CR/18/008; Final 0.1

A review of the style and performance of traditional and new setted streets in Edinburgh

Minerals and Waste Programme

Commissioned Report CR/18/008

CR/18/008; Final 0.1

BRITISH GEOLOGICAL SURVEY

MINERALS AND WASTE PROGRAMME

COMMISSIONED REPORT CR/18/008

A review of the style and performance of traditional and new setted streets in Edinburgh

Martin Gillespie and Paul Everett

Keywords

Report; setts; setted street; traditional; new; modern; performance; guidance; specification; Edinburgh.

Front cover

Traditional (left) and recently created (right) setted street style in Edinburgh.

Bibliographical reference

GILLESPIE, M R AND EVERETT, P A 2018. A review of the style and performance of traditional and new setted streets in Edinburgh. *British Geological Survey Commissioned Report*, CR/18/008. 43pp.

Keyworth, Nottingham British Geological Survey 2018

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Environmental Science Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

The Lyell Centre, Research Avenue South, Edinburgh EH14 4AP

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Cardiff University, Main Building, Park Place, Cardiff CF10 3AT

Tel 029 2167 4280 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Department of Enterprise, Trade & Investment, Dundonald House, Upper Newtownards Road, Ballymiscaw, Belfast, BT4 3SB

Tel 028 9038 8462 Fax 028 9038 8461
www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Contents

FIGURES

TABLES

Summary

Historic Environment Scotland and Edinburgh World Heritage Trust have commissioned BGS to conduct a review of setted streets in Edinburgh, with a particular focus on (i) the attributes of traditional setts and setted streets, and (ii) performance aspects of modern setts and setted streets. This report presents the outcomes of that review. The report will inform updated ‘street design guidance’ and a revised strategy for setted streets being prepared by City of Edinburgh Council.

1 Introduction

Stone setts were used to form new carriageway surfaces in Edinburgh for several centuries, and setted streets consequently are a key component of 'traditional' Edinburgh streetscape. However, during the twentieth century many setted street surfaces were concealed beneath, or replaced by, modern road-forming materials (mainly tarmac), leading to a gradual loss of traditional street character in the city.

Today, City of Edinburgh Council (CEC), Edinburgh World Heritage Trust (EWHT) and Historic Environment Scotland (HES) all take the view that setted streets are an important part of the traditional / historical environment in Edinburgh, and should be retained where possible and re-instated where practicable. This is particularly the case in the central part of the city that is designated a UNESCO World Heritage site (*Old and New Towns of Edinburgh World Heritage Site*). CEC therefore wishes to review and update its current 'street design guidance' for setted streets, and develop a revised strategy for setted streets.

A key goal for CEC is to ensure that newly formed setted streets, and historical setted streets that are repaired, are as far as possible 'in keeping' with the traditional style. However, lack of clarity about what constitutes an authentic 'traditional style' for setted streets means it is not clear if this goal is being achieved.

Another goal is to ensure that the practical implications of using setted streets (instead of tarmac) are taken into consideration in the new guidance and revised strategy. These include cost-effectiveness; setted street surfaces are expensive to create (compared to tarmac), so demonstrating that they can be cost effective (requiring minimal maintenance) over long periods is important.

Imported stone has been used almost exclusively in recent decades to form new setted streets (because, unlike Scottish stone, it is readily available as prepared setts and blocks, and is relatively cheap). However, the extent to which streets formed of imported stone can be visually 'in keeping' with traditional streets, and whether imported stone will perform as it should over the expected lifespan of a new setted street, are not well understood and need to be evaluated.

With these goals in mind, HES and EWHT have commissioned BGS to conduct a review of setted streets in Edinburgh with a particular focus on (i) the attributes of traditional setts and setted streets, and (ii) performance aspects of modern setts and setted streets. This report, which describes the outcomes of the review, will inform the updated guidance and strategy being prepared by CEC.

The report is organised as follows.

- A short review of the geological background to setts – describing the geological properties that underpin sett performance and introducing some of the terminology that features later in the report – is presented in section 2.
- The terms used to refer to the different components of setted streets are described in section 3.
- The key attributes of traditional setted streets in Edinburgh are described in section 4. The information in section 4 is based very largely on *Setts in the City*, an unpublished report compiled in 2004 by EWHT (with input from BGS).
- A list of proposed attributes that new setted streets should display in order to be 'in keeping' with the traditional style is presented in section 5; the list is based largely on information in section 4.
- An assessment of how well recently created areas of setted street replicate the traditional style, based on examination of five sites in central Edinburgh, is presented in section 6.
- The same five sites form the subject of an evaluation of the performance of recently created areas of setted street, which is described in section 7.
- Key performance indicators for setted streets, and details of the various tests that can be used to evaluate performance, are described in section 8.
- The report concludes with a brief summary of key conclusions and recommendations.

2 Geological background to setts

There are many different types of rock, and each has a set of attributes (e.g. hardness, durability, propensity to split, permeability, colour) that make it more or less suited to a range of uses in the built environment. Over time, people have learned to select and use different rock types for different purposes, such as walling, roofing, paving and decorative objects, according to their attributes. In this section we briefly review the geological background to setts and introduce some of the geological concepts and terminology that appear later in the report.

2.1 THE MAIN ROCK CLASSES AND THEIR GEOLOGICAL ATTRIBUTES

Virtually all rocks can be divided into three main classes.

- *Igneous rocks* form by solidification of magma (molten rock). Magma can solidify below the ground surface (forming intrusions) or it can erupt into the air or onto the ground (forming pyroclastic deposits and lava flows, respectively). Common types of igneous rock include *granite* and *gabbro* (which always occur as intrusions), and *basalt* and *andesite* (which commonly are erupted, but can form intrusions).
- *Sedimentary rocks* form when layers of particulate matter (e.g. sand, mud, gravel) accumulate on the ground or on the sea floor and are then buried to considerable depth where heat and pressure combine to convert them into rock. Common types of sedimentary rock include *sandstone*, *conglomerate*, *siltstone* and *limestone*.
- *Metamorphic rocks* are former igneous rocks and sedimentary rocks that have been subjected to high temperature and pressure within Earth's crust, such that their mineral and textural character changes and in effect they become new rocks. Common types of metamorphic rock include *gneiss*, *schist* and *slate*.

Metamorphic rocks and most igneous rocks are *crystalline* (formed entirely of tightly interlocking crystals), whereas most sedimentary rocks are *granular* (formed of loosely to tightly packed grains, typically with pore spaces between them). In general, granular rocks are more permeable, less cohesive, and less durable than crystalline rocks.

Any rock used to form setts must be very durable and not prone to parting along planes of weakness. Most sedimentary rocks are not particularly durable, and many have a tendency to part along the boundaries between layers of deposited matter. Some metamorphic rocks are not particularly durable and display a tendency to part, while others are very durable and lack planes of weakness; however, the most durable metamorphic rocks in general are restricted to remote, thinly populated parts of Scotland and as such have not been quarried for building purposes. By contrast, igneous rocks in general are very durable (being hard, dense and essentially impermeable), not prone to parting, and are common throughout Scotland. For these reasons, virtually all setts in Edinburgh and elsewhere in Scotland consist of igneous rock. The remaining information in this section therefore focusses on igneous rocks.

2.2 TYPES OF IGNEOUS ROCK

Igneous rocks are classified and named according to two criteria: the minerals they contain and their grain-size (i.e. the typical size of the constituent crystals).

- The mineral assemblage of an igneous rock is determined by the chemical composition of the magma. *Silica* (silicon dioxide or SiO_2) is the main constituent in all magmas, and therefore plays a key role in controlling the mineral content of igneous rocks. For example, the mineral *quartz* will only crystallise from a *silica-rich* magma, and the mineral *olivine* will only crystallise from a *silica-poor* magma. Most igneous rocks contain around ten different minerals, though the bulk (>90%) of each rock usually is formed of only three or four minerals. *Feldspar* is the commonest mineral, and is the dominant constituent in virtually all igneous rocks.

- The grain-size of an igneous rock is determined by the rate at which the magma cooled and solidified. Coarse-grained rocks (composed of large crystals) are produced when magma cools slowly, whereas fine-grained rocks (composed of small crystals) are produced when magma cools quickly. Some magmas undergo two or more distinct stages of cooling, and this produces a distinctive character - known as *porphyritic texture* - in which prominent larger crystals are enclosed in a 'matrix' of smaller crystals.

The very wide range of possible magma compositions and magma cooling histories means that geologists distinguish hundreds of different types of igneous rocks, each of which has a different name. However, many of these are rare, and most of the igneous rock globally consists of a relatively small number of rock types.

The names assigned to some of the commonest igneous rocks, and their key characteristics, are summarised in Table 1.

Table 1 Names for common igneous rocks

Rock attributes		**Composition**		
		Silica-rich	Intermediate	Silica-poor
Grain-size	Coarse-grained	***granite***	***diorite***	***gabbro***
	Medium-grained	***microgranite***	***microdiorite***	***dolerite***
	Fine-grained	***rhyolite***	***andesite***	***basalt***

Thus, *granite* is coarse-grained igneous rock that crystallised from silica-rich magma, and *microgranite* and *rhyolite* are medium-grained and fine-grained rocks respectively that also crystallised from silica-rich magma. Likewise, *gabbro* is coarse-grained igneous rock that crystallised from silica-poor magma, and *dolerite* (sometimes known as *microgabbro*) and *basalt* are medium-grained and fine-grained rocks respectively that also crystallised from silica-poor magma.

Table 1 shows the names of some of the commonest types of igneous rocks, but each category actually encompasses multiple rock types. For example, *granite*, *granodiorite* and *tonalite* are all coarse-grained, silica-rich igneous rocks, which are distinguished by different proportions of feldspar minerals.

Among non-geologists, it is common practice to use a single well-known name to refer to a range of broadly similar igneous rocks. For example, the name *granite* typically is used to refer collectively to 'granite and granite-like rocks'. This is convenient and practical, but it does mean that in some (possibly many) cases the name used to refer to an igneous rock used for building purposes may not be accurate or appropriate in a geological sense. For example, 'Black Granite', a relatively common trade name in the building stone industry, in most cases is probably gabbro or dolerite rather than granite, and as such is geologically very different from granite and will have rather different properties and attributes.

The name *whin* (or *whinstone*) in the past has been used by geologists and others as a general term for dark igneous rocks (which can be difficult to classify accurately without microscope analysis, because the dark colour makes it difficult to distinguish the different minerals in them). In practice, most of the rocks formerly described as whin are likely to be basalt or dolerite, but in some instances the term has been used to encompass gabbro and even dense, dark sedimentary rock such as sandstone from the Southern Uplands region of Scotland. Geologists no longer use the term.

2.3 MINERALS IN IGNEOUS ROCKS

Silica-rich igneous rocks (including granite, microgranite and rhyolite) consist mainly of the minerals *quartz*, *alkali feldspar* and *plagioclase feldspar* (usually shortened to *plagioclase*) in roughly equal proportions. A small proportion of *biotite* or *muscovite* (minerals from the mica family) is usually present.

Silica-poor igneous rocks (including gabbro, dolerite and basalt) consist mainly of the mineral *plagioclase* and one or more of the minerals *pyroxene*, *amphibole* and *olivine*. Plagioclase is a light-coloured mineral while pyroxene, amphibole and olivine are dark. Thus, gabbro and dolerite are usually grey overall, but they can be light grey, medium grey or dark grey depending on the relative proportions of plagioclase and other minerals.

