OR/15/058 Research around the Scotia Arc after the Second World War

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The outbreak of the Second World War in 1939 overshadowed any further interest in such long-term issues as continental drift, even though techniques developed for warfare were to be subsequently fundamental to the establishment of plate tectonics theory as the definitive culmination of the continental drift debate. How that happened has been the subject of numerous books, such as the well-known examples by Hallam (1973)[1] and Wood (1985)[2]. Another outcome of wartime activity had been the establishment of British naval outposts in the South Shetland Islands and northern Graham Land (*Operation Tabarin*) which, at war's end, were transferred to the management of the newly-formed Falkland Islands Dependencies Survey (FIDS). At the new FIDS bases scientific research became the priority and several geologists who were involved there in Antarctic work also contributed subsequently to the interpretation of the Scotia Arc.

J R F Joyce spent the 1946 austral winter at the Stonington FIDS base on the Antarctic Peninsula and then returned to work on his results at Imperial College, London. This led, in 1950, to a presentation at the annual meeting of the British Association for the Advancement of Science (BAAS), held that year in Birmingham. The BAAS meeting was a wide-ranging affair, but it included a one-day symposium to discuss "The Theory of Continental Drift"; six speakers covered aspects of biogeography and geology. In the published account of his presentation Joyce (1951)[3] figured a reconstruction of the Gondwana section of Pangaea in which the islands of the Scotia Arc were strung out along that portion of the supercontinental margin formed by South Africa and the Antarctic. He stressed the South African associations of the Falkland Islands, and proposed linking the Cretaceous strata of South Georgia with supposedly similar- aged rocks in Mozambique. The present-day spatial arrangement of the islands forming the Scotia Arc was thus seen as a partly original feature, with their arcuate distribution being strongly accentuated as a consequence of continental drift during the break-up of Gondwana. Joyce's main problem was the relatively hostile mood of the BAAS meeting, with opposition to the concept of continental drift led by the eminent geophysicist Professor Harold Jeffreys. His contribution to the BAAS meeting (Jeffreys 1951)[4] was a rather patronising and world-weary dismissal of the continental drift idea since any conceivable mechanism must, he claimed, conflict with the basic physical properties of solids and liquids that "[w]e have all learnt at school" (1951, p.79); he bemoaned the fact that "[t]his is the fourth time that I have taken part in a public discussion of this theory" (p.80), implying that the time had come to call a halt to speculation. Against this background Joyce (1951, p.87)[3] ended defensively: "The suggestion is therefore made that *if Pangaea did in fact exist* then this new organisation of continental masses and island arcs *at the opening of the Palaeozoic era* is more in accord with the known data" — italics as in original.

In his reconstruction Joyce had moved the Falkland Islands towards the south–east coast of present-day South Africa. This may have influenced, or been influenced by, the work of a near-contemporary FIDS geologist, R J Adie. Adie spent three austral winters, 1947 to 1949, at the Hope Bay and Stonington FIDS bases; the third winter was unplanned and came about when ice conditions prevented relief of the Stonington base. Thereafter he spent time in the Falkland Islands during his journey north. He was a South African geologist who had graduated from the University of Natal, from a geology department led by Professor Lester King. Alexander Du Toit had died in 1948, but the cause of continental drift had found a new champion in King so Adie would have been well-primed in its applications. Adie (1952)[5] proposed an even more radical solution to the mismatched regional geology of the Falkland Islands than had been envisaged by Du Toit. In a remarkably prescient contribution, Adie (1952)[5] used the alignment of structural and sedimentological trends to support his proposal that the Falklands had been rotated by 180° from an original position adjacent to the east coast of South Africa. This solution to the enigma of Falklands geology was completely neglected by the geological mainstream until it was 'rediscovered' in terms of microplate rotation (Mitchell and others 1986)[6] late in the plate tectonic revolution. It is now widely (although not universally) accepted in principle.

During the 1950s, the geology of South Georgia became better known through Trendall's field- work and the subsequent publication of his two FIDS scientific reports (Trendall 1953[7], 1959[8]). The 1953 report included a speculative correlation of the wacke sandstone successions with superficially similar successions in the Antarctic Peninsula and the South Orkney Islands. At that time, regional stratigraphic correlation was much influenced by the supposed graptolite from the South Orkney Islands (Pirie 1905)[9] and, as already noted, it was thought possible that the unfossiliferous Sandebugten Formation of South Georgia might correlate with the apparently Lower Palaeozoic rocks of the South Orkneys.

