A TENTATIVE ESTIMATE OF THE AGE OF THE GRABEN FAULT IN CENTRAL SHENSI AND SHANSI*

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Introduction

One of the major structural features in north China is the great fault system in central Shensi and Shansi known as the Weiho (渭河) Graben and Fenho (汾河) Craben respectively (Fig. 1). Dr. Bailey Willis seems to have the idea that the age of these normal faults can not be earlier than Pleistocene,[1] but a more precise determination may be made, even to the number of years, from a study of Hukou Falls which had been hastely visited by the auther in September, 1932, on his way back from Yenchang (延長) oil field.

Hukou-falls are located about one kilometer SSE of Hsi-Lungwang-chan (西龍王辿) (longitude $7^h - 11^m 53.^s30 \pm 0.^s09$; Latitude $36° - 11' - 29''.83 \pm 0''.08$)[2], a very small village about 35 km. NEE of Ichuan (宜川) city. In the main falls of about 20 meters in height, the whole river of Huangho, which is about 500 to 600 meters in width just above the falls, is contracted to a narrow channel of about 30 meters cutting deeply into the Triassic red shale and sandstone series. The sound of the falling waters can be heard and the clouds of rising vapors seen for a distance of several kilometers from the falls. (Figs. 2, 9).

Origin of Hukou Falls

In general, water falls may be produced by any one, or combination, of the following causes:

(1) When a stream in seeking its grade discovers sufficient difference in the resistance of the rock in its bed, a water fall or a rapid will develop.

(2) In a graciated region, the discordant relationship between the main stream and its tributaries at the point of confluence must develop water

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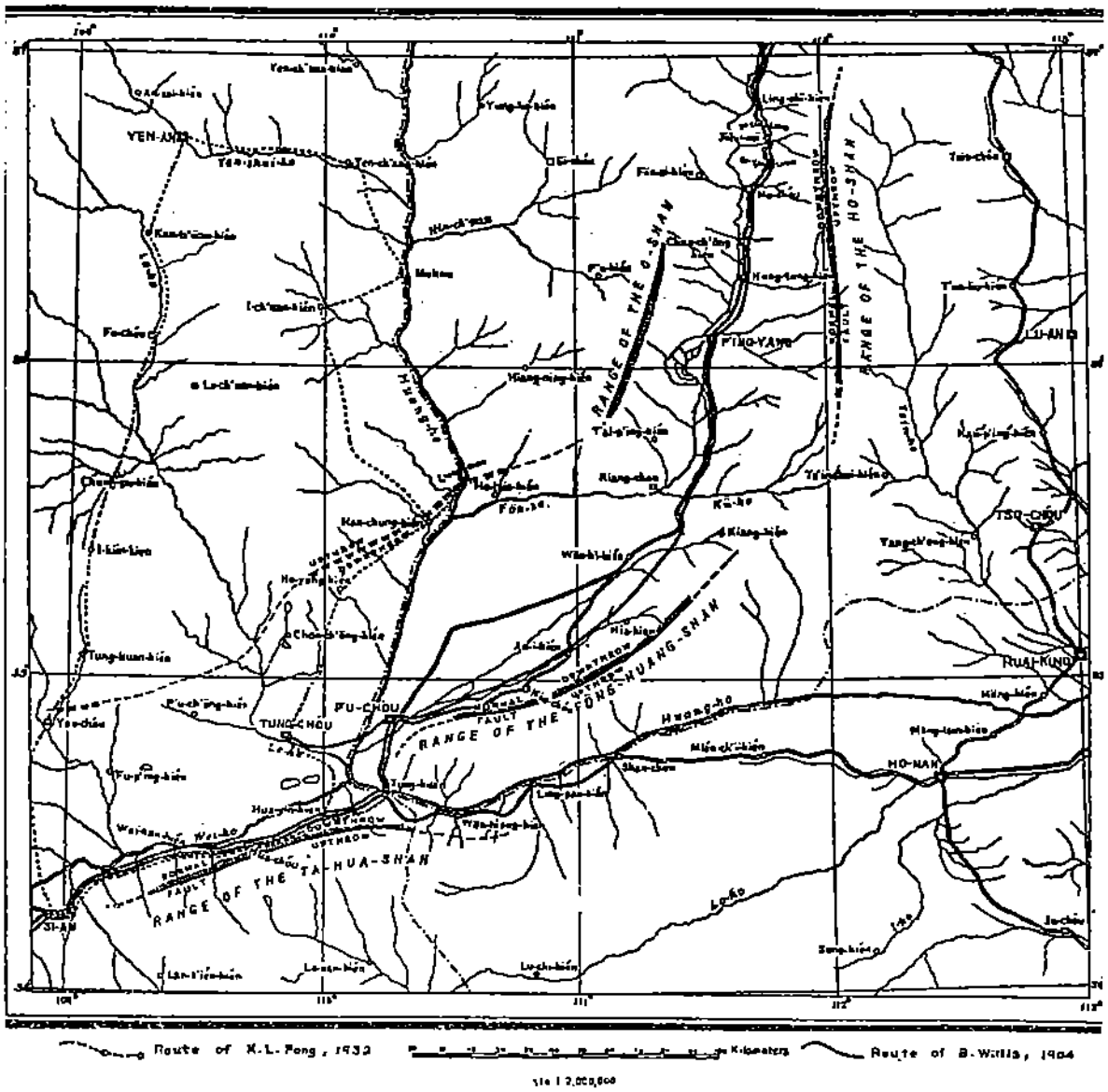

