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The last spreading episode of the West Philippine Basin revisited

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Abstract. In 1996, bathymetric data and backscattering imagery were gathered along a 20 km-wide NW-SE transect across the West Philippine Basin (WPB), between Taiwan and the Palau-Kyushu Ridge. These data reveal fine-scaled structures of the fossil spreading axis from which we infer episodes of oblique deformation and diminished magmatic supply resulting from cessation of spreading. An original NE-SW seafloor fabric is observed in the basin northeast of the Benham volcanic plateau. Since this trend is oblique to the more common E-W and NW-SE seafloor fabrics known in the WPB, it could be the result of overlap of two segments of the spreading axis. Several rhomboidal structures exist in the vicinity of the rift valley, suggesting that dextral shear occurred along the central basin rift axis during the last spreading phase. The E-W spreading segments associated with N-S nontransform discontinuities that occur between 127°E and 132°E were probably cross-cut during a final, largely amagmatic, extensional phase to produce a N130°-trending deep rift valley.

1. Introduction

1.1 Geodynamic Setting

Previous studies indicate that the West Philippine Basin (WPB) probably formed by back-arc opening from the Central Basin Spreading Center (CBSC) during Paleocene-Eocene [Lewis and Hayes, 1980; Mrozowski et al., 1982]. The CBSC is a slow spreading center that has experienced multiple spreading episodes [Fujioka et al., 1998]. According to Hilde and Lee [1984], the WPB results from two stages of opening along the CBSC (see insert on Figure 1): (1) from 60 Ma to 45 Ma (magnetic lineations 26-20), spreading occurred in a NE-SW direction at a half-rate of 44 mm/yr. (2) at approximately 45 Ma (anomaly 20), spreading slowed down to 18 mm/yr, and changed direction to N-S. Simultaneously, the former NW-SE CBSC was reorganized into numerous, short, E-W segments offset by N-S transform faults. Spreading ceased at 35 Ma. Paleomagnetic data show that between 50 and 40 Ma, the WPB underwent discontinuous clockwise rotation of approximately 50° [Hall et al., 1995].

1.2. Data Acquisition

The study area was surveyed in 1996 to acquire bathymetric and acoustic reflectivity data along a single NW-SE transect across the WPB (Fig. 1). The French R/V L'Atalante is equipped with the SIMRAD EM12-Dual multibeam swath-mapping system that collects bathymetric and backscatter data across a maximum 20-km-wide swath of the seafloor in a single

pass (with 151 beams). In this paper we present images of the CBSC and surroundings provided by this survey.

1.3. Major features of the CBSC derived from gravity data

Between 127°E and 132°E, gravity data (Fig. 1) [Sandwell et al., 1997] show a generally NW-SE -trending low (down to -60 mgals) corresponding to the CBSC. This feature is locally associated with short E-W -trending segments developed between 128°30'E and 129°30'E, and also east of 132°E. The gravity signature of the CBSC is not observed west of 127°E. Importantly, in the area with the largest negative gravity anomaly (129°30'E to 132°E), the gravity signature of three N-S nontransform discontinuities (NTDs) [Fujioka et al., 1998] located between 130°E and 132°E is offset right laterally by the CBSC.

2. New insights from swath bathymetry

2.1. Details of an inferred fossil N-S fracture zone

An S-shaped fabric is observed near two slightly curved N-S features (Fig. 2A). These N-S structures are west-facing



Figure 1. Shaded view of the satellite-derived free-air anomaly field [Sandwell et al., 1997] showing the major features of the West Philippine Basin. Dark heavy line is the shiptrack. Enclosed areas indicate the regions illustrated on Figure 2. The box shows the schematic seafloor spreading pattern of the WPB, from magnetic lineations after Hilde and Lee [1984].

