North Berwick Excursion C—Yellow Craig to Cheese Bay (Route: (Map 12))

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1 Yellow Craig: vent intrusion and agglomerate

The excursion starts from the Yellowcraig car park [NT 516 854]. Take the path eastwards through the plantation and climb the small hill of Yellow Craig which forms a roche moutonnee. The Craig is a plug, lying within the Yellow Craig Vent. consisting of hard, black microporphyritic olivine-basalt. Surrounding Yellow Craig the extensive flat at about 8 m O.D. is a post-Glacial raised beach, covered in places by dunes of blown sand. East across a wall are several low outcrops of the vent agglomerate, a brown-grey tuff full of rounded bombs and baked angular blocks. Careful study will show they include Markle basalt, mugearite, bedded tuff, mudstone, siltstone, and large blocks of microporphyritic basalt seen at Yellow Craig. Small and rather vulnerable outcrops such as these should be treated with care and not hammered. Ample opportunity will occur for collecting from the large foreshore outcrop at the next locality.

2. Longskelly Point: vent and concentric structure

Proceed due north across low sand dunes and the beach sand to the wave-cut platform of Longskelly Point. The east end of this platform is an intrusive sheet of black microporphyritic olivine-basalt. In the absence of contacts it is not clear whether the sheet was intruded entirely within the vent or extended into the flanks of the volcano. Note the prominent jointing and poorly formed columns in the hard, fissile basalt. Towards the west end of the wave-cut platform there occurs a concentric structure lying within the vent, possibly caused by collapse. Standing on the basalt plug some 25 m across in the centre of this structure, one can see concentric ridges and hollows formed by alternating hard basalt and soft agglomerate. Here also the greenish vent agglomerate contains fragments of various lithologies. The vent margin lies along a curved hollow where vent agglomerate cuts across Markle basalt lava the lava distinguished by its numerous large feldspar phenocrysts.

Offshore islands

At this point it is worth pausing to look at the four islands which enhance this coastline. Lying just offshore, Fidra is a thick sill of microporphyritic olivine-basalt, note the fine columnar structure in the basalt, the natural arch on the far side, and the low raised beach and cave on the near side. To the east the rocky Lamb is probably part of the same columnar basalt sill. Further east still, the rounded Craigleith is an essexite laccolith, and the vertical-cliffed Bass Rock is a phonolite volcanic plug. Also prominent to the south-cast is another phonolitic plug forming the conical North Berwick Law.

3. Longskelly Rocks: markle basalt and mugearite lavas

For the next 800 m the rocks on the foreshore consist of Markle basalt lava, dipping gently to the south. Round the point opposite Fidra, the junction between Markle basalt and the overlying mugearite lava to the south can be traced near H.W.M. Contrast the angular appearance of the grey. Fissile, non-porphyritic mugearite with the rounded appearance of the darker grey, crumbly Markle basalt containing numerous large feldspar and small olivine phenocrysts. The upper part of the basalt lava is autobrecciated and has amygdales and calcite veins. The high level of the wave-cut platform suggests formation during a higher post-Glacial sea level rather than at present.

4. Small intrusive plug

Located below a 'Power Cable' sign is a neat oval plug of hard black basalt. 5 m by 10 m. intruded into Markle basalt lava. The intrusion has a pale chilled margin which can be traced along the somewhat irregular contact with the lava.

5. Marine Villa: volcanic succession

See also addendum below

Towards Marine Villa, due to a change of strike, the volcanic succession of Markle basalt, mugearite and trachytic tuff is traversed in ascending order. Here the mugearite lava is very well exposed, and in it can be seen sparse feldspar phenocrysts, concentric iron-banding with bleached centres, and numerous calcite veins. Note here also the storm beaches of black microporphyritic basalt boulders, brought by currents across from Fidra; during exceptionally low tides the connecting Brigs of Fidra may be exposed. Opposite Marine Villa, used by R.L. Stevenson as the location for his short novel The Pavilion on the Links, the junction of mugearite lava and overlying red bedded trachytic tuff is repeatedly exposed by a combination of low dip, slight folding and irregular erosion. The irregular slaggy amygdaloidal top of the lava has been preserved here by the overlying tuff. The absence of a bole of red fossil soil indicates that the tuffs were deposited soon after the lava. Sections of the trachytic tuffs in low cliffs show alternation of coarse and fine bands and an agglomeratic base. Slickensided planes with slight movement are indications of the faulting occurring further west.

