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Neogene coupling between Kuqa Basin and Southern Tien Shan Orogen, Northwestern China*

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Abstract: Based on the sedimentary and subsiding features of Kuqa foreland basin, this paper presents the following characteristics of Neogene coupling relationship between Kuqa Basin and Southern Tien Shan Orogen, Northwestern China: (1) The Southern Tien Shan Orogen underwent Neogene uplifting of 4 km in height and the Kuqa Basin underwent Neogene subsidence of 4–6 km in depth accordingly beginning in 25 Ma; (2) The Southern Tien Shan Orogen moved continuously toward the Kuqa Basin, with largest structural shortening rate of greater than 53.7%, and the north boundary of the Kuqa Basin retreated continuously southward accordingly since the Miocene; (3) There are two subsidence centers with high subsiding rates and large subsiding extent, located in the eastern and western Kuqa Basin respectively, with the subsiding maximizing in the deposition period of Kuqa Formation.

Key words: Kuqa Basin, Southern Tien Shan, Coupling between basin and orogen, Neogene
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INTRODUCTION

Since the Late Cenozoic, the tectonic regimes of central Asia continent deformation have been under the control of the result of Indian-Tibetan continent collision, with its stress propagating in the remote continent interior (Guo *et al.*, 1992). As a result of the collision, the Tien Shan, Kunlun Shan, and Altyn Shan belts have been uplifting rapidly, however, the Kuqa Basin and a lot of other basins located along the northern and southern flanks of Tienshan belt have been subsiding rapidly accordingly, so the Tien Shan and the Kuqa Basin are all the results of the intra-continental subduction and relevant structural deformation (Windely *et al.*, 1990; Hendrix *et al.*, 1994; Lu *et al.*, 1994; 1999; Jia, 1997; Guo *et al.*, 1998; Jia *et al.*, 1998; Peltzer and Tapponnier, 1998; Yin *et al.*, 1998; Wang *et al.*, 2001).

The Kuqa depression located on the northern Tarim Basin of Northwestern China originated as a structural basin during the Cenozoic. The young basin was superimposed on the older Late Permian-Middle Triassic Foreland Basin (Lu *et al.*, 1994) enclosed by the Southern Tien Shan mountains to the northwest and the Northern Tarim Uplift to the southeast (Fig.1). The strata exposed in the foothills of the Southern Tien Shan, show the typical sedimentary and structural features of classic foreland basins (Dickinson, 1976; Lu *et al.*, 1994). Recent research indicated that the Kuqa Basin is different from any of the known foreland basins such as peripheral foreland and retro-arc foreland basin (Dickinson, 1976; Hsu, 1988; Li, 1992). It is a late Cenozoic reactivation and rejuve-

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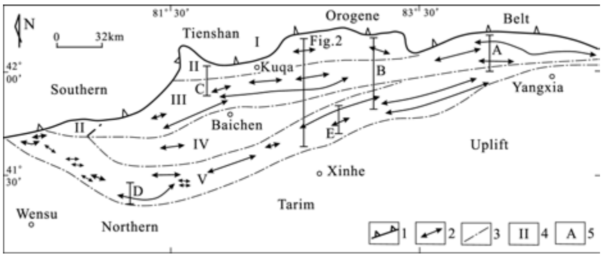

Fig.1 Sketch map of Kuqa thrust belt
I–North thrust belt, II–Sidike anticline belt, III–Keyi anticline belt, IV–Baicheng depression, V–Qiulitage anticline belt; 1–thrust fault, 2–surface anticline, 3–structural unite boundary, 4–unit number, 5–section location

nation of late Paleozoic and early Mesozoic foreland basin, and has a continental crust and developed in an intracontinental setting far from a continental margin. For this reason, Lu *et al.*(1994) described it as a rejuvenated foreland basin.

Kuqa Basin can be divided into four sub-belts from the north to the south respectively as Sidike anticline belt, Keyi anticline belt, Baicheng depression, and Qiulitage anticline belt. To the north is the northern thrust belt (Fig.1). The basin underwent a southward structural deformation, and the fault-related folds such as fault-bend fold, fault-propagation fold (Suppe, 1983; Suppe and Medwedeff, 1990), and detachment fold (Lu *et al.*, 1997; 1999; Jia, 1997; Marrett and Bantham, 1997; Chen *et al.*, 1998; Tian and Song, 1999; Liu *et al.*, 2000; Wei *et al.*, 2000; Wang *et al.*, 2002a; 2002b) developed very well in this basin.

