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A STUDY ON THRESHOLDS IN THE CHANGE OF ALLUVIAL FAN AND DELTA OF THE HUANGHE RIVER, CHINA

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ABSTRACT: In the river systems, the environmental change always undergoes a process from quantitative to qualitative change. The upper limit of the qualitative change is called threshold. When the process reaches or goes beyond the limit, the original event series will be replaced by the other event series. Investigations show that the evolution of the Huanghe River alluvial fan and delta has also under gone a process from quantitative to qualitative change. The geometric forms in each process are roughly the same. This threshold of the geometric forms not only provides us a quantitative index for plotting the periodicity of the alluvial fan and delta, but also is of importance for estimation of the trend of natural environmental change.

It is shown that there are three periodic alluvial fans of the Huanghe River since the middle Holocene and four periodic delta since 1855 A.D., the thresholds of their geometric forms are from 0.93 to 0.94 and from 1.2 to 1.21 respectively.

The changing trend in the past and the natural environmental condition at present indicates that the lower reaches of the Huanghe River has some possibilities to burst its banks at the Dongbatou–Gaocun to flow northward. Therefore some proper protection measures are suggested.

KEY WORDS: alluvial fan, Huanghe River delta, thresholds, Breach and Changing Course

Watershed is an open system with input, conversion and output of its energy and material in various forms. A river system has a series of cycle process from quantitative change to qualitative change, In the evolution of natural environment, the upper limit of qualitative change is known as threshold. The threshold is acting as a relation between different processes in the development and evolution of the natural environmental systems, and is the turning point in the developing process of the interrelated objects. With of help of the study of the threshold the frequency of natural disasters distribution and their in time and space can be better predicted. Consequently the relationship between man and natural geographical systems can then be better coordinated.

As a special geographical term, threshold was first introduced into geomorphological systems by A.S. Schumm in the 1970s[1,2]. By the study of a series of threshold phenomena in the evolution process of the Huanghe River alluvial fans and delta, this paper attempts to discuss their evolution law from quantitative to qualitative change. On the basis of this study the evolution trend of the lower Huanghe River has been predicted.

I. THE THRESHOLD IN EVOLUTION OF ALLUVIAL FANS

The evolution process of an alluvial fans is closely related to the change of the stream channel. The evolution process of a stream channel reflects the history of the development of the alluvial fan, and the evolution process of the alluvial fan records the information in the change of the stream channel.

Flowing through the Loess Plateau, the Huanghe River is characterized by the water with high silt content, and the river discharge changes a lot between dry and wet seasons. These not only have a control over the degradation and aggradation of the river bed and the change of the channel pattern but also speed up the frequency and shorten the cycle from gradual change to abrupt change in the evolution of the river bed. The Huanghe River has the characters of wide and shallow bed, unstable and changeable channel, and quick siltation. The levees along the sides of the river break down often and the river changes its course frequently. According to the statistic data, the Huanghe River underwent over 1,500 levee break-down and 20—30 stream course change in large scale during 3,000 years before 1949. Since early Pleistocene, the deposition rate in deferent geomorphic unit of the Hebei Plain increased rapidly, especially in the region of alluvial fans, the deposition rate reached 13.8 mm / a[4]during the last 50 years.

The evolution process of the alluvial fans of the Huanghe River reflects the interacted relation between water dynamics and form, gradual change and abrupt change. With the rise of the river channel caused by silt deposition, the depth of the river bed decreases, and the flowing resistance increases. As a consequence, the unstability of the river course increases. When the unstability reaches the its threshold, the river would suddenly break the levees and change its course. Then the new river channel would begin its process of gradual change again. The geometric forms of alluvial fans in the different time periods since middle Holocene can be measured quantitatively by using the method shown in Fig.1, where, a: the longitudinal axis of alluvial fan (the maximum length in parallel with river channel), b: the cross axis of fluvial fan (the maximum length perpendicular to river channel), α: the central angle. These three parameters not only show the size and form of the alluvial fan, but also reflect the boundary and dynamics conditions in the evolution process of the alluvial fan.

