex channel sand and the resistivity contrast between pay zone and top seal layer was not quite clear (generally 5~10ohmm for top seal, 8~20ohmm for pay zone), these facts could limit boundary-mapping capacity and increase the uncertainty for well path control. To overcome this, in drilling execution, multiple disciplinary engineers provided their analysis based on the real time data: geologist and petrophysicist focused on log interpretation, seismic engineer updated projection according to the on-going trajectory. All these analysis acted as a crosscheck to boundary-mapping result. After this step, the consistent instruction was delivered to well site. Besides, to ensure the execution result, well site engineers' ([Figure 9](#), included but not limited on these) opinions were also integrated into the decision loop helped by high-speed real time data transition system. This interactive discussion could include all possible information and views to place the well bore in suitable and accurate position.

After these wells were put into production, the recovery factor improved 37% satisfying the original requirement for this drilling campaign ([Figure 10](#)). Compared with [Figure 3](#), in [Figure 10](#) though in the water swept ratio kept increasing, but gas/oil ratio did not decrease. There was even an augment after the new drilling campaign's wells in production in 2014.

Summary

BZ25-1S is a typical mature marine reservoir with complex original channel sand distribution and multiphase, post-diagenesis tectonic movements. High uncertainty about reservoir connections, inconsistent boundary positions, and unidentified oil/water contacts turned out to be the main limitations to field further development. Learning how to handle these difficulties was the key to enhancing recovery efficiency and extending the reservoir's production life.

One comprehensive solution lay in a new drilling campaign. Boundary detection technology in tandem with a rotary steering system benefited the operation in both formation description and quick trajectory adjustment while drilling. The application of these new technologies satisfied the operator's precise requirement for well-path position. It also saved substantial time and work by delivering reservoir measurements and drilling optimization in one execution. By the end of June 2014, 1642 m had been drilled in four horizontal wells with average 94% NTG and 37% recovery efficiency increase. These positive and impressive results confirmed the operator's expectation of the mature field's potential and demonstrated the distinct advantage of these new technologies.

Selected References

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Figure 1. Location map for BZ25-1S field in Bohai Bay.

