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47 **Normal fault kinematics and the role of lateral tip retreat:**
48 **An example from offshore NW Australia**
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60 **Key Points:**

- 61 • We document normal fault growth in the Exmouth Plateau, offshore Australia
- 62 • Faults follow a three-stage growth model: lengthening stage, throw accumulation stage,
63 tip retreat stage
- 64 • We suggest tip retreat may be an important stage of normal fault growth

65

66 **Abstract**

67 Understanding how normal faults grow is key to determining the tectono-stratigraphic evolution
68 of rifts and the distribution and size of potentially hazardous earthquakes. According to recent
69 studies, normal faults tend to grow in two temporally distinct stages: a lengthening stage,
70 followed by a throw/displacement accumulation stage. However, this model is still debated and
71 not widely supported by many additional studies. Relatively few studies have investigated what
72 happens to a fault as it becomes inactive, i.e. does it abruptly die, or does its at-surface trace-
73 length progressively shorten by so-called tip retreat? We here use a 3D seismic reflection dataset
74 from the Exmouth Plateau, offshore Australia to develop a three-stage fault growth model for
75 seven normal faults of various sizes, and to show how the throw-length scaling relationship
76 changes as a fault dies. We show that during the lengthening stage, which lasted <30% of the
77 faults' lives, faults reached their near-maximum lengths, yet accumulated only 10-20% of their
78 total throw. During the throw/displacement accumulation stage, which accounts for c. 30-75% of
79 the faults' lives, throw continued to accumulate along the entire length of the faults. All of the
80 studied faults also underwent a stage of lateral tip-retreat (last c. 25% of the faults' lives), where
81 the active at-surface trace-length decreased by up to 25%. The results of our study may have
82 broader implications for fault growth models, slip rate variability during fault growth, and the
83 way in which faults die, in particular the role of lateral tip-retreat.

84

85 **1 Introduction**

86 Normal fault growth models have been widely debated over the past c. 20 years. The
87 propagating fault model, also referred to as the isolated fault model (Walsh et al., 2003), suggests

88 that normal faults grow via a synchronous increase in length and displacement, i.e. that when
89 faults lengthen, they also accumulate displacement. Faults can also lengthen via tip propagation
90 and linkage of these individual segments (e.g. Cartwright et al., 1995; Dawers et al., 1993;
91 Morley et al., 1990; Walsh et al., 2003; Walsh & Watterson, 1988). The constant-length model
92 instead suggests that normal faults reach their near-final lengths relatively rapidly and spend the
93 rest of their lives accruing displacement without further significant lengthening (Childs et al.,
94 2017; Fossen & Rotevatn, 2016; Hemelsdaël & Ford, 2016; Henstra et al., 2015; Jackson and
95 Rotevatn, 2013; Nicol et al., 2005, 2016; Tvedt et al., 2016; Walsh et al., 2002, 2003; see also
96 Cowie et al., 1998). More recently, Jackson et al. (2017) and Rotevatn et al. (2019) used 3D
97 seismic reflection data and physical analogue models to propose a third model, the so-called the
98 ‘hybrid growth model’. This model states that the propagating fault model and the constant-
99 length models may not in fact be mutually exclusive, end-member models, but instead represent
100 discrete kinematic phases in the life of a single fault: i.e. an initial lengthening stage (propagating
101 fault stage) is followed by a later displacement accumulation stage (constant-length stage)
102 (Jackson et al., 2017; Rotevatn et al., 2019). During the lengthening stage, which encompasses c.
103 20-30% of the duration of a fault’s life, faults reach their near-final length via the propagation
104 and linkage of relatively small, discrete segments; during this time, the fault accumulates 10-
105 60% of its total displacement (Jackson et al., 2017; Rotevatn et al., 2019). During the
106 displacement accrual stage, which takes place during the latter 70-80% of the fault’s life, the
107 fault accumulates 40-90% of its total displacement (Jackson et al., 2017; Rotevatn et al., 2019).

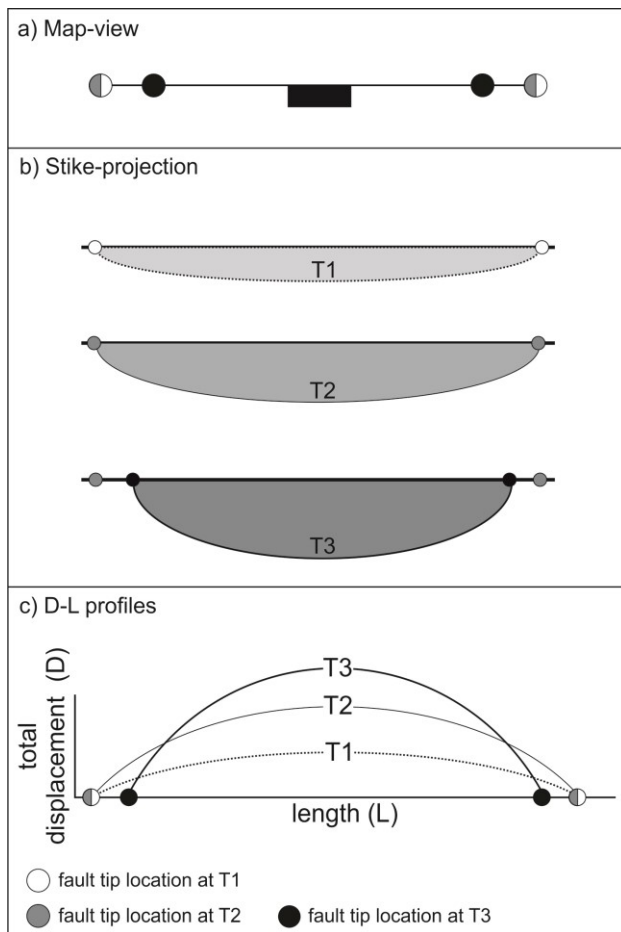
108 Whereas many studies have investigated how normal faults initiate and grow (see above),
109 few have considered what happens at the end of a fault’s life. These few studies propose that
110 faults die in two general ways: the entire trace-length of the fault remains active before slip

111 ceases, or that as the fault dies, activity is focused onto the center of the fault, leading to a
112 progressively shorter active fault trace-length (Childs et al., 2003; Meyer et al., 2002). In the
113 latter case, normal faults experience a stage of fault tip retreat, i.e., the lateral tip regions do not
114 accumulate further displacement or throw as strain is localized near the fault center (Figure 1;
115 Meyer et al., 2002). In 3D seismic reflection data, tip retreat can be observed by identifying
116 packages of growth strata that are deposited over progressively shorter along-strike lengths as the
117 fault reaches the end of its life (Meyer et al., 2002). Tip retreat has also been interpreted as a
118 result of relay breaching during segment linkage (Childs et al., 2003); however, this is what we
119 would classify as a stage of fault *growth* and not, strictly speaking, lateral tip retreat.

120 Relatively few studies have discussed the role tip retreat plays in the evolution of normal
121 faults (Childs et al., 2003; Freitag et al., 2017; Meyer et al., 2002; Morley, 2002; Nicol et al.,
122 2020), and it is therefore not usually included in fault growth models. This likely reflects the fact
123 it is very difficult or sometimes impossible to constrain the kinematics of normal faults, for
124 example in cases where growth strata are absent and/or only locally preserved. To the best of our
125 knowledge, tip retreat has also not yet been the focus of or identified in, physical or numerical
126 models. Freitag et al., (2017) show an example of tip retreat in the Columbus Basin, offshore
127 Trinidad; these are, however, thin-skinned, gravity-driven faults, and it is not clear if the
128 kinematics would apply to thick-skinned faults offsetting crystalline basement. Morley (2002)
129 also show an example of possible tip retreat in the East African Rift, but since this is a sediment-
130 starved (i.e. underfilled) basin, it is difficult to tell if the fault really experienced tip retreat, or
131 whether the observed geometries simply reflect post-fault death passive filling of hanging wall
132 accommodation. Motivated by the lack of examples that highlight the potentially important role
133 of tip retreat, we here provide a well-constrained example of tip retreat occurring on basement-

134 involved, tectonically (i.e. plate-motion) driven normal faults, as well as guidance on how to
135 identify this important process in the rock record.

136 In this paper, we use 3D seismic reflection and borehole data from the Exmouth Plateau,
137 offshore Australia to study the kinematics of thick-skinned tectonic normal faults that offset
138 crystalline basement. More specifically we: 1) constrain the temporal relationship between fault
139 lengthening and throw; and 2) investigate the role of tip retreat as faults become inactive. This is
140 an excellent place to study this process because synsedimentary normal faults are well-preserved,
141 age-constrained, and well-imaged in excellent-quality, open-source, 3D seismic reflection data.
142 The rift basin was also overfilled for much of the duration of faulting, meaning the faults are
143 flanked by well-developed growth (syn-tectonic) strata.



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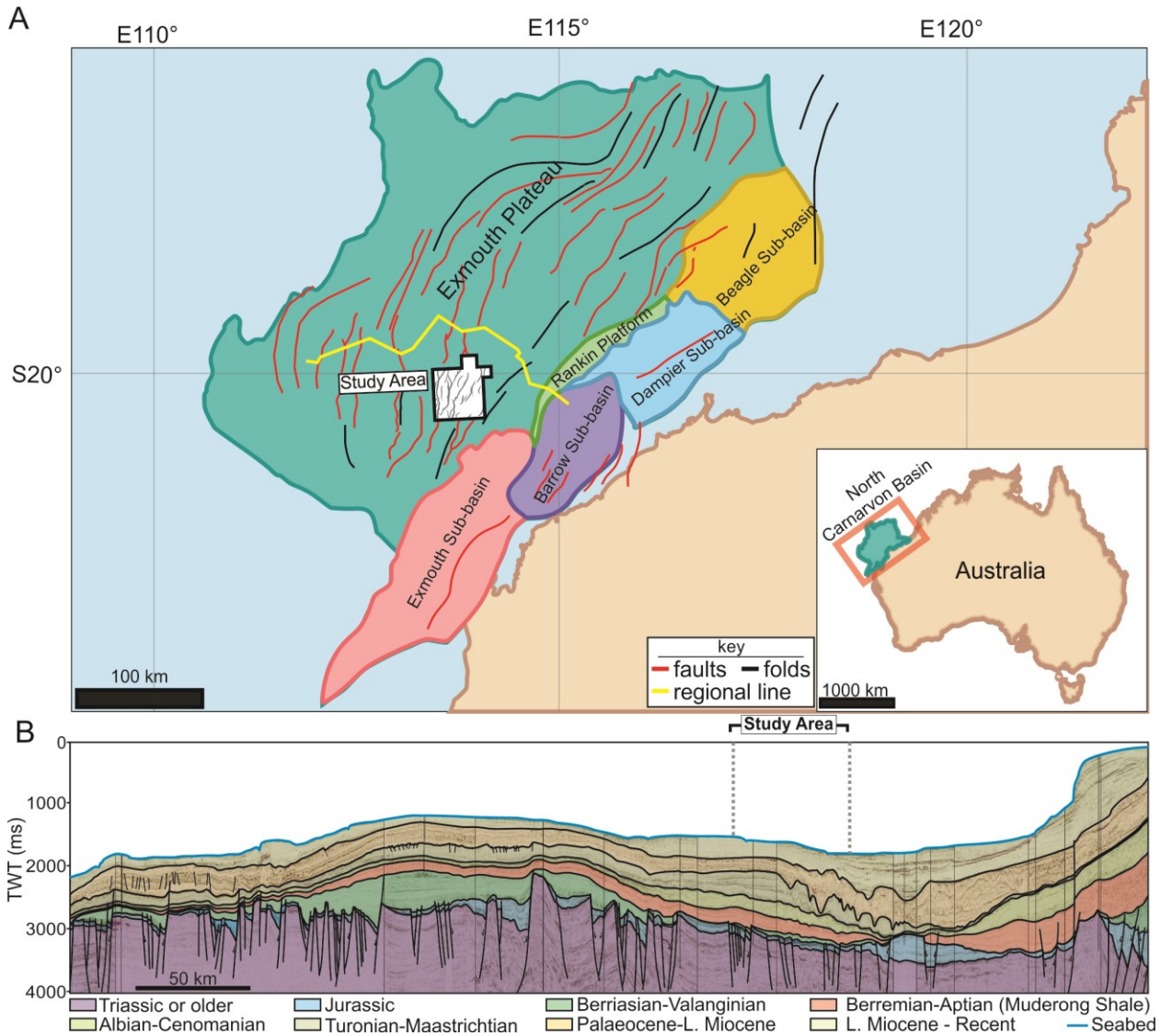
145 **Figure 1.** Conceptual models for the development of normal faults following a “hybrid fault
146 model” (Rotevatn et al., 2019) with a stage of tip retreat. Time 1 (T1) represents the
147 lengthening/propagating fault model stage, Time 2 (T2) represents the displacement
148 accumulation/constant-length model stage, and Time 3 (T3) represents a phase of fault tip-line
149 retreat. **a)** map view of the active fault trace line at T1-3. Note that the fault reaches its maximum
150 length at T1, and has a shorted active trace line at T3. **b)** Along-strike projection of throw at T1-3.
151 An increasing amount of displacement is accumulated at each stage. **c)** Displacement/length
152 profile at T1-3.