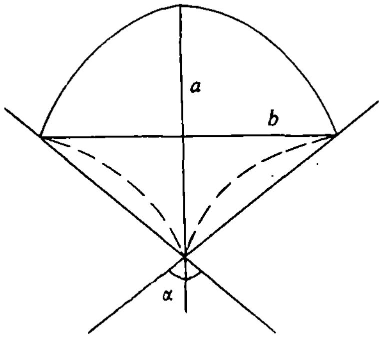

Fig.1 The sketch of morphometry of alluvial fan

By using this method, the geometric forms of three alluvial fans formed in the different periods during the middle Holocene were measured in non-dimensional way (Table 1). Table 1 and Fig.2 show that the evolution cycle of the alluvial fans has nothing to do with time, but has relation with the geometric form of the fan, that is, has relation with the length of the longitudinal and cross axes as well as the size the central angle. In the process of its development, the length of the longitudinal and cross axes and size of the central angle of the alluvial fans remained the certain proportion relation. Table 1 shows that the rate of axes length (a / b) of each alluvial fan studied, no matter how long its development time is, has a very similar value:0.94, and the central angle is 95—100° . In other words, the evolution process of an old alluvial fan stops as soon as the form parameter reaches its threshold value: $a / b = 0.94$, $\alpha = 95—100°$, and a new one begins. In the process, the peak point of the fan moves down with time and the area increases. This interaction process between gradual change and abrupt change demonstrates the coordination between dynamics and forms. In fact, the North China Plain is a deposition plain consisting of a series of fans formed by different rivers (Beside Huanghe River, there are Zhanghe River, Hutuohe River, Yongding River and Luanhe River) with different sizes and different development processes. These fans are the product of the contradiction between dynamics and forms. Not only the alluvial fans follow the geometric law of forms, the braided styled sand bars on the fans shares the same law as well. Through the field investigation of 140 bars A.H.Rachocki found that the central angle of the first-order bars is over 30° and the proportion of the longitudinal and cross axes of 82 bars is 1:2.44. The study of 42 bars by the remote sensing photos shows that the axes proportion is 1:2.35, which is very similar to the field investigation result[6]. All these demonstrate that the development of bars on the plain always retains the stable geometric forms though the network of waterway on the fan-plain is very disorder, unstable and changeable.

Table 1 The indexes of the geometric forms of the Huanghe River alluvial fans

Time of Alluvial fans	Peak point of Alluvial fans	Longitudinal axes (a)	Cross axes (b)	a/b	α(°)
Middle Holocene	Taohuayu	12.2	13.0	0.94	95
1020BC–294AD	Taohuayu	11.0	11.5	0.96	100
1494AD–1855AD	Lankao	11.1	12.0	0.93	100

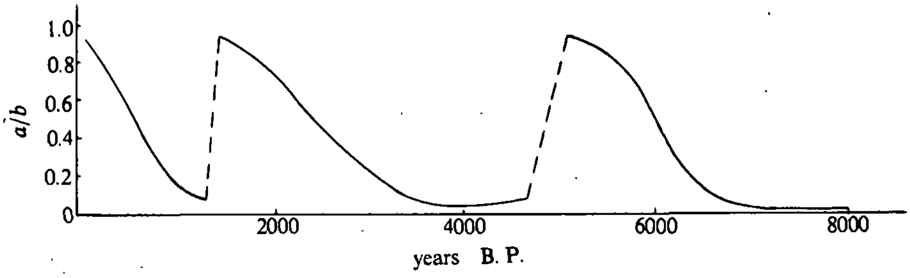

Fig.2 Relationship between the index of alluvial fan forms and the time

Although it is difficult to explain why the bar has remained a stable geometric form, from the principles of minimum power, we think that the moving medium tends to produce the geometric form with the minimum resistance force to flow. In other words, an object in water undergoes a force from running water, and this force is directly proportional to the decrease of the resistance before the resistance decreases to the minimum threshold. If the form of the object in the section parallel to the direction of flow is similar to that of the bar, the resistance coefficient of the object in running water reaches the minimum value. The bar with such a geometric form is of the minimum resistance to the running water and is more stable and more widespread distributed.

II. THE THRESHOLD IN EVOLUTION OF DELTA

The velocity, size and form of a delta mainly depends on the transfer relationship between river dynamic and ocean dynamic, and the conditions of water and sediments as well as the original geological and geomorphic conditions. Because the Huanghe River carries a great amount of sediments, the difference in discharge between dry and wet seasons is great, and because the tide effect on the river is weak, the deposition of the Huanghe River delta is far stronger than the transportation power of the ocean. A large amount of sediment has deposited at the river mouth. Consequently, the delta extends quickly and develops fully to a typical pointed cuspate delta.