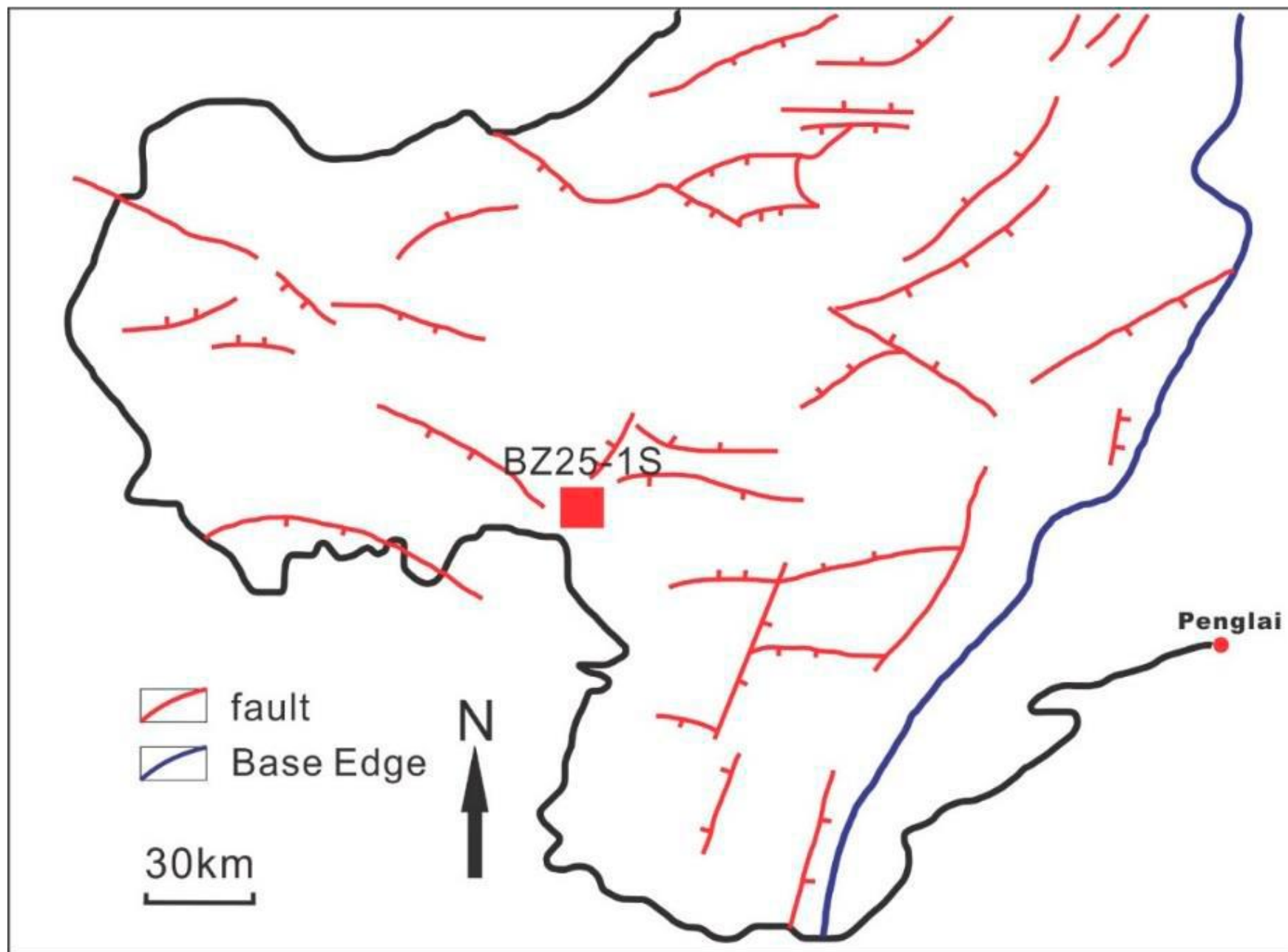


Figure 2. Simple graph for Bohai Bay Basin (modified from Yunhua et. al., 2007).

