



Title	A review of producing fields inferred to have upslope stratigraphically trapped turbidite reservoirs: Trapping styles (pure and combined), pinch-out formation, and depositional setting
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22 ABSTRACT

23 Sibiclastic tsybfidh at pinchout up dipirpoximalaltheaegim targets
24 for hydrocaxpboration especially in . See phwat p slopes is stratigraph
25 potential large volume discovery esignificant otogicsknotable to
26 ineffective containment the published literature as a result of basins
27 globally -with the discovery of heavy oil basins on upslopes
28 pinchout. This paper reviews the terms in the literature, pinchout
29 formation and depositional settings. A range of upslope tra
30 styles, including (1) depositional and stratigraphic pinchouts
31 stratigraphic pinchouts, and (2) fault-related pinchouts, are
32 trapped in slope feeder channels. The development in
33 some cases may be the most important trapping element. Bypass and
34 erosion in proximal areas is the most common mechanism. Some pinch
35 reservoirs demonstrate the ability to function as channels in a
36 transverse stratigraphic pinchout. Encouragingly, for a number of
37 pinchout cases, a variety of different slope types and
38 along the slope. Most large volume discoveries were restricted to the
39 slope environment of passive continental margins, rift and transform margins.
40 Insights to the nature and occurrence of upslope stratigraphic
41 exploration, especially for gas, are discussed in perspective.

42

43 INTRODUCTION

44 Stratigraphic traps by updip pinchouts towards the proximal basin
 45 deepwater depositional systems and in particular hydrocarbon
 46 exploration particularly in the deep water region (Figure). This slot trapping
 47 configuration for turbidite complexes embedded within deepwater
 48 exploration models including stratigraphic (Mara et al., 2003) margin
 49 pinch (Stoker, 2006) and detachment (Fuge and Isen, 2005; Worsell
 50 et al., 2006) stratigraphic (Fitch et al., 2009) and (Bjorau et al., 2006)
 51 plays. Such stratigraphic traps potentially hold large volume undiscovered
 52 frontier or mature assets that are present or have already been tested
 53 al., 2006; Bjorau et al., 2006; Stiller et al., 2006) and in commercial volumes (500 MMBO
 54 recoverable reserves) is suggested to have upslope stratigraphic turbidite
 55 fields (Tano Basin, offshore Ghana; Buzzard Field, Moray Firth, North Sea
 56 Marlim and Marlimé (Campos Basin, offshore Brazil) and in particular a
 57 particular focus on upslope stratigraphic traps in the Cretaceous
 58 deepwater sequence of the Atlantic margin of the West African Equatorial transect
 59 Cote d'Ivoire, Sierra Leone and the Atlantic margin of Guyana, Suriname,
 60 Guyana (Flinch et al., 2006; Eggor et al., 2003; Bittell et al., 2004).

61 Whilst there has been a move towards increasing the depth of later
 62 stratigraphic traps (Stiller et al., 2006; Dailly et al., 2006; Bittell et al.,
 63 et al., 2007) number of commercial discoveries by upslope traps has not
 64 remained limited. Hence, despite the potential for the high permeability of commercial
 65 success based on past exploration experience and relatively good judgement to

66 contain meso-scale traps and are of a type that can be expected to
67 leakage of hydrocarbons from the principal loggia (Stratton & Prather, 1999;
68 Prather, 2003; Lutz, 2004) a critical issue for all types of stratigraphic
69 deepwater turbidite systems, proximal, lateral or (Fig. 1) a margin
70 particularly for slope pinchout traps, because of their feeder
71 system to extend along the slope to those higher on the slope or
72 systems. Such systems are relatively difficult to solve with seismic data.
73 There is also a possibility of systems on the proximal margin which
74 or base. The nature of the proximal margin, particularly in terms of traps
75 considerably higher than compared to distal margin.

76 In this study, we review the literature on the tectonic and
77 upslope stratigraphic evolution and number of aspects critical for predicting
78 this trap type, as discussed in the literature on slope trapping
79 configuration, whether upslope trapping is a primary or secondary combined
80 structural trapping, in the context of basin development and the
81 tectono-depositional setting in which it occurs. A better understanding of
82 aspects of upslope traps is valuable in margin and slope
83 profile, and hence areas, offer the best potential for traps
84 volume discovery. In the following, the approach will be to look at
85 traps first, but in discussing each of the mentioned above, we will
86 key lessons for traps in the context of basin development and fields with
87 this trap type within the public domain.

88

89 IDENTIFICATION OF RESERVOIRS

90 The workers synthesis information previous published fields is used to have
91 upslope stratigraphically. Examples of these fields are the Eocene, the
92 total or a significant fraction of the total depends on stratigraphic
93 pinch, and are compiled from published literature. Identification was assisted
94 using consultancy data from Digital Analog Knowledge System
95 holds published data over 1400 reservoirs followed by a broader review of
96 Only well described reservoirs in the production fields in
97 currently producing and abandoned commercial and new discoveries are considered
98 owing to the lack of published information. These reservoirs include those with
99 systems presented perpendicular to the structural direction, slope pits
100 of lobes or channels, and carbon accumulation (Figure 3A). Both
101 depositional and erosional settings are considered. The term
102 pinchout in this study is defined as a late stratigraphic non-reservoir
103 against seal integrity of a well in the subsurface. Figures (3A
104 3B).

