红河断裂北段地球化学分段特征及其与地震活动性的关系

林元武

(国家地震局地质研究所,北京,100029)

摘要

红河断裂是我国境内主要的区域性活动断裂之一,根据地震地质特征,它被分为南北两段。本文引入一种新的分段法—地球化学分段法,依据断裂上温泉的密度、热储温度、循环深度和 CO_2、HCO_3^-、SO_4^-、F、Li、Sr、B 的含量等特征,把红河断裂北段进一步划分为四个亚段。笔者认为断裂带中的流体对断裂各亚段弱化程度的不同,是引起各个亚段地震活动性差异的主要原因。

关键词: 红河断裂 地球化学分段 地震活动性 流体弱化

地球物理学类核心期刊表*

序号	刊 名	序号	刊 名	序号	刊 名
1.	地球物理学报	6.	地震研究	11.	水文
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CHARACTERISTICS OF GEOCHEMICAL SEGMENTATION AND THEIR RELATION TO SEISMIC ACTIVITIES ALONG NORTHERN SECTION OF THE RED RIVER FAULT, YUNNAN PROVINCE

Li Yuanwu

(*Institute of Geology, SSB, Beijing* 100029)

Abstract

The Red River fault is one of the major regional active faults in China, it had been divided into the southern and northern segments according to the features of seismogeology. A new segmentation method, geochemical segmentation method, is introduced in this paper. Based on the features of densities, reservoir temperatures, circulating depths and concentrations of CO_2, HCO_3^-, SO_4^-, F, Li, Sr and B of the worm springs along the fault, the northern segment is further divided into four sub-segments. The seismic activities along these sub-segments of the fault differ from each other, which is thought to be mainly caused by the differences in weakness degree of each sub-segment due to the fluids in the fautl zone.

Key words: Red River fault, Geochemical segmentation, Warm spring, Seismic activity, Fluid-weakness

Introduction

The study of the active fault segmentation will play an important role in earthquake risk zoning. At present, for the segmentation of the active faults there are three methods, i. e., the nature, combination and rupture segmentation methods, which are mainly according to the data of geomorphology, seismogeology and geophysics etc., but few attention is paid to the features of the fluids in the fault.

The Red River fault is one of the major regional active faults controlled principally by right lateral strike-slip movements in China, it had been divided roughly into the southern and northern segments according to the seismo-geological features [1]. The northern segment is studied in this paper. A new segmentation method, geo-chemical segmentation method, is introduced to segment the fault in more detail according to the geochemical features of fluids discharged from the fault.

Geochemical Segmentation

In order to segment the fault in more detail, author investigated the spatial distributions of the warm springs along the fault (Table 1), and collected 14 spring samples (Fig. 1) whose contents of SiO_2, CO_2, HCO_3^-, SO_4^-, F, Li, Sr, B and $\delta^{13}C$ have been analysed and reservoir temperatures and circulating depths have been calculated (Table 2).

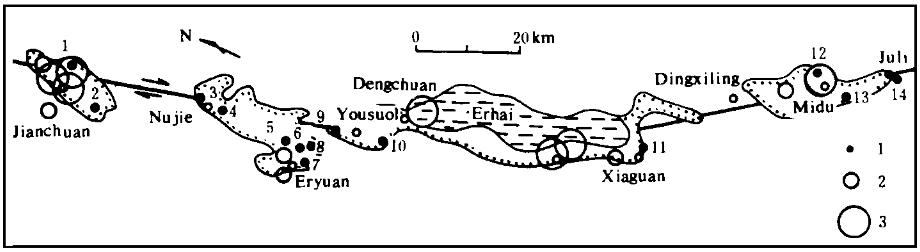

Fig. 1 Sampling locations and epicentres of M≥6.0 earthquakes.
1. Sampling location and its No. ,2. M6.0—6.4, 3. M 6.5—7.0

Table 1　　The spatial distributions of the springs

Sub-segment	Length of fault (km)	The number of warm springs				
		60—80℃	40—60℃	20—40℃	Sum total	Average of each 10km
Jianchuan	20	0	0	4	4	2.00
Eryuan	30	6	5	6	17	5.67
Dali	50	1	0	0	1	0.20
Midu	30	1	3	3	7	2.33

