Case Study of the Structural and Depositional-Evolution Interpretation from Seismic Data*

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Abstract

Based on Bally's balanced cross section concept and the sequence stratigraphy theory proposed by Vail, this paper discuss the dynamic interpretation of structural evolution and depositional evolution using 3D seismic data, and by integrated interpretation of the paleo-geomorphology, sedimentation supply with the structural evolution and depositional evolution study results, remaining oil was predicted.

The study field is on a monocline structure in the Jungar basin in western China, with depths between 3230-3480 m. And Jurassic (main producing layer) formation contacts its underlying formation as an angular unconformity. The field has been in production since 1991 with water cut around 60% at the time of 3D seismic acquisition in 2006. Well A situated in the low position outside the oilfield with 5784 tons of accumulative oil production which puzzled reservoir engineers and a 3D seismic is designed to hopefully explain why.

From study of structural evolution and depositional evolution using data from the 3D seismic survey, in only 260 ms time interval seven quasi-depositional sequences of sedimentation were identified during Jurassic period. Paleo-geomorphologic picture of the Jurassic reservoir sand revealed that the oil field sits on a paleo-incised valley fill in Jurassic, and interpretation of the flattened section (along bottom of Cretaceous K1tg) in the supply direction indicated that sedimentation supply was from north direction to the incised valley.

With the integrated study of logging and production data to above interpretation results, it is concluded that there is a lithologic variation zone corresponding to weak amplitude in seismic amplitude caused by river channel erosion in later Jurassic, and which separated out well A from the main producing zone to the west. Thus explained why we have high oil and low water production at well A which is situated at structurally low positions. The remaining oil was also predicted and proved by later production.

This case study indicated that structural and depositional evolution interpretation makes the understanding for geologic target intuitive and

effective, and by integration with logging and production information, just the 3D seismic data could give us the remaining oil prediction result.

General Statement and Introduction

Structural and depositional interpretations are the major routine steps in the 3D seismic data interpretation workflow. Their outcome, the structural maps and facies map, is the important reference for geologist in deciding drilling position. As the structural maps and facies map are only related to definitive time and the subsurface, deposition is actually a dynamic procedure involving sea level variation, tectonic movements, climate change, etc. It seems that dynamic structural evolution and depositional evolution procedure analysis would make the understanding of geologic target intuitive and effective. This article discusses the dynamic interpretation of structural evolution and depositional evolution as well as the paleo-geomorphology, sedimentation supply and prediction of the remaining oil.

Balanced cross section concept was originated from petroleum geologic interpretation of Rocky Mountains in Canada in 1950s to 1960s (Bally, 1966), and proposed and quoted formally in 1969 (Dahlstrom, 1969). In 1977, Vail, Mitchum and Thompson published "Global stratigraphic cycles between cycles and sea level changes", which reveals the relationship between seismic and strata. Based on this, Vail (1988) proposed the concept of sequence stratigraphy based on a passive continental margin sedimentary model and established sequence stratigraphy theory that is based on seismic data, logging data and geological outcrop data. This theory considered the four key factors of sediment (sea level variation, tectonic movements, climate change, sedimentation rate) and was used to study the sedimentary environments, the sedimentary patterns and the contact relations of the strata on the unconformity or its corresponding conformity. Furthermore, Galloway (1989), Embry (1993) and Cross et al. (1994) discussed stratigraphic sequence which relates the seismic and geologic information.

Background of Geology, Seismic and Production

The study field is on a monoclinal structure in the Jungar basin in western China (Figure 1a and 1c), with depths between 3230-3480 m. The field has been in production since 1991, with 54 well drilled, and the highest production was reached in 1994. 3D seismic was acquired in 2006 with water cut around 60% at that time (Figure 2a). Well A is located in the low position outside the oilfield (Figure 2c) with 5784 tons of accumulated oil produced through 2006. It seems to be in an isolated oil pocket which has no water cut. Thus mounts a technical and business challenge to predict remaining oil production. A wide azimuth 3D seismic survey covers an area of 93 km^2, with 12.5m x 12.5m CMP bin size was acquired in 2006, hopefully to help with the prediction of the remaining oil.

Structural and Depositional Evolution

Based on the Bally's balanced section concept, one two-dimensional section normal to the strike direction across the reservoir was chosen,

and flattened at the base of the Jurassic (J1b), a pseudo-balanced section (Figure 3a) was obtained. From it we can see that before the Jurassic there was an erosional period, with earlier volcanic activity. Contact of the Jurassic formation with the underlying formation is an angular unconformity.

With the strata movement before Jurassic being clarified, then Middle Jurassic (J2x) was flattened to get the pseudo-balanced section (Figure 3b) of Lower Jurassic (J1b). It can be observed that the eastern part of the studied area began to sink in Early Jurassic. There are three minor cycles of sedimentation in J1b, corresponding to three progradational reflection configurations in the seismic section within a 100ms interval.

