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1 ***Subducted seafloor relief stops rupture in***  
2 ***South American great earthquakes:***  
3 ***Implications for rupture behaviour in the***  
4 ***2010 Maule, Chile earthquake.***

5 ***Robert Sparkes, Frederik Tilmann, Niels Hovius***  
6 ***and John Hillier***

7

8 **ABSTRACT**

9 **Great subduction earthquakes cause destructive surface**  
10 **deformation and ground shaking over hundreds of kilometres.**  
11 **Their rupture length is limited by the characteristic strength**  
12 **of the subduction plate interface, and by lateral variations in**  
13 **its mechanical properties. It has been proposed that**  
14 **subduction of topographic features such as ridges and**  
15 **seamounts can affect these properties and stop rupture**  
16 **propagation, but the required relief and physical mechanisms**  
17 **of topographic rupture limitation are not well understood.**  
18 **Here we show that the rupture limits of thirteen historic great**  
19 **earthquakes along the South America-Nazca plate margin are**  
20 **strongly correlated with subducted topography with relief**  
21 **>1000m, including the Juan Fernandez Ridge. The northern**  
22 **limit of rupture in the  $M_w$ 8.8 Maule, Chile earthquake of 27**  
23 **February 2010 is located where this ridge subducts. Analysis**  
24 **of intermediate-magnitude earthquakes shows that in most**  
25 **places the subduction of high seafloor relief creates weak,**

26 **aseismic zones at the plate interface, which prevent rupture**  
27 **propagation, but that the Juan Fernandez Ridge is associated**  
28 **with a locally strong plate interface. The maximum rupture**  
29 **length, and thus magnitude, of great subduction earthquakes**  
30 **is therefore determined by the size and lateral spacing of**  
31 **topographic features where they are present on the**  
32 **subducting plate.**

### 33 ***Introduction***

34 The amount of displacement in an earthquake is commonly  
35 proportional to its rupture length (Wells and Coppersmith, 1994). This  
36 determines the area that can be affected by strong ground motion  
37 and surface deformation and, where relevant, the amplitude and  
38 length scale of associated tsunamis. In most earthquakes, rupture  
39 termination is likely to be determined by the energy available for  
40 rupture tip propagation along a plane with relatively uniform  
41 properties, but for larger potential rupture planes, there is an  
42 increased likelihood that mechanical properties vary along the plane.  
43 Mechanical heterogeneities could impede rupture tip propagation, or,  
44 alternatively, serve as rupture nucleation points. If indeed they exist,  
45 these effects may be expected to be most prominent for the largest  
46 earthquakes, and they could give rise to segmentation of very long  
47 seismogenic fault zones.

48 Globally, great megathrust earthquakes ( $M_w \geq 8.0$ ) accommodate the  
49 majority of shortening along subduction margins. They repeatedly  
50 rupture the same margin segments (Beck *et al.*, 1998, Comte *et al.*,  
51 1986), with lengths exceeding the ~100 km width of the seismogenic

52 zone. There are indications that rupture termination in great  
53 subduction earthquakes could be forced by along-strike variation of  
54 properties of the plate interface (Kelleher and McCann, 1976, Sladen,  
55 2009, Bilek, 2010, in press, Loveless *et al.*, 2010, in press). For  
56 example, coincidence of some rupture areas of great subduction  
57 earthquakes with large negative forearc gravity anomalies along  
58 subduction margins has been attributed to localized strong plate  
59 interface friction (Song and Simons, 2003, Llenos and McGuire, 2007),  
60 and rupture areas have been found to coincide with forearc basins,  
61 possibly the surface expression of subduction erosion (Wells *et al.*,  
62 2003, Ranero and von Huene, 2000). However, such forearc features  
63 can depend on as well as influence the frictional properties along the  
64 plate interface, making it difficult to establish the direction of  
65 causality.

