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Client Report 43878D.10

Evaluation of Wells and Coppersmith (1994) Earthquake and Fault Relationships in the New Zealand Context

prepared for

Earthquake Commission
Research Foundation
EQC Project 97/249

by

Mark Stirling,
David Rhoades, and
Kelvin Berryman

December 1998

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Contents

Abstract

We assess the suitability of the earthquake and fault relationships of Wells and Coppersmith (1994) for use in New Zealand seismic hazard studies. We find that the regressions of Wells and Coppersmith (hereafter referred to as "W&C") provide underestimates of the moment magnitudes (M_w) and coseismic surface displacements of large New Zealand earthquakes, and attribute much of the discrepancy to the dataset used by W&C for their analysis. Regressions developed after addition of newly published data to the W&C dataset, and addition of data originally excluded from the W&C dataset provide closer estimates of M_w and displacement to those of the New Zealand earthquakes. The remaining discrepancies appear to be due to the New Zealand earthquake dataset comprising largely paleoearthquake and pre-instrumental data, which produce larger estimates of M_w and displacement than more recent data. Lastly, we find that the coseismic displacement per unit rupture length (proportional to stress drop) is not constant for all earthquakes, but is a decreasing function of both slip rate and the total amount of slip registered across the fault.

Introduction

W&C (1994) developed a series of empirical regressions between earthquake magnitude and various fault rupture parameters from a worldwide dataset of historical earthquakes. These empirical regressions have since become the standard for use in seismic hazard analysis throughout the world. However, the regressions of W&C tend to provide underestimates of the magnitudes and single event displacements for large New Zealand earthquakes that have been observed historically or estimated from paleoseismic data (e.g. Stirling et al. 1998). For example, the M8.1-8.2 1855 Wairarapa earthquake, and M7-7.3 1888 Canterbury earthquake were about 0.5 and 0.2 magnitude units larger, respectively than the magnitudes estimated from the rupture lengths of those earthquakes with the regression equations of W&C. It is therefore possible that the use of W&C's regressions for seismic hazard analysis in New Zealand may result in underestimates in seismic hazard for large earthquakes. Another unresolved issue concerning the regressions of W&C is whether or not factors such as tectonic setting influence relationships between magnitude, displacement and other fault parameters. While W&C found no evidence for this in their analysis, the recent regression of Anderson at al. (1996) clearly shows that larger earthquakes tend to occur on slower slipping faults, for a constant rupture length.

In this study we aim to resolve the discrepancies between the predictions of W&C and the New Zealand data. Our general approach is to determine whether or not the discrepancies are due to uniqueness in the New Zealand tectonic environment, or are an artifact of the data and methods used by W&C to construct their regression equations. W&C constructed regression equations from the source parameters of $M_w \geq 4.7$ earthquakes, but excluded a lot of earthquakes from their analysis that they considered too unreliable to use. Their largest exclusions involved almost all early (approximately pre-1940) earthquakes, including several New Zealand earthquakes. Their exclusions therefore involved early instrumental data (the first seismograms date from the late 19th century), and pre-instrumental data derived from felt intensities and from field measurements of historical ruptures. In this study we compile a large dataset that includes much of the early data W&C excluded from their analysis, and also include newly published data for early historical (pre-instrumental) to recent earthquakes from the eastern Mediterranean region (Ambraseys and Jackson, 1998), pre-instrumental data from Japan (Research Group for Active Faults of Japan, 1991), and a mixture of pre-instrumental and recent data from the regressions of Anderson et al. (1996). We then construct regression equations from our worldwide dataset, and equations based on New Zealand data alone, and compare our regressions to W&C's original regressions. Since there are relatively few New Zealand earthquakes in W&C's original dataset, we boost the New Zealand component of the dataset by adding estimates of M_w and fault rupture parameters from paleoearthquake data for New Zealand active faults. We also add paleoearthquake data from Japan to increase the size of the global dataset. Our dataset therefore has considerably wider scope than any of the previous datasets used to produce empirical regressions of earthquake magnitude from fault parameters.

Method and Analysis

The estimates of earthquake magnitude and fault parameters used in this study are listed in the Appendix. In all, 283 earthquakes are listed in the dataset. Almost all of the time spent on this project went into evaluating and compiling data from existing regression analyses, searching the literature for data, and obtaining data by communication with colleagues in New Zealand and overseas. Each row in the Appendix represents a single earthquake, and provides data on the earthquake date, location, magnitude, slip type, rupture length (surface and subsurface estimates), rupture width, single event displacement (maximum and average values of surface displacement), and the values of slip rate and total slip for the associated fault. A detailed description of the dataset is given at the base of the Appendix. Since more than one estimate of magnitude is available for many of the earthquakes, we select the best estimate of magnitude from the following choices, in decreasing order of preference; (i) M_w from seismological data, (ii) M_s or M_{jma} (surface wave magnitudes) as an approximation of M_w (iii) MI (intensity magnitude) as an approximation of M_w and (iv) M_w from paleoearthquake data. We restrict our dataset to those earthquakes with $M_w \geq 6.0$, which is the approximate lower limit of M_w that is commonly associated with surface rupture (e.g. W&C 1994). W&C incorporated some earthquakes of M_w <6.0 into their analysis, but we have verified that these events did not influence their regressions significantly. However, we include in our analysis all of the pre-1940 data listed by W&C but not used in their analysis.

We develop regression equations of a similar form to those developed by W&C. The first form is used to relate M_w to the rupture length or area:

$$M_w = a + b(\log(L \text{ or } A)),$$

in which L is the surface rupture length in km, A is the fault area in km^2, a and b are empirically-derived constants, and log is to the base 10. The second form of equation is used to relate the average value of single event displacement to the rupture length:

$$\text{Log}(D) = a + b(\log(L))$$

in which L is the surface rupture length in km, and D is the average value of coseismic displacement (in metres) measured at the ground surface along L. We follow W&C's methodology and construct regressions of magnitude versus surface rupture length, and displacement versus surface rupture length. The distinction between surface and subsurface (aftershock) derived estimates of rupture length is important. Surface rupture length tends to be less than subsurface rupture length for a given earthquake, leading to systematic differences in the regressions of earthquake magnitude versus rupture length. We also construct regressions of M_w versus rupture area, in which the rupture area is calculated from the estimates of surface rupture length and downdip width of the rupture. Our emphasis on surface rupture parameters in the above regressions is driven by a need to more correctly estimate the magnitudes of future large New Zealand earthquakes from the length of surface ruptures, and from the length of fault traces in general. We therefore do not present any regressions based on subsurface estimate of rupture length in this study.

We show the results of our regression analyses of M_w versus surface rupture length, surface rupture displacement versus surface rupture length, and M_w versus rupture area in Figures 1 to

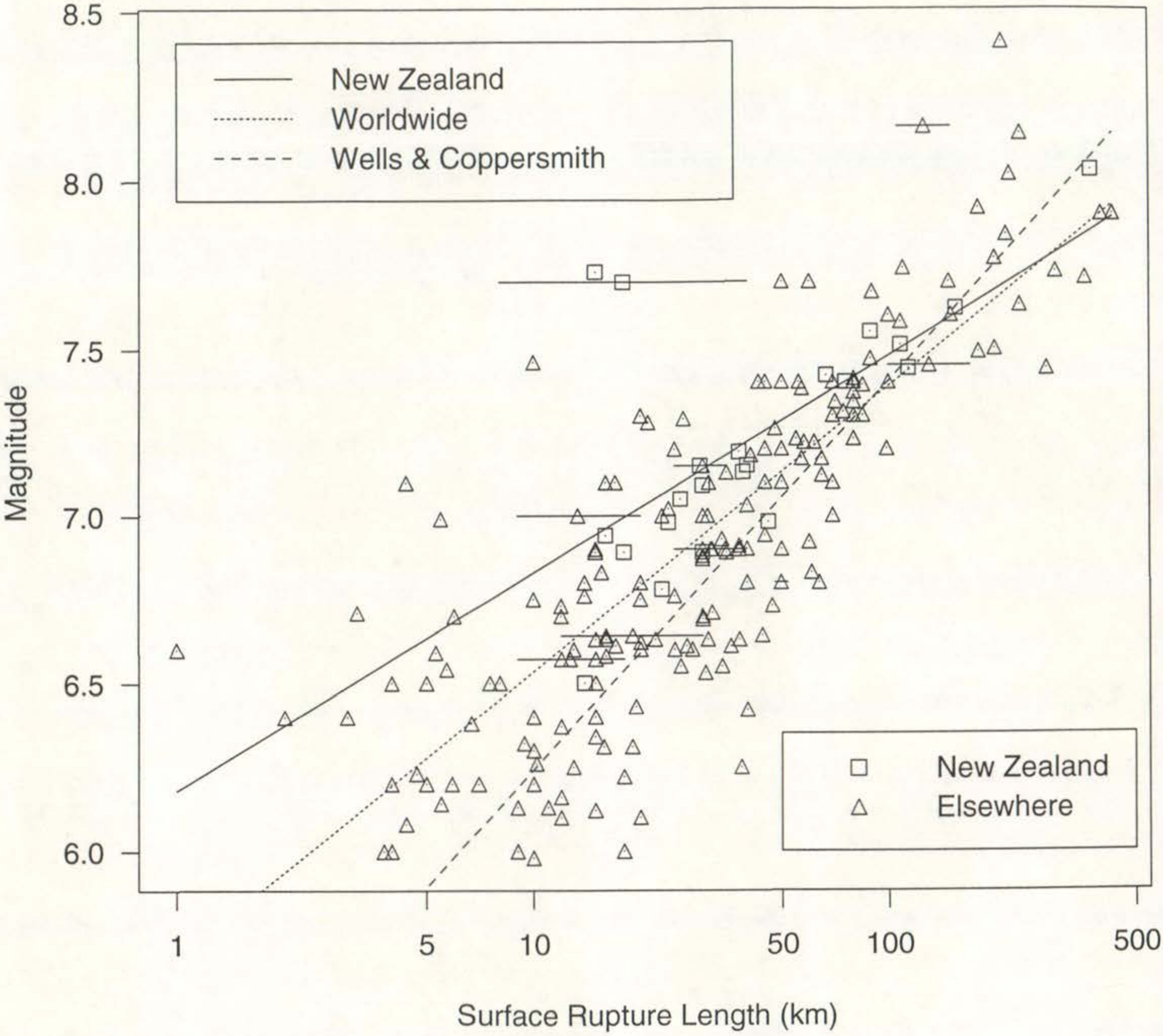

Figure 1a
Regressions of magnitude versus surface rupture length for our worldwide dataset, the New Zealand subset of the dataset, and the original regressions of W&C (labelled "Wells and Coppersmith). The error bars on some symbols reflect uncertainties in estimates of rupture length for a given earthquake. See Table 1 for parameters a and b for each of the regressions.