The coordination of original landform and the formation dynamics of the Huanghe River delta in different periods also show the suitable relationship between dynamics and forms. By means of the morphometry method shown in Fig.1, the indexes of the delta forms measured are shown in Table 2 and Fig.3. It should be mentioned that there is

Table 2 The indexes of the geometric forms of the Huanghe River Deltas

No.of deltas	Period	Longitudinal axes (a)			Cross axes (b)			a / b			α(°)		
		1	2	3	1	2	3	1	2	3	1	2	3
1	1855–1904	7.8	9.9	7.0	7.4	10.0	7.5	1.05	0.99	0.93		70	−90
2	1904–1929	9.0	14.3	9.5	7.7	13.3	9.5	1.17	1.08	1.00		80	−90
3	1929–1953	9.6	15.7	10.5	8.5	10.3	11.0	1.13	1.52	0.95		50	−90
4	1953–1976	8.0	13.5	9.0	5.5	12.8	9.5	1.45	1.25	0.95		60	−90
Average		8.6	13.35	9.0	7.25	11.6	9.4	1.20	1.21	1.20		66.3	−92

Note: 1. From the data of Pang Jiazhen; 2. From the data of Zhang Wei; 3. From the data of Ye Qing .

not yet an identical idea about the classification of the delta stage, and by now there is no agreeable idea about the delta stage. In this paper, we consider not only the delta forms, but aslo the period of its evolution process. First of all, the sediment of the delta had to have a triangular form, which was built in a certain period of time, but not a ligulate accumulation developed in a single burst. The deltas distinguished in this way have the same formation cycles. The period of delta development, except for the first stage, is around 24 years.

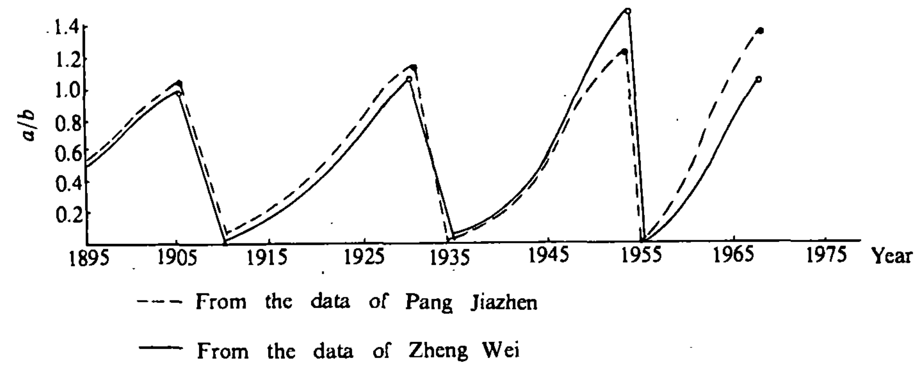

Fig.3 Relationship between time and form indexes of the Huanghe River delta

From Table 2 and Fig.3, it can be seen that the development of the Huanghe River delta underwent a similar process of gradual to abrupt changes, and the features of its formation are very similar. The thresholds of a/ b are some 1.20, the river will break the levees (abrupt change), regardless of the time for the delta's development. The river will flow in the direction of large gradient and short course. A new delta will be built up and the process of gradual change starts again, which means that the quantity is accumulated for another abrupt change. From Table 2, we can also see that, except for the first development period of the delta which reaches 49 years (42 years after Ye Qingchao), the other three periods are all around 23–25 years. This means that certain time span is needed to built certain shape of delta under the similar hydrologic and sedimental conditions. The first development period of the delta (1855–1904) is prolonged. The reason for this prolongation is that the Huanghe River had swigged on the alluvial fan for 20 years since it bursted its banks at Tongwaxiang in 1855. The sediments ware largely deposited to build the alluvial fan on the way that the river flowed to the ocean. Only little amount of sediments was carried by the river to the area of river mouth so that the time for the delta to be built up was prolonged. If the period of river's overflowing, which lasted about 20 years, is subtracted, the first period also lasted about 22–25 years. Therefore, the actual starting point of the first period is set to 1876. In 1875 it began to erect dykes along the right bank started to be constructed. In 1876, the Heze–Jiazhuang dykes project was finished. From then on the Huanghe River flew to the sea all through the Daqing River and the river course of the lower reaches became basically steady. Meanwhile, the period of normal development of the delta started.

Through the analysis of the development process of the Huanghe River delta, we can see that the process of the delta's extension towards sea is a development process of a series of small deltas constructed by the braided–style river channels, experienced a series of gradual to abruptchanges. The present Huanghe River delta is made up of these small deltas inthe way of piling, overlapping and combination. The development periodsand geometric forms of the deltas are generally similar to each other.

