Scientific Drilling in the South Atlantic: Rio Grande Rise, Walvis Ridge and surrounding areas

Rio de Janeiro, April 2-5, 2014

Report by William W. Sager

Executive Summary

A workshop was held in Rio de Janeiro, Brazil on April 2-5, 2014 to discuss scientific drilling in the South Atlantic Ocean, especially related to large igneous provinces (Rio Grande Rise and Walvis Ridge) and surrounding continental margins. It was a collaborative effort amongst Brazilian, German, French, and US scientists with 68 attendees. After keynote addresses on IODP drilling and proposal evaluation procedures, South Atlantic geology, tectonics, and continental margins, workshop participants broke into focus groups concerning the Rio Grande Rise, Walvis Ridge, and São Paolo Plateau (Brazilian continental margin), the three areas of greatest interest. Focus groups reported their deliberations and proposal teams were developed for each of these areas. Based on meeting discussions, it was decided that sufficient interest exists for three separate proposals: (1) Rio Grande Rise, (2) Walvis Ridge, and (3) São Paulo Plateau. Proponent teams were formed. Subsequent to the workshop, pre-proposals were developed for Rio Grande Rise and Walvis Ridge and submitted for the 1 October 2014 proposal deadline.

Introduction

During late 2013, a proposal was submitted to Consortium for Ocean Leadership to support US participation in a workshop on South Atlantic drilling with a focus on Rio Grande Rise (RGR) and Walvis Ridge (WR) large igneous provinces (LIPs). Precipitating factors were the interest expressed by IODP oversight panels in moving the JOIDES Resolution into the Atlantic in coming years and a groundswell of interest in the RGR and WR among scientists in North America, Europe, and South America, as well as a call by USSSP for South Atlantic workshop proposals. The first steps to organizing the workshop were taken by members of the Geological Survey of Brazil (CPRM), Brazilian Institute of Marine Sciences (UNESP), Petrobras, and several German universities. US investigators joined the effort and Consortium for Ocean Leadership sponsored a small contingent of 8 US scientists to participate. Rio de Janeiro was selected as a meeting site at the invitation of the Brazilian scientists, in recognition of Brazil's recent enrollment as a member in IODP. The workshop was held at the Windsor Plaza Copacabana Hotel near Copacabana beach in Rio de Janeiro, on April 2-5, 2014.

Scientific Motivation

Following the opening of the southern North Atlantic, West Gondwana broke up during the Early Cretaceous (Macdonald et al., 2003). Subsequent seafloor spreading resulted in the formation of the South Atlantic Ocean, opening from S to N like a zipper (e.g. Jackson et al., 2000; Franke et al., 2013). In the nascent South Atlantic basin, intermittent physical barriers at the location where the RGR and WR are today controlled the deposition of Upper Jurassic-Cretaceous anoxic sediments (Macdonald *et al.*, 2003). During the late rift and post-rift phases, further extension led to the development of basins parallel to the margins of the South Atlantic. Widespread development of unconformities and the extensive deposition of evaporites can only be observed in the basins north of the RGR/WR. Today, the South Atlantic passive continental margin comprises several basins and subbasins with variable geological evolution. With the full opening of the South Atlantic, both terrigenous and biogenic sedimentary processes have been influenced by the evolving oceanic circulation (e.g. Gruetzner et al., 2011, 2012; Hernández-Molina et al., 2010; Uenzelmann-Neben, 1998; Uenzelmann-Neben and Miller, 2003).

