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The Geology of Castle Rock, Johnstone Terrace, Edinburgh

Geology and Landscape Scotland Programme

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The Geology of Castle Rock, Johnstone Terrace, Edinburgh

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Castle Rock section above Johnston Terrace, Edinburgh

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Foreword

This commissioned report is the published product of a study by the British Geological Survey (BGS) to describe a geological section of Castle Rock, Johnston Terrace, Edinburgh, Castle Rock is a Site of Special Scientific Interest (SSSI) and a Geological Conservation Review (GCR) Site. This report was commissioned by Scottish Natural Heritage (SNH) in conjunction with Historic Scotland (HS), in advance of some work to stabilise part of the section and so partly obscure it.

Acknowledgements

Staff from Historic Scotland, especially Ian Armstrong and Stewart Mackenzie, are thanked for facilitating access to the section and rope supervisor Stuart Hogarth and his assistant Chris Ross are thanked for their assistance to the authors for roped access to the site.

Tim Kearsey, David Millward and Mike Browne (BGS) are thanked for discussions and insights into the Ballagan Formation. Professor John Underhill (University of Edinburgh) is thanked for discussions concerning faulting.

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FIGURES

Summary

This report describes the geology of the section of Castle Rock, Johnston Terrace, Edinburgh. Castle Rock is a classic ‘crag-and-tail’ feature, of which Edinburgh Castle sits on the ‘crag’ whilst the Royal Mile has been built on the ‘tail’. The site comprises basalt as part of a suite of igneous rocks related to Arthur’s Seat Volcano and a series of strata sandstone/calcareous mudstone strata of the Ballagan Formation (Lower Carboniferous). The section studied displays the contact between the basalt on which Edinburgh Castle sits and the sandstone/mudstone strata on which the Royal Mile rests. The report particularly highlights the extent to which this contact and the adjacent sedimentary strata are faulted.

1 Introduction

Castle Rock is a very prominent landmark in Edinburgh, crowned by Edinburgh Castle, which is managed by Historic Scotland. Castle Rock is a Site of Specific Scientific Interest (SSSI) and a Geological Conservation Review (GCR) Site, see Upton (2003). To prevent damage by rock fall, a small section of netting is planned to be constructed on the south-east side of Castle Rock, overlooking Johnston terrace (Fairhurst, 2012; Historic Scotland, 2012). The site being part of an SSSI, Scottish Natural Heritage has stipulated that prior to the installation of the mesh, the area to be affected should be accurately logged and recorded photographically, and the information archived by the British Geological Survey, as netting may prevent detailed logging once installed (Letter SNH to BGS, SNH ref: SIT/SSSI/91/NOT/TEN, DATED 7 June 2012).

The site has no public access, but overlooks Johnston Terrace. Access, using ropes, was arranged and organised by Historic Scotland. The section to be netted, as well as the wider outcrop, was logged by Maarten Krabbendam and Eileen Callaghan on March 1st 2013.

The GCR site is described by Upton (2003) but the description makes no mention of the fault described below. Further background to the geology of Edinburgh can be found in McAdam and Clarkson (1996) and Clarkson and Upton (2006).

Note that all orientations of planar surfaces (e.g. 250/80W) use azimuth/dip.

1.1 GEOLOGICAL SETTING

Castle Rock is a very prominent landmark in Edinburgh, crowned by Edinburgh Castle. The hill measures some 300 by 200 m and is about 40–50 m high. Castle Rock is steep-sided on all but the eastern side and forms part of a classic ‘crag-and-tail’ landform, an elongate landform formed by west-to-east ice flow during the Pleistocene (Sissons, 1971). The crag is formed by the basalt of Castle Rock itself, whereas the tail underlies the Royal Mile and comprises sandstone and calcareous mudstone of the Ballagan Formation.

The Ballagan Formation is of Tournaisian (Courceyan, c. 350 myr old) age and part of the Inverclyde Group, the oldest Carboniferous rocks in Scotland (e.g. Read et al., 2002).

Castle Rock itself is composed of basalt, and most likely represents the remnants of a conduit (or plug) of a volcano, probably broadly coeval with Arthur’s Seat volcano (Upton, 2003). Castle Rock and Arthur’s Seat Volcano form part of a wider group of intrusive igneous and volcanic rocks that formed during an intense period of volcanism during the Visean (c. 340 myr old).