The statistical results of the geometric forms of some other river deltas are shown in Table 3. The table reveals that the geometric forms are generally identical in different stages

Table 3 The indexes of the geometric forms of some river deltas

Delta	NO.	Longitu–dinal axe *(a)*	Cross axes *(b)*	*a / b*	α(°)
The delta under water outside the mouth of Xijiang River in the 1800s	1	15.1	15.1	1.0	
	2	15.5	15.5	1.0	
	3	16.0	15.4	1.04	
	average	15.53	15.33	1.01	
The delta under water outside the mouth of Xijiang River in the 1900s	1	12.0	15.1	0.79	
	2	12.0	15.5	0.77	
	3	12.8	15.4	0.83	
	average	12.27	15.33	0.80	
The Delta of Luanhe River	1	21.1	9.4	2.24	
	2	9.2	12.7	0.72	
	3	13.2	8.7	1.52	
	4	3.2	2.0	1.60	
	average	11.68	8.2	1.52	
The delta of Mississippi River	1	6.1	7.2	0.85	90
	2	4.0	4.8	0.83	90
	3	3.8	5.0	0.76	95
	4	8.7	8.3	1.05	88
	5	5.8	5.4	1.07	88
	6	2.5	2.6	0.96	60
	7	2.6	3.3	0.79	90
	average	4.79	5.23	0.90	85.56

of any of the river deltas. This illustrates fully that certain topographic conditions of geometric forms are necessary for a certain dynamic conditions in order to obtain the dynamic equilibrium.

From the viewpoint above, we can see that there exists a threshold between the different two kinds of geomorphic units in their evolution process. This reveals the internal mechanism that power moulds the forms and the forms restrict the power. The discharge and silt concentration of the Huanghe River vary a lot within a year, but the annual mean values are basically steady. Under the same dynamic conditions, the geomorphic forms developed ought to be identical. In the development processes of alluvial fans and deltas of the Huanghe River, the stream flow attempts to mould a geometric form with the least resistance (the necessary form for certain dynamic conditions) so as to obtain a dynamic equilibrium between dynamics and forms. On the other hand, Deposition of sediment and its extension attempt to obstruct the stream flow. Therefore, the dynamics of flow and forms resistance, constitute an interacted and interrestricted contradiction. Under certain hydrologic and sedimental conditions, the form resistance increases with the growth of the sediments, the dynamics of flow has to adjust to suit this increase. When the form resistance reaches a specific value, the dynamic equilibrium state in the original hydrologic and sedimental conditions, can not be maintained any longer in the landforms originally developed, that is, this geomorphic unit can not bear the flow power any more. The river will burst its banks to search for a new course which can provide the least resistance. A new process of contradictory motion of the dynamics and forms, then, starts again. This is the inherent mechanism why there exist a series of thresholds in the river development process.

III. THE TREND OF POSSIBLE LEVEE-BREACH IN THE LOWER REACHES OF THE HUANGHE RIVER IN THE FUTURE

As mentioned above, the Huanghe River is a river which carries a lot of silt. It is notorious for its quick aggradation, easy levee-breach and frequent course changes.

For several thousand years before the dykes were built in the period of the Warring States (475B.C.) dykes were built, the Huanghe River swigged or migrated in the fan-shaped area between the east of the Taihang Mountain and the west of the Tuhai River. After dykes had been constructed in the middle stage of the Warring States, the river courses regularly changed and swigged from north to south gradually. By 1286 (the 33th year of the Yuan Dynasty), the lower reaches of the Huanghe River had swigged all round on the whole North China Plain from the east foot of the Taihang Mountain to the west edge of the Huang-Huai Plain. After 1286, the Huanghe River tended to change its courses from south to north. By the levee-breach at Tongwaxiang in 1855, the Huanghe River had experienced six great courses change[3].

Since 1855 the lower reaches of the Huanghe River, under the control of the manmade dykes, has maintained steady states for 130 years. Now, the river channel of the lower reaches is a few meters higher than the ground surface outside the dykes. Especially in the Henan reach the river bed is 6—11 meters higher than the ground surface. Its ability to drain the floods has greatly decreased and the industrial and agricultural productions as well as the traffic safety along both sides of the river are seriously threatened. From the history of the river flow in the last 5,000 years, we know that the period of flowing in the northern area is the longest one, about 3,326 years, in the middle area is the shortest one, about 146 years, and in the southern area, the middle one, about 661 years. Since the river changed its course in the middle area it has flown for 122 years (not including the nine years of drainage to the Huaihe River), which is close to that of flowing in the middle area in history. Based upon the regularity of the river courses changes in history and the nature of river courses at present, we predict that it is possible for the river course to change northward transversely. The reasons are as follows:

1) Both of the two different kinds of geomorphic units of the Huanghe River have reached the critical state—the threshold value. Specially in the areas of deltas, four deltas had developed with thresholds (a/b) of 1.2 since 1855. It is evidently possible to reach another critical equilibrium state in the coming ten years, and a new delta is expected to be developed. The form resistance of the alluvial fans have already reached the threshold value i.e. 0.93. The present river course is completely an artificial one under the restraint of the dykes and it has already exceeded the conditions of natural dynamic equilibrium. How long the river keeps flowing the present course depends on how great the ability to control it is.