As to the Middle Jurassic (J2x), we can see from the flattened seismic section along J3q that the eastern part of the area continued its subsidence. Two lower order sedimentation cycles are represented by two progradational reflection events in the seismic section (Figure 3c).

Finally we can see from the seismic section flattened along K1tg (the base of the Cretaceous) that the east part of the area of interest continued to subside in Late Jurassic, and there are two cycles of sedimentation, corresponding to the two progradational reflection in the seismic section (Figure 3d).

From this study it can be concluded that in the 260 ms time interval on the seismic section, three main sedimentation cycles and seven minor cycles of sedimentation can be interpreted for the Jurassic Period. Yet it is very difficult to make such an interpretation in the conventional seismic section (Figure 1c).

Paleo-geomorphology and Sedimentation Supply Based on 3D Seismic

We know that there were three main sedimentation cycles during the Jurasic Period. Main reservoirs formed in the two minor sedimentation cycles of the Late Jurassic (J3q). Based on this study, paleo-geomorphologic picture of the reservoir (J3q) is shown in Figure 4a and 4b; it was obtained by using the base and top of the Upper Jurassic. The oil field setting is a Jurassic paleo-incised valley fill. Yet how the valley formed and the deposition setting are the major concerns.

A seismic line was selected that crosses the valley and is perpendicular to the sediment paleo-direction (Figure 4c) and flattened on the event at the base of Cretaceous (K1tg), thereby obtaining a pseudo-balanced cross section. It can be interpreted that the early fracture and volcanic movement contributed to the formation of the incised valley. The seismic reflection from inside and outside the valley show different features. By flattening the base of the Cretaceous (K1tg) event in the seismic section, a pseudo-balanced section is obtained (Figure 4d). A very clear progradational reflection character and unconformity can be observed. Interpretation of this flattened section allowed determination of the sediment-supply direction.

Depositional Evolution

Based on the interpretation of the K1tg and J3q interval, we can then subdivide the J3q reservoir into 10 layers. Seismic-amplitude slice maps for these layers were prepared, with examples given in Figure 5.

J3q deposition occurred during a lowstand that was followed by the transgression system tract. From Figure 5a, fluvial channel can be interpreted. With rise of the water level, the channel back-stepped to the north (Figure 5b, 5c, and 5c). The boundary between the Cretaceous and Jurassic (Figure 5f) represents the time when the whole area was covered by shale (clay) deposition, the seal. The abrupt change of the amplitude in the north part of the slice map, is interpreted as an erosive phase in the later stage of the shale deposition.

Integrated Approach for Prediction of Remaining Oil

Although understanding the structural and depositional evolution helped greatly in understanding the geology associated with the reservoir, prediction of the remaining oil for well A and the associated area of interest remains the challenge of most importance. It is well known that time-lapse seismic has the advantage in monitoring reservoir dynamic variations, but with only one 3D seismic data, the prediction is a challenge task.

One seismic line across the reservoir and well A (Figure 6d) was selected, and by flattening it on the base of the Cretaceous (K1tg), the resulting pseudo-balanced cross section is shown in Figure 6b. The existing producing reservoir is associated with strong seismic amplitude response. The known water well was either in the low amplitude area or in the location where the reservoir is relatively thin. All that is indicated that there is some relationship between the oil-bearing feature and the seismic amplitude. The weak seismic amplitude corresponds to the lithologic variation caused by river channel erosion in Late Jurassic; this interval in well A is separated from the main producing zone to the west. Thus, oil production at well A is from a structurally low position.

By integrating structural and depositional evolution, logging and production data, final prediction was made, and Figure 7 summarizes the prediction for this field, with these guidelines: (1) the aquifer water invasion comes from the southeast direction (yellow arrow);
(2) the remaining oil zones are associated with strong seismic amplitudes on the 2006 seismic survey (red arrows);
(3) the bands of weak seismic amplitudes are associated with the water-prone zone caused by oil-water replacement and lithologic variation. Later production confirmed this prediction.

Conclusion

Based on Bally's balanced cross section idea and concept of sequence stratigraphy proposed by Vail, structural and depositional evolution through use of the pseudo-balanced cross section from 3D seismic data was interpreted. This approach helped in analysis of the tectonic and

depositional history for the reservoir. Integrated with logging and production information, with just the one 3D seismic survey, seemingly gave us a reliable prediction of the remaining oil.

