青藏高原东北缘断层泥的研究*

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摘要

本文对青藏高原东北缘一些主要断裂（包括阿尔金、昌马、毛毛山等断裂）的断层泥首次进行了研究。在对断裂带的内部结构、围岩成分、断层泥的厚度及石英颗粒表面特征等综合分析的基础上对断裂的活动年代、活动方式及断层泥形成的深度进行了讨论。石英颗粒表面上溶蚀程度（颗粒表面的光滑程度、凹凸现象及孔洞发育情况）可划分为 6 种类型并且每种类型都有相应的年代。根据断裂的粘滑、蠕滑特征，对该区的各活动断裂进行了粘滑段与蠕滑段的划分。用红外光谱与稀土元素的分析结果，算得断层泥形成的深度在地壳 10 km 范围内。

主题词：青藏高原　断层泥　粘滑断层　蠕滑

（本文 1995 年 12 月 20 日收到）

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* 地震联合基金资助课题

第18卷 第2期 1996年6月 西北地震学报 NORTHWESTERN SEISMOLOGICAL JOURNAL Vol. 18 No. 2 June 1996

STUDIES ON FAULT CLAY ALONG NORTHEASTERN MARGIN OF QINGHAI—XIZANG PLATEAU

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Abstract

The fault clay of some principal faults, including Altun, Changma and Maomaoshan faults, along the northeastern border of Qinghai-Xizang Plateau is first studied. On the basis of the comprehensive analyses of the inner structures, country rock composition, fault clay thickness and quartz grain surface features within a fault zone, the fault activity ages and ways as well as the depth of fault gouges are discussed. The surface corrosion degrees of quartz grains can be classified into six types and each type has a corresponding age. The division standards of fault activity natures are proposed, by which the stick-slip and creep slip parts of a fault zone can be divided. Through the infrared spectroscopic analysis and rare earth element analysis, it is considered that the fault gouge formed at about 10 km depth within the crust.

Key words: Qinghai-Xizang Plateau, Fault gouge, Stick-slip fault, Creep slip

1 Introduction

Fault gouge is formed during fault activity, resulting from dynamic or thermal metamorphism. Professor Wang Jiayin published some papers on this field in the 1940s. Since 1980s the fault gouge studies have made new progress with the development of active fault researches. However, the selected research area was mainly located in Eastern and Southwestern China, but almost nothing was done in Northwestern China. In recent years, the authors studied fault gouge of more than ten principal faults along northeastern margin of Qinghai-Xizang Plateau, such as the Altun, Changma, Maomaoshan and Haiyuan faults. These studies achieved some significant results.

2 Surface Textures of Quartz Grains in Fault Gouge and the Faulting Ages

The faulting age should be related to the surface corrosion degree of quartz grain in fault gouge because the fault gouge underwent many times of chemical processes, particularly the groundwater process after it was formed in a fault zone. In the same physical and chemical conditions, the longer the process is, the intenser the surface corrosion degree of quartz grain is. The quartz is stable generally and its solubility is almost a constant or 10 ppm (Kennedy, 1959) when the PH value of solution is below 9. Therefore, the processing duration is an important factor to determine the surface corrosion degree of quartz grain. As PH values of groundwater in researched areas are generally below 9, the time correlation between processing duration and quartz surface corrosion degree should be better.

In 1985, according to electron microscope scanning results, Kanaori divided the quartz surface corrosion textures into eight types, including subconchoidal, orange peel-like, moss-like, fish-scale-like, moth-eaten, stalactitic, pot-hole and coral-like textures. Then, according to corrosion degrees, he classified the eight textures into four groups and measured the ESR ages of quartz grains in each group. Group Ⅰ corresponds to the Upper Pleistocene to Pliocene epoch, groups Ⅱ and Ⅲ correspond to the Pliocene epoch and group Ⅳ represents the Miocene epoch.

On the basis of observations, it is considered that the group I lasted too long, so it is necessary to divide it in detail to be fit for active fault studies. According to quartz surface smooth degress, concave or convex and holes and combined with other dating results by means of thermoluminescence, ^{14}C and quartz surface corrosion degree analysis, we classified it into six classes as following (Table 1).

