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1 **Two new free-access dry splitter designs (1/2 to 1/32 aliquots) for sediment fractionation.**

2

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4

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6

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8

9 **Abstract**

10 This study presents two new dry sediment splitters for use in sample fractionation for
11 micropalaeontological studies, designed so that the aliquot of interest can be recovered in a
12 single operation. The first model (adjustable) provides a single aliquot, adjustable from 1/2
13 to 1/32 fraction. The second model (fixed) divides the sediment into six aliquots of different
14 sizes. Both designs enable faster sediment splitting in comparison to the traditional
15 sequential 1/2 fraction method. The average split accuracy and repeatability across the
16 range of aliquot fractions were tested for each splitter, giving 94 % and 85 % for the
17 adjustable design, and 92 % and 84 % for the fixed design, respectively. A comparison with
18 the classic splitter method gave equal or better results. The splitters were developed at the
19 CEREGE laboratory and can be 3D printed very cheaply, and the design files have been made
20 freely accessible online (<https://github.com/microfossil/tetard-marchant-splitter>).

21

22 Keywords: micropalaeontology, microfossil, splitting, subsampling

23

24 **1. Introduction**

25 Sediment splitters are routinely used for sedimentological and micropalaeontological
26 purposes. Microfossils such as foraminifera may be very abundant in the fossil record
27 (several thousand per gram of sediment). Thus, picking an entire sample to investigate
28 absolute abundance indices (e.g. benthic foraminiferal accumulation rate, Herguera and
29 Berger, 1991), can be time-consuming. To reduce the time spent on the picking procedure,
30 foraminiferal assemblages are commonly subsampled using a dry splitter, for fossil
31 specimens, or a wet splitter, for living specimens (Murray, 2006). Several authors (Dryden,
32 1931; Patterson and Fishbein, 1989; Fatela and Taborda, 2002) recommended picking
33 approximately 300 specimens to ensure reliable statistical analyses of the assemblage
34 composition of each sample, and robust integration of rarer specimens. The typical
35 procedure is thus to repeatedly split a sediment sample by half until an aliquot containing
36 about 300 specimens is obtained. This process can be time-consuming in case of very
37 abundant microfossils, where the sample needs to be divided many times to reduce to the
38 desired aliquot size.

39

40 The wet splitter, originally developed by Elmgren (1973) has been improved through the
41 years (Jensen, 1982; Scott and Hermelin, 1993; Charrieau et al., 2018). However, the classic
42 dry splitter, also known as the “Otto” splitter, has not been revised since its creation in 1933
43 (Otto, 1933). Recent developments in technology now enable us to produce accurate 3D
44 printed parts for reasonable costs. This has motivated the design of two new inexpensive
45 splitters to reduce laboratory costs (currently several hundred euros for a splitter, and
46 several tens of euros for a supplementary bin), as well as the time required for the sample
47 splitting (many operations until the aliquot of interest is reached) and operating error

48 (multiple steps each introduce an error). As we are aiming to replace the classic “Otto”
49 splitter in our workflow, both new splitters have been designed primarily for sediments, and
50 more particularly, for foraminifera in the 63um – 3 mm range.

51

52 **2. Material and Method**

53

54 **2.1. Components**

55 The adjustable splitter is composed of eight parts (Fig 1a), from top to bottom:

- 56 -a lid, to prevent dust entering the splitter when not used,
- 57 -a sieve, to prevent particles larger than 3 mm becoming stuck into the funnel,
- 58 -a funnel, to concentrate the sediment and drop it on to the centre of the cone,
- 59 -a cone, to uniformly and randomly split and disperse the sediment,
- 60 -a body, to hold the cone straight,
- 61 -a separator, to separate the sediment into the aliquot of interest which then falls in the
- 62 receptacle, while the remainder of the sediment is retained inside the system by the
- 63 separator,
- 64 -a selector to allow the manual choice of the aliquot fraction, from 1/2 to 1/32,
- 65 -a receptacle, where the aliquot of interest is collected,
- 66 as well as
- 67 -three size M1.2 to M1.6, 5 – 6 mm long screws to attach the separator to the selector,
- 68 -three size M1.2 to M1.6, 5 – 6 mm long screws to attach the cone to the body,
- 69 -one size M2 to M2.5, 10 mm length screw to attach the separator to the cone.

