paragenesis carried by kimberlites range from 900° to 1400°C, with most falling in the range 900° to 1100°C (*22*). The latter range is similar to our H_2O-saturated solidus temperature. Therefore, we suggest that kimberlites may have been produced by H_2O-rich fluid supplied to relatively cold subcontinental mantle at depths of 150 to 300 km.

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Death and Transfiguration of a Triple Junction in the South Atlantic

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Three major lithospheric plates—Antarctic, South American, and African—meet in the South Atlantic near Bouvet Island where the Mid-Atlantic Ridge (MAR), the Southwest Indian Ridge (SWIR), and the American Antarctic Ridge converge toward a fast evolving triple junction. A major magmatic pulse has recently built a new, swollen segment of the SWIR (Spiess Ridge) that is propagating toward the MAR at a rate of 4 to 5 centimeters per year, disrupting a former ridge-ridge-ridge (RRR) triple junction. A new triple junction will be established about 70 kilometers to the north when the propagating SWIR/Spiess segment will impact with the MAR, probably within the next 1 million years. The American Antarctic Ridge will take advantage of the MAR/SWIR duel by capturing an approximately 70-kilometer stretch of MAR, whereas the Antarctic plate will increase its size.

The few areas on Earth where three major lithospheric plates meet are characterized by complex, poorly understood interactions of the plate boundaries. The MAR, SWIR, and American Antarctic Ridge (AAR) converge in a triple junction (TJ) located in the Bouvet region (Fig. 1) of the South Atlantic (*1–4*). The Bouvet TJ has been interpreted as having a ridge-transform-transform (RFF) configuration (*5*) that has prevailed during most of the last 20 million years (My) (*3*, *4*). Spreading half-rates estimated for the last few million years are 1.6 cm/year for MAR, 0.8 cm/year for SWIR, and 0.9 cm/year for AAR (*3*). The Bouvet TJ region is affected by one or more mantle plumes or hot spots. Bouvet Island marks the position of a plume (*6*) that may have influenced the structure and composition of the westernmost SWIR and easternmost AAR (*7*). The southernmost MAR may have been affected by the hypothetical Shona and Discovery plumes (*7–9*). We discuss the fast evolving geometry of the TJ and the extent to which mantle melting anomalies may affect this evolution.

High-resolution morphobathymetric and magnetometric coverage of the entire TJ region (Fig. 2) shows that the three accretionary plate boundaries converging toward the TJ are affected by ridge jumping, ridge overlapping, and ridge propagation (*10*), processes characteristic of fast spreading ridges but rare in slow spreading ridges. We obtained images of overlapping ridge segments (*11*) in the southernmost MAR, whereas ridge propagation is particularly clear in the westernmost SWIR (Spiess Ridge) segment (Fig. 2). This unstable geometry of the plate boundaries probably derives from the complex and variable distribution of stresses in the region arising from the interaction of three major plates. Another factor, valid at least for the MAR and SWIR, is that the rate of magma supply from the mantle is high relative to the spreading rate. Strong magmatic pulses may have triggered ridge propagation and jumping as well as the formation of an abnormally thick crust.

A thicker than normal crust is suggested by the abnormally shallow (by more than 1 km) axial topography of the SWIR segment adjacent to Bouvet Island and of the westernmost SWIR/Spiess Ridge segment. The Na-poor, H_2O- and light rare earth element–enriched composition of mid-ocean ridge basalt is consistent with the notion that hot spots influence both these SWIR segments (*7–9*, *12*). Stretches of MAR between the Agulhas fracture zone at 48°S and 53°S are abnormally shallow and contain enriched mid-ocean ridge basalt with high $^3He/^4He$ ratio. These anomalies were attributed to the influence of the Discovery and Shona hot spots (*7*, *8*). The MAR south of 53°S is also marked by an anomalously shallow topography. These depth anomalies, and the inferred abnormally thick

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crust and excess magma supply, support the hypothesis that positive mantle thermal anomalies are widespread below the Bouvet TJ region. This hotter than normal mantle may have influenced the evolution of the TJ. Other TJs are also close to hot spots; however, the Rodriguez TJ in the Indian Ocean does not appear to be associated with an unusually hot upper mantle (*13*).

