Vol 8 No. 5 PROGRESS IN NATURAL SCIENCE October 1998

Subsidence characteristics of Turpan Basin and its tectonic implications

SHAO Lei (邵 磊)[1], K. Stattegger[2], LI Wenhou (李文厚)[3], B. J. Haupt[2] and LIU Yiqun (柳益群)[3]

(1 Laboratory of Marine Geology, Tongji University, Shanghai 200092, China; 2. Geological and Paleontological Institute, University of Kiel, Germany; 3, Department of Geology, Northwest University, Xi'an 710069, China)

Received January 7, 1998, revised January 23, 1998

Abstract The Turpan Basin, a back-arc basin formed during Late Permian, underwent first thermal subsidence and then flexure subsidence. The thermal subsidence took place during Late Permian and Early Triassic following the period of magmatic activities in this region. The flexural subsidence was throughout the Middle Triassic to Early Tertiary induced by orogenic movements which produced periods of high subsidence rates. Accelerated subsided periods occurred during Late Triassic/Early Jurassic, Late Jurassic, terminal Jurassic/initial Cretaceous, and terminal Cretaceous/early Cenozoic, indicating the effect of the collision and accretion onto the south Asian continental margin of the Qiangtang Block in Late Triassic/Early Jurassic, the Gangdise Block in Late Jurassic and terminal Jurassic/initial Cretaceous, and the Indian subcontinent in the terminal Cretaceous/early Cenozoic. There are relatively large breaks in the variation of the petrologic and geochemical data among these events. The Turpan Basin evolved from a back-arc basin in late Paleozoic into a foreland basin in Mesozoic, and a large intermontane basin of the Tianshan Mts. in Cenozoic.

Keywords: sedimentary history, basin analysis, tectonic development, Turpan Basin.

The Turpan Basin is a relatively great intermontane basin of the Tianshan Mts. in Northwest China, and about 5×10^4 km^2 overall. It is connected to the north and northeast with the Bogda Mt. and Haerlike Mt. and towards the south with the Jueluotage Mt. (fig. 1), and located in the foreland region of the Himalayan orogenic belts formed by the collision between the Indian and

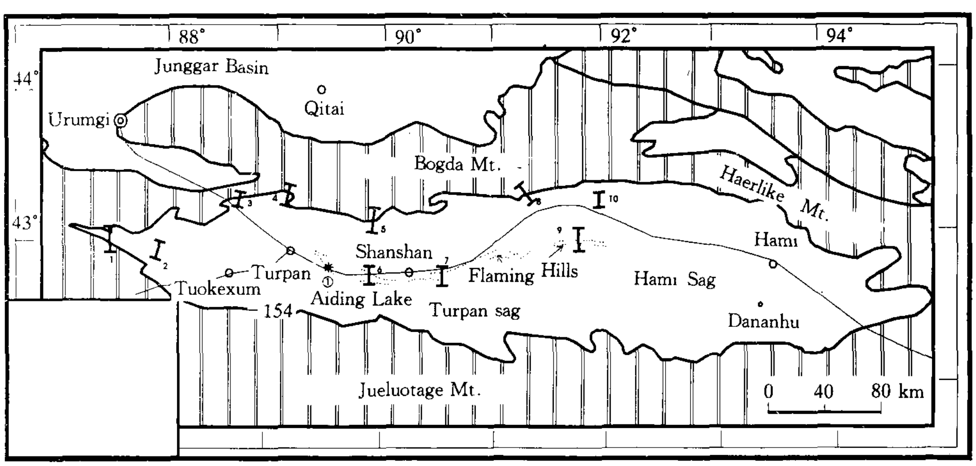

Fig 1 Location map of the studied areas in Northwest China. 1, Aiweiergou; 2, Keyayi; 3, Meiyaogou; 4, Taoshuyuan; 5, Kekeya; 6, Lianmuqin; 7, Qiketai; 8, Qijiaojing; 9, Shisanjianfang; 10, Cheguquanxi. Core profiles: 1 Sheng 101 well I, Outcrop section; *, core profile.

