On the current state of the lithosphere in Central California.

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      A. Gabrielov, A. Jin, Z. Liu, P. Shebalin, I. Zaliapin

This letter concerns the current state of the lithosphere in Central California (between latitudes 35.5°N and 39.5°N). We would like to draw your attention to our recent findings which, we believe, demand further focused monitoring of the region and additional analysis of data relevant to the lithosphere dynamics in the region.

There are two mutually supporting pieces of evidence indicating an intensified process for preparing a major earthquake in the region. One is based on the short-term premonitory seismicity patterns; the other is based on a hypothesis about the earthquake precursor related to the loading process at the brittle-ductile transition zone captured by the observed relation between the coda $Q^{-1}$ and the frequency of earthquakes with a certain magnitude $Mc$ characteristic to a seismic region. Both kinds of evidence are new and will be presented at the upcoming IUGG meeting at Sapporo, Japan. Since they have not been published we shall describe them briefly here.

**Coda $Q^{-1}$ and seismicity. K. Aki, A. Jin.**

Jin and Aki (1989, 1993) found a strong positive and simultaneous correlation between the temporal change in the coda $Q^{-1}$ and the frequency of earthquakes with a certain magnitude $Mc$ characteristic to a seismic region. The observed correlation was attributed to the “creep model” in which the following interaction is hypothesized between the brittle part and the ductile part of lithosphere: *When the creep fracture increases with the loading of the plate-driving forces, the coda $Q^{-1}$ increases and at the same time the stress in the brittle part also increases.* This increase in the stress within the brittle part has the spatial characteristic scale length comparable to the size of the creep fracture, causing the increase in the frequency of earthquakes with $Mc$. This interpretation is in harmony with the conclusion of Zoback and Zoback (2002) about the spatial variation of seismicity from a global survey of the tectonic stress: that a region is tectonically stable or active because of the respectively low or high rate of deformation in its ductile part.

The coda $Q^{-1}$-$N(Mc)$ measurement for Central and Southern California was extended recently to 2003 by Anshu Jin using the data organized by Zhen Liu (UCLA). The results are shown in Figures 1 and 2, respectively. The cross-correlation for the entire period is peaked at the zero-time shift as shown in Figure 3. We found, however, that the simultaneous correlation is disturbed before three previous major earthquakes: Kern County (Fig.4), Landers (Fig.5) and Loma Prieta (Fig. 6). The disturbance is apparently caused by the delay in the change of coda $Q^{-1}$ relative to $N(Mc)$ as shown by the cross-correlation functions for the period preceding these earthquakes (bottom panels in Figs. 4 - 6). This may be explained by a very simple idea that the strain energy stored in the brittle part reaches the saturation limit and starts flowing back to the ductile part before a major earthquake. And similar disturbance is observed now (Fig. 7).

The above brittle-ductile interaction model for the earthquake precursor has four parameters: (1) duration of the anomalous period before the target earthquake; (2) delay time of the coda $Q^{-1}$ change relative to that of $N(Mc)$; (3) the value of $Mc$; and (4) the frequency $f_p$ at which the peak in the coda $Q^{-1}$ change occurs. We have so far 7 cases for which these parameters have been estimated as shown in the table below.

**Table of parameters of the brittle-ductile interaction model for earthquake loading**

<table>
<thead>
<tr>
<th>Target earthquake</th>
<th>Reference</th>
<th>Duration</th>
<th>Delay time</th>
<th>$Mc$</th>
<th>$f_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Canyon (M=5)</td>
<td>Chouet(1979)</td>
<td>normal</td>
<td></td>
<td>1-2</td>
<td>24 Hz</td>
</tr>
<tr>
<td>Misasa, Japan (M=6.2)</td>
<td>Tsukuda(1988)</td>
<td>&gt;8 years</td>
<td>2-3 years</td>
<td>2-3</td>
<td>5-10 Hz</td>
</tr>
<tr>
<td>Loma Prieta (M=7.1)</td>
<td>Jin &amp; Aki (1993)</td>
<td>2 years</td>
<td>1 year</td>
<td>4.0-4.5</td>
<td>1-2 Hz</td>
</tr>
<tr>
<td>Kobe, Japan (M=7.2)</td>
<td>Hiramatsu et al.(2000)</td>
<td>6 years</td>
<td>2 years</td>
<td>2.6-3.5</td>
<td>1.5-4.0 Hz</td>
</tr>
<tr>
<td>Kern County (M=7.3)</td>
<td>Jin and Aki (1989)</td>
<td>4-5 years</td>
<td>1 year</td>
<td>3.0-3.5</td>
<td>1-2 Hz</td>
</tr>
<tr>
<td>Landers (M=7.3)</td>
<td>see Figure 6</td>
<td>10-12 years</td>
<td>4 years</td>
<td>3.0-3.5</td>
<td>1-2 Hz</td>
</tr>
<tr>
<td>Tangshan (M=7.6)</td>
<td>Jin (personal com.)</td>
<td>6 years</td>
<td>3 years</td>
<td>4.5-5.0</td>
<td>a few Hz</td>
</tr>
</tbody>
</table>