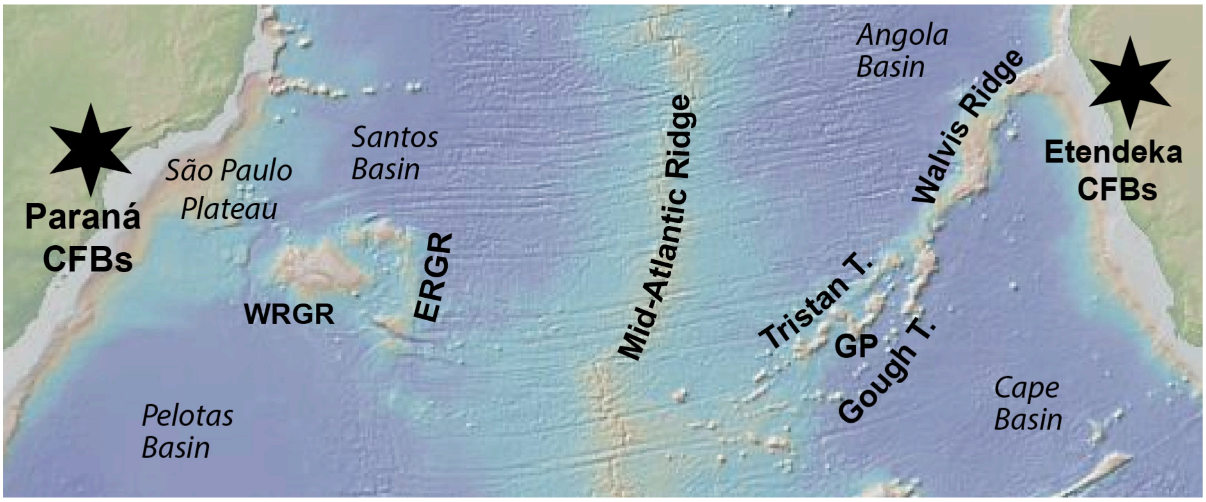

Fig.1: Overview of the central South Atlantic showing the Western and Eastern Rio Grande Rise (WRGR, ERGR), the Walvis Ridge and the Guyot Province (GP) with the Tristan and Gough seamount tracks. Locations of Paraná and Etendeka continental flood basalts (CFBs) indicated by black stars. Modified after Rohde et al. 2013. Map source: GeoMapAppp (http:/www.geomapapp.org).

The South Atlantic is considered a classic example of the correlation between continental breakup and magmatic events, resulting in conjugate large igneous provinces. The magmatism comprises thick sequences of seaward-dipping reflectors on both sides of the south Atlantic and the voluminous Paraná-Etendeka flood basalt provinces in Brazil and Namibia, respectively (e.g. Jackson et al., 2000). Magmatism is commonly linked to the Tristan-Gough hot spot, whose initial "plume head" stage created the Paraná-Etendeka basalts during the Mid-Cretaceous, followed by the "plume tail" forming the RGR and WR at the Mid-Atlantic Ridge as the South Atlantic opened (e.g., Morgan, 1971, Wilson, 1963) (Fig. 1). During the Maastrichtian, ~60 Ma, the orientation of spreading changed, as seen by the change of orientation of the Walvis Ridge, and the spreading axis began to migrate westward, away from the hotspot (Franke, 2013). The sparse data available from the RGR suggest a termination of the volcanism in the area of the RGR. Magmatism seems to have continued solely in the WR on the African plate. At <60 Ma, plume volcanism bifurcated into two separate tracks, the Tristan and Gough seamount chains (O'Connor and Duncan, 1990; Rohde et al. 2013).

With >130 Myr long activity and linkage of an age-progressive hotspot track with a flood basalt province, the WR hotspot track is one of the rare examples meeting the characteristics of a deep mantle plume (Courtillot at al., 2003). However, a radically different view of the origin of flood basalts and intraplate seamount chains explains the volcanism by shallow level processes, for example by spreading centers crossing particular fertile upper mantle regions, propagating cracks in the lithosphere or shallow mantle convection (e.g. Anderson, 2000; Foulger et al. 2005; Foulger, 2007). What is more, recent evidence from both the RGR and WR is inconsistent with the simple hotspot models that have been widely accepted for decades. Therefore, the debate over whether this volcanism originated by shallow (plate tectonic-related) processes or by deep-seated plumes originating in the lower mantle is not yet resolved, but is critical to our understanding of solid earth cycles, mantle convection and plate motion. Testing these hypotheses requires accurate age information for the onset and duration of flood basalt formation and for seamount chain volcanism correlated with variations in crustal thickness and seafloor age. Although previous work has documented age-progressive volcanism along parts of the Walvis Ridge (O'Connor & Duncan 1990, O'Connor & le Roex, 1992, O'Connor et al., 2012; Rohde et al., 2013) it's western Atlantic counterpart, the Rio Grande Rise, remains largely unexplored.

