

¹ **The Relationship between Seismicity and Fault
2 Structure on the Discovery Transform Fault, East
3 Pacific Rise**

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4 Abstract. There is a global seismic moment deficit on mid-ocean ridge
5 transform faults, and the largest earthquakes on these faults do not rupture
6 the full fault area. We explore the influence of physical fault structure, in-
7 cluding step-overs in the fault trace, on the seismic behavior of the Discov-
8 ery transform fault, 4S on the East Pacific Rise. One year of microseismic-
9 ity recorded during a 2008 ocean bottom seismograph deployment (24,377
10 $0 \leq M_L \leq 4.6$ earthquakes) and 24 years of $Mw \geq 5.4$ earthquakes obtained
11 from the Global Centroid Moment Tensor catalog, are correlated with sur-
12 face fault structure delineated from high-resolution multibeam bathymetry.
13 Each of the 15 $5.4 \leq Mw \leq 6.0$ earthquakes that occurred on Discovery be-
14 tween January 1, 1990 - April 1, 2014 was relocated into one of five distinct
15 rupture patches using a teleseismic surface wave cross-correlation technique.
16 Microseismicity was relocated using the HypoDD relocation algorithm. The
17 western fault segment of Discovery (DW) is composed of three zones of vary-
18 ing structure and seismic behavior: a zone with no large events and abun-
19 dant microseismicity, a fully coupled zone with large earthquakes, and a com-
20 plex zone with multiple fault strands and abundant seismicity. In general,
21 microseismicity is reduced within the patches defined by large, repeating earth-
22 quakes. While the extent of the large rupture patches on DW correlates with
23 physical features in the bathymetry, step-overs in the primary fault trace are
24 not observed at patch boundaries, suggesting along-strike heterogeneity in
25 fault zone properties controls the size and location of the large events.

1. Introduction

26 The Discovery transform fault, located at 4S on the East Pacific Rise (EPR, Fig. 1),
27 is ideal for investigating the relationship between seismic processes and fault structure.
28 Discovery is a segmented transform fault, comprising two fault strands separated by an
29 intra-transform spreading center. Both fault strands contain multiple repeating-rupture
30 patches that host Mw 5.4 - 6.0 earthquakes [McGuire, 2008]. Discovery was the site of a
31 2008 ocean bottom seismometer (OBS) deployment, as well as two high-resolution multi-
32 beam bathymetry surveys in 2006 and 2008. The bathymetry data enables the surface
33 structure of the fault trace of Discovery to be delineated on a sub-km scale, while the OBS
34 data provides a high-resolution seismic database. These two datasets, combined with a
35 24-year record of seismicity obtained from the global Centroid Moment Tensor (CMT)
36 catalog [Dziewoński *et al.*, 1981; Ekström *et al.*, 2012], are used to investigate whether
37 fault structure influences seismic behavior along the segmented Discovery transform fault.

38 Discovery is representative of a typical mid-ocean ridge transform fault (RTF) in that
39 the size and repeat time of the largest observed earthquakes scale with the seismogenic
40 area of the fault [Boettcher and Jordan, 2004; Boettcher and McGuire, 2009]. The largest
41 observed earthquakes on Discovery (Mw 6.0) are small compared to the full fault area and
42 repeatedly rupture the same patch of the fault (Fig. 2) [McGuire, 2008; Boettcher and
43 McGuire, 2009]. Multiple large rupture patches occur on each fault segment and these
44 patches fail when an accumulation of \sim 50 - 100 cm of tectonic slip has been reached
45 since the last large event, corresponding to a mean repeat time of 5.8 years [McGuire,
46 2008]. While the majority of plate motion on RTFs is accommodated aseismically [Bird

⁴⁷ *et al.*, 2002; *Boettcher and Jordan*, 2004], the largest events on many intermediate and
⁴⁸ fast-slipping RTFs occur on fully coupled fault patches [*Braunmiller and Nábělek*, 2008;
⁴⁹ *McGuire*, 2008; *Boettcher and McGuire*, 2009; *Sykes and Ekström*, 2012] separated by
⁵⁰ rupture barriers with low seismic coupling [*McGuire*, 2008; *McGuire et al.*, 2012].

⁵¹ In 2008, *McGuire et al.* [2012] positioned an OBS array consisting of 30 broadband
⁵² seismometers (10 collocated with strong-motion accelerometers) and 10 short-period seis-
⁵³ mometers on the Quebrada, Discovery, and Gofar transform fault system (QDG) on the
⁵⁴ EPR for a period of approximately 1 year (Fig. 1), and successfully captured an Mw 6.0
⁵⁵ earthquake on the westernmost segment (G3) of Gofar on September 18, 2008. In the two
⁵⁶ weeks prior to this event, more than 20,000 foreshocks were recorded on the OBS array
⁵⁷ [*McGuire et al.*, 2012]. These foreshocks clustered in a 10-km long zone located just east
⁵⁸ of the mainshock rupture patch. To the east of the foreshock zone is another rupture
⁵⁹ patch, which last failed in 2007 (Mw 6.2). Neither the 2008 nor the 2007 earthquakes
⁶⁰ appear to have ruptured across the foreshock region and into the adjacent patch. These
⁶¹ observations indicate that there are regions of the fault that act both as barriers to large
⁶² rupture propagation as well as loci for abundant microseismic activity, suggesting that the
⁶³ mechanical properties of the fault zone (the fault core and/or damage zone) vary along
⁶⁴ strike [*McGuire et al.*, 2012].

⁶⁵ On continental strike-slip faults, *Wesnousky* [2006] found that fault step-overs on the
⁶⁶ order of 5 km in width act as physical barriers to rupture propagation. Along RTFs,
⁶⁷ compressional or dilational step-overs, intra-transform spreading centers, and pull-apart
⁶⁸ basins can divide the fault into a series of parallel or sub-parallel fault segments [*Searle*,
⁶⁹ 1983] that may create barriers to rupture propagation. On Gofar, there appears to be a

70 small jog in the fault trace at the western terminus of the foreshock zone, corresponding
71 to a compressional bend at depth as evidenced by the microseismicity [McGuire *et al.*,
72 2012; Froment *et al.*, 2014]. The coincidence of this feature with the location of the barrier
73 zone suggests that it may influence rupture propagation.

74 In this study, we examine the relationship between surface fault structure and the lo-
75 cation and size of repeating-rupture patches, as well as the spatial relationship between
76 rupture patches and microseismicity on the Discovery transform fault. We use two multi-
77 beam bathymetry datasets, SeaBeam 2012 data collected in 2006 (grid resolution: 200 m)
78 and EM300 data collected in 2008 (grid resolution: 75 m), to delineate the fault trace on a
79 sub-km scale and relate the bathymetry to the locations of large ($M_w \geq 5.4$) earthquakes
80 that have occurred from 1992 to 2013 and microseismicity ($0 \leq M_L \leq 4.6$) recorded on
81 Discovery during the 2008 OBS deployment. The goal of this study is to improve our
82 understanding of how plate motion is accommodated along oceanic transform boundaries
83 by investigating the influence of fault structure on the seismic behavior of the Discovery
84 transform fault.