2 Geological Description of Section

The studied section occurs on the south-east side of Edinburgh Castle, just underneath Half Moon Battery, and overlooking Johnston Terrace (Figure 1a). The west side of the section is basalt, forming the bulk of Castle Rock (Figure 1b & c). The contact against the Ballagan Formation is a sharp, subvertical fault. Some 50 m east of the contact, the Ballagan Formation beds dip gently to the east (Figure 2a & b). As the contact is approached, the strata dip firstly gently to the west, but within c. 10 m of the contact they become subvertical and are cut by an anastomosing network of subsidiary faults, typically following vertical strata of mudstone separating blocks of sandstone. This subvertical network of faults appears to influence the instability of the slope.

The area of netting is in a layered sequence of mudstone and sandstone, just to the east of the fault (Figure 2a & b). The area to be netted represents relatively undisturbed sequence of Ballagan Formation (Figure 3).

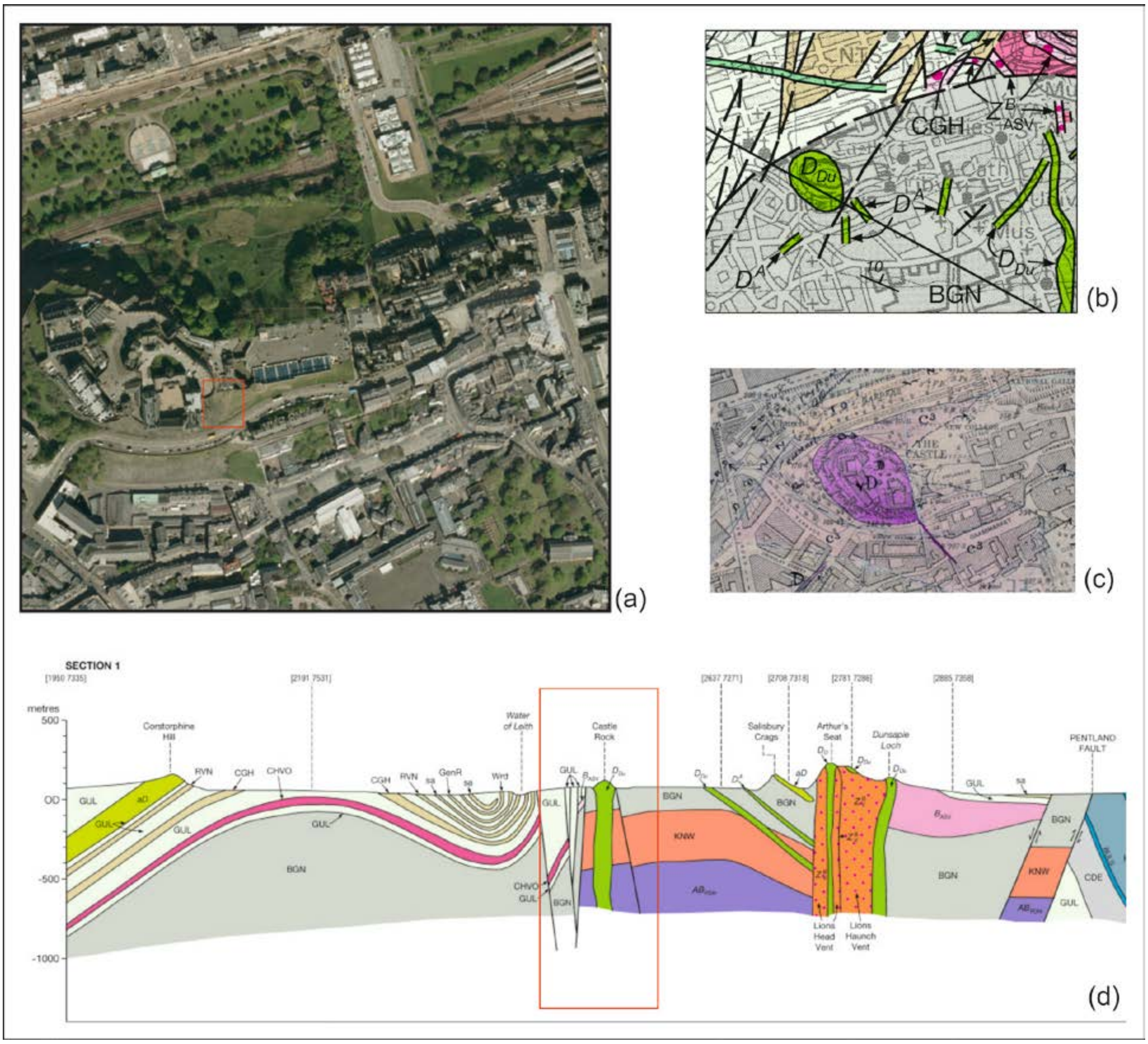

Figure 1: Overview of geological setting of Castle Rock. (a) Airphoto with area of interest highlighted. RGB Aerial Photography – ©GeoPerspectives. (b) Geological map showing outline of Castle Rock intrusion, surrounded by Ballagan Formation (BGN), extract from 1:50K, Sheet 32E, (British Geological Survey, 2003). (c) Detail from geological map (clean copy), 1857,

showing Castle Rock intrusion and fault. (d) Geological cross-section, showing vertical nature of Castle Rock intrusion as a volcanic plug as well as Arthur's Seat Volcano, intruding Lower Carboniferous formations. GUL = Gullane Formation; BGN = Ballagan Formation; KNW = Kinnesswood Formation; ABPDH = volcanic rocks of the Pentland Hills Volcanic Formation (Devonian). Extract from 1:50K, Sheet 32E (British Geological Survey, 2003).

2.1 LITHOLOGY

2.1.1 Basalt – Lower Carboniferous intrusive igneous rocks

The basalt is black to black-green, fine grained, homogeneous and generally massive. Vesicles (empty gas bubbles) up to 4–5 mm across were observed close to the (faulted) contact, which indicates relatively shallow intrusion, (Figure 2a, Point **A**) (Appendix Figure 5), According to Upton (2003), the basalt contains microphenocrysts of olivine, augite and plagioclase. Joint spacing is in the order of 10–30 cm, in an irregular or blocky network – no columnar jointing was observed on this side of the Castle. Some fracture cleavage development occurs close to the main fault (Figure 2a and b; Point **B**) (Appendix Figure 6).