6. Weaklaw Vent

See also addendum below

Just beyond a second 'Power Cable' sign the red bedded tuffs are truncated along a silicified plane, dipping at 30 degrees to the west, well-exposed at H.W.M. and in the low cliffs behind. This is taken as the edge of a small vent, about 100 m across, filled with reddish-brown poorly bedded sandy tuffaceous breccia containing grey cementstone blocks. Along H.W.M. beyond the vent are exposures of soft, yellow, bedded dolomitic tuffs containing blocks of trachyte, some markedly feldspar-phyric.

7. Hanging Rocks: intrusion breccia

See also addendum below

Intruded along a NE–W fault separating the trachytic tuffs from cementstone facies sediments is a yellow dolomitic breccia with large hornfelsed shale blocks. The south-east margin of this intrusion breccia is spectacularly displayed in two bluffs as planes dipping at 60 degrees and 45 degrees, which leave the breccia 'hanging' against the bedded volcanic rocks in the cliffs behind. By the caves in the next bluff, 5 m of rotten, purple, vesicular, porphyritic trachyte lava with an irregular base rest on 8 m of purple and cream, bedded trachytic tuff with agglomeratic bands.

8. Cementstone facies sediments and synclinal ring structure

See also addendum below

From the slopes above the caves there are fine views of gentle folding in bedded sediments on the foreshore. Close examination on descending to the shore shows that these are cementstone facies sediments, consisting of thin red-weathering, grey cementstones, some nodular, grey siltstones and mudstones, in which plant fragments and rarely shells may be found. Minor folding and faulting can be discovered within the larger structures. Just to the west, and separated from the sediments by a fault, there is an asymmetric synclinal structure, possibly caused by collapse. Prominent hard dolomitic bands alternating with softer tuffaceous bands pick out dips of up to 40° in the structure.

9. Point opposite Eyebroughy: basalt sill

A thin irregular sill of microporphyritic basalt has been intruded into dolomitic and tuffaceous sediments. The sill, cut by erosion into several parts, displays fine columnar structures varying from horizontal to vertical. Eyebroughy, a rocky tidal islet, consists of trachyte, thought to be intrusive.

10. Cheese Bay: Shrimp Bed

In the bay to the south, which reputedly owes its name to the wreck of a ship laden with cheese, gently folded sediments crop out. A band of hard red-weathering cementstone with estheriids is underlain by dark grey mudstones, black bituminous shales containing ostracods, fish scales and pyritised plants, finely colour-banded shales, and a thin fissile grey silty cementstone. This locality is noted for the occurrence of the shrimp *Tealliocaris woodwardi*, which is particularly abundant in the thin silty cementstone. A list of the numerous species of fish and plants also collected from these beds is given by Clough (1910. p. 207). More recent studies on this locality have been done by Hesselbo and Trewin (1984). Over-collection has obscured the richest beds, but fine specimens of shrimps may be obtained by splitting fragments on the beach.

11. Cheese Bay Sill

Just to the south another microporphyritic basalt sill is similarly intruded into dolomitic sediments. In the bouldery area beyond, prominent isolated stacks of basalt capped by outliers of baked sediments show the development of white trap, druses and other phenomena produced by intrusion of basaltic magma into carbonate rocks. The excursion can be completed by continuing south to Gullane (3 km) from where a service bus goes to Edinburgh, or by returning along the shore to Yellowcraig (4 km).

