Chapter 20

The Opening of the Southern Gulf of California

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ABSTRACT

The Gulf of California is a young ocean basin formed by oblique extensional motion between the North American and Pacific plates and is an example of a common class of rifts. We have developed a tectonic history for the southern Gulf based on recently obtained geological and geophysical information along with older observations. We determine rift timing and rates using as constraints the width of the Gulf, magnetic anomaly patterns, the uncentered position of the Rivera Rise within the Gulf, and the time of deposition of the Magdalena Fan. With these constraints, we construct three alternative opening models, each consistent with the available information. We propose that initial rifting of continental crust in the area began approximately 14 Ma, and that the oceanic crust was exposed no later than 8.3 Ma. Finally, we conclude that Baja California has experienced a total of 450 to 600 km of right-lateral translation since 14 Ma. This amount of displacement is greater than that which can be accommodated on the San Andreas fault zone (a term we will use for the San Andreas, San Jacinto, and Elsinore faults in southern Alta California) and must have been carried in part on faults across northern Baja California and in the offshore Continental Borderland.

INTRODUCTION

The Gulf of California is a young ocean basin formed by oblique rifting of part of the Pacific margin of the North American continent. Its rift origin is obvious in its morphology and, in fact, just the shape of the Gulf coast was included in evidence used by Wegener (1924) to support his theory of continental drift. Because the Gulf of California is one of the few places in the world where a mid-ocean spreading ridge can be traced directly into a continental rift system, it has been studied repeatedly to better understand the earliest stages of ocean formation, as well as the last stages of continental breakup (Rusnak and Fisher, 1964; Moore and Buffington, 1968; Atwater, 1970; Karig and Jensky, 1972; Larson, 1972; Mammerickx, 1980; Ness and Lyle, 1981; Yeats and Haq, 1981; Moore and Curray, 1982). Considerable new information on the Gulf of California has recently become available, including the geophysical and geological data

