'GUTTER CASTS', A NEW NAME FOR SCOUR-AND-FILL STRUCTURES: WITH EXAMPLES FROM THE LLANDOVERIAN OF RINGERIKE AND MALMÖYA, SOUTHERN NORWAY

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A new term *gutter cast* is defined and described: it includes a number of scour-and-fill structures previously called large groove casts, elongated flute casts, parallel scour structures, priels, erosional channels, runnel casts and Rinnen. Typical gutter casts with composite fillings of bioclastic limestone and calcareous siltstone are described from 6b to 6c (Lower Llandoverian) of Ringerike and 6b of Malmöya, southern Norway and are compared with examples from other areas and horizons. The original hollows (*gutter marks*) are thought to have been eroded in firm mud by water moving along helicoidal paths with horizontal axes and so are scour marks in contrast to groove marks made by tools.

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While studying the Silurian sedimentary rocks of Ringerike, southern Norway, the author discovered a number of ridges protruding from the soles of calcareous siltstones and bioclastic limestones in Stage 6b and 6c (Lower Llandovery). These he termed 'large groove casts' (Whitaker 1965, p. 709). In his thesis (1966) he described them as 'gutter-shaped depressions' (p. 17) and as 'rather large groove casts of longitudinal scour-and-fill type' (p. 44). A number of other publications have drawn attention to closely similar bottom structures, to which various names have been given: these include *shooting flow casts* (Wood & Smith 1959, p. 169), *priels* (Seilacher & Meischner 1964, pp. 145–150, Martinsson 1965, p. 194, Figs. 5, 6, Broadhurst 1968, p. 35, Worsley 1969, Ch. 3), *runnels* (P. Allen 1962, pp. 237–240, Fig. 3, Greensmith & Tucker 1967, Daley 1968, p. 116), and many other variations on the same theme, such as washouts, elongated flute casts, parallel scour structures, gouge channels, striated channels, long welts and erosional channels and furrows.

Most of the terms listed may be objected to as being insufficiently precise or because they have specific or implied genetic connotations. The term *large groove casts* suggests that, like normal groove casts, they infilled groove marks cut by moving solid objects, an idea not supported by the evidence which follows; *shooting flow cast* is obviously a genetic term implying high-velocity currents (supercritical flow); *channels* of many different sizes and origins occur in the geological column so that a more specific term is desirable; *priel*, in spite of Martinsson's attempt (1965) to dissociate it from the German term *Priel*, is likely to suggest a tidal-flat environment (see, e.g., Schäfer 1962, Fig. 2 or Reineck 1970, p. 94, Fig. 57); *washout* is usually thought of as a large filled erosional channel, often occurring in coal seams; and *runnel* was used nearly a century ago for flute casts (Williams 1881, pp. 319–320) and subsequently by Inglis & Kestner (1962) and Greensmith & Tucker (1967) for drainage channels between mud mounds on tidal flats. Thus a new term, describing the geometry of these bottom structures without implying their possible mode of origin, seems necessary.

Definition and description of gutter casts

The author proposes the term *gutter casts* (infillings of *gutter marks*) to describe the variously named structures listed above, because those with symmetrical cross-sections resemble the guttering which conducts rainwater from a roof and those with asymmetrical profiles resemble the gutter which

