THE ORIGIN AND TECTONIC HISTORY

OF THE

SOUTHWEST PHILIPPINE SEA

by

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BIOGRAPHICAL SKETCH

I was born in Washington, D.C. on July 11, 1948. My youth and adolescence was spent in Falls Church, Va. except for 1964-65 when I lived in Baghdad, Iraq and attended Al-Hikma University. I attended Oberlin Colege, Oberlin, Ohio during 1966-70 where I received a B.A. with honors in physics. From 1970 to 1972 I taught physics and 9th grade science at Swarthmore High School, Swarthmore, Pa. and attended Temple University, Philadelphia, Pa. where I finished an M.Ed. in 1972. In 1972 I entered the Dept. of Earth and Planetary Sciences at MIT, Cambridge, Ma. and transfered into their Joint Program in Oceanography with the Woods Hole Oceanographic Institution, Woods Hole, Ma. in 1973. In Oct. 1976 I shall become a Senior Assistant in Research in the Dept. of Geodesy and Geophysics, Cambridge University, Cambridge, England.

My publications include:

(1) Sclater, J.G., D. Karig, L.A. Lawver, and K. Louden, Heat flow, depth, and crustal thickness of the marginal basins of the South Philippine Sea, J. Geophys. Res., 81, 309-318, 1976.

(2) Louden, K.E., Magnetic anomalies in the West Philippine Basin, in _The Geophysics of the Pacific Ocean Basin and Its Margin_, Geophys. Monogr. Ser., vol. _19_, AGU, Washington, D.C., in press, 1976.

(3) Louden, K.E., and D.W. Forsyth, Thermal conduction across fracture zones and the gravitational edge effect, J. Geophys. Res., in press, 1976.

(4) Louden, K.E., Paleomagnetism of DSDP sediments and basalt, phase shifting of magnetic anomalies, and rotations of the West Philippine Basin, submitted to J. Geophys. Res., 1976.

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Keith Edward Louden

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ABSTRACT

This thesis is a collection and analysis of sea-floor magnetic anomalies, bathymetry, and the paleomagnetism of DSDP sediments and basalt in the West Philippine Basin, in an attempt to resolve questions about its origin as a marginal basin. Our results suggest that this basin was formed in an Eocene pulse of rapid spreading ($v_{1/2}$ = 41-44 mm/yr) in a direction (N 21°E) significantly different from later pulses which opened the more eastern basins of the Philippine Sea. The Central Basin Fault appears to be intimately associated with this spreading by nature of its structure and trend, and it may be a remanent of a former ridge system. Our preliminary calculation of paleopole positions also suggests that there was a large amount (60°) of clockwise rotation between this basin and the magnetic pole. This is consistent with rotations of the Pacific plate with respect to the magnetic pole and current directions of Philippine-Pacific relative rotations. Basement depths of 6 km in the West Philippine Basin imply that its crustal and/or lithospheric structure is different from Pacific structure of the same age.

Thesis Supervisor: John G. Sclater
Title: Associate Professor of Geophysics

SECTION I

INTRODUCTION

Much of the West Pacific margin consists of oceanic basins separating its deep trenches and their associated volcanic island arc chains from the adjacent continents of Australia and Eurasia. The origins and history of these marginal basins have long remained a controversial enigma to both past and present global tectonic theories. Pre-plate tectonic hypotheses considered these regions to be former continental areas that had subsided (e.g. Marshall, 1910; Kuenen, 1935; Glaessner, 1950). Mechanisms for this subsidence included subcrustal erosion (Lawson, 1932), crustal warping due to compression (Umbgrove, 1947) and oceanization (Beloussov and Ruditch, 1961), among many others. It wasn't until seismic refraction techniques became available in the deep oceans during the late 1950's and early 1960's that it was discovered that the crust beneath these basins was similar to that of normal oceans (Gaskell et al., 1959; Shor, 1964; Murauchi et al., 1968). These results have disproven many of the earlier theories, and while some (e.g. Beloussov, 1967) still remain possible, they are currently not widely accepted in the West.

Theories contrasting to those with continental origins include the continental drift theory of Wegener (1929) which treated these basins as extensional gaps left behind the trailing edge of a moving continent, and the expanding earth theory of Carey (1958) which considered them as extensional 'rhombochasms' between large scale lithospheric units. There were also various compressional theories which explained the arcs within and adjacent to the marginal basins as manifestations of convection currents (Vening Meinesz, 1951; Holmes, 1965; Wright, 1966; Menard, 1964). These were predated by the earlier tectogene folding concepts of Hess (1948).