Quartz is a particularly hard, durable mineral, so igneous rock with a large component of quartz (e.g. granite) in general should be harder wearing and more durable than those lacking quartz (e.g. gabbro, dolerite).

2.4 THE EFFECT OF SECONDARY PROCESSES ON IGNEOUS ROCKS

The original (primary) minerals and texture in an igneous rock can be changed by events that happen to the rock later in its geological history. For example, the rock might be subjected to strong physical alteration (*deformation*), in which case the crystals within it can become stretched and aligned. An igneous rock that lacks any obvious preferred alignment of crystals is said to be *massive*, while a rock in which some or all of the crystals have become aligned through deformation is said to be *foliated*. During deformation, the larger crystals in a porphyritic rock can become lenticular (eye-shaped), producing a texture known as *augen texture*. Some rocks might be subjected to chemical alteration, which causes *primary* minerals to be replaced by one or more *secondary* (new) minerals. Chemical alteration usually acts to weaken the rock and usually produces rock with a pronounced colour (e.g. pink or green). Virtually all igneous rocks are chemically altered to some degree because they remain hot and chemically active for a long time after they have solidified.

Igneous rocks can crack if they are subjected to geological forces, producing *fractures*. Minerals usually crystallise from water that enters the fractures, producing *veins* (mineral-filled fractures). Some veins are as strong as the rock around them, while others are less strong and therefore prone to breaking. Some veins are formed of minerals that are chemically inert, while others are formed of minerals that dissolve readily. For these reasons, veins can be a source of weakness in igneous rocks and a cause of cracking and deterioration in setts.

2.5 OTHER TERMS USED IN THIS REPORT

The term *variant* is used (mainly in section 5 and later sections) to refer to visually distinct forms of one rock type. For example, the setts in one street might all be granite, but more than one variant can be present (e.g. massive grey granite and pink foliated granite).

The terms *rock* and *stone* to some extent are interchangeable, but in general the term *stone* is used here to refer to rock that is quarried for use in the built environment.

3 Terms used to describe setted streets

The terms used to refer to the constructed elements of a setted street and features that contribute to its visual style are introduced below (in italics) and used throughout the remainder of this report.

A typical setted street consists of four layers:

- a *surface course*, which includes the setts;
- a *bedding course* (into which the setts are laid), which can be aggregate and/or mortar;
- a *base*, which usually will be macadam or aggregate with a mortar of cement or bitumen;
- a *sub-base*, which usually will be a granular material with a mortar of cement or bitumen.

The surface course, which is the only visible layer in a finished street, forms the main subject of this report. The composition and character of the other layers is determined mainly by engineering considerations (which are beyond the scope of this report). A new setted street typically is laid in *panels* – discrete, relatively small sections, the first of which is completed before the next is begun – to maximise stability (and therefore durability) of the setts and layers.

The visual 'style' of a setted street is determined by the surface layer, which includes the following features.

- The *setts*, which are characterised by the *material* (stone) used to form them, their *dimensions* (width, length, aspect ratio [i.e. length:width] and depth), and their *finish* (i.e. the character of their surfaces – sawn, cropped, textured etc).
- The *laying pattern* of the setts. Relevant terminology refers to the geometrical relationship between setts (e.g. *stretcher bond*, *herringbone bond*) and the uniformity of row width (e.g. *regular gauged width* [all rows are the same width] and *multiple gauged width* [width varies from row to row]). In the latter case, there usually is a limited number of widths, for example 90 mm, 95 mm and 100 mm.
- The *joints* (spaces between the setts), which are characterised by their width (*joint width*) and by the material used to fill them (*joint filling*).
- The *surface profile* of the street (e.g. flat or cambered crossfall, and flat or inclined longitudinal profile).
- Whether or not a *kerb* (and therefore pavement) is present; the kerb can be considered part of the setted street, so the material, dimensions, finish and prominence (height above the street surface) of the kerb stone contribute to the street style.
- Whether or not a *channel* is present; the channel can be considered part of the setted street, so the material, dimensions, finish and shape (e.g. flat or dished) of the channel stone contribute to the street style.

Photographs to illustrate some of the typical features of traditional setts are presented in Figure 1 and Figure 2.

4 Traditional setted streets: styles and materials

4.1 INTRODUCTION

Setts in the City (EWHT, 2004), an unpublished report describing the outcomes of a project that set out to "*investigate Edinburgh's setted road surfaces and associated kerbs and details to identify those factors that most contribute to the unique character and local 'Sense of Place' …*", is probably the most detailed and comprehensive modern review of setted streets in Edinburgh. The work included a survey of all the major setted streets within Edinburgh World Heritage Site, and production of a photographic record of setted surfaces. According to the report: "*Since 1986 there has been a list of [about 387] protected setted streets in Edinburgh ... of which about 174 lie wholly or partly within the World Heritage Site*". The major setted streets examined as part of the survey amounted to fewer than half of the 174 protected setted streets within Edinburgh World Heritage Site. However, the unexamined streets had only small sections of setted carriageway or were back lanes or similar. The survey also drew on *Edinburgh World Heritage Site Streetscape Survey 1999*, an unpublished document produced by EWHT.

Most of the information presented below is a summary, in the form of bulleted lists, of the key observations, conclusions and recommendations contained in *Setts in the City*. In most cases, the relevant passages in that report have been re-worded to some extent before being incorporated in the lists, but every effort has been made to retain the original meaning. Some additional information, based on observations made for the present study, is added in places to expand upon a particular point or fill a gap.

4.2 SETT DIMENSIONS AND FINISH

- Sett size varies from street to street and within discrete sections of road.
- In general, later setts are more uniform in size than earlier setts.
- Most setts are between 120 and 140 mm wide, but sett width ranges from roughly 60 to 160 mm.
- Setts in later or more prestigious streets tend to be wider and of a standard width, though there are many exceptions.
- Locally sourced, traditional Edinburgh setts were relatively long in proportion to their width, the largest being 3 to 3.5 times longer than they are wide.
- Some imported setts (brought to Edinburgh from other parts of Scotland), which began to appear in the second half of the nineteenth century, had smaller length to width ratios, of as little as 1.5 to 1. However, most granite setts (all of which were brought to Edinburgh from other parts of Scotland) continued to be of 'traditional' proportions.
- Measurements of salvaged setts suggest traditional setts typically had a depth of around 175 mm. Shorter, later setts often seem to be 10-15 mm shallower than earlier, longer setts.
- Earlier setts had a 'rough-hewn' top surface (still visible in, for example, the less worn parts of the western end of Regent Terrace). Over time, setts were finished with increasing precision and with smoother, flatter top surfaces. Many later, less trafficked, road surfaces still show evidence of a picked or droved finish to the setts.

4.3 SETT MATERIALS

- Virtually all the traditional setts in Edinburgh are formed of just three rock types – basalt, dolerite and granite.

- The basalt typically is very dark grey to black, very fine grained and has a plain, uniform texture. It was quarried in many places locally, including quarries to the north of Salisbury Crags, and probably was used only on the earliest New Town streets to be setted. Compared to dolerite, the basalt seems to have been relatively difficult to work with, being prone to breaking off in flakes when worked; consequently, basalt setts may have been more expensive than dolerite setts. Today, basalt setts are the least common of the three, and were recorded on just a handful of streets – notably Great King Street, Northumberland Street and Regents Terrace – which generally lie outside the central part of the World Heritage Site. Great King Street and Northumberland Street, built around 1820, are paved in basalt and may represent some of the oldest surviving examples of setted surfaces in central Edinburgh.
- The dolerite typically is dark grey to mid grey, medium-grained, and usually has uniform colour and texture (dolerite from some sources can have red or ochre 'hints', and some dolerites are reddish or brownish, but these have not been used commonly in Edinburgh). It is clear from the surviving setted streets that dolerite has always been used in greater quantity than other stones to form setts. It was used in the earliest periods of Edinburgh New Town expansion, and subsequently through to the twentieth century. With basalt, it was quarried from local sources from at least the early nineteenth century, and was won from an ever-increasing number of quarries as the century progressed. In a 1905 survey of quarries, 18 working quarries producing basalt and/or dolerite were recorded in Midlothian alone. Today, dolerite setts are by far the most common and most widespread of the three, and form the carriageway surface of numerous streets throughout the World Heritage Site.
- Edinburgh does not have a local source of granite (or granite-like rock), so the earliest setted streets were not formed of granite setts. From the mid-nineteenth century (essentially coincident with the rapid expansion of the rail network) granite setts were imported from different parts of Scotland; known sources include Aberdeenshire (Corrennie and Kemnay quarries), Dumfries-shire (Dalbeattie and Creetown quarries), and Argyllshire (Bonawe quarries). As a result, granite setts display a range of characteristics: those from Aberdeenshire can be foliated, and they can be grey (e.g. Kemnay) or pink (e.g. Corrennie); those from Dumfries-shire and Argyllshire are massive and typically grey. In some instances, granite setts would have been selected as the material of choice for newly laid-out streets (e.g. East Market Street, constructed around 1870), but most granite-setted streets probably represent repaving schemes, where granite setts were used to replace earlier basalt or dolerite setts. Today, granite setts are a major component of several streets in the central part of Edinburgh World Heritage Site, including St Colme Street (the western extension of Queen Street), Thistle Street, George Street, Lawnmarket, High Street, Market Street and St Mary's Street.

- There is no evidence that stone from more than one quarry was used to create new streets or new street panels (i.e. there was no deliberate mixing of stones to achieve a particular aesthetic style). Two or more rock types, or variants of a single rock type, tend to appear only where new or recycled setts have been used to repair a setted street.

4.4 LAYING

- There is little or no evidence for a consistent policy in the laying of setts.

- The earliest setts apparently were laid on any available firm base (even directly onto soil) and joints were filled with any loose material available, although stone chips, gravel and/or sand seem to have been most commonly used and most satisfactory.
- Laying typically involved the following steps:
    - the setts were sorted by width, since uniform width in any row is critical unless the carriageway curves (in gently curving sections, skilled layers accommodated the bend by laying narrower setts on the inside and wider setts on the outside);
    - after sorting, setts were bedded into a layer of crushed stone or gravel, with their long axis at right angles to the direction of travel (for a time, some parties advocated long herringbone rows on gradients to aid drainage and grip);
    - after laying, the joints were filled, typically by brushing-in whin sand, gravel, finely crushed rock or (least effectively) plain coarse sand.

4.5 KERBS & CHANNELS

- Since at least the eighteenth century, Edinburgh has consistently used 'whinstone' (overwhelmingly dolerite) to form kerbs and channels. The high quality of this building stone means that much of the original stone used to form kerbs and channels is still in place today (including nearly every carriageway in Edinburgh World Heritage Site). Basalt forms a very small proportion of all kerbing, but the central part of the World Heritage site has a few substantial areas of granite kerbing (e.g. Princes Street).
- Traditional kerbing stone has fairly standard dimensions: 125-150 mm wide and 250 mm high, with an exposed kerb face of 100-125 mm.
- During the twentieth century, granite kerbs were installed in a few of the more prestigious or busy streets. These are often double the width of normal kerbs, being roughly 250 mm wide on their top surface.
- Many streets have dished channels running alongside the kerb. Such channels may be particularly associated with streets that, in the past, had stone macadam surfacing, although this is far from clear. Channel and special details are historically important but they are not sufficiently common to be considered universal and therefore should not be seen as important elements in defining the unique historic character of Edinburgh streets.

