*Scottish Journal of Geology*, **Volume 53 (2), 2017**

# The geological work of the Scottish National Antarctic Expedition, 1902-1904

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## Synopsis

The Scottish National Antarctic Expedition (1902-1904) made the first topographical survey and geological assessment of Laurie Island, one of the South Orkney Islands. The expedition's surgeon and geologist, J.H.H. Pirie, provided competent geological descriptions but these were largely overshadowed by his misidentification of an obscure plant fossil as a graptolite. Erroneous confirmation by eminent British palaeontologists led to Triassic rocks being regarded as Lower Palaeozoic for fifty years. The mistake arose from the familiarity of all concerned with the geology of the Scottish Southern Uplands: they were led astray by the preconception that, as in Scotland, deformed 'greywacke-shale' successions would contain Lower Palaeozoic fossils. Other, more successful aspects of the expedition's geological investigations are less well-known. Fossils acquired in the Falkland Islands expanded that archipelago's poorly known Devonian brachiopod fauna, but arguably the most important palaeontological discovery lay unrecognised for ten years. A limestone block dredged from the bed of the Weddell Sea contained Early Cambrian archaeocyath fossils which, had they been promptly identified, would have been the first record of this important Antarctic palaeofauna. Instead, the Weddell Sea material complemented fossils recovered on the opposite, Ross Sea side of the Antarctic continent during Shackleton's British Antarctic Expedition (1907-1909).

## Introduction

The 1902-1904 Scottish National Antarctic Expedition (SNAE) is one of the least celebrated enterprises of the 'Heroic Era' of Antarctic exploration. Led by William Speirs Bruce (1867-1921) it set sail aboard *Scotia* on 2$^{nd}$ November 1902 from the

Firth of Clyde, bound for the Weddell Sea and the South Orkney Islands (Figs 1 and 2). Its background, organisation, lack of 'official' British recognition (perhaps aggravated by Bruce's ardent promotion of Scottish Nationalism) and controversial transfer of the facilities established in the South Orkney Islands to the Government of Argentina have all been described and debated at length elsewhere (e.g. Bernstein 1985; Speak 1992, 2003; Goodlad 2003; Swinney 2007; Dudeney & Walton 2011; Dudeney & Sheail 2014) and will not be recapitulated here. Suffice to say that the expedition was small and committed and, although very short of funds, Bruce planned an ambitious scientific and surveying programme with oceanography, marine biology and meteorology to the fore. The definition of the arcuate submarine ridge enclosing what is now known as the Scotia Sea, by means of an arduous programme of ocean sounding (Bruce 1905), is probably the expedition's best-known achievement. Geology was the responsibility of James Hunter Harvey Pirie (1879-1965), a medical doctor who was also the expedition's surgeon. Pirie took his role seriously, describing himself in his subsequent geological reports as "Geologist and Surgeon, Scottish National Antarctic Expedition".

After the expedition returned to Scotland, Pirie wrote extensively on geology and glaciology of the South Orkney Islands and on the deep sea deposits sampled from *Scotia*. Detailed palaeontological descriptions of specimens acquired in the Falkland Islands and of one important block dredged from the bed of the Weddell Sea were written-up by appropriate specialists, but inevitably their accounts have become distanced from the expedition itself. Pirie's account of the geology of the South Orkney Islands was to have been included in Volume 8 of the SNAE scientific report series, but funds ran out before it could be published. What was published by Pirie (1905) is now sadly best remembered for a palaeontological misidentification for which he was not wholly responsible. That, and the various controversies that have surrounded the expedition, have detracted from the proper appreciation of its scientific achievements. This paper reassesses the geological work of the SNAE in terms of its contemporary scientific environment and subsequent ramifications.

Of Bruce's intended series of reports detailing the scientific results of the expedition, volumes 2 to 7 were issued between 1907 and 1920 covering aspects of physics (meteorology, geomagnetism, tides), botany and zoology. Volume 8 was to have included geology and glaciology but although parts of it reached proof stage, Bruce was left with insufficient funds to proceed. Volume 1 was to have been based on the ship's log which had been maintained by Bruce, and although *The Log of the* Scotia *Expedition* was prepared by him for publication by 1911, again the lack of funds prevented its publication then. The text was not resurrected from obscurity until 1992, in an edition edited by Peter Speak, and this valuable source of information will be cited herein as Bruce (1992) despite the apparent anachronism.

The eventual distribution of the expedition's specimen collections and archive material has been broadly summarised by Swinney (2001). For the following geological assessment, of particular importance are the surviving rock specimens and Pirie's field notebook and specimen log, all now held by the National Museum of Scotland (NMS). The notebook and log form part of the NMS library's W. S. Bruce archive: box 8, files 97 and 98 respectively. Pirie's notebook contains geographical and glaciological notes in addition to his geological observations. His early records are comprehensive, but the entries become shorter and more cryptic during the later stages of the expedition. Table 1 summarises the status of the terrestrial geological specimens listed in the specimen log relative to the material now held by NMS.

## The expedition's geologist: James Hunter Harvey Pirie

Brief (and sometimes contradictory) biographical details for J. H. H. Pirie (generally known as Harvey Pirie) have been published by Bernstein (1983), Guly (2013) and Plug (2014). Born in Aberdeenshire in 1878, Pirie studied science, including geology, at Edinburgh University, but in 1899 went as an artillery officer to serve in the South African Boer War. However, once in Africa he fell ill with typhoid and was soon back in Scotland, where he resumed his studies at Edinburgh University, graduating with a medical degree in 1902. As a science student, he had worked with the ocean-floor samples collected by the 1872-1876 *Challenger* expedition and this experience may well have influenced Bruce in his appointment of Pirie to the SNAE staff. Some knowledge of geology, and the likely instruction he would have received in survey techniques as an artillery officer would also have been to his advantage. Prior to Pirie's departure for the Antarctic he received some additional informal training in geological field work from Geological Survey of Scotland personnel (Mossman in

Brown *et al*. 1906, p. 20), but did not, as claimed by Goodlad (2003, p. 60), work for the British Geological Survey.

During the expedition, Pirie (Fig. 3) contributed widely beyond his specialism, notably to the topographical survey work and as exemplified by his notes on birds, seals and weather – "Summer work in the South Orkneys" – included in Pirie & Brown (1905). For the most part, his medical services were needed only for snow-blindness and relatively minor ailments and injuries with the sad exception that, despite his best efforts, he was unable to save Allan Ramsay, chief engineer of *Scotia*, who died in the South Orkney Islands after the worsening of a pre-existing but previously undiagnosed heart condition. Pirie's other concern was bacteriology, but with the rudimentary methods available to him the results were sparse. Nevertheless he published a short report (Pirie 1912) as section 10 of Volume 3 (Botany) in the expedition's scientific report series. In it he described results from the alimentary tracts of Antarctic birds and animals, from sea water, and from sea bed sediment; attempts to cultivate airborne bacteria were deemed unsatisfactory.

After the return of the SNAE to Scotland Pirie was elected a Fellow of the Royal Society of Edinburgh in 1908. He practised medicine in Edinburgh, specialising in bacteriology and pathology, until 1913 when he joined the Colonial Medical Service and moved to Kenya. At the outbreak of the Great War in 1914 he was commissioned in the Royal Army Medical Corps and served with the Kenyan forces in East Africa. After the war, he joined the South African Institute for Medical Research, retiring from a senior position there in 1940 after a distinguished career of bacteriological research. There is no evidence to suggest that Pirie continued with his geological interests once the SNAE work was complete and he had taken up medical responsibilities in Africa. Instead, he developed an interest in Antarctic philately (e.g. Pirie 1949) and edited *The South African Philatelist* magazine for many years.

Pirie died in South Africa on 27th September 1965. A surprisingly inaccurate obituary was published by Mason (1966) and demonstrates the extent to which memories of the SNAE had been eclipsed, even in Scotland, by those of more illustrious expeditions. The obituary, published by the Royal Society of Edinburgh, inexplicably assigns Pirie's Antarctic experiences to the "Mawson Antarctic Expedition": Douglas

Mawson, after participating in Shackleton's British Antarctic Expedition, 1907-1909, led the Australasian Antarctic Expedition, 1911-1913.

## The South Orkney Islands

The South Orkney Islands lie at the northern margin of a mostly submerged continental block that rifted from the tip of the Antarctic Peninsula during the initial development of the South Scotia Ridge, most probably in the late Eocene or early Oligocene (Dalziel *et al*. 2013). The rifting formed part of the regional, post-Cretaceous tectonic movements involved in the generation of the Scotia Sea, themselves originating in the break-up of the Gondwana supercontinent from the Late Jurassic onwards. The geology of the South Orkney Islands is summarised in Fig. 2 following the most recent evaluation of Flowerdew *et al*. (2011); it was unknown at the time of the SNAE visit. The largest component of the archipelago, Coronation Island, is mostly composed of the Scotia Metamorphic Complex (SMC), an assemblage of amphibolite-facies metamorphic rocks developed in Late Triassic and/or Early Jurassic times from ocean floor rocks and the clastic sedimentary succession of the Permian to Triassic Greywacke Shale Formation (GSF) that now forms Laurie Island. There, the GSF appears as a turbidite succession deformed and metamorphosed to the greenschist facies; it was deposited in an ocean trench or trench-slope environment at the active, Pacific margin of Gondwana. The metamorphic transition from the GSF to the higher-grade SMC is seen on Powell Island, where it is unconformably overlain by the Powell Island Conglomerate derived from the GSF and associated with a Middle Jurassic flora. A younger conglomerate derived from the SMC, the Spence Harbour Conglomerate, crops out at the eastern end of Coronation Island and on the nearby Matthews Island and is associated with a Late Jurassic to Early Cretaceous marine fauna. Late Cretaceous dolerite dykes are noted by Flowerdew *et al*. (2011) as the only exposed manifestation of intrusive igneous activity.