Though Trendall's second report was not published until 1959, the manuscript is recorded as having been received in December 1954. Adie had become FIDS Chief Geologist in 1956 (he later became Deputy Director), and would have been involved in its scientific editing. The veracity of the South Orkneys 'graptolite' was probably in doubt for some time prior to its unmasking by Strachan in Adie (1957b)[10] and Trendall's 1959[8] report (completed in 1954) presented a revised, entirely Mesozoic stratigraphy for South Georgia. Therein, despite remaining uncertainties, the volcaniclastic Cumberland Bay Formation, and the quartzose Sandebugten Formation were proposed as possible facies variations within a single succession. Barker (1970)[11] has suggested that Trendall (1959)[8] envisaged the volcaniclastic sandstones as having been derived from a precursor South Sandwich arc, but this is an over-interpretation of Trendall's model in which the South Sandwich arc was more probably presented as an indicative illustration rather than a palaeogeographical specific.

Whilst Trendall worked in South Georgia, FIDS geologists were exploring the South Orkney and South Shetland archipelagos further south, and two of them, D H Matthews and D D Hawkes, attempted to fit their observations into a wider geological interpretation of the Scotia Arc.

Matthews spent the 1956 austral winter at the Signy Island base in the South Orkney Islands. In 1959, and by then at the University of Cambridge, he published an assessment of the Scotia Arc based on bathymetry and the sparse marine geophysical data that was then available. That paper (Matthews 1959)[12] presents two alternatives: either the islands of the Scotia Arc represented fragments of a disrupted continental mass, or they must be the highest parts of a mostly submerged continental block underlying most of the Scotia Sea. Citing Adie (1952)[5] he noted that continental drift was "an attractive hypothesis" to apply to the geological situation of the Falkland Islands, but found the Scotia Arc altogether less tractable. If the islands were disrupted fragments, and derived as envisaged by Barth and Holmsen (1939)[13] then breaks would be expected in the submarine ridges linking the islands; Matthews saw little evidence for such breaks. Conversely, if continental crust underlay the Scotia Sea, it would be associated with a large gravity anomaly; again, supporting evidence was not forthcoming. One complicating factor stressed by Matthews, reiterating a point raised by several previous workers, was the presence of thick clastic successions, in South Georgia and the South Orkney Islands, which required to have been deposited in proximity to a continental provenance. In a conclusion to his 1959 paper that he admitted was unsatisfactory, Matthews was forced to speculate that the Scotia Sea and arc represented some kind of transition between continental and oceanic crust. However, from this beginning, Matthews' marine geology interpretations blossomed and only a few years later he contributed to one of the seminal papers of the plate tectonic revolution (Vine and Matthews 1963)[14] that explained the pattern of linear magnetic anomalies distributed symmetrically across oceanic spreading ridges.

Hawkes worked on Deception Island, South Shetlands, during the 1957-58 austral summer, and reviewed extensive specimen collections from King George Island. He also made an interpretation of the structure of the Scotia Arc that returned to the concept of the disruption, by continental drift, of an original isthmus connecting Patagonia and Graham Land (Hawkes 1962)[15]. However, whereas Holmes (1929)[16] and Barth and Holmsen (1939)[13]had envisaged westward drift, with the isthmus breaking up to leave the islands of the Scotia Arc as abandoned relicts, Hawkes saw the islands as being driven eastwards. Starting with a linear continental connection between Patagonia and Graham Land, Hawkes proposed that an advance of 'Pacific' crust forced the break-up and the progressive eastward drift of the Scotia Arc islands. A succession of island arcs migrated eastward as part of the development of the Scotia Sea which, like Matthews, Hawkes thought of as in some way transitional between oceanic and continental states. The pre-drift, 'linear' reconstruction by Hawkes presaged the subsequently influential, rectilinear models of the early plate-tectonic era, such as that published by Dalziel and Elliot (1971)[17]. Hawkes' exposition of the Scotia Arc's origins had been guaranteed a wide audience when it was reproduced by Holmes (1965)[18] as Figure 873 in the second edition of his classic text book *Principles of Physical Geology*.

