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Reconstruction of Mesozoic and Cenozoic tectonic figurations of the North China Basin

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Abstract: The North China Basin is a composite basin, which is composed of the west sub-basin and east sub-basin. The west sub-basin is an extensional basin while the east sub-basin is a pull-apart basin. The basin is a composite basin which experienced Cenozoic rifting. The east-west and northeast trending Cenozoic grabens are superimposed on the northwest trending Mesozoic grabens of North China. The North China Basin experienced two episodes of Cenozoic rifting and thermal subsidence in response to the motion of the Tanlu Fault Zone which was controlled by tectonic evolution of the northeast Asia (e.g. opening of Japan Sea). The North China Basin entered extensive extension period in the Late Eocene and Early Oligocene. Movement of the Pacific plate played a more important role than collision between the Indian and Eurasian plates in the evolution of the Cenozoic basin, which led to the dextral strike-slip of Tanlu Fault.

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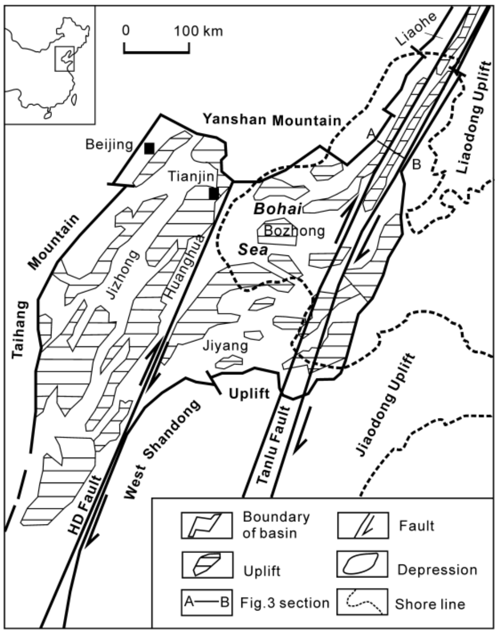
Geological setting

The North China Basin is the largest one of the Mesozoic and Cenozoic basins in the North China Block, a block unique to the Earth's other stable cratons in that it has remained active since the Mesozoic (~220 Ma) (Gao et al., 2002).

The Cenozoic North China Basin was developed on the site of a Mesozoic basin (Hou et al., 2001, 2002). The outline of the Cenozoic basin has a rhomboidal central area with slender arms that extend to both the northeast and southwest (Figure 1). The well-known Tanlu strike-slip fault zone runs in a roughly north-northeast direction through the eastern edge of the basin (Xu, 1993; Xu et al., 1993; Ross et al., 1996). The basin consists of a series of uplifts and depressions containing numerous secondary uplifts and depressions. It is comprised of six major depressions, the Jizhong, Huanghua, Liaohe, Bozhong, Jiyang and Linqing depressions (Ye et al., 1985; Liu, 1987; Lu et al., 1997; Allen et al., 1997). The offshore portion of the basin includes the Bozhong depression, the southern part of Liaohe depression, and some parts of the Huanghua and Jiyang depressions (Gong et al., 1987; Hou et al., 2003). Tertiary strata rest unconformably on a variety of older pre-rift strata and are covered conformably or unconformably by Quaternary sediments. This succession is typically 4-7 km thick within the main depression, with a maximum thickness more than 10 km in the depocenter of the Bozhong depression (Central Bohai Sea) (Ye et al., 1985; Liu, 1987; Hu et al., 2001). Lithologies are dominated by sandstone, mudstone and interbedded volcanic sedimentary rocks. The Cenozoic succession has been divided into six formations: the Kongdian, Shahejie, Dongying, Guantao, Minghuazhen, and Pingyuan Formations, which are further sub-divided into several members (Table 1). The basin experienced two phases of rifting in Cenozoic time (Ye et al., 1985; Allen et al., 1997; Hou et al., 2000, 2001).

