Award Number 07HQGR0107

John E. Ebel
Weston Observatory
Department of Geology and Geophysics
Boston College
Weston, MA 02493
(617) 552-8300
Fax: (617) 552-8388
ebel@bc.edu

Award Title: ANALYSIS OF AFTERSHOCK AND FORESHOCK ACTIVITY IN STABLE CONTINENTAL REGIONS: IMPLICATIONS FOR AFTERSHOCK FORECASTING AND THE SEISMIC HAZARD FOR STRONG EARTHQUAKES IN THE CEUS

Final Report

Submitted
July, 2008

"Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number 07HQGR0107. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government."

ANALYSIS OF AFTERSHOCK AND FORESHOCK ACTIVITY IN STABLE CONTINENTAL REGIONS: IMPLICATIONS FOR AFTERSHOCK FORECASTING AND THE SEISMIC HAZARD FOR STRONG EARTHQUAKES IN THE CEUS

Award Number 07HQGR0107

John E. Ebel
Weston Observatory
Department of Geology and Geophysics
Boston College
Weston, MA 02493
(617) 552-8300
Fax: (617) 552-8388
ebel@bc.edu

Abstract

The research project described in this proposal uses an analysis of earthquake data from several stable continental regions (SCRs) to provide the necessary information to allow seismologists on a routine basis to make accurate forecasts of future aftershocks (and possibly larger mainshocks) once a mainshock has occurred in the Central and Eastern U.S. (CEUS). This research objective is addressed in this investigation by computing those aftershock-decay parameters for Omori's Law necessary for making accurate forecasts of future aftershocks once a main shock has occurred in the CEUS, as well as to determine the probabilities that an earthquake is a possible foreshock of a larger event in the near future. From the results of this work a method is recommended for making aftershock probability forecasts soon after a large earthquake takes place in the CEUS. Also recommended is the probability that an earthquake is a foreshock of an imminent larger event. Such aftershock and foreshock forecasts would warn the public of the potential that future large earthquakes might take place, or they could inform the public about how many felt or strong aftershocks to expect.

Introduction

One area in which earthquake forecasting has been making progress is in the forecasting of the probabilities of aftershocks after a strong earthquake. For example, in California the U.S. Geological Survey (USGS) now puts out both spatial and temporal probability forecasts of aftershocks and possibly larger mainshocks on a regular basis (Gerstenberger et al., 2005; also see the web site Pasadena.wr.usgs.gov/step). The temporal aftershock forecasts are based on an Omori-Law aftershock model where the model parameters are estimated from California aftershock data (Reasenberg and Jones, 1989, 1994). In operation, an initial aftershock forecast made immediately after a mainshock is based on the average parameters for California sequences in the Reasenberg and Jones (1989) formulation. Each forecast, issued for a time period such as a week, consists of an estimate of the average number of aftershocks above some magnitude expected, the probabilities that strong aftershocks might be experienced, and the probability that an earthquake even stronger than the current mainshock will occur (i.e., that the earthquake was a foreshock of a still larger event in the near future). These forecasts can be updated as the aftershock sequence evolves with time.

Because aftershock and foreshock probability forecasts are being routinely made after strong earthquakes in California, there is great interest in extending this capability to the central and eastern U.S. (CEUS). In order to make accurate aftershock and foreshock probability forecasts in the CEUS, one needs to know for each aftershock sequence the values of the parameters for the form of the Omori aftershock law being used for the aftershock forecast. Since there are very few larger earthquakes in the CEUS that have sufficient aftershocks that the Omori-law parameters can be found, it is necessary to look at the aftershocks of earthquakes from other stable continental regions (SCRs) to get more robust statistical estimates of the means and variances of these parameters. In fact, Ebel et al. (2000) already have published the Omori-law parameters for some SCR earthquakes, which they needed for their paleoseismicity analysis. Thus, there already are some data available concerning Omori-law aftershock parameters. However, a more thorough study of aftershock and foreshock parameters for SCR earthquakes was needed in order to determine more statistically robust values of these parameters. Also, the statistics of SCR foreshocks had not yet been studied in detail by any investigators, and those statistics were needed if SCR foreshock probability forecasts are to be made. Thus, the purpose of this research report is to document the aftershock and foreshock statistics of SCR earthquakes worldwide and to explore how the SCR Omori-law parameters and foreshock statistics can be used for aftershock and foreshock forecasts in the CEUS.

