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A Preliminary Study of Rill Marks in the Yellow River Delta ①

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Abstract In recent years, the flow of the Yellow River has often been interrupted, which has resulted in exposure of channel bars and point bars, and even extensive exposure of the riverbed. Consequently, a large number of rill marks have developed. They are diverse in morphology. According to the hydrodynamic types of their formation, they can be grouped into 6 categories, i. e. the wave-eroded, backwash, seepage, rain-eroded, water-drainage and runoff rill marks. Morphologically, they can be divided into more than ten types: the linear, tooth-shaped, comb-shaped, fence-like, ear-like, braided, branched, leaf-like, flower-like, root-like, dendritic, net-like, radial etc. Their cross sections include the broad-u type (the width/depth ratio is over 2, and may reach 10—20), U-type (width/depth ratio from 1 to 2), V-type, Ω-type and (-type. Their occurrences may be attributed to the variations in composition, grain-size, color, fabric and morphology. They have 5 scales: the micro-scale (length and width within 1 cm), small-scale (length and width within 10 cm), medium-scale (length and width ranging from 10—100cm), large-scale (length and width 1—5 m) and giant— scale (length or width over 5 m).

Key words rill marks, Yellow River delta

Biography Zhong Jianhua, male, born in 1958, Professor, Post Ph. D., tectonics

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INTRODUCTION

The Yellow River is the second largest river of China, and is well-known for its heavy load as it runs through the seriously eroded Loess Plateau. The great amount of silt has blocked the river seriously, making it being a "hanging river" (Gao, 1989; Chen, 1991; Gelder, 1994). In recent years, the flow cutoff of the Yellow River is very serious, which has aroused world-wide attention. The flow cutoff of the river has caused a number of social problems. At the same time, it has exposed many new geological phenomena, which provide new areas of study for the geoscientists, especially the sedimentologists. Some of the studies have been reported (Zhong, 1996; Zhong et al. 1997, 1998a, 1998b), and this paper will present a brief introduction to the rill marks related with the cutoff of the Yellow River Delta. The study area is located in the distributary channel from Lijin to the Yellow River mouth (Fig. 1).

Rill marks is a common sedimentary structure (James, 1884; Collinso, et al., 1982; Davis, 1986; Williams, 1996; et al.) and used to be treated by the earlier research workers as biogenic fossil algae. Dawson, et al. (1868), by comparisons with the rill marks developed along the sides of the tidal channels defined

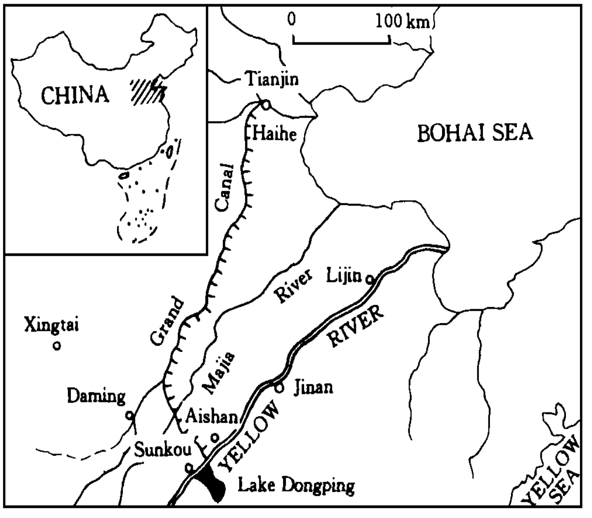

Fig. 1 Location of the study area

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them as of a non-organic origin, and considered them as good sedimentary structures of environmental significance, as they were a kind of exposed indicators . Beasley (1908)and High et al. (1968) found dendritic rill marks on both banks of an intermittent stream and attributed their occurrence to the river water surging up to the exposed argillaceous river banks. Cepek and others (1970) made deep studies of the morphology of rill marks, and pointed out that their morphology was controlled by local topography as well as the surface slope and grain size of the sediments. Plint (1989) also found a great amount of rill marks in the river-facies beds in the Pennsylvanian River of eastern Canada, and thought that their origin was related to the ripple marks surging up to the partially exposed (large) clay boulders, or to low-water-level runoff.

