


Provided by the author(s) and University College Dublin Library in accordance with publisher policies. Please cite the published version when available.

Title	Earthquake histories and Holocene acceleration of fault displacement rates
Author(s)	Nicol, Andrew; Walsh, John J.; Mouslopoulou, Vasiliki; Villamor, Pilar
Publication date	2009-10
Publication information	Geology, 37 (10): 911-914
Publisher	Geological Society of America
Link to online version	http://geology.gsapubs.org/cgi/doi/10.1130/G25765A.1
Item record/more information	http://hdl.handle.net/10197/3080
Publisher's statement	This is the author's version of Nicol, A., Walsh, J., Mouslopoulou, V., and Villamor, P., 2009, Earthquake histories and Holocene acceleration of fault displacement rates: Geology, v. 37, p. 911-914, doi:10.1130/G25765A.1. (www.gsapubs.org)
Publisher's version (DOI)	http://dx.doi.org/10.1130/G25765A.1 .

Downloaded 2018-07-20T04:52:55Z

The UCD community has made this article openly available. Please share how this access benefits you. Your story matters! (@ucd_oa) 

Some rights reserved. For more information, please see the item record link above.



1 Earthquake histories and Holocene acceleration of fault
2 displacement rates

3 **Andrew Nicol¹, John Walsh², Vasiliki Mouslopoulou^{2*}, and Pilar Villamor¹**

4 ¹*GNS Science, PO Box 30368, Lower Hutt, New Zealand*

5 ²*Fault Analysis Group, School of Geological Sciences, University College Dublin, Belfield,
6 Dublin 4, Ireland*

7 ^{*}Present address: Department of Mineral Resources Engineering, Technical University of Crete,
8 Chania, 73 100, Greece

9
10 **ABSTRACT**

11 Displacement rates for normal and reverse faults (N = 57) are generally higher when
12 averaged for the Holocene (~10 ka) than for the late Quaternary (~300 ka) and longer time
13 scales. Holocene acceleration of displacement rates could be attributed to geological processes
14 that produce increases of tectonic tempo. We propose an alternative model in which the observed
15 rate changes arise from variability in earthquake slip and/or recurrence coupled with a sampling
16 bias toward those faults that are best represented at the Earth's surface and accrued displacement
17 fastest during the Holocene. This model is consistent with displacement rates measured over time
18 intervals of up to ~300 k.y. for 129 faults from the Taupo Rift, New Zealand. Departures of
19 earthquake parameters and associated displacement rates from their long-term (>300 k.y.)
20 averages are attributed to fault interactions and occur on time intervals inversely related to these
21 long-term displacement rates and to regional strain rates.

22
23 **INTRODUCTION**

24 An increasing body of evidence suggests that faults within many systems may have
25 accrued displacement at faster rates during the Holocene (0–10 ka) than over time intervals of
26 ~300 k.y. or more (e.g., Friedrich et al., 2003; McNeill and Collier, 2004; Roberts and Michetti,
27 2004; Taylor et al., 2004). This rate increase is supported by the global data set in Figure 1 and
28 has been attributed to a number of mechanisms which increase the frequency and/or size of
29 earthquakes on individual faults. These processes include; climatically induced lithospheric
30 rebound (Hetzl and Hampel, 2005), fault linkage (Taylor et al., 2004) and strain localization
31 (Roberts and Michetti, 2004). There is no evidence to support global Holocene increases of fault
32 linkage or of the rates of plate motion and regional strain accumulation (e.g., Beavan et al.,
33 2002). Similarly, lithospheric rebound driven by deglaciation (and associated regression of Lake
34 Bonneville) (Hetzl and Hampel, 2005), which could account for an increase of displacement
35 rates over the last 10–20 k.y. on some faults in the Basin and Range, may not apply for normal
36 faults in offshore New Zealand and Gulf of Corinth, for example, where deglaciation resulted in
37 sea level rise and lithospheric loading. We therefore propose an alternative explanation in which
38 the observed acceleration of displacement rates during the Holocene reflects temporal variations
39 in earthquake slip and/or recurrence interval arising from fault interactions (e.g., Friedrich et al.,
40 2003; Nicol et al., 2006) coupled with a strong bias toward those faults that are best represented
41 at the Earth’s surface. This sampling bias decreases the likelihood of faults with Holocene
42 displacement rates lower than their long-term (\geq ~300 k.y.) averages being sampled (Fig. 1).

