NESS OF CLOUSTA TO THE BRIGS

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Introduction

The Clousta volcanic rocks, which form an ENE-trending outcrop across the centre of the Walls Peninsula in western Shetland (Figure 9.46), comprise mainly basic and acid pyroclastic rocks, with some basaltic and andesitic lavas and shallow sills, rhyolitic lava domes and ignimbrites, and concordant intrusions of felsite. These are scattered as relatively thin and localized lenses within Middle Old Red Sandstone alluvial fan and lacustrine sequences. The Ness of Clousta to the Brigs GCR site (Figure 9.49) exhibits a variety of volcanic products but is particularly noteworthy for the evidence of interaction between magma and water-saturated, unconsolidated alluvial sediments, possibly giving rise to phraeatomagmatic explosions. The composition, internal structures and three-dimensional geometry of the pyroclastic accumulations in particular have been compared to those of maars and tuff-rings.

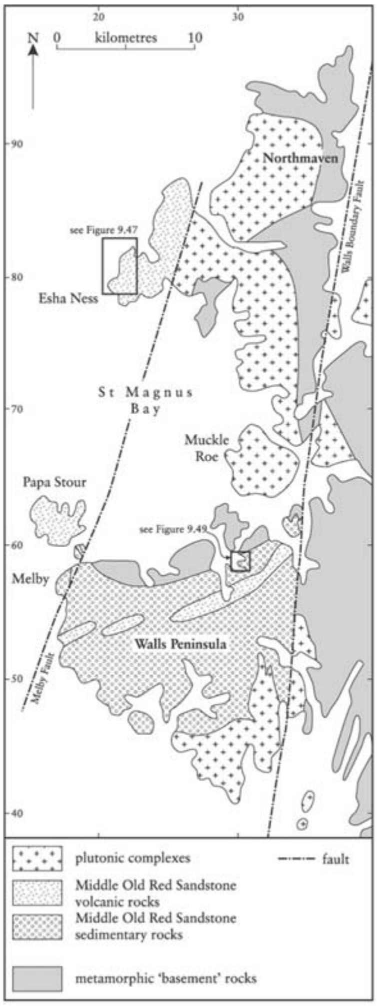

Figure 9.46: Location of Middle Old Red Sandstone volcanic rocks, major intrusions and major faults in western Shetland, after Mykura (1976).