The MAR axial valley bifurcates at its southern tip in two branches (Fig. 2), one oriented north-south (branch X in Fig. 2B), and the other northwest-southeast (branch Y), each forming a ~35° angle with the trend of the MAR. Both branches show a positive magnetic anomaly and have high sea-floor acoustic reflectivity, implying that they are (or were until recently) segments of crustal accretion. We propose that this configuration marks a RRR TJ (TJ-2 in Figs. 2B and 3) located where the two branches bifurcate at 54°43′S, 00°47′W (Fig. 2). The maximum distance between the two branches south of TJ-2 is about 33 km. This implies a maximum age of ~2 My for the TJ-2 configuration if we assume symmetric spreading at 0.8 cm/year (SWIR branch) and 0.9 cm/year (AAR branch). TJ-2 probably replaced a former RFF configuration (TJ-1 in the inset of Fig. 3) at about 2 Ma (million years ago).

We suggest, however, that TJ-2 has ceased to be active roughly 1 Ma, because the geometry of the plate boundaries had been disrupted then by a new anomalous branch of the SWIR, the Spiess Ridge. Spiess Ridge has been described as a broad, short ridge or as a large volcanic seamount (*3*, *4*, *14*). Our multibeam surveys indicate that it is a large volcanic system elongated southeast-northwest (Fig. 2A). Its summit rises to 320 m below sea level from a base roughly 50 km wide at 2000 m below sea level; it has a ~450 m deep central caldera 3.5 to 4 km in diameter. Spiess Ridge narrows and deepens to the northwest; it has a strong axial positive magnetic anomaly and V-shaped anomalies on its flanks (Fig. 2B), suggesting that the ridge has propagated to the northwest (*15*). The strong magnetic anomaly at the tip of the propagating ridge may reflect the presence there of ferrobasalts (*16*), as has been observed at the tip of other propagating ridges (*17*). We estimate that the rate of propagation w is 4 to 5 cm/year from the expression $w = 2u/\tan\beta$ (*18*), where u is the half spreading rate (in our case, 0.8 cm/year), and β is the angle (~20°) between the direction of the spreading axis and the direction of the isochron magnetic anomaly formed between the propagating ridge pseudofault and the dying ridge (Fig. 3).

Knowing the rate of propagation, the location of the propagator's tip (roughly 54°25′S, 0°32′W; Fig. 2), and the location of the source of the propagator (assumed to be at the site of minimum depth of the volcanic system where igneous injection has been maximal, roughly 50 km southeast of the propagating tip), we estimate that propagation started roughly 1 Ma. We assume that the igneous event that gave rise to the new SWIR segment started shortly before, consistent with the observation that the oldest magnetic anomaly produced by Spiess Ridge (Fig. 2B)

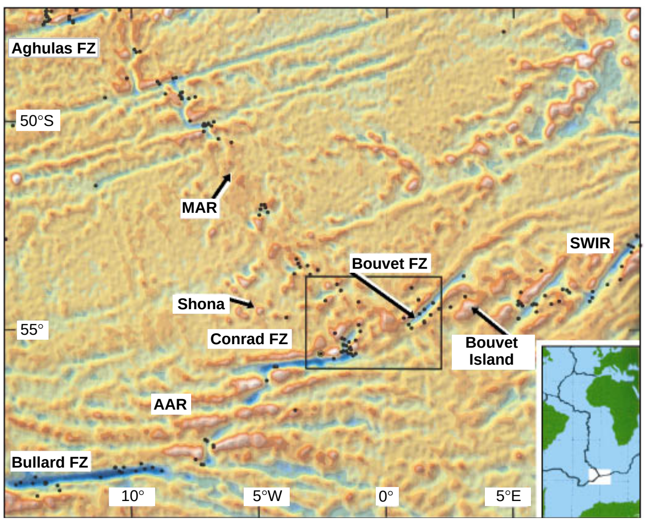

Fig. 1. Free-air gravity imagery of the Bouvet TJ region derived from satellite altimetry, version 7.2, processed by Sandwell and Smith (*1*). The dots indicate the location of earthquake epicenters (magnitude >3). The source of the data is the National Geophysical Data Center. Identification of some of the relevant features is superimposed. Superimposed is also a line limiting the area shown in Fig. 2. FZ, fracture zone.