Fig. (1) Generalized map showing the distribution of Faults in Weiho and Fenho Graben of Central Shensi and Shansi. (After Bailey Willis with the addition of Lungmen Fault which is the SE boundary of North Shensi plateau and a part of the great fault system.)

falls of the hanging valley type; or consequent water falls may be produced by the overflow of a stream over an escarpment by glacial daming.

(3) Joint-planes may be so spaced as to aid vertical excavation sufficiently to produce falls or rapids in a small scale.

(4) Consequent water falls may be produced by faulting, i.e. produced by the overflow of an antecedent stream uppon a newly formed fault scarp across the course of the stream.

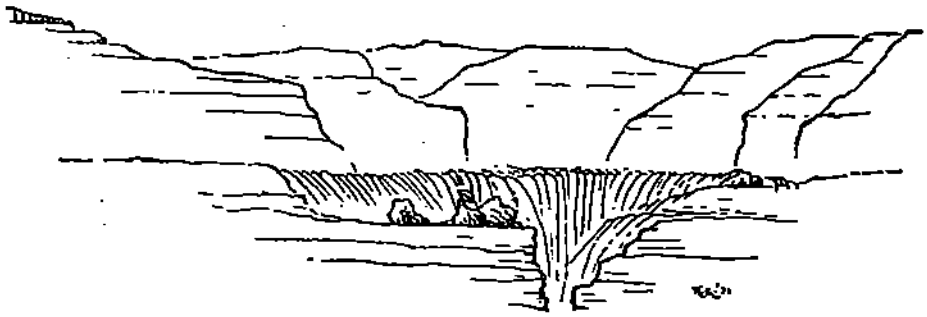

Fig. (2) General view of Hukou showing the water-falls, the nearly horizontal Triassic shale and sandstone series, the narrow gorge below the fall and the steep-sided, flat bottomed old valley of Huangho above the fall. A little loses is shown on the top of mountains of the left. Looking north from a point about ½ Km. south of the main falls.

The question, which one of the above mentioned types, or the combination of them, will be the proper origin of Hukou-falls may be settled by means of Chamberlin's method of multiple hypothesis, i.e. by applying critical test to each one of them and select the one that explains all known facts most satisfactorily.

1. The absence of igneous rocks in Hukou-Lungmen (壺口-龍門) regions may put the possibility of Hukou-falls being produced by resistant igneous formations out of the question. With regard to sedimentary formations, we would have the height of water falls so produced varies with the thickness of the hard layers, the thickness of the underlying weak layers, and the relative resistance between them. "If.....the difference between layers are but slight, or if those layers are thin, there will only be a small fall, or

perhaps only a rapid."[3] So far as we know the red shale and sandstone series in Hukou regions varies gradually from sandstone to sandy shale with no great difference in their resistances to erosion, and the thickness of individual layers is not very great so it is not to be expected from them to produce water-falls so magnificient as that of Hukou if not combined with other cause or causes.