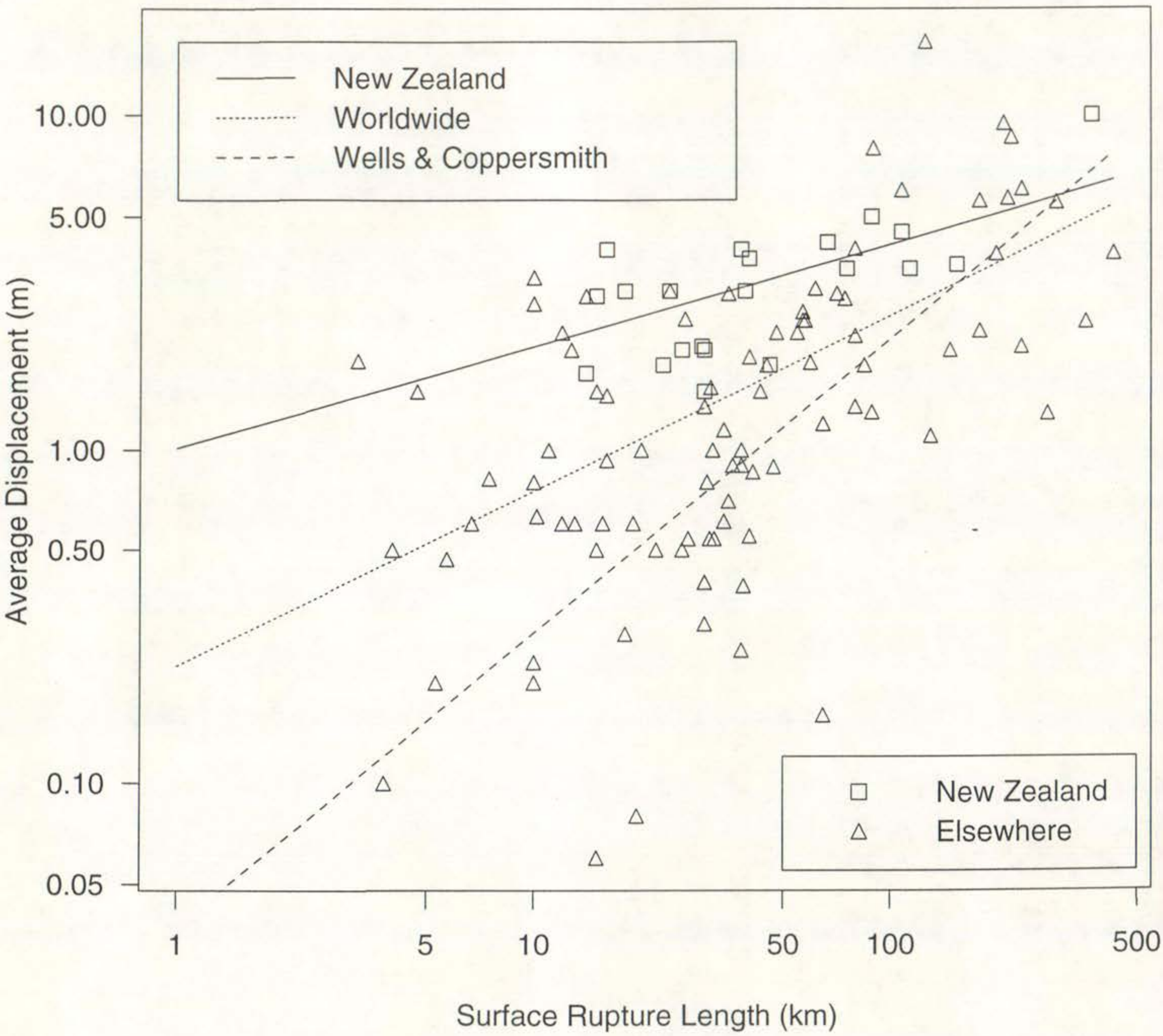

Figure 1b

Regressions of average surface rupture displacement versus surface rupture length for our worldwide dataset, the New Zealand subset of the dataset, and the original regressions of W&C (labelled "Wells and Coppersmith). See Table 1 for parameters a and b for each of the regressions

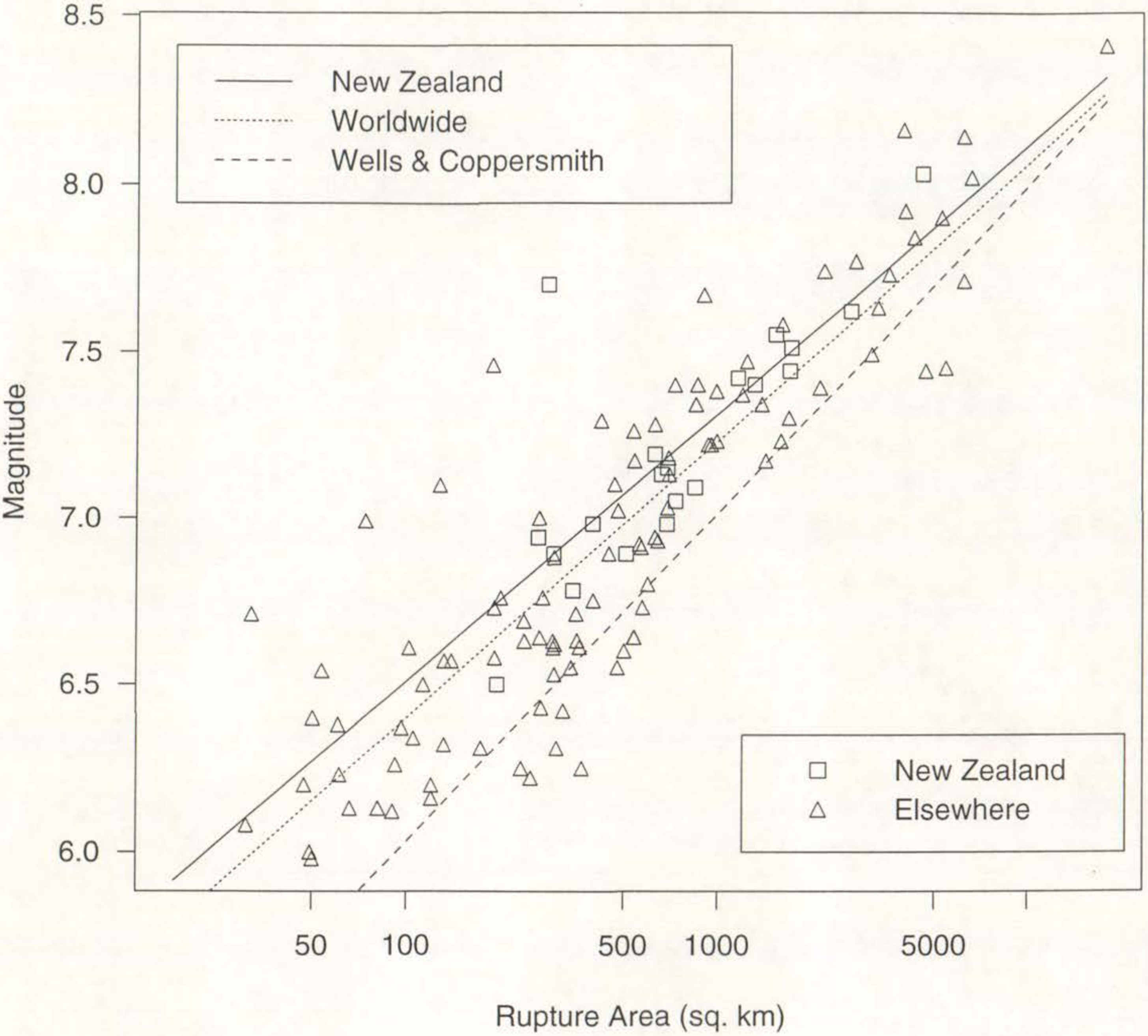

Figure 2
Regressions of magnitude versus rupture area, in which rupture area is the product of the surface rupture length and the downdip width of the rupture. See Table 1 for parameters a and b of the regressions.

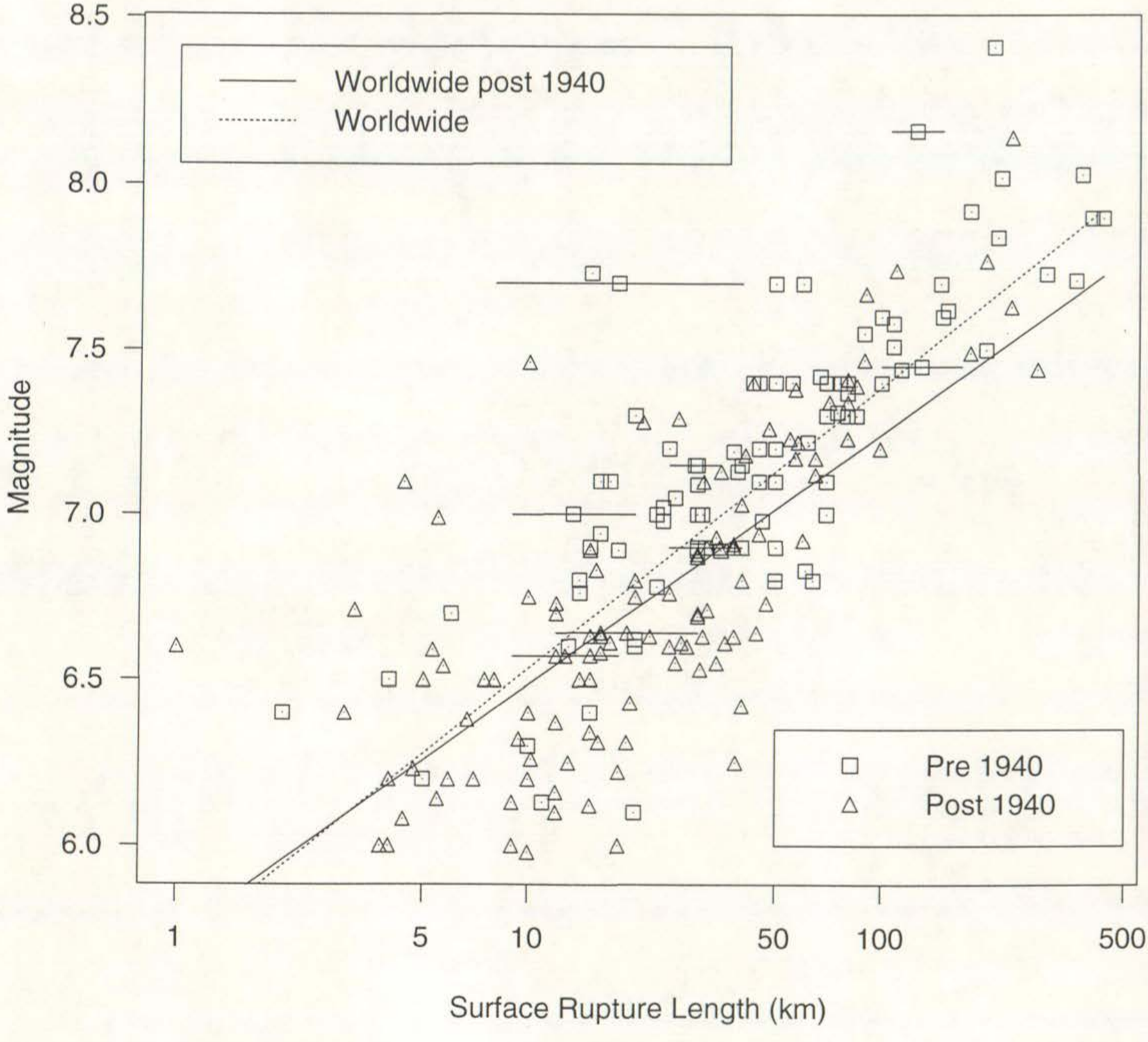

Figure 3a

Regressions of magnitude versus surface rupture length for our worldwide dataset, and for data from 1940 onwards). The error bars on some symbols reflect uncertainties in estimates of rupture length for a given earthquake. See Table 1 for parameters a and b of the regressions.

