Arthur's Seat Volcano, City of Edinburgh

[NT 266 733]–[NT 283 731], [NT 262 742] and [NT 251 735]

B.G.J. Upton

Introduction

Within Edinburgh, outcrops of Dinantian volcanic rocks occur at Craiglockhart Hill, Castle Rock, Calton Hill and Holyrood Park. Because each of these forms a high topographical feature, they have had a profound influence on the development of the city from at least Iron Age times to the present day. Edinburgh Castle and the Castle Rock on which it stands are world-famous. Calton Hill lying just north of the eastern continuation of Princes Street has provided sites for, among other things, the old astronomical observatory, Nelson's Monument, the Royal High School and St Andrew's House. Holyrood Palace is sited on a low-lying outcrop of lavas south-east of Calton Hill. The largest of these outcrops, however, is that mainly embraced by Holyrood Park to the south-east of the city centre and containing Edinburgh's highest prominence, Arthur's Seat. As with Castle Rock, the high ground within the park provided sites for human habitation some 6000 years ago.

The above-mentioned localities have major geological, as well as historical and cultural, importance. Castle Rock is the surface expression of a sub-cylindrical stock of basalt, almost certainly representing the infilled conduit of a surface volcano. The Calton Hill and Holyrood outcrops comprise lavas and tuff layers with numerous intrusions and vents occupied by fragmental deposits. The volcanic succession is some 200 m thick on Calton Hill, thickening to between 400 m and 500 m on Whinny Hill on the eastern side of Holyrood Park. These successions form part of the 20°–25° eastward-dipping limb of a synclinal structure occupied by the Midlothian Coalfield, whose eastern limb reveals the 600 m-thick East Lothian volcanic succession (see North Berwick Coast and Garleton Hills GCR site reports). The extrusive sequence is transected to the south by two major volcanic vents at the Lion's Head and the Lion's Haunch. The smaller Lion's Head Vent is cut by the Lion's Haunch Vent. A basaltic plug in the Lion's Head Vent forms the high point, Arthur's Seat.

Within the western confines of Holyrood Park, the sedimentary sequence underlying the volcanic rocks consists of the Ballagan Formation (sandstones, marls, etc.) of the Inverclyde Group. This sequence contains two sills, the Heriot Mount–St Leonard's Sill and the Dasses Sill, which are regarded as contemporaneous with the extrusive activity Approximately midway stratigraphically between these lies the much more prominent Salisbury Craigs Sill, which forms one of the most distinctive landmarks around Edinburgh. Although undated, the Salisbury Craigs Sill may be considerably younger than the igneous features mentioned above. Younger still are some (approximately) E–W-trending dykes that were intruded towards the close of the Carboniferous Period.

Following the Late Palaeozoic Earth movements that gave the easterly dip to the strata beneath Edinburgh, the geological record for the next 250 million years has been lost by erosion. The topography bequeathed to modern-day Edinburgh has been sculpted almost entirely by eastward-flowing ice during the past two million years. Among the most obvious results of this glaciation is the classic crag-and-tail topography exhibited by Castle Rock and the ridge of the 'Royal Mile' to the east (see cover photo, this volume), the steep west-facing escarpments of the Salisbury Craigs Sill and Whinny Hill lavas and their dip-slope tail towards Abbey Hill, and the analogous dip and scarp geomorphology of Calton Hill (see (Figure 2.17)). In each case the steep west-facing escarpments are formed by the igneous rocks, which presented more resistance to the glaciers that differentially eroded the softer sedimentary rocks and fault zones.

The rocks of the Arthur's Seat Volcano have played a major part in the history of geological science. The earliest geological reference appears to have been that of Atkinson in 1619, who mentioned the occurrence of 'Lapis haematite' in Holyrood Park (Clark, 1956). In the late 18th century, James Hutton realized that hot molten rock (magma) had injected sedimentary strata and that Salisbury Craigs represents a sill. Tradition maintains that Hutton used the site at the base of the sill ('Hutton's Section') to demonstrate the intrusive nature of the sill and to refute the widespread belief that 'whinstone' and basalt were marine precipitates as advocated by the popular Neptunist hypothesis. Samples of basaltic rocks from the park were used by Sir James Hall (1805) for the earliest petrological melting experiments. Among the first accounts of the geology of the park are those by Townson (1799), Boue (1820), Maclaren (1834, 1839, 1866) and Howell and Geikie (1861). There was a subsequent burst of scientific interest in the area in the later part of the 19th century which saw publications by Zirkel (1870), Allport (1874), Judd (1875), Bonney (1878), Henderson (1880), Geikie (1880) and Teall (1888). Detailed mapping by the Geological Survey led to the appearance of a revision of Howell and Geikie's 1861 memoir by Peach *et al.* (1910) and the description of the Arthur's Seat Volcano in the memoir was also issued separately in the following year (Peach, 1911). Numerous early 20th century papers include those of Day (1912, 1923, 1933), Campbell (1914), Bailey (1923) and MacGregor (1936), but the definitive accounts that form the basis for most recent descriptions are those of Clark (1956) and Black (1966). Being so accessible, in the centre of a university city, the site must be one of the most popular geological excursion venues in Britain and has featured in all excursion guides to the area (e.g. Cox and Upton in Upton, 1969; Black and Waterston in McAdam and Clarkson, 1986; Land and Cheeney, 2000).

Description

The Arthur's Seat Volcano GCR site includes all the outcrops of Early Carboniferous igneous rocks close to the city centre of Edinburgh, namely Castle Rock, Calton Hill and Holyrood Park; the latter includes Arthur's Seat itself (Figure 2.14). A cross-section of Holyrood Park shows the relationships between many of the individual features of the Arthur's Seat Volcano (Figure 2.15).

