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THE RESEARCH ON THE ACTIVE HAIYUAN FAULT IN CHINA

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Abstract

The 1920 Haiyuan earthquake (M=8.5) formed a new surface left-lateral rupture zone along the Haiyuan fault. Its length is about 215 km. The rupture zong consists of seven discontinuous echelon fault segments. The maximum horizontal component of the displacement along the rupture zone is 17 m, the average displacement is 7.07 m, and the maximum verticl component of the displacement is 5 m. The discontinuity of the displacement distribution along the rupture zone corresponds with the discontinuity of the fault's trace.

Since Holocene, 5 great earthquakes with magnitude about 8.5 have occured on the Haiyuan fault. Except for the 2nd event, all were dated by Lanzhou University with 14C: Event I is 9360 ±75 yrs B.P.; Event II 7830 yrs B.P. (insertion); Event III 6300±70 yrs B.P.; Event IV 3680±60 yrs; Event V less than 200 yrs B.P. (ie 1920 Haiyuan earthquake). The recurrence intervals of events increased progressively, and the average recurrence interval was 2325 yrs. The offset of the Haiyuan fault in the Late-Pleistocene was about 500m; since the late period of Late-Pleistocene, 200m; and since the Holocene it was about 50m. The average slip rate is about 5 mm/yr.

This paper makes an exhoustive study in the following aspects 1. the fracture zone of the 1920 Haiyuan earthquake (M=8.5); 2. the Holocdne prehistoric great earthquake on the Haiyuan fault; and 3. Late-Quaternary faulting on the Haiyuan fault.

THE RUPTURE ZONE OF 1920 HAIYUAN EARTHQUAKE

On December 16, 1920 there was a great earthquake with M=8.5 occurred near the boundary between Gansu provence and Ningxia provence of China (the epicentre is 36.7 N and 104.9 E). Its epicentral intensity was as high as XII. In this earthquake 234, 117 people were killed. The investigated area is very dry, so the manifestation of earthquake in the landforms could still be seen obviously 60 years later.

The 1920 Haiyuan earthquake formed a new rupture zone 215 km in length along the Haiyuan fault. The rupture zone consists of the seven discontinuous echelon fault segments which all are left-lateral slip except eastermost segment. These segment are different in length, dip and moving character from each other. Some left-stepping regions in the ends of the segments manifest itself in rhombic tensional basins as Shaojiashui basin in Fig. 1 and Ganyanchi basin in Fig. 4, meanwhile the right-stepping regions form compresive hill as Huangjiawashan mountain in Fig. 2. The stepping distance is commonly 2.5- 5 km. Along the rupture zone, many evidences are provided by earthquake offset micro-landforms for the displacement distribution during the 1920 earthquake. Except for a series of fault scarps, fresh facets, landslides etc, there are many kinds of landform which are offset where they cross over the faults of the zone. They all display the left-lateral motion. For example: a hill and a shallow gully in the east of Santangshang are left-laterally offset 2.5m and vertically offset 1m; a floodland at Dashagou was vertically offset 0.8m; a riverbed at Honwewe of Jingyuan county left-laterally offset 8 m; a riverbed at Diwanxian in Jingyuan county was left-laterally offset 7.7m; a ridge of a hill at Biangou in Jingyuan county, was left-laterally 17m which is the greatest displacement during 1920 earthquake; a ridge of a hill at Diwanxian, left-laterally was offset 7.7m; a spur in the west of Shachonggou, was left-laterally offset 7 m; the faultt scarp formed in 1920 earthquake is 5 m in hight at Shaojiashui in Jingyuan county; a ridge of a hill in the east of Gaoyaowan was left-laterally offset 11m, which formed a kind of shutter-ridge tectonic geomorphology.

