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.

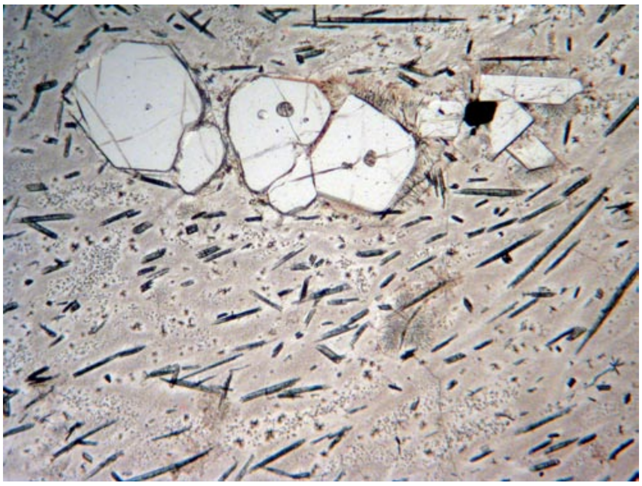
Illus 11   A very bright lustrous grey pitchstone, sparsely porphyritic, from Torr an Loisgte, Glenashdale (GLAHM 111951).

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

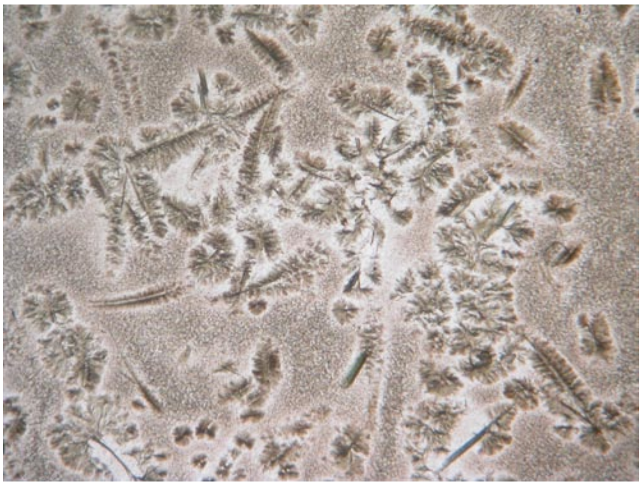
Illus 13   Porphyritic black pitchstone from the north end of Judd's No. 1 dyke, Tormore (GLAHM R14186).

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.

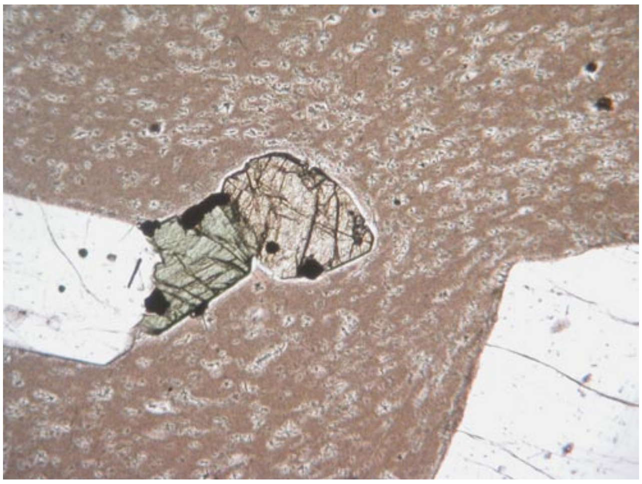


Illus 16 Quartz and plagioclase phenocrysts, with flow-aligned crystallites of amphibole. Cnoc Mor, Glenashdale (GLAHM 111967). Field of view c *2mm.*

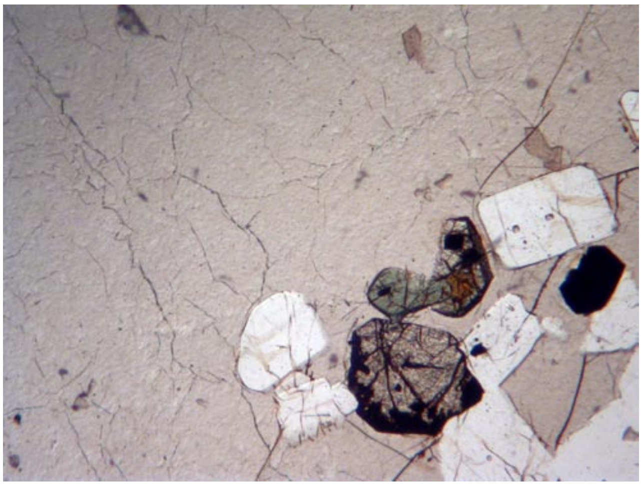


Illus 17 Pitchstone with dendritic crystallites, probably of amphibole, with 'bushy' biotite overgrowths. Dun Fionn, Corriegills (GLAHM 134054). This texture is pretty ubiquitous in Corriegills pitchstones, but is also found elsewhere. Field of view c *2mm.*