Table 1　The shapes and classification of surface textures of quartz grains in fault gouge

Textures	No Corrosion	Corrosion				
	A	B	C	D	E	F
Conchoidal	——					
Subconchoidal		——	--			
Orange peel			——	--		
Fish-scale				——		
Moss-like				——	--	
Stalactitic					——	-
Moth-eaten				-	——	--
Pot-hole						——
Coral-like						——
Epoch	Holocene	Upper Pleistocene	Middle Pleistocene	Lower Pleistocene	Pliocene	Miocene

Class A is characterized by smooth surface, no corrosion, conchoidal texture and it corresponds to the Holocene epoch. For example, the age of fault gouge on the Maomaoshan fault plane is determined to be 6 970±130 a B. P. and 4 086±100 a B. P. or newer. Class B is characterized by smooth surface, almost no corrosion or partly slight corrosion, subconchoidal texture and it corresponds to the Epileistocene epoch. The age of fault gouge on the Yumushan's east margin fault plane is analogous to that of the 4th paleoearthquake determined by Xing Chengqi, i. e. 11 000 a B. P., belonging to late Upper Pleistocene or early Holocene epoch. Based on the quartz surface corrosion degree analysis, age of Changcaogou fault gouge in the Altun fault zone is 25 000—30 000 a B. P., i. e. Upper Pleistocene. Class C is characterized by basically smooth surface, slight corrosion and orange peel-like texture and it corresponds to the Middle Pleistocene epoch. Class D is characterized by partly smooth surface, slight corrosion and concave or convex and fish-scale-like and moss-like textures and it corresponds to the Lower Pleistocene epoch. Class E is characterized by uneven surface, obvious concave or convex, stalactitic and moth-eaten textures, and it corresponds to the Pliocene epoch. Class F is characterized by intensely uneven surface, obvious hole, pot-hole and coral-like texture, and it corresponds to the Miocene epoch.

We add class A for the purpose of convenient application. Classes B, C and D correspond to group Ⅰ in Kanaori classification and class E corresponds to his groups Ⅱ and Ⅲ, class F corresponds to his group Ⅳ。

We have made the statistics and study on the surface corrosion textures of quartz grains in fault gouge from some principal active faults along northeastern margin of Qinghai-Xizang Plateau and the results are listed in Table 2. It is evident that all the corrosion textures almost exist in one sample, but the numbers of corrosion textures are different from each other. This fact shows that all faults in the area had activites with different degrees from the Miocene to Pliocene. The Changma and Maomaoshan faults are Holocene active faults. Activity of eastern segment of the Altun fault has weakened from west to east since Upper Pleistocene.

Table2 Surface corrosion of quartz grains in fault gouge from principal faults

Textures	East Altun fault		Changma fault	Eastern Yumushan fault		Northern Yumushan fault	Jiayuguan fault	Maomaoshan fault
	East part	West part		Middle part	North part			
Conchoidal		40%	60%	18%		+		50%
Subconchoidal		35%	20%	30%			+	15%
Orange peel		20%	10%	30%	62%		+	10%
Fish-scale	70%			16%		+		10%
Moss-like					30%	+	+	8%
Stalactitic			5%	5%		+		
Moth-eaten	25%		3%					5%
Pot-hole	5%	5%	2%	3%	8%	+	+	2%
Coral-like								

+ represents the existence of corrosion, but the number of quartz grains is too small to make statistics.

3 Fault Gouge Features and Fault Activity Ways

Faulting has two activity ways——creep slip and stick slip. The former is characterized by stable and slow fault movement and the latter is characterized by unstable and sudden fault movement. In recent 2o years researchers have paid attention to stick slip studies because stick slip is closely related to earthquake process. Recognizing stick-slip segment of Quaternary active fault has not only theoretcal significance but also practical value for predicting the places where earthquake will possbly occur. However, most stick-slip studies have still been done in laboratory by now and the obtained results have not been applied to practice. On the basis of our field investigations and office observations as well as previous experiment results obtained by other researchers, we propose a set of dividing standards by which we can recognize stick slip segments and creep slip segments of an active fault. These standards are given below.

3. 1　Country Rock Composition of Fault

Logan, et al. made some experiments with marble, dense limestone and sandstone-dolomite complex in 1973. The results show that stick slip would happen under suitable conditions. Our field investigations for the 1932 Changma $M_s 7.6$ earthquake show that the strongest seismic deformation and the greatest dislocation happened in the segment from Daquankou to Shiyouhe. In the segment the carbonate rock was contacted the Upper Tertiary sandstone by a fault. All the cases show that the fault gouge should be formed by fault stick slipping. The movement of northern segment of Honghe fault mainly is stick slip, and the Triassic limestone occurred along the fault segment. Therefore, it seems to us that stick slips happen mainly in the segments where carbonate rocks occurred, and secondarily in segments where strata have higher hardness and more siliceous composition. Creep slips mainly occur in crumby clay rock segments.

