

The NARS-Baja Seismic Array in the Gulf of California Rift Zone

Robert W. Clayton¹, Jeannot Trampert², Cecilio Rebollar³, Jeroen Ritsema⁴,
Patricia Persaud⁵, Hanneke Paulssen², Xyoli Pérez-Campos⁶,
Arie van Wettum², Arturo Pérez-Vertti³, and Francesca DiLuccio⁷

¹California Institute of Technology

²University of Utrecht

³Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)

⁴Intitut de Physique du Globe de Paris

⁵Lamont-Doherty Earth Observatory

⁶Universidad Nacional Autonoma de Mexico (UNAM)

⁷Istituto Nazionale di Geofisica e Vulcanologia (INGV)

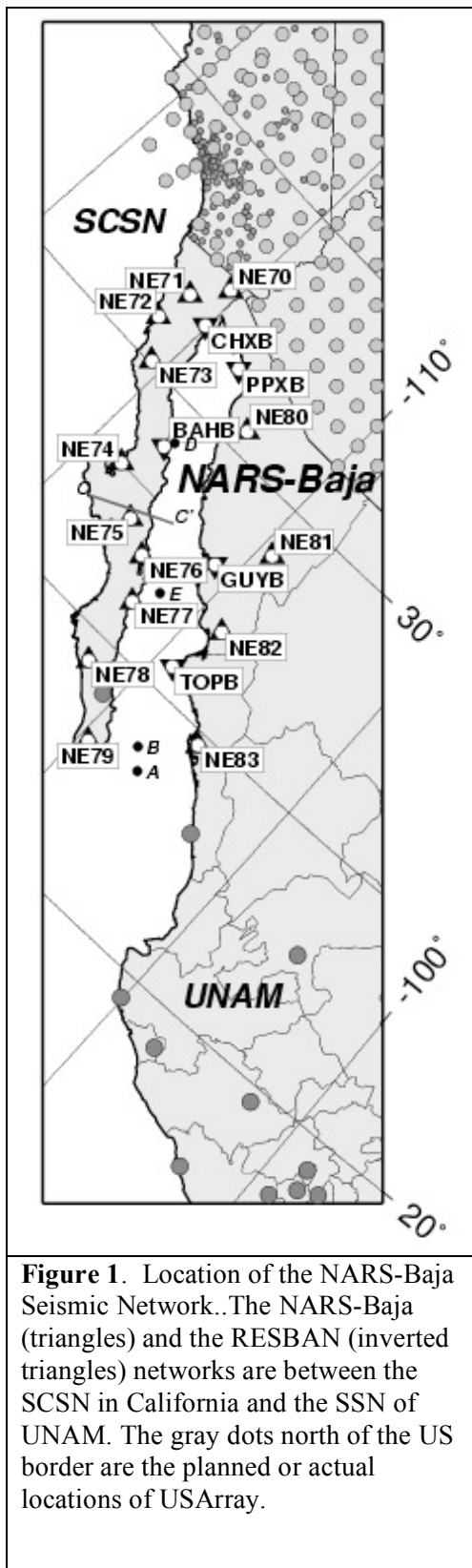
Introduction

The Gulf of California (GofC) extends ~1300 km from the fast-spreading mid-ocean ridge system of the East Pacific Rise to the San Andreas Transform Fault zone in southern California. One result of the last 6 myrs of deformation, which has been active over the full length of the Gulf, is that the Baja California peninsula is now part of the Pacific Plate. On the Sonora conjugate margin, there is a zone of active basin and range type extension. Crustal deformation within the Gulf itself ranges from classic ridge-transform structures in the south to diffuse deformation in the north. The GofC is an excellent place for studying the rifting process because both sides of the rift are accessible, and the history of plate interactions in this area is well known.

Geophysically, the GofC is largely unexplored. With some notable exceptions, data from earthquake recordings, heat flow measurements, cores and sub-bottom profiling are both sparse and dated. Improved knowledge of crustal composition and thickness, and the inferred thermal state of the upper mantle is needed for a more

complete understanding of how this plate boundary has evolved. This in turn provides a basis for explaining what role, if any, past periods of subduction may have played. It also sheds light on the mechanism by which the apparently slow transition to seafloor spreading is manifested in small segmented basins. Whether the crust in the Gulf is mainly oceanic or continental in composition has broader implications for studies on magmatism, structure and deformation. The recordings from the NARS-Baja stations provide a new dataset and a unique opportunity to determine some basic lithospheric properties on a regional scale around the entire Gulf (Trampert et al, 2003).