4.6 RECOMMENDATIONS (FROM *SETTS IN THE CITY*) FOR RETAINING AND PROTECTING SETTED STREETS

4.6.1 General recommendations

- Streets should be laid-out with a central carriageway, paved with setts and bounded by kerbs with simple paved footways and a minimum of 'clutter'.
- In the New Town, the pattern of laying-out streets geometrically with kerb lines parallel to building lines should be preserved.
- Setts should be laid at right angles to the direction of the street in a *stretcher bond*[1] pattern. They may or may not have channels or special detail at their edge adjacent to the kerb.

[1] This is sometimes referred to as a *running bond*, *half bond*, or *brick* pattern.

- Sett width should be within the range 90-140 mm, though the variation within a single street should be less than this. In general, full-size setts should be approximately 2.5 to 3.5 times longer than they are wide.
- The number of sawn surfaces should be kept to a minimum on new setts. Where setts are supplied with two opposing sides sawn, the sawn surfaces should be used to form the top and bottom surfaces of the laid setts.
- Sawn top surfaces should be tooled to roughen the surface.
- New work should be carried out with new (rather than re-used) setts. Setts that are replaced or otherwise recovered should be retained to use in repairs.
- New setts ideally should be from an indigenous Scottish source producing the same, or similar-looking, stone as the original stone. Where this is impossible or presents great financial difficulties then alien stone of an exact visual and petrological match (as determined by BS EN 12407:2000 'Natural stone test methods – Petrographic examination) may be acceptable.
- Dolerite should be used to form new kerbs. New kerbs should be approximately 150 mm wide and 300 mm deep, with an exposed face of 150 mm. Broader kerbs and kerbs formed of granite can be considered in the most prestigious and major streets, such as those in the southern part of the First New Town.
- Channels adjacent to kerbs should be retained and protected for their historic value. Where they do not already exist, they should only be introduced for sound engineering or practical reasons.

4.6.2 Protecting existing surfaces

- Historic surfaces should be retained and any repair work or new work within such an area should seek to match the materials, module and laying practice of the original. In particular, where it is necessary to lift or relay a section of setted carriageway, it should be re-laid with setts of the same stone type, size and colour as the original setts.
- Joints should be filled, as far as is technically feasible, to match the joints in the surrounding area. For example, if the surrounding area has loose fill in the joints the joints of the re-laid section should also have loose fill. Where joints are to be refilled with mortar, great care should be taken to leave the surface of the setts completely mortar free.
- Where historic elements such as channels, string courses or special features exist, they should be retained and any repair should match the existing materials, module and construction.

4.6.3 New surfaces

- Dolerite (or a similar dark, cool grey stone) should be used to form new setted surfaces within the 'outer cordon' of the World Heritage site.
- Grey stone of a cool or neutral tone, which is as similar as possible to native stone already used for setts in the area, should be used to form new setted surfaces within the 'inner cordon' of the World Heritage site. Warm grey or other 'warm' colours are considered inappropriate.
- The palette of colours should be restricted to the variation provided by a single stone (i.e. a mix of different stones should not be used).

Figure 1 Typical character of a traditional setted street in Edinburgh

Both images show roughly shaped dolerite setts (top wet, bottom dry) at the east end of Boyds Entry (a lane off St Mary’s Street in the Old Town). Note the variation in colour (light grey to dark grey) and the high length:width ratio of many setts. Units on scale bar are 1 cm.

Figure 2 Typical character of a traditional setted street in Edinburgh

Top image shows roughly shaped dolerite setts at the lower end of Cranston Street. One sett is badly cracked (possibly because the rock has been weakened by chemical alteration as evidence by the patches of pink colouration) and another is cut by two thin black lines (these are a common feature in some Edinburgh dolerite and probably are very thin basalt dykes). Units on the scale bar are 1 cm. Bottom image shows a panel of granite setts on Cranston Street. The setts are cropped on all sides (with ‘rough-hewn’ top surfaces) and are of regular width and varying length. The panel of granite setts was almost certainly inserted into Cranston Street later than the dolerite setts (i.e. as a repair).

5 Future setted streets: proposed attributes

Setted streets were created over a long period in Edinburgh, and inevitably their character changed during that time to reflect, for example, changes in availability of materials, carriageway design, and construction methods. Furthermore, some of the 'traditional' streets that survive today will include sections that were repaired or replaced long ago using materials and styles that did not match the original street, though this might not now be obvious. Thus, it is not possible to produce a succinct, simple definition of 'traditional style' that takes into account the full range of characteristics that we see today. In preparing proposals for how setted streets should be formed in future (to be 'in keeping' with traditional ones), we have identified a set of 'key attributes' and a range of 'flexibilities' (Table 2). The key attributes are those features we consider to be most typical of the traditional style, and which should be employed whenever it is possible and practicable to do so. The 'flexibilities' allow other materials or styles, which are less typical but still broadly 'in keeping', to be employed when it is not possible or not practicable to use a key attribute. These proposals are based on EWHT (2004), as described in section 4 of this report, and our own observations.

From section 4 it is clear that traditional setted streets in Edinburgh display a uniformity of character at a general level (e.g. a very restricted range of rock types, and a consistent laying pattern) but in detail display a modest degree of variability (e.g. sett size typically varies from street to street). The list of proposed attributes in Table 2 attempts to replicate these characteristics while recognising that some compromises will be necessary to meet modern standards of engineering, design and cost-effectiveness.

The proposals in Table 3 relate primarily to newly created areas of setted street. Any repair to an existing street in general should seek to replicate the materials, character and style of the original setts in areas adjacent to the repair.

Table 2 Proposed attributes of new setted streets in Edinburgh

Features		Key attributes	Flexibilities
Setts	Material	Mid grey to dark grey, massive dolerite and grey or pink, massive or foliated granite should be the only rock types used to form setts. Setts should be sourced from the same Scottish quarries as the traditional setts (or other Scottish quarries that produce similar-looking stone). Most new setted streets should use dolerite setts (to maintain the relative proportions of dolerite and granite displayed in traditional streets). Dolerite setts should be used to form principal streets, junctions, side streets and lanes in all parts of the city. Some new setted streets should use granite setts (to maintain the relative proportions of dolerite and granite displayed in traditional streets). Granite setts should be used primarily to form principal streets and important junctions in the central part of the World Heritage site. In any one street or panel, the setts should be of broadly consistent geological character (i.e. the variation in rock colour, rock composition and rock texture should be limited to that in the stone produced at the source quarry); two or more stone types, or variants of a stone type, should not be incorporated in one street or panel.	Basalt setts can be used occasionally to maintain the relative proportions of dolerite, granite and basalt displayed in traditional streets. However, basalt may be less robust than dolerite and visually is similar to dolerite, so arguably it is not essential. Imported setts of dolerite and granite that are a good match (in terms of stone character, dimensions, finish and performance) for Scottish stone in traditional Edinburgh setts can be used instead of Scottish stone, if the latter is not available or is significantly more expensive. (But see comment in section 5 about why it would be preferable in future to use the same Scottish stone that was used historically, instead of imported stone). Granite setts can be used sparingly to form side streets and lanes in any part of the city if there is a compelling design-led reason for doing so (e.g. to be visually in-keeping with surroundings, or to improve the visibility of a safety feature).
	Dimensions	Setts should be between 120 and 140 mm wide, and full-size setts should be 2.5 to 3.5 times as long as they are wide. Sett dimensions (width and/or length) should vary from street to street (to maintain the variability in character displayed in traditional streets). Sett depth should be around 175 mm.	In a minority of cases, sett width can be as little as 60 mm or as much as 160 mm (ideally, there should be a good design-based reason for this). Sett depth can be larger or smaller than 175 mm if there is a compelling engineering-based reason (e.g. to reduce the possibility of sett displacement in areas subject to unusually heavy traffic).
	Finish	All side surfaces should be cropped. Only the top and bottom surfaces can be sawn. A finish appropriate to traffic safety considerations (e.g. flame textured[2] to improve slip resistance) can be applied to the top surface[3], but should not significantly change the visual character of the carriageway surface.	None

[2] 'Flame-textured' refers to a regular, textured (roughened) finish to sett surfaces achieved by subjecting the stone surface briefly to intense heat ('flaming') so that small fragments spall.
[3] Textured surfaces probably form stronger bonds with joint fillings and bedding substrates, so it may be beneficial for the bottom surface to have a textured finish too.

<table>
<tr><th colspan="2">Features</th><th>Key attributes</th><th>Flexibilities</th></tr>
<tr><td colspan="2">Laying pattern</td><td>Setts should be laid in a stretcher bond pattern, with rows at right angles to the direction of the street.
The pattern should not be uniform (nor should it be too variable): in individual rows, setts should be of even width but varying length (while maintaining the stretcher bond character); and adjacent rows should be, to some extent, of different width (i.e. multiple gauge width).</td><td>Patterns incorporating a single gauge width or setts of uniform dimensions can be used sparingly if there is a good design-based reason for doing so.
Herringbone bond can be used sparingly if there is a good engineering-based reason for doing so (herringbone bond has higher interlocking strength than stretcher bond, so may be a more durable [cost-effective] laying pattern in areas likely to be subjected to unusually heavy loading).</td></tr>
<tr><td rowspan="2">Joints</td><td>Filling material</td><td>The filling material will depend on the engineering design. There is no requirement to replicate traditional materials, though the filling colour should not clash with, or detract from, the overall colour and visual character produced by the setts.</td><td>None</td></tr>
<tr><td>Width</td><td>Joint width will depend on the engineering design, though in general it is expected that joint width will not exceed 20 mm and will be the same (within an acceptable tolerance range) on all sides of a sett.</td><td>None</td></tr>
<tr><td colspan="2">Kerbs</td><td>Most new setted streets should include kerbs formed of blocks 125-150 mm wide and 250 mm high of locally sourced, mid grey to dark grey, massive dolerite.
The exposed face of each kerb should be 100-125 mm high.</td><td>New streets formed of granite setts can include kerbs formed of granite. These should normally be wider than (up to double the width of) normal kerbs (i.e. the top surface can be up to c.250 mm wide).
Imported blocks of dolerite and granite that are a good match (in terms of stone character, dimensions, finish and performance) for Scottish stone in traditional Edinburgh kerbs could be used instead of Scottish stone, if the latter is not available or is significantly more expensive (but see comment in section 5 about the benefits of using Scottish stone).
The exposed face of a kerb can be a different height or shape (e.g. tapered) if there is a good design-based reason for doing so.</td></tr>
<tr><td colspan="2">Channels</td><td>New setted streets can include channels formed of blocks roughly 300 mm wide of locally sourced, mid grey to dark grey, massive dolerite.</td><td>New streets formed of granite setts can include channels formed of granite.
Imported blocks of dolerite and granite that are a good match (in terms of stone character, dimensions, finish and performance) for Scottish stone in traditional Edinburgh channels could be used instead of Scottish stone, if the latter is not available or is significantly more expensive (but see comment in section 5 about the benefits of using Scottish stone).
Different channel shapes (e.g. flat or dished) can be used.</td></tr>
</table>

6 Recently created setted streets: character

Five examples of recently created (up to 15 years old) areas of setted street in central Edinburgh were examined for this project, and aspects of their character and performance were recorded. The character of the street at each site is described in Table 3 and illustrated in figures 3 to 7. Key observations are summarised below. Comments on performance of the recently setted areas are presented in section 7.