12. Dirleton Castle: Trachyte Lava

Worthy of a visit in Dirleton Village is the ruined castle built in the 13th to 15th century. The castle [NT 516 839], open all year, is sited on a trachyte crag. The red-purple stained, fine-grained trachyte lava has white feldspar phenocrysts and is typical of the trachyte lavas which form a thick pile in the Garleton Hills, but are represented on the coast only by the lava at Hanging Rocks. The return journey takes one through the charming villages of Gullane, Aberlady and Longniddry to Edinburgh.

Relative ages of the Weaklaw Tuffs, the Hanging Rocks breccias and the Marine Villa Tuffs - Addendum to localities 5, 6, 7 and 8.

By David Stephenson, formerly BGS Edinburgh, October 2022

The field evidence

The rocks at localities 5, 6 and 7, between Marine Villa and the Hanging Rocks have been described in great detail and interpreted in modern terms by Upton *et al*. (2019) and Upton *et al*. (2020). However, their field relationships and relative ages have remained enigmatic. This is in part because of the great difficulty of tracing near-horizontal geological boundaries on an extensive intertidal rock platform that is mostly covered in seaweed.

The section was first described in detail by Day (1916, 1923), who clearly made a good attempt to map the rock platform, especially in his later paper (Day, 1923, fig.1). The very small-scale map ((Map 12)) by A.D. McAdam in *Lothian Geology* suggests that improvements upon the earlier mapping were made on the 1:10560 map (NT58NW –WFidra), by N.R. Martin and A.D. McAdam, which is deposited with the British Geological Survey.

There are three main units (Figure DS1). From east to west, these are:

1. **mugearite lava**, at the local top of the Hailes Member, Garleton Hills Volcanic Formation (GHVF);
2. well-bedded trachytic tuffs, now known to include ignimbrite ash-flows, termed the **Marine Villa Tuffs** by Upton *et al*. (2020) and forming the local base of the Bangley Member, GHVF;
3. the **Weaklaw Tuffs**, forming the Weaklaw Vent (Upton *et al*., 2019).

The Marine Villa Tuffs are clearly seen to rest upon a perfectly preserved, spiky top of the mugearite lava at Locality 5 and for some 150 m to the west at the base of the cliffs. It is the relationship of these two units to the Weaklaw Vent that has been difficult to establish. Because there is an overall younging to the west throughout this coastal section, it seems to have been generally assumed, e.g. by Upton *et al.* (2019), that the Weaklaw Tuffs are younger than the Marine Villa Tuffs. However, perhaps significantly, none of the earlier authors (Day, 1923 and McAdam, 1986) have specifically said that and their small-scale maps suggest that they had recognised and traced the highly complicated boundary on the rock platform that results from the Marine Villa Tuffs resting almost horizontally on the rocks of the Weaklaw Vent over a wide area. It would be useful to check this further at a low tide.

The only direct detailed evidence is well exposed within Locality 6 at NT 5016 8595, about 50 m south-west of a rusty ?sewer pipe and directly below a brick-built observation post on the cliff top. However, this exposure has been misinterpreted by both Day (1923) and McAdam (1986). Both recognised the edge of the Weaklaw Vent here (the change from well-bedded red-brown Marine Villa Tuffs to yellowish coarser poorly sorted tuffs and breccias of the vent is obvious) but both were over-influenced by the local dip of the Marine Villa Tuffs in the low cliff, which here is 30 degrees towards the vent rocks. Day's text is difficult to understand but he seems to have assumed that the Marine Villa tuffs pass beneath the vent rocks and/or that the edge of the vent coincides with the 30-degree dip surface in a possible intrusive or faulted relationship. Elsewhere in the paper he suggested that the increased dip was due to blocks of the Marine Villa Tuff sliding into the vent. All of those interpretations implied that the Weaklaw Tuffs are the younger.