Acknowledgments

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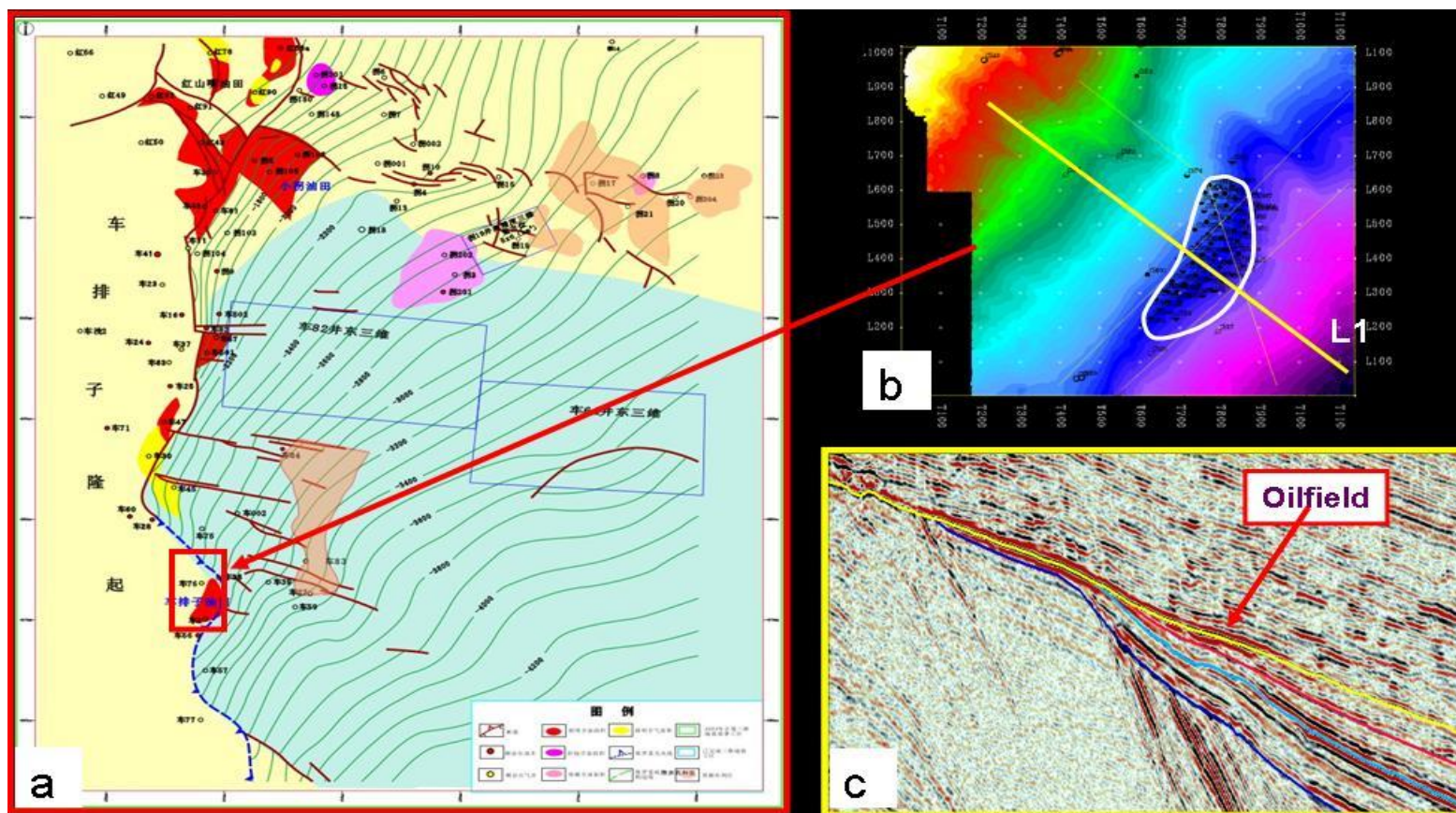
Figure1. **a**: Index map showing 3D seismic survey, Jungar basin, western China; **b**: structure map