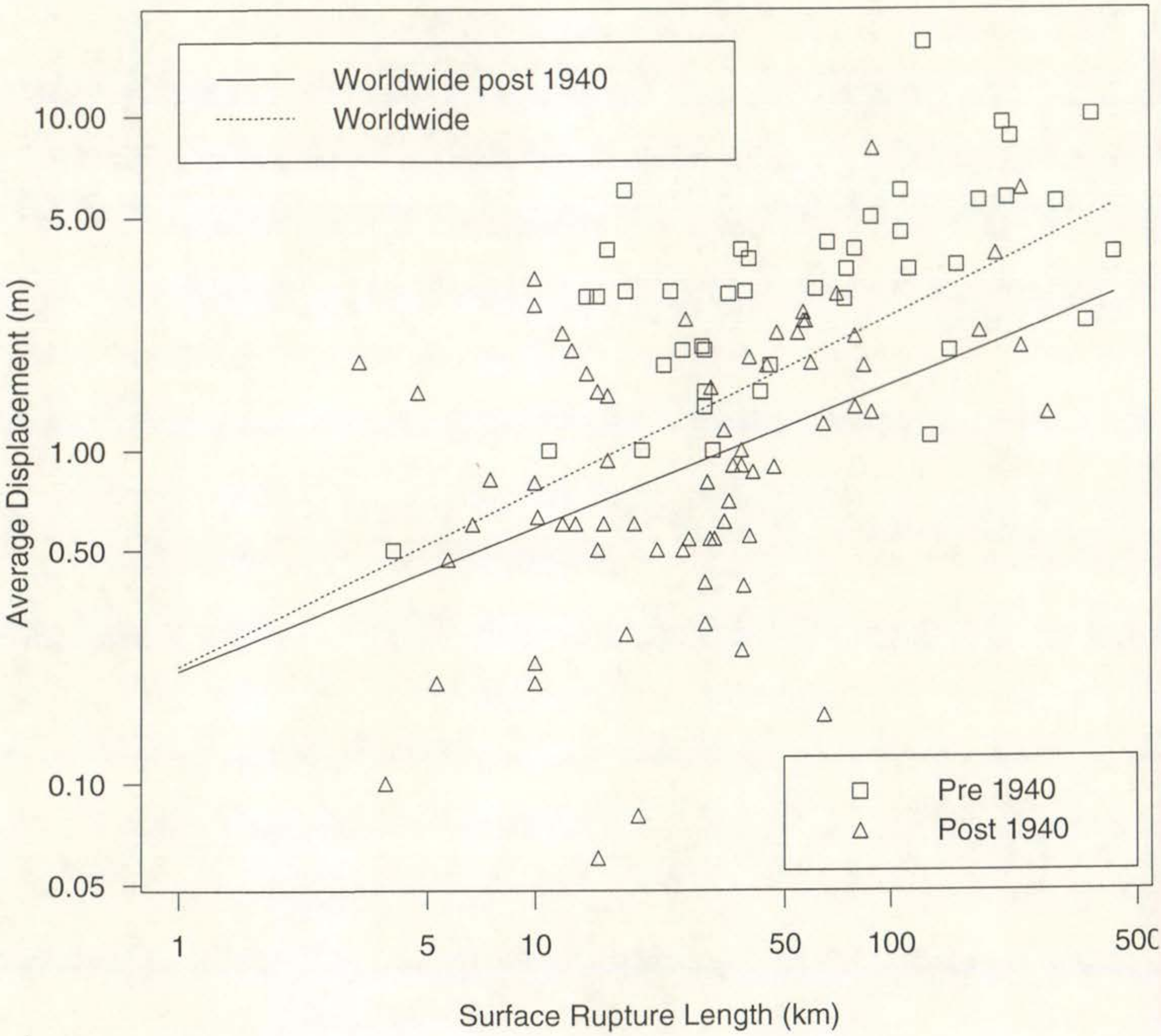

Figure 3b
Regressions of average surface rupture versus surface rupture length for our worldwide dataset, and for worldwide data from 1940 onwards. See Table 1 for parameters a and b of the regressions.

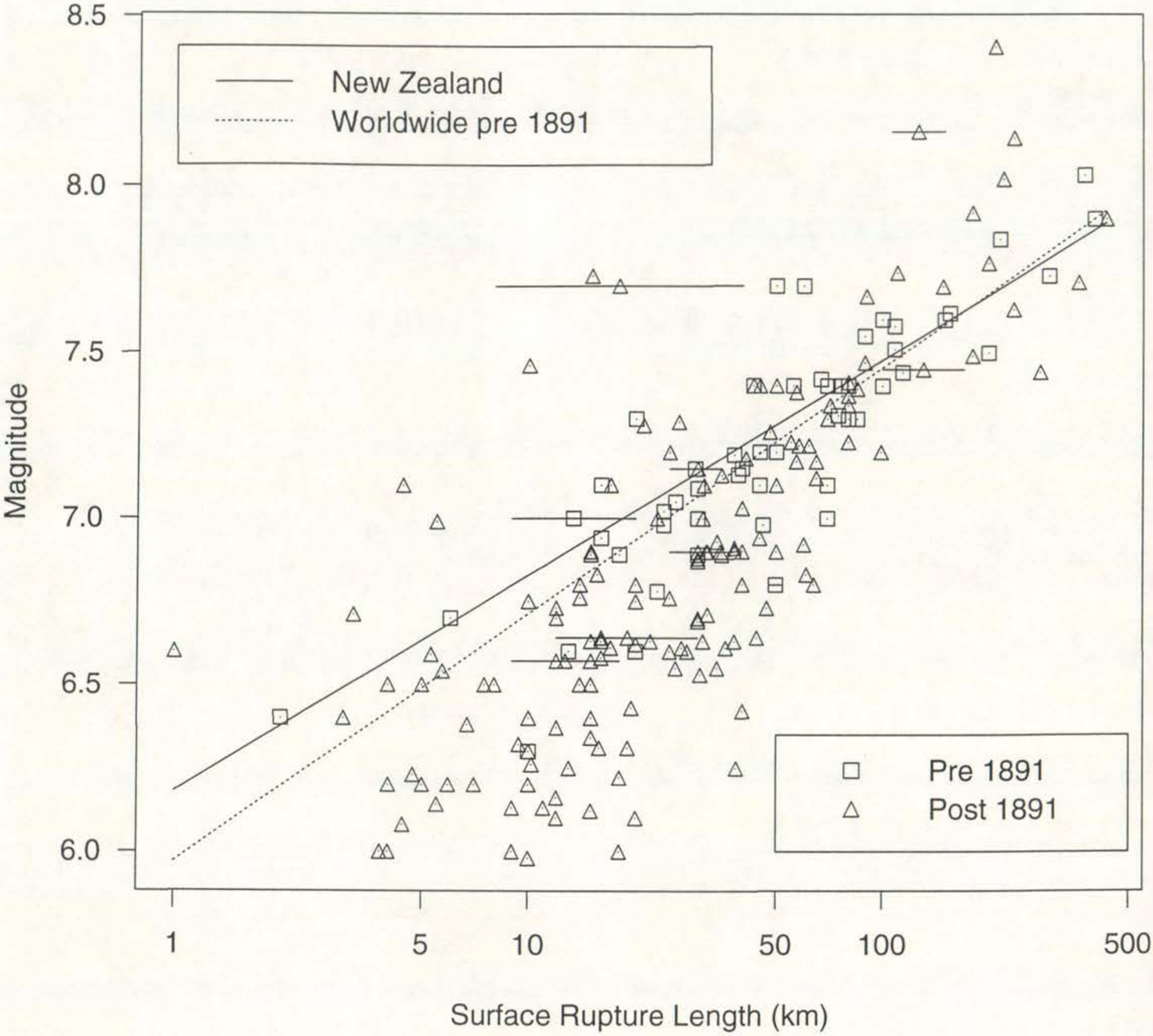

Figure 4a

Regressions of magnitude versus surface rupture length for the New Zealand subset of our dataset, and for all pre-instrumental (pre 1891) data). The error bars on some symbols reflect uncertainties in estimates of rupture length for a given earthquake. See Table 1 for parameters a and b of the regressions.

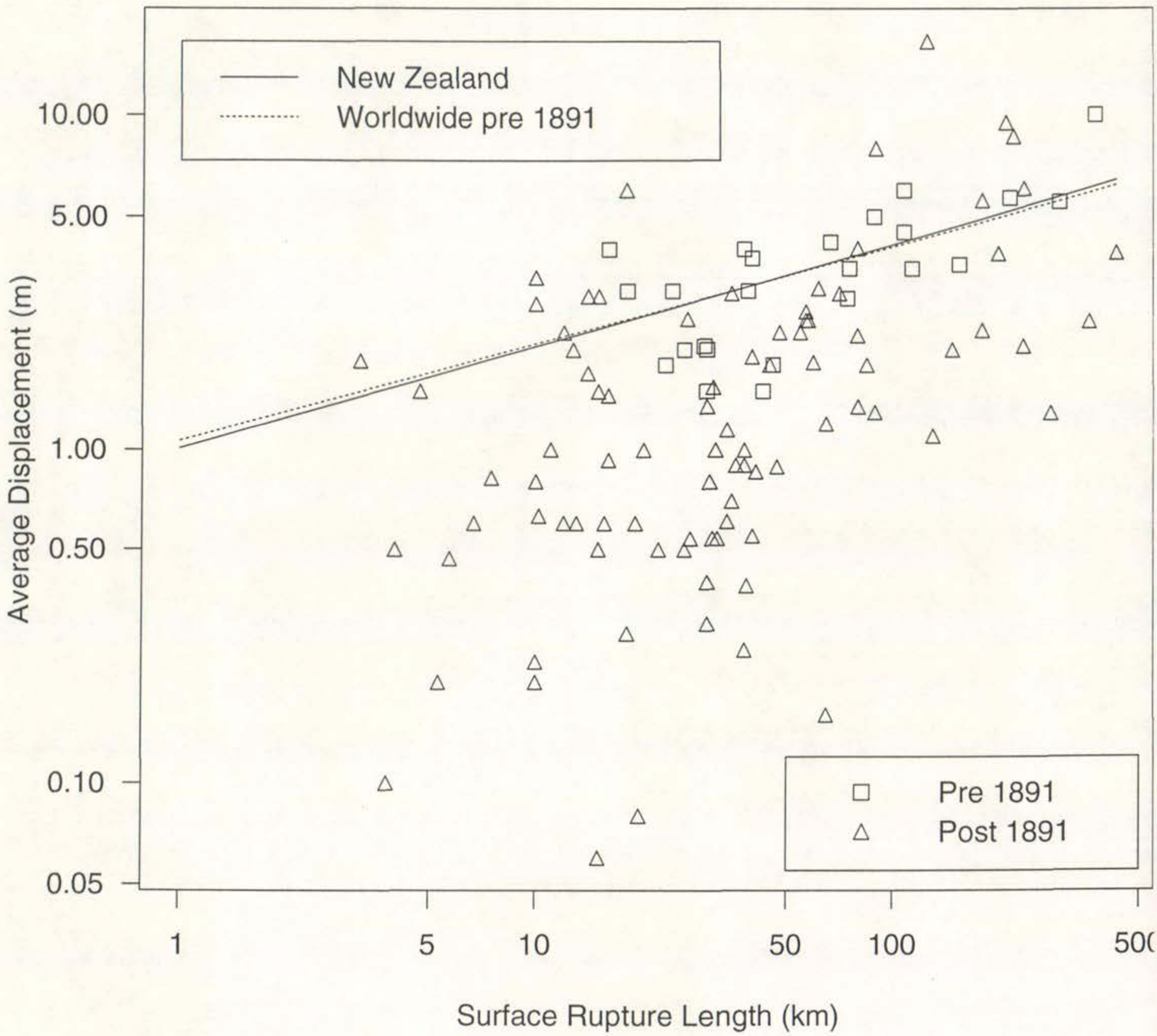

Figure 4b
Regressions of average surface rupture displacement versus surface rupture length, for the New Zealand subset of our dataset, and for all pre-instrumental (pre 1891) data. See Table 1 for parameters a and b of the regressions.

Table 1: Regression Parameters

1. Regressions of Mw on surface rupture length (L)

$M_w = a + b \times \log(L)$

Subset	N	a(sa)	b(sb)	R.s.d.
All	206	5.68(0.07)	0.85(0.04)	0.309
1940 and later	113	5.73(0.09)	0.76(0.06)	0.310
Pre 1891	54	5.97(0.10)	0.74(0.06)	0.186
NZ	23	6.18(0.27)	0.65(0.16)	0.278
W&C All (original)	77	5.08(0.10)	1.16(0.07)	0.28

2. Regressions of Mw on fault area (A)

$M_w = a + b \times \log(A)$

Subset	N	a(sa)	b(sb)	R.s.d.
All	122	4.75(0.11)	0.83(0.04)	0.262
NZ	21	4.91(0.40)	0.80(0.14)	0.224
W&C All (original)*	148	4.07(0.06)	0.98(0.03)	0.24

* Rupture areas are based on the spatial extent of aftershocks in W&C's original regressions.

3. Regressions of average surface displacement (D) on surface rupture length (L)

$\log(D) = a + b \times \log(L)$

Subset	N	a(sa)	b(sb)	R.s.d.
All	116	-0.65(0.13)	0.52(0.08)	0.392
1940 and later	70	-0.66(0.16)	0.43(0.11)	0.385
Pre 1891	27	0.03(0.16)	0.29(0.09)	0.182
NZ	23	0.01(0.16)	0.30(0.10)	0.166
W&C All (original)	66	-1.43(0.18)	0.88(0.11)	0.36

4. Regressions of the ratio displacement/surface rupture length (D/L) on slip rate (SR) or total slip (TS)

$\log(D/L) = a + b \times \log(SR)$

Subset	N	a(sa)	b(sb)	R.s.d.
All	63	-1.28(0.05)	-0.30(0.06)	0.349

$\log(D/L) = a + b \times \log(TS)$

Subset	N	a(sa)	b(sb)	R.s.d.
All	27	-1.54(0.07)	-0.15(0.08)	0.337

N=Number of data used in regression, a and b are the parameters a and b of the regression (with associated standard error in parentheses), R.s.d is the standard deviation for the dependant variable.