Closer examination shows that this is not the case. Bedding in the Marine Villa Tuffs does steepen to *c*. 30 degrees, towards the Weaklaw Tuffs but this steepening is very local and, at the base of the cliff, the base of the Marine Villa Tuffs can clearly be seen to be folded back up to rest upon the Weaklaw Tuffs at a low angle i.e. there is an open syncline (Figure DS3) and (Figure DS4). Westwards from that point, the unconformity can be seen to undulate gently over a wide area of the rock platform, commonly with just a thin ‘skin’ of the basal Marine Villa Tuffs preserved. Exposure is excellent around the syncline and there is no evidence of either a faulted or an intrusive contact between the two tuff units. The horizontal unconformable contact can also be seen very clearly beneath an overhang at the base of the cliff some 100 m to the south-west of the key locality (the point marked 'x' on plate XXIII and on figs 1 and 2 in the Day, 1923 paper). Marine Villa-like tuffs are also exposed above the Weaklaw Tuffs in the cliffs behind the Hanging Rocks (see below), as is acknowledged by Upton *et al.* (2020).

We must conclude that the Marine Villa Tuffs overlie the Weaklaw Tuffs over a wide area and are therefore younger. However, the outcrop of the mugearite lava (Hailes Member) has been traced, beneath the Marine Villa Tuffs only as far west as the rusty sewer pipe, a mere 50 m from the outcrop of the Weaklaw Tuffs but it is not seen in contact with them and, at the key locality, the Marine Villa Tuffs rest directly on the Weaklaw Tuffs with no intervening mugearite. So, the relationship between the mugearite lava and the Weaklaw Tuffs is not known (Figure DS1); maybe it could be revealed by a diligent search beneath the seaweed on the rock platform?

Sequence of main volcanic events

1. Eruption of the small Weaklaw volcano, as described by Upton *et al*. (2019), was probably contemporaneous with petrographically and geochemically similar basanitic volcanoes associated with the basal North Berwick Member of the GHVF (McAdam and Tulloch, 1985; Upton, 2003, p 54). A low but upstanding volcanic edifice with gentle slopes probably survived for some time, until….
2. After possibly a significant time interval, eruption of the mugearite lava at the top of the Hailes Member. The lava is not seen in contact with the Weaklaw Tuffs, so does the mugearite lap up against the remains of the Weaklaw volcano below current erosion level or maybe it was deflected around it?
3. The Marine Villa Tuffs were deposited, mainly by pyroclastic flow, directly upon a very fresh, perfectly preserved, rubbly to spiky top of the mugearite lava. There is no sign of reddening, weathering or erosion of the mugearite, so this was almost certainly after only a short time interval. The gently undulating hummocky surface of the tuffs is most probably primary, possibly also reflecting underlying topography on the top of the mugearite but the contact is generally subhorizontal and very close to low-water mark on the rock platform. Cross-bedding in the pyroclastic flows consistently indicates flow towards the Weaklaw volcano. Did the flows completely overtop what was left of the

volcano or were they too deflected around it - or maybe both? It seems possible that the little open syncline in the Marine Villa Tuffs at the key locality might be a primary feature, at least in part i.e. is it a result of the basal pyroclastic flow 'colliding' with a low-angled remnant of the Weaklaw volcanic edifice?