SCR Aftershock and Foreshock Data Set

To find the aftershock parameters for SCRs worldwide, where strong events are rare but substantial populations can be at risk from earthquakes, the earthquake catalogs of strong SCR mainshocks compiled by Fenton et al. (2006) and of strong SCR and intraplate earthquakes from the USGS web site (Schulte and Mooney, 2005; earthquake.usgs.gov/research/data/scr_catalog.php) were obtained. The Fenton et al. (2006) earthquake catalog only contained earthquakes to January 1990, while the USGS SCR catalog contained events to November 2003. Thus, the USGS SCR catalog was used as the master catalog of SCR events, and the Fenton et al. (2006) catalog was used as a reference when questions arose about events prior to 1990 in the USGS SCR catalog.

Since both the USGS SCR and Fenton et al. (2006) catalogs contain only larger events, there were insufficient data in these two earthquake catalogs to determine the Omori-Law parameters for aftershock sequences or to determine the incidences of foreshocks of SCR earthquakes. For this reason, it was decided search the USGS NEIC global earthquake catalog and the ISC global earthquake catalog for lists of foreshocks within about 1 month and aftershocks within 2 years of all of the mainshocks of M≥6.0 in the USGS SCR catalog. In doing this search, it was discovered that some of the events in the USGS SCR catalog were mistaken entries (Table 1). One of the events (11/14/2001) is not found in either the NEIC or ISC catalogs. Two of the other events have mistaken epicenters compared to the NEIC or ISC catalogs, and both are in fact plate boundary events with mistaken epicenters in the USGS SCR catalog. Finally, one of the events appears to be a slightly smaller foreshock (or slightly smaller additional mainshock) before a larger, nearby event. These four events were dropped from the SCR M≥6 mainshock catalog, leaving a total of 20 SCR M≥6 mainshocks that were analyzed in this study.

Table 1. Events Deleted from the USGS SCR M≥6 Mainshock Catalog

Date	Latitude	Longitude	Origin Time	Continent	Depth (km)	Mw	Note
11/14/01	7.8137	105.9438	9:30:43	AS	33	6.5	No event in NEIC or ISC catalogs on this day
10/3/01	-6.9671	137.0515	11:23:47	AU	33	6.2	PDE location - 3.50 139.72, plate boundary event
8/26/01	76.3339	-20.322	18:27:52	NA	33	6.1	ISC location 79.85 2.74, plate boundary event
11/21/72	76.58	-106.02	10:06:30	NA	29	6	Larger shock is on 12/27/1972

NA – North America
AU – Australia

Because the NEIC and ISC catalogs contain a large number of aftershocks for only a few of the M≥6 events from the USGS SCR catalog, it was decided to augment the aftershock data analyzed from these larger SCR events with aftershock sequences from SCR mainshocks with magnitudes below 6. The additional aftershock sequences were obtained from regional seismic network databases in Australia, Europe, and North America for earthquakes since the late 1960s. Many of these aftershock sequences were detected by regional seismic networks, although a few were procured through aftershock monitoring using portable seismic stations. Data centers at Geoscience Australia, Lamont-Doherty Earth Observatory, CERI at the University of Memphis, and Weston Observatory of Boston College were used to obtain aftershock sequences of SCR mainshocks.

Aftershock and Foreshock Statistics of Large SCR Earthquakes

Two separate analyses were carried out as part of this research. In the first, the data set of M≥6 SCR mainshocks discussed in the previous section was analyzed to assess the rate of foreshock occurrences prior to M≥6 SCR mainshocks and to determine the times and magnitudes of the largest aftershocks of M≥6 SCR mainshocks. Table 2 summarizes the data that were used for this analysis.

