4 Cunningsburgh

[HU 439 280]–[HU 421 274]–[HU 432 264]

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Published in: The Dalradian rocks of the Shetland Islands, Scotland. PGA 124 (1–2) 2013
https://doi.org/10.1016/j.pgeola.2012.07.007. Also on NORA

4.1 Introduction

This GCR site is named after the collection of hamlets on the south-east coast of Mainland Shetland, some 13 km south-south-west of Lerwick, that is generally known as Cunningsburgh (Figure 7.9). There, despite relatively intense metamorphism, an unusual and regionally important geological assemblage can be recognized. The east–west foreshore between South Voxter and Mail provides sections through the uppermost part of the Dunrossness Spilitic Formation, at the top of the Clift Hills Group. The rocks are dominantly sub-marine, basic pillow lavas with interbedded volcaniclastic material and intrusive bodies of hornblende metagabbro. To the south of Mail the north–south trending sea cliffs and the hillside between the cliffs and the road are composed of metalavas alternating with layers of metavolcaniclastic material and beds of metasedimentary rock. The rocks are pervasively foliated and are difficult to interpret in the field due to the intensity of metamorphism and their general dark-coloured and fine-grained nature. Inland from the north–south cliff section, the hillside drained by the Burn of Catpund is underlain by a large body of variably altered serpentinite, notable for its local development of highly unusual and controversial spinifex-like texture, which could be of considerable international interest (Figure 7.10). Along its western margin the serpentinite is in direct contact with a sequence of phyllitic chloritoid-kyanite-chlorite pelites, known as the Dunrossness Phyllitic Formation. These stratigraphically overlie the Clift Hills Phyllitic Formation that is displayed so comprehensively in the *Hawks Ness* GCR site. The Dunrossness Phyllitic Formation is seen to overlie the serpentinite structurally at the southern end of the GCR site, although it underlies it stratigraphically in the accepted order of Shetland succession.

This assemblage of rocks, following on from the sequence seen in the *Hawks Ness* GCR site, provides an illustration of the final stages in the development of a late-Dalradian extensional basin, when crustal disruption culminated in deep-seated intracontinental to oceanic magmatism. An understanding of the processes and sequence of events involved allows for a more-informed regional interpretation of an otherwise poorly known sector of the Scottish Dalradian. Detailed accounts of the local geology were given by Flinn (1967), Flinn and Moffat (1985) and Moffat (1987) and the area is covered by the Geological Survey's one-inch Sheet 126 (Southern Shetland, 1978). The rock assemblage was discussed in its regional context by Flinn (1985, 1999).

An additional feature of this GCR site stems from its considerable archaeological interest. Areas of very soft talc-magnesite schist (steatite), arising from low-temperature hydrothermal alteration of the serpentinite, were exploited in Norse times to be worked-up into various artefacts. Numerous tool-marked recesses have been left behind by the Norse workings and it has been suggested by archaeologists that there was considerable trade in steatite products from these and from other such quarries in Shetland.

4.2 Description

The Dunrossness Spilitic Formation forms the stratigraphically highest part of the Dalradian succession exposed in Shetland (Flinn *et al.*, 1972). It is almost entirely composed of mafic and ultramafic, lavas and volcaniclastic rocks formed in a sub-marine environment. The formation has been correlated broadly with either the lavas and tuffs of the Tayvallich Subgroup at the top of the Argyll Group (Flinn *et al.*, 1972), or possibly with part of the slightly later Southern Highland Group (Harris *et al.*, 1994; Flinn, 2007).

The formation dips consistently to the west at between 25° and 45°. There is no local way-up evidence but, accepting that the overall younging of the Shetland Dalradian succession is to the east, as discussed in the *Introduction* to this paper, the sequence here must be overturned. The outcrop width and dip suggest a formation thickness of about 1 km, with the ultramafic component, a large body of serpentinite, occupying upwards of one half of that, in the topographically highest but stratigraphically lowest part in the west. For the most part, the sequence is thinly foliated with some thicker and more-massive, less well-foliated units that are probably relics of the original bedding. The metamorphic foliation is generally parallel to the igneous and sedimentary layering. Folding is rare but locally the layering and foliation are intensely deformed by a series of small, strongly asymmetrical, tight to isoclinal folds. Fold hinges are subhorizontal but show a range of orientations, possibly in association with minor faulting, which complicates the structure locally. Garnet appears to have grown in two phases of metamorphism, before and after imposition of the foliation. Overall, the rocks stratigraphically above the serpentinite have been metamorphosed to lower to medium amphibolite facies. This is a significantly higher grade than is seen in the rocks of the Clift Hills and Whiteness groups to the west (see the *Hawks Ness* GCR site report).