70

71 The fixed splitter is composed of five parts (Fig 1b), from top to bottom:

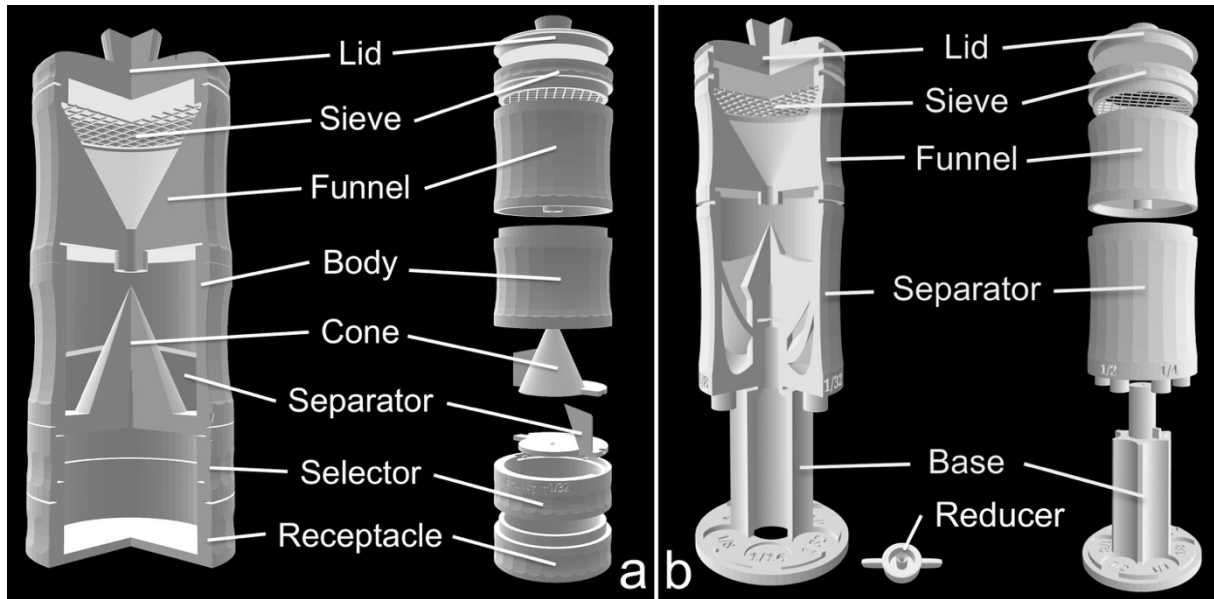
- 72 -a lid, a sieve, and a funnel as described above,
- 73 -a separator to split the sediment into six aliquots: 1/2, 1/4, 1/8, 1/16 and 2 x 1/32,
- 74 -a base to hold the vials,
- 75 as well as
- 76 -one 10 mm M2 or M2.5 screw to secure the base to the separator.

77

78 Some extra parts are also available to reduce the funnel hole size for smaller sized samples:

- 79 -2.5 mm reducer adapter and 2 mm sieve
- 80 -1.5 mm reduce adapter and 1 mm sieve