4, and provide a table of regression parameters in Table 1. For comparison, Table 2 is constructed in a similar manner to the table of parameters given by W&C (1994). We show the regressions of Mw and displacement versus surface rupture length for our worldwide dataset, the New Zealand component of the dataset, and the original regressions of W&C in Figure 1. The most obvious trends in Figure 1 are that our New Zealand regressions show larger M_w and displacements than our worldwide regressions at rupture lengths less than 200km, and that both our New Zealand and worldwide regressions show larger M_w and displacements than the regressions of W&C, for the same range of rupture lengths. Specifically, our regression lines have smaller slopes (parameter b) and larger y intercepts (parameter a) than W&C's regression lines. Similar discrepancies are observed for regressions of M_w versus rupture area (Fig. 2). The differences between our worldwide regressions and those of W&C must somehow arise from the incorporation of the new data into our analysis. Since a large proportion of these new data are pre-1940 in age (i.e. not used by W&C because they were considered too unreliable for regression analysis), it is possible that they introduce a systematic bias to our regressions. Our new regressions do not appear to simply be the by-product of a larger random scatter in the data as compared to the dataset of W&C, since the standard deviations for M_w from our regressions and those of W&C are similar ("R.s.d" in Table 1). Our approach to determining whether the pre-1940 data have introduced a systematic bias to our worldwide regressions is to compare regressions constructed from the younger (1940 onwards) subset of our dataset to our worldwide regressions in Figure 3 to examine the influence of the pre-1940 data on the latter. Since the regression curves for the 1940 onwards data are very similar to those of our worldwide curves in Figure 3 it is clear that the pre-1940 earthquake data do not introduce a bias to our worldwide curve. The differences between our worldwide regression and that of W&C (Fig. 1) are therefore due to the specific choice of data in W&C's regressions. As well as excluding almost all pre-1940 data, they also excluded a number of the more recent earthquakes from their analysis. On examination of graphs in W&C and comparison with our Figure 1 it appears that they removed all of the "outlier" data, meaning data that would increase the overall scatter in their graphs, and possibly increase the uncertainties in their analysis if included.

Increasing the size of our global database over that used by W&C accounts for about half of the discrepancy between our New Zealand regression curve and the original regression of W&C (Fig. 1). The remaining discrepancy in Figure 1 may therefore be due to unique scaling relationships between M_w or displacement and rupture length in the New Zealand environment. However, it is difficult to envisage why this would be so, since the New Zealand earthquake data come from a great variety of tectonic regimes. The discrepancies could alternatively be due to an upward bias in the estimates of M_w and displacement from pre-instrumental (i.e. pre 1891, the year of the earliest instrumentally recorded earthquake in the Appendix) and paleoseismic data, since over 80% of the New Zealand earthquakes listed in the Appendix are from these sources. To determine which of these explanations is the more realistic, we construct a regression for all of the pre-instrumental (pre-1891 and paleoseismic) data in the Appendix, and compare these to our New Zealand regressions in Figure 4. Since the regression curves all plot very close together in Figure 4, it appears that the remaining discrepancies between our New Zealand and global regressions in Figure 1 are due to the dominance of pre-instrumental and paleoearthquake data in the New Zealand subset of the data. Since these data only form a small proportion of our worldwide dataset as a whole, they have not produced a noticeable bias in the worldwide regressions.

Systematic overestimation of Mw from paleoseismic and pre-instrumental data could arise from underestimation of surface rupture length and/or overestimation of the average value of coseismic displacement along the rupture. Since the amount of coseismic displacement along a rupture tapers to zero at the ends of a rupture, scarp degradation processes would progressively obliterate the ends of a rupture, leading to reduction of the observable rupture length over time. It is also conceivable that the processes of scarp degradation would tend to preferentially remove the smallest displacements along a fault scarp, which could lead to overestimation of the average values of displacement along the fault. The discrepancies in Figure 1 may also be due to our New Zealand regressions being poorly constrained at rupture lengths less than about 20 km, in contrast to the wide range of rupture lengths represented by the global dataset. Again, this could be attributed to scarp degradation processes, which would lead to obliteration of the short rupture lengths and associated small displacements. In general the smallest displacements and rupture lengths would be more difficult to identify in the field than the larger rupture lengths and displacements, regardless of their state of preservation.

Lastly, we examine the influence of slip rate and total slip on stress drop, by constructing regressions between the displacement/rupture length (equivalent to stress drop) and the total slip, and displacement/length and the slip rate from our global dataset in the Appendix. The form of the two equations is:

$$\mathrm{Log}(D/L) = a + b(\log(SR \text{ or } TS)),$$

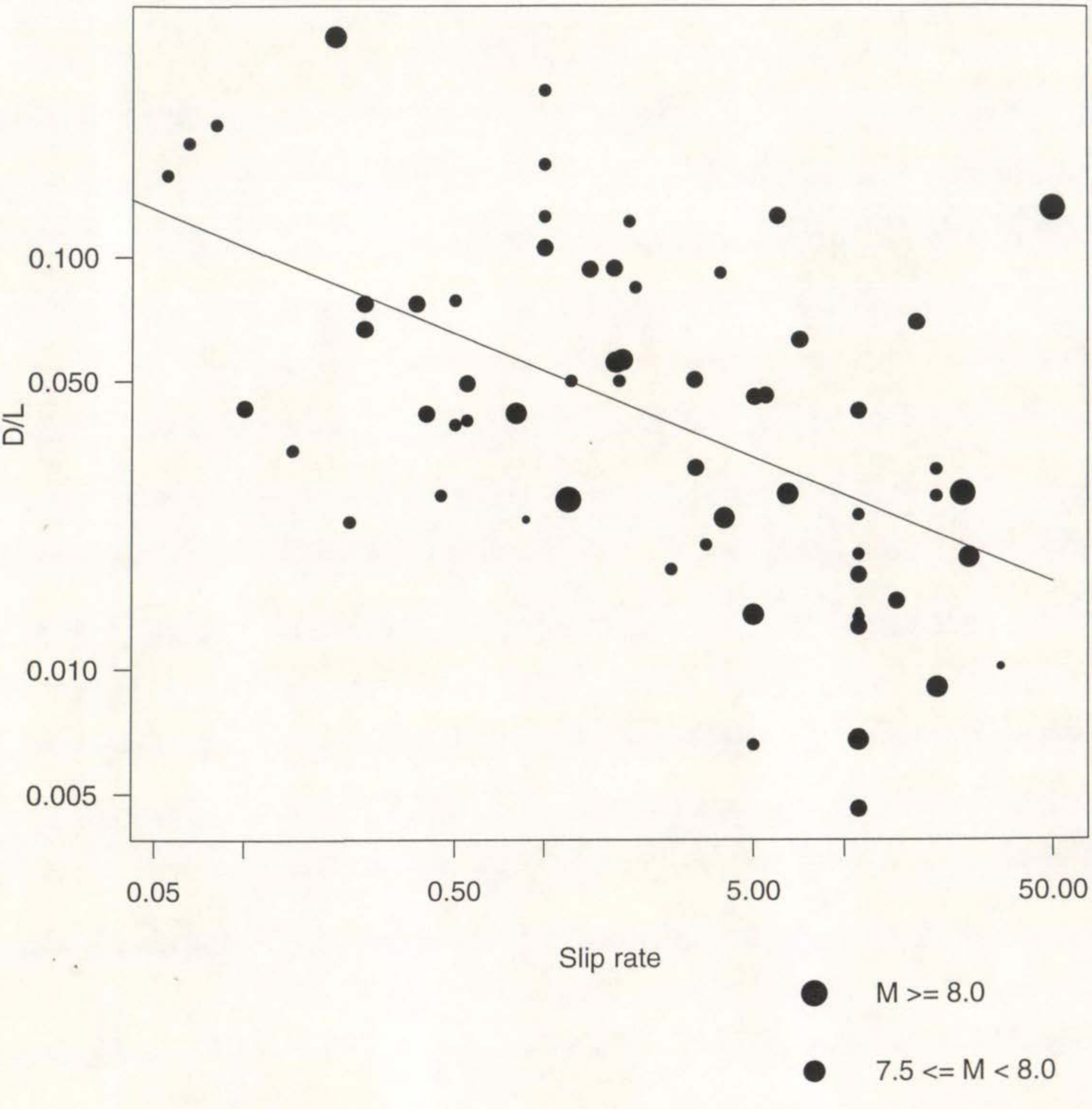

Figure 5a

Plots of displacement per unit rupture length versus fault slip rate. The size of the symbols are proportional to the M_w of the earthquake.

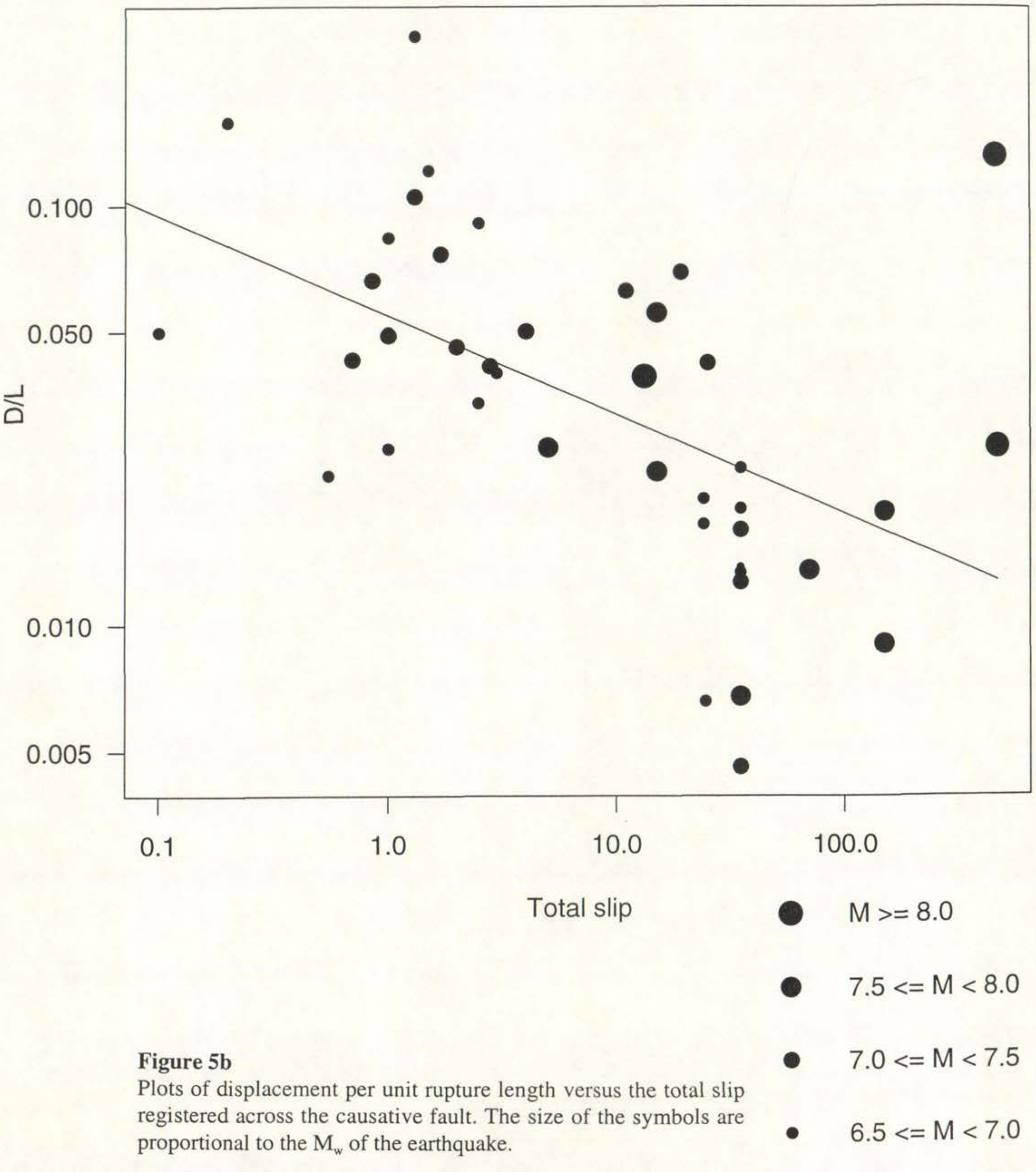

Figure 5b
Plots of displacement per unit rupture length versus the total slip registered across the causative fault. The size of the symbols are proportional to the M_w of the earthquake.

in which D is the average displacement (m), L is the rupture length (km), SR is the preferred value of slip rate, (mm/yr), and TS is the value of total slip recorded across the fault (km). The parameters a and b for each of these regressions are given in Table 1, and the regression lines are shown in Figure 5. The radius of each data point is proportional to M_w on the two graphs.

