

Research on the Characteristics of the Post-Salt Strata on the Eastern Margin of the Precaspian Basin

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Abstract

The Pre-Caspian Basin is renowned for its extensive oil and gas distribution, particularly the thick salt domes developed in the upper part of the Permian system. The sub-salt area is characterized by the deposition of carbonate and clastic rock formations, which contain abundant oil and gas reserves. Numerous scholars and technical personnel have conducted detailed research on the exploration and development of sub-salt reservoirs, while relatively less attention has been paid to the post-salt formations. This paper utilizes 3D seismic data and single-well data from oil fields, and by analyzing changes in parameters such as natural gamma and interval transit time of logging curves, combined with reflection characteristics on seismic sections, delineates stratigraphic boundaries. It focuses on the characteristics of post-salt formations in the eastern margin area of the Pre-Caspian Basin, including four secondary formations: Cretaceous, Jurassic, Triassic, and Upper Permian, and analyzes the evolutionary process of post-salt formation characteristics. This provides strong support for further geological research on post-salt oil fields in the eastern margin area of the Pre-Caspian Basin.

Keywords

Eastern Margin of the Precaspian Basin, Post-Salt, Stratigraphic Characteristics

1. Regional Overview

1.1. Regional Location

The Precaspian Basin is primarily located in the western part of the Republic of Kazakhstan, north of the Caspian Sea. The basin is approximately elliptical in shape, extending east to west, with a length of 1000 km, a maximum width of 650

m, and an area of about 400,000 square kilometers. It is one of the deepest basins in the world and also the richest in oil and gas resources in Central Asia. The study area is located on the Ural-Enba salt dome tectonic belt on the eastern edge of the Precaspian Basin, and structurally belongs to the junction zone of the Precaspian Basin and the Mugurjar fold system. The post-salt structure is relatively simple, mainly controlled by the two major salt dome structures. Large drape structures have formed around these two salt dome structures, providing a favorable structural background for the formation of post-salt reservoirs.

1.2. Natural Features

The study area is characterized by a gently sloping hilly plain with watersheds; the river valleys are asymmetric box-shaped with broad bottoms and steep edges, and the small tributaries and canyon valleys are V-shaped; the maximum height of the watershed above the river water surface line is 100 m. The study area features sand dune-like terrain covered with brown dense sandy loam soil, with a very small amount covered by brownish-black loose subclay soil. There are salt marsh areas and no forest zones. The surface part exhibits a desert landscape, characterized by a thin, barren humus soil vegetation layer, and is covered with sparse herbaceous plants that are desertified or semi-desertified. Therefore, the land in this area is unsuitable for agricultural cultivation and belongs to barren pasture. The area has an extreme continental climate, with cold winters and hot, dry summers. The annual average temperature is +6°C, with the lowest temperature in winter being -33.9°C and the highest temperature in summer being +36.7°C. The duration of snow cover is 130 - 150 days. The annual average precipitation fluctuates between 180 - 220 mm.

2. Regional Stratigraphic Framework

The eastern margin area of the Precaspian Basin generally develops three main stratigraphic depositional sequences: pre-salt sequence strata, salt-bearing strata, and post-salt strata (**Figure 1**). The division of these stratigraphic depositional sequences is mainly based on the lithology, depositional environment, and tectonic setting of the strata.

Pre-salt strata: Located above the basement of the basin, they primarily consist of Lower Paleozoic-Lower Permian strata. The pre-salt strata were deposited early and have a considerable burial thickness, reaching 3 - 4 km at the edge of the basin and 10 - 13 km in the basin center. They mainly include thick deposits of clastic rocks and carbonate rocks, with Carboniferous reef bodies developed on the paleouplifts at the edge of the basin. It is evident that this sequence contains abundant carbonate reefs and clastic fan deposits, reflecting the complex depositional environment at that time (Jing et al., 2021). Furthermore, the entire Lower Permian sequence contains the Rifian Group, further demonstrating the antiquity and complexity of this sequence.

Salt-bearing strata: Primarily developed in the Konggu Formation, consisting

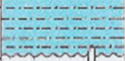
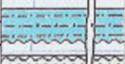
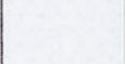
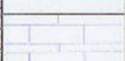
Erathem	System	Series	Stage	stratum	thickness	lithological description	reservoir		
Cenozoic	Tertiary	Upper	Neogene		790	clastic rock			
			Miocene						
		Lower	Paleogene		340	upper is limestone, lower part is mudstone			
Mesozoic	Cretaceous				168	Limestone and siltstone			
		Lower	Albian-Valladolid		300	interbedded sandstone and mudstone			
	Jurassic	Upper			500	mudstone, siltstone, sandstone			
		Middle							
		Lower							
	Triassic	Upper			160	mudstone, argillaceous siltstone and limestone			
		Middle	340						
		Lower	640						
Paleozoic	Permian	Upper	Tatar		1000	mudstone, locally intercalated with sandstone			
			Kazan						
		Lower	Kungurian			salt layer			
			Alcuin		80			clastic rock	
			Sakmarian		150				
			Acheulean		60				
	Carboniferous	Upper	Grzegorz			limestone and dolomite interbedded with anhydrite			
			Kasimovian						
		Middle	Moscow	370					
			Bashkirian	75					
		Lower	Serpukhovian	600	Primarily composed of limestone, interspersed with mudstone				
			visean						
			Tournaisian	200					
	Devonian	Upper	Famennian		300				
			Franian		300				
		Middle	Dienerian	90					
			Efarian	80					
	Silurian				400	sandstone, mudstone			
						sandstone, limestone, claystone			

Figure 1. Sequence stratigraphy column diagram of the eastern margin of the Precaspian Basin.

of salt rock and anhydrite, with a significant variation in thickness, generally ranging from 1 to 6 km. These salt layers are particularly prominent in the central part of the basin, hosting over 1500 salt dome structures of varying sizes. This plays a crucial role in the structural evolution of the basin and the accumulation of oil and gas. The presence of the salt layers leads to a complex distribution of structures in the overlying sequences, forming numerous anticlinal structural traps (Yu et al., 2011).