Specific background on the RGR and WR and overview of previous work

The RGR represents the largest bathymetric feature on the oceanic part of the South American plate and separates the Santos Basin in the north from the Pelotas Basin in the south. It is composed of two areas with distinct morphologies and geological histories (Gamboa and Rabinowitz, 1984). The western Rio Grande Rise (WRGR) forms a widespread bulge that rises to a mean depth of ~2000 mbsl. Numerous guyots and seamounts tower over this platform. The eastern part of the Rio Grande Rise (ERGR) has a north-south trend, parallel to the present Mid-Atlantic Ridge, is bounded by fracture zones, and may represent an abandoned spreading center (Gamboa and Rabinowitz, 1984). Four DSDP sites were drilled on the RGR (Maxwell, von Herzen et al., 1970, Supko, Perch-Nielsen et al., 1977; Barker, Carlson et al., 1981) but only one site, Hole 516F near the center of the WRGR, was continuously cored and reached the igneous basement. The basement at this site consists of tholeiitic basalt (characteristic of transitional mid-ocean ridge basalt and similar to the Parana-Etendeka flood basalts and Walvis Ridge) with a recently determined age of 80-87 Ma (Rohde et al., 2013). This age is in agreement with the age predicted for the oceanic crust for this region based on magnetic anomalies, supporting the model that the WRGR formed at or close to a spreading center (Gamboa & Rabinowitz, 1984; O'Connor & Duncan, 1990; Mohriak et al., 2010). Furthermore, this age coincides with the intrusion ages of most of the onshore alkaline intrusions (e.g. the Pocos de Calda region). In contrast, rocks dredged from the guyots protruding from this platform have alkali-basaltic composition as characteristic for intra-plate ocean island basalts (Fodor et al. 1977) and one of these samples was $^{40}Ar/^{39}Ar$ dated at only 46 Ma (Rohde et al., 2013). This result, and the occurrence of ash layers and volcanic breccia in Middle Eocene sediments in drill cores at Sites 516 and 357, indicates that a widespread volcanic-tectonic event affected the WRGR region during the Eocene. This event coincides with the formation of the transtensional Taubaté basin onshore and the formation of alkaline volcanic rocks in the area of Rio de Janeiro and within the Eocene sequence of the Santos and Campos Basins. Parts of the WRGR plateau were uplifted above sea level and several short-lived volcanic islands were created, which were later submerged as the plateau subsided (Gamboa & Rabinowitz, 1984; Mohriak et al., 2010). The different geochemical composition of the seamounts compared to the plateau must be caused by changes in the degree and depth of mantle melting, and/or the composition/origin of the mantle source. After subsidence, pelagic sedimentation prevailed again over the entire region. Much less is known about the ERGR, which is separated from the WRGR by a deep abyssal plain (Fig. 1). No dredge or drill samples exist from this feature.

Like the RGR, WR is a prominent bathymetric feature, but on the east side of the South Atlantic, on African plate oceanic crust. It is one of the few examples of a hotspot seamount chain that stretches from a flood basalt province on land (Etendka) to an active hotspot (e.g., Duncan et al., 1981; Morgan, 1981; Duncan and O'Connor, 1990). Furthermore, as one of the most continuous hotspot chains on the African plate, and one with many radiometric age determinations, it is a major constraint of modeled motion of the African plate relative to the hotspots. Africa itself, owing to its central position in the Gondwana continent assembly, is frequently used to determine the motion of other plates relative to the hotspots using relative motions between Africa and surrounding plates. In addition, the Tristan-Gough hotspot is considered one of the few of Earth's "primary" hotspots (i.e., likely to be a hotspot from the deep mantle; Courtillot et al., 2003) Thus, the WR is one of the most important hotspot trails on Earth.

