New insights into hydrocarbon plays in the Caspian Sea, Kazakhstan

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ABSTRACT: New exploration opportunities and improved imaging of already known prospects in the Caspian Sea, Kazakhstan, are presented, based on the acquisition, processing and interpretation of long-offset 2D seismic data acquired by CGGVeritas from 2006–2009. We have identified further examples of three already successful plays in the Caspian Sea and onshore, within open blocks in the North Caspian and North Ustyurt basins and a fourth, relatively unknown play, in the North Ustyurt basin. The already known plays include Devono-Carboniferous carbonate reefs and clastics, Triassic–Tertiary post-salt clastics and carbonates in the North Caspian basin and Jurassic–Cretaceous post-thrust clastics and carbonates in the North Ustyurt basin. The fourth play that we have identified comprises thrust faults, anticlinal structures with Late Palaeozoic–Early Mesozoic clastic and carbonate reservoirs in the North Ustyurt basin which, to our knowledge, has not been tested elsewhere in the region.

INTRODUCTION

The study area is situated in the northernmost part of the Caspian Sea, encompassing the offshore extensions of the North Ustyurt and the North Caspian basins (Fig. 1). The geology of both basins differs significantly in their Palaeozoic sequence.

The North Caspian basin is a petroleum-rich but under-explored basin located in Kazakhstan and Russia (Ulmishek 2001*a*). The sedimentary succession of the basin is more than 20 km thick in the central part of the depression (Anissimov *et al*. 2000; Ulmishek 2001*a*; Barde *et al*. 2002; Volozh *et al*. 2003; Ronchi *et al*. 2010). The drilled sequence includes a Middle Devonian–early Permian section composed of carbonate platforms, a Kungurian diapiric salt section and an overlying upper Permian–Tertiary section. The principal source rocks are Upper Devonian to lower Permian deep-water black shale facies that are stratigraphically correlatable with shallow basin-margin carbonates.

In the North Caspian basin alone, about 30×10^9 BBL oil and 250×10^{12} SCF gas has been discovered so far. A number of the discoveries in the shallow-water and coastal region of the basin are super-giants which are located in large, isolated carbonate platform reservoirs developed from the Visean to the Bashkirian (Barde *et al*. 2002; Ulmishek 2001*a*; Volozh *et al*. 2003; Ronchi *et al*. 2010). Examples of these are Kashagan and Tengiz.

The reservoirs, located in the pre-salt sequence, are similar in their depositional history, facies architecture and overall geometry to reservoirs of known super-giant fields onshore, such as Astrakhan, Karachaganak and Zhanazhol. The depth range to the top of these carbonate build-ups varies from 3500–4000 m, leading to significant overpressure conditions within the reservoirs. For example, the tops of the Kashagan and Tengiz carbonate reservoirs are 3700 m and 3900 m, respectively (Anissimov *et al*. 2000; Ronchi *et al*. 2010). Several undrilled carbonate platforms akin to already known platforms both onshore and offshore have been identified in the open blocks offshore and these are estimated to hold significant hydrocarbon reserves in the northern Caspian Sea.

In the North Ustyurt basin, more than 5 km of Jurassic–Tertiary clastic sediments overlie a relatively undrilled older sequence of Devonian–middle Carboniferous carbonates, upper Carboniferous–lower Permian clastics, carbonates and volcanics and upper Permian–Triassic clastic rocks (Ulmishek 2001*b*). The older Palaeozoic–Triassic succession has been affected by Late Triassic thrusting and remains poorly understood and completely unexplored. In the drilled, post-thrust part of the basin, oil is mainly structurally trapped in shallow Jurassic and Neocomian sandstone reservoirs (Ulmishek 2001*b*). The known source rocks are lacustrine sediments and coals within the Jurassic sequence. However, there is widely held opinion that further source-rock potential may be provided by Carboniferous deep-water facies in the adjacent North Caspian basin through lateral migration of hydrocarbons into the adjacent North Ustyurt basin.

Only a few wells have been drilled in the offshore part of the basin but these have encountered about 10^9 BBL oil, located in the Jurassic–Cretaceous sequence. None of these wells has penetrated the thrusted Palaeozoic–Triassic sequence. More than 2×10^9 BBL oil and 1.5×10^{12} SCF gas have been discovered in the entire basin, with major discoveries located on the Buzachi High. In the offshore sector, Kalamkas-more Field and the new discoveries within the Pearl block (all with up to 10^9 BBL oil combined) are all located in high porosity and high permeability thin sandstone beds of Jurassic–Cretaceous age.

The discovery of the super-giant Kashagan Field in 2000 by the Offshore Kazakhstan International Operating Company consortium (Agip, Shell, ExxonMobil, Phillips, Inpex, KMG, BG, BP Amoco, Statoil and Total) rekindled exploration interest in this part of the Caspian Sea after earlier exploration efforts in the late 1970s led to the discovery of the super-giant Tengiz Field. The Kashagan Field holds estimated recoverable reserves of more than 10×10^9 BBL oil and 21×10^{12} SCF gas.

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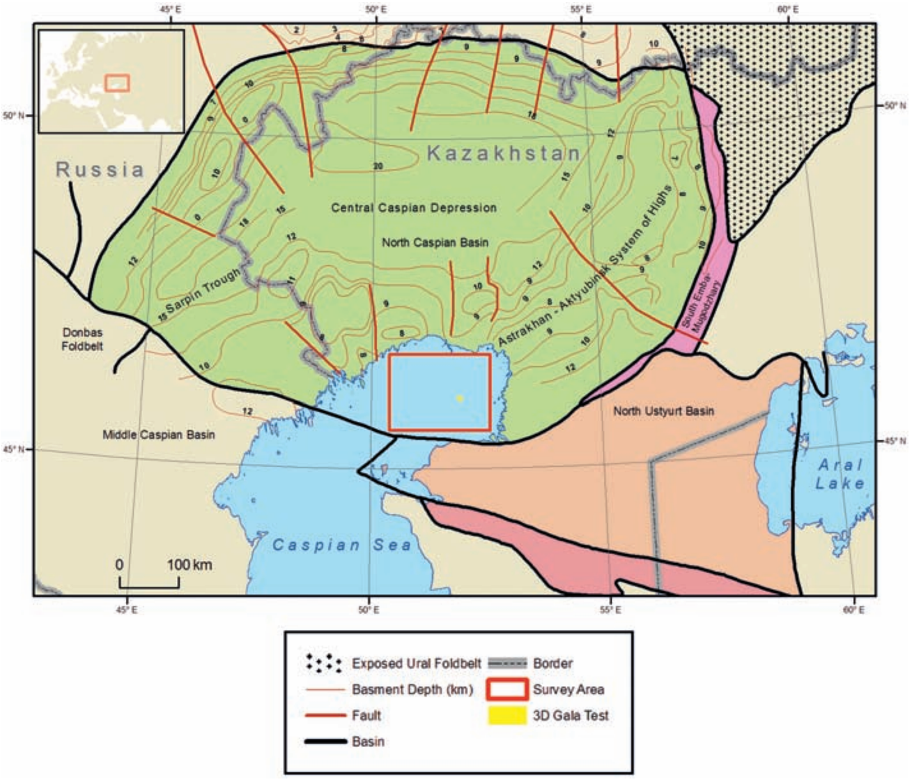

Fig. 1. Location map of North Caspian and North Ustyurt basins indicating major regional structural elements and the extension of both basins into the northern part of the Caspian Sea. The red square indicates data coverage area with the yellow outline showing the 3D test. (Redrawn from Ulmishek 2001*a*.)

CGGVeritas has acquired more than 3000 km of long-offset 2D seismic lines with the aim of unlocking the remaining potential of this part of the Caspian Sea. This study describes the results of the seismic interpretation carried out using this 2D dataset. The result of the seismic interpretation is used to present an extension of already known productive plays into the offshore open blocks. It has also led to the identification of a relatively unknown play in the offshore sector of the North Ustyurt basin.

TECTONOSTRATIGRAPHIC DEVELOPMENT

The North Caspian basin

The North Caspian basin is a pericratonic depression that formed during the Late Proterozoic–Early Palaeozoic to Tertiary (Talwani *et al*. 1998). It is bounded to the north by the Palaeozoic carbonate platform of the Volga–Ural province, to the west by the Russian Craton; with the South Emba and Donbas Foldbelts to the east and southwest, respectively (Fig. 1). It is one of the deepest basins in the world, containing more than 20 km of Palaeozoic–Tertiary sedimentary strata (Ulmishek 2001*a*).

The North Caspian basin can be divided into two areas: a pre-salt and a post-salt package, separated by Kungurian salt (Fig. 2). The pre-salt package is characteristically composed of Devonian–early Permian-age carbonate build-up with some synorogenic clastics in the lower Permian. The post-salt package is upper Permian–Tertiary in age and is composed of clastics and re-sedimented carbonates.

Interpretation of new, long-offset seismic data has shown that the structural evolution of the North Caspian basin in the Palaeozoic may have involved an initial rifting during the Riphean–Middle Devonian (Fig. 3). The possibility of this initial rift system underlying the known Palaeozoic carbonate system has also been reported by Brunet *et al*. (1999) and could be possible as it is also akin to generic basin development. This was followed by carbonate build-up during the Middle Devonian to Carboniferous. There is also evidence for continental collision and associated subsidence during the late Carboniferous (Nevolin & Fedorov 1995; Alexander *et al*. 1999; Barde *et al*. 2002). Development of platform carbonates and clastic deposition occurred along the basin margins during the late Carboniferous to early Permian while euxinic conditions prevailed in the basin centre leading to the deposition of organic-rich shales (Brunet *et al*. 1999). The relief of the carbonate platforms became more uniform as the water depth increased slowly but later transgression led to the deposition of deep-water shale facies across the carbonate platforms. These shale formations range from 150–200 m in thickness in the eastern basin-margin area (Anissimov *et al*. 2000).

During the early Permian the incipient North Caspian basin became isolated from the open sea following the collision of the Eurasian plate with the Kazakh plate and the accretion of the Turan plate to the south (Gralla & Marsky 2000; Barde *et al*. 2002). Clastic sediment input ceased, climate became arid and a sequence of thick beds of marine halite interbedded with thin black shales was deposited. During this period of salt deposition, the Caspian Basin was not completely isolated because thin layers of shale interbedded in the halite show that there was intermittent incursion of open sea into the basin through entry points created by fault interactions. The halite sequence is up to 4.5 km thick throughout the basin.

In the Permian, as the salt was accumulating at the centre of the basin, clastic sediments prograded from the east into the basin (Volozh *et al*. 2003). These clastic sediments were sourced mainly from the north–south-trending Ural Mountains.