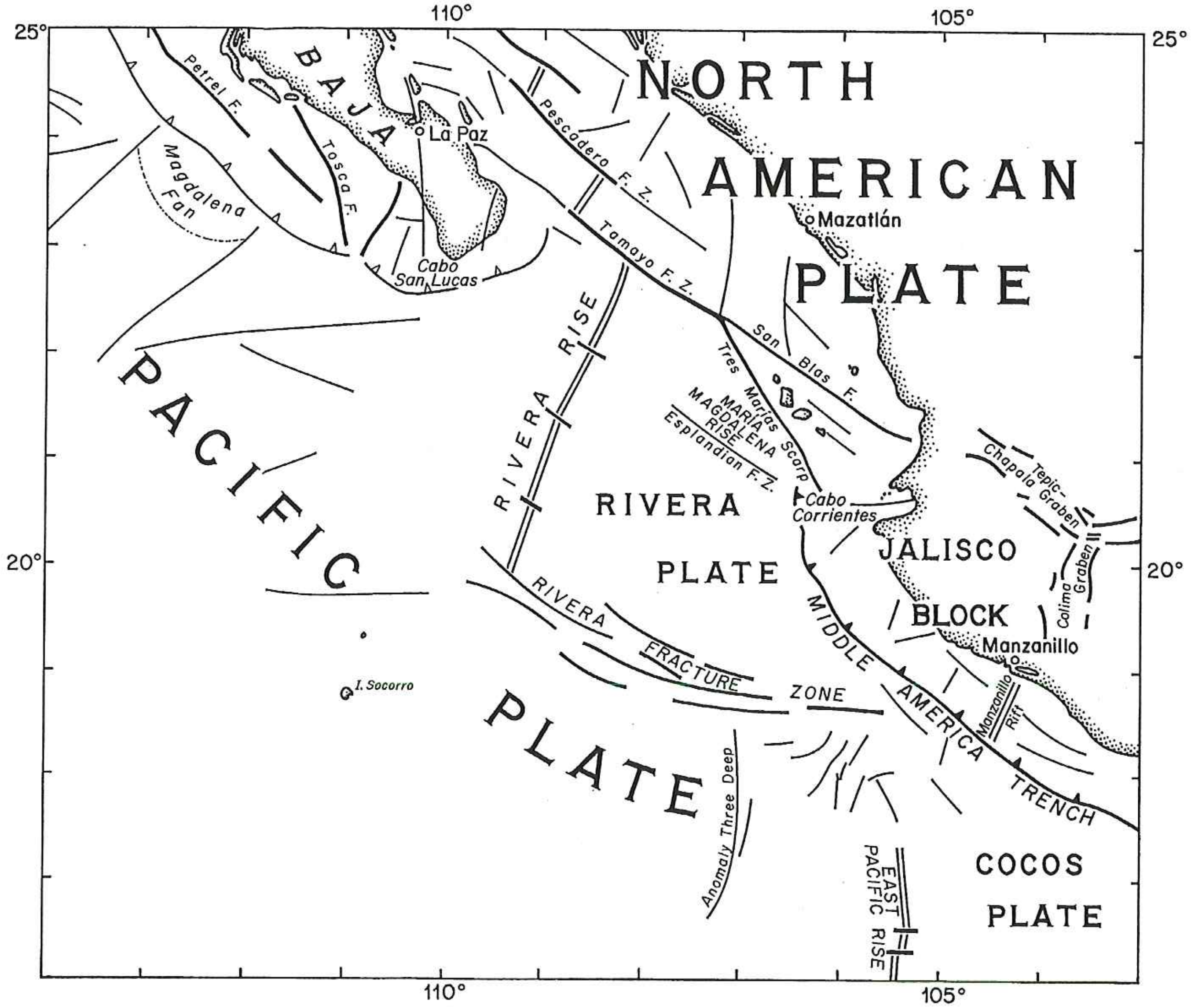


Figure 1—Tectonic and geomorphic features in the mouth of the Gulf of California. A fossil trench is shown west of the peninsula. Mercator projection.

presented in this volume and also Deep Sea Drilling Project results from Legs 63, 64, and 65 (Yeats et al., 1981; Curray et al., 1982; Lewis et al., 1983). We have incorporated the new data into three geometrical reconstructions of the opening history of the Gulf of California. Although the geologic and geophysical evidence available is still inadequate to permit the construction of a single history, only a limited number of testable models can satisfy the available data.

We confine our tectonic reconstructions to the mouth of the Gulf of California, southwest of the Pescadero fracture zone (Figure 1), primarily because of the lack of sufficient information to rigorously define the timing and geographic extent of tectonic events in the central and northern Gulf. Typical sea-floor spreading magnetic anomaly patterns are not found within the central and northern basins, and the northernmost basins themselves are nearly filled with sediments. Further field work is needed to better define the basement morphology and timing of rift-related tectonic events in the central and northern Gulf.

GENERAL ASPECTS OF RIFTING IN THE GULF OF CALIFORNIA

In the Gulf of California, rifting has caused the development of many of the morphologic features common to passive margins in the Atlantic Ocean, but the Gulf has an unusual assemblage of these features because of its youth and tectonic setting. Rifting within the Gulf of California has caused the breakup of what was previously a convergent continental margin. Today, within the southeastern mouth of the Gulf, very oblique subduction occurs along the Middle America Trench; to the north, the rift system connects to the San Andreas fault zone, including offshore transform faults. Similar rift environments are not uncommon.

Scrutton (1982) categorized two major types of passive margins, rifted and sheared. Rifted margins are formed approximately perpendicular to the direction of opening, whereas sheared margins are subparallel to the opening direction and form long, commonly en echelon transform