Figure 1. Tectonic divisions of the North China Basin



Tectonic divisions of the North China Basin (modified after Hu et al., 2001; Lu et al., 1997) HD Fault-Huanghua-Dongming strike-slip fault

Table 1. Summary of the stratigraphy and tectonic evolution of the North China Basin

Stratigraphy: Series			Formation		Age of bottom (Ma)	Sedimentary facies	Tectonic events	Volcanic activities	Episodes of evolution of basins	Events of plate teconics
	Quaternary	Holocene	Pingyuan	Q_p		Flood plain	New tectonic subsidence, Earthquake	Basalt lava	Quick settling	
					2					
										NE-SW compression Japan Sea was closed
	Late Tertiary	Pliocene	Minghuazhen	N_m		Flood plain	Thermal subsidence and Tectonic inversion, overlying on the Oligocene formations	Basalt lava, but weak activity	Post-rift	
					12					
										Japan Sea strong opened and oceanic crust occurred, N-S back-arc spreading and E-W compression
Cenozoic		Miocene	Guantao	N_g		River-alluvial plain				
					25					
			Dongying-1	E_{d1}		River	Pull-apart basin, sub-tectonic subsidence and transtensional structures	Strong volcanics, basalt lava and mafic dykes		Japan Sea opened as a pull-apart basin, Tanlu Fault dextral strike slip,
		Oligocene								Pacific plate moved to WNW, India and Eurasia collided
	Early Tertiary									
						Delta and submerged fans			Second syn-rif	
			Dongying-2	E_{d2}						
					32				(II)	
			Shahejie-1	E_{s1}		Submerged fans and shallow lake	Sub-thermal subsidence, weak activity	Weak volcanics		
										Pacific plate moved to WNW, India subducted beneath Eurasia, Tanlu Fault dextral strike slip
			Shahejie-2	E_{s2}		Delta and shallow lake				
					38					
			Shahejie-3	E_{s3}		Deep lake, alluvial fan and submerged fans	Pull-apart basin, Strong tectonic subsidence, extensional structures	Strong volcanics, basalt lava and mafic dykes		
		Eocene			42					
			Shahejie-4	E_{s4}		Narrow grabens and alluvial fans	Narrow NW-trending grabens,	Basalt flood basalt	Initial rifting	Pacific plate moved to N-NW and Tanlu Fault sinistral strike slip
			Kongdian	E_k		Alluvial fans and isolated narrow grabens	Extensional structures			
		Paleocene			65					
	Cretaceous	Late Cretaceous	Wangshi	K_{2w}		River-alluvial plain	Uplifting, inversion	Weak volcanics	Post-rift	
					97					
		Early Cretaceous				Lake and volcano				Kula plate moved northward, the collision between North China Block and South China Block continued and led to the sinistral strike-slip of Tanlu Fault
			Qingshan	K_{1q}	140					
Mesozoic							NW-trending basins, tectonic subsidence, extensional structures	K-riched andesite lava and granites, strong volcanics	First Syn-rift	
									(I)	
	Jurassic	Late Jurassic	Mengshan	J_{3m}		Lake , alluvial fans and volcano				
					150					
		Early Jurassic	Fangzi	J_{1-2f}	190	River and marshland	Intra-plate deformation,	Weak volcanics	Pre-rift basement	North China Block and South China Block collided
							Folding			
	Triassic	Late Triassic	Fenghuangshan	T_f		River-alluvial plain				

(modified after Li, 1986; Lu et al., 1997)

Depressions within the basin mostly take the form of half-grabens with the geometry of Cenozoic successions controlled by listric master faults (Ye et al., 1985; Lu et al., 1997; Allen et al., 1997). The dominant structures of the North China Basin are WNW and E-W trending uplifts and depressions in the central basin, and NNE trending uplifts and depressions in the eastern and western parts. Tanlu Fault develops in the east of the basin while Huanghua-Dongming Fault develops in the center of the basin (Hou et al., 2001; Hu et al., 2001) (Figure 1). Syn-rift deposits rest on pre-rift basement and are covered by the post-rift deposition. The North China Basin experienced a typical rifting sequence from tectonic subsidence to thermal subsidence, which has a pull-apart basin pattern, however, the Mesozoic and Cenozoic evolution of its offshore portion (Bohai Sea area) remains ambiguous.

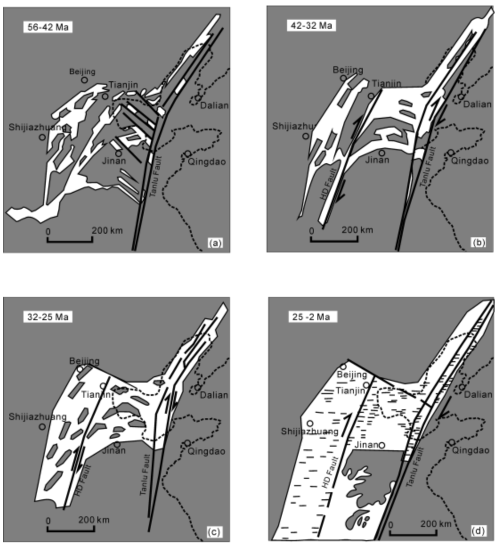
Cenozoic extension of the offshore portion of the North China Basin