Post-salt strata: Overlying the salt layer, primarily composed of strata from the Late Permian to the Late Tertiary. Among them, the Triassic, Jurassic, and Cretaceous systems constitute the main depositional sequences in the post-salt strata, predominantly consisting of clastic rock deposits, with carbonate rock deposits in certain areas, and a depositional thickness ranging from 5 to 9 km (Liang et al., 2013). These strata document the history of late-stage sedimentation and tectonic evolution of the basin.

The Mesozoic strata above the salt are a complete first-order sequence. Among them, the Triassic, Jurassic, and Cretaceous systems constitute three second-order

sequences. Current data within the study area reveal that the Mesozoic strata are primarily composed of clastic rock deposits with alternating sandstone and mudstone layers. The Jurassic strata above the salt in the western region generally feature coal seams of varying thickness. In terms of stratigraphic contact relationships, the Triassic strata, influenced by uplift and erosion during the Indosinian movement, form a residual sequence, which contacts the overlying Jurassic strata at an angular unconformity, especially near the salt dome development area, where the unconformity characteristics are more pronounced (Yang, 2014). The Jurassic and Cretaceous systems, on the whole, constitute a continuous sedimentary sequence, with conformable contact between them. Regarding the current stratigraphic thickness, except for the thinner strata at the top of the salt dome anticline, the strata between the salt domes exhibit minimal variation in thickness, with the Jurassic and Cretaceous strata having a thickness of approximately 400 - 500 m.

In the eastern margin area of the Precaspian Basin, the Mesozoic strata of the Triassic, Jurassic, and Cretaceous systems exhibit rich sedimentary characteristics due to different tectonic backgrounds and depositional environments. The Triassic strata display diverse sedimentary features, transitioning from early platform-shelf facies carbonate rocks to late deep-sea basin facies and clastic rock facies. The Jurassic strata exhibit significant sedimentary characteristics, developing into a shallow-water delta depositional system dominated by fine-grained sediments under the influence of a warm and humid paleoclimate on a gentle paleotopography. The Cretaceous strata may have deposited a thick layer of clastic rock strata.

3. Secondary Sequence Division

The post-salt strata on the eastern margin of the Precaspian Basin encompass four secondary strata: the Upper Permian of the Paleozoic, and the Triassic, Jurassic, and Cretaceous of the Mesozoic. Within the study area, the litho-electric combination characteristics of the secondary sequence stratigraphic boundaries are relatively clear.

3.1. Secondary Sequence Stratigraphic Framework

As the secondary sequence of the upper part of the Mesozoic in the eastern margin of the basin, the Cretaceous system is limited by drilling and seismic data. The upper Cretaceous strata lack necessary research data, while the lower Cretaceous strata have relatively complete data. The bottom of the lower Cretaceous strata consists of a relatively stable mudstone section, with increased natural gamma curves and sonic time difference curves. It contacts the top strata of the underlying Jurassic system abruptly, with a clear boundary. The Jurassic system is characterized by shallow-water deltas, with obvious interbedding of sandstone and mudstone. The well logging curves show obvious dentate fluctuations. Due to the relatively developed sand bodies in the subaqueous distributary channels, the lithological combination and well logging curves are significantly different from the

underlying Triassic strata. The vertical differences in well logging curves within the Triassic strata are relatively small, generally with low natural gamma and sonic time difference curves that are straight or with small dentate fluctuations, distinguishing them clearly from the overlying Jurassic strata (**Figure 2**).

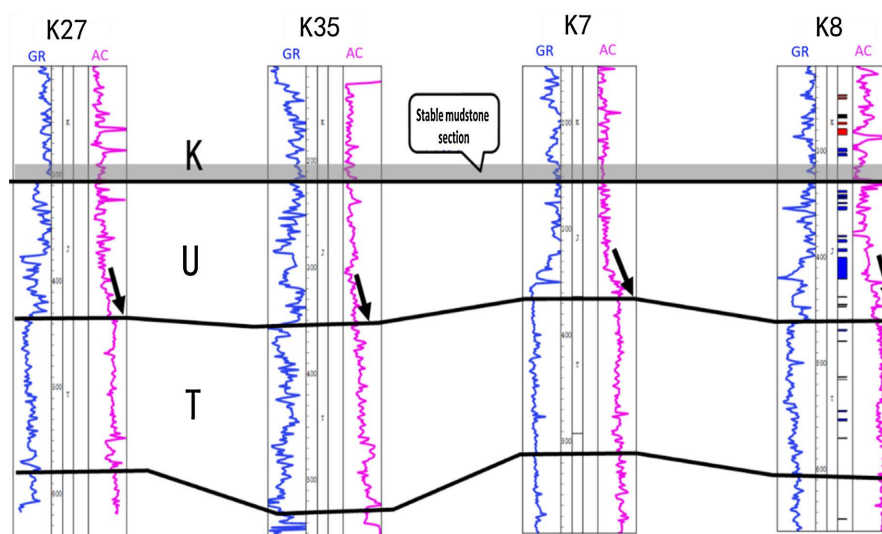


Figure 2. Logging curve markers of the Mesozoic strata in various oil fields on the eastern edge of the Precaspian Basin.

From the perspective of litho-electric combination characteristics, three sets of litho-electric combination markers are developed vertically in the Jurassic and Lower Cretaceous strata.

Based on the fine calibration of single well horizons, it can be known that the bottom mud neck section of the Cretaceous system is calibrated as a strong wave trough with good continuity. The wave peak below this trough serves as the reflection axis of the sequence stratigraphic framework interface between the Cretaceous and Jurassic systems. Between the bottom of the Jurassic system and the top of the Triassic system, multiple curves exhibit distinct steps, allowing for unified stratigraphic correlation among various oilfield blocks. These steps correspond to a set of strong wave trough reflections on the seismic section, with strong energy and good continuity. They represent the unconformity surface in the top Triassic area and can be tracked regionally (**Figure 3**).

3.2. Analysis of Sequence Evolution Mechanism

In this study, data from 44 wells in the area, combined with calibrated seismic profiles, were utilized to establish seven stratigraphic framework profiles (**Figure 4**), including three horizontal and four vertical profiles, to illustrate the characteristics of the secondary sequence stratigraphic framework in the area.

