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A PERMANENT SEISMOGRAPH ARRAY AROUND THE GULF OF CALIFORNIA

BY JAMES N. BRUNE, CINNA LOMNITZ, CLARENCE ALLEN, FEDERICO MOOSER, FRANCIS LEHNER, AND ALFONSO REYES

ABSTRACT

A permanent seismographic array has been established around the Gulf of California. Solar-powered stations are operating at Caborca, Bahia de los Angeles, Guaymas, Topolobampo and La Paz. Trailer stations using local 60-cycle power are operating at San Felipe, Rio Hardy, Rancho Meling, and Ensenada. The array is unique in the following aspects: (1) It is the only array operating in close proximity to an active region of sea-floor spreading; (2) its sophisticated low-power design and use of solar energy made siting choices simpler so that local noise sources could be minimized; (3) it is the first accurately timed array to operate in northwest Mexico.

The array has already provided important information on seismicity in the Gulf of California and has aided in several sonobuoy studies of swarms and aftershock sequences. As more data accumulate, many of the important questions concerning the seismicity, tectonics, and structure of the Gulf of California will be answered.

INTRODUCTION

An array of permanent seismograph stations has been installed around the Gulf of California as part of a cooperative project between the Institute of Geophysics of the University of Mexico (UNAM), the Mexican Federal Power Commission (CFE), the California Institute of Technology (CIT), and the University of California at San Diego (UCSD). Since September 1973, the stations have been operated by the Center for Scientific Investigations and Higher Education in Ensenada, Mexico (CICESE). The purpose of the array is to study seismicity, seismic hazard, tectonics, and crustal structure in the Gulf of California region.

Up to the present, the array has operated solely as a research tool to study special problems related to the seismicity of the Gulf, but it is anticipated that in the near future, records will be read on a routine basis and bulletins published. Several students are currently using the data in special studies.

Installation of the Gulf of California array was initiated after preliminary operation of three seismic stations near the northern end of the Gulf (El Golfo, Rio Hardy, and San Felipe). Preliminary results from these stations were reported in an earlier paper (Lomnitz *et al.*, 1970). Other seismic studies in this region include study of a major swarm of earthquakes in the Northern Gulf near Consag Rock (Thatcher and Brune, 1971), a study of the microearthquake activity along the San Miguel fault (Reyes *et al.*, 1975), and seismicity studies in the Gulf using floating sonobuoy hydrophones (Reid *et al.*, 1973; *Brune et al.*, 1972). Additional sonobuoy studies of earthquake swarms and aftershock sequences are currently underway (Reichle *et al.*, 1976). Data from the Bahia de los Angeles station was used in a study of the Delphin Basin earthquake swarm of February 1972 by Tatham and Savino (1974). A thorough study of all the data recorded on permanent Gulf of California array is being carried out by CICESE. Four temporary stations have operated in the Colorado Delta region south of Mexicali since the summer of 1974, as a cooperative study of the seismicity related to the Cerro Prieto steam field by UCSD, UNAM and CFE.

Tectonic Setting and Objectives of Seismic Studies

The recent revolution in our knowledge of tectonics, in which ocean-floor spreading plays a major role, has pointed to the Gulf of California as one of the most important areas for study to determine the mechanism and characteristics of the ocean-floor spreading process. It is now clear that the tectonic history of the Gulf of California is intimately related to the tectonic history of California and the San Andreas fault system. Opening of the Gulf is directly translated into the occurrence of major earthquakes on the San Andreas fault system.

The Gulf of California is more amenable to study than most ocean ridges because it is surrounded by nearby land, thus affording the opportunity of land-based seismic observations and comparisons with visible geology. At the same time, the Gulf's evolution has progressed to the point where its spreading processes are probably very similar to those of ridges in the centers of the major ocean basins. Refraction studies (Phillips, 1964) and surface-wave studies (Thatcher and Brune, 1973) indicate an oceanic structure for the deep parts of the Gulf. Other evidence of an oceanic structure include the high heat-flow values in the basins (Henyey and Bischoff, 1973; Bischoff and Henyey, 1974; Lawver *et al.*, 1975) and composition of volcanic rocks (Hawkins *et al.*, 1975).

