Gazetteer of Arran Pitchstone Sources

Presentation of exposed pitchstone dykes and sills across the Isle of Arran, and discussion of the archaeological relevance of these outcrops

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1 SUMMARY

The main element of the present paper is a gazetteer of exposed pitchstone sources across the Isle of Arran. In the paper's final chapter, the archaeological relevance of these outcrops is discussed. The gazetteer includes approximately 100 pitchstone sources, and the authors hope that it will become a useful tool to prehistorians working on and outwith Arran, thus adding to our understanding of how pitchstone was perceived, exchanged and used in northern Britain. In general terms, the gazetteer should provide a more rigorous basis for archaeological and geological assessment of pitchstone artefacts and sources.

2 INTRODUCTION

Volcanic glass is generally recognised by modern knappers as the ultimate lithic raw material, as it tends to flake in a highly predictable manner, and it provides sharper edges than any other form of silica (Whittaker 1994, 69). Natural glass is usually subdivided into two groups of materials, namely obsidian and pitchstone. The former is defined by having less than 1% water, no or few phenocrysts (that is, crystals in the glass) and a vitreous lustre, whereas pitchstone may have as much as 10% water, some forms are rich in phenocrysts, and all pitchstones have a tar-like lustre (Pellant 1992, 197). Aphyric, homogeneous pitchstone (that is, pitchstone without phenocrysts), such as some of the material from Corriegills on Arran, flakes almost as well as obsidian, whereas the more porphyritic varieties (that is, pitchstone with phenocrysts) are less easily controlled. Volcanic glass is known from igneous complexes throughout the world, but in Britain it is only found in western Scotland and Northern Ireland (the British Tertiary Volcanic Province or BTVP; Richey 1961; Emeleus & Bell 2005; illus 1), and only in the form of pitchstone (a more detailed geological characterisation of pitchstone is presented below in Section 3).

Although the provenance of archaeological pitchstone has been discussed on a number of occasions, first by Mann (1918) and fifty years later by Ritchie (1968), the most influential contribution in this respect is arguably that of Williams Thorpe & Thorpe (1984). Their now widely cited paper on the distribution and sources of archaeological pitchstone in northern Britain is based on petrographic, chemical and thin-section analyses of archaeological pitchstone, and by comparison of archaeological samples with samples of geological pitchstone from various parts of the BTVP, it was concluded that most, if not all, archaeological pitchstone derives from the Isle of Arran in the Firth of Clyde. As almost all of the analysed samples represented homogeneous aphyric glass (ibid, 16) they suggested that the so-called Corriegills outcrops, on Arran's east coast (see illus 24), were the most likely sources of the archaeological pitchstone. This suggestion has been accepted by many scholars as an accurate description of the archaeological reality, and it has become the logical point of departure for archaeological research into the use of Arran pitchstone in Scottish prehistory.

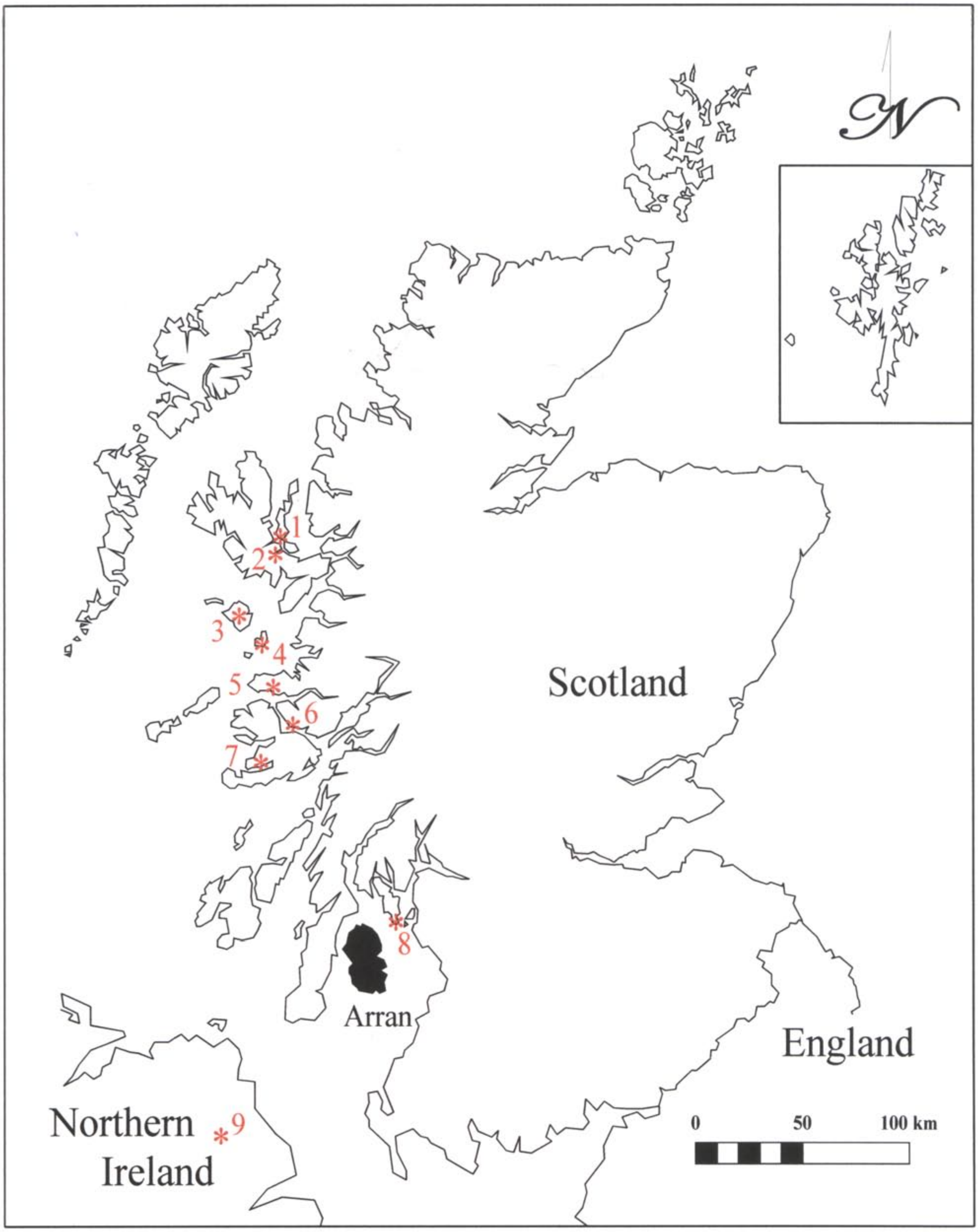
Although the sills of the Corriegills district are likely to be the main sources in relation to the approximately 1000 years of pitchstone exchange with mainland Scotland, Williams Thorpe & Thorpe's suggestions probably do not cover the situation within Arran precisely, as pitchstone procurement for local use is likely to have included many of the more localised, smaller outcrops. Recent research has shown that assemblages outwith Arran may also include non-Corriegills pitchstone artefacts (for example, Blackpark Plantation East on Bute and Barnhouse on Orkney; Ballin et al forthcoming; Ballin forthcoming (a)).

The weak point of Williams Thorpe & Thorpe's otherwise brilliant paper is the fact that they disregarded many pitchstone sources *a priori* with reference to arguments which may appear logical to a modern person, but which probably had no relevance to prehistoric people. Their main reasons for de-selection of pitchstone sources were: 1) The quality (that is, homogeneity, 'knappability') of the individual pitchstone sources; 2) the size of the outcrop; 3) the degree of exposure; and 4) source remoteness in relation to known prehistoric habitation.

Material homogeneity: It is clearly Williams Thorpe & Thorpe's presumption that aphyric pitchstone was much more desirable than porphyritic pitchstone (for example, 1984, 17–19), and in terms of the use of this material at the beginning of the Early Neolithic period, they are probably right. As recent research has shown (Ballin 2009), this phase of the Early Neolithic period was characterised by the production of exceedingly small microblades (as demonstrated by finds in radiocarbon-dated pits; for example, Fordhouse Barrow in Angus, Carzield in Dumfries and Brownsbank and Nether Hangingshaw near Biggar in South Lanarkshire; Maynard 1993, 31; Ballin & Ward 2008; Ballin 2004 (a)), and it would have been impossible to produce these (usually 6–10mm wide) blanks in porphyritic pitchstone, or even in aphyric pitchstone with large spherulites (quartz/feldspar devitrification products; see Section 3.2).

However, as the Neolithic period progressed, blades grew increasingly larger (Ballin 2009), and at some stage in the middle or later Neolithic period, the average blades were so broad and thick that it was possible to produce them in porphyritic pitchstone without risking immediate fragmentation. At Late Neolithic Barnhouse on Orkney (Ballin forthcoming (a)), three blades are between 10mm and 16mm wide, and at this site lightly porphyritic pitchstone was used, in conjunction with aphyric material; at Late Neolithic Blackpark Plantation East on Bute (Ballin et al forthcoming), 19 blades are between 10mm and 30mm wide, with two-thirds of the pieces exceeding 15mm. In this case, the assemblage is dominated by heavily porphyritic pitchstone.

Size of outcrop: The size of the outcrop may be relevant in relation to the procurement of material for large-scale 'export', but it is quite likely that the prehistoric inhabitants of Arran also exploited



Illus 1 The location of the Isle of Arran, and the distribution of pitchstone occurrences throughout the British Tertiary Volcanic Province (BTVP)

smaller local sources for their own everyday implements. In his paper on the use of quartz on Lewis, one of the authors (Ballin 2004 (b)) demonstrated how the inhabitants of prehistoric settlements along the Lewisian west coast procured most of their quartz from small local outcrops, or, as it was put, 'back-yard quarries'. It cannot be ruled out that the inhabitants of Arran also exploited so-called 'back-yard sources' of pitchstone, and not only the major outcrops listed in Williams Thorpe & Thorpe (1984).

Degree of exposure: The level of exposure may seem to be an obvious premise, as an outcrop would have had to be visible in prehistory to have been discovered and exploited. However, even this argument is dubious, as it is a very subjective measure. How exposed is *sufficiently* exposed? This question becomes particularly relevant in conjunction with argument 2, above. Another point is that prehistorically available sources may have been completely depleted, or they may have been covered entirely or partially by later soil creep, mudslides or peat formation.

Source remoteness: The argument of remoteness (that is, the distance of outcrops to known habitation/inaccessibility) seems logical to the modern mind, but it has been demonstrated in recent years how many raw materials were quarried in prehistory in extremely remote areas, such as in Shetland's North Roe area (Ritchie 1968; Ballin forthcoming (b)), in the Great Langdale area of Cumbria (Bradley & Edmonds 1993) and in fairly inaccessible parts of Perthshire (Edmonds et al 1992). In cases where a raw material was associated with non-functional values, prehistoric people apparently went out of their way to acquire it. Viewed from this angle, it cannot be ruled out that pitchstone was quarried, for example, from the many dykes and sills in 'The Granite' of northern Arran (see illus 24).

In relation to the question of remoteness/access, it may be relevant to address the problems posed by vegetation. In prehistory, vegetation cover would have obscured many sources at lower levels in southern Arran (as experienced by one of the authors in connection with his survey of the Arran outcrops), whereas the sources at higher elevations in northern Arran (a barren 'lunar' landscape) would have been visible throughout the year. Including vegetation as a factor, the 'remote' and 'inaccessible' sources near the summits of northern Arran may have been the most accessible sources, in practical terms, and several of these outcrops are of significant proportions (Tyrrell 1928).

Examination of geological maps (Ordnance Survey 1972 and 1987) and literature (for example Judd 1893; Gunn et al 1903; Tyrrell 1928) indicates that pitchstone is widely distributed across Arran (illus 24). These pitchstone sources are presented in the present paper, in the form of a gazetteer, which is the main outcome of the Arran Pitchstone Survey Project (APSP), combined with the results of examination of geological samples in the stores of the Hunterian Museum and studies of relevant archaeological and geological literature. As part of the APSP, a survey of Arran was carried out, generously funded by the Society of Antiquaries of Scotland. This investigation was undertaken by Dr Ballin, who spent seven days inspecting the island. The survey had multiple aims and objectives, such as:

- To find and examine as many as possible of the outcrops described in the geological literature; the main purpose of this exercise was to test the above points regarding potential relevance to prehistoric people (material homogeneity, outcrop size, degree of exposure and remoteness).
- To examine the known sources for obvious signs of having been quarried in prehistoric times (cf Ballin 2004 (b)).
- To sample known outcrops to provide hand samples for future archaeological and geological research (for example, to allow specialists at Lithic Research and the Hunterian Museum to be consulted by archaeological units in connection with new finds of worked pitchstone); most of the survey's samples were kept by Lithic Research (Dr Ballin), but samples were also offered to the Hunterian Museum (Dr Faithfull), and, in exchange, parts of existing hand samples were offered to Lithic Research by the Hunterian Museum.
- To find and sample new exposures, or secondary deposits which may indicate outcrops in the vicinity of the findspots.

It is hoped that the resulting gazetteer may – as a tool for future research – increase the understanding of how pitchstone was perceived, exchanged and used within as well as outwith the island. In general terms, the gazetteer should provide a more rigorous basis for archaeological and geological assessment of pitchstone artefacts and sources.

The APSP forms part of the broader Scottish Archaeological Pitchstone Project (Ballin 2009), the main purpose of which was to update Williams Thorpe & Thorpe's (1984) catalogue of pitchstone-bearing sites across Scotland as a whole (supplemented by a small number of find locations in northern England, Northern Ireland and the Isle of Man), and it is hoped that this project will lead to greater understanding of the territorial structure of Neolithic Scotland and the exchange network responsible for the prehistoric dispersion of raw and worked Arran pitchstone.

The present paper consists of three main parts, namely a) a geological section, defining and characterising pitchstone and the different varieties of pitchstone encountered on Arran; b) the actual gazetteer of Arran pitchstone, listing and characterising the presently known outcrops; and c) a brief concluding section, in which the distribution of pitchstone outcrops is discussed in relation to the distribution of worked pitchstone across Arran and Scotland.

3 PITCHSTONE – ITS PROPERTIES, FORMATION AND PROVENANCE

3.1 What is pitchstone?

Pitchstone is glassy, usually silica-rich, igneous rock with a characteristic lustre resembling that of broken pitch. Pitchstones are generally held to be hydrated equivalents of obsidians, although the usage of both terms (along with others, such as vitrophyre) has often been imprecise (cf Pellant 1992).

For example, the widely used British Geological Survey classification scheme (Gillespie & Styles 1999) gives pitchstone as an approved rock name, under '8.3 "Sack" names for rocks which are difficult to classify in the field'. Pitchstone is characterised as '. . . a glassy altered (hydrated, devitrified) igneous rock. The term has no compositional significance'. Obsidian is defined as 'a glassy fresh igneous rock. The term has no compositional significance'.

The International Union of Geological Sciences has recently published a comprehensive nomenclature scheme for these and other igneous rocks (Le Maitre 2002). Here, the term pitchstone is restricted to hydrated glassy rocks (typically 3–10% H_2O), while obsidians are nearly anhydrous (< 1% H_2O). Most pitchstones have > 5% H_2O, and most obsidians < 0.5%.

Formal nomenclature would strictly require quantitative chemical analysis of each rock specimen. However, from the relatively small available subset of analysed Arran glassy rocks, it appears that all would be pitchstones in this sense and, anyway, the water content is roughly correlated with the characteristic pitchstone lustre, which allows fairly reliable field identification.

These chemical differences do seem to be marked by differences in appearance and properties. Pitchstones typically have a duller lustre than obsidians, perhaps due to the abundance of microscopic crystallites they tend to contain. Dietrich (2005) has suggested that pitchstone may sometimes offer increased toughness relative to obsidian – it is possible that this might be related to crystallite abundance or distribution. Whether pitchstones are in general less brittle than true obsidians is unclear. Brittleness would be a very significant factor in utilisation of rock materials as tools.

3.2 Characterising pitchstones

Pitchstones may be described in terms of a number of components, such as:

1. Glassy matrix.
2. Phenocrysts: larger isolated or clustered crystals formed at depth during slow cooling.
3. Spherulites: finely crystalline, usually radiating intergrowths of quartz and feldspar, indicating devitrification of the glass phase.
4. Crystallites (formerly occasionally termed microlites): very small skeletal or dendritic crystals, often Fe-Mg silicates, in glass; banding in pitchstones is often marked by variation in crystallite density.
5. Other alteration products.

In general, a high concentration of phenocrysts or spherulites would seem likely to have a negative effect on the workability or edge-keeping properties of pitchstone. However, a small number of porphyritic pitchstone artefacts have been recovered off Arran (for example, Ballin et al forthcoming), and, on Arran, many assemblages include as much as 30% porphyritic pitchstone (for example, Finlay 1997).

Glassy rocks, including Arran pitchstones, often show flow-banding or other heterogeneity. This is largely a consequence of the very high viscosity of these melts, resulting in laminar flow during intrusion, and hence little mixing or homogenisation, compared with a turbulently convecting, low-viscosity magma. The banding is almost always emphasised by weathering, or other alteration. It doesn't usually affect the way the pitchstone breaks or flakes, although some very late folds have developed brittle axial-planar cleavage. In these cases, both the fold surfaces and the cleavages can become breakage surfaces, especially where preferentially attacked by alteration.

Alteration of glassy rocks such as pitchstone is marked by devitrification – the breakdown of the glassy component of the rock into crystalline mineral phases. This typically starts with the formation of isolated spherulites, involving very small elongated fibrous crystals growing radially from a nucleation point, which may be an existing phenocryst or crystallite. Spherulites often tend to nucleate preferentially in particular flow-bands within glassy rocks, and this can lead to emphasised flow-banding in partially devitrified rocks. Devitrified pitchstones (usually termed felsites) have a lower H_2O content than their pitchstone precursors, and are mineralogically dominated by quartz and feldspar.

When geologists compare and discuss pitchstone samples, they routinely refer to the colours of these samples. However, standard colour charts are rarely used in this context, and their use is probably limited for most geological work. Rock colour is generally quite variable due to outcrop or hand-specimen inhomogeneity (for example, layering and variation in composition), and colour may also

Illus 2 Tabular scrap from Torrs Warren, Dumfries & Galloway (Cowie 1996). This was probably the form pitchstone was traded in. In this case, the light-brown colour of the pitchstone shows that the pieces have been exposed to fire.

be highly affected by small degrees of difference in weathering or alteration (in terms of pitchstone, for example, devitrification). Both of these factors apply to the colours of Arran pitchstones, which is why the authors only use rather general subjective descriptions: attempting to be more precise would be as likely to mislead as shed light, at least given the current sample database.