Castle Rock [NT 251 735]

The rugged prominence crowned by Edinburgh Castle is composed of a steep-sided basaltic plug, 300 m by 200 m and elongated northwest–south-east in plan (see cover photo, this volume, and (Figure 2.16)). The plug cuts sandstones of the Ballagan Formation and the contact on the south-eastern side is visible from the road at Johnston Terrace. Castle Rock is an essentially homogeneous, fresh basalt ('Dalmeny' type) containing microphenocrysts of abundant olivine and less abundant augite and plagioclase.

Calton Hill [NT 262 742]

The volcanic succession at Calton Hill is bounded on its north-west side by the NE-trending Leith Links Fault and on its southern and south-eastern margins by the Calton Fault and a WSW-trending fault that passes some 90 m north of Holyrood Palace. The succession comprises a number of lavas with subordinate tuffs, all with the regional eastward dip. As with the other two faulted outcrops of volcanic rocks (a) in Holyrood Park and (b) underlying Holyrood Palace, there is a generalized progression with time from relatively primitive basalts through hawaiites ('Markle' type) to more highly differentiated mugearites. Cessation of volcanism was marked by an erosional disconformity followed by a relative sea-level rise and deposition of the Abbey Hill Shale. Basal tuffs to the west of Calton Hill are succeeded by a basalt flow *c.* 30 m thick, overlain by a tuff several metres thick. Above this are three flows ('Markle' type; probably hawaiites) with intervening thin tuff layers. The uppermost of these tuffs forms the summit of the hill on which the old City Observatory stands (Figure 2.17). Overlying this are three highly weathered mugearite flows separated by thin tuffs on the north-eastern dip-slope, which are, in turn, overlain by the Abbey Hill Shale. Three E–W-trending Stephanian quartz-dolerite dykes traversing the northern part of the outcrop mark the youngest igneous events in the Calton Hill fault block.

Holyrood Park [NT 266 733]–[NT 283 731]

At Holyrood Park, as at Calton Hill, volcanism commenced with explosive activity, locally yielding a basal tuff (presently unexposed) immediately beneath the first lava. There have been different opinions concerning the number of lavas in the Whinny Hill succession in the northern area of the park [NT 278 734]. Whilst Peach *et al.* (1910) reckoned that there are 19, Clark (1956) and Black (1966) concluded that there are only 13. Lava 1, approximately 30 m thick, forms a prominent cliff feature referred to as the Long Row [NT 276 735]. It appears to be absent from the Calton Hill succession but crops out again south of the Lion's Haunch Vent in the vicinity of Duddingston Loch [NT 284 725]. Lava 1 is compositionally similar to the basalt that forms the Castle Rock plug, although it is more porphyritic. Succeeding Lava 1 is a 30 m-thick sequence of tuffs and sedimentary rocks constituting 'the Lower Ash of the Dry Dam'. This comprises tuffs, fissile mudstones and a cherty limestone about 1 m thick, regarded as a lagoonal evaporite. The volcaniclastic mudstones and limestone contain plant fragments. At the top of this sequence, a tuff layer heralding the resurgence of volcanism is overlain by a highly por-phyritic but severely altered basalt flow *c.* 8 m thick. This flow (Lava 2, of 'Craiglockhart'-type basalt) contains macrophenocrysts of pseudomorphed olivine, together with augite and plagioclase. The flow is highly amygdaloidal, with the amygdales occupied by calcite, chlorite, haematite and quartz. The long repose period that followed the Lava 1 eruption and permitted deposition of the Dry Dam mudstones and limestone was not repeated and, from here on upwards, the succession is wholly composed of lavas and pyroclastic rocks. The 'Upper Ash of the Dry Dam', overlying Lava 2, is up to 7 m thick and contains fragments of plant and fish fossils.

Lava 3 consists of an (ankaramitic) alkali basalt ('Craiglockhart' type), with an outcrop confined to a restricted zone extending a little over 200 m south from the ruined St Anthony's Chapel [NT 276 738]. This thick (*c.* 30 m) flow shows signs of 'colonnade and entablature' structure; massive columnar jointing in its lower facies gives way above to finer-scale jointing, and the uppermost facies, some 20 m thick, is more blocky with irregular jointing. Whereas the blocks are compositionally similar, they vary in degree of vesicularity, with some blocks evidently having accumulated in a highly scoriaceous condition. Abrupt changes of attitude shown by the jointing in the lower part of the flow, turning from perpendicular to its base to sub-horizontal a few metres above, testifies to a complex cooling history. A small columnar-jointed basaltic plug at Pulpit Rock on the western flank of Whinny Hill may be the source of Lava 3 (Clark, 1956; Black, 1966). Lava 4 (*c.* 8 m thick) is seen to the south of Pulpit Rock, overlying basaltic tuff. It comprises basalt (Dalmeny' type) with abundant small microphenocrysts of fresh olivine. The flow has well-developed columnar jointing and forms the notable escarpment above the eastern flank of the Dry Dam [NT 277 735].

The higher part of the succession consists wholly of lavas. Lavas 5, 6 and 7 form distinct west-facing escarpments around the top of Whinny Hill. These basaltic to hawaiitic lavas ('Jedburgh' type) have microphenocrysts of olivine and plagioclase. They are overlain by lavas 8, 9 and 10, which are distinctly more porphyritic lavas of hawaiitic composition ('Markle' type). Lavas 11 and 12 are platy-jointed mugearites, overlain by Lava 13, a hawaiite of 'Markle' type, petrographically similar to those beneath Lava 11.