Some of the questions that we hope to eventually answer are these:

1. In detail, are the earthquakes of the Gulf region aligned along transform faults and ridge segments as simply and as precisely as has been suggested by tectonic theories and teleseismic studies? It is clear that at least in the northern end of the Gulf province (the Colorado Delta-Salton Sea region), earthquake epicenters outline a more complex pattern of deformation than that of the idealized ridge-transform fault system (Lomnitz, *et al.*, 1970). Is this an effect of the transition in mechanical properties from the ocean to the continent, or will detailed seismological studies of truly oceanic areas farther south in the Gulf show similar complexities? Some complexities have already been observed (Reichle *et al.*, 1976; Reichle and Reid, 1976; Reichle, 1975).

2. Do the areas of swarm and normal earthquakes delineate ridge and transform fault segments respectively? Initial studies indicate that swarms may occur both along transform faults and at spreading centers (Tatham and Savino, 1974; Reichle and Reid, 1976; Reichle, 1975).

3. Assuming that epicenters in the Gulf region do indeed delineate a ridge-transform fault system, how does the detailed pattern relate to the visible geology? Studies of the volcanic centers, known strike-slip faults, and heat-flow in the Colorado Delta region suggest a relatively simple picture (Lomnitz *et al.*, 1970; Elders *et al.*, 1972). Can this pattern be used in any way to predict the occurrences of geothermal steam areas?

4. How is strain accumulation and release in the Gulf of California related to the occurrences of large earthquakes along the continental San Andreas fault system? Are there significant differences in the statistics of earthquake occurrences in the two regions? How are the rates of slip on particular transform faults, as estimated from seismicity, related to the rates of slip on adjacent transform faults and connecting ridge segments? How thick is the earthquake-producing part of the crust in these areas? Preliminary studies indicate that the thickness of the earthquake-producing zone in the Gulf is only a few kilometers (Reichle *et al.*, 1976), but more data are needed.

Station Sites

The locations of the seismographic stations in the Gulf of California array are shown in Figure 1 and listed in Table 1. Five self-contained solar-powered stations are located at Caborca, Guaymas, Bahia de los Angeles, Topolobampo and La Paz. The instrumentation in these stations will be described in the next section. Three seismograph stations using trailers loaned by California Institute of Technology are operating at Rio Hardy, San Felipe, and Rancho Meling. Recently a seismographic station has also been put into operation at CICESE in Ensenada. Daily record changing is done by UNAM paid local personnel. Pertinent station information for each of the sites is listed in Table 1.

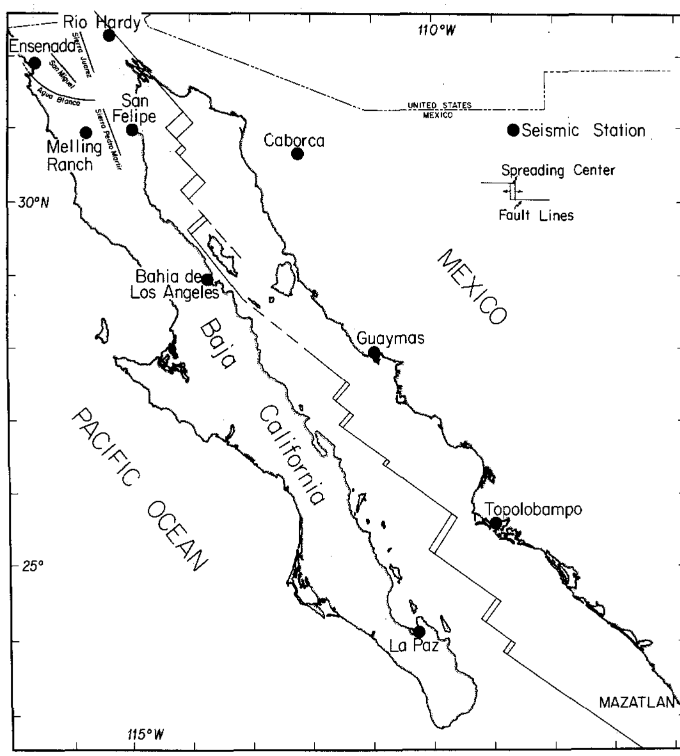

FIG. 1. Map of the Gulf of California region showing locations of seismograph stations.

Self-Contained Solar-Powered Units

Instrumentation in the solar-powered units is conventional in principle, including a sensitive short-period photographic-recording system with precise timing. However, considerable effort has been directed toward low-power consumption in order that the station may be operated from solar energy, and thus site selection made without regard to availability of commercial or other power sources. Total power consumption of the units is less than two watts. Detailed information concerning the units is available in a pamphlet of the Seismological Laboratory of the California Institute of Technology. A schematic diagram of the units is given in Figure 2 and a photograph of the Bahia de los Angeles station is shown in Figure 3.