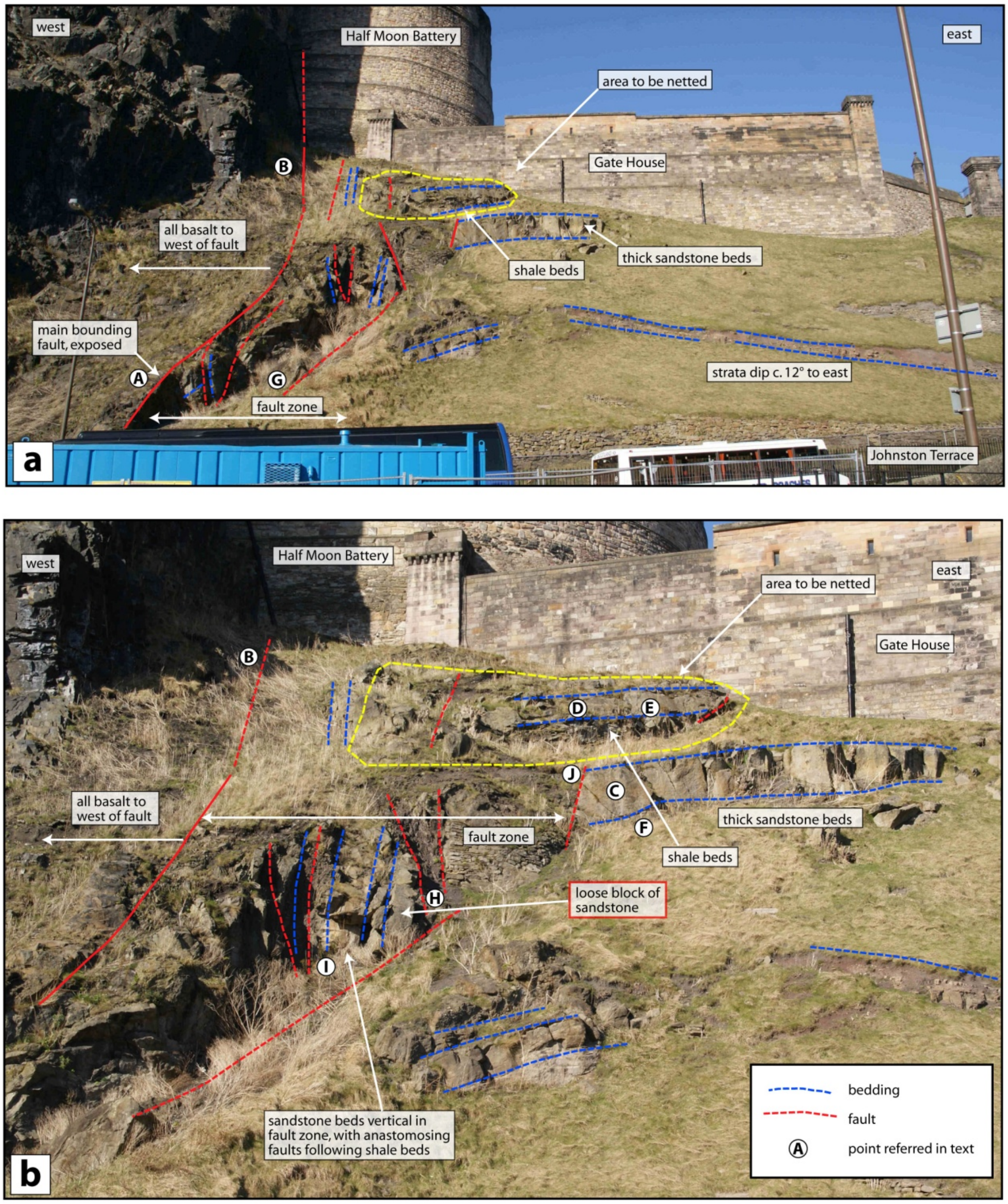

Figure 2 (a) Overview of section above Johnston Terrace, annotated with geology. (b) Detail of upper part of studied section. Approximate area to be netted is outlined in yellow.

2.1.2 Ballagan Formation – Lower Carboniferous sedimentary rocks

The Ballagan Formation comprises a sequence of sandstone and mudstone beds, alternating on a 1–4 m scale. A log of the upper part of the section, including the part to be netted, is shown in Figure 3.

