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黄河下游河道的冻裂研究^①

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摘要 黄河下游河道在冬季冰封雪冻,使得河道上发育了大量的冰冻裂痕(简称“冻裂”),形貌独特,引人注目。黄河下游的冻裂共有八种形态:缝隙状、豆荚状、直线状、三联状、锯齿状、网状、螺旋状及树枝状。后两种冻裂仅产在薄层淤泥中;其余的均产在粉砂中,与一般的干裂发育载体迥然不同,这也是冻裂的一个特殊之处。另一种发育在粉砂层中的冻裂—冰冻裂理也很特殊。冻裂的形成无疑与冰作用有关。冰融水劈的交替作用是其具体的动力学过程。

关键词 冻裂 黄河

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1 概述

岩层表面的裂痕是一种比较常见的(沉积)构造,对它的研究由来已久^[1~9]。已有的许多成果表明,岩层表面的裂痕成因有多种多样^[10~19],虽然干燥收缩是一种常见而又重要的裂痕成因方式,但其它成因的裂痕也不鲜见。我们对黄河下游的多年考察表明,冰冻也会形成裂痕(缝)。这种裂痕无论在形貌上,还是在内部结构及成因、分布上均与一般的干燥裂痕(缝)大相径庭,作为一种新的裂痕成因类型值得研究。

黄河下游近年来因断流和水量骤减而发育了一系列水——风及冰复合地质作用,形成了一系列相应的引人注目的复杂地质现象和地质体,冰冻裂痕便是其中之一(以下简称“冻裂”)。本次研究的地点选择在济南冻口至东营西河口二百余千米的河道上,具体位置见图1。

2 冻裂的特征

黄河下游的冻裂非常发育,形态多样,规模不一。可分为八类,以下简述。

(1) 树枝状冻裂。其形态与树枝惟妙惟肖(图2a及图版I-1),象大型复叶,可出现2~3级分“枝”,主“枝”最大长度可达30~50 cm,末“枝”长数厘米。宽不足1 mm到3~4 mm;深度多在1 cm以内。这是一种组合冻裂。一般发育在淤泥层中。

(2) 螺旋线状冻裂。螺旋线状冻裂是一种平面

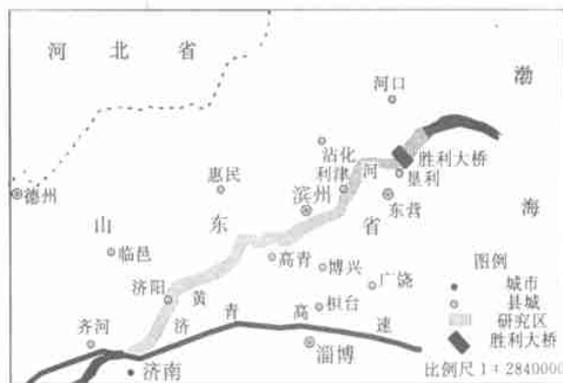


图1 研究区位置图

Fig. 1 Location of the study area

上呈螺旋线状的冻裂,多组合成花朵状(图2b及图版I-2)。“直径”多在数厘米到数十厘米。单支冻裂长5~40 cm,裂缝宽度从不足1 mm到2~3 mm,深度多在数毫米到1 cm有余。

一般的干裂难以形成这种特殊形态的裂缝。这种形态的裂缝与树枝状冰晶印痕的析出有关。同样仅发育在极薄的淤泥层中。

(3) 缝隙状冻裂。这是一种最简单的冻裂(图2c及图版I-3),平面上呈直线状,长度多在10 cm以内,宽3~5 mm者多见,深数厘米者居多;中间稍宽,两端尖窄,状如裂缝,缝壁平直,缝缘平坦不向上翻卷。