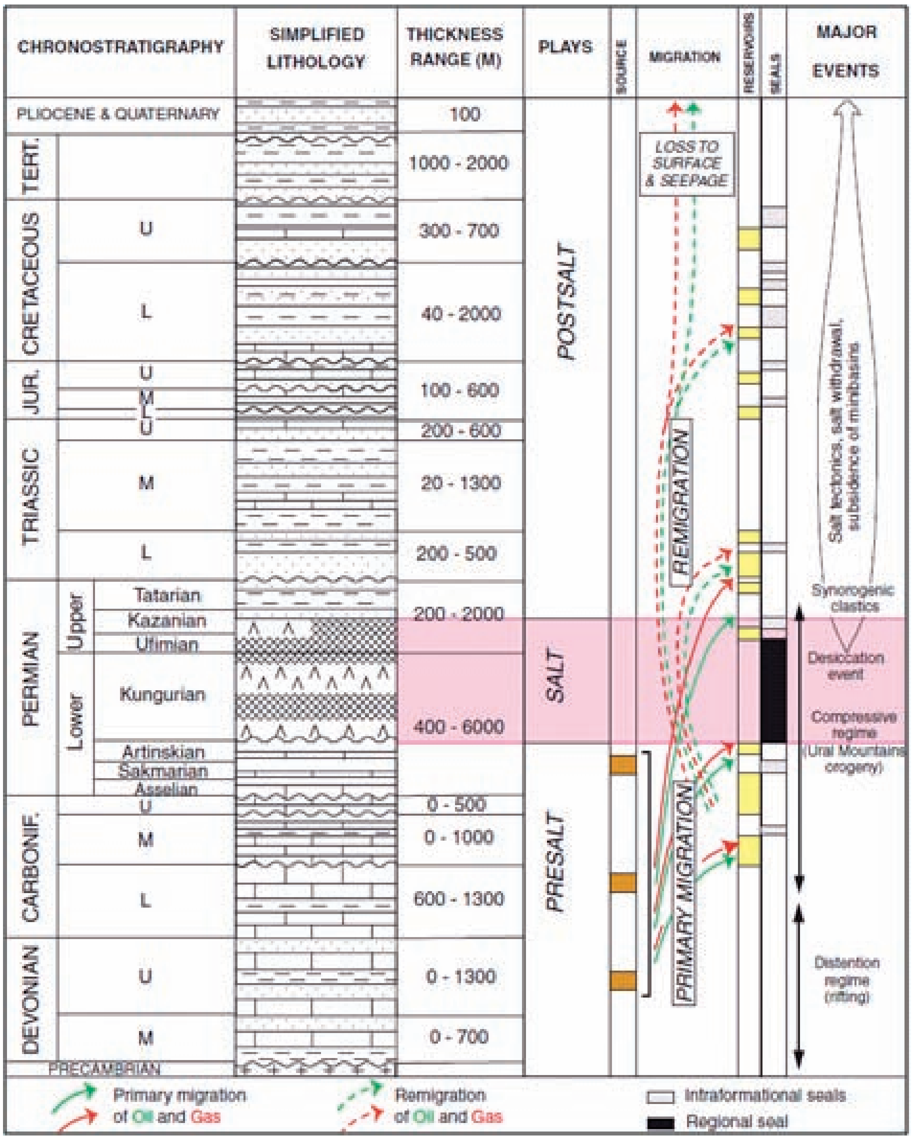

Fig. 2. Generalized chronostratigraphic framework, plays and major events in the Caspian Sea sector of the North Caspian basin (Barde *et al.* 2002).

Continental collision continued in the Urals during the Late Permian–Triassic time with rapid subsidence in the basinal areas. Thick sedimentary sequences, mostly syn-orogenic clastics, were deposited during this time (Ulmishek 2001*a*; Barde *et al.* 2002; Volozh *et al.* 2003). In addition, some upper Permian (Kazanian) carbonates, evaporites and Lower–Middle Triassic marine shales and marls were also deposited (Ulmishek 2001*a*). Deformation of the Kungurian salt started soon after its deposition, leading to the formation of large salt walls with diapir amplitudes reaching up to 5 km. Separating the salt walls are inter-dome depressions which may be several kilometres deep and contain upper Permian–Triassic sedimentary packages.

Various stratigraphic intervals of Jurassic–Tertiary sequences overlie the Kungurian salt. The post-Triassic interval, which is up to 3–4 km thick in the depressions, contains mainly clastics and re-sedimented carbonates.

North Ustyurt basin

The North Ustyurt basin is a triangular-shaped basin located between the Caspian Sea and the Aral Lake in Uzbekistan (Fig. 4). It is bounded to the south by the Mangyshlak foldbelt and to the north by the North Caspian basin. The depth to the top of basement is between 5 and 11 km (Brunet *et al.* 1999).

Seismic data and drilling have revealed that the basement of the basin probably is not a homogeneous block (Babadzhanov *et al.* 1986) and is overlain by a package of up to 11 km of sedimentary rocks. Around the Sudochi area, drilling shows that the basement is composed of thick Lower Palaeozoic, slightly metamorphosed, deep-water shales and small blocks of Precambrian crust (Ulmishek 2001*b*). These rocks were deformed and slightly metamorphosed during the Devonian and are directly overlain by Lower–Middle Devonian molasse clastics which are intruded by granites (Abidov *et al.* 1997).

The North Ustyurt basin developed during the Late Devonian as a cratonic basin with sediments consisting of platform-type carbonates and clastics unconformably overlying the deformed basement (Abidov *et al.* 1997; Ulmishek 2001*b*).

The North Ustyurt block then collided with the Russian craton margin, possibly at about pre-late Visean, judging from the geology of the NW slope of the South Emba high in the North Caspian basin or, alternatively, in the Early Permian. This led to the deposition of syn-orogenic clastics within the basin margins.

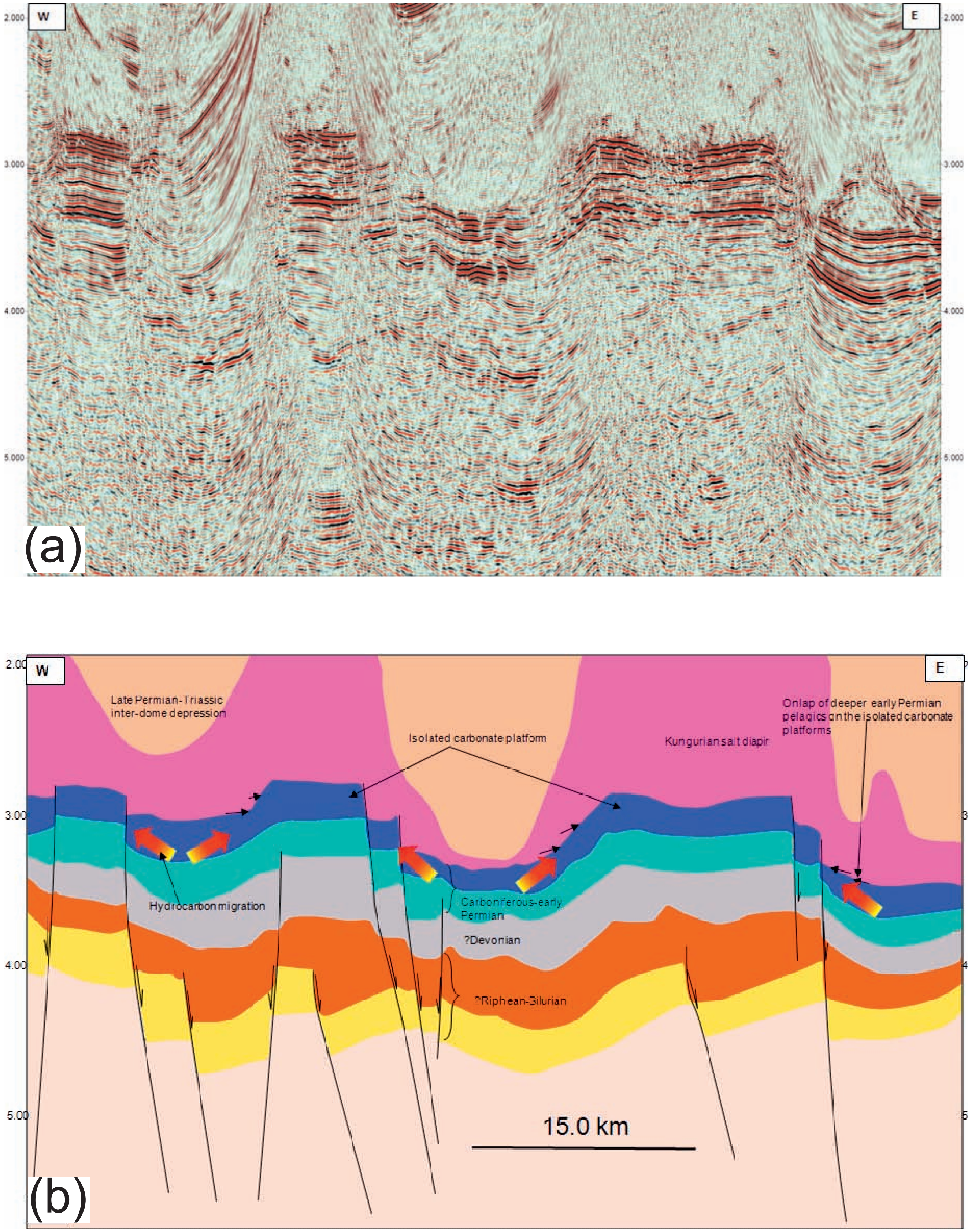

Fig. 3. (**a**) An uninterpreted and (**b**) a geoseismic interpretation of a W–E line across an open block, illustrating a possible initial rifting of the North Caspian basin and petroleum system elements of the pre-salt play (see Fig. 5 for location of seismic line).

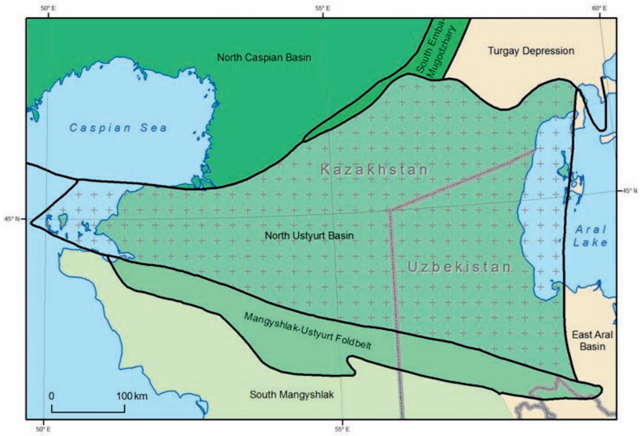

Fig. 4. Location map of North Ustyurt basin, indicating major regional structural elements. (Redrawn from Ulmishek 2001*b*.)

Late Permian–Triassic rifting in Central Mangyshlak, south of the North Ustyurt basin is indicative of post-collisional relaxation and north–south extension. The graben created by this rifting were filled with a thick sequence of clastic sediments derived from the Hercynian terrane to the east where orogenic processes continued (Ulmishek 2001*b*).

During latest Triassic–Early Jurassic time, due to the closing of the palaeo-Tethys in the south and the collision of Iran with the Eurasian Tethyan margin, the Mangyshlak rift was compressed and inverted, with thrusting occurring in the North Ustyurt basin, especially in the Buzachi Ridge and offshore (Ulmishek 2001*b*). These thrusts are clearly evident on seismic data and tend to obscure deeper geology due to the scattering of seismic energy as a result of the juxtaposition of sediments of different seismic velocities on the thrust sheets.