Geological relationships at the Hanging Rocks

Some 250 m west of the first exposures of the Weaklaw Tuffs, at the Hanging Rocks (Locality 7), two masses of pyroclastic breccia form prominent bluffs protruding from the full height of the cliff section (Figure DS5) and (Figure DS6). Previous authors have suggested that the breccias represent a volcanic conduit, or conduits, possibly emplaced along faults, and in continuity with exposures of similar breccias extending for a considerable distance to the NE across the rock platform. The affinities of the rocks in the cliff section adjacent to and behind the Hanging Rocks are of vital importance and can be examined most easily a short distance west of the Hanging Rocks at the Smugglers Caves. On the rock platform and at the base of the cliff they are clearly Weaklaw breccias. But most authors, from Day (1923) through to Upton *et al*. (2019, 2020), with varying degrees of confidence, have assigned the rocks that overlie the Weaklaw breccias at the base of the cliff to what we now term the Marine Villa Tuffs, overlain by a rotten feldspar-phyric lava. In particular, Upton *et al*. (2020, fig. 8b) showed flattened devitrified fiamme in the tuffs. They also argued from trace elements that the lava is most likely an altered mugearite (earlier workers thought it was a trachyte).
The breccias that compose the Hanging Rocks are indistinguishable from the pyroclastic breccias of the Weaklaw Vent exposed on the rock platform, with a similar range of clasts, including the characteristic ‘cored bombs’ enclosing mantle xenoliths, as described by Upton *et al.* (2019). However, they cannot have been intruded through the demonstrably younger Marine Villa Tuffs, as has been suggested or implied by previous authors. On both sides of both of the Hanging Rocks, the breccias are clearly seen to be bounded by fractures dipping seawards (NW) at 40 to 50 degrees. The fault planes so defined cut the buttresses on their seaward sides up to about a metre above their bases. Where the dominant fault planes project onto the horizontal surface of the rock platform, a few metres from the base of the rocks, Day (1916, 1923) claimed to have traced a fault for some distance. That is difficult to identify today, possibly due to shifting beach deposits, but short lengths of slickensided surfaces were identified on a recent visit.

So, the Hanging Rocks breccias are truly ‘hanging’ in both a topographical and a geological sense i.e. they expose the hanging wall of a high-angle reverse fault-zone, parallel to and possibly controlling the location of the cliff line. Breccias of the Weaklaw Vent have been thrown up on the NW side of the fault-zone and juxtaposed against a near-horizontal upward succession of Weaklaw breccias, Marine Villa Tuffs and mugearite lava, exposed in the cliff behind the erosional remnants (Figure DS2). T. Cuthbert Day had identified the geometry more-or-less correctly (e.g. see Day, 1916, figs 1 and 2) but he misinterpreted the angle of the fault plane and the direction of throw. ‘Tongues’ of breccia and ‘white trap’ apparently extending from the hanging wall breccias into the footwall succession at the western Hanging Rock were, understandably, taken as support for an intrusive contact. These features are difficult to access in a crumbly cliff but ideally, they should be investigated, together with the NW-dipping planes of dislocation. An intrusive nature of the Hanging Rocks breccias has been followed by most subsequent authors and the three-dimensional exposures, as interpreted here, could be interpreted as an intrusive contact but that would present serious problems regarding the age relationships. A faulted contact is by far the simplest and most likely interpretation and apparent ‘tongues’ of Weaklaw-type lithologies are probably tectonic slices within the complex fault-zone.

Tuffs within the sedimentary sequence west of the Hanging Rocks

West of the exposures of the Weaklaw Vent, and after about 200 m of beach sand, there is a well-exposed closed syncline, well seen from the dunes above the beach at low tide (Locality 8) (Day, 1923, fig. 1, plate XXIV). The syncline is mainly in sedimentary rocks (siltstones and dolostones) above the GHVF but its lowest beds include a *c*. 1m-thick bed of tuff, which can be traced all around the syncline. This tuff is unlike either the Weaklaw Tuffs or the Marine Villa Tuffs. It is a coarse ash- to lapilli-grade lithic tuff, composed of matrix-supported equidimensional angular clasts of almost entirely sedimentary material, probably mainly dolostone (‘dolomitic ash’ of Day, 1923). Some fine-grained, siliceous igneous clasts might be present but this has not been confirmed. Bedding is poor or absent. Other beds in ephemeral exposures to the west are of similar tuffs or ‘tuffaceous dolomitic rocks’ (McAdam and Tulloch, 1985). Given the dominance of clasts of sedimentary rock, maybe these tuffs are the products of sporadic eruptions associated with the ‘cryptovents’ around

Cheese Bay, a short distance to the south-west?

Ages of events

The failure of anyone over the past 100 years to recognise the syncline at the key locality, or to fully appreciate the subhorizontal, unconformable thin cover of Marine Villa Tuffs over much of the intertidal rock platform, has resulted in a perpetuation of Day's false assumption that the Weaklaw Tuffs overlie, and/or possibly cut through, the Marine Villa Tuffs and hence are younger. In the light of the field evidence presented here, it is now clear that the assumption by Upton *et al*. (2019) that the Weaklaw Tuffs were a product of a much later event than the Garleton Hills volcanic episode cannot be substantiated.