81

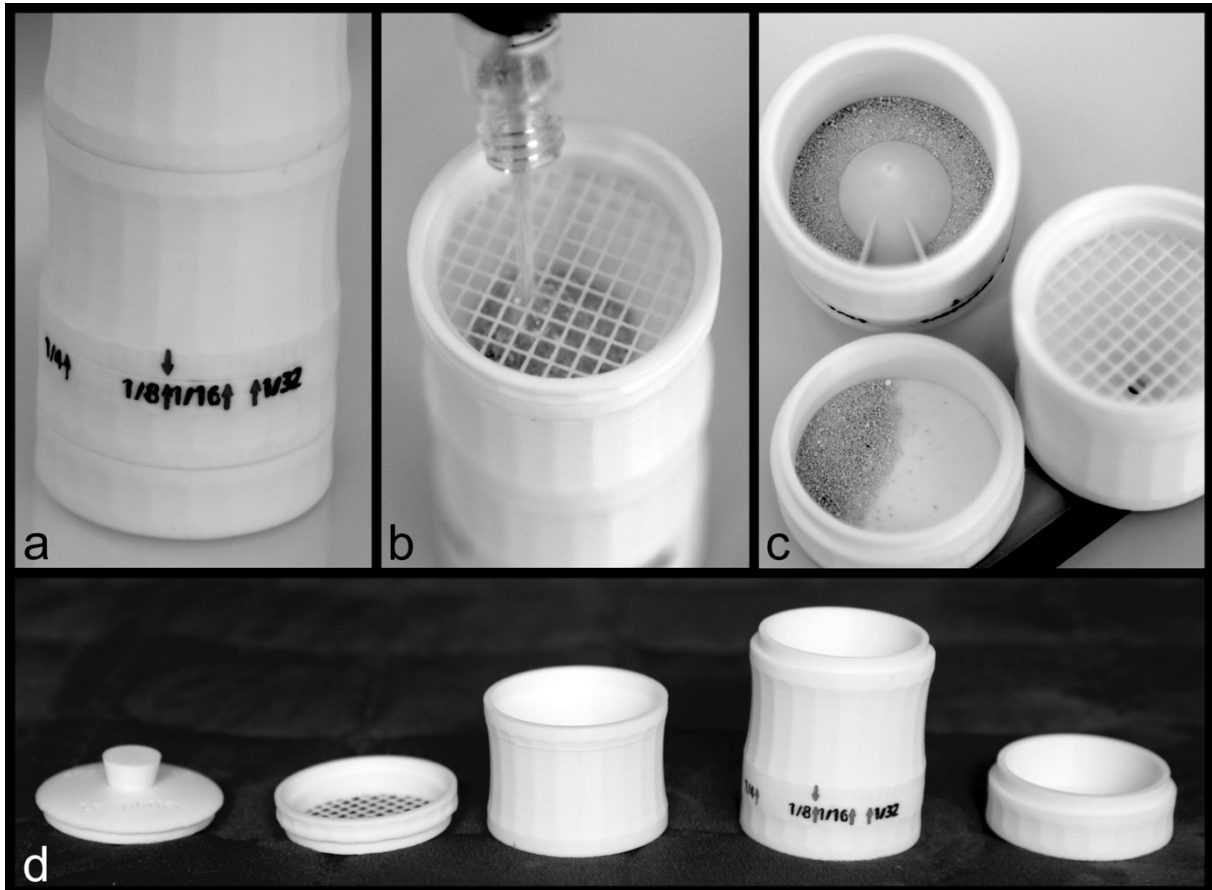


82
83 Figure 1: 3D Internal and exploded views of the adjustable (a) and fixed (b) splitters.
84

85 **2.2. Operation**

86 To use the adjustable splitter:

- 87 1) Remove the protective lid.
88 2) Choose the size of the aliquot of interest (between 1/2, 1/4, 1/8, 1/16, and 1/32) by
89 turning the selector, which in turn adjusts the separator within the splitter (Fig. 2a).
90 3) Pour the sample in the funnel (Fig. 2b).
91 4) Gently tap the splitter to ensure every particle falls into the system.
92 5) Recover the aliquot of interest in the receptacle (Fig. 2c).
93 6) Recover the remaining sample by removing the funnel component and reconnecting it
94 upside down, then flipping the whole device upside down to pour the rest of the sediment
95 back into its vial.
96



97
 98 Figure 2: Adjustable splitter, showing (a) view of the selector to choose the required aliquot,
 99 (b) sample poured in the sieve, over the funnel, (c) recovering the fraction of interest in the
 100 receptacle, (d) disassembly.

- 101
 102 To use the fixed splitter:
 103 1) Remove the protective lid.
 104 2) Pour the sample in the funnel.
 105 3) Gently tap the splitter to ensure every particle falls into the system and the vials (Fig. 3a).
 106 4) Recover the different sized aliquots from the different vials (Fig. 3b).
 107