from 3D seismic; **c**: seismic section (L1).
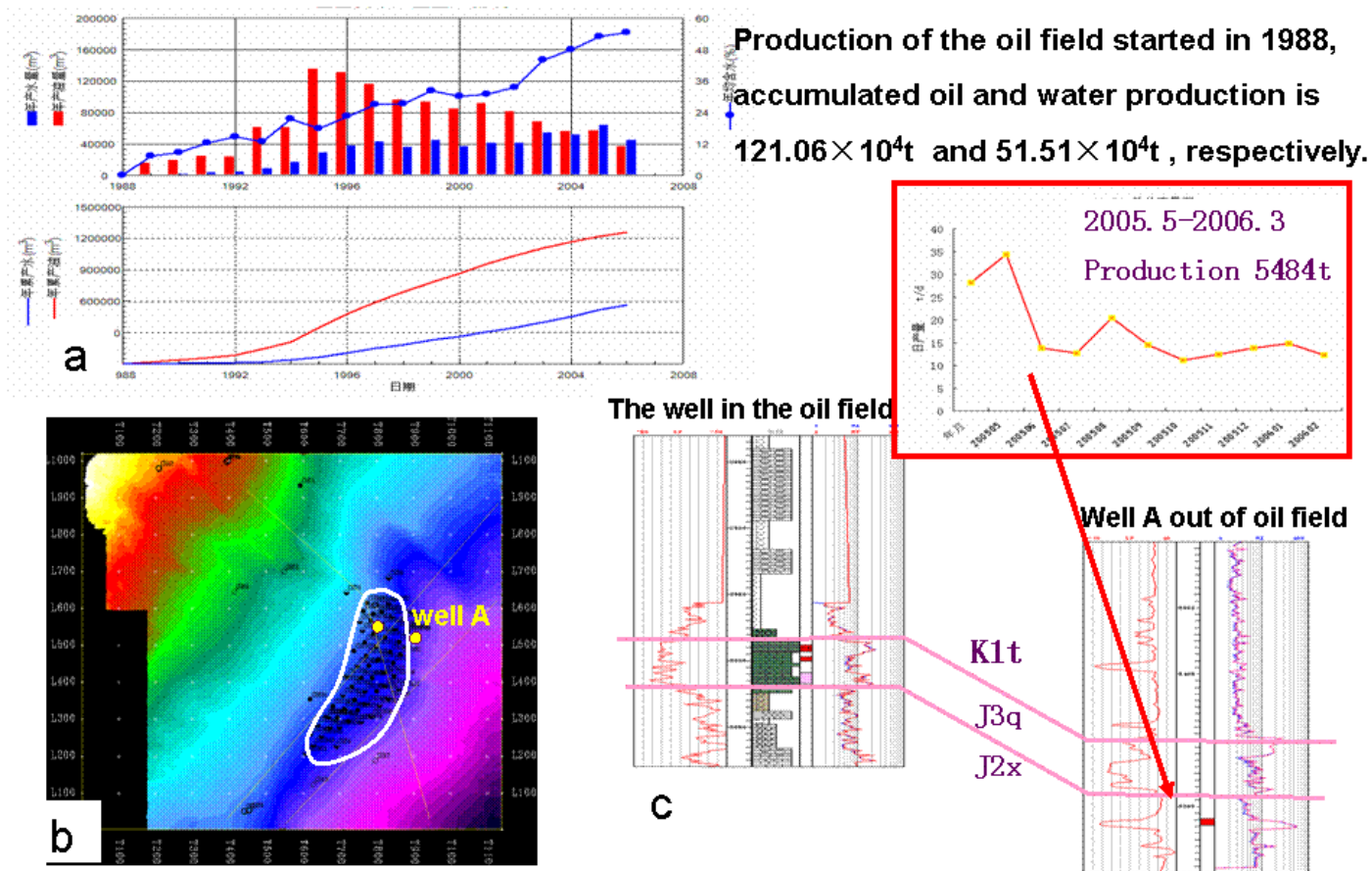
Production of the oil field started in 1988, accumulated oil and water production is 121.06×10⁴t and 51.51×10⁴t, respectively.

