Origin and inversion of fluting in granitic rocks

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Flutings are channels scored in steep slopes. They are found on granite bornhardts, blocks and boulders, and occur in a wide range of climatic conditions. Rivulets and seepages charged with chemicals and biota are capable of attacking and degrading granite, and this can occur below the surface, at the weathering front and on outcrops. Many, perhaps most, flutings are of subsurface provenance, but on exposed surfaces, algal coatings develop and so protect the beds. Abandonment and inversion of such flutings—the conversion of channels protected by algae into ribs—are the result of the cumulative weakness of the adjacent unprotected laminated rock exposed in the erstwhile, commonly floored, weathering front. At some sites, new, lateral, channels are eroded through the laminated rock to expose fresh rock in 'button-holes'. Elsewhere, however, deep localised erosion has taken place on ribs on which the algal veneer has deteriorated.

KEY WORDS: bornhardts, epigene origin, fluting, granitic rock, inversion, subsurface initiation.

INTRODUCTION

Shallow channels scored in bedrock are known variously as gutters, grooves, flutes, flutings, and their equivalents in other languages. In granitic terrains, a useful distinction can be made between the gutters or canals that drain gentle slopes, and the grooves or flutings that score steep slopes. Some gutters originate in seepages and decantation flows (Figure 1a). Some are fracture-controlled (Kluftkarren or slots: Figure 1b). Many link rock basins or gnammas, and in many instances, their courses comprise basins linked by channels with innumerable small pot-holes and plunge pools.

Not all slopes are scored by channels. Extensive sectors of convex-upward upper slopes are devoid of gutters and are interrupted only where Kluffkarren are developed or where decantation flows issue from substantial patches of regolith. The boulder and block-strwn slopes of rubbines or knolls derived from the disintegration of sheet structures lack surfaces of an area sufficient to generate runoff and gutters. Overall, bornhardts are convex in plan as well as in profile, so that runoff is largely distributory. Although volume increases downslope, there is a tendency for wash to be generally laminar unless a fracture concentrates flow or minor irregularities, such as upstanding phenocrysts, induce turbulent flow and erosion. Once initiated, channels tend to persist as a result of positive feedback.

Many gutters generated on the gentler upper slopes of bornhardts extend as flutings across steeper basal slopes, even those that are flared and overhanging. Whereas the gutters develop a broadly radial pattern (though with fracture control in places) and are widely spaced, flutings run parallel directly down the slope in a dense pattern. Flutings have been reported from several lithological settings and a wide range of climatic environments. They are especially common in the humid tropics, both inland and on the coast (Bauer 1889; Helbig 1940; Carle 1941; Tschang 1961, 1962), but are also common in Mediterranean environments (Klaer 1956; Dragovich 1966).

The origin of flutings developed in granitic rocks has given rise to several long-standing debates concerning the mechanism of formation. Some investigators favour physical weathering whereas others emphasise water-related chemical alteration. Furthermore, the significance accorded biota varies, with cause and effect difficult to separate, but flutings can, perhaps, best be explained in terms of a combination of physical abrasion and chemical corrosion (solution, hydration, hydrolysis) allied with an enhancement of chemical attack by biotic agencies (Brammer 1913; Ule 1925; Fry 1936; Scholz 1946; Klaer 1956; Alexander 1958; Tschang 1961; Demek 1964; Dragovich 1966; Scott 1967; Syers & Iskander 1973; Viles 1988; Viles & Spencer 1989).

Whether flutings developed on covered or exposed surfaces is germane to consideration of other problems concerning related features. For that reason, evidence and argument concerning the provenance of flutings are analysed before other questions are posed. Discussion is based largely, although not entirely, on observations from southern Australia (Figure 2).

SUBSURFACE OR EPIGENE?

Evidence and argument for subsurface initiation

Many, perhaps most, granitic bornhardts originated at the weathering front, at the base of the regolith and beneath the land surface (Fulcoiner 1911 p. 246; Twidale 1925a, b). In southern Australia in particular, many bornhardts and

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boulders display concave inwards or flared basal slopes that are demonstrably initiated in the subsurface (Twidale 1962; Vidal Romani & Twidale 1998, pp. 231, 254). Thus, it is possible that flutings were initiated at the weathering front when the nascent bornhardts projected into the base of the regolith (Falconer 1911: p. 246) and stood within the shallow groundwater zone.