43 The fault interaction-sampling bias model for Holocene displacement rates higher than
44 the long-term average has been tested using a compilation of displacement rate measurements for
45 64 faults from a selection of fault systems worldwide, together with constraints from a high
46 quality data set from the active Taupo Rift, which provides a means of analyzing displacements

47 on 129 faults over time intervals of 2–300 k.y. (Villamor and Berryman, 2001; Taylor et al.,
48 2004; Lamarche et al., 2006; Nicol et al., 2006; Berryman et al., 2008; Canora-Catalán et al.,
49 2008; Mouslopoulou et al., 2008). The Taupo Rift data set is unusually complete and avoids the
50 potential bias that may arise from sampling only a few of the most prominent fault traces in a
51 system. Results from analysis of our multiple fault system data set, augmented by constraints
52 derived from the active faults in the Taupo Rift, have important implications for the variability of
53 earthquake processes.

54 **TEMPORAL DISPLACEMENT RATE VARIATIONS**

55 Analysis of displacement rate variations on different time scales is achieved using 57
56 faults from seven normal and reverse fault systems together with a further seven large strike-slip
57 faults (see Figure 1 caption for details). Each fault system includes different numbers of
58 constituent faults that range in size and displacement rates and accommodate different regional
59 strain rates. Comparison of average displacements rates for the Holocene (~10 ka) against
60 average values for the past ~300 k.y. and ≥ 1 Myr on individual faults, indicates a broad positive
61 correlation, but with the scatter in data suggesting significant variability between the short- and
62 long-term rates (Fig. 1). Despite the scatter in these relations, it is clear that Holocene
63 displacement rates are generally greater than longer-term rates; individual faults usually display
64 ratios of 2–20:1 for short- to long-term values. These differences in rate are too large to be
65 accounted for by uncertainties in the displacement rates which average about $\pm 35\%$ (Fig. 1 and
66 electronic supplement). Given the diversity in the locations, fault types, regional strain rates,
67 growth histories and displacement rates for the faults in Figure 1, it is possible that the observed
68 acceleration has multiple origins. Our analysis, however, suggests that a single explanation may
69 have widespread application.

70 The maximum departure of short-term displacement rates from average appears to
71 generally decrease with increasing long-term rates; faster moving faults (e.g., >2–5 mm/yr) have
72 broadly equivalent Holocene and longer-term displacement rates (Fig. 1). As these faster moving
73 faults are generally from areas of high regional strain rates ($>10^{-15} \text{ S}^{-1}$), strain rate could be an
74 important determinant in the observed data distributions (Fig. 1). A decreased scatter of
75 Holocene displacement rates from their long-term averages for higher strain rate systems could
76 be mainly due to an associated decrease in earthquake recurrence interval (Nicol et al., 2005).
77 For high strain rate fault systems the average recurrence interval is relatively low (e.g., < 2 k.y.)
78 and, as a consequence, variations in displacement rates arising from changes in earthquake
79 recurrence or slip are less likely (than lower strain rate systems) to be reflected in the data
80 averaged over the 10 k.y. Holocene time window. By contrast, for faults within low strain rate
81 systems, recurrence intervals will approach, or may even exceed, the 10 k.y. Holocene time
82 window, and short-term displacement rates could be high because they do not sample an entire
83 recurrence interval.

84 **TAUPO RIFT FAULTS**

85 In an attempt to provide a rationale for the higher than average Holocene displacement
86 rates of Figure 1, high quality displacement and paleoearthquake data are presented for 129
87 normal faults from the Taupo Rift (North Island of New Zealand), that range in length (1–70
88 km), displacement rate (0.01–4 mm/yr) and topographic scarp height (0.3–150 m). Displacement
89 rates together with the timing and slip of paleoearthquakes have been determined for parts of the
90 rift, which is a back-arc basin extending at rates up to ~12 mm/yr across a width of 15–30 km
91 (Villamor and Berryman, 2001; Wallace et al., 2004). What distinguishes the Taupo Rift data set
92 from others, are the exceptional quantitative constraints on fault displacement accumulation, for

93 all major faults in the system and for a range of time scales, which derive from a combination of
94 the full range of conventional paleoseismological methods and geophysical tools (Villamor and
95 Berryman, 2001; Lamarche et al., 2006; Nicol et al., 2006; Berryman et al., 2008; Canora-
96 Catalán, et al., 2008; Mouslopoulou et al., 2008).

97 Displacement rates on faults from the Taupo Rift have an approximately proportional
98 positive relation with fault length, for time intervals of 10 k.y. and greater (Fig. 2). This increase
99 in displacement rate with fault size is similar to other fault systems and confirms that longer
100 faults generally move faster than short (Nicol et al., 2005; Mouslopoulou et al., 2009). The
101 positive correlation has been attributed to the proportional relation between earthquake slip and
102 fault length, with the y-axis value increasing for higher regional strain rates (Nicol et al., 2005;
103 Mouslopoulou et al., 2009). An additional important feature of Figure 2 is the progressive
104 increase in scatter of displacement rates for shorter time scales. The increase in scatter, in
105 combination with displacement profiles for faults in the Taupo Rift for the last 26 k.y. (Nicol et
106 al., 2006), support the notion that individual faults can experience short-term variations in
107 displacement rates and that, while time intervals of accelerated displacement accumulation are
108 common in the Taupo Rift, these variations are generally not synchronous on individual faults
109 and certainly not confined to the Holocene. During the Holocene, faults in the Taupo Rift have
110 displacement rates faster, slower and approximately equal to the long-term average rates
111 measured over time periods of ≥ 60 k.y. (Fig. 2).