The first item in the above table is from the first report of temporal change in coda $Q$ discovered at Stone Canyon in the creeping zone of the San Andreas fault by Chouet (1979). Unlike other regions where the greatest changes occur at the $f_p$ of a few Hz and the time constant of the change is several years, the change observed at Stone Canyon was very rapid (within a month or so) and the greatest change occurred for the highest frequency band (24 Hz). His PhD thesis at MIT suggests that the decrease in coda $Q$ appears to be concurrent with the increase in the seismicity of earthquakes with magnitude 1-2, indicating that the change represents the normal loading process according to our model. In fact there was no major earthquakes in the area during the period of his study. The characteristic earthquake in
the creeping zone is known to be about $M=5$, much smaller than the rest of the San Andreas fault zone. These observations in the creeping zone can be considered as a scaled-down version of the loading process of the plate-driving forces taking place at the brittle-ductile transition zone of the lithosphere in other regions.

According to our model, the $fp$ for coda $Q^{-1}$ change must correspond to the fracture size in the ductile part of lithosphere that also must be comparable to the size of earthquake with magnitude $Mc$. A comparison among the data from Stone Canyon, Misasa and the rest indicates that this requirement is at least qualitatively met. The magnitude of the target earthquake increases with $Mc$ and decreases with $fp$ as expected. We also observe that the duration of the anomalous period is roughly proportional to the delay time that seems to scale with the length of the recurrence time rather than the magnitude of the target earthquake. For the current anomaly in Central California shown in Figure 7, it appears that the situation is comparable to the period for Southern California before the Landers earthquake.

**Short-Term Premonitory Seismicity Patterns.** A. Gabrielov, V. Keilis-Borok, P. Shebalin, I. Zaliapin.

Many studies describe intermediate-term premonitory seismicity patterns that emerge with a lead time years before a strong earthquake (e.g. Keilis-Borok and Soloviev, editors, 2002; Keilis-Borok, 2002a; Rundle et. al, 2000; Sornette and Sammis, 1995).

Recent studies describe also short-term premonitory seismicity patterns with a lead time months instead of years. These patterns capture premonitory increase of earthquakes correlation range – a phenomenon that has been found first on the models (Gabrielov et al, 2000; Zaliapin et al, 2002) and then in observations (Keilis-Borok et. al, 2002; Shebalin et. al, 2002; Novikova et. al, 2002). Best results are obtained with the short-term pattern “chains” that has been found more recently and is not published yet. Its brief description follows.

We analyzed seismicity of San Andreas fault system within the borders shown in Fig. 8 for the period Jan. 1965 – June 10 2003; we used earthquake catalog SCSN, available at http://www.scecdc.scec.org/ftp/catalogs/SCSN.

We have found the following short-term premonitory seismicity pattern: A long chain of earthquakes close in time and space. Our study shows that such a chain can be regarded as a short-term precursor only if it is preceded by certain intermediate – term patterns formed in the same area as the chain. We considered intermediate-term patterns of eight types overviewed in [Keilis-Borok, 2002].
Retrospective analysis of the earthquake catalog from 1965 to present detects 22 such chains (each preceded by intermediate-term patterns). This is done by a single unambiguous algorithm, the same for each chain, through the whole time-space considered. Fig. 9 shows these chains in time-distance plane. We see a chain with the lead time 0.5 to 8.5 months prior to each of the 9 strongest earthquakes, from Borrego Mountain, 1968 to Hector Mine, 1999; in prediction these chains would start correct alarms. At least one earthquake in each chain lies within 50 km from the epicenter of a subsequent strong earthquake. The other 11 chains were not followed by such earthquakes within a year in an appropriate area; in prediction they would start false alarms. And the last chain is the reason for this letter. In prediction, this would be a current alarm.