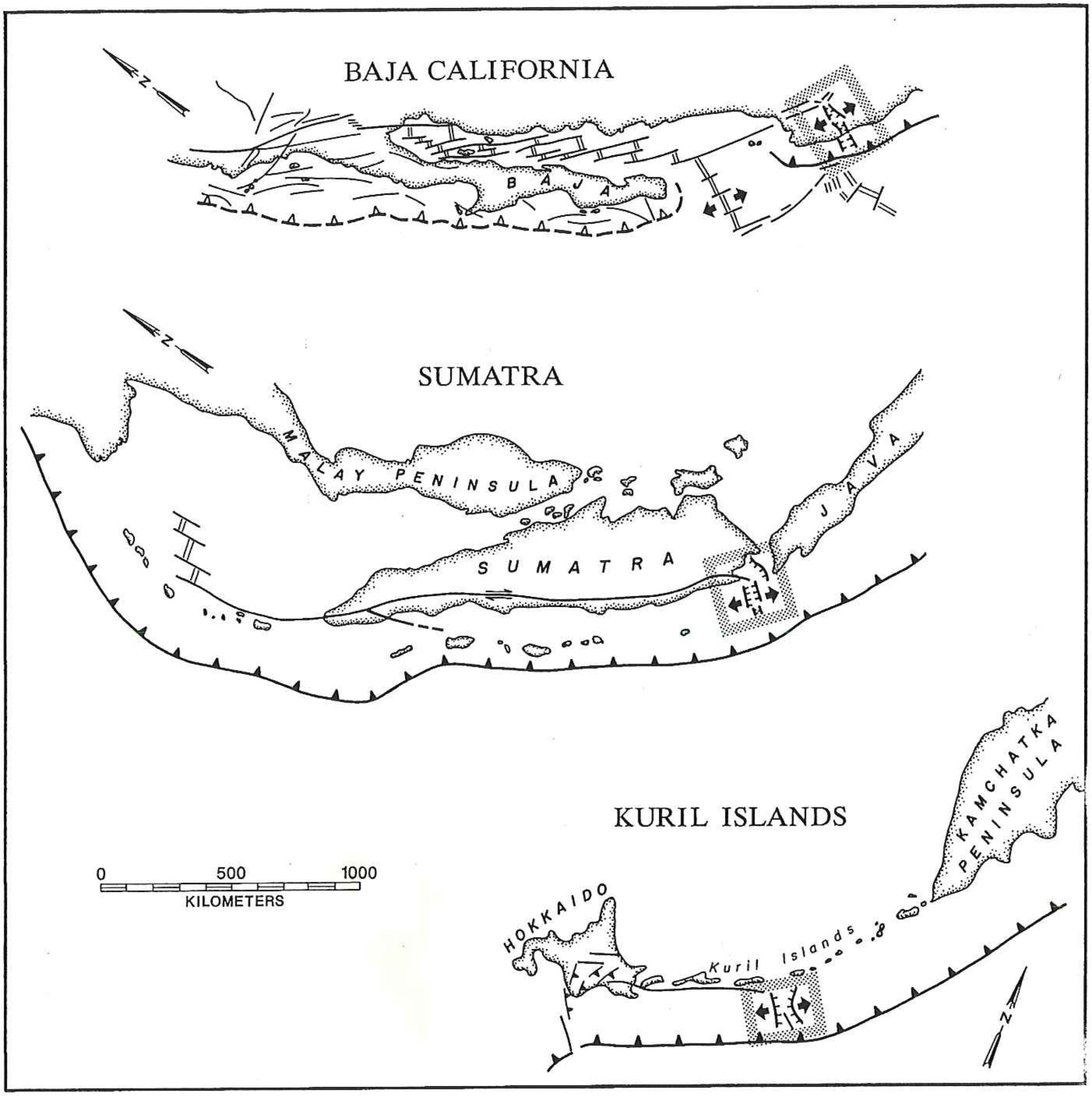


Figure 2—A comparison of rifting in the Gulf of California with other active margin rifts in the Pacific and Indian oceans. Rifting across the forearc is driven by oblique convergence and characteristically separates a continental block 200 to 300 km wide and at least 1000 km long. This block slides parallel to the margin. Depending on the regional tectonics, the forearc rift may connect with backarc spreading. Open teeth indicate an abandoned trench.

can margin during Farallon plate subduction prior to rifting. In other words, Baja California and Jalisco were completely joined; the Gulf was closed.