Karst workers, notably Bögli (1960), have differentiated between angular (V-shaped cross-section) and rounded (U-shaped) flutings in limestone, the former being sub-aerial (or 'free'), the latter formed beneath a soil or regolith (covered). Granite flutings and gutters display similarly contrasted morphologies in cross-section, though with the exception of Klufikarren, the contrast is between U-shaped, flask-shaped and trough-shaped forms. Rounded flutings (Figure 3a) occur in situations where, if only for lack of catchment and runoff, the channels are most likely the result of chemical weathering, although they are not restricted to such situations (Figure 3b). However, trough- and flask-shaped forms are found in large catchments and can be explained as reflecting lateral abrasion by streams, although the influence of lamination in allowing lateral erosion cannot be discounted (cf. gnmmas or rock basins: Twidale & Corbin 1965).

Logan (1849, 1851) suggested that flutings formed on the steep flanks of blocks and boulders in Singapore and Malaysia extend beneath a regolith of weathered granite or gneiss in situ, and that they are initiated beneath the surface. Unfortunately, these observations have not been replicated, although gutters extend a short distance along the weathering front and even converge beneath the natural soil cover (Figure 4) (Twidale & Bourne 1975). Yet, the behaviour of many flutings can be construed as suggesting a shallow subsurface origin. The steep sidewalls of many isolated blocks are scored by channels that extend only a short distance (~1 m) from the upper edge of the block (Figure 5). This behaviour can be explained in terms of epigene flows dispersing as they pass through the grassy regolith. The results of such dispersal and fading can be seen on recently exposed weathering fronts.

The most telling argument pointing to subsurface initiation, however, concerns the contrast between intensely scored and virtually smooth flared slopes, such as can be seen on the northeastern and southwest-facing flanks of the western and highest spur (S in Figure 1b) of Pildappa Rock, north of Minnipa, on northwestern Eyre Peninsula. The northern and southern catchments developed on the spur are of roughly equal area and generate similar discharges. Both were shaped by subsurface weathering for they are markedly concave or flared (Twidale 1962). The southern flank is faintly convex in plan outline so that drainage tends to diverge, is doubly flared, and carries a coating of algae. The few flutings are all extensions of gutters draining rock basins and are widely spaced (8-15 m apart) so that the basal slope is essentially smooth. By contrast, the flared northeast-facing wall of the spur is part of a structurally determined embayment (E in Figure 1b) on which drainage converges, and is scored by numerous closely spaced flutings (Figure 6).

Evidence and argument for an epigene origin

Field evidence shows that some gutters undoubtedly have been initiated on epigene or subaerial surfaces. They are found in granite exposed in river beds, for instance, the Ashburton River near Nanutarra in the northwest of Western Australia (Figure 7a) and the lower Umgeni River northwest of Durban in KwaZulu/Natal Province, South Africa. Some are attributed to subglacial streams (Dahl 1965). Rudimentary flutings have been observed in the rapids sections of river channels at Davies Creek, near Mareeba in north Queensland. Evidence that some
genuine flutings are initiated subaerially includes the
detailed morphology of a menhir at St Uzek, Brittany,
western France, where the steep northern flank is scored
by several slightly divergent channels (Lageat et al. 1994).
That they formed after the block was placed in its present
position is indicated by a flat-floored rock basin or pan
preserved on the same surface (Figure 7b). The pan formed
on a flat or gently sloping surface that was tilted by
humans through some 90° to its present position approxi-
mately 5000 years ago. The flutings, some 150 mm deep,
then developed as water trickled and later flowed down the
faintly convex flank of the block.

Other indications of an epigene origin include faintly
defined flutings visible on the walls of tafoni, which
develop subaerially, as at Murphys Haystacks, southeast of
Streaky Bay, on northwestern Eyre Peninsula (Figure 8).
Some tafoni are still expanding, with flakes of rock loosely
attached to ceilings and walls, and fallen debris scattered
over the floors. Others, however, appear to be stable and
inactive, and it is in these that faint incipient flutings are
found. They are clearly epigene in origin. The only possible
sources of moisture are rainwater that has infiltrated
through the bedrock and water due to condensation on the
inner rock surface. The volume of water involved must be
small, but the faint flutings might represent the first stage
of a subaerial development on slopes such as those bounding
the menhir at St Uzek.