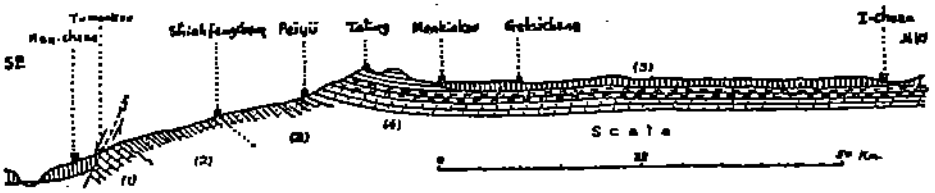

Fig. (3) Generalized section from Hancheng (韓城) to Ichuan (宜川) city showing the regional structure and stratigraphy in northern Shensi (陝西). Vertical scale greatly exaggerated. (1) Ordovician limestone, (2) Permo-Carboniferous coal series, (3) Triassic red shale and sandstone series, (4) Jurassic shale and sandstone series and (5) loess and reddish clay.

Fig. (4) Section of Shihkiakou (石家溝) about 5 Km. NW. of Hancheng (韓城) city showing the normal fault at the margin of Northern Shensi-plateau. (1) Ordovician limestone, (2) Permo-Carboniferous coal series, (3) Triassic red shale and sandstone series, (4) Loess, and (5) alluvium.

2. We don't know whether there is any evidence of glaciation in this part of Huangho valley. If there was glaciation, we should have water-falls of the hanging valley type developed at the mouth of the contributaries of Huangho other than that developed in the main valley of Huangho itself. And furthermore, we would have falls developed both above and below the main falls. The actual condition at Hukou is that there is no water fall except along the very young gorge developed below the main falls of Hukou showing that these small side-falls are developed by recent stream rejuvenation due to recession of water-falls and not due to the influence of glaciation.

3. Although the Triassic shale and sandstone series is transversed by systems of joints, we don't think they have any great influence on the development of such great falls as that of Hukou, because these falls are rather small in size, and the great NNW-SSE gorge of Huangho in a lengh of nearly 70 kilometers has little connection with them.

4. The consequent origin of Hukou-falls being developed across the fault scarp at Lungmen, has, however, the following favorable evidences and inferences:

a) The presence of fault along the SE margin of northern Shensi plateau, especially in the vicinity of Lungmen, is strongly supported by the sections made at Tumenkou (土門口), Shihkiakou (石家溝), Shangyükou (山峪口) and Lungmen (龍門) (Figs. 3-7). Although the marginal dislocation is complex in its local characters but in the main, it is a great normal fault in which the NNW is the upthrow, and the SSE the down throw, side.

Fig. (5) Section at Shangyükou (山峪口), 20 Km. NNE of Hancheng city showing the local overthrust faulting developed along the margin of northern Shensi plateau. (1) Ordovician limestone, (2) Permo-Carboniferous coal series, (3) fault-breccias, (4) rolling hills of gently dipping strata of the coal series,

b) The NNW upthrow block must have some effect on the rejuvenation of this part of Huang-ho for the development of the very young Hukou gorge or the peculiar valley feature between Hukou and Mengmen (孟門).

c) The gorge between Hukou and Lungmen is a youthful topographic form such as the recession of water falls originally initiated at Lungmen would normally produce.

d) Banks of the old river which flowed in the old valley bottom before the gorge of Hukou was cut are still plainly visible (Figs. 8, 9, 10), suggesting that this part of Huangho at least is antecedent to Lungmen faulting.

e) The depth of the steeply sided gorge, or the valley excavated after the last fault movement at Lungmen, is about 100 meters which is about the difference in elevation of the water surface just above Hukou-Falls and that just below Lungmen-rapid. In other words, we may infer that the first water falls developed in the vicinity of Lungmen had a fall of about 100 meters. Recession of water falls upstream is usually accompanied with decrease in the height of the fall on account of the inclination of the strata toward the NNW.

f) Structurally, the graben of Weiho in Shensi is simply the continuation of the graben of Fenho in Shansi (fig. 1). As the difference in elevation thus produced by faulting (or otherwise) a water fall would naturally develop at the place where the fault scarp intersect the antecedent Yellow River, that is in the vicinity of Lungmen.