II. Gulf rifting defined by Pacific-North America plate interactions:

The directions of relative motion between blocks involved in Gulf extension are in general parallel to colatitudes about the Pacific/North American (PAC/NAM) pole of rotation. We also assume, in constructing our opening models, that the blocks could not move faster than the PAC/NAM relative rate of motion. As we have discussed more fully in a companion paper (Ness et al., 1990), the location of the PAC/NAM pole of rotation has been fairly well established. However, the PAC/NAM rate of relative motion is still controversial.

Estimates of the PAC/NAM relative rate made prior to 1982 (for example, 58 km/m.y. at the colatitude of the mouth of the Gulf; Larson and Chase, 1970) have been based

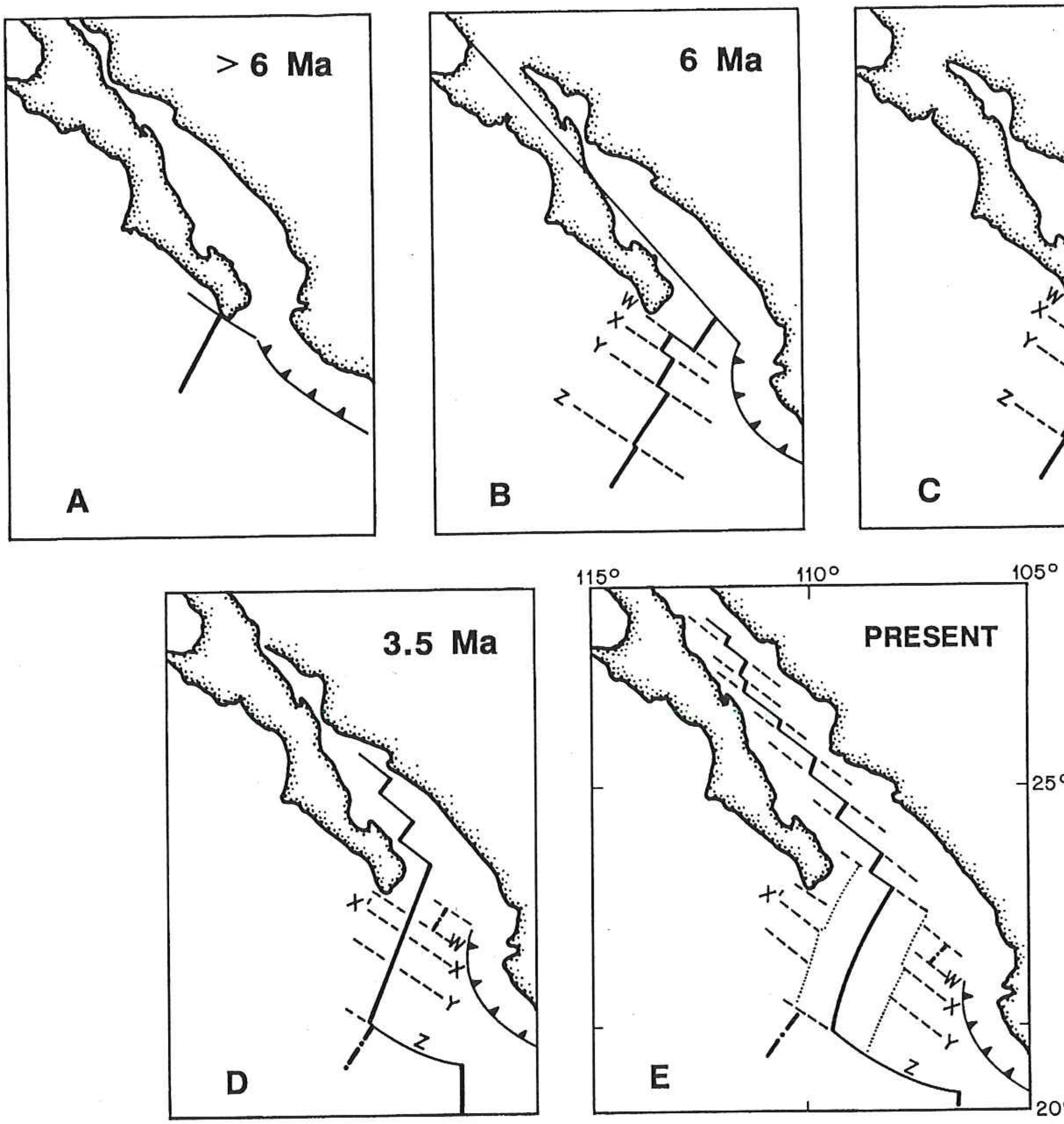


Figure 4—Mammerickx (1980) model of Gulf opening, in which two stages are needed to form the sea floor within the mouth of the Gulf. In this model, the Gulf of California began opening at about 6 Ma, but coherent spreading on the Rivera Rise was only initiated after a ridge jump at 3.5 Ma. W, X, Y, and Z are pre-3.5 Ma offsets of the Rivera Rise. W becomes the Esplandian fracture zone south of the Maria Magdalena Rise.