105 In total 20 oil and gas fields in the upslope stratigraphic belt are identified
106 were identified basins (Table 4). Recoverable reserves of these fields
107 from a few million to over 1 billion barrels, and the order of 6
108 BOE fields were discovered between 1952 and 2010, with two prominent periods
109 (between 1998-2001 and 2001-2010) corresponding to periods of high energy
110 field formation. Table 1 and Table 2

112 UPSLOPE TRUNCATION

113 For each published maps and cross sections, we understand
114 trapping (Figure 5) and a variety of trapping configurations to
115 combined with faulting, as described in the trapping (Tab. 1)
116 2). The various interpretations are summarized in
117 schematic Figure 7. For some multiple interpretations and combined
118 trap configurations, we focus on the potential importance of
119 cutting feeder channels, as exemplified in the following fields.

120

121 Pure slope traps

122 For both the considered fields, pure stratigraphic trapping principles
123 inferred trapping (Figure 8) are observed in the Buzza, English C
124 Jameson, Marlum Sul, Baudin, and Padua, and are related solely on
125 stratigraphic principles determined from seismic and well data (see
126 Authors describing these reservoirs in the respective papers). In addition,
127 also plays a partial role without any doubt in the Pardal
128 majority of the reservoirs (80%) are inferred to display depositional
129 display evidence of truncation (Figure 9).

130

131 Trap associated with faulting

132 A number of ravinic sub-Jubilee, Foinaven and a Merulipide boundaries
133 coincident with the stage (see also Figure 5). Whilst stratigraphic pinch
134 identify these, it is not a reliable, wholly representative of faulting
135

136 Jubilee Field

137 The Jubilee is one of the most prominent features in the stratigraphic
138 pinch out of the discussion of the context of the stratigraphic (see also well 1; 2011
139 Biteau et al., 2014) 2014 development which outstretches Mahogany
140 sequence seawards to the west and east and locally outcrops to the
141 north (Figure 8). In addition to the shale and siltstone assemblage
142 present in the north the sandstone and shale sequence in the north
143 (Figure 8). Cilly et al. (2012) reservoirs appear to be trapped against a
144 fault towards the east (see also 2014) suggest a combined stratigraphic
145 trapping configuration in the Tertiary fault reservoirs based on seismic
146 attributes of faulting in any of the cross sections (Figure 8). Jubilee
147 therefore may not be a simple epimorphic fault but a complex structure
148 feeder system. This is supported by the presence of the Tertiary sands
149 to occur on the plateau of the crest of the Tertiary (Trullow Ltd.
150 media 2008)

151

152 Foinaven Field

153 Significant emphasis is placed on stratigraphic trapping, which is the
154 recognition of a combined structural and stratigraphic trap (Batra et al., 1999; Carruth,
155 Loizou et al., 2006). Rather (consider the Foinaveni and Ya base
156 slope onlap trap, with T3s1 pinching out up the eastern side of the
157 However, it is also the potential importance of faulting elements illustrating
158 eastward dip. The importance of structural elements is illustrated by
159 analysis of Loizou et al. (2006) pointing to Palaeocene sections dip towards
160 the SE. Related to a combination of dip closure (due to the West African
161 against Palaeocene (Figure 4), Carruth (1993) and a hybrid of a filled
162 sandstone against a faulting groove inferred to the southern and southern
163 point (Figure 5 & 6). Normal faulting is inferred to be responsible for trapping
164 neighbouring Schiehallion and the Hayan fields turbidite reservoirs
165 (Leach et al., 1999).

166

167 Campos Basins

168 Oligocene sandstones in the Mulholland Basin are inferred
169 to be a deep deposit on the proximal slope towards the west
170 (Peres, 2003). The field is a combined structural and stratigraphic
171 configuration (Figure 5). Field limits are defined primarily by the west
172 and southward normal faulting to the east, northeast and northward
173 and Cora). Faulting at the reservoir mainly by the growth of a steeply
174 response to renewed salt withdrawal during the late Miocene (Peres, et al.
175 1993). Along the proximal westward axial graben a series of feeder systems

176 (Figure 8) Thus, the stage faulting is sufficient to suggest that it could
177 play a part in trapping.

178 From the above it is clear that a number of high pressure fields commonly
179 discussed stratigraphically are poorly controlled by considering all the
180 fields in Table 1. The third of the faults may play an important role in trapping
181 (Table 2) Post-depositional faulting of the system setting potential traps
182 critical in forming gas fields. Jubilee Oilfield in Budzagd, and
183 Glenlivet and Aggare are located on strongly faulted fields. While the
184 reservoir is difficult to confirm in these cases, it is likely that some
185 of the reservoirs in the area also exist in trapping in the system.
186 strongly faulted areas also have potential to be developed further
187 below.

188

189 FORMATION OF UPSLOPE PINCHOUTS

190 A range of processes in deepwater turbidite systems temporal and spatial
191 can give rise to pinchout development, as indicated in Figure 1 (in
192 1). Subsurface studies on proven upslope systems indicate that a process
193 responsible for pinchout development is the development of a bypass by
194 current erosion by channel erosion by mass transport (Table 2) complex

195

196 Bypasses at pinchout traps

197 In the majority of cases, these pinchouts are believed to be positional pinchouts
198 formed by a combination of gravity flow and a local palaeogeographic system
199. Detached sandstone developed on slopes of sediment transfer zones in the
200 conduits that are subsequently filled by sealings (Bouvier et al., 2010; Alba
201 (Harding et al., 1990; Newton and D'Almeida, 2005; Buzzard et al., 2013;
202 (Stephens et al., 2013; Horsman and Homery, 2014), file 135 seismic
203 and well data for these sequences and their reservoir intervals
204 younger depositional elements or systems.

