pattern to that found in the Pelotas basin (Hinz *et al.*, 1999; Schumann, 2002; Franke *et al.*, 2002, 2007). The same pattern can be observed in the Abutment Plateau, Namibian coast (Gladczenko *et al.*, 1998).

The stack with lateral shift of units "B" to "F," observed in the seismic profiles, caused an overlap of the different volcanic units. This superposition does not allow the direct relationship between the volcanic units and the magnetic responses (Figs. 5 and 6) as proposed by Moulin *et al.*, 2010.

Igneous units "G1" and "G2"

The units "G1" and "G2" comprise two types of seismic mounds: the deeper mounds (unit "G1") and the shallow mounds (unit "G2"). Both units "G1" and "G2" exhibit elongated distribution in plan-view with mounded shape in cross section (Figs. 4, 6, and 7). The mounded features are present at different crustal levels and they exhibit different relationships with the main SDRs flows. Three belts of the deeper, intracrustal unit "G1" can be recognized along a dip direction (Fig. 4), forming the belts G1', G1'', and G1'''. The belts are progressively younger and shallower from west to east, and they are downlapped by the volcanic Units "B" to "F" (or the main SDRs packages), as can be noted in Figures 6 and 7. In our interpretation, the deep-mounded features of unit "G1" are likely to be related to the feeder system of the main SDRs flows, representing the remnants of aborted spreading centers (Mohriak, 2001; Mohriak *et al.*, 2008).

A 2D forward gravity modeling has been performed for the deep seismic line A, in the northern Pelotas basin (Blaich *et al.*, 2013). This modeling required the presence of a high density crust below the SDRs wedges to fit the observed gravity values. This may be indicative of a heavily intruded lower crust and can be interpreted as the region of a feeder system related to the emplacement of the SDRs wedges (Blaich *et al.*, 2013).

The unit "G2" (shallow mounded features covered by sediments) are interpreted as volcanic centers (Fig. 10). Equivalent seismic geometries have been described as "outer highs" by Planke *et al.* (2000) and they have been drilled by the Deep Sea Drilling Project (DSDP) site 554 in Greenland (Planke and Alvestad, 1999). The published results of this drill site indicate hyaloclastic and volcanoclastic flows developed in a shallow marine environment, and they have been interpreted as the volcanic feeder system of the SDRs units (Planke *et al.*, 2000).

Volcanic unit "H"

Unit "H" has been drilled by several wells in the Pelotas and in Santos basins (i.e. 1-RSS-3RS, 2-BPS-6BP, 2-SCS-2RS and 1-SCS-1RS), as observed in the well cross section of Figure 9 (well location in Fig. 2).

The analysis performed in well 1-RSS-3RS indicates that unit "H" corresponds to a gray to brown basaltic suite having amygdaloidal texture, displays a

COPYRIGHT 2018 GCSSEPM

tholeiitic low TiO_2 affinity, and has an $^{39}Ar/^{40}Ar$ age of 118.3±1.9 Ma (Lobo, 2007).

Boreholes 2-BPS-BP and 2-SCS-2SC (Figs. 2 and 9) have neither geochemical nor radiometric analyses, but cutting descriptions refer to amygdaloidal trachyandesite, basalt, and trachyandesites having amygdaloidal textures. Intercalations of the volcanic units with calcarenite sediments and the presence of gas release textures are frequently reported in the mud log analysis of those wells. These descriptions are indicative of the extrusive character of this unit, which probably formed in shallow waters and even in subaerial depositional environments (ANP, well file reports).

Well 1-SCS-1-SC, located at the southern portion of the Santos basin (Fig. 2), drilled gray to brown porphyritic trachyandesite and basalts, having reported ages of 114±3 Ma ($^{39}K/^{40}Ar$) and 113.2±0.1 Ma ($^{39}Ar/^{40}Ar$; ANP well file report and Misusaki, 1990). We assigned this volcanic layer to unit "H", which probably overlies the older volcanic wedges "D" to "F" in the Florianópolis Platform (Fig. 4). The well log of unit "H" reveals numerous intercalations of pairs of high/low density and velocities values, probably indicative of the volcanic flows interacting with unconsolidated sediments (Fig. 9 and Table 1).

