Annual Report, 1998

In 1997 we published three papers on the evolution of stresses in southern California from 1812 to 2025--two in JGR [Deng and Sykes, 1997a, b] and one as Deng's PhD thesis [Deng, 1997]. In all three we included tectonic stress buildup for a large number of active faults in southern California (e.g. many of those in the Phase II report). We included co-seismic stress drops for 36 shocks of $M \geq 6$ since 1812. We showed that 95% of earthquakes of $M \geq 6$ of known or inferred mechanism occurred in regions of southern California that were calculated to have moved closer to failure in terms of changes in the Coulomb Failure Function (CFF). More than 85% of events of $M \geq 5$ from 1932 to 1995 and small ($M \geq 3$) and micro $M \geq 1.8$ earthquakes from 1981 until just before the Landers shock of 1992 occurred in areas that were calculated to have moved closer to failure, i.e. were areas of positive CFF. All changes in CFF were calculated as a function of time with respect to a baseline just before the large to great shock of 1812 on the San Andreas fault. We conclude that it is important to characterize earthquake triggering (like stress) in a tensorial rather than a scalar sense. That work greatly helped to identify the locations of future moderate and large earthquakes as well as sites where such events are unlikely to occur during the next few decades.

In 1998 we began an investigation of changes in the rates of moderate-size earthquakes before and after the 1992 Landers (Du and Sykes, 1998) and 1989 Loma Prieta (Jaumé and Sykes, 1999) earthquakes. The rate of occurrence of shocks of $5.5 \leq M \leq 7$ on neighboring faults in the greater San Francisco Bay area was about 20 times higher in the 25 years before the great 1906 earthquake than it was in the subsequent 65 years (e.g. Sykes and Jaumé, 1990; Jaumé and Sykes, 1996; Sykes, 1996). Likewise, the rate of occurrence of events of $5 \leq M \leq 6.2$ in an area extending out to 100 km from the rupture zone of the 1989 shock increased in the 10 to 15 years before its occurrence. Jaumé and Sykes (1999) find that the rate of events since 1990 in that magnitude range has returned to the low values for the period 1910 to 1975.

Triep and Sykes (1997) found that the frequency of shocks of $M \geq 7$ was much higher in a broad area of Asia to the north of the Himalayas in the 50 years before the giant (M_W 8.7) Assam earthquake of 1950 than it has been in the last 40 years. They also found that the slope, i.e. the b-value, of the log (frequency) - M_W relationship remained nearly 1.0 up to events as large as 8.7 from 1900 to 1950 whereas it was greater than 1.5 for subsequent events of $M \geq 7$, as it was for all other intracontinental regions. They proposed that the region was at or near a self-organized critical (SOC) state in the decades before 1950 and dropped below that state at or near its time of the giant Assam event as compressive stress in that broad region was reduced. Jaumé and Sykes (1999) argue that much of the region surrounding the 1906 rupture zone also was at or near a SOC state in the 25 years before 1906 and dropped below a SOC state as stresses were reduced by the in

1906. The b-value for the period 1883 to 1905 was nearly 1.0 up to events of M 7. Hence, the existence of a SOC state in the latter part of the cycle of stress buildup to a large event as indicated by a higher frequency of moderate-size events and a b-value of about 1.0 for them may be regarded as a long-term precursor rather than an impediment to earthquake prediction (Sykes et al., 1999).

To further explore temporal changes in the rate of moderate-size shocks and changes in their b-value, Du and Sykes (1998) examined the rates of earthquakes of $M \geq 4.0$ in the 25 years before the Landers event and in the 1 to 6 years after its occurrence in two areas of radii of 100 and 160 km. Obvious aftershocks were omitted as were events in the one-year after Landers, the latter to avoid activity such as the Big Bear event that was triggered by the Landers shock. The two left panels of Fig. 1 show the cumulative numbers of events larger than M for two 10 year-periods before Landers and for two 5-year periods before and after its occurrence for the zone of 160 km radius; the two left panels, for the same time periods but for the zone of 100 km radius. Events of $M > 4.4$ occurred more frequently in the 10 years before than in the 10 to 20 years prior to Landers (upper left panel). In the lower left panel the rate for the 5 years before Landers was clearly higher for all events of $M > 4$ than from 1993 to 1997. These differences are more subtle for the zone of smaller radius. We picked a radius 160 km since it includes much of the area that has been brought closer to failure since 1812 in terms of the Coulomb failure function (Fig. 2).