3.2.1. H1: Northern East-West Profile

The H1 profile is a near-east-west stratigraphic framework profile in the northern part of the region. The unconformity at the top of the Triassic system is not clear,

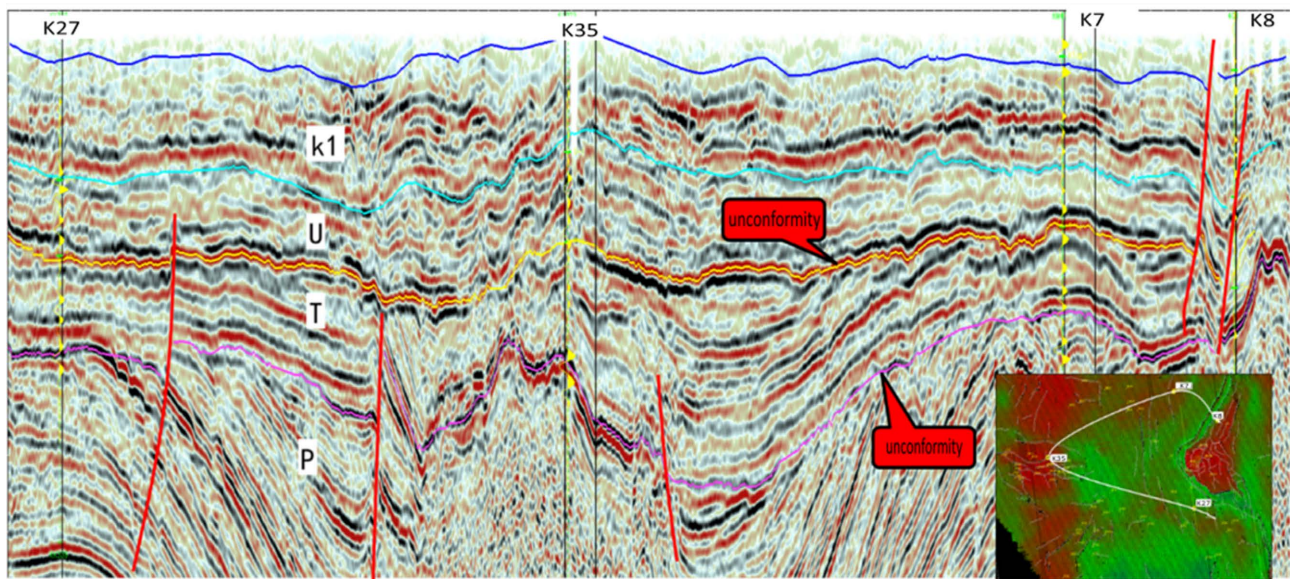


Figure 3. Characteristics of the Mesozoic unconformity section on the eastern margin of the Precaspian Basin.

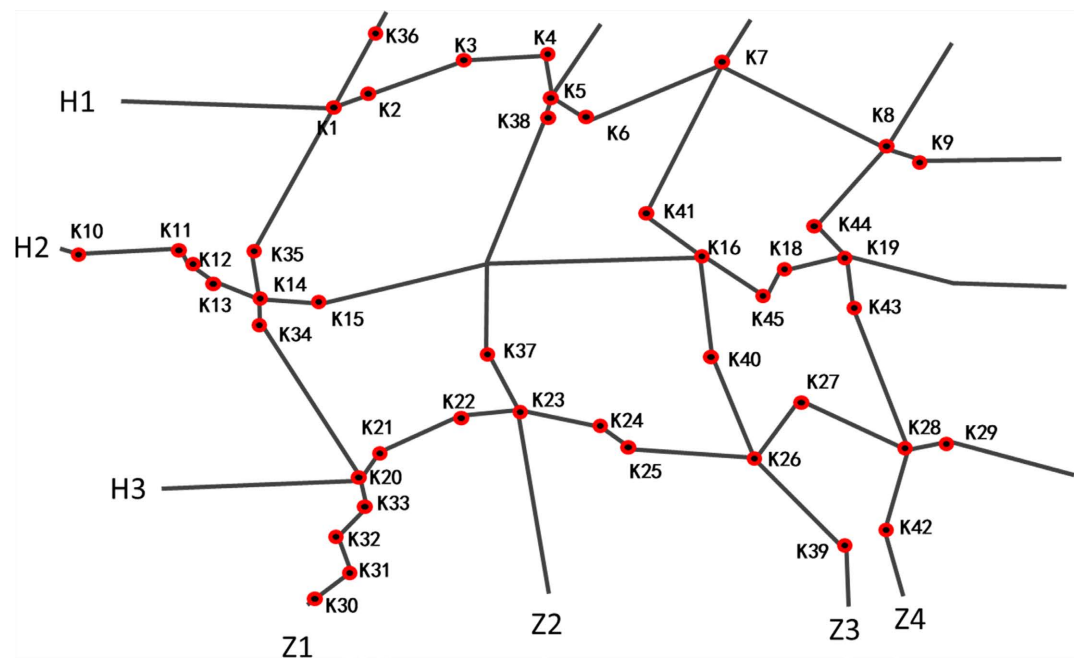


Figure 4. Base map of secondary sequence stratigraphic framework profile.

reflecting the uplift and leveling effect of the Indosinian movement on this area, which laid the paleotopographic foundation for the stable stratigraphic framework of the Yanshan cycle (Yang et al., 2011). The Jurassic-Lower Cretaceous stratigraphic framework on the profile is stable, reflecting the characteristics of stable subsidence and continuous deposition (**Figure 5**).