153 **2 Geologic setting of the Exmouth Plateau**

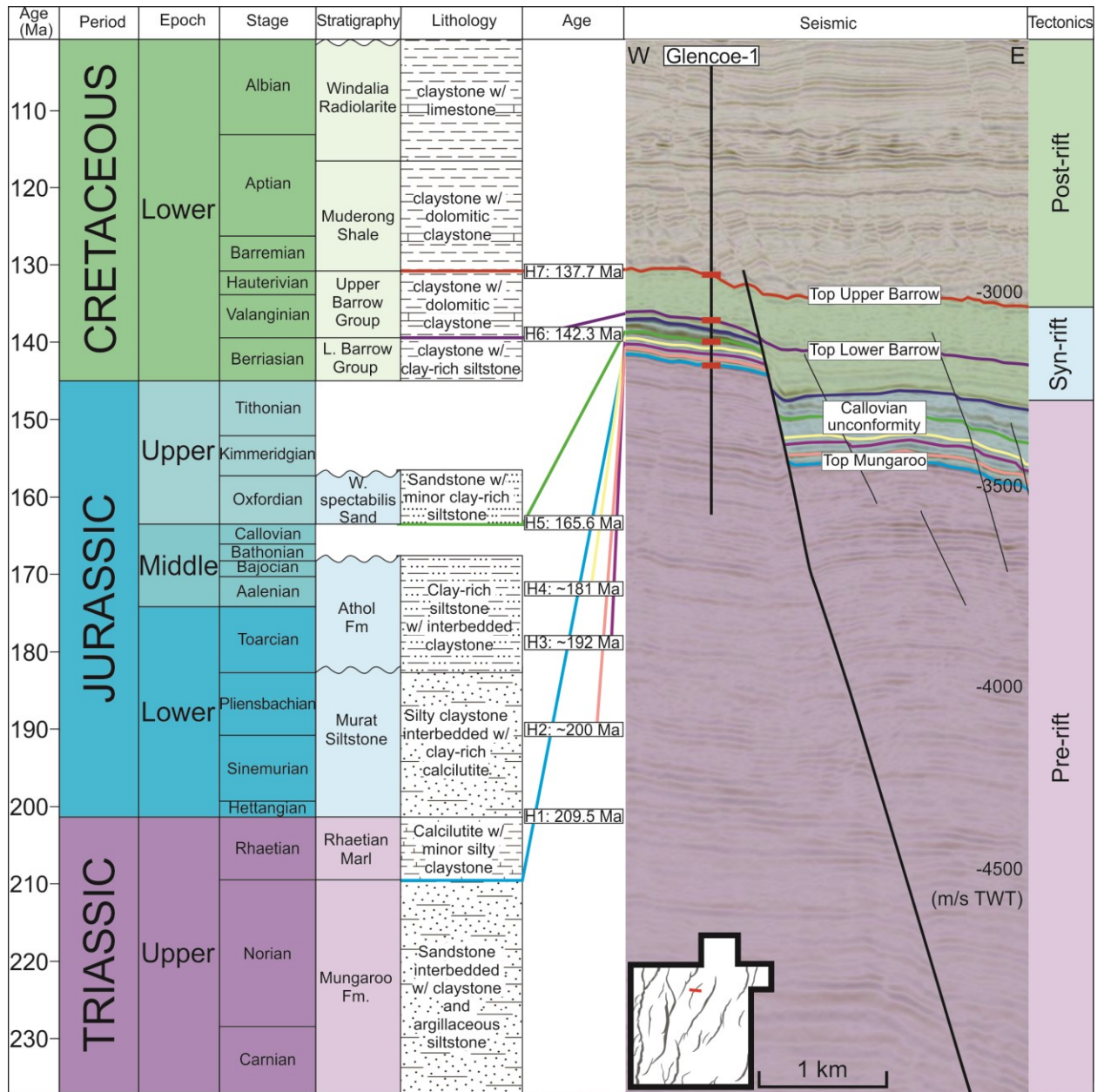
154 Our study area is located on the Exmouth Plateau, North Carnarvon Basin, offshore NW
155 Australia (Figure 2). The North Carnarvon Basin formed due to rifting in the Late
156 Carboniferous-Permian as a result of the breakup of Pangea, and the Exmouth Plateau formed as
157 a result of rifting between Greater India and Australia, creating NE-trending blocks (Gibbons et
158 al., 2012; Longley et al., 2002; Stagg & Colwell, 1994). The Exmouth Plateau is located in the
159 northern part of the North Carnarvon Basin, bounded by the continental shelf to the southeast,
160 and the Curvier, Gascoyne, and Argo abyssal plains to the SW, SW, and NE, respectively
161 (Longley et al., 2002). The Exmouth Plateau is a block of thin crystalline crust, and based on
162 geophysical evidence, it has been suggested that the Exmouth Plateau basement is continental
163 crust, however this has not been confirmed by direct sampling (Stagg et al., 2004). The
164 crystalline basement is overlain by a thick pre-rift succession, consisting of the fluvial-deltaic to
165 marginal marine, Mungaroo Formation (Triassic) (Longley et al., 2002; Stagg et al., 2004).

166 The synrift extension began in the Late Triassic (Rhaetian) until Late Jurassic
167 (Oxfordian), during which time the Murat and Athnol siltstones were deposited in a sediment-
168 starved basin (Figure 3) (Longley et al., 2002; Tindale et al., 1998). After a short period of
169 tectonic quiescence in the Late Jurassic, rifting continued in the Early Cretaceous in an over-
170 filled basin environment, during which time marine claystones (Dingo Claystone) and coarser-
171 grained, deltaic clastics (Barrow Group) were deposited (Longley et al., 2002). Rifting in the

172 Exmouth Plateau ceased in the Hauterivian, and the area became a passive margin (Gibbons et
 173 al., 2012; Longley et al., 2002). In this paper, we focus on the Jurassic-Early Cretaceous, syn-
 174 sedimentary normal faults which are generally trending N-NE.



175 **Figure 2.** Study area. **a)** Location of the Exmouth Plateau in the North Carnarvon Basin,
 176 offshore Australia (fault locations modified from Pan et al., 2020), **b)** Regional 2D seismic line
 177 across the study area, modified from Nugraha et al., (2019). The location of this regional line is
 178 labeled on Figure 2a (yellow).
 179



180
 181 **Figure 3.** Stratigraphic framework showing the key interpreted seismic horizons, their ages, and
 182 the tectonic evolution of the Exmouth Plateau (H=horizon). Ages for H1, H5, H6, and H7 were
 183 taken from Marshal and Lang (2013), and H2, H3, and H4 are relative dates assuming constant
 184 sedimentation. Information on the tectonostratigraphic framework are from Bilil et al., (2018)
 185 and Geoscience Australia.

186 **3 Data**

187 **3.1 Data**

188 The Glencoe dataset is a 3D time-migrated seismic reflection survey that encompasses
189 approximately 3900 km² of the Kangaroo syncline in the Exmouth Plateau (Figure 4). It has a
190 bin spacing of 25 m and a record length of 8 s two-way time (TWT). The vertical and horizontal
191 resolution are approximated by measuring the dominant wavelength in the interval of interest
192 ($\lambda=26.3$ m) and calculating $\lambda/4$ (where λ is the seismic wavelength), yielding c. 6.6 m within the
193 syn-rift sequence (Brown, 2011).

194 Seismic sections are displayed with normal polarity (SEG European Convention; Brown,
195 2011), where increase in acoustic impedance is represented by a peak (red), and a decrease by a
196 trough (black). Seismic inlines are orientated WNW-ESE and the survey is tied to four wells
197 (Glencoe-1, Nimblefoot-1, Warrior-1, and Breseis-1). Well-logs, formation tops, and
198 biostratigraphic ages were provided with the wells. All seismic and well data are open-access
199 and available from Geoscience Australia.

200 We have mapped seven regionally extensive seismic horizons (H1-7); H1, H5, H6, and H7 are
201 age-constrained well-tied horizons with ages from well reports, as well as ages obtained by
202 Marshall & Lang (2013) using biostratigraphy from 1500 wells around the North Carnarvon
203 Basin (Figure 3). We lack direct age-constraints for H2-4, thus we estimated their ages by
204 assuming a constant sedimentation rate between horizons of known ages (Figure 3). We also
205 locally picked additional horizons within the syn-sedimentary deposits (e.g. H5.5) that are not
206 continuous across the entire dataset; we estimated their ages based on an assumption of constant
207 sedimentation rates between overlying and underlying, age-constrained horizons. We mapped
208 and analyzed seven faults of varying sizes (8.8-42 km long, with 165-680 m of throw) to show

209 how faults of different sizes grow in the area, and to see if the styles of fault growth are scale
 210 dependent (see Figure 5 for fault locations).

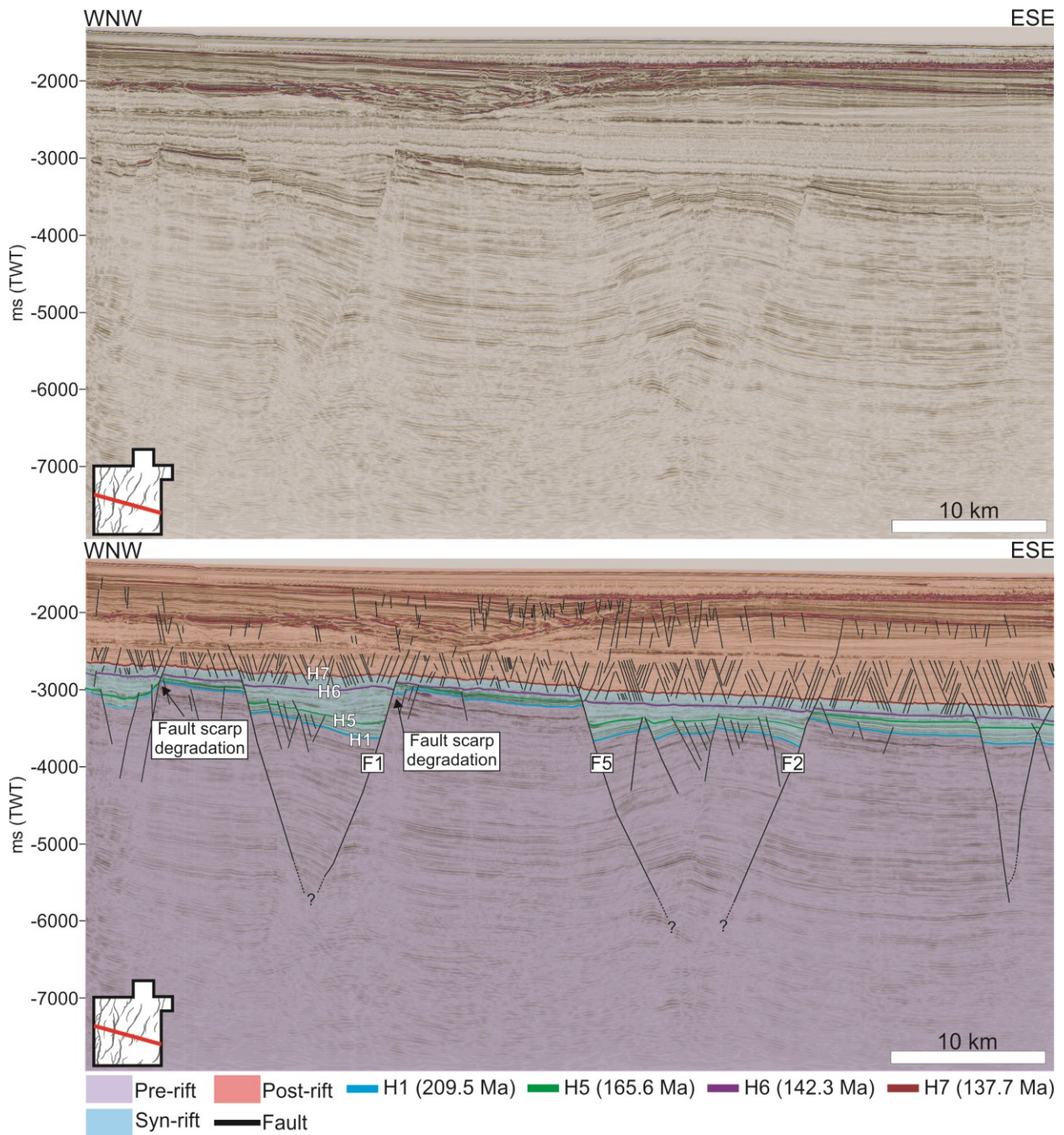
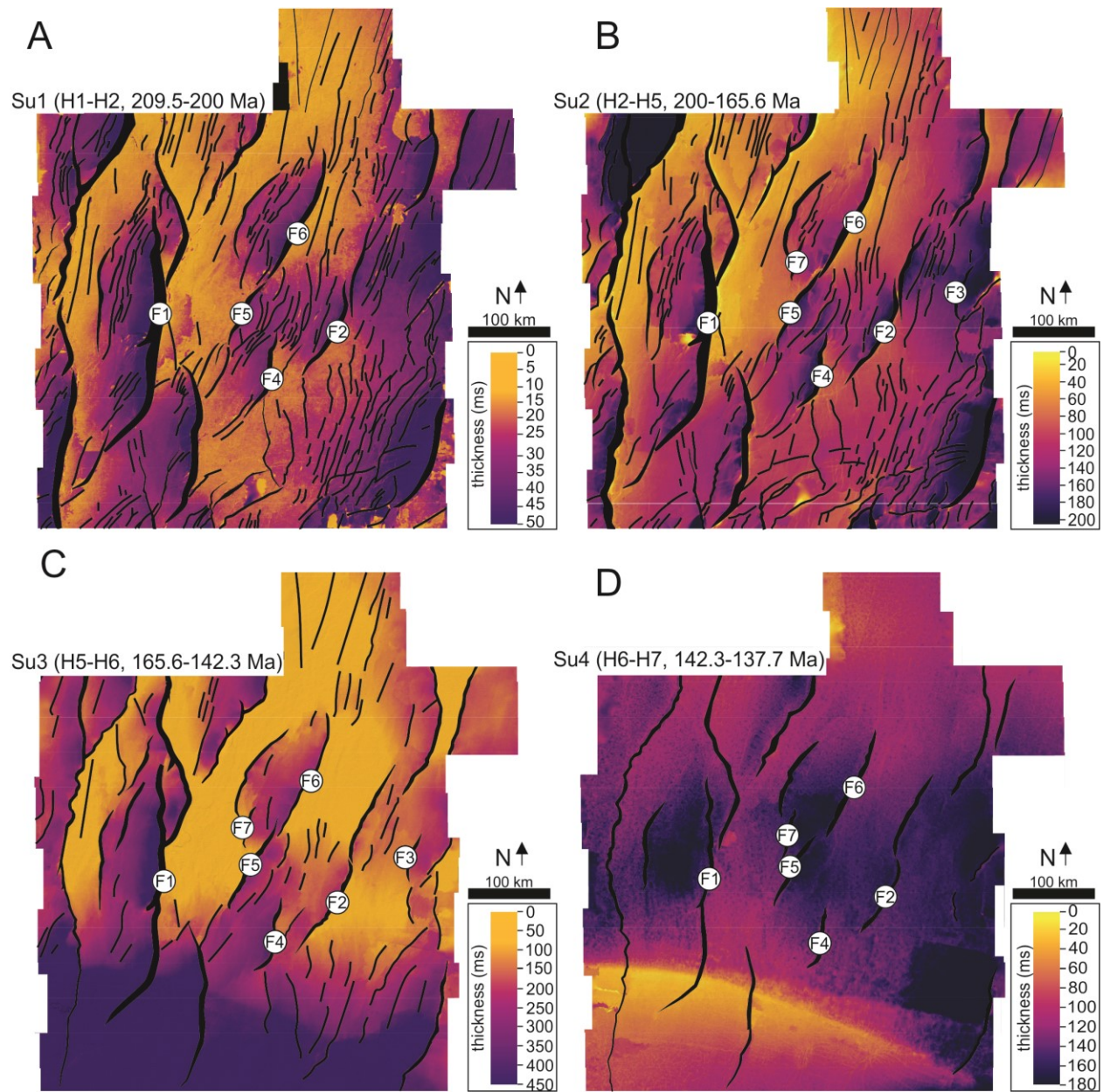


Figure 4. Representative seismic line in TWT along the central section of the 3D dataset, across strike of the studied faults. Data is show with and without interpretation.