In Fig. 1 we are dealing with that part of the logN - M_W relationship for which the number of events, N, is small and the b value has large uncertainty. Nevertheless, we were guided by the findings from the 1906, 1950, 1989 and other large shocks that it is in the magnitude band about 2 to 3 units smaller than that of the coming largest earthquake that a precursory signal is likely to exist. Keilis-Borok and his colleagues have reached a similar conclusion. Since the M_W's of small forerunning, moderate-size events are likely to fluctuate, we integrated the area under the distributions in the subfigures of Fig. 1 for $N \geq 1$ and $M \geq 4$ and computed 5-year running means to obtain more stable averages. Fig. 3 shows that average or index value as a function of time. The largest value in 25 years occurred during the 5-year period preceding Landers for the region of 160 km radius. Its value then declined markedly for the period 1992-1997. The values for the smaller area, like that for the larger, have maxima for the 5-year windows ending about 1982 and 1992 and minima for those ending about 1977, 1987 and 1997.

We are, of course, puzzled that the more pronounced anomalies in Figs. 1 and 3 arise from events between 100 and 160 km from Landers, not from the closer shocks. Is the anomaly a precursor to Landers, (which occurred on a slow-moving fault), to a coming larger shock along the southern San Andreas, which has a larger long-term slip rate or merely fluctuations in the data?

We are intrigued that the rates of moderate-size shocks within 100 to 200 km of both Landers and Loma Prieta subsequently dropped to levels typical of periods that were not followed by large earthquakes. More work may allow forecasts to be made that a large event has a low probability of occurrence in a sub-region of California in say the next 5 years.

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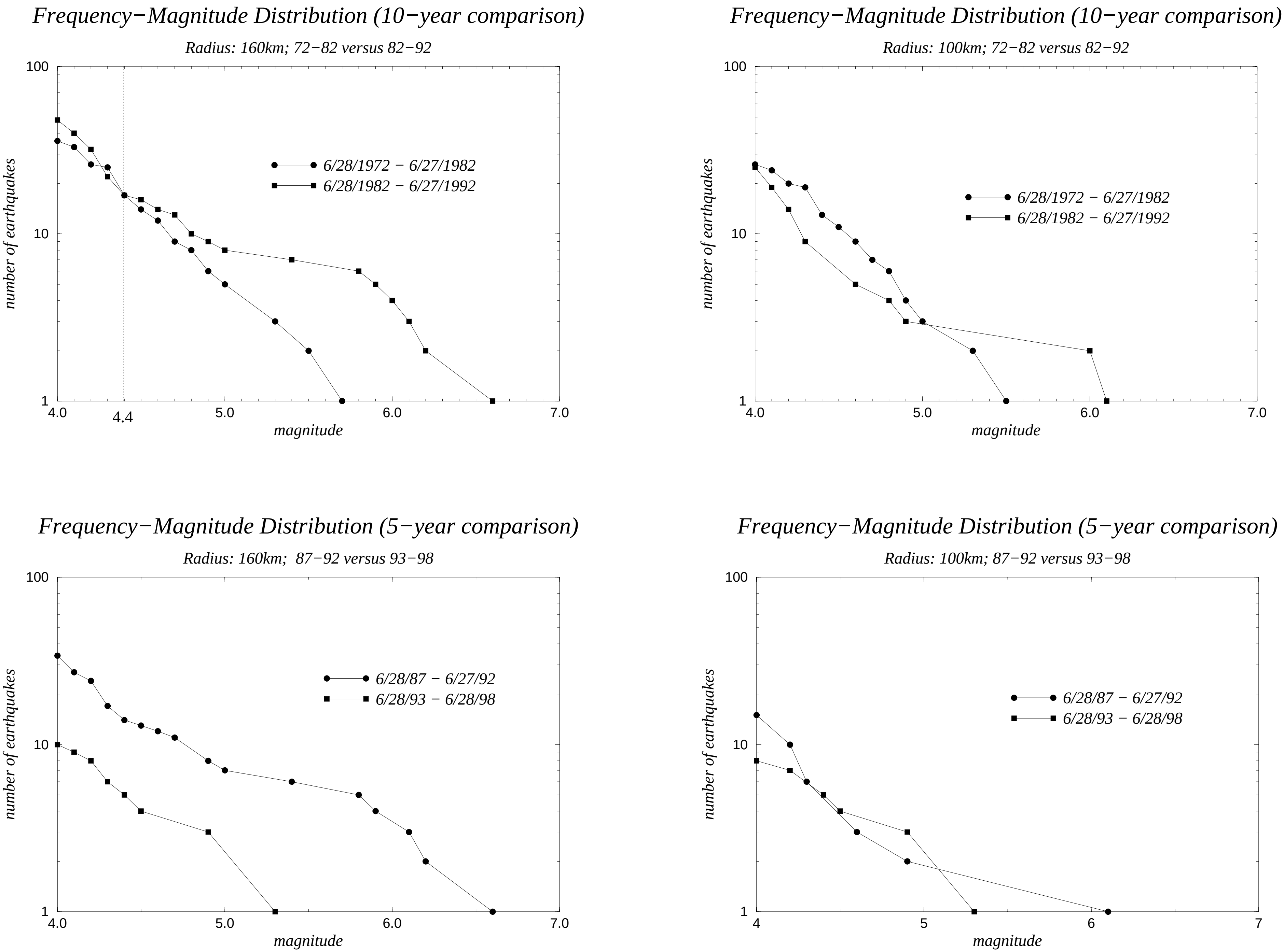