The SNAE's first landfall in the South Orkney Islands was at Saddle Island (Fig. 4) which was reached on 4 February 1903 and found to consist of "a massive hard grey-green greywacke" (Pirie 1913a, p. 2). After that short visit *Scotia* headed south-east for an exploratory cruise in the Weddell Sea, before returning to the South Orkney

Islands late in March to seek a suitable wintering site. It had been Bruce's original intention to base the SNAE at the eastern end of Coronation Island in Spence Harbour, an anchorage that had been referred to favourably in historical reports by early 19$^{th}$ century sealing captains. There was difficulty in finding the correct location, and only a very brief landing was made, but as Mossman described it, writing in Brown *et al*. (1906, 69-70), "Spence Harbour turned out a fraud, being ridiculously exposed, with very deep water. Indeed it was more of an indentation or bight than a harbour. Ellison Harbour [Ellefsen Harbour, at the southern end of Powell Island] also proved quite unsuitable, being too small, and not adapted to a vessel of the *Scotia's* size." Bruce (1992, p.76) was scathing about the earlier reports: "Spence Harbour does not exist … and Powell's Islands [sic] are not as they are mapped. Powell in the *Dove* mapped Lewthwaite Strait [between Coronation Island and Powell Island (Fig. 2)], and Brisbane of the *Beaufoy* Elleson [sic] Harbour, but neither can have visited the places." Eventually, after some hazardous exploration, a safe haven was found near the south-west point of Laurie Island, in what is now known as Scotia Bay.

From the geological perspective, the inadequacy of Spence Harbour was unfortunate. Had the SNAE been able to establish a base there then Pirie would have had ready access to the SMC and the overlying (and fossiliferous) conglomerate. Powell Island, with the metamorphic transition from the GSF and another fossiliferous conglomerate, would most probably have been accessible across the winter sea ice. Instead, Pirie (1913, p. 2) had only a few minutes at Spence Harbour during the brief landing on 23 March 1903, whilst from Scotia Bay, his work was restricted to Laurie Island and vicinity, and so to the GSF. It was mostly carried out during arduous winter sledging trips over unstable sea ice and landings from open-boat coastal traverses (Fig. 5), all made with the primary purpose of completing a topographical survey of Laurie Island.

Pirie included many passing references to the geology in his contributions to *The Voyage of the "Scotia"*, the general account of the expedition by Brown *et al*. (1906), and wrote two specialist accounts, only one of which was published. In the published paper Pirie (1905) described the variable lithofacies and structural complexity of the GSF and was particularly concerned to note the presence at one locality of putative graptolites which were thought to provide an Early Palaeozoic age for the succession. The identification of the 'graptolites' proved erroneous, an issue that will be returned to in more detail later in this account. Pirie's unpublished account, intended for inclusion in the planned volume 8 of the SNAE report series, advanced to galley proof, a copy of which is held in the archives of the British Antarctic Survey (Pirie 1913a). Correspondence between Bruce, Pirie and Brown in 1912 and 1913 that refers to the editing of Pirie's contributions prior to intended publication is held by the Scott Polar Research Institute (SPRI), Cambridge (MS101/19/33, 37, 82 and MS101/76), although the earlier references (op. cit. 33 & 37) are more probably with respect to Pirie's (1912) account of bacteriology in volume 3 (Botany) of the report series.

In the published paper, Pirie (1905) describes the characteristic rock of Laurie Island as a greenish, massive or thickly bedded, fine grained, quartzo-feldspathic greywacke. Local variations saw the grain size increase to very coarse with some granule-sized grains whilst elsewhere the proportion of mudstone increased such that shale became the dominant lithology. Foliation and deformation was widespread but apparently irregular and Pirie did not consider a true slaty cleavage to have been formed. He was able to identify folded bedding at many localities and sketched some of the examples in his notebook (Fig. 6), but the limited exposure (Laurie Island is extensively ice-covered) and the generally disruptive tectonism prevented him from developing an overall structural interpretation. The most intense deformation, described as 'gneissic banding and folding', was only referred to 'one patch of limited extent' in Pirie (1905), but Pirie (1913a) was more specific in locating it at the eastern side of Uruguay Cove (Fig. 2): on the modern geological map (Flowerdew *et al*. 2011) this area lies within a ductile shear zone.

The mudstone/shale was invariably "much cleaved and broken" and only rarely was a clear interbedded relationship with the greywacke preserved. The maximum development of shale was noted on a small offshore island at the south-east extremity of Laurie Island and it was here, on 25 September 1903, that Pirie found two shale fragments apparently carrying fossils. One of these he took to be a graptolite and described it in his notebook as seemingly a "monograptus", but "[d]iligent search over all the shaly places revealed no more fossils unfortunately." The rare discoveries were highly prized as providing an apparently Early Palaeozoic age for the greywacke succession, and to celebrate the expedition named their point of origin Graptolite Island (Fig. 2). The two fossiliferous specimens from Graptolite Island are amongst those held by NMS, with the registered numbers 1954.2.28 & 29: the putative graptolite(s) appears on specimen 29 (Fig. 7). It is easy to understand why Pirie, as a non-specialist, made that identification, but subsequent developments are less easy to understand and will be discussed in more detail later in this account. In the first published mention of the discovery, Pirie (1904a, p. 130) wrote that ”[n]ear Cape Dundas [the easternmost point of Laurie Island] a single graptolite was found, the sole fossil of the islands.”

When the SNAE returned to Scotland the specimens were promptly passed on to two eminent and authoritative palaeontologists: Ben Peach of the British Geological Survey and Gertrude Elles of Cambridge University’s Sedgwick Museum. Elles was a well-known graptolite specialist and her confirmation of Pirie’s specimen 29 as a graptolite, most probably of the genus *Pleurograptus*, was unlikely to have been challenged; Peach additionally identified phyllocarid crustacean remains on both specimens 28 and 29. This fossil association, graptolites and phyllocarids, is widespread in the Late Ordovician and Early Silurian, Moffat Shale Group strata within the Scottish Southern Uplands, an area with which Peach was intimately familiar (as demonstrated by the authoritative Geological Survey memoir (Peach & Horne 1899) then recently published). Indeed, Peach wrote (in Pirie, 1905, p. 469; 1913a, p. 5) that his interpretation was based on ”[a] wide experience of the black graptolitic shales of the Southern Uplands of Scotland.” Pirie would have had no reason to doubt the expert opinions received and made much of Peach’s written contributions to his two accounts of South Orkney Islands geology: the GSF seemed unequivocally of Early Palaeozoic age. The perceived importance of the ‘graptolite’ discovery was emphasised by the inclusion of Peach’s contribution, more-or-less verbatim, in both the general account of the expedition (Pirie in Brown *et al*. 1906, p. 160) and in the version of the expedition log prepared (by 1911) for publication by Bruce (1992, p. 163). In an additional vote of confidence, Pirie’s (1905) paper was read before the Royal Society of Edinburgh on 20 February 1905 by John Horne, at the time the most senior figure in the Scottish branch of the Geological Survey of Great Britain. Ben Peach retired later in 1905 but remained active and continued to contribute informally to the work of the Geological Survey (Mendum & Burgess 2015).

This interpretation of the GSF as Lower Palaeozoic soon took on regional significance when another Scottish geologist, undertook a geological reconnaissance of South Georgia (Fig. 1) in 1912. That island also contains a thick succession of turbidite lithologies, greywacke and mudstone broadly comparable to their counterparts in the South Orkneys. Ferguson's investigations (on behalf of the Leith-based Salvesen Whaling Company) have been assessed by Stone & Faithfull (2013). Despite some sparse fossil evidence for a Mesozoic age, Ferguson became convinced that at least part of the South Georgia succession was Lower Palaeozoic. He drew comparisons with Pirie's observations in the South Orkneys and, like Pirie, found a putative graptolite. Although most of Ferguson's specimens are now held in the Hunterian Museum, University of Glasgow, the 'graptolite' does not appear to be amongst them.

Commenting on the 'graptolite', Ferguson's mentor at the University, Professor John Gregory confirmed, ambiguously, that: "… if found in a graptolitic bed [it] would be regarded as a piece of a monoprionid graptolite … and this opinion is shared by several members of the geological school of this University who have had experience in collecting graptolites in our Southern Uplands" (Gregory in Ferguson *et al*. 1914, p.63; Gregory 1915, p. 819). Pirie concurred. In Glasgow he had seen Ferguson's specimen collection (as confirmed in a letter written by Ferguson to W. S. Bruce on 6 September 1913: SPRI MS101/39/14) and subsequently wrote (Pirie 1913a, p. 8) that Ferguson's South Georgia specimens "present remarkable similarity to the greywackes of the South Orkneys, and I think it extremely probable that they will prove to be, if not of identical age, at least older than Upper Palaeozoic." In fairness to Gregory, it should be noted that he went on to describe the South Georgia specimen as "too small for its identification as graptolitic to be anything more than a probability" (Gregory 1915, p. 819). No such doubt seemed to attach to the South Orkney Islands 'graptolite'.

In general, Pirie's (1913a) unpublished proof follows the pattern of his 1905 paper but with a little more detail of petrography and the differences in lithofacies seen across Laurie Island and in its offshore islets. He also wrote a short account of raised beaches and other evidence for changes in sea level. The contribution by Peach on the supposed graptolites and phyllocarid crustaceans was repeated verbatim from the 1905 paper with only a few minor grammatical changes. But by way of illustration, Peach provided three small sketches (maximum dimension 20 mm) of finely ridged areas in the Graptolite Island specimens (Fig. 7) that he interpreted as phyllocarid impressions, together with an idealised reconstruction of the animal taken from Jones & Woodward (1887). These sketches are only poorly reproduced in the surviving unpublished proof.