214

215 **Figure 5.** Representative isochrons of the study area with interpreted major and minor faults
 216 labeled. **a)** Seismic Unit 1: Horizon 1-2, 209.5-200 Ma, **b)** Seismic Unit 2: Horizon 2-5, 200-
 217 165.6 Ma, **c)** Seismic Unit 3, Horizon 5-6. 165.6-142.3 Ma, **d)** Seismic Unit 4, Horizon 6-7.
 218 142.3-137.7 Ma.

219 3.2 Methodology

220 In this study we used three different methods to quantify fault growth: isochron analysis,
 221 throw backstripping, and expansion index (EI) analysis (see review by Jackson et al. 2017). First,

222 we created time-thickness (isochron) maps of key stratigraphic intervals, which illustrate
223 variations in sediment thickness. This highlights across-fault hanging wall thickening, which can
224 reveal the growth history of a fault (e.g. Jackson & Rotevatn, 2013). Isochron analysis was done
225 first in order to establish the general style of fault growth (i.e. a propagating, constant-length, or
226 hybrid fault growth model), and then we conducted throw backstripping to be able to see exact
227 fault throw and length through time in the faults' lives (Jackson et al., 2017). To begin throw
228 backstripping, we created throw-length (T-x) plots by picking the hanging wall and footwall
229 cutoffs for every chosen horizon across the length of the faults (appendix figures 1-3). In the case
230 of folding or erosion (Figure 4), horizons used to calculate throw were projected across the fold
231 or eroded fault scarp (e.g. Wilson et al., 2013). Throw backstripping involves subtracting the
232 throw of a shallower horizon directly from the throw of a deeper horizon at the same along-strike
233 position, with this being repeated for successively deeper horizons (Chapman & Meneilly, 1991;
234 Peterson et al., 1992). We opted to use the "original method" of throw backstripping, where
235 throw across different horizons is simply subtracted, as we did not want to make any
236 assumptions about the style of fault growth (see Jackson et al., 2017 for more details on fault
237 displacement backstripping methods). Finally, we used EI analysis to measure variations in
238 stratal thickness across the fault by dividing the thickness of hanging wall stratal unit by that of
239 the equivalent unit in the footwall (Bouroullec et al., 2004; Cartwright et al., 1998; Jackson et al.,
240 2017; Thorsen, 1963) (See appendix figure 4). This technique shows the formation and growth of
241 depocenters, and therefore how the faults lengthened (Jackson & Rotevatn, 2013).

242 We also calculated vertical throw gradients by dividing the change in throw by the
243 change in depth of the shallowest two horizons offset across the fault. We calculated upper-tip
244 throw gradients in order to demonstrate that the top of the fault was interacting with the free

245 surface rather than acting as a blind fault; this is important when trying to understand if faults
246 experienced real tip-line retreat or not (Childs et al., 2003; Meyer et al., 2002; Walsh &
247 Watterson, 1988). Finally, we calculated fault slip rates by dividing displacement for a particular
248 time period by the duration of that time period; this was done in order to investigate whether slip
249 rates varied between the different stages of fault growth. It is important to note that we plotted
250 total throw and length through time using data derived from: (i) all seven of our seismic-
251 stratigraphically defined horizons, four of which were directly age-constrained by well data, and
252 three for which the ages were only estimated (see above); and; (ii) only our four age-constrained
253 seismic horizons. We plotted slip rate through time using only age-constrained horizons. This
254 allowed us to constrain a range of rates for time-variable parameters, which future additional
255 well data may help refine.

256 Since the basin was sediment-starved from the Early Jurassic until the Late Jurassic, as
257 evidenced by the fault scarp degradation until the deposition of H5 (Figures 4, 6a, and 8a), our
258 fault lengthening calculations are upper limit estimations. For example, if active faulting created
259 hanging wall accommodation but the basin was sediment starved, this accommodation would
260 have remained unfilled. Thus, what looks like tip propagation could just be prolonged filling of
261 the hanging wall of an inactive normal fault (see Jackson et al., 2017). It is therefore possible that
262 the faults reached their maximum lengths even quicker than what we estimate.

263 There is a level of uncertainty when attempting to map fault tip positions in 3D seismic,
264 even with high-quality data (Pickering et al., 1996). Our seismic dataset has a vertical and
265 horizontal resolution of c. 6.6 m; this means faults smaller (i.e. shorter and with less
266 displacement) than this value are not imaged, and that the tips of otherwise larger faults will also
267 not be imaged. Because of this, it is likely we are underestimating fault lengths by a few hundred

268 meters (see Pickering et al., 1996). However, this seismic imaging resolution issue applies at all
269 stages of fault growth and therefore does not impact our key observations (i.e. that EI values fall
270 below 1 near the fault tips during the later stages of their lives) and related interpretations (i.e.
271 that the active fault-trace length shortens as the fault dies).

272 We use checkshot (velocity) data from our four wells to convert throw values from
273 milliseconds two-way time (ms TWT) to depth (m) (see appendix figure 1). Throw values are
274 presented in meters. Burial-related compaction of sedimentary rocks can result in throw
275 calculations being underestimated, especially when rocks have a high shale content or are deeply
276 buried (>2 km; see Taylor et al., 2008). Decompaction typically decreases throw estimates by
277 <20% (Taylor et al., 2008), so we here give all throw and slip rate values an error to account for
278 maximum of 20% decompaction.

279 **4 Results**

280 We have completed a comprehensive geometric and kinematic analysis of seven faults of
281 various sizes (appendix figures 2-7). We first provide a detailed description of the geometry of
282 three faults (and their related growth strata) that are representative of the various fault sizes
283 identified in the study area, before describing their kinematics. Fault 1 (F1) represents the largest
284 studied fault, Fault 2 (F2) represents a mid-sized fault, and Fault 3 (F3) represents the smallest
285 studied fault in the dataset. We then present and discuss the results for all of the studied faults.

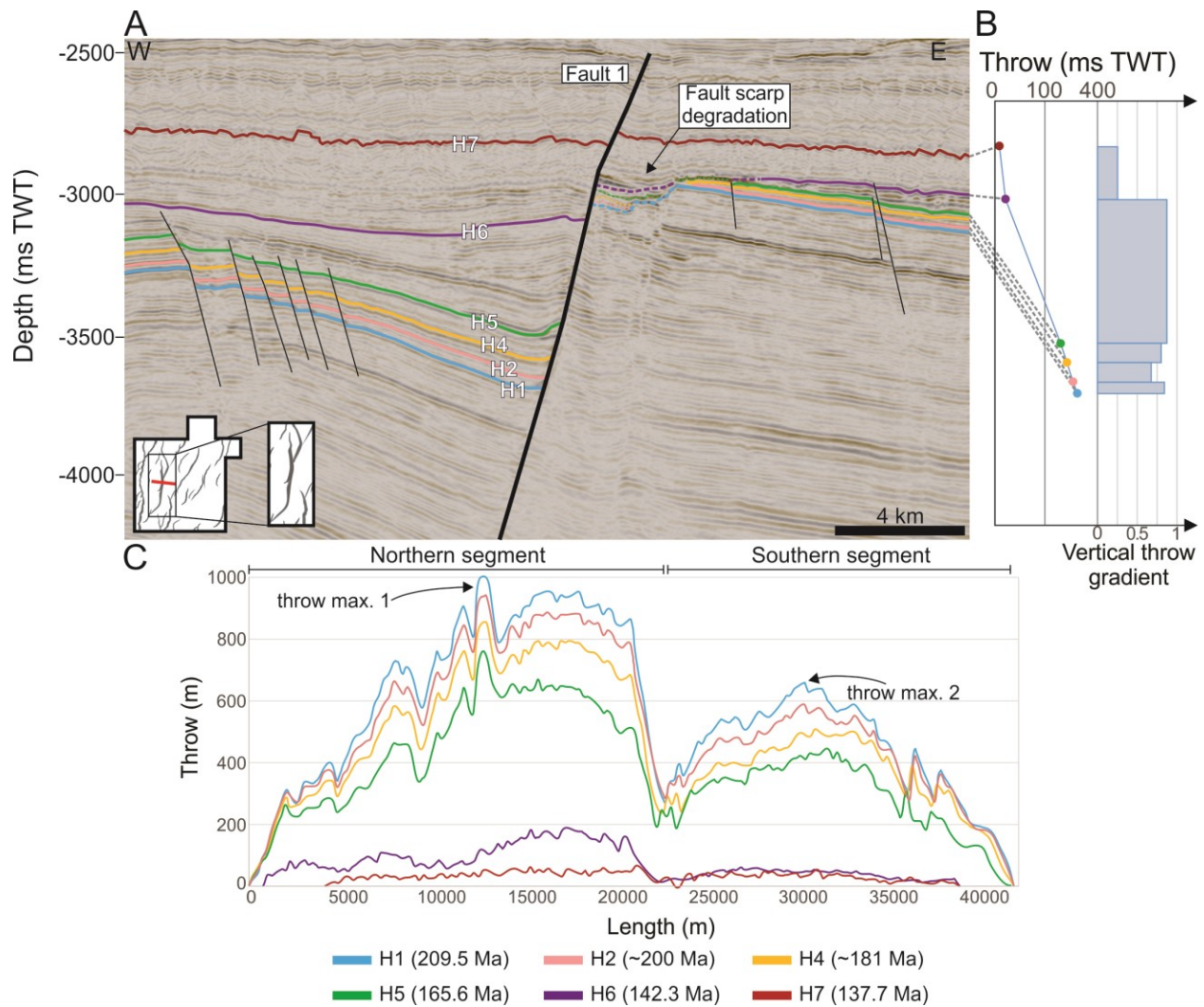
286 **4.1 Fault 1**

287 **4.1.1 Observations**

288 Fault 1 (F1), the largest fault in the dataset that has both of its tips imaged, is ~42 km
289 long, strikes N-S, and dips to the E. Based on along-strike changes in strike and throw (Figure

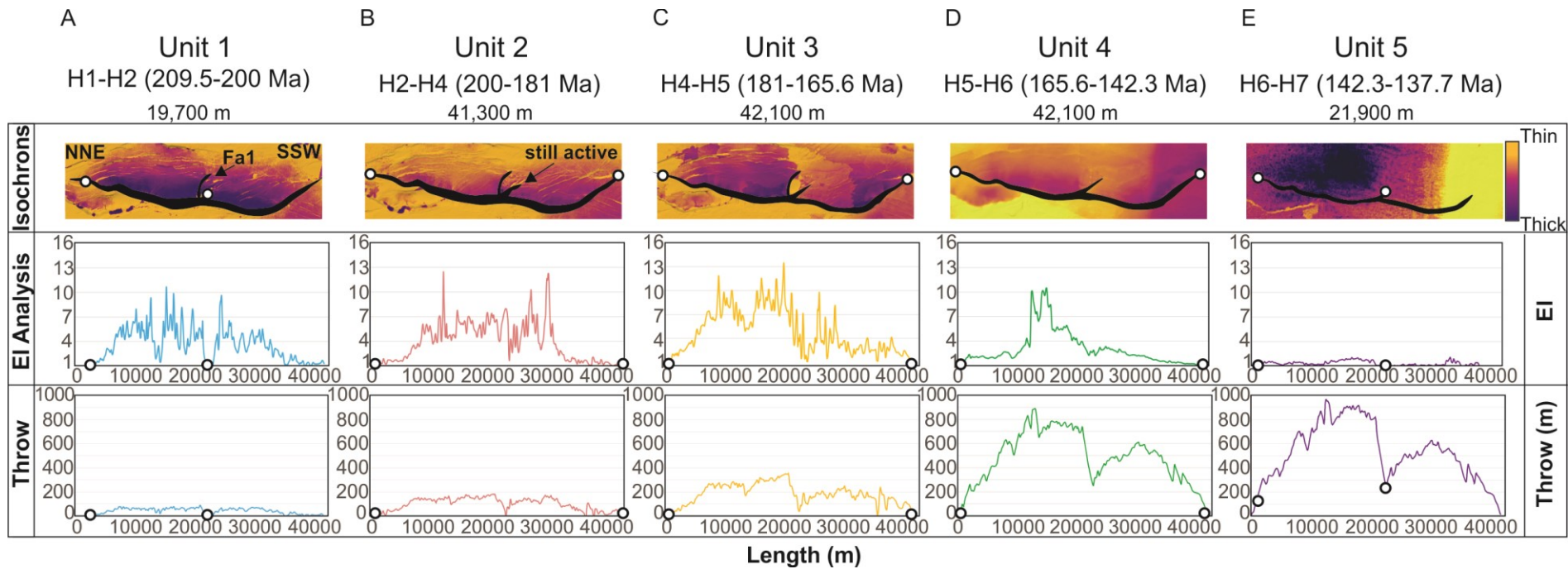
290 6c), we split F1 into a 24 km-long northern segment and an ~18 km-long southern segment
291 (Figures 5 and 6). The upper tip-line of F1 is located in Lower Cretaceous strata, where it
292 physically links to a tier of polygonal faults (Velayatham et al., 2019) (Figure 4), and its lower
293 tip-line is difficult to locate due to poor seismic imaging in the pre-rift, but F1 appears to tip out
294 deep in the study area or into the basement (Figure 4). F1 shows two clear throw maxima; a
295 northern maximum (680+136 ms TWT or 1000+200 m at H1; error shows possible
296 decompaction) near the center of the northern fault segment, and a southern maximum (433+87
297 ms TWT, 658+132 m at H1) near the center of the southern fault segment. Both segments are
298 generally characterized by approximately bell-shaped throw distributions, the peak of which is
299 skewed away from the center due to the related throw maxima being offset from the fault
300 segment center (Figure 6c).

301 There are clear wedge-shaped stratigraphic packages between H1 and H7 in the hanging
302 wall; these thicken towards F1. In contrast, pre-H1 and post-H7 strata are isopachous (Figure
303 6a). EI plots show across-fault thickening (i.e. values ≥ 1) in Unit 1 along the central parts of the
304 northern and southern segments; the unit is, however, isopachous where the two segments link
305 (Figure 7a). In contrast, EI values in Unit 2 are ≥ 1 across the link between the two segments
306 (Figure 7b). EI values are ≥ 1 across a progressively longer portion of the fault in Units 2-5
307 (Figures 7b-d), until the youngest interval, Unit 6 (Figure 7e), where the upper tip of the fault is
308 associated with EI values < 1 .



