Holy Island, Northumberland

[NU 123 416]–[NU 149 419]

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Introduction

The Holy Island coastal GCR site exhibits excellent exposures of a dyke system, related to the Whin Sill-complex, extending for over 30 km from Coldstream in the west to reefs off the east coast of Northumberland (Figure 6.2). Outcrops of quartz-dolerite extend for 2 km along the south coast of Holy Island between St Cuthbert's Isle and Scar Jockey rocks (Figure 6.33). These outcrops were formerly regarded as *en échelon* sectors of a simple dyke, but are now thought to represent sill-like transgressions within a dyke (Figure 6.34). They provide excellent accessible exposures that reveal both steeply inclined side margins and gently sloping upper surfaces. Flattened, elongate amygdales with unusual ropy flow textures on their lower inner surfaces are a particularly striking feature. The 'dyke' intrudes sedimentary rocks of the Brigantian Liddesdale Group and stands proud from the low-lying island, providing a series of rocky ridges and promontories upon which Lindisfarne Castle and other buildings of historical and archaeological interest have been constructed (Figure 6.35).

The field relationships of the 'dyke' have been described by several authors (Winch, 1822; Trevelyan, 1823; Tate, 1868, 1871; Gunn, 1900; Carruthers *et al.,* 1927). Holmes and Harwood (1928) included it in their petrographical study of the Whin Sill-complex and Holmes and Mockler (1931) produced a general summary. The most definitive account of the field relationships is that by Randall and Farmer (1970), who described the internal structure and the unusual flow textures in some detail. The intrusion was the subject of a palaeomagnetic study by Giddings *et al.* (1971) and a detailed magnetic survey of the mainland part of the dyke system was conducted by El-Harathi and Tarling (1988). However, it was the magnetic survey of Goulty *et al.* (2000) that revealed the most about the structure of the intrusion and resulted in a radical re-appraisal of its form. A weighted mean Ar-Ar age of 294 ± 2 Ma has recently been obtained from groundmass plagioclase in this intrusion (M. Timmerman, pers. comm., 2002). The 'dyke' is included in a field itinerary for Holy Island, described by Randall and Senior in the excursion guide of Scrutton (1995).

Description

The Holy Island Subswarm is the most northerly of the major dyke subswarms associated with the Great Whin Sill and is close to its northern limit (see Budle Point to Harkess Rocks GCR site report). In general, the mineralogy of the component dykes is the same as the sill, but the Holy Island 'Dyke' is porphyritic with phenocrysts of plagioclase, clinopyroxene and iron oxides in a fine-grained groundmass (Holmes and Harwood, 1928; Holmes and Mockler, 1931). On Holy Island itself there are five discrete *en échelon* outcrops, each of which has an east–west trend (Randall and Farmer, 1970). The outcrops reach a maximum width of *c.* 60 m but there is no northern contact exposed. The southern contact is undulating in places, but generally dips steeply to the south. The upper surface of each outcrop is generally irregular but in places it appears to be a planar margin to the intrusion, with a gentle dip to the east.

St Cuthbert's Isle

St Cuthbert's Isle [NU 123 416] is composed entirely of quartz-dolerite, having dominant sub-horizontal joints, and was interpreted by Goulty *et al.* (2000) as a sill-like body. Only the upper contact of the intrusion is exposed: in the eastern part of the isle the planar chilled surface dips gently to the east and the grain size of the rock increases downwards from this surface. The chilled margin contains a few microscopic amygdales, but several centimetres lower there is a marked amygdaloidal zone, 15–23 cm thick, containing numerous flattened and elongate amygdales. The largest amygdales are several tens of centimetres across; they are flattened parallel to the chilled surface and are elongated towards the NNE. The amygdales comprise calcite, purple-tinted quartz and small amounts of chlorite. Where the filling has been removed by erosion the inner surfaces of the original vesicles can be seen. These are glassy, with tachylitic margins up to 2 mm

thick. The lower inner surface of each vesicle has a ropy flow structure, similar (in miniature) to the ropy flow lobes on the surface of pahoehoe lava (Figure 6.36). The curvature on the flow lobes shows a fairly consistent flow direction to the east. These highly unusual features can also be seen near the top of the Great Whin Sill in the Budle Point to Harkess Rocks GCR site, 7 km to the southeast of here.

