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Mantle heterogeneity at the Bouvet triple junction based on the composition of olivine phenocrysts

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Abstract

Tholeiitic melts from the Bouvet triple junction (BTJ) of rift zones in the South Atlantic are moderately enriched rocks with specific lithophile-element patterns. The high $(Gd/Yb)_n$ values (up to 2.5) in some tholeiite compositions suggest the presence of garnet in the mantle source of primary BTJ melts. The high Ni and low Mn contents of the most magnesian olivines determined by high-precision probe microanalysis suggest the presence of pyroxenite, along with typical peridotite, in the melting source. The unusually wide within-sample variation in the proportions of pyroxenitic component in the source region (X_{Px} Mn/Fe = 0–90%) indicates different degrees of mantle heterogeneity beneath the spreading zone. Based on geochemical data, this component is a silica-oversaturated eclogite, reacting with peridotite to form olivine-free pyroxenite in the melting source. This component is probably represented either by subducted and recycled oceanic crust or by fragments of the ancient continental lithosphere buried into the mantle after the Gondwana breakup. The observed global and local mantle heterogeneities might have been developed during the complex geodynamic evolution of the Southern Ocean, whose opening was affected by the activity of the Mesozoic Karoo–Maud–Ferrar plume and multiple jumps of the spreading axes, which led to the involvement of fragments of the early oceanic lithosphere in the melting process.

Keywords: mid-ocean ridges; tholeiites; pyroxenitic component; peridotite; primary melts; Bouvet triple junction

Introduction

The opening of the South Atlantic Ocean during the Mesozoic was linked to the magmatic activity of the Parana-Etendeka plume. The effect of this igneous event on the development of oceanic crust was manifested in the formation of seamount groups and submarine rises, e.g., the major Walvis Ridge comprising the Rio Grande and Discovery Rises, and Shona Ridge. Plume activity has a direct influence of the geodynamic evolution of a spreading center along the Southern Mid-Atlantic Ridge (SMAR), which experienced a change in spreading direction during its evolution. The Bouvet triple junction (BTJ), located in the southernmost segment of the Mid-Atlantic Ridge and consisting of three seafloor structures, i.e., the Mid-Atlantic Ridge (MAR), American–Antarctic Ridge (AAR), and African–Antarctic Ridge (AfAR, also known in the western literature as the Southwest Indian Ridge, SWIR), is one the key geological features of the South Atlantic that records the main stages of the growth and reorganization of oceanic spreading zones. According to previous studies (Dickey et al., 1977; Douglass et al., 1995; Le Roex et al., 1982, 1983, 1985, 1992; Ligi et al., 1997, 1999; Peyve et al., 1995; Shilling et al., 1985; Simonov et al., 1996), the oceanic crust-forming process at the Bouvet triple junction was overprinted by plume magmatism related to Bouvet hotspot activity. These conditions were similar to the geotectonic setting of a number of seamounts and submarine rises north of the BTJ, in the Agulhas fault zone (e.g., Discovery, Shona Ridge).

It was found that three spreading ridges experienced a change in their configuration from ridge–ridge–ridge to the ridge–fault–fault during the evolution of the Atlantic Ocean shortly after Gondwana breakup (Dubinin et al., 1999; Le Roex et al., 1982). However, the regional tectonic setting and magmatic activity can be influenced by a change in the stress

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field as well as mantle dynamics of the BTJ segment. Bouvet Island was formed in this region approximately 2.0–2.5 million years ago (Le Roex et al., 1983). The present configuration of the BTJ appears to have remained stable for more than 1 Myr (Kleinrock and Morgan, 1988). The presence of a broad fault zone suggests that the BTJ was affected by ridge jumping and ridge overlapping (Ligi et al., 1997). The westernmost segment of the SWIR (Spiess Ridge) is a large volcanic structure trending SE–NW. The width of the ridge is 50 km; water depths at the foot of the ridge reach 1200–1400 m. The ridge is partially formed by a vast submarine caldera, 3.5–4.0 km in diameter, with flanks reaching about 320 m below sea level. The flanks of the ridge have a secondary crater, 1.0–2.5 km in diameter, reaching 800–900 m below sea level (Ligi et al., 1997). The Spiess Ridge shows a large axial positive magnetic anomaly. Unlike the Spiess Ridge, the SWIR segment located directly opposite Bouvet Island, is a typical slow-spreading ridge segment with a well-developed rift valley. Such a combination of different structures at the same location allows predictions of how geodynamics can influence ocean-floor topography and the character of regional magmatism.

The basalts from the western SWIR are moderately enriched tholeiites (Dickey et al., 1977; Le Roex et al., 1982, 1983, 1985, 1992; Peyve et al., 1995; Shilling et al., 1985; Simonov et al., 1996; Sushchevskaya et al., 1999, 2003).