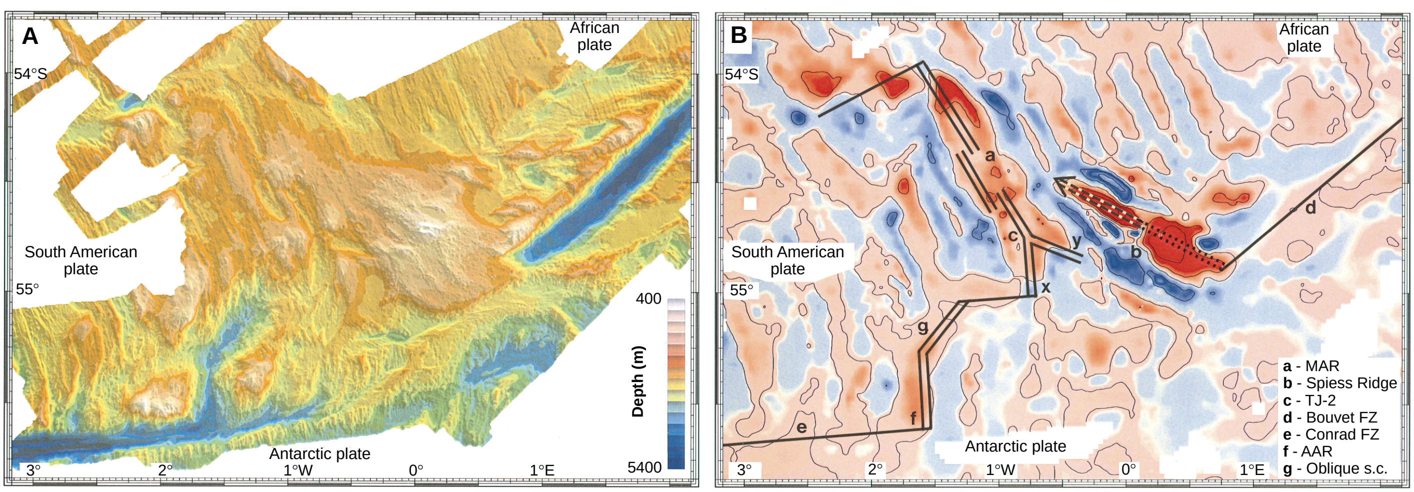

Fig. 2. (**A**) Shaded-relief morphostructural image of the Bouvet TJ region, based on 100% multibeam coverage of the area. Roughly 80% of the displayed region was surveyed in 1996 from the R/V *Gelendzhik* with a Simrad EM 12-120S, 81-beams multibeam. The rest had been surveyed in 1994 from the R/V *Strakhov* with a Finnyards ECHOS 625, 15-beams multibeam. Navigation in both expeditions was by global positioning system. Some of the morphostructural features are identified in (B). Note Spiess Ridge with a central caldera on the summit of a broad, thick volcanic system that becomes narrower and deeper toward the northwest. (**B**) Distribution of magnetic anomalies in the same region. Red indicates positive anomalies, blue negative anomalies, contour interval is 500 nT. Data were obtained with GEM model GSM 19D magnetometers. An interpretation of present-day distribution of plate boundaries is superimposed. Double line, accretionary boundaries; single line, transform boundaries; dashed line and dotted arrowed double line, Spiess Ridge, a new accretionary boundary in the making, which is propagating toward the northwest. Spreading center is indicated by s.c.

appears to be within the Matuyama epoch.

The anomalous vertical growth of the SWIR/Spiess Ridge, and its consequent rapid propagation, could be due to an unusually high rate of magma supply relative to the low (0.8 cm/year) spreading rate. When spreading cannot keep up with an overabundant magma supply, the basaltic crust tends to thicken (*19*). It is not clear whether the Spiess event is the surface expression of a new mantle plume, or of a branch of the Bouvet plume, or of a melting anomaly unrelated to a deep, plume-like source.

The igneous emplacement of the Spiess Ridge and its northwest propagation have disrupted the RRR geometry of TJ-2, flooding the western part of the Bouvet transform, thereby isolating the SWIR Y branch (Fig. 3). As a result, the SWIR Y segment is a dying ridge and TJ-2 has ceased to be a TJ. We conclude, therefore, that the Antarctic, South American, and African plates do not meet at present in a triple point, but in a broad zone of diffuse deformation.

