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RESEARCH PAPER

Extensional tectonics and sedimentary response of the Early–Middle Cambrian passive continental margin, Tarim Basin, Northwest China

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Abstract The fact that several half-grabens and normal faults developed in the Lower–Middle Cambrian of Tazhong (central Tarim Basin) and Bachu areas in Tarim Basin, northwest China, indicates that Tarim Basin was under extensional tectonic setting at this time. The half-grabens occur within a linear zone and the normal faults are arranged in en echelon patterns with gradually increasing displacement eastward. Extensional tectonics resulted in the formation of a passive continental margin in the southwest and a cratonic margin depression in the east, and most importantly, influenced the development of a three-pronged rift in the northeast margin of the Tarim Basin. The fault system controlled the development of platform – slope – bathyal facies sedimentation of mainly limestone-dolomite-gypsum rock-saline rock-red beds in the half-grabens. The NW-SE trending half-grabens reflect the distribution of buried basement faults.

1. Introduction

Passive continental margins are formed when continental crust undergoes extensional rifting and are characterized by long-term stable oceanic basins at the outer edge of the continent. As an intermediate process between continental rifting and oceanic spreading, the extension phase contains important information (Cao and Zhou, 2003; Stern, 2007). Studies of the tectonic characteristics of passive continental margins are of great significance in understanding the distribution of stress during the extensional process, analysis of eustatic change, identification of paleoocean and paleoclimate features, reconstruction of the evolutional history of basins, as well as establishment of a sedimentary model. In addition, passive continental margin sediments contain

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abundant hydrated petroleum and natural gas resources (Barr, 1992; Yang et al., 2000; Zabanbarc and Zhu, 2000).

2. Geological setting

Located in Xinjiang Uyghur Autonomous Region in China's far west and bounded by the Tianshan Mountains in the north and the Kunlun Mountains in the south, the Tarim Basin covers an area of 56×10^4 km^2 (Fig. 1) and has abundant oil/gas resources. The basin is the largest petroliferous superimposed structure in China and has experienced multiple stages of formation and reworking. The basin is characterized by an exceptional volume of sediments, prolific source rocks and provides evidence of diverse tectonic events. It is considered to have a high hydrocarbon potential area with possible reserves.

The Paleo-Tarim plate, including the paleo-continental basement formed in the Archean and Proterozoic, and was consolidated during the Neoproterozoic. The pre-Sinian crystalline basement was covered by Paleozoic marine deposits, Mesozoic and Cenozoic terrestrial deposits. During the Early–Middle Cambrian, dolomite and gypsum deposits were dominant in the west, while to the east mudstone was deposited. The maximum thickness of the Early Cambrian dolomites is 200 m, and those of the Middle Cambrian are up to 400 m.

3. Extensional tectonic features during the Early–Middle Cambrian

3.1. New structural interpretation: extensional structures

Seismic data interpretation result indicates that the Tazhong (central part of Tarim Basin) and Bachu areas (Fig. 1) were under an extensional tectonic setting during the Early–Middle Cambrian, when wedge-shaped formations were formed in half-grabens (Fig. 2a). Stratal thickness therefore changes dramatically, and the variation shown by internal seismic reflection indicates changes in lithology and facies. With a subsequent change to a compressive environment, the Tarim Basin underwent tectonic reversion on existing extensional faults and formed additional faults which dip in the opposite direction to the listric faults of the extension phase. The current tectonic framework of the Tarim Basin was formed by these two tectonic regimes (Fig. 2b).

Most half-grabens were developed successively during the Early and Middle Cambrian and contain similar sediment thicknesses. However, the shape of the Middle Cambrian grabens is more distinct than those of the Early Cambrian, implying more intense tectonic activity during that period. Small-scale half-grabens generally are long, narrow features, and when connected form a large half-graben structure, consisting of highland, slope and deep sags (Fig. 3). These large half-grabens largely controlled regional sedimentary geomorphology while smaller component half-grabens controlled the development of local strata and the distribution of sedimentary facies. Generally, seismic reflection within the half-grabens has low amplitude and strong discontinuity, indicating uniform sediments and no component variation. However, the slope and highland areas are characterized by strong amplitude and good continuity indicating a different lithological sequence with frequent change of depositional environment.