Despite the importance of WR in the global hotspot reference frame and its implications as an archetypical hotspot, the origin and evolution of the WR is less certain than ever. Morphologic changes along the ridge, especially the change mid-way along its length from a large single ridge to a profusion of smaller seamounts that trace to two active volcanoes separated by ~400 km (Tristan and Gough islands), do not easily fit a single hotspot (O'Connor and Le Roex, 1992). What is more, early radiometric dates are thought to be unreliable (Baksi et al., 1999) and recent results indicate discrepancies. Ages from nearby hotspot seamount trails imply significant changes in African plate motion relative to the hotspots as well as a discrepancy in the measured age of the Entendeka flood basalt and that predicted by the hotspot model (O'Connor et al., 1999). In addition, new ages from WR indicate a significantly higher volcanic propagation rate compared with prior models (Rohde et al., 2013). In short, the hotspot model for WR requires new data and additional work.

Whereas it was formerly thought that the RGR formed together with the WR while the Tristan-Gough plume-hotspot was located on or near the Mid-Atlantic spreading ridge (e.g. O'Connor & Duncan, 1990) and that volcanism ceased thereafter, new age determinations from Rhode et al. (2013) show that a second, much younger volcanic pulse built seamounts atop RGR. This second stage is not explained by current plume or non-plume models. In addition, in May 2013, a Brazilian-Japanese expedition with the Japanese Shinkai 6500 submersible recovered granitic and gneissic rocks from the wall of rift structures on the WRGR (Eugénio Pires Frazão, CPRM - Geological Survey of Brazil, personal communication). A dredging expedition by the CPRM in 2011 had already brought up pieces of granite and gneisses at this location, but at that time it was thought that it was probably by some mistake or accident (e.g. ballast stones). The recovery of *in situ* granitic and metamorphic rocks at the RGR possibly indicates that some parts (of unknown extent) of the RGR were not formed as a basaltic oceanic plateau, but include fragments of continental crust. During continental rifting, fragments of material from the continental margins may be detached and surrounded by oceanic crust, as 'microcontinents' in the ocean basins. Seismic studies and drilling results have shown that the Kerguelen Plateau in the Indian Ocean is underlain at least in part by continental crust (Operto and Charvis, 1995; Gladczenko & Coffin, 2001; Frey et al. 2003). Since the RGR and Kerguelen Plateau, as well as the Jan Mayen 'microcontinent' are associated with hotspots this suggests that deep mantle plumes may play a role in microcontinent formation by weakening the local lithosphere prior to breakup. Alternatively, detachment of continental material during breakup may control the location and composition of subsequent intraplate volcanism (e.g. Regelous et al., 2010).

Very little is currently known about the existence of other microcontinents buried in hotspot trails largely because they are covered by thick accumulations of younger lavas and sediments. The RGR offers, therefore, a unique area to investigate a hotspot-influenced sliver of continental crust, because continental and basaltic rocks are exposed in the walls of rift structures (Frazão et al. in prep.). New seismic reflection data, obtained by Brazilian scientists, can help to locate the transitions between continental and volcanic basement and carefully placed new basement drilling at such locations on the WRGR (and first-time, reference drilling on the ERGR) can provide constraints on the composition and distribution of continental and oceanic basement and South Atlantic rifting history. Moreover, the pairing of the RGR with the largest part of WR implies that continental material may be found there as well.

