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Review

Water invasion evaluation of Kela 2 Gas Field

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Kela 2 Gas Field is a large blocked structural reservoir with bottom water in Kuqa Depression, Tarim Basin. Reservoir is mainly deposited as delta front underwater distributary channel in Bashijiqiuke Formation during Early Cretaceous. Reservoir thickness is over 460 m and average net-to-gross ratio is 78%. There developed faults in the reservoir which has strong anisotropy, porosity of the reservoir is 10 to 18% while permeability is 1-100×10^{-3} μm^2, and fractures developed also in some areas. During 17 years of reservoir production, some wells started to produce water. Data monitor indicates that the level difference of water invasion is about 200 m between wells, and anisotropic water invasion constrains sustainable development of the gas field. This paper used core analysis, logging interpretation and seismic data to analyze faults, fractures, relationship between relatively high permeability zones and barrier beds, and it is the main control for the strong anisotropic water invasion which bottom water ascends along faults vertically. Combined with production performance data, water invasion of gas reservoir is divided into 3 patterns: bottom water ascends along faults vertically and then invades horizontally, edge water invades horizontally, and nearly homogeneous bottom water invades from deeper layers. It is predicted and warned for the water produced from gas wells, as well as it provides the basis for preventing and governing the water invasion in Kela 2 Gas Field.

Key words: Tarim Basin, Kela 2 Gas Field, water invasion influencing factors, water invasion patterns, gas field development.

INTRODUCTION

Kela 2 Gas Field is located in the Northern Kelasu tectonic zone in Tarim Basin, which is a large blocked structural reservoir with bottom water (Jia et al., 2002a, b). Reservoir is mainly deposited in Bashijiqiuke Formation during Early Cretaceous, and it mainly contains fine sandstone with few medium sandstone, glutenite and siltstone (Jia and Li, 2008; Yu et al., 2016; Mao et al., 2016). Reservoir is mainly deposited as delta front underwater distributary channel which overlap each other. Sand body has the character of large thickness (over 460 m), wide distribution, good continuity, and discontinuous thin mudstone interlayer (mean net-to-gross is 78%) (Guo et al., 2016; Yu et al., 2008; Wang et al., 2002). There developed faults in the reservoir which

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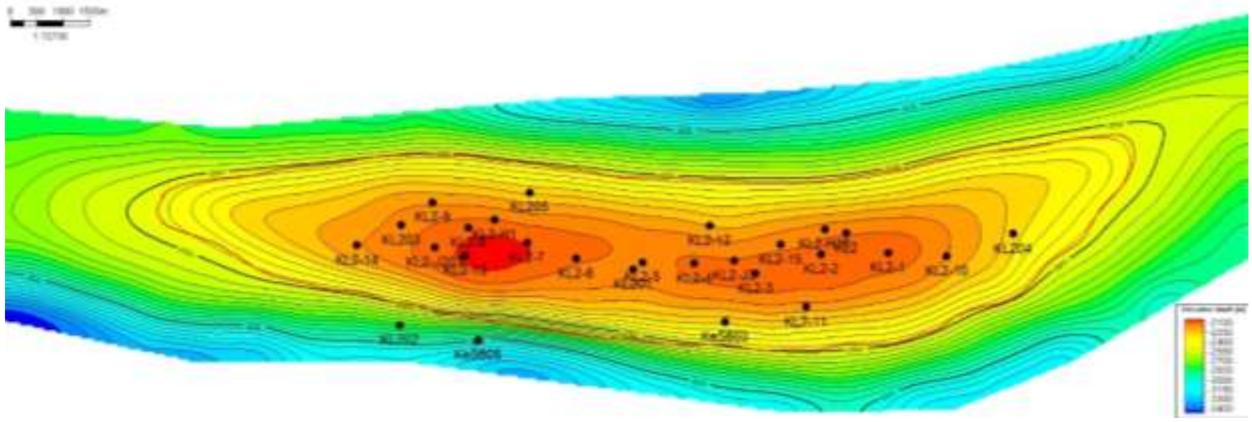

Figure 1. Structural map and well location of Kela 2 Gas Field.