In addition to these half-grabens, there are also some normal faults in the Bachu and Tazhong areas which, in combination with the half-graben structures, suggest that the pattern of deposition was developed during the Early–Middle Cambrian (Fig. 4). The basin also experienced differential tilting during lateral extensional. Tilting was minor in the western part of the Bachu Uplift, steepest in the west part of the Hetian River and moderate in the southern part of the Tazhong Uplift.

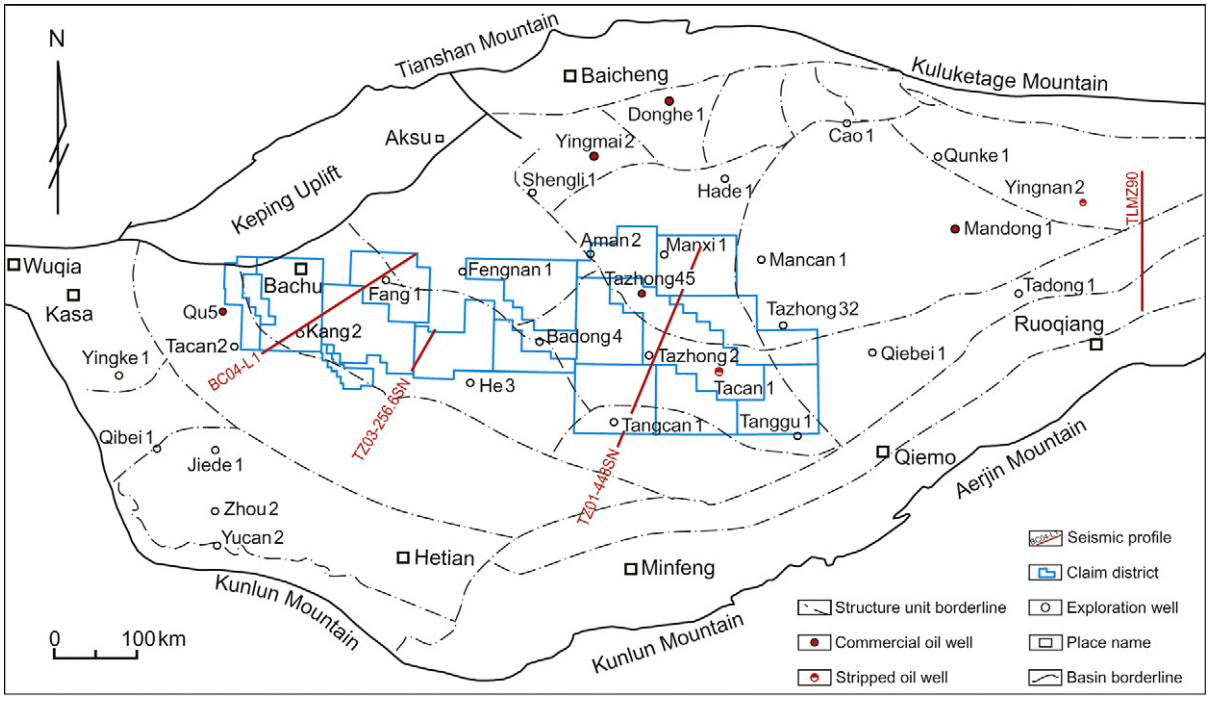

Figure 1 Location of the Tarim Basin, China.