Both of the graphs in Figure 5 show considerable scatter. However, there appears to be a tendency for the surface displacement/rupture length to be a decreasing function of fault slip rate and total slip. These results suggest that stress drop is not constant for all earthquakes, but can vary by more than an order of magnitude depending on both the present and long term activity of the associated fault.

Discussion and Conclusions

Our analysis shows that the magnitudes and associated coseismic displacements for large New Zealand earthquakes are generally larger than the values predicted from the regressions of W&C for the same rupture length. The discrepancies are a decreasing function of rupture length. We attribute the discrepancies to the dataset used in our study versus that of W&C. Regressions developed after addition of newly published data to the W&C dataset, and addition of data originally excluded from the W&C dataset (almost all pre-1940 data, along with some later data) provide closer estimates of Mw and displacement to those of the New Zealand earthquakes. We are unsure of the exact reasons that W&C made their data selection, since the uncertainty in their regression-derived estimates of Mw (as reflected by the standard deviations given in Table 1) are basically no less than ours. We also find that pre-instrumental (i.e. pre-1891) and paleoearthquake data tend to provide overestimates of M_w and coseismic displacement, and the dominance of these data in the New Zealand subset of our dataset have resulted in regressions for New Zealand that show large estimates of Mw and displacement for a given rupture length. While the standard deviations given for each of the regressions in Table 1 are such that the observed differences in Figures 2 to 4 are rarely significant beyond the 1 sigma level, the observed differences between the regression curves translate to large differences in mean estimates of M_w or displacement for a given surface rupture length. These large differences in mean estimates of M_w or displacement from regression equations in general should be thoroughly addressed in the treatment of parameter uncertainty in seismic hazard analysis. In particular, the large uncertainties in estimates of Mw and coseismic displacement that arise from the use of New Zealand pre-instrumental and paleoseismic data that can be inferred from Figures 1 to 4 should also be taken into account in seismic hazard studies, and efforts focused on reducing these uncertainties. In general, pre-instrumental (pre-1891) and paleoseismic data should be excluded from future regression analyses if they form the majority of a regression dataset. A formal assessment of the uncertainties in these data should be conducted. However, we see no problems with the general use of post 1891 data for regression analysis.

Lastly, our results indicate that stress drop (proportional to coseismic displacement per unit rupture length; Fig. 5) is not constant for all earthquakes, and that a link exists between the stress drop of earthquakes and the physical features of a fault. Specifically, the highest stress drops appear to be associated with the faults that show the smallest amounts of cumulative slip, and slowest slip rate. If stress drop correlates with the amplitude of strong ground motions (e.g. Anderson et al., 1996) then we might expect the strongest ground motions to occur on faults with the smallest amounts of cumulative slip and lowest slip rates. Incorporation of parameters such as slip rate and total slip into regressions may therefore provide useful information on the ground motions that are likely to accompany the occurrence of large earthquakes on a particular fault.

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Appendix: Earthquake Database

LOC	REG	EVENT	DATE	ST	MsorMjma	MI	Mw(geol_sfcL)	Mw(geol_subL)	Mw(seis)	M	Mo(geol-sf	Mo(geol_subL)	LGTHMNsubs	LGTHMXsut	LGTHMN	LGTHMX	WMN	WMX	Dmxsub	Davsub	Dmx	Dav	SRmn	SRmx	SRprf	TSmn	TSmx	Tprf	WC	AJ	AWS	CS	OTHER	
NZ	NZ	Wellington	paleo	S			7.38			7.42	1.48E+27				67	67	15	20			4.6	4.2	5	7.6	7.1	10	12	11			7		1,2	
NZ	NZ	Alpine	paleo	SR			8.03			8.03	1.41E+28				375	375	10	15			14	10	15	35	25			470			8		1,2	
NZ	NZ	Clarence	paleo	S			7.58			7.62	2.93E+27				155	155	15	20				3.6			4			15			9		1,2	
NZ	NZ	Ohariu	paleo	S			7.51			7.55	2.34E+27				89	89	15	20				5	0.7	4.7							10		1,2	
NZ	NZ	Porters Pass	paleo	S			7.36			7.4	1.4E+27				76	76	15	20			4	3.5	5	6			2	2			11			3
NZ	NZ	Akatore	paleo	R			6.86			6.89	2.43E+26				30	30	12	24			2	1.5	1.25	2.5		0.1		0.1			12		1,2, 25	
NZ	NZ	Ostler South	paleo	R			6.90			6.89	2.84E+26				18	18	12	23			4	3	1	1	1								1,2	
NZ	NZ	Ostler Central	paleo	R			6.98			6.98	3.78E+26				24	24	12	23			4	3	1	1	1								1,2	
NZ	NZ	Ostler North	paleo	R			6.98			6.98	3.78E+26				24	24	12	23			4	3	1	1	1								1,2	
NZ	NZ	Dunstan North	paleo	R			7.20			7.19	7.98E+26				38	38	12	23			5	4	1	1	1	1.3		1.3					1,2, 25	
NZ	NZ	Dunstan South	paleo	R			6.95			6.94	3.36E+26				16	16	12	23			5	4	1	1	1	1.3		1.3					1,2, 25	
NZ	NZ	Cardrona North	paleo	R			7.05			7.05	4.68E+26				26	26	20	40			3	2	0.25	0.25	0.25								1,2	
NZ	NZ	Cardrona South	paleo	R			7.09			7.09	5.4E+26				30	30	20	40			3	2	0.25	0.25	0.25	0.85		0.85					1,2, 25	
NZ	NZ	Pisa	paleo	R			7.13			7.13	6.32E+26				39	39	12	24			5	3	0.37	0.37	0.37	1.7		1.7					1,2,25	
NZ	NZ	Pukerua	paleo	S			7.20			7.15	7.88E+26				40	40	15	20			4	3.75	0.9	2.5	1.7								1,2	
NZ	NZ	Kerepehi North	paleo	N			6.98			6.98	3.73E+26				46	46	15	15			1.8	1.8	0.5	0.5	0.5								1,2	
NZ	NZ	Kerepehi South	paleo	N			6.78			6.78	1.86E+26				23	23	15	15			1.8	1.8	0.5	0.5	0.5								1,2	
NZ	NZ	Waiohau	paleo	NS			7.51			7.51	2.33E+27				108	108	16	16			4.5	4.5	0.1	10	0.8								1,2	
NZ	NZ	Whakatane	paleo	SN			7.44			7.44	1.8E+27				114	114	15	15			4	3.5	1	5.4	3.2								1,2	
JP	JP	Fujikawa	paleo	R			7.02			7.02	4.32E+26				24	24	20	20			18	3	6	6	6	31					15			4
JP	JP	MTL	paleo	S			7.84			7.84	7.35E+27				215	215	20	20				5.7	5	8	6.5	5		5			16			5
JP	JP	Higa-Taka	paleo	SR						7.3					85	85	20	20			3		0.6	1.5							12			6
JP	JP	Tanngo	701			7				7						18							0.04	0.16										
JP	JP	Tennryu	715	S		7				7						20							5	8	6.5	5		5					7,8	
JP	JP	Sagami-Musashi	818	R		7.5				7.5						15							0.2	0.3									7,8	
JP	JP	Yamasaki	868	S		7.1				7.1						87	20	20					0.3	0.8	0.55						19			
JP	JP	Sagami-Musashi	878	R		7.4				7.4						25							0.1	1									7,8	
JP	JP	Oumi Kita	1325	RS		6.5				6.5						37							0.1	1									7,8	
R	MD	Kwai	21/7/1336	-	7.6					7.6					100	100														36				
JP	JP	Yamashiri	1449	RS		6.5				6.5						30							0.016	0.1									7,8	
R	MT	Birjand	10/1/1493	R	7					7					30	30														39				
AF	AS	Kabul	6/7/1505	S	7.4					7.4					56	56					3		50	50	50	460	460	460		40				9
JP	JP	Atera	1586	S		7.8				7.8						70	20	20					3	5.2	5.2	7	10	8.5			17		7,8	
JP	JP	Beppu	1596	NS		7				7						11							0.02	3.2									7,8	
JP	JP	Keichou	1596	S		7.5				7.5													5	8	6.5	5		5					7,8	
JP	JP	Aizu	1611	R		6.9				6.9						15							0.3	0.8									7,8	
TR	MT	Menderes	22/2/1653	N	7.1					7.1					70	70					3									45				
JP	JP	Biwa	1662	R		7.4				7.4						40							0.1	0.1	0.1								7,8	
TR	MT	Amasya	17/8/1668	S	7.9					7.9					400	400							5	25		25	45	35		48				
JP	JP	Nikkou	1683	R		7				7						40							0.7	3									7,8	
JP	JP	Noshiro	1694	R		7				7						24							0.2	1									7,8	
R	MT	Tabriz	26/4/1721	-	7.7					7.7					50	50														49				
JP	JP	Shiraishi	1731	R		6.6				6.6						50							0.2	0.9									7,8	
GR	MT	Lamia	5/10/1740	-	6.6					6.6					20	20														50				
LE	MT	Bekaa	25/11/1759	S	7.4					7.4					100	100														52				
JP	JP	Hirosaki-Aomori	1766	R		6.9				6.9						40							0.1	1									7,8	
R	MT	Tabriz	8/1/1780	SN	7.7					7.7					60	60					6									53				
JP	JP	Odawara	1782	N		7				7					9	20	20	20					0.1	5		0.1		0.1			14		7,8,10	
TR	MT	Elmali	18/7/1784	S	7.6					7.6					150	150														54				
SY	MT	Latakia	26/4/1796	-	6.6					6.6																				56				
USA	NA	NewMadrid	1811			8.2				8.2			60	250							0.5		0.01	2				0.04			1		11,12	
TR	MT	Antakya	13/8/1822	S	7.5					7.5					200	200														57				
R	MT	Harhaz	1825	-	6.7					6.7																				58a				
GR	MT	Xanthi	5/6/1829	-	7.2					7.2					50	50														58b				
LE	MT	Bshara	1/1/1837	-	7.4					7.4					80	80														59				
R	MT	Nasratab	1838	-	7					7					70	70														60				
TR	MT	Kazlgol	2/7/1840	S	7.3					7.3					80	80														61				
JP	JP	Zennkouji	x/x/1847		7.4		6.99			7.4	3.87E+26				43	43	20	20			2.7	1.5											7,8	
NZ	NZ	Marlborough	15/101848	S		7.5				7.5						95					8	6	2.6	13.7	8			19			2			2
NZ	NZ	Wairarapa	24/011855			8.1				8.1											12.1	12.1	3.1	15.8										
TR	MT	Ulubat	28/2/1855	-	7.4					7.4					70	70														62				
TR	MT	Gemlik	11/4/1855	-	6.6					6.6																				63				
JP	JP	Hietsu	9/4/1858	S		7.1				7.1						64							1	5	3	3	3	3					7,8	
GR	MT	Vostiza	26/12/1861	N	6.6					6.6					13	13					2.4									64		x		
USA	NA	Fort Tejon	9/1/1857	S	8.3		7.78			7.73	5.91E+27				297	297	12	12			10.4	5.53	16	43		150		150	1			x		
GR	MT	Vostiza	26/12/1861	N	6.6					6.6					13	13					2.4									64		x		
IQ	MT	Zorbatia	7/12/1864	-	6.4					6.4					2	2					0.5									65				
TR	TR	Gonek	12/5/1866	S	7.2					7.2					45	45														66				