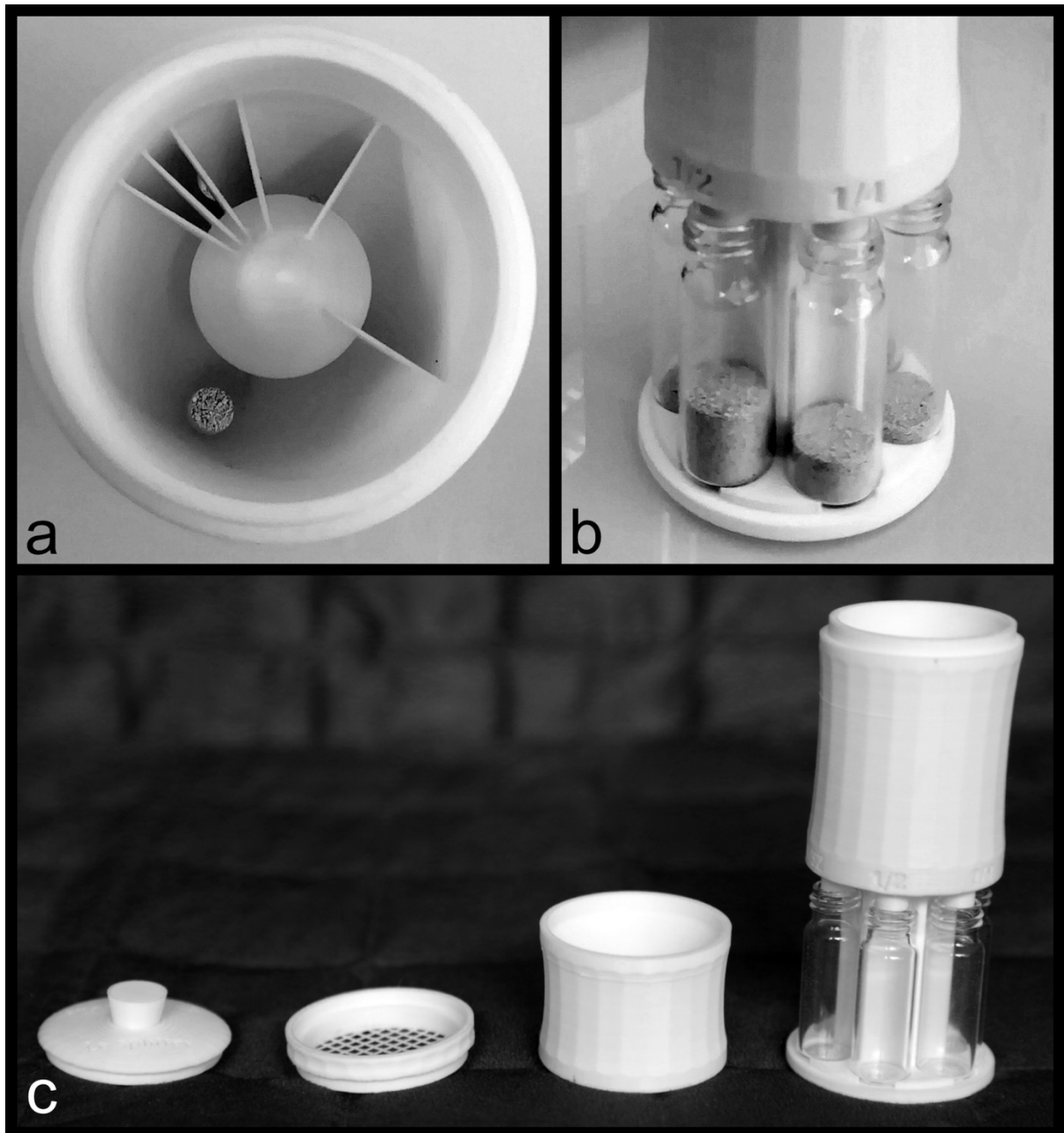


Figure 3: Fixed splitter showing (a) internal view of the separation system, (b) recovering every fraction from $1/2$ to $1/32$, (c) disassembly.

2.3. Principle

A sample is poured into the funnel which has a small hole at the bottom. To prevent blockage, the sieve prevents particles that are too big for this hole from entering the funnel. The particles fall through the hole with a motion similar to that of an hourglass, hitting the conical section below and evenly dispersing in all angles. The conical section has fins with adjustable angular spacing (adjustable splitter) or fixed angular spacing (fixed splitter) which direct the particles into a receptacle (adjustable splitter) or vials (fixed splitter) located below.

2.4. Development

122 The splitters were designed using the online Autodesk, Inc. 3D design platform “Tinkercad”
 123 (<https://www.tinkercad.com/>), and the 3D model files corresponding to each part of the
 124 splitters can be freely downloaded from [https://github.com/microfossil/tetard-marchant-](https://github.com/microfossil/tetard-marchant-splitter)
 125 [splitter](https://github.com/microfossil/tetard-marchant-splitter). The parts were printed on a Raise3D fused deposition layer type printer using 1.75
 126 mm R3D Premium PLA filament. The overall material cost was 3 to 4 euros per splitter (if you
 127 do not own a 3D printer a commercial service can be used, but they may charge more) plus a
 128 few cents for the screws.

129
 130 Approximately 100 g of filament was used for each splitter, and a minimum of 17 and 23
 131 hours were needed to print the adjustable and fixed splitters, respectively. These results
 132 were obtained using a standard resolution layer height of at least 0.20 mm for two parts,
 133 with the remainder needing to be printed at a high resolution of 0.10 mm to ensure the
 134 highest possible accuracy and quality for the system (see Table 1). Depending on the quality
 135 of the 3D printed parts, some sanding might be required.

136
 137 Table 1: Summary of the time, and amount of filament (and cost) used for each part of the
 138 two splitter designs (including printing support structure).