Eurasian plates in the Cenozoic. Moreover, it has thick and well-developed sedimentary sequences. Therefore, this basin is one of the sedimentary basins which are best viewed as a Mesozoic basin with respect to the pre-Himalayan convergent margin of southern Asia. However, there is always controversy and various views on the basin classification and the existence of the thermal subsidence in its evolutional history[1-6]. Some believe that the Turpan Basin is a foreland basin[3, 4]. This paper will discuss the classification of the Turpan Basin and its special evolutional characteristics through the analysis of petrologic and geochemical data, and the comparative analysis with the typical subsidence curve of foreland basins in other areas.

1 Method and data

The modal analyses of sandstone were implemented on 162 thin sections by counting over 300 points per thin section, using the Gazzi-Dickinson point-count method[7]. The major elements were analyzed by conventional X-ray fluorescence (XRF) techniques and the trace and rare earth elements (REE) by inductively coupled plasma emission mass spectrometry (ICP-MS). The utilized decompaction method for subsidence analysis was the backstripping method[8, 10]. Due to the limited extension of individual sections, this analysis used the composite sections of Taoshuyuan section (from Upper Permian to Lower Jurassic) and Lianmuqiu section (from Middle Jurassic to Tertiary). The absolute ages for stratigraphic divisions were derived from Harland[9]. The sedimentary facies are almost continental environment such as lacustrine and fluvial facies through time. The paleowater depth has little affection in the total subsidence of the basin, therefore, we have not considered its influence. The important data of subsidence analysis are listed in table 1

2 Exploratory data analysis

The petrological and chemical data are divided into six groups. The general differences between the groups are described by multivariable analysis and shown in star symbol plots (fig. 2)

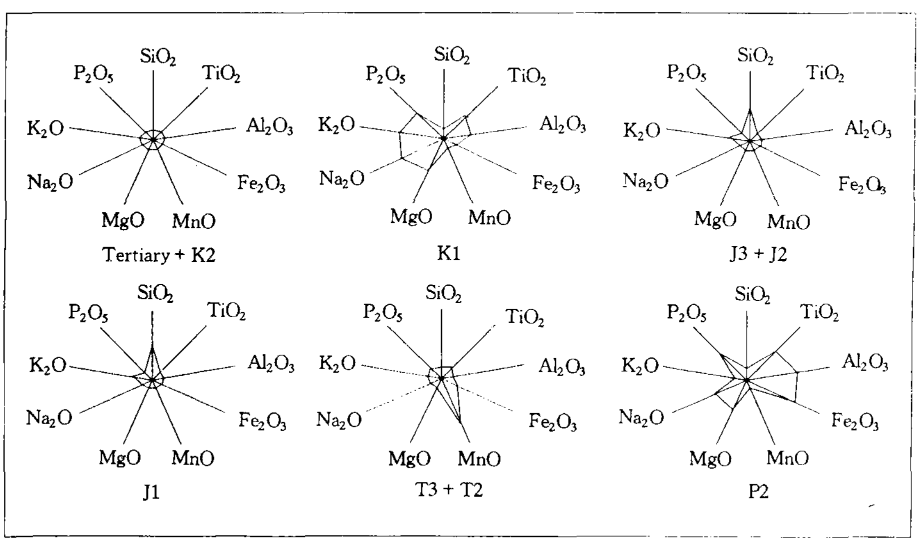

Fig. 2. Star plots of major elements of the Turpan Basin show the distributive characteristic for different periods. P2, Upper Permian; T3 + T2, Middle and Upper Triassic; J1 and J3 + J2, Lower and Upper + Middle Jurassic; K1, Lower Cretaceous; K2, Upper Cretaceous.