Reineck et al. (1979) grouped the rill marks into three categories: rill marks, swash marks and flute rill marks. Chinese researchers (e. g, Chen; 1995) called them rill mark, but some people (e. g. Liu, 1980) named them "channel trace". In short, there is no standard nomenclature. The "rill marks" mentioned in this paper refer to the traces formed by actions of flowing water or waves, rainfall, etc. (but no obvious scouring or slumping), with a depth less than 1 cm.

CLASSIFICATION OF THE RILL MARKS IN THE YELLOW RIVER DELTA

As early as over half a century ago, Richter (1935) had already made a classification of the rill marks; and later, Shrock (1948), Cepek et al. (1970) and Reineck et al. (1979) also made classification of rill marks, but all were focused on their morphology, paying little attention to their origins and formation environments, and not in a systematic way. Through study of the rill marks in the Yellow River delta for four years, the authors of this paper suggest a classification approach of the rill marks (with the overwater plain in the delta as the main reference), which is summarized in Fig. 2. From the figure we can see that the approach provides a rather detailed classification of the rill marks in the light of their origins, forms, scales and reasons for their appearance. The origin is the most important factor; it can not only determine the features of the rill marks, but also is related to the micro-environment. For example, the feather-like rill marks can occur only on a broad and open gentle slope bordering the channel barsor point bars and the riverbeds, and under the runoff action. They can neither be formed by waves, seepage or other

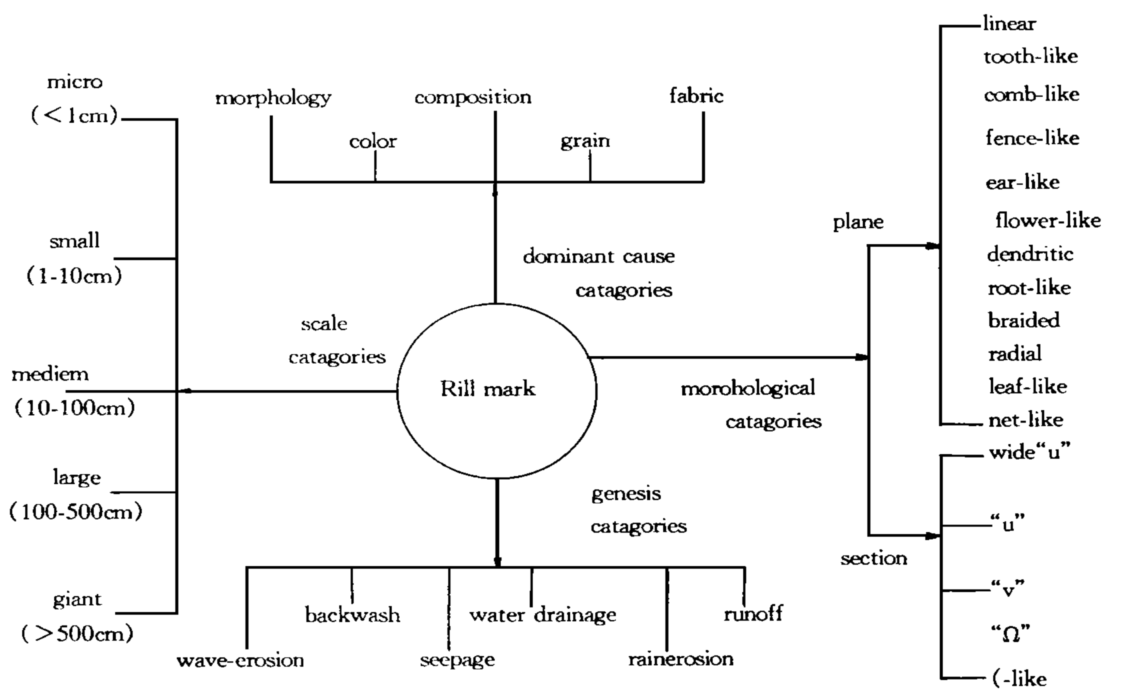

Fig. 2 Diagrammatic map showing classification of rill marks on the overwater plain of the Yellow River delta

actions, nor be formed by runoff on a steep and narrow slope.