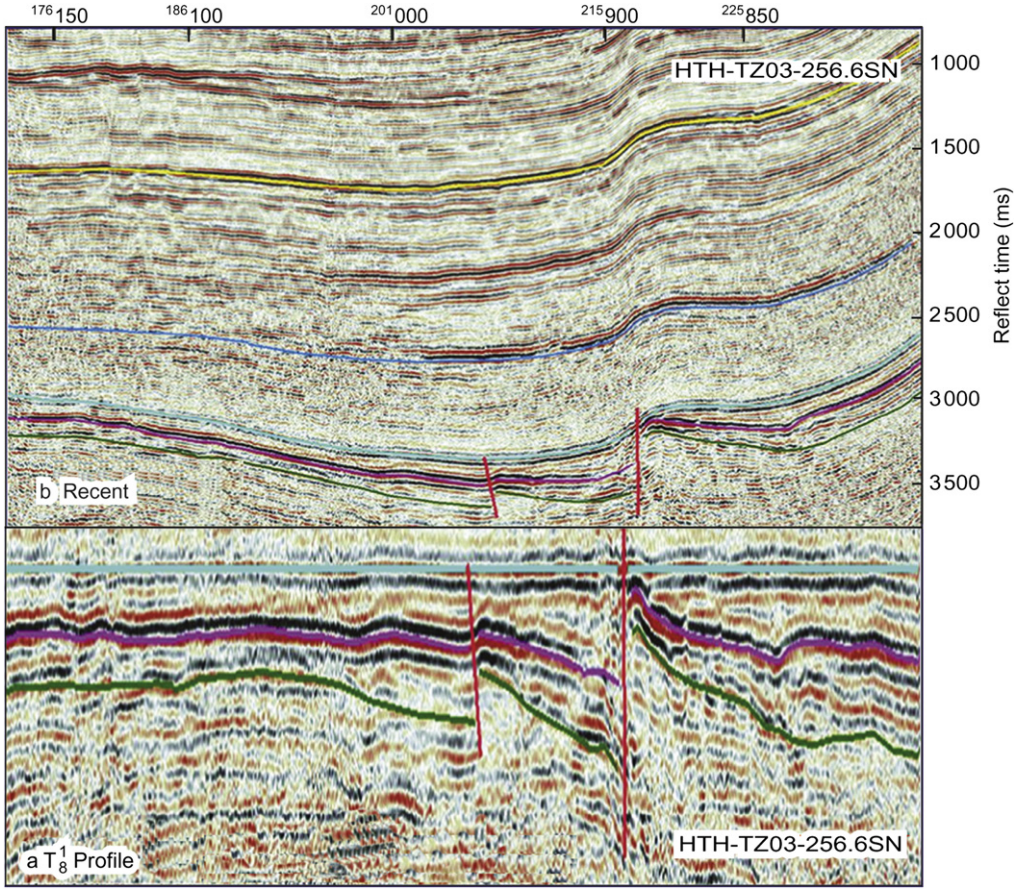

Figure 2 Middle–Lower Cambrian half-graben structures in the Eastern Bachu Uplift, Tarim Basin.

3.2. Fault distribution and vertical evolution rule

Faults in the Tarim Basin are mainly trending NW-SE with an NE or SW dip. Deposition-controlled faults are well developed along T_8^2 boundary surface (base of the Middle Cambrian), particularly in the western part of the Bachu Uplift, west of Hetian River, and in the Tazhong Uplift (Ka1, Ka2 and Ka3 block), as well as being sparse in the Shunxi area (Fig. 5a and b). The T_9^0 boundary surface also has same deposition-controlled faults within the same areas, but with decreasing scale and lower density (Fig. 5b).

In planar view, the faults that controlled half-graben deposition exhibit four patterns: relay, en echelon, parallel stripe and quasi-arch types although the latter two types only occur locally. Relay patterned faults are associated with a range of parallel, discontinuous and overlapping structural units, and are common in the Bachu-Tazhong area. En-echelon faults form near-vertical strike-slip structures and are normally associated with positive or negative flower structures. However, in extensional rift basins, bounding en echelon faults are more usually high-angle normal faults such as those commonly developed in the Tazhong Uplift (Ka2 and Ka3 block), Bachu Uplift, northeastern part of the Hetian River area, northwestern part of the Xiahe block and eastern part of the Maola block. Parallel stripe faults are associated with parallel half-grabens and the horizontal salient between them, and mainly occur in the Bachu Uplift and west of the Hetian River area. Quasi-arc patterned faults comprise two normal-bounding faults striking in different directions that control the formation of the extensional fault blocks, e.g., the intersection area of Ka2 and Ka3 blocks within the Tazhong uplift.

In a vertical sense, boundary faults of the half-grabens experienced two phases of tectonic movement: (1) Extensional movement and fault tilting (rotation) was dominant during the Early–Middle Cambrian, accompanied by a short interval of weak localized compression that did not change the overall tectonic setting of the Early–Middle Cambrian extensional structures; (2) Early–Middle Cambrian compressive-thrust folding which caused reconstruction of the half-grabens.