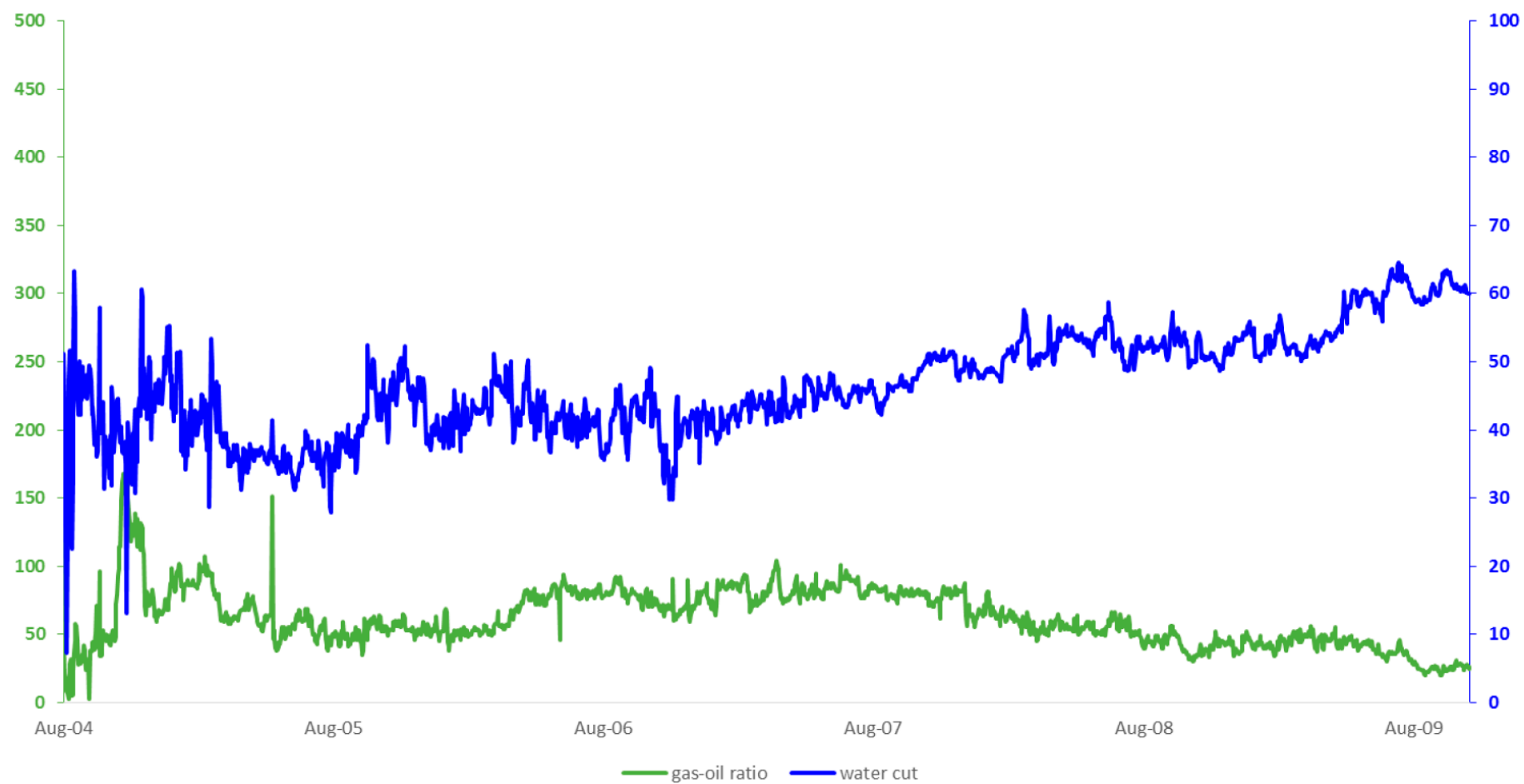


Figure 3. Production chart of initial development stage. Gas/oil ratio decreases are clearly accompanied by water-cut increases.

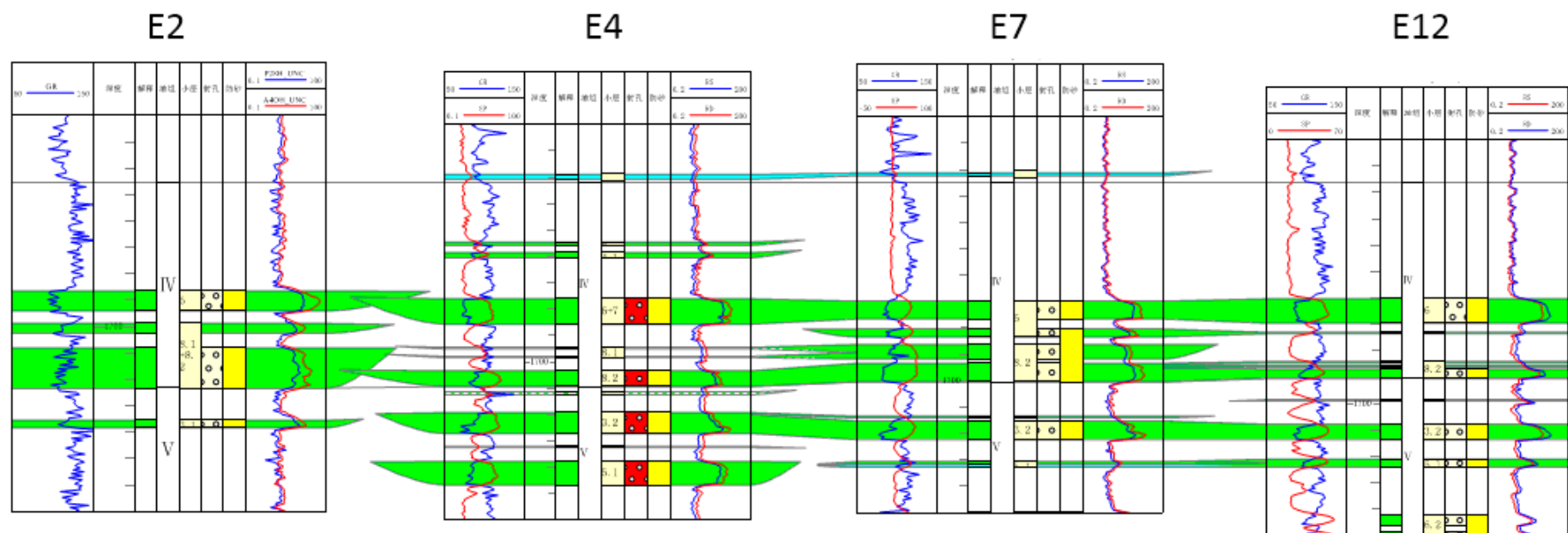


Figure 4. Well correlation for target reservoir revealed the disconnection of the sand body.

