Burntisland to Kinghorn Coast, Fife

[NT 252 864]–[NT 280 891]

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Introduction

The Burntisland to Kinghorn Coast GCR site incorporates one of the best-exposed successions of Visean volcanic rocks in the Midland Valley of Scotland. The 485 m-thick succession consists of basaltic lavas with subordinate volcaniclastic rocks (hyaloclastite, pyroclastic rocks and volcaniclastic sedimentary rocks).

Notable aspects of the site are the well-exposed internal structures of individual lava flows, a hyaloclastite unit, and occurrences within some lavas of sedimentary inclusions that locally contain important Early Carboniferous floral assemblages. The latter are described in the *Palaeozoic Palaeobotony of Great Britain* GCR volume (Cleal and Thomas, 1995) from two sites, Kingswood End and Pettycur, which fall within the area of the GCR site described here.

A detailed log of the volcanic succession by Geikie (1900) has formed the basis of most subsequent descriptions (Allan, 1924; MacGregor, 1996). The site was included in a recent re-survey of the Kirkcaldy district by the British Geological Survey (Woodhall, 1998; Browne and Woodhall, 1999, 2000). As a result of this re-survey, the volcanic rocks have been formally designated as the Kinghorn Volcanic Formation, and the exposures at this GCR site constitute the type section. Previously the volcanic rocks were either unnamed or referred to as the 'Burntisland Volcanic Formation' (Francis, 1991). Only a few geochemical analyses of the lavas have been published (Allan, 1924; Macdonald *et al.,* 1977; Smedley, 1986a, 1988a).

Description

The Early Carboniferous age of the succession at the Burntisland to Kinghorn Coast GCR site is constrained, outside of the site area, by Asbian to Brigantian miospore assemblages from fluvio-deltaic, lacustrine and marine sedimentary rocks of the Sandy Craig and Pathhead formations (Strathclyde Group) (Brindley and Spinner, 1987, 1989; Browne *et al.,* 1996). Within the site, these same strata underlie, interdigitate with, and overlie the volcanic succession (Figure 2.21).

Lavas dominate the succession, and range in thickness from 5 m to 30 m. They are typically greyish- or brownish-green-weathered, olivine- or olivine-clinopyroxene–microphyric alkali olivine basalts. Amygdales of dark-greenish-grey chlorite and/or pale-yellow calcite are typically most abundant in the lower and upper parts of individual lava flows. Brecciated flow bases and/or tops are apparent locally, but in many cases have been obscured by weathering. Some of this weathering may have taken place soon after the emplacement of the flow, but it is indistinguishable from Quaternary weathering. Many lavas rest sharply on intercalated volcaniclastic and/or siliciclastic sedimentary rocks, and have a regular basal contact. However, those resting on mudstone tend to have an irregular contact owing to the presence of load structures, and some of these lavas contain inclusions of sedimentary rock that were probably derived from the underlying sediment during the emplacement of the flow. At Pettycur [NT 2608 8625], limestone inclusions have yielded an important Early Carboniferous flora dominated by lycopsids and ferns (Gordon, 1909; Scott *et al.,* 1984, 1986; Rex and Scott, 1987).

The middle parts of the flows are the least weathered, contain the fewest and smallest amyg-dales, and commonly display cooling joints, which are locally columnar. Columnar jointing occurs in some of the flows exposed in the crags at Kingswood End (Allan, 1924), and on the coast, between Pettycur Harbour and Carlinhead Rocks e.g. [NT 2677 8611]. Geikie (1900) described occurrences of pillow lava between King-horn Ness and Linton Court e.g. [NT 2751 8728], [NT 2753 8740]. However, these polyhedral, pillow-like masses lack chilled margins, which would be expected in true subaqueous pillows, and have been produced by weathering along intersecting planar and curviplanar, horizontal and vertical cooling joints (MacGregor, 1996). In places the joint pattern is enhanced by vein-calcite along joint planes e.g.

[NT 2753 8740].