3.3. Regional kinetic setting of fault development

There have been different basins developed in the Tarim Basin over time. The Tarim Plate that consolidated in the Neoproterozoic and Mesoproterozoic was fragmented in the Early Sinian and formed an asymmetrical continental margin. During the Cambrian and Early Ordovician, the passive continental marginal basin formed due to continued extension of marginal rift basins and a decrease in plate movement (Xu, 2002; Xu et al., 2005; Peng et al., 2006). During the Early–Middle Cambrian, extension from an oceanic ridge caused the Tarim Plate to become a discrete continent that moved to the northeast. A series of half-grabens and normal faults developed during this period, which indicate that the Tarim Basin was a divergent rifted continental margin characterized by fault-angle depressions.

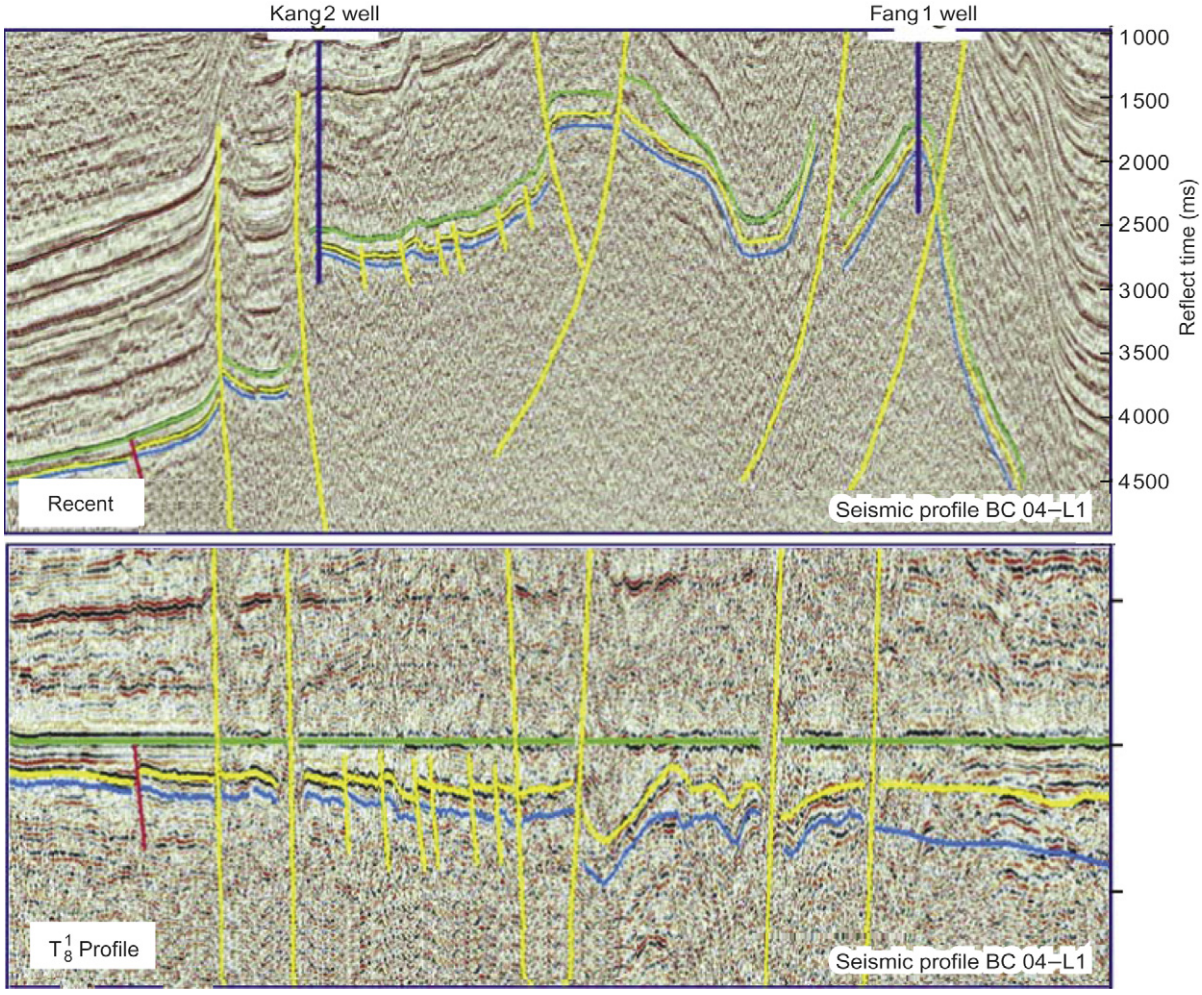

Figure 3 Early–Middle Cambrian half-graben structures in the Western Bachu Uplift, Tarim Basin.