2. Structure of the Discovery Transform Fault

85 The Discovery transform fault is a fast-slipping, left-lateral fault system composed of
86 two sub-parallel fault strands separated by an intra-transform spreading center [Searle,
87 1983] (ITSC; Figs. 1 & 3). The slip-rate on Discovery is ~ 12.6 cm/yr according to the
88 Global Strain Rate Model (GSRM v1.2) [Kreemer *et al.*, 2003]. In contrast to Gofar
89 and Quebrada, on Discovery there is a distinct lack of fracture zones beyond the ridge-
90 transform intersections, and Discovery's strike (~ 95 degrees) forms an obtuse angle with
91 the EPR. These observations are consistent with findings from earlier studies suggesting

92 that the plate geometry of the QDG fault system is still evolving [Fox and Gallo, 1989;
93 Forsyth *et al.*, 2007; Pickle *et al.*, 2009]. The segments of Discovery are both defined by
94 median valleys, and include dilational features (nodal basins and the ITSC) consistent
95 with a component of extension across Discovery caused by the obtuse angle between
96 Discovery and the EPR.

97 The western fault segment of Discovery (DW) is 36 km long and is defined by three
98 distinct structural zones (Figs. 3b & 3c). Zone A, the westernmost zone, is composed
99 of a narrow and well-defined (300 - 500 m wide) fault valley extending from the ridge-
100 transform intersection to 7 km along strike. Heading east, the fault valley broadens into
101 two consecutive lozenge-shaped basins that comprise zone B. The first basin is 4 km long,
102 2 km wide, and ~600 m deep relative to the surrounding seafloor. A small, 0.75-km wide
103 ridge separates this basin from the larger, 7.5-km long, 2.5-km wide basin to the east
104 (purple arrow, Fig. 3b). Here the strike of the fault trace changes from approximately
105 east-west to more west-northwest to east-southeast. This larger basin is the deepest part
106 of DW, ~900 m below the surrounding seafloor, and is terminated at its eastern extent
107 by a 3.5-km wide ridge that crosscuts the transform valley (yellow arrow, Figs. 3b & 3c).
108 Zone C, the third structural zone, begins east of this ridge, where there is a series of 3 - 5
109 km long en echelon ridges (pink arrow, Fig. 3b), which may be small fault strands making
110 up a splay zone. This series of ridges is bounded to the south by the primary fault trace,
111 and to the north by a 17-km long secondary fault trace.

112 The eastern fault segment of Discovery (DE) is composed of a single 27-km long fault
113 zone that progressively widens from a narrow, well-defined fault trace at the ITSC into
114 a broad, 4.5-km wide nodal basin along the inside corner of the eastern ridge-transform

115 intersection (Figs. 3b & 3c). The deepest part of DE occurs within the nodal basin and is
116 ~1,150 m below the surrounding seafloor (Fig. 3c). Small changes in strike (< 15°) occur
117 along DE; the most notable of which are found where the fault zone begins to widen ~8
118 km east of the ITSC and where it enters the nodal basin ~15 km east of the ITSC.

119 The bathymetric expression of the ITSC separating the two segments of Discovery is
120 broad and flat, with an average base width of 6 km and an average crest width of 1.4
121 km (Fig. 3). The offset distance between the primary fault traces of DW and DE is
122 ~8 km; however, the total length of the ITSC is 14 km. The excess length results from
123 sigmoidal shape of the ITSC, which may be due to fissure eruptions creating volcanic
124 ridges extending at acute angles to the spreading direction, similar to the Joseph Mayes
125 seamount on the Southwest Indian Ridge [Dick *et al.*, 2003]. Discovery's ITSC comprises
126 a region of thickened crust [Pickle *et al.*, 2009], reaching a height of 700 m above the
127 surrounding seafloor. It is anomalous compared to the ITSCs of Quebrada and Gofar,
128 which are defined by axial valleys, such as those generally associated with slow-spreading
129 ridges. Pickle *et al.* [2009] used gravity data along with the Seabeam 2112 bathymetry
130 dataset to infer crustal thickness throughout the QDG region. They found that the
131 ITSCs on Quebrada and Gofar are well-established spreading centers, defined by a thin
132 crust, variable melt supply, and depressed thermal structure. Conversely, the ITSC on
133 Discovery recently developed as the fault changed configuration, and may represent a
134 region of constructive volcanism over a pre-existing plate.

135 The 70-km long ridge segment of the EPR linking Discovery with Gofar to the south is
136 relatively narrow (1.5 - 5 km) and has a shallow axial high consistent with observations
137 from many fast-spreading ridges, e.g., *Small* [1998] and *Shah and Buck* [2001] (Fig. 3).

¹³⁸ The intersection between this ridge segment and DW (feature a, Fig. 3b) is characterized
¹³⁹ by an “axis-centered” intersection high [Barth *et al.*, 1994]. Similar morphology has
¹⁴⁰ been observed at the RTIs of other transform faults on the EPR, including Clipperton
¹⁴¹ [Gallo *et al.*, 1986; Barth *et al.*, 1994], Quebrada [Lonsdale, 1978], and Raitt [Lonsdale,
¹⁴² 1994], and is thought to result from some combination of lateral heat transport across
¹⁴³ the fracture zone leading to thermal expansion [Gallo *et al.*, 1986; Phipps Morgan and
¹⁴⁴ Forsyth, 1988], and constructive/intrusive volcanism due to excess ridge volcanism [Gallo
¹⁴⁵ *et al.*, 1986; Kastens *et al.*, 1986].

¹⁴⁶ The 35-km long EPR segment connecting Discovery with Quebrada to the north is
¹⁴⁷ characterized by a 5-km wide spreading center and a 200 - 300-m deep axial valley (Fig.
¹⁴⁸ 3). Given the fast spreading rates associated with the EPR, the presence of a median
¹⁴⁹ valley along this ridge segment is unexpected. Pickle *et al.* [2009] attributes this to the
¹⁵⁰ possibility that a portion of the extension between the Pacific and Nazca plates along this
¹⁵¹ ridge segment may be accommodated by the formation of grabens and dike injections to
¹⁵² the west, effectively reducing the spreading rate along the ridge [Forsyth *et al.*, 2007].