We have preliminary evidence that this pattern and premonitory loss of simultaneous correlation between the coda $Q^{-1}$ and seismicity $N(Mc)$ described above well complement each other. Loss of correlation indicates a time interval of years, when the strong earthquake should be expected; on that background chains indicate a time interval of months, as a second approximation.

It is worth mentioning that the USGS Working Group on California Earthquake Probabilities predicts a strong earthquake in 2003-2032 within the territory that includes the last chain (http://quake.usgs.gov/research/seismology/wg02/).

**Conclusion**

We emphasize that our findings remain hypothetical until tested by advance prediction. Moreover, even in retrospect the method based on the chain of earthquakes shows about 50% of false alarms. On the other hand we considered only a part of the data, potentially relevant to preparation of a strong earthquake. And we are sending this message in the spirit of professional courtesy to draw your attention to a possibility to test your prediction concepts by advance analysis of the data you are working with.

We trust that you will treat this message with necessary discretion: As you know a lot of damage and disruptive anxiety can be caused by prediction itself, if it is sensationalized, bypassing disaster management systems.

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A. Gabrielov, A. Jin, Z. Liu, P. Shebalin, I. Zaliapin
Reference:


Jin, A. and K. Aki, 1993, Temporal correlation between coda Q-1 and seismicity - evidence for a structural unit in the brittle-ductile transition zone, J. Geodynamics, 17, 95-120.


Novikova, O., P. Shebalin, V.Keilis-Borok. A second approximation to intermediate-term earthquake prediction: two cases histories for southeastern Mediterranean. - Problems of Theoretical Seismology and Seismicity (Computational Seismology, Iss. 33), 2002, 186-206.


Figure 1. Temporal variations of Coda $Q^c$ and $N(Mc\ 4-4.5\%)$ in central California, 1941 - 2003.
Figure 2. Temporal variations of coda $Q^{-1}$ and $N(Mc 3-3.5)\%$ for southern California, 1933 - 2003.
Figure 3. The cross-correlation function between coda $Q^{-1}$ and $N(Mc)$ for central (top, $Mc=4-4.5$) and southern (bottom, $Mc=3-3.5$) California.
Figure 4. Temporal variation of coda $Q^{-1}$ and $N(Mc \ 3.0-3.5)\%$ in southern California before the Kern County earthquake (top), and cross-correlation function (bottom). Note 1 year delay in the change of coda $Q^{-1}$. 
Figure 5. Temporal variation of coda $Q^{-1}$ and $N(Mc\ 4-4.5)\%$ before the Loma Prieta earthquake (top) and cross-correlation function (bottom). Note 1 year delay in the change of coda $Q^{-1}$. 
Figure 6. Temporal variation of coda $Q^{-1}$ and $N(Mc \ 3.0-3.5\%)$ before the Landers earthquake and cross correlation function (bottom). Note a 4.5 years delay in coda $Q^{-1}$ change.
Figure 7. Recent temporal variation of coda $Q^{-1}$ and $N(Mc\ 4.0-4.5)\%$ in central California (top) and cross correlation function (bottom). Note positive peak of the correlation coefficient indicating 3.5 years delay in coda $Q^{-1}$ change.
Fig. 8. Territory considered for detection of short-term chains. Yellow triangles are the epicenters of strong earthquakes, 1965 - 2003, targeted for prediction.
Fig. 9. Short-term chains of earthquakes (magnitude 3 to 5) vs. strong earthquakes. Distance is counted along general direction of the San Andreas fault system, as shown by the dotted line in the map (Fig. 8). Stars - epicenters of strong earthquakes. Circles - epicenters of earthquakes in a chain; their size increases with magnitude.

Red - chains followed by a strong earthquake with lead time from half a month to 8.5 months
Gray - chains that would start a false alarm
Black - Recent chain, formed by 13 earthquakes from 3/27/03 to 5/26/26; in prediction this would start a current alarm.