Pirie (1913a) also included some comments on the geology of Coronation Island, the observations made on his very brief visit to Spence Harbour having been supplemented by the examination of a small number of specimens from the south coast of the island that Ferguson had obtained in 1912 through contacts in the South Georgia whaling industry. These specimens, examples of conglomerate and metagreywackes from the SMC, suggested to Pirie that the geology of Coronation and Laurie islands was broadly similar, albeit the Coronation Island equivalent of the GSF was more intensely cleaved and at a slightly higher metamorphic grade. From his own observations at Spence Harbour, Pirie (1913a) described the eponymous conglomerate as being "composed of a mixture of rounded water-worn pebbles and of angular fragments of dark-coloured shale and mica-schist" with a notebook record that the pebbles ranged up to 4 inches (10 cm) in diameter. This matches the subsequent first-hand descriptions by Thomson (1981) and Elliot & Wells (1982).

Oddly, the only surviving SNAE specimen claimed to be from Coronation Island (1954.2.18), so presumably collected during the brief landing at Spence Harbour, is rather different. It is a very coarse quartzo-feldspathic greywacke (with many granule-sized grains) similar in lithology to several other specimens collected within the GSF on Laurie Island. There are also notebook comments describing these coarse-grained Laurie Island lithologies as 'transitional' to the Coronation Island conglomerate. From the surviving material it is not clear exactly what Pirie saw and collected during the brief Coronation Island landing. Perhaps the specimens have become confused, although there are no other lithologies amongst the SNAE collection that might be an example of the Spence Harbour Conglomerate. Given that the Coronation Island specimen is a little more tectonised than the Laurie Island examples it might possibly have originated in the SMC. In that case, could Pirie's specimen have been taken from a large clast within the Spence Harbour Conglomerate? Alternatively, could one of Ferguson's specimens have been acquired by Pirie? Whatever the explanation, the result was that the true nature of the Spence Harbour Conglomerate remained unrecognized for many years.

In both his 1905 and 1913 accounts, Pirie speculated on the regional geological associations of the South Orkney Islands. Writing in Brown *et al*. (1906, p. 161) he noted that Lower Palaeozoic rocks occurred in the Andes mountains in South America he extrapolated around a vaguely defined Scotia Arc to the South Orkney Islands which, "folded along a north-west and south-east axis, lay on one flank of this sub-Andean chain." Following the then-prevalent view, he regarded this large-scale, regional structure as "a long wrinkle on the earth's surface formed as it grew old and cooled" (Brown *et al*. 1906, p. 161). Understandably, given the paucity of available (and reliable) information, no firm conclusions were reached. Indeed, the oceanographic survey work carried out from *Scotia* had, if anything, made the problems more intractable. The submarine ridge of the Scotia Arc had been proved to extend far to the east, whilst deeper water separated the South Orkneys from South Georgia and Burdwood Bank (Bruce 1905). All of this was hard to reconcile with the contemporary consensus of ocean formation by the foundering and essentially vertical subsidence of previously continental areas, leaving behind a few small continental relics. Nevertheless, the thick succession of sedimentary rocks seen in the South Orkneys clearly required a proximal source of terrigenous sediment and so, the argument went, a landmass must once have existed nearby.

It is clear from the discussion in Pirie (1913a) that by that date he had become aware of the puzzling similarity of Falkland Islands geology to that of South Africa rather than the neighboring South America, presenting more complexity in the South Atlantic. But overall, for the origin of the South Orkney Islands, he remained impressed by "[t]he fact that the islands are composed of sedimentary rocks, along with the presence of other rocks of not very remote affinities in South Georgia and the Falkland Islands, suggesting that they are all fragments of a once extensive land." The subsequent transition of this view, via continental drift and plate tectonics, into the modern interpretation of the Scotia Arc has been reviewed by Stone (2015a). Today, the South Orkney Islands are the regarded as the emergent pinnacles of a mostly submerged continental block that rifted from the tip of the Antarctic Peninsula at about 32–34 Ma during the formation of the Powell Basin (Fig. 1), so initiating development of the South Scotia Ridge (e.g. Dalziel *et al*. 2013).

To complement Pirie's account of the geology of the South Orkney Islands, it had been Bruce's intention to include an account of the geology of South Georgia, to be written by Ferguson, in the planned (but ultimately unpublished) Volume 8 of the SNAE report series, although the expedition had not visited the island and Ferguson had no direct involvement with it, contrary to the suggestion by Leake (2011, p.146). Correspondence between Bruce and Ferguson from late in 1913 ( SPRI MS 101/39/14 & 17) confirms that Ferguson started work on the project. The intention was also confirmed by a footnote in Ferguson *et al*. (1914, p. 53) which promises that "[a] more detailed account of the geology of South Georgia, and of its rocks and fossils, will appear in one of the volumes on the results of the Scotia Expedition, which are now being published by Dr. W. S. Bruce." What became of any draft or completed account is uncertain; perhaps it became the Ferguson (1915) paper published in the *Transactions of the Royal Society of Edinburgh* and which is recorded as having been received by the Society on 2 March 1914. If so, it would have followed the pattern established by many of the zoological contributions in the SNAE reports (volumes 4 to 7), which are recorded as having been reprinted from an original publication in the *Transactions*.

There were two published geological postscripts to the South Orkney Islands work of the SNAE, both arising from additional work on the specimens collected and perhaps explaining the differences in specimen numbers shown in Table 1. Following the 1927-1928 Norwegian Antarctic Expedition, some of the SNAE specimens were sent to Norway (by D. Balsillie, then acting curator of the 'Edinburgh Museum' and most probably on loan) for comparative purposes and briefly mentioned by Holtedahl (1929, p. 99) as confirming the deformation and shearing noted by Pirie (1905). Later, R.N.R Brown (the SNAE botanist) provided nine "duplicate" specimens to the University of Michigan, USA, which were described petrographically by Stewart (1937). Of these, seven came from Laurie Island and were described as "three quartzites, two conglomerites [sic], an arkosic conglomerite, and an altered diabase?"

The latter is a unique reference to possible igneous rocks amongst the SNAE collection and may be the first record of intrusive igneous rocks from the South Orkney Islands. Because it was provided to Stewart as a ‘duplicate’ it was presumably misidentified as an indurated greywacke when originally collected. Stewart also noted a “conglomerite” from Coronation Island and a slate from Graptolite Island, and confirmed the general deformational effects. The Coronation Island specimen is not noted as being in any way different to the rest of the collection, adding to the uncertainty of just what Pirie collected at Spence Harbour and what has become of it. The specimens described by Stewart (1937) are currently still held in the collection of the Earth and Environmental Sciences Department, University of Michigan.

Finally, one correction can be made to a previous listing of the geological specimens collected by the SNAE. Stace *et al*. (1987, p. 300) included 12 specimens of volcanic rock from Ross Island as having been collected by Pirie during the expedition. That is clearly wrong. The SNAE operated in the Weddell Sea area whilst Ross Island is on the opposite, Ross Sea side of the Antarctic continent; neither Bruce nor Pirie visited it. The specimens (NMS 1954.4.1-12) may well have been collected during Shackleton’s British Antarctic Expedition, 1907-1909, which established its base on Ross Island, and then acquired subsequently by Bruce.

## The fossils reassessed

The chequered history of Pirie’s ‘graptolite’ has been summarised by several authors (Dalziel 1979; Dalziel *et al*. 1981; Stone 2015a) but is worthy of a more extended assessment. The key specimen (NMS 1954.2.29) is shown in Fig. 7a. The most eye-catching features are the four sub-parallel lines in the top left corner, shown enlarged in Fig. 7b, which might easily have been taken for graptolite stipes, although there are no signs of thecae. Pirie (1913a, p. 5) mentions “several graptolite stipes” but his notebook record for the discovery refers to only one graptolite fossil as a possible “monograptus”, and subsequent published accounts always refer to ‘a single graptolite’. Elles’ identification of *Pleurograptus* seems more likely to have derived from the branching feature shown enlarged in Fig. 7c; amongst the Southern Uplands’ Late Ordovician graptolite fauna *Pleurograptus linearis* is a slender, branching form. This then may have been the ‘single graptolite’ noted by Pirie. Nevertheless, despite uncertainty now as to which were the critical fossils, the graptolite identification by Elles, supported by Peach's phyllocarids, appeared to provide an unequivocal Ordovician-Silurian age.

The supposed phyllocarids were the finely striated and/or ridged areas noted by Pirie in his 'graptolite' specimen (1954.2.29) and in a second smaller specimen from the same location (1954.2.28). Peach (in Pirie 1905, 113) described the 'phyllocarid crustacean' in the 'graptolite' specimen as "showing a web of dark carbonaceous matter, with a succession of sub-parallel ridges". Elles' identification of the genus *Pleurograptus* implied, by comparison with the Scottish Southern Uplands, a Late Ordovician age, but Peach had some doubt about that genus. He preferred an Early Silurian age for the 'phyllocarids', again by comparison to examples from the Southern Uplands.

As previously noted, the apparently Early Palaeozoic age of the South Orkney Islands GSF turbidite succession had influenced Ferguson's (1915) interpretation of the South Georgia succession. Geological work on South Georgia subsequent to that of Ferguson (reviewed by Stone 2015b) led to the turbidite succession there being confirmed as wholly Mesozoic and mostly Early Cretaceous. Prominent amongst the contributions that established the Mesozoic age were those of the German palaeontologist Otto Wilckens who was also the first to challenge the identification of Pirie's graptolite (Wilckens 1933, p.327). He suggested that the features might be of inorganic origin although it is not clear whether he had re-examined the specimens or had seen any illustrations of them.

Nevertheless, despite the growing doubts, the original interpretation was reinforced when Cordini (1955) reported more fossil discoveries from Graptolite Island by Argentine geologists: another graptolite tentatively described as *Dicellograptus*, fragments of *Conularia*, and the impressions of 'ferns'. Cordini stressed the poor preservation of the fossil material but provided illustrations which at least demonstrate that, given the presumption of an Early Palaeozoic age, the identifications of graptolites and a conularid were not wholly unreasonable. The 'ferns' would have been more problematic: oddly, the specimen illustrated has no fern-like features and appears more similar to a *Calamites*-type plant stem impression.

Perhaps Cordini's use of 'helechos' has a subtlety of meaning that is lost in translation to 'ferns', but it is hard to see how such plant remains could be reconciled biostratigraphically with *Dicellograptus*.