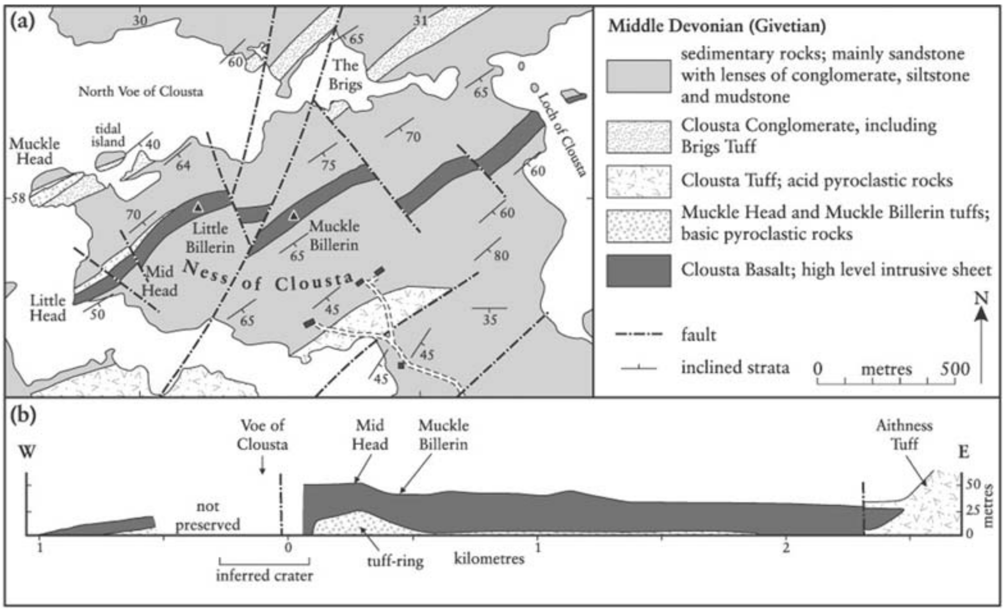

Figure 9.49: (a) Map of the Ness of Clousta to The Brigs GCR site, adapted from Geological Survey 1:10 560 sheet Shetland 42 (1967) and Astin (1982). (b) The Muckle Billerin Tuff and Clousta Basalt: reconstructed cross section based on measured sections, showing the different thickness either side of the Voe of Clousta. Vertical exaggeration ×2.5. (From Astin, 1982.)

The volcanic rocks were first noted by Peach and Horne (1884) and were described briefly by Finlay (1930). The Walls Peninsula was mapped by the Geological Survey in the 1930s (Wilson *et al*., 1935) and re-examined in detail in the 1960s, resulting in the current map and a detailed description of the volcanic rocks by Mykura (in Mykura and Phemister, 1976). A detailed, mainly sedimentological, study of the peninsula by Astin (1982) resulted in a radical re-appraisal of some of the volcanic rocks and their relationship to sedimentation. Some petrographical and geochemical details are given by Thirlwall (1979) and Astin (op. cit.).

The Old Red Sandstone rocks of Shetland occur in three distinct structural blocks separated by major N- to NNE-trending faults. The successions within each block differ in age, depositional and volcanological development, tectonic history and effects of igneous intrusion and low-grade metamorphism (Mykura, 1976). Most of the Old Red Sandstone of the Walls Peninsula occurs in the central block, bound to the west by the Melby Fault and to the east by the Walls Boundary Fault (Figure 9.46). Within this block, the Old Red Sandstone rocks rest unconformably on Precambrian metasedimentary rocks to the north and are intruded and hornfelsed in the south by the Sandsting plutonic complex (K-Ar mineral dates of 369 ± 10 and 360 ± 11 Ma by Snelling in Mykura and Phemister, 1976). They have been involved in two phases of intense folding with cleavage development, and have suffered low-grade regional metamorphism, locally up to low greenschist facies. Palynological data indicate a Givetian age (Rogers *et al*., 1989, fig. 2), making the volcanic rocks younger than those of the western block (see the Eshaness GCR site report) and comparable in age to those of Orkney (see the Point of Ayre and Too of the Head GCR site reports).

In the Walls Peninsula, the Old Red Sandstone outcrop is divided by the ENE-trending Sulma Water Fault into areas of markedly different sedimentary facies that were assigned to two separate formations of different ages by Mykura and Phemister (1976). Astin (1982) recognized four diachronous sedimentary formations which, together with the Clousta volcanic rocks, comprise a single coherent sequence that can be correlated across the Sulma Water Fault. To the north of the fault, sedimentary rocks assigned to the Sandness Formation of Mykura and Phemister represent all four of Astin's formations. The strata dip generally to the SSE at moderate to high angles and the Clousta volcanic rocks are interbedded with the upper part of this sequence, adjacent to the fault.

Description

The GCR site (Figure 9.49) occurs towards the eastern end of the outcrop of Clousta volcanic rocks, which are here intercalated with medium- to coarse-grained sandstones locally with lenses of conglomerate and minor siltstones and mudstones, all assigned to the Vatslees Formation by Astin (1982). The Clousta Conglomerate, which is up to 70 m thick and can be traced for 5 km, forms a good topographical feature (Figure 9.50) and is a stratigraphical marker throughout the area. Within the GCR site there are two lenses of basic pyroclastic rocks, the Muckle Head Tuff and the Muckle Billerin Tuff; the latter is overlain directly by a sheet of basalt, termed the Clousta Basalt (the Muckle Billerin Basalt of Astin). Astin also identified a thin lens of acid volcaniclastic rocks within the Clousta Conglomerate, which he termed the Brigs Tuff. These volcanic units are described in stratigraphical order, combining the observations of Mykura (in Mykura and Phemister, 1976) and Astin (1982) with those of the author.

