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1                                   **Inflation of ponded, particulate laden, density currents.**

2

3

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8

9   **KEYWORDS**

10   Turbidity Currents

11   Ponded Flows

12   Seafloor Basins

13   Inflation

14   Deposits

15

16 **ABSTRACT**

17 Field-based, physical modelling and analytical research approaches currently suggest that  
18 topographically confined particle-laden density currents commonly inflate to produce suspension  
19 clouds that generate tabular and texturally homogeneous sedimentary deposits. Here, a novel three-  
20 dimensional theoretical model details a phase space of the criteria for inflation as a function of flow  
21 duration, basin size and geometry, total mass transport, sediment concentration, and particle grain  
22 size. It shows that under most circumstances cloud inflation is unlikely at real-world scales. Even  
23 where inflation is possible, inflation relative to initial flow height is small except for suspensions of  
24 silt or finer-grained sediment. Tabular deposits therefore either arise from processes other than flow  
25 ponding, or deposits in confined settings may be significantly more complex than are currently  
26 understood, due to processes of autogenic compensation and channelization, with associated  
27 implications for reservoir characterisation in applied contexts. This study illustrates the potential of  
28 analytical flow modelling as a powerful complement to other research approaches.

29

30 **INTRODUCTION**

31 Density currents driven by suspended particulate material are a key mechanism for atmospheric,  
32 fluvial, and marine sediment transport. In natural or artificial basins, these flows are trapped by  
33 confining slopes and become ponded (Van Andel and Komar 1969). Key examples include  
34 hyperpycnal inflow into lakes, reservoirs, and small seas; turbidity-current inflow into bathymetric  
35 lows; and topographically confined snow or dust storms. If supply of material into a ponded flow  
36 exceeds that lost through deposition, and/or overspill, the ponded flow thickens and forms an inflating  
37 cloud eventually, filling the confining basin (Lamb et al. 2004, Toniolo et al. 2006). This process is  
38 limited only if outflow balances inflow, where a quasi-steady cloud is established (Patacci et al.  
39 2015). If the outflow exceeds inflow, then the volume of the ponded cloud decreases.

40 A common feature of confined deep-water basins is the deposition of apparently tabular  
41 deposits, attributed to basin fill by ponded turbidity currents (e.g., Twitchell et al. 2005). Inflation of

42 ponded turbidity currents is thought to produce homogeneous clouds of suspended particulate  
43 material, and thus basin-wide tabular deposits (Toniolo et al., 2006; Sylvester et al., 2015). Models  
44 of turbidite sand pinchout geometry commonly show conceptual tabular geometries for the sands  
45 remote from the confining slope (Smith and Joseph, 2004; Gardiner, 2006; Bakke et al., 2013;  
46 Spychala et al., 2017). Hydrocarbon reservoirs can be hosted in such deposits, with the degree of  
47 deposit homogeneity on the basin floor and the extent of sand deposited on the confining slopes being  
48 key factors that dictate their economic significance (Amy et al., 2013). Therefore, it is important to  
49 understand controls on deposit formation in confined settings. Here we use a novel mass-conservation  
50 model to produce computational stratigraphy, assessing the role of topographic confinement on flow  
51 ponding and inflation and thereby evaluating the likely character of associated sedimentary deposits.

52

## 53 **METHODS**

54 For density currents to pond and inflate they must first traverse their confining basin. Traverse times  
55 can be estimated by the fluid input rate into the basin,  $q_I$ , and three-dimensional basin geometry. The  
56 flow input rate into the basin is given by

$$57 \quad q_I = \begin{cases} \frac{M}{\rho_s C t_d} & t \leq t_d \\ 0 & \text{otherwise} \end{cases}, \quad (1)$$

58 where  $M$  is the total mass of sediment transported into the basin;  $C$  is the suspended-sediment  
59 concentration;  $\rho_s$  is the sediment density; and time  $t = t_d$  is the flow duration, denoted by subscript  
60  $d$  notation. For simplicity, the model is constrained to well-mixed flows, where  $C$  is approximately  
61 constant for the duration of the flow. A generic basin is considered (Fig. 1), where sidewall slopes,  
62  $S_1$  to  $S_4$ , and basin-floor length,  $L$ , and width,  $W$ , scales can vary independently. However, over the  
63 course of a single flow, change in basin bathymetry,  $\eta$ , is assumed negligible in comparison to initial  
64 basin length scales. The plan-form area,  $A$ , cross-sectional area,  $B$ , and volume,  $V$ , of the ponded flow  
65 are thus a function of flow depth,  $H$ .