The strata in Kuqa Basin represent a type of sedimentation in an inland-basin setting in the interior of a continent. It includes sediments of Permian, Triassic, Jurassic, Lower Cretaceous, Paleogene, Neogene and Quaternary. The Neogene and Quaternary strata thin southward, with the thickest sediments located on the northern edge of basin, which is 6200 m thick. The Miocene strata include Jidike Formation (N_1j) and Kangcun Formation (N_1k), with the bulk of the Pliocene strata belonging to Kuqa Formation (N_2k). The lower Quaternary series is called the Xiyu Formation, and consists mainly of conglomerate and sandstone (Lu *et al.*, 1994).

Many oil and gas fields have been found in Kuqa Basin since 1958. The main oil and gas fields are Yiqikelike oil field (found in 1958), Dawanqi oil field (found in 1995), Kela 2, Kela 3 and Yinan 2 gas field (found in 1999), Dina 1, and Dina 2 gas field (found in 2001). As exploration showed, the potential petroleum reservoirs in Kuqa Basin are vast, researches on Kuqa Basin have been intensified in recent years.

STRUCTURAL DEFORMATION

Structural Shortening Rates and uplifting height

Structural Shortening Rates (SSR) can be quantified by Balance-Section (Elliot, 1983; Rowan and Kligfield, 1989; Chen *et al.*, 1992; 1993), which is a powerful method to reconstruct structural deformation in foreland thrust belt. Calculated SSR of the Kuqa Basin and north imbricate thrust wedge based on the method of Balance-Section is listed in Table 1 indicating that the SSR in this area increase westward with SSR increasing gradually from 19.1% in Section A in the East to above 53.7% in Section D in the west. Furthermore, the structural deformation in the south is weaken than that in the north. For example, the SSR of Section E in the south is 22.9%, while the SSR of Section B in the north is 44.9%.

Table 1 Structural Shortening Rates (SSR) of Kuqa thrust belt calculated by balance-section (Lu *et al.*, 2003)

Section Name	A	B	C	D	E
Shortening Rates (%)	19.1	44.9	36.9	>53.7	22.9

With the occurrence of thrusting, the thrust nappes have been developed very well in Kuqa Basin and Southern Tien Shan since the late Cenozoic. As a result, the Southern Tien Shan and the structure sub-belts in Kuqa Basin have been uplifting rapidly. Interpretation of seismic profiles showed that the uplifting extent of the sub-belts and Southern Tien Shan varied from 2 km of the Qiulitage anticline belt in the south, to 3 km of the Keyi anticline belts in the north, and 4 km of the Sidike anticline belt in the northest (Fig.2). So the

South Tien Shan Orogen must have an uplift extent of at least 4 km as the result of the imbrication of strata of different ages.

Structural deformation time

Research on the involved strata indicated that the Sidike anticline belt in the northern Kuqa thrust belt developed earliest, beneath which the thrusting faults have been displaced since the sedimentation period of Jidike Formation. To the south, the Keyi anticline belt developed later. It was mainly formed in the sedimentation period of Kangcun Formation. The Qiulitage anticline belt developed latest, it started to develop in the sedimentation period of upper Kuqa Formation, and some anticlines such as Yaken did not develop until Quaternary (Lu *et al.*, 1999; Liu *et al.*, 2000).

COUPLING BETWEEN BASIN AND OROGEN

Subsiding features of Kuqa Basin

Regarding subsiding features, Kuqa Basin has two subsiding centers during the sedimentation period of Jidike Formation. One is near to the Well Dw102 of Baicheng City in the western Kuqa Basin with sedimentary thickness of 1600 meters and subsiding rate of 200 m/Ma (Fig.3); the other is near Well Dq5 in eastern Kuqa Basin with strata thickness of 1600 meters and subsiding rate of 200 m/Ma.

In the sedimentation period of Kangcun Formation, there were three subsiding centers distributed in Kuqa Basin. The first located at the Well Dw102 of the western Kuqa Basin, the second located in the region between Baicheng and Kuqa City, and the third located in the south of the region from the Well Yn2 to well Dq5. The sedimentary thickness of the three centers are 1300 meters, 1600 meters, and 1700 meters (Fig.4), with the subsiding rates being 108 m/Ma, 133 m/Ma, 138 m/Ma respectively.