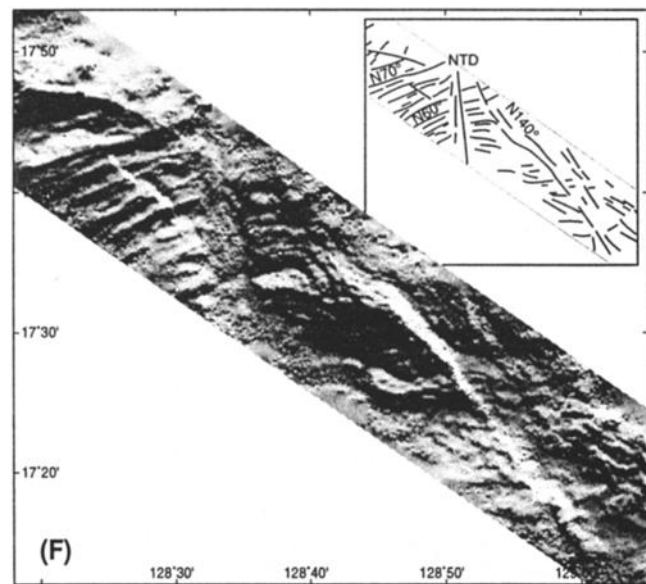
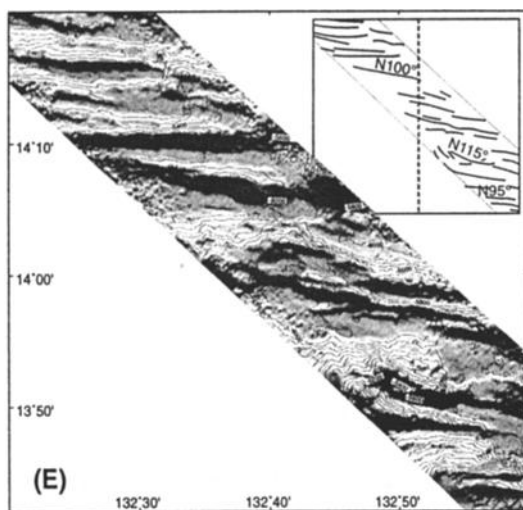
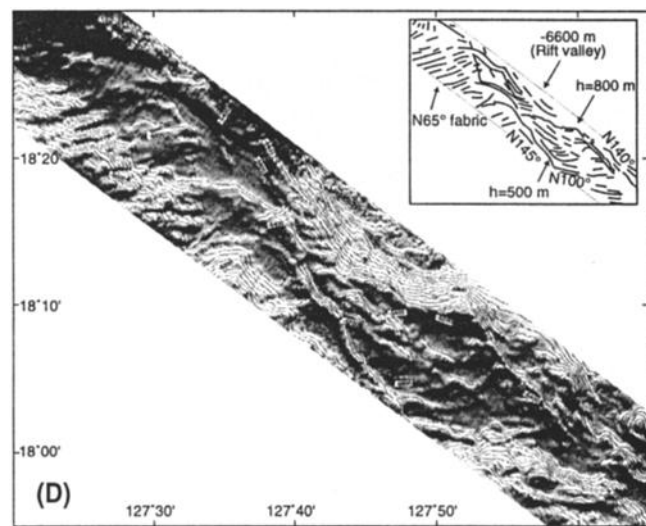
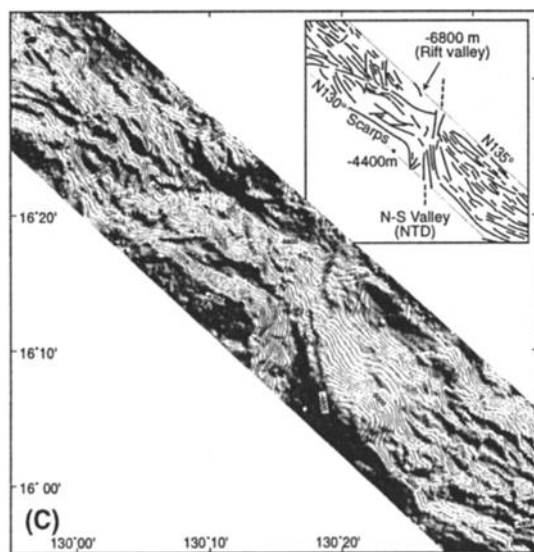
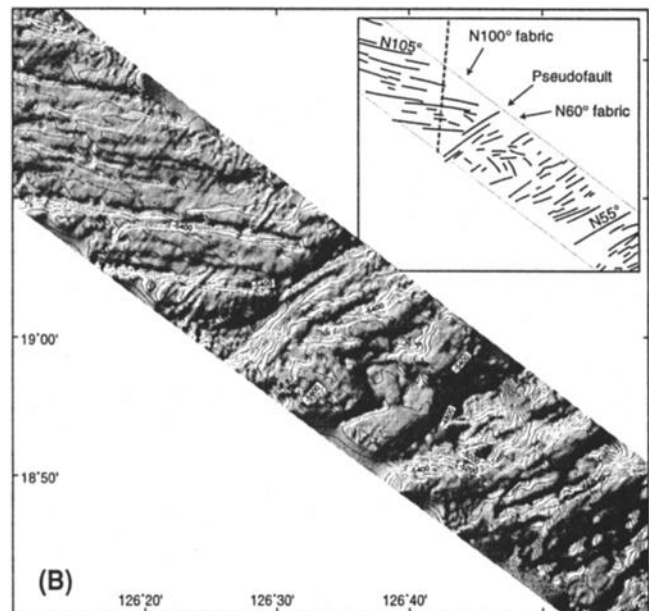
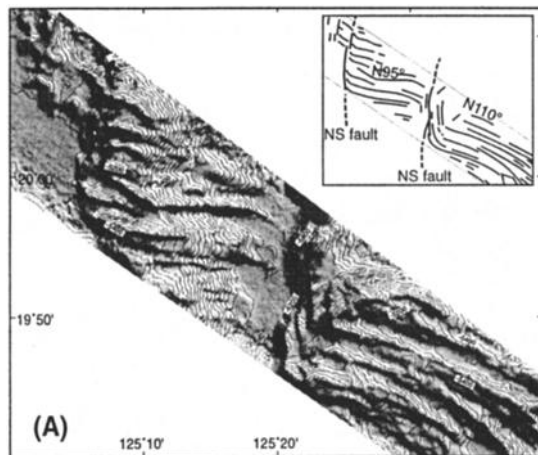