In regional terms, additional problems had been caused by the long-recognised lithological similarity of the GSF with an extensive rock succession on the Antarctic Peninsula that became known as the Trinity Peninsula Series (e.g. Andersson 1906). Plant fossils indicating an age 'no older than Carboniferous' had been recovered from the Trinity Peninsula rocks in 1946 by W.N. Croft (as reported in Adie 1957) but his premature death in 1953 had left the results unpublished. Given this background, and perhaps stimulated by the anomalies inherent in Cordini's report, a re-examination of Pirie's South Orkney Islands 'graptolites' was instigated by R. J. Adie, by that time chief geologist to the Falkland Islands Dependencies Survey (rebranded in 1962 as the British Antarctic Survey). In the opinion of Birmingham University graptolite specialist Isles Strachan, first reported by Adie (1957, p. 22; see also Stone & Faithfull, 2013, p. 64), the fossils were very poorly preserved, might equally be plant remains, and had no biostratigraphical value whatsoever. Of course, Strachan's view did not definitively rule out the presence of graptolites, which continued to be cited as evidence, albeit sparse, for the possible presence of Lower Palaeozoic strata: for example, King & Downard (1964), curiously enough in a conference volume edited by Adie. Although Strachan's comments referred only to graptolites, his suspicion that the fossils could be plant fragments was most probably also extended to the supposed phyllocarids identified by Peach.

Eventually, a more reliable age for the GSF was provided when Triassic Radiolaria, sponge spicules and rare conodonts were discovered, although not at Graptolite Island (Dalziel 1979; Dalziel *et al*. 1981). The Triassic fossils came from chert forming the small Scapa Rock at the north-west extremity of the Weddell Islands (Fig. 2), which are otherwise made up of rocks typical of the GSF. The SNAE had made a landing on the nearby Saddle Island, another outpost of the GSF, with a rather phyllitic greywacke specimen from there surviving in the NMS collection (1954.2.19). Whilst accepting that no stratigraphical relationship between the chert and the clastic rocks of the GSF could be directly observed, Dalziel *et al*. (1981) thought it likely that the Triassic age could be extended to all of the formation. Noting the presence within the

GSF on Fredriksen Island of ‘abundant carbonised stems and branches’, they reinforced the earlier suspicions that all of the fossil material recovered from Graptolite Island could be best regarded as poorly preserved plant remains.

The consensus view now regards the GSF as a Permian to Triassic deposit deformed and metamorphosed during the Late Triassic and/or Early Jurassic. Nevertheless, Graptolite Island as a geographical location seems likely to live on in perpetuity (Hattersley-Smith 1991) and the SNAE graptolite(s) still resurface occasionally in the non-geological literature, e.g. Bernstein (1985, p. 386) and Goodlad (2003, p. 69). The latter resurrection was unfortunate in that Goodlad’s account was published by the Royal Scottish Geographical Society to commemorate the centenary of the SNAE and was accompanied by a complementary, and otherwise admirable, *Workbook for Secondary Schools* that also emphasised the importance of the ‘graptolites’.

## Weddell Sea dredge samples

The oceanographical programme of the SNAE included bottom trawling at numerous sites in the Scotia and Weddell seas. This was primarily for biological and sea-bed-sediment sampling, but at several localities a variety of rock fragments was also dredged from the sea floor. The rock debris had been introduced as ice-rafted glacial erratics derived from the then largely unknown Antarctic landmass, as noted by Pirie when writing in Brown *et al*. (1906) on the rocks dredged near the most southerly point reached by *Scotia* on 7 March 1904, close to the ice barrier at the head of the Weddell Sea [74° 01´ S, 22° 00´ W]. Pirie wrote (op. cit. pp 237-238):
“That the land is of continental character is shown by the boulders brought up in the dredgings taken in the vicinity – boulders which have been picked up by the ice-sheet from the underlying rock and deposited on the floor of the ocean by the melting of the bergs. Amongst others, granites, schist, gneiss, quartzite, sandstone, slate and limestone were found, all rocks characteristic of an old continental land-surface.”

Representative collections from two sites in the southern Weddell Sea are held by NMS – four pebbles as 1954.5.27 and about forty small chipped rock fragments as 1954.5.28. The angular rock fragments have fresh surfaces and were clearly chipped from larger dredged erratics; any remaining original faces are covered with dusty, dark grey mud. Some of the rock fragments and the rounded pebbles (the latter cleaned of any original marine encrustation), have been sliced, but no thin sections have been found. .

Earlier in the expedition's progress, on 18 March 1903 and to the east of the South Orkney Islands another spectacular haul had been recovered at the expedition's 'Station 313' [62° 10´ S, 41° 20´ W] from a depth of 1775 fathoms (3246 m). About eighty pebbles and small rock chips from this locality now comprise NMS 1954.5.25. The description by Bruce (1992) in his Station Log reads "Glacial mud, or sand and boulders. Boulders over 2 cwt. Large fish, crinoids etc." Metamorphic gneiss and schist were the commonest lithologies (Pirie 1913b) and the weight given for some of the boulders, 2 cwt (about 100 kg), would suggest a size approximately equivalent to a 30 cm cube. One of the smaller pieces from this haul was a limestone which, although it went completely unremarked at the time, was to prove arguably the most important geological specimen obtained by the expedition. It contained Early Cambrian archaeocyath fossils, and had these been recognised at the time it would have been the first indication of what would eventually prove to be a widespread fossil fauna in the Transantarctic Mountains.

Whilst the SNAE archaeocyathan limestone specimen apparently languished unrecognised, archaeocyath specimens were recovered from the Ross Sea side of the Antarctic continent by Shackleton's British Antarctic (*Nimrod*) Expedition of 1907-1909. The first announcement of the discovery, in blocks of limestone breccia found in moraine adjacent to the Beardmore Glacier, was made in 1910 at the 11$^{th}$ International Geological Congress (held in Stockholm, Sweden) by Priestley & David (1912). This was followed by a full description in the expedition's scientific report (Taylor 1914) after confirmation of the discovery during Scott's British Antarctic (*Terra Nova*) Expedition of 1910-1913 (Debenham 1921).

The growing awareness of the Antarctic archaeocyath fauna may well have provoked a closer look at the limestone dredged from the Weddell Sea by the SNAE. If so, it is not clear who first identified archaeocyaths. Pirie's brief notebook description of the dredged rocks refers only to "crystalline limestone" and there was no mention of any fossil content in the earliest published descriptions: the preliminary report of the deep-sea deposits that had been sampled (Pirie 1904b) and the overall account of the expedition (Brown *et al*. 1906). Subsequently, in his expanded, final report on the deep-sea deposits Pirie (1913b) included unequivocal references to archaeocyaths. In the list of lithologies recovered at 'Station 313' he includes "one piece of fossiliferous limestone with specimens of *Archaeocyathinae*" (op. cit., p. 659); a later discussion (op. cit., p. 682) considers the regional implications as follows:

"… pieces of limestone one of which is of particular interest, containing several species of that peculiar fossil form *Archaeocyathina*. This find, although not in-situ, points to the probable occurrence of Cambrian rocks on this side of the Antarctic similar to those in which these fossils were found on the Shackleton Expedition in Victoria Land."

Pirie's (1913b) account of the deep sea deposits was published in *Transactions of the Royal Society of Edinburgh*, and it is likely that Bruce intended to follow the practice established in the zoology volumes of the *Scotia* report series and reprint the account in the planned Volume 8. That volume might also have included a reprinting of Pirie's (1913c) paper on the glaciology of Laurie Island, also published in the *Transactions*.

A detailed taxonomic description of the SNAE archaeocyaths was eventually published by Gordon (1920), but in his introduction Gordon stresses that "it was not until 1913 that Dr Bruce handed the material over to me". In his 1913 paper Pirie made no acknowledgement of any input from Gordon, but David (1915) in a presentation to the 1914 British Association for the Advancement of Science meeting (held in Australia) noted that "[q]uite lately great blocks of Archaeocyathinae limestone, dredged by Dr W. S. Bruce from depths of about 1700 fathoms to the north of the Weddell Sea, have been identified as such by Dr Gordon." For his reference to 'great blocks' David was clearly carried away by the observation that some of the dredged rocks weighed "over 2 cwt", and in his account Gordon (1920) felt it necessary to stress that the material available to him only comprised two fragments each weighing less than one pound (or less than approximately 0.5 kg) rather than the 224 pounds (2 cwt) implied by David. Both of the fragments examined by Gordon were believed by him to have come from the same limestone erratic, the "one piece of fossiliferous limestone" recorded by Pirie (1913b). There are several other small fragments of coarsely crystalline limestone in NMS.1954.3.25 but none show archaeocyath traces.

Gordon had studied geology at Edinburgh University, but had moved to Cambridge as a research student in 1910. He returned to Edinburgh as a lecturer in palaeontology in 1912, so was ideally placed as the fossil discoveries made by Shackleton's expedition aroused renewed interest in the SNAE Weddell Sea limestone erratic. In 1914 he was appointed to a lecturing post at King's College, London, and took the SNAE archaeocyaths with him. With the pressures of establishing himself in a new department against the background of the Great War it is easy to understand why the full description of the fossils took some time. They were all very small forms, mostly only a few mm across, and a systematic study of such fossils requires the preparation and examination of multiple, sequential and orientated thin sections. In the end, Gordon's work was based on 160 such sections, the manufacture of which appears to have entirely consumed the available limestone.