In addition, the along-strike variation in the degree of oceanization makes it a natural laboratory for investigating the coupling between the asthenosphere and the lithosphere. While the crustal aspect of this process has been investigated by some researchers, the state of the underlying mantle is largely unknown. Constraints on the seismic structure of the mantle beneath the GofC and surrounding region are derived primarily from the analysis of data from globally

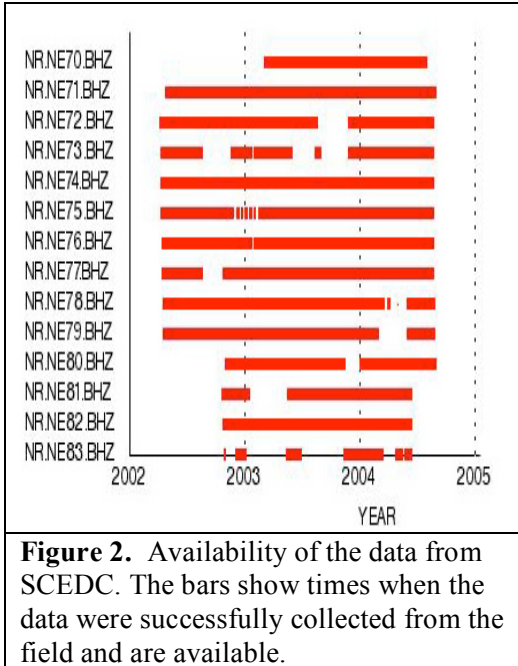


distributed stations, and they indicate that the shear velocity in upper mantle beneath the GofC is anomalously low. However the 1000 km resolution of these models is insufficient to address any of the key questions.

To obtain a more detailed image of the crust and mantle in the GofC region, a broadband network, the NARS-Baja Seismic Network, was established in 2002, as a cooperative project between Utrecht University, CICESE and Caltech (details at <http://www.geo.uu.nl/~nars>). Funding to install and maintain the network has been provided by the NSF/MARGINS program, the NWO (Nederlandse Organisatie voor Wetenschappelijk Onderzoek), and the Tectonics Observatory at Caltech. In addition in the GofC region is the RESBAN (Red Sismológica de Banda Ancha) network operated by CICESE. The other seismic networks in the area are primarily in southern California and southern Mexico (Figure 1). The NARS-Baja network bridges this data gap.

The NARS network consists of 14 broadband stations (STS-2 seismometers) that were installed in 2002 (Figure 1), and is planned to continue operations until 2007. The data from the stations are retrieved every 3-4 months and are available from the Southern California Earthquake Data Center (SCEDC) and IRIS under the network designation NR. The RESBAN network consists of 5 broadband stations (CMG-40T seismometers) and has the network code of 'RB'. The data from this network is currently being integrated with the NARS data. The data availability for the NARS network itself is shown in Figure 2. A current version of this figure and other information

obtained from the network, plus a tutorial on downloading the data is available at <http://www.data.scec.org/NARS-Baja>.



Preferential Thinning of the Lower Crust

To study variations in crustal thickness in the continental margins of the Gulf, we calculate receiver functions (RFs) from teleseismic earthquakes recorded by the NARS-Baja stations along with 17 southern California stations. RFs allow for reliable estimates of crustal thickness close to the station, but the conversion of delay time to Moho depth depends strongly on the assumed crustal velocity. From an initial 133 teleseismic events with magnitudes above 5.9 Mw, which occurred between April 2002 and March 2003, we analyzed a total of 64 high-quality events. The persistent pattern of thinner crust closer to the Gulf along the entire Baja California peninsula is remarkable (Persaud, 2003a; Persaud et al. 2003b). The results are