Table 1 Data list for the subsidence analysis of the Turpan Basin

Period/Ma	Series	Group	Formation	Thickness /m	Depth /m	ϕ_0	C /km^{-1}	P_{sg} /kg·m^{-3}
	Micoene				0			
			Putaoyuan	901	901	0.46	0.43	2695
23 Tertiary	Oligocene		Taoshuyuan	1117	2018	0.47	0.44	2694
	Eocene	Shanshan	Bakaner	258	2276	0.49	0.49	2713
56	Paleocene		Taizichun	95	2371	0.40	0.31	2644
65	Upper Cretaceous		Subashi	133	2504	0.43	0.36	2672
			Kumutage	96	2600	0.40	0.27	2650
97	Lower Cretaceous	Tugulu	Lianmuqi	163	2763	0.48	0.46	2706
			Shengjinkou	55	2818	0.48	0.45	2703
Cretaceous			Sanshilidadun	534	3352	0.45	0.39	2684
145.6	Upper Jurassic	Aiweiergou	Kalaza	218	3570	0.44	0.38	2678
			Qigu	355	3925	0.49	0.49	2713
157	Middle Jurassic		Qiketai	177	4102	0.47	0.44	2694
Jurassic			Sanjianfang	226	4328	0.47	0.44	2698
178		Shuixigou	Xishanyao	534	4862	0.45	0.39	2684
	Lower Jurassic		Sangonghe	194	5056	0.43	0.36	2668
			Badaowan	490	5546	0.43	0.37	2593
208	Upper Triassic	Xiaoquangou	Haojiagou	159	5805	0.48	0.47	2709
235			Huangshanjie	217	5922	0.48	0.47	2707
Triassic	Middle Triassic		Kelamayi	283	6205	0.48	0.47	2705
241	Lower Triassic	Upper Cangfanggou	Shaofanggou	47	6252	0.49	0.49	2711
			Jiocaiyuan	132	6384	0.48	0.47	2707
245	Upper Permian	Lower Cangfanggou	Wutonggou	138	6522	0.45	0.41	2685
			Quanzijie	214	6736	0.44	0.38	2679
Permian		Taodonggou	Taerlang	514	7250	0.38	0.27	2628
			Daheyan	69	7319	0.35	0.25	2603
256	Lower Permian		P1	?	?			

~~ ~~ or -----, Angular or parallel unconformity, ϕ_0, surface porosity; C, depth coefficient; P_{sg}, density.

In Permian, the contents of Fe_2O_3, MgO, TiO_2, Al_2O_3, Na_2O and P_2O_5 are relatively high, while in the Triassic, the group T3 + T2 has high MnO contents. It is interesting to note that groups J1 and J3 + J2 are the same, indicating a similar element distribution at this time. In the Lower Cretaceous, TiO_2, K_2O, P_2O_5, Na_2O and MgO are increasing. In the Upper Cretaceous and Tertiary (group Tertiary + K2) all elements are almost equipollent, reflecting the relatively well mixed source rock types.

In box-and-whisker plots, most variables for the major element, trace element and petrological data sets are astonishingly consistent, i.e. these plots clearly show that the variational trends of the variables can be divided into three variational periods or parts. Group P2 is the first part; groups of the Triassic and Jurassic, including groups T3 + T2, J1 and J3 + J2, build the second part; groups K1 and Tertiary + K2 are the third part (fig. 3). There are relatively large breaks in the variation of the variables among these three parts, and in each part the variation of the variables of each group is harmonious or changes little from one another. The consistency reveals the tectonic evolutional regularity of the basin and surrounding areas.