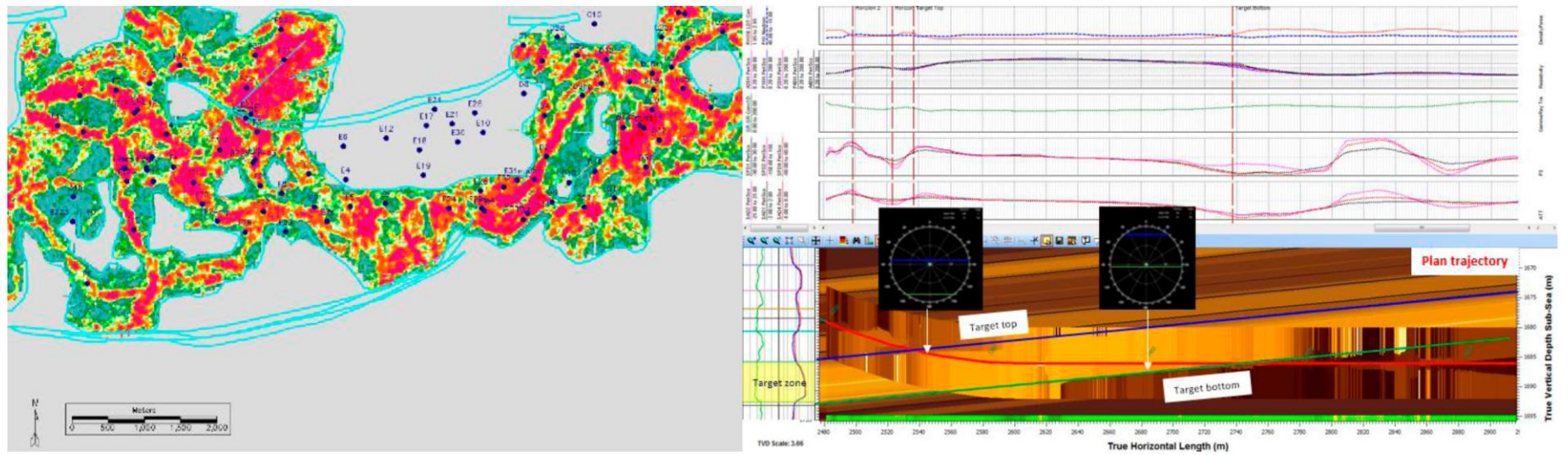


Figure 5. Field structural map and plan well's feasibility study.

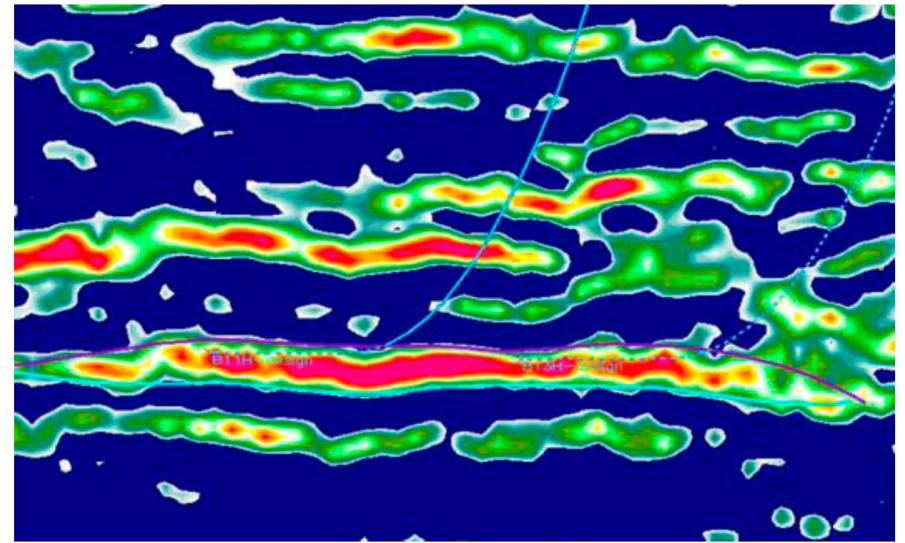
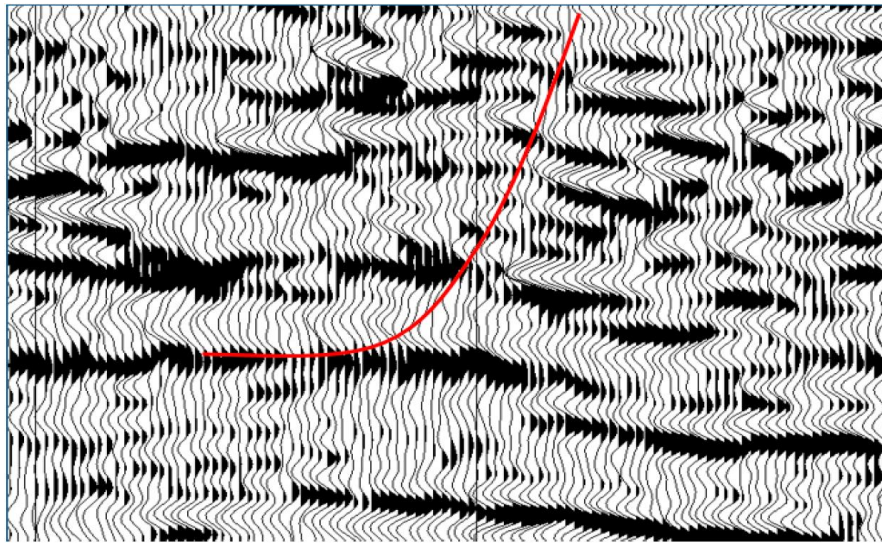