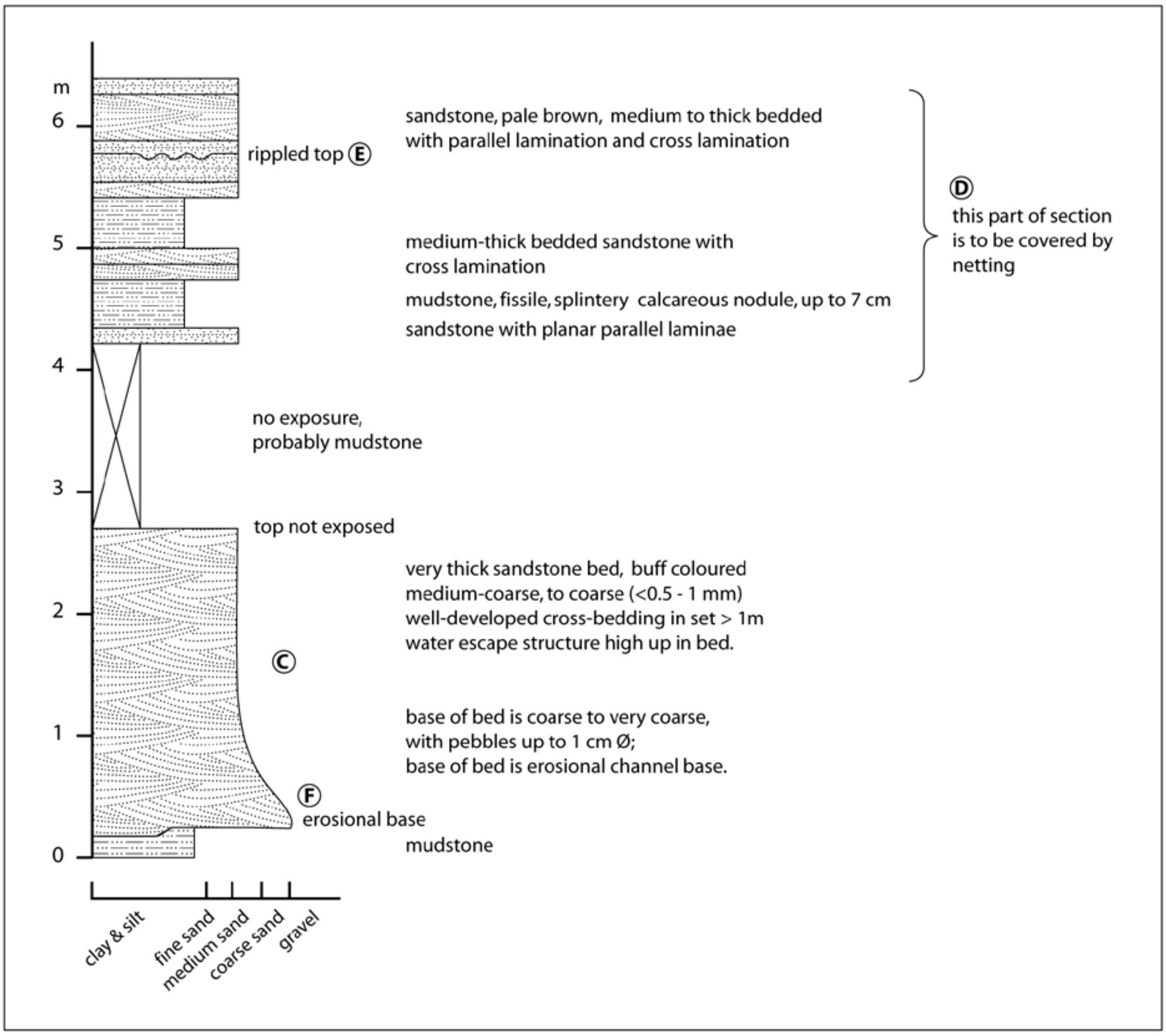

Figure 3: Sedimentary log of part of the Ballagan Formation.

2.1.2.1 Sandstone

The sandstone intervals are typically 2–3 m thick, in beds 30–100 cm thick, rarely up to 250 cm (see log on Figure 3, and Appendix Figures 7–11 for outcrop photos). The sandstone is buff in colour and mostly fine to medium grained, with sub-angular to rounded, clear quartz grains. One of the thicker beds (Figure 2b, Point **C**) shows a clear fining upwards sequence with a gravelly base (clasts up to c. 1 cm across) in a matrix of coarse sandstone, fining upwards to medium-coarse at the top (Figure 3, Appendix Figures 10 and 11). Laminations occur at cm. spacing. Many beds show cross-bedding (Appendix Figures 7, 8, 10) whilst thinner beds may show parallel planar lamination at mm scale. Further sedimentary structures include

- probable water escape structures in thick beds only (Appendix Figure 9 and Figure 2b, Point **D**);
- a wavy base to one bed, probably flow ripples on the top of the underlying bed (Appendix Figure 10 and Figure 2b, Point **E**);
- the thickest bed observed has a clear erosional base, cutting about 50 cm into the underlying mudstone, indicative of channelling (Appendix Figures 11, 12 and Figure 2b, Point **F**). This contains a basal lag of angular to sub-rounded pebbles, which include pale grey clasts probably of 'cementstone' and hard, dark clasts, which are possibly of basaltic volcanic rock

Lower down in the studied section a bed of sandstone has been tilted (it appears to be loose) and its upper bedding plane is exposed (Figure 2a, Point **G**). This bedding plane shows a very irregular, knobbly surface, with 'bumps' typically 4–5 cm across (Appendix Figures 13 and 14). The origin of this irregular surface is somewhat enigmatic. One possibility is a dissolution feature, possibly developed during diagenesis. Another possibility is that a calcitic vein network existed, but disappeared by solution.