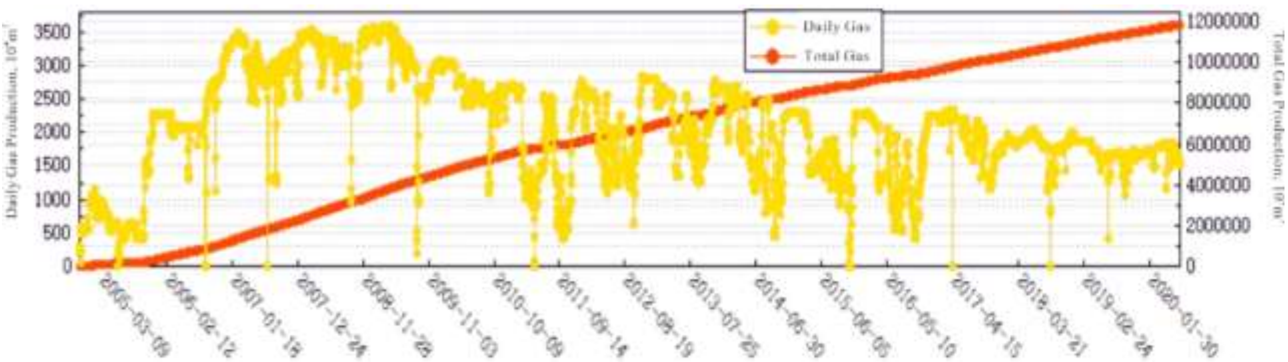

Figure 2. Gas production history of Kela 2 Gas Field.

has strong anisotropy, porosity of the reservoir is 10 to 18% while permeability is 1-100×10^{-3} μm^2, and fractures developed also in some areas (Zhu et al., 2000; Zhang et al., 2007, 2000; Xia et al., 2001). Since well KL2 discovered and several earlier explorations evaluated, it is proved the huge natural gas reserve underground and the proven reserve is 2840×10^8 m^3.

There are 22 production wells in Kela 2 Gas Field, which 16 wells are under normal production (Figure 1). Daily gas production is 1595×10^4 m^3/D (Figure 2), while the daily water production is 243 t/D (Figure 3). Total gas production is 1235 ×10^8 m^3, and the geological reserve gas recovery is 43.4%. The measured formation pressure is 37.1 MPa currently, and the formation pressure decrease 50%. After 17 years development, Kela 2 Gas Field is at the middle-late development period, some wells started to produce water (Li et al., 2009; Wang et al., 2006). Data monitor indicates that the level difference of water invasion is about 200 m between wells, and anisotropic water invasion constrains sustainable development of the gas field (Wu et al., 2019; Jiang et al., 2017; Chen et al., 2016). This paper used core analysis, logging interpretation and seismic data to analysis faults, fractures, relationship between relatively high permeability zones and barrier beds. Water invasion of gas reservoir is analyzed and it guides to reservoir development and production allocation.

WATER INVASION INFLUENCING FACTORS

Through study of anisotropy for the Kela 2 Gas Field reservoir, influence factors of gas wells are analyzed. Faults, fractures and relatively high permeability zones are the main water invasion channel, while interlayers can stop water invasion. Distance between perforation interval and bottom water, well allocation are also the main factors for the water invasion speed (Table 1).

WATER INVASION PATTERNS

With analysis of faults, fractures, relationship between relatively high permeability zones and barrier beds, water invasion of Kela 2 Gas Reservoir is divided into 3 patterns (Table 2): bottom water ascends along faults

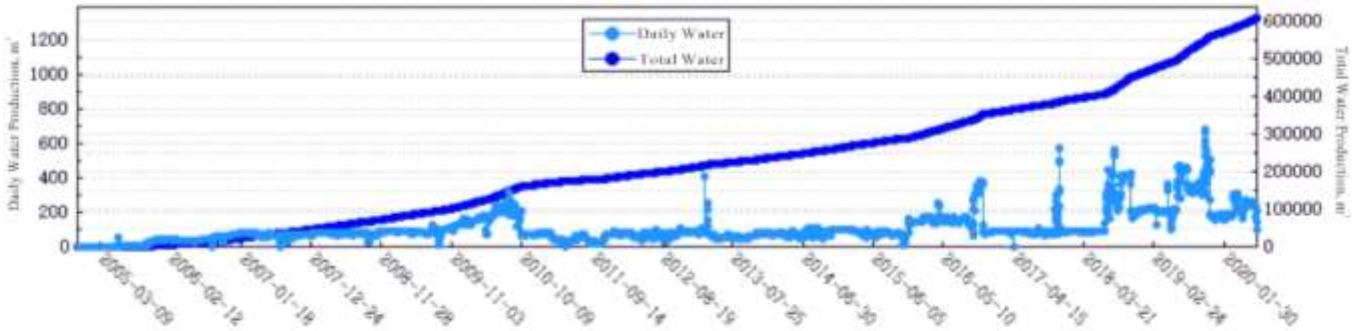

Figure 3. Water production history of Kela 2 Gas Field.