1. Housing

The station is housed in a corrugated galvanized water tank into which a door and air-intake vent have been installed, and to which floor, top closure, gable roof, and a vent

TABLE 1

THE GULF OF CALIFORNIA SEISMOGRAPH ARRAY

Code		Coordinates		Elevation (m)	Installation	Date Est.
		Latitude	Longitude			
CBR	Caborca	30°43.7′	112°09.6′	30	Low-power solar units	July 30, 1972
LAX	Bahia de los Angeles	28°56.8′	113°34.0′	50	Low-power solar units	December 31, 1971
GYM	Guaymas	27°54.6′	110°57.1′	15	Low-power solar units	March 19, 1972
TPB	Topolobampo	25°35.8′	109°03.2′	25	Low-power solar units	August 8, 1972
LAP	La Paz	24°09.6′	110°16.8′	65	Low-power solar units	August 2, 1972
RHM	Rio Hardy	32°08.5′	115°17.0′	10	Trailer	February 16, 1969
SFP	San Felipe	31°01.9′	114°49.8′	5	Trailer	April 26, 1969
RMM	Rancho Meling	30°58.8′	115°44.6′	700	Trailer	August, 1975
ENS	Ensenada	31°53.0′	116°41.0′	0	Trailer	May, 1974

chimney have been added. The galvanized roof is attached to the top closure lip in such a way that it may be rotated if necessary to orient the solar panels (which are on the roof) to the south. The vent chimney is situated under the open roof; it also provides mounting for plug connectors for the solar panels and loop antenna for the radio. Light tight cabinets provide space for the photographic recorder and drawers for storage of photographic recording paper. A red safelight and automatic turnoff are ceiling mounted and provide light for record changing operations.

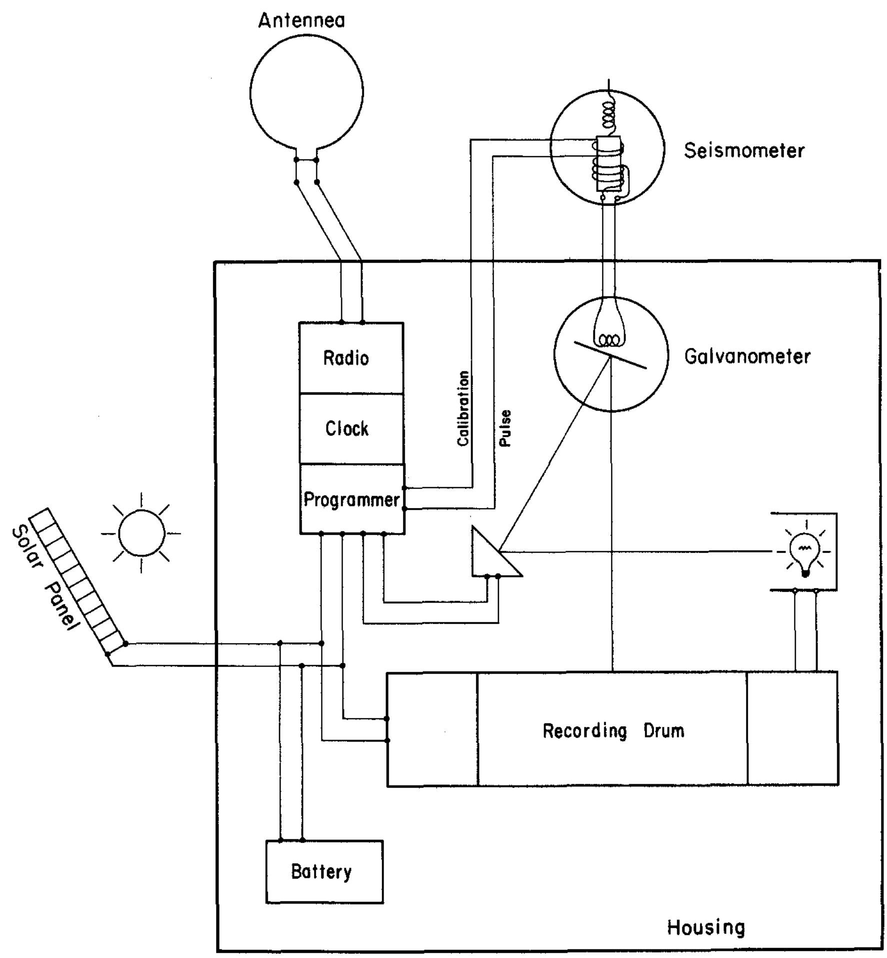

FIG. 2. Schematic diagram of low-power solar units.

