Origin of the Pacific Jurassic quiet zone

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ABSTRACT

Understanding the marine magnetic anomaly record is critical for constructing realistic geodynamo models of global geomagnetic field, polarity reversal mechanisms, and long-term geomagnetic field behavior. One of the least understood portions of the marine magnetic anomaly record is also the oldest part of the record, the Jurassic quiet zone (JQZ), where anomalies become weak and difficult to correlate. The reason for the existence of the JQZ is unclear. It has been suggested that the JQZ is a true polarity superchron, similar to the Cretaceous normal superchron. Continental magnetostratigraphic studies have suggested that the JQZ is a period of rapid polarity reversal, of low field intensity, or both. We show results of a deep-tow survey of Pacific Jurassic crust that confirms the existence of magnetic anomalies within the JQZ. We tie Ocean Drilling Program Hole 801C (167.4 Ma) into the record and show that seafloor-spreading magnetic anomalies are present around the hole and extend to 170 Ma crust. We find a rise in reversal rate with increasing age with reversal rates over 10 rev/m.y. at 160 Ma and at 167 Ma. Anomaly amplitudes decrease in the record from 155 Ma until 162 Ma, where low-amplitude anomalies are difficult to correlate. Prior to 167 Ma, anomalies regain amplitude and remain strong until the end of our record at 170 Ma. The JQZ thus appears to be a combination of low-amplitude magnetic anomalies combined with rapid field fluctuations, which could be due to either intensity or polarity changes.

Keywords: Jurassic, magnetostratigraphy, marine magnetic anomalies, geomagnetism, polarity reversals.

INTRODUCTION

The Jurassic magnetic record lacks a continuous land magnetostratigraphic section (Opdyke and Channell, 1996), which makes it imperative that we glean as much information as possible from the remaining contemporaneous marine record. Jurassic ocean crust is the oldest remaining crust in the ocean basins, which restricts the marine magnetic record to a few rare occurrences (Cande et al., 1978; Larson and Chase, 1972; Larson and Hilde, 1975; Vogt and Einwich, 1979). Jurassic quiet zone (JQZ) crust is found either at great ocean depths, which attenuate anomaly amplitudes, or is directly adjacent to continents and buried under thick margin sediments (Barrett and Keen, 1976). The best Jurassic marine magnetic record is arguably in the western Pacific, although it has the disadvantage of being in tropical latitudes where diurnal variations are large compared to sea-surface anomaly amplitudes. We can overcome the attenuation and signal-to-noise issues with a deep-towed magnetic survey of the relevant magnetic anomaly sequences. This study focuses on Jurassic crust located in the Pigafetta Basin of the western Pacific, between 16° and 21°N and 155° and 163°E (Fig. 1). At this site, anomalies are optimally expressed due to rapid spreading rates and minimal sediment cover. Pacific Jurassic crust is bounded by three sets of magnetic lineations: Phoenix lineations to the south, Japanese lineations to the northwest, and Hawaiian lineations to the east. These lineations delineate the spreading history of the Pacific plate and also define the boundaries of the Pacific JQZ (Fig. 1). The young boundary of the JQZ was originally defined as chron M22 (Larson and Chase, 1972). This was pushed back successively to M25 (Larson and Hilde, 1975), to M29 (Cande et al., 1978), and to M38 (163 Ma) (Handschumacher et al., 1988), showing that no clear boundary to the JQZ exists. A 1992 deep-tow study (Sager et al., 1998) identified anomalies from M27 back to M40 (Fig. 2) within a spreading corridor in the Japanese lineations of Pigafetta Basin that is devoid of the ubiquitous Cretaceous seamounts that cover the region. The results of that study questioned the idea that the JQZ is a period of no reversals, i.e., a magnetic quiet zone (Sager et al., 1998). The corridor also includes Ocean Drilling Program Hole 801C, which penetrates Jurassic basement without any overlying Cretaceous volcanics (Abrams et al., 1993; Lancelot and Larson, 1990; Plank et al., 2000). The Hole 801C magnetic results show a mean inclination of ~40°, implying that the crust formed at a paleolatitude of 23°S (Tivey et al., 2005). Furthermore, the downhole results also show more than one polarity reversal within the 474 m drilled basaltic crust, indicating rapid reversals (Tivey et al., 2005) during this period, consistent with contemporaneous terrestrial sections (Belkaaloul et al., 1997; Steiner et al., 1987).