	Part	Time	Filament	Printing set-up
Adjustable splitter	Lid	0h55min	11.2 g	Standard Quality (0.20 mm resolution)
	Sieve 3 mm	1h24min	8.7 g	High Quality (0.10 mm resolution)
	Funnel	5h15min	27.5 g	High Quality (0.10 mm resolution)
	Body	4h43min	22.0 g	High Quality (0.10 mm resolution)
	Cone	1h30min	7.8 g	High Quality (0.10 mm resolution)
	Separator	0h38min	5.5 g	High Quality (0.10 mm resolution)
	Selector	2h03min	10.9 g	High Quality (0.10 mm resolution)
	Receptacle	1h06min	13.3 g	Standard Quality (0.20 mm resolution)
	Total	17h34min	106.9 g (3.22 €)	
Fixed splitter	Lid	0h55min	11.2 g	Standard Quality (0.20 mm resolution)
	Sieve 3 mm	1h24min	8.7 g	High Quality (0.10 mm resolution)
	Funnel	5h15min	27.5 g	High Quality (0.10 mm resolution)
	Separator	12h39min	50.4 g	High Quality (0.10 mm resolution)
	Selector	2h56min	21.2 g	Standard Quality (0.20 mm resolution)
		Total	23h09min	119.0 g (3.58 €)
Accessories	Reducer 1.5mm	0h17min	1.4 g	High Quality (0.10 mm resolution)
	Reducer 2.5 mm	0h17min	1.4 g	High Quality (0.10 mm resolution)
	Sieve 1 mm	1h32min	9.4 g	High Quality (0.10 mm resolution)
	Sieve 2 mm	1h30min	9.1 g	High Quality (0.10 mm resolution)
		Total	3h36min	21.3 g (0.63 €)

139
 140 **2.5. Advice**
 141 Some particles may accumulate in the funnel due to static electricity if it is cleaned with a
 142 brush between splits. This issue can be prevented by rubbing the internal surfaces with a
 143 wet (distilled water) paper towel. It is also recommended to not use a brush to clean the
 144 splitter. A gentle tap after the sample is dropped into the funnel should be enough to make
 145 all the particles fall through the system, and compressed air should be sufficient for cleaning.

146 Finally, due to the way samples are typically poured into the funnel (usually by hand from
147 the side), more regular results are obtained when this operation is done quickly in one shot
148 towards the centre of the funnel, with the separator facing toward the user in the case of
149 the adjustable model. This avoids uneven distribution of the sediment in the funnel. The tip
150 of the cone can be marked with coloured paint to help give a visual indication that the cone
151 is well centred within funnel on assembly.

152
153 When working with small-volume samples (typically a smaller volume of a small size
154 fraction) there may not be enough particles to create the “hourglass effect” and particles
155 may instead fall preferentially to one side. To remedy this, the 1.5 mm or 2.5 mm reducer
156 adapters are placed in the funnel to reduce the hole size and thus flow rate. Their associated
157 1 mm and 2 mm sieves, respectively, are also employed to prevent blockage. The default 3.5
158 mm hole works well for most sample types, and thus the reducers were not considered in
159 the accuracy and repeatability tests later in this paper.

160

161 **3. Statistical validation**

162 Two statistical approaches were used to test the reliability and efficiency of the new
163 splitters. The accuracy, how close the measured values are to the theoretical expected
164 values, was measured along with the repeatability, how similar the measured values are to
165 each other. Evaluation was performed for both splitter types and each aliquot size (see
166 measurements data in supplementary material).

167

168 In particular, we performed:

169 1) Statistical accuracy and repeatability measurements, based on a large ($n = 30$) number of
170 repeated measured values of a fixed sample weight (1.9925 g of $> 150 \mu\text{m}$ sieved coarse
171 fraction of sediment from Core SO204-PC1, depth 288-289 cm). Core SO204-PC1 is a 5 m
172 long piston core that was retrieved from the South Pacific Ocean (latitude: $25^{\circ}40,41'S$;
173 longitude: $146^{\circ}42,33'W$) using a 10 m long piston corer at a depth of 2312 mbsl. This core
174 mainly consists of a white foraminifera sand. Sample 288-289 cm is only composed of
175 heterogeneous planktic foraminifera with different morphotypes, such spherical or flattened
176 shapes, and represents an “ideal” sample.

177 2) An accuracy comparison between our new splitters and a classic micropaleontological
178 splitter (the Otto splitter; Otto, 1933), based on a limited ($n = 5$) number of measurements
179 of randomised weights from 0.38 g to 2.75 g of $63 - 150 \mu\text{m}$ sieved fine fraction and > 150
180 μm sieved coarse fraction of sediments from Core SO204-PC1, depth 288-289 cm.

181

182 **3.1. Accuracy**

183 The accuracy (Eq. 1) is defined as the difference between the expected aliquot weight
184 (defined in Eq. 2) and the measured aliquot weight, divided by the expected aliquot weight,
185 and expressed in %:

186

$$187 \text{ Eq. 1 Accuracy (\%)} = 100 - \frac{|\text{Expected Aliquot Weight} - \text{Measured Aliquot Weight}| \times 100}{\text{Expected Aliquot Weight}}$$

188

$$189 \text{ Eq. 2 Expected aliquot weight} = \text{Total Sediment Weight} \times \text{Investigated Aliquot}$$