The advent of global plate tectonic concepts (Wilson, 1965; McKenzie and Parker, 1967; Morgan, 1968; LePichon, 1968), in which trenches were considered to be sites of lithospheric subduction, added more justification to these compressional theories. Problems remained, however, since it was found that high heat flow and shallow water depths, which normally are associated with active intrusion and crustal extension (Sclater and Francheteau, 1970), were reported well to the west of the island arc chains (Yasui and Watanabe, 1965; Vacquier et al., 1966; Yasui et al., 1968a, 1968b, 1970; Sclater and Menard, 1967). This high heat flow has presented major problems to the plate model (McKenzie and Sclater, 1968; Oxburgh and Turcotte, 1970).

It was not until Karig (1970) reported new evidence suggesting that crustal extension did in fact exist behind the Tonga-Kermadec island arc, that the earlier extensional theories (Deitz, 1954; Carey, 1958; Murauchi and Den, 1966; Tanner, 1968) were revived. This pioneering study was later supported by additional strong evidence of extension behind the Mariana island arc (Karig, 1971a), and led to several attempts at placing this 'inter-arc spreading' hypothesis within a plate tectonic framework (Karig, 1971b; Pacham and Falvey, 1971; Sclater, 1972; Moberly, 1972). The primary result of this work was that there appeared to be significant differences between values of heat flow and depth vs. age in the older and now no longer active marginal basins and typical results for the normal oceans. This seemed to suggest that either the crust (Karig, 1971b) or the entire lithosphere (Sclater, 1972) was thinner than normal.

Such attempts at synthesizing and comparing geophysical data in marginal basins to pre-existing global plate tectonic models have been severely hampered by several problems. Evidence for extension within active marginal basin troughs is limited and depends primarily on identification of certain topographic morphologies and sediment distribution patterns. Geochemical analysis on a few basalts dredged from the Mariana and Lau basins also shows strong similarities to rocks from major ocean ridge systems. The amount of detailed geophysical data is limited to a few well surveyed regions in these same active troughs, but the recognition of adaquate magnetic anamaly patterns that can be unambiguously identified to world-wide magnetic reversals is confined to other areas such as the Scotia (Barker, 1972) and Tasman (Hayes and Ringis, 1973) seas, which do not conform very well to the type inter-arc spreading model of Karig (1971b). This has meant that unique evolutionary histories of spreading within even the most clearly defined and well studied basins is not yet possible. Controversies exist between possibilities of these basins being either old, trapped oceanic crust or younger crust formed by inter-arc spreading. It is not yet clear whether inter-arc spreading is any different from ridge spreading in normal oceans, whether the older marginal basins have been formed in the same manner as now occurs in the active troughs landward of their island arcs, and whether the many separate marginal basins have a common origin.

Until there exist more unambiguous data, particularly basement ages from both magnetic anomaly identifications and DSDP cores, current geophysical and geological disputes over the origins of specific marginal basins cannot be resolved. It is the purpose of this thesis to add new constraints to the history of one such marginal basin, the West Philippine Basin, in hopes that this data can help to resolve present controversies over its history (see the introduction to section II) and contribute toward the over-all goal of understanding the basic processes at work in all such marginal basins. Toward this end we have done the following:

(1) Collected and plotted most of the existing magnetic data in the Philippine Sea (Appendix B),

(2) Mapped and identified a set of magnetic lineations across the Central Basin Fault in the West Philippine Basin (Section II), and

(3) Performed a detailed paleomagnetic study on basalt and sediment samples from DSDP sites 292, 290 and 294 (Section III).

Analysis of these additional data leads to the following results:

(1) The West Philippine Basin was formed south of the equator by rapid spreading ($v_{1/2}$ = 41-44 mm/yr) during the mid-to-late Eocene (35-50 mybp).

(2) The Central Basin Fault seems to be intimately associated

with this spreading by nature of the structure and trend of its topography. In addition, its deep central rift is also characteristic of the fossil ridges near the Galapagos spreading center (Anderson *et al.*, 1976). Thus the typical association in marginal basins of magnetic anomalies with bathymetric features similar to mid-ocean ridges is continued by the results of this study.

(3) The direction of this former spreading must have been distinctly different from that which exists today along the Mariana and Izu-Bonin arcs. Thus a more complicated tectonic development than originally suggested by Karig (1971a) is inevitable.

(4) Phase shifting of the magnetic anomalies and analysis of the paleomagnetic data for DSDP samples indicates that a significant rotation of the West Philippine Basin has occurred since it was formed. This result agrees with the hypothesis of Uyeda and Ben-Avraham (1972) that this basin might be a remanent of the former Kula-Pacific ridge system of Larson and Chase (1972).