The colour of archaeological pitchstone may occasionally be slightly puzzling, as it commonly deviates from that of geological pitchstone (illus 2–8 show a number of typical pitchstone artefacts, and give examples of pitchstone types and attributes commonly experienced in connection with worked pitchstone). Archaeologists occasionally find grey or light green/light brown pitchstone, for example, and in these cases, it is likely that the colours of the pitchstone artefacts may have been affected after abandonment and deposition in prehistoric times: dull grey aphyric pitchstone from archaeological sites probably always represents superficial weathering (probably superficial devitrification and leaching), which may be revealed by examination of the artefacts' chipped edges, where the original dark colour commonly shows through; and light green/light brown colours, frequently associated with micro-crazing or crumbling, are a sign of these pieces having been exposed to fire.

3.3 The four 'classic' pitchstone types

Tyrrell (1928) suggested that most Arran pitchstones fall into four categories, which he defined on the basis of textures and mineralogy: *Corriegills* (aphyric); *Glen Shurig* (quartz, feldspar, fayalite and pyroxene phenocrysts, with fayalite ≥ pyroxene) and *Tormore* (ditto, but pyroxenes much more abundant than fayalite). The *Glen Cloy* pitchstone type is chemically different, being poorer in silica, and much darker in colour, even under the microscope. However, there are many rocks which don't fit this scheme (for example pitchstones with only quartz and feldspar phenocrysts, or those where orthopyroxene is dominant, or some very highly porphyritic types).

Illus 3 Probable Early and Middle Neolithic blades and microblades from Auchategan, Argyll & Bute (Ballin 2006). Aphyric pitchstone.

Illus 4 Pitchstone cores from Auchategan (Ballin 2006). Aphyric pitchstone.

Illus 5 Late Neolithic blade-like flakes and squat flakes from Barnhouse on Orkney (Ballin forthcoming (a)). Lightly porphyritic and clearly spherulitic pitchstone.

Tyrrell's classification was never intended to be a rigid framework. There is a continuum between many of the groups, and the range of rocks is much greater than this classification suggests. We suggest that it is dropped in favour of simple descriptive names based on texture, phenocryst assemblages and glass composition.

Most of the Scottish occurrences of archaeologically usable pitchstone are in Arran, and most of the other Scottish occurrences are notably less 'glassy'. However, there are some other localities which produce material which might be mistaken for Arran pitchstone. At Fiunary, north-west of Lochaline (Morvern, Argyll), there is a composite dyke with a central unit of green glassy pitchstone, more than 1m thick (Faithfull 2007). Given its size, it may well have been used in the Neolithic, but at present little is known about this rock. Another locality which produces material rather like some of the Arran pitchstone, is Rudh' an Tangaird, on Eigg, where a small dyke of relatively homogeneous, glassy, porphyritic pitchstone is very similar to some material from the north end of 'Judd's No. I dyke' (see gazetteer entry no. 91 below), at Tormore on Arran. These and other occurrences need to be taken into account in any comprehensive review of potentially archaeologically relevant pitchstone sources.

Illus 9–21 present an overview of the variability experienced when dealing with Arran pitchstone. It has been attempted to cover attributes such as colour, lustre, flow-structures and content of phenocrysts, spherulites and crystallites.

Illus 6 Very large Late Neolithic blades from Blackpark Plantation East on Bute (Ballin et al forthcoming). Heavily porphyritic pitchstone.

Illus 7 Grey, superficially weathered pitchstone from Biggar in South Lanarkshire (Ballin & Ward 2008). The original black colour is clearly visible where the edges have been nicked.

Illus 8 Light-green burnt pitchstone flake next to an unburnt black flake, both from Biggar, South Lanarkshire (Ballin & Ward 2008).

Illus 9 Aphyric pitchstone from Dun Fionn, Corriegills (GLAHM 134054). The pitchstone shows faint flow-banding on weathered surfaces. The pale spots on broken surfaces are small spherulites.

Illus 10 Aphyric pitchstone from a 'boss' at Monamore Mill (GLAHM 111935). Pale spherulites can be seen in the dark glass, and alteration along a fracture has resulted in these coalescing to form a line of devitrified material. A thin vertical line of dark material just right of centre indicates compositional banding of the glass.

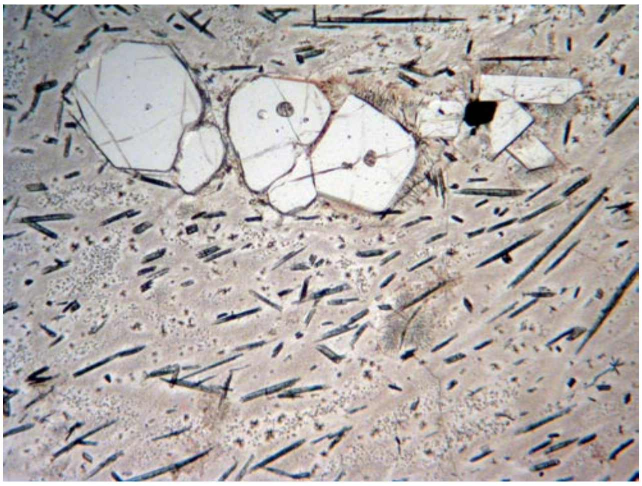
Illus 11 A very bright lustrous grey pitchstone, sparsely porphyritic, from Torr an Loisgte, Glenashdale (GLAHM 111951).

Illus 12 Porphyritic pitchstone (GLAHM 134060) from Cnocan a' Chrannchuir, near Blackwaterfoot.

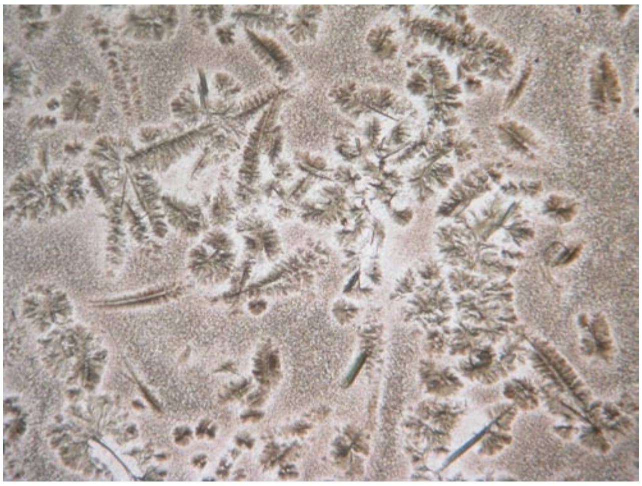
Illus 13 Porphyritic black pitchstone from the north end of Judd's No. 1 dyke, Tormore (GLAHM R14186).

Illus 14 Highly porphyritic green pitchstone (GLAHM 134050) from Glen Shurig, near Brodick. The rectangular plagioclase feldspar crystals have become pink and opaque through weathering, making them more obvious.

Illus 15 Flow-folding on weathered surface of aphyric pitchstone (GLAHM R7325) from Corriegills.

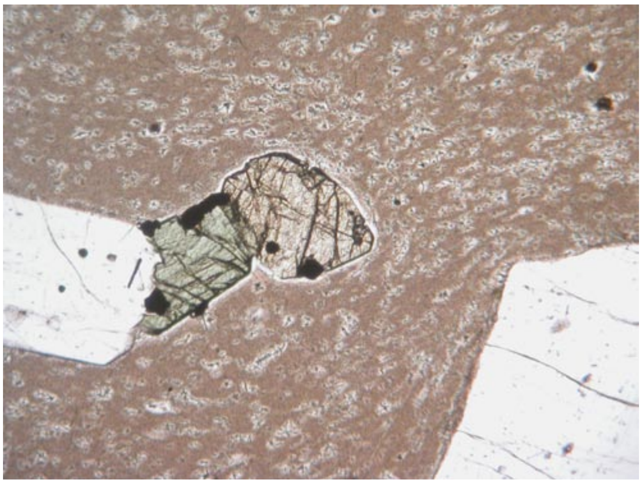


Illus 16 Quartz and plagioclase phenocrysts, with flow-aligned crystallites of amphibole. Cnoc Mor, Glenashdale (GLAHM 111967). Field of view c *2mm.*

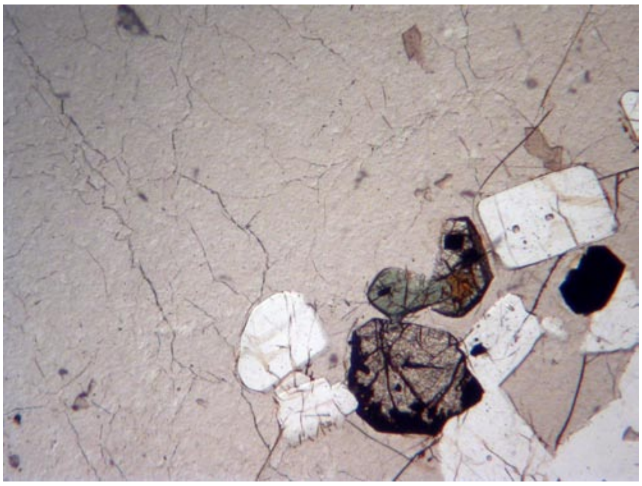


Illus 17 Pitchstone with dendritic crystallites, probably of amphibole, with 'bushy' biotite overgrowths. Dun Fionn, Corriegills (GLAHM 134054). This texture is pretty ubiquitous in Corriegills pitchstones, but is also found elsewhere. Field of view c *2mm.*

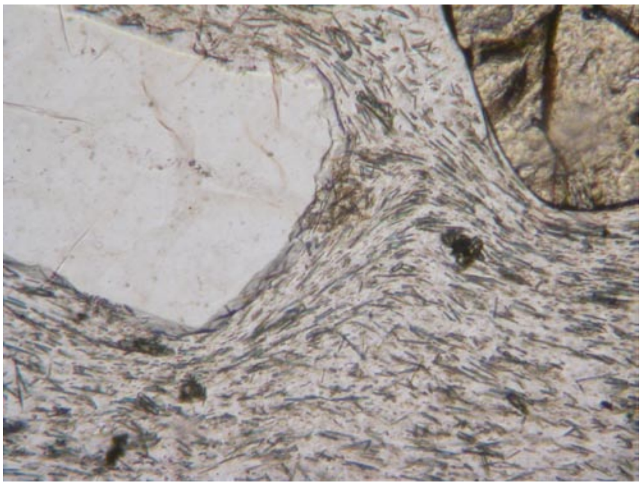
Illus 18 Dendritic amphibole crystallites, with bushy biotite? overgrowths from groundmass of porphyritic fayalite-bearing pitchstone, Cir Mhor (GLAHM 111993). Field of view c *0.5mm.*



Illus 19 Phenocrysts of plagioclase feldspar (colourless), clinopyroxene (green) and fayalite (pale brownish), in brown, crystallite-rich glass. Note glass is clear around larger crystallite clusters – a common feature of Arran pitchstones (GLAHM 134060). From Cnocan a' Chrannchuir, near Blackwaterfoot. Field of view c *2mm.*



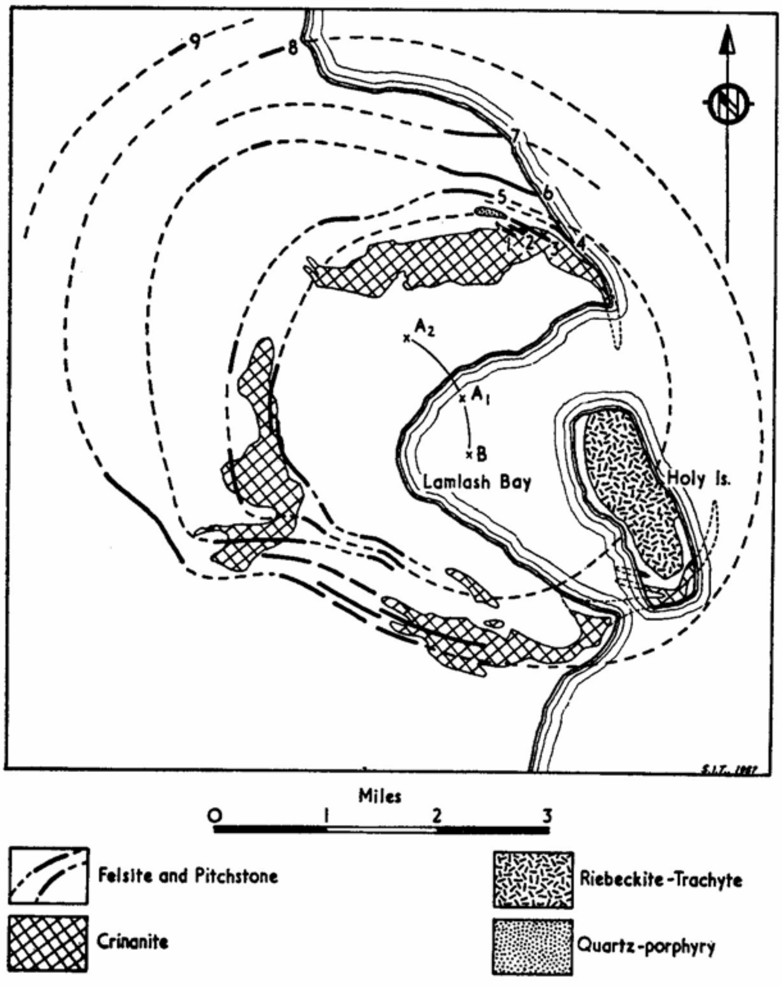
Illus 20 (left) Crystallite-free pitchstone with phenocrysts of fayalite (brownish), clinopyroxene (greenish), quartz (colourless, round) and plagioclase (colourless, rectangular). Cnoc Mor, Glenashdale (GLAHM 111968). Field of view c *2mm.*



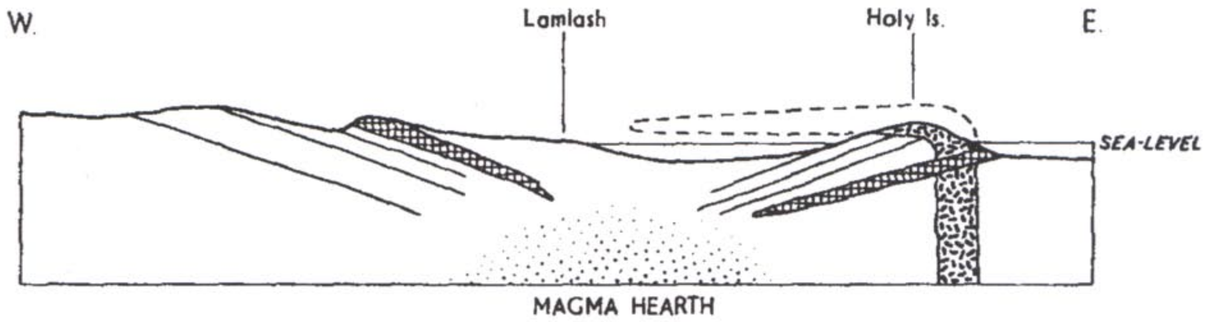
Illus 21 Phenocrysts of plagioclase (colourless) and fayalite (pale brown) in glass, with flow-banded crystallites (GLAHM 134050) Glen Shurig. Field of view c 0.5mm.

3.4 The occurrence of pitchstone

Pitchstones can occur geologically in a variety of environments. They result from the rapid cooling of silica-rich magmas (the same magmas as give rise to granitic rocks and rhyolites). Such rapid cooling is restricted to surface and near-surface geological settings. Pitchstones can therefore form as lavas or as shallow-level intrusions. Although the large Sgurr of Eigg pitchstone is a lava flow or, more likely, an ignimbrite (Brown et al 2007), most Scottish occurrences, including all the Arran ones, are intrusive sheets. Some are subhorizontal sheets or sills, while some are vertical dykes. Many are rather irregular in form, and may pass from vertical to inclined to horizontal within a few tens of metres. Frequently, they occur as 'composite intrusions', usually with a pitchstone centre, and margins of basalt, or similar rock. This juxtaposition is thought to be common because the intrusion of an initial basalt dyke provides a pre-heated conduit up which the very viscous and sluggish pitchstone magma can more easily be emplaced.



Illus 22 The Lamlash cone-sheet complex. 1. Dun Fionn II; 2. Dun Fionn III; 3. Dun Fionn I; 4. Clauchlands shore; 5. South Corriegills; 'Magmatic Rolls Quarry'; Lag a' Bheith; 6. Corriegills shore; Glen Cloy; Glen Dubh; 7. Felsite-tholeiite composite sheet at Corriegills point; 8. Brodick Schoolhouse; 9. Glen Shurig (Tomkeieff 1961, 7).



Illus 23 West to east section across the Lamlash cone-sheet complex, showing basic and acid cone-sheets and the ring-dyke of Holy Isle passing into a roof-intrusion (Tomkeieff 1961, 9).

The pitchstones of Arran are widespread, but they are a late feature of igneous activity – they are found cutting (and hence postdate) most of the other Tertiary volcanic rocks. Only a few basalt dykes seem to postdate the pitchstones. Their emplacement late in the history of the Arran igneous centre, when hydrothermal activity was waning, or absent, is probably responsible for their survival – any older glassy rocks would have been altered by such activity.

Tomkeieff (1961, 6) explains the distribution of pitchstone outcrops in the Brodick Bay/Lamlash Bay area as parts of an extensive cone-sheet complex, centred on Lamlash Bay (illus 22–23). This model explains the location and orientation of important outcrop groups like, *inter alia*, Glen Shurig, Brodick Schoolhouse, Glen Cloy, the Corriegills/Clauchland Hills sites, the Lag a' Bheith sites, and the Monamore sites.

3.5 Characterising pitchstone sources

Pitchstones can be characterised using a wide range of methods:

1. *Macroscopic*: colour; lustre; banding; phenocrysts. Non-destructive.
2. *Optical microscopy*: crystallite and phenocryst morphology, size and distribution; mineralogical identification of phenocrysts. Destructive – requires thin-sectioning.
3. *Electron beam analysis*: glass, crystallite and phenocryst characterisation – identification down to very small sizes. Enables major and minor (> 0.1–0.5% abundance) elemental analysis of most elements on areas as small as 1–2 microns. Ideally requires a flat, polished and carbon-coated surface, but limited results may be achievable without destructive preparation.
4. *Bulk analysis*: can include trace elements (< 0.1%), as well as major and minor elements, which may be useful discriminants. Such analysis is usually destructive, and can have problems with reproducibility and interpretation, when based on small samples of heterogeneous rocks.
5. *Other beam spectroscopic methods*: for example some forms of XRF, Raman or FTIR spectroscopy and so on. There is a large range of methods which have potential to provide chemical and/or mineralogical information from pitchstones. Many of these can be used non-destructively on artefacts, albeit at the expense of quantitative precision. Simpson & Meighan (1999) used X-ray fluorescence to estimate approximate Rb/Sr ratios for pitchstone artefacts.

There is no standard modern terminology covering the textures of the smaller crystalline phases in pitchstones. Nineteenth-century petrologists were fascinated by the tiny dendritic crystals, and a large *ad hoc* vocabulary of terms arose (for example belonite, baculite, trichite, globulite and so on).