(4) 直线状冻裂(图2d)。非常引人注目的一种

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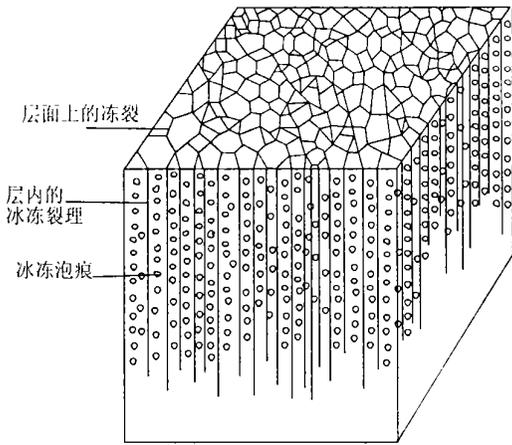


图2 不同类型冻裂的平面图

Fig. 2 Plane view of different ice-frozen fissions

冻裂,大者长度最大可达百十米(图版 I-4),宽深近十厘米。但多由一系列彼此连接的次级裂缝组合形成,根据其沿伸方向与河道的关系可以分为两种:一种是顺河道冻裂,我们将其称为“纵向冻裂”,其长度最大可达百十米;另一种是垂直河道分布,连接到纵向冻裂上,我们将其称为“横向冻裂”,长度较小,多在 20~40 cm 或更小,两者组合成窗棂状或网状。

(5) 豆荚状冻裂。状如豆荚(图 2e 及图版 I-5),长数厘米到十余厘米,缝宽 0~2 cm,缝深 2~3 cm,缝缘上翘呈唇状。上翘高度最大可达 1 cm 以上,系冰冻膨松所致。有关问题,后文详述。

(6) 锯齿状冻裂。非常常见,冻裂由一系列交角 90° ~ 120° 左右的折线状裂缝组成,状如锯齿(图 2f 及图版 I-3)。裂缝总长十几、二十余厘米,多由 4~6 个折线组成,缝宽数毫米,缝深多在 1~2 cm。

锯齿状冻裂一般顺河道方向分布。表明了它的成因可能与冻裂滑动撕裂有关。

(7) 三联状裂缝。非常常见。状如三联裂谷,但规模仅十余厘米,由三个单支裂缝组合形成,单支裂缝之间的夹角 120° (图 2g 及图版 I-6)。单支裂缝呈“V”字形,在汇合处张口;在另一端闭合,长度多在数厘米至十余厘米,缝宽 1 cm 以下,缝深小于 2~3 cm。

三联冻裂仅发育于边、心滩的(纯)粉砂中。

(8) 网状冻裂

其实,第(4)种冻裂常常是网状冻裂的构素。根据网状冻裂的形貌及内部结构可以分为两种:一种是形态不规则,呈多边形网状,缝壁参差,直径多在 10 cm 左右(图 4h 及图版图版 I-7);另一种是形态比较规则,由一系列纵横向直线状冻裂组合而成。多为复网,一级网眼直径数十厘米;三级网眼直径 10 cm 或更小(图 4i 及图版图版 I-4)。这两种冻裂踩上去都有疏

松感,尤其是后者。这是伴生大量的冰冻气泡痕(简称“冰冻泡痕”)的缘故。冰冻泡痕系孔隙水冻结转变成微球粒状冰粒,尔后又被融化所形成的冰粒铸模。

另有一种非常特殊的冻裂(图版 I-8 及图 3),其特征非常象黄土的柱状节理,但规模较小,宽度一般在 1~2 cm,高数厘米到三十余厘米,以十余厘米者多见,裂缝面宽多在 1 mm 以内,裂缝竖直者多见,少数倾斜。裂缝面平坦为主,少数略曲。这种特殊的冻裂在柴达木第四系七个泉组的粉砂和泥层中也有所见。我们把这种冻裂称为冰冻裂理。冰冻裂理一般发育在边、心滩表层的粉砂中。