The paucity of geophysical information from the Scotia Sea meant that both Matthews' and Hawkes' proposals were poorly constrained. This gap in knowledge began to be filled in the early 1960s and the complexities involved were made apparent by Griffiths and others (1964)[19]. The authors attempted an integration of gravity, magnetic and seismic data but, spread as it was over such a wide area, the interpretation remained ambiguous and the Scotia Sea crust still seemed possibly transitional. Griffiths and others (1964, p.42)[19] concluded:

"The presence of a region in the Scotia Sea with a crust which may be of mixed type raises the problem … as to whether this is relic or potential continental crust. This is a problem that at the present time has not been resolved … although the possible presence of a crust of this type lends some support to the geological speculations of both Hawkes and Matthews".

The report by Griffiths and others is recorded as having been received for publication in November 1963. Meanwhile, Matthews had been busy elsewhere, and two months earlier, in September, the collaborative Vine and Matthews (1963)[14] paper had provided a radical new insight into the significance of marine magnetic data. Through the rest of the 1960s the plate tectonic revolution gained momentum and more extensive survey data accumulated from the Scotia Sea and Arc. By the end of the decade, Barker (1970)[11] was able to present an interpretation of the region involving sea-floor spreading in the Drake Passage and West Scotia Sea over at least the last 20 million years, and in the back-arc zone of the South Sandwich Islands volcanic arc for at least the last eight million years, together creating a separate 'Scotia' oceanic plate. Barker and Griffiths (1972)[20] then established from further marine geophysical surveys that the Scotia ridges, both North and South, were indeed defined by continental blocks. They proposed the post-Cretaceous fragmentation of a continental area linking Patagonia and the Antarctic Peninsula and illustrated a tentative reconstruction that brought South Georgia to the south of the Burdwood Bank.

Stone (2015)[21] has described how one consequence of the plate tectonic revolution was the independent devising and description of mechanisms for the Scotia Arc's origins that had previously been formulated in terms of continental drift. Large-scale, global reviews by several of the leading partisans touched on the South Atlantic, usually coupling an interpretation of the Scotia Arc with the Caribbean/Antillean arc much farther to the north, and brought a new-found scientific respectability to ideas long-neglected as unfeasible but now independently rediscovered. For example, Hamilton (1966, p.178)[22] summed-up his assessment in the abstract to his paper as follows: "If the continents [North and South America and Antarctica] are regarded as having drifted westward into the Pacific Ocean basin, then the two arcs can be pictured as formed by the disruption of the narrow bridges, which lagged behind the continents." This process is essentially the circumstance described almost 30 years earlier by Barth and Holmsen (1939)[13], which in turn followed Wegener (1929, pp.94–95)[23] and Holmes (1929, pp.594–595)[16] — all three contributions were apparently overlooked by Hamilton.

As in the earlier debate, the proposal that the Scotia Arc originated by means of westward continental drift was soon followed by a proposal invoking eastward drift. Moores (1970) developed a model to explain Mesozoic orogenies at the western margins of North and South America. He envisaged a Pacific island arc system colliding with the continental margins, resulting in orogeny, but that "[w]here no continent was present (as between North and South America and south of South America), the remnants of this island arc system simply continued migration, forming the Caribbean and Scotian (*sic*) Seas" (Moores 1970, caption to figure 6, p.842). Unsaid but implied would be the detachment by the eastward-migrating 'Scotian Sea arc' of continental blocks from the South American and Antarctic Peninsula continental terminations, which were then strung-out to form the North and South Scotia Ridges. Moores' model in respect of the Scotia Arc (a very minor component of the whole paper it must be stressed) is not that far removed from the situation envisaged by Hawkes (1962)[15] wherein a thin, rectilinear continental connection between South America and the Antarctic Peninsula was disrupted by "an eastward advance of the Pacific crust" (Hawkes 1962, abstract)[15]; Moores did not cite Hawkes' paper which had also envisaged island arcs migrating eastward.