3.2.2. H2: Central East-West Profile

The H2 section is a near-east-west stratigraphic framework section in the central part of the area, with relatively developed salt structures, especially significant

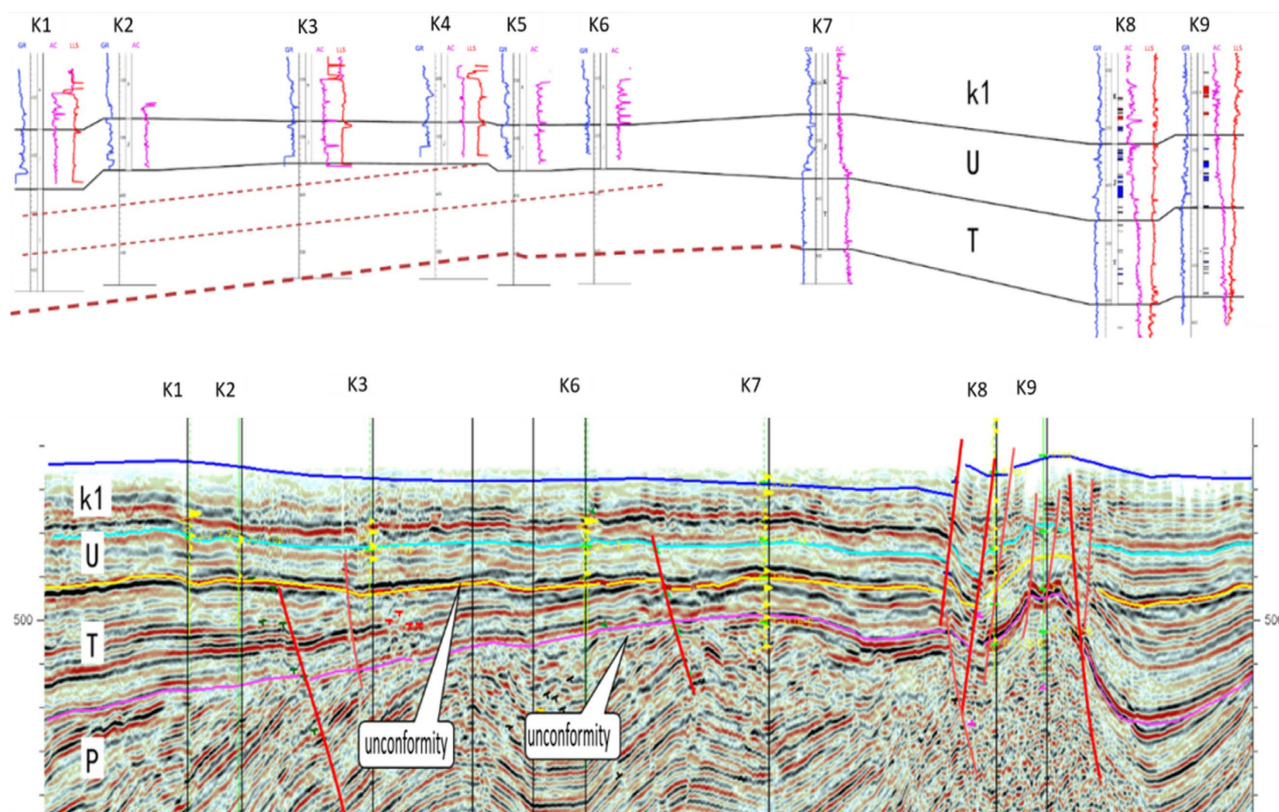


Figure 5. H1: Regional near-east-west secondary sequence stratigraphic framework.

impacts from the thickness and distribution of the Triassic strata. It reflects the control of salt tectonic activity on the overlying sedimentary layers from the Late Permian to the Triassic era in terms of paleogeomorphology. On this section, the Jurassic and Lower Cretaceous strata have a stable framework, with a slight thinning trend towards the east. The Triassic strata exhibit significant differences in lateral residual thickness due to the erosion effects of salt uplifts. At the same time, the salt dome uplift has a notable impact on the depositional paleoenvironment of the Jurassic and Lower Cretaceous strata (**Figure 6**).

3.2.3. H3: Southern East-West Profile

The H3 section is a near-east-west stratigraphic framework section in the southern part of the region, where the Jurassic and Lower Cretaceous strata are continuously deposited with a stable stratigraphic framework. The strata slightly thin towards the east, with local variations in thickness, reflecting differences in ancient topography (**Figure 7**).

3.2.4. Z1: Western North-South Profile

The Z1 section represents a near-south-to-north stratigraphic framework in the western part of the region. The Jurassic-Lower Cretaceous strata are stable and continuously deposited. The salt dome has a significant impact on the thickness of the Triassic strata, and the top surface of the Triassic is angularly unconformable to the bottom boundary of the Jurassic (Wang et al., 2004) (**Figure 8**).

3.2.5. Z2: Central North-South Profile

Z2 represents a near-south-to-north regional stratigraphic framework profile, where the Jurassic-Lower Cretaceous stratigraphic framework is stable, but there are lateral variations in local thickness, reflecting the uneven ancient topography locally along the south-to-north direction (**Figure 9**).

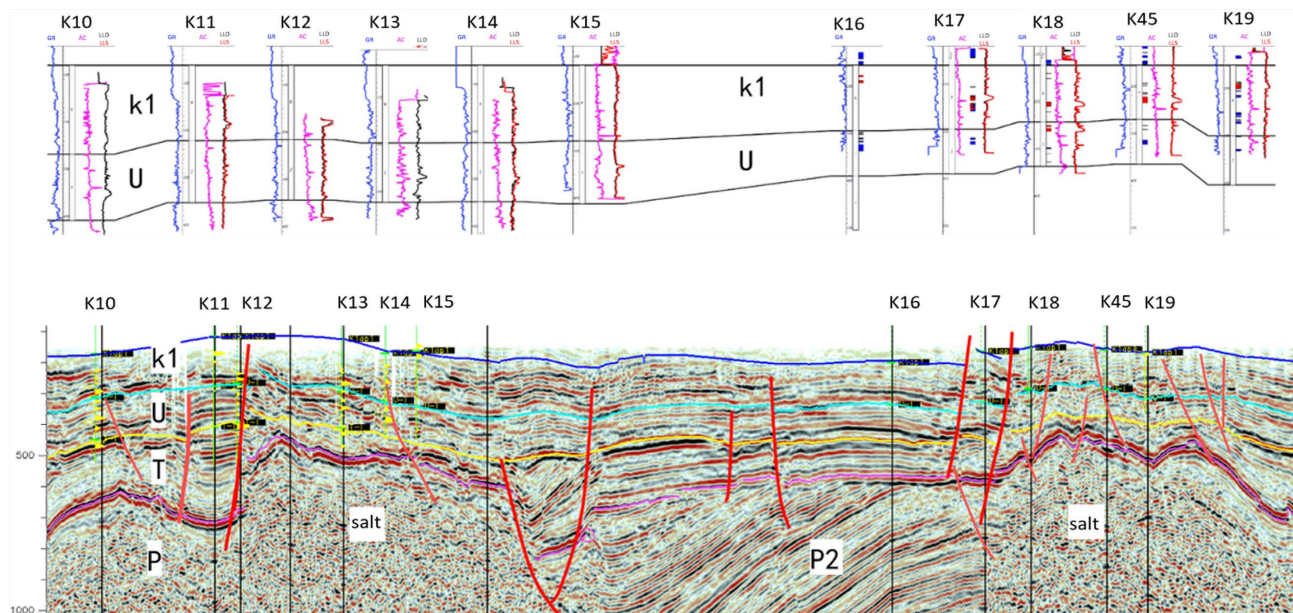


Figure 6. H2: Near-east-west secondary sequence stratigraphic framework in the central part of the region.