前两种冻裂(树枝状和螺旋状)一般发育在边、心滩表面极薄(厚度毫米)的淤泥中,而其余冻痕均发育在粉砂中。后一点与一般的干裂迥然不同。

3 成因分析

无疑冻裂是由冰冻引起的一种裂缝,其成因均与冰冻有关。但不同形态的冻裂有不同的力学成因机制及河床条件。以下简要分析之。

(1) 螺旋状冻裂与树枝状冻裂

前已叙述,螺旋状冻裂仅发育在极薄(< 1 cm)的淤泥中,这种淤泥质地非常均一,是形成螺旋状冻裂的物质基础。由于淤泥被水充分饱和,在冰冻过程中其中的水析出,结晶成螺旋状或树枝状冰晶,呈楔片状冰晶在增厚扩展过程中将两侧的淤泥挤开。白天楔片状冰晶融化,而夜晚又重新冻结,反复交替便形成了这种形态特殊的冻裂。一句话,冰晶的形态决定了冻裂的形态;冰晶的楔入(相当于根劈)作用是这种冻裂形成的早期动力。

(2) 豆荚状及三联状冻裂

两者的形成机制比较类似,现以前者分析之。这种冻裂一般发育在边、心滩非常潮湿的低洼处,冰顺层楔入是其形成的重要的动力机制。图 4 是从野外一个豆荚状冻裂所观察的实际资料绘制的,从图 4 可以看出冻裂的隆起高度是取决于冰冻拆离面的大小和多少有关。

这种冻裂同样与冰劈有关。白天气温升高,沉积物中的冰融化成冰水,在冻裂底部的楔尖处汇集,并沿层理面向两端扩渗。夜晚气温下降,水转变成冰,同时体积膨胀,使沉积物顺层面拆离,并向上隆起(图 4)。如此重复便形成了豆荚状或三联状冻裂。