Figure 6. Comparison between conventional seismic projection and reprocessed projection.

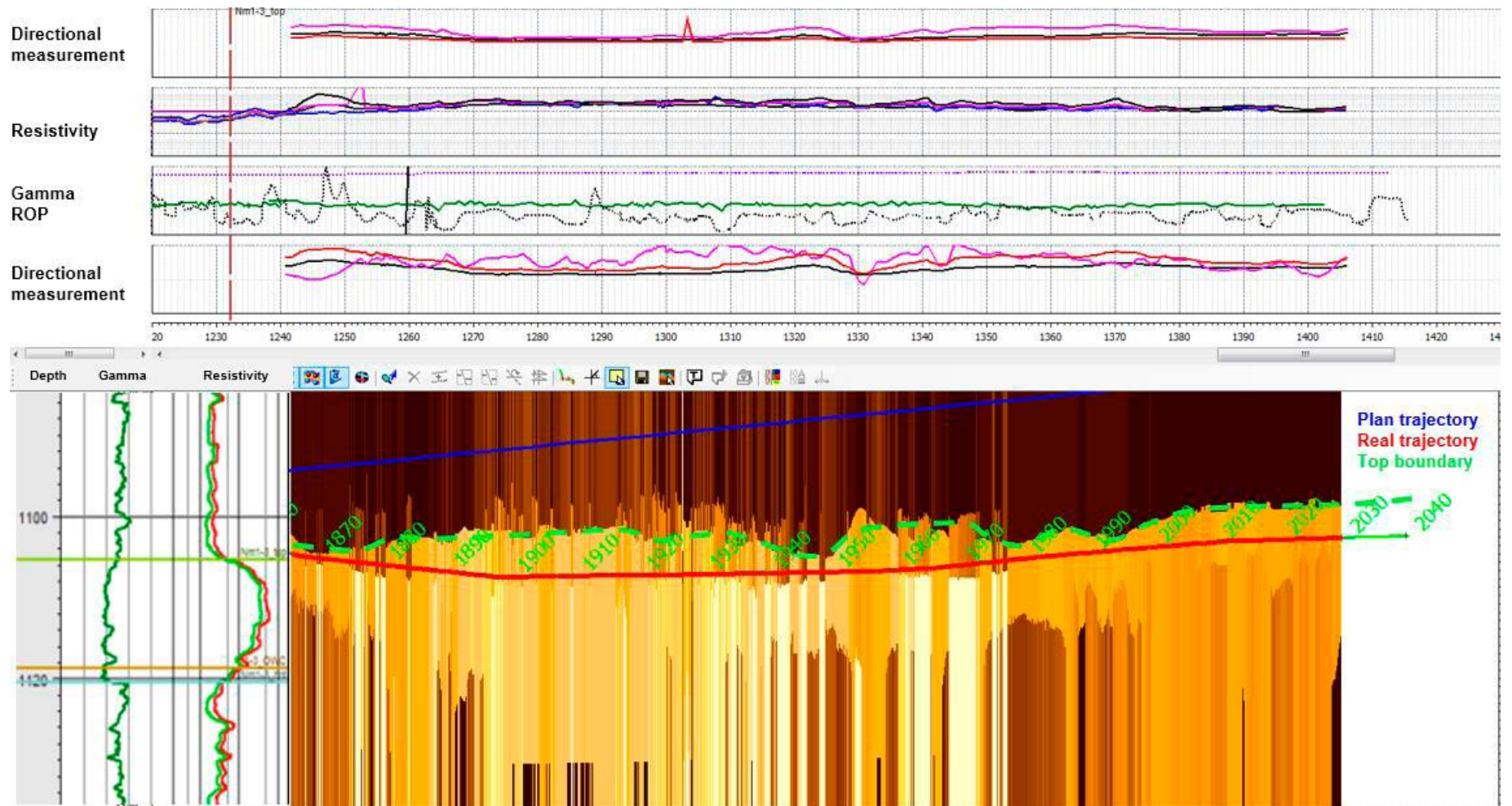


Figure 7. Application of boundary mapping technology in Bohai Bay Basin. The trajectory stays an average distance of 1~2 m from the top boundary.