66            Entering the basin, the flow is assumed to expand rapidly to the sidewall width,  $W$ . This  
67    assumption provides a first-order estimate of the flow dynamics, where depositional heterogeneities  
68    that may be formed in the developing flow near the inlet are omitted. However, it does not affect the  
69    conditions for ponded cloud inflation and simplifies the physical processes to a tractable form as  
70    discussed below. The initial flow traversing the basin floor is denoted by subscript  $t$  notation, i.e.,  
71    depth  $h_t = H_t$  and average velocity  $U_t$ . Net deposition and entrainment are initially assumed  
72    negligible (Hogg et al., 2015). The velocity on the basin floor is given by the Froude number  
73    condition,  $Fr = U_t/\sqrt{gRCH_t}$ , where  $R$  is the reduced density  $R = \rho_s/\rho - 1$ . Initial flow depth is  
74    therefore defined implicitly by the discharge, as equal to the product of flow velocity and cross-  
75    sectional area,

$$76 \quad q_t = Fr\sqrt{gRCH_t}B_t. \quad (2)$$

77    For fixed discharge the depth of the flow traversing the basin,  $H_t$ , decreases with increasing Froude  
78    number. The  $Fr$  of a density-current head decreases with flow-ambient fluid depth ratio. Here we  
79    assume the limit of an infinitely deep ambient and take the Froude number of the flow as it traverses  
80    the basin as equal to unity,  $Fr = 1$  (Shin et al., 2004). The time taken for a flow to cross a basin, and  
81    fill it to height  $H_t$ , is  $t_t = V_t/q_t$ . From Equation 2, increasing the front Froude condition has the  
82    effect of reducing the time taken,  $t_t$ , and the depth of the flow,  $H_t$ , whilst the flow traverses the basin.  
83    On crossing the basin, the flow may run up the distal slope, exchanging kinetic energy for potential  
84    energy. An energy balance yields the maximum run-up height of the flow, denoted by subscript  $r$ ,

$$85 \quad H_r = H_t \left( 1 + \frac{Fr^2}{2} (1 - E) \right), \quad (3)$$

86    where  $E = 33\%$  is the energy lost to thermal dissipation (Allen, 1985). Equation 3 is a lower limit  
87    on the flow run-up height, which may be enhanced as the center of gravity of the flow changes as it  
88    runs up the slope (Muck and Underwood, 1990).

89            After the flow has traversed the basin, mass conservation of the suspended sediment, settling  
90    with velocity  $w_s$  (Soulsby, 1997), predicts the inflation of the now ponded flow. Simply, the time rate

91 of change in the volume-integrated suspended-sediment concentration,  $VC$ , is given by the inflow of  
 92 sediment-laden fluid into the basin,  $q_I C$ , minus the area-integrated rate of sediment deposition,  $ACw_s$ ,  
 93 and overflow of sediment-laden-fluid,  $q_o C$ . Following a similar argument, the change in bed depth,  
 94  $\eta$ , is the rate of deposition divided by the change in concentration between the bed,  $C_m = 0.6$ , and  
 95 the suspension (Dorrell and Hogg, 2010). Therefore, mass conservation yields two equations for the  
 96 evolution of the ponded cloud and deposit, decoupled under the assumption that change in basin  
 97 bathymetry is negligible for a single flow (see supplementary material),

$$98 \quad \frac{d}{dt} VC = q_I C - ACw_s - q_o C, \quad (4a)$$

$$99 \quad \frac{d\eta}{dt} = \begin{cases} Cw_s / (C_m - C) & \eta < H \\ 0 & \text{otherwise} \end{cases} \quad (4b)$$

100 For simplicity, the hydrodynamic characteristics and sediment composition of the flow entering the  
 101 basin are assumed constant in time. Further, sediment is assumed to be kept in suspension by turbulent  
 102 diffusion (Dorrell et al., 2013), driven by the continuous flow into the basin. Suspension may be  
 103 enhanced by the upflow of fluid in the inflating ponded cloud. Thus, as a first-order approximation,  
 104 particulate material in suspension is assumed unstratified as the ponded cloud inflates; significant  
 105 stratification is assumed to develop only once the flow into the basin is extinguished. As the flow is  
 106 assumed unstratified,  $C$  is constant. However, variations in area and volume-averaged, inflow and  
 107 outflow concentration in a stratified flow are analogous to variations in the inflow and outflow  
 108 discharge and settling velocity. Here inflation is modeled for confined flows,  $q_o = 0$ , although  
 109 overflow acts as a hard limit on cloud inflation (Toniolo et al., 2006). As  $V$  is the depth integral of  $A$ ,  
 110 then ponded-cloud inflation (Eq. 4a) is simplified to an integral equation

$$111 \quad \int_{H_t}^H \frac{A}{q_I - Aw_s} dH = \int_{t_t}^t dt. \quad (5)$$

112 Whilst inflow discharge is greater than the rate of detrainment, the height of the ponded cloud  
 113 increases in time.

114 Eventually the inflating cloud tends to an equilibrium, denoted subscript  $e$ , where input and  
 115 detrainment balance,

116  $q_I = A_e w_s.$  (6)

117 For  $t_t \leq t < t_e$  Equation 5 has exact solutions (see supplementary material) that define ponded cloud  
118 inflation height,  $H$ , at time  $t$ . However, as the ponded-cloud volume increases, the rate of change of  
119 volume monotonically decreases to zero, (Eq. 4a). Therefore,  $H \rightarrow H_e$  is reached only at time  $t_e \rightarrow$   
120  $\infty$ . This limit is a consequence of inflation limited by the growth of the detrainment surface area,  $A$ ,  
121 with flow depth.