(3) 直线状及网状冻裂

这种冻裂与表层水分布不均有关。如果边、心滩表面以下的水分布不均匀,即有的地方多,有的地方少,那么其结果是水多的地方冰冻的隆起较高,而水少

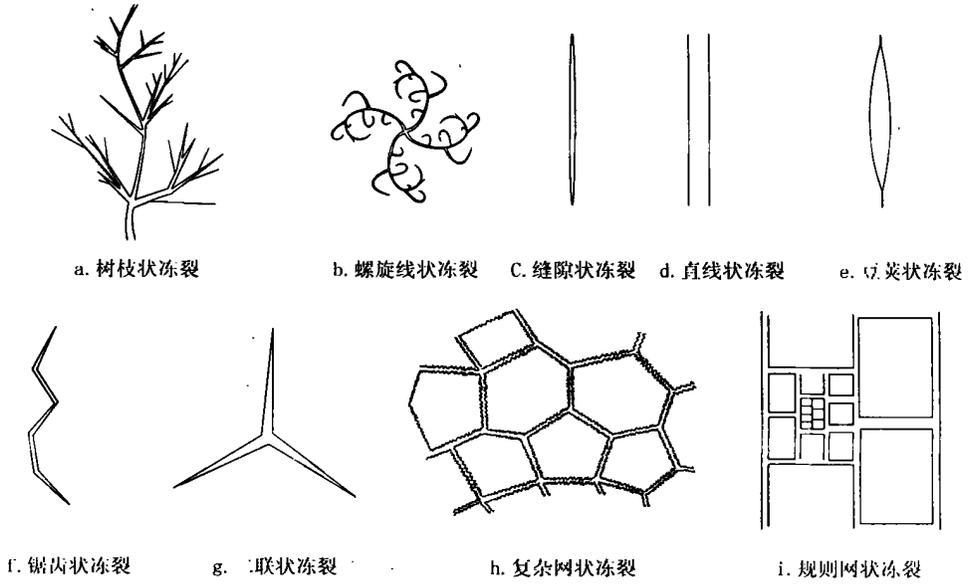


图3 冰冻裂理示意图

Fig. 3 Sketch for the frozen parting

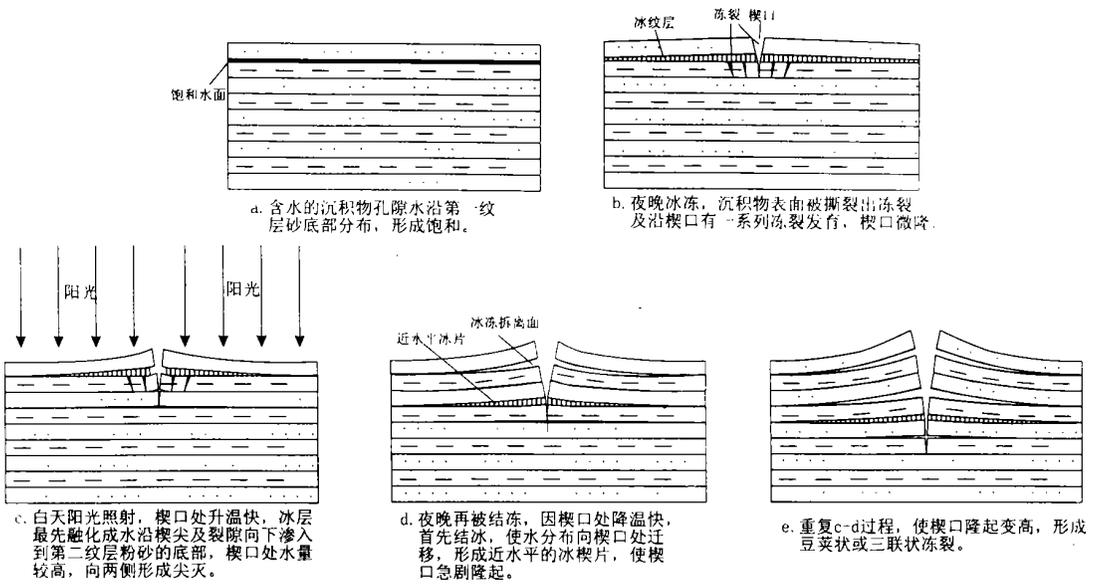


图4 豆荚状及三联状冻裂的形成过程

Fig. 4 Sketch for the formation process of the pod-like frozen crack and triple junction crack

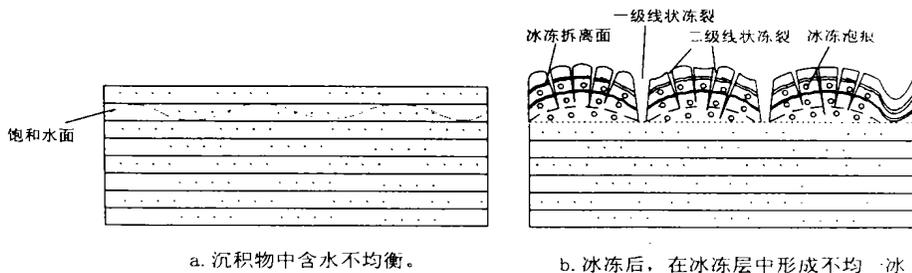


图5 直线状和网状冻裂的形成过程示意图

Fig. 5 Sketch for the formation of straight and netty frozen cracks

的地方冰冻后隆起较低,其结果是使沉积物出现差异隆起,又由于粉砂没有粘性和可塑性,所以往往又被拉断形成线状冻裂,我们用图5表示。冰冻的过程犹如食品膨化过程,形成一系列冰冻剥离面和冰冻泡痕,其结果使冰冻层膨化疏松。

(4) 缝隙状、锯齿状冻裂及冰冻裂理

无论是板片状,还是锯齿状或冰冻裂理,其形成机理与孔隙水冻结成冰粒导致粉砂体积收缩及冰劈作用有关。机理与过程同前。

4 结论及结束语

通过研究,结论如下:

(1) 黄河下游发育了大量冻裂,形貌独特,规模不一。

(2) 冰作用的物理过程是冻裂的形成机制。冰融、冰劈的交替作用是其具体的动力学过程。

(3) 冻裂的最大特征是可以发育在(纯)粉砂中,而不象泥裂仅仅发育在泥层中;其次是发育了冻裂的粉砂一般被膨化,产出疏松感觉;最后是有的冻裂形态比较特殊,非其它裂痕所有。

以上简要地介绍了黄河下游的冻裂,可以看到其形貌与内部结构,尤其是发育的载体与一般泥裂迥然不同。通过对黄河下游冻裂的研究有助于我们了解和认识岩层中类似构造的成因及其环境、气候意义。

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Study on the Frozen Cracks in the Lower Reaches of Yellow River

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Abstract The lower reaches of Yellow River is frozen in winter, as a result, a lot of frozen cracks are developed. They are noticeable with unusual appearances.

