Continental rifting—the tearing apart of continents to form new ocean basins—is a fundamental process in the growth and evolution of continents. Throughout Earth’s history, continental rifting, in concert with plate tectonics, has exerted primary controls on the distribution of landmass on our planet, the nature of the landscape along the continents’ rifted margins, and the development of economic resources along these margins. Yet we lack a full understanding of both the magnitude and cause of the stresses that drive rifting, the deformational mechanisms of extension, and the key parameters that control this deformation. Basic questions persist about the style of lithospheric extension—whether it deforms symmetrically in pure shear or asymmetrically in simple shear; about the roles of lower-crustal flow, magmatism and sedimentation in evolving rift architecture; and about the sensitivity of rift evolution to variations in key parameters such as lithospheric strength and temperature, strain rate, and crustal thickness.

Answering these and other questions is a fundamental goal of the Rupturing Continental Lithosphere (RCL) initiative of NSF’s MARGINS program. The Gulf of California was selected as one of two focus sites for the MARGINS RCL. The Gulf of California is an excellent location to study rifting processes because rifting there is young (having started only 12 million years ago) and ongoing; the “mode” of rifting varies along the length of the Gulf - narrow and abrupt in the south, wide and diffuse in the north; and a large team of scientists at CICESE have been actively studying this problem for many years, providing a substantial resource of expertise in the area.

A crustal-scale, active-source seismic experiment, funded through NSF MARGINS, was conducted in the Gulf of California in the fall of 2002. This experiment aimed to image crustal structure across conjugate margins of major basins throughout the gulf with the goals of determining the modes of extension, the influence of sedimentation and magmatism on breakup, and other features leading to a better understanding of the rifting process. The experiment involved two ships, the R/V Maurice Ewing and the R/V New Horizon. The Ewing provided the acoustic source and acquired multi-channel seismic (MCS) data using a 6-km-long streamer, and the New Horizon tended to 206 deployments of ocean bottom seismometers (OBSs). MCS and OBS data were acquired along three flow line transects across Guaymas Basin, Alarcon Basin, and between Puerto Vallarta and Cabo San Lucas. A fourth, two-part, “coast-perpendicular” transect extended from the Pacific margin across the Baja Peninsula through Bahia de La Paz and, on the Mexican mainland, across the margin south of Mazatlan and up into the Sierras. Each of these transects was instrumented with OBSs spaced 10-15 km apart and similarly spaced seismometers on land recording the offshore shots to ~100 km inland.
Highlights of the experiment and some initial results include:

• The logistical and technical program of this experiment was extremely successful. The map in Figure 1 shows the distribution of combined MCS/wide-angle profiles (blue), OBS locations (white), MCS transects (yellow), and onshore RefTek seismometers (red). This experiment involved a record 206 OBS deployments and 90 RefTek deployments using two ships and 3 land crews. Data recovery is nearly 100% and the data quality is extremely good. This success demonstrates the capabilities of the new active-source OBS fleet and the feasibility of conducting onshore/offshore experiments of this scale.

• Initial results suggest that Alarcon Basin rifting was markedly amagmatic (Figure 2). The identification and characterization of failed rifting events, one of which had been speculated on by Peter Lonsdale and other workers, provides clues to the strength of the lithosphere here. With the first look at the data, the Alarcon rifting appears to have been more or less symmetric. This symmetry is not expected for such an amagmatic rift, and so questions remain. Many of these questions will be addressed through the detailed crustal images that result from the analysis of the wide-angle data.

• In Guaymas Basin, very preliminary results of the MCS and wide-angle data suggest an asymmetric rift that has been robustly magmatic (Figure 3). Most of the crust offshore appears to be new igneous crust formed at the spreading center, but the style of magmatic emplacement appears to be asymmetric. This magmatic asymmetry may be imposed by the tectonics or it may be a consequence of deeper mantle circulation. The spreading center is offset from the geographic center of the basin. Mantle upwelling, confined to larger spatial scales than tectonic processes, may be focused beneath the center of the basin, providing an asymmetric magma supply to the rift.

• At the eastern end of the Cabo San Lucas/ Puerto Vallarta transect (see Figure 1), we have discovered that the rifted margin there has already transformed into a convergent margin. In the classic Wilson-cycle paradigm for continent/ocean interactions, old oceanic lithosphere eventually initiates subduction along previously rifted continental margins. This usually takes nearly 200 million years. Along this transect, however, the mid-American trench has taken advantage of the weak margin lithosphere and propagated northward. This discovery provides a rare opportunity to study the evolution of continental lithosphere under the influence of subduction processes at the earliest of stages in evolution. This is a very exciting find.

We are extremely pleased with the success of the fall 2002 experiment. We have barely scratched the surface of what the data have to tell us about continental rifting processes. Moreover, these data will provide the framework for subsequent geologic studies that aim to fully delineate the extensional history of the region as well as geophysical studies such as the Ritsema and recently funded Garherty/Collins passive seismic experiments, which together will delineate the deeper mantle component of this dynamic system.
Figure 1: Distribution of combined MCS/wide-angle profiles (blue), OBS locations (white), MCS transects (yellow), and onshore RefTek seismometers (red). There were 206 OBS deployments and 90 RefTek deployments. Location of Alarcon MCS data shown in Figure 2 is indicated. The Guaymas velocity model shown in Figure 3 extends from coast-to-coast along the main transect.
Figure 2: Alarcon Basin MCS profile surrounding the spreading center (see Fig. 1 for location). A prominent failed rift is seen to the east. From the apparent depth to ‘basement,’ crustal rifting was probably complete here, but seafloor spreading began in another location. Extension in this basin involved the disassembly of the continental crust into a number of large rotated blocks, with nearly complete extension between several of them. The nature of the surface at the base of these rotated blocks is not yet clear, but it should become apparent when wide-angle data have been analyzed. OBS instrument spacing along this line is ~11km.

Figure 3: Velocity model along the Guaymas Basin transect based on preliminary crude analyses of only half of the offshore instruments. Onshore instruments were not used. Numbers indicate velocity in km/s. The upper blue layer consists of sediments. The green-yellow layer probably consists of a mixture of sills and sediments and is an oceanic "Layer 2" equivalent. The orange-magenta layer is plutonic igneous crust, probably all formed at the Guaymas spreading center. Asymmetry is manifest in several ways. The velocities of the plutonic crust to the east are higher (more mafic) and have less of a velocity gradient than the velocities to the west. "Layer 2" has substantially
higher velocities to the west, reaching 6km/s near km 225. The rift axis is displaced ~25km from the center of the basin, and the top of the plutonic crust there is characterized by a very large, low-angle, down to the east surface that, since it is at the plate boundary, is very likely a fault. It may be that melt rises near the center of the basin (km 300) and builds crust to the east via mostly underplating of more residual magmas, while more evolved magmas are transported up and westward, perhaps aided by tectonism, building the crust to the west and emplacing more magmas into “Layer 2.” If this speculation has some truth to it, then crustal formation in Guaymas Basin proceeds through a tectono-magmatic asymmetry which has not previously been envisioned.