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Tilting marks: Observations on tool marks resembling trace fossils and their morphological varieties

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ABSTRACT

Tilting marks, defined here as linear tool marks having transverse ornamentation, are produced in shallow water when the oscillatory action of waves of short wavelength tilt grounded objects rhythmically in such a way that they move and push sediment aside. These tool marks can resemble trace fossils, particularly if they are bilaterally symmetrical. Even asymmetrical objects can produce symmetrical tilting marks because the shape of the mark only depends on the geometry of the ground-touching part of the object, which may be partially floating. Objects of either soft or hard consistency, such as jellyfish or wood, respectively, can produce tilting marks. Tilting marks are normally produced linearly parallel or at an angle to the direction of wave propagation and do not show sharp bends or curves. Tilting marks can be formed on plane beds as well as rippled surfaces. Tilting marks can be distinguished from trace fossils by taking into account the geometry (symmetry), the direction of movement, and the mainly linear course and the internal pattern.

1. Introduction

The term “tilting marks” was introduced to describe those sedimentary structures that are produced in quite shallow water depth when waves tilt grounded or partially floating objects repeatedly in such a way that they move and push sediment aside while tilted, leaving a structure behind (Wetzel, 1999). Tilting marks can therefore resemble trace fossils. An object may move in the direction of wave propagation or at an angle to it. Tilting marks are always produced on the surface and have no subsurface expression, which is what distinguishes them from many trace fossils. Tilting marks are often elongated, nearly straight or slightly curved, and oriented parallel or oblique to the direction of wave propagation. In addition, tilting marks are quite similar to tool marks that can be produced by objects which are moved by wind on land (Jones, 2006). Recently, observations of Precambrian sedimentary structures at Mistaken Point, Newfoundland (Canada) were interpreted as metazoan traces (Liu et al., 2010a, 2010b) or tilting marks (Retallack, 2010). This discussion shows that there is still some confusion regarding the origin and significance of tilting marks.

In order to discuss these issues, this study describes (1) the types and geometry of objects that may produce tilting marks, (2) the factors that affect the morphological variability of tilting marks, and (3) the influence of the substrate on the characteristics of the tilting marks. These new findings may be of use to recognize tilting marks and to distinguish them from other structures in the rock record or present day environment.

2. Observations

The morphology of tilting marks and how they form has been mainly studied on tidal flats because abundant tilting marks have been observed in small ponds and runnels formed during ebb tide (e.g., Davis and Fitzgerald, 2004). Tilting marks can be found very well developed on surfaces of fine-grained, unconsolidated, soft or cohesionless sediment because it is displaced easily. Tilting marks are found on rippled as well as smooth surfaces (Fig. 1A and D). Smooth surfaces form in the swash zone at high tide/water level or, alternatively, during ebb tide when in a shallow runnel where flow velocity is very high for some time. At low tide with some water remaining in a pond or runnel, small-scale waves may induce the formation of tilting marks even on such smooth surfaces (Fig. 1A). On rippled surfaces, tilting marks often show a differentiated morphology being more deeply incised and structurally more detailed on the stoss side than on the lee side of a ripple (Fig. 1D).

Tilting marks form also on the surface of incipient microbial mats. Because the microbes bind sediment particles together, only the stronger impacts of the tilted object resultant from larger than average waves may displace sediment. Therefore, on such mats the pattern constituted by pushed sediment is wider spaced and less detailed the more intense the sediment is bound by microbes, while the objects need to displace sediment-binding microbes and adhering