The thin sections were retained for many years at King's College, with several literature references to their location there (e.g. Debrenne & Kruse 1986). However, in 1984 the King's College geology department merged with that of Royal Holloway College, University of London and the King's College collection was dispersed. The then curator, Dr John Fryer, arranged for the transfer of much material, including the SNAE archaeocyaths, to The Natural History Museum, London, where they remain with the registered numbers S 10301 to S 10461 (Fig. 8).  Inevitably, a few of the thin sections are missing, whilst those dominated by the algal form *Epiphyton* are stored separately with similar taxa. Gordon had noted (1920, p. 684): "Algae often occupy the greatest bulk of the rock. Indeed, it would more properly be called an algal limestone containing Archaeocyathinae etc." – the 'etceteras' are sponge spicules and "[f]ragments of shell and the carapace of trilobites". Gordon recognised 14 different forms of archaeocyath, including six which he defined as new species. Two further species present in the SNAE erratic had been established by Taylor (1910) from his South Australia work, and Gordon noted that all of the genera from the Weddell Sea erratic were present in South Australia.

The archaeocyaths recovered by Shackleton's expedition were very poorly preserved (Taylor 1914, p. 240) and so, for many years, the much better examples from the Weddell Sea erratic stood as representative of the entire Antarctic fauna. Eventually archaeocyaths were found *in situ* (Laird & Waterhouse 1962) in what became known as the Shackleton Limestone and by the mid-1980s Debrenne & Kruse (1986, 1989) were able to describe 43 Early Cambrian archaeocyaths determined at species level from a number of locations in the Transantarctic Mountains. But despite these advances, and numerous subsequent discoveries, the original source of the Weddell Sea erratic can still only be generally assigned as most probably from the Shackleton Limestone outcrop somewhere in the Transantarctic Mountains. Nevertheless, its potential route to the South Orkney Islands is now well-established. Ice-rafted debris derived from the Antarctic continent on the southern side of the Weddell Sea (including the Transantarctic Mountains) is transported with a clockwise sense of drift (the Weddell Gyre) northwards along the coast of the Antarctic Peninsula and then eastward along the southern side of the South Orkney Islands. Recent work on a marine sediment core recovered to the south-east of those islands (ODP leg 113, site 696) has demonstrated the deposition there of sand grains derived from the Antarctic hinterland of the southern Weddell Sea, and showing features characteristic of ice-rafting, since the Late Eocene (Carter *et al*. 2017).

Quite apart from its intrinsic interest in terms of Antarctic palaeobiology, the archaeocyath fauna has much influenced the developing palaeogeography of the Gondwana supercontinent. In a comparable history to that of the SNAE erratic, one particularly curious phenomenon is the distribution of erratic clasts of archaeocyathan limestone in the diamictite deposits left across southern Gondwana by Early Permian glaciation emanating from East Antarctica: the Whiteout Conglomerate (Ellsworth Mountains, West Antarctica), the tillites of the Dwyka Group (South Africa), the Fitzroy Tillite Formation (Falkland Islands) and the Sauce Grande Formation (Argentina). As reviewed by Stone *et al*. (2012 and references therein) the comparability of the faunas in the dispersed erratics, coupled with evidence for local ice flow directions, constrains the way in which those continental elements are brought together in Gondwana reconstructions. On a larger scale, the palaeolatitudinal control provided by the archaeocyaths – reef-forming, sub-tropical organisms – has been utilised in some global palaeogeographical reconstructions (e.g. Courjault-Radé *et al*. 1992). It is noteworthy that in his original description of the SNAE archaeocyaths, Gordon (1920) had drawn attention to their small size relative to the South Australian examples. This, he speculated, arose from climatic differences, with the SNAE fauna having lived under relatively adverse conditions. Such variation might now be assigned to more localised habitat variation within a reef environment.

In recognition of Gordon's work on the archaeocyaths from the SNAE's Weddell Sea erratic, the genus *Gordonicyathus* was established by Zhuravleva (1959). Although defined from Siberian examples, representatives of this genus were subsequently recorded from Antarctica (Debrenne & Kruse 1986).

## The Falkland Islands

During the progress of the Scottish National Antarctic Expedition, *Scotia* made three calls at the Falkland Islands: 6-26 January 1903, 2-8 December 1903, and 30 January to 9 February 1904. None of the expedition's reports make any reference to geological work there and Pirie, the expedition's geologist, was a member of the team left at the South Orkney Islands for the 1903-1904 austral summer, and so only visited the Falklands once, on the way south early in 1903. However, during that one visit, Pirie examined the rocks and landscape in the environs of Stanley and although no formal report was published, his notebook documenting the observations that he made survives within the W. S. Bruce archive held by NMS. He records collecting six rock specimens, quartzite and "graphitic schist" (most probably cleaved carbonaceous mudstone) but they are not present amongst the SNAE geological specimens now held by the museum.

Pirie's notes on Falkland Islands geology have been reviewed by Stone (2017). Overall, Pirie noted the dominance of hard white quartzite (which he likened to Dalradian rocks he had seen around the island of Jura, western Scotland) which was widely current-bedded and contained local intercalations of black carbonaceous mudstone; these are the characteristic lithologies of what is now known as the Port Stanley Formation (Aldiss & Edwards 1999) of Devonian age. The strata were everywhere inclined, commonly near-vertical, and in places folded about horizontal, east-west hinges. This east-west trend then, he observed, determined the orientation of the coastal inlets and principal hill ridges. And at the coast, he was intrigued by the way in which banks of beach pebbles cut off low-lying lagoons from the sea in many of the small bays – a feature that we would now associate with a change in sea level. As with all previous geological visitors, Pirie was intrigued by the Falkland Islands 'stone runs', now interpreted as extensive periglacial blockfields made up of large quartzite boulders. Like his predecessors, Pirie struggled to envisage the likely mechanism for the creation of what he termed 'stone rivers'.

During the third visit of *Scotia* to Port Stanley, and in Pirie's absence, Bruce was presented with a collection of Devonian fossils, mostly brachiopods, by the Governor of the Falkland Islands, Mr (later Sir) William Grey-Wilson. The fossils had originated in Early Devonian strata now designated the Fox Bay Formation, but the actual specimens had been scavenged from building material brought to Stanley for the reconstruction of Government House (Bruce 1992, p. 206; Stone 2017). The Governor's fossils (Table 1), and an additional specimen of crinoids gifted by Mr A. E. Felton (NMS 1954.3.58) were described by Newton (1906), a palaeontologist with the Geological Survey based in London, who may well have received the fossils via contacts in the Survey's Edinburgh office. There are 41 specimens in the NMS collection (NMS 1954.3.30-70). In their summary of the NMS holdings of SNAE geological specimens Stace *et al*. (1987, p. 300) note 51 specimens from the Falkland Islands, but this figure includes detached fragments suffixed a, b etc.

Most of the specimens in the SNAE collection, and now held by NMS (Table 1), are rather worn and of relatively poor quality, understandably so given their origin. Nevertheless, Newton (1906) described 6 brachiopod taxa, abundant crinoid columnals and two fragments of trilobite pleurae, all contained in "buff-coloured micaceous sandstone". Of the brachiopod taxa, five had been previously described by Morris & Sharpe (1846) from the collection of much superior material made around Port Louis by Darwin (1846) during the voyage of HMS *Beagle* (1831-1836), but one (*Cryptonella baini*, see Table 2 for modern nomenclature) was a new discovery. The slight deformation shown by some of the brachiopod fossils (Fig. 9a) is characteristic of the Port Louis area at the head of Berkeley Sound (Fig. 1), and indeed Newton describes the source locality as 'Port Louis South'. Newton (1906, p. 256) also records "two fragments of trilobite pleurae, characterised by exceedingly coarse pitting". However, in the NMS collection only one specimen (1954.3.63) is identified as a trilobite and the fossil fragment is small (10 mm x 2 mm) and ambiguous.

Overall, the fossil assemblage is characteristic of the regional, Early Devonian 'Malvinokaffric' fauna which is also well represented in South Africa and South America. In the Falkland Islands it is an established feature of the Fox Bay Formation, West Falkland Group (Aldiss & Edwards 1999; Stone & Rushton 2012).

## Geology *en route* to and from the South Atlantic Ocean

### The voyage south

On the journey south brief stops had been made at Madeira and the Cape Verde Islands, three days at the former but only 12 hours at the latter. Neither island group was unknown geologically but Pirie (in Brown *et al*. 1906 p. 32) reports a sortie by boat to examine the coastal geology, fauna and flora. More detail had been included by Pirie (1903) in his contribution to a multi-author account of the voyage south sent back to the Royal Scottish Geographical Society from the Falkland Islands prior to the expedition's departure for the Antarctic. At Madeira, Pirie noted lava flows with interbedded, water-lain tuff beds and collected a fossiliferous limestone from beneath one of the flows. He speculated that it would correlate with the Miocene limestone already known from the neighbouring small island of Porto Santo. Pirie's specimen log records 12 rock specimens but these have not been traced.

Pirie was much taken by the exotic Madeira scenery: "the like of which one hardly thought existed except in pictures" (Pirie in Brown *et al*. 1906, p. 29). The next port of call, the Cape Verde Islands could not have been more different: "Instead of hillsides covered with vines, bamboos, and flowers, there is a bare, burnt, arid waste of sand and dust, rocks and ashes." In both his 1903 and 1906 accounts Pirie commented on the dissected volcanic crater forming the harbour of St Vincent and the surrounding stratified volcanic rocks cut by columnar-jointed dykes. A more geologically enigmatic prospect was offered by St Paul's Rocks in the equatorial mid-Atlantic and the expedition was anxious to make a landing to collect specimens. In the event, this was thwarted by sea conditions, with Pirie (in Brown *et al*. 1906, p. 41) describing his rescue from the shark-infested water having misjudged his attempted jump onto one of the rocks from a tossing boat that was almost wrecked in the process. This incident was the first of several when things could have gone very badly wrong for the expedition; its more well-managed attributes apart, it was also lucky!

## The voyage north

The SNAE left the South Orkney Islands on 22 February 1904, leaving behind a Scottish-Argentine meteorological party, from then on the responsibility of the *Oficina Meteorológica Argentina* at what became the *Orcadas* scientific base. More explorations in the Weddell Sea were planned, but from 7 to 14 March 1904 *Scotia* was beset in pack ice and was fortunate to escape. The warning was taken and the ship headed north.

