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# Geometry of the salt-detached Qiulitage structure (Kuqa fold-and-thrust system, NW China): Evaluating sub-salt reservoir potential through seismic and structural interpretation

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## Summary

The Kuqa fold-and-thrust belt developed in the southern foreland of the Tian Shan mountain range in NW China, accommodating Cenozoic intraplate shortening derived from the collision of the Indian and Eurasian tectonic plates. It is characterized by two main east-west striking fold-and-thrust systems separated by a wide syncline. The southern front is the so-called Qiulitage fold-and-thrust belt that comprises of a series of salt-controlled structures that are predicted to be favourable targets for exploration. The surface and subsurface geometry of the 280km-long, E-W trending Qiulitage fold-andthrust belt exhibits significant changes along-strike, and are examined and compared in the central and eastern regions for this study.

In this study, seismic data is integrated with surface and well data to create new interpretations of the Qiulitage. Interpretations are validated by methods of cross-section restoration in the central region (the restoration results are not included in this brief summary). Deformation style is strongly controlled by a décollement associated with the salt located within the Kumugeliemu Group. Additionally, shales and gypsum in the Jidike formations and upper Triassic also behaved as secondary décollements. The thrust system in the central region experienced a strong decoupling effect between pre- and post-salt sequences due to accumulation of thick salt beds, while the eastern region did not, due to the absence of salt. Shortening in the east is balanced locally, and involved the basement. Some observations dispute the existing theory, or suggest a different interpretation proposed by other studies. The analysis in this study may not only forward knowledge about the Qiulitage structure, but may also hold significant implications for future petroleum exploration initiatives.

## Introduction

The structure of the southern margin of the Tian Shan range in northwest China has been extensively studied since the 1980's. Unravelling its complex deformation styles have held significant importance to petroleum exploration efforts, since the discovery of at least 17 medium and large oil and gas fields as of 2013 (Liu, et al., 2017). The far field effects of the Indo-Eurasia collision (commencing in the Eocene) produced several fold-and-thrust belts (FTB), many exhibiting structural trap geometries with potential to host hydrocarbons, such as the Kuqa FTB.

Salt-related structural deformation largely controls the hydrocarbon accumulation of this region, as oil and gas pools are often associated with salt anticlines. Development of salt-related structures is particularly prevalent in the frontal part of the Kuqa FTB, in the Qiulitage fold-and-thrust system (Chen et al., 2004; Wang et al., 2009). The focus of this paper is to investigate the kinematic evolution and compare the

dynamic structural changes observed along-strike of the Qiulitage in the central and eastern region, using seismic profiles integrated with surface and well data.

*Stratigraphy*

For the purpose of this study, the stratigraphic succession is distinguished into pre- and post-salt sequences. The post-salt sequence spans the ages of Oligocene to Quaternary and is comprised of (from oldest to youngest) the Suweiyi, Jidike, Kangcun, Kuqa and Xiyu Fm., of predominantly sandstone lithologies. The entire post salt sedimentary sequence reaches a maximum thickness of 7000m in the hinge zone of the Baicheng syncline. Kumugeliemu salt sequences are Eocene-Oligocene in age, as constrained by magnetostratigraphy studies (Zhang et al., 2014), and consist of thick accumulations of gypsum and halite that laterally grade into detrital units (sandstones, mudstones and conglomerates). Drilling data reveal Kumugeliemu Group bed thicknesses that range between 300-3000m (Well XQ2).

Mesozoic sequences beneath the salt units range in lithologies from mudstones, sandstones and conglomerates, reflecting diverse depositional environments (Tang et al., 2004) and unconformably overlie the Paleozoic. Coal layers are found in the upper part of the Triassic sequence and lower part of the Jurassic and constitute a major décollement within pre-salt units (Li et al., 2012). Furthermore, they are the source rocks of hydrocarbons in this region.

Thrust systems facilitated the migration of hydrocarbons into the main source rock, the upper Cretaceous Bashijiqike Fm. The overlying Kumugeliemu salt beds: (1) are excellent cap rocks for the petroleum system assemblage, and (2) produce salt-related structural traps with potential to host hydrocarbons (Tang et al., 2004). Several salt-related structures have been interpreted previously, including salt pillows, allochtonous salt sheets, salt welds (Tang et al., 2004) and salt diapirs (Li et al., 2012).