Over the past two decades, a number of models for the Cenozoic tectonic evolution of the North China Basin have been proposed and reviewed (Ye et al., 1985; Liu, 1987; Hong, 1989; Allen et al., 1997; Hu et al., 2001; He and Wang, 2003; Zhao and Zheng, 2005; Wang et al., 2006). Here we do not wish provide a review of tectonic models for the North China Basin however, generally, we find these models are based predominantly on the regional geology of the onshore portion of the basin, using very few data from the offshore portion of the basin, the only paper to discuss the thermal history of offshore portion of the basin being Hu et al. (2001). To date, the tectonic evolution of Mesozoic basin is unresolved. The crustal thickness of the offshore portion of the North China Basin (Bohai Sea) is thinnest in the North China Block, suggesting that the offshore portion of the basin played an important role in the evolution of the entire basin. The high sensitive seismic reflection sections and wells collected in recent years have inspired us to research the extension of the offshore portion of the North China Basin.

We chose four representive interpreted seismic sections that cross the orientation of the master faults in Bohai Sea, the offshore portion of the basin. The construction of these balanced-cross sections was analyzed after correction of the compaction curves and thermal subsidence based on the well control and thermal history. The depth (c. 12.6 km) of detachment for the basement faulting was calculated from the earthquake source depth. The method of the construction employed for the cross-sections was introduced by Gibbs (1983). Extension estimates indicate the intensity of extension in the Mesozoic and Cenozoic. Only one section gives an extension estimate of 13.7% for the late Mesozoic time, which is similar to the major extension in the late Eocene and Oligocene (Es1-3 and Ed). This comparison may suggest that the Late Jurassic and Early Cretaceous also witnessed major extension in the evolution of the basin.

The extension estimates of the offshore portion in the Paleocene and early Eocene (Es4-Ek) were calculated to between 3.6% and 8.9%, the mean being 5.8%. The character of sediments and volcanics deposited during this period also suggest that it represented an initial rifting stage (Figure 2a). The Paleocene Kongdian Formation (Ek) and early Eocene Shahejie-4 Member (Es4) are restricted to a few isolated and narrow northwest trending grabens in the east and south of the Bohai Sea area, deposited between 56 and 42 Ma. Their sedimentation commenced with the deposition of coarse alluvial and subaqueous fan clastic rocks, generally red at their base, containing dark lacustrine mudstones in their middle and upper parts (Hou et al., 2000). In this period, the lavas were well developed in these narrow grabens (Hou et al., 2003).

Figure 2. The Cenozoic evolution of the North China Basin



The Cenozoic evolution of the North China Basin

Extension estimates in the Late Eocene and Early Oligocene were calculated from 7.0% to 31.7% with a mean of 18.1%. From 42 Ma, the North China Basin entered new period: the basin became much wider and extension rates increased (Figure 2b). The area of sedimentation expanded, resulting in the development of an interconnected rhomboidal shaped lake. The late Eocene Shahejie-3 Member (Es3) consists of alluvial fans, subaqueous clastic fans, submerged delta and lacustrine mudstones deposited between 42 and 38 Ma. These periods of sedimentation were controlled by the north-northeast or west-northwest trending growth faults. The depocentrers of Es3 were in the Liaohe Bay (north of the Bohai Sea) and Bohai Bay (west of the Bohai Sea). In this period, the volcanic rocks were well developed in the basin. The Shahejie-3 Member was deposited during a major tectonic subsidence and extension stage of the development of the North China Basin. The Shahejie-1/2 Members (38-32 Ma) consist of grey to dark mudstones interbeded with some carbonates and shales (Hou et al., 2000). In the period of their deposition, the basin was wide and deep, but tectonic subsidence was much reduced. The Shahejie-1/2 Members are considered as a period of tectonic quiescence during which the basin experienced its first stage of thermal subsidence.