Table 1. Faults, fractures, high permeability zones analysis of perforation interval in Kela 2 Gas Field.

Interlayer function	Well	Permeability ($\times10^{-3}$ μm^2)	Interlayers above GWC (number)	Thickness of interlayers (m)	Distance between faults and perforation interval (m)	Distance between perforation interval and bottom water (m)	Distance between perforation interval and edge water (m)	Fracture density of perforation interval (number/m)	Permeability max-min ratio of perforation interval
Poor blocking	KL2-14	17.6	1	0	140	172	720	0.486	4.691
	KL203	8.6	1	0	290	88	420	0.289	3.725
	KL2-J203	11.1	1	0	300	-	-	0.3	3.7
	KL2-13	6.8	1	0	181	57	200	0.055	7.937
No Interlayer	KL204	26.3	None	-	50	57	440	0.061	7.888
	KL2-10	31.9	None	-	10	170	450	0.114	11.729
	KL2-12	36.5	None	-	100	100	290	0.4275	6.919
	KL2-11	58.9	None	-	44	139	280	0.071	11.616
	KL205	14.8	None	-	268	45	150	0.035	9.393
Delay bottom water invasion	KL2-1	44.2	1	22.6	210	207	740	0.028	5.285
	KL2-2	32.7	1	22.7	87	196	870	0.008	4.031
	KL2-3	56.7	1	24.5	28	146	700	0.02	12.466
	KL2-4	82.6	1	27.7	22	200	890	0.01	4.192
	KL2-5	39.6	1	23.4	20	191	900	0.044	3.857
	KL2-6	30.3	2	20.3	35	194	1000	0.1145	6.414
	KL2-7	25.2	2	51.4	71	229	900	0.04	5.753
	KL2-8	11.1	2	29.2	0	194	810	0.171	6.716
	KL2-9	20.6	2	37.4	82	142	350	0.009	4.289
	KL2-15	47.6	2	30	230	209	710	0.028	3.883

Table 2. Water invasion zones analysis of Kela 2 Gas Field.

Water invasion pattern	Zone	Fractures	Interlayer function	Distance from edge water	Height of water invasion (m)
Bottom water ascends along faults vertically and then invades horizontally	Southwest	Partial developed	No sealing	Far	340
Edge water invades horizontally	North	Developed	Few interlayers	Close	160
	East	Partial developed	Few interlayers	Close	280
Nearly homogeneous bottom water invades from deeper layers	Middle-South	Partial developed	Sealing	Poor edge water affects	120

vertically and then invades horizontally, edge water invades horizontally, and nearly homogeneous bottom water invades from deeper layers.

Bottom water ascends along faults vertically and then invades horizontally

Well KL2-14, KL203, KL2-J203, and KL2-13 are located in the southwest part of gas field, water body uplifts 250 m, and three production wells (KL2-14, KL203, KL2-13) show water breakthrough while KL2-J203 is monitored the gas-water contact. From logging interpretation, porosity of KL2-14 is 13.4% and permeability is 17.6×10^{-3} μm^2. From seismic interpretation, there exists shattered fault zone in this area, distance between main fault and perforation bottom is 180-300 m, fault displacement is 50-70 m and fault breaks the interlayer. Fracture grows and average fracture interval is 2-3 m. Thickness of relatively high permeability (more than 30×10^{-3} μm^2) is 15.8 m below perforation zone, and production performance data shows that gas produces along high permeability zone first. High permeability zone is not only the main flow channel for gas but also for water invasion. Gas-water contact of KL2-J203 uplifts almost the same as KL2-14 and KL203, MDT test and log interpretation data show that good reservoir property has high water invasion degree, while poor reservoir property has low water invasion degree; all these indicate that water invades horizontally in this area. Kela 2 Gas Field has good reservoir property, water body migrates and spreads easily, bottom water ascends quickly along faults, fractures, relatively high permeability zone to make bottom water uplifts sharply (Figure 4).

