Earthquake Prediciton-I: Offset and Stress

(HI) California Thurs PM
Stephen N. Cohn (Caltech), Presiding

T4-2-B-1

TECTONIC IMPLICATIONS OF GRANULITE FACIES ROCKS FROM THE WESTERN TEHACHAPI MOUNTAINS, CA.

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Two pyroxene granulite facies metamorphic rocks are present in the western Tehachapi Mountains north of the North Branch of the Garlock Fault Zone (NBGF). The granulite facies rocks have yielded an 11 point Rb-Sr age of 86.1+ 13.2 ma with an initial ratio of 0.70513+.00008 (errors= 2). This age is interpreted as the age of the end of metamorphism brought about by underthrusting cold Pelona Schist present south of the NBGF beneath the granulite facies terrane. Uplift of granulite facies terrane was relatively rapid as it is unconformably overlain by lower to middle Eocene marine sediments. The granulite facies rocks are very similar to and may be correlative with charnokitic rocks present in the Santa Lucia Range of the Salinian Block and thus limit displacement along the Garlock Fault to 300 km.
Trends of foliation in the granulite terrane and the trends of metasedimentary roof pendants north of the Garlock Fault record 15 km of left-lateral drag along the Garlock Fault Zone. Structures in the overlying Tertiary sediments, including the lower Eocene Tejon Formation, cut across, at high angle, the drag related features in the granulite terrane. This indicates that there was a minimum of 15 km of displacement on the Garlock Fault prior to 50 ma.
The south branch of the Garlock Fault Zone is a major crustal boundary. Geobarometry indicates that the rocks south of the fault zone were metamorphosed at 10 km and those south of the fault zone at 27-32 km. The same difference in levels of exposure are observed on both sides of the Pastoria Thrust which is interpreted to be an older splay of the Garlock Fault Zone on which most of the displacement has occurred and has recently been modified into a thrust fault.

T4-2-B-2

SEISMIC POTENTIAL OF THE DORMANT SOUTHERN 200 KM OF THE SAN ANDREAS FAULT

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The abundance of small and relatively fresh geomorphic features along the San Andreas fault between Cajon Pass and the Salton Sea attests to the fault's activity during the Holocene Epoch. Faulted middle and late Holocene sediments of ancient Lake Cahuilla clearly demonstrate major recent activity at least between Indio and the Salton Sea. Nevertheless, initial studies of excavations across the fault near Indio have revealed that sediments of the latest high stands of the lake are right-laterally offset only about 1 m. Radiocarbon analyses indicate that the initial fillings of these latest two lakes occured sometime between 1330 and 1480 A.D. and sometime between 1630 and 1700 A.D. At the present time, slip during moderate earthquakes and creep are favored explanations for this minor offset.

The latest major disruption at the Indio site antedates an unconformity capped by a peat that was deposited sometime between 1280 and 1420 A.D. Thus, more than half a milenium may have passed since the latest great earthquake in this region. At least 3 great earthquakes have occurred within this same time period along the San Andreas fault northwest of Cajon Pass. Temporary but complete transference of slip to the San Jacinto and other fault zones west of the San Andreas is not probable, in view of the relatively low Holocene slip rates of these faults. More plausible explanations include 1) average recurrence intervals of >500 years between slip events of >10-15 m, and 2) very long periods of dormancy alternating with periods of great earthquakes that have substantially shorter recurrence intervals.

T4-2-B-3

OFFSET RATE AND POSSIBLE TIMING OF RECENT EARTHQUAKES ON THE SAN ANDREAS FAULT IN CAJON PASS, CALIFORNIA

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K.E. Sieh (same as above)

Detailed study of a flight of river terraces offset by the San Andreas fault near Cajon Pass and sediments ponded by the offset of the terraces has yielded a maximum offset rate of 3 cm/yr and some constraints on the timing of recent earthquakes on the San Andreas fault. Indirect arguments based on the relative rates of the San Andreas and the Cleghorn faults can be used to place a minimum rate of 1 cm/yr on the San Andreas in Cajon Pass. The actual rate is probably between 2 and 3 cm/yr.
A trench across the San Andreas where swamp sediments and river gravels are juxtaposed yields evidence that the last major earthquake was more than 200 yrs ago but substantial slip, probably related to several earthquakes, has occurred in the last 600 yrs. Six to 8 units, probably scarp breccias, have accumulated in the last 1200 to 800 yrs. If each unit records an earthquake, a recurrence interval of 100 to 200 yrs is inferred; however, other origins for these breccias cannot be ruled out.
Four radiocarbon dates from lake clays below the swamp sediments suggest that the onset of a lake at the trench site was about 8500 yrs ago. Since the high terrace has moved 250 m beyond the point necessary to form the lake, a maximum Holocene rate of 3 cm/yr is determined. The actual rate is probably close to this maximum. The Cleghorn fault, which offsets older terraces near Cajon Pass about 1/10 the distance that the San Andreas does, has a minimum offset rate of 1 mm/yr based on the maximum age of the Crowder Formation of 4 m.y. This minimum is probably 2 to 3 times lower than the actual rate so a Quaternary rate of 2-3 cm/yr on the San Andreas fault is inferred.