To the south of Arthur's Seat, the volcanic succession is seen on the north side of Duddingston Loch. Lava 1 and the Dry Dam volcaniclastic sedimentary layers can be readily correlated with those of Whinny Hill. Above these is a thick, coarse-grained pyroclastic unit in the vicinity of Duddingston village, within which two thin lavas can be discerned. This unit, which has no counterpart in the northern outcrops, is overlain by a series of hawaiitic and mugearitic lavas approximately correlative with lavas 8 to 13 in the Whinny Hill succession.

The lavas, in particular, have been extensively affected by relatively high-temperature hydrothermal alteration. Olivines have been pseudomorphed by calcite, iron-oxides and/or serpentine minerals. Pyroxenes are commonly chloritized and calcic plagioclases have been variously sericitized, albitized or analcitized. Amygdale and vein infillings include chlorite, haematite, calcite, chalcedony and prehnite.

The Crags (or Western) Vent forms an elongate outcrop (*c.* 200 m by 90 m) on the eastern dip-slope above the Salisbury Craigs Sill, close to the 'Camstone' sandstone quarries. It is filled with basaltic clasts, up to 40 cm across, petrographically identical to the basalts of lavas 1 and 2 (Clark, 1956). The clasts include highly amygdaloidal to scoriaceous types representing juvenile material.

The Lion's Head Vent would, prior to truncation by the Lion's Haunch Vent, have been approximately circular in plan, with a diameter of *c.* 300 m. It is filled with pyroclastic breccia, penetrated by a number of basaltic intrusions. The breccia shows crude bedding, defined by variation in clast size and dipping centrally. Clasts, up to *c.* 6 cm across, mainly of basalts similar to those of the lower lavas, are accompanied by scarcer sandstone clasts. A plexus of 'Dalmeny'-type basaltic dykes in the lower exposures coalesces upwards to form a coherent mass in the centre of the vent, now forming the summit of Arthur's Seat. The latter consists of basalt with fairly well-developed, fine-scale columnar jointing.

The cross-cutting Lion's Haunch Vent [NT 275 729] has an ovoid plan, approximately 1200 m north-east–south-west by 500 m northwest–south-east. The vent includes Dunsapie Hill [NT 282 731] in its north-eastern extremity and the basaltic intrusion of Samson's Ribs in the south-west. A WNW–ESE fault, down-throwing to the north, traverses the southwestern part of the vent. The pyroclastic breccia that occupies much of the Lion's Haunch Vent [NT 276 728] is, like that of the Lion's Head Vent, coarsely layered with the bedding dipping towards the vent interior. Much of it is very coarse relative to that of the Lion's Head Vent, with basaltic clasts up to 2 m across (Figure 2.18). Blocks of sandstone, mudstone and limestone are minor components. The breccia differs from that of the Lion's Head Vent in containing fragments of the feldspar-phyric hawaiitic ('Markle' type) lavas. There are several lavas within the vent, whose outcrops are predominantly towards the extreme south-west. Well-bedded sedimentary rocks intercalated between two of these may have been deposited in a crater lake (Black, 1966). A substantial but poorly exposed area between Arthur's Seat and Dunsapie Loch [NT 281 732] is also believed to be underlain by at least three lavas of relatively evolved feldspar-phyric basalt and hawaiite ('Dunsapie' or 'Markle' type).

Three substantial basaltic masses within the Lion's Haunch Vent are regarded as intrusive.

1. The Samson's Ribs mass, intruded along the south-western contact of the vent, shows spectacular columnar jointing. The columns, like those of Pulpit Rock, are curved (Figure 2.19). From the top of the *c.* 30 m-high cliff that forms the north wall of the road west of Duddingston Loch, the SSW-inclined columns steepen as followed down the cliff from *c.* 60° to 75° before turning outwards at much shallower angles to lie almost perpendicular to the rock face. As noted by Black (1966), the lower columns appear to have grown in response to cooling against an almost vertical side-wall whereas the upper portions grew in response to heat loss from a sub-horizontal upper surface.
2. Crow Hill, or the summit area of the Lion's Haunch Vent, consists of a mass of basalt with steep columnar jointing, surrounded by the vent breccia. The relatively fresh basalt ('Dunsapie' type) comprises approximately 30% phenocrysts of olivine, augite, plagioclase and subordinate magnetite in a finer-grained matrix. It is widely used for teaching purposes.
3. The third principal basaltic mass within the Lion's Haunch Vent lies at the north-eastern extremity where it forms Dunsapie Hill (the type locality for 'Dunsapie'-type basalt). It is crudely cylindrical in form and, like the Sampson's Ribs basalt, is thought to have been intruded along the contact zone of the vent, between the pyroclastic breccia and the Whinny Hill lavas.

The Duddingston plug lies outside the Lion's Haunch Vent and cuts the upper Duddingston tuff. It is ovoid in plan (*c.* 250 m across) and consists of olivine-clinopyroxene-felspar-phyric basalt ('Dunsapie' type).

Arthur's Seat Volcano

Sills are a prominent feature of Holyrood Park. The lowest is the Heriot Mount–St Leonard's Sill. This is a composite body some 11 m thick, in which a 7 m-thick 'core' of porphyritic basalt ('Dunsapie' type) is surrounded by an envelope *c.* 2 m thick, of an aphyric hawai-ite; there is a diffuse boundary, *c.* 85 cm wide, between the two varieties (MacGregor, 1936; Clark, 1956; Boyd, 1974).