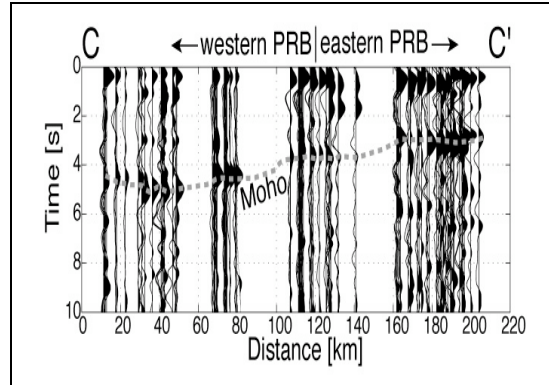
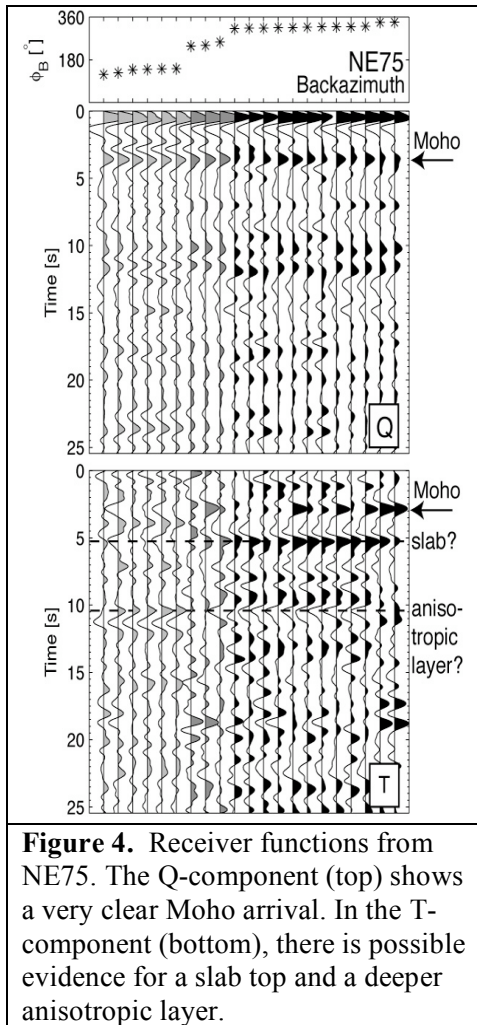


Figure 3. Crustal Thickness Profile. The crustal thickness along the profile C-C' (Figure 1) shows the thinning toward the Gulf. To construct the profile, stations have been projected onto this line. The PRB is the Peninsular Ranges Batholith.

shown in Figure 3, which is a profile along C-C' shown in Figure 1, near station NE75. This confirms similar findings along two profiles in southern California and northern Baja California (Ichinose et al. 1996, Lewis et al. 2000). Our results also support those of Langenheim and Jachens (2003), who found that along the entire Baja California peninsula, the Peninsular Ranges were composed of compositionally different eastern and western parts. On this basis, we suggest a possible rift-related mechanism of thinning by lower crustal flow from the margins into the rift zone.

What supports the topography of the Peninsular Ranges

Crustal thickness along the Baja California peninsula appears to be uncorrelated with topography. Non-Airy type compensation as in the case of the southern Sierra Nevada (Wernicke et al. 1996) is supported. The Moho beneath the Peninsular Ranges is, however, not flat nor is the crustal thickness anti-



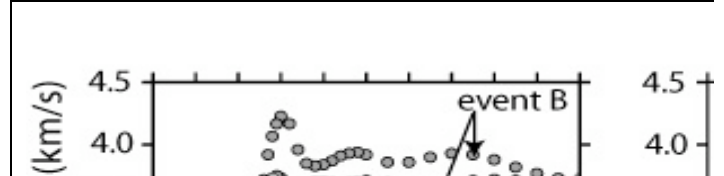
correlated with crustal density. Because the lower-density eastern PRB is thinner than the higher-density western PRB, a Pratt-type root as suggested for the southern Sierra Nevada can be ruled out. We suggest instead compensation by upper mantle density variation or the flexural rigidity of the lithosphere supports the load of the eastern PRB. Seismic observations show that the S-wave velocity in the uppermost 200 km of the upper mantle is 6-8% slower than in the PREM model (Ritsema et al., 2004). Therefore, our preferred choice is compensation by density variations in the upper mantle. This does not require lower crustal flow rather it allows for thinning of both the crust and mantle

with no decoupling in the lower crust. To determine whether the eastern PRB is supported by flexure, we are currently modeling the gravity data in this region using the results from receiver functions.