FEATURES OF THE RILL MARKS

The rill marks on the overwater plain of the Yellow River delta are grouped into 6 categories according to their origins: water-erosion, backwash, seepage water-drainage, rain-erosion and runoff rill marks. A description of their features is given below.

Wave-eroded rill marks

These are a kind of common rill marks, developed in the Yellow River in all periods, e. g. the flood, normal-water flow, low-water flow or flow-cutoff periods. The waves swash the banks, and leave a great number of rill marks on the cliffs or slopes of the banks when flowing back.

This kind of rill marks is developed mostly typically into the tooth-shaped, comb-shaped and fence-like shapes. Tooth-shaped rill marks are primary products of the comb-shaped and fence-like ones, and can partially develop into the latter through further processes. They usually develop into the comb-shaped ones on a slope, and into the fence-like ones on steep or vertical slopes. If the slope is high, and the sediments are composed of sand, silt or silty sand, the comb-shaped rill marks are usually combined with bench-like or ladder-like shapes (Plate I-1). Rill marks are not easily developed in pure silt or pure clay layers because of their poor binding and shaping properties, but are most well developed in argillaceous silt layers. Therefore, benched comb-shaped rill marks as shown in Plate I-1 are easily formed on a slope alternately composed of sand, silt and silty sand. Similarly, on a steep or vertical slope, composed of the above mentioned sediments, the development of fence-like rill marks is also unbalanced, and rill marks are most easily developed in silty sand layers. Consequently, a kind of storied fence-like assemblage of rill marks will be formed (Plate I -2)

The scale of either the comb-shaped rill marks or the fence-like ones is generally small. Although they can join together to extend as far as over 10 m or even several tens of meters, the length-width or height-width of an individual rill mark does not exceed 10 and 1 respectively. Most of the cross-sections of individual fence-like rill marks assume a "u-type" or smooth arc-type.

Wave-eroded fence-like rill marks tend to occur together with slump structures. The steep slopes where wave-eroded rill marks are developed are vulnerable to slumping under wave swash action, and therefore eroded rill marks may occur on the slumping fragments or slip blocks, often with deformed bedding at the middle part or the base. Plint (1986), in his study of the Pennsylvanian river-faces beds in eastern Canada, also found a great amount of (wave eroded?) rill marks on large clay boulders on the riverbed. They are formed by waves swashing the clay boulders partially exposed on the riverbed.

Backwash rill marks

The rapid backwash of river water will cause downward flow of the water on the surface or in the shallow part of the sediment along its surface, resulting in backwash rill marks. Such rill marks are very common in the Yellow River delta. Observations show that the rapid backwash is related to the influence and control of wind direction changes and the tidal intensity on the normal drainage of water at the Yellow River mouth. It can cause the water level to drop several to over ten centimeters, depending on the changes of wind direction and intensity of the tides.

The rill marks caused by the rapid backwash are usually small scale, and commonly seen in comb-shaped, simple dendritic, flower-like and simple root-like shapes. They are very shallow, with a depth less than 1 mm, usually penetrating only a very thin "mud", and not the sand layer below the mud (Plate I-1, 3). Some of them, however, can be a layer of very thin (< 1mm) fine silt (Plate I-4, 5, 6). This layer of thin mud or fine silt is composed of fine-grained sediments formed when the water body is relatively calm before the rapid backwash.

On the riverbeds where ripple marks are developed, the rill marks formed by rapid backwash may overlap the ripple marks.

As the backwash is mostly episodic, the rill marks sometimes show a bench-like shape, or with one or several water-level lines going through the middle, or with some secondary rill marks developed in between.