The extension estimates for the Late Oligocene range from 4.3% to 21.7% with a mean of 11.8%. This period represents the second stage of strong extension in the basin during the Cenozoic interpreted as tectonically driven by major rifting of the basin. The Dongying Formation (Ed) (32-25 Ma) consists of delta and subaqueous fan facies associations lying conformably on the Shahejie Formation (Es1-3) with the basin wider than it was during deposition of the Shahejie Formation. The uplifts appear as several isolated islands in a large rhomboidal lake (Figure 2c). Sediments were deposited in a delta-type sedimentary environment and many deltas were developed in major depressions along the north-northeast and west-northwest trending growth faults. Two large deltas are identified in the Basin, namely the Paleo-Liaohe delta and Paleo-Huanghe delta (Hou et al., 2000), while two large delta fronts filled the center of Bohai Sea. This suggests that the depocenter of the basin migrated from the margins to the center of Bohai Sea in the late Oligocene (Ed) (Hou et al., 2000). Volcanic rocks are well developed in the late Oligocene, but activity was weaker than Shahejie-3 Member (Es3) (Hou et al., 2003).

Extension estimates for the Miocene and Pliocene range from 2.4% to 5.5% (Table 2), making extension during this period almost negligible. Few volcanic rocks were developed in the Miocene and Pliocene and rather than developing large growth faults, only minor east-west trending faults were developed (Figure 2d). Neogene formations lie unconformably over the Paleocene strata in the whole North China Basin. A boundary is easily identified between the Miocene and Oligocene Formations. The Miocene Guantao Formation (Ng) (25-12 Ma) is a plains facies sedimentary sequence, which covered most of the North China Basin, the thickness of which is relatively uniform suggesting that the whole basin experienced thermal subsidence. The Pliocene Minghuazhen Formation (Nm) (12-2 Ma) lies conformably on the Guantao Formation. It is also a plains facies sedimentary sequence consisting of sandstones and mudstones. In the Miocene and Pliocene, the depocenter was located in the center of Bohai Sea, where shallow-lake facies sediments were filled by the rivers flowing in from the margins of the basin (Hou et al., 2000).

Table 2. The extension calclulation of four balanced-across sections in the offshore portion of the North

Balanced-across sections	**Periods**	**Length of sections (km)**		**Extension in each period**	**Extension ratio in each period (%)**	**Accumulated extension**	**Accumulated extension ratio (%)**	**Extension factor (β)**
	Formations	Before extension	After extension					
	Q + Nm	63.9	65.5	1.6	2.6	18.7	39.8	1.4
	Ng	62.2	63.9	1.7	2.7	17	36.3	
L1	Ed	59.6	62.2	2.5	4.3	15.3	32.7	
	Es1-3	55.7	59.6	4	7	12.8	27.3	
	Es4-Ek	53.3	55.7	2.4	4.5	8.8	18.8	
	Mz	46.8	53.3	6.4	13.7	6.4	13.7	
	Q + Nm	55.8	57.7	1.9	3.4	24	71.2	1.71
	Ng	54	55.8	1.8	3.3	22.1	65.5	
L2	Ed	44	54	10	21.7	20.3	60.2	
	Es1-3	36.7	44	7.3	19.9	10.3	30.5	
	Es4-Ek	33.7	36.7	3	8.9	3	8.9	
	Q + Nm	38	38.9	0.9	2.4	14.3	58.4	1.58
	Ng	37.1	38	0.9	2.4	13.4	54.8	
L3	Ed	35	37.1	2.2	6.2	12.6	51.2	
	Es1-3	26.1	35	8.9	31.7	10.4	42.4	
	Es4-Ek	24.6	26.1	1.5	6.2	1.5	6.2	
	Q + N	98.8	104	5.2	5.2	35	50.6	1.51

Conclusion

The North China Basin is a composite basin, which is composed of the west sub-basin and east sub-basin. The west sub-basin is an extensional basin while the east sub-basin is a pull-apart basin. The basin is a composite basin which experienced Cenozoic rifting. The North China Basin experienced two episodes of Cenozoic rifting and thermal subsidence in response to the motion of the Tanlu Fault Zone which was controlled by tectonic evolution of the northeast Asia (e.g. opening of Japan Sea). Extension estimates in the Late Eocene and Early Oligocene were calculated from 7.0% to 31.7% with a mean of 18.1%. From 42 Ma, the North China Basin entered new period: the basin became much wider and extension rates increased. The extension estimates for the Late Oligocene range from 4.3% to 21.7% with a mean of 11.8%. This period represents the second stage of strong extension in the basin during the Cenozoic interpreted as tectonically driven by major rifting of the basin. Movement of the Pacific plate played a more important role than collision between the Indian and Eurasian plates in the evolution of the Cenozoic basin, which led to the dextral strike-slip of Tanlu Fault.

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