Workshop Motivation

This workshop was developed in response to a USSSP call to submit workshop proposals to identify drilling targets/objectives in (among other areas) the southern Atlantic. Compared to other major ocean basins, the South Atlantic, in particular its southwestern and central sectors, is sparsely sampled by ocean drilling. These portions of the ocean were last drilled during DSDP times, comprising the legendary Leg 3 (which proved seafloor spreading by drilling a crustal age transect perpendicular to the South Atlantic spreading axis), Leg 39 (which drilled sites on WR and RGR on a transit across the South Atlantic), and Legs 71-75 (devoted to study the late Mesozoic and Cenozoic paleoenvironments in the South Atlantic, including drilling on the Walvis Ridge and RGR). Since that time, South Atlantic drilling has focused on paleoclimate (e.g., ODP Leg 208 which drilled WR), rather than questions about the origins of the underlying igneous crust. In the subsequent decades, major improvements in drilling, logging, borehole monitoring, and site surveying technologies have occurred, positioning the IODP to make significant contributions to knowledge of South Atlantic tectonics and geodynamics. In addition, renewed sediment drilling in the South Atlantic can address fundamental questions about basin evolution and past climate, including those detailed in the new IODP science plan "Illuminating Earth's Past, Present, and Future". For example, off southwest Africa, the Agulhas leakage (the flow of warm, salty Indian Ocean water into the Atlantic Ocean) is an important element of global ocean circulation and has particular impact on the Atlantic circulation and the Gulf Stream system. Sediments from strategically selected sites in the south Atlantic may allow reconstruction of past ocean circulation patterns and temperature distribution including changes in biogeochemical cycles (addressing the research theme "Climate and Ocean Change" of the Science Plan). In that respect, the workshop complements the IODP workshop in support of the existing drilling proposal "Paleoceanography of the Brazilian Equatorial Margin (BEM)" that was held in

February 2014. The BEM workshop, however, focuses solely on paleoceanographic aspects in the equatorial latitudes.

Whereas Earth's Deep Biosphere was explored by dedicated expeditions in the South Pacific (ODP Leg 201; IODP Exp. 329), North Pacific Ocean (IODP Exp. 337) and North Atlantic (IODP Exp. 307, 336), no subseafloor life has been investigated by drilling in the South Atlantic, hampering understanding of global geographic and evolutionary relationships between microbial communities (addressing "Biosphere Frontiers"). Thus, the South Atlantic is an obvious gap in global deep biosphere sampling. We believe that the South Atlantic provides numerous valuable objectives/targets for scientific drilling that cross multiple disciplines of Earth sciences and the proposed workshop shall help to identify them.

The dominant feature in the West Atlantic, the RGR, is largely unexplored and even though some shallow drilling has occurred on WR, it is poorly sampled. Do the RGR and WR really represent classical, large igneous provinces? What constraints can be achieved by drilling regarding their emplacement (duration, single or multiple phases of emplacement), environmental impact and relationship to seafloor spreading and the continental Parana/Etendeka volcanism and the Tristan/Gough hotspot system (addressing "Earth Connections", Challenge 8&9). Does the WRGR rather represent a "microcontinent" composed largely of continental crust intersected and buried by basaltic lava? In addition, drilling long basement cores (with many igneous flow units) of the WR and RGR will allow scientists to measure the paleolatitude record for comparision with results from IODP Expedition 330, which constrained the paleolatitude of the Louisville hotspot and improved Pacific Plate motion reconstructions (Koppers et al., 2012), the longstanding problem of true polar wander can be addressed. In conclusion, the primary goal of the workshop was to bring Brazilian and international researchers together with other international participants to discuss options, prospects and potential sites of future IODP drilling in the South Atlantic and in particular on RGR/WR and to identify a team for writing or revising drilling proposals.

Meeting Recap

Day 1: Plenary Session

- Introduction of host(s) and participants,
- Jörg Geldmacher – IODP: From Ocean Drilling to the new International Ocean Discovery Program
- Clive Neal – Writing and submitting a drilling proposal and how it is reviewed
- Kaj Hoernle – Temporal and geochemical evolution of the Tristan-Gough hotspot
- Cornelia Class – Plume source regions in the south Atlantic
- Monica Neilbron – Geology and geoctectonics of southeastern Brazil
- Gianreto Manatschal – Hyper-extended margins in the south Atlantic
- Lorenzo Colli – Rapid spreading variations in the south Atlantic: Observations and geodynamic implications
- Renata Schmitt – The Gondwana lithosphere and the South American breakup

