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1 **New middle and late Smithian ammonoid faunas from the Utah/Arizona**
2 **border: new evidence for calibrating Early Triassic transgressive-regressive**
3 **trends and paleobiogeographical signals in the western USA basin**

4

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25

26 **Abstract**

27

28 New Smithian (Early Triassic) ammonoid assemblages were sampled near the Utah/Arizona
29 border. They provide several spatiotemporal constraints on the regional Sinbad Formation
30 showing that the extent of the Smithian sea in the southwestern-most part of the western USA
31 basin is larger than previously expected, reaching northern Arizona and an area just east of
32 Kanab in Kane County, Utah. This southwestern-most excursion of the sea in the western
33 USA basin is part of the third order Smithian transgression-regression cycle, which is well-
34 documented worldwide. These new spatiotemporal constraints also indicate that the Sinbad
35 Formation spans the late middle to early late Smithian time interval in the studied area. The
36 observed transgressive trend corresponds to the warm temperatures of the middle-early late
37 Smithian and the regressive trend to the cooling phase spanning the Smithian-Spathian
38 transition. Thus, the Sinbad Formation and its marine deposits are the direct result of global
39 climatic fluctuations and related sea-level changes that occurred from the late middle
40 Smithian to the Smithian-Spathian transition. This highlights the importance of the Sinbad
41 Formation in untangling local and global changes occurring around the late Smithian, and
42 thus in overcoming a major obstacle to the understanding of the biotic recovery after the
43 Permian/Triassic boundary mass extinction. This also indirectly confirms that the western
44 USA basin is a key area containing essential information for the understanding of the Early
45 Triassic events. The taxonomic richness of late middle Smithian assemblages is much lower
46 in the studied area than in the more northern localities. However, the occurring taxa confirm
47 the known regional to global distribution of Smithian ammonoids, witnessing the major
48 global environmental changes from the middle Smithian to the early Spathian.

49

50 **Keywords:**

51 Smithian, Early Triassic, Ammonoids, Utah, Arizona, Biostratigraphy, Transgression-
52 regression cycle

53

54

55 **1. Introduction**

56

57 Our understanding of the complex biotic rediversification that occurred in the first million
58 years after the Permian/Triassic boundary mass extinction (PTBME; ca 251.9 Ma, Baresel et
59 al., 2017) requires detailed sedimentological studies to reconstruct depositional environments
60 and their evolution (Bagherpour et al., 2017; Kershaw, 2017; Olivier et al., 2018). Indeed, the
61 type of depositional settings as well as sea-level changes directly influences how the nature
62 and preservation of the fossil record is to be analyzed and interpreted (Brett, 1995;
63 Behrensmeyer et al., 2000). However, deciphering the spatiotemporal variation patterns of
64 Early Triassic depositional environments requires calibrating the sedimentary record
65 according to a biostratigraphically-controlled accurate timescale (Brühwiler et al., 2010; Ware
66 et al., 2015; Brosse et al., 2016).

67 The Early Triassic is characterized by a global long-term sea-level rise with several second-
68 and third-order transgressive-regressive sequences that can be identified worldwide (Embry
69 1988; Haq and Al-Qahtani, 2005; Haq, 2018). The western USA basin, mainly covering
70 present day eastern Nevada, Utah, Idaho and western Wyoming (**Fig 1A, B**), is one of the few
71 places where these sequences can be recognized, and it includes a notable third order
72 transgressive-regressive cycle dated from the Smithian substage (Collinson and
73 Hasenmueller, 1978; Clark and Carr, 1984; Paull and Paull, 1993, 1997; Embry, 1997; Lucas
74 et al., 2007b; Brayard et al., 2013; Olivier et al., 2014, 2016, 2018; Vennin et al., 2015;
75 Jeffrey et al., 2019). A rapid transgression towards the south and south-east is recorded within

76 the southern part of the western USA basin during the early-middle Smithian (**Fig. 1C**),
77 followed by a marked regression near the Smithian/Spathian boundary (Paull and Paull, 1993,
78 1997; Lucas et al., 2007b; Brayard et al., 2013). However, the southern-most boundary of the
79 late Smithian sea is difficult to establish. Several contributions briefly reported on the
80 presence of undetermined and poorly-preserved gastropods, bivalves and ammonoids
81 (Gregory, 1948, 1950; Blakey, 1979; Doelling and Davis, 1989) as well as scarce conodonts
82 (e.g., Paull and Paull, 1993; Lucas et al., 2007b) from several localities in southern Utah.
83 These organisms served for instance to characterize local open marine conditions, but the
84 associated timescale was poorly constrained.

85 Newly-found Smithian ammonoid faunas near the Utah/Arizona border allow us to determine
86 a more accurate minimal age for the arrival of the open sea in the southern-most part of the
87 western USA basin. Additionally, in well-characterized depositional settings, these faunas
88 allow us to constrain the minimum duration of the corresponding stratigraphic units. For the
89 first time, we also report late middle and late Smithian ammonoid assemblages from
90 northernmost Arizona demonstrating that the Smithian transgression reached this area as soon
91 as the late middle Smithian. Finally, these new ammonoid assemblages support the severe
92 biotic and climatic fluctuations known from the middle Smithian to the early Spathian in both,
93 the western USA basin and worldwide, highlighting that this basin encompasses various
94 exposures that can provide invaluable insights into the mechanisms underlying these major
95 events in the aftermath of the PTBME (Schubert and Bottjer, 1995; Goodspeed and Lucas,
96 2007; Pruss et al., 2005, 2007; Mata and Bottjer, 2011; Hofmann et al., 2013, 2017; Brayard
97 et al., 2017).

98

99 **2. Early Triassic basinal setting**

100

101 During the Early Triassic, the western USA basin was located within the northern
102 intertropical zone of the western margin of Pangea (**Fig. 1A, B**) and recorded both terrestrial
103 and marine deposits (Moenkopi and Thaynes groups, respectively; *sensu* Lucas et al., 2007b).
104 This epicontinental basin was contemporaneous with the Sonoma orogeny and is usually
105 interpreted as a foreland basin (Stewart et al., 1972; Collinson et al., 1976; Dickinson, 2013;
106 Caravaca et al., 2018). It presently covers large areas within eastern Nevada, Utah, Idaho,
107 western Wyoming and southwestern Montana. The southern part of the basin records
108 Smithian and Spathian marine deposits, whereas an earlier portion of the Early Triassic is
109 documented in the northern part (e.g., McKee, 1954; Kummel, 1957). Based on a reappraisal
110 of lithology, thickness and subsidence rates, as well as on quantitative biogeographical
111 analyses of ammonoids within the basin, Caravaca et al. (2018) and Jattiot et al. (2018)
112 showed a marked north-south differentiation of the western USA basin in terms of organism
113 distribution and tectonics. On the latter point, the southern part of the basin shows a relative
114 quiescence during the Early Triassic and can be considered more stable and much less
115 influenced by short-term tectonic deformations than the northern part, mostly likely due to the
116 stronger rigidity inherited from its basement terranes (Caravaca et al., 2018). Recently
117 published carbon and sulfur isotope curves from several localities within this basin (Thomazo
118 et al., 2016, 2019; Caravaca et al., 2017; Schneebeili-Hermann et al., 2020) show that the well-
119 known global isotopic signals were markedly influenced by local processes resulting from
120 environmental and biotic heterogeneities within the basin during the Early Triassic.

121

122 **3. Previous Smithian-early Spathian stratigraphic framework in southern Utah and**
123 **recent developments**

124

125 In the southern part of the western USA basin, and mainly in southern Utah, depositional
126 settings correspond to relatively shallow environments (tidal to outer shelf; **Fig. 1C**)
127 characterized by shale and limestone sediments. Marine facies deposited during the early-
128 middle Smithian transgression are typical and are generally represented by various microbial
129 deposits overlain by, or interfingered with, bioclastic limestones (Lucas et al., 2007a, b;
130 Goodspeed and Lucas, 2007; Brayard et al., 2011, 2013; Mata and Bottjer, 2011; Olivier et
131 al., 2014, 2016, 2018; Vennin et al., 2015; Jeffrey et al., 2019). The often-massive microbial
132 deposits exhibit complex metazoan consortia including sponges and bivalves, forming
133 laterally discontinuous bioconstructions (e.g., Brayard et al., 2011; Olivier et al., 2018).
134 Bioclastic limestones generally contain various organisms such as ammonoids, bivalves,
135 gastropods, echinoderms and lingulid brachiopods (Brayard et al., 2013, 2015; Olivier et al.,
136 2014, 2018). These microbial-bioclastic deposits are documented at many places in southern
137 Utah and correspond to the Timpoweap and Sinbad fms. The Timpoweap Fm. is now
138 considered as a junior synonym of the Sinbad Fm. (Lucas et al., 2007b).

139 In southwestern-most Utah, e.g., in the Hurricane area (**Figs. 1D, E; 2**), the Sinbad Fm.
140 overlies the Rock Canyon Conglomerate of uncertain age, which represents the hiatus in
141 marine deposits that lasted from the Late Permian to the beginning of the Early Triassic. This
142 formation is made of various breccias and thick channelized conglomerates that may fill
143 incised valleys in the Permian Kaibab Fm. (e.g., Blakey, 1979; Marzolf, 1993; Olivier et al.,
144 2014, 2018). A facies gradation between conglomerates and microbial deposits is often visible
145 between the Rock Canyon Conglomerate and the Sinbad Fm. (Nielson, 1991; Olivier et al.,
146 2014, 2018), suggesting that they belong to the same stratigraphic unit and that the Rock
147 Canyon Conglomerate may therefore be Early Triassic in age.