122

## 123 **RESULTS**

124 In Figure 2A ponded-cloud inflation rate, derived from Equation 5, compares well to  
125 experiments of topographically confined turbidity currents (see experiment L6 Patacci, 2010; Patacci  
126 et al. 2015). The experiments were conducted in a two-dimensional basin, of rectangular cross  
127 section, that was 5.12 m long, 0.35 m wide and 0.35 m and deep The basin was situated in a tank of  
128 0.8 m ambient fluid depth. Sediment used in the experiments consisted of tightly distributed fine-  
129 grained 40  $\mu\text{m}$  ballotini (non-cohesive, nearly spherical glass beads). To account for flow-ambient  
130 fluid mixing at the inlet, experiment L6 of Patacci (2010) is characterized by the recorded depth,  
131 velocity, and density of the flow as it traversed the basin, and by the duration of the flow  $t_d = 590$  s.  
132 The average height of the experimental flow as it traversed the basin was  $H_t = 0.1\text{m}$ . The flow had a  
133 front velocity  $U_t = 0.1 \text{ m s}^{-1}$ ; width and depth integration of the front velocity yields the effective inlet  
134 discharge,  $q_I = 3.6 \times 10^{-3} \text{ m}^3 \text{ s}^{-1}$ . The total mass of sediment transported into the basin,  $M = 39.4$  kg,  
135 particle density  $\rho_s = 2650 \text{ kg m}^{-3}$ , and the total fluid discharge,  $q_I \times t_d$ , defines the effective flow  
136 concentration,  $C = 0.7\%$ , Equation 1. The calculated experimental flow-front Froude number was  
137 0.93.

138 Comparison of model to experimental flow inflation is made using a clearly defined dense  
139 layer visible in the experiments (Patacci et al. 2015). Above this dense layer, there is a comparatively  
140 thin dilute suspension cloud. This dilute suspension cloud is generated by mixing of the suspension  
141 and ambient fluid entrainment, driven by flow reflection off the distal slope (Patacci et al. 2015). As

142 this layer is dilute, it is assumed of negligible importance (Patacci, 2010; Patacci et al. 2015); thus it  
143 is assumed that the experiment is well described by the entrainment-free model, Equation 4. Predicted  
144 rates of inflation are slightly greater than that observed. This can be explained by a component of  
145 mass loss through overspill, as the distal experimental basin slope was of limited height, possibly  
146 augmented by subtle stratification effects in the lower dense layer (Patacci et al., 2015).

147 The inflation of a ponded flow, Equation 5, can be parametrized by three key dimensionless  
148 variables:

$$149 \frac{q_I}{WLw_s}, \frac{w_s t_d}{H_t}, \text{ and } \frac{t_t}{t_d}, \quad (7a-c)$$

150 respectively: the ratio of inflow discharge to the rate of deposition across the initial basin area (Eq.  
151 7a); and the ratio of settling velocity to flow depth over flow duration (Eq. 7b). Initial conditions are  
152 prescribed by the ratio of run-out time to flow duration (Eq. 7c). Inflation is also dependent on basin  
153 geometry; the dimensionless parameters of basin width to length and slope aspect ratios determine  
154 how quickly solutions tend towards equilibrium flow height (Fig. 2B). However, not all ponded flows  
155 have sufficient discharge or are of sufficient duration to inflate; for example, some flows may only  
156 just reach and reflect off the distal basin slope before collapsing (i.e., reflected surge flows: Komar,  
157 1977; Patacci et al., 2015). A necessary, but not sufficient, criterion to distinguish inflating clouds,  
158 and in particular their deposits, from other ponded flows is that cloud depth,  $H$ , exceeds the run-up  
159 height of the flow,  $H_r$ , after it first traversed the basin; here the case  $H > H_r$  is referred to as substantial  
160 inflation. For flows of nearly infinite duration (such as hyperpycnal inflow into lakes, reservoirs and  
161 small seas) this is simplified to  $H_e > H_r$  (Fig. 2C). From Equation 5 it is seen that this is satisfied  
162 only if inflow discharge is greater than detrainment at the run-up height  $H_r$ ,  $q_I > A_r w_s$ . Change in  
163 basin geometry significantly affects this criterion. For example, wider basins are traversed by  
164 shallower flows and are thus more likely to inflate (Fig. 2C). Further, the criterion  $H_e > H_r$  scales  
165 linearly with  $H_r$  in two-dimensional basins. However, even in steep-sided three-dimensional basins  
166 the inflation criterion scales quadratically with  $H_r$  (Fig. 2C). This is because basin area  $A = (L +$



167  $2S_L H)(W + 2S_W H)$  is quadratic in  $H$ , where average inverse slopes  $S_L = \frac{1}{2} \left( \frac{1}{S_1} + \frac{1}{S_2} \right)$  and  $S_W =$   
168  $\frac{1}{2} \left( \frac{1}{S_3} + \frac{1}{S_4} \right)$  are non-zero.