From the Jurassic onwards, the basin developed as a gentle sag in which sediments of up to 5 km were deposited. No significant deformation has taken place since the Jurassic, except mild Jurassic fault rejuvenation.

SEISMIC DATA ACQUISITION AND PROCESSING

The seismic database consists of more than 3000 km of long-offset 2D seismic lines acquired between 2006 and 2008 (Fig. 5) over unlicensed blocks within both basins. The survey is the result of an exclusive agreement with the Ministry of Energy and Mineral Resources of Kazakhstan for the acquisition of non-exclusive seismic data over the entire open acreage of the Kazakh sector of the Caspian Sea.

The survey was recorded using a 480 channel, split-spread, 6 km cable with a sleeve airgun array source. The newly acquired lines show enhanced frequency content, improved noise suppression and multiple attenuation, and benefit greatly from Fully Ray-traced Kirchhoff Pre-stack Time Migration (PSTM).

A comparison of the existing 1995 data with the newly acquired 2006–2008 data shows a significant uplift in the imaging of pre-salt structure and the carbonate reefs, even revealing detail of the internal architecture of the reefs. There is also much improved post-salt event resolution and continuity (Fig. 6).

KEY IMAGING PROBLEMS AND POSSIBLE SOLUTIONS

The complexity of the salt structures and the velocity contrast between the salt and sediments results in difficult sub-salt imaging. There are a significant number of high-amplitude salt diapirs, long wavelength salt pillows and significant pre- and post-salt faulting encountered across the PSTM 2D sections (Fig. 7).

In addition, various velocity effects were also encountered. For example pull-ups can be observed directly below the larger salt domes because of their fast intrinsic velocities compared with the adjacent sediment fills, giving a false impression of elevated structures.

In order to overcome these velocity problems highlighted in Figure 7, a test migration in depth was carried out and the resulting section showed significant improvement in the imaging of the pre-salt carbonate platforms (Fig. 8).

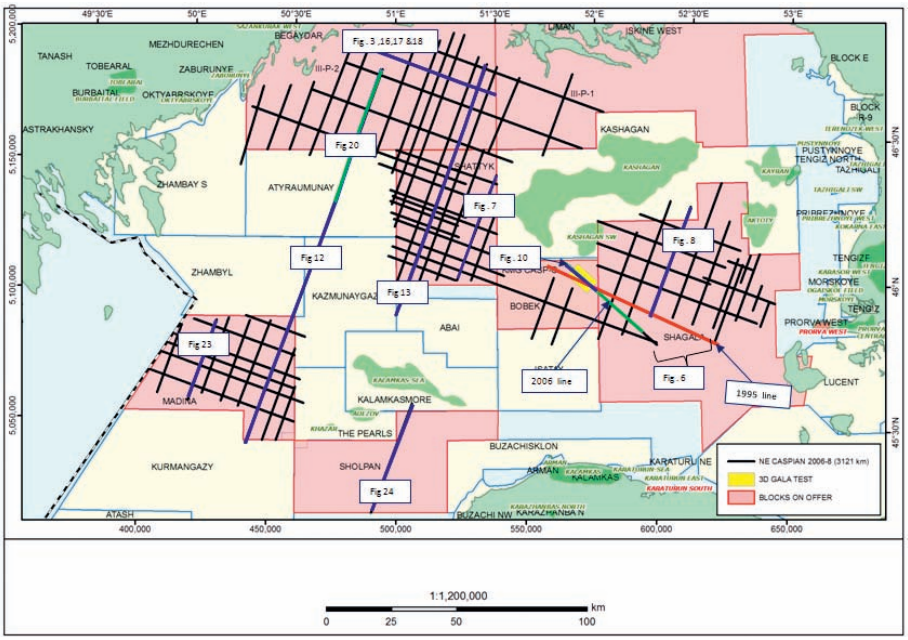

Fig. 5. Seismic coverage map for the Caspian Sea sector of the North Caspian basin with the location of seismic lines used in the illustrations.

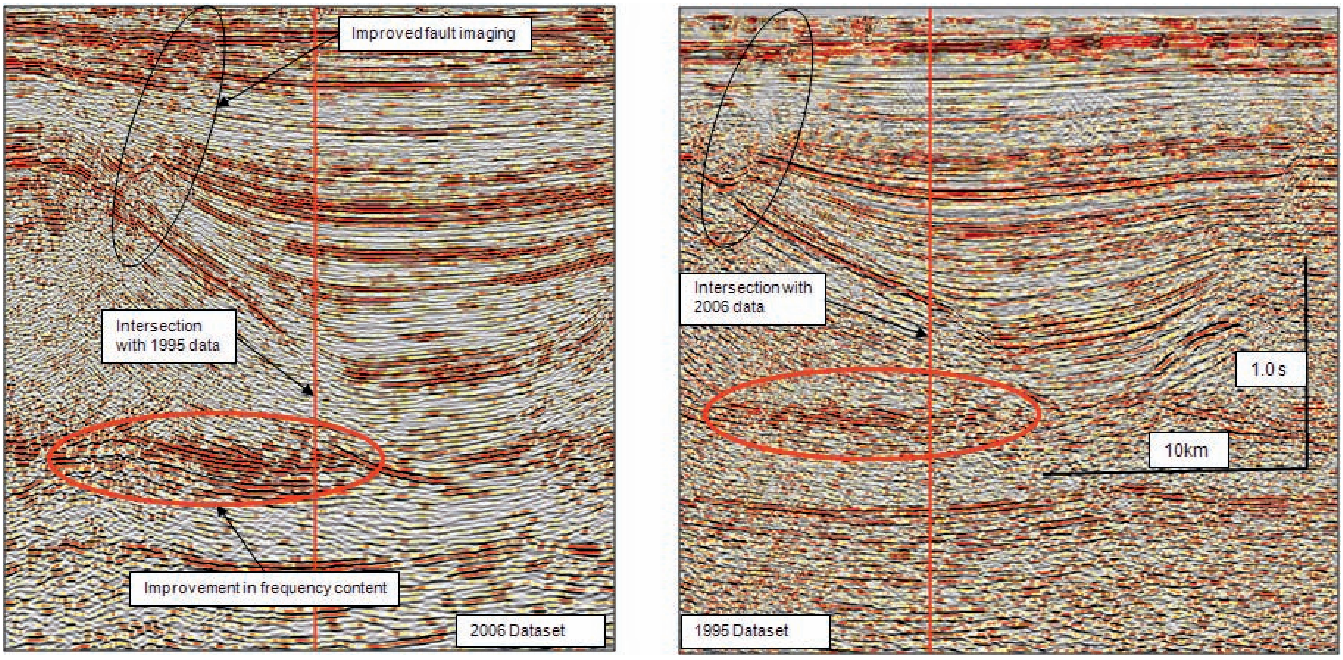

Fig. 6. Comparison of new and old seismic vintages. The new vintage (2006) shows significant uplift in the imaging of the internal geology and structure of the pre-salt carbonate reefs (see intersecting lines on the base map in Fig. 5).

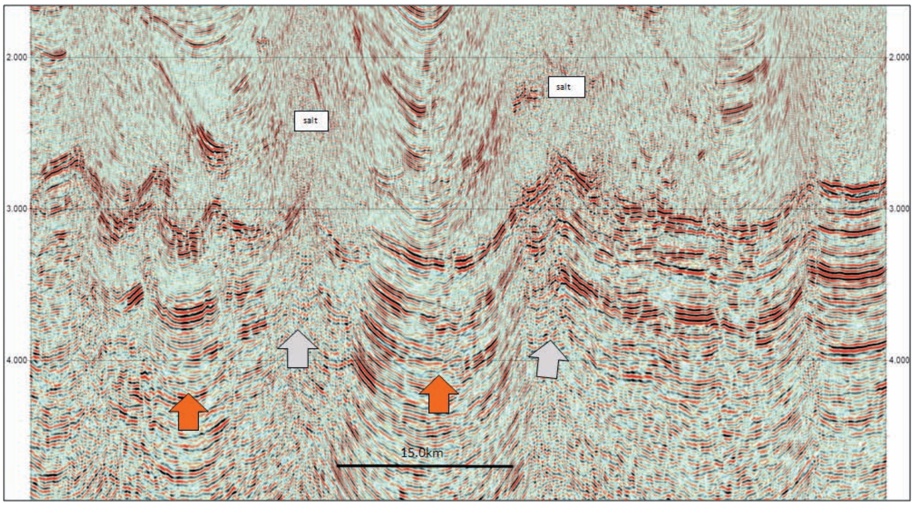

Fig. 7. Seismic line displaying common imaging problems encountered in the mapped area. The arrows show problem features highlighting apparent velocity pull-down (orange arrow) and apparent pull-up of reflectors (grey arrow).

The test depth migration using a simple depth model led to a better understanding of the pre-salt geology as well as the internal geology of the salt diapir. Additionally, reflections which appeared to be flat within the salt diapir in the time-migrated section that has been stretched to depth, were migrated to their actual dipping positions in the depth-migrated section.

The dataset was acquired employing two receiver lines 250 m apart and 400 stations per line with a 25 m station interval. About 19 shot lines were acquired orthogonal to the receiver lines, with 100 m separation, 50 m shot point interval and 235 shot points per line. This geometry allowed a crossline migration window of 6 km and resulted in a nominal 30-fold coverage along the line (Fig. 9).

The resulting, fully 3D migrated stack section shows significant improvement in the imaging of salt-walls, as out-of-plane energy, which gave the spurious, conflicting reflection events on the 2D line, was eliminated in the 3D dataset (Fig. 10). In addition, imaging below the salt is significantly improved with enhanced frequency and better continuity of events making it possible to differentiate accurately the internal geology of the reef and the stratigraphy of the post-salt deposits (Fig. 11). It should be noted that this improvement was obtained even though the fold of the 2D line was 240 whilst that of the fully 3D migrated test line was a nominal 30 fold.

SEISMIC INTERPRETATION AND ANALOGUES

Several regional unconformities and seismic markers were interpreted across the basin in order to have a better understanding of the variation in the structure of the basin and its stratigraphy. In the absence of well data, these horizons were correlated across the basin based on seismic velocities and seismic stratigraphy.