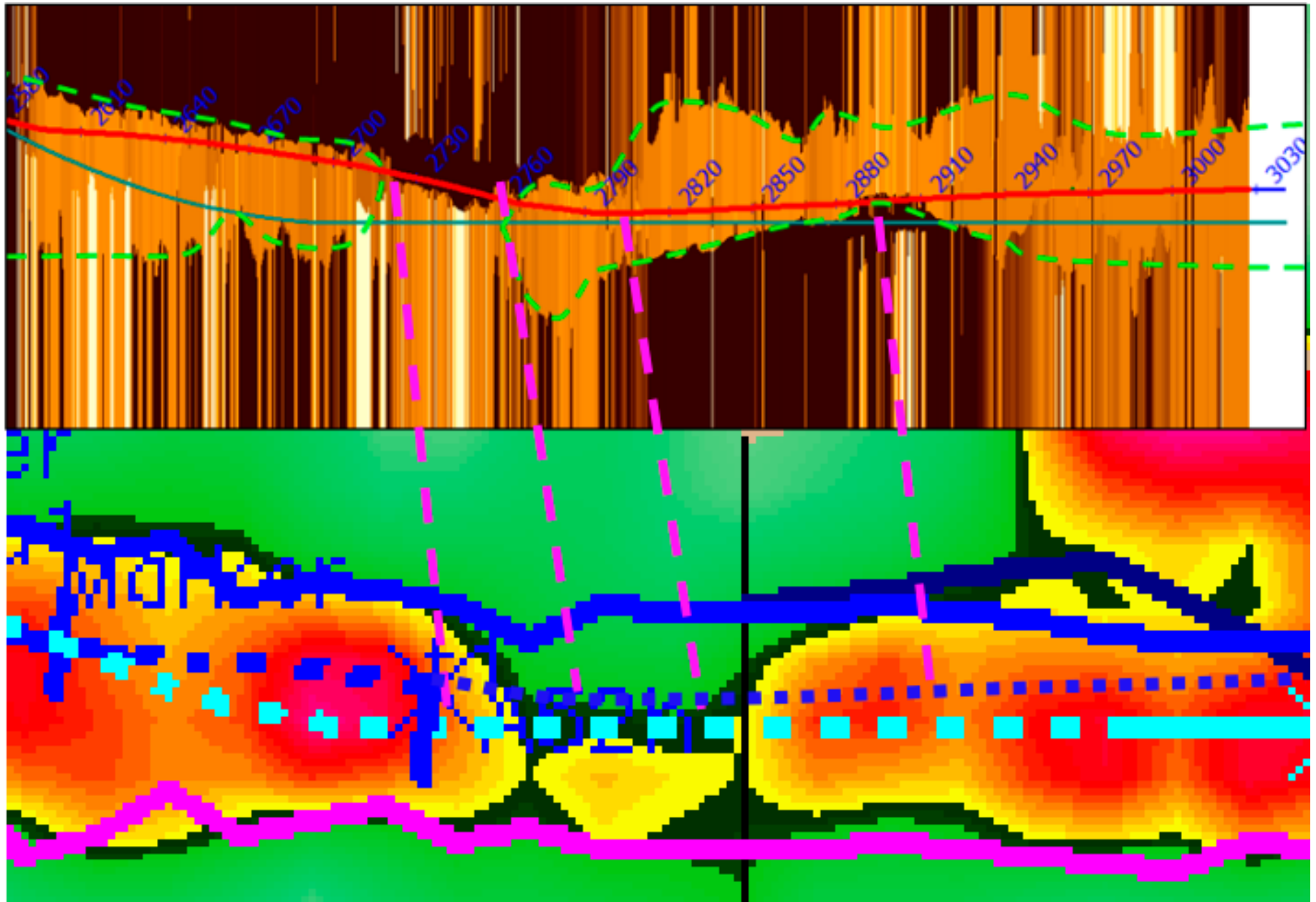


Figure 8. LWD boundary mapping result vs. seismic projection.