Two terms are often used for very small crystals: crystallite and microlite. However, usage is vague and differs between, and within, various physical and biological sciences. Use of the term microlite is widespread but unfortunate, as this term has precedence of usage as a mineral species name ($Ca_2Ta_2O_7$; Shepard 1835), and so should not be used texturally. Even among geologists working on glassy rocks, usage is very inconsistent. For example, Sharp et al (1996), describing rhyolitic glass textures, use three terms for small crystals: microphenocrysts (> 1.2 microns wide); microlites (> 0.6 microns wide); and nanolites (< 0.6 microns wide). However, Hunt & Hill (2001) use 'microphenocryst' for crystals in the range 10–500 microns, microlite for < 10 micron crystals of sufficient size to show polarisation colours and crystallite for < 10 micron crystals which do not show polarisation colours. Preston et al (2002) use the term microcrystallite to distinguish smaller crystallites.

Authors tend to use these (and other terms) to emphasise clusters in crystal-size distribution in particular groups of rocks. The degree of such clustering, and the size ranges involved, vary widely, and hence the terms have little or no absolute value (as emphasised by for example Mortazavi & Sparks 2004). Rather than attempting to create a rigorous and standard terminology, it is probably more useful for authors to use simple terms such as phenocryst, microphenocryst, crystallite and microcrystallite, but define usage in each case. We suggest that the term microlite should not be used.

Preston et al (2002) report some initial findings on crystallite compositions from Arran and other pitchstones. These locally include some unusual amphibole compositions (for example ferrowinchite), normally characteristic of metamorphic rocks, in worked artefact material, almost certainly sourced from Arran, found at Ballygalley in Northern Ireland. There is an inadequate database of detailed work on crystallite mineralogy in glassy rocks, but it may be that the anomalous composition of these crystallites reflects accidental or deliberate heating during or after the tool-making process, or it may be that these odd compositions are the result of rapid disequilibrium growth.

Crystallites are potentially a very fruitful area of investigation. They are abundant on a micro-scale, and are probably directly related to their enclosing glass – their delicate skeletal textures indicate in situ growth. They seem to have formed before solidification of the glass, as they are often flow-aligned, and they are thus unrelated to the later spherulites formed during devitrification. Larger phenocrysts can survive magma mixing, and may be inherited, or transferred, from other magmas, and their distribution is patchy on a thin-section or small-artefact scale. Crystallites, however, are usually widely present in even small samples of aphyric pitchstone. Most artefact-use involves phenocryst-poor, or aphyric pitchstone, so it is the characterisation of these materials which is of greatest interest (albeit not in the case of Blackpark Plantation on Bute; Ballin et al forthcoming). A combination of glass chemistry, and crystallite identity, chemistry, morphology and distribution is likely to be applicable to even small samples of almost all pitchstones.

4 THE GAZETTEER'S BACKGROUND

The gazetteer has been compiled mainly on the basis of the available geological literature, most of which dates to the period 1860 to 1930 (for example, Bryce 1859; Judd 1893; Gunn et al 1903; Tyrrell 1928). Detailed guides to the Arran geology were produced through the entire 20th century (for example, Gregory & Tyrrell 1924; Tomkeieff 1961; Macgregor 1983, his first edition being presented in 1965; McKerrow & Atkins 1989).

The 1-inch or 1:50,000 geological maps of Arran are a standard source of geological information, but they are a very poor source of information on pitchstone occurrences. At these scales, many pitchstone occurrences have simply had to be omitted for clarity. Different editions of the map (for example, Ordnance Survey 1972 and 1987) also include different selections of occurrences. In addition, the colour used for pitchstone intrusions, and the key letters, are very similar to those for other silicic minor intrusions. This makes it very hard to distinguish pitchstone occurrences from other compositionally similar rocks on the maps.

Judd's paper (1893) is arguably the first 'modern' discussion of Arran pitchstone, with the author discussing the definition and classification of composite dykes, clarifying the terminology surrounding acid intrusions (for example, disposing of terms such as 'trap', 'claystone' and 'hornstone') and presenting important outcrops in the north (Cir Mhor) and on the island's west coast (the Tormore dykes, now referred to as 'Judd's Dykes'); Gunn et al (1903) presents the most substantial pitchstone sources in Arran's northern half, whereas Scott (1915b) deals with the outcrops of southern Arran; and Tyrrell (1928) combines the above three papers, supplementing with information from multiple minor papers (for example, Allport 1872; Bell 1874; Glen & Young 1884; Zirkel 1894; Corstorphine 1895; Scott 1915 (a)), to produce what is probably still the pre-eminent paper on Arran's geological pitchstone and its sources.

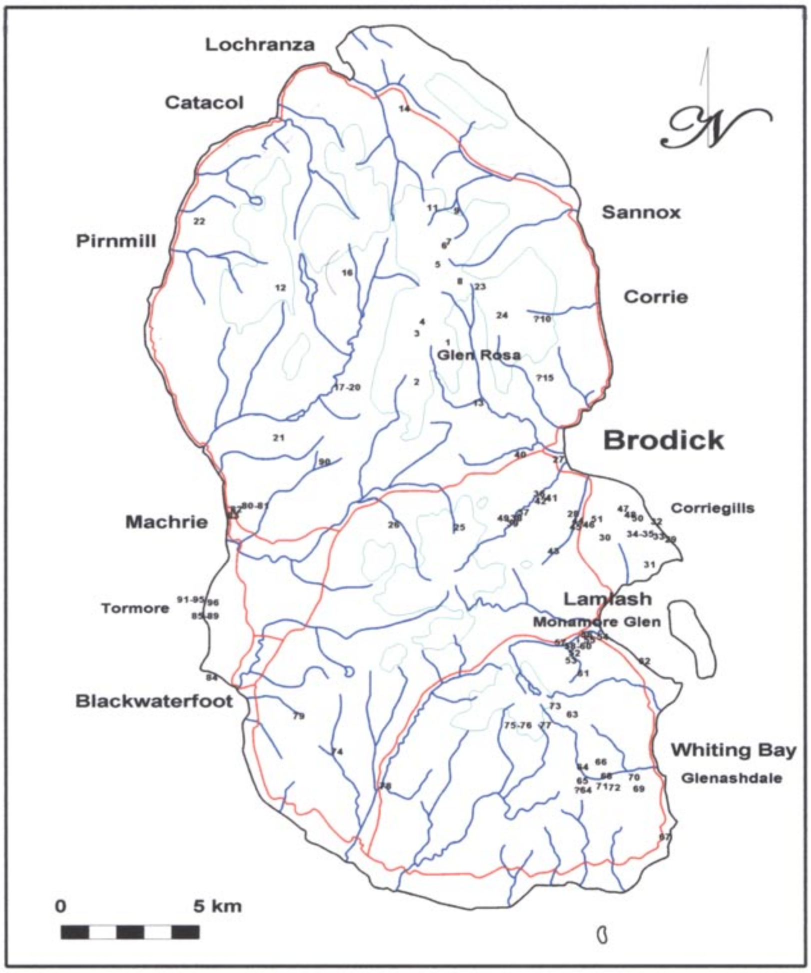
Due to the fairly comprehensive nature of Tyrrell's catalogue (1928), the authors found it natural to let this compilation form the point of departure for the production of the gazetteer. On the basis of the geological literature listed above, as well as results from the survey, outcrops were then either added to Tyrrell's catalogue, or this literature was consulted to expand on Tyrrell's occasionally very brief entries. Diagrams have been included from the primary papers to explain either the location of the outcrops, or the local, frequently complex, geological setting. A number of the most important pitchstone sub-types have been photographed, macroscopically as well as in thin-section, to give the reader an impression of the huge variation between the local forms (see geological section, above).

An important part of the production of the present paper was to re-calculate the original imperial measurements, from inches, feet, yards and miles to centimetres, metres and kilometres. This was of importance to the description of site location, as well as to the characterisation of the individual outcrops. As most of the gazetteer's captions have been copied from the original 19th- and early 20th-century literature, these include some terms which are now deemed obsolete, such as 'trap', 'claystone' and 'hornstone'. It was difficult to replace these terms in a consistent manner, as they did not always refer exactly to the same rock forms. It was therefore chosen to retain these terms in the captions, and the reader is referred to the glossaries at the end of the paper, in which they are explained.

As the original geological literature did not include national grid references, and as the same outcrops might occasionally be referred to under different names (for example, Gunn's *Birk Glen* site corresponds to one of Tyrrell's *Lag a' Bheith* locations), it was difficult to identify the individual outcrops in dense clusters of outcrops, such as, the Glen Cloy/Kilmichael sites; the Lag a' Bheith sites; the Corriegills/Clauchland Hills sites; and the Monamore Glen sites. Absolutely certain identification of these outcrops is not possible without a complete geological inspection of all Arran pitchstone sources. Consequently, it should be noted that all grid references are approximations.

The individual entries of the gazetteer include: 1) main name, and alternative names, of each location; 2) national grid reference; 3) description of the outcrop and other relevant site information; 4) attributes of the individual pitchstone forms (primarily colour and porphyritic/aphyric status); and 5) relevant references. The locations of the individual gazetteer entries can be seen in illus 24.

As part of the compilation of the present gazetteer, the authors examined pitchstone samples from the survey, as well as samples in the stores of the Hunterian Museum and Art Gallery, Glasgow. The geological collections of the Hunterian Museum and Art Gallery include a large number of specimens from Arran, most of which were collected by G.W. Tyrrell, the author of the 1928 Arran memoir. As part of this project, we have attempted to locate all the Hunterian Arran pitchstone specimens, and add them to the museum's computer catalogue, together with hand-specimen and (where available) thin-section images. As a result of this work there are now 111 Arran pitchstone records with images (plus many pitchstones from other Scottish localities, as



*Illus 24 The location of Arran's known pitchstone outcrops. The numbers on this map correspond to the site numbers in the Gazetteer. Red lines = main roads; green lines = 1200 ft contours (*c *365m); blue lines = water courses.*

well as felsites) available via the online catalogue at: http://www.huntsearch.gla.ac.uk.

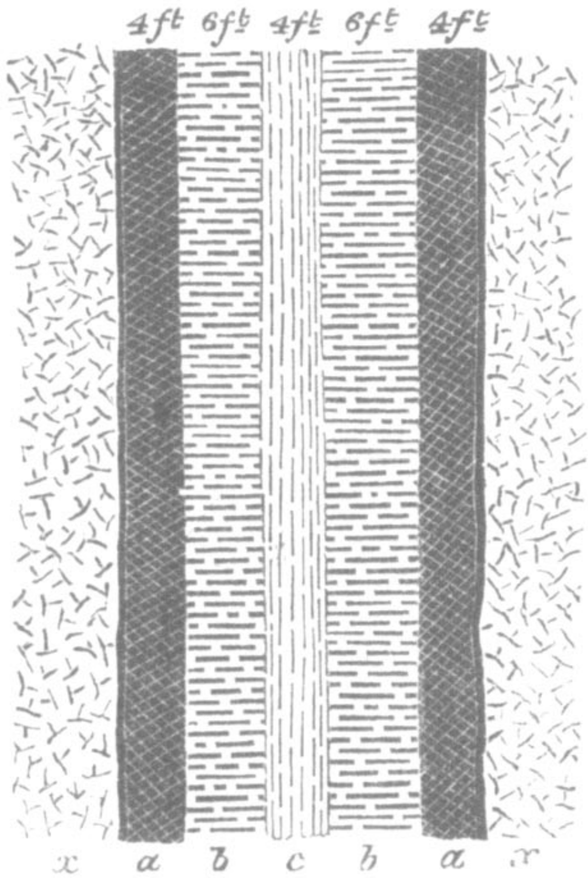
There is also a page giving direct links to various categories of pitchstones from the catalogue at: http://www.hmag.gla.ac.uk/john/pitchstone/.

This resource contains a few pitchstone occurrences which are not otherwise documented in the literature. They are included in this gazetteer. The Hunterian also contains the thin-section collection, and geological field-slips of Alex Herriot, who worked extensively on the minor intrusions of the island. These are not yet available on computer, but represent a further useful resource for pitchstone investigators.

5 GAZETTEER OF PITCHSTONE OUTCROPS ON THE ISLE OF ARRAN

North Arran (the 'Granite')

1. Beinn a' Chliabhain
   NGR: NR 970 407
   A composite dyke with basic sides and a pitchstone centre occurs 50m north of the highest point (675m), and again 300m to the east.
   Porphyritic, colour unknown.
   Gunn et al 1903, 94; Tyrrell 1928, 207.
2. Beinn Nuis
   NGR: NR 958 394
   A pitchstone dyke, 2m wide, is found approximately 500m south-east of the summit.
   Porphyritic, grey-green to dark green.
   Gunn et al 1903, 94; Tyrrell 1928, 208.
3. Beinn Tarsuinn I
   NGR: NR 958 411
   A pitchstone outcrop is visible 150m south-west of the summit. There are probably other small outcrops on this hill. 'One [dyke] is of green pitchstone, and cuts the granite sheer through in a north and south direction from bottom to top of the cliff. It is [1–1.5m] wide, prismatic across and, owing to the more rapid disintegration, depressed below the level of the granite. [. . .] The pitchstone is decomposed into a thin white film in many places along the outer edge of the dyke, next to the granite, in consequence, probably, of the oxidation and removal of the iron which enters into its composition. The dyke is in some parts of its course obscured by debris, but upon the whole is, perhaps, the best defined dyke of this rock occurring anywhere in the granite of Arran.' (Bryce 1859, 100).
   Porphyritic, grey-green to dark green.
   Gunn et al 1903, 94; Tyrrell 1928, 208.
4. Beinn Tarsuinn II
   NGR: NR 961 415
   No information available.
   Porphyritic, grey-green to dark green.
   BGS, Arran, 1:50,000, Solid edition, 1987; Ballin (2006 survey).
5. Caisteal Abhail I
   NGR: NR 966 437
   On the ridge between Cir Mhor and Caisteal Abhail, a pitchstone dyke occurs in the cliff a little south-east of the strong spring, and approximately 400m south of the point marked 858m on the BGS, Arran, 1:50,000, Solid edition, 1987.
   Porphyritic, dark, colour unknown.
   Gunn et al 1903, 94; Tyrrell 1928, 208.
6. Caisteal Abhail II
   NGR: NR 968 443
   A pitchstone outcrop occurs west of the highest point, and may be traced a considerable distance in a north-west direction by the loose fragments lying at the surface.
   Porphyritic, dark, colour unknown.
   Gunn et al 1903, 94; Tyrrell 1928, 208.
7. Caisteal Abhail III
   NGR: NR 969 444
   A pitchstone dyke may be found under a crag about 100m north of the summit.
   Porphyritic, dark, colour unknown.
   Gunn et al 1903, 94; Tyrrell 1928, 208.
8. Cir Mhor
   NGR: NR 974 430
   Pitchstone forms the centre of a composite dyke on Cir Mhor, running east–west. The dyke is exposed in a steep gully on the eastern face of the mountain, attainable by a stiff climb from The Saddle between Glen Rosa and Glen Sannox. It consists of five members: two external margins, each approximately 50cm thick, of a brown-weathering spheroidal tholeiite, which is blue on a freshly-broken surface; two interior quartz-felsites, a whitish rock with well-marked vitreous contacts against the tholeiite, each band being almost 2m thick; and finally a central band of pitchstone approximately 60cm thick, which narrows in one place to *c* 30cm. Microscopic examination shows that the felsite is merely a devitrified phase of the pitchstone. Measurements across the dyke roughly halfway up the gully show that the total width there is about 5m. Judd gives the min. and max. widths as *c* 3.5m and *c* 9m, respectively.
   Porphyritic, dark green.
   Judd 1893, 543–551; Gunn et al 1903, 94; Tyrrell 1928, 208.



Illus 25 Diagrammatic plan of the Cir Mhor dyke (CAT 8) (Judd 1893, 545): x = granite; a = augite-andesite; b = quartz-felsite; c = pitchstone porphyry (b, c = quartz-pantellerite).

Illus 26 The composite dyke of Cir Mhor (CAT 8) (Gregory & Tyrrell 1924, Plate 26B): P = pitchstone; F = felsite; T = tholeiite.

9. Coire nan Ceum
NGR: NR 974 456
At this locality, a 2m thick dyke of porphyritic felsite with pitchstone on its northern margin crosses the burn in a north-easterly direction. A short distance downstream is a thin northwest-trending basaltic dyke. A series of moraines is to be seen on the corrie floor a little higher up. These are among the most recent in the whole of Arran and were probably formed by a small glacier about 9500 BC.
Porphyritic, colour unknown.
Macgregor 1983, 120.

10. Corrie Burn
NGR: NS 00 41
A coarsely porphyritic pitchstone with phenocrysts (up to 7mm) of skeletal plagioclase, embayed quartz and euhedral clinopyroxene in a matrix of flow-banded glass was found, probably as a loose block, in the Corrie Burn, probably outside the granite. Texturally this resembles some of the pitchstones (for example Bute, An Cumhann) found associated with quartz-feldspar porphyry intrusions, but lacks K-feldspar phenocrysts.
Porphyritic, colour unknown.
Kanaris-Sotiriou & Gibb 1985; Kanaris-Sotiriou & Gibb pers comm 2007.

11. Creag Dhubh
NGR: NR 964 456
Approximately 1.5km north of Caisteal Abhail a pitchstone dyke roughly 2m wide is visible for a short distance under the scars of Creag Dhubh.
Porphyritic, colour unknown.
Gunn et al 1903, 94; Tyrrell 1928, 208.

12. Dubh Loch
NGR: NR 908 428
On the slopes of Bheinn Bharrain approximately 400m north-west of the Dubh Loch is a pitchstone outcrop, *c* 1–1.5m thick, which may be traced to the WSW for nearly 200m.
Porphyritic, yellowish, streaky.
Gunn et al 1903, 94; Tyrrell 1928, 208.

13. Garbh Allt
NGR: NR 981 387
One of the authors found a large nodule of pitchstone in the footpath descending from Beinn Nuis, on the northern side of Garbh Allt, and approximately 100m from the footbridge across the burn, at the mouth of Glen Rosa. This location may correspond to Macgregor's (1983) fig 6.12: '. . . note the presence of occasional thin dykes and crush-lines in the granite'.
Porphyritic, grey-green to dark green.
Ballin (2006 survey); Macgregor 1983, 86.

14. Glen Chalmadale
NGR: NS 95 49
Loose boulders (specimens in the Hunterian collections, Glasgow; collected by Tyrrell 1930).
Sparsely porphyritic, dark green.
Information in the archives of the Hunterian Museum.

15. Goatfell, SE
NGR: NS 00 39
On the south-east slope of Goatfell, above the woods surrounding Brodick Castle, there are some blocks of a magnificent pitchstone of a different character from most other pitchstones from The Granite. They lie in the bed of the carrier, which conveys water from the mill dam. The rock was not found in situ, as the ground is here very unfavourable for examination, the mountainside being covered with debris from the higher granitic masses and thickly coated with turf.
Porphyritic, greenish-black, dull.
Allport 1872, 7.