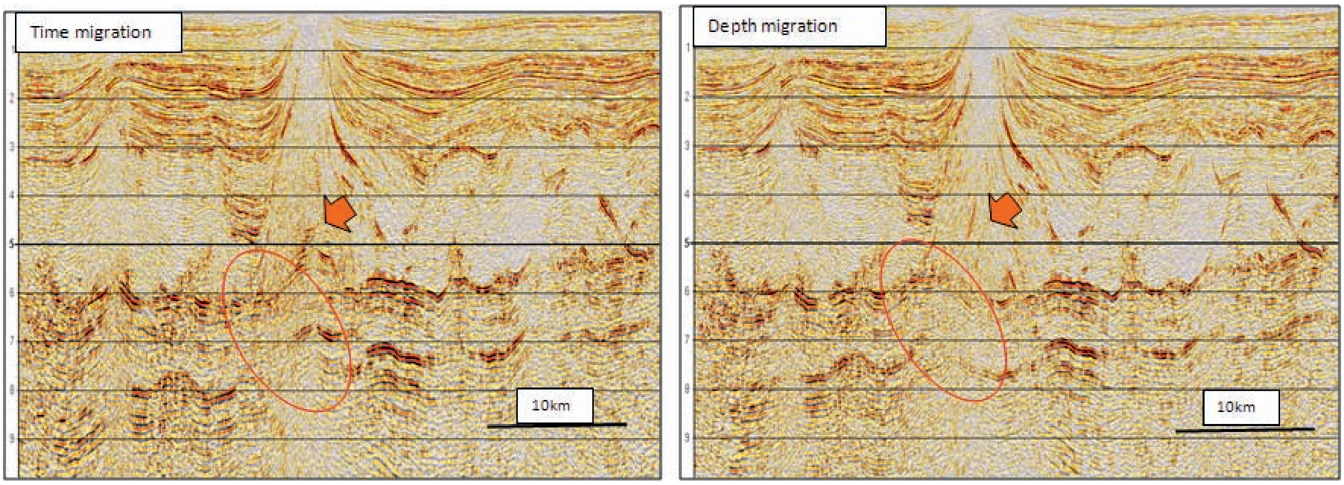

Fig. 8. Comparison of a time- and depth-migrated section stretched to depth to illustrate improved imaging of the structure and stratigraphy of pre-salt carbonate platforms (circled area) and the removal of apparent spurious events in the salt (arrow).

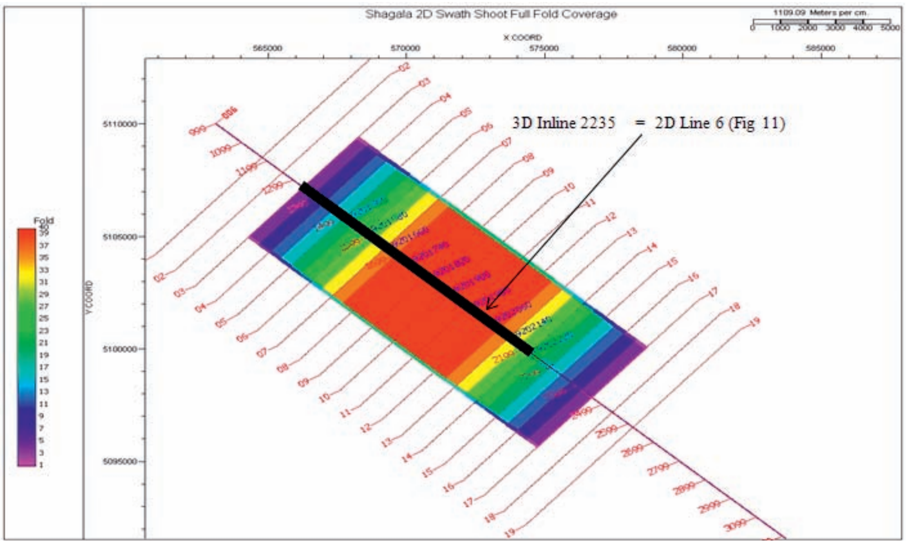

Fig. 9. Two-dimensional swath shooting configuration showing point of 2D and 3D line intersection illustrated in Figure 10. In swath shooting, the receiver lines are fixed and all the shots pertaining to the swaths are recorded with the same set of fixed receiver lines.

The interpretation shows a clear distinction between the North Caspian and the North Ustyurt basins (Fig. 12). The key distinctions include:

- a Permo-Triassic thrust system in the North Ustyurt basin which replaces the renowned diapiric Kungurian salt package in the North Caspian basin;
- a post-salt structuration in the North Caspian basin related to salt movement, whilst in the North Ustyurt basin structuration of this section is less pronounced, mainly created by drape over deeper Permo-Triassic folds and thrusts.

However, both basins also show similarities, which include:

- a regional, top pre-Jurassic, angular unconformity that cuts across both basins;
- a post-salt/post-thrust section that contains rocks of similar facies character and depositional environment.

Pre-salt play

The pre-salt play has been the key target in the onshore/offshore sectors of the North Caspian basin for some years now. Amongst pre-salt onshore fields are Orenburg, Karachaganak and Zhanazhol, while pre-salt fields located offshore include Tengiz, Kashagan, Kayran and Aktoty. The reservoirs for these fields are massive Devono-Carboniferous carbonate platforms, which are sealed by overlying Kungurian salt and transgressive shale, whilst hydrocarbons are sourced from Carboniferous shales and Devonian shaley carbonates.

In the pre-salt of the North Caspian basin, three important horizons, representing unconformities with basin-wide significance, were picked. These include the Base Salt, mid-Carboniferous and Top Middle-Devonian (Fig. 13). Amongst these three key pre-salt horizons, the Base Salt horizon is the most variable and diachronous (light blue, Fig. 13).

The mid-Carboniferous is a regional marker and represents a regional middle Carboniferous unconformity that has been penetrated by wells (Brunet *et al*. 1999). The deepest horizon picked is simply identified as Middle Devonian. This horizon forms a basin-wide unconformity. It may represent the top of the basement in the shallowest basin margin areas to the SW or the top of Devonian carbonates in the deeper part of the basin.

Examples of pre-salt fields in the Caspian Sea and further examples in the open blocks

The Tengiz Field. The Tengiz oil and gas field, discovered in 1979, is a giant field with recoverable reserves of more than

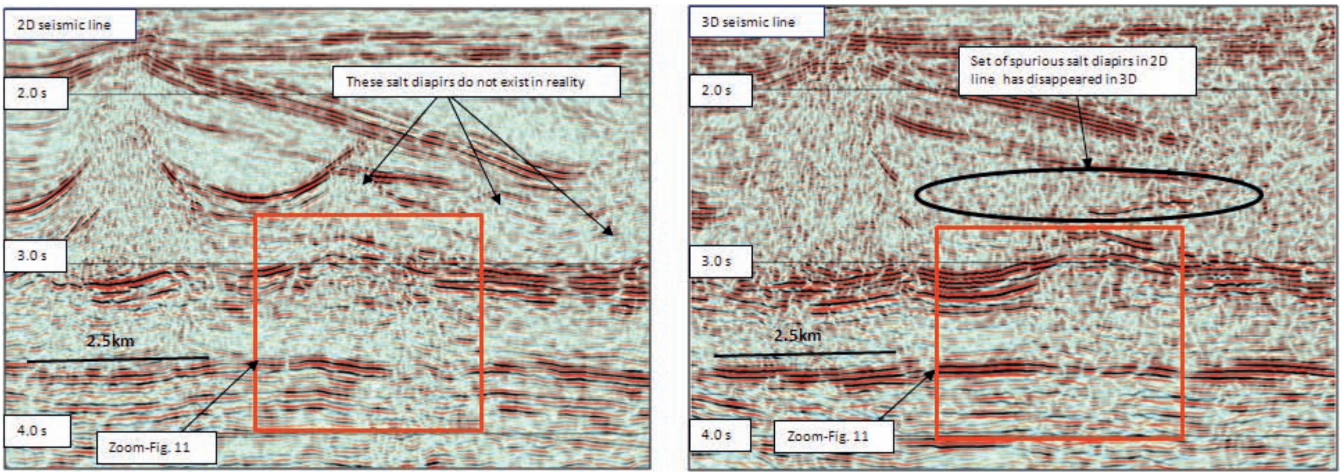

Fig. 10. Comparison between a fully 3D time-migrated seismic line and its 2D equivalent to show improvement in the imaging and understanding of geological features below the salt.

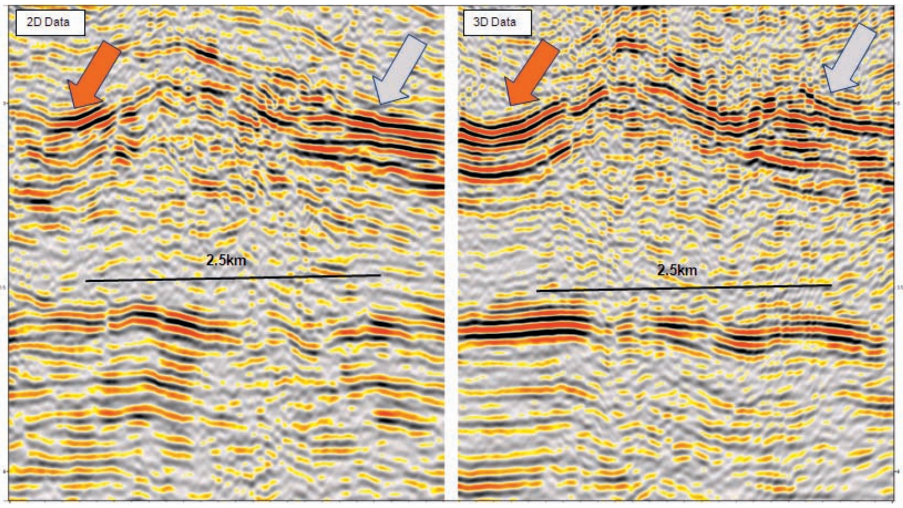

Fig. 11. A zoomed section from Figure 10 illustrating significant improvement in pre-salt imaging, with enhanced frequency and better continuity of events allowing a better understanding of the internal geology of the reef. The arrows represent similar locations on the 2D and pseudo-3D data

6×10^9 BBL oil and $13{\times}10^{12}$ SCF gas. The field comprises a massive Devonian to Carboniferous age isolated carbonate reef. The depositional architecture comprises extensive inner and outer central platform facies, a raised rim feature, a steep platform margin, and thick flank deposits (Fig. 14). The isolated reef area extends over more than 110 km^2 with the top of the reservoir at a depth of about 3900 m (Harris 2008). The upper part of the Tengiz platform forms the main hydrocarbon-bearing part of the platform. Porosity distribution varies across the reef, with matrix porosity in the centre up to 18% whilst at the margins and slope, porosity is less than 6% but permeability is higher here due to fracturing and diagenetic meteoric water dissolution.

The Kashagan Field. The Kashagan Field was discovered in 2000 and contains recoverable reserves of more than 10×10^9 BBL oil and $21{\times}10^{12}$ SCF gas in pre-salt carbonate reservoirs. It is a deep, overpressured and isolated carbonate reef with a high permeability karstified and fractured rim and a relatively lower permeability stratified interior. The feature is approximately 75 km long and 35 km wide with a margin that is elevated up to 250 m higher than the platform interior (Fig. 15). The platform flanks are steep, sloping up to 25° (Ronchi *et al*. 2010).

Both the Kashagan and Tengiz fields are sourced from Devonian–early Permian organic-rich shales which are located adjacent to the platforms. The shales were deposited simultaneously with the shallow-water carbonates and are correlatable into the deep part of the basin. Hydrocarbons migrate into the platforms through a network of faults, fractures and carrier beds. These carrier beds comprise re-deposited carbonates which are a product of the erosion of the main body of the reef during periodic sea-level falls (evident in the rock-record as regional unconformities).