Gough Island, to the south-east of Tristan da Cunha, was reached on 20 April 1904. It was thought that there had been no previous scientific investigation there, and Pirie was one of the group that effected a landing through heavy surf. He subsequently published a brief account of his geological observations (Pirie 1906) noting lava flows, some with columnar jointing, and beds of apparently water-lain tuff, all cut by a few dykes; the petrology of the basaltic volcanic rocks was described in an accompanying note by R. Campbell (1906), an Edinburgh University geologist. Pirie's specimen log lists 22 specimens collected at Gough Island, of which 17 are now held by NMS (Table 1). All are volcanic rocks except for a piece of limestone picked up on a beach (NMS 1954.1.15); it could not be related to any *in situ* source, but was accommodated by Pirie into the general supposition that all of the South Atlantic islands were remnants of an enormous and now mostly subsided continental landmass – Flabellites Land. Pirie supported that notion with reference to a piece of gneiss (a continental lithology) recorded from nearby (and also entirely volcanic) Tristan da Cunha by Schwarz (1905). It was Schwarz who had coined the name 'Flabellites Land' based on the circum-Atlantic (including the Falkland Islands) distribution of a small Devonian brachiopod fossil then known as *Leptocoelia flabellites* (Fig. 9c, Table 1).

From Gough Island the expedition made for Cape Town to replenish supplies for the long journey back to Scotland. Pirie did not make any written contribution to that part of the voyage, as described in Brown *et al*. (1906), but there are references therein to his having collected specimens during calls at St Helena and Ascension Island, both volcanic in origin. Brown *et al*. (1906, p. 281) make reference to the ‘bleak and barren cliffs of St Helena”, whilst Ascension Island appeared to be a “most uninviting and desert wilderness” (op. cit. p. 289). Pirie and his fellow scientists explored the volcanic landscape but had a difficult time leaving the landing stairs through the crashing waves: “a few of Pirie’s rocks missed the boat, and were never seen again” (op. cit. p. 300). Farther north, the Cape Verde Islands were passed with the volcanic island of Fogo seen to be smoking, but “[t]ime and the certainty of spending money prohibited us calling” (op. cit. p.305). A final call was made to Faial in the Azores archipelago, before the expedition’s triumphant return to the Firth of Clyde on 21 July 1906.

## A concluding appreciation

The SNAE and its ship, *Scotia*, are today celebrated in a number of South Atlantic place-names. The Scotia Sea was so named in 1932 in publications by the British *Discovery* Investigations (Herdman 1932) and has been formally adopted. By association, the ridge of islands, rocks and banks that enclosed the Scotia Sea became known as the Scotia Arc, but in the official gazetteer (Hattersley-Smith 1980) Scotia Ridge was preferred. Nevertheless, Scotia Arc is still in general usage. Many locations in the South Orkney Islands were named by the SNAE after its members, and most of these are now formally accepted (Hattersley-Smith 1991). They include Bruce Island and Pirie Peninsula (Fig. 2); the northernmost point of Pirie Peninsula, Cape Mabel, was named after Pirie’s wife-to-be (Agnes Mabel Kerr whom he married, in London, in 1910). In addition, there has been recent informal use (e.g. Dalziel *et al*. 2013) of Pirie Bank and Bruce Bank as names for submarine features on the north side of the South Scotia Ridge, respectively to the north and northeast of the South Orkney Islands (Fig. 1).

Arguably the most important single specimen collected by the SNAE was the block of archaeocyathan limestone dredged from the sea floor to the south-east of the South

Orkney Islands. Sadly, as an entirely unexpected discovery it was initially overlooked, its importance was not recognised for a decade and the opportunity it provided was missed. The recovery of that specimen was a very small part of the oceanographical survey work of the expedition which provided its principal scientific legacy, the identification of the physical continuity of the Scotia Arc (Bruce 1905). Pirie & Brown (1905) identified the chief scientific results in terms of the oceanographical work and the Laurie Island achievements. For the former, they noted particularly the Weddell Sea investigations and the discovery of Coats Land, and the delineation of a deep channel between the South Orkneys and the Falkland Islands. From Laurie Island they listed the topographical map, meteorology, botany, geology and zoology.

An independent and well-informed assessment was provided by Marr (1935, pp 320-321), himself an experienced Antarctic traveller, in a comprehensive account of the exploration of the South Orkney Islands:
"In addition to its pioneer oceanographical work in the Weddell Sea and its comprehensive observations on the flora and fauna, and on the geology and glaciology of Laurie Island, two notable achievements of this expedition are worthy of special mention. The first was the establishment by Bruce of a meteorological and magnetic station. ...... The second was a complete triangulated survey of Laurie Island by Bruce, assisted by Brown, Pirie and Wilton, which was made during the winter and spring of 1903 by sledge and boat parties. The conditions under which this work was done were severe, especially in winter; the precipitous nature of the coastline, cut by numerous glaciers, made land sledging impractical and the surveyors were compelled to sledge over rough sea-ice, which in the winter of 1903 was not compact and immovable but constantly shifting, so that the sledging parties were often in danger of being swept out to sea on floating ice."

Against this background, Pirie's field descriptions of the lithologies, fabrics and structures seen in the South Orkney Islands were commendably accurate given his limited formal training in geology, the sparse exposure much obscured by ice and scree, and the ubiquitous tectonic disruption. For his discovery of a 'graptolite' his Scottish background can be blamed. Familiarity with the Lower Palaeozoic geology of the Southern Uplands (newly and comprehensively described by Peach & Horne (1899) in their monumental Geological Survey memoir) would have primed him into suspecting that age for any other similar-looking succession of tectonised and metamorphosed greywacke and shale. Hence he expected to find appropriate fossils – graptolites. The same preconception presumably clouded the judgments of Elles and Peach, back in Scotland, when they confirmed the graptolite identification and, again influenced by knowledge of the local fossil associations in the Southern Uplands, Peach proposed that other obscure organic markings were the impressions of phyllocarid crustaceans. Elles and Peach were experienced palaeontologists, experts in their field, and there seems little excuse for their misjudgement. However, with their authoritative backing, Pirie would quite reasonably have unhesitatingly accepted the Lower Palaeozoic age thus defined.

The only hint of caution regarding the initial identification of the South Orkney Islands' fossils can perhaps be found in Peach's careful and consistent acknowledgement that the 'graptolite' had been "determined by Miss Elles to belong to the genus *Pleurograptus*". In the Southern Uplands this is an Ordovician genus, whereas Peach favoured a Silurian age for his supposed phyllocarids. However, any doubts that he might have had seem to have been restricted to the determined genus, rather than to the identification of a graptolite as such.

Any attempt to rationalise the geology of the South Orkney Islands and the Scotia Arc in terms of a regional model prior to the acceptance of continental drift was bound to run into difficulties. In common with most of his contemporaries, Pirie could do no better than regard the South Orkney Islands as a tiny remnant of the putative South Atlantic landmass – Flabellites Land – now subsided beneath the ocean. He was aware of the difficulties posed for that interpretation by *Scotia*'s soundings in what is now the Scotia Sea, but was equally aware of the requirement for a source, not too far removed, for the prodigious amount of terrestrial sediment contained in the GSF. It was not until 1913 that Wegener's publications initiated the continental drift debate – how that developed in the South Atlantic region has been reviewed by Stone (2015a) – but Flabellites Land was still the mainstream interpretation into the 1930s, as demonstrated by Gregory (1929) in his well-received Presidential Address to the Geological Society of London. Pirie could hardly have been expected to do better.

## Acknowledgements

I am particularly grateful to Yves Candela and Simon Howard for their assistance in locating the SNAE specimens in the National Museums Scotland Collections Centre, Edinburgh and to the staff of the National Museum research library for facilitating access to Pirie's notebooks; Beverley Ager advised on Pirie's (1913a) proof held by the British Antarctic Survey; Dale Austin located specimens at the University of Michigan; Gillian Sales (King's College, London) and Adrian Rushton (The Natural History Museum, London) were instrumental in locating Gordon's archaeocyath thin sections. In the preparation of this paper my thanks are due to Craig Woodward and Brian McIntyre (both of the British Geological Survey, Edinburgh) for their skilful assistance with, respectively, the compilation of figures and photographic images. For some of the latter I am also grateful for the help of Lorna Gilkison, Glasgow Digital Library, based at the University of Strathclyde. Helpful reviews by Teal Riley (British Antarctic Survey) and a second, anonymous referee resulted in a much improved paper, which is published by permission of the Executive Director, British Geological Survey (NERC).

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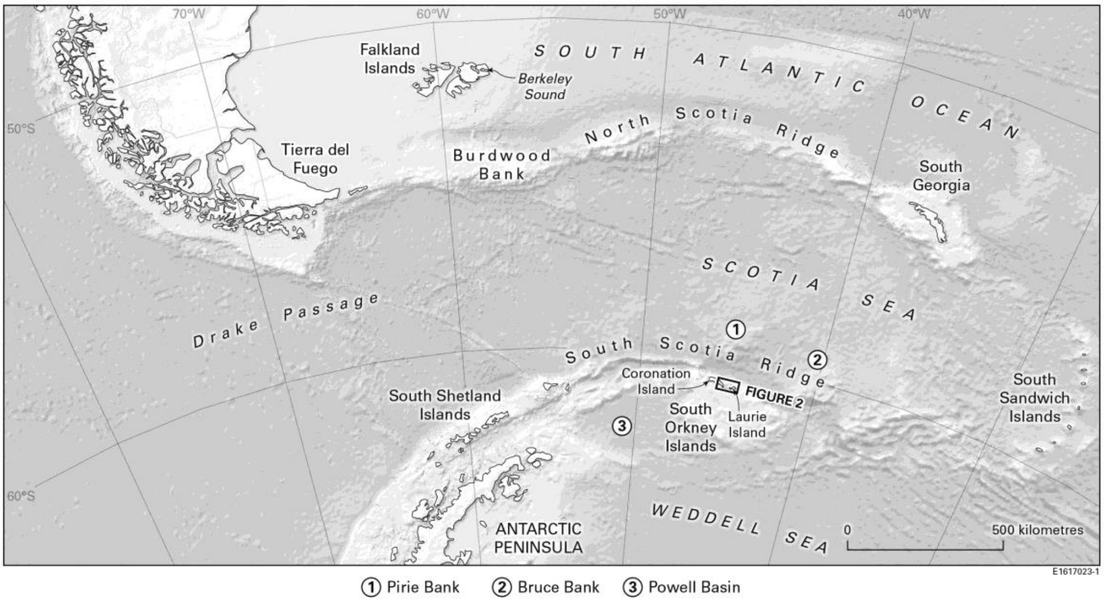


Fig. 1. The Scotia Sea and location of the South Orkney Islands, the wintering base for the Scottish National Antarctic Expedition.