112 The question is why some systems, such as the Taupo Rift, do not show a bias toward
113 higher rates on 10 k.y. time intervals while others do? Examination of short-term displacement
114 rates on the Taupo Rift faults indicate that for 2 k.y. intervals faults have approximately bimodal
115 displacement rates, i.e., they generally have higher than average displacement rates or, within

116 resolution, they do not move at all (Fig. 2). This feature is consistent with the fact that estimates
117 of the recurrence interval of large earthquakes on individual faults in Taupo Rift are ~2–3 k.y.
118 (Nicol et al., 2005). The significant number of higher than average displacement rate faults over
119 the past 2 k.y. in Taupo Rift (0-2 k.y. in Fig. 2), partly arises because measurements derive from
120 trenches which were generally located on the most clearly defined fault scarps. The smaller
121 proportion of low displacement rate faults, sometimes characterized by no discernible
122 displacement over the measured period, are not as easily identified and are therefore less often
123 sampled. While fault-scarp preservation potential is dependent on the relative rates of fault slip
124 and sedimentation (or burial), within a given system (i.e., where rates of surface processes are
125 comparable on all faults) faults which have ruptured most recently tend to have the best
126 preserved scarps and are more likely to have rates that are higher than their long-term averages.

127 The lack of sampling bias toward those Taupo Rift faults which have moved fastest in the
128 Holocene is mainly because the available data are of extremely high quality and the ~10 k.y.
129 sample window by far exceeds the average earthquake recurrence interval (~2–3 k.y.). While the
130 ~10 k.y. displacement rates measured are broadly representative of the long-term rates, they
131 nevertheless still display about one order of magnitude of scatter, even when sampled at time
132 scales approaching five times the average recurrence interval, a feature which reflects significant
133 variability in earthquake slip and/or recurrence interval. The observed Taupo Rift data
134 distributions demonstrate that, for time scales approaching, or shorter than, the average
135 recurrence interval of faults, sampling biases will result in higher than average displacement
136 rates even for very high quality data sets such as those of the Taupo Rift.

137 **IMPLICATIONS FOR EARTHQUAKE PROCESSES**

138 Figures 1 and 2 suggest that many faults experience short-term displacement rates that
139 differ from their long-term average. Temporal variations in displacement rates in the Taupo Rift,
140 particularly on timescales of 10 k.y. or less, are accompanied by changes in earthquake slip and
141 recurrence interval, which in both cases exceed an order of magnitude (e.g., Fig. 3). Similar
142 variations in earthquake recurrence intervals on individual faults have been widely observed
143 (e.g., Wallace 1987; Marco et al., 1996; Friedrich et al., 2003; Palumbo et al., 2004; Weldon et
144 al., 2004), while evidence of variable slip per event through time is beginning to emerge but is
145 less commonly reported (e.g., Palumbo et al., 2004; Weldon et al., 2004; Canora-Catalán et al.,
146 2008). Collectively, paleoearthquake studies show that it is these changes in earthquake
147 parameters for consecutive events on individual faults that produce variability in fault
148 displacement rates. This assertion is supported by the complex form of displacement-time curves
149 for individual faults in the Taupo and Taranaki rifts in New Zealand, which are directly linked to
150 the variable displacement rates (Nicol et al., 2006; Mouslopoulou et al., 2009).

151 The link between displacement rates and earthquake parameters is shown by the
152 displacement-time curve in Figure 4. This synthetic curve was generated using Taupo Rift
153 earthquake data from multiple faults by randomly choosing pairs of recurrence intervals and
154 slip/event from the population of paleoearthquakes on 0–0.3 mm/yr faults shown in Figure 3.
155 Though such a simple stochastic model does not contain any conditioning, the displacement-time
156 curve nevertheless produces average displacement rates for 10 k.y. time intervals which range
157 from 0 to 0.5 mm/yr, a variability similar to that of 5–10 km long faults in Figure 2. This model
158 provides an indication of how changes in earthquake slip and recurrence can influence fault
159 displacement rates, while the resulting displacement-time curve supports the notion that complex

160 earthquake behavior is an intrinsic property of fault systems and is a critical determinant on the
161 variability of displacement rates.