The floors of many flutings are colonised by blue-green
algae (now regarded by many as Cyanobacteria), com-
monly Calothrix spp., that need sunlight for photosyn-
thesis. Such surfaces are pitted (Twidale & Bourne 1976)
due to the preferential weathering of feldspar and mica,
leaving quartz crystals in microlief (Figure 9). Colon-
ilisation might have occurred only recently after the
exposure from beneath a thin soil cover of channels
initiated in the subsurface at the weathering front. Also,

Figure 3 Flutings with U-shaped cross-section. (a) On large re-
stabilized boulder on Pulau Sekudu (Frog Rock), Strait of Johor, Sin-
gapore T°38′N, 103°58′E; the flutings are 0.5 m wide. (b) On slope
of blocky outcrop, Cassia City of Rocks, Idaho, USA (42°03′N,
117°43′W) the channels are up to 0.75 m wide.
the many flutings incised through the laminated rock (Figure 10) typical of the weathering front (Larsen 1948 p. 115; Boyé & Fritsch 1973; Morin 1982; Twidale 1966), suggest, although they do not prove, development after exposure.

Finally, many flutings are eroded into laminated rock. The latter is typical of the weathering front and represents an early stage in the disintegration and eventual alteration of the rock. Water reacts with mica and feldspar, and small amounts of clay are produced. The clay swells on contact with water causing the rock to be disrupted, forming laminae (Larsen 1948; Hutton et al. 1977). Yet, at Yarwondutta Rock near Minnipa, northwestern Eyre Peninsula, South Australia, Disappointment Rock midway between Norseman and Hyden, Western Australia, and several other sites, the flutings cut through books of laminae, suggesting that the channels post-date exposure.

Discussion

Field evidence suggests that flutings are convergent forms, some forming on exposed rock surfaces, others at the weathering front. The possibility of an etch origin implies potential azonality (Tweedale 1987, 1990, 2002). Flutings in continental and extratropical environments, for example, in the Cassia City of Rocks (Figure 3b), in arid and seasonally cold Idaho, USA (Anderson 1931), do not necessarily imply climatic change.

Given that some flutings are of epigene origin while others originate at the weathering front in the shallow subsurface, several other aspects of fluting need to be considered in that context. What part has structure played in their formation? Again, some flutings apparently have become inverted, that is, what were the floors of the flutings now stand out as ribs. How has this inversion developed? At a few sites, a new minor landform, called a 'button-hole', evolved, and calls for explanation. Many flutings are developed below catchments that are either limited in extent or effectively non-existent. What is the origin of these forms?

STRUCTURAL CONTROL

As their German name suggests, Klufkarren (Figures 1b, 7a, b) are due to the exploitation by weathering and erosion of fissures and fractures. They are commonly V-shaped in

![Figure 4](image-url)  
(a) Extension of gutters into the natural subsurface exposed by the excavation of a water reservoir at Dumonte Rock, near Wudiana, Eyre Peninsula (33°12′S, 135°31′E). Note the natural soil level and the convergence of gutters located at the weathering front beneath the natural soil level. (b) Confluence of flutings high on 8-m-high northeast-facing flank of Pildappa Rock, Eyre Peninsula (32°45′S, 135°13′E).

![Figure 5](image-url)  
Isolated boulder, 2.3 m high, in the Traba Mountain, Galicia, northwestern Spain (43°10′N, 9°08′W), showing fading of flutings with distance beneath the former surface.

![Figure 6](image-url)  
Northeast-facing wall of spur of Pildappa Rock, Eyre Peninsula, showing flared slope scored by numerous flutings (32°45′S, 135°13′E). The wall is 8-10 m high.
cross-section, but deeper forms are flask-shaped and on lower slopes higher discharge flows produce broad and shallow trough-shaped forms.

The suggestion that those gutters and flutings that are not fracture-controlled began as ... seams rich in feldspar or mica (Douglas & Drew 2001 p. 4) is not sustained by the field evidence: zones of susceptible minerals, whether diffuse or defined in veins, sills or dykes, are not consistently associated with either gutters or flutings. Even where gutters or grooves are developed along sills, it is the discontinuity between intrusion and host rock that commonly is exploited, not the sill itself. Moreover, the irregular courses and radiating pattern of drainage channels on bornhardts (for example, South Bald Rock, Girrareen National Park, southeastern Queensland: Bayley 1999 pp. 34-35) negates the suggestion.