Undrilled reef features in open blocks

Several undrilled reefs have been imaged by the latest seismic acquisition programme carried out by CGGVeritas since 2006. The reefs range from 5–10 km in width and 30–50 km in length and may be isolated, with flat-roof tops and intervening troughs, or may occur as continuous platforms in the deeper parts of the basin.

In general, these isolated platforms were formed in the shallow-water areas of the basement-related rift system. Three key regional unconformities described as Devonian, Top Visean and Top Bashkirian have been interpreted, which represent various stages of platform growth (Fig. 16).

The platform interior deposits are typically horizontally layered cycles of shallow-water carbonates that accumulated through the aggradation of facies during sea-level highstands

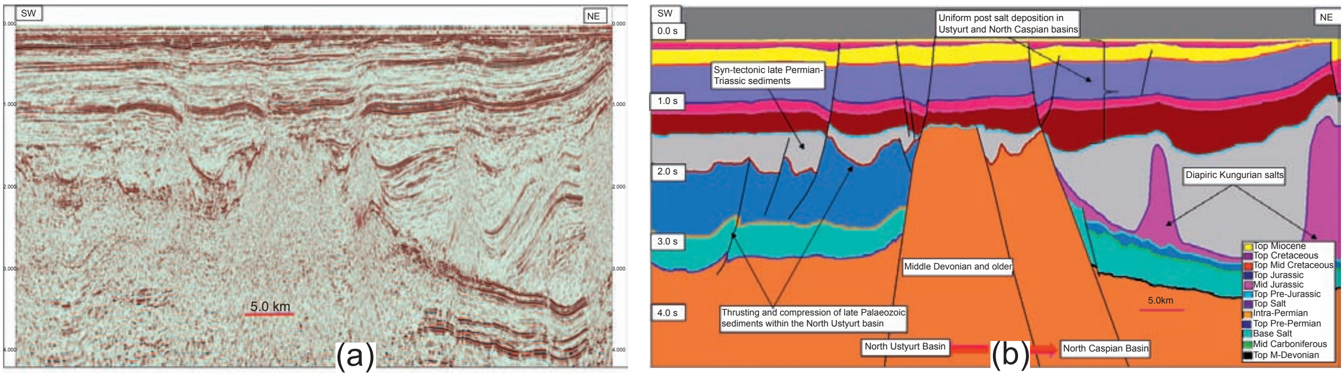

Fig. 12. (**a**) An uninterpreted and (**b**) the interpreted geoseismic section of a SW–NE seismic line across the Ustyurt and North Caspian basins, illustrating the structure and stratigraphy of both basins.

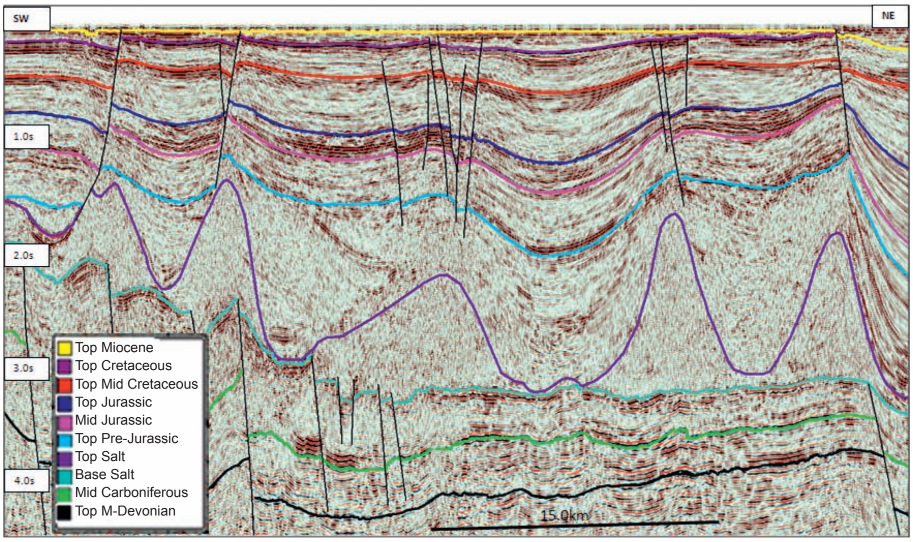

Fig. 13. SW–NE interpreted seismic line showing slight change in the structural setting and stratigraphy from the edge of the North Ustyurt basin (SW) into the deeper North Caspian basin. In the shallow part of the basin, close to the SW boundary, clastic sediments underlie the Kungurian salt and the carbonates lie deeper. Moving further NE across the platform, shallow-water carbonates lie directly below the salt.

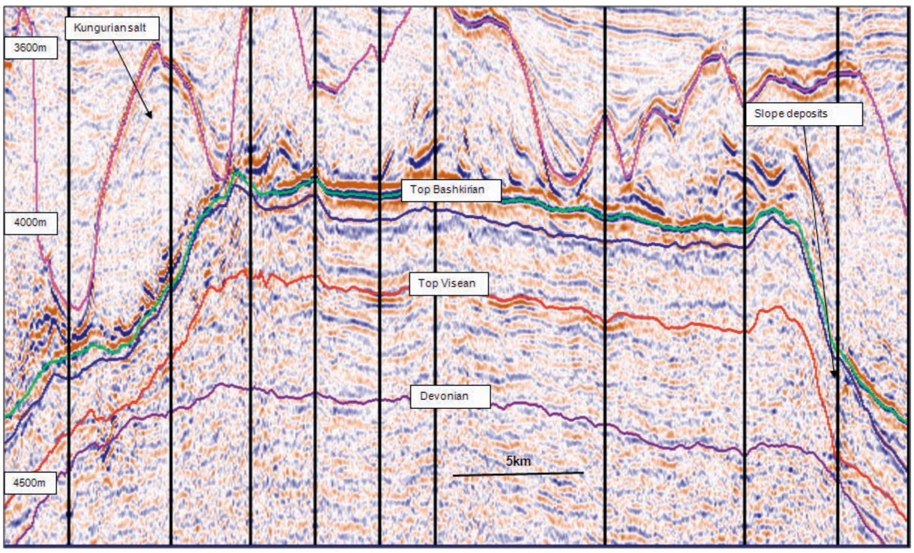

Fig. 14. Interpreted representative seismic line across the Tengiz carbonate platform (Harris 2008).

and exhibit low amplitude seismic reflections, probably related to the low impedance contrasts expected within a grossly homogeneous carbonate build-up (Fig. 17). These central facies grade laterally into the platform-edge facies with high amplitude and continuous reflections.

The central platform facies and the elevated edge facies grade into a prograding steep slope facies with high angle prograding clinoforms that onlap the platform edge and downlap the basin centre. The overlying lowstand deposits are subsequently made up of more than 4 km of evaporite sequence that

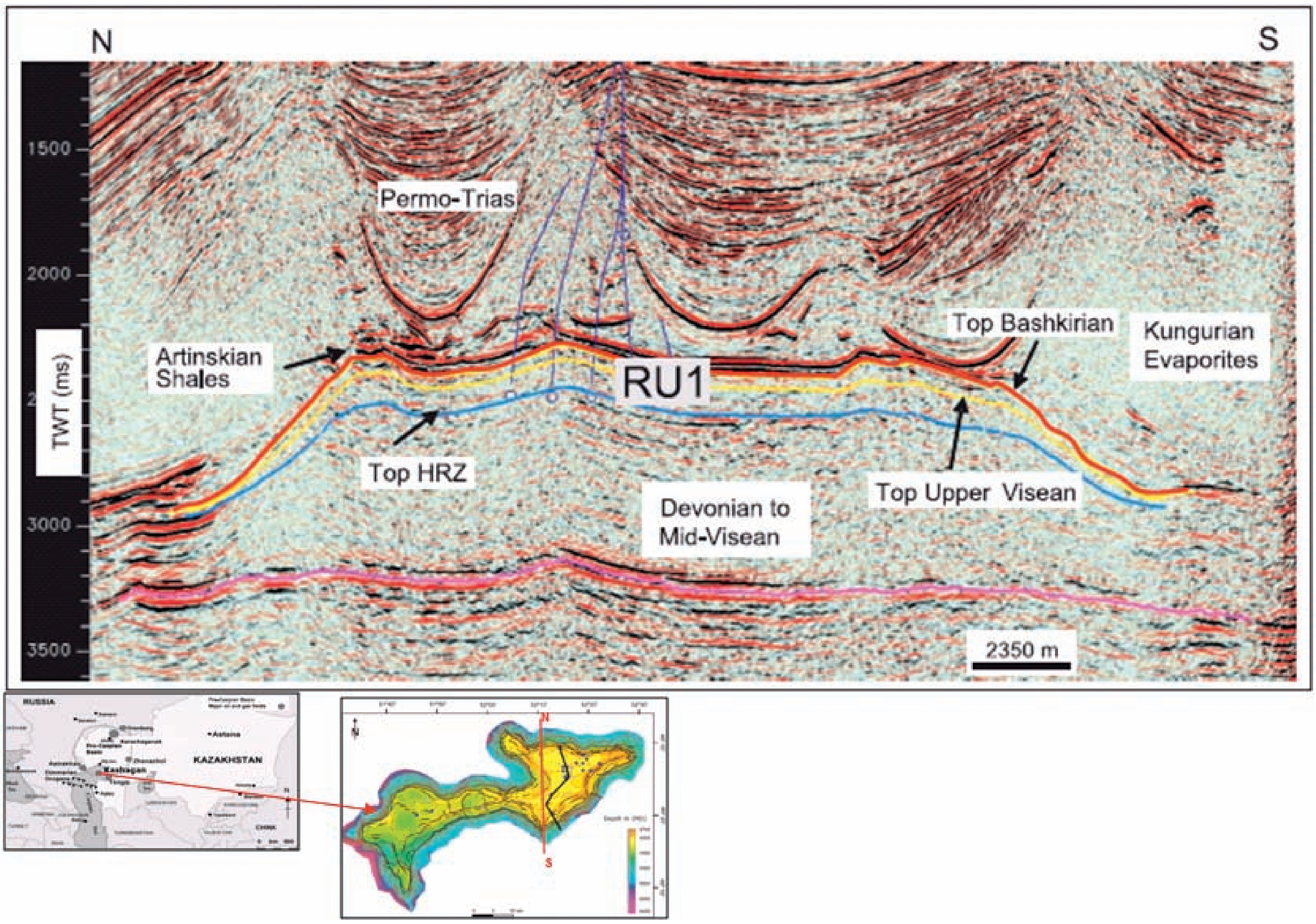

Fig. 15. Representative north–south seismic line across the Kashagan Field (Ronchi *et al*. 2010). Inset shows the line of section and location in the Caspian Sea.

contain occasional shale facies. The slope contains eroded sediments derived from the platform. Seismic facies within the slope consist of an upper slope chaotic seismic facies which downlaps the underlying regional unconformity. The lower slope on the other hand, is made of more flat-lying, parallel–sub-parallel reflectors that may represent finer eroded materials (Fig. 18).