This study utilizes new high-precision data on olivine and quench glass compositions to characterize magmatism and the nature of the enriched component in parental magmas from the Bouvet triple junction area. Our study aims to identify the main stages of the tectonic and magmatic evolution of the lithosphere of the Southern Ocean at the BTJ, using new and literature data.

Analytical methods

Locations of the dredges are shown in Fig. 1. Tholeiitic basalts were dredged during cruise S18 (dredge symbol S18) of the R/V Akademic Nikolai Strakhov and during cruise G96 of the R/V Gelendzhik-96 (G96). Rocks were dredged at 20 stations located on two main structures of the BTJ: directly opposite Bouvet Island (SWIR segment) and on the Spiess Ridge. The samples dredged are fragments of pillow lavas with well-preserved surficial quench features. Coordinates of the dredges are given in Table 1.

More than 500 olivine phenocrysts from tholeiitic basalts dredged from the BTJ area were analyzed by ion mass spectrometry on a CAMECA IMS3f microprobe at the Max Planck Institute for Chemistry (Mainz, Germany) using a 12.5 kV O^- primary ion beam, with a secondary voltage of 4.5 kV, an offset of –80 V, and a primary beam current

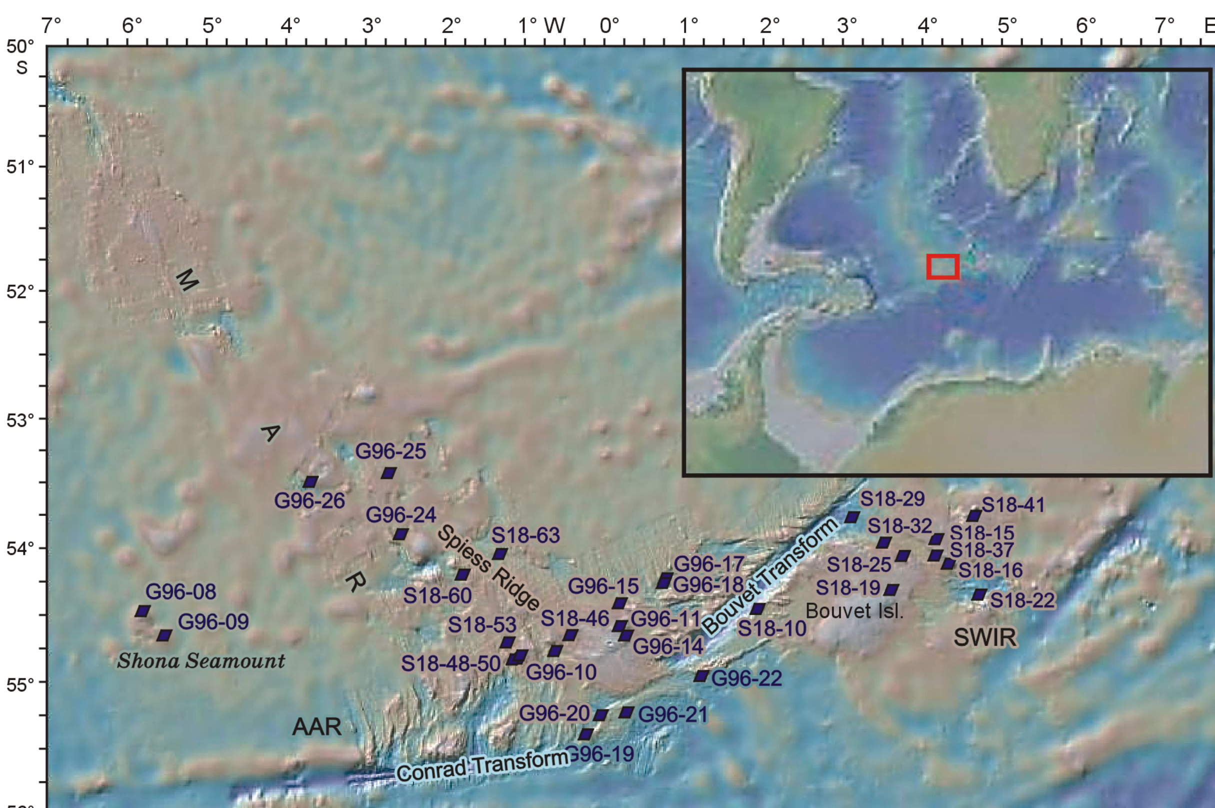

Fig. 1. Bathymetry map of the Bouvet triple junction area. Symbols indicate the location of stations dredged during cruise S18 of the R/V Akademik Strakhov and cruise G96 of the R/V Gelendzhik (G96) (Peyve et al., 1999).