162 There are insufficient data to define the precise geometries of displacement-time curves,
163 although Figures 1–2 and previous work (e.g., Wallace, 1987; Palumbo et al., 2004; Weldon et
164 al., 2004; Nicol et al., 2006) indicate that the nonlinearity depicted in Figure 4 is common. In
165 such cases the time- and slip-predictable earthquake models (e.g., Shimazaki and Nakata, 1980)
166 can, at best, only apply for part of a fault’s history. The minimum length of time required to
167 measure representative long-term displacement rates provides an estimate of the timescales of
168 displacement rate variations on individual faults (e.g., Fig. 4). Displacement rates comparable to
169 long-term values occur on time intervals as short as ~1–2, 10 and 20–60 k.y. for the 20–30
170 mm/yr San Andreas fault at Wrightwood (Weldon et al., 2004), the ~2–5 mm/yr faults in Figure
171 1 (this study) and the <1 mm/yr Taupo Rift faults (Nicol et al., 2006), respectively. The inverse
172 relation between displacement rate (and regional strain rate) and these time intervals derives
173 from the reduction of average recurrence interval with increasing displacement rate (e.g., the San
174 Andreas fault at Wrightwood has an average recurrence of ~100 yr and the Taupo Rift faults ~2–
175 3 k.y.).

176 Many processes could contribute to the observed order of magnitude changes in
177 displacement rate and earthquake slip and recurrence (e.g., Figures 3 and 4), including temporal
178 changes in fault strength, fault segmentation, fault healing rate, fault loading rate and fault
179 interactions (e.g., Wallace, 1987; Friedrich et al., 2003; Weldon et al., 2004). The uniformity of
180 the driving plate motions and the constant regional strain rates on timescales of tens of thousands
181 of years in some fault systems indicate that, in these cases, variations in earthquake slip and
182 recurrence arise from processes within the fault systems themselves rather than from changes in

183 their boundary conditions. Static stress modeling of fault systems shows that fault interactions
184 can produce variations in the rates of strain release (i.e., earthquake slip and/or recurrence
185 intervals) even when the fault strength, fault loading rates and stored stresses are approximately
186 uniform (e.g, Robinson, 2004). A corollary of the fault interaction model is that fault systems
187 which comprise fewer faults in relatively simple configurations, such as parts of some large
188 strike-slip fault systems (e.g., North Anatolian and Alpine fault systems), would be expected to
189 show less complexity in their earthquake behavior than faults in systems that comprise many
190 interacting components.

191

192 **ACKNOWLEDGEMENTS**

193 This research was funded by the Marsden Fund and FRST in New Zealand, an IRCSET Embark
194 Post-Doctoral Fellowship and by a UCD (Ireland) President's Fellowship. We thank Richard
195 Norris and an anonymous reviewer for helpful and constructive reviews.

196

197 **REFERENCES CITED**

198 Beavan, J., Tregoning, P., Bevis, M., Kato, T., and Meertens, C., 2002, The motion and rigidity
199 of the Pacific Plate and implications for plate boundary deformation: *Journal of*
200 *Geophysical Research*, v. 107, p. 2261, doi:10.1029/2001JB000282.

201 Berryman, K., Villamor, P., Nairn, I., Van Dissen, R., Begg, J., and Lee, J., 2008, Late
202 Pleistocene surface rupture history of the Paeroa Fault, Taupo Rift, New Zealand: *New*
203 *Zealand Journal of Geology and Geophysics*, v. 51, p. 135–158.

204 Canora-Catalán, C., Villamor, P., Berryman, K., Martínez-Díaz, J.J., and Raen, T., 2008,
205 Rupture history of the Whirinaki Fault, an active normal fault in the Taupo Rift, New
206 Zealand: *New Zealand Journal of Geology and Geophysics*, v. 51, p. 277–293.

207 Friedrich, A.M., Wernicke, B.P., Niemi, N.A., Bennett, R.A., and Davis, J.L., 2003, 2003,
208 Comparison of geodetic and geologic data from the Wasatch region, Utah, and implications
209 for the spectral character of Earth deformation at periods of 10 to 10 million years: *Journal*
210 *of Geophysical Research*, v. 108, no. B4, p. 2199, doi: 10.1029/2001JB000682.

211 Hetzel, R., and Hampel, A., 2005, Slip rate variations on normal faults during glacial-interglacial
212 changes in surface loads: *Nature*, v. 435, p. 81–84, doi: 10.1038/nature03562.

213 Lamarche, G., Barnes, P.M., and Bull, J.M., 2006, Faulting and extension rate over the last
214 20,000 years in the offshore Whakatane Graben, New Zealand continental shelf: *Tectonics*,
215 v. 25, p. TC4005, doi: 10.1029/2005TC001886.

