Causes and Implications of Excess Breakup Magmatism: Drilling of North Atlantic Volcanic Rifted Margins

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White Paper submitted to the INVEST 2009 workshop, University of Bremen, 23-25.9.09

Abstract
Highly successful drilling of continental break-up related volcanic rocks in the northeast Atlantic was done by the DSDP and ODP programs. However, new borehole data are required to understanding the fundamentals of mantle melting processes and how massive magmatism have caused major climate change in Earth history. The northeast Atlantic conjugate volcanic margins are particularly well-suited for obtaining borehole data useful for understanding both mantle processes and rapid climate change in the initial Eocene, the so-called Paleocene-Eocene Thermal Maximum (PETM).

The northeast Atlantic conjugate passive margins are characterized by extensive rifting and continental break-up related magmatic activity recorded by basalt flows, magmatic underplates, and intrusive complexes. Drilling of the volcanic complexes and nearby sedimentary basins may provide important new insight into mantle melting processes and how magmatism may have caused rapid climate change in the earliest Eocene.

Mantle Melting Processes
The amount of breakup-related magmatism in the northeast Atlantic cannot be explained by passive decompression melting of sub-lithospheric mantle with a normal potential temperature. Three competing end-member hypotheses are proposed for the formation of this excess magmatic activity:

1) excess magmatism results from elevated mantle potential temperatures resulting from mantle plume processes,
2) rifting induced small scale convection at the base of the lithosphere enhances the flux of material through the melt window during rifting and mid-oceanic ridge spreading, and
3) mantle heterogeneities with lower melt temperatures of the melt source may produce larger than expected magmatic productivity.

The mantle plume mechanism is essentially external to the rifting process and coincidence with the rifting process appears fortuitous. Small scale convection on the other hand is inherently connected to and produced by the rifting process. Although in the NE Atlantic we have unsurpassed constraints on conjugate crustal structure between the Norwegian-Jan Mayen-Greenland rifted margins, the relation between rifting and the anomalous excess magmatic productivity is still unresolved.

New constraints on 1) melting conditions, 2) timing of magmatism, 3) spatial and temporal variations, and, 4) eruption environment, are required to resolve the controversy. Systematic conjugate margin drilling is the only way to provide these constraints and will allow the development of a quantitatively testable framework for conjugate volcanic rifted margin formation. The first order questions addressed by the proposed drilling initiative will allow unraveling the distinct end-member models for the formation of excess volcanism during continental breakup (source composition, temperature anomaly related to a mantle plume, small scale convection).

Volcanism Causing Rapid Climate Change
The long-term transition from greenhouse to icehouse conditions during the Paleogene is marked by several profound climate anomalies. Among these is a brief period of global warming that occurred in the initial Eocene epoch, about 56 million years ago (the Paleocene-Eocene Thermal Maximum; PETM). Negative oxygen-isotope excursions in marine and terrestrial sediments, and studies of paleosoil profiles, suggest that the Earth's surface temperature increased by 5-10°C in a geological instant initiating the PETM, and that a warm climate prevailed for about 200,000 years. The climate change coincides with a rapid (~10,000 years) input of large quantities of greenhouse gases to the atmosphere. The mass of carbon released during this event is comparable to estimated future anthropogenic inputs. The study of the PETM may therefore provide important insight into the consequences of future global warming.

The carbon release mechanisms causing the PETM is disputed. We have recently published a new climate hypothesis in Nature (Svensen et al., 2004) that links volcanic activity in the northeast Atlantic to the carbon release and the rapid global warming during the PETM. The key elements of this hypothesis are:

1) intrusive emplacement of magma (molten rock with temperature of 1100^{o}C) into organic-rich sedimentary rocks at 1 to 10 km depth led to the formation of large volumes of greenhouse gases in the baked sedimentary rocks,
2) gas formation caused pressure build-up around the intrusive bodies,
3) the greenhouse gases vented to the atmosphere in explosive gas-eruptions when the pressure increased beyond a threshold value, forming several thousand hydrothermal vent complexes, and
4) mass-balance calculations show that sufficient isotopically light carbon was produced to explain the prominent carbon isotope excursion and global warming during the PETM.

Scientific drilling is required to firmly establish this hypothesis. We propose to drill one or more deep boreholes in the Vøring Basin offshore mid-Norway to accurately determine the relationship between intrusive magmatism, eruption of greenhouse gases, and the PETM. Geochemical and geological analyses of the core material should provide sufficient evidence to determine any causal relationship between intrusive volcanism in organic-rich sediments and the PETM.

Path to Achieve Goals

The initial step to achieve this white paper goal is to have a workshop with the scientists behind IODP applications 658 and 752, which form the basis for this white paper, and other interested scientist. The aim is to improve on the selection of drilling targets, re-evaluate the need for riser drilling, and obtain funding for site survey work.