309

310 **Figure 6.** a) Seismic profile illustrating F1 at its point of highest throw and its correlated throws
 311 and throw gradients, b) Vertical throw gradients for each horizon, c) Throw-distance plot
 312 illustrating the lateral variations in throw across each seismic unit. All throw values could be
 313 underestimated up to 20% due to post-depositional compaction of faulted strata (Taylor et al.,
 314 2008).



316
 317 **Figure 7.** Isochrons, expansion index analysis, and throw throughout different stages of the life of F1. The throw through time values
 318 are taken from throw backstripping, which can be seen in detail in the appendix figures. White dots indicate the length of the fault at
 319 the specified interval. **a)** Isochron showing the thickness between H1 (209.5 Ma) and H2 (200 Ma), maximum throw is 78 m, and
 320 length is 19,700m, **b)** Isochron showing the thickness between H2 (200 Ma) and H4 (181 Ma), maximum throw is 191 m and length is
 321 41,300 m, **c)** Isochron showing the thickness between H4 (181 Ma) and H5(165.6 Ma), maximum throw is 438 m and length is
 322 41,100, **d)** Isochron showing the thickness between H5 (165.6 Ma) and H6 (142.3 Ma), maximum throw is 993 m and length is

323 42,100, e) Isochron showing the thickness between H6 (142.3 Ma) and H7 (137.7Ma),
324 maximum throw is 1098 and length is 21,900 m. All throw values could be underestimated up to
325 20% due to post-depositional compaction of faulted strata (Taylor et al., 2008).

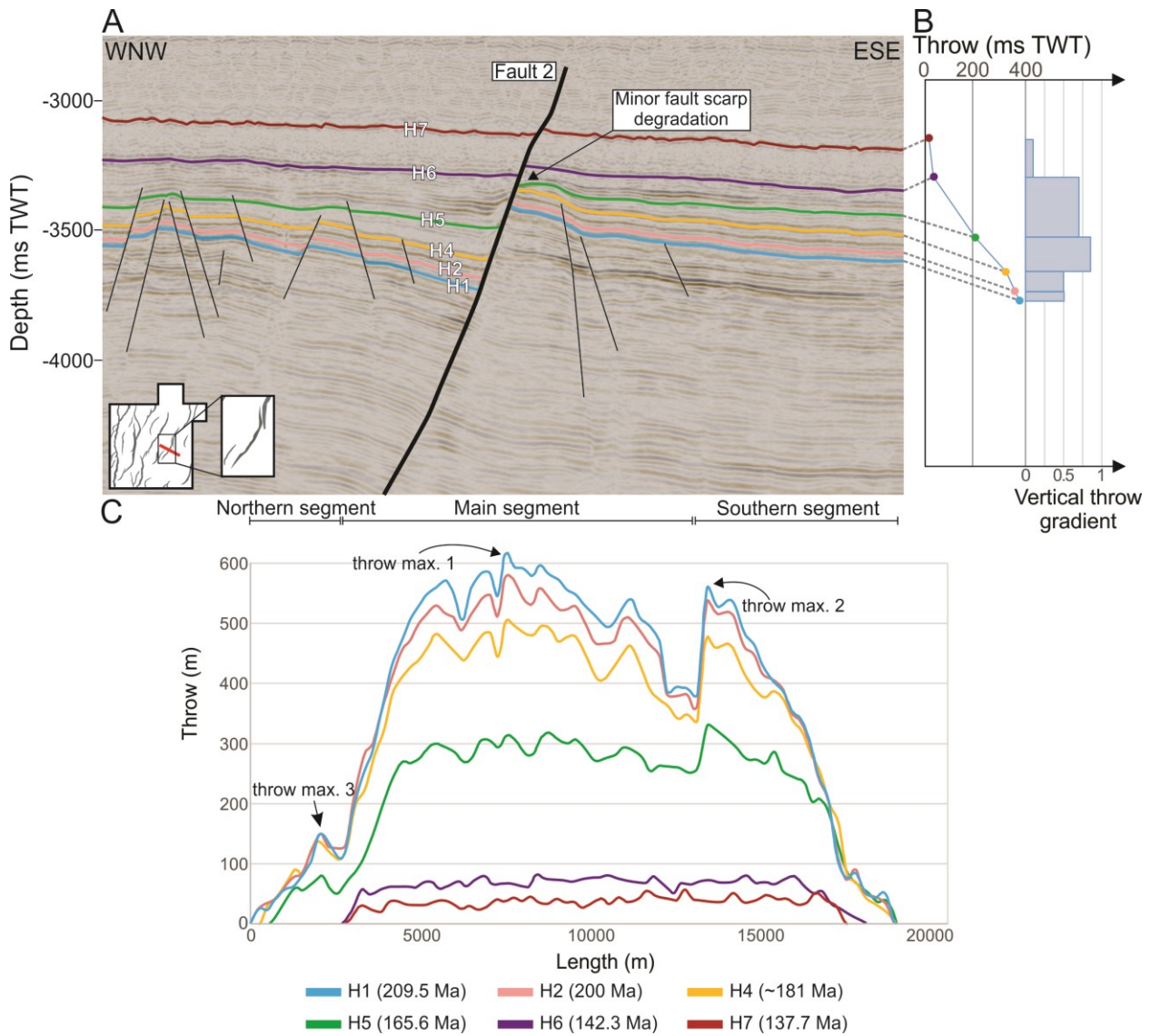
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327 **4.1.2 Interpretations**

328 We see across-fault thickening in the hanging wall between H1 and H7 (Units 1-5) in
329 cross section (Figure 6a) and in isochron thickness maps (Figure 7a-e), suggesting F1 was active
330 from 209.5 to 137.7 Ma (Early Jurassic-Early Cretaceous). In detail, however, the EI plots show
331 that different parts of the fault were active at different times. The fact that F1 is associated with
332 two discrete throw maxima (and two associated bell-shaped throw distributions), as well as an EI
333 of <1 in the middle of the fault in the first time interval (Unit 1; Figure 7a), suggests it formed by
334 the linkage of two, initially separate segments. Linkage likely occurred sometime between the
335 deposition of H2 and H4, based on EI values of >1 only occurring in units above H1. Often,
336 when faults link, their paleo-tip-lines become inactive (Childs et al., 2003). In this case,
337 however, F1 is a footwall-breached relay and the tip of the northern segment continued to accrue
338 displacement on portions of the fault tips bounding the now-breached relay ramp (Figure 7e).
339 The lack of throw in the middle of the fault is likely due to the still-active northern segment
340 paleo-fault tip accommodating strain in the middle of the fault, as well as a minor E-W fault
341 (labeled F1a in Figure 7a) that cuts perpendicularly across F1. F1 reached its maximum length by
342 the deposition of H5 (Unit 3), or possibly sooner, based on the observation of EI values ≥ 1
343 across its length for this interval (Figure 7c). During Unit 5, the lateral ends of the fault have an
344 EI value of <1 , which suggests that the fault tips became inactive at this time. Additionally,
345 during this last stage of fault growth, the breached relay ramp between the northern and southern
346 segment had an EI value of <1 , which suggests that the fault along the previously active relay
347 ramp between the two fault segments became inactive (Figure 6e).

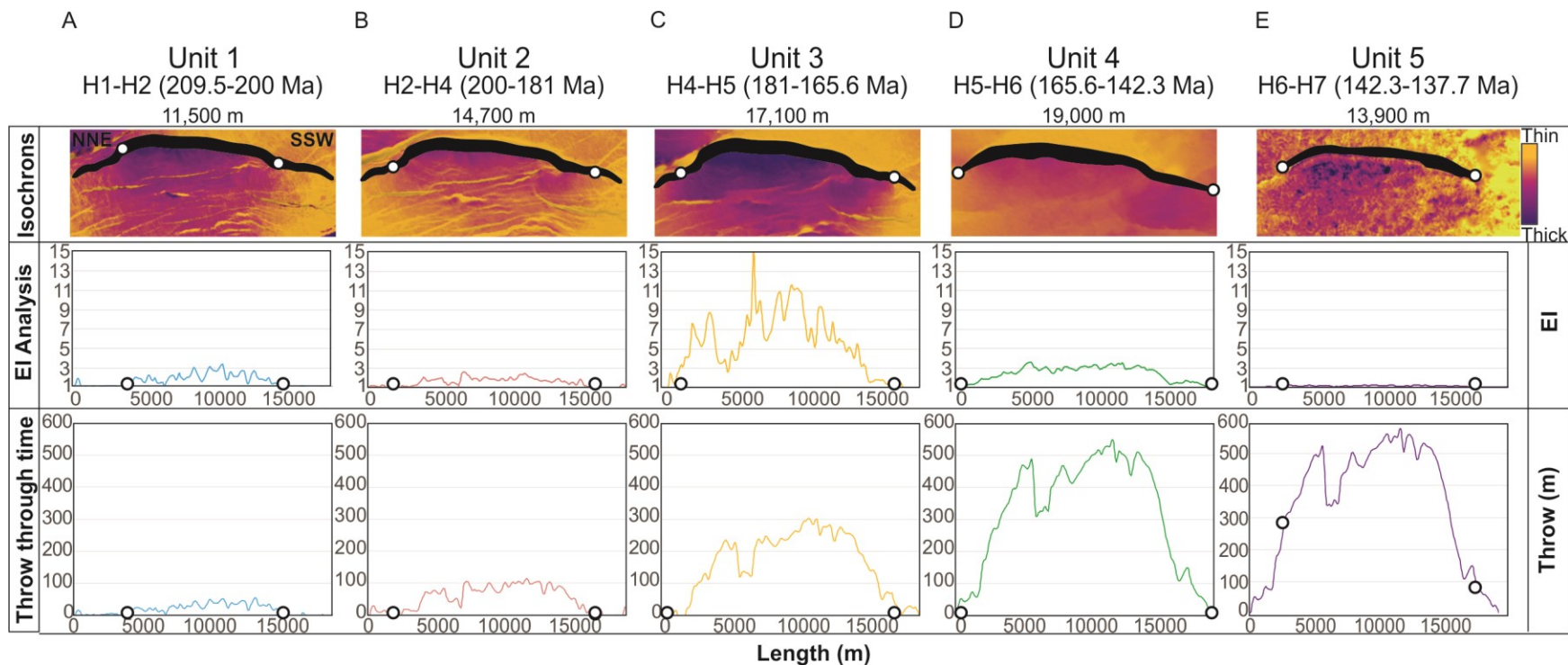
348 In summary, according to throw backstripping and EI analysis, F1 initiated after the
349 deposition of H1 (c. 209.5 ma), and within c. 9.4 Myr (13% of its total life) consisted of two
350 separate segments that were 19.7 km and 19.2 km long. During this first phase of activity, it
351 accumulated only 7% of its total throw. Approximately 18.8 Myr later, the two segments linked
352 and the outermost tips of the newly formed fault system had propagated slightly, meaning it was
353 now 41.3 km long. The fault had therefore reached c. 98% of its maximum length and accrued
354 19% of its total throw by this point (i.e. 39% of its life). Its maximum length was reached 15.7
355 Myr later, by which time it had accumulated 36% of its total throw. During the last 4.6 Myr of
356 the fault's life, the remaining throw was accrued, and the northernmost 0.9 km and southernmost
357 2.9 km became inactive.

4.2 Fault 2



359

360 **Figure 8. a)** Seismic profile illustrating F2 at its point of highest throw and its correlated throws
 361 and throw gradients, **b)** Vertical throw gradients for each horizon, **c)** Throw-distance plot
 362 illustrating the lateral variations in throw across each seismic unit. All throw values could be
 363 underestimated up to 20% due to post-depositional compaction of faulted strata (Taylor et al.,
 364 2008).



365

366 **Figure 9.** Isochrons, expansion index analysis, and throw throughout different stages of the life of F2. The throw through time values
 367 are taken from throw backstripping, which can be seen in detail in the appendix figures. White dots indicate the length of the fault at
 368 the specified interval. **a)** Isochron showing the thickness between H1 (209.5 Ma) and H2 (200 Ma), maximum throw is 55 m, and
 369 length is 11,500m, **b)** Isochron showing the thickness between H2 (200 Ma) and H4 (181 Ma), maximum throw is 116 m and length is
 370 14,700 m, **c)** Isochron showing the thickness between H4 (181 Ma) and H5(165.6 Ma), maximum throw is 303 m and length is
 371 17,100, **d)** Isochron showing the thickness between H5 (165.6 Ma) and H6 (142.3 Ma), maximum throw is 550 m and length is

372 19,000, e) Isochron showing the thickness between H6 (142.3 Ma) and H7 (137.7 Ma),
373 maximum throw is 617 and length is 13,900 m.. All throw values could be underestimated up to
374 20% due to post-depositional compaction of faulted strata (Taylor et al., 2008).

375 **4.2.1 Observations**

376 Fault 2 (F2) is a 19 km long, NNE-SSW-striking, WNW-dipping normal fault. F2
377 comprises a long (11 km) central segment that is linked at each end via abrupt bends, to shorter
378 (3-5 km) segments (Figures 8 and 9). The upper tip-line of F2 is located in Lower Cretaceous
379 strata, and its lower tip-line is difficult to locate due to poor seismic imaging in the pre-rift, but
380 F2 appears to tip out deep in the study area or into the basement (Figure 4). F2 presently has
381 three local throw maxima; a central maxima (380+76 ms TWT, 620+124 m at H1) on the main,
382 central segment, a southern maxima (348+70 ms TWT, 560+112 m at H1) that is located along
383 the southern fault segment, and a smaller, northern maxima (94+19 ms TWT, 150+30 m at H1)
384 on the northern fault segment (Figure 8b). The throw maxima are separated by two throw
385 minima that coincide with the abrupt bends in the map-view trace of F2, where the northern and
386 southern segments connect with the central segment (Figure 9). The main segment has an overall
387 symmetrical throw distribution, and the northern and southern segments are skewed to the south
388 and north respectively (Figure 8b).