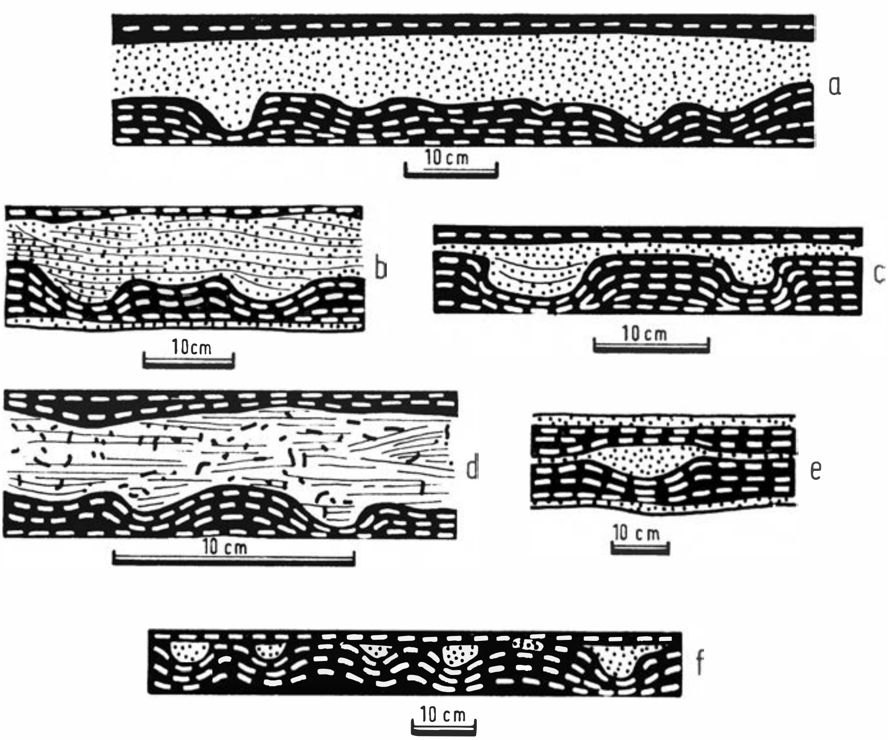

Fig. 1. Gutter casts from 6c (Llandoverian), Ringerike. a, b, d show normal gutter casts; c, e show almost separated casts; f shows fully separated casts. Black with white dashes = shale; stipple = calcareous siltstone; stipple with lines = laminated calcareous siltstone. In d, the stipple has been omitted to show the abundant *Chondrites* tubes.

Fig. 2. Normal gutter casts on bed below hammer: almost separated casts on bed 20 cm lower. 6c (Llandoverian), Hurum, Ringerike. Base of hammer head is 24 mm square.

lies between the road and the pavement. An equivalent German word would be *Dachrinnen*, which is a simple development of Kudrass's (1967) and Häntzschel & Reineck's term *Rinnen* (1968, p. 11) and Richter's *Erosions-Rinnen* (1965, Figs. 29a, b, c).

Gutter casts are down-bulges on the bottoms of sedimentary strata, of great length (usually one metre or more) compared with their width and depth (a few centimetres to several decimetres). In cross-section they have the form of small channels which may be symmetrical, with a profile resembling an inverted curve of normal distribution (Figs. 1a and 2) or semicircular (Fig. 1b, right-hand cast): others may be asymmetrical (Fig. 1b, left-hand cast). These U or V shapes may be modified by having flat bases (see Häntzschel & Reineck 1968, Fig. 1a, Bassett & Walton 1960, Fig. 6c). Some gutter casts are more irregular and may have vertical, or even overhanging, sides (Figs. 1c and 3b, c). The ends of these structures are not usually seen as they often extend beyond the limit of outcrop (Fig. 4) but small gutter casts may be seen to taper out like the long, narrow flute casts of Sestini & Pranzini (1965, Figs. 1, 7), the sinuous elongate flute casts of P. Allen (1962, Fig. 3) or the spindle-shaped erosional marks of J. R. L. Allen (1971b, Fig. 2d, 57, etc.). As with other sole structures, gutter casts may be exaggerated vertically or deformed laterally by load casting, in which case any laminae present will show that deformation has occurred. However, loaded gutter casts appear to be rare and the overhanging walls

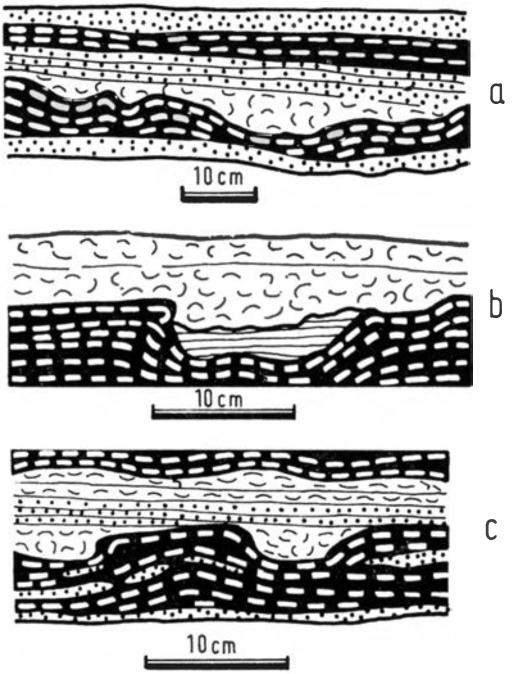

Fig. 3. Gutter casts from 6c (Llandoverian), Ringerike. Ornament as in Fig. 1: additional is shell symbol = bioclastic limestone. In a, normal filling; in b, calcareous siltstone fill is eroded and overlain by bioclastic limestone; in c, the two lithologies alternate.