Hyaloclastite, 35–40 m thick in the upper part of the succession, is exposed along the coast northeast of Kinghorn where it forms a 100 m-long wave-cut platform [NT 2734 8717]–[NT 2744 8722] (Woodhall, 1998). The base of the hyaloclastite is exposed at the southern end of the platform, where it rests on an intercalation of siliciclastic and volcaniclastic sedimentary rocks. The contact is in part irregular due to loading, but in places it truncates bedding in the underlying strata [NT 2734 8717]. The hyaloclastite consists of green- to brownish-green-weathered, structureless breccia made up of angular clasts up to 30 cm across, many of which are pillow fragments. It also contains numerous basaltic pillows and pillow fragments, 0.5 m to about 1 m across, which are green with distinctly paler-green or brownish-green chilled margins (e.g. [NT 2735 8717], [NT 2739 8723] (Figure 2.22). At the north-eastern end of the wave-cut platform [NT 2744 8722], a transition takes place, within a 5 m- to 10 m-thick zone, from hyaloclastite breccia to a coherent basalt lava, about 20 m thick. The base of the transition zone is marked by the appearance of lenticular sheets of green-weathered amygdaloidal basalt. Within the zone, these basalt sheets are separated by hyaloclastite breccia, but the thickness of intervening breccia decreases upwards [NT 2744 8722].

The volcaniclastic intercalations include primary and/or reworked pyroclastic rocks, up to about 5 m thick, in the form of various combinations of tuff, lapilli-tuff, lapilli-stone, and pyroclastic breccia e.g. [NT 2532 8651], [NT 2676 8608], [NT 2708 8633]. These deposits were probably produced by mildly explosive volcanism, which accompanied the eruption of the lava flows. A number of intercalations display a distinctive reddish-brown colouration at the top, which is interpreted as a result of baking and oxidation by the overlying lava (e.g. [NT 2540 8647], [NT 2703 8616]. Subaqueous accumulation of some pyroclastic deposits is implied where they occur interbedded with siliciclastic sedimentary rocks e.g. [NT 2528 8651]. There are some intercalations of volcaniclastic sedimentary rocks, up to about 5 m thick, in the form of tuffaceous siltstone, sandstone and/or conglomerate, made up of basalt clasts derived from the erosion of pre-existing rocks e.g. [NT 2542 8646], [NT 2536 8650].

Interpretation

The basaltic lava flows at the Burntisland to Kinghorn Coast GCR site are interpreted as the products of subaerial, effusive volcanism that probably involved hawaiian- and/or strombolian-type eruptions. Both types of eruption are dominated by effusions of low-viscosity, gas-poor magma, typically basaltic in composition, and they differ only in that magma discharge is more intermittent during strombolian eruptions (Walker and Croasdale, 1972; Blackburn *et al.,* 1976; McPhie *et al.,* 1993). During these types of eruption, only small amounts of pyroclastic material are produced, and most of this accumulates close to the vent, forming a cone of scoria-ceous lapilli and blocks, with some bombs. No such cones are preserved within the volcanic succession of this site. Therefore, the abundance of tuff in the succession is indicative of more distal accumulations of ash and/or small lapilli, which were probably deposited downwind from vents. There are only a few occurrences of coarser-grained deposits (e.g. lapilli-stone and pyroclastic breccia), which may have accumulated more proximally.

Depositional environments during the volcanism probably varied from subaerial, with scattered swamps and shallow lakes, similar to those envisaged by Rex and Scott (1987), in the Pettycur area, to shallow subaqueous lacustrine, deltaic and marine. Although many of the lavas are interbedded with sedimentary rocks, the infrequency of evidence for magma–water interaction (e.g. hyaloclastite and/or pillow lava) is consistent with dominant subaerial eruption. However, the presence of load structures at the base of, and sedimentary inclusions within, some flows indicates that some of the lavas were erupted onto a substrate of semi-lithified, possibly wet, sediment. The inclusions are considered to represent masses of sediment isolated from the substrate as portions of the basalt sank into such sediment. The presence of interbedded sedimentary rocks can be explained by a combination of regional tectonic subsidence and eustatic sea-level changes, which repeatedly drowned newly erupted lavas.