If the new SWIR-Spiess segment continues its northwest propagation at the present rate, within about 1 My it will impact with the MAR at about 54°15′S, 1°15′W. This will be the site of a new TJ (TJ-3 in Fig. 3). The ~70-km-long stretch of MAR between TJ-2 and TJ-3 will probably become part of the AAR, the MAR will recede northward, and the area of the Antarctic plate will increase. Thus, we have caught the plate boundaries in the transition between two different configurations, and we have obtained a snapshot of the recent death of a TJ and the imminent birth of a new one.

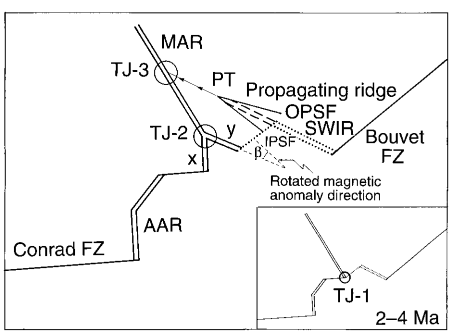

Fig. 3. Scheme outlining the evolution of the Bouvet TJ from 4 Ma to present, including a predicted configuration about 1 My in the future. The inset at lower right shows a suggested configuration valid between about 4 and 2 Ma, with a RFF-type TJ (TJ-1). The main figure illustrates a configuration valid between about 2 and 1 Ma, with a RRR-type TJ (TJ-2). The present configuration implies that TJ-2 is inactive because the SWIR-Spiess propagating ridge has disrupted the TJ-2 configuration. PT, tip of the Spiess propagating ridge; IPSF, inner pseudofault; OPSF, outer pseudofault. For significance of angle β, see text. Also shown is a predicted future configuration, with a RRR-type TJ (TJ-3) to be established within the forthcoming ~1 My.

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Activated Acetic Acid by Carbon Fixation on (Fe,Ni)S Under Primordial Conditions

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In experiments modeling the reactions of the reductive acetyl–coenzyme A pathway at hydrothermal temperatures, it was found that an aqueous slurry of coprecipitated NiS and FeS converted CO and CH_3SH into the activated thioester CH_3-CO-SCH_3, which hydrolyzed to acetic acid. In the presence of aniline, acetanilide was formed. When NiS-FeS was modified with catalytic amounts of selenium, acetic acid and CH_3SH were formed from CO and H_2S alone. The reaction can be considered as the primordial initiation reaction for a chemoautotrophic origin of life.

The origin of life requires the formation of carbon-carbon bonds under primordial conditions. Miller's experiments (*1*), in which simulating electric discharges in a reducing atmosphere of CH_4, NH_3, and H_2O produced an aqueous solution of simple carboxylic acids and amino acids, have long been considered as one of the main pillars of the theory of a heterotrophic origin of life in a prebiotic broth. Their prebiotic significance, however, is in question, because it is now thought that the primordial atmosphere consisted mostly of an unproductive mixture of CO_2, N_2, and H_2O, with only traces of molecular hydrogen (*2*).

An alternative theory is that life had a chemoautotrophic origin (*3–6*). This theory comprises several independent but complementary postulates regarding the metabolism of the primordial organisms: (i) The earliest organisms fed on CO or CO_2 at volcanic or hydrothermal sites. (ii) Their metabolism was initiated by the reductive formation of methyl mercaptan (methanethiol, CH_3SH) and its subsequent carbonylation to activated thioacetic acid (CH_3-CO-SH), akin to the reductive acetyl–coenzyme A (CoA) pathway (*5*). (iii) CH_3-CO-SH was fed into a carbon fixation cycle, akin to the extant reductive citric acid cycle (*5*). (iv) The metabolism received reducing power from the oxidative formation of pyrite from iron sulfide and hydrogen sulfide (*3*). (v) All chemical conversions of the primordial metabolism occurred in a ligand sphere, held together by bonding to the surfaces of iron-sulfur minerals (*4*), where transition metal ions such as Ni^{2+} or Co^{2+} or Se are catalytically active (*5, 6*). (vi) Subsequent evolutionary steps included the replacement of thioacids by thioesters and the conversion of at first wasteful branch products (like amino acids) into biocatalysts. These steps represent a dual feedback into the carbon fixation pathways

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