Along the rupture zone the facts of 86 horizontal and 78 vertical displacements are determined in the field (Fig. 3): the greatest horizontal displacement is 17m and the average value is 7.07m; the greatest vertical displacement is 5 m. The diseontinuity of the offset distribution along the rupture zone correspods with the discontinuity of the fault discontinuous segments, ie the displacement is zero at the end of each segment, and the displacement is maximum at center of each segment. For entire ruptur zone, the ratio of vertical displacement to horizontal displacement is commonly 0.2—0.3, but at the end of each segment is 0.7—1.0, which

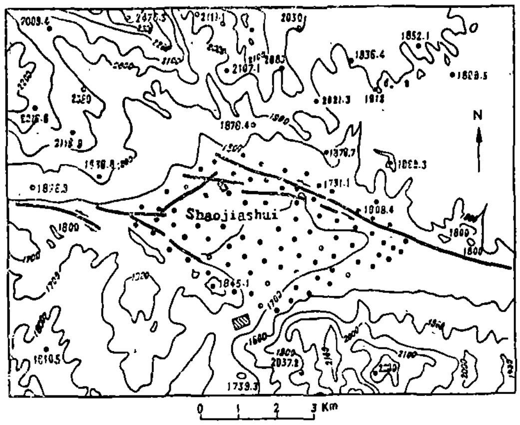

Fig. 1 The relationship between Shaojiashui basin and the rupture zone of the 1920 earthquake. It is remarkable that the basinlocates left-stapping region of the discontinuous segment end.

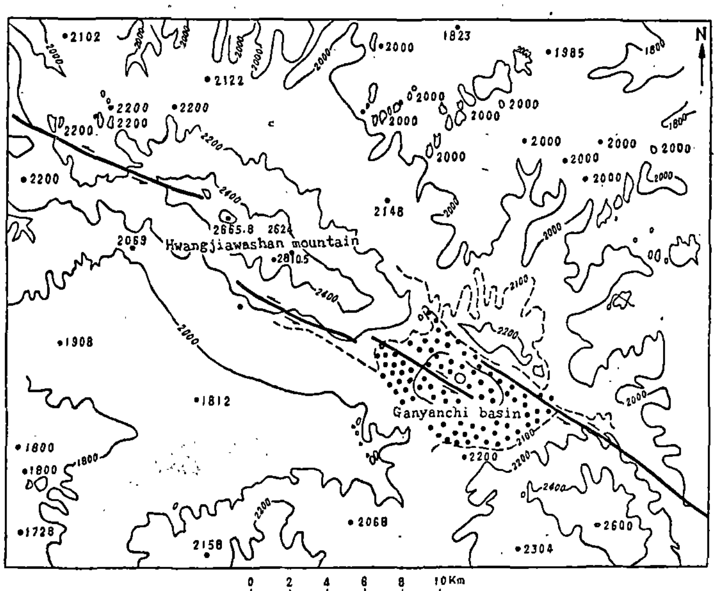

Fig. 2 The relationship between Huangjiawashan mountain and the rupture zone of the 1920 earthquake, and the relationship between Ganianchi basin and the rupture zone. Note that the mountain locates the right-stapping region andthe basin locates left-stapping reg-ion at discontinuous segment end.

suggests that the rupturing of the fault segments is gradualy stopped with increasing the component of vertical displacement.

If a fault attitude, displacement direction, and striation angle are kn wn, its fault plane snlution can be obtained with Wulff's net. The

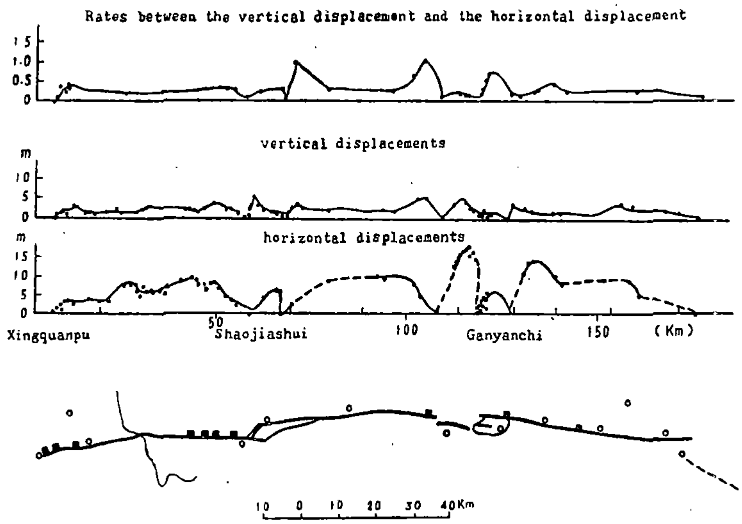

Fig. 3 The distribution of displacements during 1920 earthquake

attitude and displacement direction can be determined in field. It is difficult to determine immediately the striation angle, but the angle can be obtained by using simple geometry conversion from the vertical and horizontal displacement in matching. The fault plane solution of 1920 Haiyuan earthquake obtained with 30 suite of data investigated in the field is shown in Fig. 4.