Faulting increased gradually from southwest to northeast (Bachu – Tazhong–northeast of Tarim) (Fig. 6), with the vertical component increasing (400 m, 1600 m and 3400 m respectively) (Figs. 2–4 and 7a) from west to east (Bachu – Tazhong – east of Tarim). This implies that half-grabens and normal faults of the cratonic inner sag in western Tarim Basin were strongly influenced by the cratonic marginal depression of the eastern Tarim Basin and that the development of a three-pronged rift system in the north-east controlled the development of the faults in the basin. In addition, underlying basement faults revealed by gravity and magnetic anomalies, may have reinforced the development of faults in cap rock formations of the basin (Mial, 1995; Zhou et al., 2007). The Early–Middle Cambrian half-grabens are mainly distributed in the areas of the gravity and magnetic anomalies, including the Bachu and Tazhong areas, and were also influenced by underlying basement faults.

4. Control of extensional faults on sedimentary filling

The fault system at margin of the Tarim Basin controlled the formation, evolution and internal structural deformation of the basin, while the faults system in the basin interior dominated sedimentary evolution and later hydrocarbon accumulation events (Pigram et al., 1989; Eberlis and Erickson, 1990; Erickson, 1993).

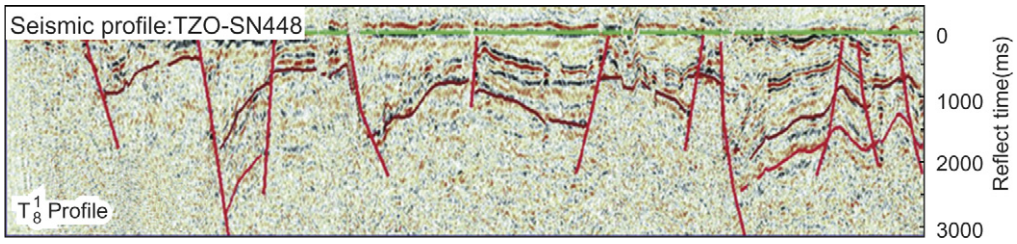

Figure 4 Extensional structures in the eastern Tazhong Uplift, Tarim Basin.

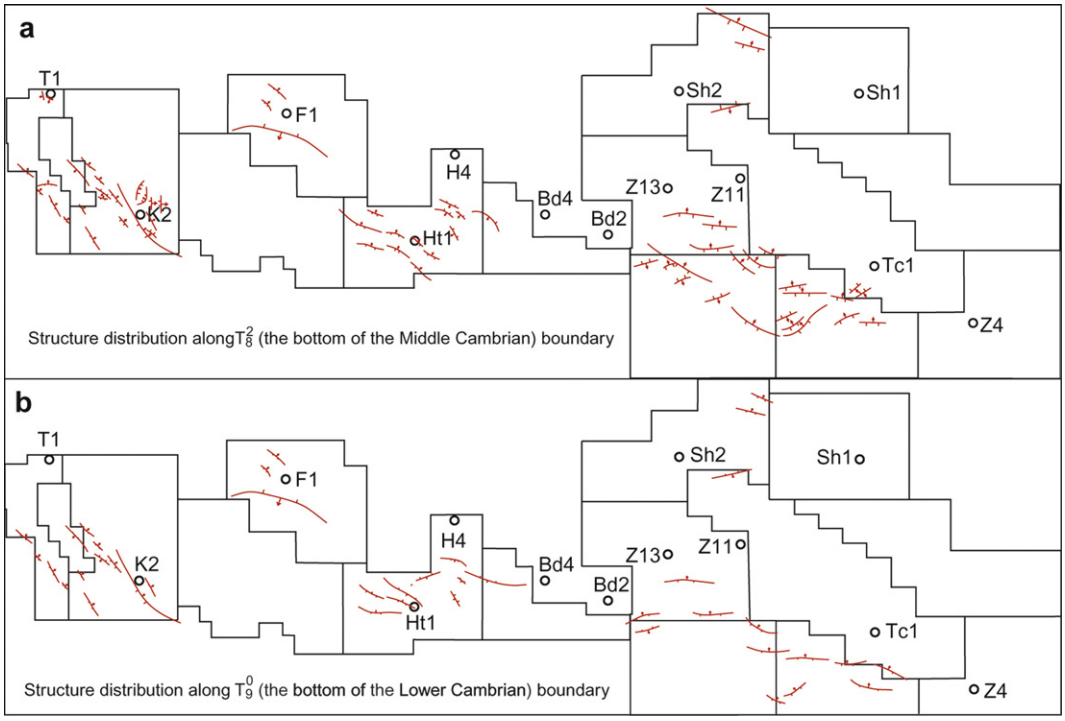

Figure 5 Fault distribution at the base of the Middle Cambrian in Central Uplift area, Tarim Basin.

