PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Discussion on the Papers on Earth Sciences

M. J. Roobol, R. J. Adie, D. J. Drewry, P. E. Baker, S. D. Weaver, P. F. Barker, A. S. Laughton, J. W. Glen, C. W. M. Swithinbank, H. Lister, G. de Q. Robin and George Deacon

Phil. Trans. R. Soc. Lond. B 1977 **279**, 207-211
doi: 10.1098/rstb.1977.0083

Phil. Trans. R. Soc. Lond. B. **279**, 207–211 (1977)
Printed in Great Britain

Discussion on the papers on Earth sciences

M. J. Roobol

Yesterday we heard how the large whales and seals were taken from Antarctica to provide oil for light and heating. This partly assisted us in attaining our present population level of 4 000 000 000. So today we are even more dependent on natural gas and oil. The Weddell and Ross Seas appear to overlie large sedimentary basins which are a part of the shelf of the Antarctic Continent. These basins could well contain oil and gas deposits. Dr Adie's description of the Antarctic Peninsula, of granodiorites and diorites intruding volcanic rocks, sounds an ideal prospect for porphyry copper deposits, while the many faults mentioned could prove to be the sites of other types of mineral deposits. Could Dr Adie tell us a little about B.A.S. efforts and plans for the exploration of these potential mineral deposits.

R. J. Adie

Until 3 or 4 years ago the policy of the British Antarctic Survey was to carry out systematic geological surveys covering all aspects of geology. Now, specific geological problems are being investigated in the field and in the laboratory.

The exploration for minerals, particularly hydrocarbons, in the Antarctic would be an attractive proposition but regrettably the Survey has neither the financial nor logistic resources to become involved in such a costly project.

Recently, the press reported that the reserves of hydrocarbons in the continental shelf areas of Antarctica were likely to exceed those of the whole of North America including the 'North Slope' area. This report supposedly emanated from the U.S. Geological Survey and embodied the results of investigations on this interesting topic.

M. J. Roobol

At the present time British universities are producing large numbers of Earth scientists – far more than are required in this country and so many find their way overseas. I cite my own experience as an example as during the past 6 years I have worked for West Indian, Canadian and American universities. As B.A.S. is unable to enter into mineral exploration it seems that such work can only be carried out by other countries or by British Earth scientists working overseas.

D. J. Drewry

In Dr Adie's reconstruction of a Carboniferous ice mass in Antarctica he indicates an ice sheet approximately co-extensive with that of the present day. The main centre of outflow is also shown close to that of the contemporary ice sheet. Frakes, Matthews & Crowell (1971) in their study of the Late Palaeozoic glaciation of Antarctica suggest that there was a migration of the centres of smallish ice sheets (*ca.* 1×10^6 km^2) from the Weddell Sea region during the early Carboniferous to northern Victoria Land by Permian times. Their interpretation does not appear to support an extensive ice sheet centred in southeast Queen Maud Land. What evidence (striae, till fabrics, palaeoslope data etc.) was used to determine the ice flow pattern in Dr Adie's diagram?

Reference

Frakes, L. A., Matthews, J. L. & Crowell, J. C. 1971 Late Palaeozoic glaciation: Part 3, Antarctica. *Geol. Soc. Am. Bull.* **82**, 1581–1604.

R. J. Adie

The diagram shown was one of Antarctica removed from its context of Gondwanaland but it illustrated the relative position of the geosynclinal trough which occupied the position of the Antarctic Peninsula during the Permo–Carboniferous. This diagram depicts *only* one position of the ice-sheet configuration during the migration of Gondwanaland across the South Pole, and the basic interpretation is not far removed from that of Frakes *et al.* (1971). The evidence for this has been given elsewhere (Adie 1975).

M. J. Roobol

Would Dr Baker like to speculate on the relationship of the Patagonian basalt plateau in relation to the Bransfield Strait and James Ross–Paulet Island volcanic provinces?

P. E. Baker

Counterparts to the Tertiary–Recent igneous and tectonic events in the South Shetland Islands–Bransfield Strait region are to be found in somewhat earlier events in the southern Andes. At least part of the Patagonian basalt plateau is broadly comparable in age and tectonic situation to the basalt-palagonites breccia plateau of the James Ross Island Volcanic Group. Both these basalt provinces appear to have developed as an indirect response to subduction along the Pacific margin of the continents. This induced thermal event may be analogous to that which sometimes results in back-arc spreading.

S. D. Weaver

The Deception Island volcanics have much higher Na_2O contents and higher Na_2O/K_2O ratios than any volcanics known to the speaker which are demonstrably associated with island arcs or back-arc basins. Can Dr Baker account for this peculiar, apparently unique, geochemistry?