190

191 This accuracy index is derived from the traditional percent error formula (Eq. 3):

192

193 Eq. 3 Percent error (%) = $\frac{|\text{Experimental} - \text{Theoretical}|}{|\text{Theoretical}|} \times 100$
194

195 3.2. Repeatability

196 For each aliquot size, the standard deviation (σ) was investigated, according to Eq. 4, where
197 x is a measurement, and m the average value of the n number of measurements:
198

199 Eq. 4 $\sigma = \sqrt{\frac{(x_1 - m)^2 + (x_2 - m)^2 + \dots + (x_n - m)^2}{n - 1}}$
200

201 The expanded uncertainty (U) is then calculated (Eq. 5) with $k = 2$ for a 95 % confidence
202 level:
203

204 Eq. 5 $U = k \times \sigma$
205

206 which finally allows the calculation of a mean repeatability index for each aliquot of each
207 fraction (Eq. 6), based on the relative uncertainty formula:
208

209 Eq. 6 Repeatability (%) = $100 - \left(\frac{U}{m} \times 100\right)$
210

211 4. Results and discussion

212 Each of the large ($n = 30$) sets of repeated measured values for each splitter and aliquot size
213 showed an overall normal distribution (see Appendix 1), allowing the computation of the
214 defined accuracy and repeatability indices. When using the adjustable splitter, the mean
215 measured aliquot weight for each aliquot size was close to the expected aliquot weight
216 (Table 2), suggesting a good accuracy across all aliquot sizes. This result is reinforced by the
217 accuracy index that averaged 94 % between aliquots, (95.27, 95.12, 92.69, 93.50, and 92.63
218 % for the 1/2, 1/4, 1/8, 1/16, 1/32 aliquots, respectively, Table 2). The mean standard
219 deviation was relatively low (0.0488, 0.0325, 0.0212, 0.0103, 0.0053 g for expected aliquot
220 weights of 0.9963, 0.4981, 0.2491, 0.1245, and 0.0623 g, respectively, Table 2), suggesting
221 good repeatability of the measurements for each aliquot size. The mean repeatability across
222 all aliquot sizes was about 85 % (89.92, 86.73, 83.13, 83.35, 82.70 % for the 1/2, 1/4, 1/8,
223 1/16, 1/32 aliquots, respectively, Table 2).
224

225 The fixed splitter also showed satisfying results, with mean measured aliquot weight also
226 very close to the expected aliquot weight (Table 2), again suggesting a good accuracy for
227 each aliquot size. These measurements resulted in an accuracy index of approximately 92 %
228 across all aliquot sizes, (95.38, 94.57, 91.09, 89.37, 89.60, and 91.08 % for the 1/2, 1/4, 1/8,
229 1/16, and both 1/32 aliquots, respectively). Even though the mean standard deviation was
230 slightly higher than for the adjustable version, it was still relatively low (0.0723, 0.0445,
231 0.0286, 0.0177, 0.0061, and 0.0061 g for expected aliquot weights of 1.3001, 0.6304, 0.3044,
232 0.1757, 0.0725, and 0.0757 g, respectively, Table 2), again suggesting a good repeatability of
233 the measurements for each aliquot size. The mean repeatability across all aliquot sizes was
234 approximately 84 % (88.85, 85.80, 81.07, 79.66, 83.12, and 83.81 % for the 1/2, 1/4, 1/8,
235 1/16, and both 1/32 aliquot sizes, respectively, Table 2).
236

237 The repeatability for both designs is acceptable considering the low cost and small amount
 238 of material required to make the splitters. Overall, the efficiency and reliability of the splits
 239 were satisfactory.

240

241

242 Table 2: Accuracy and repeatability measurements for each aliquot size for the adjustable

243 and fixed splitters.

	Investigated fraction	Investigated aliquot	Number of measurements	Total sediment weight (g)	Expected aliquot weight (g)	Mean measured aliquot weight (g)	Mean accuracy (%)	Standard deviation	Mean relative uncertainty (%)	Mean repeatability (%)
Adjustable	>150 µm	1/2	30	1.9925	0.9963	0.9711	95.27	0.0488	10.08	89.92
	>150 µm	1/4	30	1.9925	0.4981	0.4920	95.12	0.0325	13.27	86.73
	>150 µm	1/8	30	1.9925	0.2491	0.2519	92.69	0.0212	16.98	83.02
	>150 µm	1/16	30	1.9925	0.1245	0.1242	93.50	0.0103	16.75	83.25
	>150 µm	1/32	30	1.9925	0.0623	0.0618	92.63	0.0053	17.43	82.57
							Average	93.84	Average	14.90
Fixed	>150 µm	1/2	30	2.5742	1.2871	1.3001	95.38	0.0723	11.15	88.85
	>150 µm	1/4	30	2.5742	0.6436	0.6304	94.57	0.0445	14.20	85.80
	>150 µm	1/8	30	2.5742	0.3218	0.3044	91.09	0.0286	18.93	81.07
	>150 µm	1/16	30	2.5742	0.1609	0.1757	89.37	0.0177	20.34	79.66
	>150 µm	1/32	30	2.5742	0.0804	0.0725	89.60	0.0061	16.88	83.12
	>150 µm	1/32	30	2.5742	0.0804	0.0757	91.08	0.0061	16.19	83.81
							Average	91.85	Average	16.28

244

245 The adjustable and fixed splitters are both accurate, averaging around 94 % and 92 % across
 246 each aliquot size, respectively. Comparison of the accuracy of the new splitters and the
 247 classic “Otto” splitter, using random weights of fine and coarse fraction sediments (Table 3),
 248 showed that both new designs were more accurate than the classic design (90.44 % (adj.)
 249 and 90.52 % (fixed) vs 83.79 % (classic)) for both size fractions, averaged over every aliquot
 250 size.

251

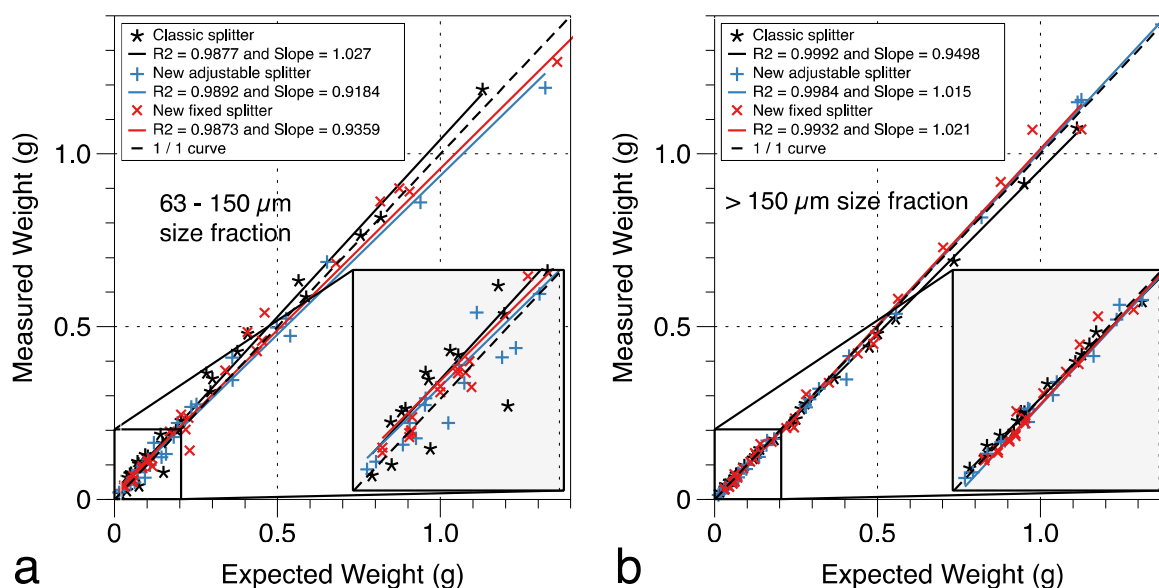
252 Table 3: Comparison of accuracy between the new splitters and the classic model.

Investigated fraction	Investigated aliquot	Number of measurements	Adjustable splitter accuracy (%)	Fixed splitter accuracy (%)	Classic splitter accuracy (%)
>150 µm	1/2	5	98.67	94.66	96.29
63 - 150 µm	1/2	5	93.01	91.90	95.37
>150 µm	1/4	5	95.07	95.37	94.63
63 - 150 µm	1/4	5	94.07	90.36	80.71
>150 µm	1/8	5	95.86	91.42	94.99
63 - 150 µm	1/8	5	84.62	88.55	78.78
>150 µm	1/16	5	95.29	91.88	91.50
63 - 150 µm	1/16	5	77.11	87.90	66.67
>150 µm	1/32	5	92.82	90.38	89.32
63 - 150 µm	1/32	5	77.89	90.84	49.62
>150 µm	1/32 (2)	5		86.61	

63 - 150 μm	1/32 (2)	5		86.35	
Mean accuracy > 150 μm			95.54	91.72	93.34
Mean accuracy 63 - 150 μm			85.34	89.32	74.23
Mean accuracy (both fractions)			90.44	90.52	83.79

253
 254 Our new designs performed best for the > 150 μm size fraction, with most of the measured
 255 weights close to the expected ones, however, the classic splitter gave lower values than
 256 expected, especially for the bigger sample weights (Fig. 4). For the 63 – 150 μm size fraction,
 257 the new adjustable and fixed splitters exhibited again measured values close to expected
 258 (Table 3; 85 % and 89 % accurate, respectively) while the accuracy of the classic splitter
 259 dropped significantly to 74 %. This is likely due to the propagation of a splitting errors in the
 260 classic design, as repeated splits are required to obtain the smaller aliquot sizes. For
 261 example, five splits are required to obtain an aliquot size of 1/32 for the classic model,
 262 whereas our new design only requires one. The classic splitter also showed more variation
 263 for the small weight measurements, corresponding to the smaller aliquot sizes (1/16 and
 264 1/32).