205 As discussed, many of the reservoirs were developed as a result of
206 Jubilee, Foinaven, Bluzet, Lagard, La Fardière. A prime mechanism
207 by which slopes were steepened encouraging erosion and by-pass on
208 (Ross et al., 1994). Buzzard provides an example of a stratigraphic pinchout
209 fault controlled but where the reservoir level is believed to ultimately
210 trap (Figure 2.1).

211 As well as oversteepened slopes, faulting can form the basis of
212 palaeogeographic encouraging local deposition patterns. The Glenlivet
213 field of the Fardière Basin provides an example of a stratigraphic pinchout
214 fault (Figure 3.1). The reservoir has an updip stratigraphic pinchout
215 it only appears because of a Cenozoic conformity (Horsman et al., 2014). Seismic
216 Palaeocene reservoir levels suggest a relatively stable platform with
217 controlled by sedimentary growth (Figure 3.18). Local deposition occurred
218 upper slope topographic lows formed on the downthrown side of a

219 al., 2014). The nearby Laxford gas discovery
220 fault controlled depocentre with slope pinchout (

221 Upslope and dip terminations observed in the Archaean
222 related depositional flows traversed a (Newman and Flanagan,
223 1993). In this case, palaeoslope is not a function of the
224 subsidence differential compaction over (Hardenburg et al., 1993).
225 Deposition of channel deposits have occurred on the relatively
226 dipping terraced slope (Newton and Flanagan, 1993).

227

228 Erosional truncation channels

229 A number of reservoirs show evidence for pinchout related to
230 younger-fine grained channel deposits in the Marlim Sul (Carnaubas
231 field, Rakhine (Bassett). In these systems, clear evidence of high quality seismic
232 data seen dissect basin fan deposits, suggesting or assisting with
233 proximal and lateral stratigraphic trap

234 The depositional model for the Oligocene Campesina system
235 shelf turbidite systems developed at the lower slope by the
236 canyons and lower slope (Peres (Figure 9.10). The lower slope
237 appear lack continuity slope, with connections on the middle and
238 slope regions (Peres, 1993). Erosional channels filled and heavily
239 the western part of slope region in the Marlim Sul and Carnaubas
240 responsible for the individual sand bodies (Peres, 1993).

241 de Castro, E2014) is of the (2010) p7 a-30 k (0.61.9 mii) (Figure
242 14B & C) In the Barracuda and M, a filled channels in which depositional
243 sand pinchouts and decrease (subsiding) (ears) and reservoir distribu
244 field dip slope towards the west

245 The Shwe gas fields (Shwe, Shwe Phayla and B, Myanmar)
246 filled channels dissect basin lobes forming isolated reservoir bodies
247 stratigraphic trap component (Ridd, 2015) (Figure 4E). These
248 reservoirs are stratigraphically trapped SE the anticline limb
249 plunging to the SW (Cliff, 2016) The system is inferred to have been
250 both the Garo and maputra and their reservoirs from the NW and
251 respect (Ridd, 2015). Whilst updip stratigraphic trapping
252 crest of the anticline in a NE direction (involving the lateral
253 stratigraphic component towards the N and NW (up the pl
254 depositional dip). Two types of channels (also recognized in the
255 with smaller larger sinuosity erosional channels with
256 prograded across and existing into deposits and are inferred to
257 sediment conduits and formed by (Figure 4D). These erosional channels
258 up to 100 m deep, greatly influence field size as well as compartment
259 reservoir (Figure 4E). In Shwe gas fields, erosional channels bounded by
260 with depositional pinchouts (seen as downlap) are responsible
261 stratigraphic trapping filled channels and depositional systems
262 suggest better trapping of water and gas (Ridd, 2015).
263 2015).

264

265 Erosional truncation by Complex (MSTCs)

266 A number of middle Miocene reservoirs are preserved in a Gulf of Mexico
 267 stratigraphic trapping related to erosional truncation and sea level
 268 deposits (Coble, 2000). These include the Nautah and Bagdad fields, composed of
 269 levee reservoirs that occur as irregular isolated remnants in channels (Fig. 15).
 270 their original depositional geometry is obscured by significant
 271 effects show no correlation to sea level fluctuations with the recognition
 272 erosional origins and some of the mass flows responsible for some
 273 prodelta sands are steeply dipping (Fig. 15A). The particular
 274 gas reservoirs are relatively small in extent and are associated
 275 sands. Such sands, however, are more extensive in some areas
 276 there were fewer episodes of erosion and transport and may play
 277 a role in trapping gas in the Ram Powell field located in the inferred
 278 to be eroded and overlain by an inter-tectonic seismic facies (e.g.,
 279 in Clemence, 2000). In the L Ram Powell reservoirs and trapping is
 280 towards the north-east is considered rather than slope stratigraphic
 281 levels.