Figure 2. A, B, C, D, E, F : Shaded relief seafloor topography maps and structural interpretations of 6 areas located along the survey. These interpretations are drawn from the analysis of bathymetric maps at 1:200000 and of the backscattering imagery acquired during the same survey (results not shown in this paper). Depth contours interval is 50 m in figures A and B and 100 meters in figures C, D, E. On boxes B and E, dashed gray N-S lines show the location of the projected bathymetric profiles shown on Figure 3.

escarpments, and trend roughly perpendicular to the N95° and N110° spreading fabrics. The vertical offset of the seafloor across these structures is between 900m and 1300m. We deduce that they are probably fossil faults associated with an inactive N-S fracture zone. By analogy with seafloor fabrics observed near active transform faults [Carbotte and Macdonald, 1994a, plate 2b; Searle, 1981; Gallo et al., 1986], the curvature of the abyssal hills indicates sinistral faulting between dextrally offset spreading segments.

2.2. An original NE-SW structural trend

At longitude 126°30'E, an original N60° structural trend abruptly interrupts N100° -trending structures (Fig. 2B). This change in strike of the tectonic lineaments probably indicates the location of a linear fossil pseudofault. Within each domain, the lineaments are straight, parallel and closely spaced, and we interpret them as relict spreading fabrics. West of 126°30'E, the height of the N100° abyssal hills does not exceed 100m, and their spacing averages 4km or less (Fig. 3A). This fabric probably formed near to a medium to fast spreading ridge [Carbotte and Macdonald, 1994b]. The NE-SW seafloor fabric is expressed for over 250km along the CBSC, between longitudes 126°30'E and 128°40'E (Fig. 2D and 2F).

2.3. A SE -trending rift valley cutting across the central part of the basin

On figure 2C, a N130° fabric is clearly expressed. Several steep (up to 1800 m of relief) northeast-facing escarpments may be related to old normal faults bounding the relict spreading axis (characterized by the -6800m isobath in this area). The position and the approximately N130° trend of this axis are confirmed by the presence of a strong NW-SE negative gravity anomaly (down to -60 mgals) between 129°30'E and 132°E (Fig. 1). Investigation of the gravity map shows that between these longitudes the N-S non-transform discontinuities (NTDs) seem to be dextrally offset by few kilometers on each side of the CBSC. Near longitude 130°15'E (Fig. 2C), a N-S, 1300 m -deep valley, probably related to a NTD [Fujioka et al.,

1998], appears to be cross-cut by the NW-SE rift valley. Similarly, significant N-S features are observed along the CBSC, at longitudes 128°35'E, 129°35'E, and 131°10'E.

2.4. Diamond-shaped structures displayed by the CBSC

Figure 2D shows well-defined rhomboidal structures which are delineated by N140° -trending, 800m -high crests, and by N100° crests with steep north-facing escarpments. These diamond-shaped structures are located along the spreading axis identified by the 6600m isobath and by a negative gravity anomaly (Fig. 1).

