Marine Physical Laboratory

Continental Borderlands Shear Structure from Seafloor Compliance Measurements

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Shear properties are poorly known for shallow water sediments because of the difficulty of making direct measurements. Deformation from low frequency waves provides information about deep structure and from high frequency waves provides information about shallow structure. Seismic reflection profiles of several major faults in this area have revealed that they are actively deforming young sediments. As the sediments are uplifted or compressed, their pore-water content may be significatnly altered; at several locations along these faults, springs have been observed where pore-water is being expelled at the seafloor, precipitating mineral deposits and supporting colonies of tubeworms. The change in shear strength associated with pore-water loss has been recognized as an important parameter in controlling fault mechanics. This project studied the elastic structure of shallow water sediments using measurements of seafloor compliance. One approach for determining shear properties is to measure seafloor deformations resulting from the loading of ocean waves, this is the approach of the compliance technique.

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Abstract

Shear properties are poorly known for shallow water sediments because of the difficulty of making direct measurements. Deformation from low frequency waves provides information about deep structure and from high frequency waves provides information about shallow structure. Seismic reflection profiles of several major faults in this area have revealed that they are actively deforming young sediments. As the sediments are uplifted or compressed, their pore-water content may be significatnly altered; at several locations along these faults, springs have been observed where pore-water is being expelled at the seafloor, precipitating mineral deposits and supporting colonies of tubeworms. The change in shear strength associated with pore-water loss has been recognized as an important parameter in controlling fault mechanics. This project studied the elastic structure of shallow water sediments using measurements of seafloor compliance. One approach for determining shear properties is to measure seafloor deformations resulting from the loading of ocean waves, this is the approach of the compliance technique.

Objectives:

This project studied the elastic structure of shallow water sediments in the California Continental Borderlands (Figure 1) using measurements of seafloor compliance. Our long range goal is to model how sediment shear properties are related to fluid flow along fault zones. Shear properties are poorly known for shallow water sediments because of the difficulty of making direct measurements. One approach for determining shear properties is to measure seafloor deformations resulting from the loading of ocean waves, this is the approach of the compliance technique.

Background:

Continental shelf sediments may be deposited with high water content which is subsequently lost during burial and/or tectonic deformation. Fluid expulsion associated with tectonic deformation may modify sediment properties including porosity and degree of lithification. It is probable that chemical and elastic changes are associated with the passage of fluid through fault zones. The parameters affecting these changes are not well understood, such as pore pressure and the depth and degree of fracture permeability. Study of shear strength near fault zones provides one approach to addressing these issues. The near-shore California Continental Borderlands contains the Newport-Inglewood Fault zone, a source of major earthquakes in recent history. Seismic reflection profiles have revealed that the Newport-Inglewood fault is actively deforming young sediments. As the sediments are uplifted or compressed, their pore-water content is altered; at several locations along this fault, springs have been observed where pore-water is being expelled at the seafloor, precipitating mineral deposits. The change in shear strength associated with pore-water loss has been recognized as an important parameter in controlling fault mechanics.

Approach:

We measure sediment shear properties by observing pressure and acceleration at the seafloor, the compliance technique. With ONR support, we have developed an instrument capable of measuring small seafloor deformations resulting from ocean surface gravity waves . A differential pressure gauge was records pressure fluctuations at long periods on the seafloor and a LaCoste-Romberg gravity meter measures seafloor acceleration. The relative amplitude of seafloor velocity (integral of acceleration) to pressure is called the compliance, and can be used to estimate seafloor elastic properties. Seafloor acceleration from low frequency waves provides information about deep structure and from high frequency waves provides information about shallow structure. Inversion of these as spectra provides a depth profile of seafloor elastic properties.

Accomplishments and Results:

We have measured seafloor elastic properties at 23 sites using the compliance technique. The measurements were made at two locations in the California Continental Borderlands: (a) a line of 16 sites crossing the Newport-Inglewood fault near Oceanside, and (b) seven sites on a sediment fan near La Jolla. Each measurement is separated from adjacent measurements by 500 to 1000 m, except for one calibration site where two instruments were deployed within 100 m of one another.

Analysis of compliance measurements made in 1995 suggested that shear properties at Oceanside vary significantly with distance from the shoreline, while shear properties of the sediments on the La Jolla sediment fan do not vary appreciably. A significant difference between the two sites is the presence of a major active fault crossing the Oceanside site.

The preliminary data suggested that deep sediment shear velocities decreased towards the fault zone, while shallow sediment shear velocities increased towards the fault. One explanation is that dewatering of deeper sediments by compressional stresses within the fault zone may supply fluids to the shallow sediments, counteracting the usual dewatering of shallow sediments by lithostatic pressure.

Additional compliance measurements in 1996, concentrating on the Oceanside site, confirm the previously observed trend and demonstrate significant changes in compliance between sites 500 m apart. Because the shear properties change significantly over such small lateral distances, the one-dimensional assumption usually used to determine shear velocities from compliance data may be invalid.