66 Incoming seafloor structures have long been suspected to have an  
67 influence on plate interface structure (Cloos, 1992, Scholz and Small,  
68 1997, Bilek *et al.*, 2003). Notably, rupture in the 1946 earthquake  
69 along the Nankai trough was deflected around a subducting seamount  
70 (Kodaira *et al.*, 2002). This may have been caused by an increase of  
71 normal stress, and hence seismic coupling, on the subducted  
72 topography (Scholz and Small, 1997), or by the formation of a weak,  
73 aseismic area where strain cannot build up (Bilek *et al.*, 2003).  
74 Regardless of the mechanism, in the case of subducted seafloor  
75 topography the direction of causality is unambiguous. If a correlation  
76 between the location of subducted seafloor topography and the  
77 extent of earthquake ruptures can be demonstrated then it is clear  
78 that the former has influenced the latter by affecting the frictional

79 properties of the plate interface. Although many previous studies  
80 have noted the apparent coincidence of incoming seamount chains  
81 and earthquake segmentation, the statistical significance of these  
82 observations has hitherto not been tested, nor is it clear how large a  
83 seamount chain has to be before it can (co-)determine rupture  
84 segmentation.

85 Acknowledging the fact that several other factors may affect rupture  
86 propagation along a subduction plate interface, we have sought to  
87 isolate and determine the strength and nature of the role of  
88 subducted topography in rupture termination in great earthquakes,  
89 and the critical size of subducted topography. We have done this by  
90 exploring the randomness or otherwise of the collocation of  
91 extrapolated seafloor relief, great earthquake rupture limits and  
92 patches of subduced background seismicity along the Pacific margin of  
93 South America between 12°S and 47°S. On this margin, the Nazca  
94 Plate moves eastward at ~65 mm/yr relative to, and is subducted  
95 under South America (Angermann *et al.*, 1999). Large sections of the  
96 Nazca Plate have smooth seafloor with topographic relief <200 m, but  
97 elsewhere seamount chains with varying relief of up to 3.5 km are  
98 carried into the subduction trench, enabling a quantitative exploration  
99 of the effect of subducting topography on seismicity. Since 1868, 15  
100 great earthquakes have occurred along the Nazca margin (See Fig. 1  
101 and Table 1), including the largest recorded earthquake,  $M_w$ 9.5 in  
102 1960. These earthquakes had rupture lengths from 150 to 1,050 km.  
103 On 27 February 2010, a ~600 km section of the Nazca margin  
104 ruptured in the  $M_w$  8.8 Maule earthquake. Here, we demonstrate that  
105 the sustained subduction of seafloor features with relief in excess of

106 ~1.0 km has systematically stopped rupture in these historic great  
107 earthquakes on the Nazca margin. We argue that in most cases  
108 rupture termination is due to the creation of weak, aseismic zones in  
109 the plate interface. In addition, we explore the possible causes of  
110 rupture termination in the 2010 Maule earthquake. It has not been our  
111 intention to carry out a global survey of subduction margins, but  
112 although the critical height of subducted topography may vary  
113 between settings, its role in stopping earthquake rupture is likely to  
114 be similar along the Nazca margin and elsewhere.

### 115 ***Constraints on Rupture Zones and Subducting*** 116 ***Topography***

117 Subduction zone earthquakes with  $M_w < 8.0$  tend to rupture distances  
118 less than 100 km and their rupture zones have aspect ratios close to  
119 one. As 100km is comparable to the width of the seismogenic zone,  
120 the endpoints of these major but not great earthquakes cannot tell us  
121 whether there are features along strike that may have stopped their  
122 rupture. Whilst some  $M_w$  7-7.9 earthquakes have ruptured larger  
123 distances, in the interest of consistency we have restricted our study  
124 to  $M_w > 8.0$ , as these great events should all have ruptured the plate  
125 interface over more than 100 km in the trench-parallel direction,  
126 making it possible to identify parts of the plate interface that may  
127 have acted as a barrier or nucleation point for earthquake rupture.  
128 Earthquakes with  $M_w < 8.0$  will be considered in the discussion section.

129 The anecdotal record of very large earthquakes along the Nazca  
130 margin stretches back to at least 1575 (Cisternas *et al.*, 2005), but  
131 events before 1868 are insufficiently documented to determine the