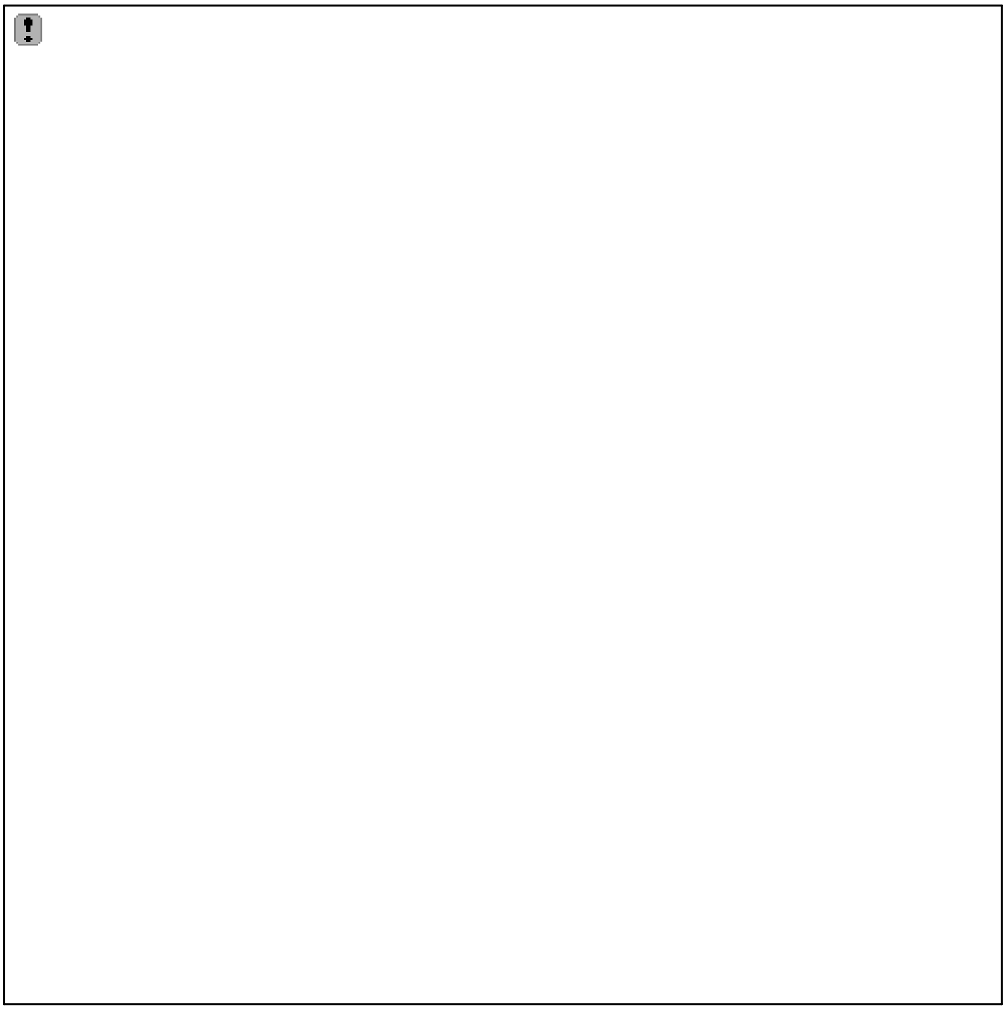

Figure 9.50: View of the Ness of Clousta to The Brigs GCR site, looking east from Muckle Head. The Muckle Head Tuff forms the rocks of the foreground; the Brigs Tuff forms the extreme right of the tidal island beyond; the upper part of the Clousta Conglomerate, dipping to the right (SSE), forms the prominent feature crossing the tidal inlet in the middle distance; and the right skyline is the ridge of Muckle Billerin, formed by the Clousta Basalt overlying the Muckle Billerin Tuff. (Photo: D. Stephenson.)