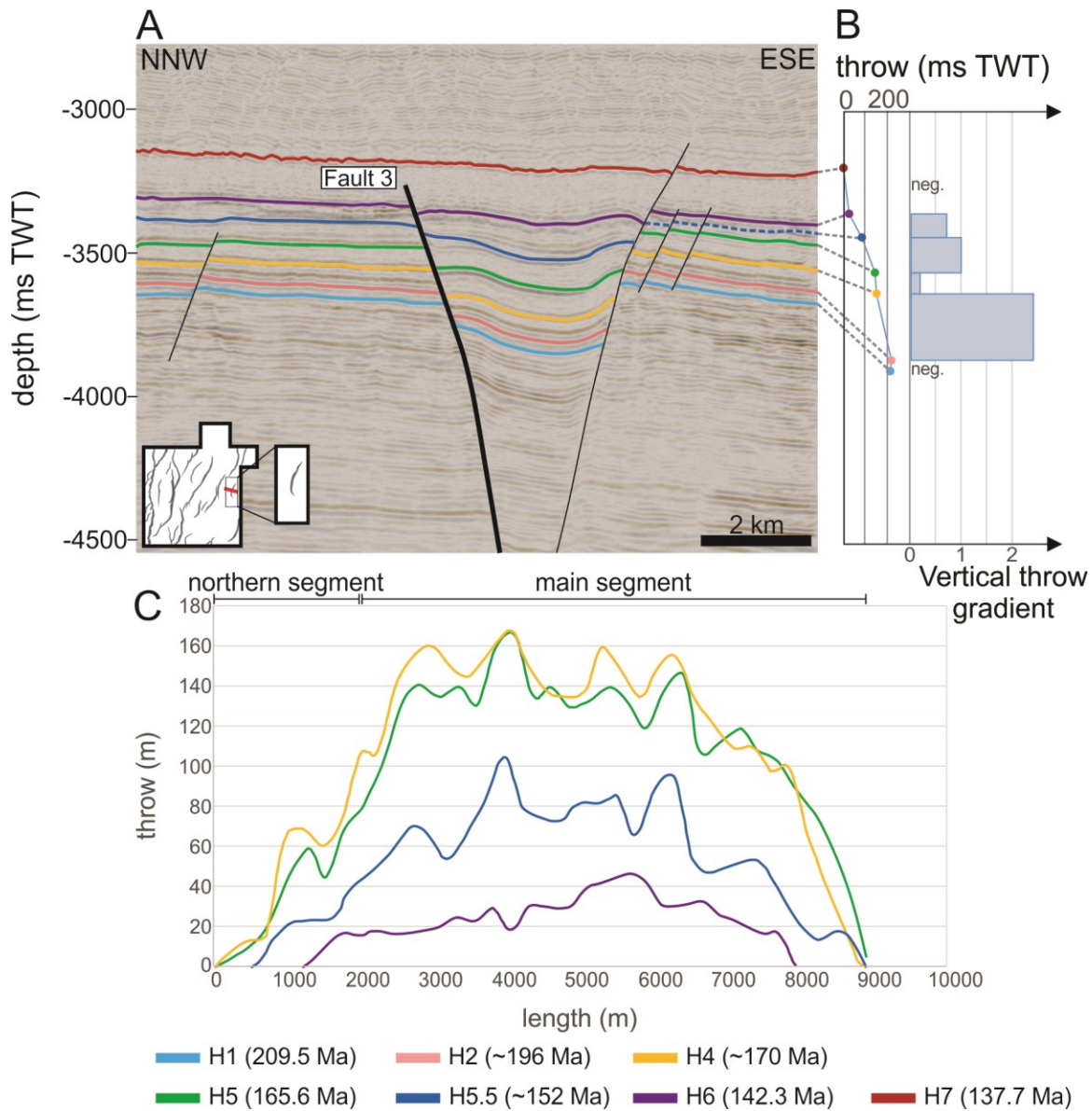
389 There are clear wedge-shaped stratigraphic packages between H1 and H7 in the hanging
390 wall, which thicken towards F2. Pre-H1 and post-H7 strata are isopachous (Figure 8a). EI plots
391 show values ≥ 1 along a progressively longer portion of the fault from the oldest to the second
392 youngest stratigraphic intervals (Units 1-4; Figures 9a-d). In Unit 5, the lateral tips of the fault
393 have an EI value that is < 1 (Figure 9e).

4.2.2 Interpretations

We see across-fault thickening between H1 and H7 (Units 1-5) in cross-section (Figure 8a) and in isochron thickness maps (Figures 9a-e), suggesting F2 was active from 209.5 to 137.7 Ma (Early Jurassic-Early Cretaceous). The fact that EI values ≥ 1 are limited to the central segment of the fault in Unit 1 (Figure 9a) suggests that F2 initiated here, an interpretation that is supported by the symmetry of the throw distribution on this segment (Figure 8b). The shorter southern segment was clearly present and active by Unit 3 (Figure 9c) and possibly already by Unit 2 (Figure 9b) times, as evidenced by EI values ≥ 1 along these segments in the corresponding interval. The throw maxima on the southern segment is skewed towards the NNE (Figure 8b), which is interpreted as a result of the mechanical interaction of the southern section with the already-existing central segment (Wilkinson et al., 2015). The northern segment was present and active by Unit 3 times (c. 28.2 Myr), based on the observation of EI values ≥ 1 along the segment (Figure 9c). This northern segment may have simply formed due to lateral (i.e. north-northeastward) propagation of the northern tip of the central segment. However, our preferred interpretation is that it initiated as a separate segment, based on: i) the observed EI distribution within Unit 4 (i.e. the EI peak is located centrally along the SSW segment; Figure 9c); ii) the fact the throw maximum is offset to the SW of the center of the mapped trace of the northern segment (Figure 8b); and, iii) the pronounced bend between the central and northern segments, which we infer reflects a now-breached relay ramp (Peacock & Sanderson 1994; Walsh et al., 1999). F2 reached its maximum length by the deposition of H5, or possibly sooner, as evidenced by EI ≥ 1 across its length during this interval. EI values drop below 1 on the lateral tips of F2 in Unit 5, which we interpret as the outer 2-2.5 km of the fault becoming inactive (Figure 9e).

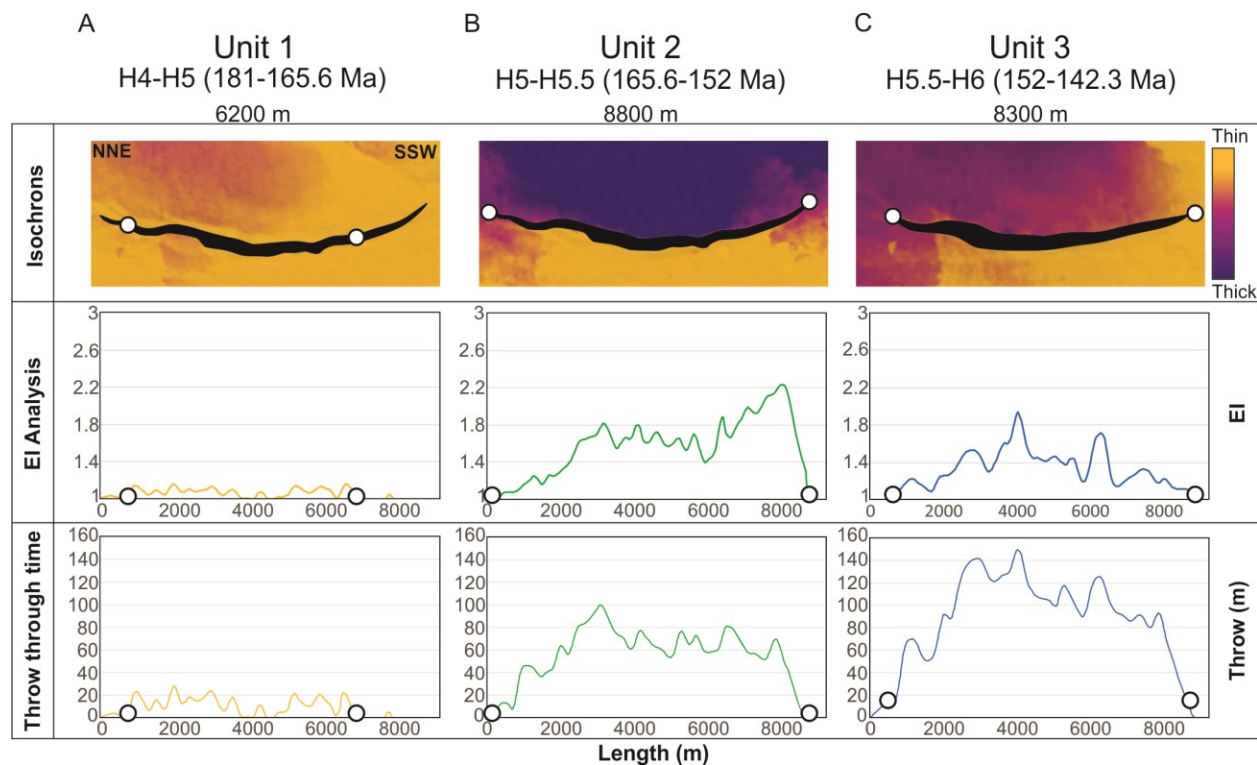
417 In summary, according to throw backstripping and EI analysis, F2 initiated after the
418 deposition of H1 (c. 209.5 ma), and within c. 9.4 Myr (13% of its total life) was 11.5 km long
419 (60.5% of maximum length). During this first phase of activity, F2 only accumulated c. 13% of
420 its total throw. Approximately 18.8 Myr later, F2 had grown via tip propagation and possibly
421 segment linkage to be 14.7 km long. At this time, the fault had reached 77.4% of maximum
422 length and only 20% of total throw by this point (39.3% of the faults life). C. 15.7 Myr later (i.e.
423 50.2% of the total life), the central segment of F2 grew via segment linkage to be 17.1 km long,
424 and accumulated c. 52.4% of total throw. Its maximum length was reached within the next 23.3
425 Myr, by which time it had accumulated c. 95.1% of its total throw. During the last 4.6 Myr of the
426 fault's life, the remaining 4.9% of throw was accrued, and the northernmost 2.6 km and
427 southernmost 2.4 km of the fault became inactive.

4.3 Fault 3



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430 **Figure 10. a)** Seismic profile illustrating F3 at its point of highest throw and its correlated
 431 throws and throw gradients, **b)** Vertical throw gradients for each horizon, **c)** Throw-distance plot
 432 illustrating the lateral variations in throw across each seismic unit. All throw values could be
 433 underestimated up to 20% due to post-depositional compaction of faulted strata (Taylor et al.,
 434 2008).



435
 436 **Figure 11.** Isochrons, expansion index analysis, and throw throughout different stages of the life
 437 of F3. The throw through time values are taken from throw backstripping, which can be seen in
 438 detail in the supplementary figures. White dots indicate the length of the fault at the specified
 439 interval. **a)** Isochron showing the thickness between H4 (181 Ma) and H5 (165.6 Ma), maximum
 440 throw is 28 m, and length is 6200 m, **b)** Isochron showing the thickness between H5 (165.6 Ma)
 441 and H5.5 (152 Ma), maximum throw is 100 m and length is 8800 m, **c)** Isochron showing the
 442 thickness between H5.5 (152 Ma) and H5(142.3 Ma), maximum throw is 149 m and length is
 443 8300 m. All throw values could be underestimated up to 20% due to post-depositional
 444 compaction of faulted strata (Taylor et al., 2008).

445 4.3.1 Observations

446 Fault 3 (F3) is an 8.8 km long, NNE-SSW-striking, ESE-dipping normal fault. Its plan-
 447 view geometry consists of a slightly curved, convex-into-the-footwall segment with a small (1
 448 km) fault branch near its northern tip (Figures 10 and 11). The upper tip-line of F3 is located in
 449 Lower Cretaceous strata, and its lower tip-line is difficult to locate due to poor seismic imaging
 450 in the pre-rift, but F3 appears to tip out deep in the study area (Figures 10). The present-day
 451 throw distribution for F3 shows two throw maxima; the main maxima (165+33 m, 83+17 ms
 452 TWT at H4) is located in the center of the main segment, with another, more minor maxima

453 (59+12 m, 37+7 ms TWT at H4) being associated with a possible northern segment (Figure
454 10b).

455 There are wedge-shaped stratigraphic packages between H4 and H6 in the hanging wall,
456 which thicken towards F3. In contrast, pre-H4 and post-H6 strata are isopachous (Figure 10a). EI
457 values are ≥ 1 across a progressively longer portion of the fault from Unit 1-2 (Figures 11a and
458 11b), and in Unit 3, the outer tips of the fault have EI values < 1 (Figure 11c).

459 **4.3.2 Interpretations**

460 We see across-fault hanging wall thickening between H4 and H6 (Units 1-3) in cross
461 section (Fig 10a) and in isochron thickness maps (Figures 11a-c), suggesting F3 was active from
462 c. 181 Ma to 142.3 Ma (Early Jurassic-Early Cretaceous). F3 likely initiated along its central
463 segment during Unit 1 and reached its maximum length by the time of deposition of Unit 2
464 (Figure 11b); this is clearly evidenced by EI values ≥ 1 along the faults entire trace-length.
465 Together with the overall bell-shaped (present) distribution of throw, these EI data (Figure 11)
466 suggest F3 grew as a single fault segment, or possibly as one large fault segment that linked with
467 a very small segment at its northern tip. During Unit 3, EI values were < 1 on the northern-most
468 part of the fault, suggesting that the F3's northern tip became inactive (Figure 11c).

469 In summary, according to throw backstripping and EI analysis, F3 initiated after the
470 deposition of H4 (c. 181 ma), and within c. 15.7 Myr (40% of its total life) was c. 6.2 km long
471 (70.5% of maximum length). During this first phase of activity, it accumulated only 18.9% of its
472 total throw. Approximately 13.6 Myr later, F3 propagated to its maximum length of 8.8 km. The
473 fault had therefore reached its maximum length and accrued 67% of its total throw by this point
474 (i.e. 75% of its life). During the last c. 9.7 Myr of the fault's life, the remaining 33% of throw
475 was accrued, and the length of the fault shortened by 600 m on the NNE tip of the fault.

4.4 Temporal evolution of throw and length

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All of the seven studied faults seem to have grown in three distinct stages: a lengthening stage, a throw accumulation stage, and a tip retreat stage. All of the faults had an early (i.e. first 20-30% of their lives) relatively rapid lengthening phase, during which time they reached 60-95% of their maximum length (see Figure 5a for isochrons across the study area, Figure 12a for values). Fault tips then grew slowly via tip propagation or segment linkage, reaching their maximum lengths after 57-93% of their lives (Figure 5b-c). After they reached their maximum length, all the faults experienced a stage during which their overall at-surface trace-lengths reduced by up to 2.5 km (up to 25% of their total length) (Figures 12a-b). Three-stage fault growth can also be seen in additional faults in Figure 5.

