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

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ABSTRACT

Great subduction earthquakes cause destructive surface deformation and ground shaking over hundreds of kilometres. Their rupture length is limited by the characteristic strength of the subduction plate interface, and by lateral variations in its mechanical properties. It has been proposed that subduction of topographic features such as ridges and seamounts can affect these properties and stop rupture propagation, but the required relief and physical mechanisms of topographic rupture limitation are not well understood. Here we show that the rupture limits of thirteen historic great earthquakes along the South America-Nazca plate margin are strongly correlated with subducted topography with relief >1000m, including the Juan Fernandez Ridge. The northern limit of rupture in the M_w8.8 Maule, Chile earthquake of 27 February 2010 is located where this ridge subducts. Analysis of intermediate-magnitude earthquakes shows that in most places the subduction of high seafloor relief creates weak,

aseismic zones at the plate interface, which prevent rupture

propagation, but that the Juan Fernandez Ridge is associated

with a locally strong plate interface. The maximum rupture

length, and thus magnitude, of great subduction earthquakes

is therefore determined by the size and lateral spacing of

topographic features where they are present on the

subducting plate.

Introduction

The amount of displacement in an earthquake is commonly

proportional to its rupture length (Wells and Coppersmith, 1994). This

determines the area that can be affected by strong ground motion

and surface deformation and, where relevant, the amplitude and

length scale of associated tsunamis. In most earthquakes, rupture

termination is likely to be determined by the energy available for

rupture tip propagation along a plane with relatively uniform

properties, but for larger potential rupture planes, there is an

increased likelihood that mechanical properties vary along the plane.

Mechanical heterogeneities could impede rupture tip propagation, or,

alternatively, serve as rupture nucleation points. If indeed they exist,

these effects may be expected to be most prominent for the largest

earthquakes, and they could give rise to segmentation of very long

seismogenic fault zones.

Globally, great megathrust earthquakes ($M_w \geq 8.0$) accommodate the

majority of shortening along subduction margins. They repeatedly

rupture the same margin segments (Beck *et al.,* 1998, Comte *et al.,*

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

3

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 subdued 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_w9.5 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 ≥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_w8.0 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 ±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°, which is generally ~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, ~18° 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.

Collocation of subducted topography and earthquake rupture endpoints

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

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

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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   $P(N_{uc} \geq N_{real})$ 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:

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

282

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 ~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° 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

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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

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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   Fernadez ridges and the South America plate margin will have rupture

430   lengths no larger than 550 km (equivalent $M_w9.1$). 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 $M_w9.5$ 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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580

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°**

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°S.**

589

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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