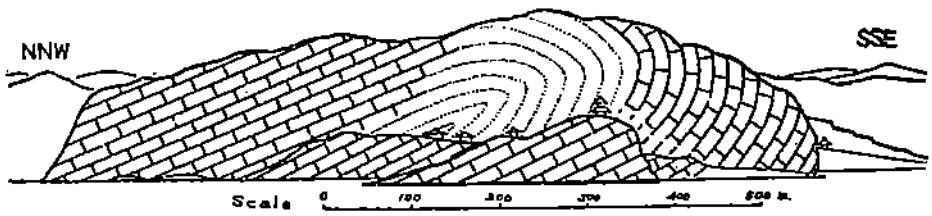

Fig. (6) Section along the NEE side of Huangho at Lungmen (龍門) showing the folding and drag effect of Ordovician limestone near the SE margin of northern Shensi plateau.

g) The fall thus produced at Lungmen could not prolong its life if there were no comparatively resistant formations retarding the grading action of the stream. The Triassic red beds mentioned above may not be strong enough to produce a great water fall by itself, but it is strong enough for the preservation of water falls which had already been started, in the same way as the Niagara limestone serves as a covering formation for the Niagara Falls in North America.

In conclusion, we should say that the origin of Hukou Falls is very likely to be the combination of causes (4) and (1) i.e. a water fall was first initiated by the displacement at Lungmen and then preserved by the presence of hard layers probably those of the Triassic red shale and sandstone series.

Migration of Water Fall and Its Relation to the Age of Fault

Since the continuously concentrated erosion of falling waters near the fall, the "fall-line" must continuously migrate upstream. The distance (D) between the original and the present sites of water falls is determined by the rate of headward migration and the time interval for the migration, or the time elapsed (T) after the faulting. The present rate of migration (V) can be accurately measured by surveying. The age of the fault will then be calculated, in number of years, by dividing D by V, or

$$T = D/V$$

Where, in the present case,

D = distance between Hukou and Lungmen,

V = average annual rate of migration at Hukou, and

T = age of the fault at Lungmen or the age of the graben-fault in central Shensi and Shansi.

Fig. (7) Section along the SWW. side of Huangho at Lungmen showing the same effect as in Fig. (6).

Factors Involved in the Rate of Headward Mirgation of Water Falls and the Influence of Regional Stratigraphy

The apparently simple equation mentioned above is complex in itself. The distance between Hukou and Lungmen can be measured in any degree of exactness, but the average velocity of migration V involves many variable factors. The force of erosion of Huang-ho and the character of the country rock lying between Hukou and Lungmen are the important ones. Furthermore the force of erosion in any river is controlled by the velocity of the stream, by the quantity

of water flowing in the stream and by the amount and kind of the river's tools. Most of these factors affecting the rate of headward migration cannot be determined quantitatively without a definite knowledge of the climate and the drainage of the past. For the sake of simplicity, we assume those indeterminable factors to be constant, then we can see the controlling influence of regional stratigraphy.

In a distance of about 70 kilometers from Hukou to Lungmen only three formations are involved in the rate of migration of water falls as shown in the following list:[3]

Name of the formation	Width of outcrop[4]	Percentage of the total distance of migration
1) Triassic red sh. & ss. series	55 km.	79%
2) Permo-Carboniferous coal series	13 km.	18%
3) Ordovician limestone	2 km.	3%

This table shows that the Triassic red series occupies a predominant part in the whole course of migration. And furthermore, the pure calcareous rock of Ordovician and the highly argillaceous rock of Permo-Carboniferous periods are not so hard and resistant to erosion as the cross-bedded and compactly cemented red shale and sandstone series of the Triassic. The actual length of time required for the water falls to pass through these formations will be more dependent on the Triassic Series than the apparent width of its outcrop. In other words, if we know the rate of migration of the water falls in the Triassic red series, i.e. the present rate, we can calculate the age of the Lungmen fault within an error of probably less than 20 per cent.