2.5. E-W structures of the last spreading stage

East of longitude 131°E, linear, parallel, N100°-trending abyssal hills, up to 1000m high, occur (Fig. 2E and 3B). They imply an approximately N10° rifting direction. The high relief of these hills suggests the fabric developed along a slow-spreading center with a low magma supply. The amplitude of the hills is 5 times greater than the amplitude of the seafloor hills observed near longitude 126°30'E. The wavelength of crests is 20 to 30 km, also 5 times larger (Fig. 3), suggesting that faulting occurred within a thickened lithosphere [Shaw and Lin, 1993]. Taken together, these features indicate a diminished level of magmatic activity for the CBSC with time.

3. Discussion and conclusion

The results from this study highlight the structural evolution associated with a failing spreading center on a small plate.

(1) An original NE-SW structural trend is identified within the WPB. This trend obliquely intersects magnetic isochrons and NTDs (Fig. 2B, 2F) and could be the result of the overlap of two segments of the CBSC. Recent studies show that the area located between two overlapping spreading centers often displays lineaments which are oblique to the global trend of the spreading axis. The consequences of the overlap are a rotation of the lithosphere between the two propagating rifts and an abrupt change in the strike of the lineaments [Goff et al., 1993; Searle et al., 1989; Larson et al., 1992; Hey et al., 1995; Kleinrock and Hey, 1989]. The development of microplates or overlapping spreading centers is consistent with the long and complex rotation history of the WPB. Additional data, such as magnetics or bathymetry, are required to test this hypothesis.

(2) Rhomboidal structures observed in the vicinity of the rift valley (Fig. 2B) suggest that dextral shear occurred along axis, probably during the last spreading episode.

(3) The N130° -trending CBSC observed between 127°E and 132°E probably reflects a late stage of NE-SW opening. The data on Figures 1 and 2 show that the seafloor fabrics and NTDs which are observed south of the CBSC (Fig. 2E) and (probably) north of the CBSC (Fig. 2A and 2B) are E-W and N-S, respectively. The N130° axial fabrics are observed only near the CBSC (Fig. 2C and 2D). At this location, the NTDs form right-stepping trends across the axis (Fig. 2C). Finally, gravity data combined with seafloor fabric data (Fig. 2) lead to the interpretation that a late phase of seafloor spreading was characterized by N-S fracture zones and E-W spreading segments. Between 127°E and 132°E, this fabric was later cross-cut during a final, largely amagmatic, extensional phase producing the N130° -trending CBSC rift. This NE-SW terminal stage of extension is assumed responsible for the offset

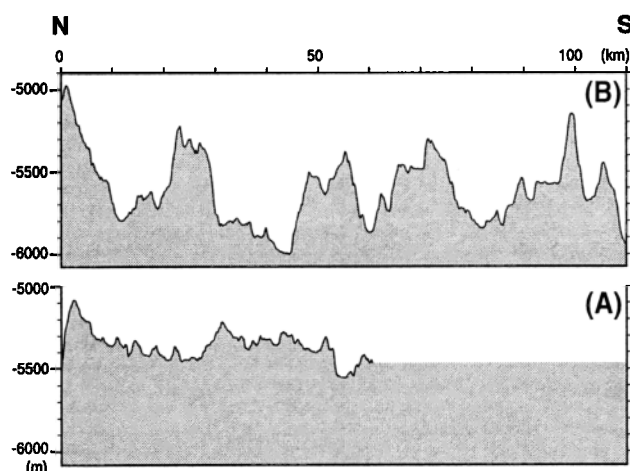


Figure 3. Bathymetric profiles normal to the structural grain, i.e. projected along a N10° direction for box B (lower profile A) and along a N-S direction for box E (upper profile B). These profiles show the change in seafloor roughness, between longitudes 126°25'E (profile A) and 132°40'E (profile B) (See location of the profiles on Figures 2B and 2E).

of the N-S NTD's in a right -lateral sense, as shown on Figure 2C. This terminal episode of NE-SW opening apparently occurred only in the central part of the basin, between longitudes 127°E and 132°E. Further to the east, the regular N100° abyssal hills trend roughly perpendicular to the last N-S spreading direction inferred in the WPB (Fig. 2E). Moreover, west of longitude 127°E, the seafloor fabric trend is also perpendicular to the N-S fossil fracture zones (Fig. 2A). Gravity data confirm that the NW-SE -trending rift valley is no longer expressed east of 132°E and west of 127°E. Why the late NE-SW extensional phase occurred only in the central part of the basin remains unknown.

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