P. E. Baker

A relatively high Na_2O content seems to be characteristic of most Pliocene–Recent basalts in the northern Antarctic Peninsula region. Deception Island is exceptional in having more differentiated rocks in which Na_2O is conspicuously enhanced. In this respect the Deception Island suite is similar to that of Santorini in the Aegean arc. Partial melting of an amphibole-bearing source rock under low P_{H_2O} conditions might explain initial soda enrichment in the melt. Subsequent fractionation of calcic plagioclase, olivine and pyroxene would tend to concentrate Na_2O in later differentiates.

D. J. Drewry

I would like to comment on Dr Baker's suggestion that alkalic, silica-undersaturated volcanic rocks (basanitoids, trachybasalts and phonolites) in the Ross Sea area may be associated with crustal extension: a relationship well documented in continental rift zones. Some support for this idea is provided by the recent geophysical investigations of Hayes & Davey (1975). They indicate that a linear, positive gravity anomaly ($> +10$ mGal), running north–south in the western Ross Sea, may be associated with a transient spreading centre or 'leaky' transform fault, related to early Cenozoic ocean-floor spreading in the southeast Indian–southwest Pacific Oceans between Antarctica, Australia and New Zealand.

Reference

Hayes, D. E. & Davey, F. S. 1975 A geophysical study of the Ross Sea, Antarctica. Initial Reports of the Deep Sea Drilling Project (Washington, D.C.). Vol. 28, pp. 887–907.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

M. J. Roobol

I should like to congratulate the Birmingham group on their tenacity in working so successfully in the difficult conditions of the Drake Passage to the Scotia arc. This area is morphologically similar to the Caribbean, yet in these warm and hospitable areas we know far less about the origin of the sea floor.

Do you find the subduction of the east Pacific lithosphere beneath the South Shetlands and Patagonia and the resulting model of back-arc volcanism (as postulated here by Dr Baker to account for the young Bransfield Strait, Patagonian and James Ross–Paulet Island volcanic provinces) compatible with the models which you have proposed?

P. F. Barker

We appreciate Dr Roobol's compliment but cannot avoid occasionally feeling grateful to Scotia Sea weather conditions, for having allowed us the area to ourselves for so long. The Caribbean, of course, is much less amenable to marine geophysics than the Scotia Sea, being older and apparently largely formed during a time without magnetic field reversals.

The likelihood of Neogene subduction at the Pacific margins of southern South America and the Antarctic Peninsula was first indicated several years ago (Barker 1970) and the suggestion that South Shetland Islands volcanism and Bransfield Strait opening are secondary effects of this subduction is also not new (Barker & Griffiths 1972; Davey 1972; Ashcroft 1972). Our own inclination is to wonder whether the James Ross–Paulet Island alkaline volcanics may not be rather less directly related to events at a plate margin, and more akin to the intra-plate activity in Marie Byrd Land and Victoria Land (Barker 1977).

References

Ashcroft, W. A. 1972 Crustal structure of the South Shetland Islands and Bransfield Strait. *Br. Antarctic Surv. Sci. Rep.* **66**, 43 pp.

Barker, P. F. 1977 The tectonic framework of Cenozoic volcanism in the Scotia Sea region – a review. In IAVCEI Special Series. Proceedings of the Symposium on Andean and Antarctic Volcanology Problems.

Davey, F. J. 1972 Marine gravity measurements in Bransfield Strait and adjacent areas. In *Antarctic geology and geophysics* (ed. R. J. Adie), pp. 39–46. Oslo: Universitetsforlaget.

A. S. Laughton

I have been very much impressed by the smooth and continuous curvature of line from the tip of South America through Burdwood Bank, the north Scotia Ridge, the Scotia arc, the south Scotia Ridge and the Antarctic Peninsula. In the models presented, Professor Griffiths has used the data of the Scotia Sea to close Drake Passage before 30 Ma, but yet has retained the curvature of South America and the Antarctic Peninsula. His reconstructions before 30 Ma have been constrained by this curvature and also by the presence of the Falkland Islands Plateau. Does he believe that this curvature existed before the break-up, and if so, how does he explain the continuity into the morphology surrounding the Scotia Sea?

P. F. Barker

We have largely neglected the question of Scotia Sea evolution in this paper, as being a more recent, more complex modification of an older, simpler plate régime, but Dr Laughton is correct in stressing the importance of the assumptions about it which we have made.