148 Previous works in southern Utah merely mentioned the occurrence in the Smithian
149 Timpoweap Fm. of e.g., “*Meekoceras*” (Reeside and Bassler, 1922; Reeside, 1943; Gregory,

150 1948, 1950; Stewart et al., 1972; Nielson and Johnson, 1979; Nielson, 1991), a long-ranging
151 Smithian ammonoid genus, which can be easily confused with many other genera when
152 poorly preserved (Brayard et al., 2013), potentially leading to biostratigraphical mistakes or
153 confusion. Additionally, these reports were often diluted or repeated in different studies (e.g.,
154 Doelling and Davis, 1989). More recently, Lucas et al. (2007b), Brayard et al. (2013) and
155 Olivier et al. (2014, 2018) identified typical late Smithian assemblages in different localities
156 of southwestern Utah. These reports indicated that the transgression had already reached
157 southwestern Utah during the middle Smithian and southwestern-most Utah (Hurricane area)
158 at least during the late Smithian.

159 The age of the Sinbad Fm. is therefore constrained by the occurrence of typical late Smithian
160 ammonoid genera such as *Anasibirites* and *Wasatchites* in its uppermost layers (Lucas et al.,
161 2007b; Brayard et al., 2013; Olivier et al., 2018; Jeffrey et al., 2019). Conodonts also indicate
162 a late Smithian age for these beds (Lucas et al., 2007b; Olivier et al., 2014). Typical latest
163 Smithian ammonoid assemblages in which e.g., *Pseudosageceras augustum*, *Xenoceltites* and
164 *Glyptopliceras* can co-occur (Brayard et al., 2013; Jattiot et al., 2017, 2018; Jenks and
165 Brayard, 2018) have not yet been found in southwestern-most Utah, suggesting that a rapid
166 regressive phase was probably already occurring at that time in this area. Age constraints for
167 the base of the Sinbad Fm., i.e. the microbially-dominated part, are much vaguer due to, e.g.,
168 the paucity and poor preservation of conodonts (Paull and Paull, 1993). However, a middle
169 Smithian ammonoid, *Owenites* sp., was recently reported from the top of microbial fenestral
170 deposits in the Timpoweap Canyon near Virgin (Olivier et al., 2014). The age of the base of
171 the Sinbad Fm. in other localities within the Hurricane area is yet to be determined.

172 The Sinbad Fm. is stratigraphically covered by the Lower Red Member, which marks a
173 regressive trend during the Smithian-Spathian transition, showing a marginal and terrestrial
174 sedimentation (Blakey, 1979; Lucas et al., 2007b). A new marine incursion is recorded by the

175 overlying Virgin Limestone Fm., which is early Spathian in age (Poborski, 1954; Hautmann
176 et al., 2013; Hoffmann et al., 2013).

177

178 **4. Studied exposures and sampled material**

179

180 Ammonoid specimens studied herein were collected from four localities near the
181 Utah/Arizona border where the Sinbad Fm. is exposed: two in Washington County, Utah
182 (Workman Wash and Honeymoon Trail); one in Kane County, Utah (White Sage Wash); and
183 one in Rock Canyon, Mohave County, Arizona (**Fig. 1D-F**). Ammonoid preservation in some
184 cases is quite good, with some shell remains preserved, for instance in Workman Wash.

185 However, internal recrystallization is common, making the collection and preparation of these
186 specimens often difficult. Also, exposing suture lines is often impossible.

187 The Workman Wash locality (**Figs. 1D, E, 2**; 37°5'56.96"N, 113°17'31.01"W) was described
188 in detail by Olivier et al. (2018). Unlike many other exposures of the Sinbad Fm. in the area,

189 it exhibits contemporaneous fossiliferous lateral deposits of the microbially-dominated unit.

190 This unit also displays moderately-diversified faunal assemblages that can be traced laterally
191 from microbial to the bioclastic deposits. Within the assemblages of the microbially-

192 dominated unit, ammonoids and large-sized gastropods are abundant (Brayard et al., 2015).

193 Ammonoids, often accumulated in large lenses and specific beds, are represented by typical
194 early late Smithian prionitid genera such as *Anasibirites*, *Wasatchites*, *Gurleyites* (specimens
195 previously attributed to *Arctoprionites* in the western USA basin) and *Hemiprionites*.

196 Contrary to many other localities in the western USA basin, *Gurleyites smithi* (ex-

197 “*Arctoprionites resseri*”) specimens sampled in Workman Wash are abundant and well

198 preserved, exhibiting a very large intra-specific variation and unexpected ornamentation.

199 These features have not yet been observed in specimens from other localities and they provide

200 new information for prionitid taxonomy and systematics (see Systematics section). Middle
201 Smithian ammonoid taxa have not yet been found at Workman Wash, indicating that the open
202 sea possibly did not reach this locality until the early late Smithian. A neighboring exposure
203 with an identical name, but located in a more northern canyon, was recently described by
204 Jeffrey et al. (2019) and shows a similar succession. However, no ammonoids were reported
205 from this site, preventing further in-depth biostratigraphical comparisons.

206 The second southern Utah site studied herein is located along a ~500 m gully on the eastern
207 edge of the Honeymoon Trail, bordering the Hurricane Cliffs (**Fig. 1D, E**; 37°1'42.93"N,
208 113°16'16.44"W). Only the topmost part of the Rock Canyon Conglomerate and the basal
209 microbially-dominated part of the Sinbad Fm. are visible here (**Fig. 2**). Our observations
210 confirmed the brief report by Perfilli and Ritter (2018), who indicated that large microbial
211 mounds are well exposed at this site and are made of various microbial deposits. These
212 microbial limestones also contain abundant 1-6 cm-high gastropod shells (possible
213 *Coelostylina* sp.) and common late middle Smithian ammonoids, such as *Inyoites* and
214 *Guodunites*, often densely packed into dm-scale lenses. A few sphaeroconic (*Juvenites* or
215 *Paranannites*) and serpenticonic (*Dieneroceras*?) ammonoids rarely occur, but they are too
216 poorly preserved for firm determination. Jeffrey et al. (2019) described a neighboring section
217 ("Cottonwood Wash"; ~700 m to the SW) where the Sinbad Fm. is well exposed but they did
218 not report ammonoids from the microbially-dominated unit.

219 The third studied site is located at the wash entrance of Rock Canyon, in Mohave County,
220 northernmost Arizona, just south of the Utah border (**Figs. 1D, E, 3**; 36°58'43.35"N,
221 113°15'37.67"W). The Rock Canyon Conglomerate is well developed, showing thick
222 channelized conglomerates filling large incised valleys. This site serves as a type section for
223 this formation (Reeside and Bassler, 1922; Nielson, 1991). Overlying microbial deposits of
224 the Sinbad Fm. are also well exposed and include abundant large gastropods (Brayard et al.,

225 2015) and two successive ammonoid assemblages. The lowermost assemblage is monogeneric
226 and contains the late middle Smithian *Guodunites hooveri* and *G. monneti*, whereas the
227 uppermost assemblage includes early late Smithian taxa such as *Anasibirites*. Ammonoid
228 occurrences at the same site were also reported by Nielson (1991) and Jeffrey et al. (2019),
229 but without firm identification and detailed biostratigraphic zonation.

230 The fourth studied site is White Sage Wash, located ~25 km east of Kanab and ~200 m north
231 of the Utah/Arizona border (**Fig. 1D, F**; 37°0'12.84"N, 112°13'51.60"W). Lower Triassic
232 rocks are relatively widespread in Kane County, but developed exposures of the Sinbad Fm.
233 are rarely investigated in detail (but see Jeffrey et al., 2019 for a recent study of two
234 neighboring localities in the Buckskin Mountains). In addition, occurrences of Smithian
235 ammonoids east of Kanab were neither firmly identified (e.g., Gregory, 1948) nor even
236 reported from the Sinbad Fm. in this area (Doelling and Davis, 1989; Jeffrey et al., 2019).
237 Only part of the microbially-dominated unit of the Sinbad Fm. is visible at the studied site
238 (**Fig. 3**), but we can reasonably assume that the local Early Triassic succession is similar to
239 those observed at neighboring sites (Jeffrey et al., 2019). Total exposed strata (only ~4.5 m
240 thick) consist of various microbial deposits that tend to locally form small wavy mounds.
241 Ammonoids and large gastropods (e.g., *Coelostylina* sp. A, *Abrekopsis*, ?*Worthenia*) are
242 abundant and often clustered in lenses, as already noted by Reeside (1943) and Gregory
243 (1948) in some neighboring exposures. Three successive ammonoid assemblages were found
244 at this site and all contain late middle Smithian *Guodunites hooveri*. Additionally, the
245 uppermost assemblage contains a rather evolute taxon that is too poorly preserved to be firmly
246 identified, but it resembles the middle Smithian genus *Dieneroceras*.

247

248 **5. The Smithian sea near the Utah/Arizona border: arrival, duration, extent, and**
249 **correlation**

250

251 *5.1. Biostratigraphical significance of sampled ammonoids*

252

253 A total of eight ammonoid taxa were identified from the four studied localities. These are
254 attributed to specific ammonoid zones permitting high-resolution correlation at a local to
255 global scale (Brayard et al., 2009a, 2013; Jenks et al., 2010, 2015; Jattiot et al., 2017; Jenks
256 and Brayard, 2018).