132 extent of their rupture zones in any detail. Since that year, 15  
133 earthquakes with estimated moment magnitude  $M_w \geq 8.0$  have  
134 occurred on the margin. For events prior to 1973, rupture zones have  
135 been determined from damage intensity and co-seismic subsidence  
136 (Kelleher, 1972, Spence *et al.*, 1999, Cisternas *et al.*, 2005), and we  
137 have used published estimates (see Table 1), with the exception of the  
138 1908  $M_w 8.0$  earthquake offshore Peru, which is insufficiently  
139 documented to be included in this study. After 1973, rupture zones  
140 can be constrained from aftershock locations (Wells and Coppersmith,  
141 1994, USGS NEIC catalog). We have done this for all recent great  
142 earthquakes, including the 2010 Maule event. Uncertainty in the  
143 mapping of rupture zones is due to the gradual decrease of slip  
144 toward the rupture tip, and the imperfect correlation between the  
145 rupture zone and the distribution of aftershocks, seismic intensities  
146 and co-seismic subsidence. The resulting uncertainty is less than 50  
147 km (Kelleher, 1972), and rupture limits determined from aftershock  
148 observations match other published rupture area estimates (Comte *et*  
149 *al.*, 1986, Delouis *et al.*, 1997, Sobesiak, 2000, Tavera *et al.*, 2002) to  
150 within 40 km. Our findings are therefore not sensitive to the exact  
151 method of defining rupture zones, and this uncertainty cannot be  
152 easily reduced for historical earthquakes.

153 Seafloor topography was constrained from the TOPEX global seafloor  
154 bathymetry dataset (Smith and Sandwell, 1997), which is created  
155 from satellite altimetry. This dataset was chosen for its consistent  
156 derivation of the depth both along the margin and in the open ocean,  
157 and for its inclusion of seamounts unmeasured by sonic soundings,  
158 but the accuracy of seamount heights may be  $\pm 100$  m or more (Marks

159 and Smith, 2007). We have calculated seafloor relief by taking the  
160 difference between the depth at a point and the mean depth of the  
161 seafloor within a radius of  $3^\circ$ , which is generally  $\sim 4000$  m. The Nazca  
162 Plate has prominent topographic features with positive relief  $>400$  m,  
163 including the Nazca Ridge (Spence *et al.*, 1999), which has relief of up  
164 to 3500 m, and several seamount chains with approximately linear  
165 trends for  $>500$  km extending to the subduction zone. Assuming  
166 some continuity of seamount chain formation through time, it is likely  
167 that associated topography has already subducted and interfered with  
168 the plate interface. However, independent evidence of subducted  
169 relief (Kodaira *et al.*, 2002) only exists in isolated locations such as the  
170 subducted Papudo seamount along the extension of the Juan  
171 Fernandez Ridge (von Huene *et al.*, 1997). Where we have found three  
172 or more topographic features with relief above a threshold value to  
173 align we have extrapolated their assumed linear trend into the  
174 subduction zone, taking into account offsets on known fracture zones.  
175 Moreover, we have assumed that in this case a topographic feature of  
176 a magnitude similar to that of the visible seafloor topography has  
177 already entered the subduction zone. The validity of this assumption  
178 can only be tested with targeted seismic surveys. The shallow dip of  
179 the seismogenic plate interface,  $\sim 18^\circ$  on average (Tichelaar and Ruff,  
180 1991), makes a correction for dip unnecessary near the plate  
181 boundary. Positive relief on the Nazca seafloor was contoured at 200  
182 m intervals upward of 400 m, and contours were extrapolated into the  
183 subduction zone by projecting the widest parts of identified  
184 topography. Likely locations of subducted relief are shown in Figures 1  
185 and 2.



186 ***Collocation of subducted topography and***  
187 ***earthquake rupture endpoints***

188 Rupturing in historical great earthquakes repeatedly arrested at 32°S  
189 and 15°S, on the subducted Juan Fernandez Ridge (JFR) and the Nazca  
190 Ridge respectively (Fig. 2). These ridges comprise the largest positive  
191 relief on the Nazca Plate. Other rupture limits are associated with  
192 subducted topography at 20°S, 25°S and 47°S. Specifically, 11 out of  
193 the 26 rupture limits in well documented great earthquakes were  
194 within 40 km of a zone with inferred subducted relief >1000 m,  
195 although only ~22% of the studied margin is within this distance.  
196 Whilst it has been possible for great earthquake ruptures to be  
197 located entirely between zones with high subducted relief (e.g., the  
198 1939 event at 35° - 37°S), rupture zones generally do not appear to  
199 have crossed subducted relief >1000 m, with only one exception, the  
200 1922 event which traversed an assumed obstruction at 28°S.