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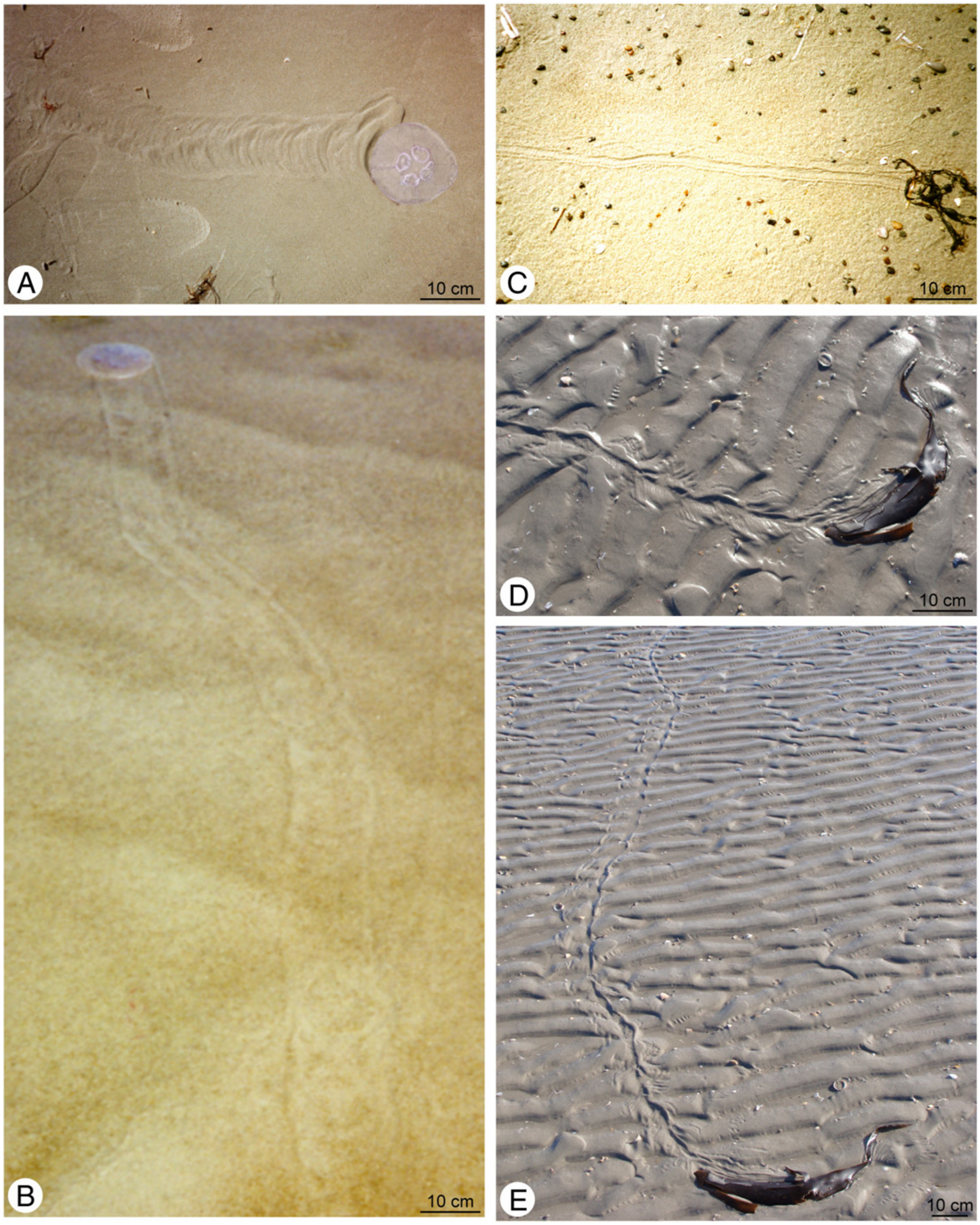

Fig. 1. (A) Tilting mark produced by the medusae *Aurelia aurita* on a plane bed; the tilting mark resembles crawling traces produced by large gastropods (see text). (B) Tilting mark produced by medusae *Aurelia aurita* on a plane bed covered with incipient microbial mat; note the slightly curved course of the tilting mark. (C) Small tilting mark produced by large seaweed while partly floating; the resultant tilting mark resembles crawling traces of gastropods. (D) Seaweed produced a tilting mark resembling the trace fossil *Polykampton*; note ornamentation resembling bundles of probes or spreiten on both sides of a central furrow. At the stoss side the tilting mark is more deeply incised and shows more detail than on the lee side. (E) Tilting marks may form over a considerable distance; same object than shown in (D).

material (Fig. 2). Structures typically of (incipient) microbial mats such as irregular lamination and wrinkle structures may be present (e.g., Noffke, 2010; Carmona et al., 2012).

Objects of very different consistency may produce tilting marks. Tilting marks can be produced by hard objects, such as empty bivalve shells (Wetzel, 1999). However, also soft, flexible objects like seaweed or jellyfish can produce tilting marks (Fig. 1). Wave tilting of a soft object can induce a wave-like deformation that propagates through the object, such as the jellyfish *Aurelia aurita* (Fig. 3). An approaching oscillatory wave lifts up the proximal tip of such a medusae lying on the sediment, starts to fold this proximal part, and then the fold migrates through the soft body concomitantly with the propagating wave (Fig. 3). When the medusae's tip that was lifted and deformed first touches the ground again at an acute angle, a little sediment is pushed. In this way the medusae moves in the direction of wave propagation or at an acute angle to it and leaves a mark behind (Fig. 3). The size of the produced tilting mark depends on the size of the sediment-pushing part of the object, in case of a soft medusae like *A. aurita*, the margin of the umbrella. The resultant tilting mark resembles crawling traces produced by gastropods; for instance, the species *Bullia rhodostoma* can produce traces as wide as 6 cm (Abel, 1935, p. 207–2014; figs. 176–195). In addition, resting seagulls can fluidize a