The Muckle Head Tuff

Muckle Head is formed from a lens of poorly sorted basaltic lapilli-tuff up to 35 m thick, which thins markedly north-eastwards over a strike length of 350 m. Only 2 m are preserved west of the Voe of Clousta. The tuff rests upon conglomerate, which may be the basal part of the Clousta Conglomerate, capping a coarsening upward sequence of slumped alluvial sandstones. Large blocks of conglomerate and sandstone occur in the base of the tuff, but their size and abundance decrease upwards. Clasts of magmatic material, mostly of basic to intermediate composition form up to 70% of the tuff and become more dominant towards the top of the lens. Most are scoriaceous or vesicular, some are flattened and some are glassy and enclose small quartz grains. Clasts of fine-grained acid igneous material are rare. The matrix is composed mostly of quartz and feldspar derived from the underlying sediments, but garnet, epidote and titanite have also been recorded. The grains are commonly well rounded, but others are fractured and angular. The tuff is well bedded throughout its thickness and cross-bedding has been recorded. Overlying the tuff are well-bedded siltstones, which pass upwards into conglomerate. Astin has correlated these siltstones with a 2–3 m-thick lacustrine unit within the fluvial Clousta Conglomerate.

The Brigs Tuff

Immediately above the thin fine-grained lacustrine unit that divides the Clousta Conglomerate, is a sheet-like, coarse-grained volcaniclastic unit, up to 12 m thick, which thins only gradually to the ENE over a distance of 3 km. The unit consists largely of subrounded to angular lithic clasts of feldspar porphyry and less abundant flow-banded felsite in a finer-grained quartzofeldspathic matrix. Pumice, or other evidence of a magmatic eruption, is conspicuously absent. The lithic clasts are up to 40 cm across, there is little lateral variation in the size of clasts and, in general, the deposit is well sorted and largely clast supported. The unit is either massive or parallel-bedded and locally it has low-angle cross-bedding, with sets up to 20 cm thick that are well seen on the tidal island (at 2990 5811).

The Muckle Billerin Tuff

Poorly sorted basaltic pyroclastic breccia and lapilli-tuff are exposed on the northern side of Little Head (2976 5765) at the base of the Clousta Basalt and can be traced for about 2 km along the NW flank of the Muckle Billerin ridge. The lens is up to 24 m thick around Mid Head, but this proximal development only extends for about 450 m along strike. Farther to the NE there is only a thin distal fringe and to the SW, on the opposite side of the Voe of Clousta, there are 8 m (Figure 9.49b). The maximum clast size shows a systematic fining from blocks up to 30 cm around Mid Head to under 2 cm distally. The rock is composed of large amounts of quartzofeldspathic sand and basaltic to intermediate magmatic material, with less abundant blocks of acid igneous rock. The juvenile material varies in amount from 10–70%; it is commonly scoriaceous and vesicular and some clasts are flattened and welded, especially in proximal areas. The quartzofeldspathic and acid material is commonly fractured and angular and is more abundant in the proximal area. The whole deposit is very well bedded, dominantly parallel-bedded, but with some cross-bedding, low-angle discordances and shallow scour and fill structures. The set height of the cross-bedding varies systematically from up to 15 cm proximally to a few centimetres distally.