- Ulrich Glasmacher – Long-term landscape evolution of the Brazilian and Namibian passive margins and links to post-rift ocean floor dynamics
- Victor Sacek – Upper mantle viscosity and dynamic subsidence of curved continental margins
- John O'Connor – Plume and plate controlled hotspot trails in the south Atlantic
- Sebastian Kollenz – Long-term landscape evolution of the passive continental margins in eastern Argentina and Uruguay based on low-temperature thermochronology and links to offshore basin evolution
- Ricardo Trinidade – Rock magnetism and paleomagnetism
- Karsten Haase – The influence of mantle plumes on continental rifting
- Juliano Magalhães Stica – Evolution of rifting on the volcanic margin of the Pelotas Basin
- Marcel Regelous – Magmatism and magmatic evolution during continental breakup in the south Atlantic
- Concluding remarks

Day 2: Additional Plenary talks and discussion

- Luciano Magnavita – The southeastern Brazilian margin: Constraints on the evolution of the São Paulo Plateau
- Roberto Ventura Santos – New geological findings on the Rio Grande Rise
- William Sager – Drilling on Walvis Ridge
- Walvis Ridge proposal discussion
- São Paulo Plateau proposal discussion
- Rio Grande Rise proposal discussion
- Focus group discussions

Day 3: Proposal Discussions

- Focus group discussions
- Summary and dismissal

Participants

The workshop brought together scientists from the entire spectrum of disciplines interested in drilling targets in the South Atlantic, not just the RGR and WR. However, the RGR and WR were chosen as "anchor" problems since the proponents know that wide interest exists in drilling these features in light of the new research results. Thus the meeting attendance was skewed towards scientists interested in RGR and WR. Participation of scientists from other disciplines was encouraged to provide the meeting with different viewpoints and science expertise. By holding the meeting in Brazil, it was possible for a large number of scientists from that nation to attend the workshop. USSSP funding allowed 8 US participants to attend the meeting.

Alphabetical list of workshop participants (bold=USSSP funded participant)

Julio Almeida	UERJ	Brazil
Ana Angélica Ligiero Alberoni		Brazil
Roberto Agular Alves	CPRM	Brazil
Mitsuru Arai	Petrobras	Brazil
Adolpho Augustin	PUCRS/CEPAC	Brazil
Isabella Carmo	Petrobras	Brazil
Cornelia Class	Lamont Doherty Earth Observatory	USA
Lorenzo Colli	LMU	Brazil
Luiz Carlos da Silva	CPRM	Brazil