(5) The well-defined age determination of the West Philippine Basin leaves little doubt that there is a significant discrepancy between its depth of over 6 km and normal depths of 5 km for oceanic crust of a similar age. The reasons for

such an offset are as yet unknown, although as earlier suggested by Karig (1971b) and Sclater (1972), the crust and lithosphere might be significantly different than normal (Appendix A; Sclater et al., 1976; Seekins and Teng, 1976). (6) There is no need in our analysis to require either non-rigid plate interactions between the Philippine and Pacific plates nor significant rotation due to inter-arc spreading. Paleomagnetic pole positions for the West Philippine Basin are consistent with present day plate motions as determined by earthquakes on the margins of the Philippine Sea (Katsumata and Sykes, 1969; Fitch, 1972; Karig, 1975). Furthermore, the paleopole positions for Guam (Larson et al., 1975) which lies on this boundary is also consistent with such a polar wandering curve. This implies that rotations along the island arc chain need not be of separate origin to the rotation between the major plates.

What becomes clear from this study is the necessity for further measurements in the Philippine Sea of the basic physical properties of its crust, upon which all other analyses rely. These include the seismic structure of the deep water basins and the magnetic properties beneath sea-floor spreading anomalies. When these measurements are made we can begin to form additional concrete constraints on the geophysical processes which have formed this one example of a marginal basin. The uniqueness or generality of this one example among many will remain uncertain for the immediate future.

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SECTION II

MAGNETIC ANOMALIES IN THE WEST PHILIPPINE BASIN

ABSTRACT

We present a comprehensive collection of magnetic anomalies in the West Philippine Basin together with several bathymetric profiles and nannofossil age dates for JOIDES sites 290 and 291. From this data we locate symmetric magnetic anomalies that have strikes roughly parallel to the Central Basin Fault. They can be identified as numbers 17-21 if the basin originated south of the equator and opened at a rate of 41-44 mm/yr. This adds justification but not total proof for the theory that the Central Basin Fault may be an extinct spreading center which slowed and then ceased spreading 40 m.y. ago. It is still possible that island arc spreading created these anomalies, but if so, the origin and evolution of such an arc cannot be simply connected to the later development of the Parece Vela and Shikoku Basins to the east. Other results show that the elevation of this region is 1 km lower than would be observed for similar aged crust in the North Pacific. If the JOIDES dates and our anomaly interpretations are correct, then the lack of a correspondingly large negative gravity anomaly suggests major differences between this extinct ridge and those known to be currently spreading.

INTRODUCTION

One of the most significant difficulties in the original formulation of plate tectonics was its failure to account for tensional features on the concave side of island arcs. Karig's later analysis of these features (Karig, 1970, 1971a) which he synthesized into his theory of inter-arc spreading (Karig, 1971b, 1974) has therefore been a major contribution to our understanding of these marginal basins. Unfortunately, there is as yet little geophysical proof that older, and now no longer active, sections of marginal basins were formed by the same processes that we observe in active troughs. This is important since only a small fraction of these basins are presently active.

The study of magnetic anomalies which could presumably yield new insights into the origins of inactive marginal basins have so far had mixed success. Results fall into two general categories:

(1) Characteristic anomalies are not apparent, but there are low amplitude lineations parallel to the trench.

(2) Characteristic anomalies that can be correlated to world-wide events are observed together with a well-defined bathymetric ridge.