Historical Records and Conclusions

After a careful search in literature we are fortunate to find some indications about the change of position of Hukou falls from south to north during

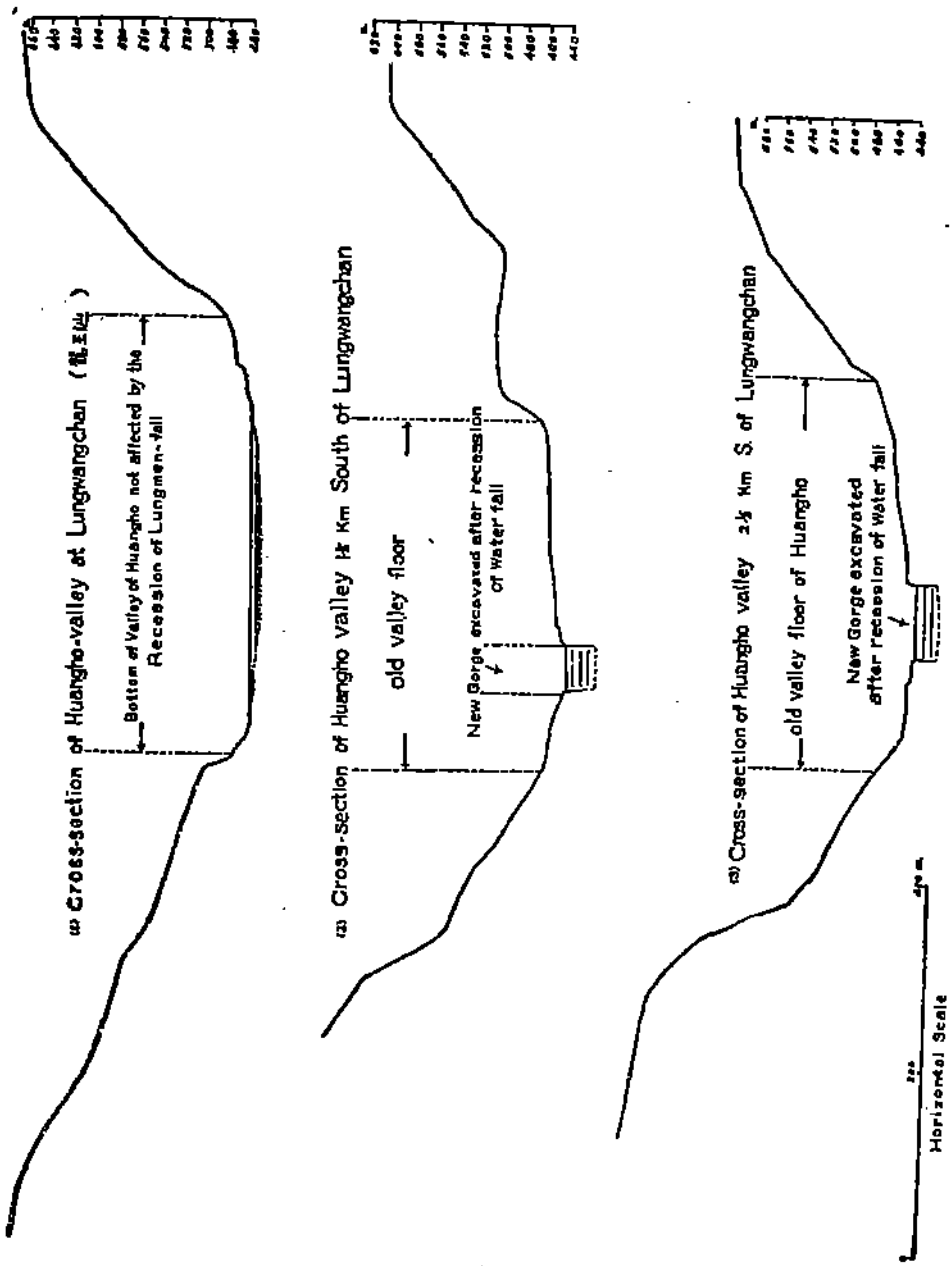

Fig. (8) (1), (2), (3). Cross sections of Huangho valley between Lungwangchan (龍王山) and Mengmenshan (孟門山) showing the valley in valley features produced by recession of falls.

historical times. The positions of Hukou marked on the map of different dynasties in Shansi-Tung-chih (山西通誌) are not accurate enough to be measured by a scale, because a little shift in printing will cause an unreasonable high or low rate of migration. The most significant historical records found are probably that of Shui-ching-chu (水經註) and Lu-shih-chung-chiu (呂氏春秋)which contain the following inscriptions:

〔孟門即龍門之上口也.實爲黃河之巨阨.此石始經禹鑿.河中激湧.……〕—(水經註)
龍門未闢.呂梁未鑿.河出孟門之上.大溢逆流.名曰洪水.大禹疏通.爾之孟門—.〕呂氏春秋)