169 For finite flows, of duration  $t = t_d$ , the maximum height of the inflated cloud is denoted  $H(t_d)$   
170  $= H_d$ . The condition for substantial inflation,  $H_d > H_r$ , is given by the criteria that: i) flow duration  
171 must be sufficient for the flow to traverse the basin,  $t_d > t_t$ ; and ii) [that] the inflow discharge is  
172 greater than detrainment at run-up height,  $q_I > A_r w_s$ . If inflow discharge, or flow duration, is  
173 decreased, inflation of ponding flows may be reduced or become impossible; see Table 1. For  
174 example: if inflow discharge is less than detrainment at initial flow height, but greater than that on  
175 the basin floor,  $LW w_s$ , the flow ponds but does not inflate; if flow duration is less than the time taken  
176 to cross the basin the “surge flow” does not inflate but reflects off the basin slope(s) until dissipated  
177 (Komar, 1977); or if detrainment across the basin floor is greater than the inflow discharge, then the  
178 accommodation space is too large for ponding and the flow is effectively unconfined.

179 Based on the inflation model, Equation 4, Figure 3 plots the phase space of the scenarios in  
180 which real-world-scale ponded flow may inflate, and the flow inflation relative to initial height, as a  
181 function of basin geometry (Fig. 3A-C) and ponded-flow makeup (Fig. 3D-F). For each plot, flow  
182 duration and one other parameter are varied, while all other variables are kept constant. Flow duration  
183 is kept as a free variable, because it is the least well constrained parameter for which a reasonable  
184 average value can be estimated. The fixed values describe: a relatively small ( $LW = 100 \text{ km}^2$ ),  
185 equant ( $W/L = 1 \text{ m/m}$ ) and steep-flanked ( $S_1 = 0.1 \text{ m/m} = 5.74 \text{ degrees}$ ) basin; a low-concentration  
186 flow (depth-average concentration,  $C = 0.3\%$ ), composed of fine sand ( $d = 177 \mu\text{m}$ ); and sufficient  
187 sediment transported to generate a deposit 6.4 m thick if uniformly distributed across the basin floor,  
188  $M/LW = 10 \text{ tonnes m}^{-2}$ . These parameters were chosen because they represent real-world scenarios  
189 where inflation would be expected, i.e., a very large fine-grained flow entering a small basin with  
190 steep flanks. In addition, the inflation estimates shown in Figure 3 are optimistic, in that they may  
191 be limited by overspill in real-world settings (Pirmez et al., 2012). Plots of calculated basin-floor  
192 deposit thickness, absolute inflation heights, and the time taken by the flow to traverse the basin are

193 provided in the supplementary material. Basin-geometry and ponded-flow variables are contrasted to  
194 characteristic basin geometries and deposit and turbidity-current conditions from ancient and modern  
195 deep-water systems; see white arrows in Figure 3 and Table 2 for original data sources.

196 Figure 3A shows that for medium to small basins (e.g., Brazos IV, BR), there is limited  
197 inflation above the run-up height of the flow. In large basins (e.g., Marnoso-Arenacea, MA) the ability  
198 to inflate the ponded cloud decreases. Moreover, only large events (leaving a deposit  $> 1$  m thick)  
199 transport enough mass per basin area to cause any inflation, with inflation of the larger events  
200 (depositing beds 5 to 20 m thick) limited to 1.5-2.0 times the original thickness of the flow (Fig. 3D).  
201 Figure 3E shows that values of depth-averaged sediment concentration in the range 0.05-0.5%, typical  
202 of observed turbidity currents, lead to the largest inflation. However, such inflation is again limited  
203 compared to the run-up height of the flow, suggesting that ponded deposits may be difficult to  
204 distinguish from surge-flow deposits in the rock record. Inflation is more significant in wider basins  
205 (Fig. 3B) and in the case of steeper confining slopes (Fig. 3C). However, basins with very steep slopes  
206 ( $> 10^\circ$ ) or that have a high width-to-length aspect ratio ( $> 2$ ), where the flow width is comparable to  
207 the basin width, represent very uncommon scenarios. Therefore, the general conclusion from Figure  
208 3 is that in real-world scenarios for sandy flows traversing a basin, inflation past the run-up height is  
209 constrained to a small area of the phase space, and that any inflation that does occur within the  
210 duration of the flow is small in comparison to the height of the flow as it travels across the basin floor.

211 The exception to the general conclusion that ponded clouds do not inflate significantly beyond  
212 1.5 times the predicted depth of the flow in the basin (see Fig. 3) is for flows of finer particle size;  
213 here quadratic decrease in settling velocity significantly enhances the potential flow inflation for silty  
214 and muddy flows (Fig. 3F). This suggests that in polydisperse flows, inflation heights of different  
215 grain sizes are decoupled, providing a means to cause planform grain-size fractionation in deposits.

## 216 **DISCUSSION**

217 The analytical model presented here suggests that turbidity currents are unlikely to form ponded  
218 sandy clouds in confined basins under most circumstances. Sandy deposits in confined basins are

219 therefore unlikely to form beneath such clouds, and this scenario of deposition can be recognized as  
220 only one of four distinct interaction styles of turbidity current with confining bathymetry (Table 1,  
221 Fig. 3G). It can be postulated that each likely has its own depositional signature:

222 i) Turbidity currents inflate to fill a basin, producing tabular beds that extend across the entire  
223 basin (Fig. 4A). Although substantial inflation of the sandy component of ponded clouds in  
224 confined basins is considered unlikely under the broad range of realistic scenarios of flow  
225 conditions, basin geometries and deposits considered, tabular deposits that may have formed  
226 under such conditions include the Lower and Middle Fans / Series 20 and 40 (sensu Beauboeuf  
227 et al., 2003 and Prather et al., 2012, respectively) of Basin IV of the Brazos-Trinity slope  
228 system, western Gulf of Mexico); these deposits can be imaged in relatively high detail using  
229 high-frequency 3D seismic data. Outcropping systems provide only quasi-3D control on bed  
230 geometry at best. Nevertheless, tabular beds in confined basins, e.g., the Castagnola system of  
231 northern Italy (Marini et al., 2016), can be considered candidates to have formed beneath sandy  
232 suspensions.