The serpentinite occupies most of the hillside above the road to the west of the coastal sections. Its basal contact with the metasedimentary, chloritoid-bearing Dunrossness Phyllites is exposed only in the sea cliffs at the southern end of the GCR site, immediately north of Lamba Taing. There, despite the complication of minor but complex faulting, the contact appears to lie parallel to the bedding traces and dominant foliation in the phyllites; there is no evidence for a significant tectonic break. A major lens of serpentinite, separate from the main body, crosses the road and intersects the coast in the middle of the GCR site and wedges out on the hillside south of the Burn of Catpund. This large lens of serpentinite also lies parallel to the foliation in the spilitic and volcaniclastic rocks.

The serpentinite has been variably steatitized and veined by talc. From several hundred metres north of the Burn of Catpund to the south end of the GCR site, the steatitization is sufficiently intense for a quarry to have been opened recently in the expectation of exploitation. The surrounding hillside is scarred by small pits opened during the Norse occupation of Shetland, a thousand years ago, for the manufacture of utensils. Some Norse pits along the Burn of Catpund have been re-excavated by the burn and one has been opened by archeologists for display purposes.

The steatite rock is about half talc and half magnesite. Where the steatitization is not too intensively developed, the rock is seen to be a clast-supported breccia composed of blocks up to about 30 cm in diameter, thoroughly cemented by the serpentinization. Broken blocks within the breccia that have been little affected by steatitization, have in places been weathered and etched to reveal that they are composed of a mass of needle-like, parallel to subparallel crystal pseudomorphs forming a distinctive spinifex-like texture (Figure 7.10). The 'spinifex' textured rocks can be traced intermittently from about 300 m north of the Burn of Catpund as far as the Burn of Mail, in a zone a hundred metres or so west of the contact of the serpentinite body with the spilitic rocks (Figure 7.9). Thin sections show that the pseudomorphs have the characteristic crystal terminations of spinifex-textured olivines, but that they are serpentinized or steatitized, as is the matrix that contains them. As is discussed below, the recognition of the spinifex-like texture provides crucial support for the interpretation of the serpentinite as an original quickly chilled, ultramafic lava, possibly a komatiite.

Also present within the serpentinite outcrop are several major lenticular layers of fine-grained non-serpentinite rocks that possibly separate individual ultramafic lavas. These are mainly metavolcaniclastic rocks, best seen on the beach at Mail and in the nearby road cutting. They also include interlayered lenses of metasedimentary rocks including very fine-grained, often graphitic gritty psammites, quartzites and pelites; one such lens crops out on the coast about 200 m south of Sands of Mail. The minerals present include biotite, garnet, chlorite, chloritoid and hornblende. The quartzites might be recrystallized cherts and there is at least one 2 m-thick bed with a melange-like texture showing tectonic stretching of the clasts within the plane of the foliation (Figure 7.11).

Sporadically distributed through the serpentinite are many near-spherical to sublenticular bodies of hornblende gabbro, 10–20 m across and forming prominent smoothly rounded knolls. Also widely scattered in this area are intrusive veins and lenses, centimetres to several metres in width, of a white to greyish rock with a siliceous patina. The rock is composed of minute aligned crystals of albite with sparse accessory hornblende and biotite. It contains 10% Na_2O and 0.5% K_2O and has been interpreted as a sodic 'keratophyre' (an albite felsite). It also contains abundant micron-sized zircons and an analysis shows 1000 ppm Zr, but it has not as yet been dated and relationships with the host serpentinite cannot be determined.

To the east of the serpentinite, between the road and the sea, are metamorphosed basic lavas alternating with volcaniclastic rocks. In thin section the lavas are seen to be composed dominantly of blue-green hornblende with epidote. Some are aphyric, others contain relict phenocrysts of plagioclase (now corroded albite), and many are amygdaloidal. The rocks are variably tectonized with phenocrysts broken and displaced in some examples and acting as microaugen within the foliation in others. They are tholeiitic Mid-Ocean-Ridge-Basalt (MORB), probably derived from a relatively enriched mantle source (Fettes *et al*., 2011). The volcaniclastic rocks are black and commonly very fine grained. Their nature is largely indeterminable in the field except where they have been polished by sand along the Mail coast; identification has been assisted greatly by thin-section examination (Flinn, 1967).