The Clousta Basalt

This sheet of basalt, which rests directly on the Muckle Billerin Tuff, is the most extensive of several in the eastern outcrops of the Clousta volcanic rocks. It forms a prominent, fault-stepped ridge extending for 2.5 km from Little Head to the shore of the Loch of Clousta and onwards, forming a string of small islands in the loch. The thickness varies from 25–40 m on the Ness of Clousta, but west of the Voe of Clousta, only 8–9 m are preserved. The basalt is aphyric and is pervasively altered, with small feldspar laths in a chloritic matrix that is replaced in parts by aggregates of green biotite, actinolite and epidote as a result of the regional metamorphism. It is vesicular throughout and has well-developed pipe amygdales at its base in places (for example on Muckle Billerin at 3064 5801). Partly remelted inclusions of tuff are also found in the base. The top surface of the sheet is well exposed on the east side of Little Head (2982 5763). Here, the contact is highly irregular, with bulbous protrusions and isolated globular to subangular pods of scoriaceous basalt in sharp contact with the overlying sediment (cf. peperite). Immediately overlying the basalt in places is a volcaniclastic coarse sandstone with quartz, feldspar and some dark igneous clasts that may be slightly flattened; it could therefore be a tuff. More generally, the contact is with purple siltstone and mudstone, the latter having large elongate vesicles. All the signs are that the basalt was intruded at a very shallow depth into the junction between tephra deposits and overlying unconsolidated wet sediments.

Interpretation

The volcanic rocks in the Clousta area were erupted on to the sands and gravels of braided river channels in an alluvial fan derived from metamorphic basement to the north (Astin, 1982). This fan bordered a shallow lake with beach ridges to the SW, which may have encroached north-eastwards at times, depositing finer-grained sediments such as those preserved in the middle of the Clousta Conglomerate. In this environment, volcanic activity is likely to have been phreatic or phreatomagmatic as a result of interaction of rising magma with groundwater or surface water, just below or at ground level. Astin has interpreted many of the pyroclastic deposits as the products of such eruptions.

The basic pyroclastic deposits of the Muckle Head and Muckle Billerin tuffs (and the Hollorin Tuff, 3 km to the WSW of the GCR site) have the composition, bedforms and geometry of phreatomagmatic deposits. The high content of detrital quartz and feldspar and the larger blocks of sandstone and conglomerate reflect the explosive excavation of a vent crater in the underlying alluvium. Indicators of lateral transport, such as cross-bedding, which characteristically decreases in set height away from the vent, coupled with finer-scale planar bedding are typical of pyroclastic surge deposits. But the high proportion of planar bedding suggests that much of the deposit resulted from ash-fall.

Astin reconstructed the original geometry of the basaltic tuffs from measured sections (Figure 9.49b). These formed very shallow cones, 700– 1000 m in diameter, with approximate height to width ratios in the range 1:18 to 1:40. Allowing for possible incomplete preservation of the original height, these are comparable with those of modern tuff-rings (1:10 to 1:30;Heiken, 1971). The Muckle Head and Muckle Billerin tuffs each show their maximum thickness, maximum clast size and greatest proportion of sediment-derived clasts close to the Voe of Clousta. Although these features imply close proximity to the vents and possible craters, there is little direct evidence to indicate their sites. Astin did however point out that the lacustrine sediments that directly overlie the Muckle Head Tuff imply a horizontal surface. Hence the thickness variation of the tuff must have been accommodated in the substrata soon after eruption, possibly by slumping and subsidence on the site of the crater. He pointed to the slumped and chaotic sandstone beds below the tuff and steep normal faults restricted to the tuff and immediately underlying sediment, as further evidence for this mechanism. Only thin representatives of the tuffs, with limited lateral extent, are found on the SW side of the Voe of Clousta and the intervening sedimentary sequence is attenuated from about 200 m in the east, to less than 20 m in the west. Astin suggested that this is evidence for active syndepositional faulting on a N–S line along the Voe, which also acted as a magma conduit and controlled the positions of the vents and possible craters.

The Muckle Billerin Tuff is overlain directly by the Clousta Basalt, which has a similar lateral extent (Figure 9.49b). Astin (1982) interpreted this as a lava erupted immediately following the tephra, a transition that is commonly observed in modern phreatomagmatic eruptions as groundwater becomes excluded from the magma conduit. However, the peperitic features at Little Head and the vesiculation (= fluidization) of the overlying mudstones provide convincing evidence that the basalt was intruded into wet, unconsolidated, fine-grained sediments deposited on top of the tuff.