Regarding foreshocks, 9 of the 20 SCR mainshocks of Mw≥6 from 1968 to 2003 had a least one foreshock of M≥4.5 within 33 days of the mainshock, and another of the mainshocks had a foreshock of magnitude 4.2. These statistics include two earthquake sequences that had multiple mainshocks of nearly equal magnitude (the 1988 Tennant Creek, Australia earthquake sequence and the 1972 Northwest Passage, Canada earthquake sequence). According to Fenton et al. (2006) there are about 4 SCR events with M≥4.5 each year worldwide. Thus, from 1968 to 2003, globally there were about 144 SCR events with M≥4.5, and so 9 out of 144 or about 6% of the M≥4.5 SCR events were followed by comparable or larger earthquakes within the following 33 days. If this foreshock rate continues into the future, then when an M≥4.5 earthquake takes place in an SCR, there is about a 6% chance that a larger earthquake will take place in the same area during the following 33 days.

Some statistics concerning the largest aftershocks that follow M≥6 SCR earthquakes can be gleaned from Table 2. Of the 18 mainshocks for which at least one aftershock was reported, the mean magnitude difference between the mainshock and the largest aftershock is 1.3 ± .7 magnitude units, with a range from 0.3 to 3.6 magnitude units. The median magnitude difference between the mainshock and the largest aftershock is 1.3 magnitude units. For 3 of the mainshocks, the largest aftershock occurred within 24 hours of the mainshock, while in 8 cases the largest aftershock occurred within 5 days of the mainshock. For 11 of the 18 mainshocks the largest aftershock took place within 30 days of the mainshock. Thus, in 61% of the cases where aftershocks were reported after SCR mainshocks with M≥6, the largest aftershock took place within 30 days of the mainshock. Table 2 also suggests that some aftershock sequences may be quite protracted, with several cases where the largest aftershock took place almost a year or more after the main shock.

The second analysis carried out on the SCR earthquake data was to determine the Omori-Law parameters that can be used to quantify the rate of aftershock occurrence with time following an SCR mainshock. As in California, the Reasenberg and Jones (1989) form of Omori's Law was used in this study to parameterize the temporal behavior of SCR aftershocks. This version of Omori's Law can be written as

$$\log_{10}(\lambda(t)) = a + b\,(M_m - M) - p\,(t + 0.05) \qquad (1)$$

where λ is the rate of aftershocks at time t in days after the mainshock of magnitude M_m, and M is the lower magnitude cutoff for the catalog that was used. The parameters a, b and p need to be determined for each aftershock sequence. In total, 13 SCR events since 1968 were found in this study to have sufficiently documented aftershock sequences that the parameters *a*, *b* and *p* could be independently determined. To derive the Omori-Law aftershock parameters for each aftershock sequence, the distribution of magnitudes of the aftershocks for a mainshock were plotted on a cumulative Gutenberg-Richter plot, from which the linear part of the distribution was identified and the *b* value measured. The magnitude below which the distribution appeared to depart from linearity was used to find the minimum magnitude for which the earthquake data appeared to be complete. Counts per day of the number of aftershocks above this minimum magnitude were then used to find the *p* value of the aftershock decay in Omori's Law. Once *b* and *p* were known, the *a* value for Equation (1) was then computed from the distribution of the aftershocks with time. Generally, it was the aftershocks in the first 10-20 days after a mainshock that were used to determine the parameter *p*. This same procedure was used by Ebel et al. (2000), from which some of the *a*, *b* and *p* values were taken for this study.

Table 3 lists the *a*, *b* and *p* parameters found for the SCR aftershock sequences analyzed in this study. The events from North America and Europe are all less than Mw 6.0, but their aftershock sequences are well determined because of regional seismic network recordings or portable seismic station monitoring of the aftershocks. Regional seismic network recording also helped detect aftershocks of the mainshocks from Australia, most of which were above Mw 6.0. Figure 1 shows how the *a*, *b* and *p* parameters found for the SCR events in this study compare to the distribution of those parameters for California. The distribution of the SCR aftershock parameters cannot be distinguished statistically from the distribution of those same parameters for aftershock sequences in California. This means that the generic California aftershock *a*, *b* and *p* parameters (a=-1.67, b=.91, and p=1.08) reported by Reasenberg and Jones (1989) also can be used to describe average SCR aftershock sequences.