¹⁵³ Directly north of the ITSC on Discovery, there is an \sim 850-km² region of complex,
¹⁵⁴ discordant terrain (Fig. 3). Rotated crustal blocks containing oblique abyssal hill fabric
¹⁵⁵ (features b1 & b2, Fig. 3b) are present within this region, and suggest a counterclockwise
¹⁵⁶ rotation of \sim 45 degrees [Forsyth *et al.*, 2007]. This region is bounded to the west (104.3W)
¹⁵⁷ by a 7-km wide rift, or pull-apart basin (feature c, Fig. 3b), that extends 35 km northeast
¹⁵⁸ of Discovery. A set of ridges (feature d, Fig. 3b) that trend roughly north-south and
¹⁵⁹ bound the rift to the west is truncated to the northwest by abyssal hill fabric (feature e,
¹⁶⁰ Fig. 3b) that cuts across the ridges at an angle of \sim 45 degrees. The rift progressively

161 deepens and curves slightly inwards towards the northeast at its northern extent. Stair-
162 stepped morphology along the flanks of seamounts (white circles in Fig. 3b) within the
163 rift indicates normal faulting. The morphology of the rift, specifically the deepening
164 and inward curvature of the tip, is strikingly similar to the secondary rifts bounding
165 the Wilkes nanoplate [Goff *et al.*, 1993] located at 9S on the EPR, the Easter Island
166 microplate [Naar and Hey, 1991] located at 25S on the EPR, and the Juan Fernandez
167 micro plate [Bird *et al.*, 1998] located at 33S on the EPR. An apparent abandoned rift
168 segment (feature f, Fig. 3b) located northwest of the rift, overprints the oblique abyssal
169 hill fabric west of this region, suggesting that the abyssal hills predate the rotation and
170 formation of this complex region. Small ridges and troughs bound this region to the
171 north and east. Similar ridges and troughs are observed at the Wilkes nanoplate, where
172 the free-air gravity anomaly suggest these features are formed, in part, by compressional
173 upwarping and downwarping of the crust [Goff *et al.*, 1993]. The similarity between
174 the morphology of the deformed region just north of Discovery and that at the Wilkes
175 nanoplate suggests a similar mechanism of formation.

3. Repeating-Rupture Patches

176 To determine the role fault structure plays in controlling the location and size of rupture
177 patches on Discovery, it was first necessary to determine absolute locations for the large
178 repeating earthquakes because location errors of up to \sim 50 km are common for mid-ocean
179 earthquakes in global seismic catalogs [Sverdrup, 1987; Cronin and Sverdrup, 2003].
180 Following the relative surface-wave relocation technique described in McGuire [2008],
181 earthquakes detected by the National Oceanic and Atmospheric Administration (NOAA)
182 hydroacoustic catalog were used as empirical Greens Functions (EGFs) to determine the

¹⁸³ absolute location for an Mw 5.5 earthquake in 1998. This event was subsequently used
¹⁸⁴ to estimate the absolute centroid locations of all other $Mw \geq 5.4$ events that occurred
¹⁸⁵ between 1992 and 2013 using relative surface-wave arrival times.

¹⁸⁶ The hydroacoustic earthquake catalog is compiled by NOAA's Pacific Marine Envi-
¹⁸⁷ ronmental Laboratory (PMEL) using data from a suite of hydrophone arrays, which were
¹⁸⁸ deployed in the eastern equatorial Pacific between 19 May 1996 and 19 October 2002 (Fig.
¹⁸⁹ 1). The hydrophones record the tertiary waves (T-wave or T-phase) of earthquakes, i.e.,
¹⁹⁰ the seismic energy of an earthquake that leaves the seafloor and travels through the water
¹⁹¹ column as an acoustic wave. While uncertainties associated with T-phase source locations
¹⁹² are small inside the hydroacoustic array (< 2 km) [Fox *et al.*, 2001], this location does
¹⁹³ not necessarily represent the true epicenter or centroid of the earthquake, but rather the
¹⁹⁴ point at which most of the seismic energy leaves the oceanic crust and is converted into
¹⁹⁵ acoustic energy. To avoid location bias that may be introduced by topographic steering
¹⁹⁶ [Fox *et al.*, 2001; Smith, 2003], only events located on or near the fault trace, away from
¹⁹⁷ topographic highs were used in this analysis.

¹⁹⁸ Thirteen events located by the hydroacoustic catalog were used to relocate the 1998 Mw
¹⁹⁹ 5.5 earthquake that ruptured a fault patch centrally located on Discovery, just west of the
²⁰⁰ ITSC. Events from the hydroacoustic catalog were chosen on the basis of their magnitude
²⁰¹ ($Mw \geq 4.4$) and location (events > 5 km off the fault trace or located on a topographic
²⁰² high were excluded). Each of these earthquakes was used as an EGF to compute a relative
²⁰³ location for the 1998 Mw 5.5 event using a cross-correlation of the first orbital Rayleigh
²⁰⁴ (R1) waves. The nucleation depth for earthquakes on RTFs is thought to be constrained
²⁰⁵ by the 600°C isotherm [Abercrombie and Ekström, 2001; Boettcher *et al.*, 2007], which is

206 relatively shallow for fast-slipping transforms on the EPR (≤ 6 km). The relative depth
 207 and distance between each EGF and the 1998 Mw 5.5 event (< 25 km) is small compared
 208 to the teleseismic distance between the events and the Global Seismic Network (GSN)
 209 stations (> 1000 s km); therefore, path effects between the EGF and the master event
 210 are assumed negligible. Seismicity in the NOAA hydroacoustic catalog is predominantly
 211 associated with transform faults, indicating that the focal mechanisms for these events
 212 should correspond to strike-slip motion on near-vertical faults [Fox *et al.*, 2001]. Given the
 213 similarity in location and focal mechanism, the R1 arrivals from the EGF and the target
 214 event are expected to have similar waveforms at the GSN stations. The primary differences
 215 between the two waveforms at a specific station are phase and amplitude, corresponding
 216 to differential arrival time and relative seismic moment respectively [McGuire, 2008].

217 For each event, seismograms were obtained from a set of GSN stations that are az-
 218 imuthally distributed around Discovery (Fig. 1). The data were bandpass filtered between
 219 0.02 to 0.04 Hz to isolate the R1 arrivals, as this bandwidth has a high signal-to-noise
 220 ratio and constant group velocity (3.7 km/s) for R1 waves in young oceanic lithosphere
 221 [Nishimura and Forsyth, 1988]. Waveform pairs with a cross-correlation coefficient ≥ 0.7
 222 were used to compute the relative distance between events. The differential times were
 223 measured from the peak of the cross-correlation function and obvious outliers (> 3 stan-
 224 dard deviations from the mean) were removed. The remaining differential times were then
 225 fit to a cosine function using the L1 norm to minimize the effect of any outliers that fell
 226 below the 3 standard-deviation cutoff. The scale and phase parameters of the cosine fit
 227 were used to obtain a relative distance and azimuth between the EGF and the master
 228 event (Fig. 4). As in McGuire [2008], standard errors were computed for the parameters

229 of the cosine fit using a bootstrap algorithm and assuming a gaussian distribution with
230 a 1-sec standard deviation for the differential travel-time measurement errors. The errors
231 were calculated as the standard deviation in location estimates after 100 iterations. Each
232 event pair resulted in a single estimated location for the 1998 Mw 5.5 earthquake; these
233 estimations were averaged to obtain the best estimate of the absolute centroid position
234 (Table 1; Fig. 5a). Three of the thirteen event pairs resulted in either a poor cosine fit, or
235 a location estimate that was more than 5 km off the fault, and their estimated locations
236 were not included in the average.