Table 3 Summary of carriageway character in areas of recently created setted street

Location	Setts			Joints		Laying pattern	Comment
	Material	Dimensions*	Finish	Filling	Width		
Junction of George IV Bridge and Royal Mile	Three variants: *Light grey, massive granite* *Mid grey, massive microgranite* *Dark grey, weakly augen-textured, foliated granite* The three are in roughly equal proportions, and distributed randomly.	93 mm wide 170-220 mm long Average aspect ratio is roughly 2:1.	All sides cropped. Top surface is flat and slightly rough (flame-textured?).	'Sika Trojan joint filling grout' (resin-based, without obvious aggregate, mid to dark grey, slightly soft).	20 mm on all sides.	The junction is divided into four panels that meet at the central point. Each panel is stretcher bond with rows at 45º to the direction of arriving traffic, and at 90º to setts in adjacent panels. All rows are of essentially identical width.	Very heavily trafficked ** Consistent sett size produces a uniform character. Dolerite blocks 780 x 300 mm in plan form kerbs 150 mm high and dished channels 300 mm wide. Three rows of kerb-parallel granite setts separate the main sett panels from the channels. Dolerite blocks bound the edge of the re-laid carriageway; presumably partly design (visual contrast) and partly function (preventing setts from becoming dislocated).
Junction of South Bridge / North Bridge and Royal Mile	Three variants: *Light to mid grey, massive microgranite* *Red, feldspar-phyric granite* *Greenish and pinkish grey, massive granite* The three are in roughly equal proportions, and distributed randomly.	100 mm wide 200 mm long Average aspect ratio is roughly 2:1.	All sides sawn. Top surface is slightly rough but distinctly curved / rounded.	Probably resin-based with aggregate of pink gravel and sand.	Somewhat variable, typically 10-15 mm.	Essentially the same as at the junction of George IV Bridge and Royal Mile (see above).	Very heavily trafficked. The design and materials used to separate the main sett panels and adjacent pavements are essentially the same as at the junction of George IV Bridge and Royal Mile (see above).

Location	Setts			Joints		Laying pattern	Comment
	Material	Dimensions*	Finish	Filling	Width		
St John Street at junction with Holyrood Road	Three variants: *Light grey massive granite* *Dark grey massive granite* *Greenish grey, massive granite*	150 mm wide 260-370 mm long Average aspect ratio is roughly 2:1.	All sides sawn. Top surface is flat and moderately rough.	Cementitious mortar with aggregate of sand. Pale grey when dry, dark grey when wet.	Very regular, 12 mm on all sides.	Regular stretcher bond at right angles to direction of travel. All rows are of essentially identical width. The same three variants laid in a herringbone bond pattern have been used in the middle part of St John Street, and on adjacent side streets.	Moderately trafficked. The three granite variants are closely similar and may have come from the same source. Compared to the light grey variant: dark grey has more dark minerals and greenish grey is more altered (epidote has replaced feldspar). A kerb of dolerite is separated from the main sett panel by a 'channel' of one row of granite setts laid at right angles to the kerb.
Top end of New Street (~50 metres of roadway leading to the junction with Royal Mile)	Two variants: *Light to mid grey, weakly feldspar-phyric, massive granite* *Yellowish mid grey, locally weakly foliated, microgranite* The two are in roughly equal proportions, and distributed randomly.	90–110 mm wide 190-250 mm long Average aspect ratio is roughly 2.2:1.	All sides cropped. Top surface is flat but quite rough (possibly sawn then flamed).	Cementitious mortar, with aggregate of sand and gravel. Light grey when dry, dark grey when wet.	Very regular, ~15 mm on all sides.	Regular stretcher bond at right angles to direction of travel. Sett width in any one row is consistent but adjacent rows are of slightly varying width.	Moderately trafficked. Kerbs 300 mm wide and typically 800 mm long of mid grey dolerite with a rough-textured surface rise 20-70 mm above the setts. Flat (not dished) channels of mid-grey dolerite blocks 300 mm wide and typically 800 mm long (same stone as kerbs) dip gently towards the kerbs.
Waverley Bridge (~30 metres of new setted street, and two c. 4x4 metre side streets leading off Waverley Bridge to the station)	Two variants: *Mid grey feldspar-phyric, massive granite* *Light grey, locally pegmatitic and locally foliated granite* The two are in roughly equal proportions, and distributed randomly.	95-120 mm wide 170-230 mm long Average aspect ratio is roughly 2:1.	All sides sawn. Top surface is flat but quite textured / rough.	Cementitious mortar, with aggregate of coarse sand.	Very regular, ~15 mm on all sides.	Regular stretcher bond at right angles to direction of travel. Sett width in any one row is consistent but adjacent rows are of slightly varying width.	Heavily trafficked (street) and lightly trafficked (side streets). Kerbs 290-300 mm wide of dark grey dolerite rise 0-110 mm above the setts. Dolerite blocks bound the edge of the carriageway; presumably partly design (visual contrast) and partly function (preventing setts from becoming dislocated).

* Does not include setts cut to meet edges or maintain the geometric character of the laying pattern.
** Terms such as *very heavily trafficked* and *lightly trafficked* are subjective and based on a brief assessment of vehicular and pedestrian traffic at the time each site was visited.

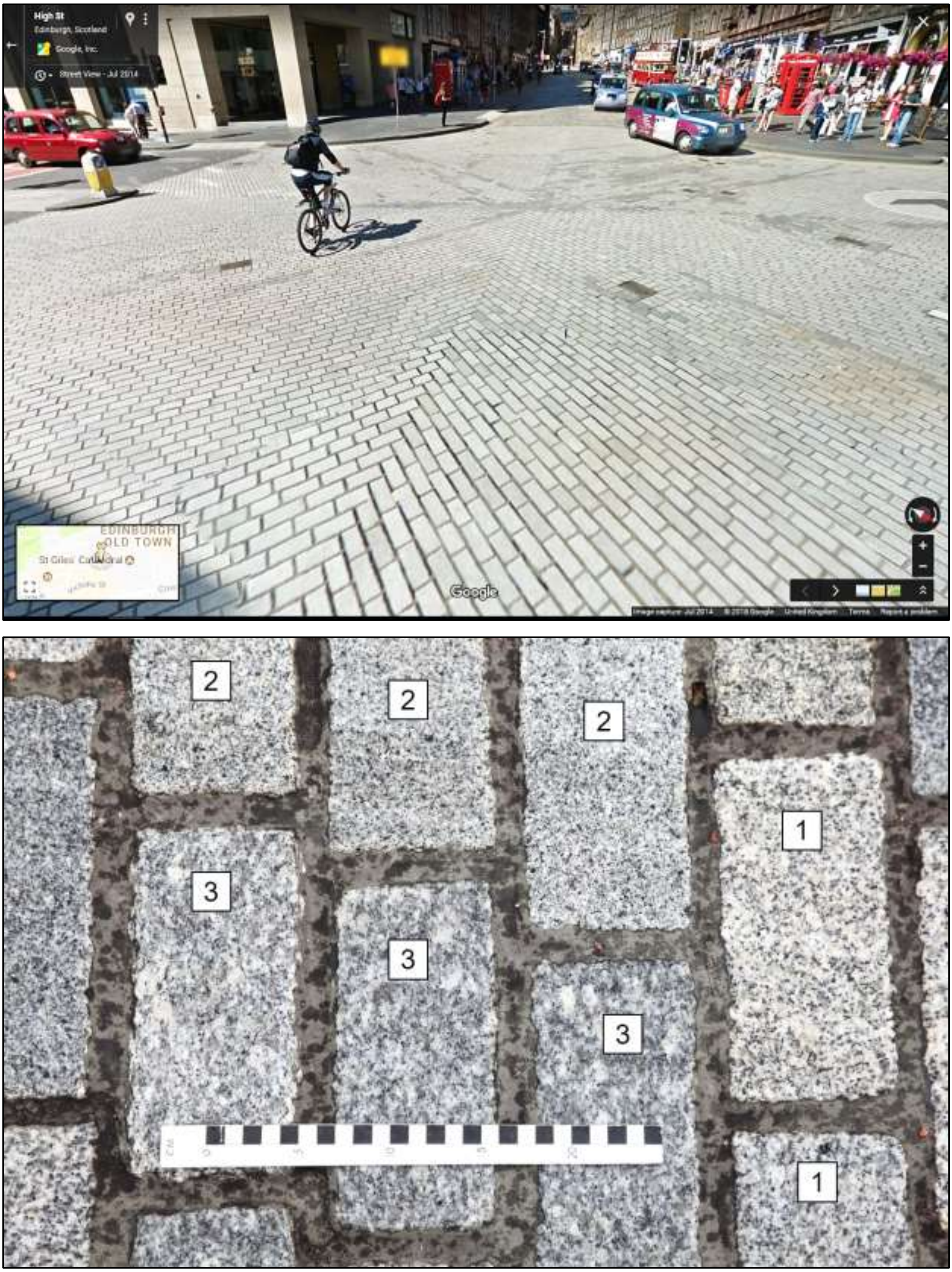

Figure 3 Modern setted street at junction of George IV Bridge / Bank Street and Royal Mile

Top: looking west across the junction.

Bottom: typical character of setts. 1 = light grey, massive granite; 2 = mid grey, massive microgranite; 3 = dark grey, weakly augen-textured, foliated granite. Units on scale bar are 1 cm.