## Theory and/or Method

Seismic interpretation was carried out using Move 2015 and Petrel 2013 software. Six seismic lines were interpreted orthogonal to the strike of the Qiulitage structure, connected by the regional E-W in-line dpm-23 (see Figure 1). Three seismic lines have been selected from both the central (Short 2, 4 and 5) and eastern regions of the Qiulitage (Short 8, 9 and 11), in order to characterize the along-strike variations in the geometry of the structure. The length of profiles interpreted ranges between 24km and 61km. Seismic lines from the central Qiulitage were originally depth-converted and were interpreted in Move 2015.

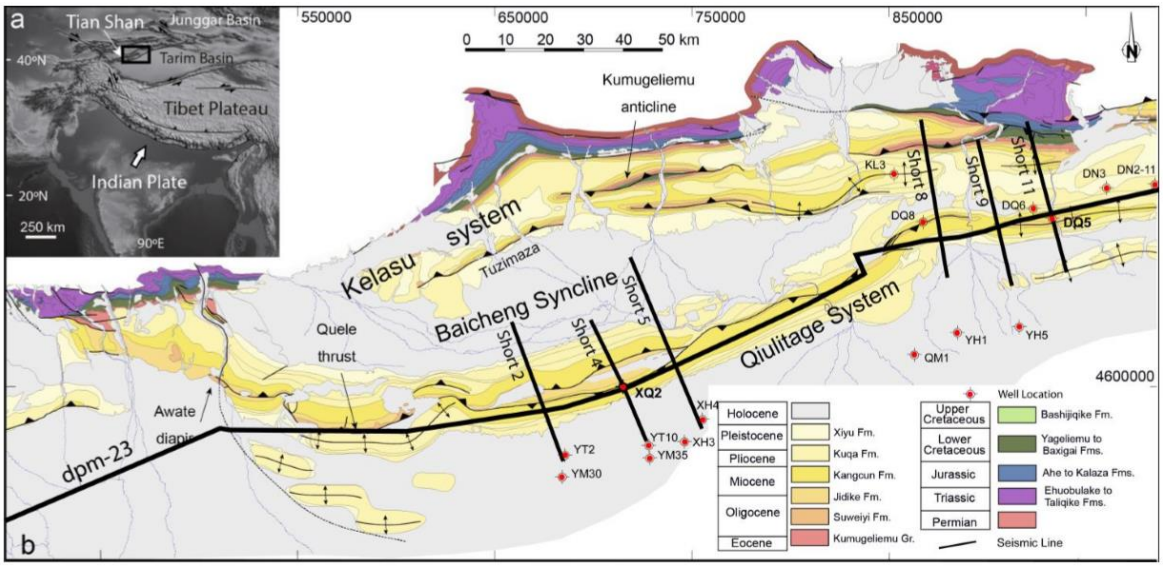

**Figure 1**. (a) Location map of the Kuqa fold-and-thrust belt and (b) Geological map of the study area and seismic lines utilized. A regional seismic line, dpm-23, is imaged along-strike of the Qiulitage structure. Inlines are named Short-XX, and are orthogonal-to-strike (NNW-SSE). Well locations are denoted in red.

The interpreted cross-sections integrate (1) seismic and well data that constrain deformation geometries at depth, and (2) surface data, including geological mapping contacts (draped over the digitized elevation model of the area), and bedding data. Over 180 surface data points were collected on two separate field expeditions conducted by the GEOMODELS team. Additional bedding data were digitized and georeferenced from previously published geological maps (Li et al., 2012).

## Examples

The Qiulitage structure in this region is ENE-WSW trending, and can be distinguished into two detachment anticlines, each cut by south-directed thrusts, and separated by a narrow syncline, as imaged in seismic profiles Short 4 (Figure 2). The dominant south-directed thrust fault terminates at the tipline in the Jidike unit, developing into a backthrust beneath the southern anticline. This type of “fishtail” feature is prevalent in the Qiulitage FTB. Growth of the southern detachment anticline predates the thrusting and folding in the northern anticline, and is synchronous with the deposition of the Jidike, Kangcun and lower Kuqa Fm., as indicated by thinning strata towards its hinge zone.