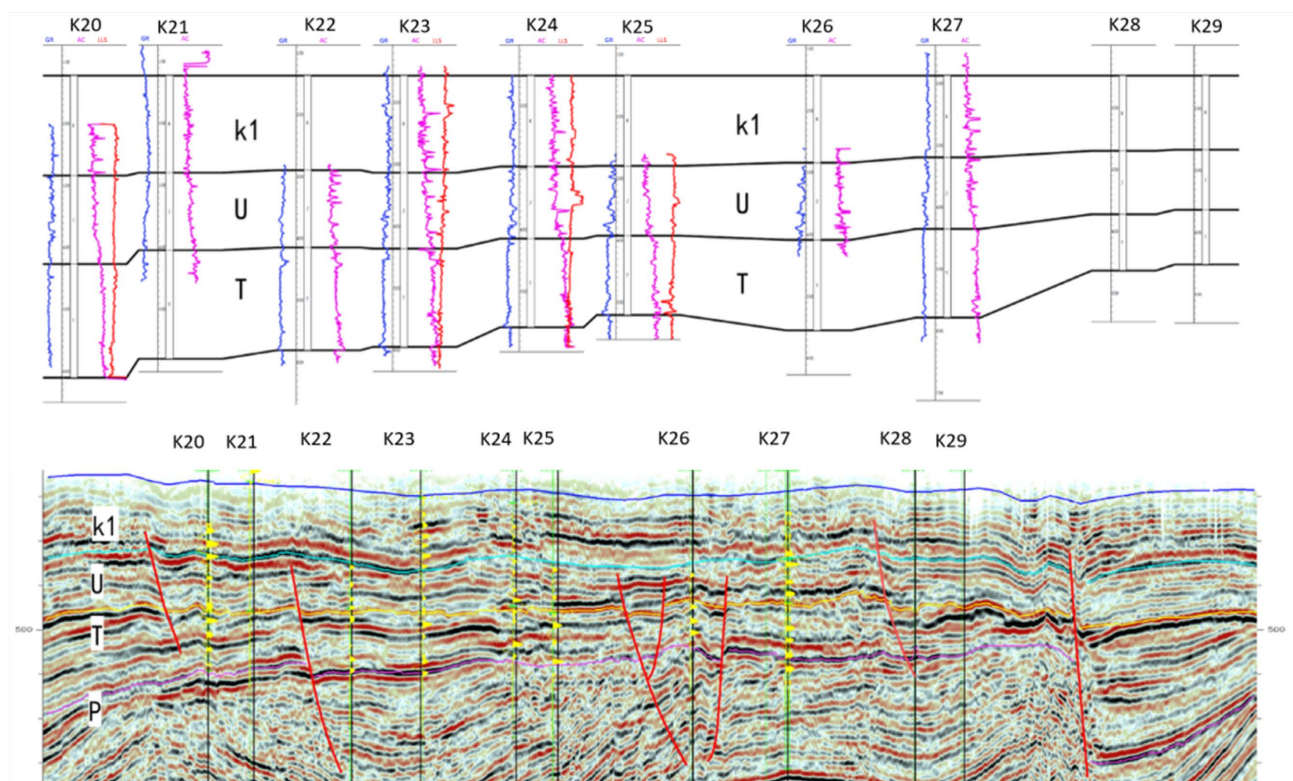


Figure 7. H3: Near-east-west secondary sequence stratigraphic framework in the southern region.