237 Three of the 10 events from the hydroacoustic catalog that were used in the relocation
238 of the 1998 Mw 5.5 earthquake were also recorded in the CMT catalog. To ensure no
239 circularity was introduced into our location procedure, we compared the location of the
240 1998 event obtained from averaging all 10 estimated locations with that obtained from
241 averaging only estimated locations based on the 7 events unique to the hydroacoustic
242 catalog. The location estimate based on the 7 events is \sim 0.5 km east of the location
243 estimate based on all 10 earthquakes. The estimated absolute location of an event becomes
244 more precise as the number of relative position estimates averaged together increases
245 (uncertainty reduces by a factor of $1/\sqrt{N}$). A discrepancy of 0.5 km is within the reduced
246 uncertainty of our averaged location (\sim 0.6 km), and is therefore not significant.

247 The 1998 Mw 5.5 event was then used as an EGF to estimate the absolute positions
248 for the remaining 14 Mw \geq 5.4 earthquakes on Discovery recorded in the CMT catalog
249 between 1992 and 2013 (Table 2, Fig. 5b). Each relocated event fell into one of five distinct
250 patches; three on the DW (patches DW1, DW2, DW3) and two on DE (patches DE1, DE2)
251 (Fig. 6). These rupture patches, defined as areas on the fault where overlapping ruptures

(centroids ≤ 5 km apart) repeatedly occur, include the four patches initially identified by McGuire [2008] and one additional patch with earthquakes in 2005 and 2012 (dark green circles in Fig. 2). There was an Mw 5.6 earthquake in 1991 that may have ruptured either DW2 or DW3, but there were too few reliable stations to compute a robust location.

Mean rupture lengths were estimated for each rupture patch using:

$$R_L = \left(\frac{M_{0avg}}{\Delta\sigma} \right)^{2/3} Z^{-1} \quad (1)$$

where M_{0avg} is the averaged seismic moment release of all earthquakes belonging to that patch, $\Delta\sigma$ is the static stress drop that is assumed to be constant at 3 MPa [Allmann and Shearer, 2009; Boettcher and McGuire, 2009], and Z is the maximum depth of rupture that is assumed to be 5 km, consistent with the mean depth of the microseismicity on Discovery and Gofar [McGuire et al., 2012]. To obtain equation 1, we follow Boettcher and Jordan [2004] and assume average earthquake slip, D , scales as the square root of the rupture area, A , as $D = \Delta\sigma\mu^{-1}A^{1/2}$. Combining the equation for D with the equation for seismic moment ($M_0 = \mu AD$, where μ , the shear modulus, is 44.1 GPa, the value obtained for the lower crust from the Preliminary Earth Reference Model (PREM) [Dziewonski and Anderson, 1981] gives us equation 1.

Rupture patch DW1 has an estimated length of 10 km and is the largest patch on Discovery, hosting Mw 5.9 - 6.0 earthquakes (Fig. 6). Rupture patch DW2 is located ~ 5 km east of patch DW1 and hosts Mw 5.5 - 5.8 earthquakes with an estimated rupture length of ~ 6 km. The smallest rupture patch on Discovery is DW3, located just west of the ITSC. DW3 has a length of ~ 3 km and fails in Mw 5.4 - 5.5 events.

The calculated locations for the two 5-km long rupture patches on DE (patches DE1 and DE2) are just south of the fault trace (Fig. 6). Patch DE1 is located 9 km east of the

273 ITSC and is \sim 2 km south of the transform valley. Patch DE2, the easternmost rupture
274 patch, is located \sim 3 km south of the fault valley. This is likely due to event mislocation.
275 Figure 5b shows the location uncertainty associated with each earthquake relocated in
276 this study, calculated using the bootstrap method. For both patches, the fault trace is
277 within the computed location uncertainty. There is additional uncertainty associated with
278 the velocity structure underlying Discovery. The relocation scheme assumes an R1 wave
279 velocity value that is representative of young oceanic lithosphere and does not take into
280 account localized variations. While the path effects between the EGF and the event being
281 relocated is typically considered negligible compared to the path effects between the events
282 and the GSN stations, it is possible that there is some unknown local variation, particularly
283 underlying the ITSC, that is significant enough to affect the relocation scheme. These
284 uncertainties, combined with the lack of fault structure south of the eastern segment in
285 the bathymetry data suggest that patch DE1 and DE2 actually lie on the eastern fault
286 trace.

4. Microseismicity

287 The 2008 OBS deployment on the QDG fault system recorded 24,377 earthquakes (0.16
288 $\leq M_L \leq 4.58$, magnitude of completeness for DW: 0.9 & DE: 2.0) on Discovery between
289 January 1 and December 31. There were no large repeating earthquakes on Discovery
290 during the deployment period. The Antelope software package was used to generate an
291 earthquake catalog from the OBS data using standard short-term average to long-term
292 average (STA/LTA)-based detection algorithms [Houliston *et al.*, 1984] for P-waves and
293 wavelet-based detections [Simons *et al.*, 2006] for S-wave arrivals (see Supplementary
294 Information for detailed methodology). On DW, the majority of earthquakes in the catalog

295 cluster within 5 km of the primary fault trace (gray circles, Fig. 7). Earthquakes extend
 296 outside both the western RTI (Fig. 7; Area I) and eastern ITSC-intersection (Fig. 7;
 297 Area II). There is a 2-km long zone located at \sim 104.5W on the western fault segment in
 298 which very few earthquakes occurred (Fig. 7; Area III). A small cluster of earthquakes is
 299 located on the crustal block just north of the possible splay zone (\sim 104.22W). On DE,
 300 which is outside the OBS array, the majority of recorded earthquakes cluster north of the
 301 transform valley within 16 km of the ITSC.