Fig 1. Frequency-Magnitude Distribution for different regions and time periods

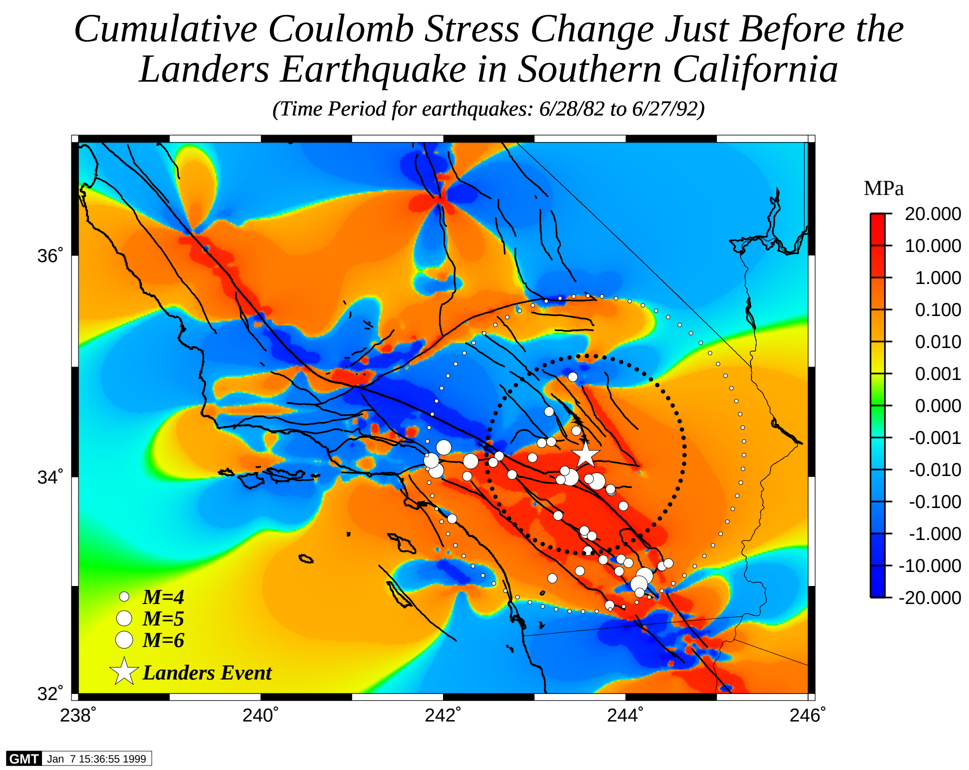

Fig 2. Cumulative Coulomb Stress Change and Moderate-Seismicity

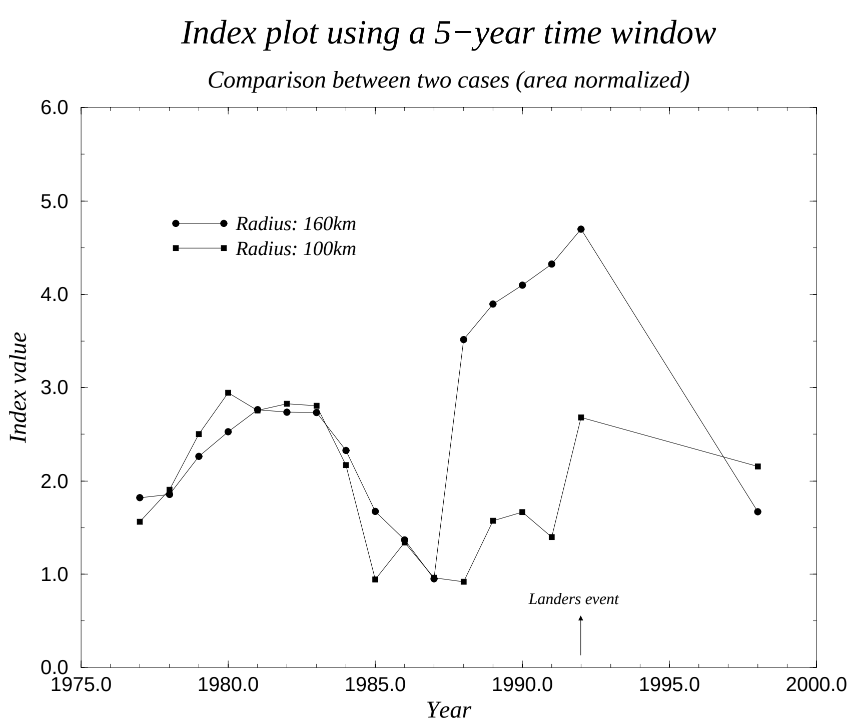

Fig 3. The change of "Index Value" with time