16. Iorsa Valley I
NGR: NR 934 432
In a stream roughly 1.5km north-east of the outlet of Loch Tanna there is a pitchstone dyke, *c* 1–1.5m thick, with a course due north.
Coarsely porphyritic, dark green.
Gunn et al 1903, 94; Tyrrell 1928, 209.

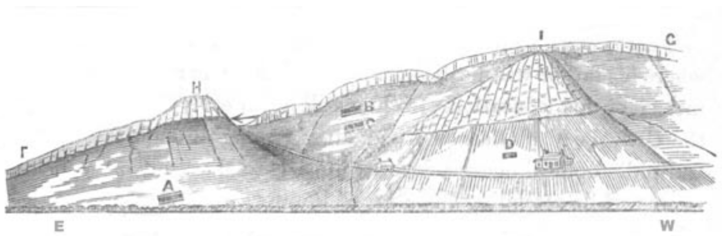
17–20. Iorsa Valley II a–d
NGR: NR 938 391
Near the heads of two small streams, approximately 1–1.5km north of Loch Nuis, dykes and sills of various kinds of pitchstone crop out in at least four places.
Porphyritic, dark green.
Gunn et al 1903, 94; Tyrrell 1928, 209.

21. Iorsa Valley III
NGR: NR 909 373
Approximately 600m SSW of the outlet of Loch Iorsa a pitchstone outcrop with a width of 2–3m is visible for about 10m.
Porphyritic, dark green.
Gunn et al 1903, 95; Tyrrell 1928, 209.

22. Penrioch
NGR: NR 885 455
North-east of Penrioch and nearly 800m ESE of Auchmore or South Thundergay is a remarkable pitchstone, only visible for approximately 6m.
Porphyritic, black.
Gunn et al 1903, 94; Tyrrell 1928, 208; Robinson 1931.

23. Saddle, The
NGR: NR 982 428
To the east of Cir Mhor, and nearly 400m south-east of The Saddle, is a pitchstone source, running WNW.
Porphyritic, greenish grey.
Gunn et al 1903, 94; Tyrrell 1928, 208.

24. Stachach, Goatfell
NGR: NR 990 417
On the ridge called Stachach, *c* 300m north of the summit of Goatfell, is a minor pitchstone source. This dyke is composed of a light-grey felsite, enclosing xenoliths of a darker igneous rock (variolitic tholeiite in thin-section). Small pitchstone fragments are scattered all over the outcrop, and as these also contain the basic xenoliths, it is probable that the felsite is merely a devitrified pitchstone.
Porphyritic, dark brown.
Tyrrell 1928, 210.



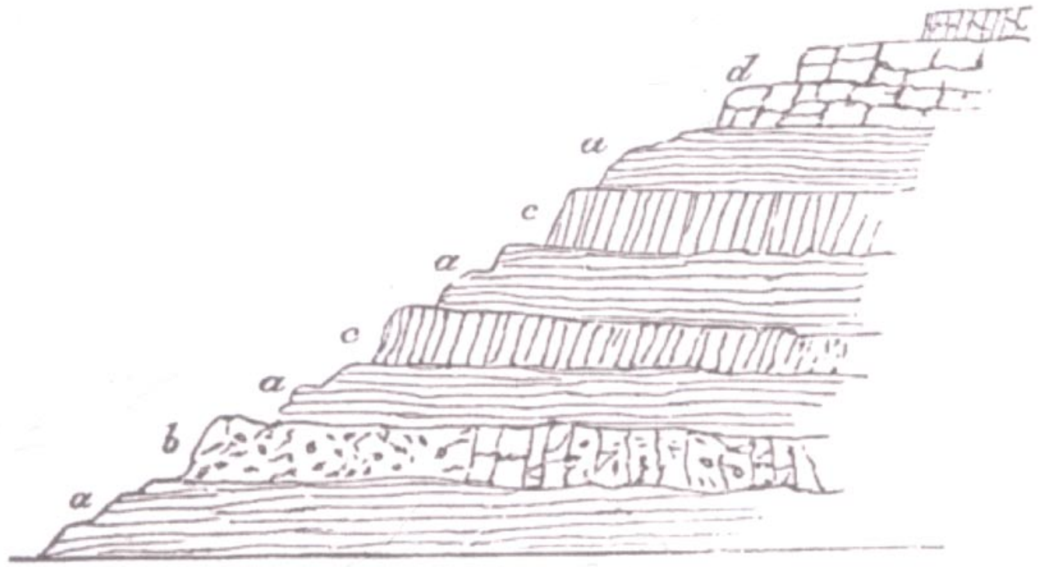
Illus 27 The Dun Fionn II pitchstone outcrops (CAT 28–29): B & C = the two higher outcrops. Continuation of the upper source behind Dun Fionn, indicated by arrow; D = portion of outcrop seen near South Corriegills (supposed continuation of shore outcrop A); F & G = Trappean ridge, extending from Clauchlands Point towards Lamlash Road; Dun Fionn (H) forming part of same; Dun Dhu (I), of claystone porphyry, rising a little in front, with a hollow between (Bell 1874, fig A).

Central Arran

25. Allt nan Calaman
NGR: NR 973 340
Loose boulders near the head of Allt nan Calaman (specimens in the Hunterian collections, Glasgow; collected by Tyrrell 1930).
Black, porphyritic.
Information in the archives of the Hunterian Museum.
26. Glenloig
NGR: NR 950 341
In a small stream on the west side of the main valley, 1km south-east of Glenloig Farm, there is a pitchstone dyke, approximately 1m wide. It runs in a north-west direction and hades south-west. The dyke cuts the explosion-breccia of the Central Ring Complex.
Texture unknown, dark green.
Tyrrell 1928, 212.

Brodick Bay

27. Brodick Schoolhouse
NGR: NS 009 365
The Schoolhouse pitchstone is exposed in the Schoolhouse garden, and in the wood to the west. It appears to be a sill injected into the steeply-dipping New Red Sandstone of that area. It also contains feldspar and olivine crystals, and is often beautifully flow-banded.
Porphyritic, dark-green to black.
Gunn et al 1903, 94; Tyrrell 1928, 210; Macgregor 1983, 80, fig 6.2.
28. Carn Ban
NGR: NS 015 346
Gunn reports that, on the south-east side of this old cairn, *c* 1200m south of Invercloy, are many small fragments of pitchstone, '. . . probably nearly in place'. He assumes the presence of a small pitchstone outcrop, but the existence at the location of a cairn suggests that the finds could be of a cultural character. Gunn's finds should be examined, and the site inspected, to clarify whether this site represents a pitchstone source or a small settlement site.
Porphyritic, dark grey to black.
Gunn et al 1903, 94.
29. Clauchland shore ('The Great Pitchstone')
NGR: NS 051 337
This is the pitchstone which has so often been described as the Corriegills pitchstone. It is, however, properly on the Clauchlands, and not on the Corriegills shore. It is visible near the base of the crags for 150m, and dips SSW at 30°, nearly as the sandstone below it, but it clearly cuts the sandstone, though there is little alteration caused by it. Nearly 200m south of this it is visible on the foreshore for about 15m. The maximum thickness may be estimated at *c* 7m.
Generally aphyric but a few well-shaped crystals of quartz are also present, dark bottle-green.
Gunn et al 1903, 93; Tyrrell 1928, 213; Macgregor 1983, 94, fig 7.15a.
30. Clauchland Hills
NGR: NS 027 337
On the path from the Lamlash Road (Cnoc na Dail forest car park) to Dun Fionn, there is a stretch of maybe 20–30m where small pitchstone pebbles can be found. This variety is – from a prehistoric knapper's point of view – beyond doubt the best-quality pitchstone to be found on the island, being absolutely homogeneous, and resembling obsidian greatly.
Aphyric, almost black.
Ballin (2006 survey).
31. Clauchlands Cottage
NGR: NS 042 327
On the southern slope of the Clauchland Hills a pitchstone dyke occurs in the burn near Clauchlands Cottage. Its direction appears to coincide with that of the burn at the point, that is, NNW.
Texture unknown, black.
Gunn et al 1903, 93; Tyrrell 1928, 213.
32. Corriegills shore ('The Small Pitchstone')
NGR: NS 046 343
About 450m south-east of the mouth of the Corriegills Burn a felsite sheet, associated with pitchstone on its lower (northern) margin, crosses the shore in a WNW direction. Where best exposed on the shore it is some 6–7.5m thick but it decreases rapidly in thickness seawards to a metre or so. It has been intruded along the bedding of the red sandstones, here dipping to the SSW at between 25° and 35°. Its upper margin is highly irregular and appears to be much more steeply inclined than the sediments. Its sill-like form is seen when traced inland, where it cuts the raised beach cliff and appears in both branches of the Corriegills Burn about 1.6km to the WNW (see North Corriegills I & II, below).
Aphyric, dull greenish-grey to green – near the sandstone with a wrinkled appearance like ropy lava, '. . . perhaps the finest spherulitic rock in Britain' (Tyrrell 1928, 212).
Gunn et al 1903, 93; Tyrrell 1928, 212; Macgregor 1983, 92, fig 7.11a.



Illus 28 The two higher Dun Fionn outcrops (CAT 28–29; B and C in fig 6.2): a = sandstone; b = feldspar porphyry; c = pitchstone; d = overlying trap (Bryce 1859, 114).

33. Dun Fionn (Clauchland Hills) I
NGR: NS 046 338
On the southern slopes of Dun Fionn, below the fort, a dark spherulitic pitchstone sill cuts the dolerite of the Clauchland Hills. It can be traced westwards by means of loose fragments. It is probably a continuation of the lower of the sills described below.
Aphyric, dark green.
Gunn et al 1903, 93; Tyrrell 1928, 213; Macgregor 1983, 98, fig 7.6.

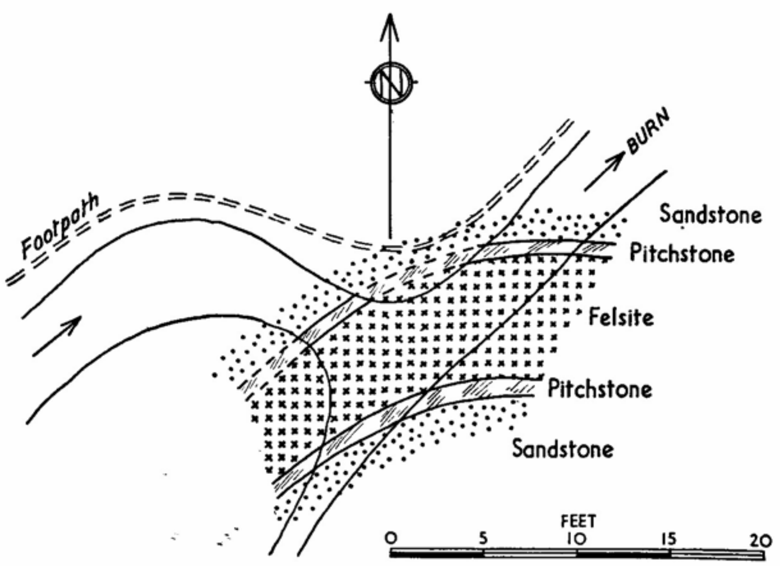
34–35. Dun Fionn (Clauchland Hills) II–III
NGR: NS 041 339
The term Dun Fionn pitchstone may properly be applied to two exposures on the slope above the Dun Fionn path halfway between Dun Dubh and Dun Fionn. These two exposures form sill-like outcrops just beneath the scarp of the Clauchland dolerite sill. The lower one shows a thickness of *c* 6m, and the upper one of *c* 3.5m. No contacts are visible, and the outcrops cannot be traced more than about 50m in any direction when they disappear under the turf.
Aphyric, dark-green.
Bell 1874; Gunn et al 1903, 93; Tyrrell 1928, 213; Macgregor 1983, 98, fig 7.6.

36. Glen Cloy (Scott's Sill)
NGR: NS 003 351
The Glen Cloy pitchstone is part of a composite sill occurring in the bed of the stream in Glen Cloy, at a point about 300m ESE of the house of High Glen Cloy. The total thickness of this sill, most of which is felsite, is *c* 3.5m. Overlying the felsite, and generally separated from it by a joint-plane, is another intrusion, the thickness of which is approximately 30cm. It is a black rock of flinty appearance, with isolated porphyritic feldspars, and traversed by numerous veins of quartz and calcite. On the south side of the burn the two rocks can be seen in contact, the line of contact being perfectly sharp and well-defined. At the upper surface of this black rock its appearance gradually becomes more glassy, and finally it passes to a black lustrous pitchstone, the thickness of which varies between 10 and 12cm. It shows the same porphyritic minerals as the black rock, and apparently differs from the latter only in the glassy nature of the groundmass. It also contains, occasionally, inclusions of the overlying conglomerate.
Porphyritic, black.
Gunn et al 1903, 94; Scott 1915 (a), 140; Tyrrell 1928, 137.

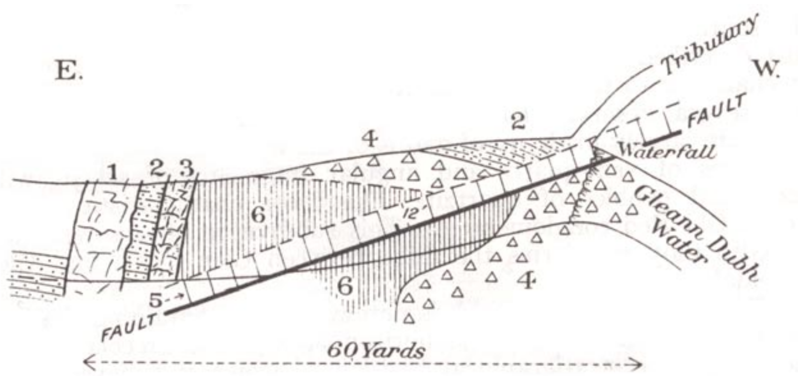
37. Glen Dubh I
NGR: NR 996 346
A quartz-felsite dyke, about 7.5m wide, and trending NNW to SSE, occurs in the Glen Dubh Water about 100m above its confluence with the Glen Ormidale Water. This is a grey rock with numerous small angular xenoliths of variolitic tholeiite and it becomes a dark, pitchstone-like material at its western contact.
Porphyritic, dark grey.
Tyrrell 1928, 211.

38. Glen Dubh II
NGR: NR 995 344
Two hundred metres farther up the Glen Dubh Water a massive quartz-felsite sill occurs, intersecting the Permian basaltic breccia horizon. At both lower and upper edges it is chilled to a banded, greenish, pitchstone-like rock, the upper contact being against the breccia, and the lower against a basalt dyke. This sill is of the same petrographic character as the above-described dyke.
Porphyritic, banded, green.
Tyrrell 1928, 211.

39. Glen Dubh III
NGR: NR 994 343
Just above the second eastern tributary to the Glen Dubh Water, *c* 400m SSW of the confluence with the Glen Ormidale Water, there is a massive felsite dyke, approximately 9m wide and trending NNW to SSE. On its western side it appears to have a chilled pitchstone edge against a *c* 2.5m-wide dyke of porphyritic basalt.
Porphyritic, colour unknown.
Tyrrell 1928, 211.

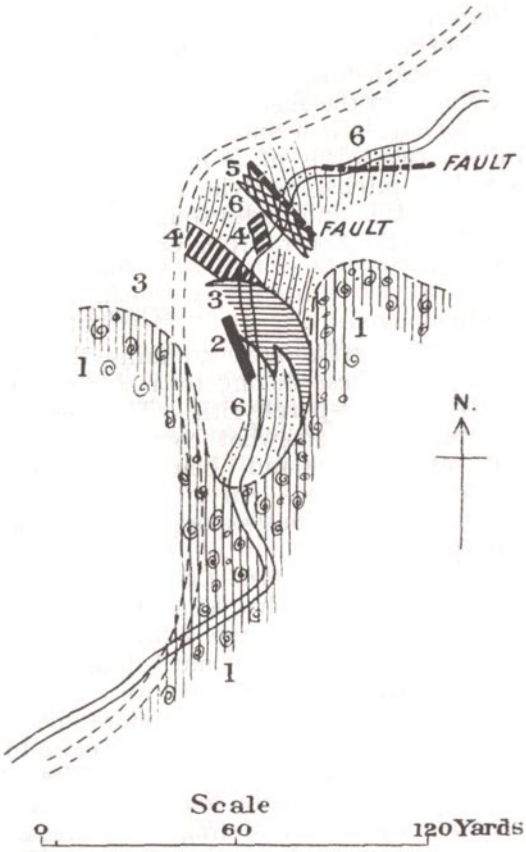


Illus 29 Plan of the Glen Cloy felsite-pitchstone sheet (CAT 30; 'Scott's Sill') (Tomkeieff 1961, fig 7).



Illus 30 Map of exposures in Glen Dubh Water. 200m above the confluence with Glen Ormidale: 1 = porphyritic basalt dyke; 2 = New Red Sandstone; 3 = dyke of dense basalt; 4 = New Red Sandstone volcanic breccia; 5 = crinanite dyke; 6 = felsite sill (Tyrrell 1928, fig 5).

40. Glen Shurig
NGR: NR 995 366
This outcrop occurs as a 1.5m-thick dyke in the lower Old Red Sandstone, and is exposed in the bed of the road leading from the String Road to West Shurig Farm. The exposure is much obscured by vegetation and drift material.
Porphyritic, dark-green.
Gunn et al 1903, 94; 1915 (a), 147; Tyrrell 1928, 210; Macgregor 1983, 88, fig 6.23.
41. Kilmichael I
NGR: NS 006 351
A pitchstone outcrop, probably a sill, is exposed for 1–1.5m in the hillside 400m north of Glenrickard and approximately 300m SE of the Glen Cloy exposure (location 30).
Porphyritic, black.
Scott 1915 (a), 141; Tyrrell 1928, 210.
42. Kilmichael II
NGR: NS 004 351
This outcrop is indifferently exposed in a small burn in the wood north-east of Kilmichael, approximately midway between The Glen Cloy outcrop and Kilmichael I.
Porphyritic, coal-black.
Scott 1915 (a), 141; Tyrrell 1928, 210.
43. Lag a' Bheith head
NGR: NS 008 330
Near the head of the main western branch of the Lag a' Bheith, approximately 3–3.5 km SSW of Brodick Pier, there are exposures of a complex of pitchstone, felsite and basalt, which are rather hard to interpret. The complex is bounded by a fault on its north-eastern side which brings it down against Triassic marls and cornstones. Basalt adjacent to the fault is much crushed and slickensided. The main exposure of pitchstone occurs at a little fall a few metres higher up the burn.
Porphyritic, green.
Gunn et al 1903, 93; Tyrrell 1928, 211.