302 Earthquakes in the Antelope-generated catalog were relocated using the HypoDD
 303 double-difference algorithm [*Waldhauser and Ellsworth, 2000*] to estimate more robust
 304 positions. The microseismicity was divided into 7 overlapping groups, subset by longi-
 305 tude (Fig. 7). Groups 1 - 4 cover DW, group 5 is centered on the ITSC, and groups 6
 306 and 7 cover DE. The earthquakes within group 7 were located $>$ 20 km outside of the
 307 OBS array and were not relocatable. Only earthquakes that had detections on 5 or more
 308 stations (minimum of 10 associated P and S arrivals) were used in the relocation analysis
 309 (17,017 events). Differential arrival times were calculated via waveform cross-correlation
 310 for P and S waves. A window of 2.56 seconds centered on the arrival was extracted from
 311 each waveform, and subsequently tapered and bandpass filtered between 5 - 12 Hz for S
 312 waves and 5 - 15 Hz for P waves. Event pairs required a minimum of 6 differential time
 313 observations per pair with a cross-correlation coefficient \geq 0.75. Catalog arrival times
 314 were not used due to the higher uncertainty associated with the increased percentage of
 315 mis-identified phases. The relocation of events within groups 1 - 4 were based on a mini-
 316 mum of 9 observations per event pair, as these groups fall within, or directly adjacent to,
 317 the OBS array. Relocations for events within groups 5 and 6 were based on a minimum

318 of 8 and 6 observations per pair, respectively, as these groups are located increasingly
319 farther outside the OBS array. A one-dimensional version of the P-wave velocity model
320 developed by *Roland et al.* [2012] for the Gofar transform fault was used. The Vp/Vs
321 ratio of 1.87 was obtained by fitting a linear least squares regression to differential S-wave
322 versus P-wave arrival times for the two stations located on the fault trace (D01 & D07;
323 Figs. 1 & 8). This Vp/Vs ratio is on the upper end of the expected range from studies of
324 oceanic crustal rocks [*Christensen*, 1972; *Anderson*, 1989; *Barclay et al.*, 2001] and may
325 reflect localized high porosity, as was interpreted by *Roland et al.* [2012] and *McGuire*
326 *et al.* [2012] for Gofar.

327 A total of 12,635 earthquakes out of the original 17,017 ($\sim 74\%$) were successfully relo-
328 cated using the HypoDD algorithm (pink circles in Fig. 7). For events located inside the
329 overlapping region of two groups, final location estimates were obtained by averaging the
330 relocated positions (median difference in position estimates from all overlapping groups is
331 ~ 1.8 km). The large cluster of events on DE tightens up slightly, but remains predomi-
332 nantly located north of the fault trace. These events fall outside the OBS array, thus their
333 locations are less certain than those on DW. Along DW, the location of the microseis-
334 micity tightened up along the fault trace so that 95% of events were within 3 km of the
335 fault trace. The latitudinal spread of the microseismicity is likely due to a combination
336 of unaccounted for location uncertainty and the occurrence of events in the damage zone
337 surrounding the fault core (e.g., *Valoroso et al.* [2014]). Microseismic activity extends
338 ~ 4.5 km outside the western RTI and ~ 9 km beyond the ITSC intersection. The region
339 of reduced seismicity in Area III is more distinct in the relocated catalog. Earthquakes on

³⁴⁰ either side of this region have moved outward relative to their initial locations, forming a
³⁴¹ gap within which there is no microseismicity at all.

³⁴² Perhaps the most striking observation is the extension of microseismic activity beyond
³⁴³ the western RTI and ITSC-intersection (Areas I & II; Fig. 7); such activity is not observed
³⁴⁴ on the neighboring Gofar transform fault. Although seismic activity has been observed
³⁴⁵ along the fracture zones of other RTFs, these events are primarily associated with shorter-
³⁴⁶ lived aftershock sequences related to mainshocks that occurred on the active transform
³⁴⁷ [Bohnenstiehl *et al.*, 2004] or complex stress regimes related to the Mendocino Triple
³⁴⁸ Junction [Sverdrup, 1987]. On Discovery, the extension of microseismicity beyond the
³⁴⁹ active fault boundaries occurs throughout the entire deployment period. Comparison of
³⁵⁰ waveform arrivals between a few of the events located west of the RTI and events located
³⁵¹ on the active western fault segment suggest that these events do occur outside the RTI
³⁵² and are not mislocated (see Supplementary Information). The extension of events beyond
³⁵³ the endpoints of DW is in line with the general trend of seismicity on the active fault
³⁵⁴ trace and with the strike of the fault itself, suggesting that events in Areas I and II (Fig.
³⁵⁵ 7) may be related to the propagation of fracture zones. The change in the strike of the
³⁵⁶ microseismicity from approximately east-west to more northwest-southeast coincides with
³⁵⁷ the change in strike of the active fault trace, and indicates that the surface fault trace
³⁵⁸ reflects aspects of the fault structure at depth. The inflection point in the strike of the
³⁵⁹ microseismicity appears to lie within the 3-km long microseismic gap (Area III; Fig. 7).
³⁶⁰ This gap appears to be real (see Supplementary Information), reflecting an area of the
³⁶¹ fault that was completely locked during the OBS deployment. McGuire and Collins [2013]

³⁶² used seafloor geodesy to show that within millimeter-level precision, this part of the fault
³⁶³ was indeed locked during 2008.

5. Discussion

³⁶⁴ The relationship between seismicity and fault structure in zones A and B on DW (Fig.
³⁶⁵ 9) is strikingly similar to what is observed on the western end of the G3 segment of the
³⁶⁶ Gofar transform fault, also studied during this experiment (Figs. 1 & 2) [McGuire *et al.*,
³⁶⁷ 2012; Froment *et al.*, 2014]; where strongly coupled fault patches are separated by zones
³⁶⁸ of abundant microseismicity that do not appear to rupture in the large earthquakes. Zone
³⁶⁹ A on Discovery comprises the narrow, well-defined fault trace that extends from the RTI
³⁷⁰ eastward \sim 7 km along the fault. This zone appears to be a barrier to large ruptures as
³⁷¹ there are no $M_w > 5$ earthquakes recorded in this region over the 45 year span of the CMT
³⁷² catalog (see Fig. 2 for the past 24 years), although the CMT catalog is only complete
³⁷³ down to M_w 5.4 for QDG. Zone A is structurally and mechanically comparable to western
³⁷⁴ end of G3 [McGuire *et al.*, 2012; Froment *et al.*, 2014], which is also relatively narrow,
³⁷⁵ well-defined, devoid of large events, and contains abundant microseismicity. On both
³⁷⁶ faults, the western RTI is defined by an intersection high that spills over onto the older
³⁷⁷ plate with prominent abyssal hill fabric. Microseismicity on westernmost G3 appears to
³⁷⁸ split into two branches, suggesting that the fault zone in this region may be composed of
³⁷⁹ two sub-parallel fault strands [Froment *et al.*, 2014].

³⁸⁰ Zone B encompasses the largest repeating-rupture patch on Discovery, DW1, which is
³⁸¹ located in the deepest portion of the fault within the two adjacent lozenge-shaped valleys.
³⁸² The gap in the microseismicity is located within zone B, coinciding with the centroid
³⁸³ location of patch DW1 (Fig. 9). The lack of microseismicity in the large rupture patch

384 is consistent with the accumulation of a slip deficit between earthquakes and supports
385 the interpretations that the patch is fully coupled. The extent of rupture patch DW1
386 corresponds to the narrowing and shallowing of the transform valley as it exits the two
387 consecutive valleys at either end of zone B. The eastern extent of DW1 also coincides
388 with the 3.5-km wide cross-transform ridge (yellow arrow, Fig. 3b). Mechanically, zone B
389 on DW is comparable to segment 2 on G3, which includes the rupture patch that hosted
390 the 2008 Mw 6.0 earthquake [Froment *et al.*, 2014]. Microseismicity within the Mw 6.0
391 rupture patches on G3 during the interseismic period is minimal [McGuire *et al.*, 2012],
392 similar to DW1.