These paragraphs show that the work of excavation of Lungmen Gorge was done by Emperor Yü (帝禹) in a date of about 2283 B C.[5] and the site of excavation is not at the present Lungmen (locally called Yümen 禹門) but at the upper end of the Greater Lungmen Gorge,[6] locally known as Mengmenshan (孟門山). The total amount of upstream erosion since 2283 B. C. is the length of the narrow channel from the present site of Hukou Falls to Mengmenshan in a distance of about three kilometers as measured from the 1 : 100,000 military map of Shensi. These Data give the average rate of headward migration of Hukou Falls of about 0.71 meter per year. Consequently, the time required for the total migration from Lungmen to Hokou in a distance of about 70 kilometers will approximately one hundred thousand years (98,592 years which is about the age of the fault along the southeastern margin of northern Shensi plateau or the age of Weiho and Fenho graben because they belong to the same structural unit. This result, even inaccurate and uncertain as the nature of the problem should be, is, however, within the limits of various estimates of tht length of Pleistocene epoch which has been calculated by Wright, Penk, and Schuchert as 25,000, 1,500,000 and 2,000,000 years respectively.[7]

Acknowledgement

The author wishes to express his thanks to Drs. W. H. Wong and K. D. Yang for their kindness to send him copies of Mr. Fang's report on the Topographic and Hydrographic Survey of Hukou regions.[2] The cross-sections (Fig. 8) showing the valley in valley structure of Yellow River in the vicinity of Hukou is drawn from Fang's map.

References

(1) Bailey Willis: Research in China, Vol. I, pp. 166, 175-181

(2) 方俊:測量壺口地形及水力報告,民國二十二年八月,國防設計委員印行.

(3) Tarr & Martin: College physiography p. 125, (1930 Edition)

(4) Width of outcrop are measured from "Geological Atlas of Eastern Asia" Scale 1:2,000,000; Tokyo Geographical Society.

(5) The authenticity of this early record is however doubted by some historians.

(6) 李儀祉: "龍門與壺口" [水利] 第一卷,第五期,第335-347頁,民國二十年十一月中國水利工程學會發行. [予以爲龍門之義, 亦可擴大言之, 以孟門爲其上口,以禹門爲其下口,則經義與地理俱符矣]

(7) Knopf, Schuchert, Kovarik, Holmes and Brown: "The Age of the Earth", Bulletin of U. S. National Research Council, No. 80, June, 1931.

Explanation of Plate I.

PLATE I

Fig. 9. Cliff of Triassic red shale and sandstone series along the west bank of the old valley of Huangho at a point about ½ Km. north of village Hsilungwangchan (西龍王池) showing the thickness of individual layers of the red series and the steepness of the old valley walls of Huangho. Looking toward SW.

Fig. 10. A general view of Hukou Falls showing the rising vapor from the main-falls at the middle, the narrow gorge in the fore ground below the falls, and the lower terrace (at both sides of the gorge) representing the old valley bottom before the rejuvenated down-cutting due to recession of water falls (compare with the cross-sections of Fig. (8)). Looking north from a point about ½ Km. south of the main Hukou-falls. The man nearest to the river is standing in a pot-hole formed by the gyratory motion of the swift current below the falls.

Fig. 11. A photography correspond to the SSE half of Fig. (6) showing the regional NNW-dip of the massive Ordovician limestone near the marginal fault-scarp of northern Shensi plateau at Lungmen. Looking NEE toward the East-Temple of Emperor Yü in Shansi side from the West-Temple of Emperor Yü in Shensi side.