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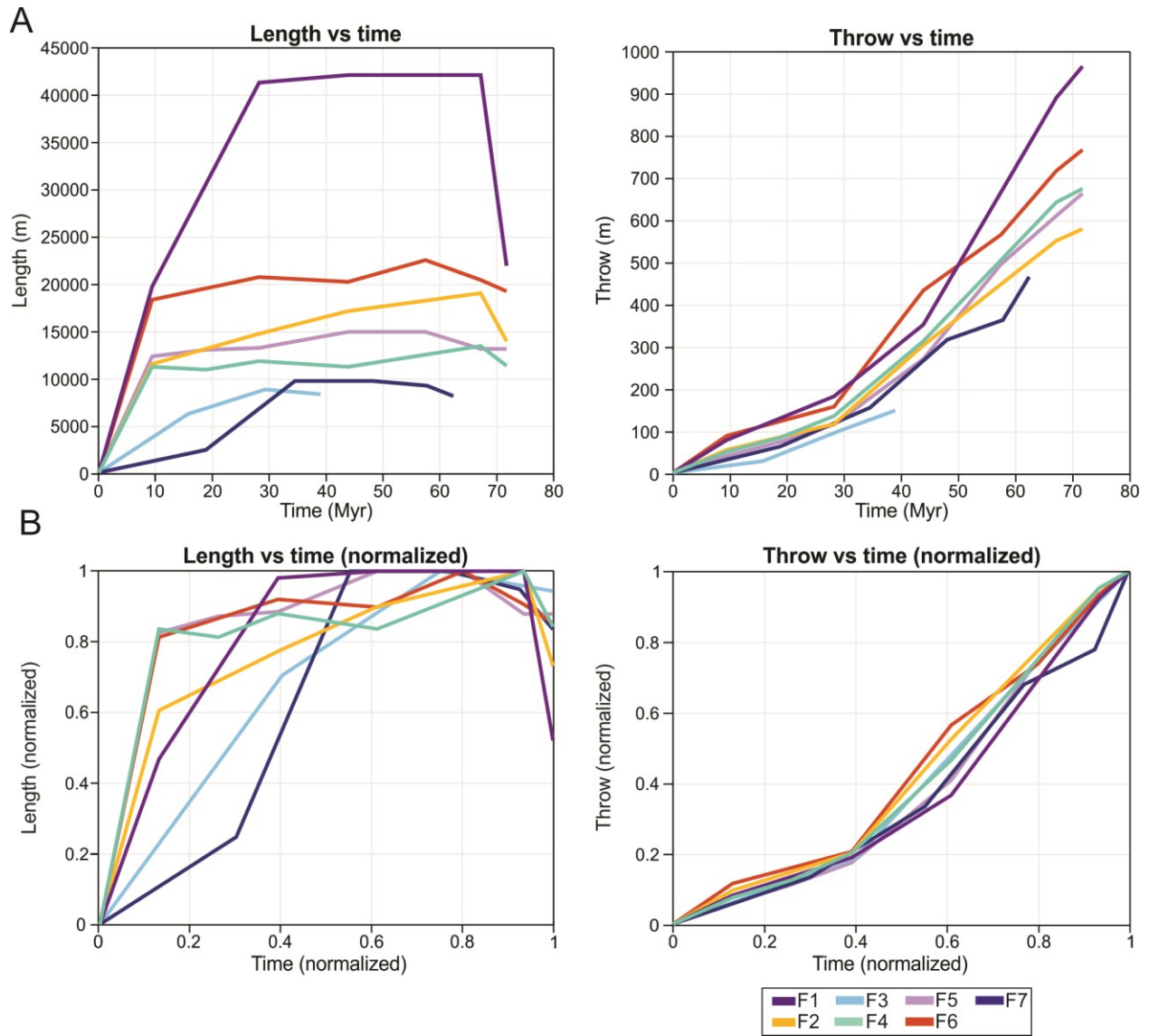
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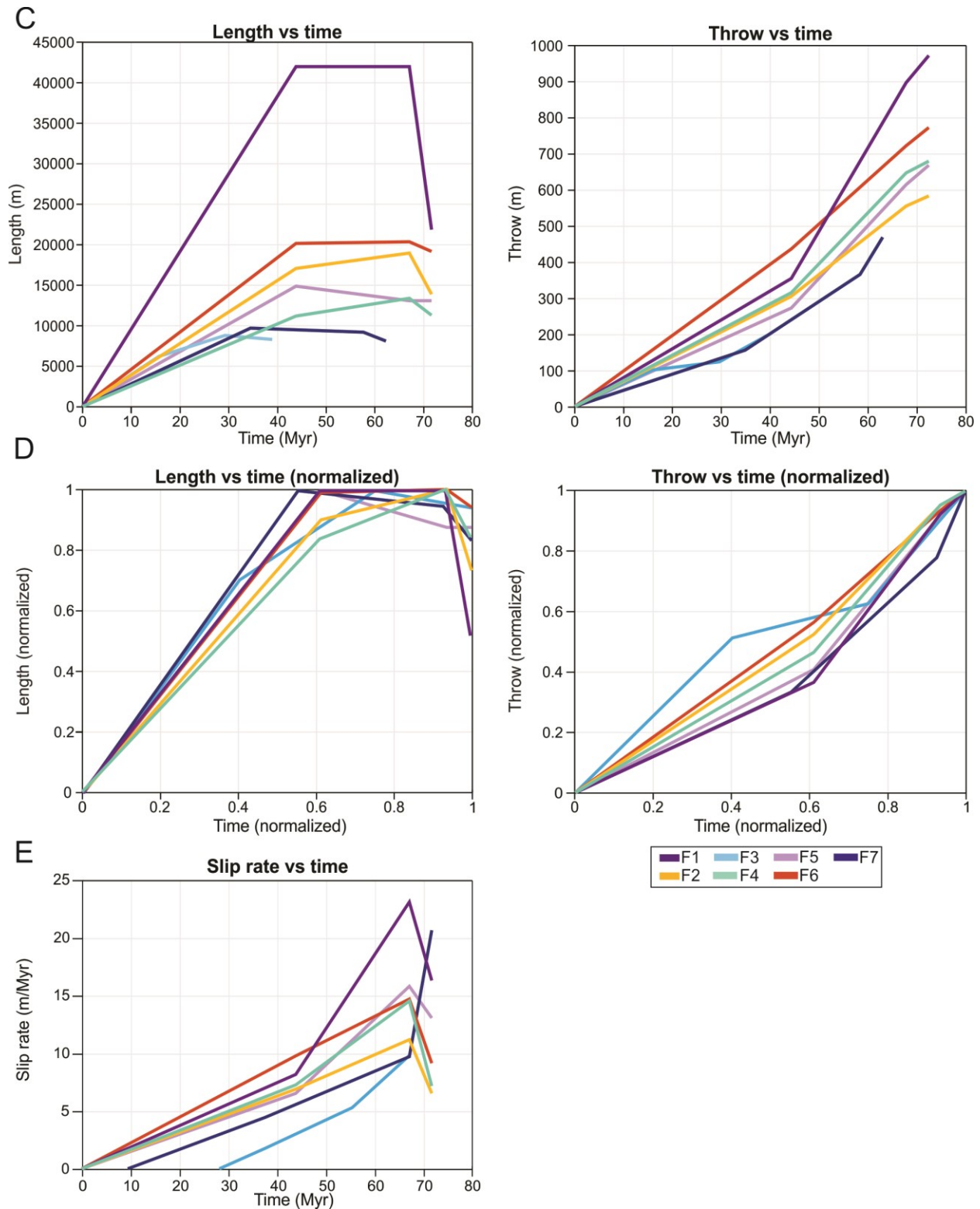
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Because of these shared kinematics, all of the faults studied displayed similar temporal changes in their throw-length scaling relationship (Figures 12b and 12c). The three-stage kinematics identified above also correlated with changes in throw (Figure 12b and 12d) and slip rate (Figure 12e). For example, during the lengthening stage, slip rate was relatively low ($1.8+0.51-9.7+2.0$ m/Myr). During the subsequent throw accumulation stage, there was an abrupt increase in slip rate (to $5.3+1.0-23+4.6$ m/Myr). Slip rate decreased slightly ($6.5+1.2-20.7+4.8$ m/Myr) as the faults died. It should be noted that the slip rate during the first half of the fault's life (until deposition of H5) is likely underestimated due to the basin being somewhat sediment starved during this period. A higher slip rate would mean the time difference between

495 the lengthening and throw accumulation stages is smaller.



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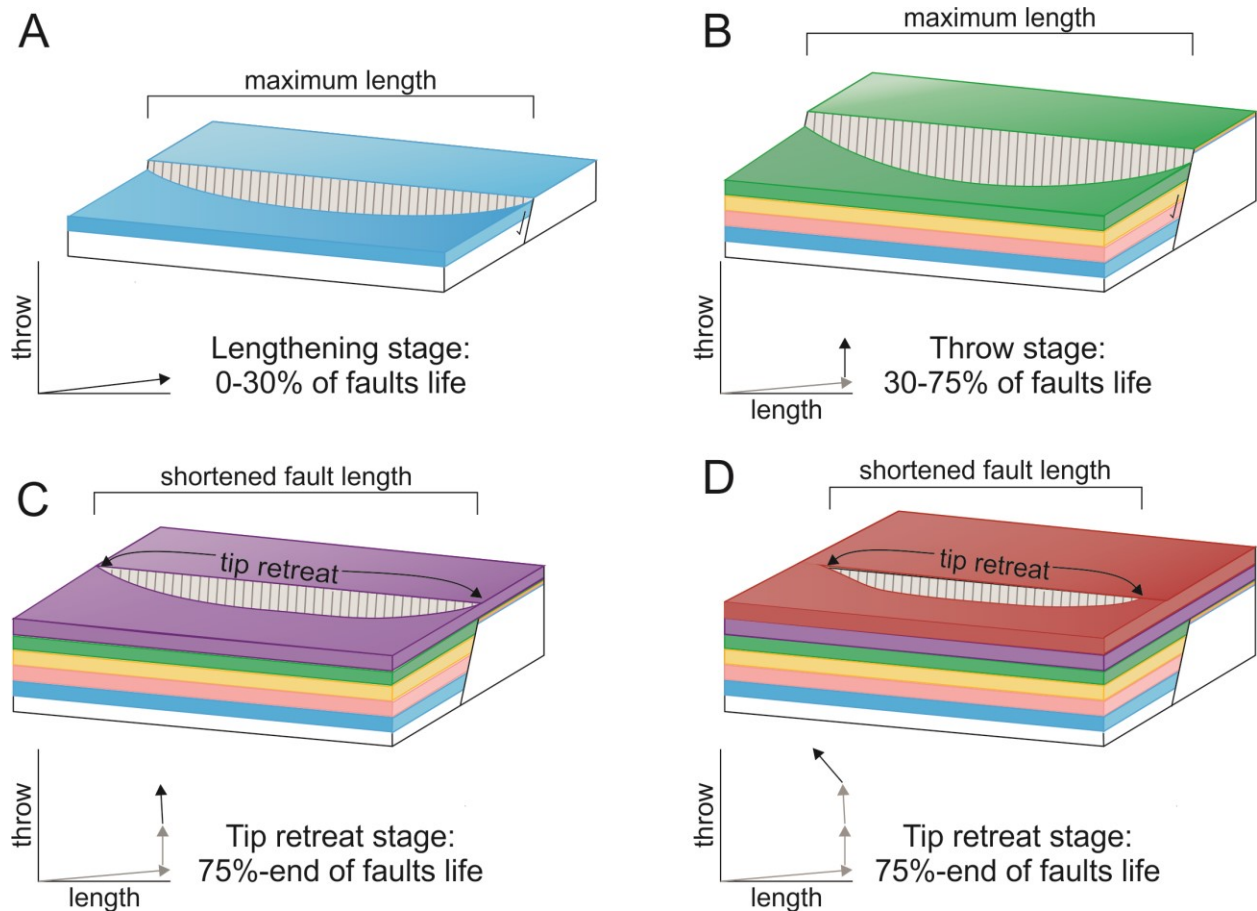
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 498 **Figure 12.** throw and lengthening through time for F1-7 in time and normalized. The
 499 lengthening, throw/displacement, and tip retreat stages of faulting are labelled in the normalized
 500 graphs. **A-b)** Throw and length through time, including all studied horizons, including H2-4
 501 which are not age-constrained. **C-f)** Throw, length, and slip rate through time, only including

502 horizons that have been directly age-constrained. All throw values could be underestimated up to
503 20% due to post-depositional compaction of faulted strata (Taylor et al., 2008).

504 **5 Discussion**

505 **5.1 Implications for fault growth models**

506 Our study identifies three key stages of fault growth on the Exmouth Plateau, offshore
507 NW Australia. First, there was an initial lengthening stage; all of the faults reached 60-95% of
508 their maximum length within the first 20-30% of their lives (Figure 13a). Maximum length was
509 later reached via tip propagation or segment linkage. Second, there was then a throw
510 accumulation stage that lasted from ~30-75% of the faults' lives; during this time, faults
511 lengthened very little and experienced an increased slip rate (Figure 13b). Third, the tip retreat
512 stage, which that lasted for the final 25% of the faults' lives, and during which the faults
513 experienced tip-line retreat and throw was partitioned towards the center of the fault (Figure 13c
514 and 13d). Our findings are generally consistent with the model of Rotevatn et al. (2019), with
515 two exceptions. First, the fault maximum length is not always reached during the initial
516 lengthening stage; i.e. our results demonstrate that, while the bulk of lengthening happens
517 relatively quickly, 5-40% can subsequently occur during lateral tip propagation and/or segment
518 linkage. Variations in when a fault reached its maximum length was likely controlled by whether
519 a fault links with a nearby segment or not, a process perhaps dictated by the ability of the faults
520 to breach intervening relays. Second, there was a stage of tip retreat, a behavior characterizing
521 the end of life of all the studied faults (Figures 13c and 13d). Further work on normal faults
522 imaged in 3D seismic reflection data may reveal this is a more common aspect of normal fault
523 behavior than currently thought, meaning this stage of fault growth or more precisely, death,
524 could be included in general fault evolution models (Nicol et al., 2020).



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Figure 13. Schematic models showing the phases of fault growth. **a)** Fault lengthening stage, when faults establish their near-maximum length within the first 30% of their lives **b)** Fault throw accrual stage, where faults have already reached their maximum length, and throw rate increases **c)** the beginning of the tip retreat stage, where the tips of the fault become inactive and **d)** the continuation of the tip retreat stage, where the active fault trace line is progressively shorter.