Eastwards along the coast from the Sands of Mail, the rocks are exceedingly difficult to interpret. Most are black and fine grained, but in thin section they prove to be basic metavolcaniclastic rocks. Some weathered exposures reveal faint cross-sections of pillow structures (e.g. at [HU 441 282]) and the sequence might be largely composed of fragmented pillow lavas. Also present, especially adjacent to the Old Red Sandstone to the east of Aith Voe, are exposures of graphitic quartzite and phyllitic pelite. Inland there are a number of hornblende gabbro bosses with the same appearance as those seen to the west within the serpentinite; although here some are schistose and boudinaged, Flinn (1967) reported the preservation of an ophitic texture. An unusually large example crops out on the coast at The Pows [HU 437 278]. They might have originated as intrusions into the volcanic sequence.

4.3 Interpretation

The interpretation of the origin of the serpentinite is crucial in any assessment of the wider geological significance of the Cunningsburgh GCR site in relation to the late history of the Dalradian basin in Shetland. When it was first mapped in the late 1950s, the serpentinite was interpreted as comprising one or more sub-marine, ultramafic lava flows (Flinn, 1967). However, this interpretation was regarded as petrologically impossible at the time and was not published until the recognition of the spinifex-like texture by Flinn and Moffat (1985) suggested the possibility of a komatiitic protolith for the serpentinite.

The term ‘komatiite’ was introduced by Viljoen and Viljoen (1969) to describe ultramafic lavas from the Baberton Mountain Land, South Africa. They are now known to be fairly widespread in Archaean greenstone belts but are rare in younger geological assemblages; for an overall review see Arndt and Nisbet, (1982). The high concentration of magnesium (up to 32% MgO) and related elements in komatiitic lavas indicates a high temperature (*c*. 1600°C), a high degree of melting of mantle material and consequently an unusually high heat flow and/or the tapping of an exceptionally deep and hot mantle source. Hence the presence of the ultramafic lava within the Shetland Dalradian has potentially profound implications for the tectonic development of the depositional basin.

Apart from the high MgO values, the most distinctive feature of komatiitic lavas is the common primary crystallization of olivine as long intermeshed crystals in a glass matrix, to produce what is known as ‘spinifex texture’ (after the spiny intermeshed leaves of Australian Spinifex grass). However, the spinifex nature of the texture in the Cunningsburgh rocks was disputed by Nesbitt and Hartman (1986) who thought it more likely to be an example of the well-documented ‘pseudo-spinifex’ or ‘jackstraw’ texture that develops through the regrowth of olivine during prograde metamorphism of serpentinite (Collerson *et al.*, 1976). The distinction between this pseudo-spinifex and true spinifex texture is best based on examination of thin sections of fresh samples. However, the Cunningsburgh rocks are both serpentinized and steatitized, destroying these distinctive thin-section features. The distinction in this case has to be based on the study of the textural patterns revealed on suitably weathered rock surfaces (Figure 7.10).

Nesbitt and Hartmann (1986) presented various arguments against the presence of komatiitic lavas at Cunningsburgh and elsewhere in the Caledonian–Appalachian Orogen, possibly infuenced by the fact that occurrences in post-Archaean rocks were at that time regarded as exceedingly rare or non-existent. Proterozoic and Phanerozoic komatiitic occurrences are no longer regarded as quite so rare, but it is difficult to reach any conclusions about original magmatic liquid compositions from rocks that are as altered as the Cunningsburgh serpentinites, and the origin of the spinifex-like texture remains somewhat enigmatic. However, even if the Cunningsburgh rocks were not originally komatiites, it is still possible that they originated as basaltic lavas, in which Mg concentrations even higher than those of typical komatiites can arise by olivine fractionation and accumulation (see the *Ardwell Bridge* GCR site report).

In a robust defence of their original interpretation, Flinn and Moffat (1986) pointed out that the complex metamorphic history implied by the Nesbitt and Hartmann interpretation of the origin of the spinifex-like texture does not fit the known geology of the Cunningsburgh area. In particular, there is no evidence in Shetland for a high-grade metamorphic event (of at least upper amphibolite facies) that would have been necessary to produce prograde olivine growth after one episode of serpentinization but before the brecciation and the final serpentinization and steatitization. They re-iterated their belief that a volcanic origin for the serpentinite in the top of an extensional basin requires the fewest assumptions, creates the fewest problems and fits the observed structural and metamorphic history most simply.