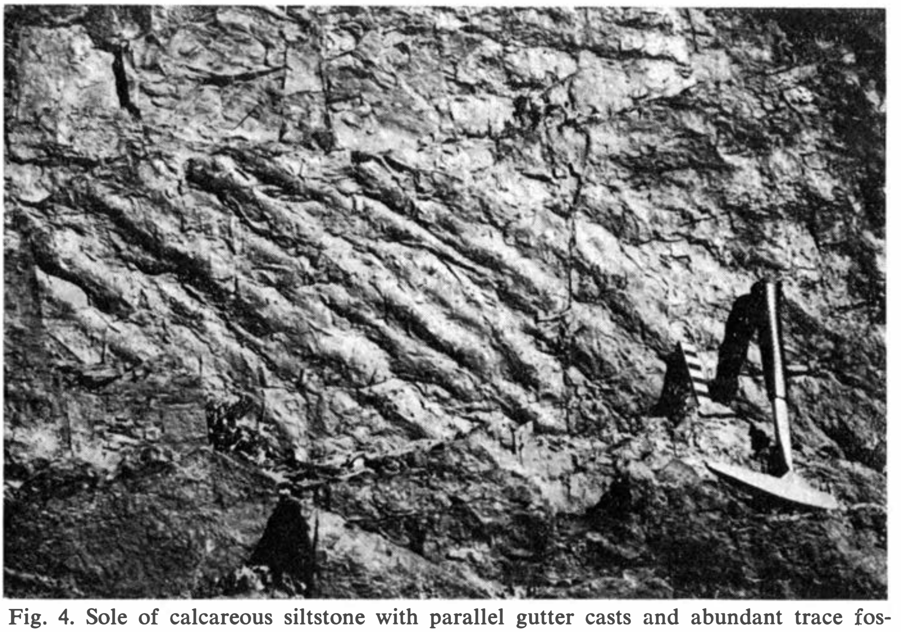

Fig. 4. Sole of calcareous siltstone with parallel gutter casts and abundant trace fossils, 6c (Llandoverian), Avløs station, Bærum (scale in cm). (Exposure destroyed during road widening.)

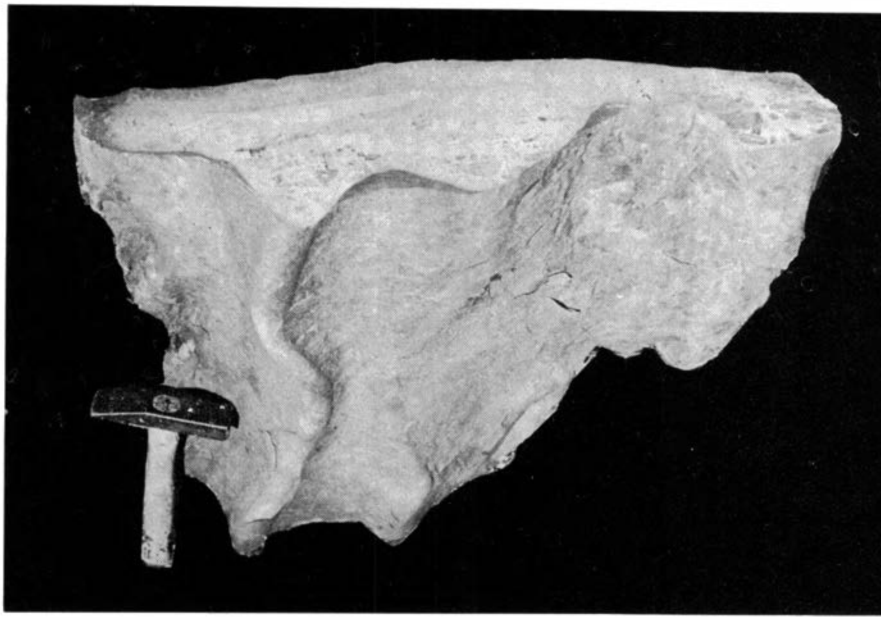

Fig. 5. Undersurface showing sinuous gutter casts, 6c, Limåstangen, Ringerike (length of hammer head is 11.6 cm).

are original features (e.g. Fig. 3b; Daley 1968, p. 116, Bridges 1972, Fig. 2, cross-section A).

On the base of a bed, gutter casts may be closely or widely spaced. Their trend may be remarkably straight (Fig. 4) or somewhat sinuous (Fig. 5). They may show anastomosing relationships (Bailey 1962, Fig. 3.8, Worsley 1969, Fig. 3xv) but this is rare.

The term *gutter marks* applies to the initial troughs cut into the muddy floor of the depositional basin, but these original structures, like flute and groove marks, are unlikely to be preserved.

The lithology of the gutter mark infillings is either dominantly calcareous, consisting of laminated calcareous siltstone or bioclastic limestone, or else siltstone to medium sandstone. Less commonly greywacke and, exceptionally, granule conglomerate occur. Fillings may consist of more than one lithological type, and these may have gradational or sharp junctions; graded bedding has been reported and alternations of calcareous siltstone with bioclastic limestone are common (Fig. 3a–c). Where the fill is laminated, cross-sections show the laminae to be flat-lying (e.g. Prentice 1962, Fig. 2) or slightly sagging (catenary) curves (e.g. Fig. 1b, c; P. Allen 1962, Fig. 3A2, 3A3). Longitudinal sections tend to show a gentle dip down-current, the current sense being determined from prod casts. Whole or broken fossils such as brachiopods, bivalves, polyzoa, wood fragments, etc., have been found in gutter fills, and trace fossils such as *Chondrites* (Fig. 1d) may occur.