Illus 31 Sketch-map of exposures in the main western headwater of the Lag a' Bheith, 2 miles SSW of Brodick Pier: 1 = felsite sill; 2 = basalt dyke; 3 = shattery basaltic intrusion; 4 = pitchstone dykes; 5 = crushed basalt dyke along fault; 6 = marls, cornstones, and sandstones of the Trias period (Tyrrell 1928, fig 28).

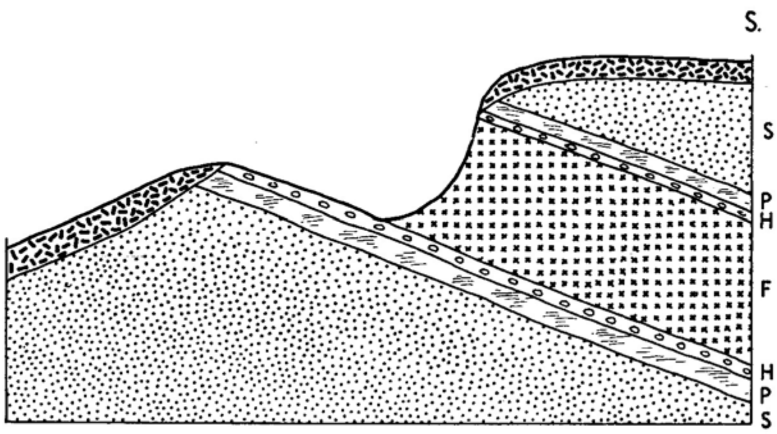
44. Lag a' Bheith I
NGR: NS 017 341
A thick pitchstone occurrence is exposed in the Lag a' Bheith burn, just above the point where the old Brodick–Lamlash road crosses the burn. It appears to be a sill as it passes beneath the strata of New Red sandstone in an obscure section on the upstream side of the exposure. Downstream it is flanked by a basalt dyke.
Texture unknown, dark-green.
Gunn et al 1903, 93; Tyrrell 1928, 214.

45. Lag a' Bheith II (Gunn's Birk Glen)
NGR: NS 018 341
A pitchstone outcrop is visible in the old Brodick–Lamlash road nearby.
Texture unknown, dark green.
Gunn et al 1903, 93; Tyrrell 1928, 214.

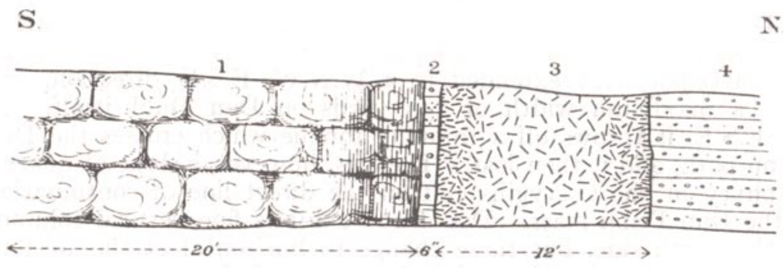
46. Lag a' Bheith quarry (Tomkeieff's 'Magmatic Rolls Quarry')
NGR: NS 020 341
In this quarry a complete section of a *c* 7.6m thick felsite sheet is seen. The felsite is a light-coloured porous rock with platy and poorly developed columnar jointing combined. On both margins the felsite is rimmed by spherulitic hornstone bands, about 2–5cm thick, and 10–15cm thick banded pitchstone. Immediately west of the quarry pitchstone and felsite are seen in the stream bed of Lag a' Bheith (locations 43–45, above); no doubt the continuation of the quarry outcrop.
Aphyric, dark green to black.
Tomkeieff 1961, 10, fig 5; Macgregor 1983, 102, fig 7.11.

47–48. North Corriegills I–II
This is a sill of felsite which at two places has a selvage of pitchstone. It runs from the road near North Corriegills, by a somewhat sinuous course in a general ESE direction, until it reaches the Corriegills shore at a point approximately half a kilometre south-west of the mouth of the Corriegills Burn. Its total length is therefore about 1.5km. The rock is traceable by means of fragments across the fields to the shore, where a remarkable section is exposed (Corriegills Shore, above).
Tyrrell 1928, 212.

47. North Corriegills I
NGR: NS 032 348
Follow the Corriegills road for a distance of about 1km. Here the road forks, one branch leading to North Corriegills and the shore at Dunan, the other to South Corriegills. Pitchstone associated with felsite outcrops in the northern branch of the Corriegills Burn; however, a better section of this



Illus 32 Lag a' Bheith quarry ('Magmatic Rolls Quarry'), N–S section: S = sandstone; P = pitchstone; H = hornstone with magmatic rolls; F = felsite (Tomkeieff 1961, fig 5).



Illus 33 Section across dykes on the eastern slope of Sgiath Bhan, between Glen Dubh and Glen Ormidale, Brodick: 1 = massive quartz-felsite becoming banded and pitchstone-like on its northern edge against 2; 2 = thin strip of sandstone and conglomerate; 3 = basaltic dyke, chilled edges shown by the size of the stippling; 4 = New Red Sandstone sediments (Tyrrell 1928, fig 27).

intrusion occurs in the southern branch of the burn at locality 48.
Aphyric, dark-green.
Gunn et al 1903, 93; Tyrrell 1928, 212; Macgregor 1983, 97, fig 7.2.

48. North Corriegills II
NGR: NS 034 347
About 90m downstream from the road a felsite-pitchstone sill forms a series of small waterfalls in the burn. Careful examination of the outcrops reveals massive, spherulitic felsite underlying indurated sandstone and underlain by pitchstone.
Aphyric, dark green.
Gunn et al 1903, 93; Tyrrell 1928, 212; Macgregor 1983, 97, fig 7.3.

49. Sgiath Bhàn
NGR: NR 990 342
On Sgiath Bhàn, the ridge that separates Glen Ormidale from Glen Dubh, are a number of large outcrops of quartz-porphyry dykes, which are associated, perhaps accidentally, with basaltic members. On the eastward slope of the hill, and trending ENE, there is a massive dyke of quartz-porphyry at least 7m wide. The southern contact is not seen, but towards the northern contact the rock becomes fine-grained and banded parallel to its vertical margin. At the actual junction with a strip of baked sandstone, it is practically a pitchstone. On the other side of the strip of baked sandstone there is a basalt dyke *c* 4m thick. Traced upwards, this dyke suddenly crosses the quartz-porphyry, and then resumes its former direction, but now on the southern margin of the acid dyke.
Texture and colour unknown.
Tyrrell 1928, 201.

50. South Corriegills
NGR: NS 038 345
A felsite sill runs on an approximately parallel course to that of the North Corriegills sill (locations 32, 47–48), and about 400m south of it, through the district of South Corriegills. It is well exposed in the road, and there is a beautiful spherulitic rock which is distinctly pitchstone-like in places. It cannot be traced any farther east from this point, but westwards it runs as far as Corriegills Wood. Its length is thus approximately 800m. At a spot 100m west of the road Gunn found a pitchstone exposure about 7–8m in length. This is probably connected with the felsite sill.
Aphyric, dark-green.
Gunn et al 1903, 93; Tyrrell 1928, 213; Macgregor 1983, 98, fig 7.4.

51. Strathwillan
NGR: NS 023 342
A pitchstone, probably a sill, occurs near the junction of two stone dykes, about 400m east of the Brodick–Lamlash road and 650m ENE of the Lag a' Bheith outcrops.
Texture and colour unknown, dark.
Gunn et al 1903, 93; Tyrrell 1928, 214; Macgregor 1983, 97, fig 7.3.

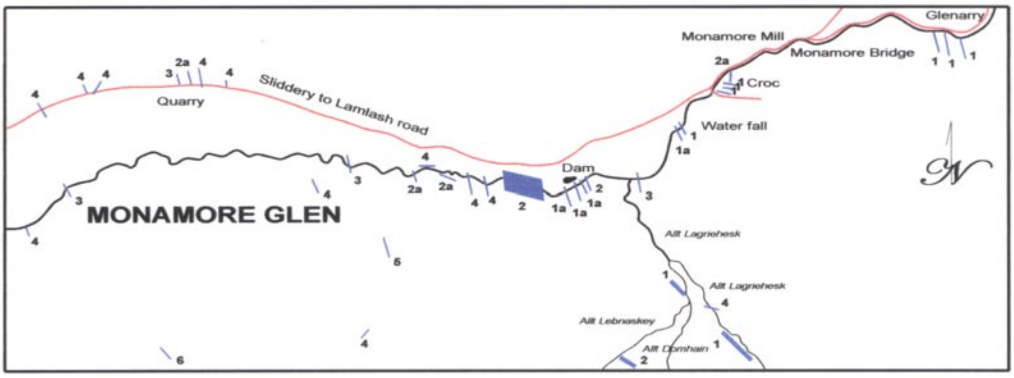
Lamlash Bay

52. Allt Lagriehesk
NGR: NS 015 295
'Pitchstone was seen by Gunn in the Alt Lagriehesk, about 300m SSW of the Woollen Mill.'
Aphyric, colour unknown.
Tyrrell 1928, 215.

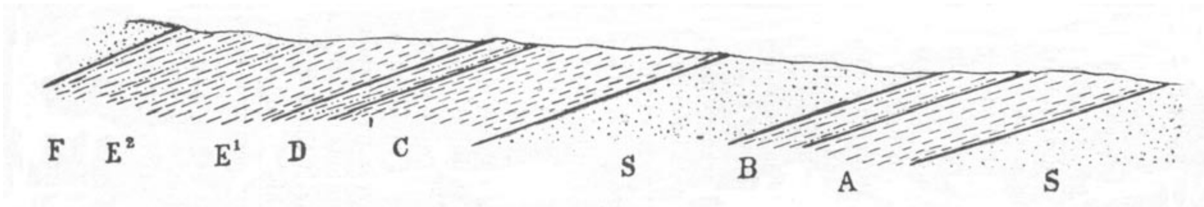
53. Allt Lebnaskey
NGR: NS 015 294
Near the point in Allt Lebnaskey, where Rao reported a pitchstone exposure, a small lithic scatter was found (Ballin's 2006 survey). The artefacts included one pitchstone scraper, some pitchstone fragments of probable flakes and tabular scrap, as well as burnt flint. The question is, whether Rao actually found geological pitchstone in situ, or whether he assumed the presence of an outcrop on the basis of secondary material. This must be checked, to find out whether this location represents a small settlement site only, or a small settlement site in conjunction with a small pitchstone outcrop.
Aphyric, dark green to black.
Rao 1959, 239.

54. Cordon Wood
NGR: NS 025 301
Pitchstone occurs in the wood approximately 100m south-west of Cordon, Lamlash, as part of a small felsite sill in that locality.
Texture and colour unknown.
Tyrrell 1928, 215.

55. Croc
NGR: NS 021 299
'Pitchstone was seen by Gunn at a point on the moor 250m ESE of Croc.'
Texture and colour unknown.
Tyrrell 1928, 215.



Illus 34 Minor acidic sills and dykes in Monamore Glen: 1 = pitchstone sills; 1a = pitchstone dykes; 2 = felsite sills; 2a = felsite dykes; 3 = olivine-tholeiite dykes; 4 = tholeiite dykes; 5 = tachylyte dykes; 6 = craignurite dykes (redrawn from Rao 1959, 239).



Illus 35 Section in Monamore Glen: S = sediments, c *9m thick between the sills; A = pitchstone,* c *6m; B = devitrified felsite,* c *3m; C = pitchstone,* c *7.5m; D = platy felsite,* c *1.25m; E^1 and E^2 = spherulitic pitchstone, partly devitrified,* c *7.5m; F = devitrified rock,* c *3m (Scott 1915 (b), 31).*

56. Glenarry
NGR: NS 020 300
'Further, three thin sills of pitchstone are exposed near Glenarry'.
Aphyric, colour unknown.
Rao 1959, 237, 239.

57. Mill Dam
NGR: NS 011 298
Near the head of the unnamed tributary which falls into the Monamore Burn, a little above the Mill Dam, at a point 600m SSW of the seventh milestone on the Ross Road, there is a well-marked felsite sill which appears to underlie the coarse dolerite of the Monamore complex. This sill has a pitchstone-like facies at the above-mentioned point.
Aphyric, colour unknown.
Tyrrell 1928, 215.

58. Monamore Burn I
NGR: NS 018 301
In the Monamore Burn, near the farm of Croc, there occur three pitchstone outcrops and a dyke of felsite. Beginning the section at the small runnel which enters the burn from Croc, and working westward, the first dyke to be encountered is one of hard, dark felsite, the direction of which is approximately NNW to SSE, judging from its jointing. After a blank interval of *c* 7m, a pitchstone sill occurs in sandstone which dips 5–10° to the west. The lower part of the sill consists of a much-jointed pitchstone, which is immediately overlain by a green devitrified rock. The thickness of the complex is approximately 10m.
Aphyric, bottle-green.
Scott 1915 (b), 16; Tyrrell 1928, 214; Macgregor 1983, 186 Note 22.

59. Monamore Burn II
NGR: NS 017 300
After an interval partly occupied by sandstone, a second pitchstone sill consisting of four members appears. At its base, there is about 8m of green pitchstone, followed by 1–1.5m of hard, green, platy felsite, then by 3m of spherulitic pitchstone, passing upward into a banded variety, and finally, at the upper contact, there is *c* 2m of a banded green rock of felsitic appearance.
Aphyric, dark green.
Scott 1915 (b), 16; Tyrrell 1928, 214.

60. Monamore Burn III (Woollen Mill)
NGR: NS 015 299
The third pitchstone outcrop occurs upstream at the Woollen Mill, about 150m south-west of the above exposures. It makes a strong bar across the stream, striking north-west to south-east. The rock consists of a brown, banded, spherulitic glass, the banding being parallel to the edge of the dyke. At the margins it becomes red and devitrified. The upstream margin plunges abruptly through the sandstone like a dyke with a steep hade, but the downstream margin appears to overlie a ledge of sandstone in almost horizontal position, and hence is sill-like.
Aphyric, dark green but also brown to red, banded.
Scott 1915 (b), 16; Tyrrell 1928, 214.

61. Monamore Cairn
NGR: NS 017 288
Pitchstone pebbles are plentiful in the area immediately around the cairn (a 10m band around the cairn was inspected, as in 2005/06 the forest around the cairn had been harvested and ploughed). It has been suggested (Affleck et al 1988, 46) that the recovery

of pitchstone pebbles may indicate the dispersal of pitchstone across Arran by glaciers, but the uneven distribution, with some parts of the island being completely devoid of any pitchstone (for example, most of the area between Cnoc na Dail and Glen Dubh) and with pebble sources usually being spatially severely restricted (like the Clauchland Hills source), does not support this. It is more likely that small localised scatters of pitchstone pebbles indicate small local (presently obscured) outcrops.
Aphyric, dark green to black.
Ballin (2006 survey); also see MacKie 1964.

62. Shore dyke, opposite Holy Island
NGR: NS 041 292
No additional site information available.
Texture and colour unknown.
Macgregor 1983, fig 15 (unnumbered exposure).

Whiting Bay

63. Allt Dhepin I
NGR: NS 014 272
In the stretch of moorland between Urie Loch and Loch na Leirg there occur two pitchstone exposures which may be parts of one and the same intrusion. One of these appears on the old Lamlash–Kilmory track about 800m south-east of Urie Loch (see below). What is apparently its continuation occurs *c* 800m to the south-east, in the eastern branch of a tributary of the Allt Dhepin. Only one face of this dyke is exposed, and its thickness cannot, therefore, be measured. It has a marked platy fracture parallel to its vertical edge, and is traversed by numerous thin veins of felsite up to *c* 8cm in width, interjected roughly parallel to the walls of the dyke.
Porphyritic, greenish-black or greyish-black.
Scott 1915 (b), 25; Tyrrell 1928, 215.

64. Allt Dhepin II
NGR: NS 018 253
Along the steeply-plunging eastern edge of the Garbad quartz-dolerite, several of the small tributary burns of the Allt Dhepin reveal exposures of felsite which occasionally have a pitchstone-like facies. With this persistent intrusion may perhaps be correlated a felsite mass in the gorge of the Allt Dhepin. At one point this is a dyke, but it passes rapidly into a little columnar sill which is injected at the base of the Garbad quartz-dolerite sill. Numerous dykes and sills of felsite occur in this area, but it is not always easy to decide whether they belong to the quartz-dolerite-craignurite series, or to the later pitchstone-felsite suite. Many of the larger masses unquestionably belong to the former.
Texture and colour unknown.
Tyrrell 1928, 216.

65. Cnoc an Fheidh
NGR: NS 016 249
A NNW to SSE-orientated dyke of pitchstone occurs on the slope approximately 400m south-east of Cnoc an Fheidh (268m OD), about 1200m NNW of Loch Garbad.
Porphyritic, colour unknown.
Tyrrell 1928, 216.

66. Cnoc Mor
NGR: NS 025 256
A little north-east of Cnoc Mor, on the north side of Glen Ashdale, *c* 2.5km WSW of Whiting Bay Pier, is a pitchstone outcrop. From the available evidence, it appears to represent a dyke running WNW to ESE and must be from 5 to 7m in width.
Lightly porphyritic, black when fresh, slaty-blue when somewhat weathered. Steel-grey forms are also known from this source.
Tyrrell 1928, 216.

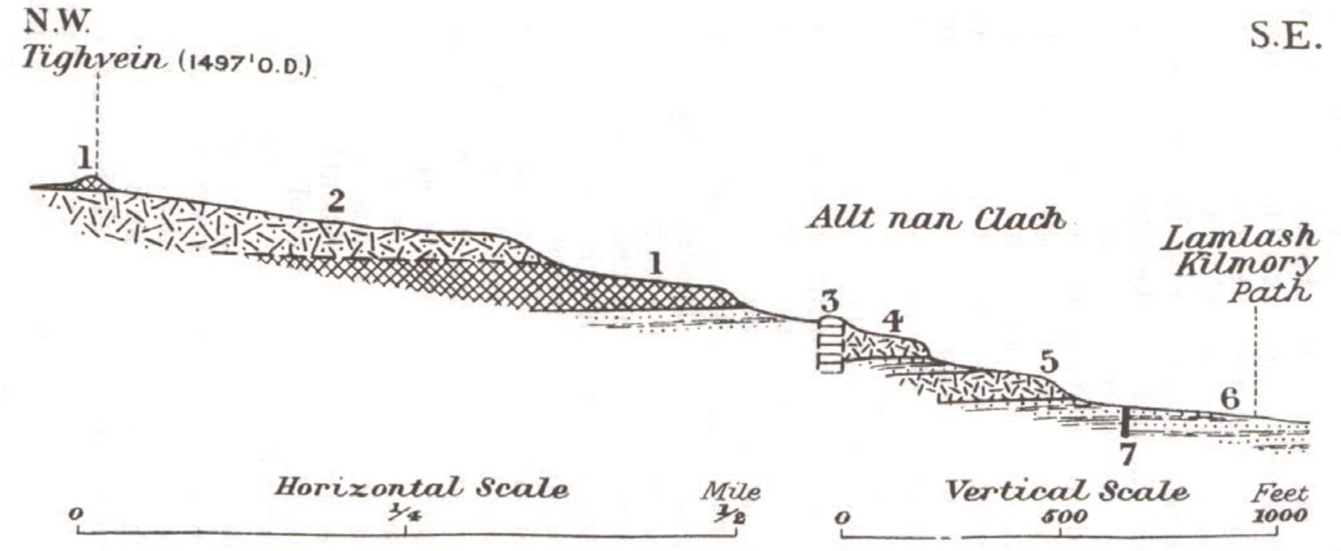
67. Dippin
NGR: NS 049 227
Xenoliths(?) of pitchstone on a tholeiite dyke cutting a crinanite sill in a road-side quarry. The location is near the 12th milestone, on the main road SW of Largybeg Point.
Coarsely porphyritic, black.
Tyrrell 1916, 193.