The extensional faults developed in the Early–Middle Cambrian controlled the pattern of Middle–Lower Cambrian sedimentation.

The Cambrian was a time of rapid continental break-up. During the Early Cambrian, the North Kunlun and South Tianshan rift basins developed on the southwestern and northern margins of the Tarim Basin, respectively, with the Altun-Qimantag uplift forming in the southeast (Wu and Li, 2002; He and Jia, 2005). An open and restricted platform developed in the western cratonic depression due to a high rate of subsidence (Fan et al., 2007; Gao et al., 2006a; Gao et al., 2006b). The eastern part of the Tarim Basin was a cratonic marginal depression as a result of intense extension. Due to different extents of rifting, an abyssal trough formed in the eastern part of South Tianshan in contrast to a neritic shelf in the western part. The Xingdi Fault is the bounding fault between South Tianshan and the cratonic marginal depression of eastern Tarim, with a bathyal basin in the south and a shallow platform, possibly a subsea low uplift area in the north (Jia et al., 2007; Jiang et al., 2008).

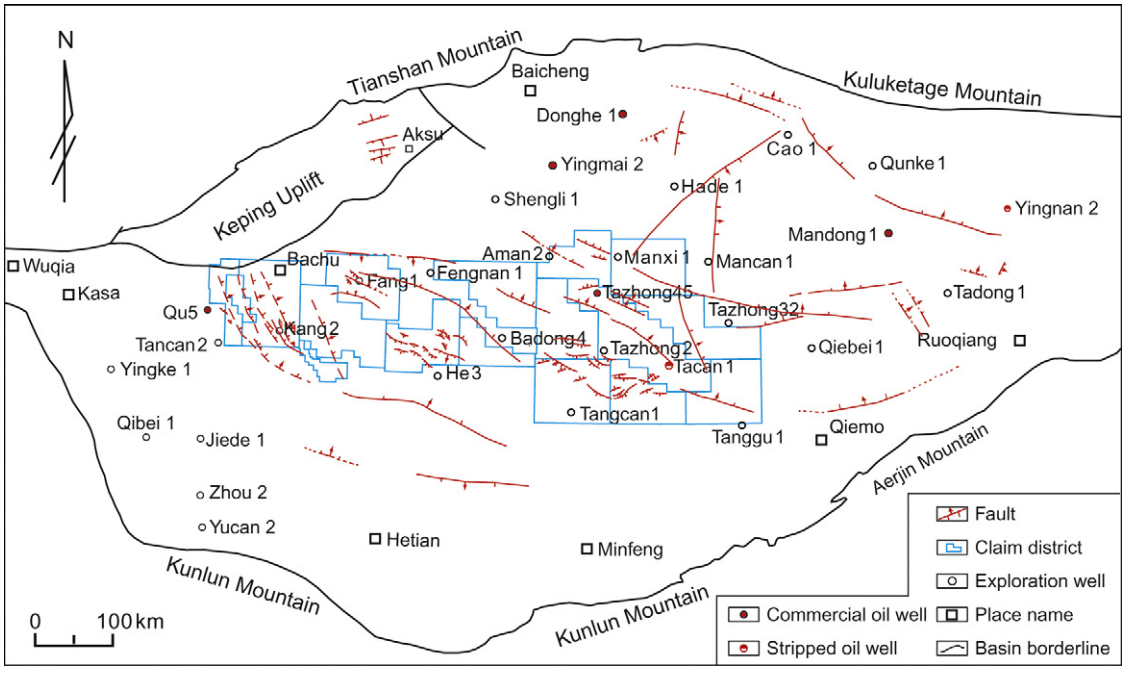

Figure 6 Extensional fault distribution of the Central Uplift area of the Tarim Basin during the Early Caledonian.