2) From the development regulation of the river courses in history, we can see that the Huanghe River had rolled from north to south over the North China Plain and now is in the process of swinging from south to north. The period of flowing is close to that of flowing in the middle area in the history. The river is very possible to burst its banks northward.

3) The geotectonic conditions show that the depression in the north of Shandong Peninsula is stronger than that in the south, especially in the Kaifeng, Jizhong and Huanghua depressions. The Bohai Bay subsides mainly, and the amount of subsidence increases gradually from the shore plain to the center of the Bohai Sea. Calculated according to the deposition rate, the rate of subsidence in the last 110,000 years is 0.5 mm/ a in the area of Cangzhou, 1.0 mm/ a in the south area of the Luanhe River, and 1.0 mm/ a in the lower reaches of the Liaohe River. The Yellow Sea to the south of Xuzhou remains basically steady.

4) The study on the present channel and the landforms inside and outside the dykes, shows that the ground surfaces are higher in southern bank than in the northern. The ground surface outside the right bank dyke is 2—5 m higher than that outside the left bank dyke in the reaches from Huayuankou to Jiahetan. The cross sections also show that the

height of the ground outside the right bank dyke is higher than that outside the left, the difference of the height between them is about 2 m. Therefore, the river course will probably change northward.

In the longitudinal direction, the possible place of the future river course change is in the middle and upper reaches of the river. The statistical results of the northward levee–breaches of the lower reaches of the Huanghe River from 1855 to 1934 are listed in Table 4. In order to diminish the effects of accidental factors, the number of levee–breaches is counted every ten years. The distribution of the density of levee–breaches along the river is obtained for time span. The reaches with the highest density are the main sites at which levee–breaches took place. Fig. 4 shows the trend of the changes of main breaching sites.

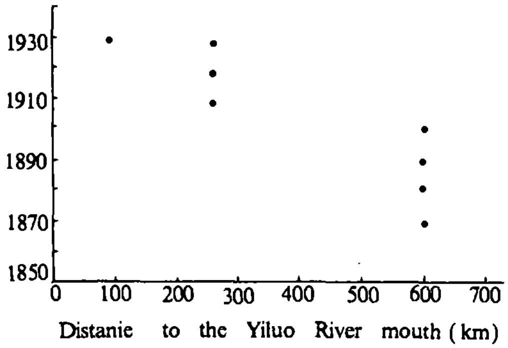

Fig.4 The trend of northward levee–breath of the lower reaches of the Huanghe River from 1855 to 1934

Table 4 The density of northword levea breach of the lower reaches of the Huanghe River from 1855 to 1934

Time Span	No. of Years	Yilou River Mouth–Dongbatou		Dongbatou –Sunkou		Sunkou –Luokou		Luokou –Lijing	
		No.	Density	No.	Density	No.	Density	No.	Density
1855–1864	10			1	0.05			2	(0.12)
1865–1874	10			2	0.11			3	(0.18)
1875–1884	10			1	0.05	2	0.12	14	(0.83)
1885–1894	10			6	0.32	4	0.25	14	(0.83)
1894–1904	10			5	0.25	2	0.12	9	(0.54)
1905–1914	10			6	(0.32)				
1915–1924	10			3	0.16				
1925–1934	10	2	(0.12)	35	(1.84)				

From Fig.4 and Table 4 we can see that there exists a trend of the main levee–breach site change: it moves from downstream to upstream. At first, levee–breaches concentrated in the lower part of the lower reaches. Afterward, the breaching sites moved upstream discontinuously. At present, the main breaching sites have moved to the reaches near Dongbatou. From this analysis, we predict that the place with the highest possibility of levee—breach in the future is located in Dongbatou—Gaocun, Henan Province. This section in the lower reaches of the Huanghe River also has the maximum height difference between the ground surfaces outside and inside the dykes. The channel patterns in this part are mainly the braided—style river channels,and the river course is not steady; dangers appear often. It is necessary to keep watch on it in order to prevent flooding. Meanwhile, if it is possible to perform an artificial levee—breach, we suggest to change the river course northward from this area. Only in this way, will it fit the natural environmental conditions in the lower reaches of the Huanghe River.

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