Ricardo Ivan Ferreira da Trinidade	IAG USP	Brazil
Elton Luis Dantas	UnB	Brazil
Daniel Françoso de Godoy	UNESP	Brazil
Iata Anderson de Souza	UNESP	Brazil
Nolan Dehler	UFRJ	Brazil
Débora Faller		Germany
Laura Valadares Fonseca	CPRM	Brazil
Sérgio Luis Fontes	OBS Nacional	Brazil
Eugenio Pires Frazao	CPRM	Brazil
Joao Batista Freitas	CPRM	Brazil
Jörg Geldmacher	GEOMAR	Germany
Ulrich A. Glasmacher	University Heidelberg	Germany
Peter C. Hackspacher	UNESP	Brazil
Barry Hannan	San Diego State University	USA
Vadim Harlamov	CPRM	Brazil
Karsten M. Hasse	University Erlangen	Germany
Roberto Heemann	PUCRS/CEPAC	Brazil
Monica Heilbron	UERJ	Brazil
Kaj Hoernle	GEOMAR	Germany
Izabel King Jack	Marinha do Brasil	Brazil
Luigi Jovane	USP	Brazil
Joao Marcelo Ketzer	PUCRS	Brazil
Sebastian Kollenz	University Heidelberg	Germany
Patrick Korner	University Heidelberg	Brazil
Renato Kowsmann	Petrobras	Brazil
Christian Lacasse	CPRM	Brazil
Maria Aline Lisniowski	CPRM	Brazil
Luciano Magnavita	Petrobras	Brazil
Gianreto Manatschal	University Strasbourg	France
Dennis Miller	Petrobras	Brazil
Christian Muller	DAAD	Germany
Clive Neal	Notre Dame University	USA
John M. O'Connor	Alfred Wegener Institute	Germany
David Peate	University of Iowa	USA
Ivo Pessanha	CPRM	Brazil
Marcel Regelous	University Erlangen	Germany
Marli Carina Siqueira Riberio	UNESP	Brazil
Claudio Riccomini	USP	Brazil
Sebastian Rieger	University Heidelberg	Germany
Cesar Rigotti	Petrobras	Brazil
Tyrone Rooney	Michigan State University	USA
Victor Sacek	IAG USP	Brazil
William W. Sager	University of Houston	USA
Reginaldo Santos	CPRM	Brazil
Roberto Ventura Santos	CPRM/UnB	Brazil
Renata da Silva Schmitt	UFRJ	Brazil
Susan Schnur	Oregon State University	USA
Anke Schwarz		Germany
Valdir Silveira	CPRM	Brazil
Antonio Carlos Pendrosa Soares	UFMG	Brazil
Natasha Stanton	UFRJ	Brazil
Juliano Magalhaes Stica	Petrobras	Brazil
Cornelia Strebi	University of Heidelberg	Germany
Peter Szatmari	Petrobras	Brazil
Heitor Tozzi	FUGRO	
Claudio Valeriano	UERJ	Brazil
Adriano Roessler Viana	Petrobras	Brazil
Marta Cláudia Viviers	Petrobras	Brazil
Stella Woodard	Rutgers University	USA

Meeting Conclusions

Pre-meeting discussion indicated interests in developing drilling proposals for RGR and WR and those themes were carried through the meeting. During the meeting, Gianreto Manatschal, from University of Strasbourg in France, gave a talk extolling reasons for drilling the hyper-extended São Paulo Plateau located on the Brazilian continental margin between the Santos and Pelotas basins (Fig. 1). His proposal was received favorably by meeting participants. Although the WR proposal had been submitted previously (IODP Proposal 669 in 2007), the meeting helped to focus discussion indicating that revisions were necessary to make it currently competitive. Given changes in the IODP proposal evaluation procedure, meeting participants agreed that the best path was to submit pre-proposals for all three projects.

Proposals for the WR and RGR were seen as independent, but linked because the accepted explanation for the formation of these two LIPs is synchronous formation by the same hotspot (Tristan-Gough). The approach for both proposals is to core thick successions of basaltic flows for geochemical, isotopic, and geochronologic studies. Results from both projects will help understand south Atlantic mantle plumes and their evolution. RGR drilling will focus on the main, western RGR and will test in particular whether this LIP has a continental affinity as suggested by rocks recovered recently by dredge and submersible. Deep holes on both RGR and the older WR would be used to determine paleolatitudes for the hotspot and determine how the hotspot has moved with time and in comparison with Pacific hotspots cored during ODP Leg 197 (Emperor Seamounts) and IODP Expedition 330 (Louisville Seamounts). WR coring, in particular, can test hotspot motion during the period most likely to have seen significant polar motion, prior to 90 Ma. Thus, WR drilling should target deep holes on the oldest part of the ridge, but also plan on two shallow holes near the middle to examine the geochemical and isotopic differentiation of the Tristan and Gough seamount lineaments.

Proponents interested in continental margin extension felt that coring the São Paulo Plateau, the passive margin of northeast Brazil, is an excellent way to learn about the evolution of continental rifting and margin formation. The São Paulo Plateau exhibits evidence of hyper-extension and mantle exhumation that can be cored with a transect offshore of Brazil. By drilling continental margin sediments as well as igneous basement (both oceanic crust and exhumed mantle) the SPP drilling project would test models of continental rifting as well as recovering samples from the oldest oceanic crust in the south Atlantic.

Workshop Publication

A brief summary of the workshop and its deliberations was published in EOS for 8 July 2014 (Santos et al., 2014).

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