Table 2　　Geochemical characteristics of the samples

Subsegment	sample No.	T (C)	SiO_2 (ppm)	Reservoir tem. (C)*	Circulating** depth (km)	Li (ppm)	Sr (ppm)	B (ppm)	F (ppm)	CO_2 (ppm)	HCO_3^- (ppm)	SO_4^{2-} (ppm)	$\delta^{13}C$ (‰)
Jianchuan	1	22	18.06	105	4.5	0.40	1.2	0.6	2.95	4.79	316.50	17.80	−7.64
	2	23	16.15	95	4.1	0.26	2.3	0.5	3.40	6.30	281.60	15.27	−7.13
Eryuan	3	80	62.07	140	6.0	1.56	4.4	2.9	4.50	19.27	706.66	129.65	−1.91
	4	69	116.25	230	9.9	1.70	5.0	3.4	6.65	16.85	773.27	229.67	−1.41
	5	78	53.83	130	5.6	0.24	5.6	0.5	4.37	58.20	580.71	288.67	−4.32
	6	69	38.38	105	4.5	0.24	5.6	0.5	4.43	55.09	460.58	238.58	−4.85
	7	78	30.65	120	5.2	1.20	0.75	3.2	4.24	101.73	928.30	314.56	−2.26
	8	42	83.38	190	8.2	0.88	2.2	1.0	8.55	33.90	1313.33	466.34	−1.47
	9	78	98.44	195	8.4	1.30	4.7	2.8	5.36	3.97	289.98	237.99	−4.35
	10	52	53.79	170	7.3	1.47	5.1	2.4	4.20	15.80	257.49	103.72	−5.30
Dali	11	74	100.00	205	8.8	1.30	0.7	2.2	2.53	45.90	568.00	304.00	−5.24
Midu	12	56	20.00	70	3.0	=	0.2	=	1.82	5.73	362.00	30.00	−4.78
	13	72	33.51	95	4.1	=	2.0	1.0	2.60	9.33	427.56	45.63	−9.01
	14	36	23.90	90	3.9	0.21	2.0	=	0.60	7.44	246.14	27.50	−12.31

Note: = Concentration level less than detection limit.

* The reservoir temperature calculated according to the reference [2].

** The circulating depth calculated according to the reservoir temperature and the average geothermal gradient in Xiaguan [3].

Based on the data in table 1 and 2, from which it can be seen that the numbers, reservoir temperatures, circulating depths and concentrations of chemical components of the springs along various sections of the fault differ from each other, the northern segment of the Red River fault is further divided into four sub-segments, i. e., Jianchuan, Eryuan, Dali and Midu sub-segments. For Eryuan sub-segment, the number of the springs is larger, the average reservoir temperature and circulating depth are higher than 60 C and deeper than 2. 6km respectively, and the concentrations of CO_2, HCO_3^-, SO_4^-, Li, F, Sr and B are one to several times more than those at Jianchuan and Midu sub-segments. There is only one spring along the Dali sub-segment 50km long, the other parameters of the spring are similar to those along the Eryuan sub-segment.

Weakness Effect of Fluids along Fault

The water-rock interaction is very active within 20 km above the upper continental crust. Under the action of water, the compressive strength of rock will be reduced by 20—80%, and the friction force of fault will be rdeuced by 30—90%[4]. The shearing stress which is big enough to slide a wet fault is much less than that of a dry fault [5]. Under the stress corrosion effect, the strength of basalt can be reduced 100,000 times [6]. These above indicate that fluids within a fault will much reduce the strength of rocks and strongly influence the srtess state of the fault.

The density and circulating depth of the spring reflect the width and depth of the water-rock interaction along the fault, thus the stress state of the fault will vary with the number and circulating depths of the springs along the fault. The mechanical parameters, such as rupture strength and toughness of fault, etc., are reduced with rise in temperature of water [6]. The higher temperature will serve to produce hydrothermal alteration of rocks so as to reduce the strength of the fault.

According to above discussions of this section and the features of the densities, circulating depths and reservoir temperatures on each sub-segment in the paragraph of geochemical segmentation, it is deduced that the weakness degree caused by water on the Eryuan sub-segment is much higher than those on Jianchuan, Midu and Dali sub-segments.