265
 266 The individual measurements for each experiment can be found in Appendix 2.
 267



268
 269 Figure 4: Relationship between the expected and measured random weights test, performed
 270 on the (a) fine (63 – 150 μm) and (b) coarse (> 150 μm) fractions.
 271

272 5. Conclusion

273 Two new splitter designs, one with a single adjustable aliquot size going into one receptacle,
 274 and another one with multiple fixed aliquot sizes going into separate vials, were presented.
 275 Several tests were conducted to test their efficiency and reliability, giving an average
 276 accuracy of 94 % and 92 % and a repeatability of 85 % and 84 %, for the adjustable and fixed
 277 splitters, respectively. Comparison with a classic splitter model has shown the new designs
 278 give equal or better results for the coarse > 150 μm fraction, and better results for the fine
 279 63 – 150 μm fraction.
 280

281 Furthermore, the new designs save a considerable amount of time when splitting, as they
282 give the aliquot size of interest directly in one operation. Both designs are freely available
283 online and each splitter can be easily 3D printed, enabling laboratories to be equipped with
284 more tools for each user as the need arises.

285
286 Finally, both splitters are currently being incorporated into the workflow here at CEREGE and
287 we have successfully used it to process 191 samples from piston Core MD02-2519
288 (22°30.89'N; 106°39.00'W; 955 mbsl) retrieved off Mazatlan, Mexico (Beaufort, 2002).
289 Sediment retrieved from this core is mostly composed of dark sediment grains, benthic and
290 planktic foraminifera, radiolarians and other biogenic debris, and correspond to a typical
291 case study (different from the ideal planktic foraminiferal sand used for tests). No issue
292 linked with the nature of the sediments was encountered during the processing of the
293 samples from this core.

294
295

296 **Acknowledgements**

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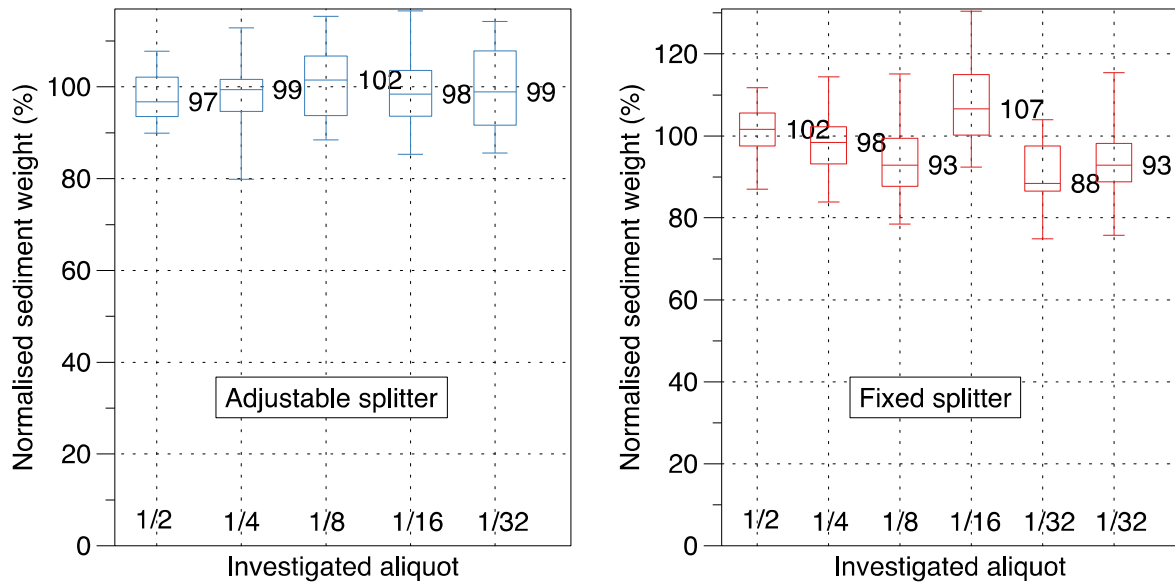
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 333



334
 335 Appendix 1: Whisker box plots for the normalized repeated measured values for each
 336 splitter and aliquot size. Numbers next to the boxes correspond to the median measured
 337 value (in % of the expected value).