NEW DEEP-TOW MAGNETIC DATA

We collected 1550 km of deep-towed profiles between 21° and 17°N extending from M33 in the north to the rough-smooth (R-S) basement and magnetic boundary in the south, thought to be the oldest limit of JQZ crust (Abrams et al., 1993; Handschumacher et al.,

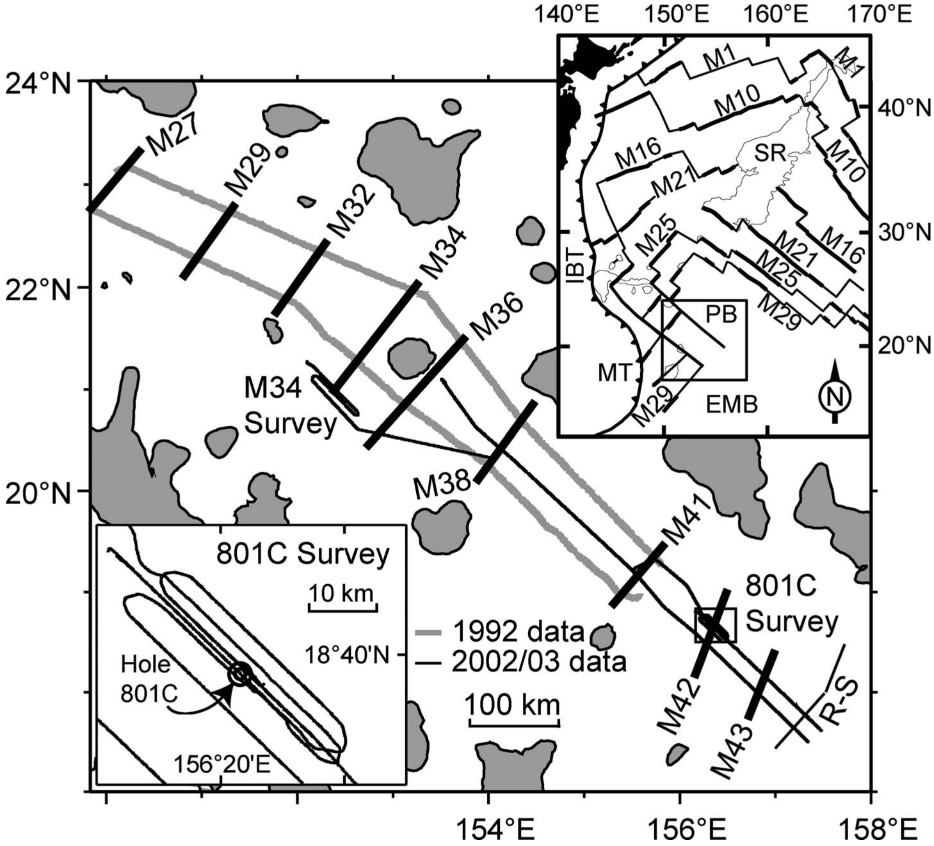

Figure 1. Location map of deep-tow magnetic survey showing 2002–2003 survey tracks (black) and 1992 survey tracks (gray) with major chrons identified. Gray areas are bathymetry shallower than 3500 m. Upper right inset shows Pigafetta Basin (PB) in western Pacific Ocean with major magnetic isochron lines identified by M chron numbers. Marianas Trench (MT) is shown by hachured line; SR—Shatsky Rise, IBT—Izu-Bonin Trench, EMB—Eastern Mariana Basin. Lower left inset shows detailed tracklines around Hole 801C (black circle). R/S is rough-smooth boundary (see text).

