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Cretaceous paleomagnetic apparent polar wander path for the Pacific plate calculated from Deep Sea Drilling Project and Ocean Drilling Program basalt cores

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Abstract

The apparent polar wander path (APWP) of the Pacific plate still has many uncertainties owing to the fact that paleomagnetic data are difficult to obtain for oceanic plates. After more than three decades of coring by the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) there are now a large number of reliably dated basalt cores recovered from the Pacific plate and this provides an opportunity to determine paleomagnetic poles based on igneous rock samples, considered by many scientists to be the most reliable data type. Cretaceous Pacific plate basalt core data were compiled, corrected using a standard technique, divided into groups based on age, and combined to calculate five mean paleomagnetic poles with ages of 80, 92, 112, 121, and 123 Ma, the latter two being for two different coeval regions. In all pole analyses, the lack of azimuthal orientation for cored samples leads to large uncertainties in pole locations along a nearly east–west direction. This difficulty was mitigated by using declination data from magnetic anomaly inversions of dated Pacific seamounts for azimuth constraint. The two nearly same-age poles were calculated because paleocolatitudes from Ontong Java Plateau (OJP) are discordant compared to those from other Pacific locations. I interpret the discordant OJP results to indicate that the plateau is on crust that had an early history as an independent plate. The other poles (80, 92, 112, and 123 Ma) fall on a northeast-trending line that suggests slow apparent polar wander during the Early and mid-Cretaceous, followed by rapid polar wander between 92 and 80 Ma. Comparison of the 123 Ma pole with previously published paleomagnetic data of Jurassic age implies southward apparent polar wander followed by a turnaround. Because the 123 Ma pole is the farthest from the geographic pole, it implies the turnaround happened near that time and that the Pacific plate has moved ∼40° northward since then. The 80 Ma pole stands ∼17° from the geographic pole, indicating that ∼60% of the northward drift occurred prior to that time and ∼40% afterwards.

Keywords: Pacific plate; Paleomagnetism; Cretaceous; Mesozoic; Paleomagnetic pole; Basalt; Polar wander; Deep Sea Drilling Project; Ocean Drilling Program

1. Introduction

Paleomagnetic APWP have far-reaching implications because they reflect plate motion and are therefore useful for understanding tectonics, reassembling continents, and for back-tracking sites used for paleoclimate studies. In addition, they likely contain information about the long-term behavior of the geomagnetic field (e.g., non-dipole geomagnetic field components) and motion of the spin axis relative to the mantle (i.e., true polar wander, TPW) (e.g., Livermore et al., 1984; Besse and

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Courtillot, 2002). For most continental plates, a large number of individual paleomagnetic poles exist that can be averaged to produce an APWP, often using a sliding window in age with a width of 10–30 Myr. The result can be a detailed APWP that describes much of the tectonic history of that plate (e.g., Irving and Irving, 1982; Besse and Courtillot, 2002).

The situation for oceanic plates is much different because it is difficult to obtain oriented samples from the ocean bottom. As a result, fully oriented sample measurements, the type of paleomagnetic data most often gathered from land, are rare. The Pacific plate is a notorious example of this problem. Despite being the largest plate on Earth, the number of fully oriented outcrop paleomagnetic data are few and restricted mostly to young islands. Instead, most Pacific paleomagnetic data are either derived from geophysical data, such as inversion of seamount magnetic anomalies (Richards et al., 1967) or asymmetry analysis of magnetic lineations (Schouten and McCamy, 1972; Cande, 1976), or they are measured from samples obtained in azimuthally unoriented cores (Cox and Gordon, 1984). As a result of both the scarcity of sample data and uncertainties about errors in some data types, the Pacific APWP is poorly defined and major trends and features of the Pacific APWP are still a source of debate (e.g., Sager and Koppers, 2000; Cottrell and Tarduno, 2000; Riisager et al., 2004).

Because basalt flows are usually considered to be accurate recorders of geomagnetic field direction, basalt core data may be the most reliable of all oceanic data sets. The trouble with basalt core data has been their relative scarcity, inaccurate or absent radiometric dates, and the fact that measurements from many igneous units are necessary to average secular variation. During the DSDP, few holes drilled deeply into basalt, so the total number of basalt core paleomagnetic data was small. Nevertheless, Cox and Gordon (1984) summarized Pacific DSDP basalt core paleomagnetic data and calculated two poles, for Early and Late Cretaceous, consistent with other types of paleomagnetic data. They also predicted a hook shape for the Pacific APWP (Fig. 1). After 20 years of additional coring by the ODP, there are significantly more basalt core paleomagnetic data for the Pacific plate. In addition, radiometric dating techniques have greatly improved (e.g., Pringle, 1993; Koppers et al., 2003a,b), so that now many basalt cores have high-precision dates. This situation suggests that Pacific basalt core data can be re-examined profitably. In this study, I analyze Cretaceous Pacific DSDP and ODP basalt core data and calculate paleomagnetic poles for age groups with sufficient numbers of independent magnetic units. This study is focused on Cretaceous cores because few pre- and post-Cretaceous data are available. The objective was to define the Cretaceous APWP with basalt data and to examine polar wander trends.

1.1. Prior results: Pacific APWP

Published poles for the Pacific APWP give an outline of polar motion and provide several working hypotheses that may be examined with new data. The proposed hook shape of the APWP implies southward polar motion during the Late Jurassic and Early Cretaceous (Larson and Lowrie, 1975; Cox and Gordon, 1984; Larson and Sager, 1992), a turnaround and possible stillstand ∼35° from the spin axis (Tarduno and Sager, 1995), and subsequent northward motion during the Late Cretaceous and Cenozoic (Cox and Gordon, 1984; Sager and Pringle, 1988). One version of the APWP contains a rapid spurt of northward polar motion at ∼84 Ma (Sager and Koppers, 2000); although, some researchers doubt this event because of uncertainty about the reliability of seamount magnetic anomaly inversion data on which it is based (Cottrell and Tarduno, 2000). One independent, global composite APWP based on continental rock data suggests an earlier rapid shift may have occurred at ∼110 Ma owing to TPW (Prévot et al., 2000) and because this is a global event, should be reflected in the Pacific APWP.

Poles for defining Cretaceous Pacific APWP are mainly derived from core and remote geophysical data, each with certain limitations and uncertainties. Many of the paleomagnetic poles used to define the APWP are from inversions of magnetic anomalies over seamounts (Richards et al., 1967; Sager and Pringle, 1988; Sager and Koppers, 2000). Two critical assumptions of this method are that a seamount has an overall homogeneous magnetization (or nearly so) and that the magnetic anomaly is caused solely by remanent magnetization. These assumptions may be a good approximation for some seamounts because many Cretaceous Pacific seamount anomalies are simple and consistent with an overall magnetic homogeneity, many seamount poles have consistent locations, and many agree with independent paleomagnetic data (Sager, 1987; Sager and Pringle, 1988). Nevertheless rock magnetic data indicate that induced and/or viscous magnetization may be significant in some seamounts (Gee et al., 1989) and some seamount paleomagnetic poles imply the same (Sager et al., 1993; Sager, 2003). As a result, some researchers question the validity of conclusions based on seamount anomaly data (Parker, 1991; Cottrell and Tarduno, 2000).

Another geophysical technique that has been used to obtain Pacific paleomagnetic poles is the analysis of