The relatively primitive basanitic nature of lava bombs and fragments within the tuffs and breccias of the Weaklaw Vent suggest that it was most likely contemporaneous with the petrologically similar 'Red Group' of vents, associated with the earliest GHVF eruptions that produced the North Berwick Member (McAdam and Tulloch, 1985). That would make the vent significantly older than the mugearite lava at the top of the Hailes Member, although no contact relationships have as yet been discovered at this site. The Marine Villa Tuffs at the base of the Bangley Member form an undulating subhorizontal relatively thin sheet, erupted shortly after the mugearite, that is unconformable upon the Weaklaw Tuffs. The breccias of the Hanging Rocks that were formerly interpreted as having been intruded through both the Weaklaw Tuffs and the Marine Villa Tuffs as the latest volcanic event, are parts of the Weaklaw Vent that have been juxtaposed against a younger volcanic succession by faulting.

Thin beds of tuff within a sedimentary sequence to the west of the Hanging Rocks post-date the GHVF and might be associated with 'cryptovents' around Cheese Bay.

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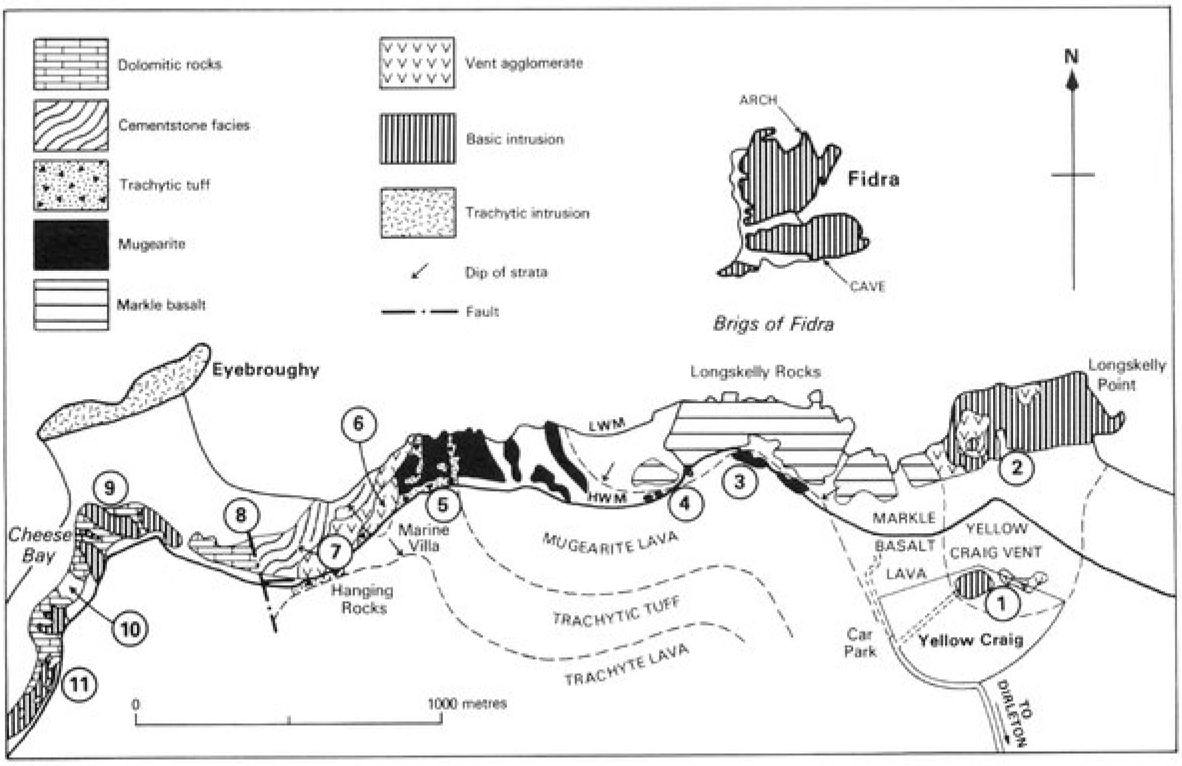
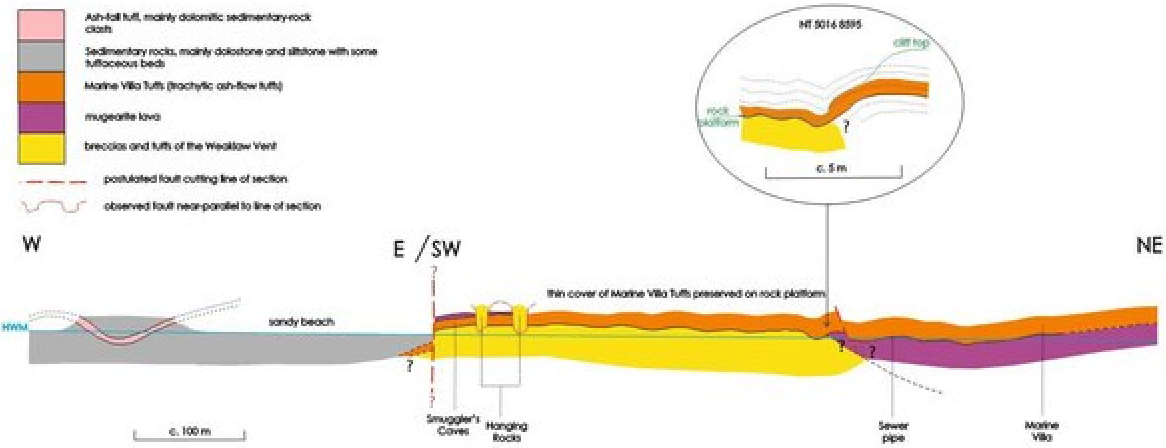