282

283 TECTONIC POSITIONAL SETTING OF UPSLOPE PINCHOUTS

284

285 Pinchout significance

286 Reservoirs were assessed in terms of their being, slope type and position
287 published literature evaluation of available semi-regional (Fig 10) where the scheme
288 proposed by other authors (2016) categorising slope type; it is possible that
289 iii) gross depositional (GD) Fig 10. The distribution of reservoirs in this
290 scheme is shown in Figures 11 to 17 for all reservoirs considered for those where
291 structure has not been implicated. Table 2) slope trapping (see
292

293 Tectonic setting

294 Reservoirs are referred to as slope stratigraphic traps where they are found in tectonic settings
295 including extensional, convergent (Fig 17, Table 2) and basin settings
296 including the rift setting of the outer Moray Firth (offshore Shetland, Central North
297 Sea failed rift) of the Central North Sea and margin settings of the Cameroonian
298 Santos basins (offshore Brazil) and the NE Gulf of Mexico basin (offshore
299 include the Joazeiro Basin (Central Brazil) convergent margin and include those
300 of the rear Rakhine Basin (offshore foreland of the Permian Basin
301 (onshore Texas and New Mexico) and the extensional margin and rift basins
302 margin and rift basins which account for the majority of Fig 17).
303 17).

304

305 Slope type

306 Regional dip profiles of selected Fig 18 showing that slope stratigraphic
307 traps are located in (a) the northern GOM reservoirs - and also in the southern

308 systems (e.g. Fig. 10). Whilst the Shweta involves all prograding
309 margins were deposited the margin of grades is indicated by a
310 an erosional truncation. The margin would occur in a regular profile due to fa-
311 hends considered as a prograde system. No examples of slope trapping
312 identified from ponded systems in association with graded slopes
313 common followed by stepped margins.

314

315 Slopes and GDE

316 Proven upslope traps occur in a belt of the upper slope
317 basin (Fig. 11); the slope and lower slope locations are shown.
318 Reservoirs in this location are formed by slope traps (e.g. S. U. Brahma, Jameson,
319 Young North and Shwe) and submarine valley deposits.
320 eastern GOM formed by erosional remnants also appear to be
321 Reservoirs higher up on the slope include stepped (e.g. Brahma) as
322 as well as submarine valleys (e.g. S. U. Brahma) of GDE, most upslope
323 occur with faults (Fig. 12).

324

325 Grain size

326 Evaluation of reservoir grain size indicates that most reservoir
327 fine grained and medium with few coarse sands (Fig. 13). Compared to
328 other turbidite reservoirs, those with upslope pinchout traps tend to

329

330 DISCUSSION SETTINGS PRONE TO UPSLOPE PINCHOUTS

331 Out of grade erosional margins are a very common feature of the
332 turbidite system development, and by implication contrast with high grade
333 margins (e.g., Ross & Edlén, 1994; Halden et al., 2005). Practically
334 instead view of slope environments of graded slopes are passive
335 trappings. They result from the present and past pinchout development requiring
336 trapping limited by tectonic setting, slope position and reservoir
337 reservoir position. Documented examples of reworked slope pinchouts
338 demonstrating pinchouts are known from tectonic and depositional
339 including extensional, compressional and strike-slip tectonic settings
340 occur in passive margins and highly developed passive margins
341 As such, reservoirs are located on graded, and stepped slope type
342 position on the slope and affiliated with different gross depositional
343 reservoirs include those with a range of gross depositional environments
344 including as the valley, perched fans and aprons. Hence, opportunities exist
345 wide range of basins and deepwater depositional environments.

346 In terms of volume, however, as assumed by (2003) the majority of
347 giant oil fields are found in limited number of settings, principally:
348 slope of graded passive margins (and in the case of drift and
349 transform margins). Graded slopes of passive margins are large
350 cumulative volumes by the giant fields with the Carriacou Basin located
351 the top of the slope. Jubilee, Foinaven and Buzzard provide examples
352 slopes. These occur relatively high up on the slope profile in as

353 reservoirs in some aprons which extend the slope (Table
354 3; Figure 17)

355 From a sequence stratigraphy perspective, deepwater strata
356 lowstand systems tracts with turbidite basins, often as
357 detached lowstand bodies above the same level (Van der
358 al., 1999). The majority of slopes are, however, are not
359 reported to occur above the stratigraphic level of the
360 pinchout of Paleocene reservoirs on to a top Cretaceous unconformity.
361 Reservoirs of the Oribi field are interpreted as a lowstand body at the
362 a progradational clinof orm sequence (Brook et al., 1995) and a
363 pinchout in the common form of upslope terraces (type 2
364 (base, lateral accretion) as provided by intertidal water shales or
365 pelagic sediments (Wright and Brett, 1992; Carruth, 2003; Ray
366 2014). The lack of association between upslope stratigraphically
367 boundaries is simply a reflection of incomplete knowledge of the sequence
368 system. Alternatively, it may indicate a major sequence boundary is not
369 development of robust stratigraphic traps, the lack of development
370 systems or porosity.