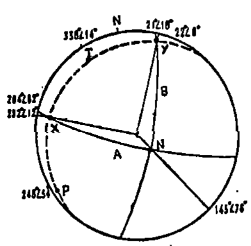

Fig. 4 The fault plane solutionmechanism of the 1920 Haiyuan earthquake from the data in field.

THE HOLOCENE PREHISTORIC GREAT EARTHQUAKE ON THE HAIYUAN FAULT

The geological and geomorphologic evidences of the prehistoric large earthquakes are found at some places on the Jingtai-Haiyuan segment of the active Haiyuan fault trace. We illustrate the following three examples:

1. The artificial trenched section at Santangshang in Jingtai county (Fig. 5).

There are evidences of 5 events in the section. The evidence for Event I is the fall wedge underneath the section, the wedge falled down 0.8 m. The evidence for Event II is that the wedge formed in Event I was offset again by the secondary faults F_2, and that the secondary fauluts are terminated under the unit 13. The evidence for Event III is a scarp collapsing wedge III, and the unit 13, ie earthquake pond sediment. The evidence for Event IV is a scarp collapsing wedge IV and unit 15 which is earthquake pond sediment, too. The evidence for Event V (ie 1920 Haiyuan earthquake) is a scarp V and the secondary faults F_5. The total vertical displacement of the 5 events is just equal to the total displacement of the erosional surfat at the Holocene bottom(4 m).

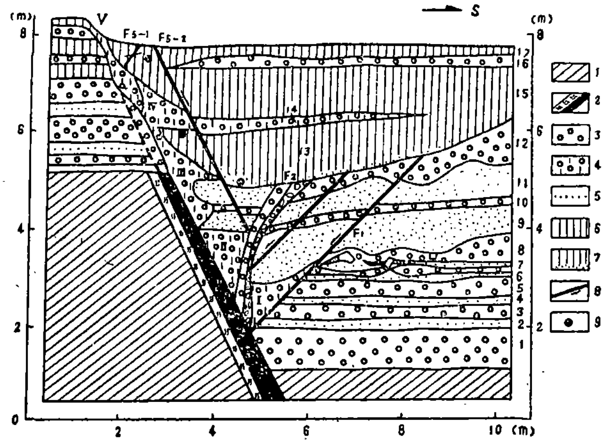

Fig. 5 The Holocene prehistoric earthquake section at Santangshang in Jingyuan county. 1 The Neogene system orange clay. 2 The black fault clay. 3 The middle-thinc grain gravel. 4 The scarp colluvial deposit, the filled fissure, and the earthquake wedge. 5 The tiny grain gravel. 6 The secondary loess…the pond deposit of prehistoric earthquake. 7 The loess with gravel. 8 The secondary faulut. 9 The radio-carbon example.

2.The artificial trenched section at Shenjiazhuang in Jingtai county (Fig. 6).

In this section, there is a filled fissure which is controled by 3 secondary faults. All the 3 secondary faults terminated under the most upper soil layer. The ^{14}C age of the event is 9360±75 yrs B.P. The event may correspond with Event I in the section of Fig. 5, because it is 1 st event after forming the erosional surface of the Holocene bottom.

3.The small channels were offset twice at Bianqianggou in Jingyuan

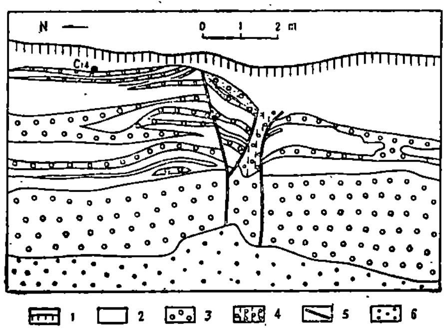

Fig. 6 The section of the prehistoric earthquake at Santangshang in Jingyuan county. 1 the soil; 2 the secondary loess 3 thetiny grain gravel; 4 the filled fissure; 5 the secondary fault; 6 the sand layer.

county (Fig. 7 —D, d).