233 ii) Ponded turbidity currents may extend across the whole basin, but do not inflate. The  
234 architectural style of associated deposits may vary significantly. Deposition from a current  
235 reflected off the confining slopes may induce tabularity; in this case paleocurrent data, where  
236 available, might indicate variable paleoflow orientations (Haughton 1994, 2001; Amy et al.,  
237 2007; Tinterri and Tagliaferri, 2015). With flows that ran parallel to the long axis of a thin  
238 basin, the Tabernas-Sorbas system is a candidate for such depositional types (Fig. 3B).  
239 Alternatively, beds might taper distally, and possibly show subtle autogenic stacking effects  
240 (Fig. 4B), for example the Upper Fan / Series 70 perched apron (sensu Beauboeuf et al., 2003  
241 and Prather et al., 2012, respectively) of Brazos-Trinity Basin IV.

242 iii) Turbidity currents are of insufficient duration to fill the basin. In this case, individual current  
243 characteristics will determine the loci of deposition; sequences of similar currents might  
244 produce ordered, compensationally stacked lobes (Deptuck et al., 2008, MacDonald et al., 2011,

245 Prelat and Hodgson, 2013), whereas flows of varying character could produce disordered  
246 deposits (Fig. 4C).

247 iv) Turbidity currents end within the basin, possibly, though not necessarily interacting with lateral  
248 topography. Associated deposits are likely to show autogenic effects in their architecture,  
249 including lobe compensation and channelization (Fig. 4D). Such deposits are likely to conform  
250 to the style of unconfined lobes, which are described by an extensive literature (e.g., Deptuck  
251 et al., 2008, MacDonald et al., 2011, Prelat and Hodgson, 2013).

252 Analytical modelling provides new constraints on the likelihood of inflation of ponded turbidity  
253 currents, suggesting that a range of flow processes and depositional products is likely in confined  
254 settings. A consequence is that the stratigraphic architecture generated by confined flows is likely  
255 much more complex than previously thought; sandy deposits in confined basins are unlikely to form  
256 from inflated ponded clouds and therefore could be tabular for another reason, or more heterogeneous  
257 in their planform distribution (Figs. 3, 4). Future work is needed to explore the dynamics and relative  
258 likelihoods of the extended range of interaction styles postulated. Theoretically based flow models  
259 offer a new means to test and upscale the results from complementary experimental models, to  
260 provide better constraint on the interpretation of field scale observations of sedimentary architecture.  
261 The present model, however, does not take flow grain size or density stratification into account and  
262 cannot therefore realistically predict bed pinchout geometries, including the height to which turbidites  
263 drape slopes. Both outcrop and seismic case studies suggest that different grain size fractions in a  
264 flow may pond to different heights (Badalini et al., 2000; McCaffrey and Kneller, 2001, Smith and  
265 Joseph, 2004, Twichell et al., 2005; Gardiner, 2006). To provide a better-calibrated constraint on  
266 the dynamics and relative likelihoods of the range of interaction styles of ponded flows with their  
267 confining bathymetry, the model should be extended to incorporate stratification effects.

268

269 **CONCLUSIONS**

270 Deposits confined gravity current in, for example, seafloor mini-basins are commonly modelled as  
271 being nominally tabular. A potential mechanism to generate such tabularity is the inflation of ponded  
272 gravity currents in the basin to produce a homogeneous suspension from which the deposits are  
273 ultimately formed. Here we discuss the conditions for ponded-cloud inflation and use a simplified  
274 mass-conservation model to show that substantial inflation of ponded flows is unlikely in real-world  
275 basins where: i) three-dimensional variations in basin geometry increase the detrainment surface area  
276 rapidly with increasing ponded-cloud depth; ii) detrainment in real-world scenarios is much greater  
277 than expected sediment supply; and iii) flows are of insufficient duration to traverse the basin before  
278 their supply into the basin is extinguished. The exception to this general rule is the inflation of gravity  
279 currents dominated by fine-grained sediments, where detrainment decreases quadratically with  
280 particle size. From the mass-conservation model we are able to investigate a phase space of basin and  
281 flow conditions where ponded currents may inflate. We also delimit the various regions where  
282 inflation is impossible, where the source flow either deflates through detrainment, is of insufficient  
283 duration to traverse the basin (i.e. reflected surge flows) or is effectively unconfined. The modelled  
284 case study suggests that deposit tabularity either arises for a reason other than sedimentation from an  
285 inflated suspension cloud, or that basin fill may be more heterogeneous than commonly modelled.  
286 Linking analytical modelling of flow dynamics and deposit structure (tabularity in this case) is  
287 demonstrated to be a technique complementary to experimental modelling and analysis of field data.