Seepage rill marks

The slow recession of water will cause water in the sediments to seep out from the steep banks or slopes of the point bars and channel bars or natural levee. Or, in other cases, water after heavy rains will seep into the above-mentioned bars or levees, and then seeps out. The flow of seepage water along the slopes will result in rill marks. Therefore, the seepage rill marks will only be formed on the slopes or steep walls related to the above three sedimentary faces. One of the major features of the seepage rill marks is their irregular scale: the length-width of the small ones does not exceed several centimeters while the large ones may reach several meters. Morphologically, they are dominated by curved, braided, dendritic and root-like ones (Plate Ⅰ-7). As seepage is relatively stable, the depth-width ratio of the rill marks is relatively large. Some may be as large as 1∶2.

Water-drainage rill marks

These are a special kind of seepage rill marks, in which the seepage flow is drained, and the rill marks occur in a radial shape around the mud-sand volcanic orator formed by water drainage, some resembling a chrysanthemum (Plate I-8).

These rill marks are linear, being deeper near the crater, and shallower towards the periphery. Micro-deltas can be seen at the end of the rill marks.

They are not easily formed under natural conditions (only occasionally), and are mostly related to cases of trampling by men or other animals (like sheep or oxen). Obviously, these rill marks are not important.

Rain-eroded rill marks

These are the most elaborate rill marks (Plate I-9, 10). These unique marks will occur when the rain lashes the margins of the point bars and channel bars, or those of the water passages or scoured channels. However, it must be noted that rainwater only sinks within the rill marks, and there is no water flow coming from outside the marks, which differs from the runoff rill marks.

These rill marks are mainly ear-like, dendritic or special leaf-like. The ends are as fine as threads, while the "root" parts are relatively wide and deep, reaching over 5 millimeters in width and several millimeters in depth. The cross-sections are V-or U-shaped. The length of a single rill mark is generally below 10—15 or 10—20 centimeters. In general, these rill marks are mostly of small scale, with a few of medium scale.

Runoff rill marks

These rill marks are the most complicated and most highly developed ones. Rainwater forms into small runoff flows on the point bars and channel bars or levels. During flow, the runoff flows leave behind great amounts of rill marks in different scale and morphology, forming the most complicated rill mark scenery on the overwater plain of the Yellow River delta.

Such rill marks are dominated by large to medium-scale, mostly several tens of centimeters to several meters, and the maximum may exceed 10 m. Their widths are mostly from several centimeters to over 20 cm, and the depths from several millimeters to 1 cm. Morphologically, they are dominated by linear, braided, dendritic, root-like, net-like, banana and ginkgo leaf-like and radial ones.

The linear rill marks may be grouped into three categories: the straight line, curved and snaking. The first two are generally developed on relatively high (> 5°—10°) slopes, mostly the outer margins of point bars and channel bars, whereas the last one is usually found on slopes of a smaller gradient (< 5°), such as the flat surface in the center of the point bars and channel bars.

Dendritic rill marks are the most commonly seen, and are usually of medium to small scales. According to their morphological and structural features, they can be grouped into two categories, the "tree-like" and "bush-like" ones. The former is characterized by the pattern of secondary rill marks being merged into a trunk, whereas there shows no change from trunk to branches in the latter.

Root-like rill marks refer to those in which several secondary rill marks are branched out from a trunk. Therefore, they have reversed features with the dendritic ones in structure and configuration. Such marks are generally developed on the segment where the slope suddenly becomes gentle. On the lowered slope, the collected runoff is again scattered, forming a number of small runoffs, and hence the root-like pattern. They are of medium to small scale in general.

Net-like rill marks are the most complicated ones, generally developed on the flat surfaces of the point bars and channel bars or the gentle slopes on both sides of the riverbeds. According to the shape of the mesh, they can be divided into the rhomboid, sub-rounded, grid and irregular ones. The rhomboid rill marks have a rhomboid mesh with a diameter mostly of 1—2 cm. They are formed by very shallow (depth < 1—2 cm) planar runoff of relatively high-velocity (> 10 —20 cm/s), and generally developed on relatively high slopes (> 10°) or scoured channels (Plate I-11). The sub-rounded or grid rill marks occur on flat (< 5°) slopes of the point bars and channel bars, generally of medium, large or even giant scales. The mesh size of such rill marks range from several to several tens of centimeters. A single rill mark may be several millimeters to 1—2 cm, with the depth mostly less than 1—2 mm. Their cross—sections are generally "u"-typed or shallow arc-types) with the width depth ratio exceeding 5. The complicated net-like rill marks have an irregular mesh, with crisscrossed marks resembling a spider's web (Plate I-12). This type of rill mark is mostly of medium to large scale, generally developed on gentle slopes (< 5°) of the point bars and channel bars.