201 To test the statistical significance of our observations, we have  
202 compared the distribution of historical rupture zones with simulated  
203 patterns of rupture zones along the margin. Using a Monte Carlo  
204 approach, and observing that even in the absence of any subducted  
205 relief rupture limits from neighbouring earthquakes tend to collocate,  
206 forming subduction zone segments (Beck *et al.*, 1998), we have  
207 concatenated the rupture lengths of the thirteen sufficiently  
208 constrained historical earthquakes (not including the 2010 Maule  
209 earthquake), locating the first earthquake randomly along the South  
210 American margin, and repeating 2000 times. Two scenarios,  
211 representing end-member hypotheses for earthquake-topography  
212 interaction, were applied. In the first, 'unconstrained' scenario,

213 subducted topography has no effect on rupture propagation. In this  
214 scenario, the next rupture in a sequence was started at the limit of  
215 the preceding earthquake.

216 This process was repeated to link 13 rupture zones, with rupture zone  
217 limits lying in nearby-pairs. The total length of this group exceeds the  
218 length of the margin along which the actual earthquakes occurred,  
219 due to overlap of ruptures over the record interval. Simulated rupture  
220 limits outside the geographic range of the historic earthquakes (12°S  
221 – 47°S) were discarded, and equal coverage along the margin was  
222 maintained. Note that proximity of rupture limits is a feature shared  
223 by most, but not all actual earthquake rupture zones (see Figure 2).  
224 Pairs of neighbouring rupture ends are a natural consequence of a  
225 segmented subduction zone in which earthquakes do not generally  
226 have overlapping rupture zones, irrespective of the mechanism of the  
227 segmentation.

228 In the second, 'constrained' scenario, rupture was stopped by  
229 subducted relief of a given minimum size  $H_{min}$ . The next earthquake  
230 rupture zone was located immediately beyond this relief. Relocated  
231 rupture limits were scattered at random within 50 km of the  
232 restricting topographic feature to represent the uncertainty of the  
233 actual observations. The alternative that earthquake rupture starts  
234 rather than stops on high subducted topography is not explored in  
235 detail for reasons given in the discussion, below.

236 If subduction of high standing seafloor topography has an effect on  
237 earthquake rupture propagation, then this effect may act some  
238 distance from the subducted feature, and the apparent width of a

239 feature varies with  $H_{min}$ . To account for this, and for the uncertainty in  
240 the rupture endpoint location, we have varied the search distance  $S_D$   
241 within which earthquake rupture endpoints are deemed to be  
242 associated with subducted topography. For a given search distance  $S_D$   
243 and  $H_{min}$ , the simulation routine was repeated 2,000 times, generating  
244 a total of 26,000 earthquakes. The number of rupture limits for a  
245 specified  $S_D$  was normalized for comparison with the 26 limits of  
246 historic rupture zones.  $S_D$  was varied in steps of 5 km.  $H_{min}$  was varied  
247 in 200 m increments.

248 Historical data plot between the average results simulated for the  
249 constrained and unconstrained scenarios, and are close to the results  
250 of the constrained model at moderate relief, 800 – 1200 m, and  
251 search distances of 35 – 45 km (Fig. 3 a,b). This suggests that along  
252 the Nazca margin, features larger than 800 m commonly stop  
253 earthquake rupture propagation, and agrees with anecdotal  
254 observations.

255 An alternative test procedure, using earthquakes with  $M_w \geq 8.0$   
256 sampled randomly from the logarithmic Gutenberg-Richter  
257 relationship between earthquake magnitude and frequency rather  
258 than the historical earthquake catalogue, and assigning rupture area  
259 according to a common earthquake magnitude-length scaling law  
260 (Wells and Coppersmith, 1994), has yielded comparable results  
261 (supplementary information). A further alternative in which  
262 earthquakes were distributed individually rather than being linked  
263 together also produced equivalent findings.

## 264 ***Statistical significance of collocation***

265 The collocation of historical rupture limits with subducted topography  
 266 has not arisen by chance, according to a statistical significance test  
 267 based on the probability density function of the distribution of  
 268 simulated unconstrained earthquakes. In this test, we have  
 269 determined the probability  $P$  that the number of rupture limits located  
 270 within a given search distance  $S_D$  from subducted topography of a  
 271 given size  $H$  for randomly positioned, unconstrained earthquakes  
 272 exceeds the number of historical rupture limits that meet the same  
 273 criteria.