Where there is abundant infilling sediment, the gutter casts occur on the

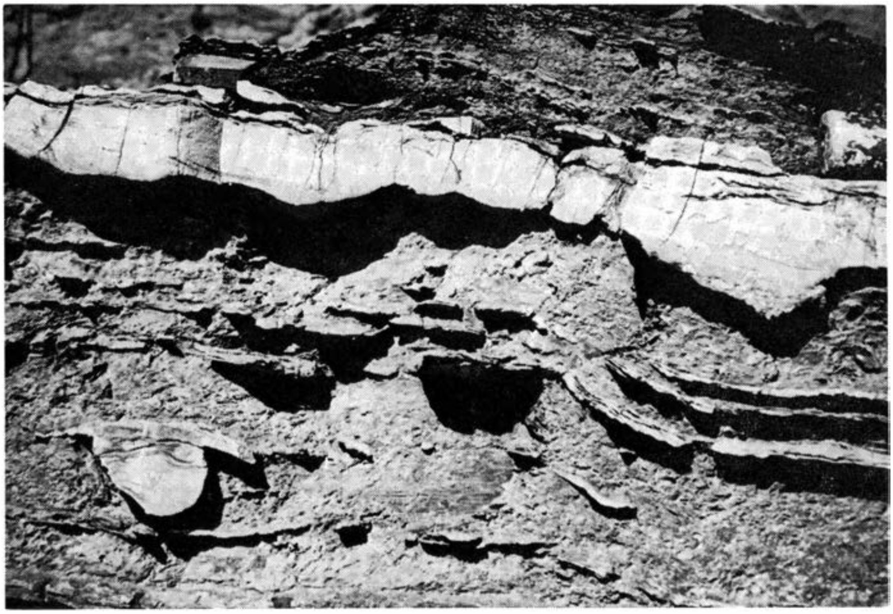

Fig. 6. Gutter cast (top right) with 2 cm of bioclastic limestone at base: separated gutter cast (bottom left). 6bα, Malmöya, Oslofjorden.

base of a bed which may be several times thicker than the casts (e.g. Fig. 1a, b, d), but where there is less sediment the gutter casts may be joined by only a thin connecting bed (Fig. 1c, e) or there may be only enough material to fill, completely or partially, the gutter marks and so a series of disconnected rod-like structures remains (Figs. 1f, 2, 6; Whitaker 1965, Fig. 2, Kudrass 1967, Fig. 2, channel horizon 4, Daley 1968, Fig. 3). These may be called *separated*, *incomplete*, *isolated*, *detached* or *starved* gutter casts, from terms which are in use for ripple structures similarly lacking in sediment supply. The term *separated* gutter casts is preferred.

The under-surface of gutter casts may show prod casts and often have striation casts, parallel with or at a slight angle to the trend of the gutters, or, where well developed, spiralling round the convexity of the casts (Kudrass 1967, Fig. 1, Worsley 1969, Fig. 3xx): the significance of this discrepancy in trends will be discussed later. Under-surfaces also commonly show trace fossils as convex hyporeliefs (Fig. 4), especially on the side walls.

The trend of gutter casts accords with other orientational features such as aligned fossils (e.g. stem polyzoa) which may occur at the base of, within or above the gutter casts (Whitaker & Gatrall 1969). Gutter casts may thus be used for determining palaeocurrent trends: when prod casts and laminations dipping longitudinally also occur, the actual current sense may be found. They may also be used as 'way-up' criteria, as in the sequence of turbidites at Marble Cliff, north Cornwall, which are shown by numerous gutter casts to be inverted (Tucker 1969, Figs. 2, 3).

Llandoverian gutter casts from Ringerike

Gutter casts are abundant on some bedding planes in Stage 6b and 6c (Lower Llandoverian) of Ringerike, southern Norway, and a short description of these, with illustrations, will serve to bring out the main characters of gutter casts in more detail. 6b and 6c is well exposed along the scarp faces of the ridges north of Vøltikollen, on Burudåsen and Steinsåsen and on the north-east and east shores of Sælabonn (an embayment of the lake Tyrifjorden), also at the end of the peninsula Limåstangen, a distance along the strike of about 10 km. These localities are marked on geological map 1 of Kiær (1908). 6b consists of thick calcareous sandstones and bioclastic limestones. 6c is made up of rapidly alternating beds of calcareous siltstones, bioclastic limestones and shales, usually a few centimetres thick, sometimes as much as a few decimetres in the lower parts of the succession where, however, gutter casts are rare. Occasionally, coarse fragmental limestones with angular fragments of sandstone and shale occur, with large ripple forms (Broadhurst 1968). The gutter casts are seen on the bases of some of the thinner calcareous siltstones and bioclastic limestones, more commonly