All the frozen cracks may be broadly divisible into eight types according to their shapes including fissure-like,

pod-like, linear, triple-junction-like, sawtooth-like, netty, spiral and branched.

The fissure-like crack has simplest shape. It is a straight, narrow, short fissure in plane and is a slaty sheet in space. The length is mostly below ten centimeters, and the width is not beyond one centimeter, and the depth is also mostly below ten centimeters. The both ends of the crack is sharp and flat, and the widdle is relatively wide and in relief.

The cross section is like "v". The length is several centimeters to more than ten centimeters, and the width is one to two centimeters and the depth is one to three centimeters.

The straight linear frozen crack has a relatively simple shape and but the sizes are variable. The smaller one is decades of centimeters in length and several centimeters in width and in depth. The length of larger ones is in the range of from decades of meters to more than one hundred of meters, and the width and depth are all below ten centimeters. Commonly, they extend along the river course.

The triple-junction-frozen-cracks are rather similar to triple junction rifts, but their sizes are considerebly small. In fact, they are an assamblage frozen cracks, being consisted of three single frozen cracks with an interangle of about 120° .

The compound ones mean that large net contains small net and the simple type has only one rank. This netty frozen crack that consists of a series of straight linear frozen cracks is relatively complex.

The sawtooth-like frozen cracks is actually an assemblage type that is made up of a series of short, linear frozen cracks with an interangle of about 120° . Also, their sizes are small and their length range mostly from ten to thirty centimeters and their width are not beyond one centimeter.

The netty frozen crack is a rather complicated type. That consists of straight linear and curved frozen cracks. It may be divided into two types: Compound type and simple type. It may be divided into two to three ranks. The single frozen crack is straight linear or slightly curved and its length is several centimeter to decades of centimeters and its width is several millimeter.