Only two subsiding centers developed in Kuqa Basin during the sedimentation period of Kuqa Formation. The first is called Baicheng depression, has strata thickness of 4000 meters, and subsiding rate of 1428 m/Ma; the second is called Yangxia depressions, and has strata thickness of 3600 meters, and subsiding rate of 1286 m/Ma (Fig.5).

The above analysis indicates that the Kuqa

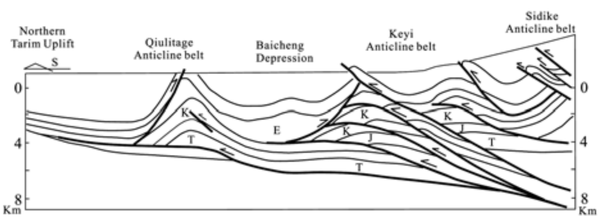

Fig.2 Sketch section of Kuqa thrust belt
Strata: T–Triassic, J–Jurassic, K–Cretaceous, E–Paleogene

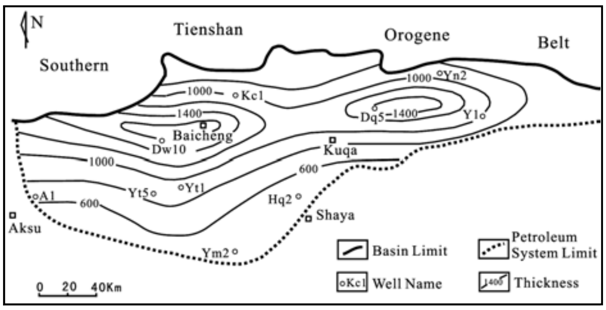

Fig.3 Thickness contour of Jidike Formation in Kuqa Basin

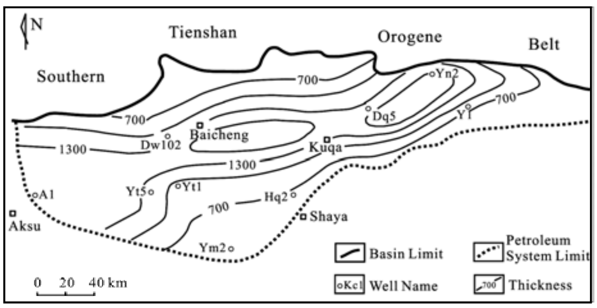

Fig.4 Thickness contour of Kangcun Formation in Kuqa Basin

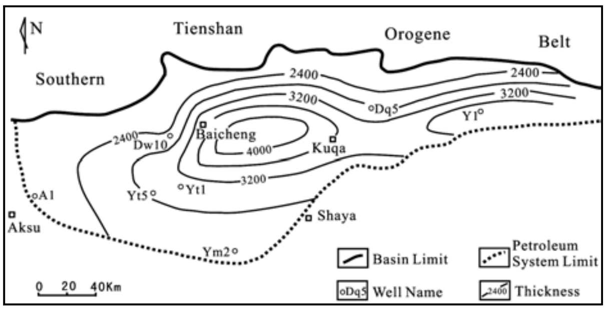

Fig.5 Thickness contour of Kuqa Formation in Kuqa Basin

Basin had very high subsiding rates and thus accepted very thick deposits during the sedimentation periods of Jidike, Cangcun and Kuqa Formation of Neogene. At the same time, the subsiding centers in the basin were also moving southward and eastward continuously.

Coupling between Kuqa Basin and Southern Tien Shan

Based on the fact that the structural deformation in Kuqa Basin took place mainly after the sedimentation period of Jidike Formation, and the thrust and deformation intensity decreased from the north to the south, the southern edge of Kuqa Basin can be regarded as unchanged, while the northern edge is still moving southward. The magnitude of the motion obtained by Balance-Section reconstruction is about 6 km in the east, and 21 km in the west of the Kuqa Basin respectively (Table 1). So we can reconstruct the northern edge of the original Kuqa Basin during the sedimentation periods of Jidike Formation by moving the present northern edge to the north a distance of 6 to 21 km (Figs.6, 7, 8).