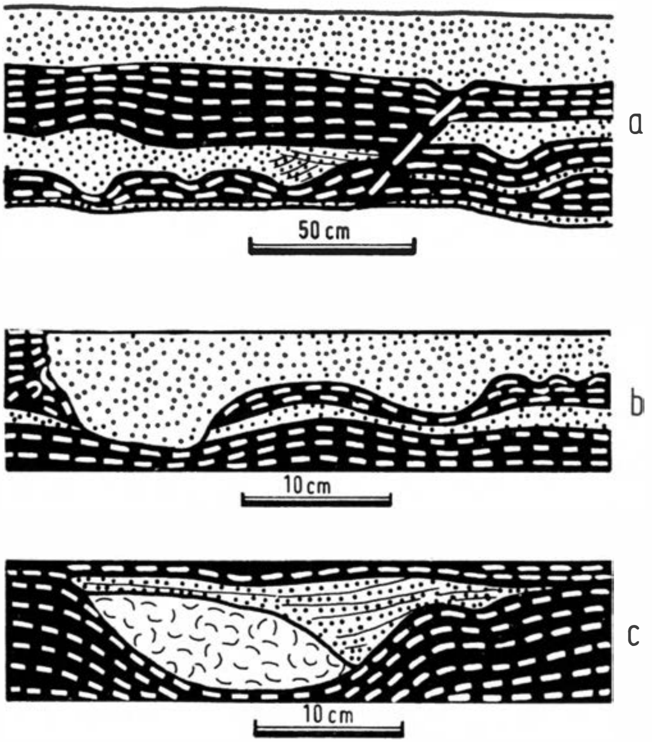

Fig. 7. Gutter casts from 6c (Llandoverian), Ringerike. Ornament as in Fig. 3. In a, metadepositional fault has small gutter sited above it; in b, left-hand gutter was cut through a lower bed of siltstone; in c, a separated gutter cast has bioclastic limestone at the base, sharply overlain by siltstone.

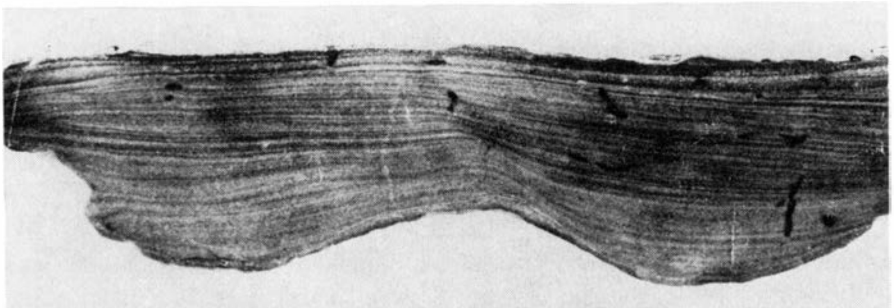

Fig. 8. Cross-section of two gutter casts filled with laminated calcareous siltstone, the left-hand cast filling slightly faster than the other. The black objects are mudstone-filled burrows. 6c, Hurum, Ringerike. (The specimen is 17 cm long: its accession number is 22269, University of Leicester, Geology Department.)

within the upper 10 metres of 6c. Occasionally, separated gutter casts are seen (Figs. 1f, 7c). Generally the casts are about 8 cm wide and 4 cm deep. They may have smooth symmetrical cross-sections (Figs. 1a, e, 2, 8) or one side may be steeper (Fig. 1b, left-hand cast, Fig. 7c), vertical, or even overhanging (Figs. 1c, 3b, c). This is not due to load-casting as the laminated fill is not deformed.

There is a clear relationship between the casts and the underlying shale. The shales were eroded, leaving small parallel channels which immediately, or not long afterwards, were filled with sediment. The shale laminae now abut against the gutter fills, sometimes with terracing, but are usually bent downwards by later compaction, as in Figs. 1 and 3c. This compaction was sometimes sufficient to deform underlying thin calcareous siltstones, as in Fig. 7a. In only one example, below Burudåsen, has a gutter mark been seen to cut through both a shale and an underlying siltstone: this is sketched in Fig. 7b. In another case, a gutter mark seems to have been located over a plane of weakness in the shale, where a small metadepositional thrust broke through to the sediment-water interface (Fig. 7a, top right).