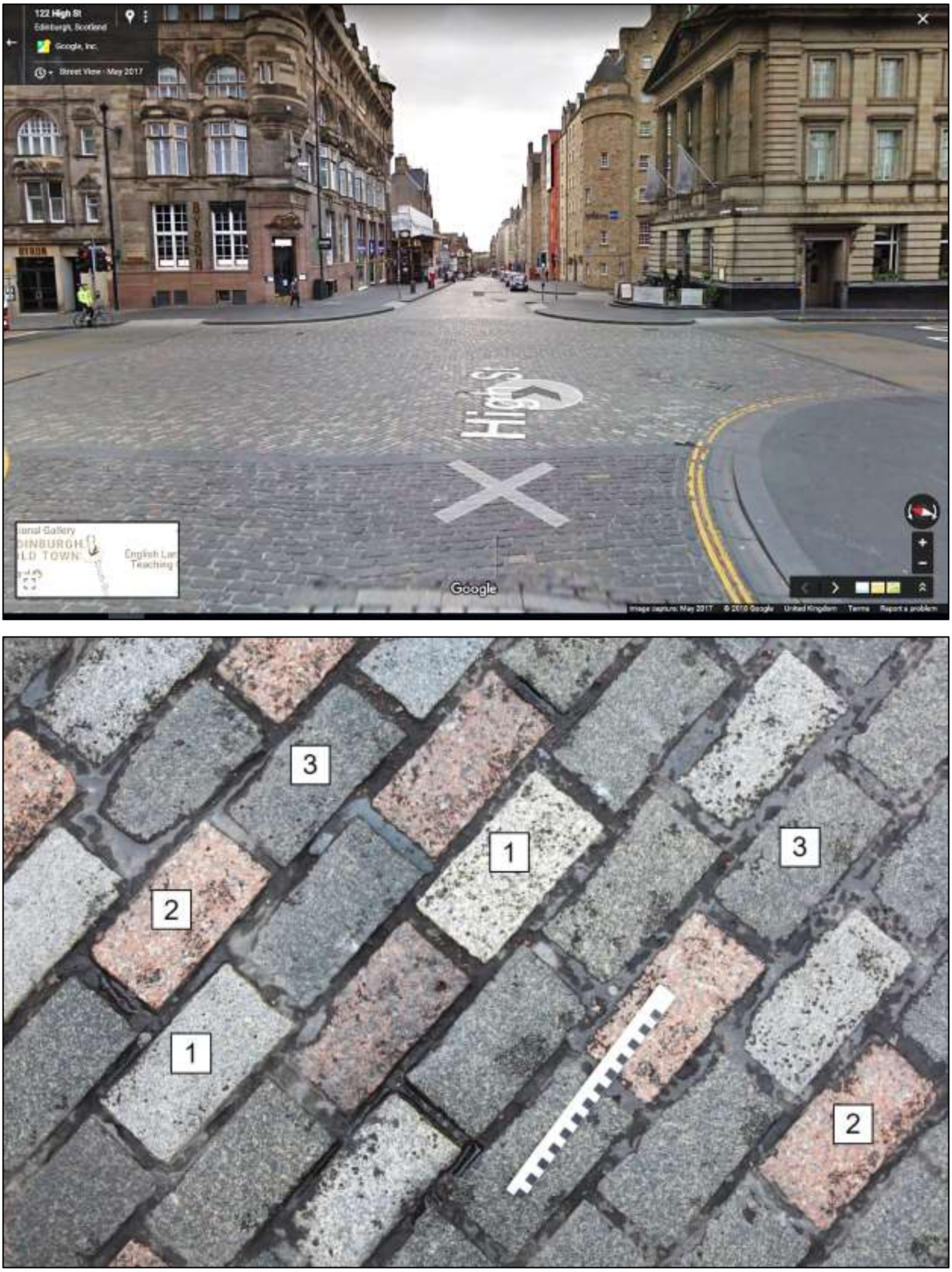

Figure 4 Modern setted street at junction of North Bridge / South Bridge and Royal Mile

Top: looking east across the junction.

Bottom: typical character of setts. 1 = light to mid grey, massive microgranite; 2 = red, feldspar-porphyritic granite; 3 = greenish and pinkish grey granitic-rock. Units on scale bar are 1 cm.

Figure 5 Modern setted street at junction of St John Street and Holyrood Road

Top: looking east across the junction.

Bottom: typical character of setts. Sawn blocks of [1] light grey granite, [2] dark grey granite and [3] greenish grey granite are distributed randomly. Units on scale bar are 1 cm.

Figure 6 Modern setted street at junction of New Street and Royal Mile

Top: looking north along New Street from Royal Mile.

Bottom: typical character of setts. 1 = light to mid grey, locally feldspar-porphyritic granite; 2 = mid grey (slightly yellowish), locally weakly foliated, microgranite. Units on scale bar are 1 cm.

Figure 7 Modern setted street on Waverley Bridge

Top: looking southeast across a typical area of modern setts.

Bottom: typical character of setts. 1 = mid grey granite with pink phenocrysts of alkali-feldspar; 2 = light grey, locally pegmatitic and locally foliated granite. Units on scale bar are 1 cm.

This is a small sample of the recently created setted streets in Edinburgh, so is unlikely to be wholly representative; nevertheless, it is considered to provide a reasonable insight to the character of recently created areas of setted street in central Edinburgh.

The following observations (based on the descriptions presented in Table 3) can be made.

- In all cases, granite setts have been used to form the carriageway surface. Dolerite has been used in some cases to form kerbstones and channels. No other rock types are used.
- At each site, two or three granite variants have been used (i.e. in no case has just one granite variant been used).
- Different granite variants have been used at each site (i.e. up to twelve different granite variants are represented at the five sites).
- In all cases, setts formed of the different granite variants have been used in roughly equal proportions and are distributed randomly in the carriageway.
- Much of the granite has a character that is broadly similar (though not identical) to the Scottish granite used in traditional setts (in terms of colour and mineral-textural features). However, some does not: notably rock that has a greenish or yellowish tinge.
- Setts of different dimensions (length and width) have been used at each site. Taking all sites together, sett width ranges from 90 to 150 mm and sett length ranges from 170 to 370 mm (shorter lengths have been used in places to maintain the stretcher bond pattern). In most cases, the average aspect ratio (length:width) of setts is approximately 2:1.
- Setts of consistent length have been used at just one site; at all other sites setts of varying length have been used.
- Setts of consistent width have been used at three sites; this means sett rows at these sites are of consistent width (single gauge width), producing a regular pattern. At two sites, setts of varying width have been used (though the setts in any one row are of consistent width); this means sett rows are of inconsistent width (multiple gauge width), producing a somewhat irregular pattern.
- Sett ‘finish’ is variable; in two cases setts have cropped sides and in three cases the sides are sawn. In four cases the top surface is flat and slightly to moderately rough (textured, possibly involving a flame finish), and in one case the top surface is distinctly curved / rounded (unclear if this is due to wear or design).
- The joint filling material is variable. In two cases, a resin-based filling has been used; in one of these there appears to be no aggregate, and in the other one there is an aggregate of pink gravel and sand. In three cases, a cementitious mortar has been used with an aggregate of sand ±gravel. The resin-based fillings have been used in very heavily trafficked carriageways whereas the cementitious fillings have been used in moderately trafficked to lightly trafficked carriageways; it is unclear whether or not this is deliberate.
- Joint width generally is consistent at any one site but varies between sites, from 10 to 20 mm. There appears to be no consistent relationship between joint width and either joint filling (resin-based vs cementitious) or sett finish (cropped vs sawn).
- The same laying pattern – regular stretcher bond – is used at all sites (though it was noted that herringbone bond has also been used in an area adjacent to one of the sites). At major intersections (e.g. George IV Bridge and Royal Mile), sett rows generally are laid at 45º to the direction of travel, whereas on one-way or two-way streets sett rows are laid at right angles to the direction of travel.

The most obvious ways in which recently created areas of setted street (based on the five areas described earlier in this section) depart from traditional character (as described in section 4) are summarised in Table 4.

Table 4 Comparison of the character of recently created and traditional setted streets

Recently created streets	Traditional streets
In all cases, granite setts have been used.	Streets formed of dolerite setts are more common than streets formed of granite setts, particularly in less prestigious streets (side roads, lanes etc).
Some granite setts have a green or yellow tinge.	All granite setts are grey or pink.
In every case, a mixed palette of stones (multiple granite variants) in roughly equal proportions has been used.	Individual streets or panels are constructed using stone from a single source; stone from multiple sources (creating a 'mixed palette') was not used.
In several cases, setts with sawn sides have been used.	Setts always have cropped sides.
In some cases, all the setts (and therefore sett rows) are the same width.	In most cases, setts (and therefore sett rows) are of varying width.
Joints are filled with resin-based or cementitious material.	Joints are filled with loose sand or gravel.
In some areas, setts have been laid in a herringbone bond pattern.	Essentially all setts are laid in a stretcher bond pattern.
In all cases, channels are formed of granite setts, and not dished.	Channels are formed of dolerite, and usually dished.
In one case, the channels consist of a single row of 'normal size' setts laid parallel to adjacent setts.	Channels typically are formed of dolerite blocks that are much larger than adjacent setts and laid at right angles to them.

The following general comments can also be made.

- The exclusive use of setts formed of granite is atypical of Edinburgh's traditional setted streets (where setts formed of dolerite are more common), but strictly speaking not out of keeping. However, ensuring that some (ideally most) new streets are formed of dolerite setts would be more in-keeping with traditional proportions.
- Most of the imported granite is broadly similar to the Scottish granite that was used traditionally to form setts, and could be considered a reasonable (though not perfect) visual match; however, granite with a yellow or green tinge is not typical, and such stone should be avoided.
- There are several reasons why it would be preferable in future to use the same Scottish stone that was used historically, instead of imported stone. For example: (i) the Scottish stone naturally will provide the closest match to existing setts in terms of visual appearance and performance; (ii) the Scottish stone has a proven pedigree, whereas imported stones commonly do not (and therefore may not perform as well as expected); (iii) it might be easier to control (or influence) long-term security of supply of Scottish stone, whereas the availability and character of imported stone may change frequently and without notice; and (iv) it might be easier when dealing with local suppliers, to specify setts with features that are in-keeping with traditional style (e.g. in terms of dimensions and finish). Setts formed of dolerite are now available commercially in Scotland, and there is an opportunity to work with the recently formed Scottish Stone Group to make setts formed of Scottish granite commercially available again.

7 Recently created setted streets: performance

The performance of recently created areas of setted street was assessed at the five sites described in section 6 and Table 3. The main observations are summarised below.

7.1 JUNCTION OF GEORGE IV BRIDGE / BANK STREET AND ROYAL MILE

- Virtually all of the granite setts are intact (not broken). A small proportion are cut by thin, dark veins, which probably are formed mainly of the minerals chlorite and quartz. Most of these veins are intact, but one or two show signs of incipient parting (i.e. the sett may be near to cracking into two pieces along the vein). One sett has cracked vertically and normal to its long axis; the cause is not clear, but it may have parted along a very thin vein of chlorite and quartz.
- Many setts show signs of incipient cracking within 2–5 mm of, and parallel to, their sides (Figure 8). The cracks seem to be more common and/or better developed parallel to the long sides of setts. Natural outcrops of granite commonly display ground-parallel fractures (known as *sheet joints*), which form because the rock 'relaxes' (expands) as the weight of overlying rock is removed by uplift and erosion. The cracks in these granite setts may result from a similar process; i.e. the rock may have expanded slightly after being cut into setts (this might happen if the stone comes from a part of the world where the ground is experiencing geologically rapid uplift). Alternatively, the cracks may be developing as a result of physical damage incurred adjacent to cropped surfaces during cropping. Whatever their origin, the cracks are likely to lead to progressive disintegration of sett edges and development of rounded top surfaces.
- The top surfaces of setts may display signs of very minor granular disintegration. This is where abrasion is likely to be most significant, so some deterioration is to be expected. Treatments such as 'flaming', which are used to create a textured surface, may make the affected surface somewhat more prone to granular disintegration. Top surfaces are not obviously developing a polish (surfaces are still slightly rough).
- The resin-based joint filling in general appears to be in good condition. However, it is cracking / disintegrating locally, and in places the top surface of the filling is relatively 'deep' with the result that water tends to pond in (and takes longer to dry from) these places and detritus tends to gather in them. It is not clear if these areas were deeper at the time the filling was created or if the filling has worn more here. Either way, the fact that water is ponding here and detritus is gathering means these areas are now likely to wear and disintegrate more quickly than other areas.
- There are no signs of setts becoming dislocated, and the sett–filling bonds appear to be tight in most cases. However, lingering wetness along some sett–filling contacts after rain suggests incipient cracks may be developing along the contacts. Water and debris will enter any such cracks and accelerated decay can then be expected.
- Patches of orange-brown staining are developing on granite setts within a few centimetres of iron manhole covers (Figure 8). A joint with resin-based filling always separates the stained sett from the manhole cover, so the stone and the likely source of iron appear not to be in direct contact (at least at the carriageway surface). The iron staining seems to be forming where the joint fillings are deepest / most decayed. The iron might be moving by capillary action from the manhole cover to the sett across the top surface of the filling, or the transfer may be happening beneath the filling (i.e. below the

ground surface). The discolouration probably affects only the surface of the setts, and is unlikely significantly to reduce stone durability.