The Dasses Sill, considerably higher up the sedimentary succession, is a more complex body, possibly consisting of several lenticular bodies, thickest in the south close to the Lion's Head pyroclastic breccia and pinching out northwards towards the St Margaret's Fault. Here too, a composite character has been shown by Oertel (1952) and Rutledge (1952). The compositional contrast is more extreme than in the St Leonard's Sill, involving a change from basalt to benmoreite (Boyd, 1974). The correlation of a section of sill at Girnal Crag [NT 280 726], farther east between the Lion's Haunch Vent and Duddingston Loch, has been contentious. Mitchell and Mykura (1962) considered the Girnal Crag Sill to be a continuation of the St Leonard's Sill, but Boyd (1974) concluded on petrographical grounds that it correlates with the passes Sill.

Another small sill within Holyrood Park that probably accompanied the principal volcanic activity is that on Whinny Hill [NT 278 734]. The Whinny Hill intrusion comprises 'a sill-like mass of Craiglockhart-type basalt' (Black, 1966), traceable for some 300 m and lying between lavas 6 and 7. A smaller body of identical basalt, with oval plan and vertical contacts, lying about 50 m to the west, was regarded by Black (1966) as the probable feeder to this sill.

The Salisbury Craigs Sill, attaining a maximum thickness of *c.* 40 m, presents a commanding feature in the park (Figure 2.20). Lying roughly midway between the Dasses and St Leonard's sills, it thins and cuts out south towards the contact of the Lion's Haunch Vent. Over much of its outcrop the sill is generally conformable with the sedimentary rocks into which it is intruded but it steps down northwards through the strata in the vicinity of the St Margaret's Fault. There are, however, some notable disconformities along the well-exposed lower contact, including the famous 'Hutton's Section', where the magma has prized off a section of the underlying strata in a similar manner to that seen at the South Queensferry to Hound Point GCR site (see GCR site report). Towards its southern end, several thin sheets of hornfelsed sediment are intercalated near its upper surface. The contact with overlying sedimentary rocks is visible towards the north. The sill consists of analcime-dolerite (teschenite), which is coarse grained in the interior but fine grained in its marginal facies. Some large-scale layering in the sill, apparent from variations in the colouring, has never been investigated in detail but probably relates to variations in the modal content of olivine. The dolerite comprises plagioclase, olivine, augite, magnetite, apatite and analcime. Thin veinlets of microsyenite represent late differentiates in the southern part of the sill and there are some veins of haematite up to several centimetres wide, including one that has been preserved from quarrying, known as 'Hutton's Rock'.

Interpretation

The Upper Devonian to Lower Carboniferous sandstones, marls and mudstones of the Edinburgh region are mainly terrestrial clastic deposits laid down in intraplate fluvial, lacustrine and/or lagoonal environments. One may envisage an equatorial lowland terrane whose surface lay close to sea level and in which volcanism commenced at around 340 Ma. At the onset of volcanism, rising magmas encountered either standing water or waterlogged sediments at, or close to, surface level and Surtseyan-type phreatomagmatic eruptions resulted.

At near-surface levels the rising magmas would have reached levels of neutral buoyancy (particularly in the low-density Lower Carboniferous sediments) where they spread laterally as sills. Some batches, however, clearly reached surface level and erupted as small basaltic volcanoes. Initial gas release, largely of steam from heated meteoric water, drilled sub-cylindrical conduits that were followed and enlarged by rising magma. Castle Rock probably originated in this manner; a small cinder cone a few hundred metres high and with an external diameter of about 2 km has been eroded away, but the central plug of basalt remains. It has not been dated. Lava 1 contains quartz xenocrysts mantled by augitic reaction zones, and although such fea tures are rare in the other basalts of the region, they are typical of the Castle Rock basalt. This led Black (1966) to conclude that Lava 1 erupted from the Castle Rock volcano and flowed eastwards. If this is correct, it places activity at Castle Rock as the oldest in the north-eastern part of Edinburgh (although it is probably younger than the lavas at Craiglockhart). Black (1966) suggested, on slender evidence, that Lava 2 flowed from a southerly source within the Lion's Head Vent, whereas Lava 3 is inferred to have been supplied through a subsidiary centre to the north at Pulpit Rock (Clark, 1956; Black, 1966). Since the columnar joints of Lava 3 are presumed to have grown normal to the isothermal surfaces as cooling proceeded, the geometry of these surfaces was subject to continuous change, possibly through the action of percolating water. The blocky and scoriaceous nature of the uppermost part suggests proximity to a vent, and a lava fountain may have played above the columnar-jointed Pulpit Rock Vent. Flow 4 is correlative with the basalt plug occupying the core of the Lion's Head Vent and it was inferred that the lava erupted from this vent and flowed northwards until diverted by a lava cone around the Pulpit Rock Vent (Black, 1966). Lavas 5, 6 and 7, however, probably flowed northwards from the Lion's Haunch Vent (Black, 1966).

Interaction of hot rocks and/or magma with near-surface water would have played a major part in the formation of all the tuffs and pyroclastic breccias of Calton Hill and Holyrood Park. Most of the volcaniclastic rocks appear to show signs of some subaqueous reworking, although those of the Crags, Lion's Head and Lion's Haunch vents may have been largely ash-fall tuffs and scree (talus) deposits within the confines of steep-walled craters. The nature of the thick pyroclastic deposits at Duddingston, however, is scarcely known because of lack of exposure. There is a strong asymmetry in the stratigraphy north and south of the Lion's Haunch Vent, with pyroclastic beds to the south taking the place of the dominant lavas in the north. To explain this, Black (1966) surmised that strong northerly winds were responsible for the concentration of ash-fall deposits on the southern side of the main vents. At its maximum development the volcano may have risen to about 1000 m above sea level, with a cone-base of up to 5 km diameter.