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5.2 The role of tip retreat

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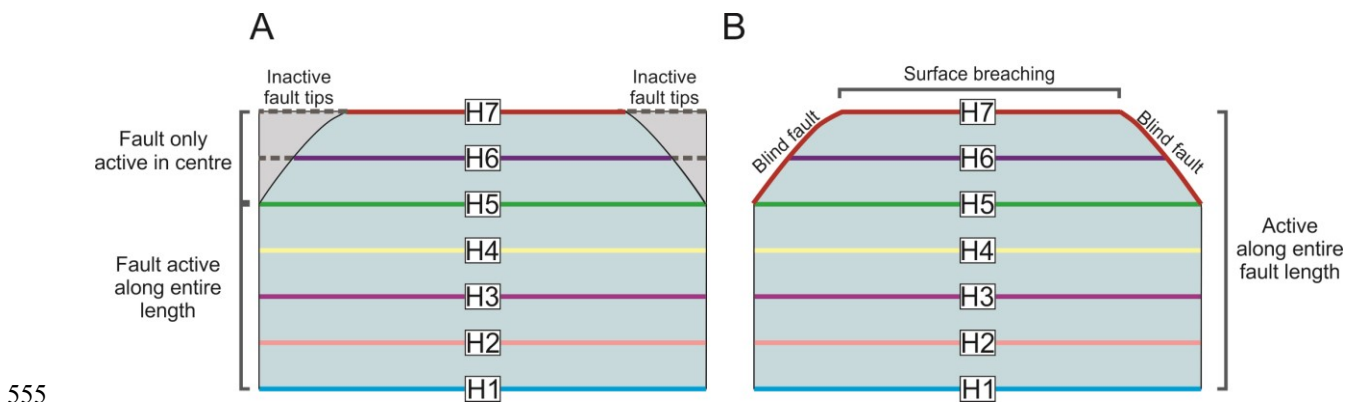
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Fault tip retreat was present on one or both tips of all of the faults in our study. This process has, however, only very rarely been described. Meyer et al., (2002) note a stage of tip retreat on Tertiary normal faults in the Vulcan Sub-basin, NW Shelf, Australia. The reasons why fault tips might retreat may have been overlooked because of a historical focus on how normal faults grow as opposed to how they die, and/or because high-quality, age-constrained seismic

540 reflection data, with numerous mappable horizons within fault-related growth strata, are not
541 available.

542 All of the studied faults decreased in length (by up to 2.5 km, or 25% of their trace-
543 length) during the last 14 million years (25%) of their lives by retreat of one or both of their
544 lateral tips. This could be explained by two hypotheses. The first hypothesis is that the faults
545 were experiencing late-stage *true* tip retreat; i.e. strain became localized near the fault center,
546 leading to progressively shorter surface trace. We would expect that fault surface ruptures
547 shortened as the fault gets closer to death (Figure 14a). An alternate hypothesis is that tip-line
548 retreat was only *apparent* and was related to the faults having an elliptical geometry during the
549 later stages of faulting, due to it having a plunging upper tip-line (i.e. during deposition of H5-7;
550 Figure 14b). In this scenario, the fault would have intersected the free-surface along
551 progressively shorter trace-lengths, with the fault tips being blind (Figure 13b). An increase in
552 sediment accumulation rate relative to fault slip rate could drive this progression. The fault
553 geometries associated with both hypotheses would look similar in seismic data (Figures 14a and
554 14b).



556 **Figure 14.** Schematics showing two possibilities for the apparent tip line retreat in this study.
557 Fault planes along dip are shown, and colored lines indicate the active length of the fault at the
558 time of the deposition of the associated horizons (H1-7). **a)** Fault length remains constant from
559 H1-5 and becomes active a progressively shorter distances across H6 and H7, which can be

560 interpreted as lateral tip retreat. **b)** The fault remains active across the entire length of the fault,
561 but in the later stages of faulting (H6-7) the fault only breaches the surface in the center of the
562 fault, and the fault tips remain active at depth, acting as blind faults.

563
564 We argue that we are seeing true fault tip retreat because if retreat was only apparent and
565 related to the faults elliptical shape, we would expect vertical throw gradients across the horizons
566 to be similar to those encountered on blind normal faults (Childs et al., 2003; Meyer et al., 2002;
567 Walsh & Watterson 1988). For a blind fault, only modest strain can be accommodated by the
568 rock volume without upward tip propagation. In the case of the upper tip of a blind fault, a
569 maximum vertical displacement gradient of <0.1 is typical (Baudon & Cartwright, 2008; Childs
570 et al., 2003; Meyer et al., 2002; Walsh & Watterson, 1988). We measured the maximum vertical
571 displacement gradients between H6 and H7 in the center of the faults and found values between
572 0.08-4.5 (Figures 6b, 8b, and 10b), which is higher than that typically found for blind faults
573 (Walsh & Watterson, 1988) (Figure 13). Such high vertical displacement gradients suggest that
574 the *entire length* of the upper tip-line must have intersected the free-surface (Baudon &
575 Cartwright, 2008; Childs et al., 2003; Meyer et al., 2002), and that a portion of the fault had
576 become inactive during the later stages of the fault's life, before the deposition of H6 and H7.

577 When verifying that the tip retreat we see is real, it is important to ensure that the faults
578 are not sediment-starved during the latter stages of their development (post-Jurassic). A reported
579 example of possible tip retreat comes from the East African Rift (Morley, 2002); however, in this
580 case it is possible that the faults became inactive earlier than assumed, and what appears to be tip
581 retreat is only (passive) sediment filling of a starved basin. In our study, we argue the faults were
582 not sediment-starved at the end of their lives (Berriasian-Hauterivian), given appreciable
583 amounts of sediment were deposited in the footwall of the faults during deposition of H5 to H7
584 (Figures 6a, 7a and 9a).

5.3 Slip rates and slip rate variability

We document a distinct, order-of-magnitude increase in slip rates from as little as 4 m/Myr to as much as 23 m/Myr, some 40-50 Mya after the studied faults initiated, around the time of the deposition of H5 (c. 165.6 Ma). These rates fall towards the lower end of long-term slip rates determined from the analysis of seismic reflection data imaging other natural extensional basins in a range of geodynamic setting (e.g. 4-1000 m/Myr; Nicol et al., 1997). However, these rates are broadly consistent with rates calculated over the relatively long timescales (i.e. >40 Myr) considered here (i.e. 25 m/Myr; North Sea example in figure 2 in Nicol et al., 1997). We note that the increase in slip rates in our NW Shelf examples temporally correspond to a time when many of the minor faults became inactive (see minor faults that tip-out below H5; figures 4 and 5a-c), when strain localized onto the large faults presently defining the basin structure. Similar relationships between increasing fault slip rates (or related subsidence rates) and strain localization are documented in several other natural rifts (e.g. Gawthorpe et al., 2003) and are reproduced in numerical models (e.g. Cowie & Roberts, 2001; Gupta et al., 1998), with this relationship thought to reflect stress-feedback interactions during fault system growth. Long-term fluctuations in slip rate could also reflect changes in regional strain rate, related to the fundamental plate-driven processes driving deformation (Nicol et al., 1997; Mouslopoulou et al., 2009). More specifically, the marked increase in slip rates could reflect an increase in regional strain rate associated with rifting and, ultimately, continental break-up. However, we cannot independently constrain the rate of plate boundary processes during the time interval considered here (i.e. Middle Jurassic to Early Cretaceous), principally because the time-equivalent margin facing the NW Shelf is not preserved.

607 **6 Conclusions**

608 We use 3D seismic data from offshore NW Australia to study normal fault growth
609 through time. We show that the majority of the studied faults had three distinct stages of fault
610 evolution. During the first stage, the “lengthening stage”, the faults accumulated at least between
611 60-95% of their final length and accrued between 10-20% of throw. This stage lasted for up to
612 30% of the faults’ lives. The second stage, termed the “throw stage”, fault slip rate increased, and
613 the remainder of maximum fault length was reached. We also suggest that these faults had a third
614 stage of fault growth, the “tip retreat stage”, where the active trace line of the fault decreases by
615 up to 25% and throw continues to be accrued. More evidence is needed to determine how
616 prevalent tip retreat is, but it could be an important part of late stage fault growth and possibly
617 should be included in future fault growth models.

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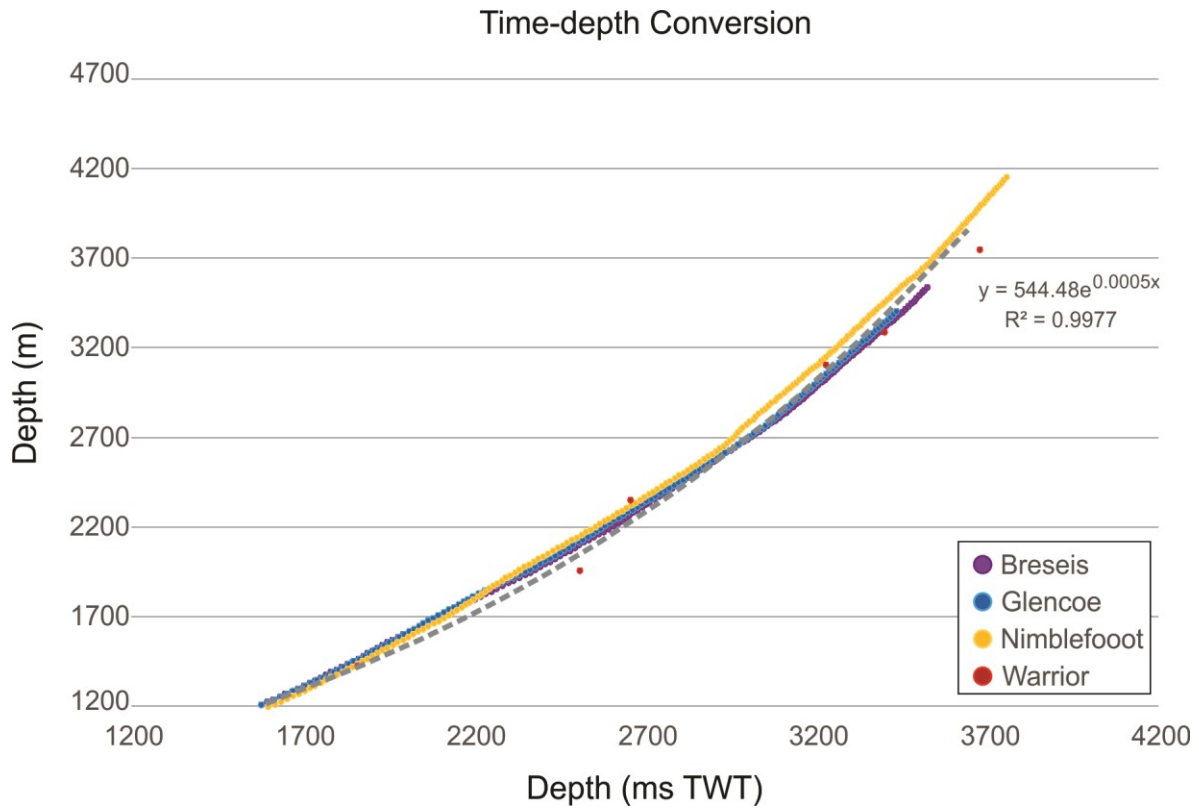
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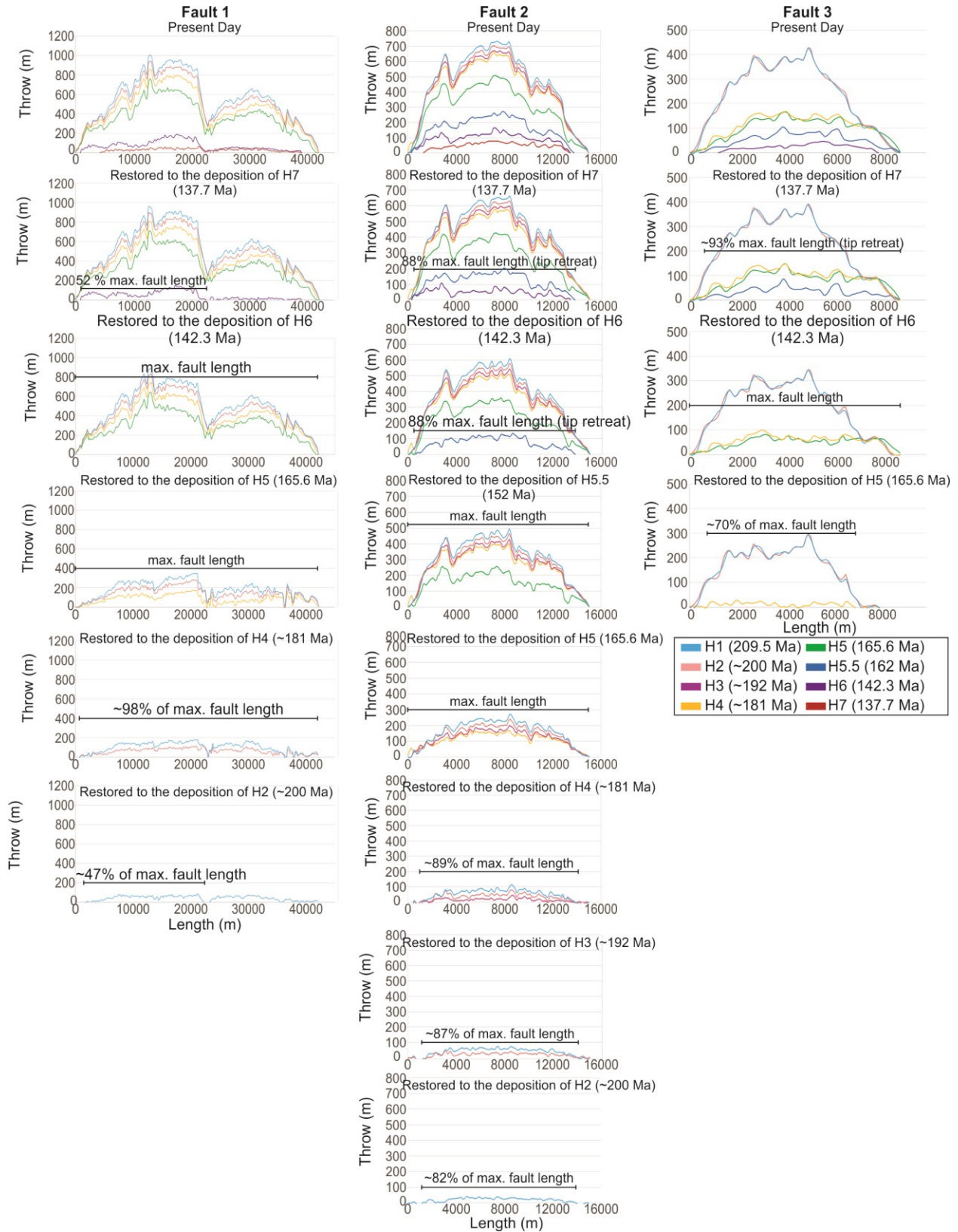
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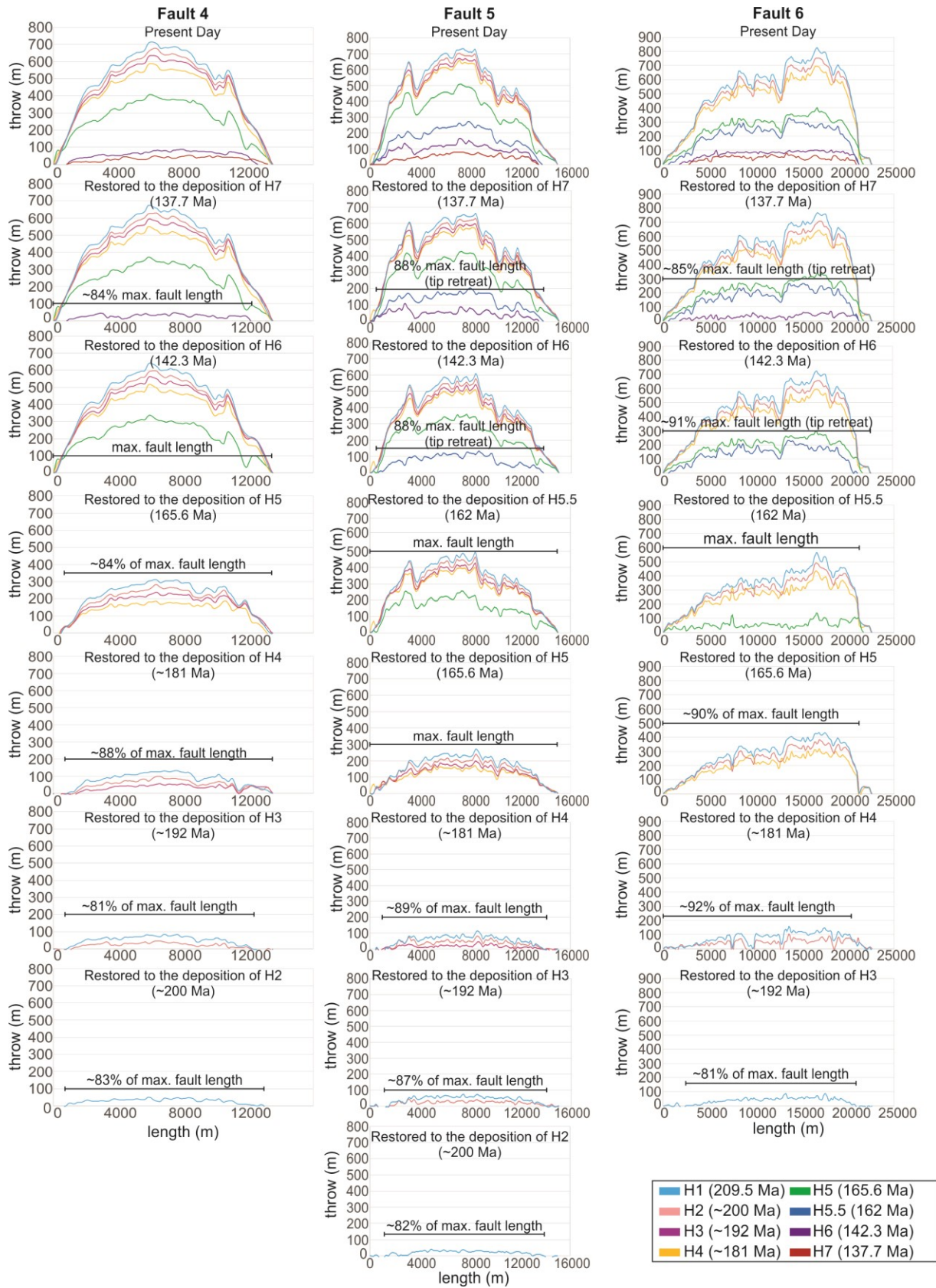
781 **Appendix figure 1.** Time-depth conversion for the 4 four wells in the study area: Breseis-1,