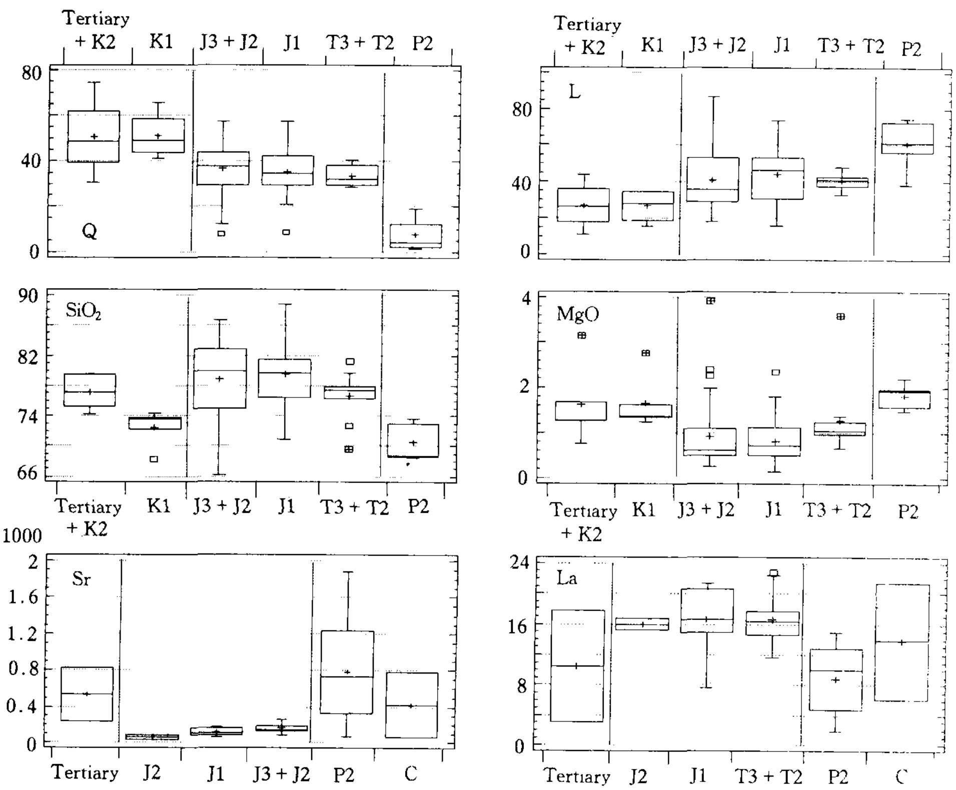

Fig. 3. Box-and-whisker plots of some variables of the Turpan Basin show that there are three variational parts between the data sets: first part = Upper Permian; second part = Triassic + Jurassic; third part = Cretaceous + Tertiary Q, quartz; L, lithic fragments; C, Carboniferous.

3 Subsidence curve analysis

The primary subsidence mechanisms for sedimentary basins are generally two types: the thermal subsidence and flexural subsidence. The thermal subsidence is driven by thermal reequilibration after magmatic activities as magma cools, which leads to contraction of the crust and builds a sedimentary basin. The best example for thermal subsidence is the ocean floor located between ocean ridge and convergent boundary. Its subsidence curve at first is strongly concave-2down and then further smooth downward (fig. 4). This indicates that at the beginning the subsidence rate is very great, and the sedimentary basin is in a rapid subsidence period. After the cooling of magma the sedimentary basin is only slowly further subsidence on account of the weight of sediments and water load. Flexural subsidence is led by tectonic force, the emplacement of a thrust belt load and the weight of the load forming sedimentary basin such as foreland basin. The subsidence curves of these basins consist of segmented lines (fig. 4), reflecting the rate of thrusting in the adjacent orogenic belt and sedimentation rate in the basin. Segmented subsidence curves may reflect the discontinuous movement of the thrust belt. When the stress is great, the subsidence rate of the basin is high, otherwise, the subsidence rate is small.

Due to the special geological position, the Turpan Basin, as well as other west Chinese basins, was classified as one basin type[8], and also called foreland basin or in very general terms intermontance basin[2,3,6]. Fig. 5 shows the curves of total subsidence, tectonic subsidence and paleowater depth. The total decompacted paleosediment thickness is over ten thousand meters from the Upper Permian to Miocene. The highest rates of subsidence were present throughout the Late Permian and Early Triassic, active tectonic subsidence throughout the Middle Triassic and Jurassic, relatively reduced activity during the Cretaceous Period and increased activity in the Early Tertiary. In addition, periods of accelerated basin subsidence occurred during the Late Permian and Early Triassic, Late Triassic/Early Jurassic, Late Jurassic, terminal Jurassic/initial Cretaceous, and terminal Cretaceous/early Cenozoic. In gereral, high rates of subsidence coincide very well with peaks in coarse clastic deposition and there are commonly major unconformities before these periodic high rates of subsidence.

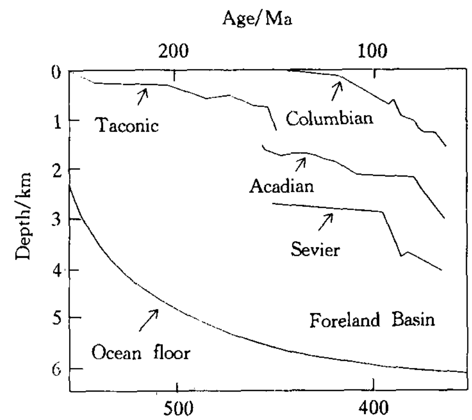

Fig. 4. Subsidence curve diagrams for foreland basins and ocean floor (after Angevine *et al*. 1990), displaying that the flexural subsidence curve of foreland basin consists of segmented lines and the thermal subsidence curve of ocean floor is strongly concave-down and then further smooth downward.