Intrusion of sills is likely to have been instrumental in the episodic inflation of near-surface sedimentary strata, leading to emergence and allowing subaerial weathering and plant growth. Since plant fragments are commonly encountered in the volcaniclastic rocks, we may envisage the volcanic hills as having been forested for long periods between the occasional eruptions. The Dasses, Girnal Crag and St Leonard's sills may have been emplaced very early in the volcanic history 'into soft, pliable sediments' (Oertel, 1952). Subsidence and inundation following Lava 1 allowed deposition of the well-bedded ashes with intercalated lagoonal sediments seen in the lower part of the Dry Dam to the north and the lower part of the lower ash at Duddingston. The plant fragments within the Dry Dam sequence are inferred to have been washed down into shallow waters from the adjacent forested volcano flanks. The Dry Dam volcaniclastic mudstone unit thickens south towards the Lion's Head Vent, which may have been growing at the time through explosive action. The Crags Vent, which was probably surmounted by a basaltic cinder cone approaching 1 km diameter, may have developed fairly early, possibly contributing to the ashes of the Dry Dam (Black, 1966). The whole of the Whinny Hill–Lion's Head–Lion's Haunch area is clearly very shallowly dissected, and the larger basaltic outcrops within the two vents probably had surface expressions as confined lava lakes (cf. Oertel, 1952). Lava 4 may have been a northward overflow from the Lion's Head lava lake.

The Duddingston plug was possibly a feeder conduit for a parasitic basaltic volcano developed at a late stage in the volcanism on the south-eastern flanks of the main edifice. The Edinburgh volcanoes may thus have been distributed along a WNW–ESE lineament, *c.* 2.5 km long, exhibiting a very generalized migration of activity over time from Castle Rock in the WNW to the Duddingston plug in the ESE.

The younger products associated with the Lion's Haunch Vent tended to have more highly fractionated hawaiitic and mugearitic compositions, suggesting that magma ascent rates generally decreased with time, allowing time for fractionation to occur. However, analogous compositions did appear earlier if the surmise is correct that the Dasses, St Leonard's and Girnal Crag sills were early intrusions. The observation that these sills are composite, with more highly fractionated magma having been intruded ahead of more primitive basaltic magmas, suggests that they were fed from compositionally stratified chambers (dykes?) at depth (Boyd, 1974).

Basanitic magma originating from comparatively small-fraction melting, at greater mantle depths than the preceding activity, arose to form the Salisbury Craigs Sill. Although the depth at which the sill was intruded is uncertain, the vesicularity near the upper surface makes it unlikely that it was intruded at much more than a kilometre or two beneath a cover of sedimentary and volcanic rocks. Whilst the layering features could be due to in-situ differentiation they more probably reflect differences in the crystal content of successive magma batches as the sill inflated.

Although the Salisbury Craigs dolerite has not been dated, it may be significantly younger than the volcanic rocks. The principal reasons for so thinking are (a) the observation that it thins towards the main Holyrood Park vents and (b) that it is notably more silica-undersaturated than the other rocks (Peach *et al.,* 1910). It is cut (at 'the Cat's Nick') by a thin (*c.* 1 m) E–W-trending quartz-dolerite dyke of the late Stephanian swarm (see Chapter 6). This dyke provides an upper time limit for the Salisbury Craigs Sill, which is probably of Late Carboniferous age.

Whereas some of the secondary mineralization affecting the igneous rocks probably accompanied hydrothermal activity associated with the volcanism, further modification would have taken place in association with deep burial and deformation during the Variscan Orogeny. The Lower Carboniferous rocks revealed at the surface today would formerly have lain at a depth of several kilometres beneath Upper Carboniferous, Permian and possibly younger formations prior to uplift and erosion.

The rocks described above are still not precisely dated. Several of the fresher intrusive bodies could be dated by Ar-Ar methods. Dating of the Salisbury Craigs Sill, while highly desirable, is likely to present difficulties on account of secondary alteration. There is ample scope for further research within the site, such as a proper petrological investigation of the Salisbury Craigs Sill, for which a continuous drill-core would be desirable, and a modern volcanological study of the various volcaniclastic rocks.