Immediately below this zone is a further amygdaloidal layer, about 0.8 m thick, in which the amygdales are small and spherical. This layer can be traced across much of the isle, suggesting that the upper surface of the intrusion was nowhere more than a metre or so above the current erosion surface.

Immediately to the south-east of the isle, a south-facing dolerite scarp, less than 1 m high and trending east-west, is exposed at low tide. This has been interpreted by Goulty *et al.* (2000) as the southern margin of a dyke, in continuity with the flat-lying sill that forms the main outcrop of St Cuthbert's Isle.

Heugh Hill

The Heugh Hill outcrop is up to 30 m across and extends some 500 m from the coast opposite St Cuthbert's Isle to the slipway at Steel End [NU 130 417]. The sharp, steeply inclined southern contact is magnificently exposed almost continuously along the full length of the outcrop, but the northern contact is not exposed. The dominant cooling joints are almost vertical and perpendicular to the southern margin, but a strong joint set also occurs parallel to the margin. Marginal parts of the intrusion generally contain small spherical amygdales. Adjacent to the contact the Acre Limestone and overlying mudstones are both thermally metamorphosed. The limestone is recrystallized to a white marble, but in places fossils (corals, brachiopods and orthoceratids) are remarkably well preserved very close to the contact. The mudstone is baked and altered, with prominent dark 'spots' up to 2 cm in diameter, over a distance of about 5 m from the contact. Thin mineral veins and disseminated pyrite occur in this area. Xenoliths are common in the marginal part of the dolerite. Of particular note are three small rafts of saccharoidal limestone in the southern margin of the intrusion about 60 m from the western end of the outcrop, and a xenolith of baked mudstone just to the east of where the path across Heugh Hill emerges at the coast. Farther east, where the country-rock sandstone contains ferruginous nodules, some nodules seem to have been incorporated in the dyke margin. In the eastern parts of the outcrop, the southern contact is undulating and in places forms almost horizontal benches, below which flattened amygdales may be observed similar to those at St Cuthbert's Isle. The bench surfaces and the steeper contacts are coated with patchy 'skins' of sedimentary rock. At Steel End [NU 130 416], a smooth chilled surface is exposed at low tide that dips gently to the east. This surface reveals numerous clustered and elongated amygdales; abundant ropy flow structures are seen and the original quartz-calcite infills are better preserved than at St Cuthbert's Isle.

Castle Hill

The outcrop of dolerite at Castle Hill is almost 60 m wide. The undulating southern margin is exposed above the beach, where sub-horizontal sections form a series of benches, some up to 3 m wide. The most obvious bench, at Cockle Stone [NU 134 417], has the appearance of a manmade quay and has in fact been used as such. Thin skins of sedimentary rock coat the margin in places and flattened vesicles with ropy textured bases may be found on the benches. Curving cooling joints are parallel to the undulating contact. Near the castle a small offshoot from the main intrusion extends for 11.5 m into the surrounding mudstones. This apophysis is composed of 'white whin', dolerite altered by circulating mineral-rich fluids. The rock exposed below and to the east of the castle is vesicular and fine grained, with pervasive horizontal jointing.

Scar Jockey

At Scar Jockey dolerite crops out on the shoreline but no contacts are exposed. Prominent joints dip at 20° to the south-east and are typical of those along the northern margin of the other outcrops (Randall and Farmer, 1970).

Plough Rock and Goldstone Rock

The Plough Rock, 1 km from shore, is composed entirely of dolerite and marks the edge of a reef known as Plough Seat, which is partially visible at very low tides. Dolerite is further exposed 3.5 km offshore on the Goldstone Rock.