274 Our underlying assumption is that the number of rupture limits falling  
 275 randomly near topographic features ( $N_{uc}$ ) can be determined directly  
 276 from the unconstrained distribution of rupture zones. Within groups of  
 277 26 simulated earthquake limits ( $N_{total}$ ), those within a given distance of  
 278 subducted topography were counted, and their probability function  
 279  $\mathbf{P}(N_{uc} \geq N_{real})$  was determined. The probability of the unconstrained  
 280 simulation ( $N_{uc}$ ) having at least as many rupture limits near significant  
 281 topography as the actual data ( $N_{real}$ ) is given by:

$$282 \quad \mathbf{P}(reproduced) = \mathbf{P}(N_{uc} \geq N_{real}) = \sum_{n=N_{real}}^{n=N_{total}} \mathbf{P}(N_{uc} = n)$$

283 Figure 3c shows a diagonal region in  $S_D - H_{min}$  space in which  
 284 correlation is strongest between relief and rupture endpoints. This is  
 285 because increasing  $S_D$  and  $H_{min}$  concurrently causes the same area of  
 286 the margin to be considered. The minimum relief at which subducted  
 287 features affect the location of rupture limits is equivalent to the lowest  
 288 relief within this domain of significant correlation. At this relief the

289 number of subducted topographic features included is maximal, and  
290  $S_D$  smallest, without adverse effect on the correlation.

291 For  $H > 1000$  m and  $S_D = 40$  km, rupture limits and subducted  
292 topography are significantly correlated, with  $P = 1.4$  % (Fig. 3c). Note  
293 that no features have a maximum positive relief between 800 m and  
294 1200 m. This limits the precision with which we can define critical  
295 relief for rupture collocation. Relief  $> 1000$  m admits the same number  
296 of subducted features as  $> 800$  m, but the additional width of features  
297 caused by using the lower threshold does not increase the amount of  
298 collocation.

299 Subducted relief  $< 800$  m does not appear to stop or start earthquake  
300 rupture propagation. The Nazca plate has much topography with relief  
301 of 400 - 800 m, but at  $S_D = 40$  km,  $P = 4.3$  % for  $H > 800$  m, whereas  
302  $P$  increases to 28 % for  $H > 400$  m, indicating the absence of  
303 significant correlation at this relief threshold. Nevertheless,  
304 subduction of topography  $< 800$  m may still affect the slip distribution  
305 in particular earthquakes (Kodaira *et al.*, 2002).

## 306 **Discussion**

307 Collocation of subducted topography and rupture limits could arise  
308 from rupture initiation or termination. Assuming that the epicenter  
309 location denotes the initiation of rupture, it can be determined  
310 whether topography starts or stops great earthquakes. Six out of  
311 thirteen studied earthquakes had epicenters within 40 km of  
312 topography with  $H > 1000$  m, whilst  $\sim 22$  % of the margin lies within  
313 this distance (See Fig. 2). The chance of this occurring at random is 22

314 %, according to an analysis of the synthetic distribution of epicenters,  
315 equivalent to the analysis of endpoints summarized above. This  
316 correlation is much weaker than the match between rupture endpoints  
317 and topography. None of the six events have rupture zones which  
318 cross subducting topography, but in all rupture has extended away  
319 from the topography. Hence, the subduction of seafloor relief >800-  
320 1000 m is likely to impede or stop earthquake rupture, even if rupture  
321 nucleated on or near to that topography.

322 In the absence of significant subducting topography, earthquake  
323 rupture may be stopped by other factors, either structural (e.g.  
324 forearc structure or geometry of the slab) or because there is  
325 insufficient release of energy to propagate the rupture tip, even in the  
326 absence of any structural changes. In fact, for all of the 14  
327 earthquakes considered here at least one of the endpoints was not  
328 close to subducted topography.

329 Effective and continued rupture arrest by subduction of high standing  
330 seafloor topography may require topographic features to be spaced at  
331 less than the width of the seismogenic zone. Along the Nazca margin,  
332 the width of this zone is ~100 km. Greater separation between  
333 topographic features of sufficient size within an alignment could leave  
334 gaps in the barrier to rupture propagation. This may be the case for  
335 the seamount chain at 28°S where features with relief >1000 m are  
336 up to 200 km apart. Its trend was crossed by the 1922 great  
337 earthquake, the only such traverse on record.