Anisotropy, slab remnants and the upper mantle

In the RFs, arrivals below the Moho may give an indication of anisotropy since they show a polarity reversal on the transverse component (SH) of the receiver functions and have larger amplitudes than would be expected from a dipping layer. Based on the apparent 180° symmetry in transverse energy at 10 s, e.g., symmetry about the S and N back azimuths in the case of NE75 (Figure 4), we assume that the anisotropic layer beneath this station has a horizontal symmetry axis polarized in a N-S direction. A delay time of 10 s with respect to the P-arrival translates to ~100 km depth, therefore one explanation for these observations may be that the anisotropy is derived from shearing at the base of the lithosphere. There is evidence that an anisotropic layer also exists beneath stations NE76 and NE79.

We have also found possible evidence for a slab beneath NE75. The T-component RFs show a prominent arrival between 5-6 s that is either not clear in the Q-components (SV) or is polarity reversed (Figure 4). The negative polarity in the Q-component is indicative of the slab top. This agrees with the electrical slab image of Romo et. al. (2003). Variations in the 410-km mantle discontinuity are also detectable with RFs. In a preliminary analysis of a few deep RFs, we have detected a possible upwarping of the 410-



discontinuity, but no appreciable structure on the 670-discontinuity (Persaud et al, 2003a). This study will need to include more earthquakes before these results are reliable.

Using surface waves to constrain crust and upper mantle velocities

In an effort to create a 3D map of velocities in the GofC, we are currently carrying out a surface wave dispersion study of regional earthquake data recorded by the NARS-Baja array. This study is conducted with both Love and Rayleigh waves. We will use a number of earthquakes to create a 2D map of the phase velocities in the region, which can then be used to determine the 3D structure. Our initial results show noticeable differences in the group velocities of different paths. An example of this are the dispersion curves shown in Figure 5, which are from a pair of nearby earthquakes in the mouth of the Gulf. The differences in the curves show that there are structural variations into the mantle.

Locating seismicity and active structures

Detailed and accurate seismicity catalogs have greatly aided tectonic studies in California by locating active structures. Focal mechanisms and moment tensors additionally help by giving the direction of slip. Earthquake catalogs report an artificially low rate of seismicity and poorly constrained source locations in the GofC simply because few seismic stations have been deployed in the region. Therefore, an important function of the network is to locate seismicity in the GofC and to determine the mechanisms of the major events. CICESE is particularly interested in this

component of the study since they are the institution responsible for reporting the seismicity for this area. The CICESE group is working on a regional earthquake catalog (Rebollar, 2000) and has performed a detailed waveform fitting of two major events in the Gulf (López-Pineda and Rebollar, 2004). These are shown in Figure 6. This type

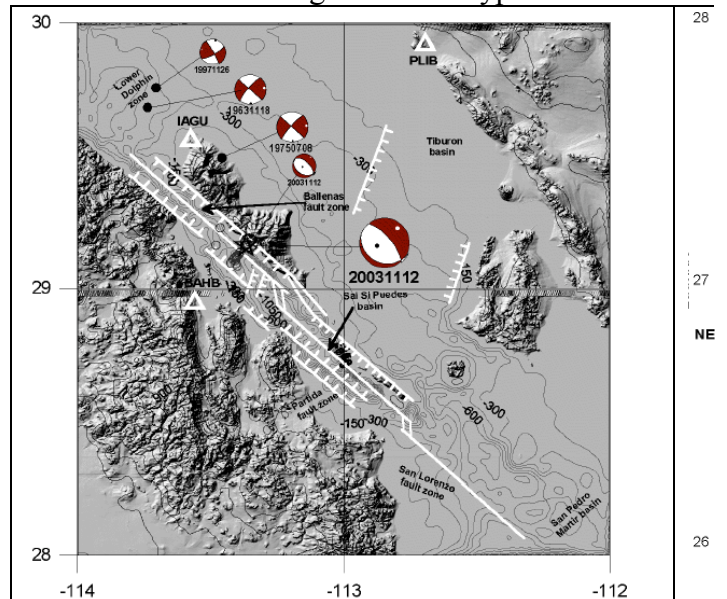


Figure 6. Location of two major Gulf Earthquakes. The left shows the transform between the ridge segments in the Guaymas solution is labeled 1, the NEIC 2, and the CICESE study in aftershocks triggered by the main event (a star) toward the right. The circles are its aftershocks. The locations of these two event

of analysis is important for determining the active deformation in the Gulf. In addition, knowing where the seismicity is diffuse or sharply delineated is important for understanding the kinematics of this region.

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