The housing unit is mounted on a steel skid base and may be carried either on a special trailer provided for the purpose, or on a flatbed truck. Rings are provided at the base corners for lifting and for anchoring when emplaced. Normally the housing is emplaced with the door to the north to minimize direct sunlight on the door, and thus reduce the possibility of light leaks.

2. Instrumentation

The instrumentation includes a seismometer, a recorder, a clock with drum drive and radio programming, a time-signal radio, solar panels, batteries, and charge regulator for power.

(*a*) *Power system.* The power system consists of solar panels on the roof which convert sunlight to electric power; a solid-state regulator efficiently controls this power in charging of the batteries, which provide power during dark periods. Battery capacity is adequate for 48-hr no-charge operation. Load and charge-rate monitoring is provided by meters mounted on one of the electronic apparatus panels.

(*b*) *Timing system.* The timing system consists of a precise frequency source, a radio, and time pulse-processing circuits. The precise frequency source provides 60-Hz power to

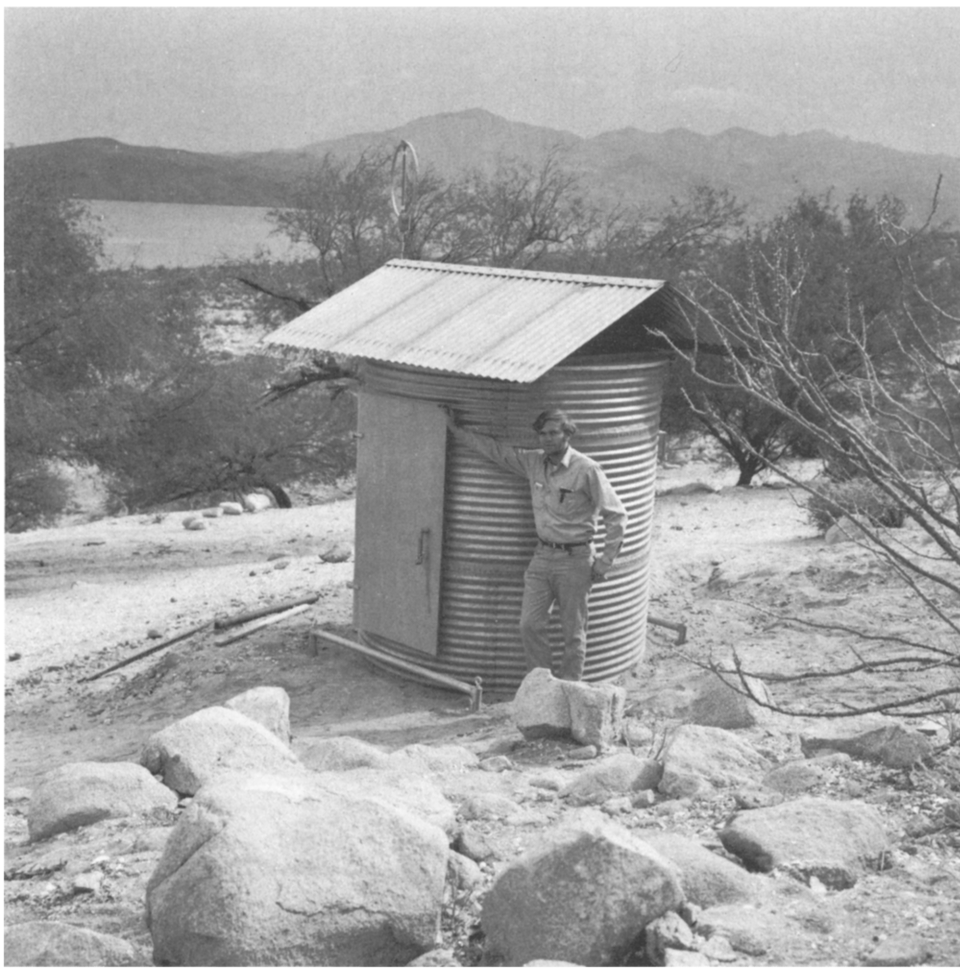

FIG. 3. Photograph of low-power solar unit in operation at Bahia de los Angeles.

a motor mechanism (programmer) which generates contact closures once per minute and once per hour. This mechanism also provides a means of comparing the clock minute closure to absolute time.