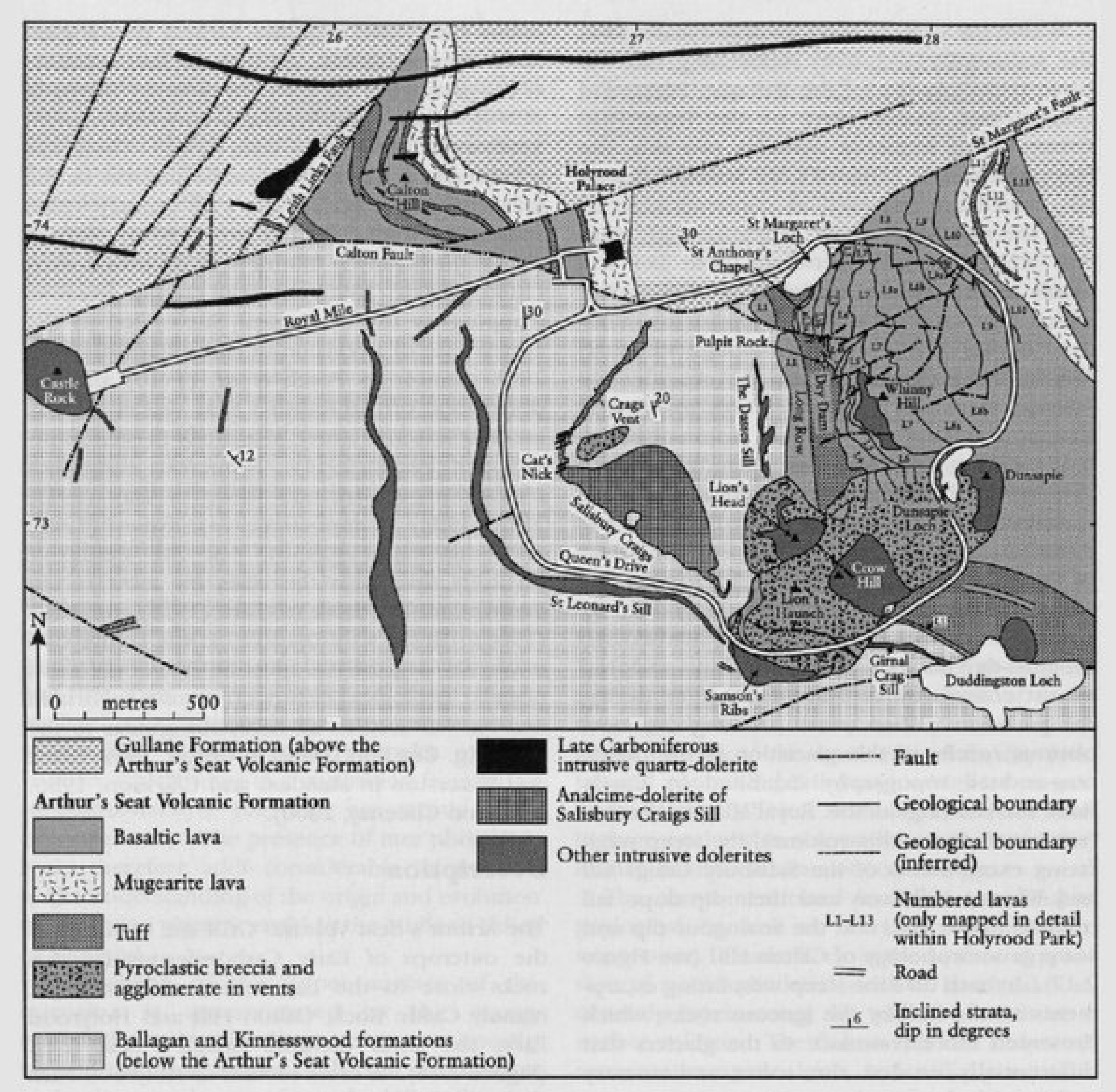
Conclusions

The outcrops of igneous rocks forming the Castle Rock, Calton Hill and much of Holyrood Park constitute one of the prime geological sites in Scotland if not in the whole of Great Britain. The site is representative of (1) early Visean volcanism and (2) the Late Carboniferous suite of alkali dolerite sills in the east of the Midland Valley. The various outcrops of igneous rocks that constitute 'Arthur's Seat Volcano' dominate the landscape of the city and are a vital part of its cultural heritage (the site of the Scottish Parliament is on the edge of the GCR site, as is the architectural World Heritage Site of the 'Old Town'). Splendid examples of many classic volcanic features are easily accessible to the specialist and general public alike, all within the confines of the inner city. These include the lavas and intervening tuffs, penecontemporaneous sedimentary strata, intrusions of various forms (plugs, sills and dykes), as well as volcanic vents infilled with pyroclastic breccia.

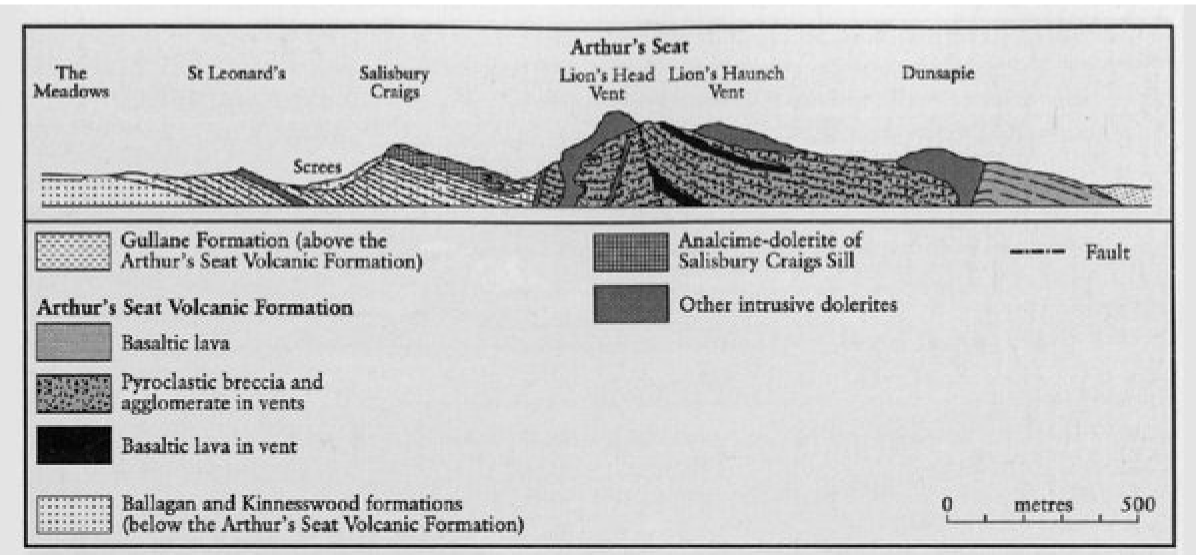
The site has great historical significance in the development of geological science and has played a continuing role in the evolution of ideas on volcanic rocks since the days of Hutton and Hall in the late 18th and early 19th centuries. It is undoubtedly of national importance and, from the worldwide interest that it has generated over two centuries, it can be argued that it is also of international importance. In brief, the value of this site, historically, scientifically and scenically, cannot be over-emphasized.

