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MICRO-RIPPLES ON SILT-DOMINATED BEDS: OBSERVATIONS AT THE GLACIER AUSTERDALSISEN, NORWAY[1]

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ABSTRACT

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Micro-ripples (wavelength 0.5-2.0 cm, amplitude less than 0.2 cm) form on silt-dominated beds at the margins of ephemeral stream channels in reworked glacial lake sediments as a result of unidirectional currents, oscillatory flow or both. Pulsation of flow and the presence of bed irregularities much larger than the dominant particle size result in local stress concentration, and micro-ripples may form even though the mean stress is below the theoretical threshold for the grain sizes involved. Grain shape and composition may be partly responsible for differentiation of crest and trough material. X-ray diffraction studies have confirmed that samples of sediments from micro-ripple troughs and crests at one site differ in mineralogical composition, and differences of grain size and shape are confirmed by scanning electron microscope investigations.

INTRODUCTION

In May 1959, the level of the lake Austerdalsvatnet at the western margin of the Norwegian glacier Austerdalsisen was lowered by means of a flood-relief tunnel (THEAKSTONE, 1964). A 70 m thick sequence of glacial lake sediments overlain by coarser outwash material was exposed (THEAKSTONE, 1976). The river Kamplielva, which flows to Austerdalsvatnet, now runs through the predominantly fine-grained sediments for about 2400 m (Fig. 1). River discharge is at a maximum in May and June as a result of snow melt; during the rest of the year it is relatively low and many of the braided channels within the sediments are dry, or occupied only after heavy rain. Channel beds generally become coated by wind-blown sediments soon after water ceases to flow over them.

Bedforms within the Kamplielva channels include wave- and current-generated micro-ripples (THEAKSTONE, 1977). Most apparently are destroyed or buried as water flow ceases, or soon afterwards; few are preserved on dry channel beds. Observations of micro-ripples, which result from the interaction of water motion and bed material, have been made at Austerdalsisen during the summers of 1976, 1977 and 1978. Micro-ripples are present at many sites within the Kamplielva channels. The channel beds at such sites are firm, and the silt/clay fraction of samples of bed material ranges between 68 and 95% by weight, with a mean of 83%. Because of their small size, it is very difficult to collect separate samples of ripple crest and trough material. Precise measurement of ripple amplitude beneath flowing water has not been possible. The observations at Austerdalsisen, together with the results of laboratory investigations of water flow over silt beds by other workers, suggest that the presence of grains of different shapes and densities influences the nature of the micro-ripples.

MICRO-RIPPLES AT A DISTRIBUTARY JUNCTION

The depth of the water in the main channel in one braided reach of Kamplielva decreases rapidly towards the margin, the bed sloping steeply up to the head of a small distributary channel. At the point of diffluence, micro-ripples are present on a minor point bar and on the outer edge of a small mid-channel bar. Ripple crests are light-coloured, troughs dark-

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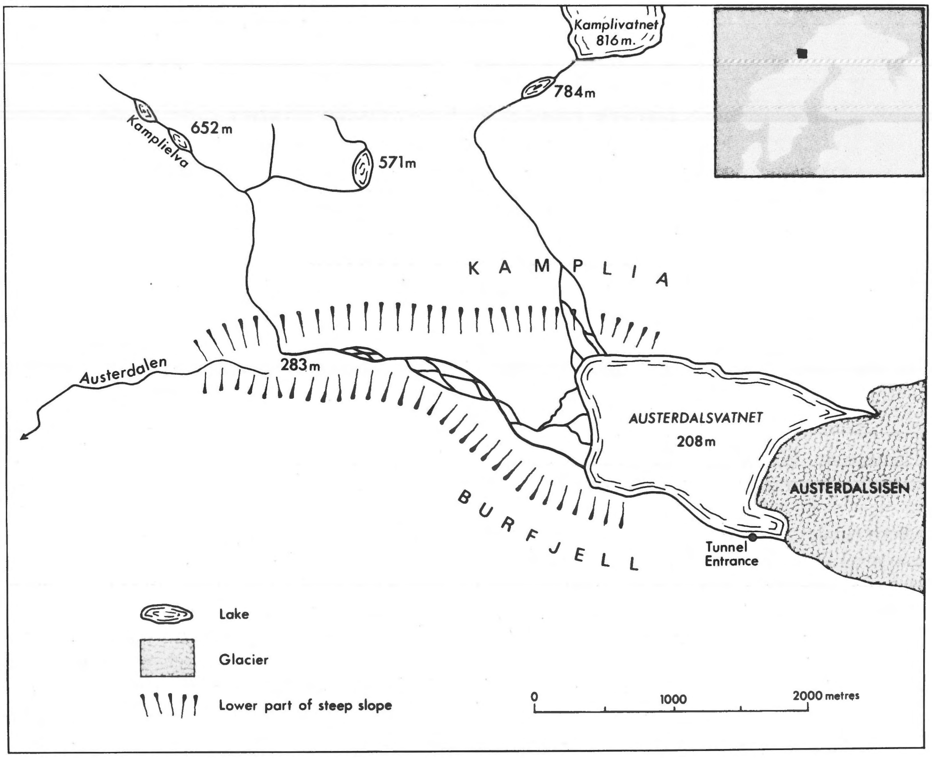