Moore and Curray were apparently driven to such a model by their wish to limit translation of the peninsula to 300 km on the San Andreas fault zone in Alta California and by their desire to use the age that Site 476 passed below sea level as a mark of initial rifting in the Gulf. There is considerable debate among California geologists as to how much shear between the Pacific and North American plates is distributed west of the San Andreas fault (Howell et al., 1974; Graham and Dickinson, 1978; Luyendyk et al., 1980). Recent investigations involving measured fault displacements, paleomagnetics, and precise geodetic surveys all agree that shear along the North American margin also occurs west of the San Andreas fault zone (Minster and Jordan, 1984; Hornafius et al., 1986; Weldon and Humphreys, 1986; Humphreys and Weldon, 1990). One recent study (Hornafius et al., 1986) concludes that 260 km of right-lateral shear has occurred west of the San Andreas fault since 16 Ma, compared with approximately 300 km of shear on the San Andreas during the same time period. Furthermore, vertical motions near the tip of the peninsula have involved both submergence and uplift since the mid-Miocene. Immediately on shore, at the tip of Baja California, the San Jose del Cabo Trough formed in the middle Miocene and subsided sufficiently to deposit relatively deep marine diatomaceous muds between 6.5 and 3.2 Ma (McCloy, 1984). Since that time, the trough has shoaled and is now above sea level. We attach no particular tectonic significance to the time Site 476 submerged.