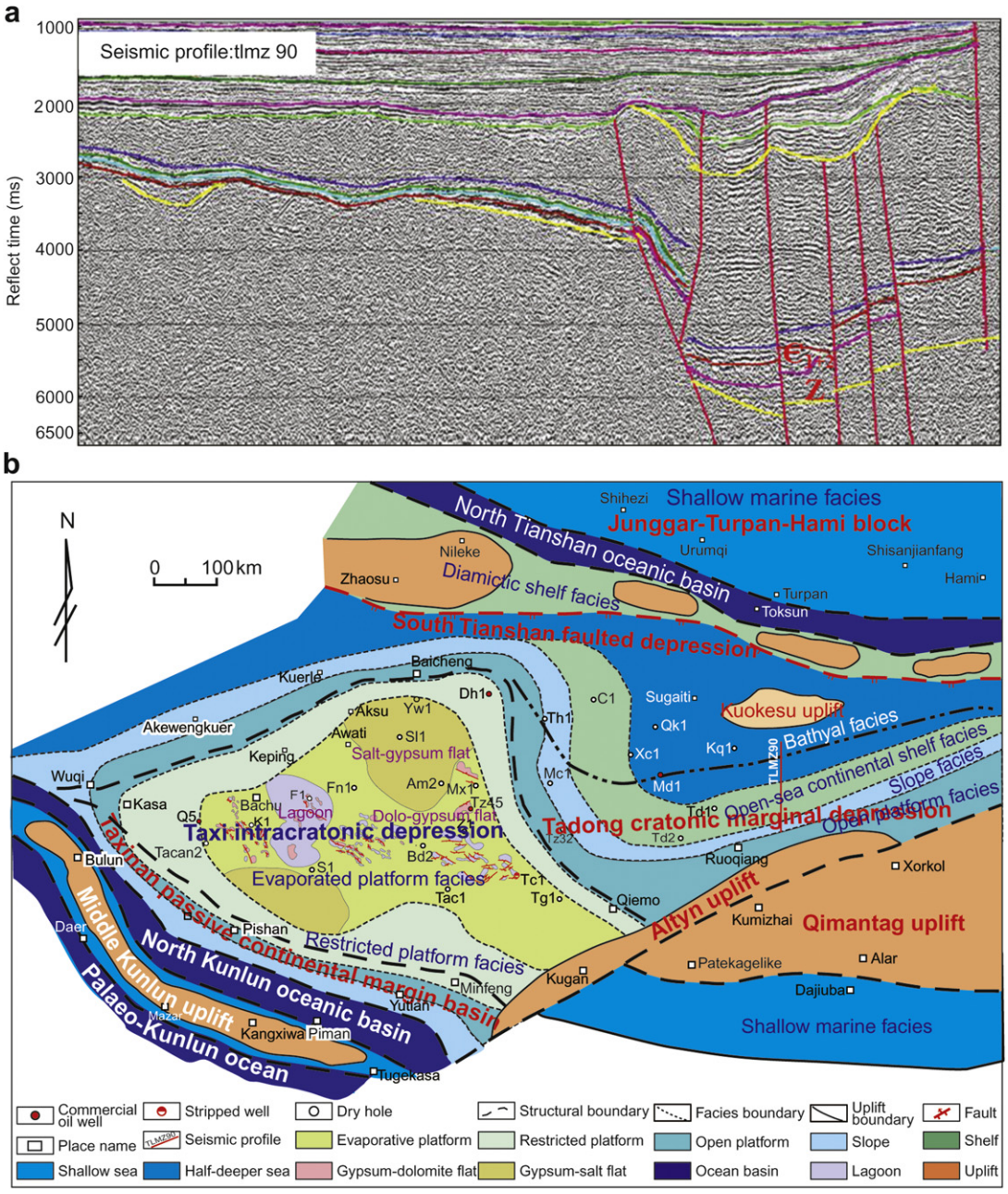

Figure 7 Tectono-sedimentary characteristics of the Middle Cambrian passive continental margin of the Tarim Basin.