Application of the Results of this Study to Aftershock Forecasting in the CEUS

This study suggests that the kind of aftershock forecasting that is currently carried out in California can be applied in the same way to stable continental regions on a global basis. As soon as a large SCR earthquake occurs, the generic California aftershock parameters can be used to make an initial estimate of the probabilities of the number of expected aftershocks above some minimum magnitude in the coming days. This can be the basis of an initial public forecast of the number of aftershocks that can be expected. In many cases, the aftershock activity within the first ½ to 1 day of a mainshock should be sufficient to update the Omori-Law *a* parameter and to issue revised forecasts of the probabilities of aftershock activity at various magnitudes. If a large number of aftershocks are recorded, the *b* and *p* Omori-Law parameters can be calculated for the aftershock sequence and the forecast aftershock probabilities can be further refined. Obviously, if a strong SCR earthquake takes place at a locality which is being monitored by a regional or local seismic network, then many aftershocks will likely be recorded and there will probably be sufficient data to update the *a*, *b* and *p* parameters. Even if a strong SCR earthquake takes place at a locality where there is no regional or local seismic network monitoring, global monitoring of the larger aftershocks by agencies like the USGS NEIC may allow the *a*, *b* and/or *p* parameters in Omori's Law to be updated if a sufficient number of aftershocks are detected. Thus, even for poorly monitored SCR areas it may be possible to issue revised aftershock probability forecasts after some aftershock activity has been detected teleseismically.

In addition to forecasting the probabilities of numbers of events at different magnitude levels, the statistics in this study provide a basis for forecasting the possibilities of strong aftershocks. The largest aftershock is most likely about 1.3 magnitude units less than the magnitude of the main shock. Based on the SCR data set analyzed in this study, the largest magnitude aftershock has a 40% chance of occurring within 5 days of the main shock and a 70% chance of occurring within 60 days of the main shock. However, about 30% of the time the largest SCR aftershock will occur more than 60 days, and perhaps as late as 1½ years, after the mainshock. Also, if the initial SCR event that triggers the forecast has M≥4.5, then the statistics described above suggest that there is about a 6% chance that a comparable or stronger earthquake will take place near the same location during the subsequent 33 days.

The aftershock sequence of the April 18, 2008 M 5.2 Mount Carmel, Illinois earthquake can be used to illustrate how aftershock forecasting might take place in the CEUS. Immediately after the Mount Carmel mainshock took place, an aftershock forecast could have been issued based on the generic California aftershock model of Reasenberg and Jones (1989). That forecast would state that about 29 aftershocks of M≥2.0 could be expected during the next 24 hours, and about 43 aftershocks of M≥2.0 could be expected during the next 7 days. The largest aftershock expected would be about M 3.9, and there was perhaps a 6% chance that a larger event could take place. The first 24 hours after the main shock yielded 8 earthquakes of M≥2.0, many fewer than the 29 that were initially forecast. This rate of aftershocks during the first day after the mainshock can be used to find a revised a parameter in Equation (1), yielding the following revised Omori-Law parameters: a=-2.22, b=0.91, and p=1.08. Based on these Omori-Law parameters, a second forecast issued exactly 1 day after the Mount Carmel mainshock would specify about 2 aftershocks of M≥2.0 could be expected during the next 24 hours, and about 4 aftershocks of M≥2.0 could be expected during the next 7 days. In fact, 2 aftershocks with M≥2.0 were observed during the second day after the mainshock and 8 aftershocks with M≥2.0 were observed during the 7 days after this second forecast would have been issued. The largest event observed during the aftershock sequence through July 8, 2008 was M 4.6. This is 0.6 magnitude units smaller than the mainshock and is one standard deviation greater than the mean mainshock-aftershock magnitude difference.

Conclusions

The research project described in this proposal uses an analysis of earthquake data from several stable continental regions (SCRs) to provide the necessary information to allow seismologists on a routine basis to make accurate forecasts of future aftershocks (and possibly larger mainshocks) once a mainshock has occurred in the Central and Eastern U.S. (CEUS). This research objective is addressed in this investigation by computing those aftershock-decay parameters for Omori's Law necessary for making accurate forecasts of future aftershocks once a mainshock has occurred in the CEUS, as well as to determine the probabilities that an M≥4.5 earthquake is a possible foreshock of a larger event in the near future. From the results of this research a method is recommended for making aftershock probability forecasts soon after a large earthquake takes place in the CEUS. Also recommended is a probability estimate that an earthquake is a foreshock of an imminent, larger event. Such aftershock and foreshock forecasts would warn the public of the potential that future large earthquakes might take place, or they could inform the public about how many felt or strong aftershocks to expect. The results of the analyses presented in this report can have a direct impact on reducing the losses from future earthquakes in the CEUS. Forecasts of aftershock and foreshock probabilities will be useful for emergency managers, public officials, and search-and-rescue teams. Such forecasts will also help the public to understand the potential for future earthquake activity following the occurrence of a felt or a damaging earthquake.