782 Glencoe-1, Nimblefoot-1, and Warrior-1.



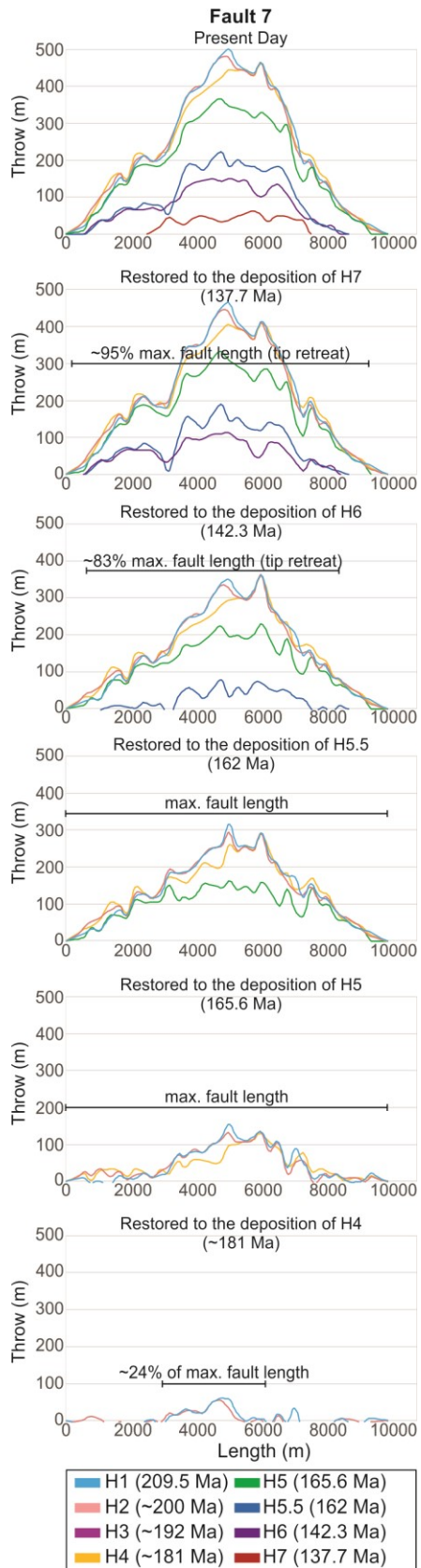
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Appendix figure 2. throw backstripping faults 1-3



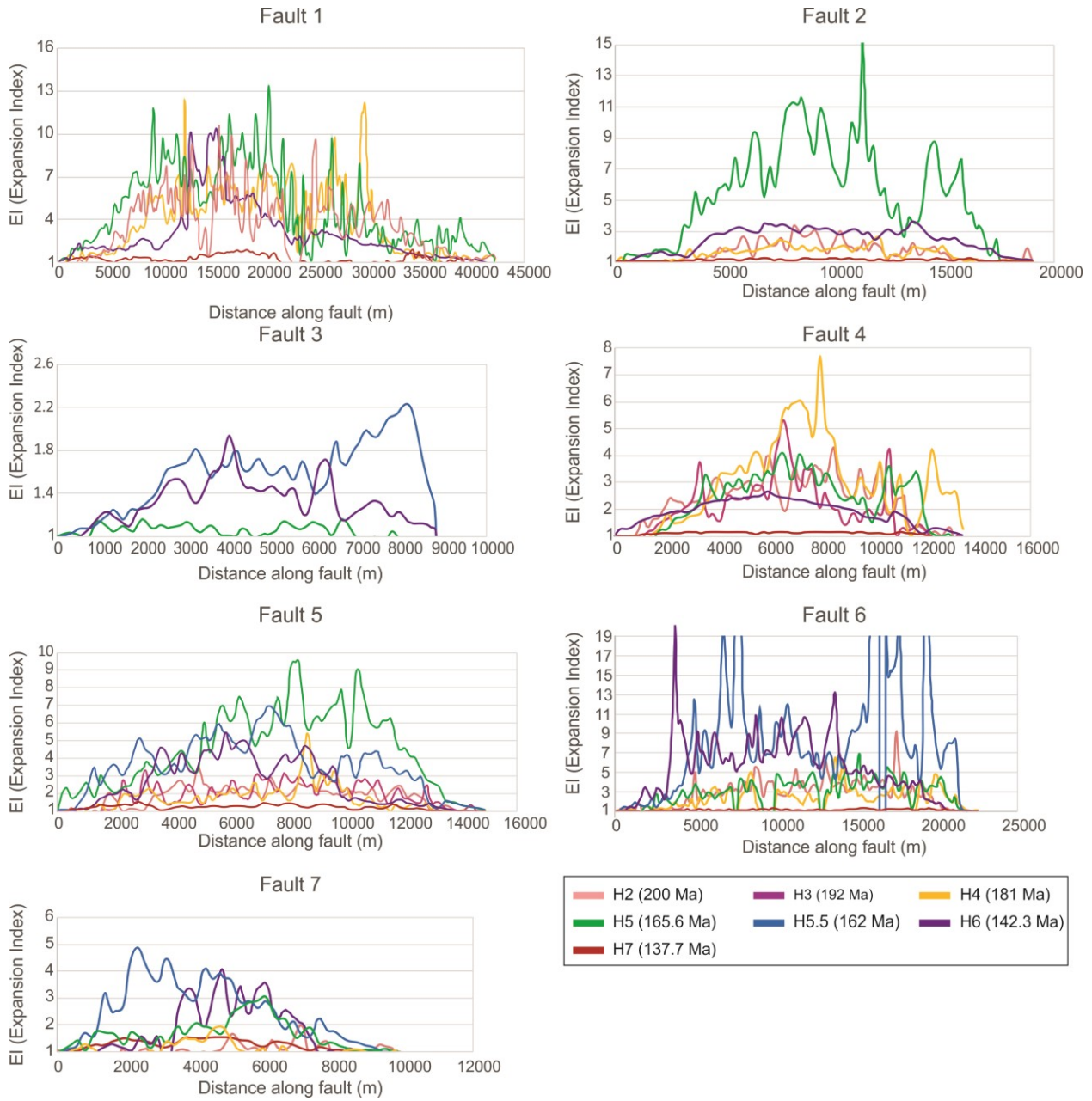
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786 **Appendix figure 3.** Throw backstripping faults 4-6



787

788 **Appendix figure 4.** Throw backstripping fault 7



789

790 **Appendix figure 5.** EI Analysis for faults 1-7

791

| Fault | Horizon | Time (Ma) | Time Accrued (Myr) | Length (m) | Throw (m) | Slip rate (m/myr) |
|-------|------------|-----------|--------------------|------------|-----------|-------------------|
| 1 | H1 (start) | 209.5 | 0 | 0 | 0 | 0 |
| | H2 | 200.1 | 9.4 | 19,700 | 78 | 9.3 |
| | H4 | 181.3 | 28.2 | 41,300 | 181 | 5.1 |
| | H5 | 165.6 | 43.9 | 42,100 | 351 | 11.2 |
| | H6 | 142.3 | 67.2 | 42,100 | 890 | 23.1 |
| | H7 | 137.7 | 71.8 | 21,900 | 963 | 16.3 |
| 2 | H1 (start) | 209.5 | 0 | 0 | 0 | 0 |
| | H2 | 200.1 | 9.4 | 11,500 | 55 | 6.0 |
| | H4 | 181.3 | 28.2 | 14,700 | 116 | 3.4 |
| | H5 | 165.6 | 43.9 | 17,100 | 303 | 12.4 |
| | H6 | 142.3 | 67.2 | 19,000 | 550 | 10.8 |
| | H7 | 137.7 | 71.8 | 13,900 | 578 | 6.5 |
| 3 | H4 (start) | 181.3 | 0 | 0 | 0 | 0 |
| | H5 | 165.6 | 15.7 | 6200 | 28 | 2.3 |
| | H5.5 | 152 | 23.9 | 8800 | 100 | 6.3 |
| | H6 | 142.3 | 39 | 8300 | 148.5 | 7.5 |
| 4 | H1 (start) | 209.5 | 0 | 0 | 0 | 0 |
| | H2 | 200.1 | 9.4 | 11,200 | 50 | 5.3 |
| | H3 | 190.7 | 18.8 | 10,900 | 84 | 3.6 |
| | H4 | 181.3 | 28.2 | 11,800 | 135 | 5.4 |
| | H5 | 165.6 | 43.9 | 11,200 | 313 | 11.3 |
| | H6 | 142.3 | 67.2 | 13,400 | 641 | 14.1 |
| 792 | H7 | 137.7 | 71.8 | 11,300 | 673 | 7.0 |

793 **Appendix figure 6.** Table showing fault horizon age, length, throw, and slip rate for each horizon of faults 1-4.

794

| Fault | Horizon | Time (Ma) | Time Accrued (Myr) | Length (m) | Throw (m) | Slip rate (m/myr) |
|--------------|----------------|------------------|---------------------------|-------------------|------------------|--------------------------|
| 5 | H1 (start) | 209.5 | 0 | 0 | 0 | 0 |
| | H2 | 200.1 | 9.4 | 12,300 | 40 | 4.4 |
| | H3 | 190.7 | 18.8 | 13,000 | 74 | 3.6 |
| | H4 | 181.3 | 28.2 | 13,200 | 115 | 4.8 |
| | H5 | 165.6 | 43.9 | 14,900 | 270 | 10.6 |
| | H5.5 | 152 | 57.5 | 14,900 | 495 | 17.9 |
| | H6 | 142.3 | 67.2 | 13,100 | 609 | 12.9 |
| | H7 | 137.7 | 71.8 | 13,100 | 662 | 13.0 |
| 6 | H1 (start) | 209.5 | 0 | 0 | 0 | 0 |
| | H2 | 200.1 | 9.4 | 18,300 | 88 | 9.9 |
| | H4 | 181.3 | 28.2 | 20,700 | 157 | 3.8 |
| | H5 | 165.6 | 43.9 | 20,200 | 432 | 16.8 |
| | H5.5 | 152 | 57.5 | 22,500 | 565 | 12.4 |
| | H6 | 142.3 | 67.2 | 20,400 | 716 | 17.9 |
| | H7 | 137.7 | 71.8 | 19,200 | 766 | 9.1 |
| | 7 | H2 (start) | 200.1 | 0 | 0 | 0 |
| H4 | | 181.3 | 18.8 | 2400 | 62 | 3.2 |
| H5 | | 165.6 | 34.5 | 9700 | 155 | 5.9 |
| H5.5 | | 152 | 48.1 | 9700 | 316 | 12.2 |
| H6 | | 142.3 | 57.8 | 9200 | 362 | 6.2 |
| 795 | | H7 | 137.7 | 62.4 | 8100 | 465 |

796 **Appendix figure 7.** Table showing fault horizon age, length, throw, and slip rate for each horizon of faults 5-7.

797

798