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Axial morphology along the Southern Chile Rise

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ABSTRACT

Morphology of four spreading segments on the southern Chile Rise is described based on multi-beam bathymetric data collected along the axial zones. The distribution of axial volcanoes, the character of rift valley scarps, and the average depths vary between Segment 1 in the south, terminating at the Chile Triple Junction, and Segment 4 in the north, which are separated by three intervening transform faults. Despite this general variability, there is a consistent pattern of clockwise rotation of the southern-most axial volcanic ridge within each of Segments 2, 3, and 4, relative to the overall trend of the rift valley. A combination of local ridge-transform intersection stresses and regional tectonics may influence spreading axis evolution in this sense.

1. Introduction

The Chile Rise extends south from the Valdivia fracture zone system as a series of spreading segments that increase in proximity to the Chile trench until the triple junction is reached. The intersecting segment is being overridden by the South American Plate (Fig. 1); thus the Chile Triple Junction (CTJ) is the only place on earth where an actively spreading mid-ocean ridge is being subducted under a continental plate. This plate boundary geometry provides a natural laboratory for investigation of the interplay between surface tectonics and underlying mantle processes, specifically upwelling patterns and associated magma production that supplies new forces. Detailed morphologic patterns observed within the axial zone of the four southernmost segments provide initial insights into some aspects of this interplay. Ridge subduction has occurred elsewhere in the past so results from the current Chile system can provide insight into evolution of ancient ridge–trench, and associated micro-plate systems. With a half rate of 30 mm/yr (Cande et al., 1987), the Southern Chile Rise sits at a threshold, typical of intermediate spreading ridges, where a variety of factors can influence the axial structure (Baran et al., 2005; Martinez et al., 2006). This paper presents maps of new data, reports on the observed trends and character of the axial volcanoes and fault scarps, and discusses potential regional influences on the pattern. While the new coverage is modest, mostly a single bathymetric swath that just reaches the edge of the axial zone, it identifies persistent clockwise rotation trends in the southern ends of three successive segments. These new data allow us to begin to place the plate boundary evolution into a context of regional controlling forces.

The bathymetry data were obtained on two R/V Melville cruises (MV1003 and MV1016) in 2010. The first was part of an NOAA Ocean Exploration study (INSPIRE-Chile 2010; International Southeast Pacific Investigation of Reducing Environments) that emphasized water column plume mapping and seafloor sampling of biological specimens within seep and prospective hydrothermal vent areas. The bathymetric data provided context for these targeted studies. The second cruise represented opportunistic data acquisition during an equipment testing program. The INSPIRE-Chile 2010 cruise obtained essentially complete coverage of the axial zones of Segments 1 and 2, immediately north of the Chile Triple Junction (CTJ) at a resolution improved relative to prior data. Subsequently, almost complete coverage of the axial zones of Segments 3 and 4 was obtained, much of which is the first available ~100-m resolution data. Regional bathymetric data were available from prior cruises by Chilean, French, German and U.S. scientists (Cande et al., 1987; Bourgois et al., 2000).

The INSPIRE-Chile 2010 EM122 data, obtained at ~1.5 kt speed during tow-yo runs, required modest ping editing prior to gridding (50 m spacing). These data (weight = 1.0) were then combined with the regional grid values (100 m spacing, weight = 0.25) and surface fit using GMT (Wessel and Smith, 1998) to produce a 50-m grid. Artifacts are evident along regional tracks but the axial regions are best illustrated with this choice of surface 'tension' and grid spacing. MV1016 data, collected at underway speeds, have not been edited significantly; these data were gridded at 100 m spacing.

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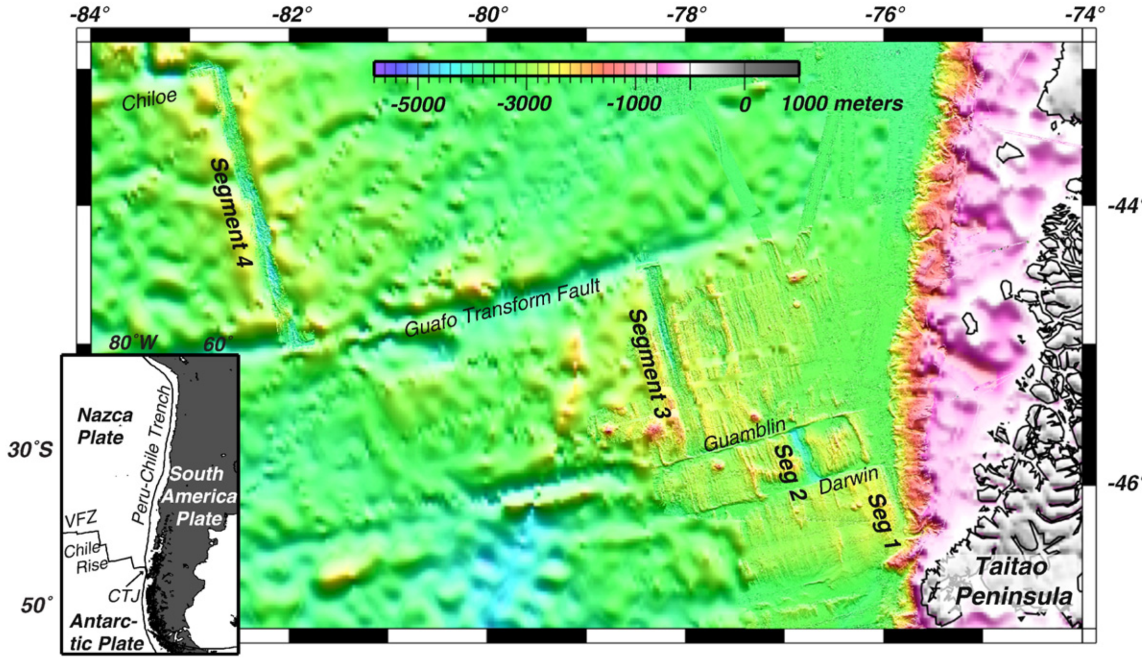