Consequently, the Dunrossness Spilitic Formation, including the serpentinite, is regarded as the final volcanic infill to the late-Dalradian extensional basin that is still preserved in Shetland. Following the deposition of the Laxfirth Limestone, early sedimentation in the basin was interrupted by a series of relatively minor volcanic eruptions giving rise to the Asta Spilitic Formation (see the *Hawks Ness* GCR site report). But the later volcanism that created the Dunrossness Spilitic Formation was an event on an altogether different scale. Not only is the formation a kilometre or more thick, but it commenced suddenly with the eruption of a thick sequence of ultramafic lavas. This unusual event is most readily explained by a rapid acceleration of crustal rifting beneath the extending basin, causing adiabatic melting in the mantle immediately below with generation and emplacement of high-temperature, magnesium-rich magmas (Flinn, 2007). The spinifex-like texture, the brecciation and the serpentinization could all be due, in part at least, to sub-marine emplacement of the ultramafic magma; certainly they are all early-formed features. The emplacement of the ultramafic magma was followed by the more-usual eruption of basaltic magma of tholeiitic Mid-Ocean Ridge affinities in the form of lavas, volcaniclastic material and eventually pillow lavas. Their higher grade of metamorphism than any of the rocks in the Clift Hills and Whiteness groups to the west might have been caused, at least in part, by residual heat associated with the ultramafic magmas. The intrusion of small globular masses of the same magma in the form of hornblende gabbro would seem to require special conditions or circumstances that are not fully resolved.

Apart from the sub-marine lavas and volcaniclastic deposits, the original protoliths for the sedimentary components of the Dunrossness Spilitic Formation were interbedded mudstones and sandstones of deep-marine, probable turbiditic facies. Accessory lithologies present possibly included chert and a melange-type rock that might have originated by sedimentary slumping before being tectonized.

The onshore outcrop of the Dunrossness Spilitic Formation is given additional importance by a substantial offshore extension beneath Old Red Sandstone strata, as indicated by major coincident gravity and aeromagnetic anomalies. These anomalies continue as far north as the island of Unst, suggesting that the extensional basin eventually developed into an intracontinental rift on the edge of Laurentia at the time of the opening of the Iapetus Ocean (Flinn, 2007). It has even been suggested by Flinn (2001) that the Shetland Ophiolite could have been obducted from this basin at about 500 Ma.

A possible ophiolitic association of the serpentinite and pillow lava sequence in the Cunningsburgh area was noted by Garson and Plant (1973) and was further hinted at by Nesbitt and Hartmann (1986). This interpretation invoked limited sea-floor spreading during basin extension, but also invited consideration of cold serpentinite diapirism into growing oceanic fracture zones. However, apart from the presence in the Cunningsburgh area of serpentinite and pillow lavas, no convincing evidence has been adduced which in any way suggests the presence of an ophiolite-complex. At the time that these suggestions were made it was still common for all serpentinite occurrences to be interpreted automatically as ophiolites.