This unit is an extensive and relatively thin, flat lying volcanic layer, which postdates and overlays the SDRs main packages in deep water (Figs. 6, 7, 9, and 10). Unit "H" shows parallel to sub-parallel reflection configuration, sheet drape external form, and a low structural relief. Unit "H" represents the final episode of the postrift volcanic flows.

Volcanic unit I

Unit "I" represents the latest magmatic episode of the Pelotas basin and consists of several volcanic constructions or build-ups that are only present on the oceanic crust (Figs. 11A to C, seismic lines locations in Fig. 2). Unit "I" increases in magnitude from south to north, in the direction of the São Paulo Plateau in the Santos basin (Fig. 1). They can vary from isolated volcanic cones up to large volcanic structures (Figs. 11A to C). Until now, none of these constructions have been drilled in the Pelotas basin, consequently, no radiometric ages from these postrift events are available; however, geological correlation with oceanic volcanic islands in neighboring basins and known magmatic cycles onshore allowed several authors to estimate ages for these cycles, which probably range from Late Cretaceous to Early Paleogene (Asmus, 1984; Cainelli and Mohriak, 1998; Mohriak *et al.*, 2002 and references therein).

COPYRIGHT 2015 CCSSEPM

The physical continuity of the volcano-stratigraphy described in the Pelotas basin has been investigated in the Namibia conjugate margin in West Africa using two regional selected seismic profiles, key well correlations, and a palinspastic reconstruction map at 125 Ma using GPLATES software (Seton *et al.*, 2012). The location of the exploratory wells and the seismic lines reconstructed at prebreakup times is indicated in Figure 12. The regional seismic profiles, named as the "northern profile (northern Pelotas and Walvis basins), and the central profile (central Pelotas and Lüderitz basins), exhibit a quite conspicuous volcanic symmetry in both margins by displaying similar packages of SDRs (Figs. 13 and 14).

The northern profile across the northern Pelotas and Walvis basins (Figure 13A) shows a voluminous development of SDRs. At least five sequences of SDRs can be recognized and tentatively correlated in both margins before the development of the oceanic crust. The correlation has been tested in the conjugate margins by exploratory boreholes that have drilled volcanic rocks younger than the Serra Geral–Etendeka flood basalts. When reconstructed to their predrift position, wells 2-BPS-6-BP (Brazilian margin) and 1911/15-1 (Namibian margin) indicate that they sampled two equivalent volcanic units (Fig. 13B) below the Albian carbonates. The well 2-BPS-6-BP penetrated distinct volcanic units (units "H" to "C"). The radiometric age obtained for volcanic unit "C" (wedges of tholeiitic/high TiO_2 SDRs basalts) is not reliable, but these SDR units are stratigraphically positioned above the lower unit "A" (ca. 124/125 Ma) and below the upper unit "H" (ca. 113/118 Ma).

The borehole 1911/15-1, in the Walvis Basin, drilled two volcanic units named as Groups W1 and W2-1 (Holtar and Forsberg, 2000). The lower group W1 comprises 563 m of a series of basaltic lava flows that display a typical SDR configuration and are separated by tuffaceous layers and occasionally very thin beds of siliciclastic strata (Figs. 12, 13A and 13B). Petrographically, the lavas display textural variations from massive, glassy, and non-amygdaloidal layers to reddened and amygdaloidal textures, suggesting cycles of subaerial lavas flows intercalated with sediments. Chronologically this unit has been assigned an age not younger than Barremian (ca. 130-125 Ma) by Holtar and Forsberg, 2000. We suggest that the volcanic layer W1 correlates with the volcanic unit "C" in the Pelotas basin (Figs. 9 and 13).

The upper group W2-1 consists of 76 m of muddy limestones, marls, and glauconitic claystones at the base, and two major flows of basalts at the top. Structurally this unit displays sub-horizontal seismic reflections (Fig. 13A). Unfortunately, there are no published radiometric ages for the volcanic units of well 1911/15-1, but the fossils in the carbonates rocks of

COPYRIGHT 2015 SEPM

W2-2 group above the W2-1 basalts indicate an age from late Aptian to middle Albian (Holtar and Forsberg, 2000). This suggests that the W2-1 basalts are possibly correlated with the younger basalts in the northern Pelotas exploratory well (volcanic unit "H").