Interpretation

The igneous and intrusive nature of the 'dyke' at Holy Island was recognized by early authors (Winch, 1822; Trevelyan, 1823). On early one-inch-scale geological maps of the 1870s all the outcrops on Holy Island and further *en échelon* segments on the mainland were joined as one long sinuous dyke. Gunn (1900) recognized the discontinuous nature of the dyke and a revision of the six-inch maps took place during the 1920s (Carruthers *et al.,* 1927).

Holmes and Harwood (1928) suggested that the Holy Island 'Dyke' and its mainland equivalents were intruded into pre-existing tension cracks developed during a period of Late Carboniferous east-west compression, which was also responsible for the Holburn and Lemmington anticlines. This theory was accepted by many authors (e.g. Robson, 1954, 1977; Westoll *et al.,* 1955; Shiells, 1964; Wilson, 1970). However, Carruthers *et al.* (1927) noted field relationships suggesting that the dykes post-dated the compression event, and Jones *et al.* (1980) pointed out that the tension gashes occur between shear faults that offset the axis of the Holburn Anticline. The magnetic survey of El-Harathi and Tarling (1988) showed that there are four distinct sub-parallel ENE-trending dykes in the mainland part of the subswarm, rather than numerous small offset segments, and they interpreted this as proof that dyke emplacement was not related to an east-west compressional event. They suggested that the dykes represent the infilling of tensional fractures formed after the compressional event, perhaps during isostatic adjustment between the Cheviot Massif and the Northumberland Trough.

Giddings *et al.* (1971) proposed that at the time of crystallization of the Holy Island 'Dyke', the magnetic pole was at latitude 38° N and longitude 177° E. This is consistent with its formation close to the equator in latest Carboniferous or Early Permian times when the ancient geomagnetic field was reversed. This location is statistically indistinguishable from that determined for the Great Whin Sill by Creer *et al.* (1959). However, the recently obtained Ar-Ar date of 294 ± 2 Ma is significantly younger than the even more precise 297.4 ± 0.4 Ma U-Pb date from the Great Whin Sill (see Upper Teesdale GCR site report) and may re-inforce views that the sills and dykes are not quite coeval.

The steeply inclined, chilled southern contacts to the intrusion on Holy Island imply a dyke-like body, but several of the outcrops also exhibit planar chilled upper surfaces that dip gently to the east. Sub-horizontal jointing is dominant close to these contacts, increasing in intensity towards them, and parallel zones of flattened elongate amygdales also occur. The sub-horizontal contacts were originally interpreted as the upper termination of a dyke within the Carboniferous sedimentary pile (Randall and Farmer, 1970). Such a blunt termination is most unusual in dykes, which normally taper and pinch-out upwards, yet this interpretation persisted until a detailed magnetic survey by Goulty *et al.* (2000) suggested a form that fits the field observations much more convincingly (Figure 6.34). The magnetic survey suggests that most of the outcrops (Heugh Hill, Castle Hill and Scar Jockey) are formed from a sill that 'turns down' to the south to become a steeply inclined dyke. (The northern margin has been removed by erosion, so it is not known whether the sill continued farther to the north or whether it turned up within a short distance to continue as a dyke.) To the south of these outcrops, the intrusion levels out to form another sill-like sector, seen only on St Cuthbert's Isle. This then turns down to the south into a dyke, seen only in the small scarp south-east of the isle, but traced by its magnetic anomaly to the south of all of the outcrops (Figure 6.33). Although the sill-like sectors have a slight dip to the east, they must also step up to the east, as they transgress up through the stratigraphy of the host rocks in this direction. Hence the intrusion has the form of a step-and-stair transgression that steps upwards both to the north and to the east, though probably as part of an overall dyke-like body with only minor sill-like sectors. The overall form is in fact hinted at by the bench-like 'steps' that have long been recognized in the steep contacts on the southern margin of the main outcrops.