393 The clear pattern observed on both western G3 and western DW, where a large rupture
394 patch is confined by small-scale bathymetric features and surrounded by zones of low
395 seismic coupling and high rates of microseismicity, is not observed in zone C on DW.
396 Zone C is the most complex region of Discovery. The highest density of microseismicity,
397 two repeating-rupture patches, DW2 and DW3, and a zone of small en echelon ridges that
398 extend from the cross-transform ridge to the ITSC are all located within zone C (Fig. 9).
399 The high concentration of microseismicity within zone C coincides with the location of
400 DW2, suggesting very different behavior to that observed for DW1 and the G3 rupture
401 patches. It is possible that the secondary fault trace and some of the small en echelon
402 fault strands are active in addition to the primary fault trace, and may accommodate
403 some of the microseismicity in this zone. There is a small cluster of earthquakes between
404 patches DW2 and DW3. Patch DW3 contains some microseismicity, though some of this
405 seismicity may be associated with activity on the ITSC.

406 The majority of the microseismicity on DW locates in the crust shallower than 6 km
407 (Fig. 9b), as expected from the short transform fault length and fast slip rate on Discovery,
408 consistent with observations on Gofar [McGuire *et al.*, 2012]. While some microseismicity
409 in Figure 9b appears to extend well into the upper mantle, these depths are not well
410 constrained due to insufficient station spacing. The depth resolution is poorest outside of
411 the array, where the deepest seismicity is shown.

412 On both G3 and DW, small structural features on the order of 0.5-km or greater coincide
413 with some of the rupture patch boundaries. On G3, there appears to be an ~600-m wide
414 step-over in the fault trace at the western end of the foreshock zone that separates the
415 two large repeating-rupture patches. This step-over coincides with a 600-m long bend
416 in the trend of the microseismicity as it exits the foreshock zone [Froment *et al.*, 2014].
417 On DW, the structural features that correlate with the extents of the rupture patches do
418 not appear to offset the primary fault trace in the cross-transform direction, though the
419 ability to detect such offsets is limited by the resolution of the bathymetry data (75 - 200
420 m).

421 Observations from both Discovery and Gofar suggest that step-overs in the fault trace
422 are not required for a structural feature to act as a barrier to rupture propagation. Small
423 structural features, including step-overs in the fault trace, may be associated with an
424 increased damage zone width or intensity. Enhanced fracturing in the damage zone may
425 allow for increased porosity and subsequent dilatant strengthening during large events,
426 providing a mechanism for halting rupture propagation. Increased porosity has been
427 invoked to explain the observed decrease in P-wave velocities in the foreshock zone on G3
428 in the weeks leading up to the Mw 6.0 mainshock [McGuire *et al.*, 2012; Roland *et al.*,

429 2012; *Froment et al.*, 2014]. Dilatant step-overs in the fault trace have been observed
 430 to stop rupture on continental strike-slip faults [Sibson, 1987; *Harris and Day*, 1993;
 431 *Wesnousky*, 2006], through a process thought to involve extensional fracturing at the
 432 rupture tip, leading to reduction in fluid pressure and subsequent dilatant strengthening
 433 [Sibson, 1987]. Compressional step-overs may also stop rupture due to an increase in
 434 the mean and normal stresses acting on the fault [Harris and Day, 1993; *Wesnousky*,
 435 2006]. In both cases, field observations on continental strike-slip faults [Knuepfer, 1989;
 436 *Wesnousky*, 2006] agree with dynamic rupture models [Harris and Day, 1993] and indicate
 437 a step-over of \sim 5 km will stop rupture propagation. Furthermore, *Harris and Day* [1993]
 438 found that in dynamic rupture models, the dimension of fault step required to stop rupture
 439 was dependent on rupture velocity and stress drop. For subshear rupture-velocities and
 440 stress drops of 3 MPa, compressional and dilatational step-overs were found to stop rupture
 441 at dimensions less than 1-km.

442 Even with the complexity in zone C, all but one of the structural features in the fault
 443 trace that we are able to resolve (Fig. 3) correlate with either the boundary of a large
 444 earthquake rupture patch or are the foci of abundant microseismicity (Fig. 9). Rupture
 445 patch DW2 is bounded to the west by the narrowing of the possible splay zone as it
 446 approaches the cross-transform ridge. The eastern terminus of DW2 may be associated
 447 with one of the en echelon faults that make up the possible splay zone. Patch DW3
 448 is the smallest rupture patch on Discovery and is located just west of the ITSC. The
 449 eastern end of DW3 extends to the ITSC-intersection. The length scale of segmentation
 450 derived from the structural complexity in zone C matches the length of rupture patches
 451 DW2 and DW3. The only feature that is not observed to correlate with either the end of

452 a repeating-rupture patch or abundant microseismicity is the small, 0.75-km wide ridge
453 that separates the two lozenge-shaped valleys located near the center of the DW1 rupture
454 patch in zone B.

455 The relationship between fault structure and seismicity on the eastern segment of Dis-
456 covery is not well-constrained. DE is composed of a single fault valley that progressively
457 widens from a narrow, well-defined fault trace near the ITSC to a broad, deep nodal basin
458 approaching the eastern RTI. DE hosts two repeating-rupture patches, DE1 and DE2, as
459 well as a cluster of microseismicity located just north of the fault trace (Fig. 9). The OBS
460 network did not cover DE, which significantly increased the magnitude of completeness
461 and reduced the location accuracy of the recorded microseismicity. In addition, the 1998
462 Mw 5.5 event used to relocate the large, repeating earthquakes was located on DW. It is
463 possible that the velocity structure under the ITSC may have influenced the relocation
464 procedure, and thus reduced the accuracy of the large events locations on DE compared
465 with DW. Acknowledging the uncertainty in the large event locations, it appears that
466 DE1 occurs along the part of the fault that is still relatively narrow and well-defined,
467 while DE2 is located within the nodal basin.

468 Evidence of stress-transfer can be seen in 3 sets of $Mw \geq 5.4$ earthquakes that occur
469 minutes apart in adjacent patches. On August 23, 1996, DW2 hosted a Mw 5.8 earthquake
470 \sim 23 minutes after a Mw 5.9 earthquake ruptured DW1. The same pattern repeated on
471 December 17, 2012, with only \sim 6 minutes between events. On July 23, 2007, DW3
472 ruptured in a Mw 5.5 earthquake \sim 3 minutes prior to a Mw 5.6 rupture on patch DW2.
473 In all 3 cases, the second earthquake was located about 1 - 2 rupture lengths from the

⁴⁷⁴ first, and patch DW2 was the last to rupture. These observations suggest that either
⁴⁷⁵ static or dynamic stress transfer may be an important triggering mechanism on DW.