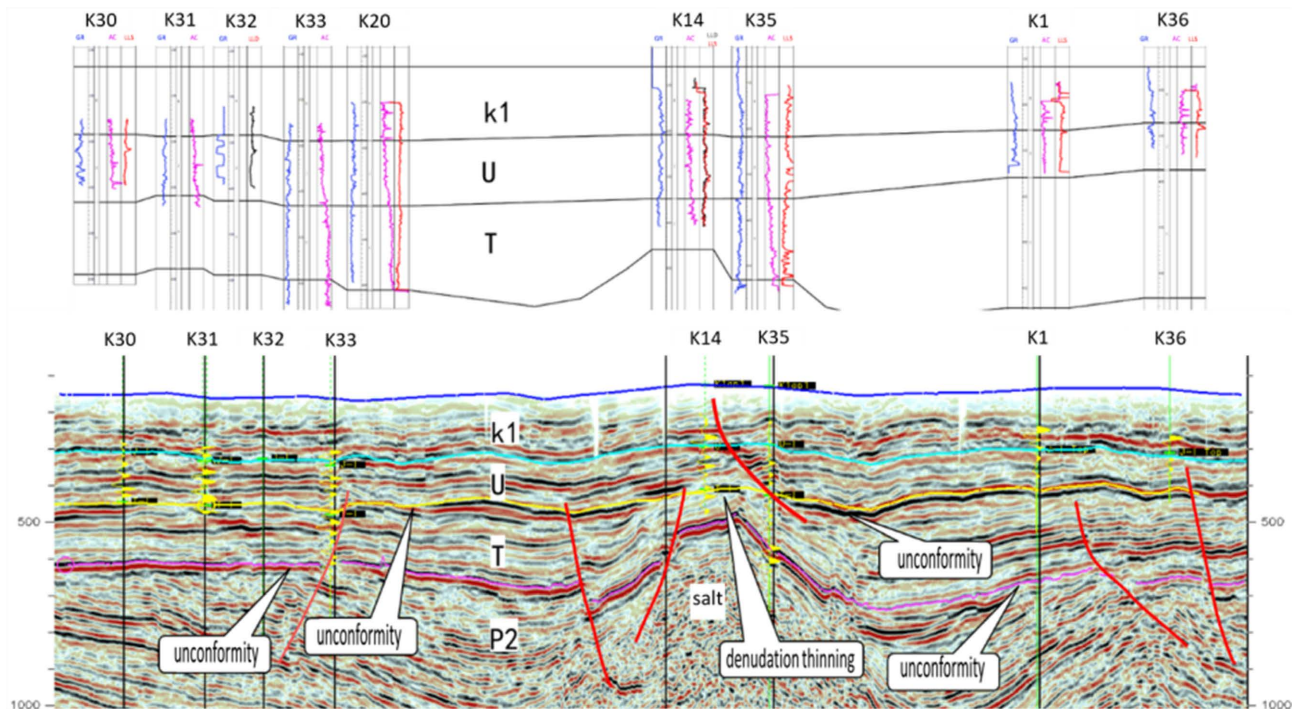


Figure 8. Z1: Secondary sequence stratigraphic framework in the western region, oriented approximately in a north-south direction.

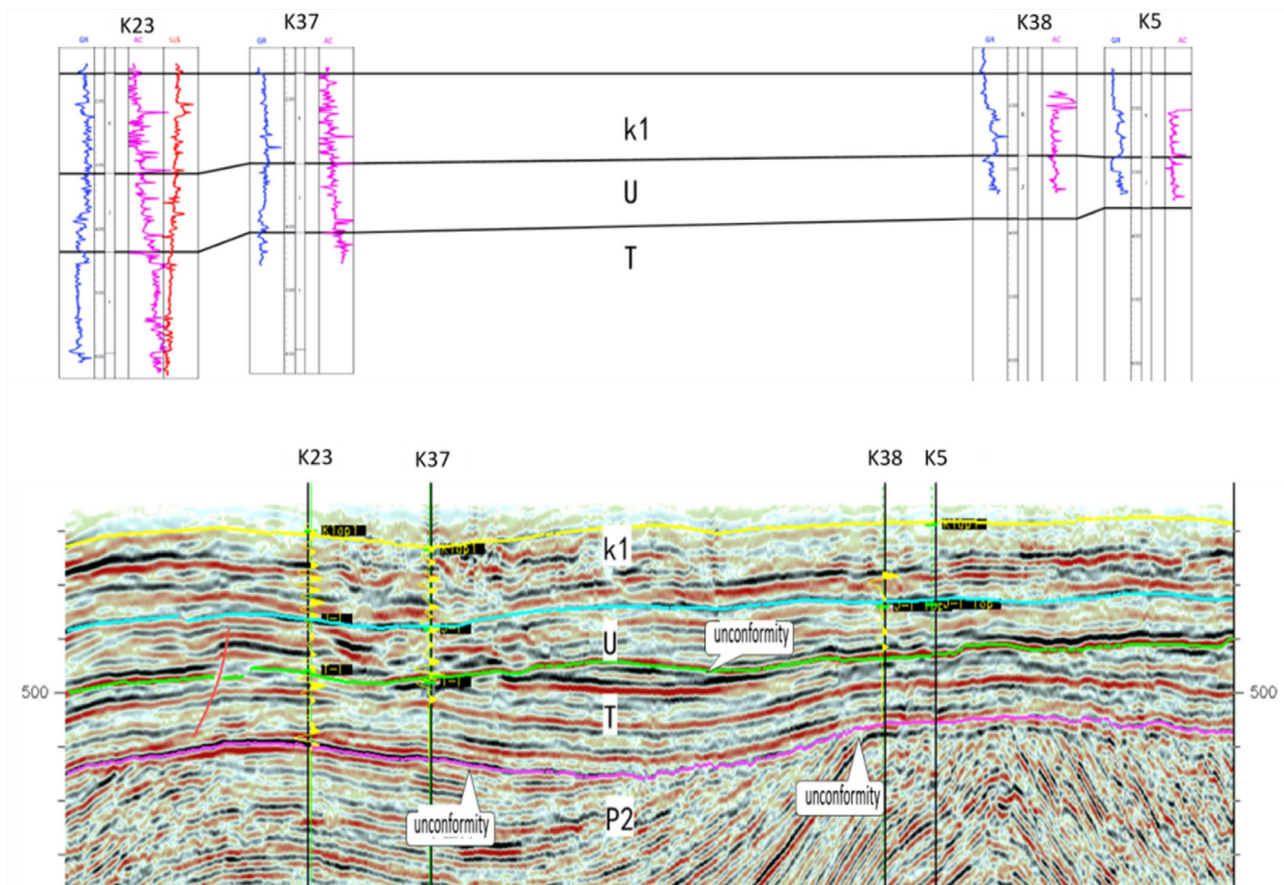


Figure 9. Z2: Near-south-north secondary sequence stratigraphic framework in the central part of the region.

3.2.6. Z3: The Secondary East-West Section

Z3 is a near-south-to-north stratigraphic framework profile in the sub-eastern region. Overall, the secondary sequence stratigraphic framework characteristics are similar to those of the south-to-north profile of Z2. The Jurassic-Lower Cretaceous stratigraphic framework is stable, with little variation in stratum thickness and continuous deposition. The Triassic strata are reduced in thickness due to the influence of local salt dome uplift (Figure 10).