2005. 5−2006. 3
Production 5484t

The well in the oil field

Well A out of oil field

K1t

J3q

J2x

Figure 2. **a**: Production curve of the oilfield; **b**: location of well A; **c**: production status of well A.
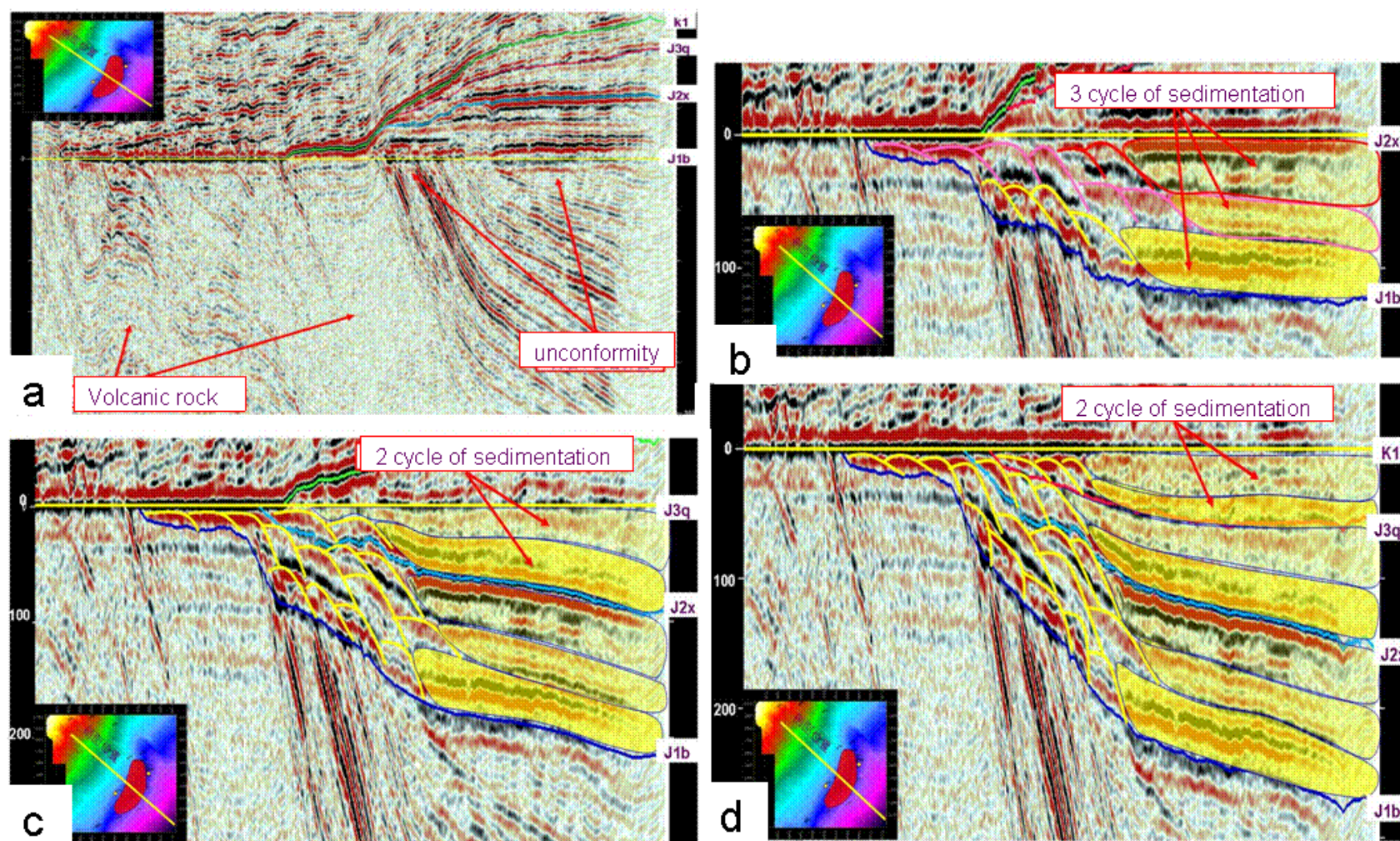
Figure 3. **a**: Seismic section L1 flattened along base of Jurassic J1b; **b**: L1 