216 Marco, S., Stein, M., and Agnon, A., 1996, Long-term earthquake clustering: A 50,000-year
217 paleoseismic record in the Dead Sea Graben: *Journal of Geophysical Research*, v. 101, B3,
218 p. 6179–6191, doi: 10.1029/95JB01587.

219 McNeill, L.C., and Collier, R.E.L., 2004, Uplift and slip rates of the eastern Eliki fault segment,
220 Gulf of Corinth, Greece, inferred from Holocene and Pleistocene terraces: *Journal of the*
221 *Geological Society*, v. 161, p. 81–92, doi: 10.1144/0016-764903-029.

222 Mouslopoulou, V., Nicol, A., Walsh, J.J., Beetham, D., and Stagpoole, V., 2008, Quaternary
223 temporal stability of a regional strike-slip and rift fault intersection: *Journal of Structural*
224 *Geology*, v. 30, p. 451–463, doi: 10.1016/j.jsg.2007.12.005.

225 Mouslopoulou, V., Walsh, J.J., and Nicol, A., 2009, Fault displacement rates on a range of
226 timescales. *Earth and Planetary Science Letters*, v. 278, p. 186-197,
227 doi:[10.1016/j.epsl.2008.11.031](https://doi.org/10.1016/j.epsl.2008.11.031) .

228 Nicol, A., Walsh, J.J., Manzocchi, T., and Morewood, N., 2005, Displacement rates and average
229 earthquake recurrence intervals on normal faults: *Journal of Structural Geology*, v. 27,
230 p. 541–551, doi: [10.1016/j.jsg.2004.10.009](https://doi.org/10.1016/j.jsg.2004.10.009).

231 Nicol, A., Walsh, J.J., Berryman, K., and Villamor, P., 2006, Interdependence of fault
232 displacement rates and paleoearthquakes in an active rift: *Geology*, v. 34, p. 865–868, doi:
233 [10.1130/G22335.1](https://doi.org/10.1130/G22335.1).

234 Palumbo, L., Benedetti, L., Bourles, D., Cinque, A., and Finkel, R., 2004, Slip history of the
235 Magnola fault (Appennines, Central Italy) from ³⁶Cl surface exposure dating: evidence for
236 strong earthquakes over the Holocene: *Earth and Planetary Science Letters*, v. 225, p. 163–
237 176, doi: [10.1016/j.epsl.2004.06.012](https://doi.org/10.1016/j.epsl.2004.06.012).

238 Roberts, G.P., and Michetti, A.M., 2004, Spatial and temporal variations in growth rates along
239 active fault systems: an example from Lazio-Abtuzzo, central Italy: *Journal of Structural*
240 *Geology*, v. 26, p. 339–376, doi: [10.1016/S0191-8141\(03\)00103-2](https://doi.org/10.1016/S0191-8141(03)00103-2).

241 Robinson, R., 2004, Potential earthquake triggering in a complex fault network: the northern
242 South Island, New Zealand: *Geophysical Journal International*, v. 159, p. 734–748, doi:
243 [10.1111/j.1365-246X.2004.02446.x](https://doi.org/10.1111/j.1365-246X.2004.02446.x).

244 Shimazaki, K., and Nakata, T., 1980, Time-predictable recurrence model for large earthquakes:
245 *Geophysical Research Letters*, v. 7, no. 4, p. 279–282, doi: [10.1029/GL007i004p00279](https://doi.org/10.1029/GL007i004p00279).

246 Taylor, S.K., Bull, J.M., Lamarche, G., and Barnes, P.M., 2004, Normal fault growth and linkage
247 in the Whakatane Graben, New Zealand, during the last 1.3 Myr. *Journal of Geophysical*
248 *Research*, 109, B2, B02408, doi:10.1029/2003JB002412.

249 Villamor, P., and Berryman, K., 2001, A late Quaternary extension rate in the Taupo Volcanic
250 Zone, New Zealand, derived from fault slip data: *New Zealand Journal of Geology and*
251 *Geophysics*, v. 44, p. 243–269.

252 Wallace, L., Beavan, J., McCaffrey, R., and Darby, D., 2004, Subduction zone coupling and
253 tectonic block rotation in the North Island, New Zealand: *Journal of Geophysical Research*,
254 v. 109, no. B12, doi: 10.1029/2004JB003241.

255 Wallace, R.E., 1987, Grouping and migration of surface faulting and variations in slip rates on
256 faults in the Great Basin Province: *Bulletin of the Seismological Society of America*, v. 77,
257 p. 868–876.

258 Weldon, R., Scharer, K., Fumal, T., and Biasi, G., 2004, Wrightwood and the earthquake cycle:
259 what a long recurrence record tells us about how faults work: *GSA Today*, v. 14, doi:
260 10.1130/1052-5173(2004)014<4:WATECW>2.0.CO;2.