The sill-like parts of the intrusion are characterized by amygdaloidal zones in much the same way as a lava flow. The amygdales are infills of vesicles that formed by the exsolution of volatiles from the magma, probably following rapid decompression as a result of injection into the near-surface sedimentary pile. The rapid release of volatiles causes undercooling, which leads to rapid crystallization of the magma, hence explaining the fine-grained linings around the vesicles (Randall and Farmer, 1970). The quenched linings must have remained plastic for long enough to allow

flattening, elongation and the development of flow structures by the still-molten magma moving through the intrusion. The flow structures at the base of the vesicles resemble pahoehoe ropy flow structures on the surface of lava flows and can be used to infer local flow directions (Figure 6.36). Randall and Farmer (1970) constructed rose diagrams from their field data to deduce the modal flow directions at three different localities. All three sites showed evidence that the final, local horizontal component of the flow direction was from west to east. The appearance of the flow structures is very similar to ropy flow structures described by Smythe (1930b) towards the top of the sub-horizontal Great Whin Sill at Harkess Rocks west of Bamburgh. There, the flow direction indicated by these structures suggests that final movement of magma in the Great Whin Sill was from east to west (see Budle Point to Harkess Rocks GCR site report).

Conclusions

The Holy Island 'Dyke' is an extremely well exposed component of an E–W-trending dyke system at the northern margin of, and related to, the Whin Sill-complex. The upstanding rocky ridge is a significant landscape feature that has clearly influenced the defensive and monastic settlements of Lindisfarne, one of the prime historical sites in Britain.

The exposures comprise several outcrops of quartz-dolerite that show a confusing variety of contact-related features, some steeply inclined and some near horizontal. Originally these were attributed to several *en échelon* segments of a dyke that terminated close to the present land surface at a broad, gently sloping, near-planar upper surface. However, a geophysical survey has shown that the features are better explained by a series of step-and-stair transgressions that result in alternating dyke-like and sill-like sectors of the intrusion. This re-interpretation has in no way detracted from the potential international importance of the site, which preserves a wide variety of interesting features associated with such structural perturbations in an otherwise regionally persistent major dyke.

Of particular interest are near-horizontal joints and zones of large flattened and elongate amygdales that are prominent close to the upper contacts of the sill-like sectors. The original inner surfaces of the gas bubbles are revealed where the infilling material has been removed by later erosion and these show miniature 'ropey' flow structures. Such structures, which are very rare or possibly unique worldwide, have been used to determine the final flow direction of magma in the dyke.