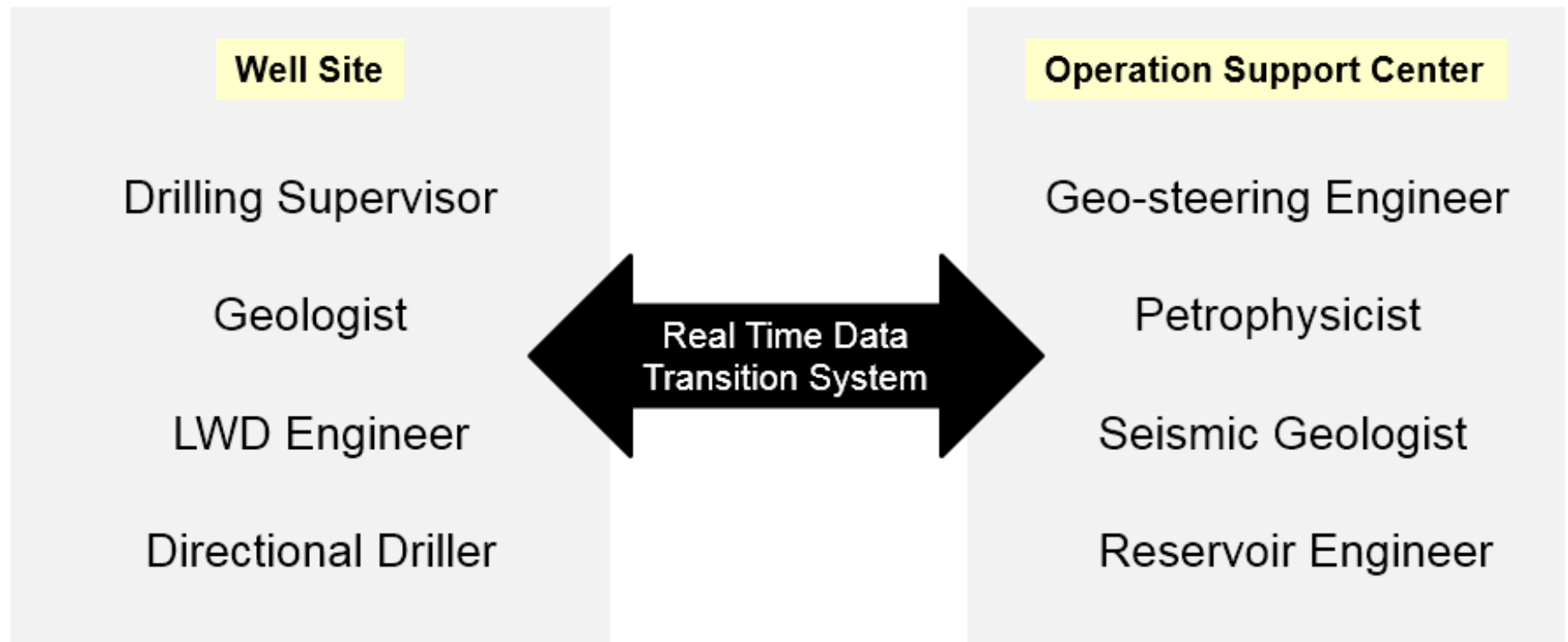


Figure 9. The collaboration schematic used in BZ25-1S drilling campaign.