A small channel is offset left-laterally 11m on the scarp at Bianqianggou in Jingyuan. This is a tectonic landform formed in 1920 earthquake. There is the beheaded channel on the site 13 m east from tht above channel and parallel with it. The beheaded channel, obviously, had been offset by another Event befor the 1920 earthquake. This event can be Event IV. Same tectonic landform also appeared 600m away on the east from the site. The beheaded channels may be restored as shown in Fig. 7, thus all of the geomorphology phenomena belong to two events, Event IV and Event V.

Comparing the relative location of each prehistoric event with the 1920 fractured zone at every site which shows the evidences for enents, the order of every event is obtained. The tectonic geomorphology pheno-

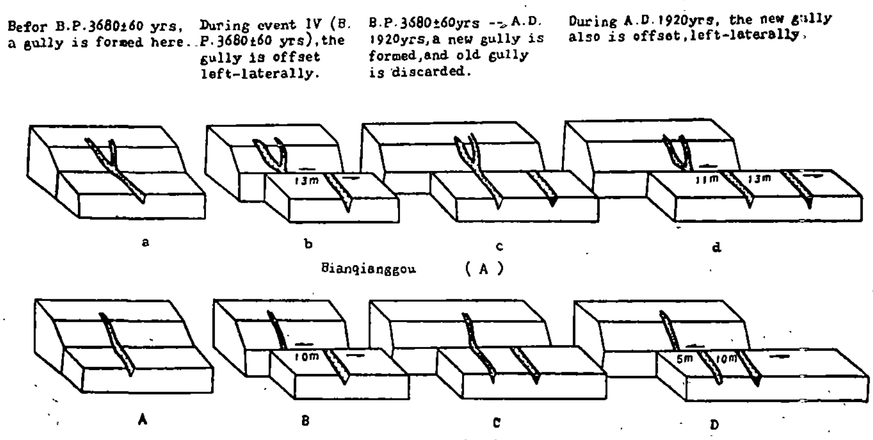

Fig. 7 The restored illustration of the beheaded channels at Bianqianggou

mena with same order number means that they were formed in the same event (Table 1), so that we obtained the displacement distributions of those events (Fig. 8). The Fig. 8 shows that the displacement distributions of the events are similar that of the 1902 earthquake, and it suggests that their magnitudes and epicentral locations are almost same as that of the 1920 earthquake.

Above mentioned evidences show that 5 great earthquakes have occurred on the Haiyua fault since Holocene. The 1920 Haiyuan earthquake was latest one of them.

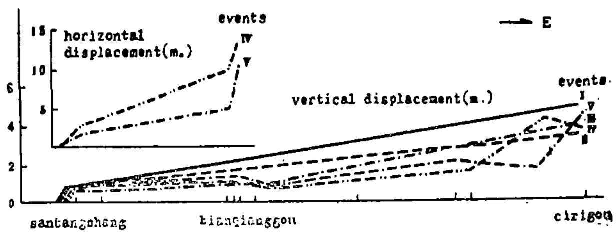

Fig. 8 the displacement distribution of the Holocene great earthquakes along the Haiyuan fault

Except for Event II, all were dated by the ^{14}C-laboratory of Lanzhou University (Fig. 9): Fvent I is 9360±75 yrs B.P., Event III 6300±70 yrs B.P., Event IV 3680±60 yrs B.P., Event V less than 200 yrs B.P. (ie 1920 A.D.) and the Event II is about 7830 yrs B.P. by in terpolation. IT is well worth noticing that the interval of great shocks may trend to lengthen. The average recurrence interval of great earthquekes is 2325 yrs.

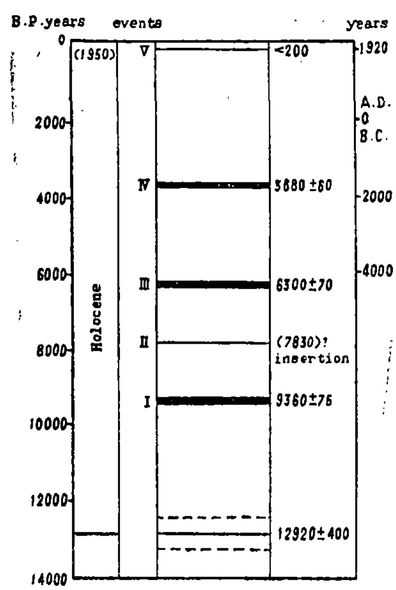

Fig. 9 Dates of the Holocen great earthquakes at Santangshang in Jingtai county

LATE-QUATERNARY FAULTING ON THE HAIYUAN FAULT

Before Eraly-Pleistocene, the faulting showed mainly compressive character. After Middle-Pleistocene, the tensional-separate basins started to appear on the Haiyun fault, which means that the fault began with left-lateral slipping and since then to present the left-lateral slipping has been continuing.