In the Middle Cambrian, following formation of the North Kunlun Ocean, a passive continent margin began to form in the Yecheng – Hetian – Yutian area in the southwest of the Tarim Basin, and on which open platform slope sediments were deposited. The eastern Tarim area was still a cratonic marginal depression during this period. With the onset of regional regression, evaporate platform sediments were deposited in the cratonic depression of the western Tarim area. Compared with Early Cambrian developments, this indicates an expansion of the platform southeast of Tazhong and toward the western part of north Tarim (Yu et al., 2000; Zhang et al., 2007). Influenced by the southwestern passive continental margin and northeastern cratonic marginal depression, extensional faulting in the cratonic depression of western Tarim controlled the deposition of lagoonal sediments. The distribution of lagoons was consistent with the SE-NW strike direction of the faults along the Central Uplift area (Fig. 7b). On the southern and northern sides of the depression, gypsum-salt flats were formed and other areas in the depression were characterized by the presence of gypsum-dolomitic flats.

In general, Early–Middle Cambrian deposition with half-grabens indicates decreasing water depth (Fig. 8). In the slope area, from bottom to top, redbeds, halite and gypsum evaporates developed successively. Controlled by extensional faulting, gray or dark gray dolomite and limestone were formed in the lower part of the half-grabens, i.e. indicating a reducing environment. Reddish interbedded of gypsum, salt deposits and mudstones were formed on the slopes of the half-graben, suggesting near-surface turbulent deposition environment. The overlying sediments mainly include red or red-brown mudstones deposited under subaerial conditions. The slope evaporates layers form good hydrocarbon reservoir-seal rocks of the underlying dolomitic oil/gas reservoir.

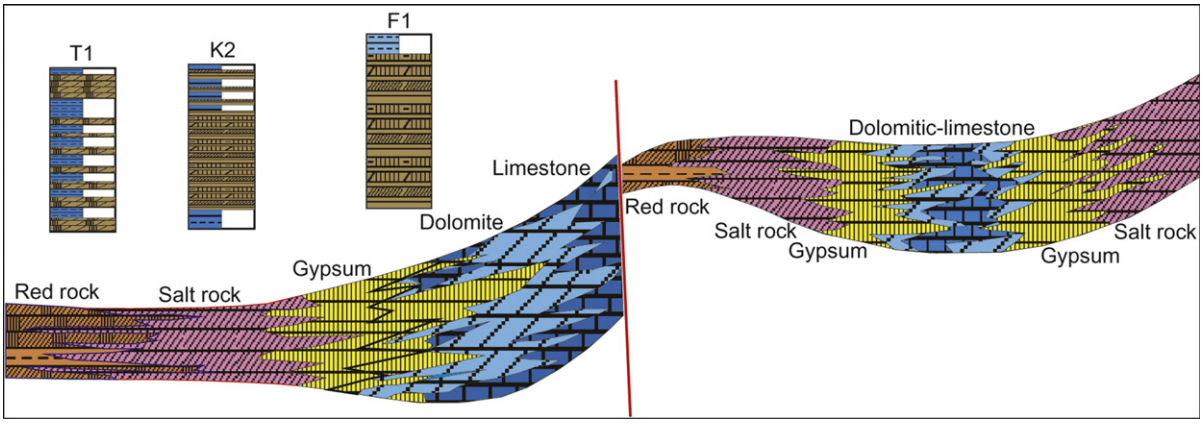

Figure 8 Sediment distribution in the Middle Cambrian half-grabens, Tarim Basin.

5. Conclusions

(1) The Tarim Basin is an extensional basin of Early–Middle Cambrian age and contains half-grabens bounded by normal faults. The half-grabens have a linear distribution along the area of Central Uplift in the basin. The controlling faults were NW-SE striking and have increasing displacement from west to east.

(2) The formation of Early–Middle Cambrian extensional structures were associated with the development of a passive continental margin in the southeast and a cratonic marginal depression in the east of the Tarim Basin. Half-grabens were the products of intensive extension during the formation of divergent continental margin. Their development was dependent on the extent and location of extension, and their distribution was influenced by underlying basement faults.

(3) The faults system controlled the sedimentation patterns and the evolution of deposition in the Tarim Basin. During the Middle Cambrian, when the structural framework of intracratonic depression in western Tarim – cratonic marginal depression in eastern Tarim–depression in South Tianshan formed, platform, slope, and abyssal basin facies sediments were deposited, respectively. Controlled by extensional faulting a lateral transition of limestone, dolomite, gypsum rocks, salt rocks and red beds were developed successively on steep to gentle slopes within half-grabens of the basin.

Acknowledgments

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