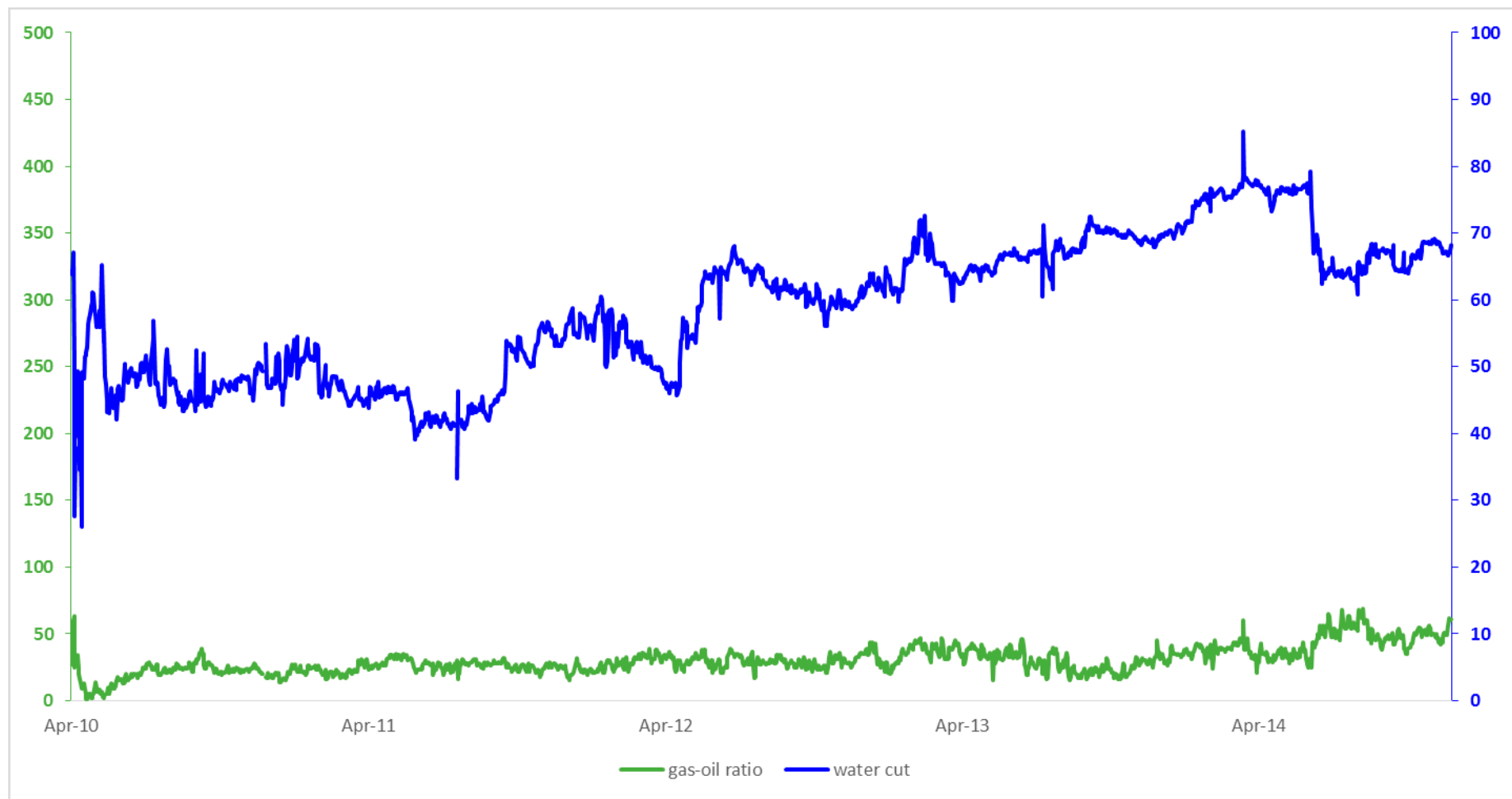


Figure 10. Production chart – after the new horizontal wells are put in production in 2014, gas-oil ratio increases, accompanied by significant water cut decrease.