257 *Inyoites oweni* was found at a single locality, Honeymoon Trail, indicating the presence of the
258 late middle Smithian *Inyoites* horizon, which is widely found in the southern part of the basin
259 at the top of the *Owenites* beds (e.g., Brayard et al., 2013) and at several places worldwide
260 (Jenks et al., 2015). It co-occurs with *Guodunites hooveri*, which is abundant throughout the
261 studied area. This taxon is restricted to the *Inyoites* horizon and is thus characteristic of the
262 late middle Smithian in the southern part of the basin (Brayard et al., 2009a, 2013; Stephen et
263 al., 2010) and the top of the regional middle Smithian UAZ4 as defined by Jattiot et al.
264 (2017). Although rare, *Guodunites* also occurs in late middle Smithian assemblages of the
265 *Owenites* beds at Crittenden Springs, NE Nevada (Jenks and Brayard, 2018). Additionally,
266 *Guodunites* is typically found in late middle Smithian ammonoid assemblages in Oman
267 (Brühwiler et al., 2012a), Vietnam (Shigeta et al., 2014) and South China (Brayard and
268 Bucher, 2008). These new findings are also consistent with the report of the occurrence of
269 *Owenites* sp. in the Sinbad Fm. at the more northern locality of Virgin Dam (Olivier et al.,
270 2014).

271 In the more complete sections at Workman Wash and Rock Canyon, sampled ammonoids in
272 the upper part of the Sinbad Fm. correspond to the typical prionitid assemblage of early late
273 Smithian age. This assemblage includes the cosmopolitan genera *Anasibirites* and
274 *Wasatchites*, and is found throughout the basin (e.g., Brayard et al., 2013; Jattiot et al., 2017,

275 2018) and also worldwide (see Jenks et al., 2015 for global correlations). It corresponds to the
276 regional UAZ5 as defined by Jattiot et al. (2017). Typical latest Smithian ammonoid taxa such
277 as *Xenoceltites*, *Glyptopliceras* and *Pseudosageceras augustum* were not found in the
278 uppermost beds of the Sinbad Fm. likely indicating that the sea had already receded from the
279 area by this time.

280

281 5.2. Richness and abundance of sampled ammonoids

282

283 Although relatively abundant in all studied localities, ammonoids show a very low taxonomic
284 diversity compared to the more northern localities in the basin (Brayard et al., 2013; Jattiot et
285 al., 2017, 2018; Jenks and Brayard, 2018), with the richest assemblages mainly recorded
286 during the late Smithian. Late middle Smithian ammonoids such as *Guodunites* or *Inyoites* are
287 typical of the southern part of the basin (e.g., Jattiot et al., 2018); it is therefore not surprising
288 to find them near the Utah/Arizona border. Unexpectedly, some taxa typical of the middle
289 Smithian in this part of the basin, such as *Churkites*, or more cosmopolitan taxa, such as
290 *Meekoceras gracilitatis*, are supposedly absent. This is striking, because although often
291 reported from the studied area, the iconic *M. gracilitatis* was actually probably misidentified
292 (see Brayard et al., 2013).

293 The unusual very low richness of late middle Smithian ammonoid assemblages in the
294 southwestern-most part of the basin can be explained by the shallow seas in this area (mostly
295 peritidal settings) that may have been favorable to only a few taxa. Jattiot et al. (2018) has
296 already pointed out that the distribution of middle Smithian ammonoids within the western
297 USA basin was highly contrasted, both in terms of abundance and richness, according to
298 north-south and south-north gradients. These authors emphasized the role of the terrigenous
299 load, and thus turbidity, in the water column and hydrodynamics in the spatial segregation of

300 taxa. They suggested that taxa preferentially found in the southern part of the basin (such as
301 *Guodunites*) were more tolerant to higher terrigenous load levels than taxa with northern
302 affinities. Peritidal settings as found in the studied area, and especially recorded in the
303 microbially-dominated unit of the Sinbad Fm., rarely show a high terrigenous load. However,
304 they were potentially more subject to higher temperature and salinity levels than in more
305 northern localities, possibly favoring a few taxa more tolerant to these conditions. There is no
306 strong evidence for taphonomic bias, mechanical sorting or differential transport that could
307 explain why some species appear to occur abundantly in this shallow setting. The
308 combination of (i) the observed preservation of shells without damage, and (ii) the presence in
309 neighboring areas with similar depositional settings, of diversified ammonoid assemblages
310 including various taxa with morphologies similar to those collected here, better argue for a
311 causal relationship between species paleoecology and local environmental conditions.
312 However, this point deserves further investigation by continuing to explore nearby
313 fossiliferous localities.

314 Late Smithian ammonoid assemblages include highly cosmopolitan taxa (Brayard et al., 2006,
315 2007). These assemblages are typical and are recognized throughout the basin (Lucas et al.,
316 2007b; Brayard et al., 2013; Jattiot et al., 2017, 2018; Jenks and Brayard, 2018) and
317 worldwide (see Brühwiler et al., 2010; Zakharov and Abnavi, 2013; Shigeta et al., 2014;
318 Jenks et al., 2015; Jattiot et al., 2016 for reviews in different basins). They show a low
319 taxonomic richness and serve to mark the base of the late Smithian. Indeed, they follow a
320 major extinction event at the middle/late Smithian boundary and correspond to the beginning
321 of marked shifts in environmental conditions such as cooling and anoxia (e.g., Grasby et al.,
322 2013; Goudemand et al., 2019; Zhang et al., 2019). On that ground, early late Smithian
323 ammonoid assemblages observed in the southwestern-most USA basin provide an excellent

324 record of the global environmental fluctuations that took place at that time as they correspond
325 to the warmest temperatures reached during the Smithian-Spathian transition (see section 5.4).

326

327 *5.3. Local and regional constraints on the Smithian sea*

328

329 The new ammonoid assemblages from the area near the Utah/Arizona border show that the
330 Smithian sea extended farther south than previously known, reaching northern Arizona and
331 the eastern part of Kane County, Utah. They also indicate that marine deposits corresponding
332 to the Sinbad Fm. span the late middle to early late Smithian interval in this area (**Fig. 4**).

333 Except for the Workman Wash site, the oldest ammonoid assemblages found in the lower
334 beds of the Sinbad Fm. are all of late middle Smithian age. The thin beds that characterize the
335 transition between the Rock Canyon Conglomerate and the Sinbad Fm. are devoid of
336 characteristic fossils, but the proximity of these beds with strata containing late middle
337 Smithian ammonoids as well as the apparent absence of a sedimentation break suggests that
338 they are very close in age. Because the microbial facies of the Sinbad Fm. progressively
339 overlie the Rock Canyon Conglomerate (Nielson, 1991; Olivier et al., 2014), we can
340 hypothesize that at least the upper part of this formation is likely Smithian in age. At
341 Workman Wash, index fossils have not yet been found in the lowermost beds. We therefore
342 cannot confirm a potential late middle Smithian age for these beds or that the open sea
343 reached this locality slightly later than expected, i.e. during the late Smithian.

344 The age of the Sinbad Fm. at the more northern localities of Cedar City and Kanarraville has
345 been shown to span at least the late middle Smithian and late Smithian (Lucas et al., 2007b;
346 Brayard et al., 2013). Thus, from Cedar City south to the Utah/Arizona border, exposures of
347 the Sinbad Fm. are almost coeval, suggesting a very rapid transgression during this interval.
348 Slightly older strata are probably present in the Cedar City and Kanarraville areas, indicating

349 that the transgression reached these localities first, but age constraints are still lacking to
350 determine its exact timing (Brayard et al., 2013). Finally, the late middle to late Smithian age
351 of the Sinbad Fm. in the entire southwestern-most region of Utah further justifies the
352 synonymization of the Timpoweap Fm. with the Sinbad Fm. (Lucas et al., 2007b).

353

354 *5.4. Connections with global climatic and biotic events*

355

356 Overall, one of the most important pieces of information provided by these new
357 biostratigraphic data is that the advancement of the sea throughout the relatively large studied
358 area, as well as its retreat, was extremely rapid (a time span less than that of an ammonoid
359 zone). The amount of time recorded by the Sinbad Fm. in this area is also rather restricted as
360 it corresponds only to the *Inyoites* horizon-*Anasibirites multiformis* beds interval. If we
361 translate this biostratigraphic interval into an approximate duration based on the present-day
362 estimates provided by Brühwiler et al. (2010) for Smithian ammonoid UA zones, this
363 epicontinental sea likely persisted in the area near the Utah/Arizona border for a period less
364 than 100 kyr. This relatively short-term marine incursion into the southern-most western USA
365 basin is part of the Smithian third order transgressive-regressive cycle, which is known in
366 several basins worldwide (e.g., Paull and Paull, 1997).

367 During the Smithian, the southern part of the western USA basin exhibited relatively shallow
368 environments and is characterized by a relative tectonic quiescence (Caravaca et al., 2018). In
369 such a context, where regional and global tectonic controls can likely be ruled out (e.g.,
370 Olivier et al., 2014; Haq, 2018), the observed transgressive/regressive cycle in the studied
371 area is probably related primarily to climatic changes (Olivier et al., 2014). In the current
372 absence of reported evidence for intermittent high-latitude continental ice-sheets for the Early
373 Triassic, such rapid m-scale eustatic fluctuations may be explained either by the variations in

374 storage of aquifers and lakes (Hay and Leslie, 1990; Jacobs and Sahagian, 1993; Haq,
375 2018) or by the thermal expansion and retraction of ocean waters (Gornitz et al., 1982; Schulz
376 and Schäfer-Neth, 1997).