Fig. 1
The area west of the glacier Austerdalsisen

coloured (Fig. 2). Bifurcations of the ripples are common. The surface of the mid-channel bar bears larger current-generated ripples resulting from essentially unidirectional flow. Widely-spaced transverse micro-ripples are present on the bed of the narrow channel between the two bars. Channel bed material is largely (73%) silt; the small size of the ripples has prevented separate collection of crest and trough material.

The micro-ripples at the distributary junction appear to form as small water-surface waves move into water less than 20 cm deep. Lapping onto the beach at the channel margin, the waves produce linear ripples about 1.5 cm apart, with continuous crests parallel to the shoreline (Fig. 2, bottom left). Where the point bar juts into the stream, wave refraction resulting from shoaling causes ripples to curve. Immediately beyond the point bar, waves from the main stream, moving up the narrow distributary channel, produce isolated transverse micro-ripples; the large spacing of the ripples, in places more than 20 cm, probably reflects a paucity of mobile sediment. Complex micro-ripples at the margin of the mid-channel bar, including in places a polygonal-like pattern, appear to result from interference between waves arriving from different directions.

MICRO-RIPPLES ON A SHELVING BEACH

Micro-ripples form on a shelving beach of fine-grained sediments at the margin of a channel within the delta which Kamplielva has built into Austerdalsvatnet in recent years (Fig. 3). Their mean wavelength is about 0.7 cm; their amplitude appears generally to be less than 0.1 cm, but precise measurement beneath the water has not been possible. Ripple crests, continuous and relatively straight, frequently are more than 70 cm long. Bifurcations are very rare, although 'new' ripple crests often interpose between formerly adjacent ones. Colour differentiation of the crests and troughs is marked.

Some of the waves reaching the shelving beach are generated by friction at the air/water interface, but most are caused by pebbles which rise above the stream surface. Ripple-crest continuity under deeper water more than 20 cm from the shoreline may be maintained partly by the low-velocity current in the stream channel. As the waves responsible for ripple formation move into shallower water near the channel side, they are refracted and tend to approach the beach parallel with the shoreline or even with an upstream component; this causes the ripple crests to adopt a 'splaying' attitude. A faint but distinct pattern, visible in the offshore zone, probably results from interference between the refracted waves and current pulsations within the stream. Near the stream margin,