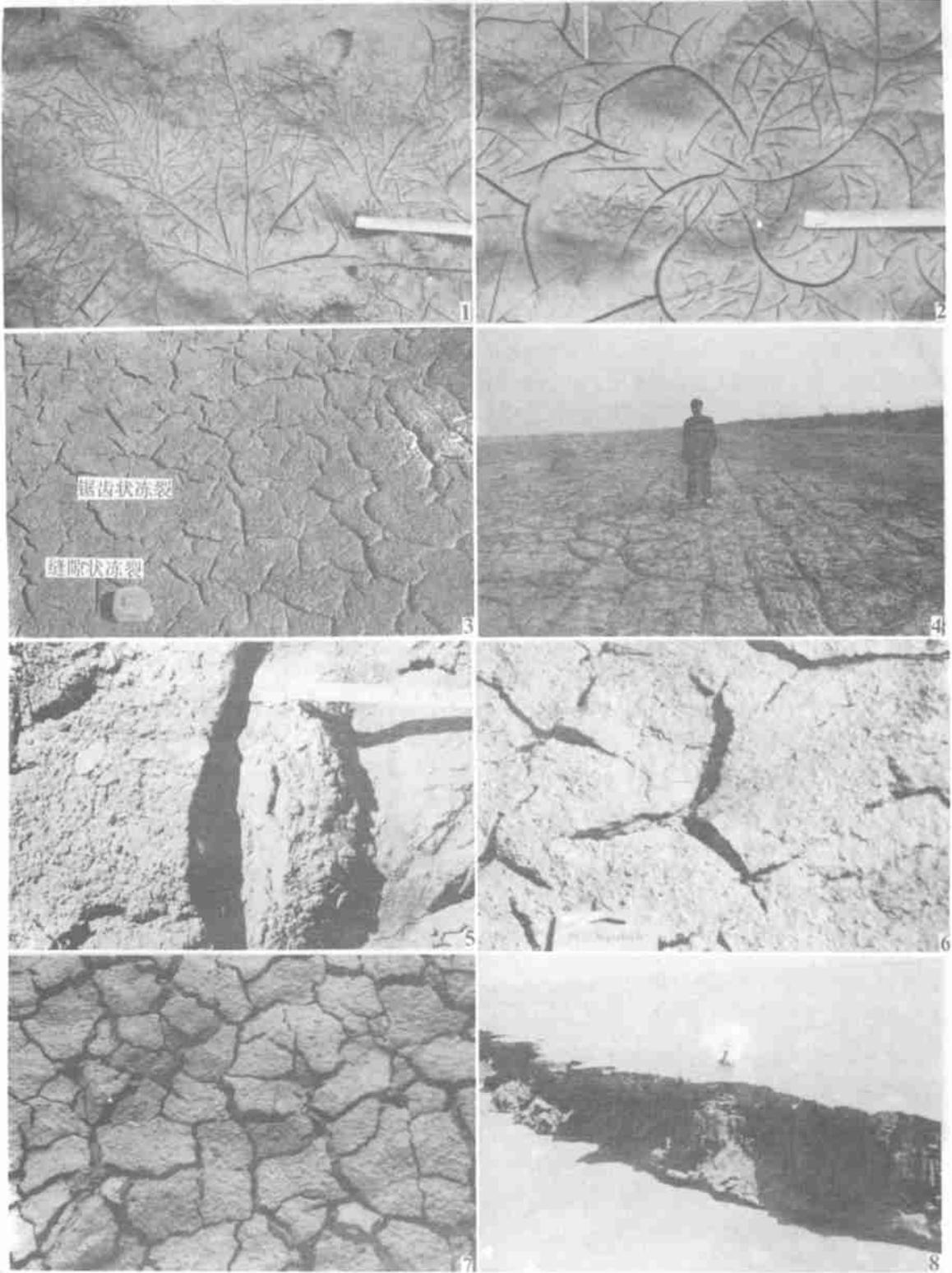
Also, the spiral frozen crack is an assemblage type, but their patterns are considerably unusual and single frozen crack has spiral form and several frozen cracks assemble to form flower-like pattern. The single frozen crack is in the range of five to forty centimeters in length and several millimeters in width.

The branched frozen crack is rather complex in form and, also, is an assemblage type. Genenally, the size is small and the length is mostly in the range of ten to twenty centimeters and the width is below one centimeter.

The last two type genenally develop in thin mud layer and the other generally develop in silt layer. Another frozen crack (frozen parting) is also considerably noticeable.

The formation of frozen cracks, undoubtedly, is related to ice action and the interaction of ice melting and ice wedging is their concrete dynamatic process.

Key words frozen crack, Yellow River



图版 I 说明 1. 螺旋线状冻裂。单支的螺旋线状冻裂围绕一中心排列成花朵状。形态极为独特。摄于滨州下游 200 m 左右的边滩上。2. 树枝状冻裂。三级分枝, 非常复杂, 发育于极薄的淤泥中。摄于滨州浮桥下游 200 m 左右的边滩上。3. 缝隙状冻裂与锯齿状冻裂。最简单的一种冻裂。摄于济南泺口边滩。4. 直线状冻裂。规模巨大, 长数十米以上, 宽深多在 10 cm 以内, 顺边滩分布。摄于胜利 I 号边滩。5. 豆荚状冻裂。平面上如豆荚, 两端尖窄低平, 中部宽圆隆起。摄于利津浮桥附近。6. 三联状冻裂。与三联裂谷形态上非常相似, 三支支冻裂以 120° 左右夹角相交, 在相交处张开, 向外收敛尖灭。摄于东张心滩。7. 网状冻裂。不规则网状, 冰冻膨化, 非常疏松, 图版 IV 右侧的网状冻裂相对规则。纵横交错, 组合成窗棂状。摄于胜利 I 号边滩。8. 冰冻裂理。状如黄土柱状节理, 但规模甚小。摄于利津浮桥下游 1 km 处。