68. Glen Ashdale Burn
NGR: NS 027 249
A short distance downstream of a little waterfall, and some 37m or so downstream from a stone wall, xenolithic dolerite appears. About 90m upstream from the wall the feldspathic quartz-dolerite is followed by a slabby-jointed, deeply weathered, highly feldspathic quartz-dolerite which is succeeded by spherulitic felsite. The top of the sill is seen at a bend in the burn 128m upstream from the wall: it passes under baked sandstone, above which comes a thin felsitic intrusion, the uppermost part of which is a dark-banded pitchstone-like rock.
Lightly porphyritic, dark green to black, banded.
Macgregor 1983, 149.

69. Torr an Loisgte I
NGR: NS 039 245
A composite dyke of pitchstone and felsite occurs south of Torr an Loisgte on the south side of Glen Ashdale, cutting the scarp of the Dippin crinanite in that locality. It strikes approximately NNW, and can be traced about 70m southwards, although it cannot be followed on to Torr an Loisgte. The marginal parts of the dyke, each *c* 1m thick, are composed of pitchstone; the central part, almost 3m thick, is a banded spherulitic felsite. The junctions between the two varieties are perfectly sharp, and the intrusion must therefore be regarded as composite. The dyke hades 45° to the south-west, and appears to occupy a NNW–SSE line of movement.
Lightly porphyritic, dark green (E) or grey (W).
Scott 1915 (b), 22; Tyrrell 1928, 216; Macgregor 1983, 150, fig 15.13.

70. Torr an Loisgte II (burn)
NGR: NS 038 250
Boulders of pitchstone are numerous in the burn which descends from Torr an Loisgte to Glen Ashdale, but no pitchstone in situ could be found.
Porphyritic, dark green.
Tyrrell 1928, 216.

71. Torr na Baoileig I (W)
NGR: NS 025 247
As an example of the felsite masses of the district, which show no association with the more basic rock types, the Torr na Baoileig intrusion may be examined in the Allt Dhepin gorge. Access is obtained by crossing the feature formed by the Baoileig quartz-dolerite a short distance east of the lower end of the gorge of the Baoileig Burn. The rock is somewhat poorly preserved coarse spherulitic felsite or granophyre. Towards the south end of the gorge, and on the left bank of the stream, the margin of the intrusion transgresses hardened sandstone and marl. Locally, the contact rock is a pink and green banded felsite, sometimes associated with a green pitchstone. The felsite and sediments are cut by a rotted basic dyke.
Porphyritic, green.
Macgregor 1983, 150, fig 15.11.

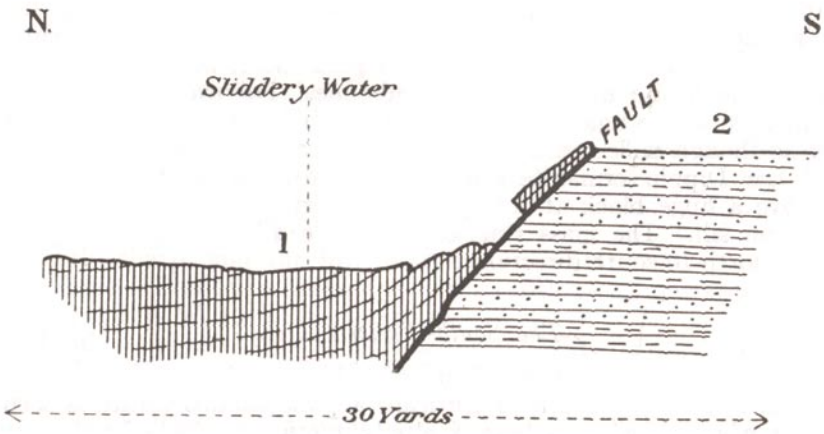


Illus 36 Section from Tighvein to the head of the Allt nan Clach: 1 = augite-diorite; 2 = micro-granite; 3 = pitchstone; 4 = quartz-dolerite; 5 = craignurite; 6 = Triassic sediments; 7 = basaltic dyke (Tyrrell 1928, fig 17).

72. Torr na Baoileig II (E)
    NGR: NS 030 246
    A pitchstone dyke is seen in the depression between Torr na Baoileig and the scarp of the Dippin crinanite sill, at a point about 800m WSW of Torr an Loisgte. In one exposure it appears to cut the Baoileig felsite, in another the crinanite. A boulder of pitchstone was found halfway up the crinanite scarp. The dyke appears to run ENE to WSW.
    Porphyritic, green.
    Tyrrell 1928, 216; Macgregor 1983, 150, illus 15.12.
73. Urie Loch
    NGR: NS 008 275
    In the stretch of moorland between Urie Loch and Loch na Leirg there occur two pitchstone exposures which may be parts of one and the same intrusion. One of these appears on the old Lamlash–Kilmory track about 800m south-east of Urie Loch. It trends north-west to south-east and has a thickness of 6 to 7m. What is apparently its continuation occurs *c* 800m to the south-east, in the eastern branch of a tributary of the Allt Dhepin (see 63 above).
    Porphyritic, green.
    Scott 1915 (b), 25; Tyrrell 1928, 215.

South Arran

74. Allt an t-Sluice
    NGR: NR 929 259
    A pitchstone sill is visible in the Allt an t-Sluice, a headwater of the westernmost tributary of the Sliddery Water. The exposure is approximately 3km ESE of Kilpatrick Point. Roughly 3m of pitchstone is visible; it forms a ledge in the bank of the stream, in the channel of which red marly sandstone is seen.
    Porphyritic, colour unknown.
    Tyrrell 1928, 217.
75. Allt an t-Stuie I (W)
    NGR: NR 995 268
    Two pitchstone dykes occur near the head of the eastern headwater of the Allt an t-Stuie (or: An Sloc), the main branch of the Kilmory Burn. The exposures are located *c* 800m SSW of the summit of Tighvein. They trend in a NNW to SSE direction. The western dyke cuts 'felsophyric quartz-porphyry'.
    Porphyritic, green.
    Corstorphine 1895, 448; Scott 1915 (b), 24; Tyrrell 1928, 216.
76. Allt an t-Stuie II (E)
    NGR: NR 995 268
    Two pitchstone dykes occur near the head of the eastern headwater of the Allt an t-Stuie (or: An Sloc), the main branch of the Kilmory Burn. The exposures are located *c* 800m SSW of the summit of Tighvein. They trend in a NNW to SSE direction. The eastern dyke intersects the dolerite of the Tighvein complex.
    Porphyritic, green.
    Corstorphine 1895, 448; Scott 1915 (b), 24; Tyrrell 1928, 216.
77. Allt nan Clach (Glas Choirein)
    NGR: NS 003 268
    Near the head of the Allt nan Clach, one of the headwaters of the Kilmory Burn, approximately 800m to 1km south-east of the summit of Tighvein, there is an exposure of pitchstone, the relations of which are very obscure, because it is entirely surrounded by peat. It forms a low, flat-topped knoll elongated in a WNW to ESE direction, and measuring 100m by 30m. It may form part of a thick dyke, or it is possibly a lenticular swelling on a sill-like mass.
    Coarsely porphyritic, green.
    Scott 1915 (b), 25; Tyrrell 1928, 215.
78. Burican
    NGR: NR 947 252
    Just above Glenrie Bridge, on the Sliddery Water, *c* 550m south of Burican Farm, a pink-banded felsite is seen, with what appears to be a faulted junction against the Triassic sediments. The nearly horizontal, slabby joint-planes of the igneous rock turn up until they become almost vertical at the junction. The absence of shattering suggests that the felsite has come up along the fault. The Burican pitchstone forms a ledge between the road and the Sliddery Water above the felsite. It slopes down towards the



Illus 37 Junction of felsite against Triassic sediments, Sliddery Water, just above Glenrie Bridge (Burrican): 1 = felsite, with slabby jointing; 2 = Triassic sediments (Tyrrell 1928, fig 29).

river, and has a visible thickness of 7m. It seems probable that it represents the upper part of the banded felsite.
Porphyritic, green.
Scott 1915 (b), 26; Tyrrell 1928, 217; Macgregor 1983, 185, Note 21.

79. Cnocan a' Chrannchuir (Allt na Craoibhe)
NGR: NR 916 272
This occurrence is in a small burn called Allt na Craoibhe, on the north-east side of Cnocan a' Chrannchuir, about 2.5km south-east of Blackwaterfoot. It is very poorly exposed, consisting of scattered blocks of pitchstone, and approximately ½m of the rock in situ. From the fact that baked whitish sandstone is seen nearby on the same level, the exposure is thought to be part of a dyke.
Porphyritic, green to dark green.
Tyrrell 1928, 217.

Machrie Bay and Drumadoon Bay

80–81. Auchagallon I a–b
NGR: NR 897 348 and 898 349
In the stream *c* 400m north-east of the village there are two pitchstone dykes close together, and the more northerly of the two is accompanied by felsite. Both range somewhat north of east.
Porphyritic, colour unknown.
Gunn et al 1903, 95; Tyrrell 1928, 209.

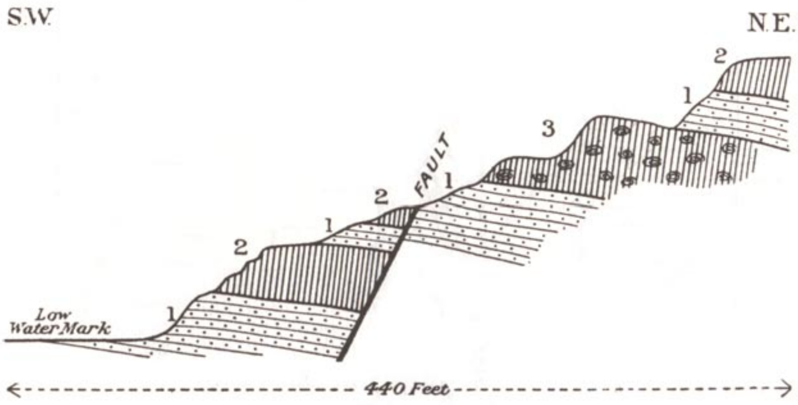
82. Auchagallon II
NGR: NR 892 347
A small pitchstone dyke occurs in the old sea-cliff to the west of the village on the north side of a sandstone quarry.
Porphyritic, light green to dark green or black.
Gunn et al 1903, 95; Tyrrell 1928, 209.

83. Auchagallon III
NGR: NR 891 345
A pitchstone outcrop also occurs on the shore about 80m south of the jetty (Cleiteadh Buidhe).
Porphyritic, brown.
Gunn et al 1903, 95; Tyrrell 1928, 209.

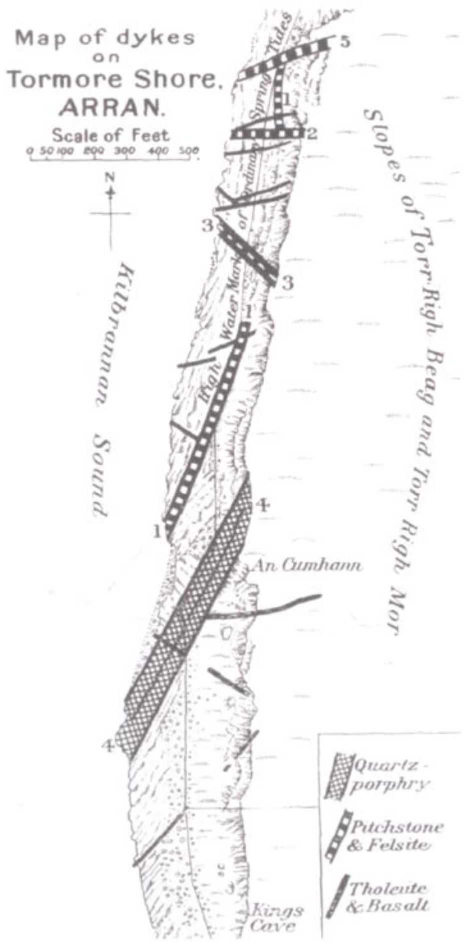
84. Drumadoon Point
NGR: NR 884 287
On reaching the northerly part of Drumadoon Point, the relations between the 'Doon' and the Point can be discussed, bearing in mind the structure in the 'Needle' at the south of the sill. The dykes cutting the porphyry are interesting, especially those at the northerly end of the lower porphyry, and the porphyritic pitchstone a little farther to the south. The base of the lower porphyry is exposed both in the north and in the south, where it is basified and grades to basalt with xenocrysts.
Porphyritic, colour unknown.
Tomkeieff 1961, 30.

85–89. King's Cave I–V
NGR: NR 883 309
Five separate exposures of pitchstone occur on the shore and in the cliff bounding the raised beach to the south of King's Cave, halfway between Tormore and Drumadoon. Three of these exposures are in and about a recess in the cliff made by a small stream. Just below the path on the south side of the recess there is a pitchstone sill *c* 7m thick, resting on sandstone and dipping SSE at 5–10°. A little higher up there is a small mass of shattered pitchstone. At a higher level on the opposite side of the recess there is first a sill of spherulitic felsite about 10m thick, and then another of banded pitchstone. Assuming that the spherulitic felsite is the same intrusion as the lowest pitchstone, an assumption for which there is petrographic warrant, the relations of the four igneous masses may be explained as in the section (illus 38) by means of a north-west to south-east fault running along the line of the above-mentioned gully.
This fault-plane appears to be occupied by a felsite-pitchstone dyke, for felsite is found on the shore at the north-west end of the line, and a pitchstone dyke is recorded by Gunn at the south-east end near the head of the gully. In the cliff bounding the raised beach immediately to the south of the above-mentioned exposures, another sill of pitchstone is exposed, which may represent a third horizon of this rock.
Porphyritic, greyish green to dark green, banded.
Gunn et al 1903, 95; Tyrrell 1928, 220; Tomkeieff 1961, 29.

90. Machrie Burn
NGR: NR 925 362
A dyke of pitchstone, *c* 2m in width, crosses this stream in a NNW direction about 1200m NNE of Cnoc na Ceille. The stream here is called Allt Airidh Niall.
Porphyritic, light green.
Gunn et al 1903, 95; Tyrrell 1928, 209.



Illus 38 Section across pitchstone exposures south of King's Cave, c 1.5 km north of Drumadoon: 1 = New Red Sandstone sediments; 2 = pitchstone; 3 = spherulitic felsite (Tyrrell 1928, fig 31).

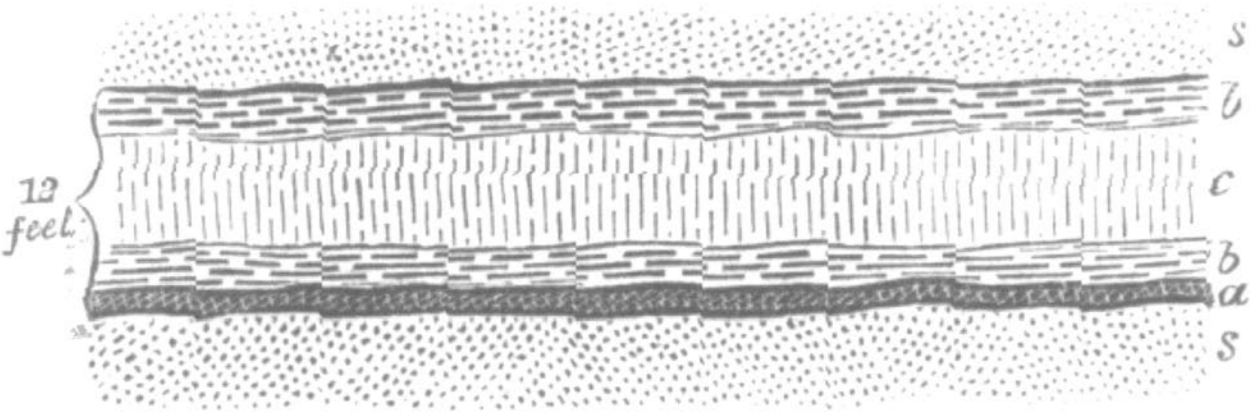


Illus 39 Map of dykes on the Tormore shore, based on Judd (1893, 552):1 = tholeiite-pitchstone composite dyke (Judd's No. I dyke), composite at south end but only pitchstone at north end; 2 = tholeiite-pitchstone composite dyke (Judd's No. II dyke); 3 = tholeiite-pitchstone composite dyke (Judd's No. III dyke); 4 = composite dyke of quartz-porphyry and tholeiite (Judd's No. IV dyke); pitchstone dyke (Judd's No. V dyke) (Tyrrell 1928, fig 30 – with later amendments).