Leaf-like rill marks are a kind of attractive rill mark in the Yellow River delta. They have two types, the banana leaf-like and ginkgo leaf-like ones. The former have a pattern in which one or more main rill mark(s) extends along the gradient of the slope, while a series of nearly parallel secondary rill marks join it at a right or oblique angle (Plate I-13). They are mostly of medium to large scale. The latter assume a fan-leaf shape, and tooth-shaped at the front edge. The rills converge from the top towards the base of the fan. There are a number of trunks. Each has some secondary rills (Plate I-14), generally of small or medium scale. The top of the fan is oriented to the upstream of the slope.

Radial rill marks are special and seldom seen. Those observed in the Yellow River delta develop on the dome-like gas caps of the gas heave structures (Plate I-15). A single rill mark is like a straight line or slightly curved, with the depth being several millimeters to 1 cm, length being over ten cm to several tens of centimeters, and depth less than 1 mm. The "tails" are converged at the center of the gas cap, and the front parts are diverged towards the periphery of the cap.

Fence-like rill marks are also a typical type in the Yellow River delta. They are usually developed on the slumped steep banks of the point bars and channel bars or natural levee. The fine runoff or planar flows along the slumped steep banks "engrave" a series of vertical and nearly parallel rill marks (Plate I-16). A single rill mark is generally 3—6 mm wide, 3—5 cm deep, but some may have a width smaller than the depth. Their cross-sections assume a "U" type, a few in a "V" type. They are sometimes developed together with mud-sand stalactites, occurring either on top of the latter or alternated with them (Plate I-17). Because of the scouring and erosion of the runoff flows, the steep banks where the fence-like rill marks are developed are often slumped to form a series of slump blocks, which causes changes to the occurrence of the vertical fence-like rill marks,

Table 1　Features, geneses and formation environment of the rill marks in the Yellow River delta

Genetic type	Scale	Morphology	Formation process and major features	Environment of occurrence
Wave-erosion	micro-medium	tooth-shaped, comb-shaped, fence-like and linear	A series of such rill marks are formed when waves slash the steep cliffs of point bars and channel baes, often resulting in slumping, so that they move and migrate together with the slip blocks. Often accompanied by deformed stratification. Commonly seen.	On outer margins of point bars and channel bars
Backwash	micro-small	comb-shaped, dendritic, flower-like, root-like and linear	They are formed by flows of water on the surface or shallow part of the sediments along the slopes caused by rapid backwash of water. Very shallow, with the depth less than lmm. Very well developed.	On point bars, channel bars and riverbeds
Seepage	small-large	linear, braided, dendritic, and root-like	The recession of water will cause water in the sediments to seep out from the steep banks or slopes of the point bars and channel bars. Or, water after heavy rains will seep into the above-mentioned bars and then seeps out. The flow of seepage water along the slopes will result in rill marks. Relatively well developed.	On the periphery of point bars and channel bars, or within the scoured channels
Water-drainage	small	chrysanthemum-like and radial	The water flows from the mud-sand volcanic crater formed by water drainage, resulting in radial or chrysanthemum-like rill marks. Occasionally found.	In the scoured channels of point bars and channel bars
Rain-erosion	micro-small	ear-like, dendritic and leaf-like	These marks occur when the rain directly lashes the margins of the point bars and channel bars, or those of the scoured channels. They are generally complicated and of smallscale. Quite developed.	On the outer margins of point bars and channel bars, or on the margins of scoured channels
Runoff	medium-large	linear, braided, dendritic, root-like net-like, leaf-like and radial	Rain on the point bars and channel bars forms into small runoff flows, which leave behind a variety of complicated rill marks. Some of them may further develop into scoured channels. Often associated with slumping and deformed structures. Very well developed.	On point bars, channel bars, or steep cliffs and slopes

and consequently, they become oblique or even horizontal. by water flows, then their appearance may be explained

DISCUSSION ON THE GENESIS OF RILL MARKS

If the rill marks can be considered as being caused by the following 5 factors: composition, grain size, color, fabric and morphology.