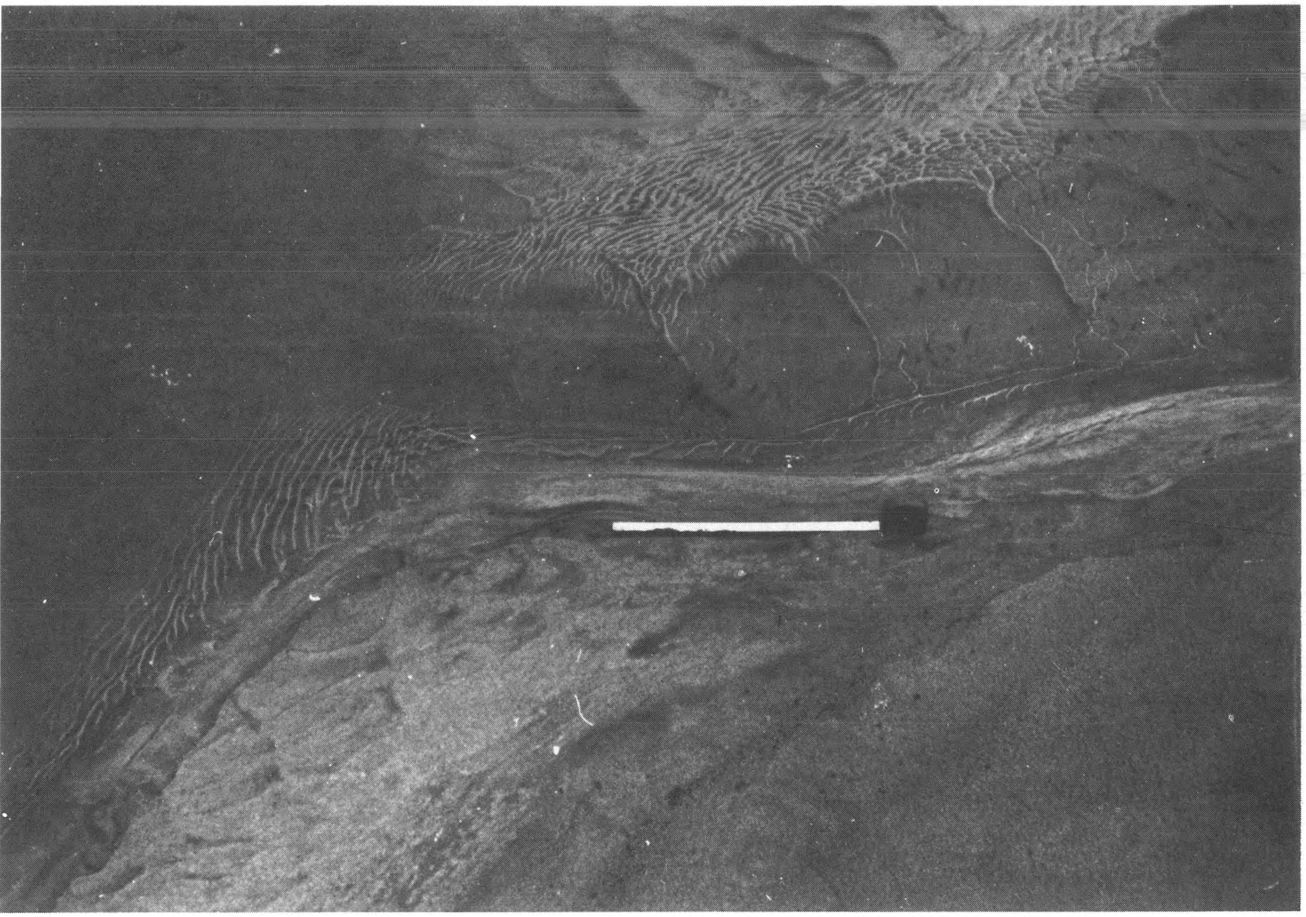

Fig. 2
Wave-generated micro-ripples at a distributary junction. Water flow in the main channel (left) is from bottom to top. In the shallow distributary (top right), it is to the right. Ripple bifurcation is common. The polygonal pattern of micro-ripples on the mid-channel bar (top right) is the result of wave interference.

surges which move through the shallow water generate minor ripples transverse to the current. Because current velocity decreases towards the channel margin, the orientation of these small linear ripples is oblique to the channel axis and crosses the refracted waves at a marked angle. Observations suggest that the apparent ripple troughs may be stationary parts of the silt bed, the moving sediment consisting solely of light-coloured material piled into separate ridge-like crests.

MICRO-RIPPLES AT THE MARGIN OF A PIPING DEPRESSION

Circular depressions 2-4 m in diameter, which result from piping of sediments, are common at the surface of the Kamplielva delta. Most contain pools of water 1-2 m deep. Delta distributary streams have broken into some of the depressions and water now flows slowly through them. At the edge of one pool, the crests of micro-ripples in the gently-shelving 40-50 cm wide zone of shallow water are continuous for distances up to 70 cm; their orientation is oblique to the shoreline and some bifurcate. Ripple wavelength is 1.5-2.0 cm and the amplitude generally is not more than 0.2 cm. At one point, the zone of micro-ripples is interrupted by a small lateral bar, downstream of which there is a series of transverse ripples 0.2-0.5 cm high.