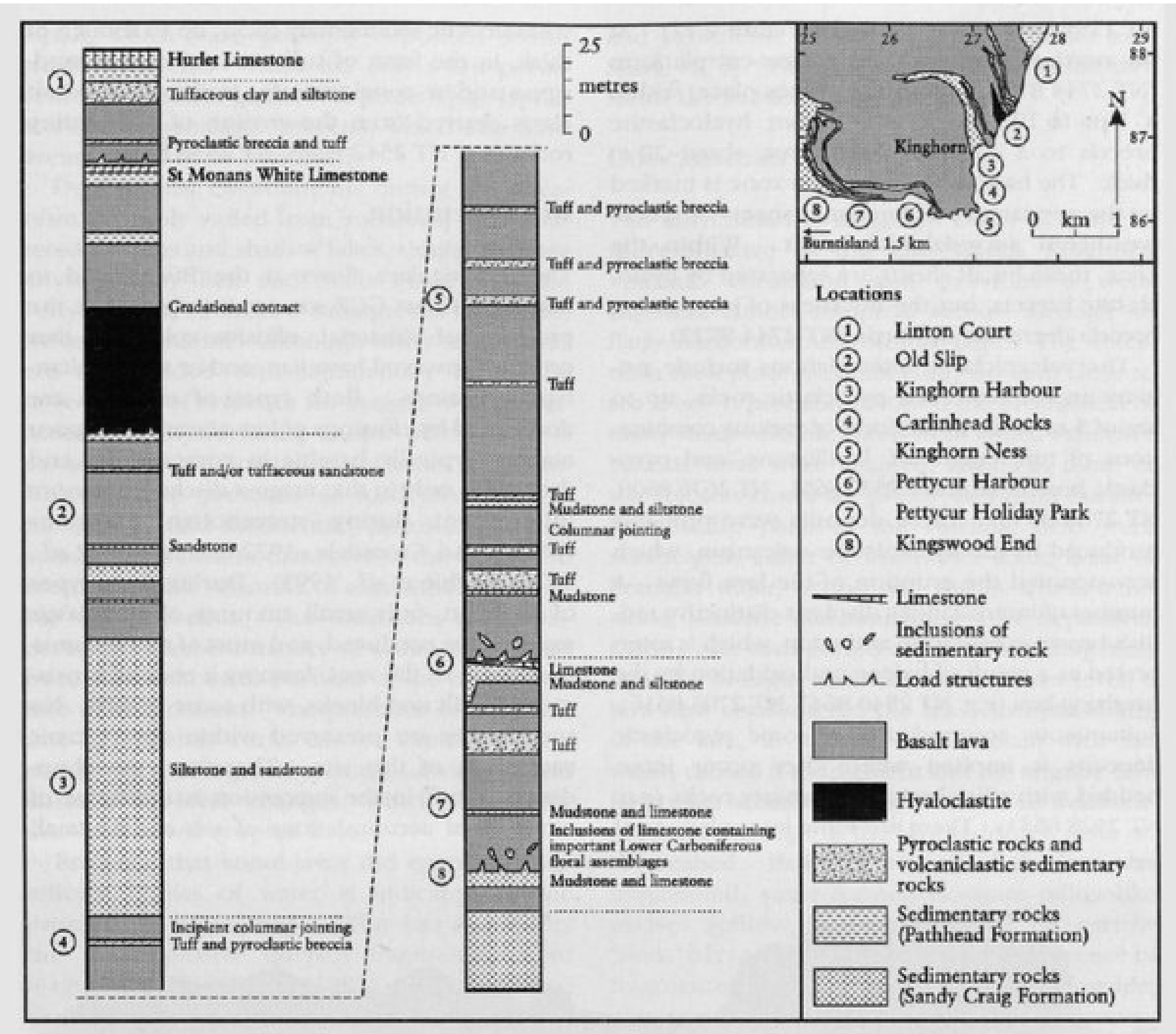
Evidence that some lavas did encounter significant bodies of water is indicated by the presence of hyaloclastite. This has formed by the non-explosive quench fragmentation of magma (McPhie *et al.,* 1993). That exposed along the coast north-east of Kinghorn is capped by basalt lava, which displays no evidence of subaqueous emplacement. This relationship is similar to that present in lava deltas, formed as subaerially erupted lava flowed into water (Jones and

Nelson, 1970; Moore *et al.,* 1973; Fumes and Sturt, 1976; Cas and Wright, 1987). Consequently, the hyaloclastite north-east of Kinghorn is interpreted as having formed the lower, subaqueous part of a lava delta. The transition upwards from hyaloclastite to basalt lava marks the approximate water level during delta formation, and consequently the 35–40 m thickness of the hyaloclastite provides an indication of minimum water depth. The presence of the trace fossil, *Rhizocorallium,* in siliciclastic sedimentary rocks immediately beneath the hyaloclastite, suggests that the delta formed during or soon after a marine transgression. The thickness (5–10 m) and complexity (alternating sheets of lava and hyaloclastite) of the transition zone is possibly due to the combined effects of tidal variation and subsidence of the lava delta (Fumes and Sturt, 1976). The overlying coherent basalt lava forms the subacrial part of the delta.