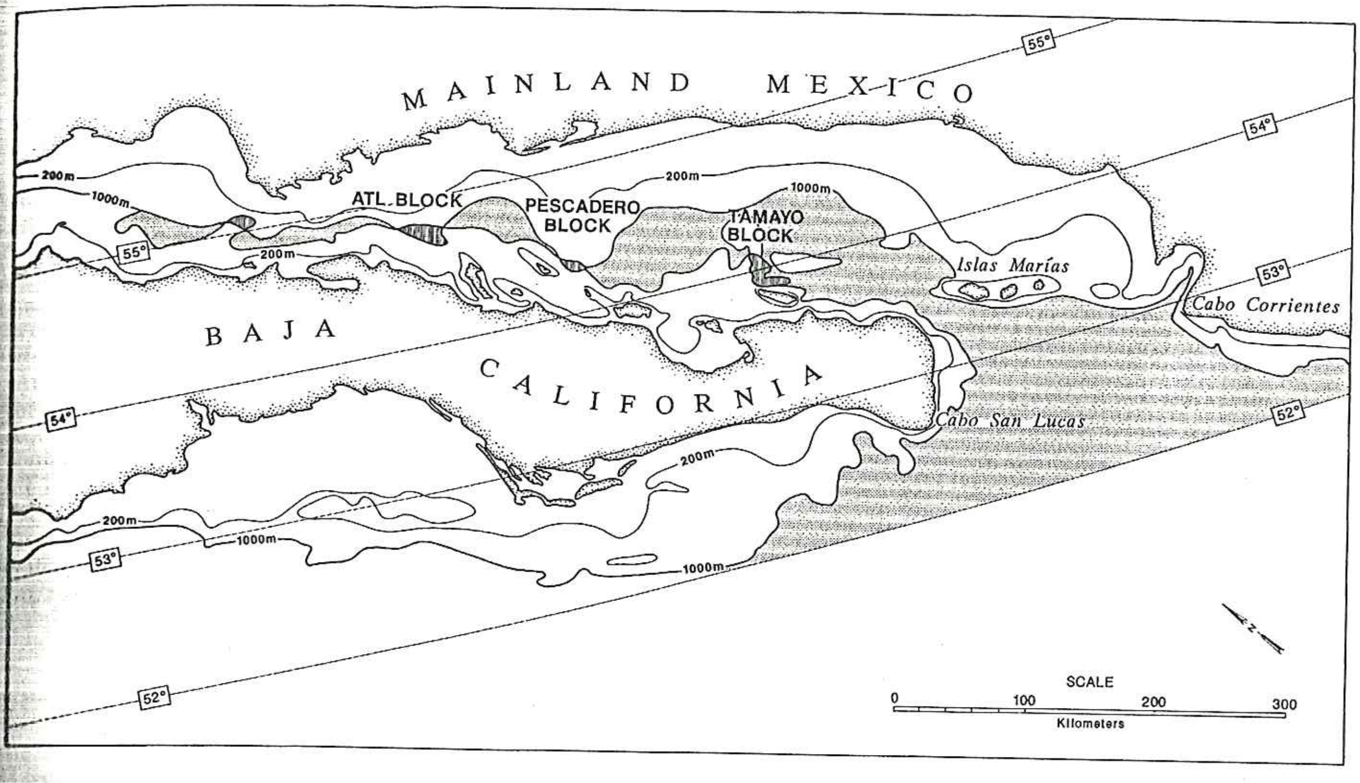


Figure 5—Moore and Curray (1982) closure of the mouth of the Gulf, redrawn here using bathymetry from Plate 2 (this volume). The initial position of the peninsula was determined by the size of basins in the northern and central Gulf of California and, principally, by the 300 km of motion known to have occurred along the San Andreas fault system. Note that this "closure" leaves four rhombochasms more than 1000 m deep in the southern Gulf, including an embayment approximately 150 km wide at the mouth and another of the same width interior to the Islas Marias. The smooth lines shown are lines of latitude about the PAC/NAM best-fitting-pole of Minster and Jordan (1978). They constitute the closure flow lines.

RECONSTRUCTING THE OPENING OF THE MOUTH OF THE GULF

We have developed three different reconstructions for the opening history of the Gulf of California; the first uses a "slow" PAC/NAM rate of about 50 km/m.y. from DeMets et al. (1987), and the second uses a "fast" 65 km/m.y. PAC/NAM rate from Ness et al. (1990). Both models use the idea presented by Mammerickx (1980), that sea-floor spreading began at a fossil spreading center represented by the Maria Magdalena Rise and then jumped northwest to the Rivera Rise at about 4 Ma. The third model shows that the uncentered position of the Rivera Rise within the mouth of the Gulf could have evolved without the necessity of a ridge jump.