References
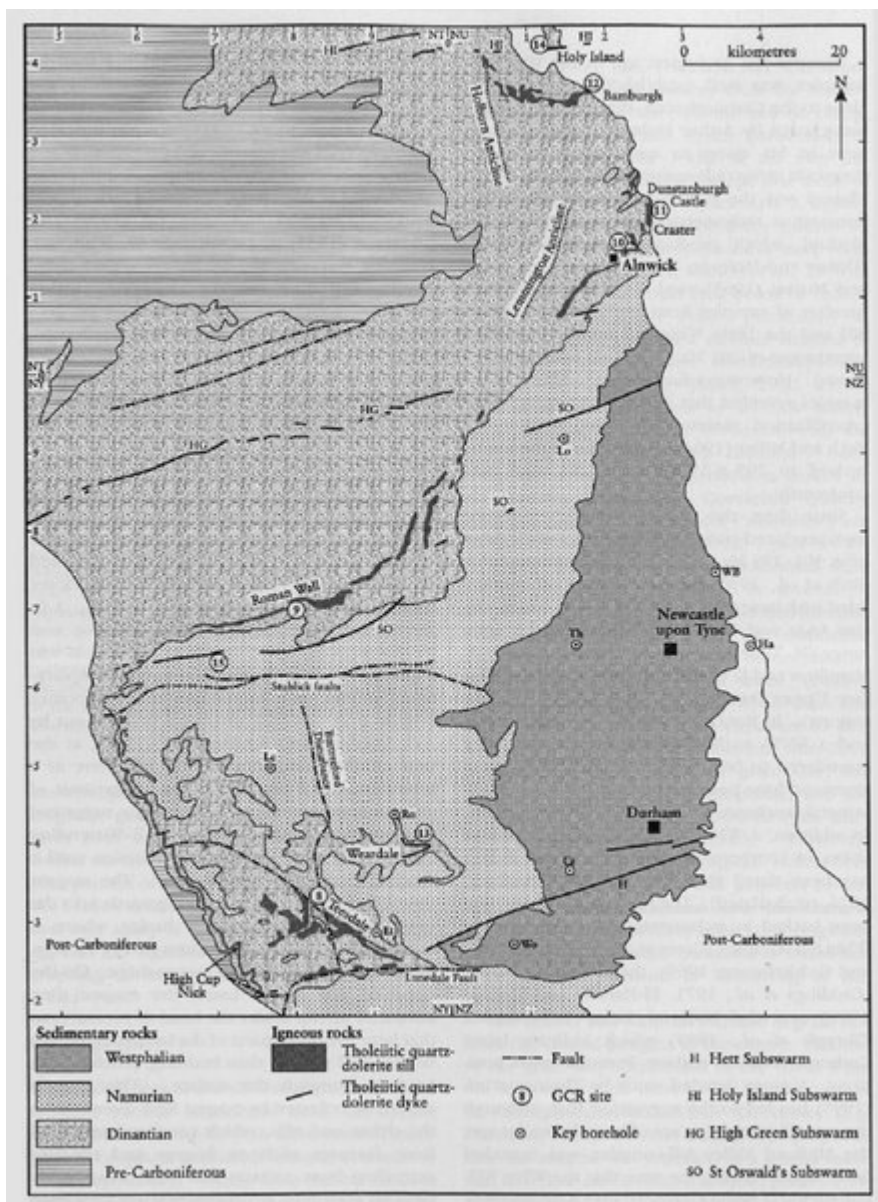
(Figure 6.2) Map of north-east England, showing the area intruded by the Late Carboniferous tholeiitic Whin Sill-complex and associated dyke subswarms. GCR sites: 8 = Upper Teesdale; 9 = Steel Rigg to Sewingshields Crags; 10 = Longhoughton Quarry; 11 = Cullernose Point to Castle Point; 12 = Budle Point to Harkess Rocks; 13 = Greenfoot Quarry; 14 = Holy Island; 15 = Wydon. (Key boreholes: Cr = Crook; Et = Ettersgill; Ha = Harton; Lh = Longhorseley; Lo = Longcleugh; Ro = Rookhope; Th = Throckley; WB = Whitley Bay; Wo = Woodland.) After Francis (1982); and Johnson and K.C. Dunham (2001).
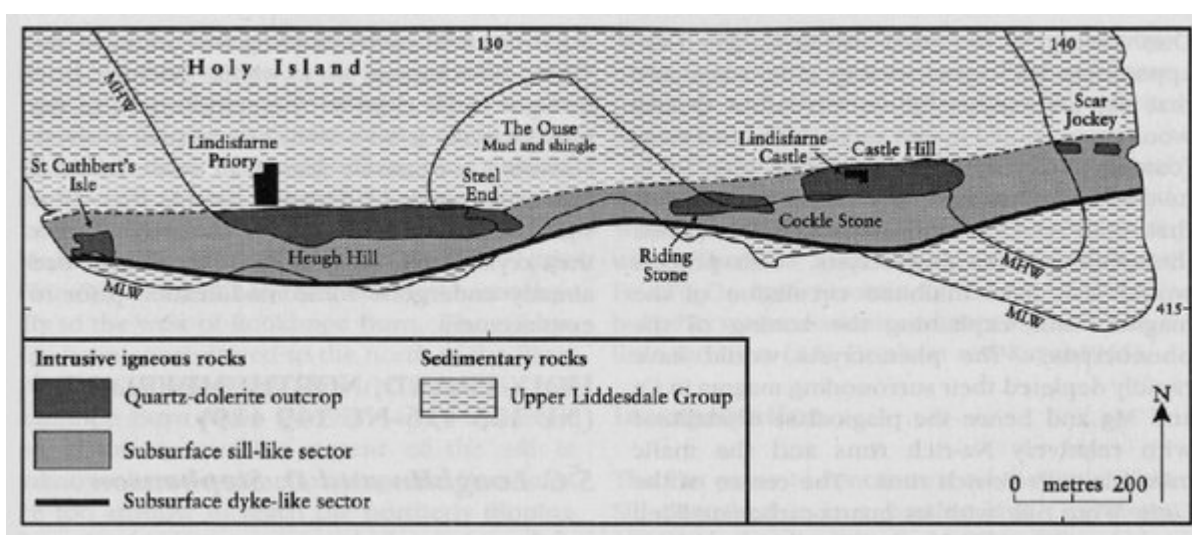
(Figure 6.33) Map of the Holy Island GCR site. After Goulty et al. (2000).
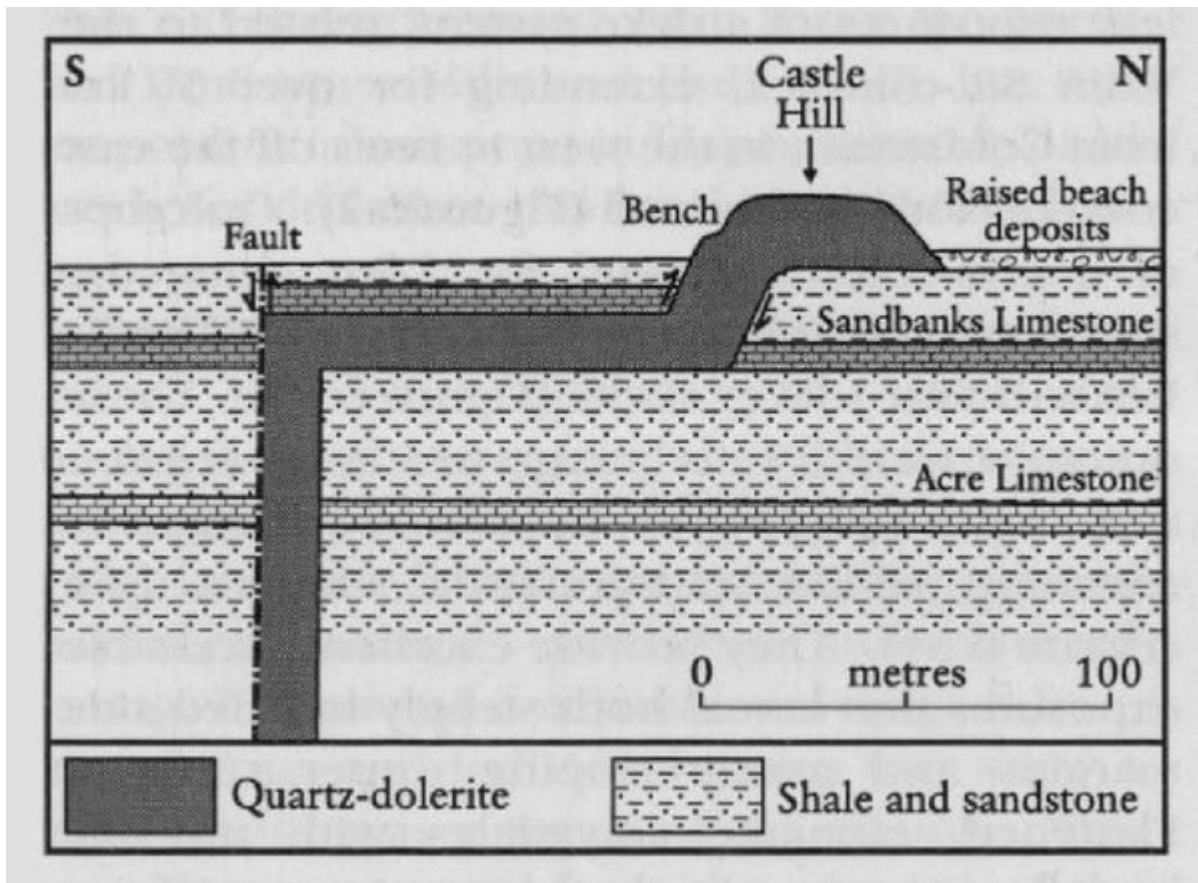
(Figure 6.34) Sketch of a south–north section through the centre of Castle Hill, Holy Island, showing the alternating dyke-like and sill-like sectors of the intrusion. After Goulty et al. (2000).