The small bedforms at the margin of the piping depression reveal the effects of both water-surface waves and low-velocity currents near the channel side. Both the lateral bar and the transverse ripples downstream of it result primarily from deposition of fine-grained sediment transported by currents. The micro-ripples with crests oblique to the channel margin, however, are caused principally by wave action, although weak currents flowing down the gentle slope between the ripple crests may help keep the troughs free of sediment.

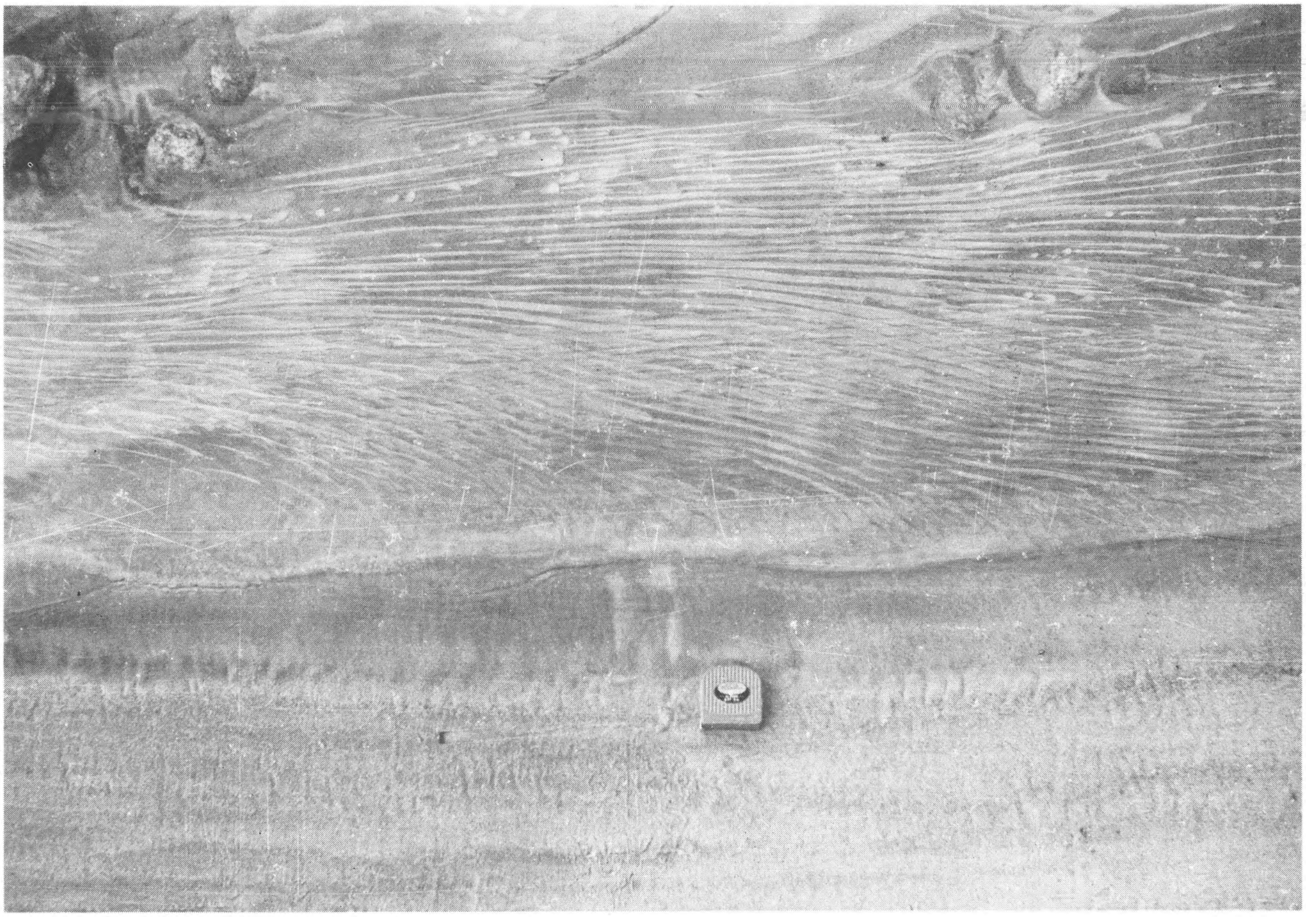

Fig 3
Vertical view of the margin of a stream channel in the Kamplielva delta. Wave-generated micro-ripples in silt at the stream bed are affected by refraction in shallow water. Bifurcation is rare. Faint interference marks (centre) result from the interaction of waves and unidirectional currents. The tape is 5 cm across. Flow is from left to right.