Fig. 1. Bathymetry along the Southern Chile Rise shows spreading segments and fracture zones; illumination angle NNE. Inset shows main tectonic elements: VFZ—Valdivia Fracture Zone; CTJ—Chile Triple Junction. Segment 1 terminates in the south at the CTJ. New multibeam bathymetry data along the ridge axes are overlain on regional grid (compilation of German, French, and Chilean data by I. Grevemeyer incorporates partial flank coverage of Segments 1–3), and satellite-based predicted bathymetry (Smith and Sandwell, 1997).

2. Morphologic observations

The axial morphology of the Chile Rise varies along the four segments extending north from the Chile Triple Junction-Segments 1 through 4, respectively. The general character of Segments 1 and 3 is similar to other intermediate spreading rate axial zones (Kappel and Ryan, 1986), with 5–8 km wide, fairly linear rift valley within which a 1–2 km wide volcanic zone occurs. As noted by previous workers (Klein and Karsten, 1995; Bourgois et al., 2000), Segment 2 is deeper than the adjacent segments, with average axial depth of almost 4000 m compared to 3200–3300 m depths along Segments 1 and 3. Segment 4 comprises a series of elongate sub-basins slightly offset from one another along the overall rift trend. Axial depths for Segment 4 range from ~4000 m in the sub-basins, through an average of ~3650 m, to a shoal section of ~2750 m near the southern end. Below we describe the morphology of the axial zone along each segment, from south to north.

Segment 1 is 50 km long and the depth of the rift valley floor is consistently ~3200 m to the north of where slope sediments begin to fill the central graben (~46°05′S, Fig. 2A). The pre-existing EM12 bathymetry data (Bourgois et al., 2000) showed the main morphology of this segment and those authors adopted the termination of high-backscatter volcanic structures against the scarp at the toe of the slope at 46°09′S as the precise location of the triple junction. Our higher resolution (narrower sonar beam) coverage shows additional detail within the rift axis, and we include the section that continues to be bounded by small western rift wall fault scarps in our defined segment length, which extends south to ~46°16′S. A chain of volcanic structures <400 m in diameter tracks the central graben in the northern half of the segment (Fig. 2A). From 46°06′to 46°12′S, several axial seamounts with diameter ~1 km are evident above the sediment fill, most located on a likely fault-controlled shelf on the slope side of the spreading axis, but a few occur near or just west of the center of the rift. There is a deviation in axial linearity evident on the western valley wall between ~46°08′ and 46°11′S, where scarps strike several degrees west of the main axial trend. Axial volcanoes within this section are distributed more widely across the median valley but do not clearly line up with the deviated scarp trend. Western valley wall scarps along the southern, unsubducted portion of the axial valley 46°12–16′S resume the main trend of the segment. Fault scarps extend linearly for 12–15 km distances throughout the segment and have throws of 50–75 m within the rift valley floor.

Segment 2, which is offset about 50 km west along the Darwin transform fault, is characterized by an almost 1 km deep rift valley (Fig. 2B). The nodal basins at the ends of this 43 km long segment are more than 4000 m deep and the central portion of the segment has axial depths ~3800 m. Small, linear volcanic chains occur along most of the axis but their location within the rift valley varies along strike (Fig. 2B). As the volcanic features rise above the nodal basin in the north, they are centered within the main rift valley. In the central part of the segment, the volcanic chain hugs the eastern scarp of the rift. In the south half of the segment, the chain has crossed the axis and tracks along the western edge of the rift valley floor before activity apparently tapers off ~45°56′S. In the southern half of the segment, the axial volcanoes trend about 16° clockwise from the average trend of the rift valley, projecting obliquely into the Darwin fracture zone.

Segment 3 is the most linear of the southern Chile Rise segments studied; it extends 152 km and has two clear deviations in axial linearity (45°20′S and ~45°05′S, Fig. 3A). Linear scarps are sub-parallel throughout the segment though individual sections often curve slightly near their terminations. Contiguous scarp lengths are 5–15 km with corresponding throws of 75–400 m. Distinct volcanic cones in the southern end of Segment 3 (Fig. 2C) are generally small (350–500 m diameter, <75 m high). A rifted linear high makes up the axial zone in the section from 45°25′ to 45°40′S. Volcanic cones are sparse in this area but increase in number and continuity as the rifted high transitions to a graben approaching the Guamblin transform fault to the South. Similar to Segment 2, the volcanic features associated with this apparent recent activity in the southern end of the segment trend 8° clockwise from the overall (end-to-end) trend of Segment 3. An increase in the size of the conical axial volcanoes, to diameter ~1 km, and a tendency for them to be flat-topped occur throughout the northern part of Segment 3 (top of Fig. 2C, where the pattern begins and continues northward, Fig. 3A). Spacing between these features is 2–4 km in the central and northern portions of the segment. The interval 45°10′–