⁴⁷⁶ *Liu et al.* [2012] modeled seismic cycles on RTFs using rate and state-dependent friction
⁴⁷⁷ to explore the relationship between earthquake behavior and global RTF scaling relations.
⁴⁷⁸ This model does not require along-fault heterogeneity in material properties in order to
⁴⁷⁹ satisfy the observed scaling relations of *Boettcher and Jordan* [2004] and *Boettcher and*
⁴⁸⁰ *McGuire* [2009], but it does require large nucleation zone sizes and an increase in the
⁴⁸¹ characteristic slip distance with fault width. The results of *Liu et al.* [2012] correspond to a
⁴⁸² multimode hypothesis of earthquake rupture [*Boettcher and Jordan*, 2004] in which a fault
⁴⁸³ patch transitions between seismic and aseismic slip over many earthquake cycles. In these
⁴⁸⁴ models, the large earthquakes jump around between cycles nucleating in different patches
⁴⁸⁵ of the fault until eventually the entire fault has ruptured. The $M_w \geq 5.4$ earthquakes
⁴⁸⁶ observed on Discovery and Gofar, however, repeatedly rupture the same fault patches
⁴⁸⁷ over the 24 years of the CMT catalog used in this study (Fig. 2), following the single-
⁴⁸⁸ mode hypothesis of *Boettcher and Jordan* [2004] and suggesting that rupture patches and
⁴⁸⁹ barriers remain stable over multiple seismic cycles. Therefore, along-strike heterogeneity
⁴⁹⁰ in fault properties is likely the cause of the slip deficit.

6. Conclusion

⁴⁹¹ This study examined the correlation between fault structure and seismic behavior on
⁴⁹² the Discovery transform fault, located at 4S on the East Pacific Rise. The western fault
⁴⁹³ segment of Discovery is composed of three distinct mechanical zones, including a zone
⁴⁹⁴ that acts as a barrier to large rupture propagation, with no large earthquakes and abun-
⁴⁹⁵ dant microseismicity, a fully coupled zone with large earthquakes, and a complex zone

496 with multiple fault strands and abundant seismicity. While fracture zone traces are not
497 evident in the bathymetry, microseismicity extends beyond the western RTI and the ITSC-
498 intersection, suggesting nascent fracture zone formation. The rotated block of complex
499 terrain centered immediately north of the ITSC may be an active nanoplate similar to that
500 just north of the Wilkes transform fault, and suggests a complex regional stress regime
501 surrounding Discovery. The obtuse angle of Discovery to the EPR combined with the lack
502 of fracture zones and extension of microseismicity beyond the active fault trace suggest
503 that Discovery is a relatively young and still evolving transform fault.

504 The primary focus of this study is whether or not structural features evident in the
505 bathymetry data, including small step-overs in the surface fault trace, are a controlling
506 factor in the size and location of the large, repeating-rupture patches. There are no step-
507 overs in the fault trace ≥ 1 km that coincide with the endpoints of the large rupture patches
508 on Discovery. Rupture patch boundaries do correlate with other structural features that
509 do not offset the fault trace, such as the 3.5-km wide cross-transform ridge and the small en
510 echelon faults, suggesting that step-overs greater than 1-km are not required to terminate
511 ruptures on RTFs. The large repeating-rupture patches are separated by 5 - 10 km long
512 regions that do not rupture in $Mw \geq 5.4$ earthquakes. The rate of microseismicity varies
513 strongly between the largest rupture patch (DW1) and the neighboring regions of the
514 fault zone, similar to what is observed on Gofar. These observations suggest that along-
515 strike heterogeneity in fault and damage zone properties partitions RTFs into regions that
516 either fail in large, repeating earthquakes or regions that act as barriers to large rupture
517 propagation and generate abundant microseismicity. It is these heterogeneities, rather
518 than any large (≥ 1 -km wide) step-over in the fault trace, that appear to limit the size of

519 the largest repeating earthquakes on RTFs, and prevent them from rupturing the whole
520 fault.

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Table 1. Hydroacoustic (t-phase) events used in the relocation of the 1998 Mw 5.5 event.

Dates and times are UTC.

| Event # | Lat | Long | Date | Time | Mw | Est. 1998 event Lat | Est. 1998 event Lon |
|---|---------|-----------|---------|----------|-----|---------------------|---------------------|
| 1 | -3.9970 | -104.3990 | 8/23/96 | 21:56:16 | 5.9 | -4.0269 | -104.2096 |
| 2 | -4.0070 | -104.2530 | 8/23/96 | 22:19:06 | 5.9 | -4.0353 | -104.1658 |
| 3 | -4.0120 | -104.0020 | 6/8/97 | 21:02:43 | 5.1 | -4.0253 | -104.1933 |
| 4 | -4.0180 | -103.9090 | 8/21/97 | 3:49:49 | 4.4 | -4.0090 | -104.1674 |
| 5 | -4.0360 | -103.9580 | 5/7/00 | 6:18:45 | 4.4 | -4.0281 | -104.1830 |
| 6 | -4.0170 | -104.2200 | 6/26/01 | 15:22:32 | 4.7 | -4.0331 | -104.1908 |
| 7 | -4.0150 | -103.9870 | 7/23/01 | 10:34:34 | 5.1 | -4.0050 | -104.1785 |
| 8 | -3.9810 | -104.0680 | 7/23/01 | 9:43:08 | 5.3 | -3.9833 | -104.2014 |
| 9 | -3.9930 | -104.0400 | 7/23/01 | 10:06:57 | 4.4 | -3.9875 | -104.1983 |
| 10 | -4.0290 | -103.9760 | 7/30/01 | 4:34:49 | 5.6 | -4.0168 | -104.2092 |
| Averaged centroid location for the 1998 Mw 5.5 event: | | | | | | -4.0150 | -104.1897 |

Table 2. Estimated centroid locations of the 15 Mw \geq 5.4 repeating earthquakes. Dates and times are UTC.

| Rupture Patch | Date | Time | Lat | Long | Mw |
|---------------|------------|----------|---------|-----------|-----|
| DW1 | 8/23/1996 | 21:56:13 | -4.0010 | -104.3893 | 5.9 |
| | 6/26/2001 | 12:34:00 | -3.9941 | -104.3887 | 6.0 |
| | 12/17/2012 | 17:41:37 | -4.0740 | -104.4068 | 5.9 |
| DW2 | 8/23/1996 | 22:19:04 | -3.9944 | -104.2616 | 5.8 |
| | 11/29/2001 | 17:07:06 | -4.0020 | -104.2634 | 5.5 |
| | 7/23/2007 | 6:03:55 | -4.0189 | -104.2644 | 5.6 |
| | 12/17/2012 | 17:46:50 | -4.0121 | -104.2726 | 5.8 |
| DW3 | 11/15/1998 | 4:51:49 | -4.0150 | -104.1897 | 5.5 |
| | 11/26/2003 | 17:32:55 | -4.0267 | -104.2022 | 5.4 |
| | 7/23/2007 | 6:00:38 | -4.0318 | -104.1867 | 5.5 |
| DE1 | 8/21/2005 | 9:49:54 | -4.0237 | -104.0647 | 5.8 |
| | 1/17/2012 | 15:27:52 | -4.0041 | -104.0649 | 5.4 |
| DE2 | 9/16/1995 | 22:49:22 | -4.0339 | -103.9733 | 5.6 |
| | 7/30/2001 | 4:34:50 | -4.0272 | -103.9565 | 5.6 |
| | 5/24/2009 | 9:57:16 | -4.0514 | -103.9591 | 5.7 |