There are Many hill ridges and water courses are offset where they cross over the Haiyuan fault trace, and the older the water coarses, the more their displacements.

Becouse the 14C age of the 1st terrace is about 10,000 yrs, for the creeks in which there is not 1st terrace, their ages shoulb be within the Holocene. Their left-lateral displacement are about 20—60m. For instance, the Holocene creek developed on the 3th terrace surface was left-laterally offset about 60m at Hongwewe in Jingyuan county; a ridge of the hill at Xibaihe in Haiyuan county was left-laterally offset 50m; a series of creeks developed on the 1st terrace in the east of Biaanqianggou in Jingyuan county were left-laterally offset 20-30m.

The creeks formed in the late period of Late-Pleistorcene are larger than the Holocene, and within the former creeks had formed 1st tarrace. Their lfte-lateral displacement are larger, too, about 200m. For example, all the four creeks in the east of Gaoyaowan in Jingyuan county was left-laterally offset 200m.

All the offset data in the area investigated show that Since the Late-Pleistocene the offset of the fault zone reaches 500m, since the late period of Late-Pleistoene 200m, and since the Holocene 50m (Fig.10.)

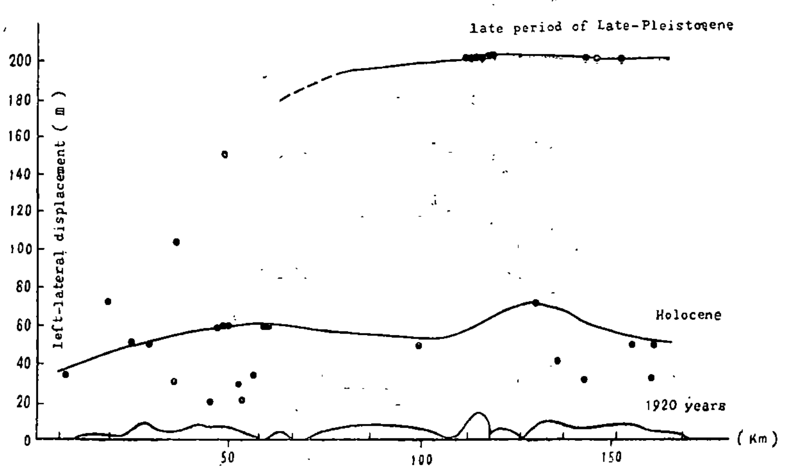

Fig.10 The distribution of displacement along Haiyuan fault since Late-Quaternary

Table 1

location		tectonic geomorphology type and displacement \ events	I	II	III	IV	V
Jingtai county	Santangshang	teotonic geomorphology type	normal sediment	normal sediment	normal sediment	normal sediment	normal sediment
		vertical displacement (m)	0	0	0	0	0
	Dashagou	teotonic geomorphology type	dipped wedge	terminated secondary faults	fault pond	fault pond	fault scarplet
		vertical bisplacement (m)	0.8	0.8	0.8	0.8	0.8
	Shenjiazhuang	tectonic geomorphology type	scarplet and fracture	—	—	—	—
		vertical displacement (m)	0.7	—	—	—	—
Jingyuan county	Wezitan	tectonic geomorphology type	—	—	earthquake terrace	earthquake terrace	fault scarplet
		vertioal displaceement (m)	—	—	0.7	0.7	0.7—1.5
	Hongwewe	tectonic geomorphology type	—	—	earthquake terrace	earthquake terrace	earthquake terrace
		vertical displacement (m)	—	—	2	1	1
	Gaoyaowan	teotonic geomorphology type	—	—	—	fault scarplet	fault scarplet
		vertical displacement (m)	—	—	—	1.5	1
Haiyuan county	Dagoumen	tectonic geomorphology type	—	—	—	earthquake pond	earthqake pond
		vertical displaoement (m)	—	—	—	3.4	1
	Cirigou*	tectonic geomorphology type	fault scarplet collapsing wedge	fault scarplet collapsing wedge	fault scarplet collapsing wedge	fault scarplet collapsing wedge	—
		vertical displacement (m)	3.4	3.6	3.5	4.8	—
Jingtai county	Santangshang	tectonic geomorphology type	normal sediment	normal sediment	normal sediment	normal sediment	normal sediment
		horizonic displacement (m)	0	0	0	0	0
Jingyuan county	Bianqianggou	tectonic geomorphologe type	—	—	—	offset gully	oefset gully
		horigontic displacement (m)	—	—	—	10	5
	Bianqianggou	tectonic geomorphology	—	—	—	beheaded gully	beheaded gully
		horigontal displacement (m)	—	—	—	13	11