4 Discussion

Due to the Hercynian movement in the late Paleozoic, volcanic and intrusive activities as well as flysch deposits were quite extensively developed in this region during the Carboniferous and Early Permian[11]. Since the Late Permian these activities had slowly ceased, the basin was in an extensional situation[12]. The curves of basin subsidence from the Late Permian to Early Triassic are strongly concave-down forming the highest subsidence rate of the basin, McKenzie[13] suggested that the greatest subsidence of theoretical models of thermal subsidence occurred within about 50 Ma after the onset of extension. This situation was presented also in the Turpan Basin. These segments of the curves reflect thermal subsidence following the period of magmatic activities in this region and mark the beginning of the evolution of the basin. According to the extensional situation, volcanic acitvities and the thermal subsidence, the Turpan Basin should be a back-arc basin in this period. Moreover, the

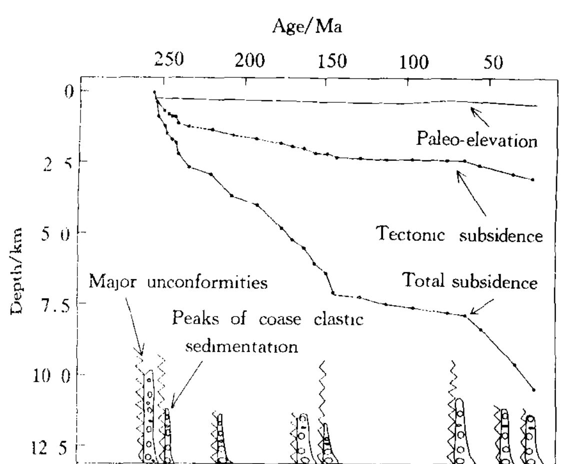

Fig 5 Subsidence history diagrams for the Turpan Basin, displaying that the Turpan Basin underwent first thermal subsidence and then flexural subsidence. The thermal subsidence took place during the Late Permian and Early Triassic The flexural subsidence was throughout the Middle Triassic to Early Tertiary. There are several accelerated subsidence periods associated with the alluvial coarse clastic sediments commonly overlying major unconformities.

subsidence curve and the sandstone composition reflect that there was a tectonic movement at the Late Permian/Early Triassic. At this time the Tarim Block transported toward the north and converged with the Kazakstan Plate[14]. This tectonic event disturbed the thermal subsidence curve of the basin.

During the Middle Triassic and Early Tertiary, the total subsidence rate of the basin is generally in a high scale, although the tectonic subsidence is obviously less than before. There are several accelerated subsided periods in these times. Their segments of the curves are typical of flexural loading subsidence. Accelerated subsided periods occurred during the Late Triassic/Early Jurassic, Late Jurassic, terminal Jurassic/initial Cretaceous, and terminal Cretaceous/early Cenozoic. The variation of the sandstone composition has a great spring point between Jurassic and Cretaceous. The Jueluotage Mt., located in the south of the basin, was the importnat provenance region for the basin in the Triassic and Jurassic, while the Bogda Mt., located north of the basin, had gradually folded and uplifted late, and was an important source region for the basin in the Cretaceous and Tertiary[3, 11].

Liu et al.[15] pointed out that the Qiangtang Block at the Late Triassic/Early Jurassic, the Gangdise Block during the Late Jurassic, terminal Jurassic/initial Cretaceous, and the Indian Subcontinent during the early Cenozoic collided and converged with the Eurasian Plate respectively. Therefore, the acceleratively subsided events can be regarded as the influence of the collision and convergence on this area.

Hendrix et al.[4] displayed a subsidence history diagram of the Turpan Basin in their paper. However, the rapid subsidence period during the Late Permian and Early Triassic has not been displayed on their diagram. Therefore, they believed that the Turpan Basin is only a flexural subsidence basin. In addition, the diagram shows that the higher rates of subsidence occurred shortly after coarse clastic deposition. However, this situation did not appear in our study According to the subsidence curve of the basin (fig. 5) and detailed observations in the field, it is clear that the thermal subsidence existed in the basin and the higher rates of basin subsidence occurred with coarse clastic deposition at the same time, reflecting a coincidence of the rapid tectonic subsidence and the strong erosion in the nearby source regions.