STUDIES OF RIPPLE TROUGH AND CREST MATERIAL

Because of the very small size of the micro-ripples and their restriction to sub-aqueous situations, attempts to obtain separate samples of trough and crest material generally have been unsuccessful; almost inevitably, some mixing occurs. At some sites, field observations suggest that light-coloured sediments move over relatively immobile, dark-coloured material to form widely-spaced ripple crests. Samples were collected from one such site in August 1977; whilst it is considered likely that the sampled bed/trough material is free of the more mobile sediments, the sample of ripple crest material may have been 'contaminated' by some of the underlying sediment. Examination of the samples has revealed some differences.

X-ray diffraction studies indicate that certain minerals present in the sediments of the micro-ripple troughs are absent from the crests (Fig. 4): preliminary analysis suggests that the mobile fraction lacks orthoclase and bytownite. Although quartz, calcite, muscovite, lepidolite, microcline, albite and almandine are present in both samples, some may be contaminants of the ripple crest material incorporated during sampling; the dark colour of the underlying sediments reflects the abundance there of the heavy mineral, almandine.

Scanning electron microscope studies reveal that, in general, sediment particles collected from ripple troughs are coarser than those of the crests and that they are predominantly angular and sub-angular, whereas particles from the crests are mainly sub-angular and sub-rounded.

DISCUSSION

In contrast to the numerous sand-bed studies carried out, relatively few flume studies of water flow over fine sediment beds have been reported (PARTHENIADES, 1965; GRISSINGER, 1966; REES, 1966; PARTHENIADES & PAASWELL, 1970; WHITE, 1970; MANTZ, 1973, 1977). MANTZ (1973, 1977) noted that, as water flow increased over a plane bed of equidimensional grains of