261 **FIGURE CAPTIONS**

262 Figure 1. Comparison of displacement rates averaged over the Holocene (~10 k.y.) with average
263 values for the million year (≥ 1 Myr) (A) and Late Quaternary (~300 k.y.) (B) time intervals
264 using a global data set of 65 faults. The names, locations (country and fault system), fault types,
265 displacement rates (and their uncertainties) and data sources for the faults are given in the
266 electronic supplement. The faults have a range of sizes, with lengths of 10–700 km and total
267 displacements of up to ~315 km, and slip rates of ~0.01–30 mm/yr. Symbols are as follows:
268 unfilled triangle, strike-slip (San Andreas, Alpine, Dead Sea Transform, North Anatolian,

269 Awatere, Sumatra and Itoilawa Shizuoku tectonic line faults); unfilled diamond, Taupo Rift
270 (normal faults); unfilled circle, Corinth Rift (normal faults); unfilled square, Apennines (normal
271 faults); filled triangle, New Zealand Hikurangi margin (reverse faults); filled diamond Taranaki
272 Rift (normal faults); filled circle Wanganui Basin (reverse and normal faults) and filled square,
273 Basin and Range (normal faults). Regional strain rates are greater or less than 10^{-15} S^{-1} for
274 unfilled and filled faults, respectively. Contours of the Holocene/Late Quaternary or Myr
275 displacement rate ratios are illustrated.

276 Figure 2. Taupo Rift displacement rate vs fault length for sample intervals of 2, 10, 60 and 300
277 k.y. Displacement histories for normal faults have been charted for volcanic horizons ranging in
278 age from 2 to 300 k.y. (e.g., Villamor and Berryman, 2001) using displacements from trenches (2
279 and 10 k.y.), topographic scarp heights (10, 60 and 300 k.y.), and seismic reflection lines and
280 outcrop (300 k.y.) (e.g., Villamor and Berryman, 2001; Nicol et al., 2006; Lamarche et al., 2006;
281 Berryman et al., 2008; Mousloupolou et al., 2008). Data for the last 2 k.y. (~0-2 ka, solid blue
282 squares) and older 2 k.y. (~2 ka, open blue squares) sample intervals are discriminated.
283 Horizontal dashed lines labeled 2 k.y. RL and 10 k.y. RL indicate the lower resolution limit of
284 displacement rate for 2 and 10 k.y. data respectively.

285 Figure 3. Plot illustrating variations in excess of one order of magnitude of earthquake slip/event
286 and recurrence intervals for consecutive paleoearthquakes recorded in trenches across 26
287 individual faults in the Taupo Rift (e.g., Berryman et al., 2008). Displacements for up to 13
288 volcanic tephra and fluvial sediment layers in each trench record as many as seven surface-
289 rupturing paleoearthquakes (~Mw 5.8–6.8) on each fault over the last ~26 k.y. (Villamor and
290 Berryman, 2001; Nicol et al., 2006; Berryman et al., 2008). Slip/event and recurrence intervals of
291 less than 0.1–0.3 m and 1–2 k.y., respectively, are sub-resolution and while their inclusion may

292 modify the recurrence and slip populations, they are unlikely to entirely remove the variability of
293 these earthquake parameters. Slip/event and recurrence intervals with a common long-term (~60
294 k.y.) displacement rate indicate different earthquakes on the same fault..

295 Figure 4. Stochastic displacement-time profile for a notional normal fault with a long-term
296 displacement rate of ~0.14 mm/yr and total displacement of 27.2 m produced in 31 earthquakes
297 over 200 k.y. Profile constructed by randomly sampling recurrence interval and slip/event pairs
298 from the paleoearthquake distribution for those faults in Figure 3 with long-term displacement
299 rates of 0–0.3 mm/yr. Grey smoothed curve is a running average of 10 k.y. sample intervals.
300 Numbers above rectangles indicate average displacement rates for selected 10 k.y. time intervals.

301 ¹GSA Data Repository item 2009xxx, xxxxxxxx, is available online at
302 www.geosociety.org/pubs/ft2008.htm, or on request from editing@geosociety.org or Documents
303 Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