The discharges of CO_2 from the springs along the Red River fault are thought to derive mainly from metamorphism according to their ^{13}C content. The ^{13}C content of CO_2 derived from metamorphism is in the range from +5. 0 to −5. 0‰, which is richer than that from the mantle and decomposition of organic material. If the CO_2 derived from metamorphism in the spring increases, the ^{13}C content of the dissolved carbon will become richer. The ^{13}C contents of the springs along the fault vary directly as the total contents of HCO_3^- and CO_2 (Fig. 2a) change, and increase with deepening of the circulating depths (Fig. 2b). These explain that the higher the concentrations of HCO_3^- and CO_2 and the deeper the circulating depths of the springs, the more the CO_2 from metamorphism in the springs. $\delta^{13}C$ and the concentrations of HCO_3^- and CO_2 on the Eryuan sub-segment are much higher than those on Jianchuan and Midu sub-segments, these results show that the proportions of CO_2 from metamorphism in the springs of the former are greater than the latter. The CO_2 and HCO_3^- are thought to reduce the strength of rock and frictional force of fault in two ways: (1) the metamorphic CO_2 is produced at depth in the crust, which is able to develop high pore pressuer at depth so as to reduce the effective positive pressrue of the fault surface; (2) high concentrations of HCO_3^- and CO_2 will serve to strengthen alteration of rocks and minerals. Such being the case, the strength and frictional force of Eryuan sub-segment would be less than those of Jianchuan and Midu sub-segments.

$SO_4^=$, F, Li, Sr and B in the springs may be leacheates, the higher their contents, the stronger the leaching-effect of water, so the leaching-effect of water on rocks on the Eryuan sub-segment is stronger than that on Jianchuan and Midu sub-segments.

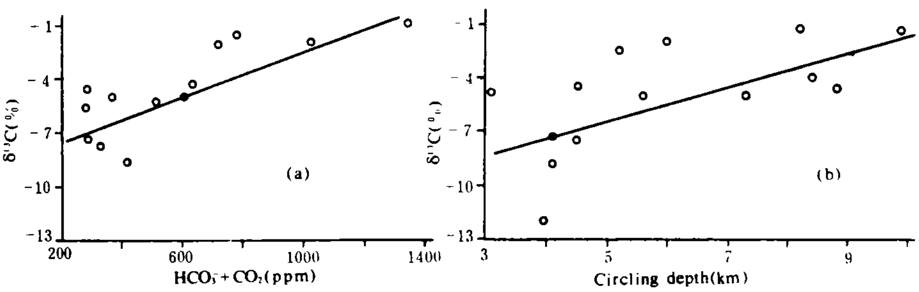

Fig. 2　Relation of $\delta^{13}C$ to total contents of HCO_3^- and CO_2 and circulating depths of the springs.

Dali sub-segment where the spring is rare is weakened very locally and limitedly by the fluids, so its weakness degree caused by the fluids is the lowest.

To sum up, the weakness degree on Eryuan sub-segment is the highest, comparatively, those on Jianchuan and Midu sub-segments are lower.

Difference in Seismic Activity of Each Sub-segment and Its Cause

The seismic activity along various sub-segments of the fault is known to differ obviously from each other. The activities of $M<4.5$ earthquakes (1965—1987) on Eryuan sub-segment are much more frequent but of $M\geqslant 4.5$ earthquakes (A. D. 886—1987) are more infrequent than the other sub-segments (Fig. 1, Fig. 3a). The highest magnitudes on Eryuan, Jianchuan, Dali and Midu sub-segments are $6\frac{1}{4}$, $6\frac{3}{4}$, 7 and 7 respectively. In addition, a strong earthquake occurred at Midu in the past 1000 years [7]. The seismic energy can more clearly show the defference in seismic activity between sub-segments (Fig. 3b). The seismic energy of $M<4.5$ and $M\geqslant 4.5$ earthquakes of Eryuan sub-segment is respectively 4.8 times more than and 1/6 less than that of other sub-segments. The focus depths of $M\geqslant 3.0$ earthquakes on Eryuan sub-segment are deeper than the other sub-segments (Fig. 3c). The cause of the difference in difference in sesmic activity between sub-segments will be discussed as follows: The effective frictional stress of the fault and the compressive and shearing strengths of the rocks are the smallest on Eryuan sub-segment because its weakness degree due to the fluids is the highest. This region is corresponding to the slipped region where the tectonic stress will be released easily and a great tectonic stress can't be accumulated, so its seismic activities display that M<4.5 earthquakes are frequent but M ≥ 4.5 earthquakes are infrequent and the magnitude is smaller. However, the effective frictional stress of the fault and the compressive and shearing strengths of rocks are greater on Jianchuan, Dali and Midu sub-segments because their weakness degrees caused by the fluids are lower. These sub-segments can be referred to as the locked regions where great tectonic stress will be accumulated because the faults slip difficultly and the tectonic stress can't be released easily, their seismic activities display that M < 4.5 earthquakes are infrequent but M ≥ 4.5 earthquakes are more frequent and the magnitudes are greater.