338 According to our findings it is likely that there is a causal link between  
339 subducted topography and great earthquake rupture limits. Along-

340 margin rupture could be stopped by subducted topography either  
341 because it forms a strongly coupled patch within the seismogenic  
342 zone (Scholz and Small, 1997), too strong to break in the rupture, or  
343 because it forms a weak, aseismic patch (Bilek *et al.*, 2003) which has  
344 no stored strain to release. Assuming that the long-term rate of  
345 shortening is uniform along the subduction margin, the local strength  
346 of the plate interface affected by subduction of topography may be  
347 reflected in the seismic moment release between great earthquakes,  
348 when these patches are expected to catch up with slip elsewhere  
349 along the margin. Strong patches are likely to have a relatively high  
350 rate of seismic moment release in small and intermediate size  
351 earthquakes in these intervals. Weak patches cannot accumulate  
352 elastic strain and are expected to have subdued background  
353 seismicity.

354 We have calculated the cumulative moment release between great  
355 earthquakes over 35 years since 1973, including all shallow,  
356 intermediate size earthquakes (depth < 50 km,  $M_w$  5.0-7.9) within a  
357  $0.5^\circ$  moving window, but excluding aftershocks within two months of  
358 a great earthquake, as well as the largest intermediate event in each  
359 zone, which results in a more robust estimate (Frohlich, 2007) (Fig. 2).  
360 Five of six locations along the margin with subducted topography  
361 >1000 m have low background moment release. Instead, substantial  
362 background moment release tends to be concentrated at great  
363 earthquake rupture limits away from subducted topography, showing  
364 that segment boundaries do have residual strain and that subducting  
365 topography changes the way in which this is released. The anti-  
366 correlation of tall subducted topography and maxima of intermediate

367 seismicity indicates that this topography usually acts to weaken the  
368 plate interface, promoting aseismic deformation and hence impeding  
369 earthquake rupture along the margin. Weak interplate coupling  
370 associated with subducted topography has been observed for the  
371 Nazca Ridge (Perfettini *et al.*, 2010) and in Japan (Mochizuki *et al.*,  
372 2008).

### 373 **2010 Mw 8.8 Maule, Chile Earthquake**

374 Along the Nazca margin there is one exception to the collocation of  
375 subducted, high seafloor topography and minimum background  
376 seismicity. At 32°S, potentially very tall (>2 km) subducted  
377 topography of the JFR coincides with a peak in background seismicity  
378 (Fig. 2). This location is of special interest because it is where  
379 northward rupture propagation in the 2010 Maule earthquake  
380 arrested. The hypocenter of this earthquake was located offshore at  
381 35.8°S, 72.7°W, at an estimated depth of ~38 km, with a thrust  
382 mechanism, striking at 18°N, parallel to the margin and dipping 18° to  
383 the east (USGS NEIC Catalog). Aftershock locations indicate that the  
384 earthquake ruptured the Nazca margin over a length of ~600 km (Fig.  
385 1), occupying a known seismic gap (Ruegg *et al.*, 2002). Along the  
386 South American margin, its rupture length was exceeded in historical  
387 times only in the 1960  $M_w$  9.5 earthquake. Rupture extended  
388 northward to 33.1°S, overlapping the 1906 and 1985 rupture zones  
389 and stopping within 22 km of the subducted JFR. Although this is  
390 consistent with our finding that subducted topography >1,000 m is  
391 likely to stop rupture propagation, we believe that it is the presence of  
392 a strong patch in the plate interface, borne out by high intermediate



393 seismicity at this location, rather than the weakening effect of  
394 subduction of seafloor topography that has arrested northward  
395 rupture propagation in 2010. Uniquely, this is also the location of a  
396 subducted fracture zone, a change in the gradient of the subducted  
397 slab (Barazangi and Isacks, 1976), and a transition from a sediment  
398 filled to starved trench with an associated change from subduction  
399 accretion to subduction erosion (Bangs and Cande, 1997). High  
400 background moment release at 32°S, and the elevated plate interface  
401 strength it implies are likely to be the compound effect of all these  
402 factors, indicating that the weakening effect of subduction of high  
403 seafloor topography can be drowned out by strengthening due to  
404 other asperities.

405 Rupture in the Maule earthquake propagated southward to 38.6°S,  
406 unimpeded by significant subducted topography. At its southern limit,  
407 the 2010 rupture area overlaps the northern edge of the 1960 rupture  
408 area, indicating that the earlier earthquake may not have released all  
409 stress in this area. The southern rupture limit coincides with a large  
410 peak in background seismicity, a pattern found in at least eight  
411 historic great earthquakes on the Nazca margin (Fig. 2).

