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Early Tertiary Volcanism and the Opening of the NE Atlantic

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Introduction

L. M. Parson & A. C. Morton

A conference dealing with 'Early Tertiary volcanism and the opening of the NE Atlantic' was held at the Geological Society of London, Burlington House, London, on 18 and 19 March 1987. The meeting was supported and promoted by three of the specialist groups of the Society (Volcanic Studies, Marine Studies and Petroleum groups), and carried the endorsement of the Norsk Petroleumsforening. This broad-based support reflects the truly multidisciplinary nature of the meeting, which saw contributions from geophysicists, geochemists, geochronologists, volcanologists, petroleum geologists, structural geologists, petrologists, sedimentologists and biostratigraphers. The conference was attended by over 180 delegates from throughout the N Atlantic borderlands, who enjoyed the presentation of 34 papers and five posters, and contributed to a number of lively and spirited discussion periods.

This volume contains 37 papers, four of which appear as extended abstracts, and some in forms very different to that presented at the meeting. For practical reasons some authors have combined manuscripts, some contributions presented at the meeting were not available for inclusion in this publication, and some papers have been included despite not being presented at the meeting. The papers have been grouped into six categories, essentially on the basis of structural and geographic setting, but these categories also serve to emphasize the multidisciplinary approach of the current research.

Volcanic and tectonic framework

The first group of papers deals with the volcanic and tectonic framework on which the subsequent regional studies are based. These papers deal not only with the regional plate-tectonic setting during the Palaeogene, but also with the Icelandic hot-spot, in particular its character and role in the inception of seafloor spreading, its relevance to the excessive volcanism, and its possible cause.

Dipping reflectors and NE Atlantic evolution

The large number of papers falling into this group reflects both the strong interest and perhaps the lack of agreement in these fields. Description and discussion of volcanic margins throughout the NE Atlantic provides a broad spectrum of the degree of development of volcanism and structural context. However, recent geochemical data from Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) results have provided some of the most interesting finds. Powerful evidence is presented to show the existence of varying types of crustal contamination in the dipping reflector sequences and in the underlying associated extrusives. Without doubt, one of the greatest advances has been made in the field of geochemical assessment of the margin evolution, and the acquisition of further geochemical data from more NE Atlantic dipping reflector sequences must be considered to be a high priority.

E Greenland and the Faeroe Islands

The first geographical grouping of papers covers the E Greenland margin as well as the Faeroes block, and includes detailed accounts of the trace element and isotopic compositions of E Greenland lavas and dykes and valuable geochronological and palaeomagnetic studies that have further constrained timing of models of the development of the E Greenland margin.

Volcanism in basins to the N and W of the British Isles

Aspects of Tertiary volcanism in pre-existing Mesozoic rift basins that border the NE Atlantic to the N and W of the British Isles, such as the Faeroe Basin, Rockall Trough and Porcupine Seabight Basin, are covered by this group of papers. These studies depend heavily on results of hydrocarbon exploration, and include analyses of deep commercial borehole samples and studies of commercial seismic data, combined with data acquired by the British Geological Survey (BGS) during shallow drilling. Of particular interest is the association of peraluminous cordierite-bearing dacites overlain by tholeiites found in the northern Rockall Trough, because this sequence is remarkably similar to the association found on the Vøring Plateau margin. Prior to these discoveries, peraluminous extrusives had not been recorded in the NE Atlantic Igneous Province, and they may represent a volcanic association particular to these pre-existing deep sediment-filled Mesozoic rift basins. There is clearly a need for more deep drill sites in this structural setting.

From Morton, A. C. & Parson, L. M. (eds), 1988, *Early Tertiary Volcanism and the Opening of the NE Atlantic,* Geological Society Special Publication No. 39, pp. ix–xii.

British Tertiary Igneous Province

This section deals predominantly with stratigraphic aspects, as the petrogenesis of the extrusives and intrusives has already been studied in considerably greater detail than the offshore areas, or even the Faeroe–E Greenland province (e.g. Thompson 1982). Important constraints are put on some of the timing of volcanic events within the British Tertiary Volcanic Province by radiometric and isotopic data presented in the following set of papers. Regional stress patterns are assessed over the NW margin and can be compared with the larger scale tectonic review presented early in the volume.