(Figure 6.35) The south coast of Holy Island, clearly showing the overall apparent dyke-like nature of the quartz-dolerite intrusion, which provides the site for the castle in the far distance and shelters the priory in the middle distance. St Cuthbert's Isle, in the foreground, is formed from a sill-like step in the intrusion. (Photo: P MacDonald.)
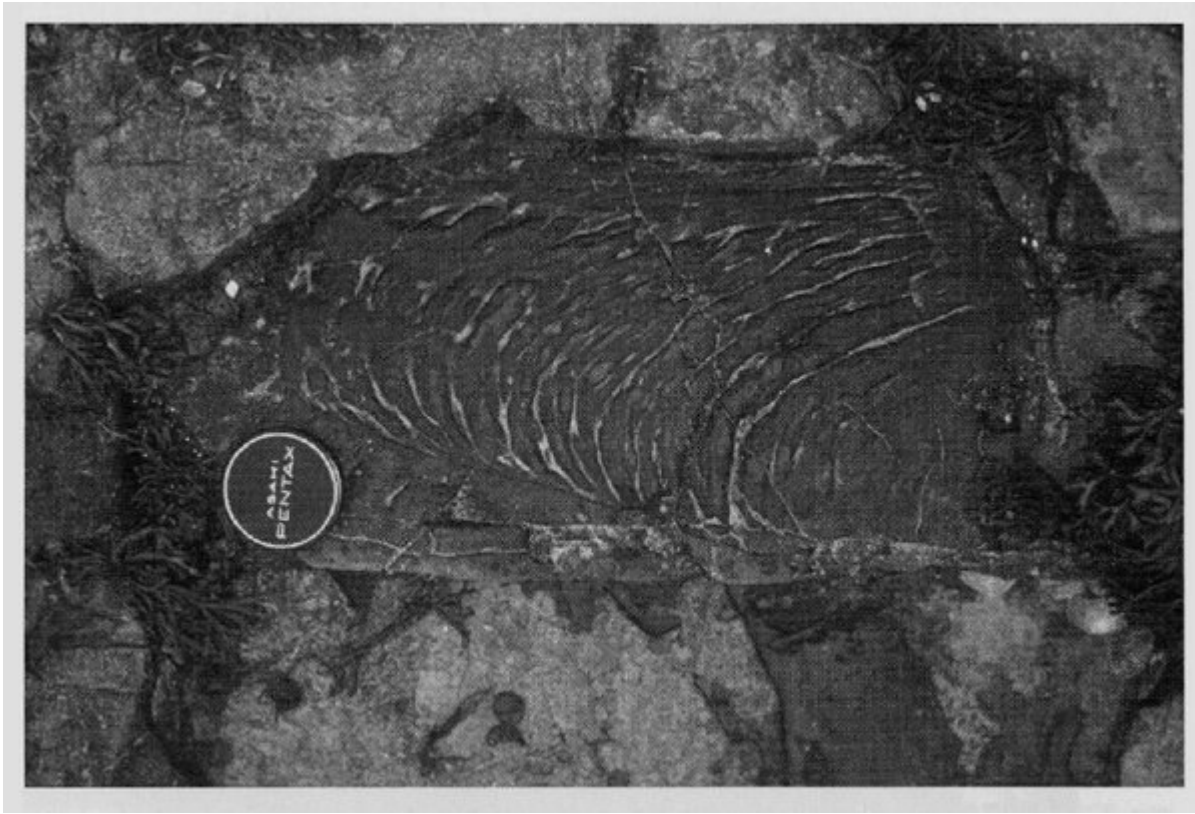
(Figure 6.36) Ropy flow structure on the lower inner surface of a large flattened amygdaloidal cavity (the amygdaloidal 'fill' having been eroded away), St Cuthbert's Isle, Holy Island GCR site. The lens cap is 50 mm in diameter. (Photo: D. Stephenson.)