371 Relatively grainy turbidite systems have been proposed
372 stratigraphically as a sequence (Reading & Richardson, 1994; Ols
373 2005). This is due to their -to be built low early in the greater by
374 material (high efficiency) (Mutter & Normark, 1987) which is supported
375 in this analysis the systems examined consist of a fine sandstone

376 are relatively grainier compared to other turbidites. The combination of
 377 oversteepened slopes in conjunction with fine grained systems
 378 sediment bypass is critical to the development of marginal depositional
 379 prone to bypass and erosion may develop in the form of a graded margin
 380 carbonate margins with enhanced slope (Rosenfeld et al., 1994).
 381 have been discussed (Llanos and Zaitsev, 1994). Reservoirs from the Permian
 382 Jameson and Young North fields are examples of upslope traps in associated
 383 margins that may have developed by means of oversteepened ca
 384 forming detached turbidite systems from steep margin the
 385 context of low grade margins undergoing slope readjustment,
 386 overstratigraphically graded margins, (2001) also experienced
 387 episode of gradual such that flows predominantly bypassed these
 388 may be a result of a seismicity related overstratigraphically graded
 389 Reservoirs of the Campos, Rakhine and eastern GOM basins with
 390 clinof orm geometries may be considered within this

391 The notion of a detached turbidite (of the type described by
 392 by a channel transition (CLTZ) is an important aspect of turbidite
 393 pertinent to stratigraphic interpretation (Wynn et al., 2002; Van der M
 394 2013; Stevenson et al., 2015) detached turbidites from a deep
 395 system may develop in sediments, caused by a flow exiting the channel or
 396 over a slope commonly deemed to promote erosion (Wynn et al., 2002;
 397 2002; Brooks et al., 2016). It may be an important process producing
 398 this study does not have a clear indication for stratigraphic interpretation
 399 on CLTZ indicate the same process always results in a complete bypass which

400 sea floor examples containing coarse sand beds (Wynn et al., 2002) and crop examples
401 containing thin sand beds (Van der Hilt et al., 2014). The evidence for the effectiveness
402 of CLTZ is a robust pinchout traps, without relying on other
403 truncation and faulting.

404

405 KEMPLICATIONS FOR EXPLORATION

406 Existing reservoirs with upslope stratigraphic traps are significant for future
407 future exploration and specifically applicable to the evaluation of
408 within the many number of factors have been identified that improve
409 identification of subsurface assets help explore opportunities

410 • The range of tectonic and depositional settings is encouraging for exploration, since many basins and deep
411 petroleum systems are robust stratigraphic traps. However, it is interesting
412 to note that most giant discoveries have been made on the slope of graded passive margins and intraslope
413 rift transform (Fairgins)

414 • Upslope stratigraphic traps, including giant discoveries, occur on
415 marginal (Figure 10). Slope type the reservoirs are highly discriminate opportunities
416 suggest that previous studies may be inferred from a phycem (Rabell et
417 al., 1994; Jacobson et al., 2005; and Olsen,)2005

418 • The pinchout traps examined are rarely associated with major
419 tectonic-stratigraphic boundaries. Rather, they are positioned

422 truncation (Figure 3) This may indicate that facies are prone to updip lea
 423 base seal.
 424 δ. Targeting systems with limited maximum grain size are a key to the
 425 slope as a critical success factor. Sediment grain size and slope
 426 fundamental controls on downslope sediment transport by processes
 427 sediment gravity flow systems with upslope stratigraphic traps
 428 relatively limited grain sizes combined with the presence of
 429 progradation carbonate margins possible to gain size and
 430 palaeoslope should therefore be taken into consideration
 431 δ. Faulting through upslope areas is a key to the success of a
 432 discovery (Figure 8). Some reservoirs previously interpreted as slope
 433 stratigraphic traps, to be in fact continuation traps with faulting
 434 Jubilee, Foinaven, Lagan. Faulting through the coarse grained systems
 435 where it is difficult for flows to be sealed in some depositional
 436 systems on to to cross basin faults, should have a high sealing
 437 only limited offsets may be required to do this. Faulting through
 438 of providing a potential trapping mechanism, if a robust pinch out
 439 fault mapping and analysis should be a key component of the exploration
 440 δ. Mud prone channels and mass transport deposits are a key to the
 441 effective trap and (Figure 5) This is a key to the success of a
 442 past discovery. Identification and mapping of these features is positive evidence
 443 reservoir pinch out should be particularly where they are associated
 444 amplitude and however, predicting the potential for these depositional
 445 elements may be challenging, particularly in frontier areas.

446 lithology prediction and containment may carry high uncertainty
447 Understanding erosional truncation belts is important to
448 connectivity volume which may be negatively affected in areas of interest

449

450 CONCLUSIONS

451 Deepwater stratigraphic traps continue to be important targets
452 and seem likely to be significant oil and gas discoveries and frontiers
453 Achieving success remains challenging due to complex geology and containment
454 Complicated and past commercial traps provide insight into trapping
455 configurations and pinchout formation - depositional systems and traps
456 pinchout. traps importantly, demonstrates their occurrence of tectonic
457 depositional settings in graded- and deformed margins. The majority of
458 discoveries have been made in the hope of graded passive margins and
459 inslope on steeply eroded and transport traps in the slope of the
460 the bypass sediment by transport flows but not by the channels
461 and mass transport complexes in the slope, in the traps and
462 such many existing fields may be predicted in the traps. The results suggest
463 a number of factors: faulting in upslope areas and the connection
464 pinchout systems, complexed sedimentation and junction
465 with steep slopes and erosional truncation by and deep
466 filled channels and mass transport complexes may help define
467 prospects and make the traps a viable research avenues to
468 explore to understand upslope and traps systems.