377 The time interval represented by the Sinbad Fm. is coeval with a dramatic and sudden global
378 climatic change, as it spans the passage from middle Smithian warm temperatures to much
379 colder temperatures during the late Smithian and Smithian-Spathian transition. Warmest
380 temperatures were initially assumed to have occurred at the Smithian/Spathian boundary
381 based on $\delta^{18}\text{O}$ conodont data analyzed by conventional gas isotope ratio mass spectrometry
382 (Sun et al., 2012; Romano et al., 2013). Nevertheless, recently published $\delta^{18}\text{O}$ conodont data
383 analyzed by sensitive high-resolution ion microprobe indicated that the warmest temperatures
384 were reached during the middle and early late Smithian, followed by a cooling phase during
385 the rest of the Smithian and the Smithian-Spathian transition (Goudemand et al., 2019). The
386 observed transgressive trend therefore corresponds to the middle-early late Smithian warmer
387 temperatures and the regressive trend to the cooling phase spanning the latest Smithian and
388 Smithian-Spathian transition. Thus, the Sinbad Fm. and its marine deposits seem to be the
389 direct result of global climatic fluctuations and related sea-level changes that occurred from
390 the late middle Smithian to the Smithian-Spathian transition.

391 These climatic and sea-level changes have also been associated with several other
392 environmental perturbations such as changes in carbon and sulfur cycles (Payne, 2004;
393 Horacek et al., 2007b; Galfetti et al., 2007; Song et al., 2014; Zhang et al., 2015; Stebbins et
394 al., 2019; Thomazo et al., 2019) and anoxia (Horacek et al., 2007a; Shigeta et al., 2009;
395 Grasby et al., 2013; Sun et al., 2015; Clarkson et al., 2016; Zhao et al., 2020). They also
396 coincide with a major extinction of nekto-pelagic organisms such as ammonoids and
397 conodonts during the late Smithian (Tozer, 1982; Dagys, 1988; Hallam, 1996; Orchard, 2007;
398 Stanley, 2009; Jattiot et al., 2016). Much caution should be heeded when interpreting the

399 detailed timing and spatial extent of these perturbations, as well as their underlying causal
400 processes such as volcanism and redox changes (reader can refer to e.g., Hammer et al., 2019
401 and Thomazo et al., 2019 for recent examples of discussion). Our knowledge of the short late
402 Smithian time interval has improved recently by showing that successive cosmopolitan
403 ammonoid assemblages thrived during this time interval (e.g., Jenks et al., 2015).
404 Mechanisms controlling the major extinction at the middle/late Smithian boundary and the
405 marked dominance of prionitids at the beginning of the late Smithian are still hypothetical, but
406 they probably can be primarily related to the warm temperature reached at that time.
407 Ammonoid assemblages that followed correspond to the cooling phase, finally leading to the
408 installation of the more endemic assemblages of the early Spathian. This change supports a
409 link between ammonoid diversity *s.l.* and distribution, and rapid fluctuations of the latitudinal
410 gradient of sea-surface temperature during the Smithian-Spathian transition (e.g., Brayard et
411 al., 2006). Contemporary changes in other environmental parameters such as redox conditions
412 or continental weathering may have also influenced ammonoid diversity, but their effects are
413 presently much harder to assess (e.g., Jattiot et al., 2018). Thus, the observed
414 sedimentological and paleontological changes recorded in the Sinbad Fm. are consistent with
415 coeval global climatic and biotic events. This also emphasizes that detailed and replicated
416 field studies conducted within a regional sedimentary basin by revealing basin-wide
417 paleontological, sedimentological and geochemical signals and variabilities can provide
418 valuable and meaningful clues to environmental changes and evolutionary processes during a
419 global crisis.

420

421 **6. Conclusions**

422

423 New Smithian ammonoid assemblages sampled near the Utah/Arizona border provide for the
424 first time several spatiotemporal constraints on the regional Sinbad Fm. (western USA basin),
425 highlighting its importance for understanding environmental and biotic events during the
426 middle and late Smithian, *ca.* 1 myr after the Permian/Triassic boundary mass extinction. This
427 new information also highlight the significance of the Sinbad Fm. for disentangling local *vs.*
428 global signals near the late Smithian. Newly obtained age constraints and correlation also
429 have important consequences for the understanding of the western USA basin dynamics and
430 architecture.

431 1) The late middle to late Smithian age of the Sinbad Fm. in all of southwestern Utah as well
432 as central Utah further justifies the synonymization of the Timpoweap Fm. with the Sinbad
433 Fm.

434 2) The taxonomic richness of late middle Smithian assemblages is much lower in the studied
435 area than in more northern localities. Occurrences of some taxa characteristic of the southern
436 part of the basin, such as *Guodunites* and *Inyoites*, support the view of a spatial segregation of
437 ammonoids within the western USA basin during the middle Smithian. However, the absence
438 of certain middle Smithian iconic taxa, such as *Churkites* and *Meekoceras gracilitatis*, in this
439 part of the basin is still in need of clarification. Sampled assemblages of late Smithian
440 ammonoids include cosmopolitan taxa that are typical of this time interval worldwide and
441 reflect the late Smithian crisis.

442 3) The biostratigraphical constraints obtained for the Sinbad Fm. demonstrate that the
443 southern-most extent of the Smithian sea in the southwestern-most part of the western USA
444 basin is further south than previously realized, reaching northern Arizona and eastern Kane
445 County, Utah.

446 4) This southwestern-most excursion of the sea in the western USA basin belongs to the third
447 order Smithian transgression-regression cycle, which is well-documented worldwide.

448 5) Within the studied area, the Sinbad Fm. spans the late middle to early late Smithian
449 (*Inyoites* horizon – *Anasibirites* beds), representing presumably a short time interval, probably
450 less than 100 kyr based on present-day estimates of Smithian ammonoid UA zones.

451 6) The rapid transgression-regression cycle recorded in the Sinbad Fm. appears to be
452 primarily linked to known concomitant global warming followed by cooling changes, which
453 led to the late Smithian extinction and to the more endemic ammonoid assemblages of the
454 early Spathian.

455

456

457 **7. Systematic paleontology**

458

459 Systematic descriptions mainly follow the classification of Tozer (1981), and that
460 further refined by Brayard et al. (2013), Jattiot et al. (2016, 2017) and Jenks and Brayard
461 (2018). Quantitative morphological ranges for identified species are illustrated by scatter
462 diagrams based on classical measurements of the diameter (D), and corresponding whorl
463 height (H), whorl width (W) and umbilical diameter (U). Scatter diagrams of H, W and U, and
464 H/D, W/D and U/D are provided only when the number of measured specimens is higher than
465 four. Measurements are given in **Supplementary Table A**. The number of sampled
466 specimens (fragmentary to complete) for each taxon and locality is indicated as “n=”.

467 Repository of figured specimens is abbreviated UBGD (Université de Bourgogne, Géologie
468 Dijon). WW: Workman Wash; HT: Honeymoon Trail; RC: Rock Canyon; WSW: White Sage
469 Wash.

470

471 Order Ammonoidea Zittel, 1884

472 Suborder Ceratitina Hyatt, 1884

473 Superfamily Meekoceratoidea Waagen, 1895

474 Family Proptychitidae Waagen, 1895

475 Genus *Guodunites* Brayard and Bucher, 2008

476 **Type species:** *Guodunites monneti* Brayard and Bucher, 2008

477

478 *Guodunites hooveri* (Hyatt and Smith, 1905)

479 **Figs. 5A-M**

480

481 1905 *Aspidites hooveri* Hyatt and Smith, p. 153, pl. 17, figs. 1–12.

482 1932 *Clypeoceras hooveri* – Smith, p. 63, pl. 17, figs. 1–12.

483 v 2009b *Guodunites hooveri* – Brayard et al., p. 476, pl. 2, figs. 1–30.

484 2010 ?*Clypeoceras hooveri* – Stephen et al., figs. 6e, f, i.

485 v 2013 *Guodunites hooveri* – Brayard et al., p. 170.

486 v 2017 *Guodunites hooveri* – Jattiot and Bucher in Jattiot et al., p. 18, pl. 4., figs. L-V.

487

488 **Occurrence:** Documented from the basal microbially-dominated part of the Sinbad Fm. in

489 HT, RC (ROC2-A; n = 18) and WSW (WSW 1, WSW 2, WSW 3; n = 19). Apparently absent

490 from WW.

491

492 **Description:** For thorough description and illustration of this classical middle Smithian

493 species in the western USA basin, readers are invited to consult Brayard et al. (2009b, 2013).

494 This taxon can be easily recognized by the main following diagnostic features: a platyconic

495 shell with an involute coiling and a narrowly rounded venter, slightly convex flanks with

496 maximum thickness near mid-flanks, an egressive coiling at submature stage, a deep

497 crateriform umbilicus, and marked, projected lirae on outer shell (Brayard et al., 2009b,

498 2013). Weak folds are sometimes visible on the specimens presented here, but no delicate
499 strigation as in some specimens from other sites (e.g., Brayard et al., 2009b). Suture line
500 typically subammonitic with crenulated saddles, but only the overall architecture can be seen
501 on our recrystallized specimens.