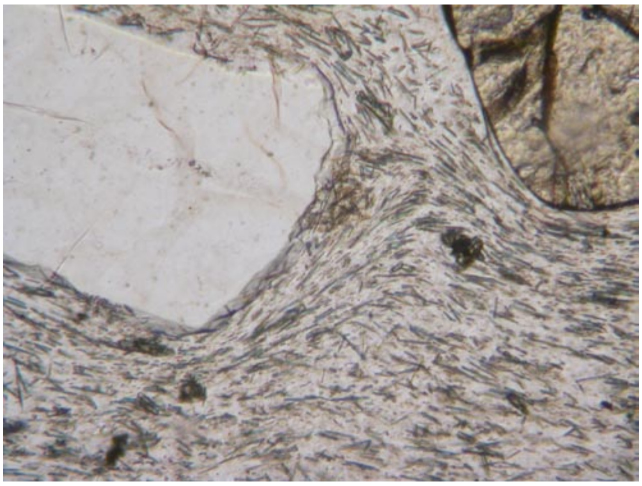
Illus 18 Dendritic amphibole crystallites, with bushy biotite? overgrowths from groundmass of porphyritic fayalite-bearing pitchstone, Cir Mhor (GLAHM 111993). Field of view c *0.5mm.*



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.*



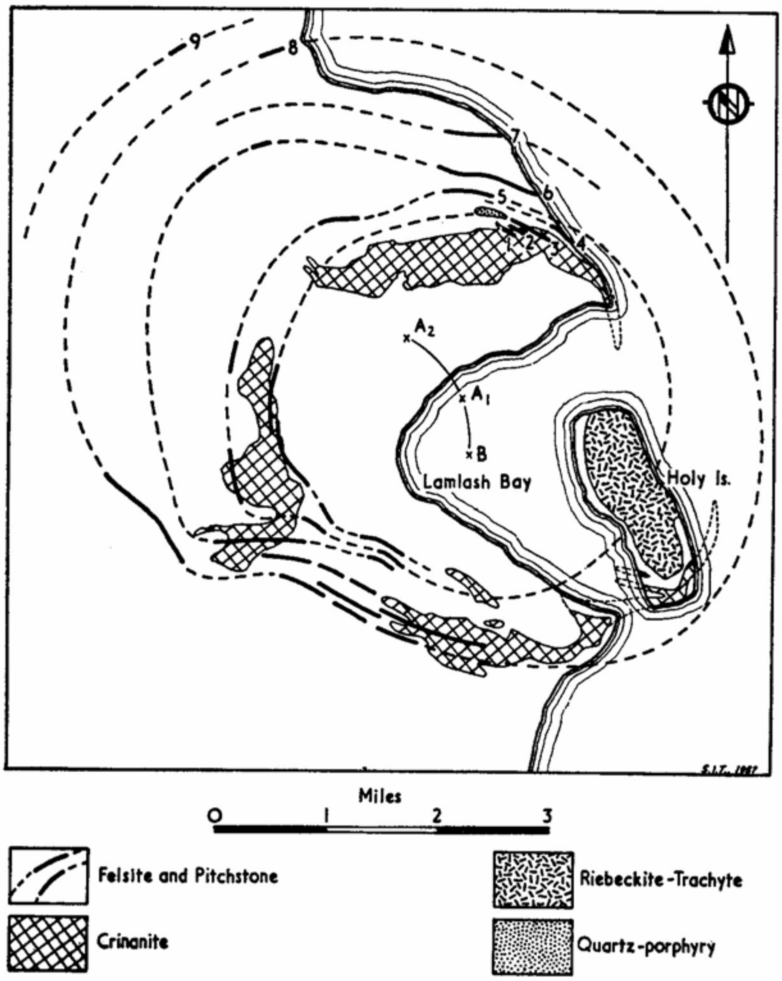
Illus 20 (left) Crystallite-free pitchstone with phenocrysts of fayalite (brownish), clinopyroxene (greenish), quartz (colourless, round) and plagioclase (colourless, rectangular). Cnoc Mor, Glenashdale (GLAHM 111968). Field of view c *2mm.*



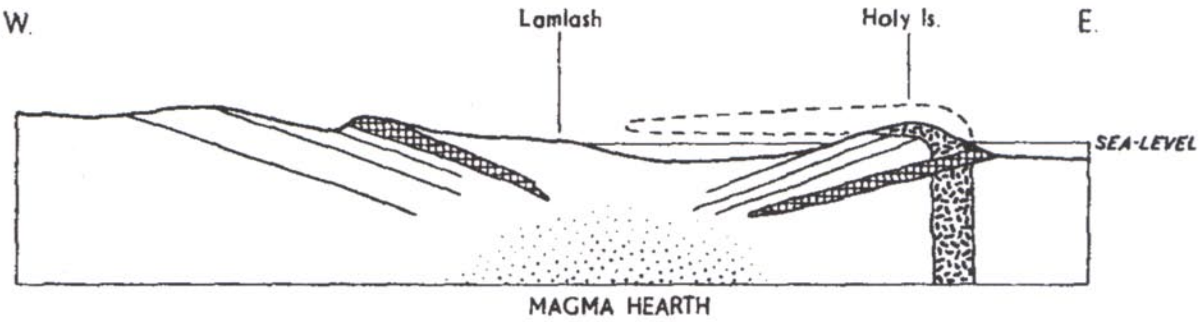
Illus 21 Phenocrysts of plagioclase (colourless) and fayalite (pale brown) in glass, with flow-banded crystallites (GLAHM 134050) Glen Shurig. Field of view c 0.5mm.

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.