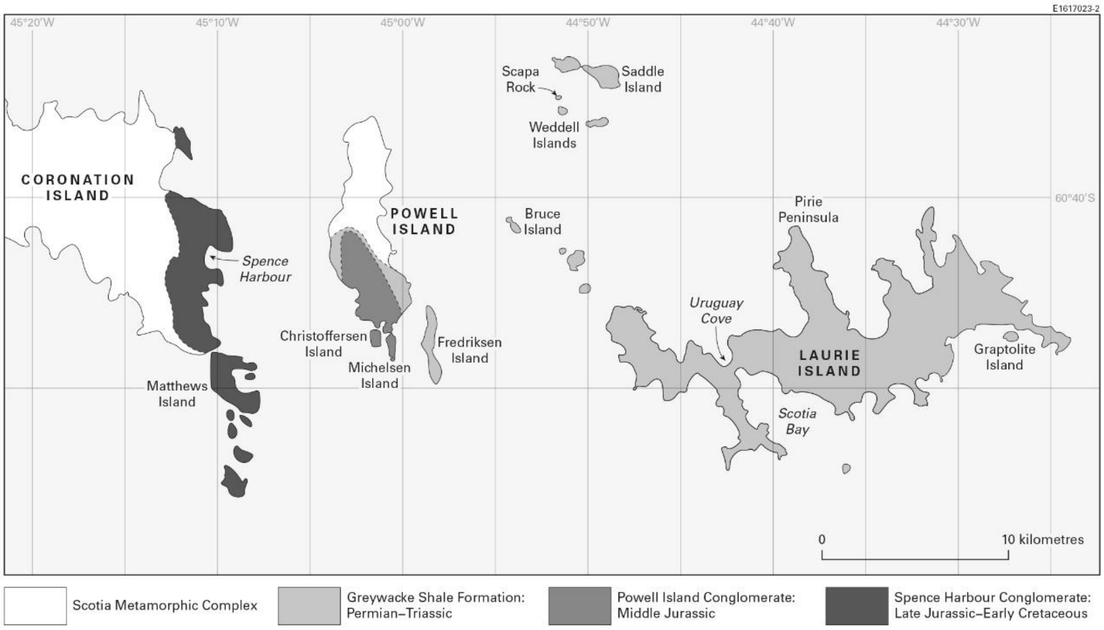


Fig. 2. Outline geology of the South Orkney Islands. The SNAE 1903 winter base was established on the narrow neck of land between Scotia Bay and Uruguay Cove. After Flowerdew *et al*. (2011)

Fig. 3. J.H.H. Pirie and fellow members of the team that remained in the South Orkney Islands during the 1903-04 austral summer whilst *Scotia* was taken north to the Falkland Islands and Buenos Aires for stores and refit. Image dated February 1904. From left to right: A. Ross (scientific assistant), W. Cuthbertson (artist), J.H.H. Pirie (geologist and surgeon), W. Martin (seaman and scientific assistant), R.C. Mossman (meteorologist), W. Smith (cook). Glasgow Digital Library, based at the University of Strathclyde.

Fig. 4. The expedition's first landfall at Saddle Island, 4 February 1903. J.H.H. Pirie is probably the figure second from the left. W.S. Bruce does not appear to be in the picture so was probably the photographer. Glasgow Digital Library, based at the University of Strathclyde.

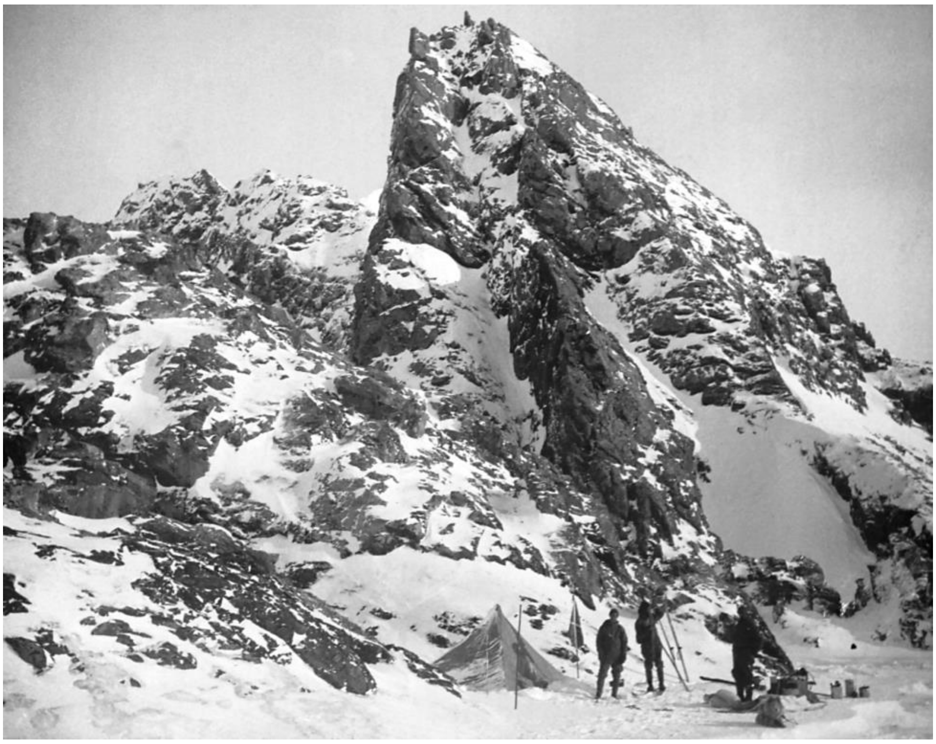

Fig. 5. A field camp on the south coast of Laurie Island, September 1903. Glasgow Digital Library, based at the University of Strathclyde.

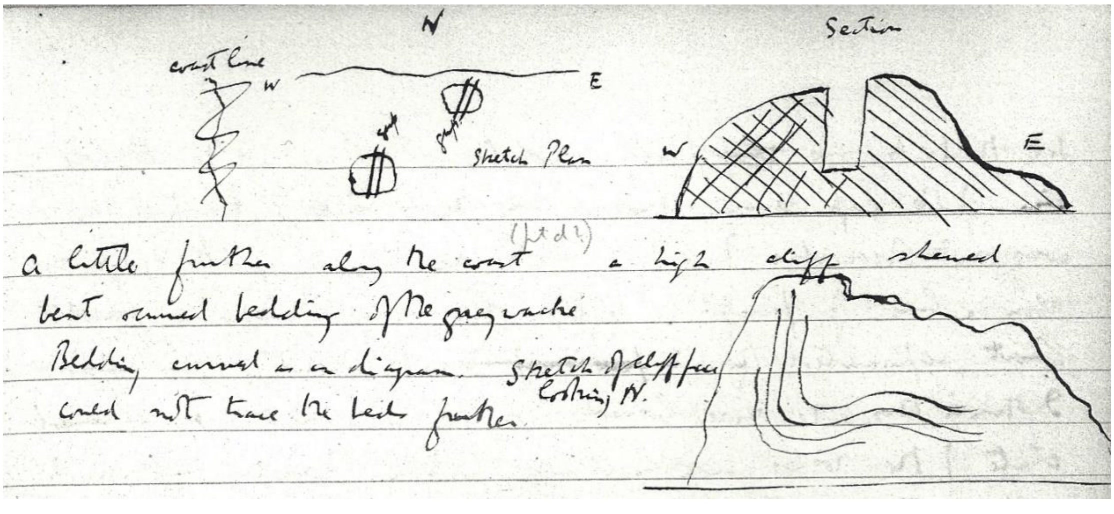


Fig. 6. An extract from Pirie's geological field notebook. The uppermost sketch illustrates a suspected fault gulley cutting across a small offshore island. W. S. Bruce Archive (Box 8, File 97), National Museum of Scotland.