1988) (Figs. 1 and 2). Two additional areas of detailed surveys were conducted: one in a sequence of rapid reversals near M34 and a second area adjacent to Hole 801C (Fig. 2). Magnetic field measurements utilized a 3-axis vector magnetometer mounted on the deep-tow sidescan vehicle DSL-120A towed at ~1 knot at a survey altitude of ~100 m above the seafloor. This survey altitude combined with a mean sediment thickness of 300 m gives a maximum lateral resolution of ~500 m; for fast-spread crust at 67 km/m.y., this yields ~7.5 k.y. lateral temporal resolution. The near-bottom magnetic data are continued upward to a level plane at a mid-water depth of 3 km, approximating seafloor depths of 3–4 km for typical sea-surface anomalies (Fig. 2). Anomaly age is established by taking the M26r age of 155.3 ± 3.4 Ma from the Argo Abyssal Plain (Ludden, 1992) and 167.4 ± 1.4 Ma from Hole 801C basaltic crust dating (Koppers et al., 2003). These age tiepoints suggest an average half-spreading rate of ~67 km/m.y. over this 15 m.y. period and predict that the oldest crust adjacent to the R-S boundary reaches ca. 170 Ma in age.

The new profiles extend the older 1992 survey lines (Sager et al., 1998) and include a line that bisects them to help improve anomaly correlation (Fig. 2). The profiles show the overall character of the magnetic anomaly sequence from M27 to the R-S boundary (Fig. 2). A clear decrease in magnetic anomaly amplitude is observed from M27 through M37 (155–162.5 Ma). Prior to this time, anomalies have markedly low amplitude and are difficult to correlate. This low-amplitude zone (LAZ) lasts for 250 km (~4 m.y.), after which the anomalies regain amplitude just north of Hole 801C (Fig. 2). To model the measured anomaly record we constructed a block model and identified new chrons extending from M40 through to M44 (see Table DR1[1]). A good fit to the observed data is obtained with a synthetic profile calculated using the block model and a phase shift of −176° (Fig. 2).

DISCUSSION

McElhinny and Larson (2003) suggested that the marine magnetic record provides a proxy for geomagnetic field intensity, arguing that if the JQZ is partly due to low field intensity then it should be present in marine magnetic anomaly amplitudes. This suggestion builds on initial observations by Larson and Hilde (1975) and Cande et al. (1978), who found a decrease in magnetic anomaly amplitude into the JQZ and who suggested that one possible cause was a decrease in geomagnetic field strength. Terrestrial measurements of paleofield intensity now support the idea that the Jurassic was a period of low field intensity (e.g., McElhinny and McFadden, 2000). We can extend the McElhinny and Larson (2003) record from M19 to M29 with our new data set, and find a continued decrease in intensity through to M37, when amplitudes appear to reach a minimum that lasts for ~4 m.y.; i.e., the LAZ (Fig. 3). Anomaly amplitude rebounds at M41 (ca. 167 Ma) around Hole 801C until the end of the record ca. 170 Ma (Fig. 3). Thus, reduced magnetic anomaly amplitude through the LAZ is one reason for the existence of the JQZ.

Although anomaly amplitude decreases, a strong reversal pattern remains except in the LAZ (Fig. 2). In particular, the detailed survey around Hole 801C shows conclusive evidence of spatially correlatable anomalies with significant amplitude at mid-water depths (~100 nT), indicating that seafloor-spreading magnetic anomalies are present (Fig. 2). The anomalies are also consistent with the results from downhole logging and rock core measurements in Hole 801C indicating multiple polarities downhole that suggest magnetic reversals rather than intensity fluctuations (Steiner, 2001; Tivey et al., 2005). Thus, we believe that the anomalies in the vicinity of Hole 801C are seafloor-spreading lineations indicative of magnetic reversals.