The central profile across the Central Pelotas and Lüderitz basins (Fig. 14A) displays a lesser degree of magmatic activity during the Gondwana breakup compared to the northern profile, and as a consequence, only two sequences of SDRs (volcanic units "B" and "C") have been identified in the Pelotas profile before the formation of the oceanic crust. The diminishing of the magmatic volume from the northern to the central segments of the rift basin, in both the Brazilian and Namibian margins, has also been reported by Stica *et al* (2013), Koopman *et* al (2014), and Holtar and Forsberg (2000). The well 1-RSS-3RS, located in the shallow water portion of the Pelotas basin (Fig. 14B), has drilled two volcanic units below a stratigraphic succession interpreted as a Late Aptian rift deposits. The upper unit, assigned to the volcanic unit "H," consists of approximately 180 m of a tholeiitic/ low TiO_2 basalt, and the lower unit, here assigned as unit "A" (Fig. 9), consists of 520 m of alkaline/high TiO_2 basalt, dated as 118.3 ± 1.9 Ma and 125 ± 0.8 Ma respectively (Table 1, Lobo, 2007).

The well 2513/8-1 in the Lüderitz basin has drilled basalts assumed to be older than 120 Ma by its stratigraphic position below Lower Albian sediments (Green *et al.*, 2009). Structurally these volcanic rocks are located at the top of a wedge of rift deposits, probably of Barremian age (Green *et al*, 2009). Unfortunately the scarcity of published information about this well does not allow the precise correlation of this basaltic unit with the volcanic units "H" or "A" from the central Pelotas basin. However, the presence of synrift deposits below these volcanic rocks suggest a younger volcanic episode (Early Albian/Late Aptian), at the transition from W3 to W2 stratigraphic units of Holtar and Forsberg (2000), thus indicating a probable correlation with the flat layers interpreted as volcanic unit "H" in the Brazilian margin borehole. It is important to note that the "H" volcanic layer in the Pelotas basin well 1-RSS-3-RS is located below a rift unit interpreted as Late Aptian, whereas the equivalent layer in the well 2513/8-1 offshore Namibia is placed above the Barremian-Aptian rift sequence.

A contrasting difference observed in this cross section in the central Pelotas–Lüderitz basins is the remarkable asymmetry of the postrift sedimentary successions. The Tertiary section of the Pelotas basin is approximately three times thicker than the Tertiary section of the Lüderitz basin (Fig. 14A). This large difference seems to be controlled by the deposits of the Rio Grande Cone in the Brazilian Margin, which is characterized by an extremely thick depocenter of Tertiary sediments in the central to southern segment of the Pelotas basin (Fig. 2).

Summary and Conclusions

The conjugate margins of the Pelotas basin, in southern Brazil, and the Namibia basin (Walvis and Lüderitz basins), in southern West Africa, can be classified as volcanic rifted margins in which magmatic activity displays a temporal and geographical evolution from continental breakup to oceanic crust formation (Garland *et al.*, 1996; Gladczenko *et al.*, 1998). The magmatic cycle that starts prior and along with the Gondwana breakup displays two major magmatic subcycles: the prerift Paraná-Etendeka continental flood basalts and the syn-/postrift volcanic successions of Pelotas, Walvis, and Lüderitz basins, which are characterized by thick wedges of SDRs (Courtillot *et al.*, 1999; Gladczenko *et al.*, 1997).

The age of the Paraná-Etendeka province ranges from Valanginian to Barremian, with a peack of magmatic activity during the Hauterivian. In both the Paraná and Etendeka provinces, the magmatic activity seems to start and finish with alkaline rocks, but the main volcanic activity consists of tholeiitic basalt flows. The lava flows of the Paraná continental flood basalts reach their maximum thickness in the central part of the Paraná basin and pinch-out towards the continental margin of the Santos and Pelotas basins, where Precambrian rocks crop out near the coastline.