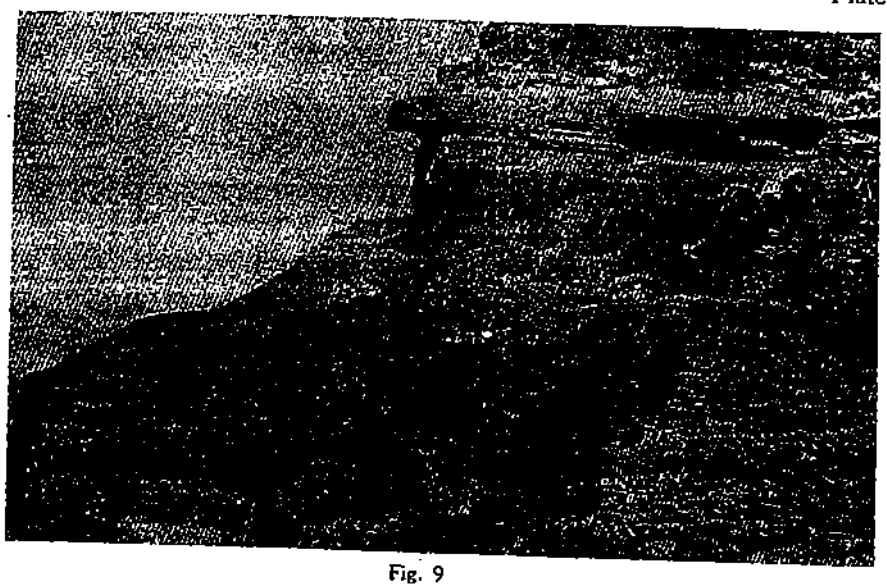

Fig. 9

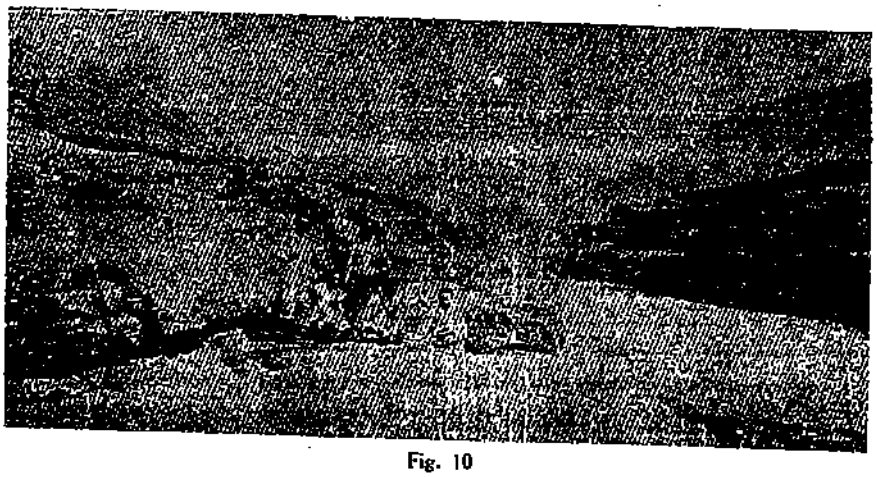

Fig. 10

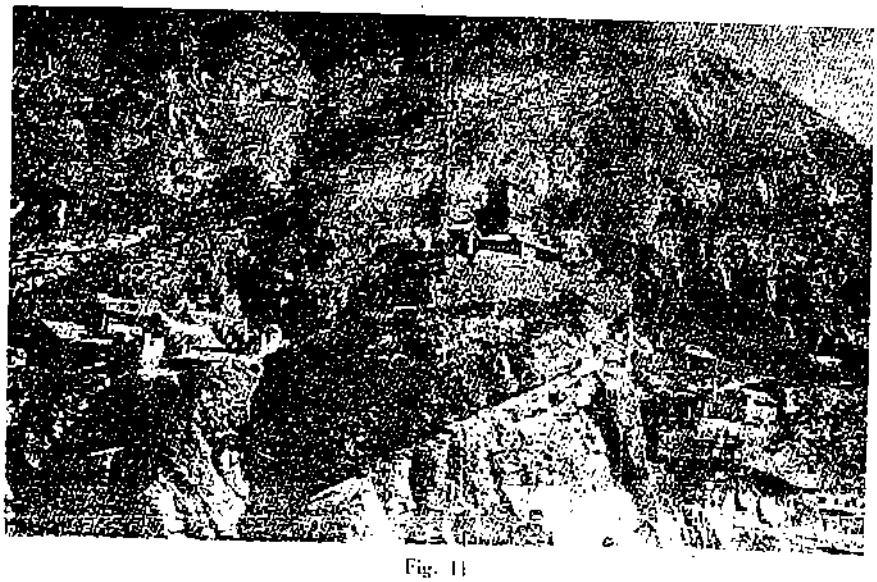

Fig. 11