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418

419 Table 1. Constraints on ponded cloud inflation.

Flow Type	Cloud Height	Dynamical Constraints
ia) substantial inflation	$H_d > H_r$	$q_l > A_r w_s, t_d \geq t_t$
ib) limited inflation	$H_t < H_d \leq H_r$	$A_t w_s < q_l \leq A_r w_s, t_d \geq t_t$
ii) ponding	$0 < H_d \leq H_t$	$LW w_s < q_l \leq A_t w_s, t_d \geq t_t$
iii) surge	n/a	$q_l \geq LW w_s, t_d < t_t$
iv) unconfined	n/a	$q_l < LW w_s, t_d < t_t$

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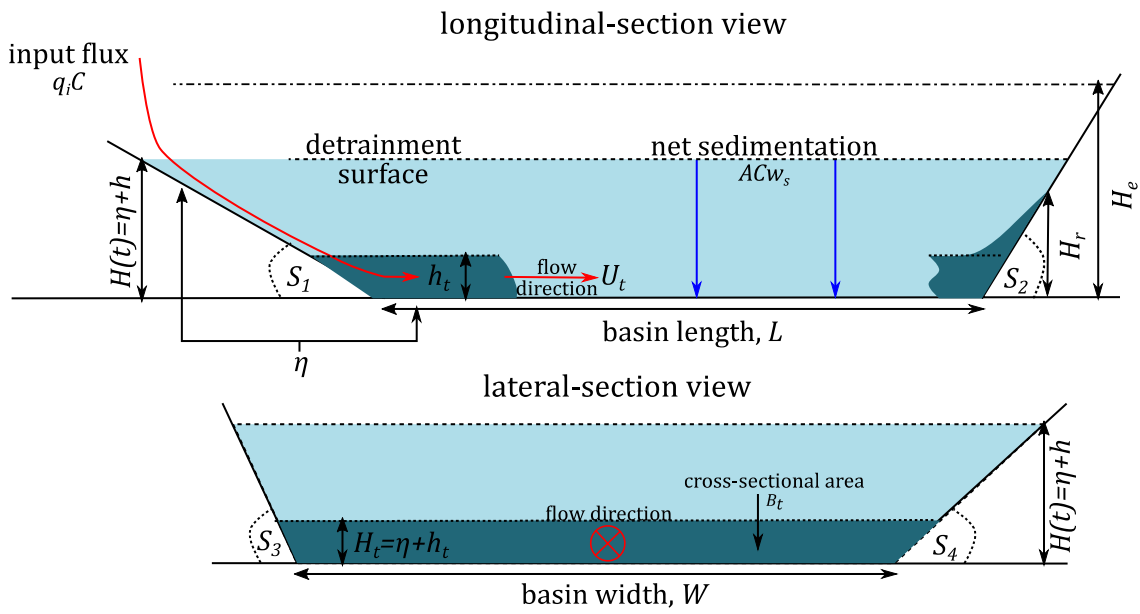
423

424 Table 2. Empirical data sources used in Figure 3.

	System	Source	Data
BR	<u>Brazos system, Basin IV</u>	Pirmez et al. 2012 Expedition 308 Scientists 2006	Basin Geometry Bed Thickness
CA	<u>Castagnola, Unit 1</u>	Felletti 2002 Marini et al. 2016	Basin Geometry Bed Thickness
CC	<u>Congo Canyon, flows 1-11</u>	Cooper et al. 2013	Flow Duration
GC	<u>Gaoping Canyon, flow 1</u>	Carter et al. 2012	Flow Duration
HC	<u>Hueneme Canyon, event 2</u>	Xu 2010	Flow Concentration
MA	<u>Marnoso Arenacea, Unit III</u>	Argnani and Ricci Lucchi 2001 Tinterri and Tagliaferri 2015	Basin Geometry Bed Thickness
MC	<u>Monterey Canyon, event 2</u>	Xu et al. 2004 Xu 2010	Flow Duration Flow Concentration
TS	Tabernas-Sorbas	Haughton 1994 Haughton 2001	Basin Geometry Bed Thickness

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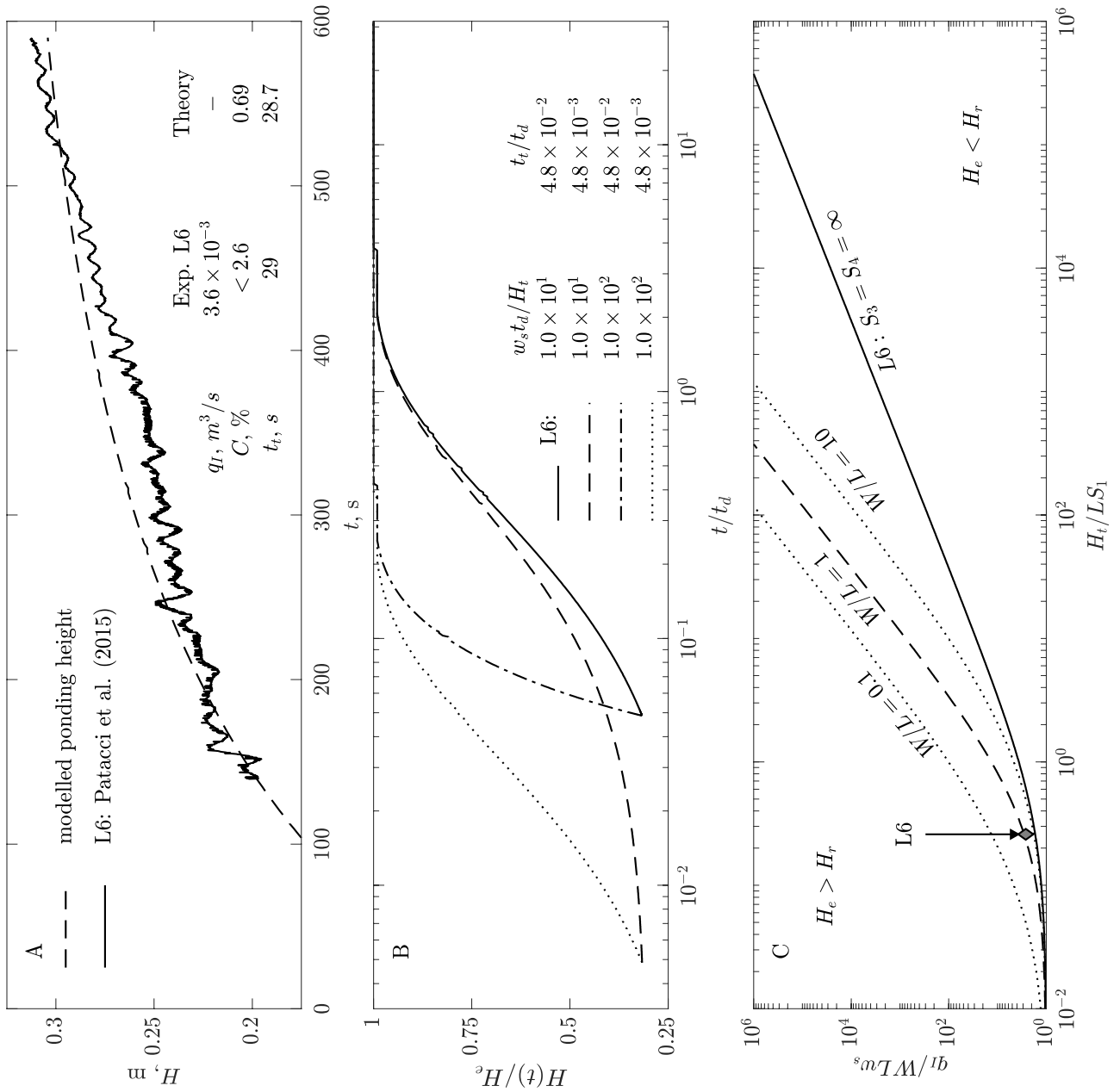
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428 Figure 1. Schematic diagram of simplified model basin showing longitudinal and lateral-section

429 views of the initial basin-floor flow and later ponded cloud inflation.



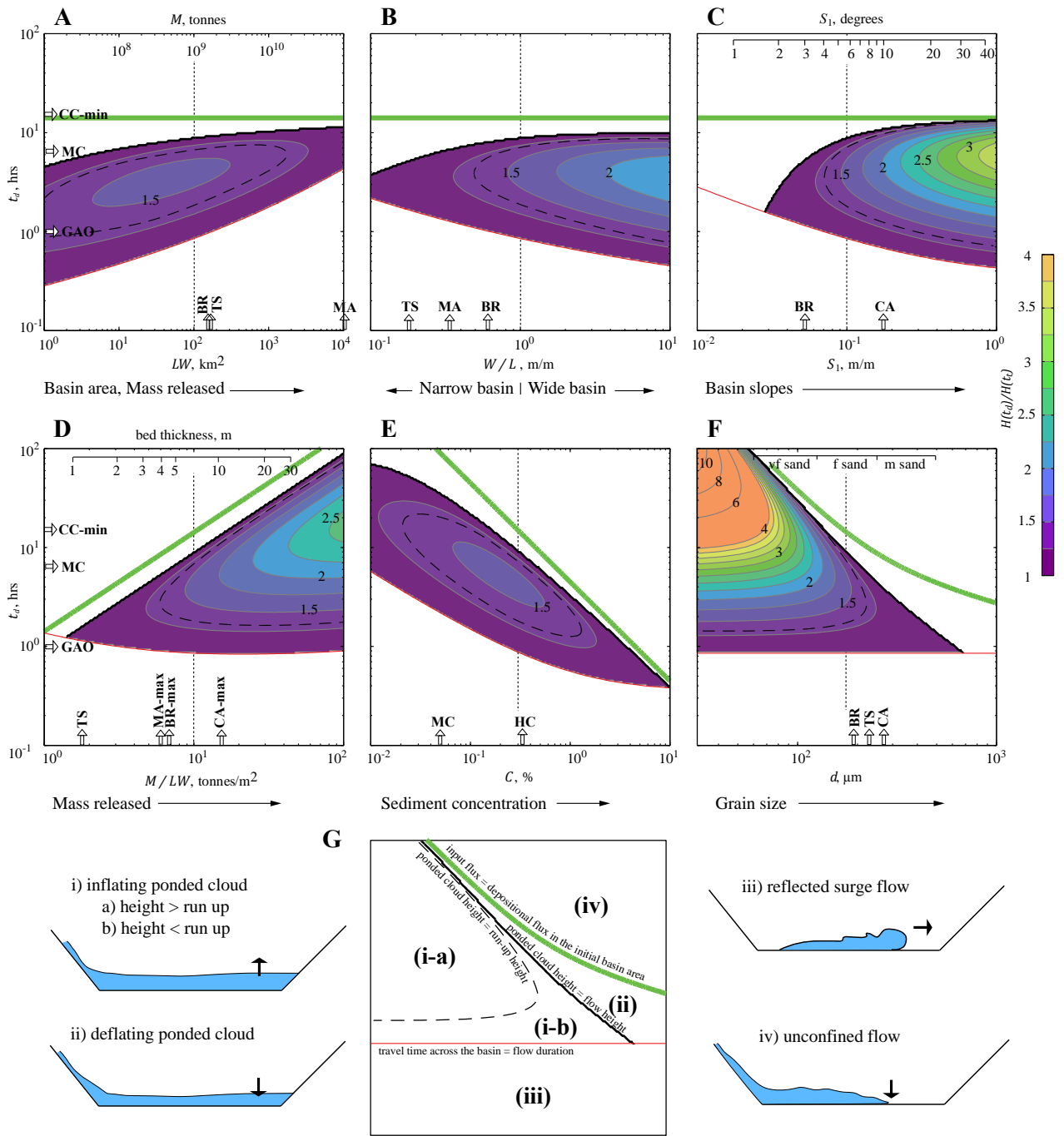
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431 Figure 2. A) Comparison of predicted (Eq. 5) and empirical (Exp. L6: Patacci et al., 2015)