7.2 JUNCTION OF SOUTH BRIDGE / NORTH BRIDGE AND ROYAL MILE

- Virtually all of the granite setts are intact (not broken).
- Cracks developed near to, and parallel to, sett sides (see section 7.1) are not obviously developed, but conchoidal (curved) fractures are developed locally, notably in several adjacent setts close to the west edge of the junction (Figure 9).
- The (?resin-based) joint filling is in relatively poor condition, being quite badly decayed in places and unevenly preserved (Figure 9). Rainwater tends to pond in joints where the filling is most decayed. As at the previous site (section 7.1), the fact that water is ponding here means these areas are now likely to wear and disintegrate more quickly than other areas.
- The carriageway surface has suffered subsidence locally, notably around manhole covers, and is distinctly uneven.
- There is no evidence that setts are becoming iron-stained near to manhole covers.

7.3 ST JOHN STREET AT JUNCTION WITH HOLYROOD ROAD

- Setts show no sign of cracking, polishing, dislocation or discolouration.
- The surface of the cementitious joint filling in places appears to be deeper than normal and stays wetter for longer after rain; the filling therefore seems to be decaying faster locally, possibly due to localised loading and accelerated wear.
- Hairline cracks along sett–filling contacts become apparent as the carriageway surface dries out after rain (Figure 10). These cracks, which are common at this site, may be due to stress as the surface is repeatedly loaded and unloaded by passing traffic, but they may also or alternatively be due to shrinkage of the cementitious mortar. The smooth, flat surfaces presented by sawn setts (such as these ones) probably produce a weaker bond with joint filling than do the irregular surfaces presented by cropped setts. Thus, sett–filling contacts in panels formed of setts with sawn sides may be more prone to cracking when subjected to loading/unloading forces or shrinkage.

7.4 TOP END OF NEW STREET

Setts and joint filling appear to be in good condition, with no sign of cracking, polishing, dislocation or discolouration (Figure 10). This may reflect the newness of the carriageway, but the cropped sides of the setts may mean the sett–filling contacts are less prone to cracking than where setts with sawn sides have been used (see section 7.3).

7.5 WAVERLEY BRIDGE

- Most setts are in good condition, showing no sign of cracking, polishing, dislocation or discolouration. However, a few setts show signs of incipient cracking close to, and parallel to, their sides (Figure 11).
- Hairline cracks along sett–filling contacts become apparent as the carriageway surface dries out after rain (Figure 11). These may be forming for the same reasons proposed in section 7.3.

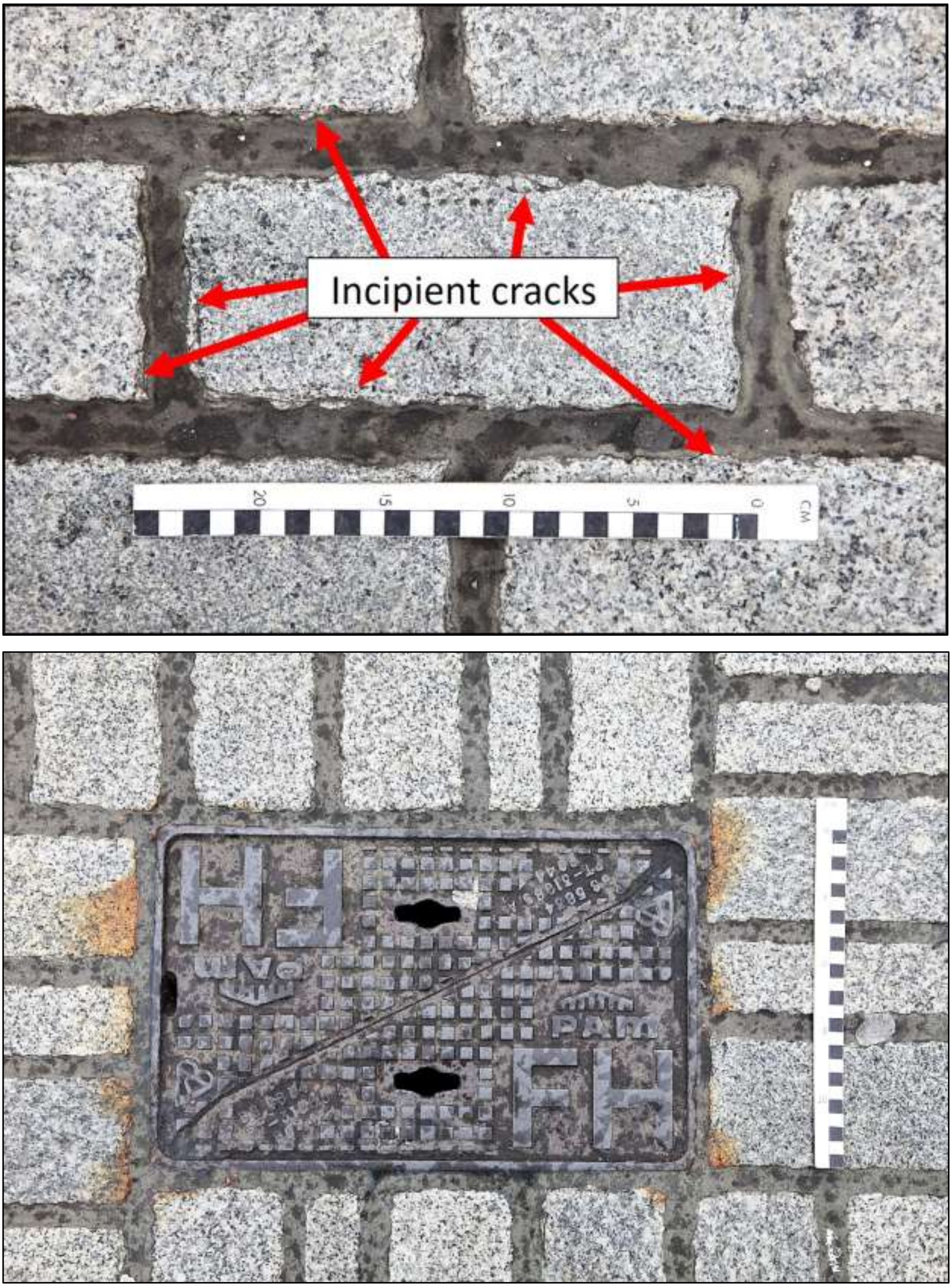

Figure 8 Performance issues in a recently setted area at the juntion of George IV Bridge / Bank Street and Royal Mile

Top: incipient thin cracks developing near to, and parallel to, the cropped sides of setts. Bottom: orange-brown iron staining developed locally on setts adjacent to a manhole cover. See text for details. Units on scale bar are 1 cm.

Figure 8 Performance issues in a recently setted area at the juntion of South Bridge / North Bridge and Royal Mile

Top: Conchoidal (curved) fractures developed in adjacent setts. Bottom: numerous cracks and evidence for uneven wear developed in ?resin-based joint filling. See text for details. Units on scale bar are 1 cm.

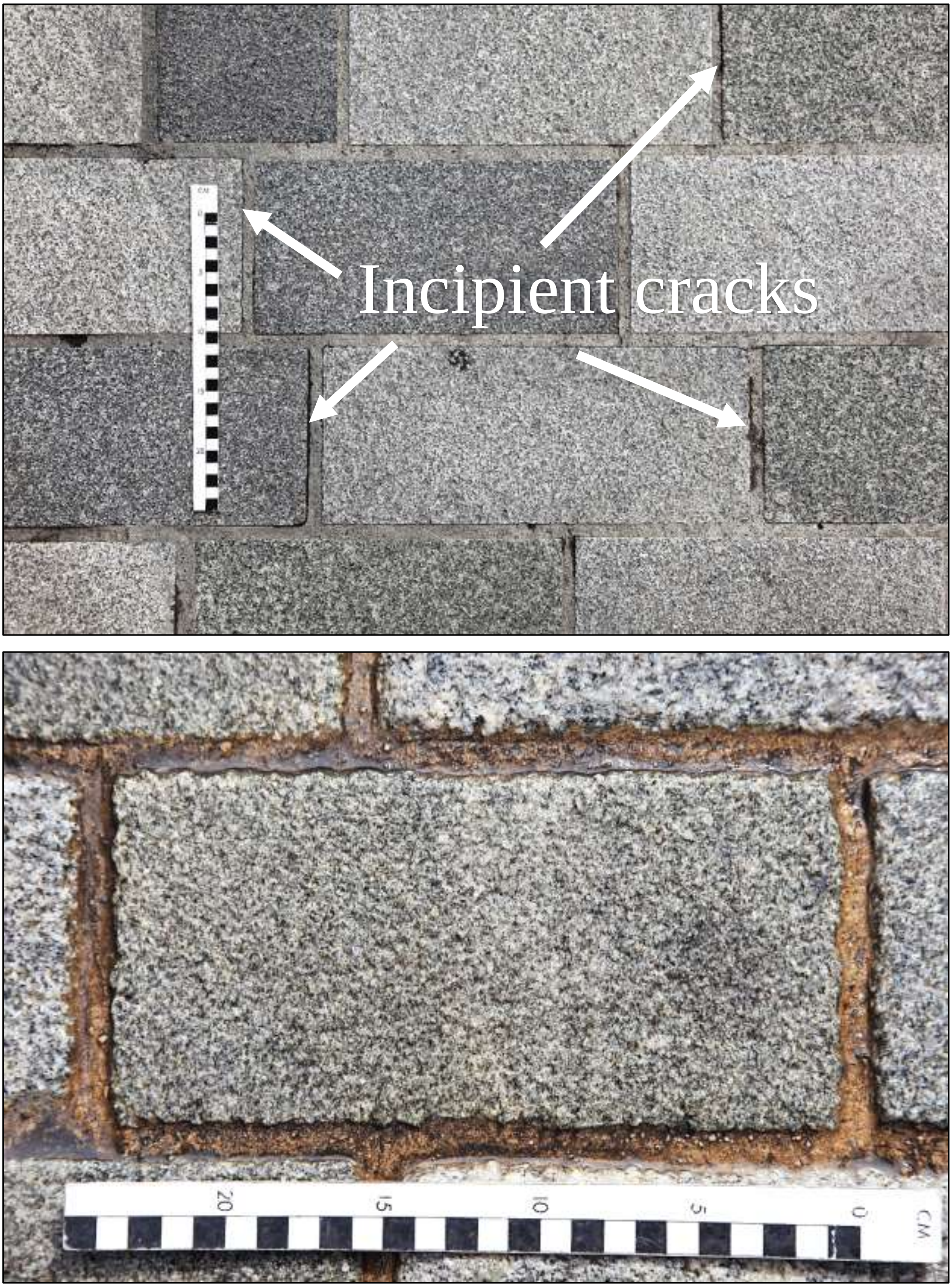

Figure 9 Performance issues in recently setted areas at St John Street and New Street

Top: carriageway surface at St John Street showing hairline cracks (highlighted by dark residues of drying rainwater) developed along the contacts between sawn setts and cementitious joint filling. Bottom: carriageway surface at New Street showing cropped setts and cementitious joint filling, both of which are in good condition. See text for details. Units on scale bar are 1 cm.