Current controlled by contact closures and the code output of the radio are summed in the time distribution panel and directed to the recorder. The 60-kHz radio code with a 1-pulse-per-second format comes from the U.S. National Bureau of Standards Station WWVB, Ft. Collins, Colorado. The radio code output is in the form of DC pulses; an audio output is also available.

The precise frequency source is fitted with an amplifier for providing 60-Hz power to the recorder drive motor. The time distribution panel sums the clock and radio pulses (rather than having one override the other). This increases the readability of clock corrections relative to the radio code.

(*c*) *Seismometer.* The seismometer is a Johnson-Matheson instrument having a free period of 1.25 sec. It consists of a mass suspended by a spring, and coil-magnet transducer which generates a signal when the suspending frame is moved relative to the mass by ground motion. A test deflection device is included so that the mass may be displaced by an electric signal, thus providing for routine calibration checks.

(*d*) *Recorder.* The recorder consists of a standard photographic recording drum with a light source, optical system, and sensitive galvanometer. An electromagnetic device deflects a mirror, and thus the light beam, when energized by timing signals from the clock and radio. Hence, time marks are superimposed in the form of offsets of the trace. The recorder is fitted with controls for adjusting recording lamp intensity and time mark amplitude. A T-pad attenuator is included in the galvanometer circuit for adjusting seismic sensitivity. Calibration pulses are automatically applied to the seismometer whenever the red safe-light is turned on or off. Until 1975 galvanometers with a 1-sec free period were used. Since the summer of 1975, galvanometers with a natural frequency of 5 Hz have been used.

Trailer Units

The units at Rio Hardy, San Felipe and Rancho Meling are recording in small modified recreational trailers loaned by CIT. The trailers contain photographic recording drums with galvanometers, a WWVB radio, and clock and a programmer. Seismometers are located outside the trailers and connected by cable. They are operated by local 60-cycle, 110-V power. Local personnel are employed for record changing.

Initial Operation

Although numerous small problems occurred in the initial period of operation, they were soon overcome. The stations have now been operating more or less regularly since 1973. The solar-power design has been highly successful and was crucial in finding low-noise sites since the requirement for local power was obviated.

One of the main sources of noise has been galvanometer oscillation when the steel tank is subjected to strong winds. Since these galvanometers have been replaced with shorter-period ones (5 Hz) which are less sensitive to motion of the tank, this source of noise has been reduced greatly.

The photographic records are now being sent to CICESE in Ensenada where they are developed and filed after preliminary analysis. For the initial months of operation, the records were developed and stored at CIT, but all records have now been moved to Ensenada. Personnel from CICESE make regular maintenance trips to the various stations. Current financial support of the array is provided by the Institute of Geophysics of UNAM through a contract with CICESE. UCSD is providing some replacement equipment and upgrading of the array under a contract from NASA.

Preliminary Results

Although the important contributions from the Gulf of California array will occur in research papers in the future, we describe some preliminary results here. One of the most surprising results has been the low level of microearthquake activity in the Bahia de los Angeles station up until the recent Ballenas Channel earthquake. Although two relatively large swarms of earthquakes were recorded from the Delphin Basin to the north, no high level of microearthquake activity has been observed from the nearby transform fault between Isla de la Guarda and the Baja Penninsula. This may have been related to the lack of slip observed by Vacquier and Whiteman (1973). The recent Ballenas Channel earthquake ended a 17-year seismicity gap (Reichle *et al.*, 1976). Aftershock activity extended along about 100 km of the transform fault in Ballenas Channel.

Several swarms of earthquakes have been recorded and this seems to be a common mode of stress relief in the Gulf. Two swarms occurred in the Delphin Basin between