502

503 **Measurements:** See **Supplementary Fig. A** and **Supplementary Table A**. Estimated
504 maximal size: ~15 cm (Brayard et al., 2009b, 2013).

505

506 **Discussion:** *Guodunites hooveri* can be distinguished from *G. monneti*, by its deeper
507 umbilicus and its more involute coiling. Until this study, the latter had not been found in
508 central and southern Utah suggesting a strong exclusion of these two species within the
509 western USA basin as shown for several ammonoid taxa by Jattiot et al. (2018). However,
510 three specimens sampled from Rock Canyon and White Sage Wash (**Fig. 5N-P**) show a rather
511 more evolute coiling and more compressed whorl section than typical *G. hooveri* specimens,
512 and thus are likely *G. monneti* (see next section). Both *Guodunites* species are characteristic
513 of the middle Smithian, *G. monneti* being more cosmopolitan than *G. hooveri*, which is
514 restricted to the western USA basin (Brayard et al., 2009b, 2013; Jattiot et al., 2017).

515

516 *Guodunites monneti* Brayard and Bucher, 2008

517 **Figs. 5N-P**

518

519 See Jattiot et al. (2017) and Jenks and Brayard (2018) for updated synonymy lists for this
520 species.

521

522 **Occurrence:** Two specimens sampled from bed ROC2-A and one from bed WSW3 in the
523 microbially-dominated part of the Sinbad Fm. Not yet found in other studied sections.

524

525 **Description:** Large sized, compressed specimens represented by an internal mold showing a
526 moderately involute coiling and a narrowly rounded venter. Umbilicus shallow with an
527 egressive coiling. Preserved ornamentation consists only of weak, probable lirae, visible on
528 the umbilical margin and barely perceptible on flanks. The suture line of our specimens is
529 poorly preserved and only shows high saddles and indented lobes. Its overall structure fits
530 with suture lines illustrated by e.g., Brayard et al. (2009).

531

532 **Measurements:** See **Supplementary Table A.**

533

534 **Discussion:** These rare specimens mainly differ from other sampled *Guodunites* specimens by
535 their less crateriform umbilicus and slightly more evolute coiling, thus corresponding to *G.*
536 *monneti*. This species has not yet been reported from central and southern Utah.

537

538 Family Inyoitidae Spath, 1934

539 Genus *Inyoites* Hyatt and Smith, 1905

540 **Type species:** *Inyoites oweni* Hyatt and Smith, 1905

541

542 *Inyoites oweni* Hyatt and Smith, 1905

543

544 1905 *Inyoites oweni* Hyatt and Smith, p. 134, pl. 6, figs. 1-16; pl. 69, figs. 1-9; pl. 78, figs., 1-
545 8.

546 1932 *Inyoites oweni* – Smith, p. 80, pl. 6, figs. 1-16, pl. 40, figs. 1-8, pl.69, figs. 1-9.

- 547 1934 *Inyoites oweni* – Spath, p. 138, fig. 37.
- 548 1968 *Inyoites spicini* Zakharov, p. 151, pl. 30, fig. 2.
- 549 1973 *Inyoites oweni* – Collignon, p. 12, pl.1, fig. 9.
- 550 ? 1995 *Inyoites oweni* – Shevyrev, p. 34, pl. 3, figs 2-4.
- 551 2010 *Inyoites oweni* – Stephen et al., figs. 5a, b.
- 552 v 2012a *Inyoites oweni* – Brühwiler et al., p. 34, pl. 21, figs. 1-6.
- 553 ? 2012a *Inyoites* sp. indet. Brühwiler et al., p. 35, pl. 21, figs. 8a-c.
- 554 v 2013 *Inyoites oweni* – Brayard et al., p. 185, fig. 49a-t.
- 555 v 2017 *Inyoites oweni* – Jattiot and Bucher in Jattiot et al., p. 24, pl. 8, figs. A-G.
- 556 v 2018 *Inyoites oweni* – Jenks and Brayard, p. 56, figs. 54q-t.

557

558 **Occurrence:** A unique specimen documented (but not sampled) from the microbially-
559 dominated part of the Sinbad Fm. in HT. Not yet found in the other studied sections.

560

561 **Description:** See Brayard et al. (2013), Jattiot et al. (2017) and Jenks and Brayard (2018) for
562 a thorough description and illustration of this typical late middle Smithian species in the
563 western and southern parts of the western USA basin. Main diagnostic features include (i) a
564 moderately involute and highly compressed shell bearing a characteristic high, pronounced
565 keel, (ii) a shallow umbilicus, (iii) very conspicuous slightly sinuous fold-like ribs varying
566 greatly in strength and width, and (iv) ribs rapidly fade away on the outer half of the flanks
567 where they are gradually transformed into delicate, dense and sinuous lirae. Suture line not
568 visible on our specimen.

569

570 **Measurements:** Estimated maximal size: ~8 cm (Brayard et al., 2013).

571

572 **Discussion:** Two additional *Inyoites* species (*I. beaverensis* and *I. stokesi*) are known from the
573 Smithian of the western USA basin (Brayard et al., 2013; Jenks and Brayard, 2018). *Inyoites*
574 *beaverensis* is older (early middle Smithian) and mainly differs from the type species by its
575 more evolute coiling, its near-absence of ornamentation and its smaller keel (Brayard et al.,
576 2013; Jattiot et al., 2017). Intermediate forms between *I. beaverensis* and *I. oweni* were also
577 reported from the late middle Smithian of Nevada (Jattiot et al., 2017). *Inyoites stokesi* co-
578 occurs with *I. oweni*, but differs by its barely perceptible keel as well as its slightly more
579 involute coiling. *Inyoites oweni* is typical of the late middle Smithian in the western USA
580 basin and facilitates correlation worldwide (e.g., with the *Inyoites* horizon of the *Owenites*
581 beds in South China; see Brayard and Bucher, 2008).

582

583 Family Prionitidae Hyatt, 1900

584 Genus *Gurleyites* Mathews, 1929

585 **Type species:** *Gurleyites smithi* Mathews, 1929

586

587 *Gurleyites smithi* Mathews, 1929

588 **Figs. 6A-Q, 7A-S, 8A-O, 9A-J, 10A-H**

589

590 ? 1929 *Goniodiscus ornatus* Mathews, p. 34, pl. 6, figs. 6-10.

591 ? 1929 *Goniodiscus* (?) *varians* Mathews, p. 35, pl. 7, figs. 26-39.

592 1929 *Kashmirites resseri* Mathews, p. 38, pl. 8, figs. 4-7.

593 ? 1929 *Anasibirites edsoni* Mathews, p.27, pl. 4, figs. 29-32

594 ? 1929 *Anasibirites bassleri* Mathews, p.28, pl. 4, figs. 33-35

595 ? 1929 *Anasibirites mojsisovicsi* Mathews, p. 30, pl. 5, figs. 1-3

596 1929 *Gurleyites smithi* Mathews, p. 43, pl. 10, figs. 1-6.

- 597 1929 *Gurleyites bastini* Mathews, p. 44, pl. 10, figs. 7-11.
598 p 1929 *Gurleyites chamberlini* Mathews, p. 44, pl. 11, figs. 3-5.
599 1929 *Gurleyites milleri* Mathews, p. 45, pl. 9, figs. 10-12.
600 1929 *Gurleyites boutwelli* Mathews, p. 45, pl. 8, figs. 1-3.
601 1932 *Kashmirites resseri* – Smith, p. 67, pl. 81, figs. 9, 10.
602 ? 1932 *Anasibirites mojsisovicsi* – Smith, p. 73, pl. 80, figs. 1-2.
603 1932 *Anasibirites bastini* – Smith, p. 70, pl. 80, figs. 3-5.
604 ? 1932 *Anasibirites ornatus* – Smith, p. 75, pl. 80, figs. 11, 12.
605 1932 *Anasibirites smithi* – Smith, p. 76, pl. 80, figs. 13-15.
606 1961 *Arctoprionites* sp. indet. Tozer, pl. 20, figs. 1, 3.
607 v 1962 *Arctoprionites* sp. indet. Kummel and Steele, p. 699, pl. 101, fig. 2.
608 ? 1976 *Gurleyites debilis* Wang and He, p. 296, pl. 7, figs. 23-24.
609 1994 *Arctoprionites williamsi* Tozer, p. 83, pl. 34, figs. 1-4.
610 v 2013 *Anasibirites* cf. *angulosus* – Brayard et al., p. 195, fig. 65.
611 v 2013 *Arctoprionites resseri* – Brayard et al., p. 198, fig. 67.
612 2015 *Arctoprionites resseri* – Piazza, p. 52, pl. 2, figs. e-g.
613 v 2017 *Arctoprionites resseri* – Jattiot and Bucher in Jattiot et al., p. 34, pl. 12, figs. N-X.
614 2017 *Arctoprionites resseri* – Piazza in Piazza et al., fig. 4C-D.
615 p v 2018 *Hemiprionites typus* – Jenks and Brayard, figs. 78D-F, 79G-I only.
616 v 2018 *Arctoprionites resseri* – Jenks and Brayard, p. 92, fig. 86-87.
617 2020 *Arctoprionites resseri* – Jattiot et al., p. 55, pl. 28P-U.

618

619 **Occurrence:** Abundant in the microbially-dominated unit of the Sinbad Fm. in WW (BRC; n
620 = 85).