469 include constraining gas-saturated bangles for retraction of the
470 development of e-folds and systems and its detachment in
471 seafloor and ancient outcrop systems

472

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679 VITA

680 Lawrence A. ~~As~~ Associate Professor in the School of Earth Sciences
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685 CAPTIONS

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687 Figure Examples of play models where upslope stratigraphic trap
688 exploration targets (A) an African Transform Margin model showing det
689 rift slope channel and turbidite systems (from Wells 2011); (B) Porcupine Basin (off
690 model showing detached Cretaceous and Paleogene strata (see
691 Affairs Division) (C) Seismic section showing a graben and complex (T
692 TC 3) offering potential for pre-Cretaceous, offshore Ghana (fro
693 2011; image courtesy of CDEG & New Ventures

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697 Figure S2 Schematic diagram illustrating the various depositional
698 large-scale stratigraphic traps in a deepwater alluvial system. The
699 proximal pinchout on the landward margin may be a
700 systems are attached to upslope shelf or fluvial sands.

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704 Figure (A) Proximal oblique stratigraphic trap configurations for de
705 shown map (views in section) (B) Termination types a
706 with upslope stratigraphic truncation (1) Depositional pinchout o
707 margin unconformity; 2) intraformational depositional pinchout
708 truncation; 3) truncation by a major unconformity. These are
709 onto regional unconformity traps, lateral depositional traps and
710 regional subcrop traps, respectively (2006).

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712

713 Figure 6-4a. Global distribution of discovered conventional oil and gas reserves
714 with upslope stratigraphic correlation. The figure shows the discovery record for
715 fields, along with Estimated Ultimate Recovery (EUR) and EUR play type.
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720 Figure 5. Simplified maps of fields with the stratigraphic traps show
721 outlines, structure contours (top or near top reservoir), infer
722 direction and location of depositional basins (s) low/high source
723 (Newton & Flanagan, 1993), Buzzard (Doré & Robins, 2005), Foinaven
724 (Horseman et al., 2014), Jameson (Bloomer, 1990), Nautilius (Bodd
725 2006), Jubilee (Dailly et al., 2012), Marlim Sul (Candido & Cor

726

727 Figure 6 Geological sections based on seismic data with a dip slope stratigraphic
728 trapped fields: A) Shetland Basin, Foinn, Central North Sea; B) Staraia Buza
729 Witch Ground Graben, Central North Sea, Alba field; D) Eastern
730 fields; E) Rakhine Basin, Shwe field. Modified from Basins & Clastic
731 (1999), Roberts (2005), Harding et al. (1990), Godo (2016), Y
732 Ltd Media Release (2008), Cesp Basin Cycetaceous Unconformity.

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735

736 Figure 5 Summary of interpreted mapping styles for reservoirs discussed

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740 Figure 8.11. A) RMS amplitude extraction of the Mahogany
741 & Agyapong, and B) seismic lines showing onlap related pinchout at the
742 (from Jewell and Oulson, 2012) showing upslope pinchout but
743 reservoir level (from Jewell and Oulson, 2012) showing upslope pinchout but
744 The Mahogany discovery well and the top of the Mahogany
745 horizon) is shown in seismic sections.

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748

749 Figure 9. Finnaven Field. (A) Seismic-based geological interpretation of the Finnaven subbasin
750 Shetland (Loizou et al., 2006) with permission of the Geological Society of London.
751 Composite structure map showing hydrocarbon fields and faults. The map shows
752 NW-SE faulting and a high-angle (inverted) boundary. The map is based on data used
753 with permission of the Geological Society of London. The map shows the
754 southeast-southwest boundary and inferred sediment entry points.

755

756

757 Figure 10. Marlím field. (A) Seismic profile for the eastern 2003 Brazil
758 and used with permission of Onshore Technology (B) interpreted basin phy-
759 distribution and structure of the Orinoco Ptarmigan (C) main amplitude map showing un-
760 permission of AAPG. (D) Main amplitude map showing un-
761 shown. (E) Main amplitude map showing un-
762 least one of the following: (1) used with permission of AAPG.
763 sediment transport direction. (2) indicate thicker (3) and (4) used
764 depositional model of the Orinoco Ptarmigan system during late stages of the
765 1993 and used with permission of AAPG. Abbreviations: (R) Continental Rift M-
766 Transitional Megasequence, (SC) Small Megasequence, (M)
767 Transgressive Megasequence, (MR) Marine Regressive Megasequence.

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771 Figure 3 Summary of processes that may generate upslope stratig
772 or deposition in a rotational upslope area as in (A) a slope failure; (B)
773 gravity flow erosion and bypass; (C) fan slide failure; (D) a nonse
774 erosion by a mud mass flows; (F) erosion by bottom vents in a
775 systems that are detached at the time of deposition, later, the
776 that become detached through erosional decapitation.