The sedimentary record

The next section deals with the sedimentary record of the volcanic and tectonic events associated with the NE Atlantic opening, and in particular deals with the record of early Tertiary volcanism in the North Sea sedimentary record. Despite unresolved differences in interpretation of the provenance of the pyroclastic deposits found at particular levels within the Palaeogene sequences, these studies provide important information on the timing of activity in the NE Atlantic borderlands. It is clear that with continued work, particularly on the geochemistry of individual tephras, the sources of the volcanics will be further constrained, thus allowing precise biostratigraphic dating of volcanic activity.

Review of igneous activity

The volume is completed by an exhaustive and far-reaching review of igneous activity in the NE Atlantic borderlands, the first such attempted for well over a decade, since the review by Noe-Nygaard (1974).

Overview

It is impossible in a short introduction to comment on all the highlights of the meeting. However, important advances were made in several directions. Much of the meeting was devoted to the igneous activity at the continental margin itself, and helped to focus the attention of geochemists, petrologists and volcanologists familiar with the classic onshore localities of Scotland, Ireland, Iceland, Faeroes and E Greenland onto the less well-known but volumetrically and geographically more extensive offshore volcanics. Considerable effort was made to encourage presentations which would address general but long-standing problems of the 'rifting' to 'drifting' transition at volcanic passive margins, of which the NE Atlantic is arguably the best example world-wide. Many of the uncertainties concerning the structure and evolution of specific margins addressed during the early part of the meeting stem from a limited appreciation of the fundamental processes contributing to continental break-up and sustaining early seafloor spreading. These processes, involving localized magmatic activity on an enormous scale, need to be fully understood and modelled before more detailed scenarios can be objectively appraised. The timing and the mechanisms by which volcanic passive margins progress from subaerial rift phase to the almost inevitable submarine seafloor-spreading phase are controlled by deep crustal behaviour and magma supply, but locally perturbed by anomalies such as the Iceland mantle plume. Several papers address these aspects, and this move away from local studies of short sections of margins is to be welcomed.

The problems of evolution of specific volcanic passive margins, however, falls within the domain of geophysical and geological sampling. The seaward-dipping reflector sequences forming the blanket to many ocean–continent transitions world-wide are particularly abundant on the conjugate flanks of the E Atlantic N of 55°N. The debate over the timing of the onset of true seafloor spreading at these margins persists, and despite a significant increase in the quality of data available, both in terms of seismic reflection and refraction profiles and deep sampling results, the schools of thought still agree to differ. Although it is possible that some dipping reflector sequences described from passive margins elsewhere are non-volcanic in origin (Grow *et al.* 1983), deep drilling during DSDP Leg 81 and ODP Leg 104 has confirmed that this cover sequence is basaltic in the NE Atlantic at least. In many respects, these basalts resemble those generated at mid-ocean ridges, apparently providing support for proponents of a subaerial seafloor-spreading origin for the dipping reflectors. However, detailed geochemical and, particularly, isotopic studies show that the sources of the extrusive sequences drilled in the NE Atlantic have not only an oceanic component but also undoubted continental and/or subcontinental lithospheric components, and that continental (in its broadest sense) contamination of dipping reflector basalts themselves is not uncommon and can continue to high levels in the sequence. As White (1987) has recently pointed out, in these volcanic passive margins there must be an area between unstretched continental crust and true oceanic crust consisting of stretched and intruded crust, probably with an increasing igneous component oceanwards. The consequent futility of attempting to define a meaningful 'ocean–continent transition' on volcanic passive margins is reflected in the increasing use of the term 'transitional crust'.

The contributions also provide a fascinating insight into the nature of the magmas that were available immediately prior to and at the inception of seafloor spreading in the NE Atlantic. Basaltic rocks show a range from N-type mid-ocean ridge basalt (MORB) (e.g. in the dipping reflector sequence SW of Rockall), through T-type MORB (e.g. on the Vøring margin) to E-type MORB (as in E Greenland). The role of the subcontinental lithosphere is also evident: a contribution from an enriched subcontinental lithospheric source is postulated for early E Greenland extrusives, whereas the SW Rockall Plateau dipping reflector basalts are inferred to have a significant contribution from a depleted subcontinental lithospheric reservoir. Similarly, magmas derived by anatectic melts of continental crustal material are also in evidence, the most interesting perhaps being the peraluminous extrusives documented from the NE Rockall Trough and the Vøring Plateau.