Figure 7 (a) Grooves scoured in granite exposed in the bed of the Ashburton River at Nanutarra, northwestern Western Australia (22°32’S, 115°30’E). The base of the pile supporting the bridge is approximately 2 m wide and the gutters vary in width between 20 and 50 cm. (b) Northern slope of the menhir, approximately 6 m high, at St Uzé, Brittany, western France (44°13’N, 6°26’W) showing rock basin and flutings.

Figure 8 Boulder with tafoni at Murphys Haystacks, some 35 km southeast of Streaky Bay, northwestern Eyre Peninsula, South Australia (33°01’S, 134°29’E), with shallow bare channels scored on the steep inland side. The tallest boulder stands approximately 2.5 m in height.

Figure 9 Pitted floor of channel, 0.75 m wide, coated with algae low on the eastern slope of Ucomiltichie Hill, ~40 km south of Munipa, Eyre Peninsula, South Australia (33°12’S, 137°14’E).
INVERSION

Like rock basins or grammas (Twidale & Corbin 1963), even gutters that originated at the weathering front become morphologically differentiated after exposure. In particular, some become inverted and others are further eroded.

Many gutters can be traced without break from the gentle upper convexity of an inselberg into flutings that score the steeper basal slope, even where, as is frequently found, the latter is overhanging. But at several sites, these gutters extend on to the overhanging slope not in channels, but in ridges or ribs (Figure 11a–c). That the ribs are indeed former channel floors is indicated by their retention of a coating of black algal remains.

Such inversions have been noted at Yarwondutta and Pildappa rocks near Minnipa, and Turtle Rock near Wudinna, northwestern Eyre Peninsula, South Australia. They also occur in the southern Yilgarn Craton of Western Australia at Wave Rock, at The Humps near Hyden and at McDermid and Disappointment Rocks, west of Norseman. Most inversions are extensions of upper slope gutters, particularly those originating in soil-filled and vegetated rock basins, and in an immediate sense, can be attributed to algal protection of the bedrock surface for all known inverted channels in granite carry a cover of algae or algal remains and are black. The inverted flutings form ribs. They cannot be attributed to any structural factor because they are demonstrably of the same surficial laminated granite characteristic of much of the outcrop and dominant on the basal slopes (Figure 10).

Figure 10  Flutings eroded in laminated rock, northern slope of Yarwondutta Rock, near Minnipa, Eyre Peninsula (32°46'S, 135°10'E). Note plunge pool due to separation of flow during heavy runoff, and hammer standing in the depression.

Figure 11  (a) Inverted fluting, 0.5–0.7 m across, seen in profile on the northern slope of Turtle Rock, near Wudinna, Eyre Peninsula (32°30'S, 135°32'E), and (b) similar inversion developed on the gentle northern slope of Disappointment Rock, west of Norseman on the southeastern Yilgarn Craton, Western Australia (32°08'S, 120°56'E). Note the black algal coating developed at both sites. (c) Flared slope, 4.5 m high, at the northern end of Yarwondutta Rock, Eyre Peninsula (32°48'S, 135°10'E) showing irregular brow at upper shoulder of slope (especially clear at left), inverted flutings (ribs with dark algal coat), and plunge pool formed (see Figure 10) as a result of separation of flow.

The evidence concerning the role of algae is, however, ambiguous. On the one hand, and as already mentioned,
algae are associated with the development of pronounced pitting in the floors of gutters (e.g. on the eastern flank of Ucomitchie Hill south of Minnipa, northwestern Eyre Peninsula). On the other hand, all inverted flutings carry a vence of algae, and even the few inverted gutters noted on moderately steep slopes are veneered by an algal cover. They occur downslope from rock basins carrying soil and vegetation and from which issue low-velocity decantation flows (Figure 11b). Algae can colonise most types of surface but are most prolific where water flow is not rapid. The floors of gutters even on gentler slopes are devoid of algae, suggesting that colonisation occurs either where algae are prolific (downslope from rock basins) or on steep or overhanging slopes where, during and following heavy rains, runoff separates and water is available only occasionally and in trickles.