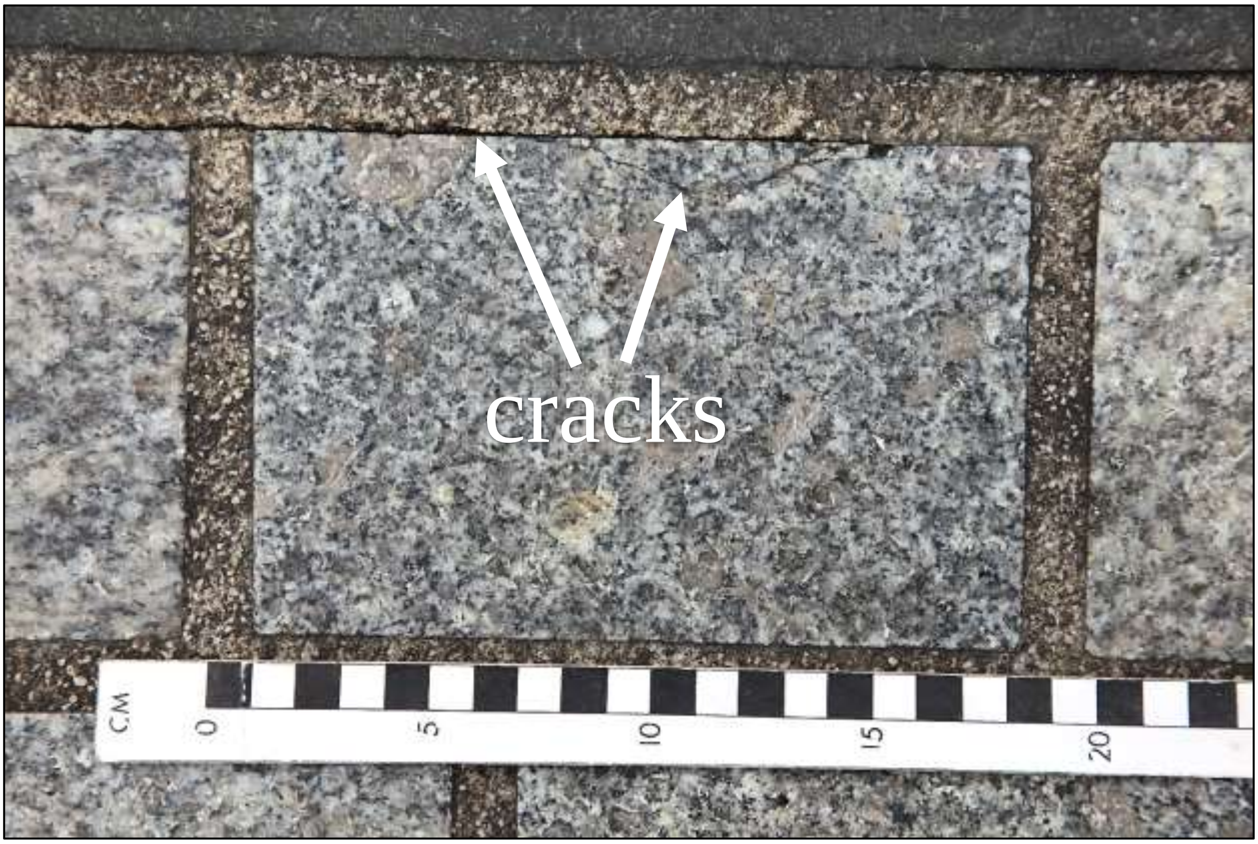

Figure 10 Performance issues in a recently setted area at Waverley Bridge

Top: hairline crack developed in granite next to the long edge of a sett, and a hairline crack developed along the contact between sawn setts and cementitious joint filling. Bottom: hairline crack developed along the contact between sawn setts and cementitious joint filling. See text for details. Units on scale bar are 1 cm.

8 Performance indicators for setts and setted streets

Setted streets should be aesthetically pleasing and they should meet the practical needs of street users, but the ideal setted street should also be safe, durable and cost-effective (requiring minimal maintenance during its projected lifespan). To an extent, all these attributes can be controlled by appropriate design and good quality construction, but in some cases tests are required to indicate material performance characteristics. To be safe, the stone should be resistant to polishing and uneven wear; to be durable, the stone should be resistant to granular disintegration (i.e. breaking into its constituent crystals) and cracking; and to be cost-effective, setts should be both safe and durable (reducing the need for costly intervention). No material can ever be completely resilient in these respects, but optimising performance should be a key aim when specifying materials for constructing or repairing a setted street. However, cost-effectiveness also depends on the performance of the setted street as a whole, rather than just the individual setts. This section of the report therefore considers performance indicators for setts and setted streets separately.

8.1 PERFORMANCE INDICATORS FOR SETTS

Performance indicators for natural stone setts can be divided into two types: *geological performance indicators* and *geotechnical performance indicators*. Table 5 presents summary details for a set of 'desirable natural properties' that can be evaluated using these indicators.

8.1.1 Geological performance indicators

These are observable geological features that have the potential to improve or diminish the performance of a stone when used as a sett. Features with the potential to diminish performance typically are distributed unevenly in a stone and therefore may not be represented in geotechnical tests or observed in a casual visual assessment. Such features include: chemical alteration and physical alteration of the stone, which could make it susceptible to granular disintegration; fractures, veins and dykes, which may make the stone susceptible to cracking under load or through mineral dissolution; and nodules and other localised features that may weather and abrade more slowly than the enclosing rock (ultimately standing proud and presenting a possible trip hazard) or more quickly than the enclosing rock (creating pits in which water and debris can accumulate). An assessment of geological performance indicators usually requires an examination of the stone by a geologist using the unaided eye (visual examination) or a microscope (petrographic analysis).

The type of stone used to form a building stone product is usually indicated by the supplier in the trade name of the product or in product specification details, but the geological terms used by suppliers are sometimes applied inaccurately or inconsistently (as indicated in section 2.2). It can make sense, therefore, to have the stone type verified independently by a geologist if stone of a particular type or character is required for a project.

8.1.2 Geotechnical performance indicators

These are measurable attributes used to determine how well a stone is likely to perform in a given circumstance (e.g. when subjected to a heavy load or repeated freeze / thaw cycles). Many such attributes are intrinsic properties of the stone and therefore can be evaluated by subjecting a representative sample of the stone to a standard laboratory test.

The British and European standard *BS EN 1342:2012: Setts of natural stone for external paving. Requirements and test methods* defines the dimensional requirements, methods of measurement, permissible deviations, conformity and acceptance criteria for the man-made properties of a sett, and specifies the appropriate performance indicator tests that should be used to evaluate the intrinsic natural properties of a stone. However, it does not define threshold values or other criteria for judging 'acceptability' for most of the tests that assess intrinsic natural properties, because these will vary depending on the setting and function of the street (e.g. projected traffic loading) and its intended lifespan; the designer / road engineer must set these on a case-by-case basis. Suggested ‘acceptance limits’ for most of the relevant geotechnical tests of natural properties (including compressive strength, water absorption, freeze / thaw resistance, Magnesium Sulphate Soundness, abrasion resistance, and resistance to polishing) are provided in chapter 3 of the report *Natural stone surfacing - good practice guide* (Society of Chief Officers of Transportation in Scotland, 2004; referred to hereafter as ‘the SCOTS report’). Most (perhaps all) of the igneous rocks that have been commonly used as setts in traditional and new setted streets in Edinburgh probably exceed the suggested minimum acceptance limits for these natural properties.

Slip resistance is the property that, arguably, is most likely to degrade significantly over time, and as such has implications for both the safety and cost-effectiveness of a setted street. Slip resistance is controlled by the texture of the top surface of a sett, which depends on man-made factors (i.e. how the sett was produced [e.g. sawn, cropped] and finished [e.g. flame-textured]), and an intrinsic natural property (resistance to polishing). Slip resistance is the only geotechnical test described in *BS EN 1342:2012* that is not determined wholly by an intrinsic natural property. In this instance, the standard advises a limit for slip resistance (USRV >35) that is generally considered safe. One geotechnical test, which produces a measure called the Polished Stone Value (PSV), gives an indication of resistance to polishing, but the rate at which in-service slip resistance will degrade cannot be assumed from a PSV. Monitoring and periodic testing is the only way to assess whether or not the slip resistance of in-service setts remains acceptable. The top surface of setts can be re-textured if slip resistance falls below acceptable limits, but using new stone setts with high initial USRV and PSV in the first instance will reduce (and possibly eliminate) the need for intervention, thereby improving cost-effectiveness.

Stone suppliers generally provide a set of geotechnical test data for their product, but it is important to check that these have been conducted in full accordance with the methodologies described in *BS EN 1342:2012* (or whatever document succeeds it).

Table 5 Desirable natural properties of setts, associated performance indicators and tests

Desirable natural property	Possible cause of poor performance	Performance indicator	Appropriate test	Sources of further information
Resistance to granular disintegration	Constituent crystals are insufficiently cohesive	Altered minerals and minerals prone to weathering are rare or absent	Petrographic analysis	Seek advice from a geologist, and/or assurances from supplier
		Mechanical durability is sufficient for intended function	Freeze / thaw resistance	Refer to BS EN 1342:2012 and guidance in the SCOTS report
			Magnesium Sulphate Soundness (MSS)	
			Abrasion resistance	
Resistance to water penetration	The stone is permeable (i.e. water can penetrate it, promoting decay) due to open fractures and/or connected pores	Stone permeability and porosity are low	Water absorption	Refer to BS EN 1342:2012 and guidance in the SCOTS report
			Determination of open porosity	
Resistance to cracking	The stone is brittle and/or The stone contains natural or fractures or incipient fractures due to blasting	Stone strength is sufficient for intended function	Compressive strength	Refer to BS EN 1342:2012 and guidance in the SCOTS report
		Fractures are absent … or … Fractures are present but are geologically healed and do not contain minerals susceptible to weathering	Visual examination & petrographic analysis	Seek advice from a geologist, and/or assurances from supplier
			Compressive strength	Refer to BS EN 1342:2012 and guidance in the SCOTS report
Resistance to slip *	Surface texture is insufficiently rough to provide adequate traction	Resistance to slip is sufficient for intended function	Unpolished Slip Resistance Value	Refer to BS EN 1342:2012 and guidance in the SCOTS report
Resistance to polishing	Lack of hard minerals in the stone allow its surface to become polished	Resistance to polishing is sufficient for intended function	Polished Stone Value (PSV)	Refer to BS EN 1342:2012 and guidance in the SCOTS report
Resistance to uneven wear	The stone has unevenly distributed geological features that differ from the host rock, such as nodules and cavities	Features that might cause uneven wear are absent	Visual examination & petrographic analysis	Seek advice from a geologist, and/or assurances from supplier
Resistance to discolouration	The stone contains iron-bearing minerals that are susceptible to weathering (e.g. pyrite and calcite)	Iron-bearing minerals that are susceptible to weathering are absent	Visual examination & petrographic analysis	Seek advice from a geologist, and/or assurances from supplier

* Strictly speaking, this is influenced primarily by man-made properties (the 'finish' applied to sett surfaces) but it is included here as a 'desirable natural property' because the natural texture (e.g. crystal size) of a stone will affect the roughness (and thereby slip resistance) of cropped surfaces.