3. 2　Inner Structure of Fault Zone

Shimamoto T, et al. (1981) pointed out that the inner structure of fault zone was closely related to activity ways of fault. When a fault is slipping, mechanic natures of clay minerals in fault zone differ from those of the complex mixed by clay minerals and other minerals. According to this fact, they proposed the concept of two-layer fault gouges. We have also observed that the two layer fault gouges with different composition are distributed along the greatest slipping segment of the 1932 Changma $M_s 7.6$ earthquake on the Changma fault. In the east Yumushan fault, double-colour fault gouges are together distributed in the segment where there are paleoearthquake remains. Two layer fault gouges associated with other stick slipping may be important for determining the stick slip segment.

3. 3　Thickness of Fault Gouge

If fault gouges are too thick, clay layers will easily produce ductile deformation, which favours creep slipping. Ductile deformation wrinkles were observed in the thick fault gouge of the segment from Bagexia to Daba in the eastern Altun fault. The thin layer of fault gouge favours producing textural blocking, which will promote stick slipping occurrence. In the northern Qilian fault, the thicknesses of fault gouge observed in the segments where there are strong seismic deformation and evident paleoearthquake remains are all thinner than 2 m. Now we are studying the maximum thickness needed by stick slipping and the favourable thinckness initially leading to creep slipping.

3. 4　Optical Features and Surface Textures of Quartz Grains in Fault Gouge

By optical microscopic study, most mineral grains, particularly quartz grains in fault gouge from Changcaogou, Honggou and Baixianghe faults are sharp-edged or semi-angular, and plastic deformation traces like undulatory extinction and deformation wave almost are not observed. By electron microscope scanning, most quartz grains in fault gouge are angular or semi-angular, and pounding trenches and pits (wedge pit, tongue pit etc.), step joints, conchoidal fractures, radial rupture edges, straight scratches, wallner lines, fatigue waves, etc. are all formed by rapid dislocation. Quartz grains in fault gouges of Hongyaozi and Daba faults are rounded or subrounded, their surfaces have arc scratches and wrinkles, and drag-and-winding deformations occurred near fault planes, which are resulted from fault creep slipping.

According to the above standards and prehistorical and recent seismic data as well as newer stratum deformations, we propose a preliminary method for dividing the activity ages and ways of active fault in the selected area (Table 3).

Table3 The activity ages and ways of active faults in studied area

Faults	Holocene	Upper Pleistocene	Middle Pleistocene	Lower Pleistocene	Pliocene	Miocene
East Altun	∼∼∼	∼∼∼	---	-•-•-	-•-•-	-•-•-
West Altun	-—	———	---	-•-•-	-•-•-	-•-•-
Changma	———	—--	---	-•-•	-•-•	-•-•
Hanxia—Dahuanggou		∼∼∼	∼∼∼	∼∼∼	∼∼∼	∼∼∼
Minle—Damaying		∼∼∼	∼∼∼	∼∼∼	∼∼∼	∼∼∼
East Yumushan	———	———	---	-•-•-		
North Yumushan	———	—--	---	-•-•-		
Jiayuguan	—	———	---	-•-•-		
Maomaoshan	———	---•-•	-•-•-	-•-•-	-•-•-	-•-•-

——stick slip; --inferred stick slip; — •-• unknown active way; ∼∼creep slip

4 Formation Depth of Fault Gouge

We analysed quartz grains in ten fault gouge samples from the east Altun fault by using ultrared-spectrometry. Based on the position difference of wavenumber, the absorption peak of 780 cm^{-1} is shorter than that of 800 cm^{-1}, which shows that the quartz grains formed below 325℃. Therefore, it can be considered that fault gouges were formed within 10 km depth in the upper crust. In addition, the ratio Eu/Sm of rare earth elements in fault gouges has an average value of 0.184, which approximates to that in granite, so the formation depth of fault gouge should be in the crust.

Determining the activity ways of an active fault is very complicated. Our study on this subject is only a preliminary exploration. Many problems will still need to be studied in the future.

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