flattened on Middle Jurassic J2x; **c**: L1 flattened on Late Jurassic J3q; **d**: L1 flattened on base of Cretaceous K1tg.
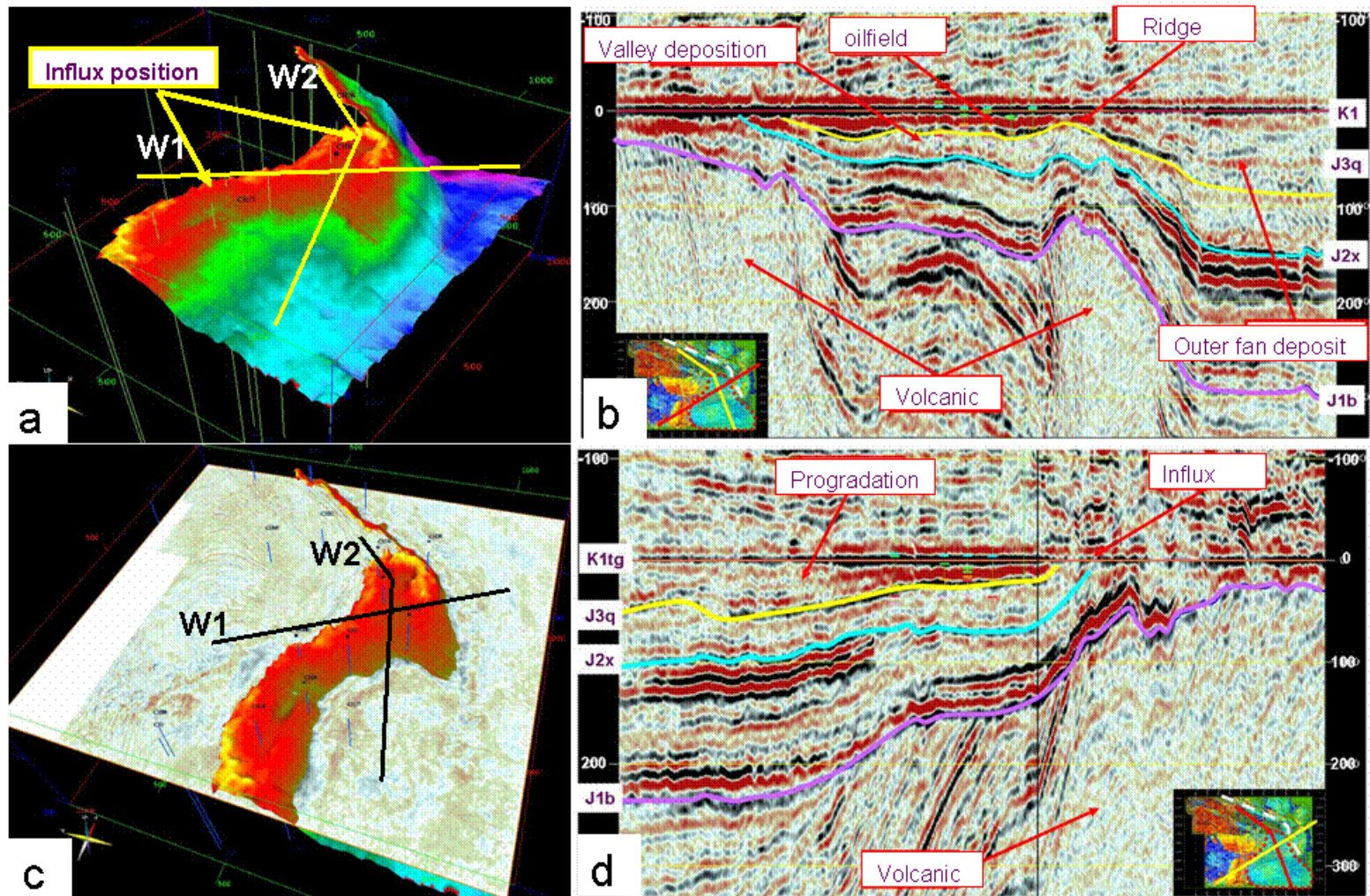
Figure 4. **a**: Paleo-geomorphology at the top of J3q sand; **b**: seismic section with w1 flattened on base of Cretaceous K1tg; **c**: paleo-geomorphology plus seismic time