As the water diffuses with time on the fault surface, the slipped region expands, the average shear stress in this region decreases and transfers to the locked region to maintain a qusei-static equilibrium [8]. Similarly, under the action of the fluids and the regional stress field, a part of the tectonic stress will transfer from Eryuan sub-segment (the slipped region) to the neighbouring sub-segments (the locked region), i. e., Dali and Jianchuan sub-segments. Such being the case, the strong earthquakes would prepare in the region where the weakness degree caused by the fluids is lower, especially on Dali sub-segment.

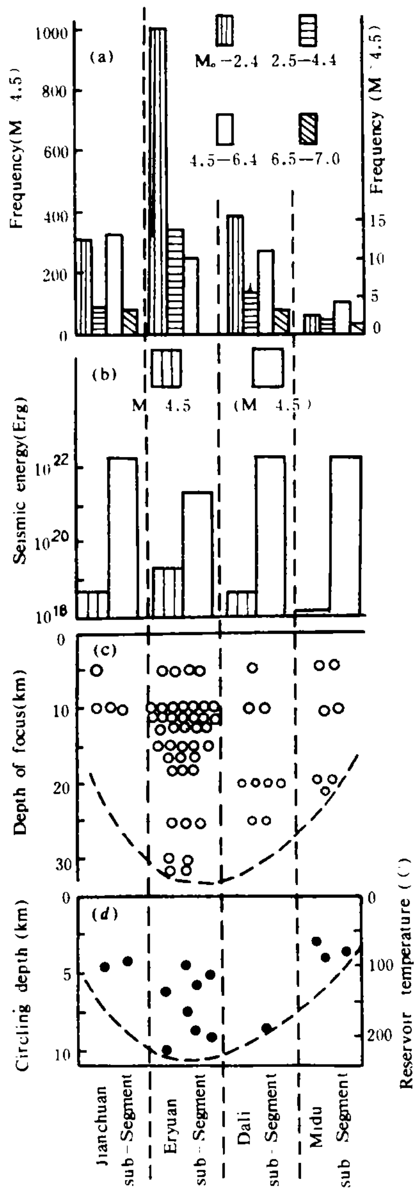

Fig. 3 Characteristics of seismicities, circulating depths and reservoir temperatures of springs.

Conclusion

Based on the densities, circulating depths, reservoir temperatures and the features of the chemical components, the northern segment of the Red River fault is further divided into four of the fluid on various sub-segments of the fault differs from each other. The weakness degree caused by the fluids on Eryuan sub-segment is much greater than the other sub-segments.

The seismic activities of M<4.5 and M≥4.5 earthquakes along these sub-segments differ from each ohter too. The Eryuan sub-segment is characterized by frequent earthquakes of M<4.5 but infrequent earthquakes of M≥4.5 and smaller magnitude. The Dali, Jianchuan and Midu sub-segments by infrequent earthquakes of M<4.5 but frequent earthquakes of M≥4.5 and greater magnitude. It is suggested that the differences between seismic behaviors of these sub-segments might be mainly caused by the differences of weakness degree of various sub-segments due to the fluids. To some extent, the circulating depths of the springs would contoll the seismic focal depths because they reflect the depths of the weakness-effect of the fluids on the fault.

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