References

1. ↑ HALLAM, A. 1973. *A Revolution in the Earth Sciences*. Oxford University Press, Oxford. 127 pp.
2. ↑ WOOD, R M. 1985. *The Dark Side of the Earth*. George Allen and Unwin, London. 246 pp.
3. ↑ 3.0 3.1 JOYCE, J R F. 1951. The Relation of the Scotia Arc to Pangaea. The Advancement of Science, 8, 82–88.
4. ↑ JEFFREYS, H. 1951. Mechanical Aspects of Continental Drift and Alternative Theories. *The Advancement of Science*, **8**, 79–80.
5. ↑ 5.0 5.1 5.2 ADIE, R J. 1952. The position of the Falkland Islands in a reconstruction of Gondwanaland. *Geological Magazine*, **89**, 401–410.
6. ↑ MITCHELL, C, TAYLOR, G K, COX, K G. and SHAW, J. 1986. Are the Falkland Islands a rotated microplate? Nature, 319, 131-134. MOORES, E. 1970. Ultramafics and Orogeny, with Models of the US Cordillera and the Tethys. Nature, London, 228, 837–842.
7. ↑ TRENDALL, A F. 1953. The Geology of South Georgia: I. *Falkland Islands Dependencies Survey Scientific Reports*, No.7, 26 pp, 2 plates, fold-out map.
8. ↑ 8.0 8.1 8.2 TRENDALL, A F. 1959. The Geology of South Georgia: II. Falkland Islands Dependencies Survey Scientific Reports, No. 19, 47 pp, 5 plates, fold-out map.
9. ↑ PIRIE, J H H. 1905. On the Graptolite-bearing Rocks of the South Orkneys. *Proceedings of the Royal Society of Edinburgh*, **25**, 463–470.

10. ↑ ADIE, R J. 1957b. The petrology of Graham Land: III. Metamorphic rocks of the Trinity Peninsula Series. *Falkland Islands Dependencies Survey Scientific Report*, **20**, 26 pp.
11. ↑ 11.0 11.1 BARKER, P F. 1970. Plate Tectonics of the Scotia Sea Region. *Nature, London*, **228**, 1293–1296.
12. ↑ MATTHEWS, D H. 1959. Aspects of the Geology of the Scotia Arc. *Geological Magazine*, **96**, 425–441.
13. ↑ 13.0 13.1 13.2 BARTH, T F W, and HOLMSEN, P. 1939. Rocks from the Antarctandes and the Southern Antilles. *Scientific Results of the Norwegian Antarctic Expedition 1927–1928*, **18**. I Kommisjon Hos Jacob Dybwad, Oslo. 64 pp + 4 plates.
14. ↑ 14.0 14.1 VINE, F J, and MATTHEWS, D H. 1963. Magnetic anomalies over oceanic ridges. *Nature, London*, **199**, 947–949.
15. ↑ 15.0 15.1 15.2 HAWKES, D D. 1962. The Structure of the Scotia Arc. Geological Magazine, 99, 85–91.
16. ↑ 16.0 16.1 HOLMES, A. 1929. Radioactivity and Earth Movements. Transactions of the Geological Society of Glasgow, 18, 559–606.
17. ↑ DALZIEL, I W D, and ELLIOT, D H. 1971. Evolution of the Scotia Arc. *Nature, London*, **233**, 246–252.
18. ↑ HOLMES, A. 1965. Principles of Physical Geology (2nd edition). Nelson, London and Edinburgh. 1288 pp.
19. ↑ 19.0 19.1 GRIFFITHS, D H, RIDDIHOUGH, R P, CAMERON, H A D, and KENNETT, P. 1964. Geophysical investigations of the Scotia Arc. British Antarctic Survey Scientific Report, No. 46, 43 pp.
20. ↑ BARKER, P F, and GRIFFITHS, D H. 1972. The evolution of the Scotia Ridge and Scotia Sea. *Philosophical Transactions of the Royal Society of London*, **271**, 151–183.
21. ↑ STONE, P. 2015. Geological exploration of South Atlantic islands and its contributions to the continental drift debate of the early 20th century. *Proceedings of the Geologists' Association*, **126**, 266–281.
22. ↑ HAMILTON, W. 1966. Formation of the Scotia and Caribbean arcs. *Geological Survey of Canada Paper*, **66–15**, 178–185.
23. ↑ WEGENER, A. 1929. Die Ehtstehung der Kontinente und Ozeane (4th edition). Friedrich Vieweg and Sohn, Braunschweig. English translations as The Origin of Continents and Oceans were published in the USA by Dover Publications Inc. (1966) and in the UK by Methuen and Co., London (1967).

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