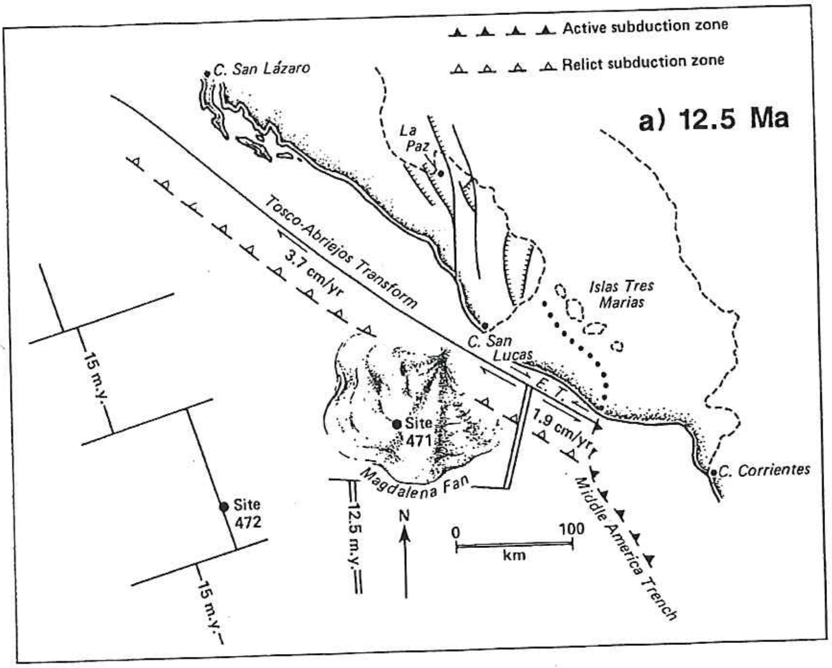
Each model is divided into an early, slow, continental rift phase of opening followed by sea-floor spreading. We have assumed that extension during early rifting was slow and only sufficient to expose true deep-sea floor. During this time most of the slip between the Pacific and North American plates occurred along the Tosco-Abreojos fault zone. In the subsequent sea-floor spreading phase, we have assumed that oceanic crust was always generated at the same rate as that observed today on the Rivera Rise (an average of 54 km/m.y.). These assumptions allow us to define a minimum age for the ocean basin within the mouth of the Gulf. Initial slow rates of extension during the sea-floor-spreading phase would require that the mouth of the Gulf be even older than indicated by our models.

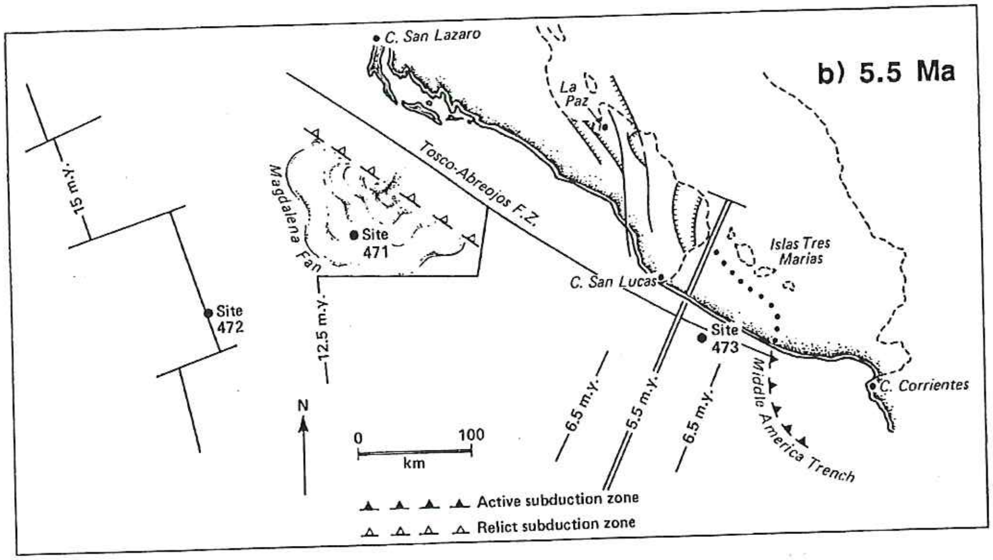
Other assumptions include: (1) the Magdalena Fan formed at the mouth of the Gulf during initial rifting, at approximately 14 Ma; (2) all the crust within the mouth of the Gulf (between the continental slopes of the peninsula and mainland Mexico) is oceanic and was generated by Gulf drifting; and (3) all the motion of blocks and plates involved in opening of the Gulf has been along PAC/NAM flow lines. For simplicity, in all the models shear between the Pacific plate and the peninsula is represented to have occurred at the base of the continental slope, despite the fact that the Tosco-Abreojos fault zone cuts across the continental shelf.