Drilling has shown that the slope facies contain different types of rock materials depending on the position of the well on the slope. On the upper part of the slope, the carbonate sediments are more brecciated due to the short distance the sediment has travelled from its source (platform centre). These upper slope sediments are also more liable to dissolution due to the high impart of meteoric water during diagenesis (Fig. 19). Due to the higher permeability associated with these sediments, wells located on the slope of these carbonate platforms are more productive, giving higher flow rates compared to those within the platform centre.

On the central platform, the facies may be higher porosity grainstones or lower porosity packstones depending on the environment of deposition. Permeabilities and, hence, flow rates for these facies are lower as these are less affected by diagenetic meteoric water dissolution.

Post-salt play

The post-salt play in the North Caspian basin is often overlooked because of the smaller size of its reserves compared to the deeper massive accumulations in the carbonate platforms. About six horizons, representing key unconformities and seismic markers, were mapped (Fig. 20). These horizons range from the top of the Kungurian salt to the Tertiary.

Salt movement has been responsible for the creation of post-salt traps. Apart from traditional types of traps related to salt dome crests, key salt-related trapping configurations that offer exploration targets in the North Caspian basin include salt-flank traps, turtle structures, crestal, and extensional fault-related traps. Some examples of these structures have already been drilled but many remain untested in the study area.

Salt flank and unconformity-related accumulations

Many examples of reservoir pinch-out against salt walls have been identified. The salt walls provide seal as hydrocarbons migrate from deeper source rocks and feed overlying carrier beds. In addition, stratigraphic traps, such as unconformity-related traps and accumulations within reservoirs developed above salt diapirs, may contain significant potential (Fig. 21). The Kemerkol Field is a good example of an oil field with trap related to pinch-out on a salt wall and accumulation above salt diapirs in an unconformity-related stratigraphic/structural trap. It is located in the Atyrau region, SW Kazakhstan and was discovered in 1991. The Triassic sandstone reservoirs have porosities in the range of 27–40% and gross reservoir thicknesses of 38–49 m (Republic of Kazakhstan Ministry of Natural Resources and Protection of Environment, 1999).

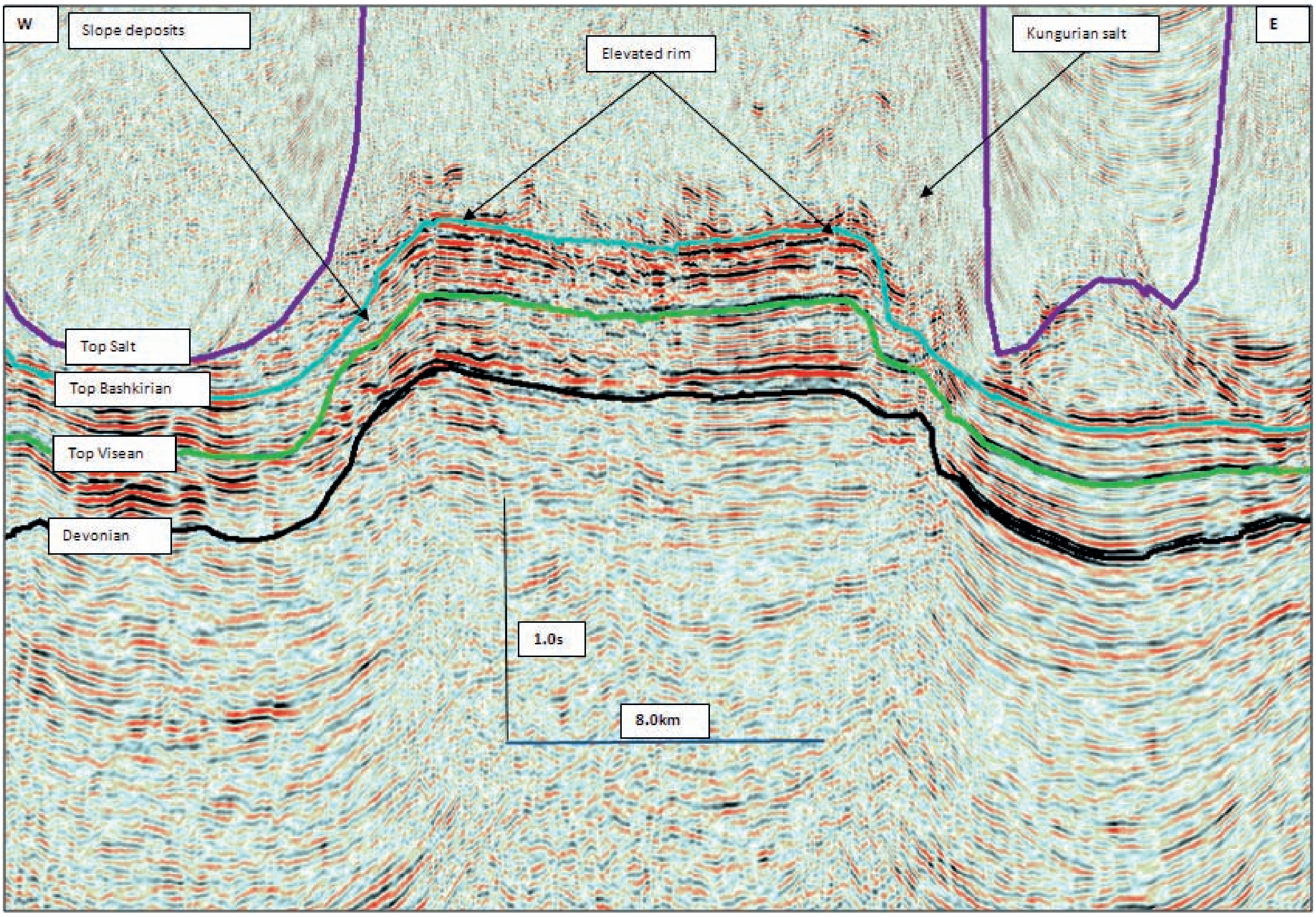

Fig. 16. Representative seismic line across an undrilled carbonate reef in an open block.

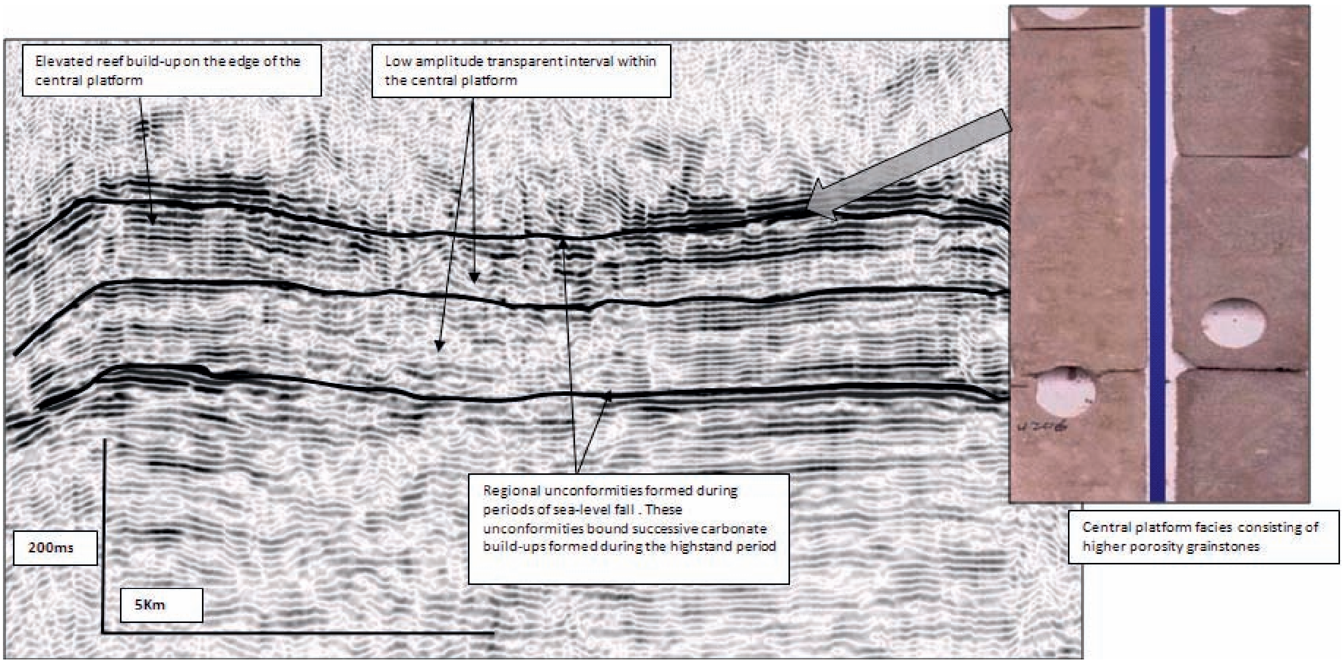

Fig. 17. Interpreted seismic line (central carbonate platform) showing the nature of seismic facies and facies from cored intervals of wells from nearby fields (core from Kenter *et al.* 2008).