Further outcrops of buff sandstone beds, c. 50 cm thick and with obvious laminations and cross-bedding occurs further eastward below the Esplanade; these dip gently to the east.

2.1.2.2 Mudstone

The mudstone is grey, reddish to green-grey, and thin to medium bedded (2–30 cm). These colours are indicative of pedogenic (soil-forming) alteration of the mudstone. Much of the mudstone is highly fractured, obscuring many sedimentary structures. Calcareous nodules occur widely and are typically 3–7 cm across. These are likely to be pedogenic nodules which form in soils in arid to semi-arid environments. This along with the colouration suggests this mudstone is a palaeosol (fossil-soil.) In some beds they are rare, in others abundant (Appendix, Figure 15).

2.2 STRUCTURE: FAULTING

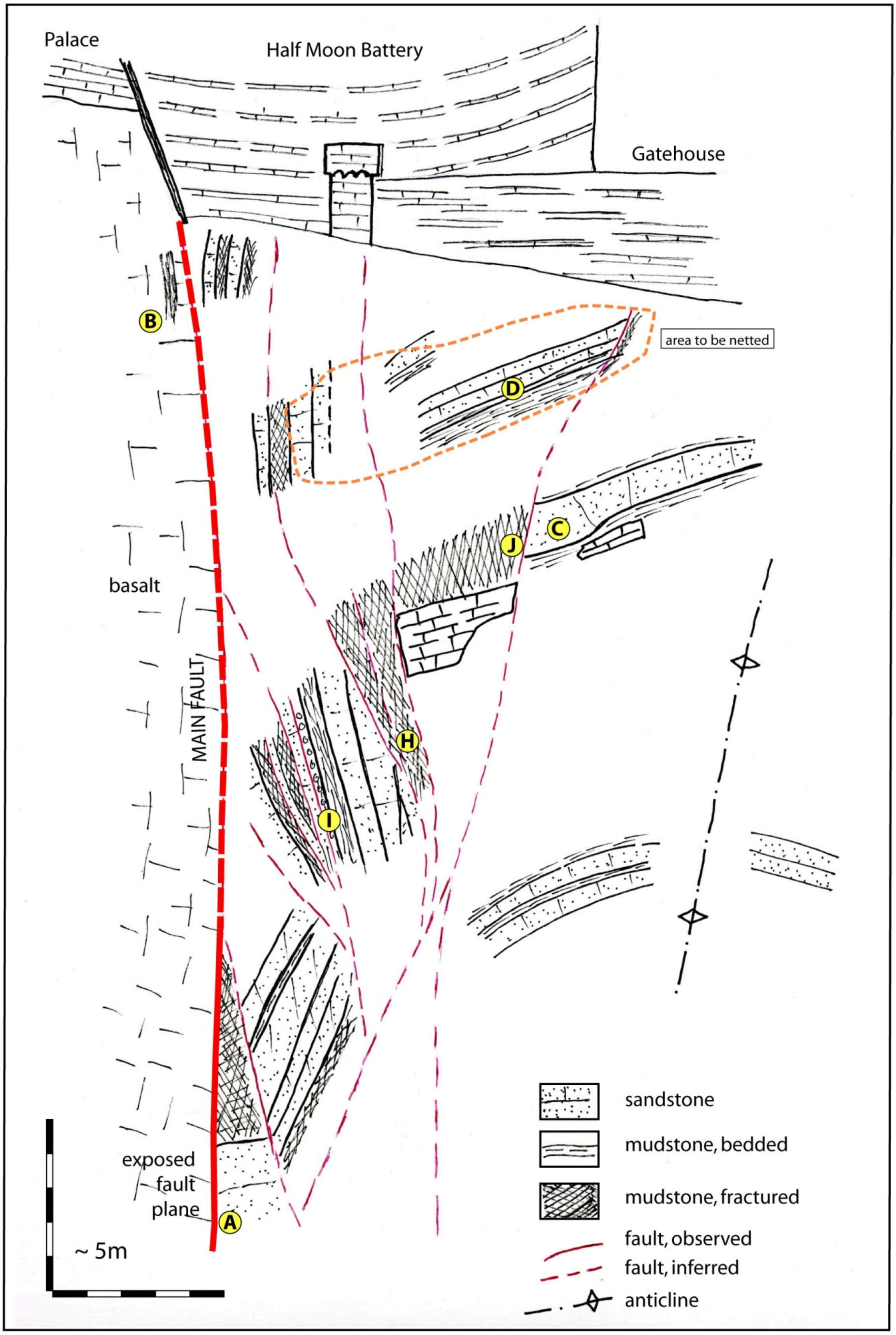

Figure 4: Sketch diagram showing overview of fault zone.