Palaeomagnetic data (Blundell 1962; Dalziel, Kligfield, Lowrie & Opdyke 1971) lend support to the existence of a curvature and orientation for the Antarctic Peninsula similar to that of the present day back to about 90 Ma, some 60 Ma before Drake Passage started to open. We ourselves originally conceived of the persistence of this curvature, and hence of a rigid,

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

cuspate junction between the peninsula and South America from the time of Gondwanaland break-up (*ca.* 130 Ma) until 30 Ma ago, with only those sections north of Cape Horn and south of Elephant Island lying at the Pacific margin. This view has become untenable however, in the face of growing geological indications that South Georgia, the South Orkney Islands and Burdwood Bank must have lain close to or at an actively-subducting (i.e. Pacific) continental margin for much of that time. The models presented here include this requirement, and no longer regard the close connection between Elephant Island and Cape Horn as long-lived before 30 Ma ago.

Thus some continuity of curvature east of Elephant Island and Cape Horn is to be expected and reflects this earlier state. However, even directly east of these sites the continuity in detail is only partial, and becomes more tenuous the farther east one goes. The north and south Scotia Ridges are formed of continental fragments; any one block contains only part of a Pacific margin sequence and the geological features typically are truncated at the block margins. The process of disruption associated with Scotia Sea formation has in general elongated the north and south Ridge, preserving a rather spurious gross continuity, but there is no support on more detailed examination for a view of the long eastward loop of the Scotia arc as an original feature whose great length has been conserved.

Of course even very young island arcs are sometimes curved, and curvature is a common feature of subduction; essentially cuspate junctions of two such arcs are not unknown (Kamchatka–Aleutian, Kurile–Japan, for example). In our model A the cusp can be regarded as essentially a response to an older offset in the Gondwanaland margin; in models B and (more especially) C it may be possible to eliminate the cusp, so that the curvatures of southern South America and the Antarctic Peninsula are continuous.

References

Blundell, D. J. 1962 Palaeomagnetic Investigations in the Falkland Islands Dependencies. *Br. Antarctic Surv. Sci. Rep.* **39**, 24 pp.

Dalziel, I. W. D., Kligfield, R., Lowrie, W. & Opdyke, N. D. 1971 Palaeomagnetic data from the southernmost Andes and the Antarctandes (abstr.). *Eos* **52**, 921.

D. J. Drewry

What governed the choice of inland boundary of the Antarctic Peninsula–Ellsworth Land fragment in your reconstruction? Would a different configuration significantly alter the fit provided by your two models?

P. F. Barker

The questions raised by Dr Drewry are essentially answered in the text. In summary, because so little is known of the geology of the largely ice-covered interior of West Antarctica, our boundaries were not tightly constrained. However, both models, which to some extent are end-members of a continuum, assume the Antarctic Peninsula plate to be large; most alternative boundary locations reduce its size, thereby constraining its movement even less. Thus, the exact position of the inland boundary (provided that it occurs *somewhere*) is probably not very important for resolving between one model and another for the reconstruction of Gondwanaland.

J. W. Glen

Has Dr Swithinbank any evidence whether the deep trenches that he found when echo-sounding deep floating ice are over-deepened valleys in the sense that they rise markedly in the oceanward direction like fjords?

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

C. W. M. Swithinbank

Unfortunately, we have no evidence that bears on this. Where the ice sheet is floating we get total reflexion from the ice/water interface and thus know nothing about the depth to the sea bed. It will be possible to detect over-deepening if it occurs in trenches filled with grounded ice; and seismic sounding could provide an answer where the ice is afloat.

H. Lister

Dr Robin's extensive profiles of deep continental ice showed no marked changes indicative of major ice streams. This contrasts with the deep profiles shown by Dr Swithinbank where discrete ice streams were so striking. Could he comment on these differences, please?

G. de Q. Robin

Many studies have shown that discrete ice streams are typical of the outer section of ice sheets and are infrequent at a distance of more than 100 or 200 km in from the edge of the ice sheet. Our studies show that on the interior of the Antarctic ice sheet, where temperatures are so low that viscosities of the ice are two or three orders of magnitude below that of ice near the melting point, the upper layers of ice tend to move as a relatively rigid sheet. As this moves over bedrock irregularities, large variations of deformation rate must occur in the lower levels of ice, as can be seen from our pictures of internal layering. We therefore regard the inland sections of ice sheets as undergoing 'sheet flow', as distinct from the peripheral regions where the ice is readily channelled into ice streams and outlet glaciers, as shown particularly by Dr Swithinbank's work presented at this meeting.

Sir George Deacon, F.R.S.

Fuller knowledge of the continental shelves round Antarctica would probably further our understanding of the history of the continent. A line of soundings up the continental slope generally shows the depth decreasing to less than 400 m, and then increasing again to 600–1000 m, before sloping up to the actual coastline. The maps are still not very detailed, but the shelf troughs seem often to run parallel to the coast. I believe it was Nordenskjöld who called them 'Vortiefe'. It would be interesting to make seismic soundings across the outer bank and acoustic pictures.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES