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Citation for published version:

Lüdmann, T, Betzler, C, Eberli, GP, Reolid, J, Reijmer, JJG, Sloss, CR, Bialik, OM, Alvarez-zarikian, CA, Alonso-garcía, M, Blättler, CL, Guo, JA, Haffen, S, Horozal, S, Inoue, M, Jovane, L, Kroon, D, Lanci, L, Laya, JC, Mee, ALH, Nakakuni, M, Nath, BN, Niino, K, Petruny, LM, Pratiwi, SD, Slagle, AL, Su, X, Swart, PK, Wright, JD, Yao, Z & Young, JR 2018, 'Carbonate delta drift: a new sediment drift type', *Marine geology*. <https://doi.org/10.1016/j.margeo.2018.04.011>

Digital Object Identifier (DOI):

[10.1016/j.margeo.2018.04.011](https://doi.org/10.1016/j.margeo.2018.04.011)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Marine geology

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1 Carbonate delta drift: a new sediment drift type

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55 ABSTRACT

56 Based on high-resolution reflection seismic and core data from IODP Expedition 359 we
57 present a new channel-related drift type attached to a carbonate platform slope, which we
58 termed delta drift. Like a river delta, it is comprised of several stacked lobes and connected to

59 a point source. The delta drifts were deposited at the exit of two gateways that connect the
60 Inner Sea of the Maldives carbonate platform with the open ocean. The channels served as
61 conduits focusing and accelerating the water flow; Entrained material was deposited at their
62 mouth where the flows relaxed. The lobe-shaped calcareous sediment drifts must have formed
63 under persistent water through flow. Sediment supply was relatively high and continuous,
64 resulting in an average sedimentation rate of 17 cm ka^{-1} . The two delta drifts occupy 342 and
65 384 km^2 , respectively; with a depositional relief of approximately 500 m. They have a sigmoidal
66 clinoform reflection pattern with a particular convex upward bending of the foresets. In the
67 Maldives the drift onset marks the transition from a sea-level controlled to a progressively
68 current dominated depositional regime. This major event occurred in the Serravallian about 13
69 Ma ago, leading to the partial drowning of the carbonate platform and the creation of shallow
70 seaways. The initial bank-enclosed topography resembles an “empty bucket” geometry which
71 is rapidly filled by the drift sediments that aggrade and prograde into the basin. Thereby the
72 depositional environment of the delta drifts changes from deep water (>500) to shallow-water
73 conditions at their topsets, indicated by the overall coarsening upward trend in grain size and
74 the presence of shallow water large benthic foraminifers at their top.

75 Keywords: delta drift, carbonate platform, drift sedimentation, bottom current, clinoform,
76 Maldives

77 INTRODUCTION

78 Current-controlled carbonate deposits have so far not been systematically investigated in
79 contrast to their intensively studied siliciclastic counterparts (Faugères et al., 1999; Stow et al.,
80 2002b; Viana and Rebesco, 2007; Rebesco and Camerlenghi, 2008; Rebesco et al., 2014).

81 Several studies, however, document their importance, especially in tropical carbonate
82 platforms (Anselmetti et al., 2000; Betzler et al., 2009, 2013, 2014; Isern et al., 2004; Eberli et
83 al., 2010; Lüdmann et al., 2012, 2013). For the Maldives, Lüdmann et al. (2013) demonstrated

84 that since the Middle Miocene carbonate sedimentation in the Inner Sea was dominated by
85 ocean currents entering the archipelago interior via gateways between the atolls. This
86 situation resulted in the deposition of 10 mega-drift sequences. This is in contrast to the
87 standard sequence stratigraphic model that describes carbonate platform geometry and
88 depositional setting as a response to relative sea-level changes (Schlager, 2005 and references
89 therein). Recent studies show that sea-level-controlled highstand shedding plays an essential
90 role in sediment supply; However, currents could be the main agent transporting carbonate
91 debris from the platform top and distributing it to the surrounding margins (Betzler et al.,
92 2013, 2014, 2015; Lüdmann et al., 2013).

93 The Maldives, a large N-S elongated isolated carbonate platform southwest of the southern tip
94 of India, are situated on an approximately 900 km long and 100 to 125 km wide submarine
95 ridge consisting of a double row of atolls enclosing a deep basin, the Inner Sea (Fig. 1). It can
96 be considered as a type locality for calcareous drift deposits. Here, in the deep water realm of
97 the Inner Sea giant elongated drift bodies formed with geometric and seismic characteristics
98 comparable to their siliciclastic counter parts with a typical mounded geometry and an
99 associated moat (Lüdmann et al., 2013). Based on geometries depicted in reflection seismic
100 profiles, we identified a new calcareous drift type at the mouth of the gateways. These drifts
101 have a lobe-shaped external geometry with a clinoformal, prograding internal reflection
102 configuration. We named the new sediment drifts delta drifts because they have much in
103 common with river or tidal deltas. In 2015, during IODP Expedition 359 two platform-to-basin
104 transects were drilled north and south of Goidhoo Atoll as well as in the Inner Sea (Betzler et
105 al., 2016a; 2017a, b). The cores and well logs through the delta drift deposits provide the
106 sedimentological and stratigraphic data for the comprehensive analysis of the new drift type
107 that is presented here (Fig. 1). This research presents new diagnostic criteria that allow the
108 classification of carbonate sediment drifts and provide the base for further detailed studies of
109 its sedimentological characteristics and facies associations. Results from this research will also

110 potentially provide depositional models that could lead to a re-evaluation of carbonate
111 deposits elsewhere and in the geological record that meet the new diagnostic criteria.

112 GEOLOGICAL BACKGROUND

113 The Maldives carbonate platform rests on a 55-57 Myrs old volcanic ridge. The Inner Sea basin,
114 which is 300 to 350 m deep on average, is underlain by a fault-controlled en-echelon graben
115 system (Purdy and Bertram, 1993; Aubert and Droxler, 1996) (Fig. 1). Reconstruction of the
116 long term evolution of the Maldives was based on seismic data and industrial wells NMA-1 and
117 ARI-1 from Elf Aquitaine and Shell as well as scientific drillholes of ODP leg 115 (Backman et al.
118 1988; Aubert and Droxler, 1992, 1996; Purdy and Bertram, 1993; Belopolsky and Droxler, 2003,
119 2004), and on the M74/4 cruise data (Betzler et al., 2009, 2014; Lüdmann et al., 2013).

120 Subsidence was generally low averaging about 0.15 mm yr^{-1} to 0.045 mm yr^{-1} based on
121 Pleistocene grainstones of Rashdo Atoll (Gischler et al., 2008) and calculated from basalt
122 depth of ODP Site 715 (Backman et al., 1988) located at the eastern margin of the Maldives
123 (Fig. 1).

124 The Maldives are an isolated platform system far from any siliciclastic source assembling an
125 almost complete Cenozoic sedimentary succession of exclusively calcareous material (Aubert
126 and Droxler, 1992; Purdy and Bertram, 1993; Backman et al., 1988), with minor amount of
127 aeolian dust (Betzler et al., 2016b). Sedimentation started with lacustrine deposits filling
128 Eocene grabens accumulating sedimentary rocks in an anoxic environment (Aubert and
129 Droxler, 1996). Eocene relative sea-level rise provoked neritic carbonate bank growth on the
130 shoulders of the graben structures. A rimmed platform with a protected lagoon developed
131 during the Early to Late Oligocene transition. In the Early Miocene (21.5 Ma) banks aggraded
132 and prograded and a large central basin (the palaeo-Inner Sea) developed, surrounded by a
133 narrow peripheral reef complex that faces the Indian Ocean (Aubert and Droxler, 1992, 1996;
134 Betzler et al., 2009, 2012, 2016b). Seismic data show that the palaeo-Inner Sea was connected

135 via the NE-Kardiva Channel (Fig. 1) with the Indian Ocean since the Middle Miocene (Aubert
136 and Droxler 1996; Lüdmann et al., 2013). Bottom currents could enter the semi-enclosed basin
137 from the NE and flow along its western flank (Lüdmann et al., 2013). Aggradation of the
138 platform margin continued into the Middle Miocene forming an “empty bucket” geometry of
139 the palaeo-Maldives. During the late Early Miocene (18.15 Ma), the flat-topped carbonate
140 bank margins started outbuilding towards the central part, thus beginning to narrow the size
141 of the “empty bucket” (Betzler et al., 2016b). At the end of the Middle Miocene, the sea-level
142 controlled depositional regime abruptly changed to a predominately current dominated
143 system. This significant transition occurred about 13.0 Ma ago and is attributed to the onset
144 and/or intensification of the Indian monsoon (Betzler et al., 2009; 2012; 2016b). This change to
145 a current dominated system resulted in partial bank drowning of the platform margin, leading
146 to the opening of passages that connect the Inner Sea with the Indian Ocean. Since then, 10
147 mega-drift sequences were deposited in the Inner Sea (Lüdmann et al., 2013; Betzler et al.
148 2017a). Contemporaneously, the remaining atolls switched from a prograding to an aggrading
149 mode (Betzler et al., 2009, 2016c). Drift sedimentation initiated in the northern part of the
150 Inner Sea with the deposition of lobe-shaped drift bodies at the mouth of the gateways
151 adjacent to the Goidhoo Atoll (Fig. 1). The northern gateway has a present width of ca. 12 km
152 and a length of ca. 17 km as well as a swell depth of 510 m. The dimension of the southern one
153 is almost the same but with 420 m it is shallower. At 5.8 Myr ago, when the depocenter
154 migrated eastward, large elongated mounded drifts developed with associated moats along
155 the eastern basin flank (Lüdmann et al., 2013). The latter are related to a northward flowing
156 bottom current that entered the Maldives from the south. Recent studies demonstrate that
157 the shallow water inner atoll environment likewise is current dominated (Betzler et al., 2015).

158 Present information on the oceanographic setting of the Maldives is rare (Knox, 1976). Figure 1
159 shows the general bottom current pattern based on our cruises M74 (winter monsoon) and
160 SO236 (summer monsoon) in the northern part of the archipelago (Lüdmann et al., 2013).

161 During the summer monsoon, prevailing wind direction is towards east. Bottom currents
162 (below 150 m water depth) enter the Inner Sea from the western gateways and exiting the
163 Maldives to the east. In the central Inner Sea a southward flow dominates. The situation turns
164 back during the winter monsoon, then bottom water masses entering the Inner Sea from NE
165 and leaving it through the western gateways. The central Inner Sea is marked by a northward
166 flow. This hydrodynamic pattern is overprinted by tidal currents that act especially in the
167 narrow gateways and shallow channels of the atolls (Kench et al., 2009).

168 DATA SET AND METHODS

169 The seismic data based on industrial and two multidisciplinary scientific cruises in 2007 and
170 2014, respectively. During these cruises a 144-channel digital streamer system with an active
171 length of 600 m was used. Details about data acquisition and processing can be found in the
172 initial IODP report Expedition 359 (Betzler et al., 2016a) and an earlier work by Lüdmann et al.
173 (2013). IODP Expedition 359 was aimed to reconstruct the paleoceanographic evolution of the
174 Maldives over the past 23 Myr. To achieve the scientific goals, eight sites were drilled (U1465-
175 U1472), aligned along two transects covering shallow to deep-water deposits (Fig. 1). The
176 standard coring systems, the advanced piston corer (APC), extended core barrel (XCB), and
177 rotary core barrel (RCB) were used. The APC was utilized in the upper portion of each site to
178 obtain higher quality cores, with the exception of the platform top Site U1469 where only the
179 RCB system was applied. Total penetration for the entire expedition was about 8,725 m with
180 the deepest drilled single hole reaching 1,003.7 m below seafloor (Hole U1471E). However,
181 due to lithification of the carbonates in the deeper sections at each site, total recovery was
182 less than 50 % (3,096 m). Downhole wireline logging was successfully performed at 4 sites
183 (U1466 to U1468 and U1471). For the characterization of the sediment drift the
184 lithostratigraphy, biostratigraphy, downhole logs as well as the physical properties of the IODP
185 Leg 359 cores were used. A detailed description of methods can be found in the IODP
186 Expedition 359 reports (Betzler et al., 2016a, 2017a).

187 For time/depth conversion of the mapped sequence boundaries previous velocity models
188 (Lüdmann et al., 2013) were fine-tuned by using the VSI velocity data acquired during IODP
189 Expedition 359. Additionally, core lithology was correlated with the seismic facies and major
190 lithological boundaries were tied to the mapped seismic unconformities (Betzler et al., 2017b).
191 By the use of post-cruise data some of the drift sequences ages were slightly corrected.
192 Seismic-core-log correlation was carried out with the interpretation software package Petrel
193 (Schlumberger). The 3D sequence surfaces are calculated in Petrel from the picked horizons
194 using the convergent interpolation algorithm and a 100 x 100 m grid size.

195

196 SEISMIC ARCHITECTURE AND FACIES

197 Seismic line M74-65 that runs through the western Kardiva Channel into the Inner Sea basin
198 delineating a high-resolution cross-sectional view of the platform margin displays an apparent
199 change in the geometry of prograding clinoforms (Fig. 2). The older clinoforms (marked as
200 carbonate platform in Fig. 2) have horizontal topsets and steep concave foresets that are part
201 of a prograding shallow-water platform. These concave clinoforms are overlapped by a large
202 prograding sediment body with convex upward clinoforms, the delta drift (delineated as delta
203 drift in Fig. 2). This abrupt change of geometry marks the transition from sea-level controlled
204 platform progradation to current-controlled drift deposition at ca. 13 Ma ago (Betzler et al.,
205 2016b). The delta drift in front of the channel north of the Goidhoo Atoll has a slightly
206 mounded geometry in which the apex of the mound (located at the position of Site U1468, Fig.
207 2) is higher than the top of the former prograding platform despite being partially eroded (Site
208 U1466; Fig. 2). Seismic line SO236-21 that is perpendicular to the dip of the delta drift displays
209 channels carved into the prograding clinoform bodies (Fig. 3). Additionally, seismic line SO-
210 236-21 shows the typical bi-directional downlap pattern of a lobe and its mounded across-
211 strike geometry. A second prograding delta drift body, with similar geometries and seismic

212 facies occurs in front of the channel south of Goidhoo Atoll (Fig. 4). The stacked lobes can be
213 subdivided into three seismic mega-drift sequences (DS1-DS3) separated by major angular
214 unconformities, characterized by onlap and downlap terminations (Figs. 2-4, red arrows).
215 Basinward, the unconformities pass over into correlative conformities. North of Goidhoo Atoll
216 mega-sequence DS1 can be further divided into two larger subsequences DS1a and DS1b. The
217 seismic sections perpendicular to the depositional strike of the lobes (Figs. 2 and 4) display the
218 nearly sigmoidal external shape of the sequences (DS1-DS3). They are characterized by gently
219 dipping upper and lower segments and a thicker, more steeply inclined middle segment of
220 prograding foresets. The upper segment shows a divergent reflection pattern with dip angles
221 of 1°-3°. The thicker middle segment has foresets dipping basinward with angles of 3°-5°. The
222 transition zone between the upper and middle segments is indicated by a continuous
223 steepening of the slope forming a convex break-in-slope morphology (Figs. 2B and 4B, black
224 curved lines). The lower segment is characterized by basinward thinning bottomsets that
225 exhibit real or apparent downlap termination when their thickness falls below seismic
226 resolution. Commonly the reflections indicate that strata are parallel and concordant with the
227 sequence boundaries. Seismic line M74-62 south of Goidhoo Atoll runs southward of the
228 deepest channel bed (Fig. 4). Here, the sequences DS1 to DS3 apparently pass over into the
229 reef at the platform edge which was drowned at a later stage in the Tortonian compared to
230 the northern channel. However, according to margin collapse the reflector transition from the
231 edge to the slope strata is obscured and cannot be accurately determined (CS; Fig. 4). Most of
232 the sediment was probably supplied from the immediately adjacent channel to the north that
233 has cut into the platform top.

234 North of Goidhoo Atoll, the delta drift is marked in cross section by a depression like incision at
235 the contact to the drowned Middle Miocene platform edge (Fig. 2). Here, parts of DS1 to DS3
236 are eroded and the depression is unconformably filled with younger sediments. At Site U1466,
237 the hiatus spans ca. 6 Mill. yrs. (Middle Miocene to Pliocene time) (Fig. 5). The channel axial

238 profiles (Fig. 1) allow its spatial reconstruction which forms a local elliptical incision elongated
239 along the drowned platform edge at the mouth of the northern channel (E, Fig. 5). Its major
240 and semi axis is about 6.5 and 1 km, respectively. The maximum incision depth of 60 m is
241 reached at profile M74-65 (Fig. 2).

242

243 Another specific feature seen in downdip view of the delta drifts is horizontal to down-cutting
244 reflections that interrupt the uniform clinoform geometry as demonstrated in profile M74-65
245 (dashed black box; Fig. 2). In cross sectional view, this zone is the rim of a dip-parallel channel
246 cut deeply into the foreset strata (dashed black box; Fig. 3). The southward dipping channel
247 layers that are cut along strike create side echos and generate pseudo-horizontal down-
248 stepping reflections. These dip-parallel channels in the drift sequences DS1 and DS2 cut at
249 their base into underlying deposits, which is of particular importance. The channels are
250 concentrated in DS1b, reaching varied widths of 500 m to 1 km and depths of 10s of meters to
251 150 m (Fig. 3). The channels depict linear conduits that are restricted to the steeper middle
252 segment of the drift clinoforms and fading out basinward. There are no deep-sea fans attached
253 to the mouth of these channels. After initial incision, the channels exhibit a divergent,
254 aggradational infill pattern while the channel axis remains in the center. Laterally, the channel
255 infill passes over into the layering of the drift sequences that form the delta drift, while the
256 channel represents a local depocenter. In places, the channel can be traced as a smooth
257 depression in the overlying foresets strata (depression; Fig. 3). In contrast to the
258 aforementioned channels the platform sequences show a series of gullies (Fig. 3). They are
259 considerably smaller in dimension reaching widths of only 100-300 m and depths of 10-15 m.
260 Line SO236-21, oriented strike-parallel to the platform sequences displays a successive
261 downward transition from proximal platform strata below DS1 to more distal strata. Here, the
262 gullies are restricted and aligned along the most proximal strata representing the middle slope

263 part of the platform clinoforms (Figs. 2 and 3). In general, our profiles depict that the gullies
264 occur at the steeper upper to middle slope part.

265 At the base of DS1 wavy bottomsets appear near the toe-of-slope (Figs. 2 and 4). The waves
266 have wavelengths of ca. 500 m and heights of 10-15 m. They have a distinct asymmetric shape
267 and increasing wavelength in down-dip and in up-dip direction. A 3D image of their
268 distribution demonstrates a slope-parallel N-S trend with the steep and shorter flank facing
269 basinward (Fig. 6). Their stacking pattern indicates an upslope-migration (arrows; Fig. 6A).

270 The formation and early evolution of the delta drifts is depicted in Figure 7. The computed
271 surfaces of DS01 to DS04 illustrate their development of in front of the gateways north and
272 south of the Goidhoo Atoll. Surface DS01 represents the antecedent depositional topography
273 with a continuous platform to the west of the paleo-Inner Sea, which was an approximately
274 500 m deep “empty bucket” surrounded by steep platform flanks (Fig. 7A). The onset of
275 currents at about 13.0 Ma gradually carved channels into the carbonate platform. In the
276 course of time these channels became deeper and wider (Figs. 7B-D). Compared to the
277 southern channel, the northern one is much wider leading to the assumption that the effect of
278 the bottom current was more pronounced in the north. Surfaces DS02 to DS04 (Figs. 7B-D)
279 document the coeval progradation of the delta drifts into the Inner Sea and their successive
280 deflection to the south. 3D geometry and cross sectional view of the delta drifts reveal their
281 overall lobe-shaped morphology (Figs. 3 and 7). The lobes attained a maximal width of 16-17
282 km and a length of ca. 25 km, resulting in an area of 342 and 384 km², respectively. Their
283 stratigraphic thickness reached up to 535 m and thereby filling the empty bucket in front of
284 the channels.

285 The seismic facies of the delta drifts generally consists of continuous parallel reflections of low-
286 to medium-amplitudes but in places, packages of strong reflections are observed (Figs. 2 and
287 4). These are particularly distinctive for the foresets of the southern delta drift clinoforms.

288 Here, in the interval between 1,000 and 1,700 m very strong amplitude reflections occur in
289 DS1-DS3 at the steepest part of their slope (Fig. 4). In contrast, the northern delta drift shows
290 intervals of alternating medium to strong amplitude reflectors at the bottomsets of DS1 and
291 the flat topped apex of DS2, between 26,000 and 30,800 m and 25,200 to 28,400 m,
292 respectively (Fig. 2).

293 LITHOLOGY AND AGE CONTROL

294 Sedimentation rates

295 The base of drift sequence DS1 at Sites U1466 and U1468 is dated to ca. 13.0 Ma, 11.7 Ma for
296 DS2, to 10.55 Ma for DS3 and to 8.8 Ma for DS4 (Betzler et al., 2016b, 2017b). In the thickest
297 portions of the drift sequences, sedimentation rates lie around 17.0 cm ka⁻¹ (DS1), 21.0 cm ka⁻¹
298 (DS2) and 13.5 cm ka⁻¹ (DS3). The entire delta drift was accumulated over 4.2 Myr with an
299 average rate of 17 cm ka⁻¹. For the underlying platform sequences the sedimentation rate is
300 significantly lower with about 4.4 cm ka⁻¹ at the proximal location of Site U1466 and 3.2 cm ka⁻¹
301 at the more distal location of Site U1468 (Betzler et al., 2016a).

302 Lithological content

303 Cores from Expedition 359 Sites U1466, U1468, U1471 and U1472 were drilled in order to
304 characterize the facies of the drift sequences (Figs. 5 and 8A). Unfortunately, because of the
305 deep incision at the former platform edge, large parts of the proximal deposits of DS1 and DS2
306 are missing in the northern transect, which makes the study of the downslope trends more
307 difficult (Fig. 5). The delta drift deposits overlie the slope and basinal deposits of the drowned
308 Middle Miocene platform. The platform sequences exhibit alternations of light (highstand) and
309 dark, organic-rich (lowstand) layers (Fig. 9A). The lighter layers are thicker and formed by
310 highstand shedding when the platform is flooded and most sediment is produced and
311 exported, in contrast, the thinner darker layers are deposited during lowstand phases when
312 the platform is exposed and sediment supply is reduced as is the case for similar deposits

313 elsewhere (Droxler and Schlager, 1985; Schlager et al., 1994; Eberli et al., 1997). Bioturbation is
314 common in the platform sequences and individual trace fossils can be discriminated. In
315 contrast, the overlying drift strata are nearly uniform in color and a distinct lamination is
316 absent. Bioturbation is detectable; however, the bioturbation degree is too high to identify
317 individual burrows.

318 The lower part of the northern delta drift deposits (DS1a), consists of lithified, medium- to
319 coarse-grained grainstone and packstone with abundant planktonic and benthic foraminifers,
320 including minor large benthic foraminifers such as *Miogypsinoides* sp., *Lepidocyclina* sp.,
321 *Amphistegina* sp., and *Borelis* sp., together with other fragmented bioclasts in the proximal
322 part, Site U1466. At the distal part, Site U1468, the lowermost facies of the delta drift consists
323 exclusively of planktonic and small benthic foraminifers (Fig. 5). Bioturbation is very intense
324 throughout, destroying the original texture. The vertical and lateral grain-size distribution for
325 the northern delta drift shows coarser grained materials for the foresets of DS1a at Site U1466
326 (Fig. 10A) associated with a thin interval of finer bottomsets at Site U1468 (Figs. 2 and 5). With
327 continuous progradation of the delta drift lobes, the deposits become finer at the proximal
328 Site U1466 (Fig. 5).

329 At Site U1466, delta drift sequence DS1b is composed of medium- to coarse-grained,
330 unlithified to partially lithified wackestone that gradually changes to packstone and grainstone
331 towards the top of the sequence. The main components are small-sized benthic foraminifers,
332 locally with some large specimen, planktonic foraminifers and minor bioclasts including red
333 algae, bryozoans and *Halimeda* plates. Towards the top of the sequence, the facies changes
334 into packstone and grainstone and large benthic foraminifera become the dominant
335 component. This trend abruptly ends at the erosional unconformity with a sharp increase in
336 planktonic foraminifers in the facies. In the more distal Site U1468, the sequence comprises
337 packstone (Fig. 10A) that gradually changes upcore into wackestone (Fig. 10B). The main
338 components are planktonic and small benthic foraminifers with rare sponge spicules. For DS1b,

339 Site U1466 displays a coarsening upward trend; however, its top is eroded. Comparing the
340 time equivalent strata of DS1b at Site U1468, the aforementioned trend of the topsets at the
341 proximal Site is associated with no significant grain size variations of the bottomsets at the
342 distal site. The facies of DS2 (missing at the proximal Site U1466) is composed of medium- to
343 fine-grained packstones starting from the base of the sequence up to 178.5 mbsf at Site
344 U1468. From this depth up to 150 mbsf, there is an overall coarsening-upward trend to a
345 rudstone at the top of the sequence (Fig. 5). Locally, shorter intervals of coarsening-upward
346 and fining-upward occur. The coarser intervals are rich in large benthic foraminifers
347 (*Amphistegina* sp., *Lepidocyclina* sp., *Miogypsinoides* sp., *Heterostegina* sp., *Operculina* sp.,
348 and *Sphaerogypsina globulus*) and locally in echinoid spines, red algae, mollusk fragments,
349 branching and encrusting bryozoans, *Halimeda* plates. Aggregated grains are also present (Fig
350 10C and 10E). Planktonic foraminifers are absent in this sequence and the abundance of large
351 benthic foraminifers increases upcore reaching a maximum at the top of the sequence. The
352 facies of DS3 is similar to those from the top of DS2 with large benthic foraminifer-rich
353 rudstones (Fig. 5). Bioturbation in sequences DS2 and DS3 is intense and single burrows are
354 not identified. In the southern transect there was an active carbonate platform by the time of
355 the initial delta drift deposition (Fig. 4). The platform sediments at Site U1470 (Fig. 8A) are
356 coeval to the drift sequences DS1 to DS3 and consist of shallow water carbonates with
357 abundant corals and coralline algae. Site U1471 (Fig. 8A), in a more distal position, displays a
358 distinct facies for the delta drift sequences. Here, the facies in DS1 consists of alternating fine-
359 grained planktonic foraminifer-rich packstone and grainstone. Planktonic foraminifers,
360 calcareous bioclasts, and calcareous nannofossils are abundant, and benthic foraminifers are a
361 minor component. Bioturbation is abundant to common. Grainstone intervals often have a
362 sharp basal contact with the underlying packstone. The overlying sequence DS2 consists of
363 very fine to fine-grained wackestone to packstone with abundant planktonic foraminifers, and
364 common to present sponge spicules, radiolarians, and calcareous nannofossils. Delta drift

365 sequence DS3 in its proximal position (Site U1472; Fig. 8A), comprises medium- to coarse-
366 grained partially lithified planktonic foraminifer-rich grainstone and packstone. The main
367 components are abundant planktonic foraminifers, benthic foraminifers, and aggregate
368 grains/intraclasts. Among the large benthic foraminifers there are *Amphistegina*,
369 *Lepidocyclina*, and *Miogypsina*. Mollusk fragments, gastropods, echinoid fragments, coral
370 remains, as well as *Halimeda* and red algae fragments are present to rare. Basinwards, at Site
371 U1471, DS3 facies changes into fully lithified very fine to coarse-grained planktonic
372 foraminifer-rich wackestone to packstone that gradually evolve to packstone and grainstone,
373 at the top of the sequence. Towards the top of the sequence benthic foraminifers and mollusk
374 fragments are common.

375

376 Logs and physical properties

377 Figures 5 and 8A show the core (NGR) and high-resolution downhole (HSGR) natural gamma
378 radiation profiles. The total gamma radiation signal is dominated by the contribution of
379 uranium, with only minor contribution from thorium or potassium (Betzler et al., 2016a).
380 Uranium variations most likely relate to the amount of organic matter. There is a clear
381 discrepancy between NGR and HSGR at Site U1468 (Fig. 7) which may be explained by a closed
382 caliper during downhole logging, leading to an inadequate borehole size correction of the
383 HSGR. Here, the NGR measurements are more reliable. In general, the sequences DS1 to DS3
384 of the delta drift show a gamma radiation with a smoother overall trend but with a clear
385 difference in the distal part of the northern and southern transect, respectively (U1468 and
386 U1471; Figs. 7 and 8A). In the north the values are lower and show less variability. However, at
387 both sites the sequence boundaries DS1-DS3 are marked by changes in radiation, especially at
388 Site U1471. As a distinctive feature at Site U1468 there is a pronounced increase in NGR at the
389 top of sequence DS2. Both NGR und HSGR data from Site U1468, as well as NGR data from Site

390 U1466 (below the depth where logging data could be recorded), show a pronounced interval
391 of increased organic matter content within the bottom sets of the platform sequences with a
392 high variability of the gamma radiation

393 Physical properties at the proximal Site U1466 exhibit a continuous increase in bulk density
394 with depth to about 300 mbsf while porosity decreases (Fig. 9B). Below that depth density and
395 porosity remain nearly constant. This trend is also expressed by the seismic facies, the less
396 dense drift sequences exhibit much lower reflection amplitudes compared to the platform
397 strata (Fig. 5). At distal Site U1468, there is an abrupt change at about 45 mbsf to nearly
398 constant values below. This depth coincides with the unconformable contact between delta
399 drift topset and overlying younger sheeted drift strata. The latter are characterized by low bulk
400 density and high porosity, whereas, generally, the delta drift sequences DS1 to DS3 show a
401 normal density and porosity trend with increasing burial depth.

402

403 DISCUSSION

404 We classify the herein described lobe-shaped sedimentary bodies as drift deposits that mainly
405 accumulated through the action of persistent bottom currents. We denominate these bodies
406 delta drifts, they represent different features compared with contourite fans. The latter,
407 originally described a siliciclastic fine grained fan-shaped body from the Vema Channel in the
408 Brazilian basin, downstream of a deep-water gateway which was assigned it to abyssal plain
409 contourites (Mézerai et al., 1993; Faugères et al., 2002; Hernández-Molina et al., 2008). .
410 Carter and McCave (1994) used the term fan drift attributed to a turbidite fan that extended
411 into a drift. Locker and Laine (1992) introduced a companion system comprising a submarine
412 fan/drift interaction. Such deposits, however, are different from the delta drifts we observed
413 in the Maldives. *Sensu stricto* a contourite drift is defined as a sediment drift, principally
414 formed by deep-water bottom currents (Stow et al. 2002a), however, the delta drifts observed

415 in the Maldives are not related to deep water bottom currents. Additionally, the term
416 contourite emphasizes current orientation with respect to the bathymetric contours. The
417 newly discovered delta drift is related to a relatively shallow water gateway and predominantly
418 formed by currents that expand at the exit of the gateway and preferably run downslope as an
419 underflow perpendicular to the isobaths. It can be best described as delta-like current-
420 controlled deposits. The northern delta drift consist of four lobes and the southern one of
421 three lobes resembling sequences DS1a, DS1b, DS2-DS3 and DS1-DS3, respectively.

422

423 Delta drift characteristics

424 There are several lines of evidence that indicate the current-controlled nature of the delta
425 drifts. A compilation of their characteristics is found in Figure 11. First a comparison of the
426 clinoform architecture of the platform and the drift sequences (DS1-DS3) clearly underpin their
427 differences, because they exhibit an obvious contrast in slope curvature: the sea-level driven
428 platform clinoforms have a distinct concave shape created by the foresets whereas the drift
429 sequences exhibit a convex upward geometry (Figs. 2, 4 and 11). The 3D image clearly
430 documents that the lobe-shaped sedimentary bodies are connected to the basinward channel
431 exits and so do not represent a sea-level controlled regression of the platform margin (Fig. 7).
432 Furthermore, typical gravitational foreslope deposits like slumps or debris flows have not been
433 identified in either core samples or the seismic data. In addition, gullies as we found in the
434 platform sequences (Fig. 3) do not exist in the delta drift. The only indication for downslope
435 gravity-induced mass transport is observed in the distal part of the drift at Site U1471. Here,
436 convolute bedding and soft-sediment deformation occurs at the base of the wackestone
437 interval in drift sequence DS1 (Fig. 8A). They might be products of sediment remobilization
438 (Phillips, 2006). However, taken into account that no clear grading was identified in these
439 layers and that some contacts were gradational at both, the base and top of the grainstone

440 layers, it is more likely that these intervals represent high-current events related to the
441 migration of bottom current.

442 Several observations argue for the action of long-lasting bottom currents and meet the criteria
443 established by Stow and Faugères (2008) for the recognition of drift deposits. (1) The absent of
444 bedding and lamination structures. In contrast to the gravity-controlled deposits of the
445 platform sequences typical black and white layers or distinct laminations are lacking in the
446 delta drift strata which are uniform in color. (2) Grain size from sand to clay. The grain size
447 varies from coarse sand (e.g. large benthic foraminifers) to fine carbonate debris. (3) The
448 degree of bioturbation. The latter is intensive and continuous (see results section). (4)
449 Variable, low to moderate sedimentation rates. Cycles of normal and inverse grading point to a
450 persistent bottom current flow with variation in mean current velocity or sediment supply. The
451 latter was relatively high and the average sedimentation rate of 17 cm ka^{-1} of the delta drifts
452 notably differs from the platform sequences with 4.4 to 3.2 cm ka^{-1} . It is comparable to rates
453 on mounded drifts, assigned to $5\text{-}30 \text{ cm ka}^{-1}$ by Stow et al. (2008). When accommodation
454 space was filled and the top of the delta drifts reached the swell depth of the channels, current
455 speed increased as indicated by the dominance of grain- and rudstones (Fig. 5, U1466 and
456 U1468). This point to intensification in transport energy of the current leading to the re-
457 deposition of larger components and the winnowing of the finer fraction. The filled
458 accommodation space resulted in a shallowing of the environment as evidenced by the
459 dominance and diversity of large benthic foraminifers and the occurrence of coralline algae
460 and *Halimeda* plates.

461 In general, the delta drifts show a proximal to distal fining trend. Basinward, very fine to fine
462 sand-sized carbonate grains dominate and grainstones are rare. The occurrence of grainstones
463 could be related to winnowing of the fine fraction by the postulated slope-parallel current that
464 slightly deflected the depositional center of the delta drifts to the south (red arrow; Figs. 7B to
465 7C). However, this current played only a minor rule in the formation of the delta drifts.

466 The wavy bottomsets at the base of the delta drift are herein interpreted as cyclic steps, as
467 described for similar up-slope migrating down-slope asymmetrical sedimentary structures
468 (Cartigny et al., 2011). The cyclic steps near the toe-of-slope are typical for the early stage of
469 delta drift development, when the slope profile is steeper (Figs. 2 and 4). In their up-section
470 they fade out, most likely related to a change in hydraulic regime associated with successive
471 reduction in slope curvature. Unfortunately, the recovery in DS1a at Site U1468 is very low and
472 details of the sedimentary facies of the cyclic steps cannot be determined. Principally, they
473 represent a lithified packstone interval with no significant differences to the overlying strata.

474 Another specific feature of the delta drift are channel-like features that cut into the lobe
475 surface down-current from the lobe apex (Fig. 3). They might be an indication for a multicore
476 bottom current with individual flows (Fig. 11). The current remained stationary along these
477 incised tracks while sedimentation continued over the entire lobe. Contemporaneously, the
478 current channels were filled above the incision level and prevailed as depressions where the
479 current stayed active (Fig. 3). The depositional elements of the mapped delta drift slope
480 channels are not comparable to siliciclastic deep water channels or slope valleys as described
481 for example by Deptuck et al. (2007), McHargue et al. (2011), Janocko et al. (2013). These
482 include high-amplitude reflection patches, lateral accretion packages, onlap fill patterns and
483 channel-levee-overbank complexes.

484 Giant excavation structures in the topsets of the delta drift lobes like the oval-shaped
485 depression at the contact to the northern channel mouth represent another distinctive
486 feature. Here, the loosely packed, non-cohesive delta drift strata onlap the former cemented
487 platform edge (Fig. 2) and a bottom current intensification may have been responsible for the
488 excavation. When the confined and accelerated bottom current that exits the channel reaches
489 a threshold velocity it may generate a turbulent flow at the lithological contact, eroding into
490 the unconsolidated delta drift beds by sweeping away the sand-sized carbonates. When this
491 process lasted for longer periods it created the observed large oval-shaped depression in front

492 of the platform edge that was later refilled by younger sediments (Figs. 2 and 7b-7D).
493 According to the bio-stratigraphy of Site U1466 the excavations formed after the deposition of
494 delta drift sequences DS1 to DS3 (Fig. 5).

495

496 Depositional environment

497 Prerequisites for a delta drift development are: a persistent sediment supply from a point
498 source and sufficient available accommodation space. Suitable point sources in carbonate
499 platform setting are inter-atoll gateways that connect the open ocean with the platform
500 interior shedding huge volumes of material from different source areas into a receiving basin.
501 The water masses flowing through the channels catch up fallout from the water column of
502 dominantly planktonic microfossil assemblages from the Indian Ocean side as well as
503 calcareous debris driven from the adjacent atolls and produced by the organisms living in the
504 gateways (Fig. 7B, green arrows). An additional source are benthic organisms including large
505 foraminifers colonized the flattened top of the delta drift and planktic organisms living in the
506 water column above the drift. Erosion of the former drowned platform top played only a minor
507 role in the sediment budget. We calculate the total volume of the northern delta drift to be
508 142 km^3 and the redeposited material eroded from the channel base accounts for only 0.05%.
509 On the western side of the archipelago, the west-east flowing current driven by summer
510 monsoon winds is stronger and the dominant driver pushing Indian Ocean water masses into
511 the Inner Sea (Purdy and Bertram 1993; Storz and Gischler, 2011). This dominant current
512 direction explains the distinct lobe-shaped morphology at the exit of the two gateways.
513 Changes in the flow regime possibly triggered by major oceanographic or climatic alternations
514 have result in the formation of major unconformities separating the delta drift sequences DS1-
515 DS3.

516 In the case of the Maldives, these gateways formed by partial drowning of the surrounding
517 platform top in the late Middle Miocene ca. 13 Ma ago and were initiated by a modification in
518 water mass circulation induced by the beginning of monsoon intensification (Betzler et al.,
519 2009, 2016b). Smaller inlets are still common for the modern Maldives atolls implying that the
520 reef rim facing the ocean is generally not a closed feature. The mechanism behind the
521 transformation of these inlets into large gateways remains speculative and needs further
522 research. Compared to the small inlets, the gateways allow the exchange of large volume of
523 water between the surrounding ocean.

524 Accommodation changes related to relative sea-level may have played only a minor role in the
525 formation the delta drifts. Figure 8B documents that the drift sequences DS1-DS3 were
526 deposited during a phase of minor sea-level fluctuations as shown by benthic foraminiferal
527 $\delta^{18}\text{O}$ values for the Atlantic and Pacific (Cramer et al., 2011). Coevally, there was no substantial
528 influence on sea-level based on ocean basin dynamics (Müller et al., 2008). A rough estimation
529 of the post-Middle Miocene subsidence rate provides a low value of 0.044 mm yr^{-1} that fits
530 very well with the rate deduced from ODP Site 715 (see Geological Background). For the
531 calculation we used the top of the carbonate platform at the base of DS1 (13.0 Ma) at Site
532 U1465 as a past sea-level indicator (Fig. 2). It lies at the present depth of ca. 570 mbsl. Because
533 of its thin sedimentary cover consisting of loosely packed carbonate sand (Fig. 5; Site U1465)
534 compaction is negligible. Paleo-sea level was almost the same as today (Kominz et al., 2008).
535 Coral reefs growing at rates of 10 mm yr^{-1} (Schlager, 2005) could easily catch up with the low
536 subsidence rate.

537 Accommodation during the growth of the delta drifts was mainly controlled by the preexisting
538 depositional topography of the Inner Sea and the magnitude of sediment supply. At the ocean
539 facing margin of a carbonate platform a delta drifts cannot develop because accommodation
540 space is generally too large; the slope profile generally rapidly declines to abyssal depth and
541 sediment export outside the platform through the gateways is negligible. The delta drifts

542 developed in a shallower basin with few hundred meters of water depth. The Maldives palaeo-
543 Inner Sea with an approximate 500 m water depth fits in this category (Fig. 7A). The gateway
544 delivering the sediments is not changing its base level, in fact the delta drift attached to the
545 gateway exit aggrades up to this level and at the same time outbuilds into the interior basin
546 filling the Inner Sea and eventually has a crest that is higher than the spill height of the channel
547 (Fig. 2). The bottom current in the gateway provides a steady sediment supply and distributes
548 the sediments after leaving the gateway along the slope profile, generating a Gaussian
549 curvature and keeping the angle-of-repose below a threshold for triggering significant slope
550 failure. Distinct changes in current speed occurred as documented by the waning and waxing
551 structures of the sediments. They are possibly related to variations in monsoon wind strength
552 as well as widening and/or deepening of the gateway induced by sea-level fluctuations. These
553 variations in current speed could have also influenced the organic matter proportion in the
554 delta drift sequences as indicated by the natural gamma radiation. Wetzel et al. (2008)
555 proposed that higher current speeds generally winnow out organic matter. There is a slight
556 trend in increasing gamma ray values at the top of each sequence, which in turn is related to a
557 decrease in current speed. However, variations in nutrient supply is another important factor.

558

559 CONCLUSIONS

560 Reflection seismic data together with cores and logs from IODP Expedition 359 document a
561 new sediment drift type located in front of two gateways. We term this new type a delta drift
562 and classify it as a channel-related drift that is emplaced under a long-term, current-driven
563 sediment flux regime. Our data do not show indication of significant gravity-controlled
564 sedimentation in the delta drift. The drift bodies form stacks of individual lobes in front of two
565 gateways. Both delta drifts are nearly identical and are deposited in front of the edge of a

566 drowned carbonate platform. The main characteristic of the delta drifts discovered on
567 Maldivian carbonate platform are:

- 568 • The delta drifts are situated in the Inner Sea basin at the downstream exit of a shallow
569 and over time deepening gateway. In contrast to a fluvial delta system, the delta drifts
570 accumulated considerably below base level;
- 571 • Individual lobes may built up stacks that resemble a delta drift;
- 572 • Current flow was wide-ranging on the drift body perpendicular to the isobaths. Smaller
573 channels running downdip are developed on top of the delta drift lobes indicating that
574 they must have been fed by a multicore current;
- 575 • The delta drifts exhibit progradation with pronounced sigmoidal clinoform geometry.
576 Their spatial extent is about 342-384 km² and the depositional relief reaches up to 500
577 m;
- 578 • The delta drifts show a distinct coarsening upward trend in grain size, related to a
579 shallowing of the depositional setting when accommodation space is filled up to the
580 level of the feeder channel bed;
- 581 • During the early phase of deposition, when the depositional profile of the slope was
582 still concave from the underlying distal slope clinoforms, cyclic steps developed at the
583 toe-of-slope;
- 584 • Large excavations with depths of up to 80 m may occur where the bottom current
585 overflows beds of consolidated and unconsolidated material and turns into a turbulent
586 flow. They reach dimension of 10 km² and preferably develop at the onlap termination
587 of the former cemented platform edge and the loosely packed coarse delta drift
588 topsets.

589

590 Acknowledgements

591 Our special thanks go to the IODP Expedition 359 drilling crew, ship's crew and scientific staff
592 of the Drillship JOIDES Resolution. The expedition was funded by the US National Science
593 Foundation (NSF); the European Consortium for Ocean Research Drilling (ECORD); the Ministry
594 of Education, Culture, Sports, Science and Technology, Japan (MEXT); the Ministry of Science
595 and Technology (People's Republic of China); the Korea Institute of Geoscience and Mineral
596 Resources; the Australian Research Council and the New Zealand Institute for Geological and
597 Nuclear Sciences; and the Ministry of Earth Sciences (India). The German Federal Ministry of
598 Education and Research is thanked for funding the seismic surveys (03S0405, 03G0236A).
599 Additional acknowledgements go to the companies HALLIBURTON-LANDMARK,
600 SCHLUMBERGER and CEGAL Geosciences for providing university grants for the seismic
601 processing software PROMAX and seismic interpretation software PETREL as well as its
602 BLUEBACK plugin. We thank M. Rebesco, as the editor of this manuscript, and T. Mulder as
603 well as D.A.V. Stow, as reviewers, for their very helpful comments that considerably improved
604 the manuscript.

605

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756 Fig. 1: A) Map of the study area (red box) in the northern part of the Maldives. B) Distribution
757 of seismic lines (black lines) and the location of IODP Expedition 359 Sites as well as ODP Site
758 716 and 715. Indicated is the general present bottom current pattern below a water depth of
759 about 200 m (compiled after Lüdmann et al., 2013). Example seismic profiles are marked in
760 orange. Present reefs are color-coded (yellow: island; blue: reef; green: 10-100 fathoms). WM:
761 winter monsoon; SW: summer monsoon.

762 Fig. 2: A) Part of reflection W-E seismic line M74-65 that crosses the top of the Middle
763 Miocene carbonate platform and delta drift north of Goidhoo Atoll in dip direction (for
764 location see Fig. 1). B) Interpreted version showing mapped boundaries of the drift mega-
765 sequences. Drift sequence DS1 can be subdivided into subsequence a and b. Indicated are the
766 positions of the IODP Expedition 359 drillsites. Indicated in grey is the delta drift which rests on
767 the exponential clinoforms of the former platform margin. Red wavy line marks a local
768 erosional unconformity. Dashed lines exhibit possible fault traces. Red arrows show reflector
769 termination. Black boxes reveal to an area of side echoes (see also cross line in Fig. 3) and an
770 excavation zone (see text for further explanation). CS: collapse structure. Dip indicator:
771 average velocity applied 1600 m/s.

772 Fig. 3: A) Part of reflection N-S seismic line SO-236-21 that crosses the former platform talus
773 and delta drift north of Goidhoo Atoll in strike direction (for location see Fig. 1). B) Interpreted
774 version showing mapped boundaries of the drift mega-sequences. Drift sequence DS1 can be

775 subdivided into subsequence a and b. Displayed in grey are the mounted delta drift lobe strata
 776 in strike view, underlain by the former platform foresets. Dotted black line indicates base of
 777 incised channel that are crossed perpendicular to their downdip trend. Red wavy line marks a
 778 local erosional unconformity. Black triangles point to the location of gullies that occur
 779 exclusively in the platform sequences and are absent in the drift sequences. Red arrows show
 780 reflector termination. Dashed black lines exhibit possible fault traces. Black boxes indicate an
 781 area of side echoes (see also cross line in Fig. 2 and text for further explanation).

782 Fig. 4: A) Part of reflection W-E seismic line M74-62 that crosses the top of the Middle
 783 Miocene carbonate platform and delta drift south of Goidhoo Atoll in dip direction (for
 784 location see Fig. 1). B) Interpreted version showing mapped boundaries of the drift mega-
 785 sequences. DS1 is underlain by the prograding platform foresets, above in grey the sigmoidal
 786 clinoforms of the delta drift lobe. Marked with black lines are the clinoform roll-overs. Red
 787 arrows show reflector termination. Dashed black lines exhibit possible fault traces. CS: collapse
 788 structure. Dip indicator: average velocity applied 1600 m/s.

789 Fig. 5: Lithostratigraphic correlation of the IODP Expedition 359 Sites along the northern
 790 transect (see also Fig. 1). It crosses the platform top (U1465), the proximal upper slope
 791 (U1466) and the more distal middle slope (U1468) setting. Indicated are the boundaries of the
 792 drift sequences (DS). In color are DS1 to DS3, representing the deposits of the delta drift
 793 discussed in the text. Marked in green are the stratigraphically equivalent parts of DS1 and DS2
 794 in Sites U1466 and U1468, respectively. In addition, core and log total gamma radiation are
 795 plotted with the seismic data (distance 250 m) at the well location (red line) in the background.
 796 Depth is shown in mbsf.

797 Fig. 6: A) Detail of profile M74-65 (see Fig. 2 for location) showing aggradational asymmetric
 798 cyclic steps with steeper basinward flank (transparent black arrows indicate upslope
 799 migration). B) 3D view of cyclic steps at the base of drift sequence DS1. Color-coded is the dip

800 angle indicating a low upslope and a high downslope inclination of the margin-parallel
801 sediment waves. It is characteristic for up-slope migrating asymmetrical cyclic steps after
802 classification of Cartigny et al. (2011).

803 Fig. 7: Sketch of the Maldives palaeo-topography in the study area. View is to the west. A)
804 Surface DS01 representing the initial “empty bucket” phase of the Inner Sea ca. 12.9 Ma ago.
805 During this time the Inner Sea formed a semi-enclosed basin connected to the Indian Ocean via
806 the northeast Kardiva Channel (Fig. 1). With the deposition of DS1 the platform top partially
807 starts to drown and two proto-channels formed that connect the paleo-Inner Sea with the
808 Indian Ocean. B) Top of delta drift sequence DS1 (DS02) demonstrating the lobe-shape infill of
809 sequence DS1 attached to both waterways. The depocenter is deflected slightly southward by
810 a south directed contour current (red arrow). Green arrows indicate possible sediment
811 sources. C) Top of delta drift sequence DS2 (DS03) showing the progradation of sequence DS2
812 into the Inner Sea basin. DS2 continued to be deflected southward. Channel widening
813 dominates over channel incision by platform backstepping. D) Top of delta drift sequence DS3
814 (DS04) revealing the final stage of delta drift formation ceasing at ca. 9.0 Ma. Indicated are the
815 positions of the IODP Expedition 359 Sites. Isolines show depth in TWT. Red arrows indicate an
816 assumed slope-parallel current, entering the Inner Sea from the deep eastern Kardiva Channel
817 (see Fig. 1 for location). CS: collapse structure; E: excavation.

818 Fig. 8: A) Lithostratigraphic correlation of the IODP Expedition 359 Sites along the southern
819 transect (see also Fig. 1). It crosses the platform top (U1470), the proximal upper slope
820 (U1472) and the more distal middle slope (U1471) setting. Indicated are the boundaries of the
821 drift sequences (DS). In color are DS1 to DS3, representing the deposits of the delta drift
822 discussed in the text. In addition, core and log total gamma radiation are plotted with the
823 seismic data (distance 250 m) at the well location (red line) in the background. Depth is shown
824 in mbsf. B) $\delta^{18}\text{O}$ curve for the South Atlantic and Pacific after Cramer et al. (2011) with location
825 of the delta drift sequences DS1 to DS3.

826 Fig. 9: A) Core section 61X (379.2 mbsf) and 70X (466.6 mbsf) of Site U1468 showing typical
827 drift and platform slope strata, respectively (see Fig. 1 for location). Characteristic is the color
828 change of the platform slope sequence. B) Bulk density and porosity measured on cores from
829 Sites U1466 and U1468.

830 Figure 10: Facies of the delta drift (scale bar for core photographs =1 cm, scale bar for
831 photomicrographs =1 mm). A) Core photograph of a fine-grained bioclastic packstone at Site
832 U1468. B) Core photograph of an unlithified wackestone with intraclasts at Site U1468. C) Core
833 photograph of a large benthic foraminifera-rich rudstone to grainstone with fining upward at
834 Site U1468. Echinoid spines and intraclasts are common. D) Photomicrograph of the fine-
835 grained packstone at Site U1466. E) Photomicrograph of the rudstone to grainstone facies at
836 U1468 with abundant *Amphistegina* and intraclasts. See also figure 5 for location of samples.

837 Fig. 11: Summary of the delta drift characteristics, including a sketch showing the channel-
838 related drift in strike and dip view. Gnstn: grainstone; pkstn: packstone; rdstn: rudstone;
839 wkstn: wackestone.