Acid pyroclastic rocks are a major feature of the Clousta volcanic rocks in general, forming large complex lenses such as the Clousta Tuff, west of the Voe of Clousta, and the Aithness Tuff to the east. These larger bodies are built almost entirely from ash-fall tuffs with a large magmatic component, much of it erupted in a plastic state and commonly welded. In the GCR site, only the Brigs Tuff is dominantly acid. This thin lens contains hardly any erupted magmatic material; angular clasts of feldspar porphyry and flow-banded felsite were interpreted by Astin as having originated from the break-up of small pre-existing lava domes or shallow intrusions, such as are found elsewhere among the Clousta volcanic rocks. Some clasts are quite rounded and may have come from the underlying alluvial gravels, along with the quartzofeldspathic sand that forms the matrix of the deposit. Clearly this was generated almost entirely by phreatic eruptions. The well-bedded and sorted nature suggests dominant ash-fall, but the cross-bedding indicates some pyroclastic surge. Measured sections suggest a height to width ratio of about 1:50, notably shallower than the basic tuff-rings and more comparable with modern day maars.

The compositions of the Clousta volcanic rocks are notably less varied than the volcanic sequences elsewhere in Shetland at Papa Stour, Melby and Eshaness (see theEshaness Coast GCR site report), and Astin (1982) drew attention to the compositional gap between the basaltic and rare andesitic rocks and the more voluminous acid rocks.Thirlwall (1979) concentrated on analyses of the basic rocks, concluding that they have similar characteristics to those at Eshaness, transitional between calc-alkaline and tholeiitic, and were derived from similar parental magmas. Variation in these rocks was explained by low-pressure fractionation of olivine, clinopyroxene and plagioclase. Astin studied the acid rocks in more detail and concluded that, in view of the compositional gap and the presence of only K-feldspar, the acid rocks are more likely to have originated by partial melting of crustal rocks.

As with the other Mid-Devonian volcanic rocks of Shetland and Orkney, the Clousta volcanic rocks were erupted in an extensional basin setting, while retaining geochemical characteristics that are possibly attributable to earlier subduction (see theEshaness Coast GCR site report). However, being located in the Walls structural block and slightly younger than the other sequences, they are more demonstrably related to the western Shetland plutonic complexes, both temporally and spatially (see Chapter 8: Introduction). These plutons are themselves closely related to the compressive deformation and metamorphism that affected the Old Red Sandstone rocks of the Walls block soon after deposition;Mykura and Phemister (1976) attributed the lack of deformation in rocks close to the Sandsting pluton to pre-deformation hornfelsing, but Astin (1982) implied that this hornfelsing resulted from early crystallization of the outer part of the pluton, which was followed by the main deformation and metamorphism as a result of continuing diapirism and isostatic rise of the plutons. So, it is possible that the volcanism, like the plutonism, may have been related to this Mid- to Late Devonian compressive event, the last phase of Caledonian folding in Britain, which post-dates the main extensional event(s) responsible for the development of the Orcadian Basin.

Conclusions

This GCR site represents the Clousta volcanic rocks of the central, Walls structural block of Old Red Sandstone outcrops in Shetland. Their Givetian age means that they, along with less extensive outcrops on Orkney, represent the youngest Caledonian volcanism in Britain. Although the rocks have subduction-related characteristics, they were erupted in an extensional basin setting, shortly before a reversion to compressive deformation and pluton emplacement.

The rocks were erupted onto an alluvial fan bordering on a lake margin, an environment that resulted in a preponderance of eruptions that involved the explosive gasification of ground and/or surface waters. Measured sections have enabled the three-dimensional form of the deposits to be determined which, together with the sedimentological and compositional features of the volcanic rocks, have suggested the presence of basic tuff-rings and an acid maar. Such features have not been described elsewhere in the Old Red Sandstone volcanic province of Britain and indeed are rarely well preserved in the geological record. An associated basaltic sheet has been intruded into wet unconsolidated sediments at a shallow depth and exhibits good textural features at its upper contact, comparable with those of many other sites in the province.

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