621

622 **Description:** Compressed and moderately involute prionitid showing a slightly egressive
623 coiling, and a sulcate to delicately arched venter, many specimens exhibiting a tabulate
624 venter. Ornamentation is characteristically highly variable among specimens and sometimes
625 throughout ontogeny. It generally consists of forward projected, bullate, elongated and
626 sinuous ribs that stem near the umbilical shoulder and fade rapidly toward the venter (see also
627 description of “*Arctoprionites resseri*” in Brayard et al., 2013; Jattiot et al., 2017; Jenks and
628 Brayard, 2018). The newly sampled, well-preserved specimens from Workman Wash indicate
629 that these ribs may cross the venter, resulting in a slightly crenulated venter. Some rare
630 specimens also exhibit elevated bullate ribs that almost form tubercles in a manner similar to
631 *Wasatchites*. Specimens with a more evolute coiling generally exhibit a stronger
632 ornamentation, thereby complying with Buckman's rules of covariation (Westermann, 1966;
633 Monnet et al., 2015). Umbilical margin is broadly arched with an inclined wall.
634 As a complement to previous works, our abundant and well-preserved material shows a
635 feature not previously reported for this taxon, which consists of a strigation on the venter and
636 on the flanks, most often on both sides of the ventrolateral margin. These spiral lines can be
637 seen at all growth stages, but often do not continue throughout the entire ontogeny.
638 Additionally, they are more or less well expressed and are apparently independent from the
639 venter shape. This strigation may also occur asymmetrically on the venter of some specimens
640 and more rarely, may shift a little further towards the internal part of the flank. One specimen
641 also exhibits on its inner whorls, regularly spaced relief that strongly resembles megastriae
642 (**Fig. 9I-J**). The suture line is rarely observable on our specimens and is often incomplete.
643 However, it is typical of the genus with three large, arched saddles, decreasing in size from
644 the ventrolateral to the umbilical margin. Lobes are well indented.
645

646 **Measurements:** See **Supplementary Fig. B** and **Supplementary Table A**. Estimated
647 maximal size: ~15 cm (Jenks and Brayard, 2018).
648

649 **Discussion:** The genus *Gurleyites* is a typical example of the complicated taxonomy of
650 prionitids as members of this family show a marked intraspecific variation. The newly
651 sampled material leads us to merge all *Gurleyites* species and two *Goniodiscus* species
652 erected by Mathews (1929) with the more recent taxon *Arctoprionites* erected by Spath
653 (1930), including specimens described as *Kashmirites resseri* by Mathews (1929), as well as
654 all Mathews' specimens that fit well within the now known much wider intraspecific variation
655 of *Gurleyites smithi*. Since *G. smithi* is the type species of *Gurleyites* and has priority,
656 *Arctoprionites resseri* is now considered to be a junior synonym. Jattiot et al. (2016)
657 tentatively synonymized some *Gurleyites* species with *A. kingianus*. This similarity was also
658 discussed by Spath (1934) who highlighted the existence of a few intermediate juvenile forms
659 between e.g., *Anasibirites* and *Gurleyites*, and by Tozer (1971) who synonymized *Gurleyites*
660 with *Anasibirites*. In 1930, Spath erected the new genus *Arctoprionites* for *Goniodiscus*
661 *nodosus* from Spitsbergen (Frebald, 1930), which also served as a new genus name for
662 specimens of “*Kashmirites resseri*” from the western USA basin. *Arctoprionites nodosus*
663 closely resembles *Gurleyites smithi* (see Jenks and Brayard, 2018 for explanations on
664 potential differences between these two species). Even though we consider *A. nodosus* to be a
665 possible valid species, typical of the Boreal late Smithian, it is extremely difficult to justify
666 why it also should not be placed within the genus *Gurleyites*. Spath (1934) erected three
667 additional prionitid taxa from Spitsbergen, i.e., *Gurleyites freboldi*, *Hemiprionites gardwoodi*
668 and *Arctoprionites tyrrelli*, which are very close to *A. nodosus* and actually are probably
669 variants of this species. In terms of whorl shape and coiling geometry, these four taxa are
670 practically indistinguishable from *Gurleyites smithi* (compare our **Supplementary Material**

671 **Fig. B** and measurements of *A. nodosus* provided by Piazza, 2015), the only difference being
672 slight but apparently consistent differences in ornamentation (e.g., shape and trajectory of
673 ribs, and nodes on the flanks of *A. nodosus* appear to be placed farther toward the venter than
674 on *Gurleyites smithi*). These ornamental variances can justify a separate species, but probably
675 not a separate genus. Therefore, we place *A. nodosus* within *Gurleyites* and invalidate the
676 genus *Arctoprionites*.

677 *Gurleyites smithi* shows a rather large geographic distribution as do most early late Smithian
678 prionitid genera, (e.g., Spitsbergen: Frebold, 1930, Piazza et al., 2017; British Columbia:
679 Tozer, 1994; Timor: Jattiot et al., 2020). It is found at several places in the eastern and
680 southern parts of the western USA basin, but is often rare (Brayard et al., 2013; Jattiot et al.,
681 2017; Jenks and Brayard, 2018). However, this is not the case at Workman Wash, where the
682 taxon occurs abundantly.

683 The newly sampled material also leads us to reassign certain specimens attributed to *H. typus*
684 by Jenks and Brayard (2018; figs. 78D-G, 79G-I) to *Gurleyites smithi* (note that these
685 specimens show a very weak ventral strigation; see implications hereafter). In addition, it
686 leads us to integrate specimens of *Anasibirites cf. angulosus* illustrated by Brayard et al.
687 (2013) into *G. smithi*. *Gurleyites debilis*, erected by Wang and He (1976) for prionitid
688 specimens from southern Tibet, may fit within *G. smithi*. However, the poor preservation and
689 inadequate illustration of these specimens prevent a firm assignment. Specimens assigned to
690 *Gurleyites* and *Arctoprionites* have also been reported from South Primorye (e.g., Zakharov,
691 1978), but detailed comparisons based on more illustrated material are needed before these
692 assignments can be validated.

693 The observed spiral lines on the venter and on the flanks are a newly observed ornamental
694 feature indicating that *Gurleyites*, similar to another Prionitidae, *Hemiprionites* (e.g., Jattiot et
695 al., 2017; Jenks and Brayard, 2018), exhibits strigation on well-preserved specimens.

696 Although strigation has occasionally been documented and illustrated for *Hemiprionites*, this
697 feature has rarely been integrated into taxonomic descriptions and discussed. This also
698 indicates that, like many other Smithian families (e.g., Flemingitidae, Arctoceratidae,
699 Proptychitidae), the Prionitidae include at least two representatives that exhibit strigation, and
700 that this ornamentation is therefore common among Smithian ammonoids.

701 Newly sampled specimens of *Gurleyites smithi* illustrate that this species exhibits a very large
702 intraspecific variation. Notably, it overlaps the intraspecific variation of *Hemiprionites typus*.
703 Specimens of *G. smithi* exhibiting weak ornamentation may indeed be confused with some
704 “robust” specimens of *H. typus*, which may bear highly sinuous, bullate folds and ventral
705 strigation. However, in contrast with *G. smithi*, *H. typus* specimens apparently do not exhibit a
706 prominent relief near the umbilical margin and sometimes bear a minute depression just
707 below the ventral shoulder (see Jattiot et al., 2017 and Jenks and Brayard, 2018 for a
708 discussion on the diagnostic nature of the latter’s ornamentation). Some large specimens of *G.*
709 *smithi* may also display later growth stages that resemble those of *H. typus* (**Fig. 8L-O**). Some
710 workers may therefore see a morphological continuum between these two taxa. Based on this
711 and other recent studies, this indicates that they, at the very least, are very closely-related
712 prionitid species. *G. smithi* specimens are on average slightly more evolute than typical *H.*
713 *typus* (**Supplementary Fig. C**), but this observation is highly dependent on the robustness of
714 their ornamentation. Additionally, some rare specimens of *G. smithi* have elevated bullate ribs
715 that may almost form tubercles (**Fig. 8A-C, F-H**). Such specimens can thus be confused with
716 poorly preserved *Wasatchites* specimens. However, they differ by their highly variable
717 ornamentation throughout ontogeny; this ornamentation is generally weaker than that of
718 *Wasatchites*. Nevertheless, these specimens suggest a rather close phylogenetic affinity
719 between *Gurleyites* and *Wasatchites*. Finally, one specimen also bears megastriae on its inner
720 whorls (**Fig. 9I-J**); this feature is remindful of the megastriae observed in *Anasibirites*

721 species, thus also supporting a possible close phylogenetic link between *Anasibirites* and
722 *Gurleyites*. This resemblance between both genera, found in a few *Gurleyites* specimens, was
723 earlier noticed by Spath (1934).

724 The suture line of *G. smithi* and its variability have rarely been well illustrated. The overall
725 architecture of the suture line observed on our specimens fits well with those documented
726 from specimens sampled at Palomino Ridge and Crittenden Springs, Nevada, and illustrated
727 by Jattiot et al. (2017) and Jenks and Brayard (2008), respectively. This observation suggests
728 that the intraspecific variability of the suture line is somewhat restricted for this species. By
729 contrast, saddles of *H. typus* appear more pinched and its first lateral saddle more flared (see
730 also Jenks and Brayard, 2018 for comparison). However, the number of suture lines illustrated
731 for *H. typus* is still rather restricted, thus preventing a precise assessment of its intraspecific
732 variability.