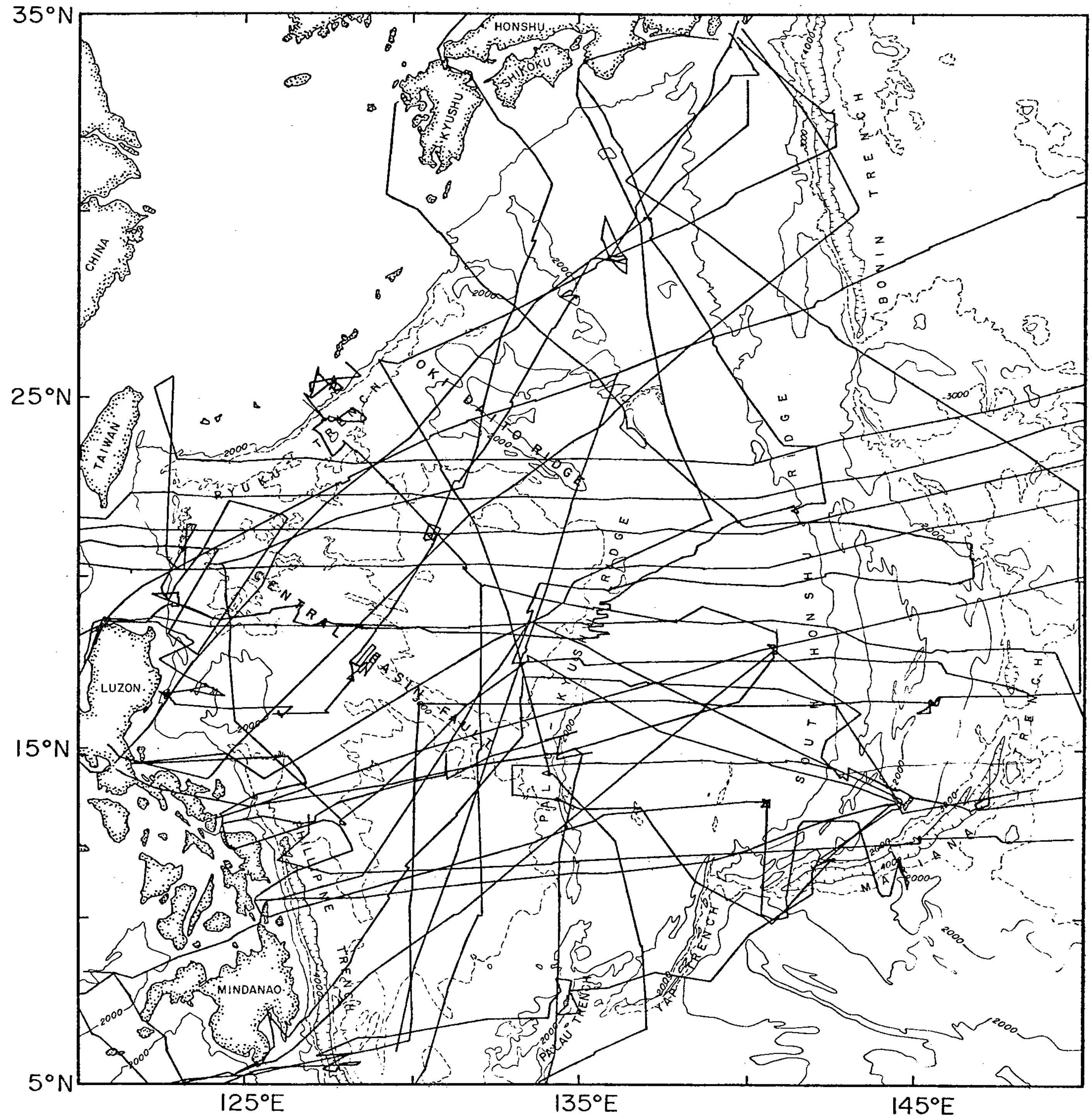
The Japan Sea typifies the first case (Isezaki and Uyeda, 1973) and is similar to what is observed in the actively spreading basins of the Tonga (Lawver, personal communication) and Mariana (Karig, 1971a) island arcs. The apparent lack of characteristic magnetic signatures is explained by the diffuse nature of inter-arc as opposed to mid-ocean ridge spreading, and is one of the differences that distinguish these two spreading modes (Karig, 1970; Matsuda and Uyeda, 1971). The second type is observed in the Tasman (Hayes and Ringis, 1973) and Scotia (Barker, 1972) seas and is typical of mid-ocean ridges.

The possibility of ridge spreading in marginal basins raises several questions. If ridge spreading exists, is it related to inter-arc spreading or are there two separate processes that together determine the history of these basins? Can such ridge spreading be related to mid-ocean ridge systems of the past or does it have a separate origin?

A good place to seek the answer to these questions lies in the Western Philippine Sea. This region (Figure 1) is separated from the eastern sections of the Philippine Sea by the Oki-Daito and Palau-Kyushu Ridges. Its main bathymetric feature is the Central Basin Fault (Hess, 1948) which runs NW-SE and splits the area into nearly equal halves. This trend is quite different in direction to that observed in the ridges to the east, which run north-south and parallel to the Mariana and Bonin trenches. What makes the West Philippine Basin of interest is that it is the only region where ideas favoring alternative modes of spreading have been in direct dispute. Karig proposed that this region was formed in an Eocene pulse of inter-arc spreading - an older manifestation of what is presently occurring in the Mariana Trough (Karig,

FIGURE 1

Ship tracks superimposed on a 2000 m, 3000 m, and 4000 m contour map of the Philippine Sea (Chase and Menard, 1969). Major bathymetric features are identified.


35°N
25°N
15°N
5°N
125°E
135°E
145°E
HONSHU
SHIKOKU
KYUSHU
CHINA
TAIWAN
LUZON
MINDANAO
BONIN TRENCH
RYUKYU TRENCH
OKI DAITO RIDGE
CENTRAL BASIN FAULT
KYUSHU RIDGE
SOUTH HONSHU RIDGE
PALAU TRENCH
YAP TRENCH
PHILIPPINE TRENCH
MARIANA TRENCH
2000
3000
4000