In general, the morphology of rill marks (concave surfaces of sediments caused by scour of running water) are of the mentioned in the literature. Compositional rill marks are formed as different compositions of the sediments enabled them to record the flowing traces of water. For example, in the vicinity of the Shengli Bridge, relatively pure quartz sands are seen to gather by the water flow, forming a quartz sand belt along the flow. Although there is no obvious form of rill marks, the quartz sand belt clearly shows the trace of water flow. Therefore, such a phenomenon can also be considered as a kind of rill mark, compositional rill mark attributed to the composition of the minerals. Moreover, compositional rill marks can be formed by plant fragements, carbonized debris and clay etc. (Plate I-18). Changes of grain size can also record traces of water flow, which will not be discussed here, as some of them can be seen from the compositional rill marks. Similarly, color variations can record the trace of water flow (Plate I-18). The changes of color are in fact caused by changes of sediment composition, and will not be discussed either. The flow of water can cause directional arrangement of non-spherical sediments and record the trace of water flow, forming fabric rill marks. This phenomenon mainly occurs in rill marks formed by plant fragments or carbonized debris. It is based on these causes of formation of the rill marks that we grouped them into five categories, as illustrated in previous sections.

The rill marks in the Yellow River delta are summed up in Table 1 for convenience of correlation (Fig. 2).

CONCLUSION

The above gives a brief introduction to the rill marks in the Yellow River delta, from which it can be seen that they are of various geneses and complex morphologies. Although they are all products of an exposed environment, there are differences in genesis and formation environment (Table 1). These differences may be of a reference value to the detailed analysis of the environment. Our work is only in the preliminary phase, and there are many problems to be further studied. Comments and suggestions are welcome.

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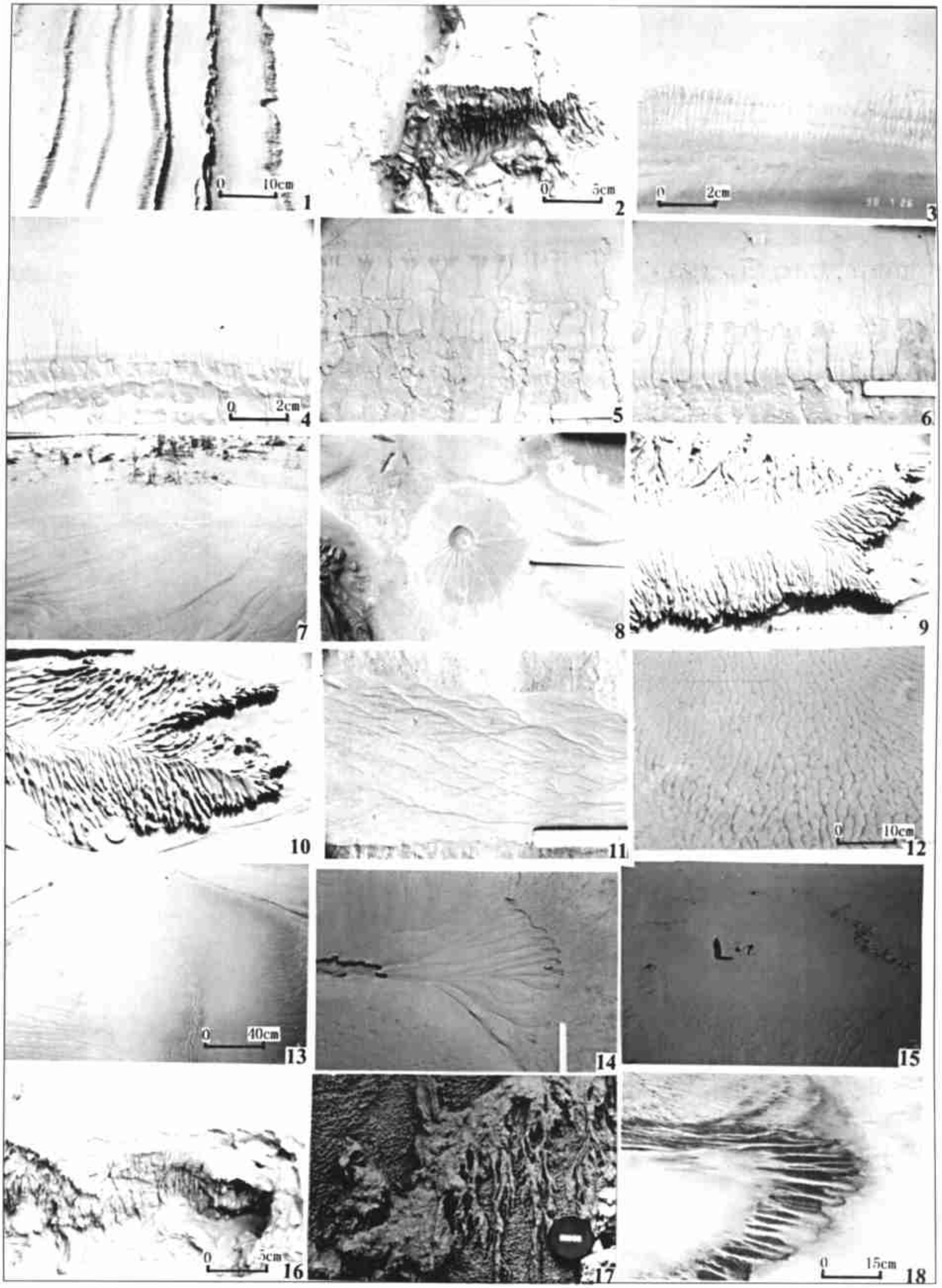
Explanation of Plates