*after Zhang wiqi

By above-meontined offsets of the microlandforms, the average slipping rate of 5 mm/yr is obtained on the Haiyuan fault; Based on the average displacement of the 1920 Haiyuan earthquake (7.07m) and the average recurrence period of the great earthquake (2325 yrs), the average slipping rate of 3.01 mm/yr is obtained on the Haiyuan fault. The diffe rence between the two values probably is the rate of the fault creep and the displaement of the middle earthquakes.

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海 原 活 断 层 研 究

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摘 要

1920年海原8.5级地震沿海原断层形成了一条长达215公里的新的地表破裂带，破裂带由7条不连续雁列断层段组成，破裂带最大水平位移为17m，平均

水平位移为7.07m，最大垂直位移为5m。位移分布的不连续性与断层的不连续性是相适应的。

海原断层全新世以来已经发生了5次8.5级左右的大地震。除了第二次地震年代为内插外，其它的年代均由兰州大学14C实验室测定出来：地震Ⅰ距今9360±75年，地震Ⅱ距今7830年（内插），地震Ⅲ距今6300±70年，地震Ⅳ距今3680±60年，地震Ⅴ小于200年即1920年地震。地震重现间隔是逐渐增加的，平均重现间隔为2325年。晚更新世以来海原断层左旋位移了500m，晚更新世晚期为200米，全新世以来为50m，平均左旋滑动速度为5mm/yr.。

大地震前复杂震源系统的非线性阶段及其所伴随的非稳态现象

受现代统计物理学研究进展的某些启发，作者以极大的热情投入了大震前非稳态过程的研究，结果是非常令人鼓舞的。这里仅作简要报导。

1.大地震发生前介质的应力应变曲线的非线性阶段是大地震前各种非平衡态前兆现象出现的基础。非线性阶段可以从测震学指标中得到。例如蠕变曲线的加速，小震频次的加速，b值曲线向低值弯曲等都是在时间进程上出现的非线性表现。与此同时在此阶段还伴随着大大偏离平均状态的非平稳态。目前能找到的非平稳体指标是地震活动性的密集平静的起伏，大震前较大地震的频次偏离平均b值曲线，地震波速度和振幅比（A_P/A_S）偏离平均状态的急剧起伏等。在非线性阶段出现的大量的非平稳态现象与统计物理学中突变事件前系统内出现的大大偏离原来的平均状态的非稳态现象非常的一致。这说明现代统计物理学的成果可以应用于地震预报的研究。非平稳态现象是未来突变事件的预兆，因此在预测突变事件（如大震）时具有重要意义。

2.大地震前非线性阶段以及所伴随的非稳态现象的相似性。尽管大地震之间有差异，然而大地震前的非线性阶段以及非稳态现象具有共性。甚至中强地震也有类似现象。这一结果符合现代统计物理学中的分数维，即具有自相似特征。通俗的说，就是不论大、小地震均在地震前存在非线性过程以及非稳态现象。

3.特别有趣的是非线性阶段与地震空区时间之间存在固定的比例关系。对于浅源地震，其比例关系约为1:5。这一数值接近现代统计物理学中普适常数（临界指数）4.6692。因此5可能是大地震发生的临界指数，並具有普适特性。这将为地震的长期预报（几十年尺度）提供物理依据。

进一步的研究工作还很多，例如期望能找出不同层次的发震临界指数，以便对中、短期以及临震预报提供依据。初步的研究表明现代统计物理学研究成果引用到地震预报的研究工作中具有广泛的前景。

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