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780 Figure 2 Buzzard field depth structure map of the T(Do Buzz
781 Robbins, 2005 used with permission of the Geological Society of
782 map of top reservoir (Payetaad, 2010 with permission of the Geo
783 London) the main accumulations are west oriented normal faults tha
784 field into three main regions referred to as the Southern, Cen
785 smaller structural (CD) seismic lines showing stratigraphic thin
786 updip towards the west (Don & Robbins, 2005 permission of the Ge
787 of London) (E) Depositional model for the Buzzard Sandstone Mem
788 used with permission of the Geological Society of London

789

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791 Figure 3 Glenlivet (A) Far offset amplitude versus time (dB) line through
792 the Glenlivet Prospect showing a strong amplitude anomaly as
793 anomaly from Horseman et al. 2014 and used with permission of the
794 (C) Three dimensional perspective showing reservoir depth structure showing
795 amplitude as surface attribute. (D) Sandstone deposits interpreted from
796 information and from Glenlivet and neighboring prospects graphically
797 trapped sandstones in topographic (Figure 3 from Speck et al. et
798 2013) and used with permission of EA

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802 Figure 4 Examples of filled channels that aid upslope remittance of
803 and Rial bas (A) Map of Marlim and Marlim Sul bas and seismic
804 interpreted mud canyons channels on the base floor (from Peres,
805 and used with permission) (B) NW-SE Air Photo section from Marlim Field
806 (230 deep and 3.9 km wide filled channel that erodes into the reservoir
807 (from Bruhnan, 2004 with permission) (C) AAPG rich lobes dissected
808 mud filled channels in the Barra Branca Field (used with permission of
809 (D). Maximum amplitude map of top G5-f2 lobe showing a network of
810 larger low-velocity, erosional channels dissecting the Shwe
811 & Kim, 2014 used with permission) (E) SIF (Kieffer fig. 14 D) of the
812 Shwe field displaying a region of high amplitude to the Shwe
813 (GR) and resistivity (Res) logs of same area (Yang & Kim, 2014 with permission
814 of Elsevier

815

816 Figure 5 Reservoirs with upslope pinchouts related to gas transport
817 and used with permission of the Geological Association of Canada
818 Miocene of the eastern Gulf of Mexico with slumps and debris
819 depositional systems. (B) Map of the Nautilus Field showing
820 laterally and updip plateaus and scours shown by greyed lines in
821 direction of flow of gas. A seismic section through the Nautilus Field
822 separated by faults coat the base of the mass transport deposits
823 Hydrocarbon remnant sands are shown as red event beds
824 in the dip seismic section showing the Bullfield carbonate platform
825 slumped interval.

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829 Figure 10. Summary of the classification scheme used to describe re

830 Prather et al and 2016 with permission of Wiley and Sons

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833
834 Figure 17. Number of reservoirs in a given slope stratigraphic traps by type
835 slope type (B); position on the coast (C) and distance (D) bars for
836 all reservoirs considered in this study (Table 1). The bars with the structure
837 trapping components have been (ii) referred to as pure stratigraphic
838 Numbers indicate the commercial reserves (in million barrels) for all reservoirs
839 Abbreviation: Toe of slope (ToS).

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842

843 Figure 10 Frequency of turbidity events and grain size preserved with different
844 trap types. Dark grey bars show slope strata (light grey bars show
845 Abbreviations: very fine sand (VFS); fine sand (FS); medium sand (MS);
846 conglomerate (Cg).

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850 Figure S19 Schematic summary of depositional setting of upslope
851 commercial discoveries to date including those with offshore oil f
852 environments that have previously been used as stratigraphic traps bu
853 structural component to their updip trapping mechanism (see T

854

Table 1. Deepwater turbidite reservoirs with inferred upslope stratigraphic trapping.

Field - Reservoir Interval	Reservoir age	Basin	Water depth (m)	Discovery year	HC type	Reserves	Status	References
Alba - Nauchlan	Middle Eocene	Central North Sea	600	1984	Oil	400	Decline	Harding et al. (1990), New (1993), Moore (2014)
Barracuda - Carapebus	Eocene-Oligocene	Campos	600-1200	1989	Oil	867	Producing	Bruhn et al. (2003), Rang (2010), Defeo (2010), Defeo
* Buzzard - Buzzard Sandstone	Late Jurassic	Central North Sea	600	2001	Oil	550	Producing	Doré, G. & Robbins (2005) (2006), Ray et al. (2010)
English Colony - Stevens Sands	Miocene	San Joaquin Onshore	-	-	Oil	1.6*	Abandoned	Hewlett & Jordan (1993), (2017)*
* Foinaven - Vailla Fm	Paleocene	Faroe-Shetland	400-600	1992	Oil	415	Producing	Straccia & Prather (1999)
* Glenlivet - Vailla Fm	Paleocene	Faroe-Shetland	500	2009	Gas	-	Development	Stephensen et al. (2013), (2014), Loizou (2014)
Jameson - Jameson-Cook	Early Permian	Permian Onshore	-	1952	Oil	45.3*	Mature	Bloomer (1990)*, Bloomer
* Jubilee - Mahogany	Turonian	Tano	1100	2007	Oil	>600*	Producing	Jewell (2011), Dailly et al. (2014), Kelly & Doust
* Laggan - Vailla Fm	Paleocene	Faroe-Shetland	600	1986	Gas-Cond-	-	Producing	Gordon et al. (2010), Loiz
* Lagoa Parda - Lagoa Parda	Early Eocene	Espirito Santo	0-200	1978	Oil	24	Decline	Bruhn (1993), Bruhn et al. (1991)*
* Marlim - Carapebus	Eocene-Oligocene	Campos	650-1050	1985	Oil	1700	Decline	Candido & Cora (1992), Pe et al. (2003), Defeo de Ca
Marlim Sul - Carapebus	Eocene-Oligocene	Campos	720-2600	1987	Oil	1150	Producing	Peres (1993), Bruhn et al.
Nautilus, Pabst, B - Miocene Sands	Miocene	Northern GOM	-	1985-2003	Gas	-	Producing	Godo (2006)
* Oribi - 14A Sequence	Early Cretaceous	Burdasp	120	1990	Oil	20*	Mature	Burden & Davies (1997a; 1
Sea Lion - SL10-SL20	Lower Cretaceous	North Falkland	450	2010	Oil	242	Development	MacAulay (2015)
Shwe, Shwe Phyu, - G Series	Late Pliocene	Rakhine	90-600	2004	Gas	755	Producing	Yang & Kim (2014)
Young North - Bone Spring	Early Permian	Permian Onshore	-	1991	Oil	1.5-3*	Mature	Montgomery (1997)*