Two contrasting lithologies may fill the gutter marks. One may be entirely of bioclastic limestone, sometimes with near-spherical smooth and ribbed brachiopods (such as *Plagiorhynchus*) at the base, grading up into smaller shell fragments: in one case, a concave-up orientation was found. The other lithology may be of laminated calcareous siltstone, the laminae being horizontal or inclined from one side of the cast (Fig. 1b), or from both sides, giving a catenary-shaped curve (Fig. 1c). One gutter may fill slightly faster than its neighbour, as in Fig. 8. More usually, the fill is composite, with a bioclastic lower part with a sharp erosional top over which laminated calcareous siltstone is distributed, as in Figs. 3a and 7c. Much more rarely, siltstone is followed by bioclastic limestone as in Fig. 3b, or the two lithologies may alternate (Fig. 3c). Frequently the bed joining the gutter casts has a rippled top (Fig. 3c): where measurable, the ripple foresets indicate

Table 1. Mean trends of gutter and striation casts, Malmöya (from Worsley 1969).

Division	Gutter casts No. of beds	Gutter casts No. of readings	Gutter casts Mean trend	Striation casts No. of beds	Striation casts No. of readings	Striation casts Mean trend	Difference between means
6bβ	11	24	24° ±7°	9	9	55° ±13°	31°
6bα	27	183	40° ±2°	20	21	62° ±11°	22°
6aβ	3	15	50° ±5°	19	21	68° ± 7°	18°

transport directions varying from 0 to 90° with the gutter cast trends (Whitaker 1965).

Besides brachiopods, the Ringerike gutter casts may contain tentaculitids and stem polyzoa, often oriented parallel with the gutters (Whitaker & Gatrall 1969) and trace fossils such as *Chondrites* (shown in section in Fig. 1d). Hypichnial burrows occur commonly on the bottoms of gutter casts, as do striation and prod casts, the former giving (like the gutters in which they occur) only the trend of the currents, the latter giving in addition the actual sense of water transport. By measuring the trends of 249 gutter casts from 6c at Ringerike, the author determined a vector mean of 083°, ± SD 18° (Whitaker 1965, 1966).

Llandoverian gutter casts from Malmöya

The author has described similar gutter casts from Llandoverian strata elsewhere in the Oslo region, namely Skien, Oslo (Fig. 4) and Malmöya (Whitaker 1965, 1966) and has studied examples (still with similar trends) at the same horizon in Dalarna, Sweden. Worsley (1969) has since described the Malmöya structures in much greater detail. He has kindly allowed me to summarize his results here.

On Malmöya and adjacent islands, 44 horizons, mainly in Stage 6b, show gutter casts, 30 % of which are separated, occurring as isolated 'rods' of massive siltstones. Their mean trends (with the sense of palaeocurrent movement determined from prod casts) are shown in Table 1 together with the mean directions of striation casts on other bedding surfaces. It will be seen that at each of the three levels, there is a small but significant difference between the mean trends of the two types of structures, the striations always being in a more easterly direction. In one case, there is anastomosis of two gutters (Worsley 1969, Fig. 3xv).

The Malmöya gutters, like those at Ringerike, may contain bioclastic material, calcareous siltstone, or both. Fig. 6 (bottom left) shows a separated gutter cast filled with siltstone, whereas the other cast (top right) has two centimetres of bioclastic limestone overlain with laminated siltstone. Often the junction between the two lithologies may be more distinct than the one illustrated. Other gutters may be filled with bioclastic limestone, in which brachiopod single valves are dominantly convex upwards and stem polyzoa are aligned parallel with the long axes of the gutters. Siltstone fills may have planar laminations, but cross-lamination is common at several gutter cast horizons, the dip of the foresets showing that the depositional currents diverged from the gutter trends by 50–60° on either side, coming from the west and south. The significance of these observations by Worsley is discussed in the following section.

Origin of gutter casts

In the literature, channels and flute marks are attributed to current scouring action while groove marks are said to be cut by tools sliding or dragging in a turbidity current or, in the case of sand grains, in a fluidized flowing-grain layer (Sanders *in*: Middleton 1965, p. 207). Only rarely are the tools found at the down-current ends of grooves. Easily disintegrated fragments of sandstone and shale which would seldom be preserved are invoked for the origin of many groove marks (e.g. Wood & Smith 1959, p. 182, Sanders *in*: Middleton 1965, pl. IIA). These tools, being irregular in shape, produce groove marks varying considerably in cross-section. Similar irregular cross-sections would result from a flowing-grain layer (Sanders *in*: Middleton 1965, pl. IIB). In contrast, gutter marks are much more regular, often having smooth, symmetrical cross-sections shaped like an inverted curve of normal distribution. The author therefore rejects an origin involving large tools or flowing-grain layers and postulates that the firm cohesive mud bottom was gouged by moving water currents bearing only small tools (such as sand grains or shell fragments which produced the striation casts) but no larger fragments. This is in line with some other authors who have also attributed their structures to scour.

By studying the gutter casts in detail, it is possible to suggest how this scouring takes place (Whitaker 1966, p. 18). The slight sinuosity of many gutters suggests similarities with a miniature meandering river, in which case it might be expected that the current flow within the gutter mark would have a helical motion about a horizontal axis (see, for example, J. R. L. Allen 1970, Figs. 4.4c, 4.5) and that the walls of gutter marks on the convexities of 'meanders' would be steeper than those on the concave parts. Bridges (1972) has evidence from his Llandoverian gutters from the Gullet Quarry, Malvern Hills, that this relationship holds good. Kudrass's gutter cast (1967, Fig. 1) appears to have steeper sides on the convex parts, but usually there is insufficient exposure along the length of these structures to be able to check this point. More thorough excavation and study of this possible relationship seems necessary.

There is, however, independent evidence for helical flow along the sinuous gutters. This is provided by the commonly occurring striation casts, which are often arranged across the casts at a small acute angle to the gutter trends, giving a rope-like effect. As early as 1881, Williams (p. 319) observed this in one of his channels at Ithaca, New York: '. . . lines run diagonally down the one side the channel across the bottom and up the other; some of the lines are fine and thread-like and appear entirely uninfluenced by the depth of the channel down and across which they swept'. Kuenen (1957, p. 242) commented that the oblique scratches of Williams are probably the result of vortices. On the rather smaller scale of gutter casts, a clockwise 'twist' of striation casts is well seen in Kudrass (1967, Fig. 1). Worsley (1969, Fig. 3xx) illustrates a similar spiral twist. Dzulynski & Walton (1965, p. 94) also mention spiralling of minor striations across large grooves. In some straight gutters, striations are parallel with the gutter trends and no evidence for spiral flow can be adduced from these.

Elongate fossils tend to lie along the bases of gutter casts in roughly parallel orientation, e.g. tentaculitids and stem polyzoans (Whitaker & Gatrall 1969, Worsley 1969, p. 186, Fig. 4i), orthoconic nautiloids (Bailey 1962, Fig. 3.9) and turreted gastropods (Daley 1968, Fig. 3B). Worsley noted that the mean stem polyzoan orientation was up to 10° from the mean gutter trend. Daley (1968, p. 119) pointed out that perfect orientation of *Potomactis turritissima* is not observed and attributed this to overcrowding or to insufficiently strong currents. The present author suggests that varying spiral currents might produce the arrangement of the gastropods seen in Daley's Fig. 3B, but would not wish to rely on orientation of 'rollable' objects such as tentaculitids, orthoconic nautiloids and high-spired gastropods to support his postulate of helical flow.

Assuming that helicoidal flow with horizontal axes eroded and maintained at least the sinuous gutter marks, how did the vortices originate and operate? Secondary flows of this type can form spontaneously, as when current velocity changes suddenly (Kolář 1956, p. 105) or behind obstacles, but since the ends of gutter casts are seldom seen it is not often possible to decide between these two origins. Even the gently sloping ends of some small gutter casts, which might suggest spontaneous generation of horizontal vortices, could have been initiated behind a lump of eroded clay resting temporarily on the sea bed before being moved or broken up, or in hollows formed by fossils, e.g. Martinsson's teichichnian burrows (1965, Fig. 5), Ten Haaf's burrows (1959, p. 40) and P. Allen's *Equisetites lyelli* rhizomes and sunken logs (1962, p. 240). Gutters running along the sides of resistant coral masses were pointed out to the author at Limåstangen, Ringerike, by D. Worsley. In the rare cases where both ends are seen, the upcurrent end is steepest (P. Allen 1962, Fig. 3, Prentice 1962, p. 174, Daley 1968, Fig. 2a), which suggests that the vortices are initiated rather quickly but die out more slowly, as do those forming flute marks.

Once initiated, horizontal helicoidal flows would proceed downcurrent, eroding the muddy sea- or lake-floor, even undercutting the gutter walls (note the evidence for undercutting rather than load casting on p. 410). A single helix might cut a lone gutter, but a pair, rotating in opposite senses, might be more effective (see below) and a whole series of pairs of counterrotating vortices cutting closely spaced gutters, as in Fig. 4, might be expected. This has been shown to be possible by Casey (1935).