733

734 Genus *Wasatchites* Mathews, 1929

735 **Type species:** *Wasatchites perrini* Mathews, 1929

736

737 *Wasatchites perrini* Mathews, 1929

738 **Figs. 9K-L**

739

740 1929 *Wasatchites perrini* Mathews, p. 40, pl. 9, figs. 1–9

741 1929 *Wasatchites meeki* Mathews, p. 41, pl. 7, figs. 1–3; pl. 8, figs. 11–14.

742 1929 *Wasatchites magnus* Mathews, p. 41, pl. 11, figs. 1, 2.

743 1929 *Wasatchites quadratus* Mathews, p. 42, pl. 7, figs. 23–25.

744 ? 1929 *Kashmirites thornei* Mathews, p. 38, pl. 6, figs. 22–25.

745 1929 *Kashmirites wasatchensis* Mathews, p. 36, pl. 6, figs. 26–28.

- 746 ? 1929 *Kashmirites gilberti* Mathews, p. 38, pl. 7, figs. 4–8.
747 1929 *Keyserlingites seerleyi* Mathews, p. 39, pl. 8, figs. 8–10.
748 1932 *Kashmirites meeki* – Smith, p. 67, pl. 81, figs. 1, 2.
749 1932 *Kashmirites wasatchensis* Smith, p. 69, pl. 81, figs. 3–5.
750 1932 *Kashmirites perrini* – Smith, p. 67, pl. 81, figs. 6–8.
751 1932 *Kashmirites seerleyi* Smith, p. 68, pl. 81, figs. 11, 12.
752 p 1961 *Wasatchites tardus* Tozer, p. 71, pl. 19, figs. 1a-b (only).
753 1994 *Wasatchites perrini* – Tozer, p. 79, pl. 29, figs. 5a-c; pl. 35, figs. 2-4.
754 v 2010 *Wasatchites perrini* – Stephen et al., fig. 7c.
755 v 2013 *Wasatchites perrini* – Brayard et al., p. 191, figs. 13d, 59a-k.
756 v 2017 *Wasatchites perrini* – Jattiot and Bucher in Jattiot et al., p. 28, figs. 13d, 59a-k.
757 v 2018 *Wasatchites perrini* – Jenks and Brayard, p. 87, fig. 83.

758

759 **Occurrence:** Documented from the microbially-dominated unit of the Sinbad Fm. in WW
760 (BRC; n = 2) and its upper part in RC (ROC3-A; not sampled).

761

762 **Description:** Reader should refer to Brayard et al. (2013), Jattiot et al. (2017) and Jenks and
763 Brayard (2018) for detailed descriptions and discussions of this typical early late Smithian
764 taxon. This species exhibits a rather large intraspecific variation, but the shell is generally
765 moderately involute with a trapezoidal whorl section. Its ornamentation consists of (i) very
766 conspicuous tubercles on umbilical shoulders that become more bullate or nodate on mature
767 whorls, but then tend to rapidly lose strength near the aperture, and (ii) alternating strong and
768 weak, fasciculate ribs that stem from the tubercles and cross the venter. The venter is also
769 subtabulate to slightly arched. Suture line unknown from the studied specimens.

770

771 **Measurements:** Sampled specimens are all fragmented, preventing measurements. Estimated
772 maximal size: ~20 cm (Jenks and Brayard, 2018).

773

774 **Discussion:** *W. perrini* can be distinguished from other co-occurring taxa by its conspicuous,
775 regularly spaced ornamentation. This species is not very abundant in the western USA basin
776 compared to, e.g., *Anasibirites*. A second species of *Wasatchites* (*W. cf. distractus*) has been
777 reported from the early late Smithian at one locality within the western USA basin, i.e.,
778 Crittenden Springs, Nevada (Jenks and Brayard, 2018). This species, previously known only
779 from the Tethys (e.g., Brühwiler et al., 2012b, c), mainly differs from the type species by its
780 more broadly rounded venter at all growth stages, the mid-flank position of its tubercles, and
781 its more radially directed ribs. *Wasatchites* is an emblematic early late Smithian prionitid that
782 shows a large cosmopolitan distribution (e.g., Brayard et al., 2006). It is thus a helpful taxon
783 that can be used as an auxiliary marker to *Anasibirites* to delineate the early late Smithian
784 worldwide.

785

786 Genus *Anasibirites* Mojsisovics, 1896

787 **Type species:** *Sibirites kingianus* Waagen, 1895

788

789 **Remark:** Jattiot et al. (2016) provided a comprehensive review of the taxonomy of the
790 various iconic late Smithian *Anasibirites* species. We follow the conclusions of this work and
791 thus do not include the complete description and synonymy list for each sampled species.
792 Reader should refer to Jattiot et al. (2016) for complete synonymy lists (see also our remarks
793 on species included in *G. smithi*).

794

795 *Anasibirites multiformis* Welter, 1922

796 **Fig. 11A-P**

797

798 v 2016 *Anasibirites multiformis* – Jattiot et al., p. 184, figs. 10N–S, 21–23 [cum syn.].

799 v 2017 *Anasibirites multiformis* – Jattiot and Bucher in Jattiot et al., p. 30, pl. 11, figs. G-AA.

800 v 2018 *Anasibirites multiformis* – Jenks and Brayard, p. 79, figs. 74D-F, G(4,5), 75.

801

802 **Occurrence:** Documented from the microbially-dominated unit of the Sinbad Fm. in WW
803 (BRC; n = 28) and its upper part in RC (ROC3-A; n = 2).

804

805 **Description:** Rather involute, compressed prionitid with near isometric growth.

806 Ornamentation typically consists of weak and dense megastriae throughout ontogeny. Suture
807 line unknown for sampled specimens.

808

809 **Measurements:** See **Supplementary Fig. D** and **Supplementary Table A**. Estimated
810 maximal size: ~10 cm (Jattiot et al., 2016).

811

812 **Discussion:** This species is abundant within the studied area, but is mainly represented by
813 small-sized specimens, generally < 4 cm (**Fig. 11**). As shown by Jattiot et al. (2016), the
814 occurrence of megastriae mimicking the intercalation of strong ribs only on the inner whorls
815 (often <20 mm) is essential for distinguishing *A. kingianus* from *A. multiformis*. The latter
816 display weaker and denser megastriae throughout ontogeny. *A. multiformis* is also less
817 variable with a generally more compressed whorl and near isometric growth. *A. multiformis* is
818 much more abundant than *A. kingianus* in the western USA basin (Jattiot et al., 2016; Jenks
819 and Brayard, 2018). *Anasibirites* is an iconic genus utilized worldwide to define the base of
820 the late Smithian (e.g., Brühwiler et al., 2010), as it shows a highly cosmopolitan distribution

821 that includes Siberia, Spitsbergen, British Columbia, western USA, Timor, Spiti, Salt Range,
822 Kashmir, Afghanistan, South China, Oman, South Primorye and Japan (e.g., Jattiot et al.,
823 2016).

824

825 Genus *Hemiprionites* Spath, 1929

826 **Type species:** *Goniodiscus typus* Waagen, 1895

827

828 *Hemiprionites typus* (Waagen, 1895)

829 **Figs. 10A-H, 12J-S**

830

831 1895 *Goniodiscus typus* Waagen, p. 128, pl. 9, figs. 7-10.

832 1929 *Goniodiscus typus* – Mathews, p. 31, pl. 5, figs. 12-21.

833 1929 *Goniodiscus americanus* – Mathews, p. 32, pl. 5, figs. 22-27.

834 1929 *Goniodiscus shumardi* – Mathews, p. 33, pl. 6, figs. 11-14.

835 1929 *Goniodiscus utahensis* – Mathews, p. 33, pl. 6, figs. 29-31.

836 1929 *Goniodiscus slocomi* – Mathews, p. 34, pl. 6, figs. 15-17.

837 1929 *Goniodiscus butleri* – Mathews, p. 35, pl. 6, figs. 18-21.

838 1932 *Anasibirites typus* – Smith, p. 76, pl. 80, figs. 6-8.

839 1932 *Anasibirites utahensis* – Smith, p. 77, pl. 80, figs. 9, 10.

840 1934 *Hemiprionites typus* – Spath, p. 331, figs. 114ac.

841 v p 2008 *Hemiprionites* cf. *H. butleri* – Brayard and Bucher, p. 58, pl. 29, figs 1, 4, 7 only,

842 text- fig. 50.

843 2012b *Hemiprionites typus* – Brühwiler and Bucher, p. 103, figs. 89A-AH.

844 v 2013 *Hemiprionites* cf. *H. typus* – Brayard et al., p. 197, fig. 66.

845 v 2017 *Hemiprionites typus* – Jattiot and Bucher in Jattiot et al., p. 31, pl. 12, figs. A-M, pl.
846 13, figs. A-X.

847 p v 2018 *Hemiprionites typus* – Jenks and Brayard, p. 81, figs. 77, 78A-C, 78G-R, 79A-
848 F, 79J-O.

849 2020 *Hemiprionites typus* – Jattiot et al., p. 56, pl. 29A-AN.

850

851 **Occurrence:** Documented from the microbially-dominated unit of the Sinbad Fm. in WW
852 (BRC; n = 20).

853

854 **Description:** See taxonomic revision of *Hemiprionites* species by Jattiot et al. (2017). The

855 type species shows a compressed shell with variable involution and a typical marked

856 egressive coiling at mature stage. A small depression on the outer edge of the flank, just

857 below the ventral margin, is also visible on some specimens (e.g., **Fig. 12N**). Spiral lines are

858 sometimes visible on the venter and/or near the ventrolateral margin (e.g., **Figs. 12K, R-S**).