5 Conclusions

The Turpan Basin formed during the Late Permian, underwent first thermal subsidence and then flexural subsidence. The evolution of the basin can be divided into four periods: the rapidly subsiding period (from the Late Permian to Early Triassic); the actively subsiding period (from the Middle Triassic to Jurassic), reduced subsiding period (Cretaceous) and increased subsiding period (Paleogene). Due to the first thermal subsidence, it should not be a foreland basin, otherwise was a back-arc basin in the late Paleozoic. The thermal subsidence took place during the Late Permian and Early Triassic following the period of magmatic activities in this region. The flexural subsidence was throughtout the Middle Triassic to Paleogene induced by orogenic movements which produced periods of high subsidence rates. Accelerated subsided periods occurred during the Late Triassic/Early Jurassic, Late Jurassic, terminal Jurassic/initial Cretaceous, and terminal Cretaceous/early Cenozoic, indicating the collision and accretion onto the south Asian continental margin of the Qiangtang Block in the Late Triassic/Early Jurassic, the Gangdise Block in Late Jurassic and terminal Jurassic/initial Cretaceous, and the Indian subcontinent in the terminal Cretaceous/early Cenozoic. The Turpan Basin evolved from a back-arc basin in the late Paleozoic into a foreland basin in the Mesozoic, and a large intermontane basin of the Tianshan Mts. in the Cenozoic.

Acknowledgement We thank very much Prof. Wang Pinxian and Lao Qiuyuan for giving a lot of support and help in the writing of this paper. The chemical analyses were made in the Chemical Analytical Laboratory of the Geological and Paleontological Institute of the Christian-albrechts-University of Kiel, Germany.

References

1 Carroll, A R , Liang, Y. H , Graham, S A. et al , Junggar basin, northwest China: trapped late Paleozoic Ocean, *Tectonophysics*, 1990, 181: 1.

2 Hu, J Y , Zhao, W Z., Qian, K. et al , Fundamental characteristics of petroleum geology in NW China, *Acta Petrolei Sinica* (in Chinese), 1996, 17(3): 1.

3 Wu, T , Zhang, S. H., Wang, W. H., The structural characteristics and hydrocarbon accumlation in Turpan-Hami coal-bearing basin, *Acta Petrolei Sinica* (in Chinese), 1996, 17(3): 12

4 Hendrix, M S., Granham, S. A., Carroll, A. R et al., Sedimentary record and climatic implications of recurrent deformation in Tianshan: Evidence from Mesozoic Strata of the north Tarim, south Junggar, and Turpan basin, northwest China, *Geological Society of America Bulletin*, 1992, 104: 53.

5 Allen, M B , Windley, B. F , Zhang, C. et al., Basin evolution within and adjacent to the Tianshan Range, NW China, *Geological Society of London Journal*, 1991, 148(2): 349.

6 Chen, F J , Wang, X. W , Zhang, G. Y. et al. Tectonic features and geodynamics of Mesozoic and Cenozoic foreland basins in China, *Earth Science—Journal of China University of Geosciences* (in Chinese), 1996, 21(4): 366.

7 Dickinson, W R., Interpreting detrital mdoes of graywacke and arkose, *Journal of Sedimentary Petrology*, 1970, 40: 695

8 Allen, P A , Allen, J R., *Basin Analysis*, Oxford, London: Blackwell Scientific Publications, 1990, 3—281.

9 Harland, W B., Armstrong, R. L., Cox, A V. et al. *A Geologic Time Scale* 1989, New York: Cambridge University Press, 1990, 1—263

10 Angevince, C L , Heller, P L , Paola, C., *Quantitative Sedimentary Basin Modeling*, AAPG, 1990 1—133.

11 Shao, L , *Sedimentology and Evolution of the Turpan Basin (NW China)*, Kiel: Kiel University Press, 1996, 80: 34.

12 Tao, M X., Tectonic environmental Analysis of Turpan-Hami Basin, *Acta Sedimentologica Sinica* (in Chinese), 1994, 12 (4): 40.

13 Mckenzie, D P , Some remarks on the development of sedimentary basin, *Earth and Planetary Science Letters*, 1978, 40: 25

14 Lin, J L , APW paths for the North and South China blocks, *Seismology and Geology* (in Chinese), 1985, 7(1): 81.

15 Liu, Z Q., Xu, X., Pan, G. T. et al., *Tectonics, Geological Evolution and Genetic Mechanism of Qinghai-Xizang Plateau*, Beijing: Geological Publishing House, 1990, 5(10): 106.