To obtain a reversal rate we took the CENT94 time scale of Channell et al. (1995) over the 155–168 Ma period and calculated the number of reversals within a sliding 4-m.y.-long window with a step of 1 m.y. The same calculation was run on our block model (Table DR1; see footnote 1) (Fig. 2), and we obtain higher reversal rates compared with CENT94 (Fig. 4); this is not surprising because it is based on the deep-tow record. A maximum reversal rate of ~14 rev/m.y. is found at 167 Ma, followed by a decrease in reversal rate. A secondary peak of 12 rev/m.y. is found at 160 Ma. Such rapid reversal rates are supported by the existing continental mag-

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[1] GSA Data Repository item 2006163, Table DR1, Deep-tow polarity reversal model boundaries and ages with reversed polarity periods identified, is available online at www.geosociety.org/pubs/ft2006.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

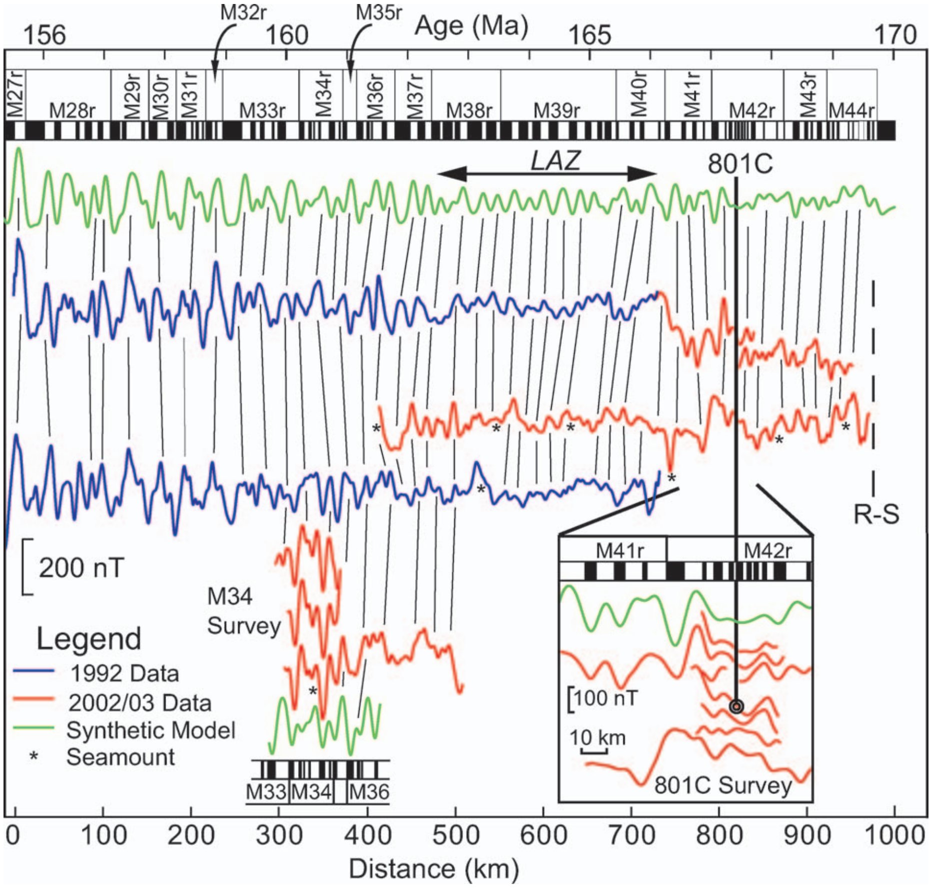

Figure 2. Composite plot of deep-tow magnetic anomalies measured across Pacific Jurassic quiet zone continued upward to mid-water level (3 km depth) and projected onto 135° azimuth. Inset shows correlation of detailed surveys around Hole 801C. Red lines are new 2002–2003 data, blue lines are 1992 deep-tow profiles, and green line is forward model based on block model shown at top (Table DR1; see footnote 1). Amplitude of forward model is based on that of observed data. LAZ refers to low-amplitude zone from M38 through M40. Asterisks indicate small seamounts that disturb overlying magnetic field. R/S indicates rough-smooth boundary of Abrams et al. (1993) and Handschumacher et al. (1988).