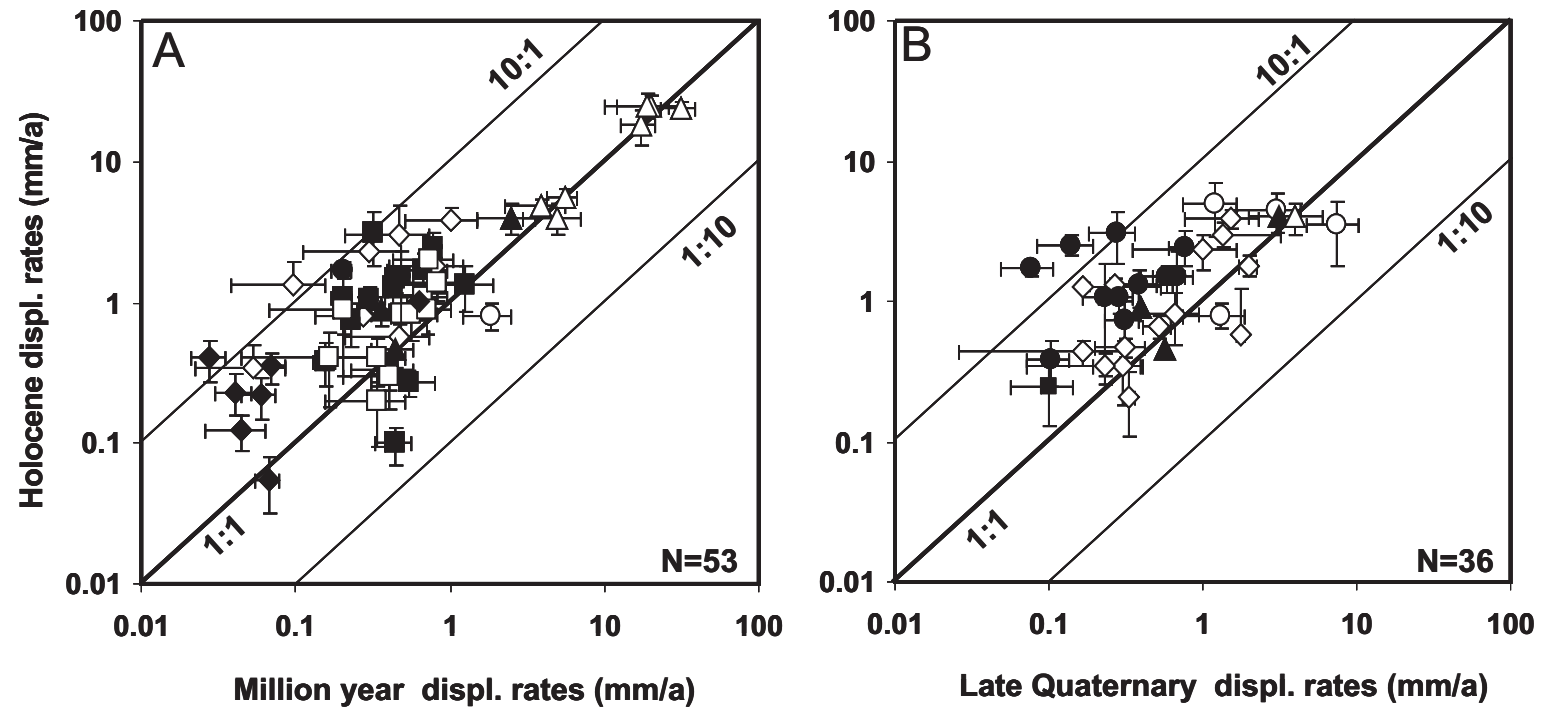


Figure 1

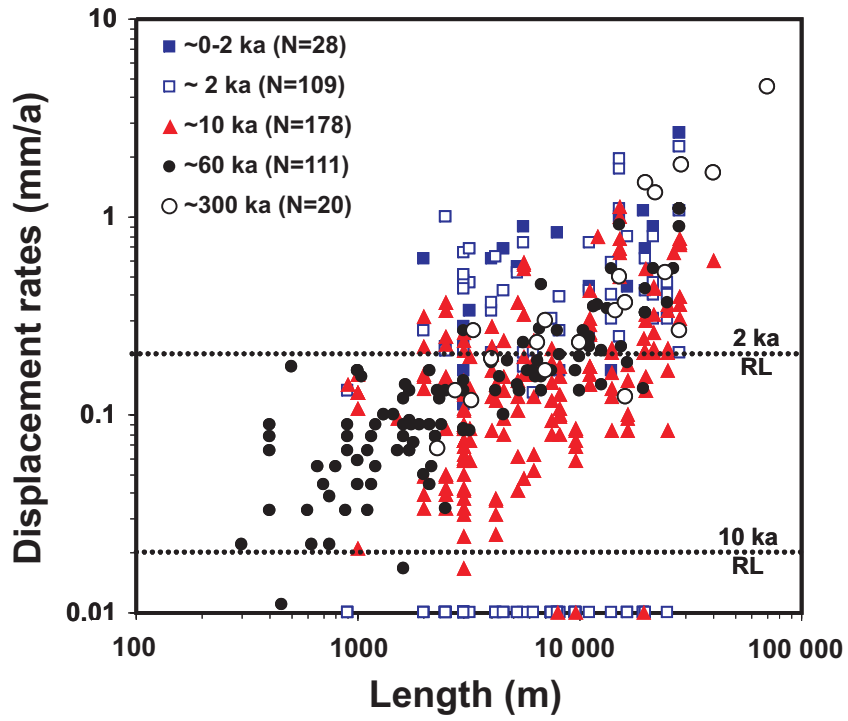


Figure 2