Table 2. Foreshocks and Aftershocks of M≥6 SCR Mainshocks from 1968-2003

Date	Lat.	Lon.	Origin Time	Depth (km)	Mw	mb	Ms	# FS	Max FS	Max AS	Time Max AS (days)	Location	Note
1/26/01	23.44	70.31	3:16:40	16	7.6	6.9	7.9			5.9	1.9	Bhuj, India	M4.6 foreshock 33 days before mainshock
12/23/00	-7.83	135.89	7:13:36	13.7	6	5.7	5.3			4.7	15	Aru Islands	Only 2 aftershocks reported
11/8/00	77.04	-77.83	6:59:59	17	6	6	-					West side of Baffin Bay	No foreshocks or aftershocks reported
8/10/97	-16.15	124.34	9:20:34	20	6.2	5.8	5.9			4.2	22	Collier Bay, Australia	Only 4 aftershocks reported
9/29/93	18.08	76.49	22:25:51	12	6.2	6.3	6.3	1	4.7	5.1	71	Khillari, India	M4.9 foreshock 31 days before mainshock
12/25/89	60.05	-73.54	14:24:34	2.9	6	6.2	6.3	1	5.1	4.0	2.9	Angava Peninsula, Quebec	Only 3 aftershocks reported
1/22/88	-19.90	133.86	12:04:59	6.3	6.6	6.1	6.5			5.8	0.3	Tennant Creek, Australia	Multiple mainshocks
5/21/84	32.69	121.51	15:39:04	44.5	6.1	5.7	6	1	5.5	4.8	0.04	Jiangsu Province, China	Only 7 aftershocks reported
12/22/83	11.86	-13.51	4:11:30	8	6.2	6.4	6.2					Guinea	No foreshocks or aftershocks reported
6/2/79	-30.82	117.11	9:48:00	6.2	6.1	6	6.1	17	5.2	5.1	0.9	Cadoux, Australia	

4/23/79	-16.62	120.16	5:45:11	31.2	6.1	5.9	5.7	1	4.7	4.8	4.6	Northwest of Australia	Only 5 aftershocks reported
1/18/76	77.82	18.47	4:46:22	5.5	6	-	-			4.5	546	Svalbard	Only 2 aftershocks reported
9/27/74	2.65	-71.36	4:09:00	20.6	6.3	5.5	-			4.9	3.1	Eastern Colombia	Only 2 aftershocks reported
9/23/74	-0.30	12.76	19:28:14	2.7	6	-	-			5.2	536	Southwest Africa	Only 1 aftershock reported
5/10/74	28.18	103.99	19:25:17	9.9	6.8	-	7.1			5.5	36	Sichuan Province, China	M4.5 foreshock 33 days before mainshock
12/27/72	76.76	-107.09	22:59:27	3.3	6.3	5.7	6			5.4	36	Northwest Passage, Canada	Multiple mainshocks
3/24/70	-22.05	126.67	10:35:21	15	6	-	5.9			5.3	352	Lake Mackay, Australia	
9/29/69	-33.19	19.34	20:03:30	15	6.4	5.9	6.3			6.1	197	South Africa	
10/14/68	-31.52	116.98	2:58:51	5	6.6	6	6.9	15	4.2	5.7	1.0	Meckering, Australia	
5/15/68	-15.92	26.10	7:51:18	25.5	6.8	5.7	-			3.2	33	Zambia	

FS – Number of foreshocks observed
Max FS – Magnitude of the largest foreshock
Max AS – Magnitude of the largest aftershock
Time Max AS – Time in days after the mainshock when the largest aftershock took place

Table 3. Determinations of *a*, *b* and *p* Parameters of Omori's Law for SCR Earthquakes