In cross-section, ideal vortices will be circular, but they may also be elliptical, oval, almost square or rectangular, etc. resulting in the variable cross-sections observed in actual gutter casts. Three examples from the Marnoso arenacea of Italy (Kuenen 1957, Fig. 10) suggest the erosive action of paired vortices for each gutter mark. Experimental work by J. R. L. Allen (1969) produced rectilinear longitudinal grooves which resemble gutter casts but are an order of magnitude smaller (Figs. 3, 5). Allen invoked vortices with horizontal axes associated with moving aggregates of clay flakes to account for the formation of the grooves (Fig. 2c). More recently, Allen (1971a) produced mature grooves by prolonged current action on plaster of Paris beds and attributed this to paired horizontal vortices (Figs. 4b, 6). He comments (p. 56): 'If secondary flows of the type known to occur during turbulent motion through sharp-cornered channels (e.g. Prandtl 1952) had created the markings, one would have expected for the structures a transverse spacing of about 10 cm, which is an order of magnitude larger than the spacing observed': that is, a spacing shown by many gutter marks. The same author (Allen 1971b), in the most comprehensive study of erosional marks yet made, demonstrated the production of spindle-shaped erosional marks by oppositely-rotating paired horizontal vortices.

Other structures attributed to horizontal vortices include longitudinal ripple marks (Berry 1961, Bailey 1962, p. 89, Tanner 1962); parting lineation and sand ribbons (Allen 1968, p. 30, 1970, pp. 67–70); harrow marks (Karcz 1967); sand bars in rivers (Tanner 1963, Allen 1968, p. 31); and, on a much larger scale, submarine sand waves (Houbolt 1968).

To return to gutter casts, can anything be said about current velocities needed to form them, the depth of water requisite, and the ways in which they filled? Firstly, fairly high current velocities appear to be necessary to erode them from a cohesive mud bottom, certainly high enough to orient elongated shells in the areas between gutters, as observed by Bailey (1962) and Worsley (1969). High velocities would also result in secondary vortices of large pitch, accounting for the acute angles (normally 10–20°) between vortex-produced lineations and the general primary flow which governs the overall trend of the gutters.

Secondly, there seems to be no special depth of water favouring the formation of gutter marks. Casey's experiment (1935) produced small gutter marks under only 3 cm of water. Häntzschel & Reineck explain their Rinnen (1968, p. 36) as due to 'episodical and transient emergence of the bottom of the sea' which they estimate was normally 6 to 40 m deep: it was not a tidal-flat environment. Daley's (1968) examples are from very shallow water, Dyer's (1970) linear erosional furrows are common in water of depth 1 m below low water mark, and Goldring's (1971) from relatively shallow water (intertidal to at least 3 m): his gutters are at right-angles to the shoreline and are attributed to wave action, as are Norrman's examples from the lake Vättern (1964). P. Allen (1962), Prentice (1962) and Greensmith (1965) described gutters from shallow deltaic environments. Martinsson's (1965) Cambrian examples were formed in a bay, not very deep, but below wave action: there was no emergence. In south Norway, Worsley's Stage 6a and 6b gutters are of somewhat greater depth indicated by shallower water faunas lying to the southwest (1971), the area around Malmöya showing shallowing during 6c and 7, (1969). Whitaker's 6c gutter casts (1965, 1966) were probably formed in comparable depths, with similar shallowing afterwards. Finally, there are the gutters from turbidite successions (Bailey 1962, McBride 1962, Wood & Smith 1959, Wezel, Parea (both *in*: Angelucci et al.) 1967, Tucker 1969), which present views would regard as relatively deep water. So unless some criteria can be established to differentiate between gutter casts of varying depth, they cannot, on their own, be used as depth indicators.

Thirdly, how were gutter marks filled? Presumably the deep-water gutters associated with turbidite sequences were filled by turbidity current action, while the shallow-water gutters were filled by sediment carried by normal currents (e.g. tidal ebb currents). It is the marks of intermediate depth whose origins are debatable. The coarse bioclastic bases followed by finer-grained siltstones suggest currents of decreasing velocity and turbulence (Broadhurst 1968, p. 35), but the frequent occurrence of a sharp junction, sometimes erosive, (Fig. 7c) between these two lithologies points to a two-stage process. Whitaker (1965, 1966) accounted for the gutter fillings by invoking 'atypical turbidity currents initiated at zero depth' and the presence of graded fills, and of one gutter cast with concave-up shells, might support this view. Häntzschel & Reineck (1968, pl. 4, Fig. 1) show shells having all orientations, but Worsley (1969, p. 154) claims that the Malmöya shells are constantly convex-up and argues against a turbidity current origin. The decelerating currents deposited silt (often laminated) over the bioclastic material, but this could have been brought about by either type of current, turbidity (Bouma's Division B) or traction, as could the capping of rippled silt with more variable direction of origin. Perhaps the gutters were cut and then filled soon afterwards by calcareous turbidites, their tops eroded by normal currents which later laid down silts from directions oblique to the gutter trends. Where no bioclastic material is present (see e.g. Fig. 8), the entire fill may be of this traction type. More detailed work is necessary to resolve these difficulties of interpretation.

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