USA, CA		Hayward	21/10/1868	S	6.8					6.8					48	52	12	12	0.9		8	10					2		x		
GR	MT	Fokis	1/8/1870	N	6.7					6.7					6	6			2									67			
JP	JP	Hamada	14/3/1872	SR	7.1		6.92			7.1	3.07E+26				16	16	8	8	8	8									20	7,8	
USA	WUS	Owens Valley	26/3/1872	SN	8		7.58			7.58	2.92E+27				108	108	15	15	11	6	1	3		10	20	15	3		x		28
TR	MT	Amik Gol	3/4/1872	-	7.2					7.3					20	20												68			
TR	MT	Golcuk I	3/5/1874	S	7.1					7.1					45	45			2		5	5	5	22	27	27		69			13
Mexi	NA	Pitaycachi	3/5/1887	N	7.4				7.31	7.31					75	75			5.1	2.85							4		x		
TR	MT	Banaz	30/9/1887	N	6.3					6.3					10	10			0.5									73			
NZ	NZ	Canterbury	01/09/1888	S						7.15					25	35			2.6	2.05	15	20	17.5			19			3		
Japa	JP	Nobi	27/10/1891	S	8		7.37			7.37	1.45E+27				80	80	15	15	8.3	4.02	1	10		3	5	4	5		x		
PK	AS	Chaman	19/12/1892	S	6.9					6.9					30	30					50	50	50	460	460	460		75			9
TR	MT	Malatya	2/3/1893	S	7.1					7.1																		76			
#GR	MT	Martin	27/4/1894	N	6.9					6.9					25	40			1.9	1								77	x		15
Japa	JP	Rikuu/Senya	31/8/1896	R	7.2			7.16	7.4	7.2		7.01631E+26	36	50			21	21	4.6	2.59							6		x		
?Jap	JP	Sanriku	15/6/1896	RS			8.41			8.41	5.24E+28				210	210	75	100		9.5									x		
#TR	MT	Mender	20/9/1899	N	6.9					6.9					40	40			1									78	x		
#BU	MT	Struma	4/4/04	N	7.2					7.2					25	25			2									79	x		
#AL	MT	Scutari	1/6/05	N	6.3					6.3					10	10			1									80	x		
TR	MT	Malat.	4/12/05	S	6.8					6.8											5	5	5	22	27	27		81			15
USA	NA	San Francisco	18/4/06	S	7.8		7.80		7.9	7.9	6.32E+27				432	432	10	15	6.3	3.9	15	28		150		150	7		x		
#IR	MT	Silakhor	23/1/09	S	7.4					7.4					45	45			2.5									82	x		
#PK	AS	Baluch	20/10/09	S	7.1					7.1					50	50												83			
#TR!	MT	Ender.	9/2/09	S	6.4					6.4					15	15												84			
JP	JP	Anegawa	x/x/1909	RS		6.8				6.8											0.1	1								7,8	
#TR	MT	Marmara	9/8/12	NS	7.4					7.4					50	50			3		5	25		25	45	35		85	x		
#TR	MT	Burdur	3/10/14	NS	7					7					23	23			1.5									86	x		
Italy	MT	Avezzano	13/1/15	N	7		6.57	6.62	6.62	6.62	9E+25	1.08E+26	24	24	20	20	15	15	2	1	1	1.5		1	1	1	8		x		26
USA	NA	Pleasant Valley	3/10/15	N	7.6		7.22			7.22	8.51E+26				62	62	15	15	6.7	3.05	0.3	1		1		1	9		x		25
TR	MT	Samsun	24/1/16	S	7.2					7.2																		87			
JP	JP	Oomachi	x/x/1918	RS	6.5	6.5				6.5					4	4				0.5										7,8	
Chin	AS	Kansu	16/12/20	S	8.5		8.11		8.02	8.02	1.85E+28				220	220	20	45	11	8.63				12	14.5	13.25	10		x		9
Japa	JP	Tango	7/3/27	SR	7.3		6.76	7.03		6.76	1.77E+26	4.41525E+26	35	35	14	14	13	16	3	2.9	0.04	0.16					11		x	7,8	
Keny	AF	Laikipia	6/1/28	N	7					7					31	31			3.4								12		x		
#BU	MT	Plovdiv	14/4/28	N	6.8					6.8					64	64			0.5									89	x		
Bulg	MT	Papazili	18/4/28	N	6.9					6.9					50	50			3.5								13		x		
#TU	MT	Kop. Dagh	1/5/29	R	7.3					0					70	70			2.1									91			
NZ	NZ	Murchison	16/6/29	R		7.7	7.16			7.7	6.91E+26				8	40	16	16	6.8	6	0.2	0.2	0.2							2,9	
Iran	MT	Salmas	6/5/30	NS	7.4				7.15	7.15					30	30			6.4	1.35							14		x		
Japa	JP	North Izu	25/11/30	SR	7.3		7.00	6.87	6.89	6.89	4.03E+26	2.5311E+26	22	22	35	35	11	15	3.8	2.95	1	2	2	1		1	15		x		
New	NZ	Hawkes Bay	2/2/31	RS	7.8				7.73	7.73			110	110	15	15			4.6	2.9							16		x		
Chin	AS	Kehetuohai-E	10/8/31	S	7.9		7.82		7.92	7.92	6.79E+27				180	180	20	25	14.6	5.59							17		x		
Japa	JP	Saitama	21/9/31	S	6.7			6.45		6.45		6E+25	20	20			10	10		1							18		x		
#GR	MT	Ieriss	26/9/32	N	6.9					6.9					15	15			2									93	x		
USA	NA	Cedar Mountain	21/12/32	S	7.2				6.83	6.83			80	80	61	61			2.7								19		x		
Chin	AS	Changma	25/12/32	RS	7.7					7.7					148	148			6.2	2	3.2	7.7	5	65	75	70	20		x	1,14	
USA	NA	Long Beach	11/3/33	S	6.3			5.98	6.38	6.38		1.176E+25	5	23			13	15		0.2	0.1	6	0.6	0.2	10	5	21		x		
#IR	MT	Buhabad	28/11/33	R	6.2					6.2					5	5			1									94	x		
USA	NA	Parkfield	7/6/34	S					6.1	6.1					20	20			0.2		29	39				150			4		
Taiw	AS	Tuntzuchio/Chih.	21/4/35	SR	7.1					7.1					17	17			3.2								23		x		
PK	AS	Quetta	30/5/35	R	7.6		8.16			8.16	2.22E+28				106	150	20	50		16.5	50	50	50	460	460	460		95	x		9
JP	JP	No name	7/11/35	SR	6.4		6.13			6.13	1.98E+25				11	11	6	6		1									21		8
Turk	MT	Kirsehir	19/4/38	S	6.8					6.8					14	14			1								24		x		
Turk	MT	Erzihcan	26/12/39	S	7.8		7.71			7.71	4.59E+27				360	360	15	20	7.5	2.43	5	25		25	45	35	25		x		
JP	JP	No name	2/8/40	R	7.5		7.45			7.45	1.89E+27				100	170	35	50	1.5	1.1									22	7,8	
USA	NA	Imperial Valley	19/5/40	S	7.2		6.93	6.85	6.92	6.92	3.13E+26	2.34698E+26	45	45	60	60	8	11	6	1.83	18	23					26		x		
#IR	MT	Muhamvad	16/2/41	SR	6.1					6.1					12	12			0.5									98			
Turk	MT	Erbaa	20/12/42	SN	7.2		6.73			6.73	1.57E+26				47	47	10	15	2	0.89	5	25		25	45	35	27		x		
Japa	JP	Sikano	10/9/43	S	7.4		6.23	6.79		6.23	2.75E+25	1.9305E+26	33	33	4.7	4.7	13	13	2.5	1.5							28		x		
Turk	MT	Kastamonu	26/11/43	S	7.5		7.44			7.44	1.84E+27				280	280	14	20	1.9	1.29	5	25		25	45	35	29		x		
Turk	MT	Bolu	1/2/44	S	7.5		7.49			7.49	2.15E+27				180	180	15	20	3.6	2.28	5	25		25	45	35	30		x		
#TR	MT	Saphane	25/6/44	NS	6					6					18	18			0.3									102			
JP	JP	Mikawa	13/1/45	RS	6.8		6.57			6.57	8.91E+25				12	12	11	11		2.25	0.05	0.08	0.065						23	7,8	
Turk	MT	Ustukrart	31/5/46	S	6					6					9	9			0.3		5	25		25	45	35	31		x		
Peru	SA	Ancash	10/11/46	N	7.2				7.28	7.28			28	28	21	21	30	30	3.5								32		x		
Taiw	AS	Tainan	4/12/46	S	6.7					6.7					12	12			2.15								33		x		
#IR	MT	Dustab.	23/9/47	SR	6.8					6.8					20	20			1.3									105	x		
Japa	JP	Fukui	28/6/48	SR	7.3			6.85		6.85		2.34E+26	30	30			13	13	2	2	0.01	1					34		x		
TU	MT	Ashkhab.	5/10/48	R	7.2					7.2																		106			
Turk	MT	Elmalidere	17/8/49	S	6.9					6.9					38	38			1.6	0.9	5	25		25	45	35	36		x		