## 412 ***Conclusions***

413 Along the South American Nazca margin rupturing in great  
414 earthquakes is likely to be impeded by subducted topography with  
415 positive relief >1000 m, engaged in the seismogenic part of the plate  
416 interface. In general, this appears to be due to mechanical weakening  
417 of the plate interface, thus preventing the buildup of stresses required  
418 for the propagation of very large earthquakes. This effect may require

419 the actual presence of a topographic feature within the seismogenic  
420 zone, and could dissipate after the feature has been transported  
421 through this zone. On the subducted Juan Fernandez Ridge it may be  
422 overprinted by other factors that have strengthened the plate  
423 interface sufficiently to arrest rupturing in the 2010 Maule earthquake.  
424 Along margin sections with subducted relief <800 m, rupturing in  
425 historical great earthquakes has been unimpeded. The length of such  
426 sections may impose an upper bound on the possible earthquake size,  
427 limiting hazard in some places. If this is true, then the largest  
428 earthquakes between the intersections of the Nazca and Juan  
429 Fernandez ridges and the South America plate margin will have rupture  
430 lengths no larger than 550 km (equivalent  $M_w$ 9.1). In contrast, rupture  
431 could be unimpeded between the JFR and the Chile Rise, over a length  
432 of 1,450 km, enabling an earthquake rupture 33% longer than in the  
433 1960  $M_w$ 9.5 event on this segment of the Nazca margin.

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570 **Figure 1: Historic great subduction earthquakes along Pacific margin of**  
571 **South America. Where epicenters plot outside identified rupture zones, this**  
572 **is likely due to inaccuracies in locating earthquakes before the global**  
573 **installation of seismometers. Areas with more than 1000 m relief are**  
574 **marked on shaded seafloor topography. Black dots and lines show the**  
575 **inferred location of subducted topographic highs, grey regions show the**  
576 **area within 50 km of these highs. Inset: Detailed view of the area of the 27**  
577 **February 2010 Maule earthquake. Red dots show aftershocks between**  
578 **February 27 and March 8, with size scaled by magnitude.**

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581 **Figure 2: Latitudinal distribution of seismicity and subducted relief**  
582 **along Nazca margin. Earthquake rupture zones and epicenters are shown as**  
583 **black bars and white stars, respectively; thin black line is seismic moment**  
584 **release in  $M_w < 8.0$  earthquakes at depths less than 50 km since 1973 ( $0.5^\circ$**   
585 **moving windows). Also shown are areas with inferred subducted seafloor**  
586 **relief, binned at 200 m vertical intervals. Grey bars mark areas with likely**  
587 **subducted relief  $> 1000$  m, transposed to the upper axes for comparison. An**  
588 **exception to separation of relief and moment release is the JFR at  $32^\circ\text{S}$ .**

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590 **Figure 3: Relation between (inferred) subducted seafloor relief and**  
591 **rupture limits in actual and simulated earthquake distributions. Circles**  
592 **show limits of 13 actual earthquake ruptures. Triangles and squares show**  
593 **results for simulations in which rupture limits are/are not constrained by**  
594 **subducted seafloor features, respectively. Synthetic results are based on**  
595 **2000 runs with 13 earthquakes each. A) Number of earthquake limits within**  
596 **search distance from (inferred) subducted seafloor relief >1000 m. B)**  
597 **Number of earthquake ruptures within 40 km of (inferred) subducted**  
598 **seafloor relief of varying size. Error bars denote the inter-quartile range of**  
599 **the synthetic results. Note how the plot of observed earthquake rupture**  
600 **limits approaches that of topographically constrained, synthetic ruptures.**  
601 **C) Probability of the observed correlation of earthquake rupture limits and**  
602 **subducted seafloor relief being reproduced by chance by an unconstrained**  
603 **synthetic distribution. Strongest topography – rupture limit correlation**  
604 **(marked in white) occurs between 1000 - 1600m relief and 40 - 80km search**  
605 **distance. The diagonal nature of the domain with low  $P$  is due to a trade-off**  
606 **between relief and area searched; increasing relief narrows admitted**  
607 **topographic features, reducing the area searched for a given  $S_D$ .**  
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