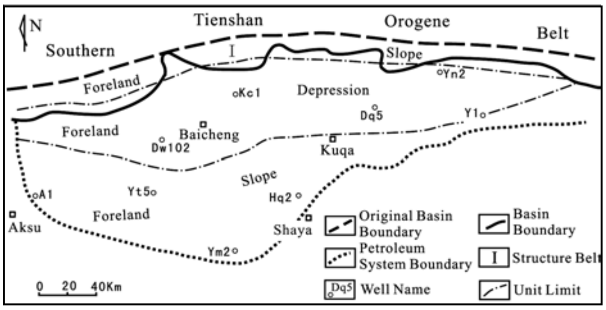

Fig.6 Coupling of Kuqa Basin and Southern Tien Shan Oregen during the Jidike period

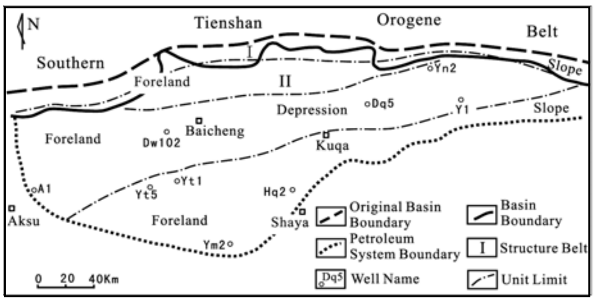

Fig.7 Coupling of Kuqa Basin and Southern Tien Shan Oregen during the Kangcun period

During the sedimentation period of the Jidike Formation, only the Sidike anticline belt had been formed in Kuqa Basin. The deepest subsiding area of the foreland depression was in the region from Baicheng City to the well Dq5, and the subsiding extent was reduced gradually toward the Northern Tarim Uplift, the foreland uplift of Kuqa Basin at that time (Fig.6).

From the sedimentary thickness and subsiding rate, we can conclude that the Southern Tien Shan had at least an uplift height of 1600 meters and uplifting rate of 200 m/Ma during the sedimentation period of Jidike Formation. Our research result (uplifting rates between 138.8 and 198.8 m/Ma in this sedimentary period) is very similar to that of Yang *et al.*(2003).

During the sedimentation period of Kangcun Formation, almost all of the structures started to develop except some anticlines in the east. At the same time, the north edge of Kuqa Basin moved southwards evidently (Fig.7).

We can also conclude from the subsiding features above that the Southern Tien Shan had at least an uplift height of 1700 meters and uplifting rate of 138 m/Ma during the sedimentation period of Kangcun Formation.

Compared with the above two stages, the sedimentation period of Kuqa Formation was the most important stage for the basin evolution. In this period, almost all of the structure sub-belts of Kuqa Basin developed except the Qiulitage anticline belt in the south of the basin, which only started to develop in this period. At the same time, the northern edge of Kuqa Basin moved southwards with largest displacement (Fig.8).

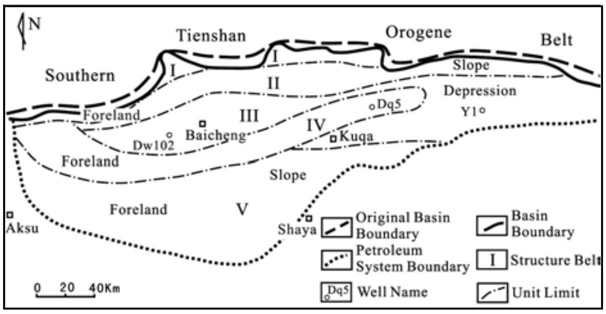

Fig.8 Coupling of Kuqa Basin and Southern Tien Shan Oregen during the Kuqa period

Furthermore, it was also the most important uplifting stage for Southern Tien Shan during the sedimentation period of Kuqa Formation. Based on the subsiding analysis, we can conclude that the Southern Tien Shan must have an uplifting height of 3600 meters and uplifting rate of 1286 m/Ma during the sedimentation period of Kuqa Formation.

CONCLUSION

(1) As a result of the Indian-Tibetan continental collision, with its stress propagating to the remote continent interior during the Late Cenozoic, the Tien Shan has been uplifting rapidly, and Kuqa Basin has been subsiding rapidly accordingly.

(2) The southern Tien Shan orogen underwent late Cenozoic uplifting of at least 4 km in height and Kuqa Basin underwent Late Cenozoic subsidence of 4–6 km in depth accordingly beginning in 25 Ma.

(3) The southern Tien Shan moved continuously toward Kuqa Basin with largest structural shortening rate of greater than 53.7%, and the north boundary of Kuqa Basin retreated continuously to the south accordingly since the Miocene.

(4) There were two subsiding centers with high subsiding rates and large subsiding extent distributed in the eastern and western Kuqa Basin respectively, and the subsiding maximized during the sedimentation period of Kuqa Formation.

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