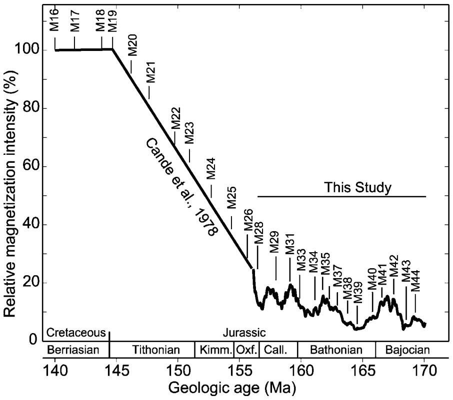

Figure 3. Magnetic anomaly amplitude plot following McElhinny and Larson (2003), showing decrease in anomaly amplitude beginning at M19 and continuing until M39, after which amplitude is variable.

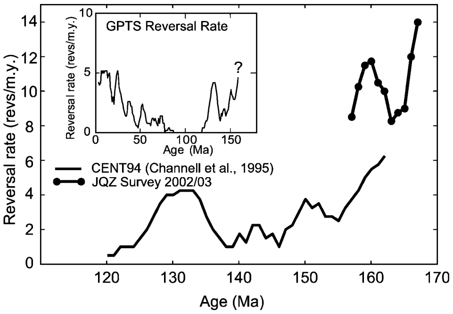

Figure 4. Reversal rate plot of Jurassic crust showing peak in reversal rate of 12 rev/m.y. at 160 Ma followed by decrease and then increase to 14 rev/m.y. Reversal rate calculated using 4-m.y.-wide sliding window every 1 m.y. using CENT94 (Channell et al., 1995) and compared with block model based on new survey data over Jurassic quiet zone (JQZ) (Table DR1; see footnote 1). Inset shows complete marine geomagnetic polarity time scale (GPTS) reversal rate.

netostratigraphic work (Ogg, 1995; Ogg and Gutowski, 1996; Steiner et al., 1985; Steiner and Ogg, 1988). The peak in reversal rate at 160 Ma was checked by obtaining a set of three profiles over this rapidly reversing sequence of M33–M34 (Fig. 2). The anomalies show a strong correlation over a lateral distance of 10 km, suggesting that ocean crust accretion is sufficiently rapid that an accurate and unambiguous record of rapidly varying field behavior can be recorded by the crust. It is also clear that the age of the crust (older than 160 Ma) has little influence on the overall fidelity of this record.

CONCLUSIONS

From our results, we can state that magnetic reversals occur throughout the JQZ, although the exact reversal rate is uncertain because we cannot unambiguously identify reversals from magnetic profiles alone. Anomaly amplitude decreases monotonically until M37 (162.5 Ma), where anomalies become difficult to correlate due to their weak amplitude for a period of 4 m.y., which we call the LAZ. A period of weak geomagnetic field intensity where intensity fluctuations dominate over polarity reversals is one possible reason for the existence of the LAZ. Alternatively, the LAZ could be a disrupted zone, perhaps with Cretaceous lava overprints, or a diffuse zone of spreading, because we see a change in azimuth of spreading from 25° prior to this period to 45° after this period. Prior to the LAZ, anomaly amplitudes are strong up to the R-S boundary. The overall trend of weakening anomaly amplitudes into the JQZ gives rise to the appearance of a quiet zone. Nevertheless, we find ample evidence of magnetic reversals, most notably at Hole 801C, where correlatable anomalies are clearly present and the downhole logging and rock core results (Steiner, 2001; Tivey et al., 2005) suggest that directional changes (i.e., reversals) rather than intensity changes are responsible for the anomalies.

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