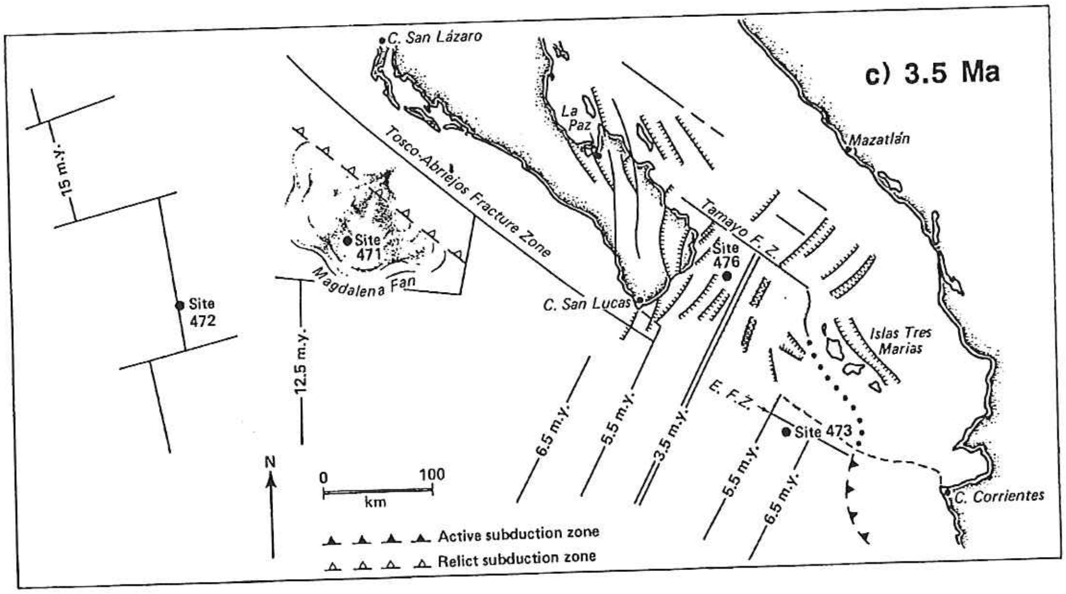
Model I—"Slow" (50 km/m.y.) Pacific/North American Relative Rate of Motion

The first model uses the DeMets et al. (1987) PAC/NAM relative rate of motion of about 50 km/m.y. and includes a fossil spreading ridge active prior to 4 Ma (Figure 7). The slow rate can be used to create a self-consistent model of Gulf rifting similar in many ways to the fast model.

The "slow" reconstruction has three important features. First, because the mouth of the Gulf is 450 km wide, sea-floor spreading must have started within the mouth of the Gulf no later than 9 Ma, after an initial rifting phase lasting 5 m.y. Because a PAC/NAM relative motion of 50 km/m.y. is slightly less than the average rate of crustal generation at the Rivera Rise (54 km/My), subduction (actually, highly


Active subduction zone
Relict subduction zone
a) 12.5 Ma
C. San Lázaro
La Paz
Tosco-Abriejos Transform
3.7 cm/yr
Islas Tres Marias
C. San Lucas
E. T.
1.9 cm/yr
Site 471
Magdalena Fan
15 m.y.
Site 472
15 m.y.
12.5 m.y.
N
0
100
km
Middle America Trench
C. Corrientes


C. San Lazaro
b) 5.5 Ma
La Paz
Tosco-Abreojos F.Z.
Magdalena Fan
Site 471
15 m.y.
Islas Tres Marias
C. San Lucas
Site 472
Site 473
12.5 m.y.
C. Corrientes
N
0
100
km
6.5 m.y.
5.5 m.y.
6.5 m.y.
Middle America Trench
Active subduction zone
Relict subduction zone


C. San Lázaro
c) 3.5 Ma
La Paz
Mazatlán
15 m.y.
Tosco-Abriejos Fracture Zone
Tamayo F. Z.
Site 471
Site 476
Magdalena Fan
Site 472
C. San Lucas
Islas Tres Marias
12.5 m.y.
6.5 m.y.
5.5 m.y.
3.5 m.y.
E. F. Z.
Site 473
6.5 m.y.
6.5 m.y.
N
0
100
km
C. Corrientes
Active subduction zone
Relict subduction zone