slice at the top of J3q; **d**: seismic section with w2 flattened on base of Cretaceous K1tg.
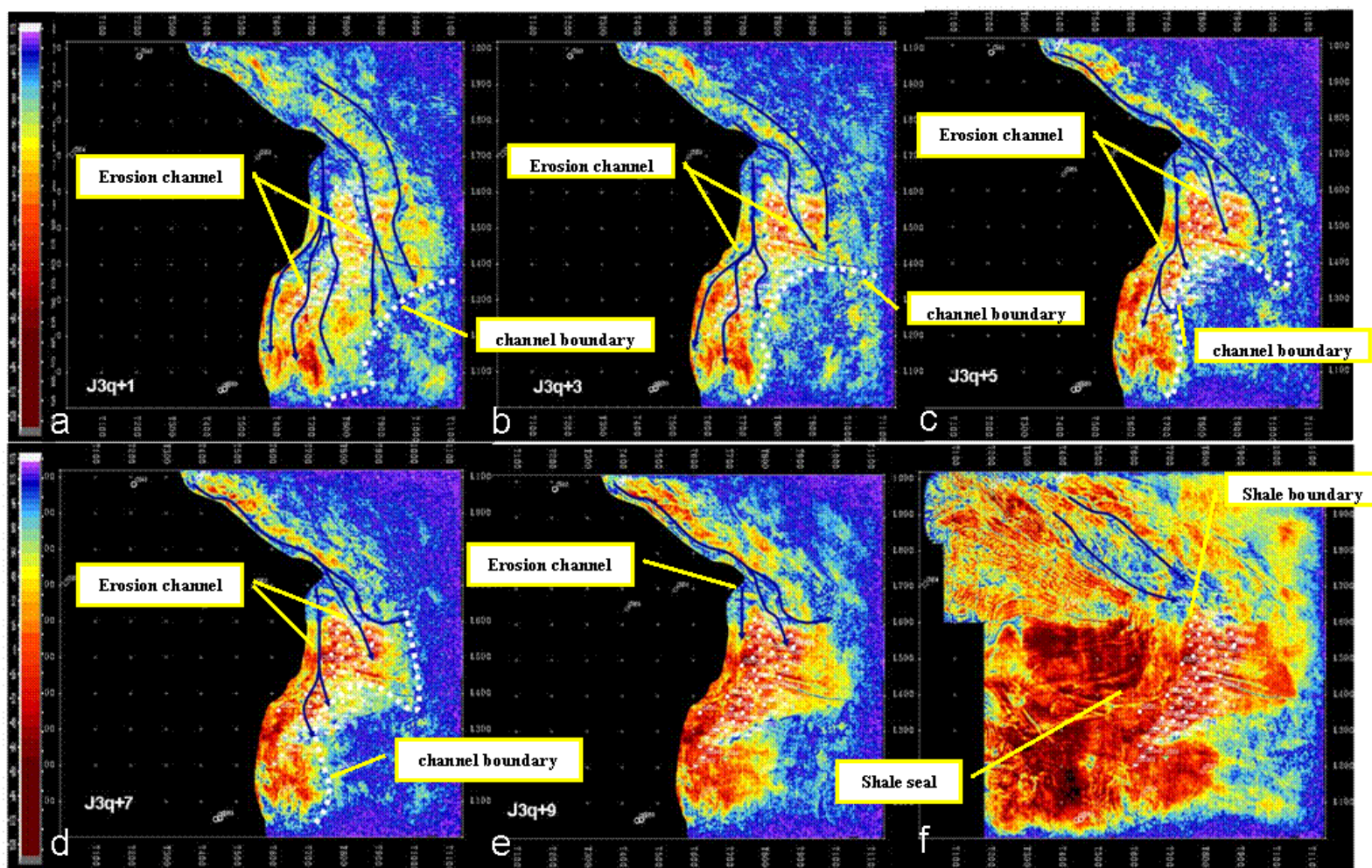
Figure 5. Seismic amplitude slices. **a**: J3q+ 1; **b**: J3q+ 3; **c**: J3q+ 5; **d**: J3q+ 7; **e**: J3q+ 9; **f**: Cretaceous K1tg.
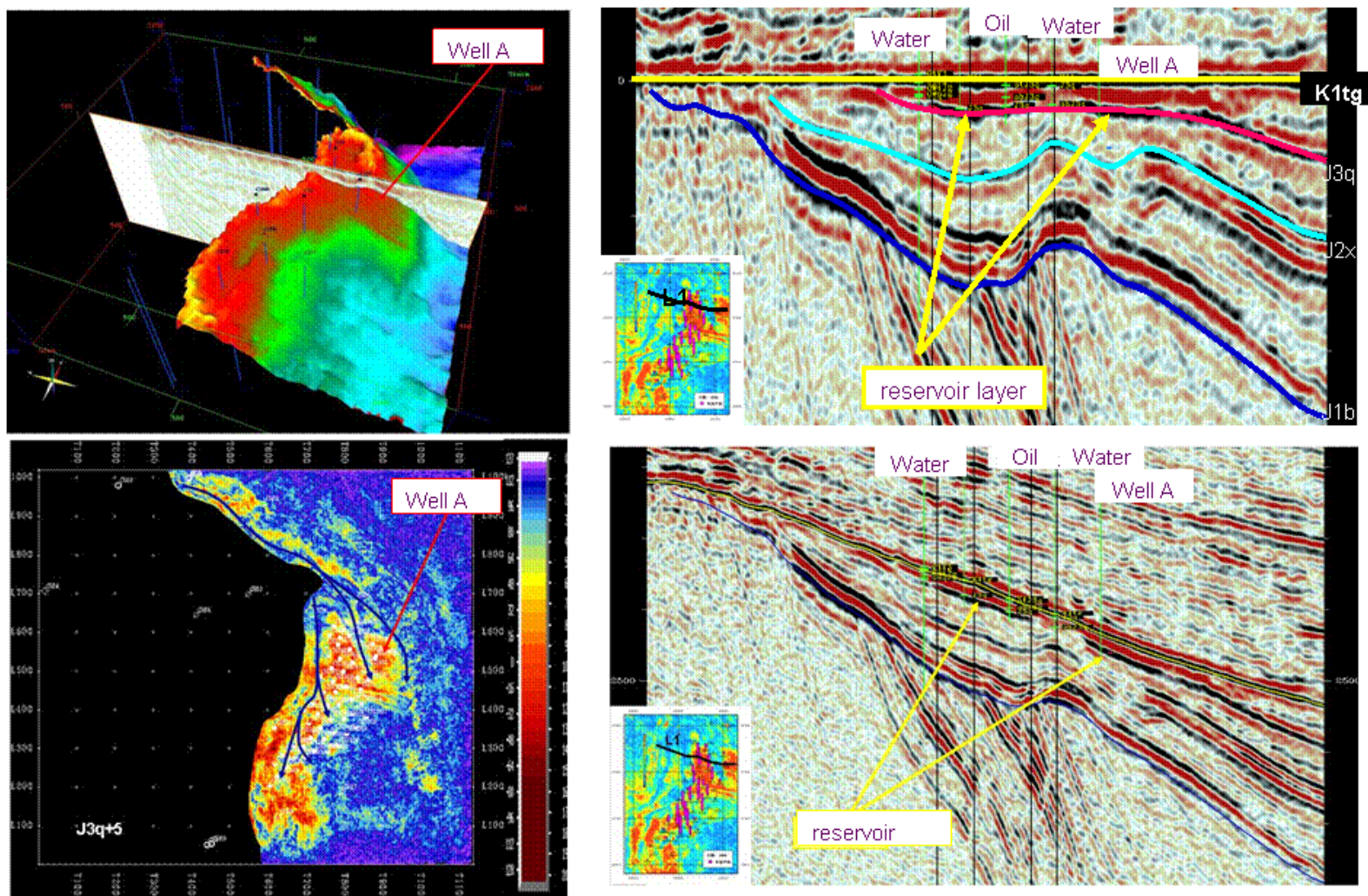