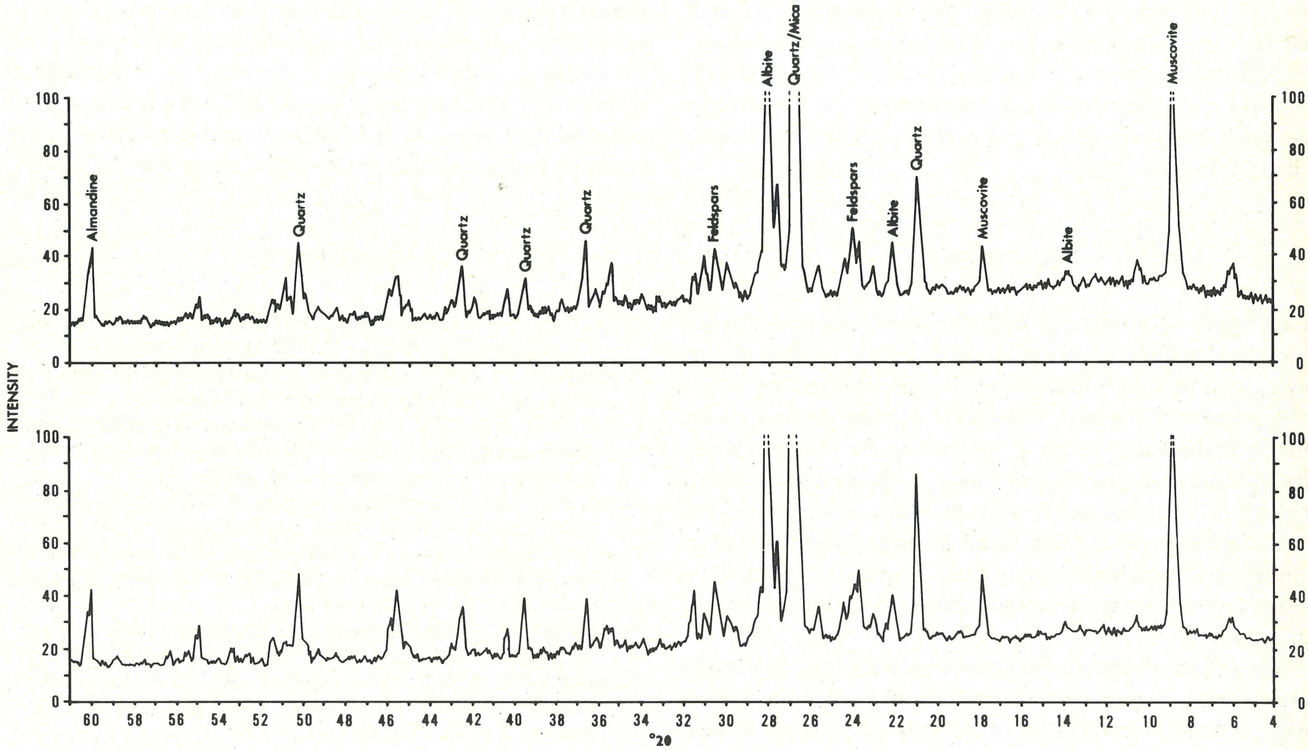

Fig 4
X-ray diffraction patterns for sediments from ripple troughs (bottom) and ripple crests (top).

fluvio-glacial silt, small ripples developed, whereas parting lineation developed on a similar bed of fine-grained fluvio-glacial mica flakes. REES (1966), who found that well-sorted silt particles did not display cohesive properties, reported that there were two threshold conditions for the initiation of motion of such particles at the bed, depending on whether or not excess sediment was being carried in suspension.

SUNDBORG (1956) suggested that, for unidirectional currents, the critical erosion velocity decreases with particle size into the silt range before increasing with decreasing size for particles finer than 0.05 mm (4.3 ϕ). MANTZ (1977), however, concluded that, whilst the threshold stress does increase for small particle sizes, approaching the theoretical maximum value, it is almost constant when particles are larger; Mantz considered that no empirical proof had been provided of the existence of a 'transitional region' in which the threshold stress dips. Under oscillatory waves, the shear stress is at a maximum when the current is accelerating, declining to a minimum during the subsequent decelerating phase. KOMAR & MILLER (1975) suggested that wave-generated ripples develop at slightly higher fluid stresses (bottom orbital velocities) than the threshold necessary to cause particle motion and that, for medium sands and finer particles, this threshold agrees well with that under a unidirectional current.

The high threshold stress for particle motion above smooth fine-grained beds reflects the low boundary Reynolds number. As unidirectional current velocity increases, an increasing number of grains become liable to movement. However, random variations of grain shape, weight and exposure must result in local variations of susceptibility to erosion. Laboratory plane beds are not reproduced in the Kamplielva channels, and movement of particles at the bed is likely to occur over a wide range of bed shear stresses. Brief fluctuations of water velocity near channel margins increase the stress on exposed particles (GRASS, 1970) and must result in random variations of local erosion and deposition of grains at the bed.

For particles within the fine sand, silt and clay ranges, grain shape and density (mineralogical composition), as well as grain size itself, may be important factors in the development of ripples. Where a bed consists predominantly of silt, roughness elements larger than the dominant particle size are likely to be present: in the low velocity conditions at the Kamplielva channel margins, silt particles might not move if such irregularities did not increase the overall shear resistance of the bed, and hence the local concentration of shear stress.

Because of irregularities at the bed, or as a result of variations of water-surface waves, wave-generated micro-ripples may be formed at stresses below the theoretical threshold for the particle sizes involved. Small waves generated by wind, by obstructions rising above the water surface or by flow pulsations within a channel may mobilise fine particles under shallow water – perhaps no more than 2 cm deep; the frequency with which such waves arrive at the channel margin may be an important factor in the development of small ripples there. The orientation of the ripples may be influenced by refraction of waves in shoaling water, by interference of waves arriving from different directions, or by interference between incoming waves and backwash down the sloping channel margin.

CONCLUSION

Laboratory investigations and theoretical analyses suggest that the threshold stress necessary to initiate particle motion as a result of either unidirectional or oscillatory flow over a fine-grained bed is high and that it depends in part on the nature of the fluid, including the amount of sediment which is transported in suspension. However, in the Kamplielva channels, flow pulsation and bed irregularities much larger than the dominant particle size result in local concentrations of stress, and micro-ripples may form despite the mean stress being well below the theoretical threshold for the sizes of the grains involved.

The form of the micro-ripples at Austerdalsisen reflects the interaction of waves, currents and bed material in the shallow and generally shoaling zone of the channel margins. Studies have indicated that ripple trough and crest material may differ in composition, particle shape and possibly particle size. The differing reactions of grains of different shape and/or density to the applied stresses may be responsible for the striking colour contrast between ripple crests and troughs, or between mobile, ripple-forming particles and the underlying bed.

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