8.2 PERFORMANCE INDICATORS FOR SETTED STREETS

There are no recognised performance indicators for joint fillings or for setted streets as a whole. However, the long-term durability, and therefore cost-effectiveness, of a setted street depends on how all the component parts (setts, joint filling, and support layers) perform, individually and collectively. The observations presented in section 7 of this report suggest that maintaining the bonds between sett surfaces and the joint filling is more important in determining the overall durability (and therefore cost-effectiveness) of a modern setted street than any other aspect. The evidence suggests that the bond is stronger and will last for longer when setts have cropped (rough) sides rather than sawn (smooth) sides, but the durability and influence of different joint filling materials is more difficult to gauge and predict. When cracks form along the bond (or in any other place), water, salt and granular debris will enter them at which point processes such as freeze-thaw cycles, dissolution, salt crystallisation, and abrasion will occur within the crack, leading to an ever-greater rate of deterioration. It is suggested, therefore, that crack development in joint filling should be considered a key performance indicator for the surface layer of modern setted streets. Currently, there is no quantitative measure of crack development (as far as we know), so setted streets should be monitored regularly (perhaps annually) for cracks and associated issues (such as sett displacement and subsidence), and a strategy should be put in place for dealing with problems in the most cost-effective manner. New streets and new repairs should be designed and constructed in such a way as to minimise crack development. The best means of achieving this can be learned through trial and error, but in the interests of improving cost-effectiveness as quickly as possible it would be worth reviewing experiences elsewhere (including other local authorities in the UK and overseas) and initiating formal tests and monitoring of different combinations of sett finish, filling material and construction method.

The British standard *BS 7533: Pavements constructed with clay, natural stone or concrete pavers* (BSI 2009, 2010) provides specifications for constructing paved streets. The standard is divided into several parts, presented as separate documents, each dealing with different materials and pavement types. Parts 7, 10 and 13 are relevant to setted streets. The relevant parts of *BS 7533* specify the methods and materials to be used for designing and laying the setted street as a whole. The SCOTS report also provides information on this process, and includes informative commentary on *BS 7533*.

9 Summary and recommendations

Setted streets were created over a long period in Edinburgh, and inevitably their character changed during that time to reflect, for example, changes in availability of materials, carriageway design, and construction methods. Some of the 'traditional' streets that survive today will include sections that were repaired or replaced long ago using materials and styles that did not match the original street, though this might not now be obvious. Thus, it is not possible to produce a succinct, simple definition of 'traditional style' that takes into account the full range of characteristics that we see today. However, it is possible to identify a set of 'key attributes' of traditional setted streets – features that are most typical of the traditional style – and use these to inform how new setted streets should appear, if they are to be 'in keeping' with traditional streets. The key attributes of traditional setted streets in Edinburgh are listed in Table 2 of this report, and can be summarised as follows. To be 'in keeping' with traditional streets, the setts used to form any new area of setted street should:

- be formed of mid- to dark grey dolerite (though similarly coloured gabbro and basalt would also be acceptable) or grey to pink granite; the stone should be visually similar to the Scottish stones used to form the surviving traditional streets;
- consist of one rock type (i.e. they should be all dolerite or all granite, not a mix), and usually just one variant of that rock type;
- be between 120 and 140 mm wide, and 2.5 to 3.5 times as long as they are wide;
- have cropped sides and textured tops;
- be laid in a stretcher bond pattern, with rows at right angles to the direction of the street; in individual rows, setts should be of even width but varying length (while maintaining the stretcher bond character), and adjacent rows should be, to some extent, of different width.

Blocks 125-150 mm wide and 250 mm high of mid- to dark grey dolerite should be used to form new kerbs and channels, though granite can be used on streets formed of granite setts; granite kerbs typically would be wider than normal kerbs (the top surface can be up to c.250 mm wide).

Some compromises obviously will be necessary to meet modern standards of engineering and design, and any new street design guidance should identify a range of permissible 'flexibilities' that allow other materials or styles, which are less typical but still broadly 'in keeping', to be employed when it is not possible or not practicable to reproduce one of the 'key attributes'. Proposed flexibilities are summarised in Table 2 of this report.

To maintain the character of Edinburgh's historic streetscape at a citywide scale, CEC should aim to ensure that:

- setted streets in general display a uniformity of character (e.g. in using a very restricted range of rock types and a consistent laying pattern) but in detail display a modest degree of variability (e.g.in varying sett dimensions from street to street);
- most setted streets are formed of dolerite, with a subordinate proportion (mainly prestigious streets and junctions) formed of granite.

Any repair to an existing street in general should seek to replicate the materials, character and style of the original setts in areas adjacent to the repair.

Recently created setted streets (based on a sample of five sites examined for this study) to an extent follow the traditional style, notably in using setts formed of granite and dolerite, and in generally employing a stretcher bond pattern. However, they depart from the traditional style in a number of respects, and as such arguably could do better in replicating the appearance and character of traditional setted streets. Perhaps most notably:

- granite setts have been used exclusively (whereas traditional streets formed of dolerite setts are more common than streets formed of granite setts);
- some of the granite (notably rock with a yellow to green tinge) is not a good visual match for traditional Scottish granite;
- a mixed palette of stones (multiple granite variants) in roughly equal proportions has been used at every site (whereas individual traditional streets typically were formed using a single variant of one stone type);
- in some cases, all the setts (and therefore sett rows) are the same width, which creates a rigidly uniform pattern (unlike traditional streets where adjacent sett rows typically are of varying width, which 'softens' the visual character);
- the length to width ratio of full-size setts typically is around 2:1, whereas in traditional setts it is 2.5 to 3.5;
- sett sides are always sawn (not cropped);
- non-traditional joint fillings, notably resin-based and cementitious fillings, have been used in all cases; however, this is clearly necessary to meet modern standards of engineering and durability, as many setted streets experience substantially greater traffic volume and loading in the 21st century than they did historically.

Virtually all of the setts used to form new areas of setted street in recent decades have been imported, partly because imported setts are widely available and relatively cheap, and partly because setts prepared from indigenous Scottish stone generally have not been available commercially. There are several reasons why it would be beneficial to use the same Scottish stone that was used historically to create new setted streets and repair existing streets. For example, stone from the original quarry sources obviously would provide the closest match to existing setts in terms of visual appearance and performance, and has a proven pedigree whereas imported stones commonly do not (and therefore may not perform as well as expected). Furthermore, it might be easier to control (or influence) long-term security of supply of indigenous stone, whereas the availability and character of imported setts may change frequently and without notice. It should also be easier to encourage local suppliers to produce setts with features that are 'in keeping' with the traditional style (e.g. in terms of dimensions and finish). Setts formed of Scottish dolerite are now available commercially, but Scottish granite setts are not. However, growing interest in re-establishing a strong Scottish stone industry, and in re-instating setted streets, means there is an opportunity for CEC to work with other local authorities, conservation organisations (including HES and EWHT), and Scottish quarriers (notably the recently formed Scottish Stone Group) to make Scottish granite setts commercially available again.

Performance indicators for natural stone setts can be divided into two categories. *Geological performance indicators* are observable geological features that have the potential to improve or diminish the performance of a stone. They include structural weaknesses (e.g. cracks and veins) and minerals with the potential to weaken or discolour the stone, and in general should be assessed by a geologist. *Geotechnical performance indicators* are measurable attributes used to determine how well a stone is likely to perform in a given circumstance. They include stone strength, resistance to disintegration and resistance to polishing, and in general should be assessed using geotechnical tests. Most (perhaps all) of the igneous rocks that have been commonly used as setts in traditional and new setted streets in Edinburgh probably exceed minimum acceptance limits for most performance indicators.

A brief review of sett performance in recently created setted streets (based on the same five sites described above) showed that the setts in general appear to be performing well, though at one site cracks have developed within some setts, near to and essentially parallel to their sides. In time, these will cause the setts to become rounded, which will reduce slip resistance. The most common, and potentially the most serious, performance issue is hairline cracks developing in the joint filling, and particularly along the contacts between setts and joint fillings. The cracks are most common in cementitious fillings, and may be a result of shrinkage in the mortar and/or repeated loading and unloading stress. Cracks were observed most commonly along the contacts between joint fillings and setts with sawn (smooth) sides, which probably form a weaker bond than setts with cropped sides.

Setted street surfaces are expensive to create (compared to tarmac), so demonstrating that they can be cost effective (requiring minimal maintenance) over long periods is important if they are to attain the support of both the public and planning committees. The long-term durability of a setted street (which is a key determinant of its cost-effectiveness) depends on how all the component parts (setts, joint filling, and support layers) perform, individually and collectively. A key conclusion of this review is that the bonds between sett surfaces and the joint filling is more important in this respect than any other aspect of the surface layer in a setted street. The evidence suggests that the bond is stronger and will last for longer when setts have cropped (rough) sides rather than sawn (smooth) sides, but the durability and influence of different joint-filling materials is more difficult to gauge and predict. When cracks form along the bond (or in any other place), water, salt and granular debris will enter them at which point processes such as freeze-thaw cycles, dissolution, salt crystallisation, and abrasion will occur within the crack, leading to an ever-greater rate of deterioration. As such, crack development in joint filling should be considered a key performance indicator for the surface layer of modern setted streets. Currently, there is no quantitative measure of crack development (as far as we know), so setted streets should be monitored periodically for cracks and associated issues (such as sett displacement and subsidence), and a strategy should be put in place for dealing with emerging problems in the most cost-effective manner. New streets and new repairs should be designed and constructed in such a way as to minimise crack development. The best means of achieving this can be learned through trial and error, but it would be worth reviewing experiences elsewhere (including other local authorities in the UK and overseas) and if necessary initiating formal tests and monitoring of different combinations of sett finish, filling material and construction method.

Setted streets that are well designed, well engineered and well constructed using durable materials should require little or no maintenance over several decades and therefore have the potential to be both sustainable and cost-effective. Measures should be put in place to limit the degree to which utility companies need to access infrastructure beneath setted streets, and to mitigate the impact on the long-term visual and structural integrity of setted street surfaces when they do.

References

BRITISH STANDARDS INSTITUTION. 2009. BS 7533-13:2009. *Pavements constructed with clay, natural stone or concrete pavers. Guide for the design of permeable pavements constructed with concrete paving blocks and flags, natural stone slabs and setts and clay pavers*.

BRITISH STANDARDS INSTITUTION. 2010. BS 7533-7:2010. *Pavements constructed with clay, natural stone or concrete pavers. Code of practice for the construction of pavements of natural stone paving units and cobbles, and rigid construction with concrete block paving*.

BRITISH STANDARDS INSTITUTION. 2010. BS 7533-10:2010. *Pavements constructed with clay, natural stone or concrete pavers. Guide for the structural design of trafficked pavements constructed of natural stone setts and bound construction with concrete paving blocks*.

BRITISH STANDARDS INSTITUTION. 2012. BS EN 1342:2012. *Setts of natural stone for external paving. Requirements and test methods*.

EDINBURGH WORLD HERITAGE TRUST. 2004. *Setts in the City. Setted street surfaces in the world heritage site*. Unpublished and possibly unfinished document. Available online at: www.ewht.org.uk/uploads/downloads/Setts in the City Full Text, 2 Nov 04.pdf

EDINBURGH WORLD HERITAGE TRUST. *Streetscape Survey 1999.* Unpublished document.

SOCIETY OF CHIEF OFFICERS OF TRANSPORTATION IN SCOTLAND. 2004. *Natural stone surfacing – good practice guide*. 2nd Edition. Available online at: www.scotsnet.org.uk/natural-stone-surfacing-good-practice-guide.html.