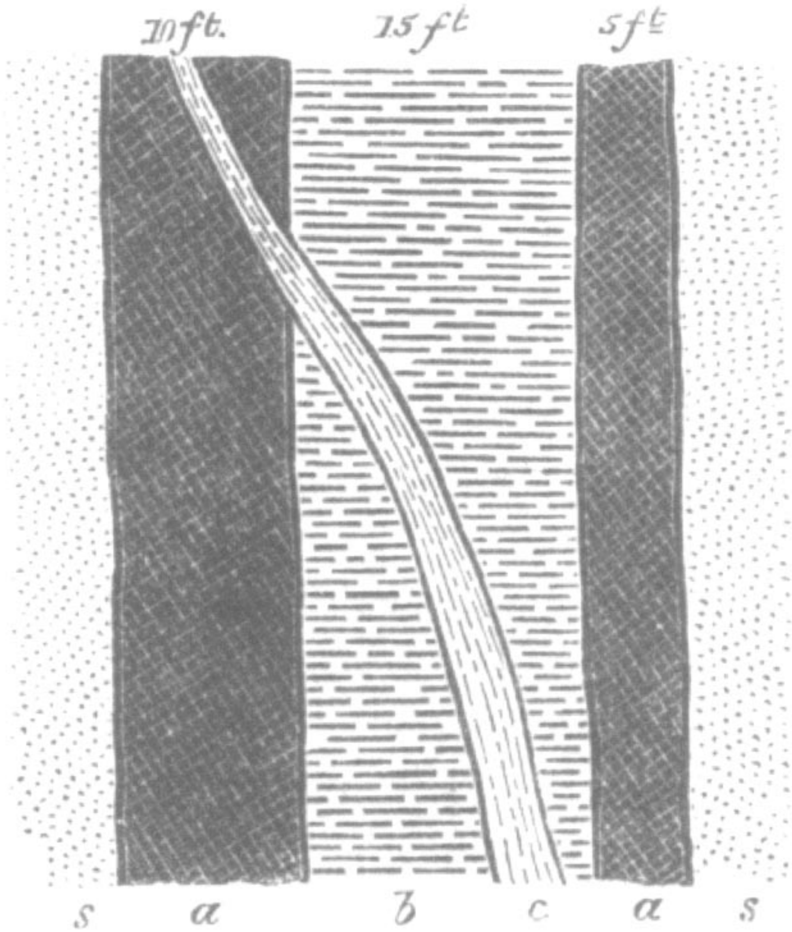
91. Tormore (Judd's No. I Dyke)
NGR: NR 884 315
This is the largest pitchstone intrusion on the Tormore shore. The Tormore shore is the 1½km-long strip of rocky coast which stretches southwards from the southern side of Machrie Bay. The dyke appears at low-water mark 200m north of An Cumhann, and runs in a NNE direction. At high-water mark, however, its direction becomes more northerly, and it ultimately passes from sight under boulders and raised beach material. It reappears at the northern end of the section for 100m or so, with a northerly course. Its total exposed length is thus about 600m. At the northern end of the outcrop the pitchstone appears to be a vertical dyke, but towards its southern extremity, according to Judd, it hades at less than 60°. At its northern end it consists entirely of pitchstone; the southern exposures, however, show the pitchstone passing on both sides into banded, spherulitic felsite. On its eastern margin, moreover, a band of dark tholeiite intervenes between it and the adjacent sandstone.
Sparsely porphyritic to porphyritic, dark green to dark bluish-black.
Judd 1893, 554; Gunn et al 1903, 95; Tyrrell 1928, 218; Tomkeieff 1961, 27.

92. Tormore (Judd's No. II Dyke)
NGR: NR 885 316
This dyke occurs near the north end of the Tormore section. It runs east to west, and appears to intersect the north to south dyke. Its thickness is *c* 9–10m. Its sides are composed of tholeiite weathering in the usual spheroidal fashion, but the centre is a quartz-felsite which occupies about half the width of the dyke. A pitchstone dyke or vein, 15–60cm in width, is found sometimes intersecting the felsite, and at other times the adjoining tholeiite.
Porphyritic, dark green.
Judd 1893, 555; Gunn et al 1903, 95; Tyrrell 1928, 218; Tomkeieff 1961, 27.

93. Tormore (Judd's No. III Dyke)
NGR: NR 884 315
About 120m south of Judd's Dyke No. II, another composite dyke occurs, which trends north-west to south-east. It is from 12m to 15m wide, and is mainly composed of tholeiite. Somewhat asymmetrically



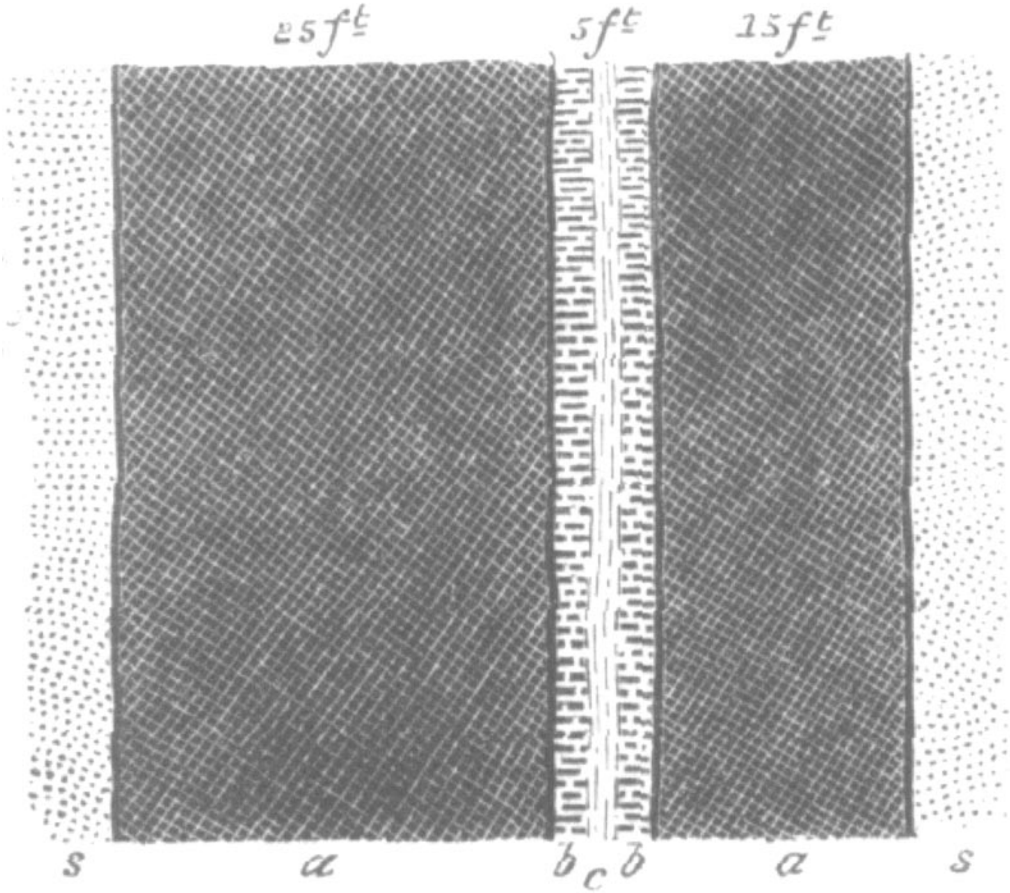
Illus 40 Diagrammatic plan of Judd's No. I Dyke: a = tholeiite; b = banded and spherulitic felsite (andesite); c = pitchstone (andesite); s = sandstone (Judd 1893, fig 2).



Illus 41 Diagrammatic plan of Judd's No. II Dyke: a = tholeiite; b = quartz-felsite (dacite); c = pitchstone-porphyry (dacite); s = sandstone (Judd 1893, fig 3).

placed there is a median band of acid rock about 1.5m thick, of which the central *c* 60cm consists of pitchstone, and the remainder of quartz-felsite.
Porphyritic, dark green.
Judd 1893, 556; Gunn et al 1903, 95; Tyrrell 1928, 218; Tomkeieff 1961, 27.

94. Tormore (Judd's No. IV Dyke)
NGR: NR 8840 3116
A poorly exposed area of highly porphyritic yellowish-brown pitchstone occurs close to HWM, on the east outer margin of the large composite dyke at An Cumhann (Judd's No. IV dyke). This is almost certainly a glassy variant of the porphyry making up the central part of this large dyke.
Highly porphyritic, yellowish-brown.
Kanaris-Sotiriou & Gibb 1985.



Illus 42 Diagrammatic plan of Judd's No. III Dyke: a = tholeiite; b = quartz-felsite (dacite); c = pitchstone (dacite); s = sandstone (Judd 1893, fig 4).

95. Tormore (Judd's No. V Dyke)
NGR: NR 885 317
'Southwards from Leacan Ruadh, the path follows the 25-foot raised beach until it is crossed by a pitchstone dyke, Judd V, which, contrary to the information in the *Memoirs* [that is, Tyrrell 1928], forms a prominent exposure of some 12 feet (*c* 3.5m). The edges are undulose but the exposure can be traced into the cliff. It terminates the northerly end of the long north–south dyke, Judd I.' (Tomkeieff 1961, 27.)
Porphyritic, dark green.
Judd 1893; Tyrrell 1928, 218; Tomkeieff 1961, 27.

96. Tormore
NGR: NR 886 315
In the path behind (east of) Judd's dykes, there are some pieces and nodules of pitchstone. They may derive from one or more of the known dykes, extending inland, or they may indicate the presence of other (now possibly obscured) local intrusions.
Porphyritic, dark green.
Ballin (2006 survey); Faithfull (various geology excursions).

6. DISCUSSION

6.1 The survey's immediate results

In connection with the survey, numerous exposures were examined. As a result of the survey, a substantial pitchstone sample collection for future research and consultations was formed, and a small number of samples were added to the already extensive pitchstone collections at the Hunterian Museum. Although many large and small pitchstone outcrops were already known at the time of the survey, the investigations on Arran produced four new minor pitchstone locations, namely gazetteer entries 13 (Garbh Allt), 30 (Clauchland Hills), 61 (Monamore Cairn) and 96 (Tormore).

In terms of the sources' potential relevance to prehistoric people (the combination of material homogeneity, outcrop size, degree of exposure and remoteness), the survey confirmed many of the authors' initial thoughts. Vegetation, for example, is clearly a problem, and it was frequently impossible to find, in particular, minor outcrops in areas affected by, for example, the growth of heather. Along watercourses, finding outcrops was hampered by vegetation in general, as well as by algae growth. Shore dykes were frequently obscured by general wear, discolouration and algae growth. During high tides, shore dykes would be covered by water, and in rainy seasons exposures in narrow gullies would become inaccessible due to the occurrence of flash-floods (as experienced in connection with the investigations along the tributaries of the Monamore Burn and in Glen Dubh).

The discovery of loose pitchstone sources behind Tormore shore and in the Clauchland Hills – the latter yielding raw material of exceedingly high quality – suggests that there may in prehistoric times have been more sources available than the outcrops listed in the gazetteer. The obsidian-like pitchstone of the Clauchland Hills site (gazetteer entry no. 30) was discovered on a slope, and it is not unlikely that a potential 'mother-lode' may have been obscured by, for example, soil creep or general erosion. Pitchstone of this quality forms part of larger mainland assemblages, such as those from Luce Bay and Biggar.

However, many of the practical problems experienced by archaeological and geological surveyors could be overcome by prehistoric people living on Arran, people who knew their local environment intimately. Most likely, the inhabitants of Arran would have had procurement strategies which could be adapted to changing circumstances. Obviously, different sources could be exploited at different times of the year, reflecting the changing vegetation, tides, weather, etc., but it is also likely that different sources would be visited depending on whether raw material was needed for limited domestic usage or bulk exchange. As already mentioned, different outcrops were clearly exploited in the earlier and later parts of the Neolithic period.

No actual pitchstone quarries (that is, worked sills and dykes) were encountered during the survey. It is possible that prehistoric people on Arran mined all their raw material from natural exposures, such as the great sill at Dun Fionn, where huge blocks break off regularly and roll down the slopes, or from the island's shore dykes or natural exposures in cliff faces. However, the question of potential quarrying of pitchstone in prehistoric times is practically impossible to answer, as the rapid weathering of exposed pitchstone sources would have removed obvious signs of this process (as for example the attributes observed and described in connection with the examination of a quartz quarry on the Isle of Lewis; Ballin 2004 (b)). This is probably a combined effect of pitchstone being much softer and much more brittle than, for example, flint (on Moh's exponential scale from 1 to 10, flint has a hardness of 7, whereas pitchstone has a hardness of *c* 5–5.5).

Basically, the question of how, and from which specific sources, pitchstone was procured by prehistoric people on Arran can only be approached in one way, namely by undertaking a study which compares multiple archaeological samples (from different parts of Arran and from different periods) with geological samples from the various parts of the island, and which includes glass, crystallite and phenocryst characterisation. This will be discussed further in Section 6.2 below.

6.2 The archaeological evidence

As shown in the gazetteer, approximately 100 pitchstone outcrops are presently known from Arran. The catalogued outcrops differ considerably in terms of the material's flaking properties ('knappability'), as well as in terms of outcrop size, exposure and remoteness. As touched upon in the paper's introduction, the latter three factors may not have excluded a source from exploitation (if symbolic values were in any way involved), whereas poor flaking properties might have. However, 'poor flaking properties' is a relative concept, the definition of which depends on the attributes of the intended end-product: if an industry aimed at manufacturing delicate microblades, large phenocrysts – as well as large spherulites – were to be avoided, whereas an industry aiming at producing more robust, broad blades or flakes would be able to exploit almost any

Table 1 The raw material distribution of the more substantial assemblages from the Arran Prehistoric Landscape Project (numbers according to Finlay 1997)

	Quantity				Per cent			
	Flint	Aphyric pitchstone	Porphyritic pitchstone	Total	Flint	Aphyric pitchstone	Porphyritic pitchstone	Total
Kilpatrick Settlement 16/1	82	159	28	269	30	59	11	100
Kilpatrick Cairn 16/2	38	59	30	127	30	46	24	100
Kilpatrick Cairn 16/3	24	25	5	54	44	46	9	99
Kilpatrick 'Fernie Bank' field boundary	24	67	23	114	21	59	20	100
Machrie Moor Cairn 24/1	33	111	4	148	22	75	3	100
TOTAL / AVERAGE	201	421	90	712	28	59	13	100

form of pitchstone, as long as it was not marred by numerous closely spaced planes of weakness, and as long as the raw material was not too devitrified.

Scottish non-Arran assemblages are mostly in aphyric pitchstone, although recent research has shown that, occasionally, porphyritic pitchstone may be present in small numbers. Only the recently discovered assemblage from Blackpark Plantation East on Bute (Ballin et al forthcoming), and assemblages from adjacent Bute sites (for example, Dunagoil, The Plan and Kingarth Quarry; Mann 1918, 147; Finlay 2003; Mudie & Richardson 2006), are dominated by porphyritic material.

On Arran, porphyritic pitchstone appears to have been more widely used. The substantial assemblages from *The Arran Prehistoric Landscape Project* (Barber 1997; Finlay 1997) included on average 13% porphyritic pitchstone, with some assemblages (Kilpatrick Cairn 16/2) having as much as 24% porphyritic pitchstone (Table 1). If flint is excluded from the equation, the average ratio of aphyric:porphyritic pitchstone is 82:18%, with that of Kilpatrick Cairn 16/2 being 66:34%.

During Haggarty's (1991) excavation of a number of mainly Neolithic and Early Bronze Age monuments at Machrie Moor, western Arran, 1,696 lithic artefacts were recovered: flint makes up 38%, aphyric pitchstone 33%, porphyritic pitchstone 28%, and artefacts in other lithic raw materials 1%. The ratio of aphyric:porphyritic pitchstone is 54:46%. At Machrie Moor, the individual ratios of aphyric and porphyritic pitchstone forms varied from site to site and from context to context, but the average ratios clearly demonstrate that, on this location, porphyritic pitchstone was used approximately as frequently as aphyric pitchstone.

The report on the lithic material from the Mesolithic site of Auchareoch, southern Arran, only states that aphyric and porphyritic pitchstone were present, but without quantifying the two sub-assemblages (Affleck et al 1988, 46). In total, this site yielded 418 pitchstone artefacts and 3,983 pieces of worked flint. The report on the Monamore chambered cairn and its archaeological finds (MacKie 1964) does not characterise the lithic artefacts in detail, as its primary aim was to present and discuss the burial monument. However, it is apparent that more than one form of pitchstone was present at the site.

Although the increasing numbers of Scottish pitchstone artefacts (approximately 5,600 pieces have been examined in connection with the Scottish Archaeological Pitchstone Project) and pitchstone-bearing sites (approximately 350) (Ballin 2009) have allowed basic conclusions to be made – such as the fact that other sources than the Corriegills outcrops were exploited for use on Arran as well as for exchange – it is presently difficult to indicate how many, and which specific outcrops were exploited. This is mainly due to the fact that, since Williams Thorpe & Thorpe's (1984) limited attempts at provenancing archaeological pitchstone, almost no pitchstone artefacts have been exposed to geochemical analyses (one noticeable exception being the assemblage from Ballygalley in Northern Ireland; Preston et al 2002).

However, *explaining* the variation in pitchstone use is even more difficult than *identifying* the probable sources. Analysis of pitchstone artefacts in connection with the Scottish Archaeological Pitchstone Project highlights two main trends, namely 1) a somewhat higher ratio of porphyritic pitchstone on Arran as well as in Argyll & Bute/Southern Hebrides than in the remaining parts of Scotland, and 2) a higher ratio of porphyritic pitchstone in the later Neolithic than in the earlier part of that period (Ballin 2006; Ballin & Ward 2008; Ballin 2009; forthcoming (a); Ballin et al forthcoming).

The two trends are not mutually exclusive, and a higher than average ratio of porphyritic pitchstone may be regionally as well as chronologically diagnostic. The apparently higher ratio of porphyritic pitchstone in the region immediately north of Arran, and a lower ratio in, for example, the Central Belt and south-west Scotland, may reflect different prehistoric territories and alliances (Ballin 2006, 29). The former area may have been allied with groups in adjacent northern Arran (exploiting sources from the Schoolhouse outcrop and further north on Arran), whereas the latter area may have been allied with groups in adjacent eastern Arran (exploiting sources in the Corriegills district, Clauchland Hills, the Fairy Glen and the general Lamlash Bay area).

The general increase in the exploitation of porphyritic pitchstone in the later Neolithic period (as demonstrated by the assemblage from Barnhouse on Orkney and Blackpark Plantation East on Bute; Ballin forthcoming (a); Ballin et al forthcoming), may – at least to a degree – be a function of technological changes, as the later Neolithic production of broad blades did not *exclude* the use of porphyritic pitchstone the way Early Neolithic microblade manufacture did (see above). The various possible explanations will be discussed in more detail in the final report from the Scottish Archaeological Pitchstone Project (Ballin 2009).

To the Scottish lithics specialist, the provenancing of pitchstone is presently a very (unsatisfactorily) simplistic affair, as it is only possible to distinguish between aphyric and porphyritic pieces. Even this is not straightforward, as it is not always possible, without the use of microscopic analysis, to distinguish unequivocally between the two main forms of pitchstone:

- Although some varieties of pitchstone are clearly aphyric and some clearly porphyritic, pitchstone seems to represent a continuum, ranging from almost obsidian-like forms (Clauchland Hills, catalogue entry no. 30), over lightly porphyritic forms (some Glenashdale outcrops), to coarsely porphyritic forms (for example, Iorsa Valley, Dippin, and Allt nan Clach).
- Some generally porphyritic outcrops include noticeable bands of almost aphyric material, such as the Schoolhouse outcrop and several sources along Arran's west-coast (for example, Tormore and Auchagallon).
- It may occasionally be very difficult to distinguish between porphyritic forms, defined by the presence of phenocrysts, and aphyric forms with large and/or irregular spherulites (for example some Lag a' Bheith varieties, and some of the pitchstone from Tomkeieff's 'Magmatic Rolls Quarry' immediately east of the Fairy Glen).

However, even if it were possible to discriminate macroscopically between aphyric and porphyritic pitchstone, pitchstone provenancing – and thereby analyses of prehistoric territorial structures and exchange networks – would obviously benefit from the development of a standard approach with finer resolution. Several methods for the characterisation of pitchstone sources are presented in Section 4, but the effort should be made to define a generally applicable methodology, which would allow archaeologists to define pitchstone varieties more precisely than simply as being aphyric/porphyritic (in Tyrrell's terminology: Corriegills Type/non-Corriegills Type) or, in terms of provenance, as deriving from a fairly small enclave on Arran's east-coast or from the remainder of Arran.