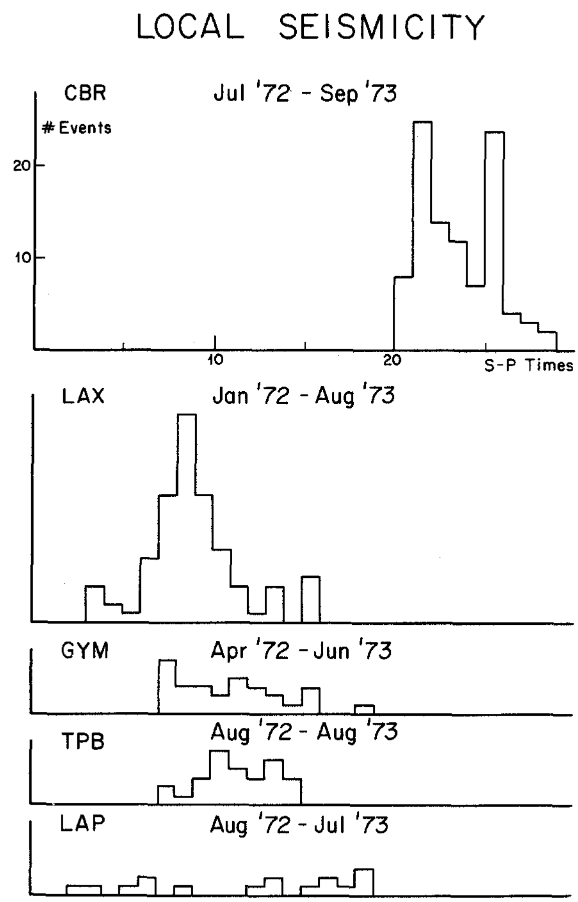

FIG. 4. Histogram of numbers of events for given S – P times at several of the Gulf of California array stations.

February 19–23, 1972 and October 10–13, 1973. For the first swarm, only the stations Bahia de los Angeles, San Felipe and Rio Hardy were in operation. S – P times at the Bahia de los Angeles station were used by Tatham and Savino (1974) in studying the mechanism of the 1972 swarm. For the 1973 swarm, sonobuoys and temporary stations were also operated. This swarm was recorded on most of the Gulf array. The main aftershock activity was apparently about 15 km south of the center of the Delphin Basin (Reichle and Reid, 1976; Reichle, 1975). A swarm of about 1000 very small events in the Guaymas Basin were recorded on floating hydrophones during the Exito expedition of Scripps Institution of Oceanography (Reid *et al.*, 1973).

Three relatively large events with aftershock sequences have been recorded on the array; a magnitude 5.5 earthquake near the Farallon Basin on March 25, 1973, a magnitude 6.3 earthquake near the Guaymas Basin on May 31, 1974, and a $M = 6.8$ earthquake in Ballenas Channel on July 8, 1975. In all cases, floating hydrophone arrays were deployed by IGPP/SIO to study aftershocks (Reichle *et al.*, 1976, Reichle, 1975).

In order to demonstrate the approximate nature of local seismicity recorded on the array, we have plotted histograms of numbers of events of a given S – P time for a period of a few months at each of the stations (Figure 4). At Caborca most of the local events had S – P times of 20 to 30 sec and came from the Gulf of California, mainly the Delphin Basin and northward. At Bahia de los Angeles, up until the July 8, 1975 Ballenas Channel earthquake, most local events had S – P times of 8 to 10 sec and came from the Delphin Basin region (the two large swarms in 1972 and 1973 were excluded from the count). There were a few events with S – P times of 3 to 5 sec and these probably came from the transform fault just south of the Delphin Basin. At Guaymas, the local events had S – P times ranging from about 7 to 20 sec and represent seismicity in the Guaymas Basin and along the transform faults extending northwestward and southeastward. The minimum S – P time observed, about 7 sec, is consistent with the distance to the nearest part of the Guaymas Basin. At Topolobampo, the local events had S – P times concentrated between 8 and 15 sec and represent seismicity near the Farallon and Carmen basins. At La Paz, there were a number of events with short S – P times (3 to 10 sec). This is quite surprising since the active spreading centers and transform faults in the Gulf of California and the East Pacific Rise are too distant to cause these events. The events probably come from the major N–S fault which cuts the Baja Penninsula near La Paz or from faults near the west coast of Baja opposite La Paz. Small earthquakes were located by NOAA near the west coast on August 21–22, 1969. A number of events with S – P times ranging from 12 to 20 sec were also recorded at La Paz and these probably emanated from the adjacent Gulf of California faults. Overall, the seismicity of the Gulf is characterized by a relatively low level of background seismicity interrupted by earthquake swarms and occasional moderate earthquakes. As more data accumulates, we expect to answer many of the fundamental problems outlined earlier in this paper.

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Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California 92093 (J.N.B., A.R.)

Instituto de Geofisica
Universidad Nacional Autonoma de Mexico
Mexico 20, D.F., Mexico (C.L.)

Seismological Laboratory
California Institute of Technology
Pasadena, California 91125 (C.A., F.L.)

Comision Federal de Electricidad
Department of Geology
Mexico 20, D.F., Mexico (F.M.)

Centro de Investigaciones Cientificas y Educacion Superior de Ensenada
Avenida Gastelum 898
Ensenada, B.C., Mexico (A.R.)

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