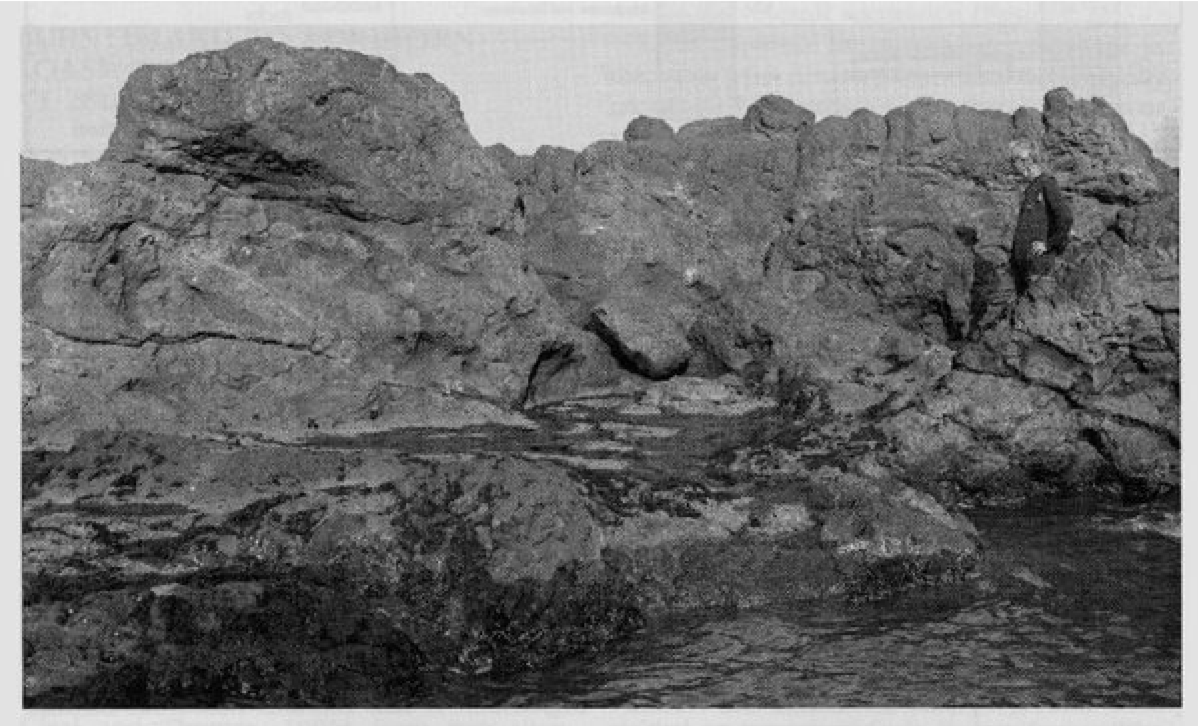
Conclusions

The Burntisland to Kinghom Coast GCR site is representative of the late Visean Kinghorn Volcanic Formation and provides a well-exposed, almost complete section through an Early Carboniferous volcanic field. The volcanism took place predominantly on land close to sea level. It probably involved the production of many small volcanic cones from which extensive basaltic lavas were erupted, although none of the volcanic cones are preserved within the site. Periodically, parts of the volcanic field were submerged, either by freshwater lakes, areas of brackish water, or the sea, within which mudstone, siltstone and sandstone were deposited. During one such period of partial submergence, possibly brought about by a rise in sea level, a lava flow encountered the sea. Abrupt cooling of the lava, as it came into contact with the water, caused it to fragment and the angular lava fragments accumulated by continuous avalanching from the edge of the lava to form a delta on the seabed. However, not all of the lava was fragmented; some formed elongate pillow-like masses (pillow lava) surrounded by narrow 'skins' of rapidly cooled lava. This occurrence of fragmented lava, with associated pillow-like masses, is one of few within the Carboniferous–Permian Igneous Province of northern Britain.

[References](#)



(Figure 2.21) The volcanic succession exposed in the Burntisland to Kinghorn Coast GCR site.



(Figure 2.22) Basaltic pillows with hyaloclastite in the Kinghorn Volcanic Formation on the shore at Bellypuff, north-east of Kinghorn [NT 2740 8725]. (Photo: British Geological Survey, No. D5217, reproduced with the permission of the Director, British Geological Survey, NERC.)