2.2.1 Overall structure

A schematic overview of the structure is given in Figure 4. Ballagan Formation strata below the Esplanade, well away from the contact, dip gently to the north-east (060/12E). Within c. 50 m of the contact with the Castle Hill intrusion, the strata are folded over in an open anticline and dip gently to the west (258/25W). Within 10–20 m of the contact, the strata become highly disrupted and are rotated into vertical orientations. Subvertical beds of mudstone become highly fractured and are interpreted to have behaved as faults. The contact of the Ballagan Formation with the Castle Hill intrusion is a planar, sharp subvertical fault.

2.2.2 Main fault

The main contact between the Castle Rock basalt intrusion and the Ballagan Formation is a planar, subvertical fault. A fault scarp is exceptionally well exposed at the base of the outcrop (Figure 2a, Point **A**) (fault plane 282/85 W). This fault plane shows very well developed fault grooves (coarse fault striations) 1–4 cm wide and 0.5–1 cm deep, plunging at 350/68 (Appendix Figure 16, 17). These fault grooves probably indicate the main fault movement, which is thus subvertical. The main fault rises up and runs towards the western end of Half Moon Battery (Figure 2, 4). Just below the wall, the fault is not exposed, but the basalt shows a 1 cm spaced fracture cleavage (orientation 340/90) over a 20 cm wide zone (Figure 2a, Point **B**; Appendix, Figure 6).

2.2.3 Anastomosing fault zone

East of the main fault, a 10–15 m wide zone is occupied by an anastomosing (branching) network of faults in mudstone and sandstone (Figures 2, 4). Within this zone, strata are rotated vertically, and subvertical zones of mudstone are highly fractured, with bedding features commonly destroyed (Appendix Figures 18, 19, 20 and Figure 2b, Point **H**). A subvertical fracture cleavage has developed in these zones (Appendix Figure 20). These zones of fractured mudstone are inferred host faults, separating metre-scale lozenge-shaped fragments of more intact sandstone and mudstone (Figure 18, Figure 2b, point **I**). Where exposed, the eastern limit of the fault zone is a sharp fault (340/90) of fragmented, fractured mudstone against coherent sandstone (Appendix, Figure 19 and Figure 2b, Point **J**). On one fault surface, developed between a sandstone and a mudstone bed, slickenlines are developed on a thin bedding-parallel calcite vein (Appendix, Figure 21 and Figure 2b, near point **I**). These slickenlines are subhorizontal (132/05), showing that at least some subhorizontal, strike-slip movement has occurred along the fault zone.

3 Conclusions

Castle Rock itself is a very good, clear and well-exposed example of a volcanic plug, in a prominent position in Edinburgh, a city with a strong heritage in terms of the development of the history of geology. Together with Arthur's Seat Volcano, they clearly show volcanic activity in the geological past. In the GCR description (Upton 2003) no mention was made of the faulted nature of the eastern contact of Castle Rock intrusion: this is now rectified in this report. Fault zones are commonly poorly exposed, as they erode easily and covered in younger deposits or soil. The fault zone as exposed above Johnston terrace, therefore, is an important site. The exposure of a grooved fault plane at the base of the section is particularly special, as few such grooved fault planes are exposed in Scotland, let alone in such a prominent position. Fortunately, the grooved fault plane is not to be netted, and is well visible from Johnston Terrace.