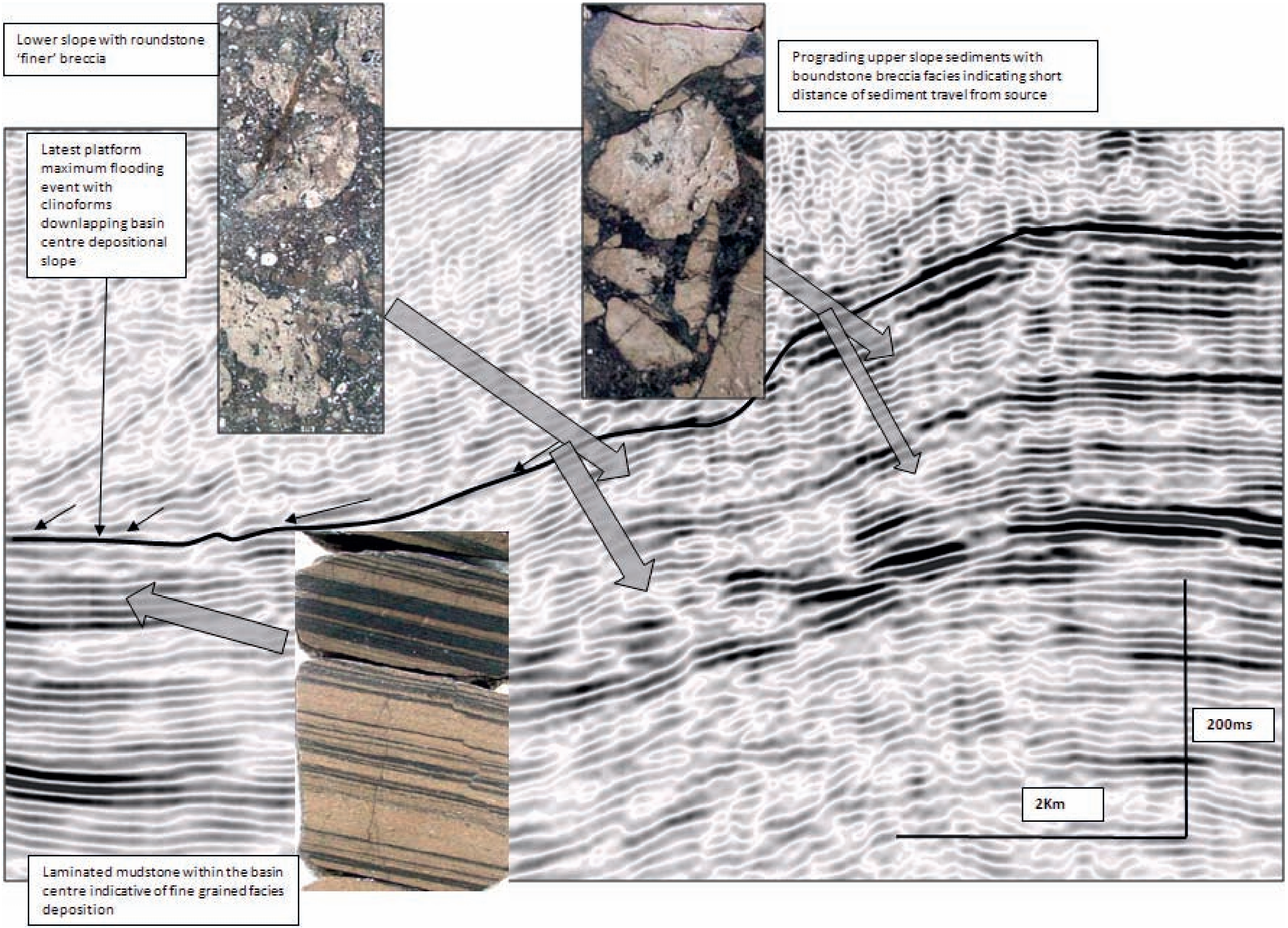

Fig. 18. Interpreted seismic line (slope and basin centre) showing the nature of seismic facies and facies from cored intervals of wells (core from Kenter *et al*. 2008). The cores were taken from the Tengiz Field and represent facies from different sections of the isolated carbonate build-up.

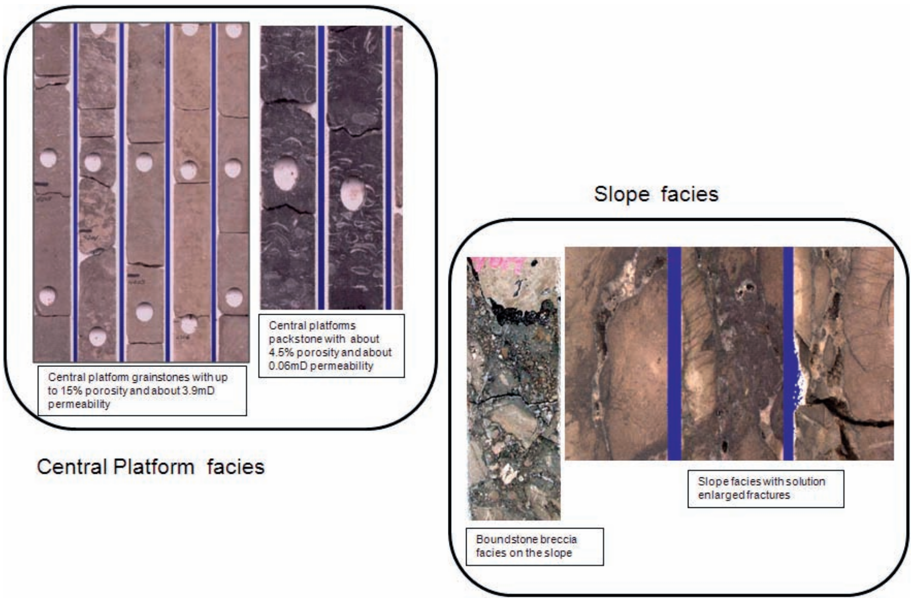

Fig. 19. Interpreted core illustrating the nature of facies on the slope and central platform (Harris 2008; Kenter *et al.* 2008). These cores were taken from the Tengiz Field and represent facies from different sections of the isolated carbonate build-up.

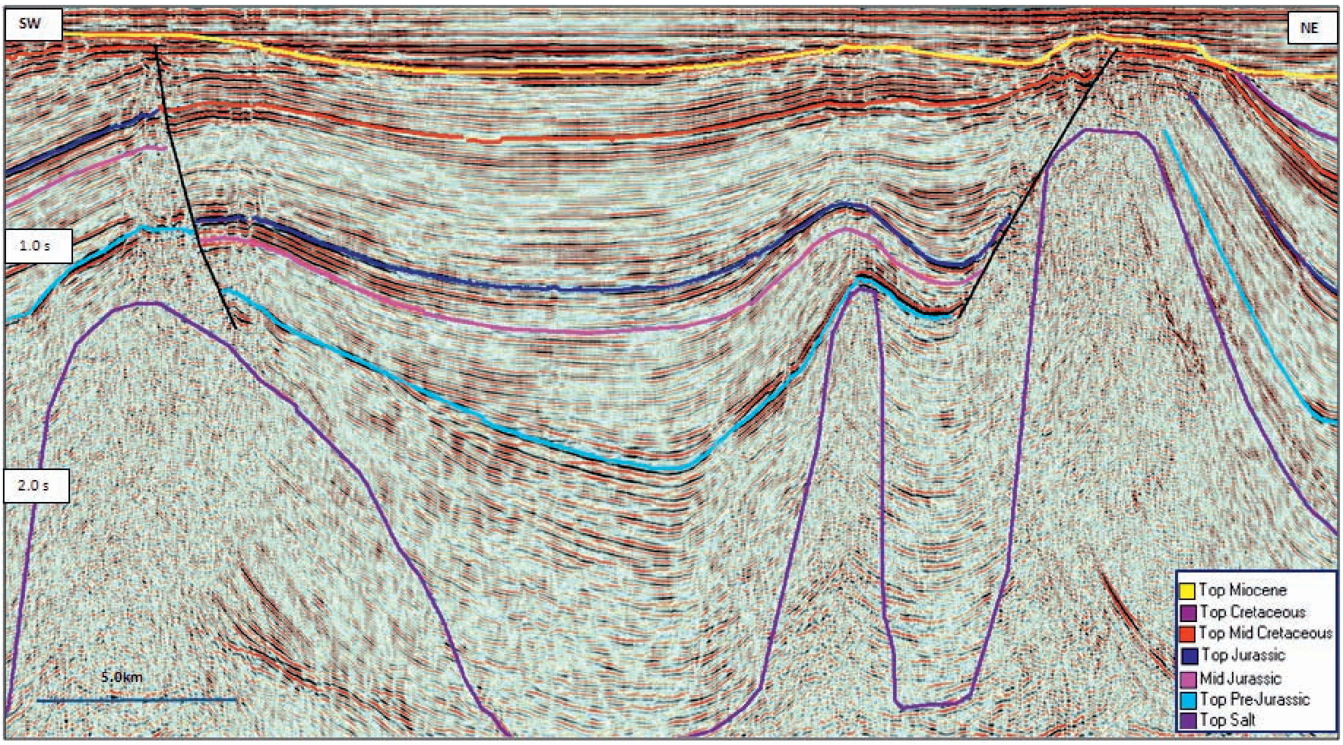

Fig. 20. Interpreted regional SW–NE line illustrating key post-salt seismic horizons.

Crestal and extensional fault-related traps

Several discoveries have been made with hydrocarbons trapped against impermeable shales across extensional faults overlying salt diapirs in the North Caspian basin. The Aiyrtau Field in central Kazakhstan is an example. The field was discovered in 1993 in Jurassic sandstone reservoirs with porosities of more than 37% (Republic of Kazakhstan Ministry of Natural Resources and Protection of Environment, 1999). Within the open blocks, numerous examples of this structural trapping style exist and may contain significant potential (Fig. 22).

Thrust play

The thrust play identified in this study lies within the northernmost extension of the North Ustyurt basin. It has previously been commonly assumed to be part of the pre-salt section of the North Caspian basin. However, our interpretation shows that it is related to a Late Permian–Lower Triassic thin-skinned contractional event that resulted in the folding and thrusting of the pre-Triassic sediments. The thrust sheets and folds are overlain by a syn-orogenic Triassic interval (Fig. 23). The thrusted system and its overlying syn-orogenic Triassic section are unconformably overlain by the base Jurassic unconformity.

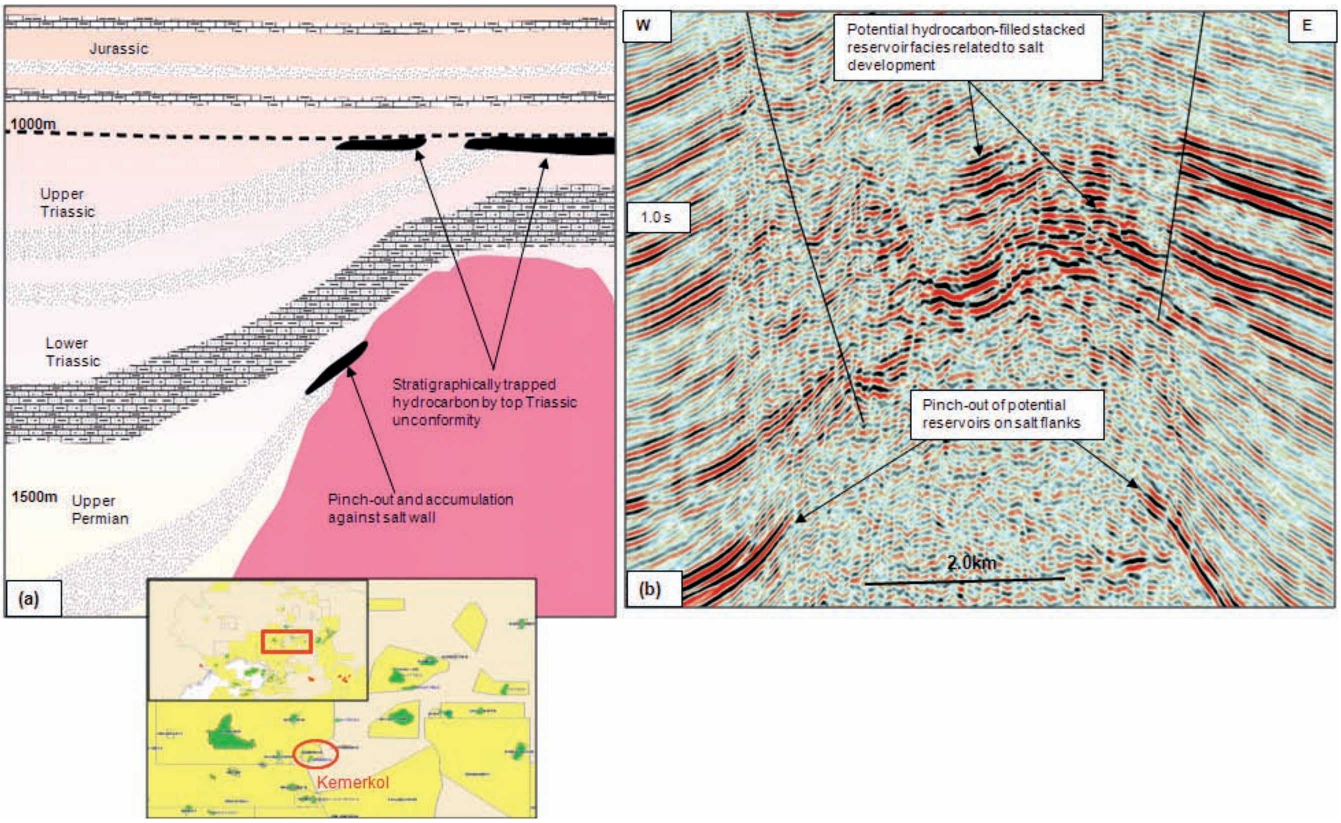

Fig. 21. (**a**) A geological section across Kemerkol Field and (**b**) an interpreted west–east seismic line across one of the open blocks showing traps related to pinch-out against the salt wall and trapping within reservoirs developed above salt diapirs as observed in the analogous Kemerkol Field. (Geological section redrawn from Republic of Kazakhstan Ministry of Natural Resources and Protection of Environment 1999.) Inset map is the location of Kemerkol Field, onshore Kazakhstan.