The debate over the timing of the onset of volcanism in the NE Atlantic and the age relationships between distinct areas has continued for many years, largely because of the poor biostratigraphic control inherent with these predominantly terrestrial sequences. However, it is becoming apparent that the increased resolution of radiometric age dating, using the ^{40}Ar-^{39}Ar method, together with more critical evaluation of conventional K-Ar data, used in combination with palaeomagnetic data, is a powerful approach, and has been used to great effect in the British Tertiary Province in particular. However, the volcanic history can perhaps be best resolved when the effects of terrestrial volcanism are seen in the marine sedimentary record, and in this regard the North Sea and adjacent offshore Mesozoic basins provide valuable data. Thus, the record of Hebridean-derived basaltic volcaniclastics in the early part of the post-Danian Palaeocene of the North Sea confirms that the major part of the basaltic activity in the British Province can be constrained to the magnetic anomaly chron C26R. Similarly, the discovery of an early Selandian tuff sourced from the Faeroe/E Greenland Province confirms that there was basaltic activity in the Faeroes (and possibly, by inference, in E Greenland) as early as C26R, confirming the assignment of the two magnetic normal polarity zones in the Faeroes Lower Series to anomalies 26 and 25. Thus, the currently accepted view that Tertiary volcanism in E Greenland began during C24R (Soper *et al.* 1976) now appears to be regionally anomalous, and it is perhaps now the time to re-evaluate the somewhat scanty data set on which this inference was made.

The increased understanding of the stratigraphic development of volcanism in response to the opening of the NE Atlantic might also prove useful in resolving the long-standing debate on the age of the Palaeocene–Eocene boundary, estimated at between 53 Ma (Curry & Odin 1982) and 57.8 Ma (Berggren *et al.* 1985). The sequences on the NE Atlantic borderlands have been, and will continue to be, of key importance in constraining the age of the boundary, and the combination of radiometric and palaeomagnetic studies of the terrestrial sequences with biostratigraphic studies of the volcaniclastics in the sedimentary record will undoubtedly prove invaluable here. The evidence presented in this volume would favour an age of ca. 58 Ma for anomaly 26, considerably younger than the 60.2–60.8 Ma range preferred by Berggren *et al*, but closer to its estimated age on the Curry & Odin timescale.

Summary

In summary, the results of this meeting clearly demonstrate the need to maintain a high degree of deep sampling and deep seismic work, together with integrated trace-element and isotope geochemistry. These approaches have resulted in major advances in understanding of the evolution of the NE Atlantic volcanic passive margin in the last decade, and deserve continued support. More precision is also available with regard to the timing of magmatic activity at the margin, and this has been derived mainly from the interpolation of data from adjacent land studies. Despite this, an integrated model of NE Atlantic margin formation, combining timing and detailed assessment of component volcanic and tectonic events, is still awaited. Until this is achieved, in what can rightly be termed an ideal natural laboratory for the study of volcanic passive margins, the origin and formation of such margins elsewhere will remain unclear.

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References

BERGGREN W. A., KENT D. V. & FLYNN J. J. 1985. Jurassic to Paleogene, part 2. Paleogene geochronology and chronostratigraphy. *In:* SNELLING, N .J. (ed) *The Chronology of the Geological Record.* Memoir of the Geological Society of London, **10**, pp. 141–198.

CURRY D. & ODIN G. S. 1982. Dating of the Palaeogene. *In:* ODIN, G. S. (ed) *Numerical Dating in Stratigraphy, Part 1.* Wiley, London, pp. 607–630.

GROW J. A., HUTCHINSON D. R., KLITGORD K. D., DILLON W. P. & SCHLEE J. S. 1983. Representative multichannel seismic profiles over the US continental margin. *In:* BALLY A. W. (ed) *Seismic expression of structural styles.* American Association of Petroleum Geologists Studies in Geology, **15 (2)**.

NOE-NYGAARD A. 1974. Cenozoic to Recent volcanism in and around the North Atlantic Basin. *In:* NAIRN A. E. M. & STEHLI F. G. (eds) *The Ocean Basins and Margins (Vol. 2).* Plenum Press, New York, pp. 391–443.

SOPER N. J., DOWNIE C., HIGGINS A. C. & COSTA L. I. 1976. Biostratigraphical ages of Tertiary basalts on the East Greenland continental margin and their relationship to plate separation in the Northeast Atlantic. *Earth and Planetary Science Letters*, **32**, 149–157.

THOMPSON R. N. 1982. Magmatism of the British Tertiary Volcanic Province. *Scottish Journal of Geology*, **18**, 49–107.

WHITE R. S. 1987. When continents rift. *Nature*, **327**, 191.

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