Edge water invades horizontally

KL2-12 is located in the north part of Kela 2 Gas Field. From logging interpretation, porosity of KL2-12 is 13.6% and permeability is 36.5×10^{-3} μm^2. From seismic data, we can see that the main interlayer is under gas-water contact, faults develop in small scale and fractures develop (fracture interval is about 2-3 m). Relatively high permeability zone develops and its thickness is about 15.8 m, distance between perforation zone and bottom water is 100 m while distance between perforation zone and edge water is 290 m. There developed fractures and high permeability zones around the well. Edge-bottom water migrate through fractures and relatively high permeability zone (Figure 5).

KL2-10 and KL204 are located in the east part of Kela 2 Gas Field. Interlayer is below gas-water contact, main faults develop through bottom to top while small faults develop also. Porosity of KL2-10 is 14.8% and permeability is 31.9×10^{-3} μm^2. Porosity of KL 204 is 13.9% and permeability is 26.3×10^{-3} μm^2. From gas production profile, high gas production intervals have the good permeability, which indicate that high permeability zones are developed around this area (Figure 6). The reservoir has good property and poor developed fractures, and bottom water ascends along faults and relatively high permeability zone vertically and then invades horizontally (Figure 7).

Nearly homogeneous bottom water invades from deeper layers

This water invasion pattern is distributed in the middle-south part of Kela 2 Gas Field. Although water invasion is not monitored in this area, gas-water contact of KL2-11, KS603 and KS604 uplifts 100-120 m compared to the origin gas-water contact. In the middle part (well KL2-2, KL2-3, KL2-4, KL2-5 and KL2-6), interlayer is above gas-water contact, faults develop in small scale, interlayer cannot break faults, thus interlayer can stop bottom water ascending along faults vertically. In the south part (KL2-11, KL603 and KL604),

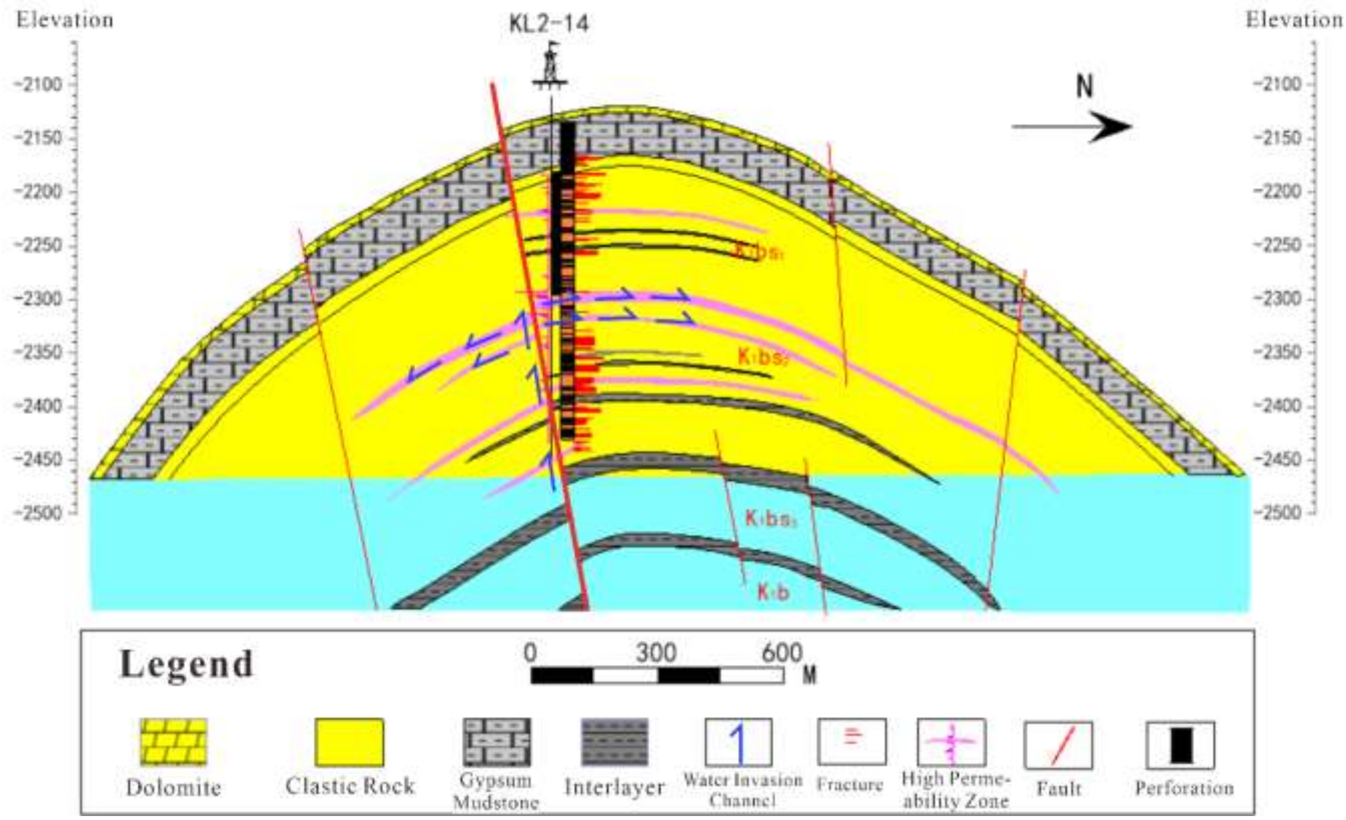

Figure 4. KL2-14 water invasion profile.

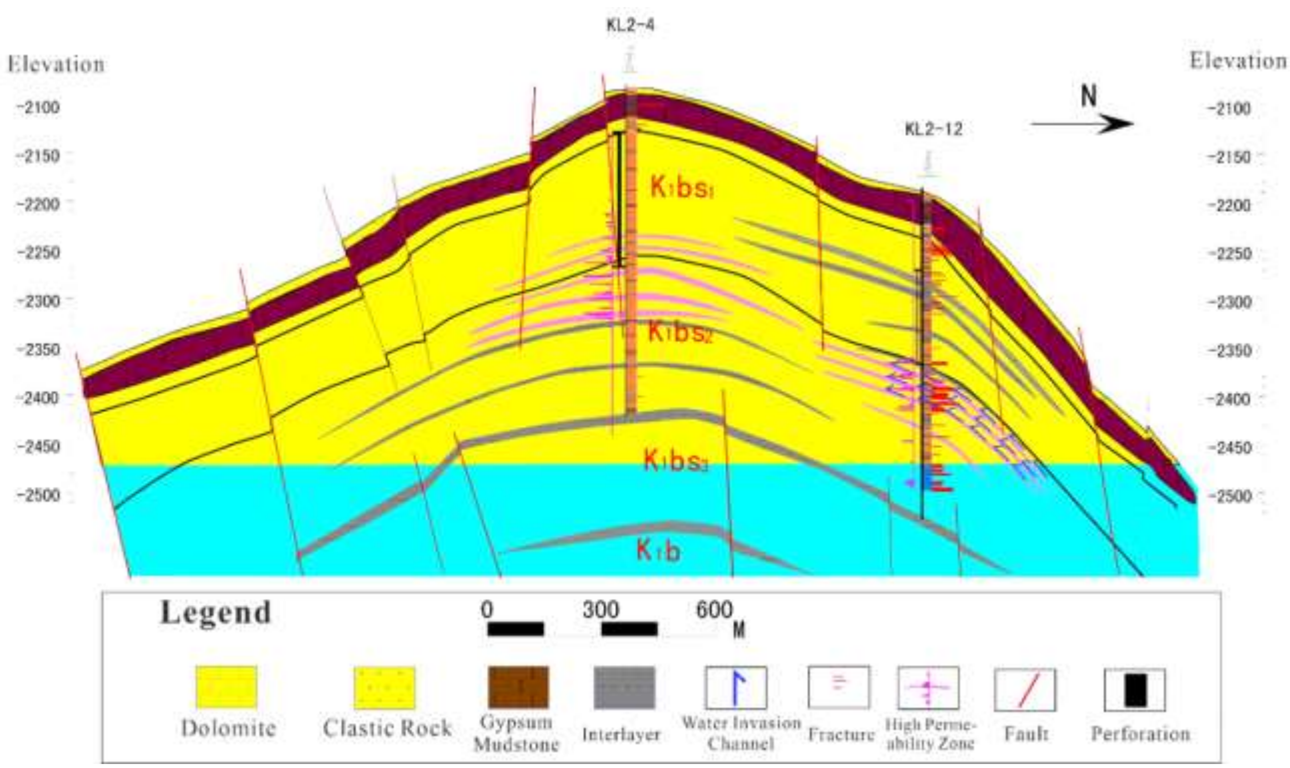

Figure 5. KL2-12 water invasion profile.

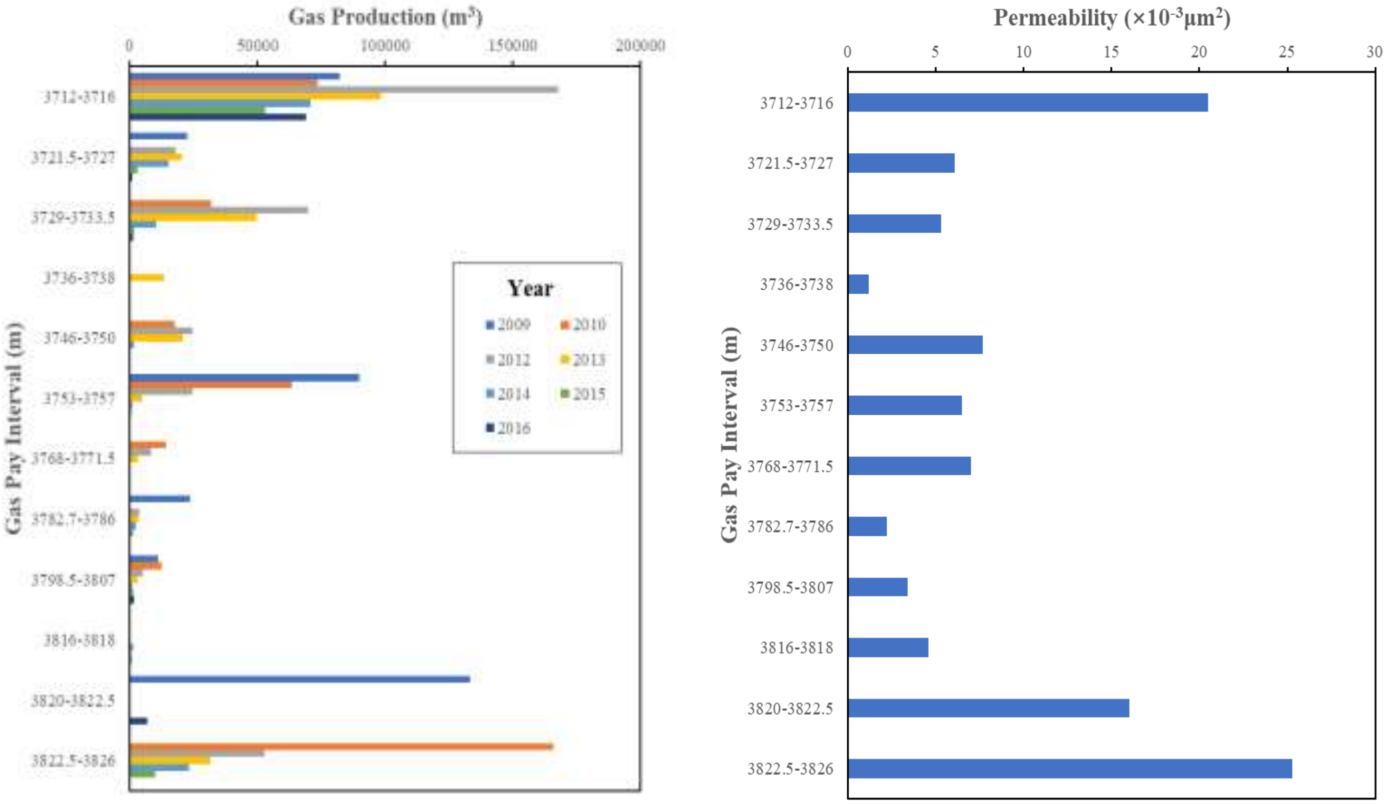

Figure 6. Comparison between gas production profile and permeability for well KL2-14.

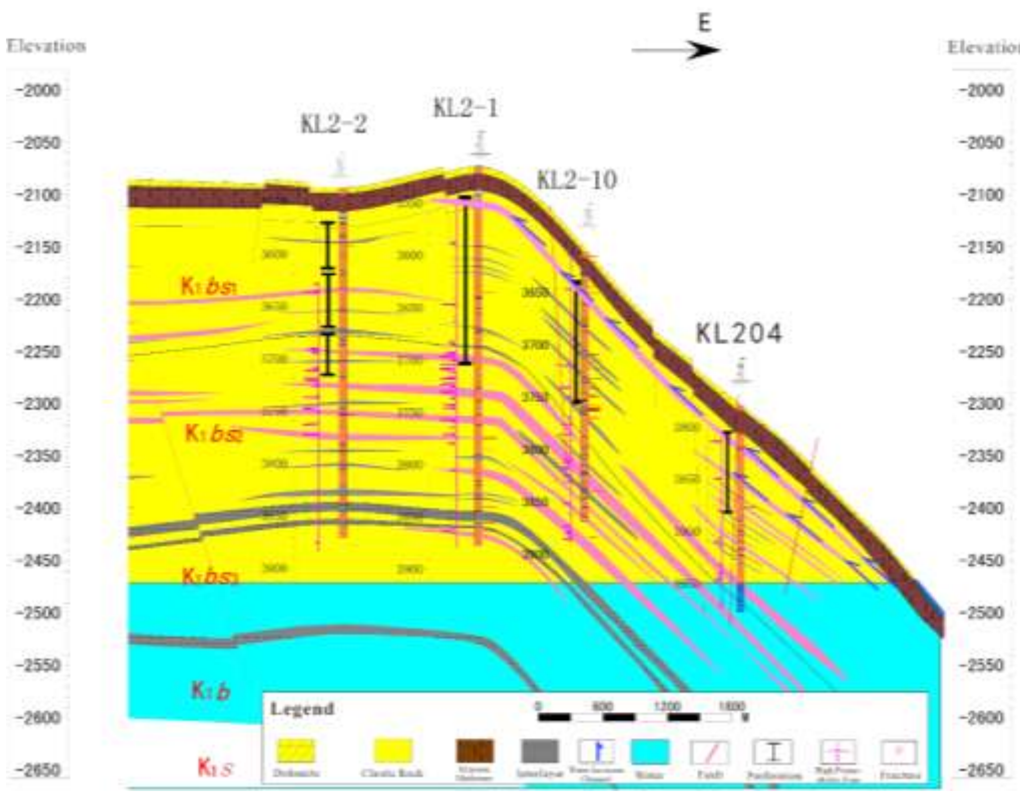

Figure 7. KL204-KL2-10 water invasion profile.

interlayer is below gas-water contact, but there develop less and small-scaled faults around gas-water contact, fractures develop less, gas-water contact uplifts in small amplitude, all these show that bottom water is not active in this area. Distance of boundary fault is over 100 m in south area; fault and gypsum mudstone can stop some edge water. Drilling data of well KS6 also indicates that this fault has the sealing ability. High density drilling fluid (2.01-2.1 g/cm^3) indicates that there is no leakage during well KS6 drilling in the south part of fault, but there exists leakage during well KS604 drilling (drilling fluid density is 1.9-1.92 g/cm^3) in the north part of fault. It indicates that formation pressure declines slightly and this fault has the ability to stop water invasion.

CONCLUSION

Kela 2 Gas Field has already been in the middle-late development period, serious inhomogeneous water invasion results in a difficult situation to keep gas field stable production. By evaluation of water invasion, it could provide a basis for efficient and scientific development for Kela 2 Gas Field.

Geological factors affecting the water invasion are mainly interlayers, faults, fractures, and high-permeability zones. Mutual configuration of multiple factors affects the water invasion of the Kela 2 Gas Field.

Water invasion of Kela 2 Gas Field is divided into 3 patterns: bottom water ascends along faults vertically and then invades horizontally, edge water invades horizontally, and nearly homogeneous bottom water invades from deeper layers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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