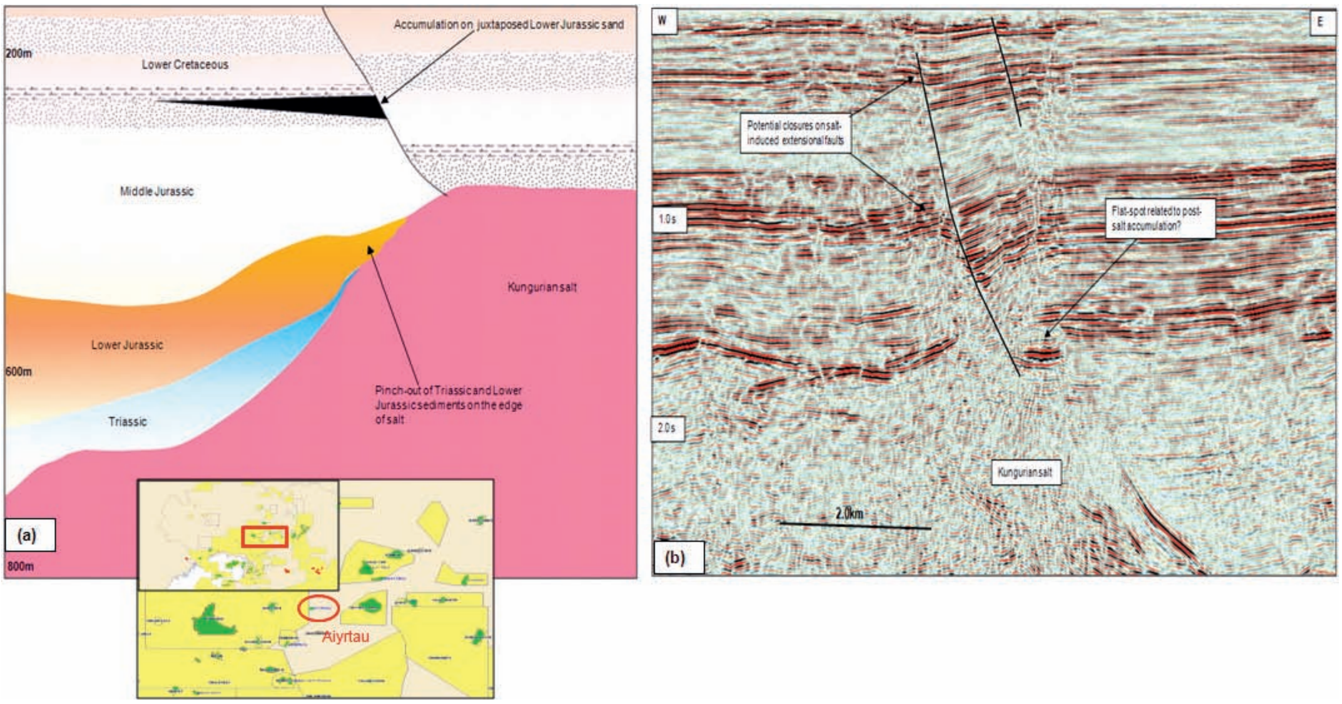

Fig. 22. (**a**) A geological section across Aiyrtau Field, illustrating a drilled extensional, fault-related accumulation within the post-salt play and (**b**) an interpreted west–east section in the open block showing potential post-salt accumulation related to salt-induced extensional fault, as seen in the Aiyrtau Field (Geological section redrawn from Republic of Kazakhstan Ministry of Natural Resources and Protection of Environment 1999.)

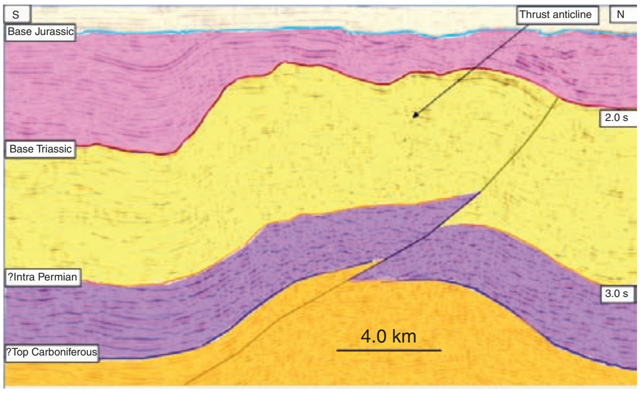

Fig. 23. South–north interpreted seismic line across a section of the North Ustyurt basin illustrating the nature of the thrusted play.

There is currently no record of any well penetrations into the thrusted section of the North Ustyurt basin offshore and only a few wells have penetrated the section onshore. As far as is known, all of the fields within this basin produce from the post-thrust section. However, the Permo-Triassic thrust anticlines and folds provide potential structural traps. Further potential is possible within unconformities and other subtle stratigraphic features. Reservoirs for the structural targets may be located within the thrust sheets, with seals provided by interbedded shales and syn-orogenic argillaceous facies. It is expected that migration of hydrocarbons into these structures would be from deeper source rocks within the Palaeozoic sequences. However, it may also be possible for lateral hydrocarbon migration from the adjacent North Caspian basin.

Post-thrust

Until now the post-thrust section has been the key target within the North Ustyurt basin and even this remains significantly under-explored in the offshore areas. Recently, discoveries have been made on the Kalamkas Sea and Pearl Blocks offshore within the post-thrust section. The trap consists of drape over deep-seated thrust anticlines (Fig. 24). Similar to the discoveries made in the onshore area, the reservoirs of fields offshore consist of interbedded sand–shale layers of Cretaceous and Jurassic age with sealing, in most cases, provided by intra-formational shales and overlying argillaceous sediments. Within known fields, such as Karazhanbas, Kalamkas and Arman, Jurassic sediments vary from 200 m to 1000 m thick and are made up of siltstones and sandstones interbedded with shales (Talwani *et al*. 1998). Cretaceous sediments, which range in thickness from 150 m to 850 m also contain interbedded sand–shale sequences (Talwani *et al*. 1998). Individual sandstone beds comprise fluvio-deltaic sediments and tend to be in the range of 1–10 m thick. However, the sand–shale sequences are massively stacked so that multiple reservoir levels are present in each field.

CONCLUSION

We have attempted to showcase exploration targets within the open blocks of the offshore North Caspian and North Ustyurt basins that are similar to already known plays both onshore and offshore. In addition, we have identified a possible Permo-Triassic thrust play which has not been drilled offshore and have also established that the offshore extension of the North Ustyurt basin demonstrates a significantly different structural and depositional development from the North Caspian basin from the mid-Permian to Early Triassic.

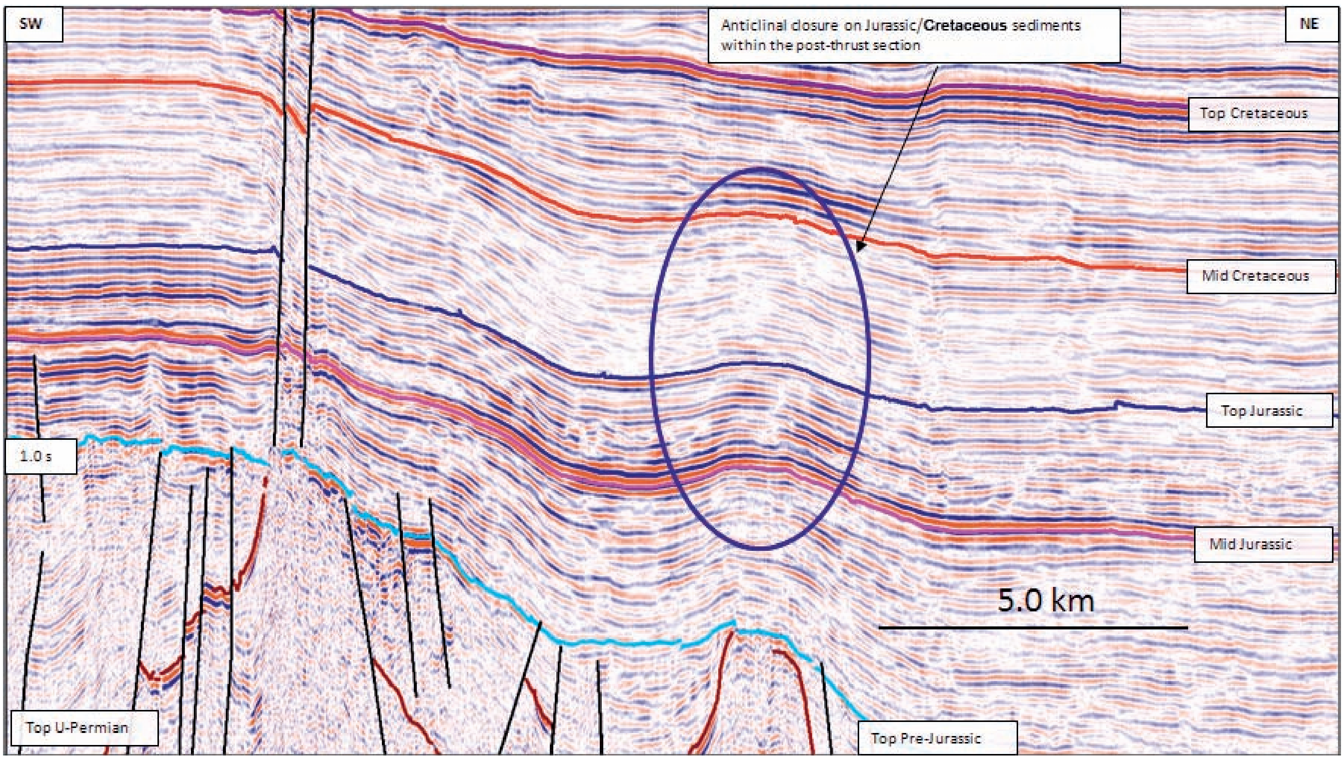

Fig. 24. Interpreted seismic line across the North Ustyurt basin illustrating structure and stratigraphy of the post-thrust section.

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