In the past year, we have developed a finite difference computer code that relates compliance measurements to two-dimensional seafloor structure (Figure 2). This code will allow generation of a consistent two-dimensional model of seafloor shear velocity structure. Specifically, are investigating whether changes in seafloor structure centered at the fault zone can match the observed compliance values. A watergun reflection survey over the Oceanside experiment site provides accurate details of the fault location and sediment thickness to aid in construction of a final two-dimensional shear velocity model.

Accomplishments and Results:

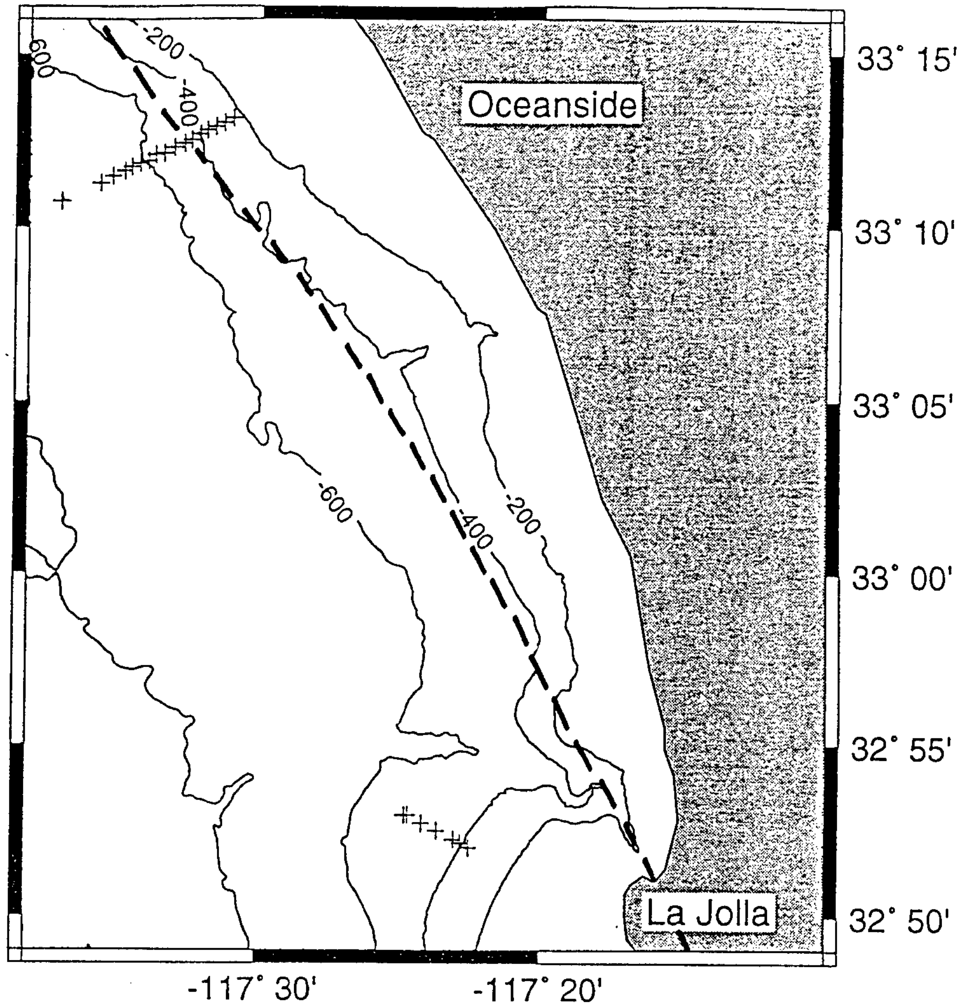

Figure 1. California Continental Borderlands measurement sites are designated by crosses. Lines of measurements were conducted near Oceanside and near La Jolla. The Oceanside sites cross the Newport-Inglewood fault zone (dashed line), whereas the La Jolla sites are on a non-faulted sediment fan.

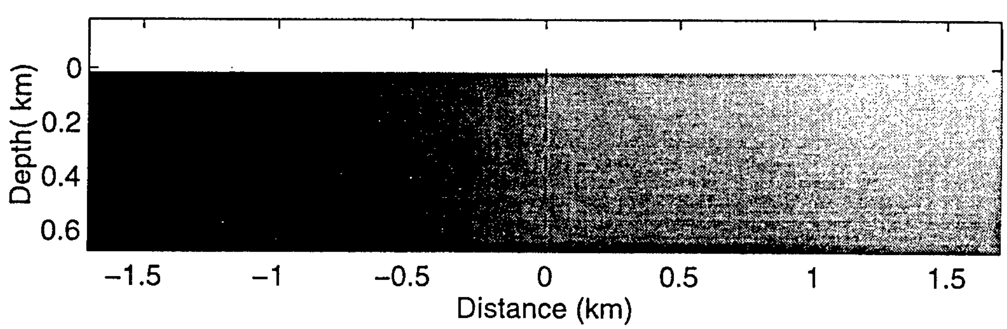

Figure 2. Compliance finite different model of seafloor sediment acceleration due to ocean waves at 60 sec period. A vertical fault (dashed line) separates the model into two regions with different shear modulus, with 20% lower shear modulus to the left of the fault. Lateral variations in compliance occur in a narrow region adjacent to the fault.

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