Japa	JP	Imaichi	26/12/49	R	6.3				6.3			11	11			7	7									37			x		
#TR	MT	Kursunlu	13/8/51	S	6.9				6.9					32	32			0.67									108				
Chin	AS	Damxung	18/11/51	S	8	7.49	7.72	7.67	7.67	2.16E+27	4.8E+27	200	200	90	90	10	10	12	8							40			x		
Taiw	AS	Yuli-Juisu	24/11/51	SR	7.4				7.4					43	43	17	17	2.2								41			x		
USA	NA	Kern County	21/7/52	RS	7.7	7.19	7.23	7.38	7.38	7.78E+26	8.736E+26	64	64	57	57	15	20	3	2.6	3	8.5					42			x		
#IR	MT	Turud	12/2/53	R	6.5				6.5					8	8			1.4									109				
Turk	MT	Canakkale	18/3/53	S	7.2	7.16		7.22	7.22	7.03E+26				58	58	15	18	4.35	2.45	5	25		25	45	25	43			x		
USA	NA	Arroyo Salada	19/3/54	S	6.2			6.27	6.27			15	15			12	12									44			x		
#GR	MT	Sofades	30/4/54	N	6.7				6.7					30	30			0.92	0.3								111				15
USA	NA	Rainbow Mountain	6/7/54	N	6.3	6.15	6.01	6.22	6.22	2.12E+25	1.2936E+25	11	11	18	18	14	14	0.9	0.28							45			x		
USA	NA	Stillwater	24/8/54	N	6.9	6.56	6.48	6.55	6.55	8.71E+25	6.6612E+25	26	26	34	34	14	14	0.81	0.61							46			x		
USA	NA	Fairview Peak	16/12/54	SN	7.2	7.03	6.99	7.17	7.17	4.4E+26	3.85875E+26	50	50	57	57	6	15	5.8	2.45	0.01	1		0.7		0.7	47			x		25
USA	NA	Dixie Valley	16/12/54	SN	6.8	6.95	6.93	6.94	6.94	3.4E+26	3.1752E+26	42	42	45	45	14	14	3.8	1.8	0.3	1		3		3	48			x		25
Mexi	NA	San Miguel	9/2/56	SR	6.9	6.37	6.37	6.63	6.63	4.46E+25	4.455E+25	22	22	22	22	12	15	0.9	0.5	0.1	0.5		0.5	0.6	0.55	49			x		16
GR	MT	Velestin	8/3/57	NS	6.6				6.6					1	1												112				
Turk	MT	Abant	26/5/57	S	7	6.42			6.42	5.28E+25				40	40	8	8	1.65	0.55	5	25		25	45	35	51			x		
Mon	AS	Gobi-Altai	4/12/57	S	7.9	7.98	8.05	8.14	8.14	1.18E+28	1.50233E+28	300	300	236	236	20	35	9.5	6.07			1.2				52			x		17
USA	NA	Lituya Bay	10/7/58	S	7.9	7.61	7.77	7.77	7.77	3.26E+27	5.7036E+27	350	350	200	200	12	16	6.6	3.88							53			x		
Iran	MT	Firuz.	16/8/58	R	6.6				6.6					28	28			1.5									114				
USA	NA	Hebgen Lake	18/8/59	N	7.6	6.93	7.08	7.29	7.29	3.14E+26	5.3352E+26	45	45	26.5	26.5	15	17	6.1	2.47	0.8	2.5					54			x		
JP	JP	Kita-Mino	19/8/61	RS	7	6.57			6.57	8.91E+25				9	18	10	12	2.5	2	0.01	0.1	0.055	0.2	2	0.2			24		7,8, 27	
JP	JP	Kita-Miyagi	30/4/62	R	6.5	6.16			6.16	2.16E+25				12	12	10	10	0.6	0.6									25		7,8, 27	
Iran	MT	Ipak	1/9/62	R	7.2				7.2					99	99			1								56			x		
Japa	JP	Wakasa-Bay	26/3/63	S	6.5		6.24	6.28	6.28		2.88E+25	20	20			8	8		0.6							57			x		
Japa	JP	Niigata	16/6/64	R	7.5		7.49	7.59	7.59		2.178E+27	80	80			25	30	6	3.3	0.01	1					60			x		
#TR	MT	Manyas	6/10/64	NS	6.8				6.8			60	60	40	40												116				
USA	NA	Antioch	10/9/65	S	4.9			6	6			3	3			6	6									62			x		
USA	NA	Parkfleld	28/6/66	S	6.4	6.37	6.34	6.25	6.25	4.5E+25	4.095E+25	35	35	38.5	38.5	7	13	0.2	0.39	29	39					63			x		
Turk	MT	Varto	19/8/66	S	6.8	6.30	6.61	6.88	6.88	3.6E+25	1.02E+26	85	85	30	30	10	10	0.15	0.4	5	25		25	45	35	65			x		
TR	MT	Varto	20/8/66	SN	6.2				6.2					7	7												118				
Mon	AS	Mogod	5/1/67	S	7.4	7.00	7.00	7.03	7.03	3.99E+26	3.99E+26	40	40	40	40	15	20	3.5	1.9							67			x		
Turk	MT	Mudurna Valley	22/7/67	S	7.4	7.10	7.06	7.34	7.34	5.67E+26	4.96125E+26	70	70	80	80	15	20	2.6	1.35	5	25		25	45	35	68			x		
#TR	MT	Tunceli	26/7/67	S	6				6					4	4												122				
Alba	MT	Dibra	30/11/67	SN	6.6			6.75	6.75			62	62	10	10			0.5	0.2							69			x		
Gree	MT	Agios-Efstratios	19/2/68	S	7.2			7.1	7.1			70	70	4.4	4.4			0.5								70			x		
USA	NA	Borrego Mountain	9/4/68	S	6.8	6.44	6.51	6.63	6.63	5.78E+25	7.452E+25	40	40	31	31	10	13	0.39	0.54	1.4	5		24	24	24	71			x		
New	NZ	Inangahua	24/5/68	RS	7.1		6.59		7.1		9.7416E+25	41	41			18	18	0.52	0.44	0.1	0.1	0.1				72			x		2
Iran	MT	Dasht-e-Bayaz	31/8/68	S	7.1	7.28	7.37	7.23	7.23	1.06E+27	1.452E+27	110	110	80	80	20	20	5.2	2.2							73			x		
Aust	AU	Meckering	14/10/68	RS	6.9		6.42	6.61	6.61	9.72E+25	5.4E+25	20	20	36	36	10	10	3.6	0.9							74			x		
USA	NA	Rampart	29/10/68	S	6.5			6.69	6.69					30	30	8	8									75					
Turk	MT	Alasehir Valley	28/3/69	N	6.5	6.44	6.42	6.71	6.71	5.7E+25	5.346E+25	30	30	32	32	11	11	0.82	0.54							76					
Peru	SA	Pariahuanca	24/7/69	R	5.7			6.14	6.14					5.5	5.5			0.7								78			x		
Japa	JP	Gifu	9/9/69	S	6.6		6.27	6.34	6.34		3.24E+25	18	18			10	10	1.5	0.6							80			x	7,8	
Sout	AF	Ceres	29/9/69	S	6.3			6.37	6.37			20	20			9	9									81					
Peru	SA	Huaytapallana	1/10/69	RS	6.2			6.63	6.63			30	30	16	16			2								82					
Chin	AS	Tonghai	4/1/70	S	7.5	6.97	7.10	7.26	7.26	3.65E+26	5.69531E+26	75	75	48	48	10	12.5	2.75	2.25							83			x		
Turk	MT	Gediz	28/3/70	N	7.1	6.77	6.89	7.18	7.18	1.8E+26	2.76318E+26	63	63	41	41	17	17	2.8	0.86							84			x		
Japa	JP	Akita	16/10/70	RS	5.8		5.93	6.13	6.13		9.975E+24	14	14			8	11		0.25							85			x		
USA	NA	San Fernando	9/2/71	RS	6.5	6.65	6.67	6.64	6.64	1.19E+26	1.26582E+26	17	17	16	16	14	20	2.5	1.46	2	7.5		2.5		2.5	86			x		
#TR	MT	Burdur	12/5/71	N	6.2				6.2					4	4			0.3									129				
Turk	MT	Bingol	22/5/71	S	6.7			6.63	6.63					38	38			0.6	0.25	5	5	5	22	27	24.5	87			x		13
Iran	MT	Qir-Karzin	10/4/72	R	6.9			6.75	6.75			34	34	20	20	20	20	0.1								90					
USA	NA	Sitka	30/7/72	S	7.6		7.62	7.7	7.7		3.375E+27	180	180			10	15		5							91			x		
Paki	AS	Hamran	3/9/72	R	6.3			6.19	6.19			13	13			14	14									92			x		
Nica	CA	Managua	23/12/72	S	6.2				6.2			15	15	5.9	5.9	8	8	0.67								95			x		
Chin	AS	Luhuo	6/2/73	S	7.3	7.06	7.12	7.47	7.47	4.86E+26	6.006E+26	110	110	89	89	13	15	3.65	1.3	10	20	15				96			x		18
Chin	AS	Tibet	14/7/73	N	6.9			6.95	6.95			27	27													98					
Japa	JP	Izu-Oki	8/5/74	SR	6.5	5.86	6.19	6.54	6.54	7.64E+24	2.4111E+25	18	18	5.7	5.7	8	11	1.25	0.47							100			x		
JP	JP	No name	9/11/74	SN	6.5	6.23			6.5	2.77E+25				7.5	7.5	15	15		0.82									26		7,8	
USSF	AS	Tadzhikestan	11/8/74	RS	7.3		6.86	7.06	7.06		2.43E+26	30	30			20	25	1.2	1.2							102			x		
Chin	AS	Haicheng	4/2/75	S	7.4			6.99	6.99			60	60	5.5	5.5	12	15	0.55								104			x		
USA	NA	Pocatello Valley	28/3/75	N	6		6.06	6.06	6.06		1.575E+25	15	15			10	10		0.35							105			x		
Japa	JP	Oita Prefecture	20/4/75	SR	6.1		6.04	6.32	6.32		1.44E+25	10	10			10	20		0.32							106				7,8	
Turk	MT	Lice	6/9/75	R	6.7	6.40		6.55	6.55	5.07E+25				26	26	13	13	0.63	0.5							111			x		
PK	AS	Baluch	3/10/75	S	6.5				6.5					5	5			0.04		50	50	50	460	460	460		132				9
Guat	CA	Motagua	4/2/76	S	7.5	7.47	7.50	7.63	7.63	2.02E+27	2.21277E+27	257	257	235	235	13	15	3.4	2.05							112			x		
USSF	AS	Uzbekistan	8/4/76	R	7			6.83	6.83			30	30			15	20									113			x		
Italy	MT	Friuli	6/5/76	R	6.5			6.49	6.49			19	19			10	10									114			x		
USSF	AS	Uzbekistan	17/5/76	R	7		6.98	6.84	6.84		3.726E+26	48	48			15	19.5		1.5							115					