References

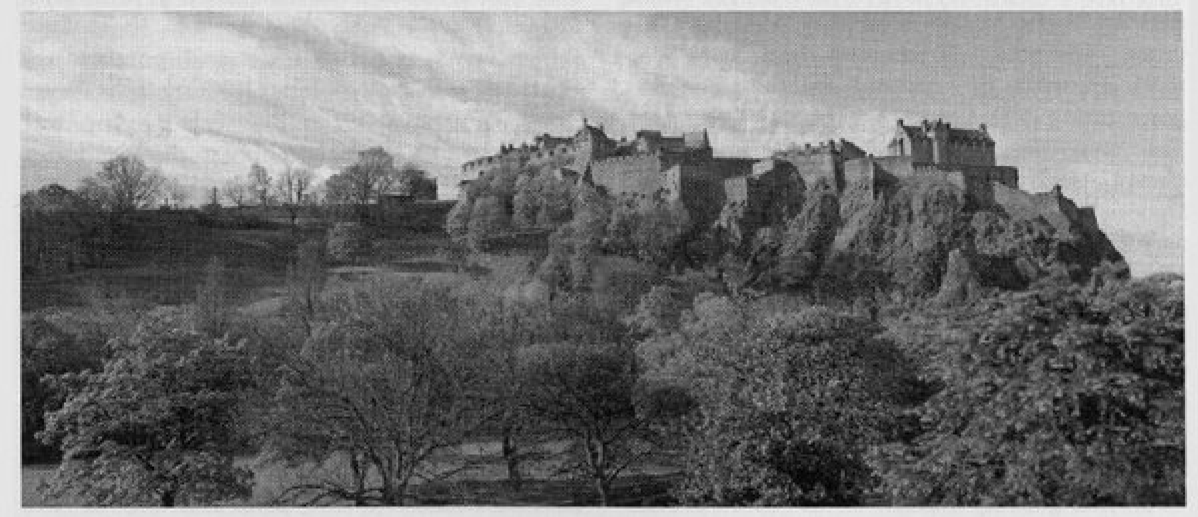
(Figure 2.17) General view across Calton Hill (old observatory and monument on the summit), towards the Arthur's Seat Volcano and the Salisbury Craigs Sill, Edinburgh. (Photo: P Macdonald.)



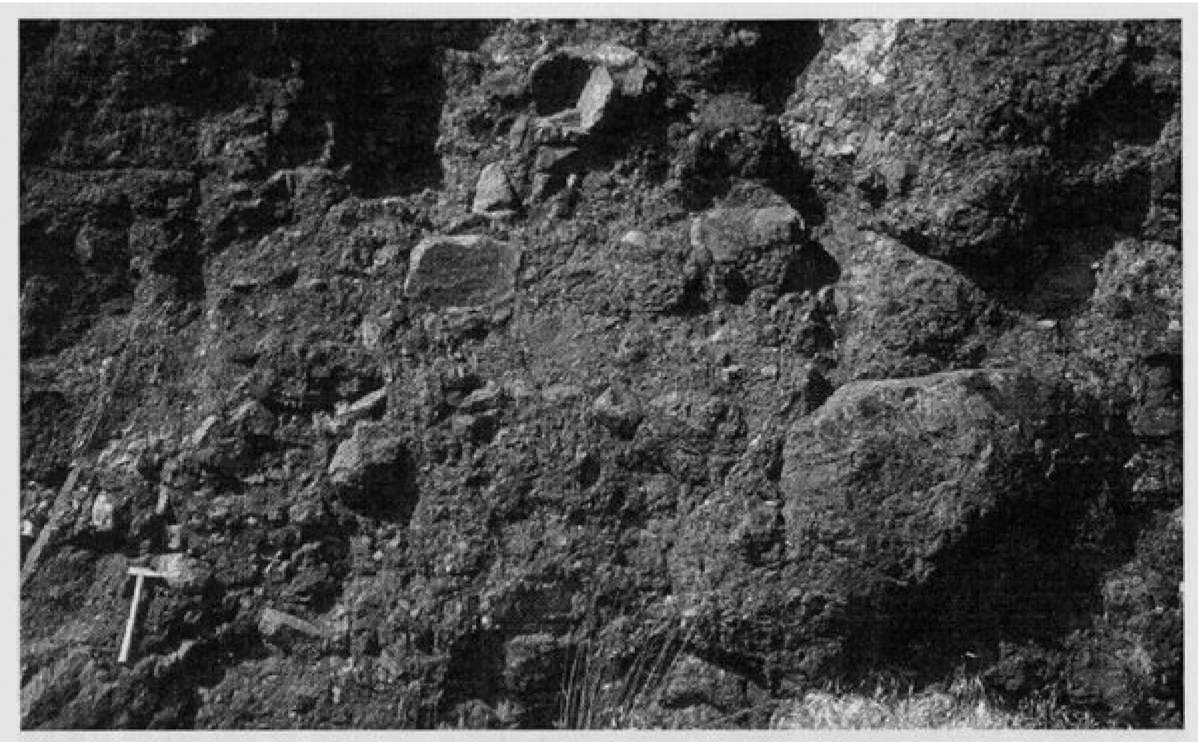
(Figure 2.14) Map of the area around the Arthur's Seat Volcano. After Land and Cheeney (2000); and British Geological Survey 1:10 000 Sheet NT 27 SE (2000).