(Map 12) Yellow Craig to Cheese Bay.



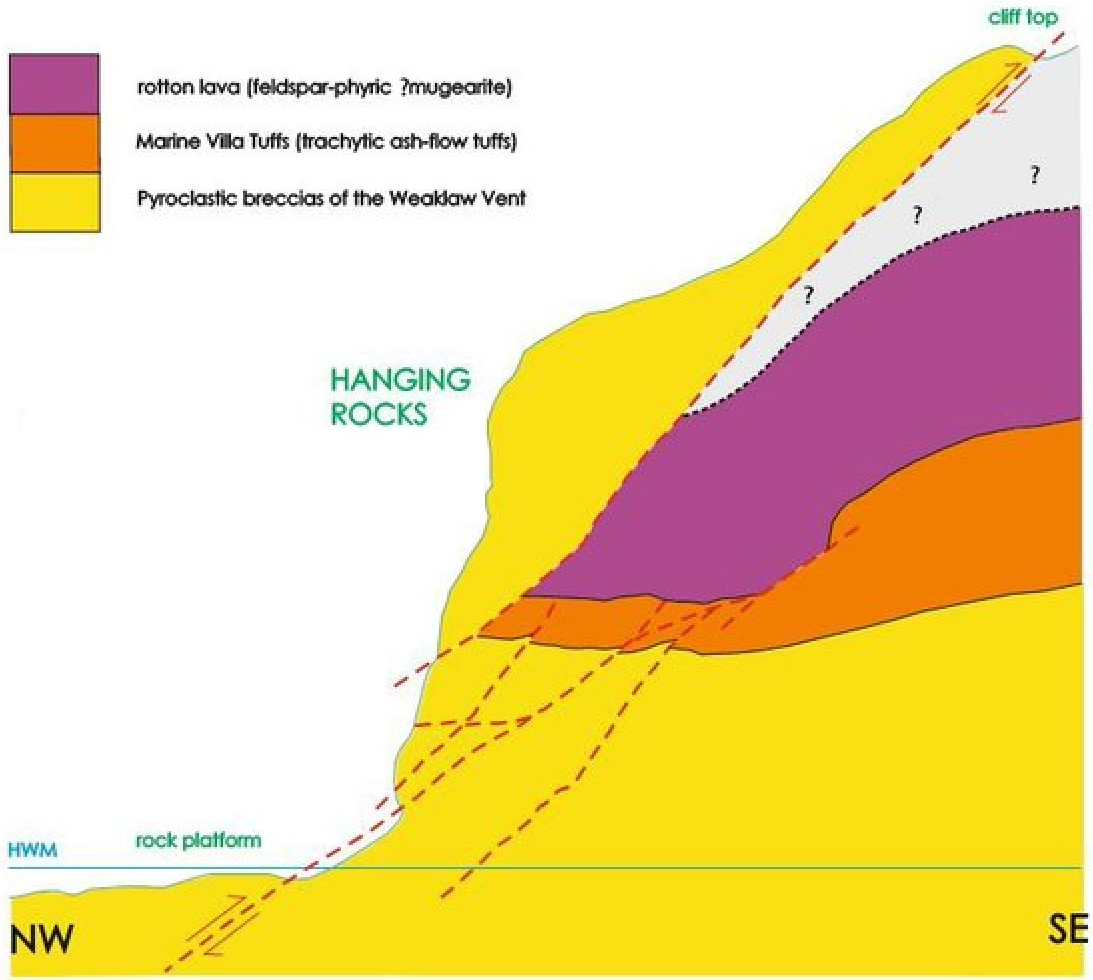
(Figure DS1) Sketch section along the high-water mark, from Marine Villa to the beach west of the Hanging Rocks. The inset shows detailed relationships at the key locality [NT 5016 8595].

(Figure DS3). The key locality at [NT 5016 8595], viewed towards the south-west. Well-bedded Marine Villa Tuffs in the low cliff on the left dip to the right (north-west) at c. 30 degrees. The fallen blocks lie along the axis of an open syncline. To the right (north-west) of the blocks, a thin 'skin' of Marine Villa Tuffs can be seen draping over a very shallow domed surface (with rucksack) of paler, coarse, massive Weaklaw Tuffs, that is elongated away from the camera. A dark recess in the cliff in the distance marks the overhang where near-horizontal, well-bedded Marine Villa Tuffs overlie Weaklaw Tuffs. Compare with Day (1923, plate XXIII) where, on both photos, the recessed overhang is marked 'x'.

(Figure DS4) The key locality at [NT 5016 8595], viewed towards the north-east. Marine Villa Tuffs in the cliff; blocks along the syncline axis; and thin skin of Marine Villa Tuffs just above point of stick. Note the coarse texture of the Weaklaw Tuffs in the foreground. On the rock platform in the distance (top left) is a horizontal feature formed by the basal Marine Villa Tuffs.

(Figure DS5) The western Hanging Rock. A mass of coarse pyroclastic breccia is juxtaposed against Weaklaw Tuffs at the base of the cliff and bedded Marine Villa Tuffs above by a reverse fault trending parallel to the cliff and dipping towards the camera at 40 to 50 degrees. The cliffs here are crumbly and inaccessible but the higher beds can be seen at the Smuggler's Caves, some 50 m to the west.

(Figure DS6) The western face of the western Hanging Rock, showing the complex reverse fault-zone represented diagrammatically in (Figure DS2).



(Figure DS2) Sketch section NW to SE across the Hanging Rocks to illustrate emplacement of pyroclastic breccias of the Weaklaw Vent against younger volcanic rocks by a complex high-angle reverse fault trending parallel to the cliff line. The sketch is a stylised view based upon a photograph of the western face of the western Hanging Rock (Figure DS6). Most of the face above the base of the Marine Villa Tuffs is crumbly and inaccessible and hence parts of the interpretation might be inaccurate.