The pitchstone occurrences on Arran are potentially much more 'characterisable' than most lithic materials. They show a remarkable range of mineralogical and textural features (even in small fragments) for such a compositionally restricted suite of rocks. Given a suitable database of well-characterised geological occurrences, there is considerable potential for tightly constraining archaeological sources. Such a database should allow much more rigorous testing of hypotheses about sources and movement of pitchstone artefacts within Arran, as well as more widely in northern Britain. Currently, analytical data for Arran pitchstone crystallites are restricted to three localities (Preston et al 1998), out of nearly 100 now known on the island. We do not yet know how much intra-locality compositional and mineralogical variation exists, but from the thin-section evidence, it seems likely that considerable discrimination between localities will be achievable.

This methodology should aim to combine research objectives (territoriality, exchange networks, socio-economical organisation) with practical concerns. The latter includes:

- Examining the extent of intra-outcrop mineralogical, textural and compositional variation (at least at selected localities) as well as looking at a broad spread of localities.
- Non-destructiveness: approaches which do not destroy or damage archaeological artefacts (to the degree that this is possible) should be favoured. Modern SEM and EDAX methods, for example, offer the possibility of imaging, and at least semi-quantitative compositional information on untreated artefacts.
- Price: any effort at developing a standard approach for the identification and provenancing of Arran pitchstone forms would probably require a relatively large number of samples to be analysed; the price per analysed sample should therefore be kept as low as possible.
- Logistics: for any approach to become 'standard', analysts should have easy access to institutions and individuals capable of carrying out the preferred spectrum of methods (cf list in Section 4.6).

Although we feel that it would be potentially rewarding to look into the provenance of pitchstone artefacts from Scotland outwith Arran (for example: 1) which outcrops do the small numbers of porphyritic pitchstone derive from?; 2) could proportions of the aphyric pitchstone derive from the Monamore Glen or the Fairy Glen rather than from the Corriegills area *sensu stricto*?; and 3) is it possible that a very small number of local sources could have been exploited in prehistoric time, such as Fiunary in Argyll and Rudh' an Tangaird on Eigg?), we would recommend first focusing on lithic assemblages from

Arran itself, as these assemblages are expected to include pitchstone from many more sources than, for example, mainland assemblages.

An Arran-based case study should include finds from various parts of the island, as well as from all stone-using periods, and the benefits would be twofold, namely 1) the development of a relevant methodology (discussed above), and 2) answers to specific questions regarding within-island 'territories' (within an area as geographically limited as Arran, territorial units would – in post-Mesolithic times – probably be defined more by lineage and clan than by tribe) and procurement/exchange patterns. Although very few assemblages from Arran have yet been published, assemblages have now been recorded from all parts of the island (eg Donnelly & Finlay forthcoming), and including finds from all main prehistoric periods. Once a methodology has been defined – and tested on the interpretation of an archaeological material (assemblages from Arran) – attention can again be turned towards the characterisation, provenancing and interpretation of archaeological pitchstone from mainland Scotland and the islands north of Arran.

We believe that the Arran pitchstones offer the potential to examine the archaeological sources, usage and movement of material, locally and regionally, at an unusual, and perhaps unique level of precision and detail. We hope that this gazetteer might represent the first step in the creation of the detailed database of well-characterised pitchstone sources, which would be needed to support such work.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

It has been chosen in the text to refer to Macgregor 1983 instead of MacDonald et al 1983, as 1) the guide in question was created by Dr A D Macgregor; 2) it is still popularly referred to as 'Macgregor's Excursion Guide to the Geology of Arran'; and 3) the 1983 edition has only been altered slightly in comparison to previous editions.

Affleck, T; Edwards, K J & Clarke, A 1988 'Archaeological and palynological studies at the Mesolithic pitchstone and flint site of Auchareoch, Isle of Arran', *Proc Soc Antiq Scot* 118, 37–59.

Allport, S 1872 'On the Microscopic Structure of the Pitchstones of Arran', *Geological Magazine* IX (1), 1–10.

Ballin, T B 2004 (a) 'The lithic assemblage from Fordhouse Barrow, House of Dun, Angus', unpublished report.

Ballin, T B 2004 (b) 'The worked quartz vein at Cnoc Dubh, Isle of Lewis, Western Isles. Presentation and discussion of a small prehistoric quarry', *Scottish Archaeological Internet Reports* 11 (http://www.sair.org.uk/sair11/index.html).

Ballin, T B 2006 'Re-examination of the Early Neolithic pitchstone-bearing assemblage from Auchategan, Argyll, Scotland', *Lithics* 27, 12–32.

Ballin, T B forthcoming (a) 'Detailed characterisation and discussion of the pitchstone artefacts from Barnhouse – Orcadian pitchstone in the light of recent research into Scottish archaeological pitchstone', *The New Orkney Antiquarian Journal*.

Ballin, T B forthcoming (b) 'The Felsite Industrial Complex of North Roe. Observations from a fact-finding mission to Shetland', *Proceedings of Conference held by the British Neolithic Studies Group, at the British Museum 2005*.

Ballin, T B 2009 *Archaeological Pitchstone in Northern Britain. Characterization and interpretation of an important prehistoric source*. British Archaeological Reports British Series 476. Archaeopress, Oxford.

Ballin, T B & Ward, T 2008 'General characterisation of the Biggar pitchstone artefacts, and discussion of Biggar's role in the distribution of pitchstone across Neolithic northern Britain', *Biggar Archaeology Projects* (http://www.biggararchaeology.org.uk/pdf_reports/SR_PITCHSTONE_REP_08.pdf).

Ballin, T B; Barrowman, C & Faithfull, J 2008 'The unusual pitchstone-bearing assemblage from Blackpark Plantation East, Bute', *Transactions of the Buteshire Natural History Society* XXVII, 23–51.

Barber, J (ed) 1997 *The Archaeological Investigation of a Prehistoric Landscape: Excavations on Arran 1978–1981*. Scottish Trust for Archaeological Research Monograph 2, Edinburgh.

Bell, D 1874 'Note on the Pitchstones at Corriegills, Arran', *Transactions of the Geological Society of Glasgow* IV, 190–3.

Bradley, R & Edmonds, M 1993 *Interpreting the axe trade. Production and exchange in Neolithic Britain*. Cambridge University Press, Cambridge.

Brown, D J; Bell, B R & Muirhead, D K 2007: *Silicic pyroclastic volcanism in the North Atlantic Igneous Province (NAIP): a re-interpretation of the Sgurr of Eigg Pitchstone, NW Scotland. Abstracts of the Volcanic Magmatic Studies Group, Winter Meeting, January 2007* (http://www.davidjbrown.org.uk/presentations/eigg%20vmsg%20oxford.pdf).

Bryce, J 1859 *Geology of Clydesdale and Arran*. Richard Griffin and Company, London, Glasgow.

Callegari, E & Pertsev, N N 2007 *A systematic nomenclature for metamorphic rocks: 10 Contact Metamorphic Rocks. Recommendations by the IUGS Subcommission on the Systematics of Metamorphic Rocks*. Recommendations, web version of 01.02.07 (http://www.bgs.ac.uk/SCMR/docs/papers/paper_10.pdf).

Corstorphine, G S 1895 Ueber die Massengesteine des südlichen Theiles der Insel Arran, Schottland. *Tschermak's Mineralogische und Petrographische Mitteilungen* 14 (5), 443–70.

Cowie, T G 1996 'Torrs Warren, Luce Sands, Galloway: a report on archaeological and palaeoecological investigations undertaken in 1977 and 1979', *Transactions of the Dumfriesshire & Galloway Natural History & Antiquarian Society* LXXI, 11–105.

Dietrich, R V 2005 *Gemrocks: Ornamental & Curio Stones* (http://www.cst.cmich.edu/USERS/DIETR1RV/Default.htm [Obsidian]).

Donnelly, M & Finlay, N forthcoming 'The Arran Ring Main Water Pipeline: Lithic Report'.

Edmonds, M, Sheridan, A & Tipping, R 1992 'Survey and excavation at Creag na Caillich, Killin, Perthshire', *Proc Soc Antiq Scot* 122, 77–112.

Emeleus, C H & Bell, B R 2005 *The Palaeogene volcanic districts of Scotland*. British Regional Geology 3. British Geological Survey, Nottingham.

Faithfull, J 2007. *Non-Arran Scottish pitchstones in the collections of the Hunterian Museum*. (http://www.hmag.gla.ac.uk/john/pitchstone/).

Finlay, N 1997 Various entries in: J. Barber (ed.) 1997 *The Archaeological Investigation of a Prehistoric*

Landscape: Excavations on Arran 1978–1981. Edinburgh: Scottish Trust for Archaeological Research Monograph 2.

Finlay, N 2003 'Bute Foragers to Farmers Project (Kingarth; North Bute parishes), lithic scatters', *Discovery & Excavation in Scotland* 4, 36.

Gillespie, M R & Styles, M 1999: *BGS Rock Classification Scheme. Vol. 1. Classification of igneous rocks*. British Geological Survey Research Reports (2nd edition). RR 99–06.

Glen, D C & Young, J 1884 'Notes on the Spherulitic Rock of Corriegills and the Banded Pitchstone of Invercloy, Arran', *Transactions of the Geological Society of Glasgow* VII, 352–7.

Gregory, J W & Tyrrell, GW 1924 'Excursion to Arran. July 27th to August 3rd, 1923', *Proceedings of the Geologists' Association* 35, 401–23.

Gunn, W; Geikie, A; Peach, B N & Harker, A. 1903: *Scotland. The Geology of North Arran, South Bute, and the Cumbraes, with Parts of Ayrshire and Kintyre*. Memoirs of the Geological Survey. James Hedderwick & Sons/HMSO, Glasgow.

Haggarty, A 1991 'Machrie Moor, Arran: recent excavations at two stone circles', *Proc Soc Antiq Scot* 121, 51–94.

Hunt, J B & Hill, P G 2001 'Tephrological implications of beam size – sample-size effects in electron microprobe analysis of glass shards', *Journal of Quaternary Science* 16, 105–17.

Judd, J W 1893 'On Composite Dykes in Arran', *Quarterly Journal of the Geological Society of London* XLIX, 536–64.

Kanaris-Sotiriou, R & Gibb, F G F 1985 'Hybridisation and the petrogenesis of composite intrusions; the dyke at An Cumhann, Isle of Arran, Scotland', *Geological Magazine* 122 (4), 361–72.

Le Maitre, R W (ed) 2002 *Igneous Rocks: A Classification and Glossary of Terms. Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks.* 2nd Edition. Cambridge University Press, Cambridge.

Macgregor 1983 = MacDonald, J G; Herriot, A & King, B C 1983: *Macgregor's Excursion Guide to the Geology of Arran*. Geological Society of Glasgow, University of Glasgow, Glasgow.

MacKie, E 1964 'New Excavations on the Monamore Neolithic Chambered Cairn, Lamlash, Isle of Arran, in 1961', *Proc Soc Antiq Scot* 97 (1963–64), 1–34.

Mann, L M 1918 'The Prehistoric and Early Use of Pitchstone and Obsidian', *Proc Soc Antiq Scot* LII, 140–9.

McKerrow, W S & Atkins, F B 1989 *Isle of Arran*. Geologists' Association Guide 32.: Dinkyprint, London.

Maynard, D 1993 'Neolithic pit at Carzield, Kirkton, Dumfriesshire', *Transactions of the Dumfriesshire & Galloway Natural History & Antiquarian Society* LXVIII, 25–32.

Middleton, R 2005 'The Barnhouse Lithic Assemblage' *in* C Richards (ed) 2005 *Dwelling among the monuments. The Neolithic village of Barnhouse, Maeshowe passge grave and surrounding monuments at Stenness, Orkney*. McDonald Institute for Archaeological Research, Cambridge.

Mortazavi, M & Sparks, R S J 2004 'Origin of rhyolite and rhyodacite lavas and associated mafic inclusions of Cape Akrotiri, Santorini: the role of wet basalt in generating calcalkaline silicic magmas', *Contributions to Mineralogy and Petrology* 146, 397–413.

Mudie, G & Richardson, P 2006 'Excavation of a Possible Neolithic Structure, Lithic Finds and Later Ditch Features at Kingarth Quarry, Isle of Bute', *Scottish Archaeological Journal* 28(2), 105–24.

Ordnance Survey 1972 *Arran. Scotland Special Sheet. Solid Edition. 1:50,000 Series*. British Geological Survey, Southampton.

Ordnance Survey 1987 *Arran. Scotland Special Sheet. Solid Edition. 1:50,000 Series*. British Geological Survey, Southampton.

Pellant, C 1992 *Rocks and Minerals. The visual guide to over 500 rock and mineral specimens from around the world*. Eyewitness Handbooks.: Dorling Kindersley, London.

Preston, R J; Hole, M J; Still, J & Patton, H 1998 'The mineral chemistry and petrology of Tertiary pitchstones from Scotland', *Transactions of the Royal Society of Edinburgh: Earth Sciences* 89, 95–111.

Preston, J; Meighan, I; Simpson, D; & Hole, M 2002 'Mineral Chemical Provenance of Neolithic Pitchstone Artefacts from Ballygalley, County Antrim, Northern Ireland', *Geoarchaeology* 17 (3), 219–36.

Rao, M S 1959 'Minor Acid Intrusions and Dykes of Lamlash – Whiting Bay Region, Arran', *Geological Magazine* XCVI (3), 237–46.

Richards, C (ed) 2005 *Dwelling among the monuments. The Neolithic village of Barnhouse, Maeshowe passage grave and surrounding monuments at Stenness, Orkney*. McDonald Institute Monographs.:McDonald Institute for Archaeological Research, Cambridge.

Richey, J E 1961 *Scotland: The Tertiary Volcanic Districts*. British Regional Geology 3. Edinburgh: Natural Environment Research Council. Institute of Geological Sciences. Geological Survey and Museum / Her Majesty's Stationery Office.

Ritchie, P R 1968 'The stone implement trade in third-millennium Scotland', *in* J M Coles & D D A. Simpson (eds.): *Studies in Ancient Europe. Essays presented to Stuart Piggott,* 119–36. Leicester University Press, Leicester.

Robinson, P J 1931 'The pitchstone porphyry of Penrioch, Arran', *Transactions of the Geological Society of Glasgow* XVIII (1928–1931), 295–9.

Scott, A. 1915 (a) 'A composite sill in Glen Cloy, Arran', *Transactions of the Geological Society of Glasgow* XV (1912–1915), 140–50.

Scott, A. 1915 (b) 'The pitchstones of South Arran', *Transactions of the Geological Society of Glasgow* XV (1912–1915), 16–36.

Sharp, T G; Stevenson, R J & Dingwell, D B 1996 'Microlites and "nanolites" in rhyolitic glass: microstructural and chemical characterisation', *Bulletin of Vulcanology* 57, 631–40.

Shepard, C U 1835 'Microlite, a New Mineral Species', *American Journal of Science* 1, 361–2.

Simpson, D & Meighan, I 1999 'Pitchstone – a new trading material in Neolithic Ireland', *Archaeology Ireland* 13, 26–30.

Tomkeieff, S I 1961 *Isle of Arran*. Geologists' Association Guides 32. Benham and Company Limited, Colchester.

Topping, P 2005 'Shaft 27 Revisited: An Ethnography', *in* P Topping & M Lynott (eds) *The Cultural Landscape of Prehistoric Mines*. Oxbow Books, Oxford.

Tyrrell, G W 1916 'The Petrography of Arran III', *Geological Magazine*, New Series, Decade VI, Vol. III, 193–6.

Tyrrell, G W 1928 *The Geology of Arran*. Memoirs of the Geological Survey, Scotland.: Department of Scientific and Industrial Research/HMSO, Edinburgh.

Warren, G forthcoming 'Chipped stone', *in* M Johnson, C Flitcroft & L Verrill *The Calanais Fields Project: Excavation of a Sub-Peat Prehistoric Field System at Calanais, Isle of Lewis: Excavations 1999–2000*.

Whittaker, J C 1994 *Flintknapping. Making and Understanding Stone Tools*. University of Texas Press, Austin.

Williams Thorpe, O & Thorpe, R S 1984 'The distribution and sources of archaeological pitchstone in Britain', *Journal of Archaeological Science* 11, 1–34.

Zirkel, F 1894 *Lehrbuch der Petrographie*. II. Verlag von Wilhelm Engelmann, Leipzig.

9 GLOSSARIES

Glossary I

Current rock names applied to glassy, and related rocks (modified from North American Geologic-map Data Model Steering Committee (2004), Le Maitre (2002), and Gillespie and Styles (1999)).

Felsite – informal field term for fine-grained, pale-coloured igneous rocks, usually occurring as minor intrusions. May form by the devitrification of glassy rocks.
Obsidian – vitric igneous rock that is non-hydrated, is generally dark-coloured, and has few or no phenocrysts, and a bright, glassy lustre.
*Perlite** – vitric igneous rock characterised by hydrated glass with a distinctive spherical fracture texture.
Pitchstone – vitric igneous rock characterised by hydrated glass with a dull lustre.
Porphyry – (geological usage) informal field term for conspicuously porphyritic rocks, especially where the groundmass is fine-grained and hard to characterise. Common in Arran, Bute and Cumbrae, and probably sometimes originally glassy.
*Vitrophyre** – vitric igneous rock that has conspicuous phenocrysts in a matrix of glass.

*Terms approved in the USA, but not given as valid by Le Maitre, or Gillespie and Styles.

Glossary II

Obsolete rock terms used in the older literature on Arran pitchstone.

The 19th-century geological literature on Arran uses many terms which are poorly defined, and hence it can be difficult to establish what is meant when they are used. Some of the more frequently used terms relating to fine-grained rocks are discussed below.

Claystone – obsolete term for fine-grained materials made largely of clay minerals. Usually synonymous with mudrock (ie, a sedimentary rock). However, sometimes used for igneous rocks which have been thoroughly altered to soft clay-rich material, or finegrained clay-rich material in fault-zones. Curiously Bryce (1859) includes under claystone the riebeckite felsite of Holy Isle – an extremely hard, tough and un-clay-like material!
Clinkstone – hard, fine-grained rock (usually igneous) which makes a metallic or musical clinking sound when struck.
Greenstone – poorly-defined, vague and obsolete term usually used to refer to basaltic igneous rocks, usually somewhat altered. Also used to refer to serpentine-rich marbles and metabasic rocks.
Hornstone – obsolete term for tough, flinty-looking fine-grained rocks which break with conchoidal fracture. Partly corresponds to the modern term hornfels, but also used for cherts, or igneous rocks with similar physical properties.
Trap – obsolete term for fine-grained igneous rocks, usually basaltic in composition, and dark coloured. Used for both lavas and minor intrusions.