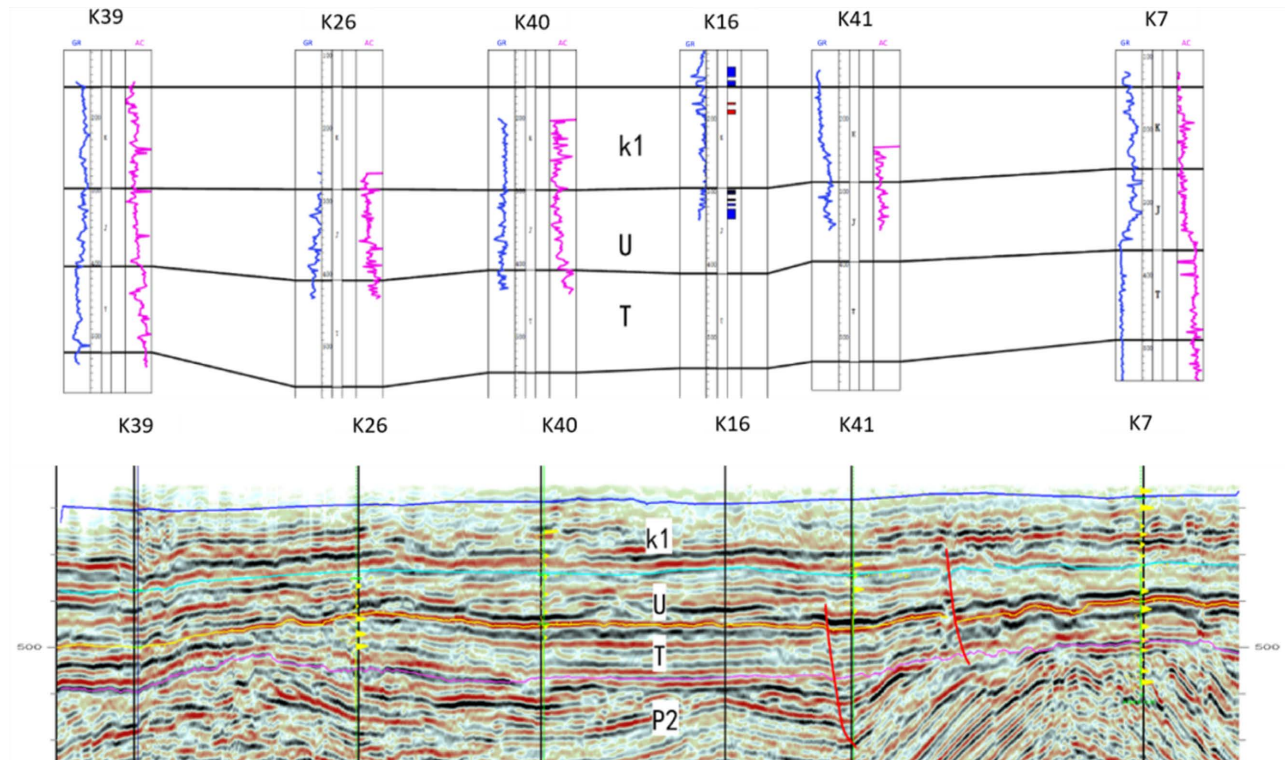


Figure 10. Z3: Regional secondary eastern near-south-north secondary sequence stratigraphic framework.

3.2.7. Z4: Eastern North-South Profile

The Z4 section represents a near-south-to-north stratigraphic framework section in the eastern part of the region, with a stable stratigraphic framework. The thickness of the Jurassic-Lower Cretaceous strata tends to increase from west to east, while the thickness of the strata at the location of salt domes in the eastern part of the region slightly decreases (Figure 11).

4. Distribution Characteristics of Secondary Strata

Based on the well logging data and seismic data from individual wells, the secondary stratigraphic boundaries in the post-salt area on the eastern edge of the Precaspian Basin were determined, and the distribution characteristics of the secondary strata were analyzed.

4.1. Planar Structural Features

From the structural maps of the top surfaces of the five strata, namely the Permian

salt rock, Upper Permian, Triassic, Jurassic, and Lower Cretaceous, it can be observed that the Permian and Triassic strata are relatively significantly influenced by salt domes, exhibiting a draped morphology. In contrast, the later Jurassic and Lower Cretaceous periods saw a relatively flat terrain, with the northwest being higher and the southeast relatively lower (**Figure 12**).