SCR Aftershock Parameters										
Event Name	Date	Time	Lat.	Lon.	Mag.	Mag. Type	Min. Mag.	*b* value	*p* value	*a* value
Miramichi, NB [1]	1/9/82	12:53:52	46.98	-66.66	5.5	Mw	1.7	0.81	1.01	-0.77
Goodnow, NY [1]	10/7/83	10:18:46	43.94	-74.25	5.1	Mc	1.5	0.85	0.74	-2.50
Swabian Jura, Germanhy [1]	9/3/78	5:08:00	48.30	9.02	5.7	ML	1.0	0.53	0.98	-0.80
Lleyn, Wales [1]	7/19/84	6:56:00	52.96	-4.38	5.4	ML	0.6	0.66	1.02	-1.16
Roermond, Netherlands [1]	4/13/92	1:20:00	51.17	5.95	5.8	ML	2.0	1.05	1.29	-2.62
Au Sable Forks, NY [2]	4/20/02	10:50:47	44.51	73.68	5.1	MbLg	1.5	0.60	0.78	-1.55
Mt. Carmel, IL [3]	4/18/08	9:36:59	38.45	-87.89	5.2	Mw	1.5	0.56	0.78	-1.20
Bhuj, India [4]	1/26/01	3:16:41	23.42	70.23	8.0	Mw	4.5	1.40	1.51	-3.77
Tennant Creek, Australia [1]	1/22/88	12:04:59	-19.84	133.99	6.8	ML	1.8	0.91	0.96	-1.59
Meckering, Australia [5]	10/14/68	2:58:51	-31.52	116.98	6.6	Mw	2.5	0.92	1.00	-2.67
Cadoux, Australia [5]	6/2/79	9:47:59	-30.83	117.18	6.2	ML	2.0	0.80	1.22	-1.78
Lake Mackay, Australia [5]	3/24/70	10:35:17	-22.05	126.61	6.7	ML	3.5	1.08	1.18	-2.17
Burakin, Australia [5]	9/28/01	2:54:56	-30.54	117.06	5.2	ML	2.0	0.84	0.82	-1.65

[1] *a*, *b* and *p* values from Ebel et al. (2000).

[2] Aftershock data provided by W.-Y. Kim, Lamont-Doherty Earth Observatory.

[3] Data provided by M. Withers, CERI, University of Memphis.

[4] Data from the USGS NEIC.

[5] Data from the Geosciences Australia web site (http://www.ga.gov.au/). Information about the earthquakes on this web site can be found from Leonard (2008).