There are several magma types in the Paraná continental flood basalts and they have been grouped into high and low TiO_2 suites, which are related to melting of different mantle masses. In a general sense, the high TiO_2 suites are more abundant in the northwest and the low TiO_2 are more important in the southeast of the province (Garland *et al.*, 1996; Peate, 1997).

During Barremian to Aptian times, the Pelotas basin developed relatively narrow rift troughs during the main extensional phase. This is expressed by small rift blocks controlled by antithetic faults affecting prerift sediments (Paleozoic sediments from the Paraná Basin) and Serra Geral basalts, and subsequently the magmatism shifted the main locus from inland to oceanward. The first magmatic phase of the Pelotas volcanism started with the volcanic unit "A," in a synrift tectonic domain, at the Barremian/Aptian boundary. Compositionally this volcanism initiated with alkaline/high TiO_2 basalts. Subsequently, the volcanism evolved into a series of SDR wedges (units "B" to "F") of tholeiitic/high TiO_2 basalts during the Aptian. The SDR wedges display an oceanward evolution, becoming younger basinward and developing unconformities between the different wedges, thus reflecting the changes in the structural configuration of the basin during the late rift/early postrift transition. Additionally, deep and shallow mounded features that can be identified in the seismic records (units "G1" and "G2") may represent magma conduits (magma feeder systems) in the crust. The highly intruded and rather dense lower crust is supported by 2D forward gravity modeling.

COPYRIGHT 2010 SEPM

Regionally, the SDR wedges (Units "B" to "F"), decrease in number of wedges and in the volumes of magmas involved from north to south. This behavior has also been observed in the conjugate West African margin. The north to south SDRs evolution, observed in the vicinity of the Rio Grande/Walvis chain, behaves in an opposite way to the SDR wedges that occur in the Southern South Atlantic margin along the Argentinean coast (Hinz *et al.*, 1999; Schumann, 2002; Franke *et al.* 2002, 2007). The magmatic activity in the transitional crust of the Pelotas basin finishes with the flat volcanic layers of unit "H," in a postrift stage around late Aptian times. Compositionally this unit "H" is made of tholeiitic /low TiO_2 basalts.

The Pelotas volcanic province exhibits a geochemical evolution from alkaline to tholeiitic affinities and from high to low TiO_2 basalts. Experimentally, the partial melting of less than 25% of an enriched lherzolite mantle source at adiabatic decompression can explain the evolution from alkali basalt to olivine tholeiitic basalt, tholeiitic basalt, and quartz tholeiitic basalt (Jaques and Green, 1980). Alkaline rock implies lower degree of partial melting and very high pressure regimes (Wilson, 1989). Later, during the evolution of the rifting, the increment of the lithospheric thinning and the higher degree of partial melts might explain the shift of this volcanism into tholeiitic affinities (Wilson, 1989). The high TiO_2 suites are interpreted to be related to a high pressure (or depth) of magma generation, a lower adiabatic decompression with a lesser degree of partial melts, and minor lithospheric thinning of a garnet-rich lithospheric mantle source (Lobo, 2007). The low TiO_2 suite, on the contrary, reflects: a lower pressure regime, a higher amount of adiabatic decompression associated with a greater degree of partial melts, and a major lithospheric thinning of a garnet-free lithospheric mantle source (Lobo, 2007). The evolution of the volcanism the Pelotas volcanic province is in agreement with the increase of the lithospheric thinning during the rifting process.

In both magmatic provinces across the southern South Atlantic (Paraná-Etendeka and Pelotas/Walvis-Lüderitz) there is a clear impact of the Tristão da Cunha plume, but according to the numerous published geochemical studies, the effect of the plume appears to be, in general, more thermal than compositional, with the exception of volumetrically minor lavas in both margins. The effect of the plume is also reflected in the high velocity/density lower crust (underplate) extending below the rift zone and the of the Paraná basin. The underplate effect has been recorded and modeled in several gravity, magneto-telluric, and refraction studies in both conjugate margins (Gladczenko *et al.*, 1997, 1998; Molina *et al.*, 1988), and is expressed in the deep seismic profiles available in the southeastern Brazilian and southwestern African continental margins (Bauer *et al.*, 2000).

COPYRIGHT 2015 GCSSEPM