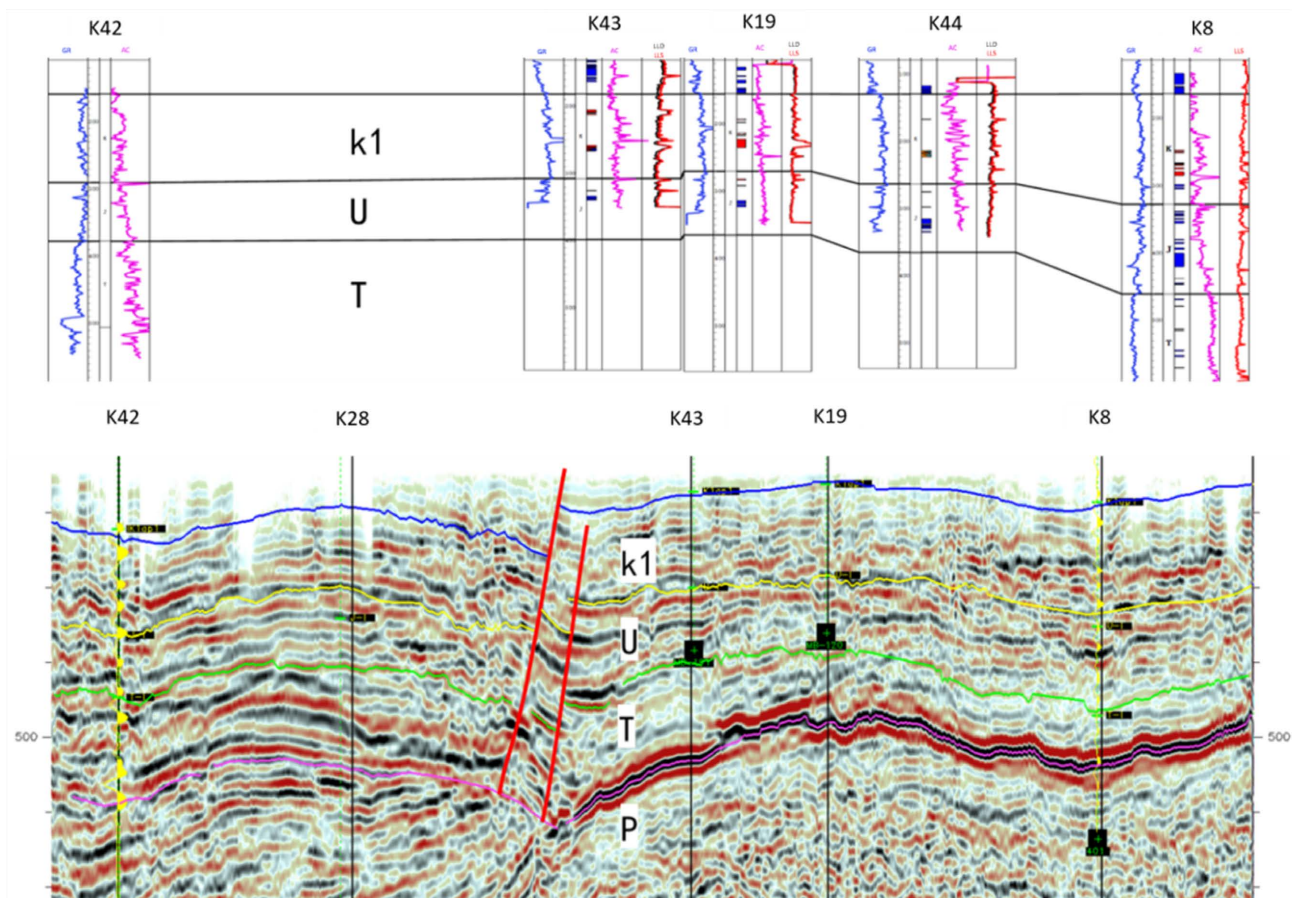


Figure 11. Z4: Near-south-north secondary sequence stratigraphic framework in the eastern part of the region.

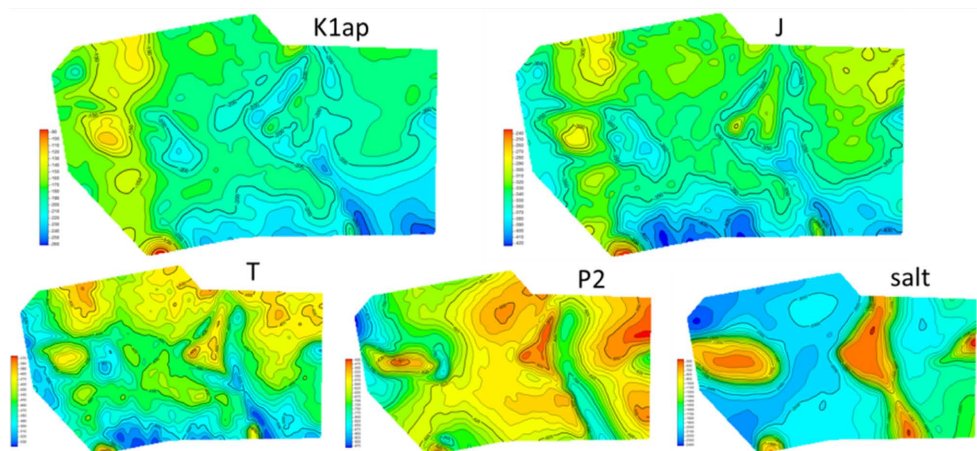


Figure 12. Structural map of the top surface of the secondary strata above the salt in the eastern margin area of the Precaspian Basin.

4.2. Thickness Distribution Characteristics

From the distribution of secondary strata thickness, it can be observed that the Upper Permian is most significantly influenced by the distribution of salt domes. The strata thickness is the thinnest at the top of the salt domes, gradually increasing in thickness outward, forming a distinct drape structure. The Triassic strata follow, with a noticeable thinning of strata thickness at the top of the salt rock. The Jurassic and Upper Cretaceous strata are still influenced by the salt domes in the east, with the thickness at the top of the salt domes being relatively small (Liu et al., 2003). The distribution of strata thickness in the Upper Permian is primarily controlled by the salt domes, while the thickness of the Triassic, Jurassic, and Lower Cretaceous strata is influenced by the overall sedimentary environment on top of the control by the salt domes. Overall, the thickness is greater in the west, with the strata thickness in the east being relatively smaller (**Figure 13**).

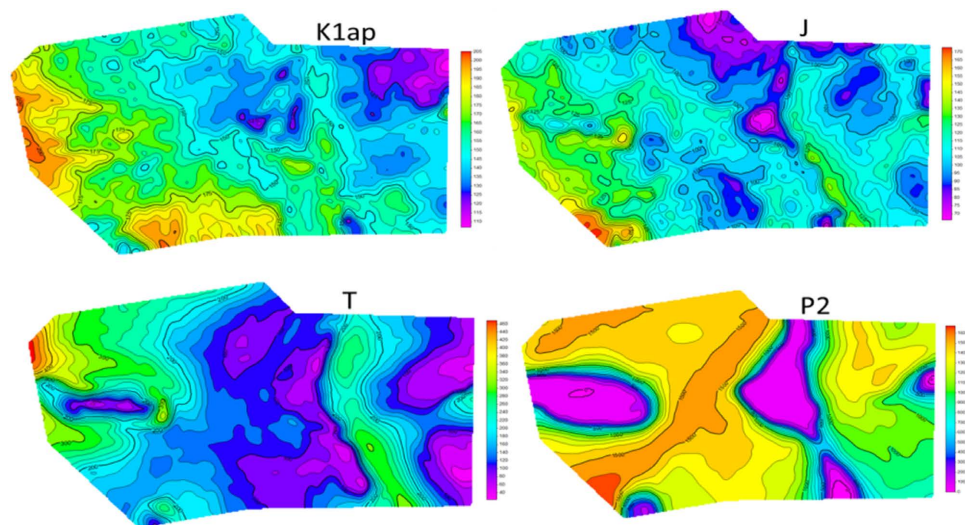


Figure 13. Thickness map of the secondary strata above the salt in the eastern margin area of the Precaspian Basin.

5. Conclusion

The secondary sequence stratigraphic boundaries above the salt on the eastern edge of the Precaspian Basin are clearly characterized, and well logging curves and seismic data play a significant role in stratigraphic correlation. By analyzing changes in parameters such as natural gamma and sonic time difference of well logging curves, combined with reflection characteristics on seismic profiles, the stratigraphic boundaries can be accurately delineated. Due to the influence of salt structures, the top surfaces of the Late Permian and Triassic systems are unconformable, while the Jurassic and Cretaceous strata are distributed throughout the region with clear boundaries.

The strata of the Late Permian and Triassic systems form a drape structure on the basis of salt domes, with a thin salt top that gradually thickens outward. The strata of the Jurassic and Cretaceous systems are stably distributed, with relatively

thicker strata in the west.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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