T4-2-B-4

RECENT IN-SITU STRESS MEASUREMENTS AT DEPTH IN THE WESTERN MOJAVE DESERT

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Hydraulic fracturing stress measurements were made in an ~0.6 km-deep hole drilled 32 km from the San Andreas fault in the western Mojave Desert. Preliminary analysis of the data indicates that there is an unexpectedly small increase in the magnitude of the horizontal principal stresses and the difference between the horizontal principal stresses with depth in this well. With the exception of a measurement at 492 m the maximum and minimum principal stresses increase with depth from about 130 and 75 bars at 180 m to about 175 and 110 bars at 546 m. At 492 m, both the maximum and minimum principal stresses attain their greatest values of about 120 and 230 bars, respectively. The magnitudes of the horizontal principal stresses observed in this well are remarkably similar to those seen over the same depth range in an ~1 km-deep hole drilled only 4 km from the San Andreas fault in this same region. Based upon these two relatively deep holes, there appears to be little difference in the near- and far-field magnitudes of the horizontal principal stresses in the western Mojave Desert. This is in contrast to our previous results in shallow holes about 200 m deep which indicated an increase in both horizontal principal stresses and deviatoric stress with distance from the fault. These new findings have important implications for mechanical models of the San Andreas fault that predict the magnitude of shear stress on the fault at depth.

T4-2-B-5

ANALYSIS OF DEEP IN SITU STRESS MEASUREMENTS IN THE MOJAVE DESERT: IMPLICATIONS FOR THE STATE OF STRESS ALONG THE SAN ANDREAS FAULT

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A suite of measurements of in situ stress, obtained with the hydrofrac technique near Palmdale, California, is the basis of an elastic analysis of the state of stress in the Mojave desert adjacent to the San Andreas fault. The measurements were made at depths extending from 80 to 849 m and at distances from the fault between 2 and 34 km. The elastic solution indicates a state of deviatoric stress typical for continents in that the inferred gradient of shear stress with depth is about 7.6 MPa/km. The state of stress does not appear to vary significantly either with distance from the San Andreas fault or along the strike of the fault. The average shear stress in the upper 14 km along the fault is about 54 MPa, a result that is incompatible with recently proposed estimates of stress based on the analysis of heat flow data. This finding is consistent, however, with estimatesof fault strength based on laboratory determinations of the coefficient of friction for samples of San Andreas fault gouge if, as appears to be the case, the regional state of deviatoric stress is limited by the strength of the fault zone. On this basis, the coefficient of friction for the San Andreas fault zone inferred from the stress field results is about 0.44.

T4-2-B-6

INFLUENCE OF THERMAL STRESS ON IN SITU STRESS MEASUREMENTS

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Seasonal temperature variations at the Earth's surface are capable of producing thermal stresses that can, and have, masked tectonic stresses in the upper several m. In situ stress measurements from the Palmdale area taken in January and June of 1980 strongly suggest a large thermal effect in the upper 5 m. Realistic geometries and rheologies are used for the outcrop setting with a surrounding alluvial basin for finite element modeling of the heat conduction and resulting thermal stress calculations. The two dimensional grid used has 396 nodes and 357 quadralateral elements, with refined grid spacing of about 50cm in the upper few m. A time varying temperature with a period of one year and maximum range of 20°C is applied at the surface. Boundary conditions are adiabatic with no displacement on the bottom and adiabatic with no horizontal displacement on the sides. Modeled thermal stresses are in good agreement with the exponential decay from 5 MPa at the surface, to the background level of 1 MPa below 5 m during the June measurements. Additional evidence for the thermal origin of the near surface stress field is the observed near equality of the two principal stresses. The ratio is nearly 1.0 in the upper 5 m, whereas the ratio locally exceeds 2.0 below 5 m where a tectonic origin is inferred. Measurements made in January to depths of 8 m showed near zero stresses, rather than tensile stresses of comparable magnitude to the June data. This observation along with the June data in the 5-12 m range, shows that material properties are very different in compression than in tension. Tensile stresses cannot be supported in the near surface because of fractures in the rocks. Rather, the cracks open in tension and the rock mass remains relatively stress free between the cracks.

T4-2-B-7

DRILLING HOLES FOR EARTHQUAKE PREDICTION

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During the last five years a large number of holes have been drilled for several projects in the earthquake prediction program. These holes have been drilled for the measurement of in-situ stress, the emplacement of explosives for seismic profiling, and for the emplacement of instruments. Out of this experience a sufficient data base has been gathered to make some generalizations about the granitic textured, crystalline rocks near active fault zones. The physical properties of these rocks are dominated by macrofractures rather than pervasive microfractures or grain boundary discontinuities. Seismic velocity, permeability, porosity, and hardness, as judged by drilling, are measurements which correlate with one another and suggest a systematic distribution of these macrofractures. There is also evidence to suggest that the distribution of macrofractures