432 measurements of inflation height of a ponded cloud. B) Dimensionless inflation rate as a function of

433 equilibrium flow depth and flow duration . C) Criterion for inflation above flow run-up height of

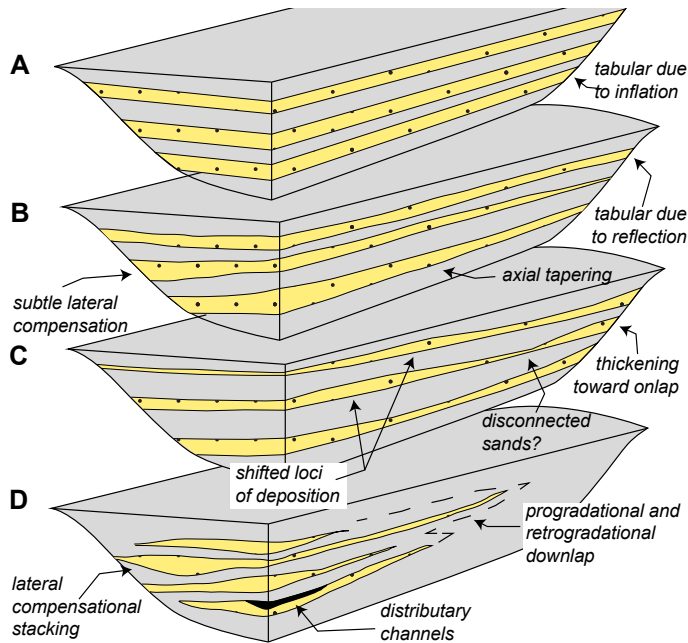
434 infinite-duration ponded flows.



435

436 Figure 3. Phase space of the ratio of ponded cloud height to flow height as a function of flow duration  
 437 and: (A) basin size; (B) width to length aspect ratio; (C) basin slope; (D) mass released; (E) flow  
 438 concentration; and (F) particle diameter. Basin geometry and flow conditions kept constant across  
 439 plots A-F are  $LW = 100$  km<sup>2</sup>,  $W/L = 1$  m/m,  $S_1 = S_2 = S_3 = S_4 = 0.1$  m/m,  $M/LW = 10$   
 440 tonnes/m<sup>2</sup>,  $C = 0.3\%$  and  $d = 177$   $\mu$ m, whose values are shown as vertical dashed lines in parts A)  
 441 to C), respectively. White arrows denote real world examples (single values or max/min values);  
 442 abbreviations and data sources are shown in Table 2. Part G identifies four distinct flow regimes i-iv,

443 delimited by: solid black line, denoting  $H_d = H_t$  (ponded-cloud height = flow height); dashed black  
 444 curve, denoting  $H_d = H_r$  (ponded cloud height = run-up height); thin red line, denoting  $t_t/t_d$  (travel  
 445 time across the basin = flow duration); thick green line, denoting  $q_I = LWw_s$  (input flux =  
 446 depositional flux in the initial basin area).



447  
 448 Figure 4. Idealized basin-fill architectures under the four ponding scenarios identified in Figure 3: A)  
 449 Tabular beds that extend across the entire basin; B) basinwide sands that may show some degree of  
 450 compensation or tapering, or that may be tabular; C) disordered deposits with shifting loci of  
 451 deposition and possible disconnected sands; and D) effectively unconfined deposits showing lobe  
 452 compensation and channelization.