Chin	AS	Tangshan	27/7/76	S	7.9	6.74	7.30	7.46	7.46	1.61E+26	1.12613E+27	70	70	10	10	15	24		3	2.75							116				
Chin	AS	Songpan, Huya	16/8/76	SR	6.9			6.71	6.71			30	30			12	12										117				
Chin	AS	Songpan, Huya	21/8/76	R	6.4			6.37	6.37			12	12	12	12	8	8										119				
Chin	AS	Songpan, Huya	23/8/76	SR	6.7			6.58	6.58			22	22			11	11										120				
Turk	MT	o Caldiran	24/11/76	S	7.3	7.15	7.29	7.23	7.23	6.68E+26	1.0935E+27	90	90	55	55	18	18		3.7	2.25							121		x		
Iran	MT	Khurgu	21/3/77	R	6.9			6.73	6.73			32	32														123				
Arge	SA	Caucete	23/11/77	R	7.4			7.48	7.48			80	80			30	30										127				
Japa	JP	Izu-Oshima	14/1/78	S	6.6	6.10	6.90	6.71	6.71	1.78E+25	2.775E+26	50	50	3.2	3.2	10	10			1.85							129		x		
Gree	MT	Thessaloniki	20/6/78	N	6.4	5.81	5.92	6.43	6.43	6.52E+24	9.408E+24	28	28	19.4	19.4	14	14		0.22	0.08							131		x		
Iran	MT	Tabas-e-Golshan	16/9/78	R	7.5	7.33	7.29	7.39	7.39	1.24E+27	1.07892E+27	74	74	85	85	17	37		3	1.8							135		x		
Yugo	MT	Montenegro	15/4/79	R	6.9			6.98	6.98			50	50			29	29										139				
Aust	AU	Cadoux	2/6/79	R	6.1	6.02	6.04	6.12	6.12	1.35E+25	1.44E+25	16	16	15	15	6	6		1.5	0.5							140		x		
USA	NA	El Centro	15/10/79	S	6.7	6.51	6.66	6.53	6.53	7.32E+25	1.224E+26	51	51	30.5	30.5	8	12		0.35	0.8	18	23					144				
Iran	MT	Kurizan	14/11/79	SR	6.7			6.61	6.61			28	28	17	17	6	6		1.1								145				
Iran	MT	Koli	27/11/79	SR	7.1	7.07	7.12	7.17	7.17	5.15E+26	5.94E+26	75	75	65	65	22	22		4.1	1.2							146		x		
Mexi	NA	Mexicali Valley	9/6/80	S	6.4			6.4	6.4			28	28			8	8										152				
Japa	JP	Izu-Hanto-Toho	29/6/80	S	6.2			6.39	6.39			14	14			10	10										153				
Gree	MT	Almyros	9/7/80	N	6.4			6.59	6.59			36	36	5.3	5.3				0.2	0.2							154				15
Alge	AF	El Asnam	10/10/80	R	7.3	6.82	6.99	7.1	7.1	2.16E+26	3.8115E+26	55	55	31.2	31.2	15	15		6.6	1.54							156		x		
Italy	MT	South Apennines	23/11/80	N	6.9	6.76	6.89	6.91	6.91	1.71E+26	2.7E+26	60	60	38	38	15	15		1.15	1	0.2	1		1	1	1	157				26
Chin	AS	Daofu	23/1/81	S	6.8			6.64	6.64			46	46	44	44	10	15		1.5		5	10					158		x		
Gree	MT	Corinth	24/2/81	N	6.7	6.62	6.82	6.63	6.63	1.08E+26	2.16E+26	30	30	15	15	16	16		1.5	1.5							160		x		
Gree	MT	Corinth	25/2/81	N	6.4	6.43		6.31	6.31	5.47E+25				19	19	16	16		1.5	0.6							161				
Gree	MT	Corinth	4/3/81	N	6.4	6.35	6.55	6.25	6.25	4.21E+25	8.424E+25	26	26	13	13	18	18		1.1	0.6							162		x		
Iran	MT	Golbaf	11/6/81	RS	6.7			6.57	6.57			16	16	15	15				0.11	0.06							163				
Iran	MT	Sirch	28/7/81	RS	7.1			7.12	7.12			75	75	65	65				0.5	0.16							164				
JP	JP	No name	21/3/82	RS	7.1	6.64			6.64	1.13E+26				12	30	20	40		2.1	0.6								27		7,8	
Nortl	AF	Dhamer	13/12/82	N	6			6.34	6.34			20	20	15	15	7	7		0.03								168				
USA	NA	Coalinga	2/5/83	RS	6.5			6.38	6.38			27	27			15	15										170				
JP	JP	No name	26/8/83	RS	6.8	6.40			6.4	4.95E+25				10	10	5	5			3.3								28		7,8	
USA	NA	Borah Peak	28/10/83	NS	7.3	6.83	6.82	6.93	6.93	2.23E+26	2.16315E+26	33	33	34	34	18	20		2.7	1.15	0.07	0.3		2.5		2.5	174		x		25
Turk	MT	Pasinier	30/10/83	SR	6.9			6.73	6.73			50	50	12	12	16	16		1.2								175				
Wes	AF	Guinea	22/12/83	SN	6.2			6.32	6.32			27	27	9.4	9.4	14	14		0.45								177				
USA	NA	Morgan Hill	24/4/84	S	6.1			6.28	6.28			26	26			8	10				3	6.4					178				
Italy	MT	Lazio-Abruzzo	7/5/84	N	5.8			6	6			4.5	4.5			10	10										180				
Japa	JP	Naganoken-Seibu	14/9/84	S	6.1		6.24	6.24	6.24		2.88E+25	12	12			8	8			1							183			7,8	
New	CC	New Britan	10/5/85	S	7.1			7.19	7.19			50	50			15	15										187				
New	CC	New Ireland	3/7/85	R	7.2			7.23	7.23			48	48			23	23										188				
USA	NA	Kettleman Hills	4/8/85	R	5.9			6.09	6.09			20	20			8.3	8.3										189				
Chin	AS	Wuqai	23/8/85	R	7.3			6.89	6.89			12	12	15	15				1.7								190		x		
Cana	NA	Nahanni	5/10/85	R	6.6			6.64	6.64			32	32			16	16										191				
Alge	AF	Constantine	27/10/85	S	5.9	5.38	5.88	6	6	1.48E+24	8.19E+24	21	21	3.8	3.8	13	13		0.12	0.1							192				
Cana	NA	Nahanni	23/12/85	R	6.9			6.75	6.75			40	40			17	17										193				
Taiw	AS	Hualien	20/5/86	R	6.4			6.37	6.37			20	20			24	24										200				
USA	NA	No. Palm Springs	8/7/86	SR	6			6.13	6.13			16	16	9	9	9	9		0.01		14	25					201				
USA	NA	Challant Valley	21/7/86	S	6.2			6.31	6.31			20	20	15.8	15.8	11	11		0.11								203				
Taiw	AS	Hualien	14/11/86	R	7.8			7.33	7.33			48	48			26	26										206				
New	NZ	Edgecumbe	2/3/87	N	6.6	6.60	6.84	6.5	6.5	1E+26	2.2848E+26	32	32	14	14	14	14		2.9	1.7	1.3	2.8		1.5	1.5	1.5	209				19
USA	NA	Whittier Narrows	1/10/87	R	5.7			6.01	6.01			5	5			6	6				1.7	1.7	1.7				214				20
USA	NA	Elmore Ranch	24/11/87	S	6.2	5.88	6.20	6.2	6.2	8.28E+24	2.484E+25	30	30	10	10	12	12		0.28	0.23	0.5	1.5					215		x		21
USA	NA	Superstition Hills	24/11/87	S	6.6	6.39	6.42	6.61	6.61	4.81E+25	5.346E+25	30	30	27	27	11	11		0.92	0.54	2	6		24	24	24	216		x		
Aust	AU	Tennant Creek	22/1/88	R	6.3	6.09	6.16	6.26	6.26	1.74E+25	2.2113E+25	13	13	10.2	10.2	9	9		1.3	0.63							217		x		
Aust	AU	Tennant Creek	22/1/88	RS	6.4	5.96	6.15	6.38	6.38	1.09E+25	2.106E+25	13	13	6.7	6.7	9	9		1.1	0.6							218		x		
Aust	AU	Tennant Creek	22/1/88	R	6.7	6.42	6.47	6.58	6.58	5.36E+25	6.3612E+25	19	19	16	16	12	12		1.9	0.93							219		x		
Chin	AS	Lancang-Gengma	6/11/88	S	7.3	6.71	6.95	7.13	7.13	1.47E+26	3.36E+26	80	80	35	35	20	20		2.2	0.7							221				
Chin	AS	Gengma, Yunnan	6/11/88	S	7.2			6.83	6.83			46	46	15.6	15.6				1.1	0.6							222				
USSF	AS	Armenia	7/12/88	RS	6.8			6.76	6.76			38	38	25	25	11	11		2								225				
USA	NA	Loma Prieta	18/10/89	SR	7.1			6.92	6.92			40	40			16	16	0.2			12	28		150		150	227		x		
Cana	NA	Ungava	25/12/89	R	6.3	5.99	5.99	5.98	5.98	1.2E+25	1.2E+25	10	10	10	10	5	5		2	0.8							229				
Japa	JP	Izu-Oshima	20/2/90	S	6.4			6.37	6.37			19	19			12	12										230				
Iran	MT	Rudbar-Tarom	20/6/90	RS	7.7			7.41	7.41			90	90	80	80				1								232		x		
Phili	CC	Luzon	16/7/90	S	7.8			7.74	7.74			120	120	110	110	20	20		6.2		10	20					233	41			
Turk	MT	Erzincan	13/3/92	S	6.8			6.87	6.87			38	38	30	30				0.2		5	25		25	45	35	238				
USA	NA	Joshua Tree	23/4/92	S	6.3			6.27	6.27			15	15			13	13										239				
USA	NA	Landers	28/6/92	S	7.6	7.18	7.15	7.34	7.34	7.54E+26	6.5844E+26	62	62	71	71	12	12		6	2.95	0.08	2		1.6	4	2.8	240				21
USA	NA	Big Bear	28/6/92	S	6.7			6.68	6.68			20	20			10	10										241				
JP	JP	Noto Peninsula	7/2/93	S				6.6	6.6					25	25	20	20											13			22
India	AS	Latur	29/9/93					6.4	6.4					3	3				1										x		9
USA	NA	Eureka Valley	17/5/93	N	5.8			6.08	6.08			16.7	16.7	4.4	4.4	7	7		0.02								244				

USA	NA	Northridge	17/1/94	R		6.7	6.7	8	16			17.5	23.3	1.2		1	1	0.3	0.3	0.3		5	x	20,24	
R	MT	Lut	23/2/94	RS	6		6			4	4										148				
NZ	NZ	Arthurs Pass	18/6/94	R		6.7	6.7	30	40			4	7												23
GR	MT	Kozani	13/5/95	N	6.5		6.5			15	15				0.09						149		x		
TR	MT	Dinar	1/10/95	NS	6.2		6.2			10	10										150				
Japa	JP	Kobe	17/1/95	SR		6.9	6.9			30	40				1.9	0.6	1.5					6	x		

Description of Table

Column 1, "Loc": Country

Column 2, "REG": Geographic region; NZ=New Zealand, JP=Japan, MT=Eastern Mediterranean, AS=Asia, OC=Oceania, NA=North America, CA=Central America, SA=South America, AU=Australia, AF=Africa

Column 3, "EVENT": Earthquake or fault name

Column 4, "DATE": Date=Earthquake date; paleo = paleoearthquake

Column 5, "ST":Slip type; S=strike-slip, R=reverse-slip, N=normal-slip. Slip types with two letters denote oblique-slip motion, with the order of letters denoting the dominance of one slip type over the other

Column 6, "MsorMjma": Surface wave magnitude

Column 7, "MI": MI=Magnitude derived from interpretation of intensity data

Column 8, "Mw(geol_subL)": Moment magnitude derived from geological data with the equations logMo=16.1+1.5Mw, in which Mw=moment magnitude and Mo=seismic moment (Column 12)

Column 9, "Mw(geol_sfcL)": Moment magnitude derived from geological data with the equations logMo=16.1+1.5Mw, in which Mw=moment magnitude and Mo=seismic moment (Column 13)

Column 10, "Mw(seis)": Moment magnitude measured from seismological data

Column 11, "M": The magnitude chosen as the most reliable estimate of the moment magnitude of the earthquake

Column 12,"Mo(geol_subsL)": Seismic moment calculated with the equation Mo=uLWD, in which Mw=moment magnitude, Mo=seismic moment, u=rigidity modulus (3e+11 dyne/cm^2), L=SUBSURFACE rupture length (mean of Columns 14 and 15), W=rupture width (mean of Columns 18 and 19), and D=average surface displacement (Column 23)

Column 13,"Mo(geol_sfcL)": Seismic moment calculated with the equation Mo=uLWD, in which Mw=moment magnitude, Mo=seismic moment, u=rigidity modulus (3e+11 dyne/cm^2), L=SURFACE rupture length (mean of Columns 16 and 17), W=rupture width (mean of Columns 18 and 19), and D=average surface displacement (Column 23)

Column 14,"LGTHMNsub": Minimum-bound SUBSURFACE rupture length (km)

Column 15,"LGTHMXsub": Maximum-bound SUBSURFACE rupture length (km)

Column 16,"LGTHMN": Minimum-bound SURFACE rupture length (km)

Column 17,"LGTHMX": Maximum-bound SURFACE rupture length (km)

Column 18,"WMN": Minimum-bound rupture width (km)

Column 19,"WMN": Maximum-bound rupture width (km)

Column 20,"Dmxsub": Maximum-bound SUBSURFACE displacement (m)

Column 21,"Davsub": Average SUBSURFACE displacement (m)

Column 22,"Dmx": Maximum-bound SURFACE displacement (m)

Column 23,"Dav": Average SURFACE displacement (m)

Column 24,"SRmn": Minimum-bound fault slip rate (mm/yr)

Column 25,"SRmx": Maximum-bound fault slip rate (mm/yr)

Column 26,"SRmx": Preferred, or mean fault slip rate (mm/yr)

Column 27,"TSmn": Minimum-bound estimate of total slip (km)

Column 28,"TSmn": Maximum-bound estimate of total slip (km)

Column 29,"TSprf": Preferred, mean, or only estimate of total slip (km)

Column 30,"WC": Data are derived from Wells and Coppersmith (1994), and the index number from their original table is shown

Column 31,"AJ": Data are derived from Ambraseys & Jackson (1998), and the index number from their original table is shown

Column 32,"AWS": Data are derived from Anderson et al. (1996), and the index number from their original table is shown.

Column 33,"CS": Data are derived the PhD work of Christian Stock (pers comm. 1998)

Column 34,"OTHER": Data are derived from the following references; 1=Stirling et al. (1996), 2=Stirling et al. (1998), 3=Cowan et al. (1996), 4=Shimokawa et al. (), 5=Tsutsumi et al. (1991), 6=Awata et al. (1995), 7=Kumamoto (1998), 8=Research Group for Active Faults of Japan (1991), 9=Yeats et al. (1997), 10=Mizuno et al. (19), 11=Russ (1979), 12=Zoback (1979), 13=Barka & Kadinsky-Cade (1988), 14=Peltzer et al. (1988), 15=Ambraseys & Jackson (1990), 16=Hirabayashi et al. (1996), 17=Ritz et al. (1995), 18=Molnar & Deng (1984), 19=Beanland et al. (1989), 20=Dolan et al. (1995), 21=Website of the Southern California Earthquake Center (SCEC), 21=Dokka (1983), 22=Tsukuda et al. (1994), 23=Abercrombie et al. (1998), 24=Yeats et al. (1994), 25=minimum estimate of total slip for dip-slip fault from rangefront relief, 26=A.Michetti (pers comm. 1998), 27=Kawasaki (1975), 28=Beanland & Clark (1994)

General Comments: "A" quality events are those for which moment magnitudes are measured directly from seismological data (Column 10), B quality events encompass all the remaining historical earthquakes, and C quality events are those for which moment magnitudes and fault parameters are derived wholly from paleoseismic data. This Table is limited to earthquake magnitudes of ≥ 6.

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