Appendix

Figure 5: Basalt within 50 cm of faulted contact, note vesicles and lack of damage (fractures). ©NERC BGS Photograph P815478

Figure 6: Basalt; main fault just off photo to the right. Narrow zone of fault-parallel fracture cleavage. Scale bar 50 cm long with 10 cm intervals; viewed towards the north. ©NERC BGS Photograph P815486

Figure 7: Top of section, this is part of area to be netted. Sandstone and mudstone beds of Ballagan Formation. Scale bar 50 cm long with 10 cm intervals; viewed towards the north-west. ©NERC BGS Photograph P815431

Figure 8: Sandstone bed with cross-bedding. Hammer is 33 cm long, view to north-north-west. ©NERC BGS Photograph P815438

Figure 9: Sandstone bed with cross-bedding with possible water escape structures. Bed c.1.8 m thick. Scale bar 50 cm long with 10 cm intervals; viewed towards the north-west. ©NERC BGS Photograph P815450

Figure 10: Bedding plane between two sandstone beds. Wavy bed probably wave or flow ripples filled in by upper bed. Hammer head is 11 cm long, view to north-north-west. ©NERC BGS Photograph P815436

Figure 11: Sandstone bed (c.2m thick) with cross-bedding and erosional, channelized base. Pebbly at base (see Figure 13). Granulation seams (‘deformation bands’) are visible on the left-hand side of the photo and may be related to overall faulting. Scale bar 50 cm long with 10 cm intervals; viewed towards the north-west. ©NERC BGS Photograph P815452.

Figure 12: Detail of base of erosional channel in sandstone (c. 2 m thick). Pale grey pebbles are derived from calcareous nodules; black clasts are probably volcanic in origin. Scale bar has 10 cm intervals. ©NERC BGS Photograph P815453

Figure 13: Bedding plane: top of sandstone bed (tilted block). ©NERC BGS Photograph P815482

Figure 14: Top-bedding plane of sandstone bed (see Figure 13):`Irregular, knobbly surface of enigmatic origin, possibly calcareous or siliceous nodules. ©NERC BGS Photograph P815483

Figure 15: Subvertical beds of mudstone and sandstone (left), younging to the left. Mudstone layer rich in calcareous, pedogenic nodules, left of hammer. Hammer head is 11 cm long, view to north-north-west. ©NERC BGS Photograph P815461

Figure 16: Main fault plane exposed at base of section. Basalt. Fault plane marked by steep fault grooves, c. 1 cm deep. Scale bar 50 cm long with 10 cm intervals; viewed towards the north-west. ©NERC BGS Photograph P815474

Figure 17: Main fault plane exposed at base of section. Basalt to the left and sandstone/mudstone to the right. Fault plane marked by steep deep grooves. (see Figure 17). View to the north. ©NERC BGS Photograph P815480

Figure 18: Centre of fault zone. Mudstone and sandstone strata turned vertically. Bedding features preserved in central mudstone bed, but mudstone beds to the left are densely fractured and form subsidiary fault zones. Scale bar 50 cm long with 10 cm intervals; viewed towards the north-north-west. ©NERC BGS Photograph P815459

Figure 19: Fault on east side of fault zone. Sandstone bed to the right with densely fractured mudstone to the left. Fault plane just to the right of the hammer. Hammer is 33 cm long, view to the north. ©NERC BGS Photograph P815454

Figure 20: Fault within fault zone. Mudstone strata turned vertically and densely fractured with subvertical fracture cleavage. Retaining wall to the right. Scale bar 50 cm long with 10 cm intervals; viewed towards the north. ©NERC BGS Photograph P815456

Figure 21: Slickenlines on bedding - parallel calcite vein at (stratigraphic) base of sandstone bed, now subvertical. Suggests a component of subhorizontal movement. ©NERC BGS Photograph P815467

Glossary

anastomosing	forming a branching network
calcareous	composed mainly of calcium carbonate
crag and tail	a feature formed by glacial action, a ridge comprising a hill of resistant rock and and tail of softer rock
cross-bedding	gently dipping laminations within a sedimentary bed, indicating deposition by flowing water
diagenesis	any chemical, physical or biological change undergone by a sediment after its deposition
fracture cleavage	a cleavage defined by closely packed fractures
microphenocrysts	very small crystals in a fine-grained igneous rock
slickenlines	the individual streaks and grooves on a fault plane
younging	the direction in which strata become stratigraphically younger