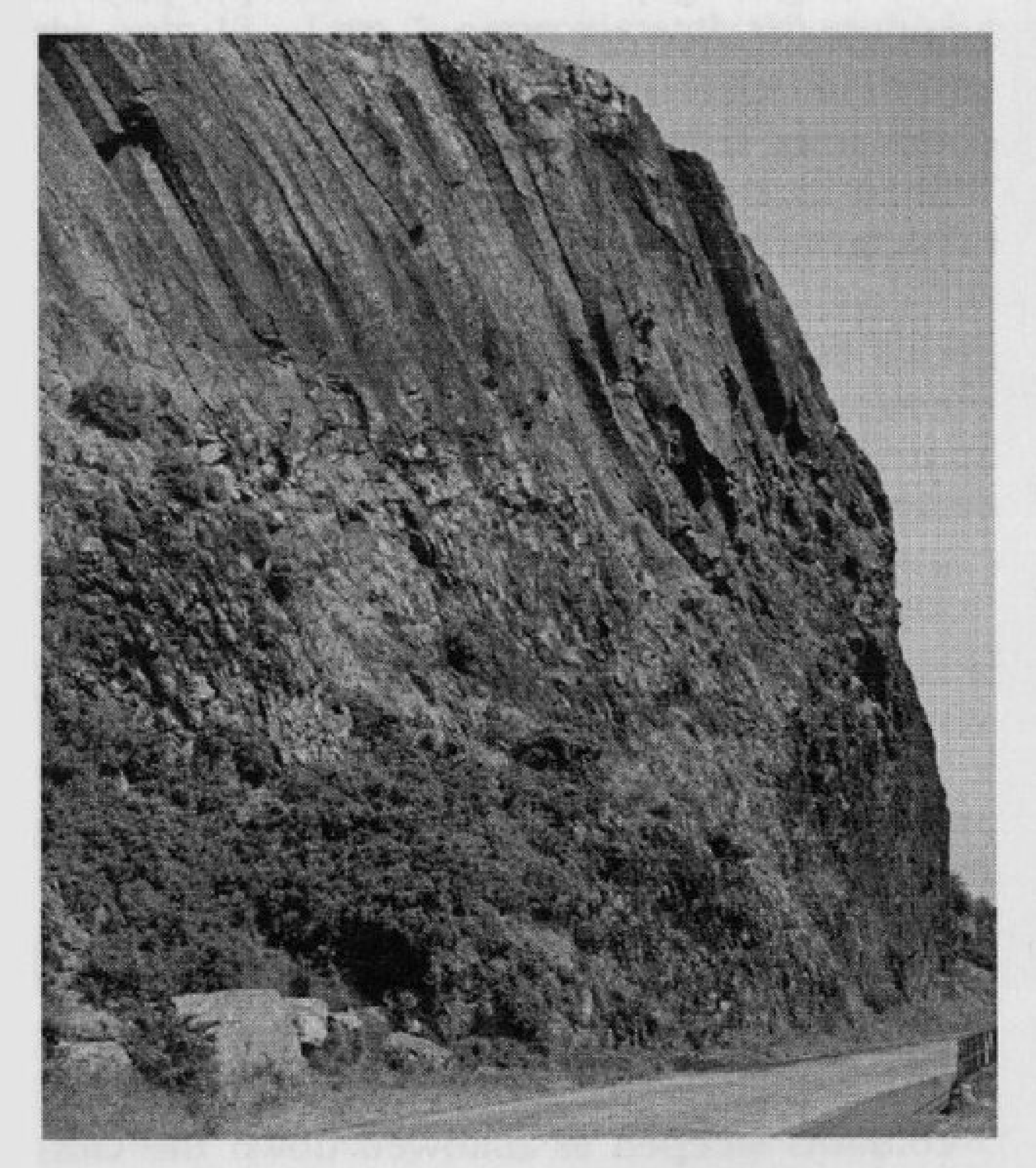
(Figure 2.15) Cross-section of the southern part of Holyrood Park, Edinburgh, passing through the Arthur's Seat Volcano. After Mitchell and Mykura (1962).



(Figure 2.16) Castle Rock from Princes Street Gardens, Edinburgh; a plug of olivine basalt within the Arthur's Seat Volcano GCR site. Note the glacial 'tail' to the left (east), protected by the plug. (Photo: British Geological Survey, No. MNS5624, reproduced with the permission of the Director, British Geological Survey, © NERC.)



(Figure 2.18) Pyroclastic breccias, consisting of blocks of basalt in a matrix of red tuff, Lion's Haunch Vent, Arthur's Seat Volcano GCR site. The hammer shaft is about 35 cm long. (Photo: British Geological Survey, No. D3461, reproduced with the permission of the Director, British Geological Survey, NERC.)



(Figure 2.19) Spectacular columnar jointing of basalt in vent intrusion, Samson's Ribs, Arthur's Seat Volcano GCR site. (Photo: British Geological Survey, No. D3465, reproduced with the permission of the Director, British Geological Survey, © NERC.)

(Figure 2.20) The analcime-dolerite sill of Salisbury Craigs, Arthur's Seat Volcano GCR site. (Photo: British Geological Survey, No. D5403, reproduced with the permission of the Director, British Geological Survey, © NERC.)