Figure 1. Base map: 2006 SeaBeam 2112 bathymetry data of the Quebrada, Discovery, and Gofar transform faults. Fault segments are numbered following *Searle* [1983]. In the text, D1 and D2 are referred to as DE and DW for clarity. Data are gridded at a 200-m resolution. White circles, triangles, and stars respectively indicate the locations of the short-period, broadband, and broadband plus strong motion seismometers deployed during the 2008 OBS experiment. The star and triangle bordered in orange on Discovery represent stations D01 and D07, respectively. These two stations are referenced in section 4. The rectangle surrounding the Discovery transform fault delineates the area shown in figure 3. Inset: Smith and Sandwell global topography data (v 15.1, 2013) for the equatorial Pacific. Blue triangles indicate the location of GSN stations used in the relocation analysis. Black triangles indicate the positions of the NOAA PMEL hydroacoustic array during the 1996 - 2001 deployment. Discovery is indicated by the gold star.

Figure 2. Map and space-time evolution of $M_w \geq 5.0$ earthquakes on Quebrada, Discovery, and Gofar transform faults between Jan. 1, 1990 and March 1, 2014, modified from *McGuire* [2008] and *McGuire et al.* [2012]. All earthquakes (circles) are sized by magnitude. Events on Quebrada and Gofar are shown at their CMT catalog locations. Events on Discovery are shown at their relocated longitude, and are offset in latitude so that all events are visible on the map. Earthquakes with overlapping ruptures (defined as relative centroid locations <5 km, see McGuire 2008) are represented by circles of the same color. The vertical gray lines denote the location of mid-ocean ridge segments (thick lines) and intra-transform spreading centers (thin lines).

Figure 3. (a) Bathymetry of the Discovery transform fault and possible nanoplate. Foreground data: 75-m resolution EM300 multibeam bathymetry data collected in 2008. Background data: 200-m resolution SeaBeam 2112 multibeam bathymetry data collected in 2006. Both datasets use the same color scale. (b) Interpreted geology of the Discovery transform fault and possible nanoplate. a: axis-centered ridge-transform intersection high, b1 & b2: rotated crustal blocks, c: rift, d: north-south ridges, e: NE-SW trending abyssal hills, f: abandoned rift. The thick white line outlines the region of rotated terrain that comprises the possible nanoplate. Solid white lines denote apparent compressional ridges. Long-dashed white lines indicate extensional zones, arrows indicate direction of extension. Short-dashed white lines indicate possible faults that offset features. White dashed-dotted lines highlight abyssal hill fabric. Circles outline some of the seamounts in the area. Black solid lines show the location of the EPR on either end of Discovery and outline the intra-transform spreading center. Black long-dashed lines show the primary fault traces; short-dashed black line indicates the secondary trace on the western segment. Black dotted lines outline the two consecutive lozenge-shaped valleys on the western fault segment, and delineate the width of the fault valley. Orange arrow denotes direction of rotation of the nanoplate. (c) Cross-section with depth from DW - DW¹ of the western fault segment. (d) Cross-section with depth from DE - DE¹ of the eastern fault segment.

Figure 4. Relative relocation of the 1998 Mw 5.5 master event using a 2001 Mw 5.3 event located by the NOAA/PMEL hydroacoustic catalog as an EGF. (a) Aligned Rayleigh waves of the EGF (gray) and master event (black) filtered between 0.02 and 0.04 Hz at GSN stations. (b) Differential arrival times (gray) and best fit estimates from the cosine function (black). The master event is located 15 km from the NOAA/PMEL event, at an azimuth of 269 degrees.

Figure 5. (a) Relocation of the 1998 Mw 5.5 earthquake. Blue circles show the location of events from the NOAA/PMEL hydroacoustic catalog used to calculate relative positions for the 1998 event. Orange circles denote relative position estimates of the 1998 event. The orange polygons outline the uncertainty in each relative position estimated from the bootstrap algorithm described in the text. The orange star with the blue border represents the absolute centroid of the 1998 event obtained by averaging the relative relocations. (b) Relocation of the repeating Mw \geq 5.4 earthquakes in the CMT catalog. Stars represent the estimated centroid positions relative to the 1998 Mw 5.5 event. Polygons outline the estimated uncertainty in position. In both panels, the black lines denote the western and eastern fault traces of the Discovery transform (solid: primary, dashed: secondary).

Figure 6. (a) repeating-rupture patch locations on the Discovery transform fault. White stars denote the averaged location of earthquake centroids for each patch. Red lines represent the estimated rupture length centered on each centroid. The repeating earthquakes in each rupture patch are shown by their focal mechanism and year. (b) A zoomed in view of the fault structure and extent of the rupture patches on DW.

Figure 7. Microseismicity on the Discovery Transform Fault. Gray circles: STA/LTA catalog locations. Gray circles with orange border: Events from the STA/LTA catalog that were successfully relocated by HypoDD. Pink circles: Relocated positions. White solid lines denote the location of the EPR and outline the ITSC. White dashed lines indicate the width of the fault valley on both the western and eastern fault segments. Areas I, II, and III are described in the text.

Figure 8. The difference in S-wave first arrival times (y-axis) versus P-wave (x-axis) first arrival times for micro-earthquakes on DW recorded at stations D01 and D07 (see Fig. 1 for station locations). The red line represents a linear least squares regression to the data and is indicative of the Vp/Vs ratio in the lower crust between the two stations.

Figure 9. (a) Map-view of the seismicity on the Discovery transform fault. Red ellipses are centered on the rupture patch centroid locations and indicate rupture length. Microseismicity is represented as a density plot (boxes are 1-km by 1-km). White lines denote the primary (solid) and secondary (dashed) fault trace. Blue dashed lines denote the ridge segments and the ITSC. Gold stars represent the broadband seismometers and gold triangles indicate broadband seismometers with strong motion sensors. The density plot shows that the majority of recorded microseismicity occurs along the western fault segment. The highest density coincides with rupture patch 2, located in the splay zone. The seismic gap coincides with DW1, the largest rupture patch. (b) Cross-section along the western segment of Discovery showing a density plot of the microseismicity with depth for $b - b^1$. All microseismicity is projected into a single vertical plane. Boxes are 1-km by 1-km. Vertical gray lines indicate the location of the EPR and ITSC.