Plate Ⅰ 1. Comb-shaped rill marks, arranged in bench or ladder forms, with color rill marks developed on the right side. Wave-eroded origin. 2. A Fence-like rill marks. The cross-section assumes a "U" type. Associated with slump structures. Wave-eroded origin. 3. Backwash comb-shaped rill marks. Developed on mud film, very shallow. A number of water level lines can be seen. 4. Backwash dendritic rill marks. Developed on mud film, very shallow. These are under the process of formation, and very damp on the surface. 5, 6. Backwash rill marks, with high gradient of slope, 15°—20°. The rill marks are flower-like or dendritic, with a number of water level lines developed. Developed on argillaceous silt film, with the depths less than 1 mm. 7. Curve-patterned, branched and dendritic seepage rill marks. They are of large scale, the maximum reaching 5—6 m, and developed on the slope bordering Shengli-I point bar and the riverbed. There are large seepage areas at the top ends of the rill marks, and they are still growing. 8. Radial and chrysanthemum-like rill marks. Developed on the periphery of mud sand volcanoes formed by water drainage. 9, 10. Special leaf-like rain-eroded rill marks. Very elaborate. 11. Rhomboid net-like runoff rill marks, formed by high-velocity shallow water (depth less than 1 cm). Developed in scoured channels and ditches. 12. Large-scale irregular net-like runoff rill marks. The meshes are complicated in shape and criss-crossed. 13. Large banana leaf-like runoff rill marks. There is one (or more) trunk, with a number of secondary rill marks convergent to it, closely resembling the leaf of banana. 14. Medium-scale ginkgo leaf-like runoff rill marks. The outline of the rill marks is very similar to the leaf of ginkgo. Their appearance is attributed to their composition and color. 15. Radial runoff rill marks, developed on the gas caps of large gas heave structures. The rill marks are scattered towards the periphery from the center of the gas cap in a radial pattern. 16. Runoff rill marks developed on the vertical cliff of the western river mouth point bar. They are formed by mud and water running along the steep cliff. 17. Runoff rill marks developed on the mud and sand stalactite. 18. Rill marks formed by plant fragments, carbonized debris which are shown by their different compositions.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