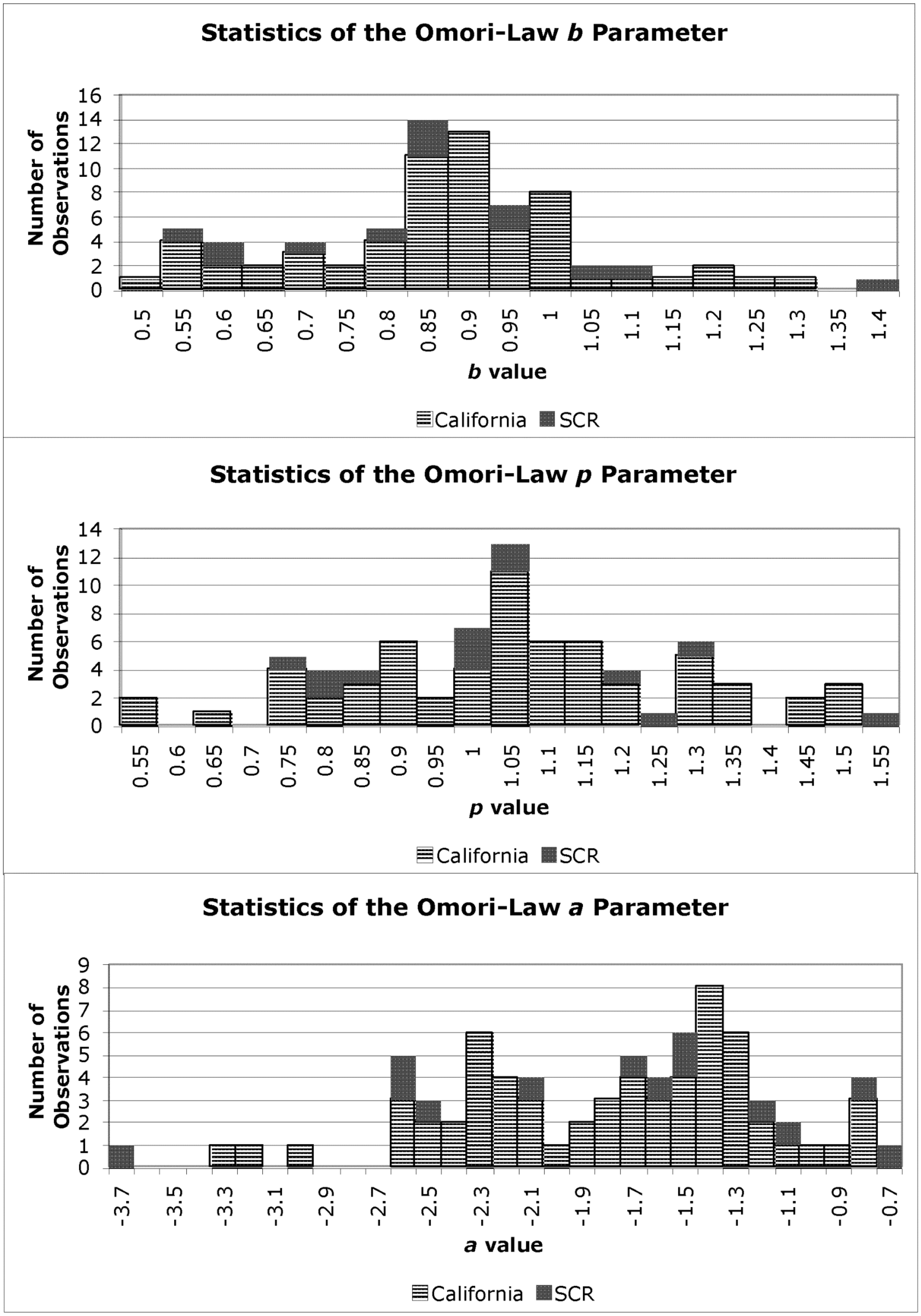

Figure 1. Distributions of the Omori-Law parameters *b*, *p* and *a* for California earthquakes from Reasenberg and Matthews (1990) and for the SCR earthquakes from this study.

References

Ebel, J.E., K.-P. Bonjer and M.C. Oncescu (2000). Paleoseismicity: Seismicity Evidence for Past Large Earthquakes, *Seism. Res. Lett.* **71**, 283-294.

Fenton, C.H., J. Adams and S. Halchuk (2006). Seismic hazards assessment for radioactive waste disposal sites in regions of low seismic activity, *Geotech. Geol. Eng.* **24**, 579-592, doi: 10.1007/s10706-005-1148-4.

Gerstenberger, M.C, S. Wiemer, L.M. Jones, and P.A. Reasenberg (2005). Real-time forecasts of tomorrow's earthquakes in California, *Nature* **435**, 328-331.

Leonard, M. (2008). One Hundred Years of Earthquake recording in Australia, *Bull. Seism. Soc. Am.* **98**, 1458-1470, doi: 10.1785/1020050193.

Reasenberg, P.A. and L.M. Jones (1989). Earthquake Hazard After a Mainshock in California, *Science* **243**, 1173-1176.

Reasenberg, P.A. and L.M. Jones (1994). Earthquake Aftershocks: Update, *Science* **265**, 1251-1252.

Reasenberg, P.A. and M.V. Matthews (1990). Response, *Science* **247**, 343-345.

Schulte, S.M., and W.D. Mooney (2005). An updated global earthquake catalogue for stable continental regions: reassessing the correlation with ancient rifts, *Geophys. J. Int.* **161**, 707-721, doi: 10.1111/j.1365-246X.2005.02554.x.

Publications Based on This Research

Ebel, J. E., and Moulis, A. M., (2007). Analysis of Aftershock Activity in Stable Continental Regions: Implications for Aftershock Forecasting after Strong Earthquakes in the CEUS, *EOS Trans. AGU* **88(52)**, Fall Meet. Suppl., Abstract S43A-1064.

Ebel, J. E., and Moulis, A. M., (2008). Aftershock and Foreshock Forecast Probabilities in Stable Continental Regions, to be submitted to *Science*.