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856 ¹Principal hydrocarbon reports of recoverable field reserves (MMBOEs) are not necessarily long-widespread, field
 857 summary. Websites accessed December 2016 stratigraphic trap in the pre-salt zone previously been discussed as st
 858 but may also have a structural component to their updip trapping mechanism (see Table 2 & Figure 7).
 859

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Table 2. Trapping configuration of deepwater turbidite reservoirs

Field - Reservoir Interval	Field trap type	Updip trapping	Updip stratigraphic pinchout style	Lateral trapping	Downdip limit
Alba - Nauchlan	Stratigraphic	SP (?with comp. closure)	DP	SP (?compactio dip closure)	OWC?
Barracuda - Carapebus	Combination	SP	ET (mud-filled channels)	SP	SP and faulting closure?)
Buzzard - Buzzard Sandstone	Stratigraphic combination	SP	DP	SP or faulting	OWC
English Colony - Stevens Sands	Stratigraphic	SP	DP	SP	OWC
Foinaven - Vailla Fm	Combination	SP (dip closure probably fault a	DP and/or faulting	Faulting	OWC
Glenlivet - Vailla Fm	Combination	SP (assisted by depositional faulting)	DP associated faulting	SP	Faulting
Jameson - Jameson-Cook	Stratigraphic	SP	DP	SP	-
Jubilee - Mahogany	Combination	SP (probably fault assisted)	DP and/or faulting	SP	OWC
Laggan - Vailla Fm	Combination	SP (probably fault assisted)	DP and/or faulting	SP or faulting	GWC
Lagoa Parada - Lagoa Parada	Combination	SP and dip clos (faulting?)	DP and/or faulting	SP and dip clos	OWC
Marlim - Carapebus	Combination	SP and faulting	DP and faulting	SP and faulting	Faulting
Marlim Sul - Carapebus	Combination	SP	DP and ET (mud-filled channels)	SP	-
Nautilus, Pabst, B - Miocene Sands	Stratigraphic	SP	ET by MTD	SP	OWC or SP
Oribi - 14A Sequence	Combination	SP (possibly fault	DP	SP and faulting	OWC
Sea Lion - SL10-SL20	Stratigraphic	SP	DP	SP	OWC
Shwe, Shwe Phyu, - G Series	Stratigraphic	SP	ET (mud-filled channels)	SP	SP?
Young North - Bone Spring	Stratigraphic	SP	DP	SP	-

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862 Abbreviations: Stratigraphic Pinchout, SP; Depositional pinchout, DP; Erosional truncation, ET.

Table 3. Setting of deepwater turbidite reservoirs with inferred upslope stratigraphic trapping

Field - Reservoir Interval	Tectonic Setting	Slope Type	Slope Position	GDE
Alba - Nauchlan	Rift (post-rift)	Graded	Middle or lower slope	Submarine valley
Barracuda - Carapebus	Passive margin	Graded	Toe-of-slope	ToS apron
Buzzard - Buzzard Sandstone	Rift (syn-rift)	Out-of-grade (stepped)	Middle slope (at local step)	Perched apron
English Colony - Stevens Sands	Transform	Graded	Upper slope	Submarine valley
Foinaven - Vaila Fm	Rift (post-rift)	Out-of-grade (stepped)	Middle slope	Submarine valley
Glenlivet - Vaila Fm	Rift (post-rift)	Out-of-grade (?stepped)	Upper slope	Perched apron
Jameson - Jameson-Cook	Foreland	Graded	Middle slope or toe-of-slope	Submarine valley and ToS apron
Jubilee - Mahogany	Transform	Out-of-grade (stepped)	Upper or middle slope	Perched apron
Laggan - Vaila Fm	Rift (post-rift)	Out-of-grade (stepped)	Upper slope	ToS apron
Lagoa Parada - Lagoa Parada	Passive margin	Out-of-grade	Upper slope	Submarine valley
Marlim - Carapebus	Passive margin	Graded	Toe-of-slope	ToS apron
Marlim Sul - Carapebus	Passive margin	Graded	Toe-of-slope	ToS apron
Nautilus, Pabst, B - Miocene Sands	Passive margin	Graded	Lower slope or toe-of-slope	Remnant slope sands
Oribi - 14A Sequence	Transform	Graded	Toe of slope or basin fill	Submarine valley or ToS apron
Sea Lion - SL10-SL20	Rift (post-rift)	Out-of-grade (?stepped)	Upper slope or basin fill	ToS apron
Shwe, Shwe Phyu, - G Series	Forearc	Out-of-grade	Toe-of-slope or basin fill	ToS apron
Young North - Bone Spring	Foreland	Out-of-grade	Lower slope or toe-of-slope	ToS apron