Figure 6. A (upper left). Paleo-geomorphology at the top of J3q and a well-tied seismic section through well A. B (upper right). Seismic section flattened on base of Cretaceous K1tg. C (lower left). Seismic amplitude slice of J3q. D (lower right). Well-tied seismic section.
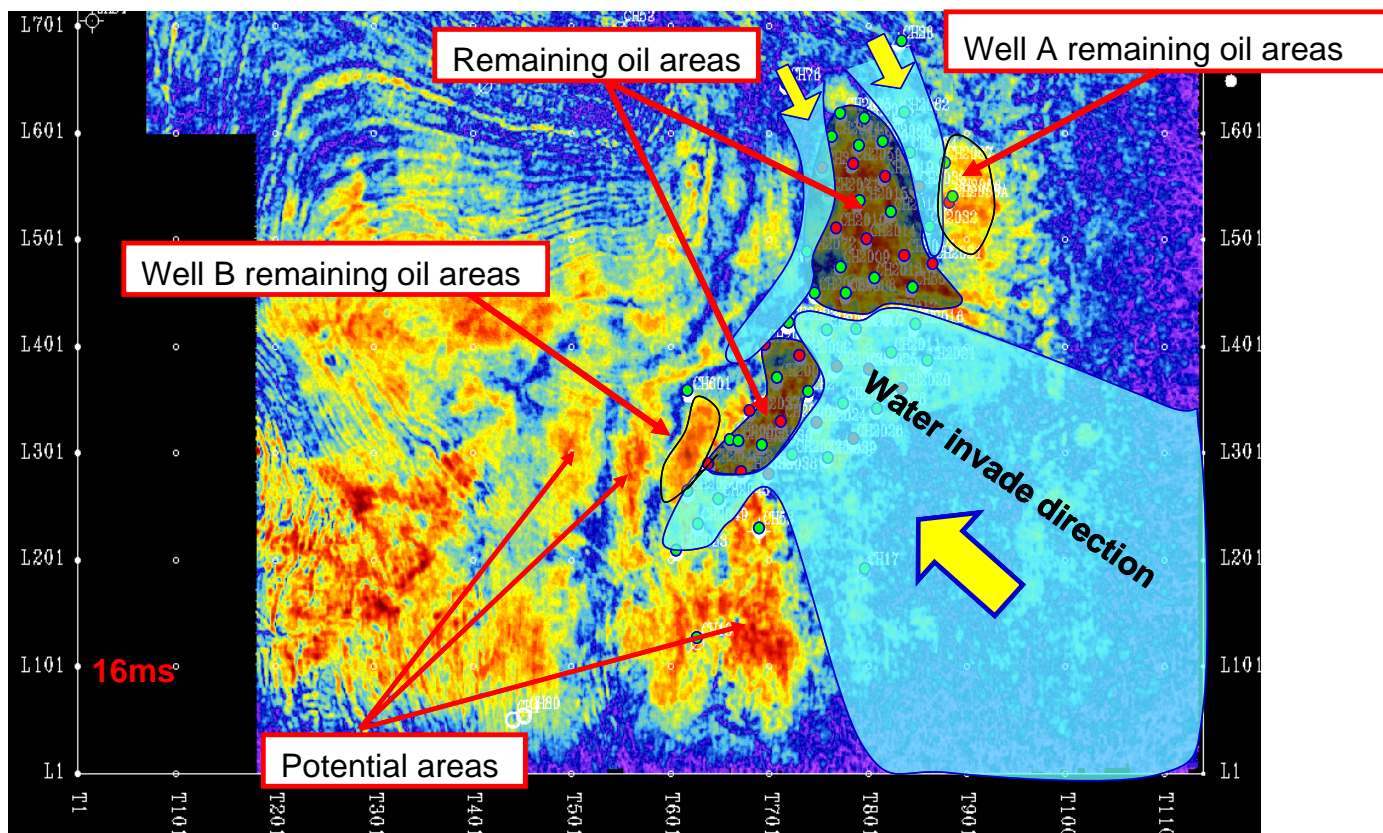
Figure 7. An integrated interpretation of remaining oil.