This dilemma can be resolved by reference to the laminated character of the bedrock exposed on the surface of bornhardts. Let us suppose that on steep slopes, trickles of water do not differentially weather the granite and remove the products of alteration but that algae colonise in sufficient density to protect the surface, even though the rock is laminated. When alive, and when water is available, the algae form a gelatinous vence. In July 2001, heavy rains fell at Yarwondutta and Pildappa rocks. Some runoff flowing slowly and in sheets adhered to the steep and even to overhanging basal slopes where surface tension

![Figure 13](image)

Figure 13 Sketch showing why left and right laterals are deeply scored at the base of a domical hull.

![Figure 14](image)

Figure 14 Disintegrated channel floors on 14 m-high Wave Rock, Hyden, Western Australia (32°27'S, 116°51' E).
on the wet gelatinous surface was evidently sufficient to overcome gravity. Only a little water diverged from these ribs. The adjacent slopes, however, are laminated and the direct wash, though limited in volume, evidently causes backwearing, leaving the protected erstwhile channels in local positive relief.

In an immediate sense, inversion is due to diversion of flow at the shoulder between convex upper and concave lower slopes where induration has produced a projecting lip protected by algae. More generally, a projecting brow is developed just below the shoulder. It can be attributed to two opposed processes. On some basal slopes, such as sectors of those that border Pikdappa and Turtle Rocks, the jutting brow is simple and lichen-covered, but elsewhere, as on the northern margin of Yarwondutta Rock (Figure 11c), the brow extends irregularly downslope and is interrupted or breached by algal-coated ribs. Like many other exposed rock surfaces, granite acquires a surficial induration due to the precipitation of minerals, particularly oxides of silicon, iron and manganese (Whitlow & Shakesby 1988) at or near the former hill-plain junction. More importantly, pronounced weathering occurs just beneath the land surface where moisture, and hence biota, are abundant. The undercutting of the basal slopes and isolation of the brow at Yarwondutta Rock, and elsewhere, can be attributed to weathering associated with a shifting water-table in addition to the impacts of water draining from gutters on the exposed rock surface.

**BUTTON-HOLES**

At a few sites, flutings developed on overhanging and flared slopes display lenticular depressions cut into the floors of the channels. They are well-defined and readily noted for they expose fresh shiny pink or grey granite that stands in marked contrast with the dull grey-brown colour of the weathered rock surface. Such lenticular depressions found in the floors of flutings are termed "button-holes" (J. R. Vidal Romani pers. comm.) (Figure 12a, b). They are most commonly found in the newer lateral or diverted channels, adjacent to the algal-veneered and protected ribs of erstwhile channels, and thus occur in pairs on either side of ribs (Figure 12a).

Some lateral channels display contrasted degrees of erosion. On the northern slope of Turtle Rock, for example, at the higher western end of the elongate dome, button-holes are developed to the left of some of the ribs (i.e. in terms of the channel flow; they are left bank occurrences), but at the eastern end, it is the right channel that is more deeply eroded. This can be explained by the change of direction of flow from convex upper slope to steep basal (Figure 13).

Wave Rock is a prominent flared slope, 14-15 m high and more than 100 m long, developed on the northern slope of Hyden Rock, in the southern Yilgarn Craton of Western Australia (Twidale 1968; Twidale & Bourne 1998, 2001). There, button-holes occur on what were inverted channels or ribs, for the floors of some of the erstwhile channels are disintegrating (Figure 14). Button-holes are not only developed but many are in process of formation. One possible explanation for such occurrences involves human intervention at the site. The natural drainage of the site was disturbed in 1961 when a wall was built to divert runoff from the flanks of the bornhardt into a reservoir dammed in a valley a few hundred metres west of Wave Rock. Prior to this construction, natural drainage trickled down the overhanging flared slope. These seepages were colonised by algae, and were thereby protected. The algae retained water so that the granite beneath the linear flutings was preferentially attacked by solution, hydration and hydrolysis, and effectively rotted. While the algal veneer persisted, this altered zone was protected, but with the building of the wall above the flared slope, seepage either ceased or was severely reduced. The algae died and rotted, the thin but critical coating was lost, and the laminated rock beneath crumbled and fell under gravity or was washed away during heavy rains. Stages in disintegration take the form of linear channels with many minor scars, hollows and alcoves beneath a thin breached skin of indurated floor rock to button-holes from which all of the rotted rock has been stripped.