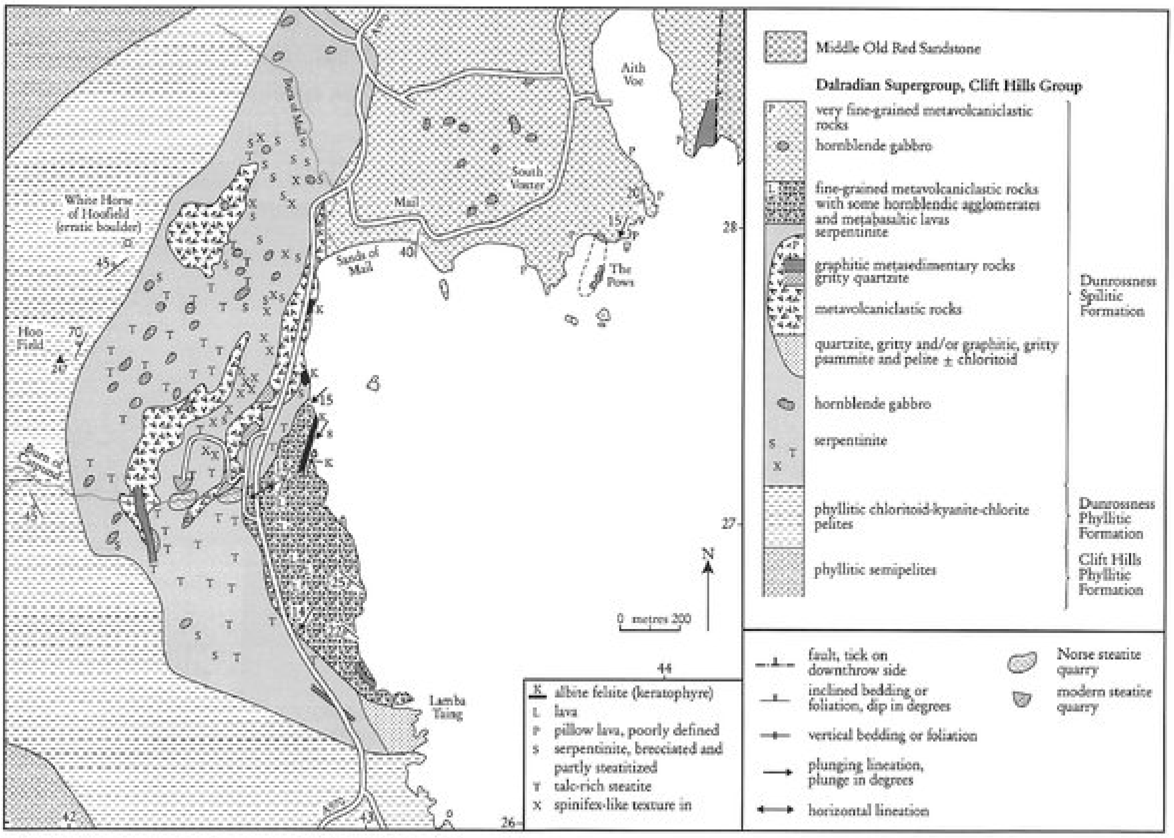
4.4 Conclusions

The coast to the east and south of Mail and the hillside inland from the coast at the Cunningsburgh GCR site, provide excellent exposures of the Dunrossness Spilitic Formation, the youngest Dalradian unit present in Shetland. It is largely metavolcanic in origin and comprises sub-marine lavas and various volcaniclastic rocks, interbedded with minor metasedimentary lithologies of deep-water facies. The volcanic succession has been intruded by comagmatic hornblende gabbro and by albite felsite (‘sodic keratophyre’) of unknown affinity. All of the rocks have been deformed and metamorphosed, up to middle amphibolite facies in places; some of the finer grained rocks have a phyllitic texture.

The metavolcanic rocks include basaltic pillow lavas and brecciated ultramafic rocks that are interpreted as high-magnesium lavas. Clasts within the latter have spectacular and highly distinctive elongate pseudomorphs after crystals of olivine, which have been likened to the spinifex texture characteristic of unusual high-temperature lavas known as komatiites. Unfortunately later serpentinization has obliterated details of the texture and its origin has been the subject of debate, but the presence of komatiites in post-Archaean rocks is rather unusual, and the possibility of their presence in Shetland is highly significant and of international interest.

The rock assemblage illustrates the final phase in the development of the Dalradian extensional basin in the Shetland area. An abrupt increase in the rate and depth of extensional faulting is considered to have caused generation of the highly unusual ultramafic lavas, followed by eruption of more-typical, within-plate basaltic lavas. A considerable thickness of the basaltic lavas and associated volcaniclastic rocks built up as the basin filled; since many of the lavas are pillowed, sub-marine eruption is confirmed. The volcanic sequence can be traced offshore by geophysical methods as far north as the island of Unst, and it might have formed the floor of an intracontinental basin on the edge of Laurentia from which the Shetland Ophiolite was obducted. Hence, the geological features preserved within the Cunningsburgh GCR site have profound implications for the wider interpretation of the Dalradian succession both in Shetland and in the Scottish mainland.

[References](#)



(Figure 7.9) Map of the area around the Cunningsburgh GCR site.

(Figure 7.10) Spinifex-like texture preserved as pseudomorphs after olivine in a block of brecciated and then serpentinized ultramafic rock. Hillside south-west of Sands of Mail, Cunningsburgh [HU 4261 2744]. Coin is 26 mm in diameter. (Photo: D. Flinn, BGS No. P 550134.)

(Figure 7.11) Tectonically stretched clasts within a debris-flow deposit, probably volcaniclastic, interbedded with spilitic lavas of the Dunrossness Spilitic Formation on the coast south-west of Mail, Cunningsburgh [HU 429 278]. Hammer shaft is 28 cm long. (Photo: P. Stone, BGS No. P 726608.)