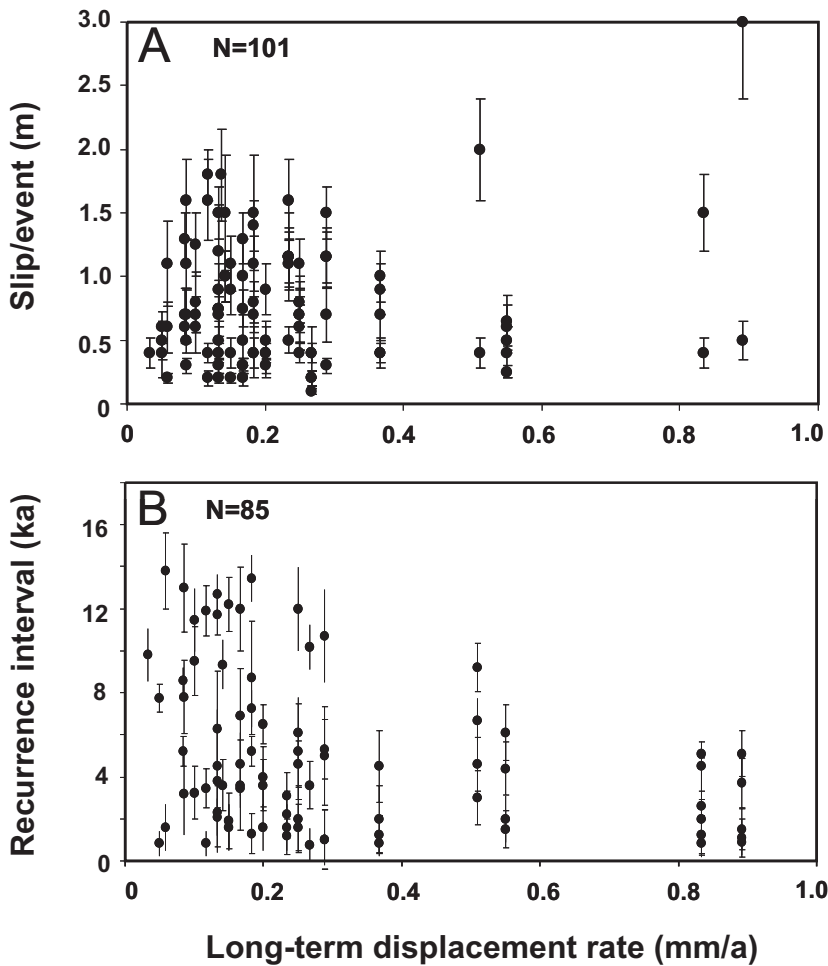


Figure 3

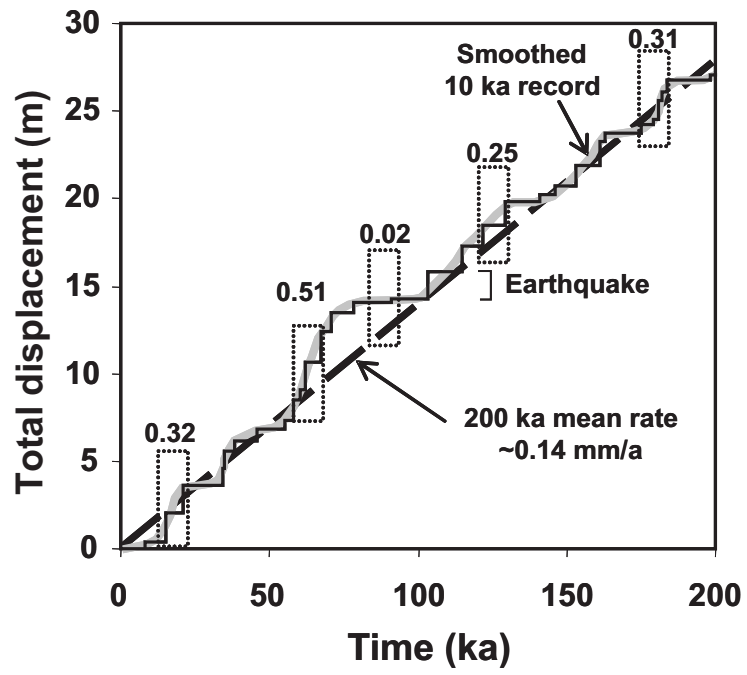


Figure 4