This suggested sequence of events finds support in a photograph of Wave Rock taken in 1940 and pre-dating the construction of the diversion wall (R. & V. Mouritz pers. comm. 2002). The flared slope is partly in shade and the view is general rather than focused on the flutings, but they appear not to have been degraded in 1940.

Button-holes at some other sites can be attributed to a similar disintegration of channel floors following the abandonment of flutings as a consequence of natural diversion of flow due to chance blockages of the original channels by debris. The evacuation of detritus and associated organisms from the rock basins that are an integral part of the drainage system in some catchments could have a similar effect. Such elimination could be the result of either natural erosion or of anthropogenic actions, such as the clearing of basins of debris by early settlers and travellers in order to enhance water storage capacity and quality.

However, basically, button-holes appear to be the result of weathering by water either beneath channels that remain intact because of the protective influence of living algae (thus demonstrating the effectiveness of live algae as

**Figure 15** Fluted boulders on the slope opposite Yee Rock, Karimun Island, western Indonesia (1'04'N, 105°27'E). The boulder behind and left of the man-made structure is approximately 10 m high.
a conservative factor) or where moisture is concentrated, as in zones lateral to ribs that, even though they carry an algal mat, cause some runoff to be shed on to adjacent surfaces.

**FLUTINGS BELOW LIMITED CATCHMENTS**

Isolated blocks with minor sections of gutters preserved on their crests occur in many places, for example, at Caloot, in the western Murray Basin, South Australia, and at Bruce and Waycotts Picnic Rocks, in the southern Yilgarn Craton of Western Australia, but these pose no problem because they are obviously remnants of domical surfaces that survive after the rest of the original sheet structure has disintegrated.

Flutings developed on the sidewalls of large isolated blocks and boulders standing on hill slopes, and even on the crests of hills, are not so readily explained (Figure 15). Examples are recorded from Karimun Island in western Indonesia, Pulau Ubin and Pulau Sekudji (Frog Island) off Singapore, various sites in peninsular Malaysia, and in the Traba Mountain of Galicia, northwestern Spain, at Saldanha, in the Western Cape Province of South Africa, on Remarkable Rocks on Kangaroo Island, South Australia, and at Granite Rock, near Geelong, Victoria.

Such features pose a problem for although some of the examples noted are preserved on what may reasonably be construed as sheet remnants, others stand on isolated blocks that are not readily interpreted in such terms. The flutings are shaped by running water in some shape or form, yet are served by catchments seemingly inadequate to supply the runoff necessary to erode the features. It can, with reason, be argued that minor trickles active over a long period could achieve erosion and channel cutting, but the difficulty is particularly acute where, as at Yee Rock on Karimun Island, as a result of the differential weathering of the exposed upper flatish surface of the block, a narrow and irregularly shaped brow separates the head of the flutings from the busined upper surface (Figures 11c, 15). Such flutings could be due to runoff along the weathering front when the blocks and boulders were still covered by gnis. This finds support in the rounded form of some of the channels and the crevulations (solution ripples) in their walls (Figure 15) (see also Jennings 1985 pp. 74–75). If these sidewall flutings are attributed to subsurface water flow through an all-enveloping matrix of gnis, the concentration of weathering and erosion on steep rock faces can be explained in terms of gravity, and the essentially minor impact of water standing on the gelite upper slopes of blocks can be understood in terms of the contrast between a permanently moist covered site as opposed to one exposed and subject to periodic drying.

Alternatively, the flutings can be attributed to trickles derived from rain falling directly on the wall, particularly as at Yee Rock and elsewhere in the humid tropics, where the waters are warm and soon acquire chemicals and biota (Bennett 1991). Notable flutings are also found in coastal regions where runoff originating as spray contains halite that causes salt weathering (haloclasty) and in arid regions where salts are washed from the lower atmosphere (Hutton 1976). Even at some distance from the ocean, the desert terrain is characterised by numerous salinas from which salt crystals have been observed to have been deflated and carried in suspension in high winds.

**CONCLUSION**

The evidence and argument concerning the epigene or subsurface origin of flutings are inconclusive and they might well evolve in both settings, although most appear to be initiated at the weathering front. Inversion is the result of the protection by algae of gutters draining to the steepened basal slopes in contrast to the degradation of less well protected adjacent slopes by wash and gravity. Bottom holes are due to intense erosion of the laminated zone, although at some sites, such erosion appears to accompany changed local environments resulting in the loss of protective algal cover.

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