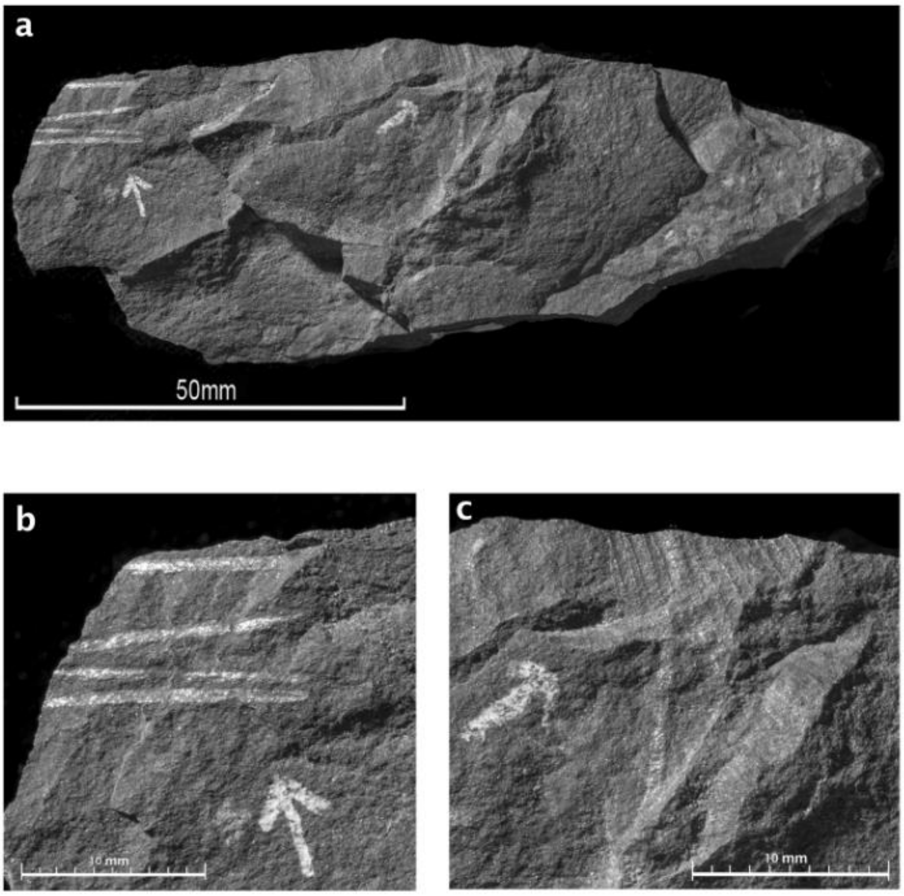


Fig. 7. The apparently fossiliferous slaty mudstone specimen recovered by Pirie from Graptolite Island: a) The whole specimen; b) Detail of features that may have been regarded as graptolites; c) Detail of the feature most probably identified by G. Elles as *Pleurograptus* sp., which overlies an area interpreted by B.N. Peach as the carapace impression of a phyllocarid crustacean. NMS specimen 1954.2.29. Photograph by Brian McIntyre, British Geological Survey.

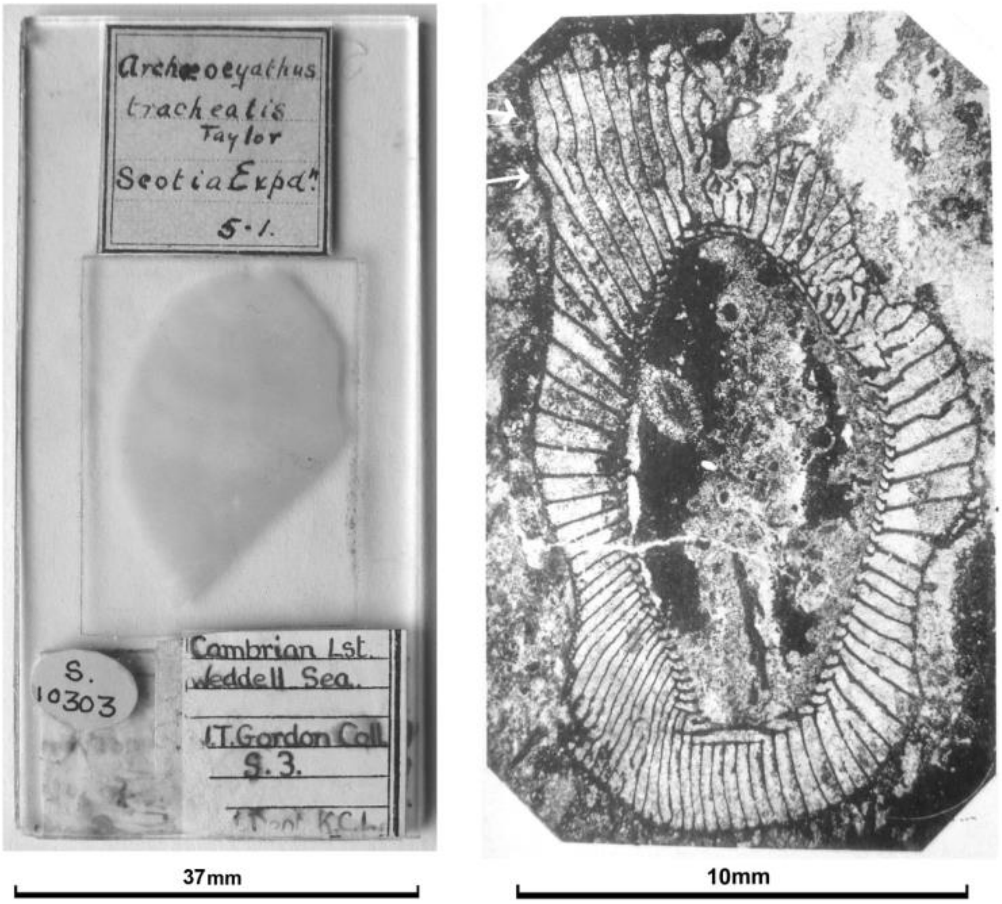


Fig. 8. An example from Gordon’s thin section collection, derived from the Weddell Sea limestone erratic and now held by The Natural History Museum, London.

a. One of the original thin sections. A detail from the upper part of the rock slice is shown as part b. As well as defining six new species Gordon divided Taylor’s genus *Archaeocyathus* to establish the new genus *Thalamocyathus*.

b. A transverse section of the largest archaeocyath (*Thalamocyathus trachealis*) described by Gordon (1920, Plate 2, fig. 18: reproduced by permission of The Royal Society of Edinburgh). NHM specimen S 10304.

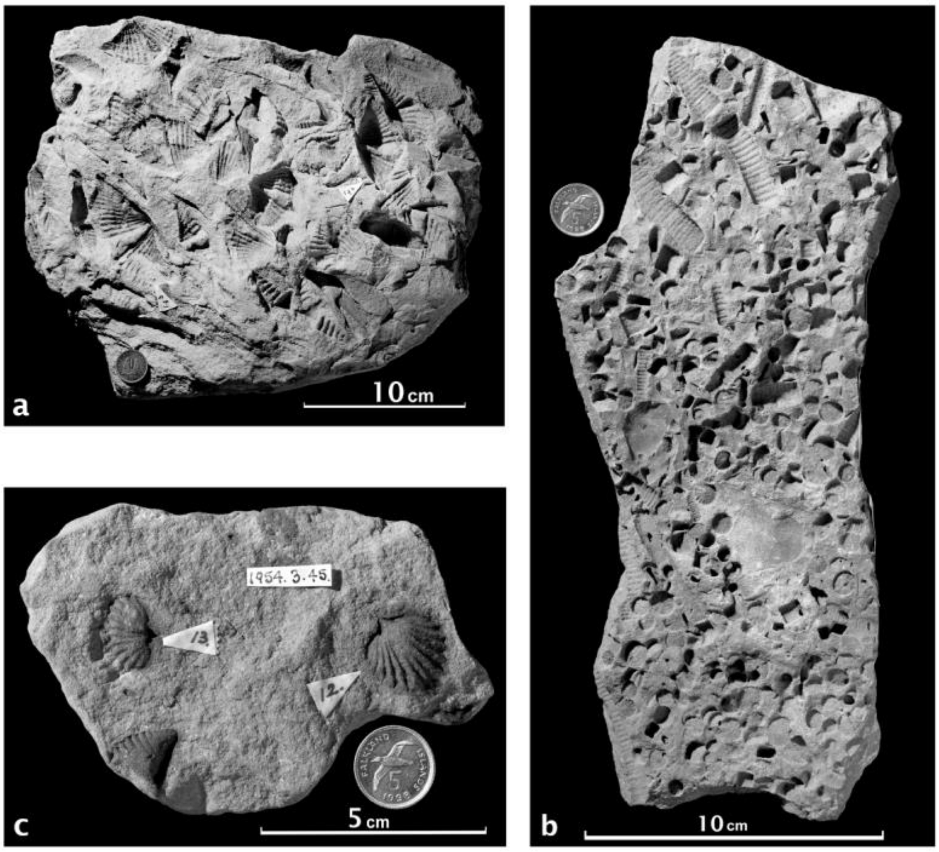


Fig. 9. Devonian fossils in Fox Bay Formation sandstone recovered by the SNAE from the Falkland Islands and now held by the National Museum of Scotland (NMS).

a. Brachiopods from 'Port Louis South' figured by Newton (1906) as *Spirifera antarctica* but now assigned to *Australospirifer hawkinsii* (Table 2). Note the distortion of some of the fossils. NMS specimen number 1954.3.31. Photograph by Bill Crichton (NMS).
b. Crinoid impressions in a sandstone slab from Westpoint Island, an outlying island in the far west of the Falklands archipelago. NMS specimen number 1954.3.58. BGS image number P599486.
c. Brachiopods from 'Port Louis South' figured by Newton (1906) as *Leptocoelia flabellites* but now assigned to *Australocoelia palmata* (Table 2). NMS specimen number 1954.3.45. BGS image number P599488.

| Location | Expedition specimen log | Museum holdings |
| --- | --- | --- |
| South Orkney Islands | 24 rock and mineral specimens and one collection of limpet shells "[f]rom screes and moraines – carried up by birds, prob. penguins." | 16 rock specimens, mostly greywacke. Reference numbers 1954.2.18-29 and 1954.2.70-73. |
| Falkland Islands | No details listed | 41 specimens of sandstone with fossil impressions, mostly brachiopods. Reference numbers 1954.3.30-70 |
| Gough Island | 22 rock specimens | 17 rock specimens, mostly volcanic. Reference numbers 1954.1.1-17 |

Table 1. A summary of the status of the SNAE's terrestrial geological specimens now held by the National Museum of Scotland.

| Nomenclature used by Newton (1906) | Modern nomenclature after Cocks as cited in Aldiss & Edwards (1999) |
| --- | --- |
| | |
| *Spirifera antarctica* | *Australospirifer hawkinsii* |
| *Leptocoelia flabellites* | *Australocoelia palmata* |
| *Chonetes falklandica* | *Pleurochonetes falklandicus* |
| *Orthotetes* sp. aff. *O. sulivani* | *Schellwienella sulivani* |
| *Cryptonella baini* | *Pleurothyrella falklandica* |
| *Orbiculoidea baini* | *Orbiculoidea falklandensis* |

Table 2. The Falkland Islands fossil brachiopod species identified by Newton (1906) and the modern nomenclature that is currently used to describe them.