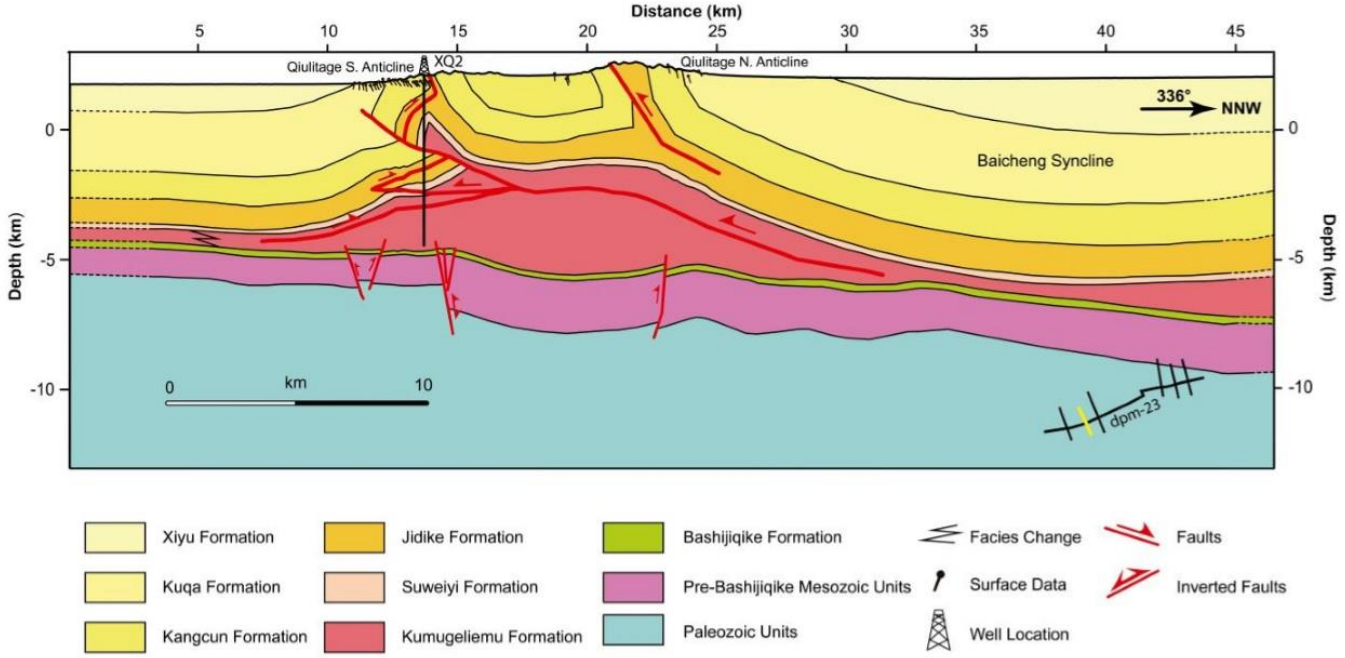


Figure 2. Cross-section interpretation of depth-converted 2D seismic profile Short 4, including the position of Well DQ2.

Structures in this region is interpreted to be defined as a typical break-back sequence, wherein the younger of the two main foreland directed thrusts originated in the hanging wall of the older thrust. The core of the Qiulitage anticline consists of thick accumulations of Kumugeliemu salt, with thicknesses varying from 3000-4000m (as constrained by well data) that are higher beneath the southern anticline. Beneath the Kumugeliemu salt, Mesozoic strata are thicker towards the north, controlled by several short-displacement, steeply dipping reverse and normal faults. The most significant thickness change in the Mesozoic is related to a fault located beneath the southern anticline. Thicknesses of the Mesozoic units found in the hanging wall of this fault are generally several hundred meters greater than in the footwall. A major inverted normal fault (inherited from Mesozoic times) has been interpreted in this part of

the section. Generally, the central region of the Qiulitage can be characterized by folds and thrusts detached along the Kumugeliemu salt, overlying a less deformed Mesozoic sequence.

## Conclusions

Presently, six oil and gas fields have been discovered in the Kuqa fold-and-thrust belt, therefore understanding the role of salt tectonics in governing the evolution of the Qiulitage structural belt is imperative to future petroleum exploration.

Prospective locations for hydrocarbon accumulation are locally recognized in the upper Cretaceous Bashijiqike Fm., found beneath the Kumugeliemu salt beds, which behave as excellent cap rocks. Salt-related structural traps that are the main targets for exploration include hanging-wall fault anticlines, duplex structures and pop-up traps, overlain by salt sequences (Li et al., 2012). In the eastern region of the Qiulitage, where the Dina gas field (a deep Mesozoic fold structure) was found, deep folds underlying salt beds may be excellent targets for exploration. Although in this region, the salt sequences are not as thick, posing a potential problem to accumulation of hydrocarbons. In the central Qiulitage, the salt sequences are continuous and thick, and therefore viable structural traps may occur in the footwall of Mesozoic normal faults.

The interplay of salt tectonics and multiple décollements along the structure contribute to the complexity of the region; therefore constraining the subsurface geometries have been a challenging task. The results of this investigation contribute to regional understanding of the structural evolution of this fold-and-thrust system and the configuration of its petroleum system, in order to direct future reservoir management initiatives.

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