859 Flexuous and slightly biconcave growth lines are visible and may bundle into small folds that

860 may cross the venter. Suture line ceratitic with a deep and flared first lateral lobe. Saddles

861 appear pinched.

862

863 **Measurements:** See **Supplementary Fig. E** and **Supplementary Table A**. Estimated

864 maximal size: ~10 cm (Jattiot et al., 2017).

865

866 **Discussion:** *H. typus* is a characteristic early late Smithian taxon. It can be distinguished from

867 another co-occurring *Hemiprionites* species, *H. walcotti*, by its often wider venter and

868 umbilicus, as well as by more egressive coiling and the existence of a small depression near

869 the ventral margin on some specimens. Another *Hemiprionites* species, *H. roberti*, is

870 documented from the western USA basin but is late middle Smithian in age (Jenks et al.,
871 2010). *H. roberti* does not exhibit egressive coiling and has a funnel-shaped umbilicus. The
872 morphological variability of *H. typus* partly overlaps with *Gurleyites smithi*, but the latter
873 appears more ornamented and slightly more evolute, and has a somewhat different suture line
874 (see *G. smithi* discussion).

875

876 *Hemiprionites walcotti* (Mathews, 1929)

877 **Fig. 12A-I**

878

879 p 1922 *Anasibirites multiformis* Welter, p. 17, figs. 4-7, 11-14.

880 1929 *Goniodiscus walcotti* Mathews, p. 32, pl. 6, figs. 1-5.

881 1934 *Hemiprionites timorensis* Spath, p. 331.

882 v p 2008 *Hemiprionites* cf. *H. butleri* – Brayard and Bucher, p. 58, pl. 29, figs. 2, 3, 6 only.

883 v 2008 *Hemiprionites klugi* Brayard and Bucher, p. 59, pl. 30, figs. 1-4.

884 p 2012a *Hemiprionites* cf. *H. butleri* – Brühwiler and Bucher, p. 33, pl. 19, figs. 10 only.

885 p 2012b *Anasibirites angulosus* – Brühwiler and Bucher, p. 103, figs. 87H-J, N-P only.

886 2012b *Hemiprionites klugi* – Brühwiler and Bucher, p. 103, figs. 87Q-AB.

887 v 2017 *Hemiprionites walcotti* – Jattiot and Bucher in Jattiot et al., p. 34, pl. 14, figs. A-Y.

888 v 2018 *Hemiprionites walcotti* – Jenks and Brayard, p. 83, figs. 79Q-V.

889 2020 *Hemiprionites walcotti* – Jattiot et al., p. 57, pl. 29AT-BG.

890

891 **Occurrence:** Documented from the microbially-dominated unit of the Sinbad Fm. in WW

892 (BRC; n = 5).

893

894 **Description:** See taxonomic revision of *Hemiprionites* species by Jattiot et al. (2017). This
895 species exhibits a more involute and less egressive coiling than the type species. The
896 umbilicus is deep with a steeply inclined wall. Radial folds are sometimes visible together
897 with flexuous growth lines following the trajectory of the folds. Suture line unknown for
898 sampled specimens.

899

900 **Measurements:** See **Supplementary Fig. F** and **Supplementary Table A**. Estimated
901 maximal size: ~7 cm (Jattiot et al., 2017).

902

903 **Discussion:** See *H. typus* discussion.

904

905

906 **Declaration of Competing Interests**

907 Authors have no competing interests to declare.

908

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917

918

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1289

1290

1291 **Figure captions**

1292

1293 **Fig. 1.** Early Triassic (A) and present-day (B) locations of the western USA basin. C)
1294 Schematic distribution of depositional environments within the southern part of the western
1295 USA basin during the Smithian. D-F) Map of southern Utah and northern Arizona showing
1296 the location of the sampled localities.

1297

1298 **Fig. 2.** Stratigraphic logs showing the main faunal occurrences at Workman Wash and
1299 Honeymoon Trail (Washington County, Utah). Stratigraphy follows the main units defined by
1300 Lucas et al. (2007b) and described by Brayard et al. (2015), Olivier et al. (2018) and Jeffrey et
1301 al. (2019). RCC: Rock Canyon Conglomerate.

1302

1303 **Fig. 3.** Stratigraphic logs showing the main faunal occurrences at Rock Canyon (Arizona) and
1304 White Sage Wash (Utah). See Fig. 2 for references and legends.

1305

1306 **Fig. 4.** Temporal extent of the deposition of the Sinbad Fm. at each studied locality as
1307 determined by newly-found ammonoid assemblages. See Fig. 1 for abbreviations. The gray
1308 shaded area corresponds to the end of the marine deposits of the Sinbad Fm. The age for the
1309 base of the Sinbad Fm. at WW remains tentative because late middle Smithian ammonoids
1310 have not yet been found at this locality.

1311

1312 **Fig. 5.** A–M: *Guodunites hooveri*. N–P: *Guodunites monneti*. Specimens A–C and N–O from
1313 bed WSW3, White Sage Wash, Utah, late middle Smithian. Specimens D–M and P from bed
1314 ROC2-A, late middle Smithian. A: UBGD 32220; B: UBGD 32221; C: suture line of UBGD
1315 32221 at H = 12.7 mm; D–F: UBGD 32222–32224; G–H: lateral and ventral views of UBGD
1316 32225; I: UBGD 32226; J–K: lateral and ventral views of UBGD 32227; L–M: lateral and
1317 ventral views of UBGD 32228; N: UBGD 32229; O: suture line of UBGD 32229 at H = 9.3
1318 mm; P: UBGD 32230. Black arrows indicate the position of the corresponding ventral view.
1319 Scale bars: 10 mm, except C and O: 5 mm.

1320

1321 **Fig. 6.** A–Q: *Gurleyites smithi*. All specimens from bed BRC, Workman Wash, Utah, early
1322 late Smithian. A–D: lateral, apertural and ventral views of UBGD 32232; E–F: lateral and
1323 ventral views of UBGD 32233; G–H: lateral and ventral views of UBGD 32234; I: UBGD
1324 32235; J: UBGD 32236; K: UBGD 32237; L–M: lateral and ventral views of UBGD 32238;
1325 N: lateral view of two specimens on block UBGD 32239; O: ventral view of the specimen on
1326 the left of UBGD 32239; P–Q: lateral and ventral views of UBGD 32240. Black arrows

1327 indicate the position of the corresponding ventral view. Note presence of ventral strigation in
1328 A, D, H and O. Scale bars: 10 mm.

1329

1330 **Fig. 7.** A–S: *Gurleyites smithi*. All specimens from bed BRC, Workman Wash, Utah, early
1331 late Smithian. A–B: lateral and ventral views of UBGD 32241; C–D: lateral and ventral views
1332 of UBGD 32242; E–F: lateral and ventral views of UBGD 32243; G: UBGD 32244; H–I:
1333 lateral and ventral views of UBGD 32245; J: UBGD 32246; K: UBGD 32247; L–M: lateral
1334 and ventral views of UBGD 32248; N–P: lateral, ventral and apertural views of UBGD
1335 32249; Q–S: lateral and ventral views of UBGD 32250. Black arrow indicates the position of
1336 the corresponding ventral view. Scale bars: 10 mm.

1337

1338 **Fig. 8.** A–O: *Gurleyites smithi*. All specimens from bed BRC, Workman Wash, Utah, early
1339 late Smithian. A: UBGD 32251; B–C: lateral and ventral views of UBGD 32252; D–E: lateral
1340 and ventral views of UBGD 32253; F–G: lateral and ventral views of UBGD 32254; H:
1341 UBGD 32255; I: UBGD 32256 (specimen in the background is probably *Hemiprionites*
1342 *typus*); J: UBGD 32257; K: UBGD 32258; L–M: lateral and ventral views of UBGD 32259;
1343 N–O: lateral and ventral views of UBGD 32260. Black arrows indicate the position of the
1344 corresponding ventral view. Identification of UBGD 32259 (L–M) and UBGD 32260 (N–O)
1345 may be questionable as outer whorls overlap with intraspecific variation of *Hemiprionites*
1346 *typus*, but their overall shape and ornamentation, especially folds on inner whorls, fit within
1347 *G. smithi*. Scale bars: 10 mm.

1348

1349 **Fig. 9.** A–J: *Gurleyites smithi*. All specimens from bed BRC, Workman Wash, Utah, early
1350 late Smithian. A–B: lateral and ventral views of UBGD 32261; C–E: apertural, ventral and
1351 lateral views of UBGD 32262; F–G: lateral and ventral views of UBGD 32263; H: suture line

1352 of UBGD 32264 at H = 16.3 mm; I–J: lateral and ventral views of UBGD 32265. K–L:
1353 *Wasatchites perrini*. Lateral (K) and ventral (L) views of specimen UBGD 32231, from bed
1354 BRC, Workman Wash, Utah, early late Smithian. Black arrow indicates the position of the
1355 corresponding ventral view. Scale bar: 10 mm.

1356

1357 **Fig. 10.** A–H: blocks with *Gurleyites smithi* and *Hemiprionites typus*. All specimens from bed
1358 BRC, Workman Wash, Utah, early late Smithian. A–B: lateral and ventral views of specimens
1359 on block UBGD 32266; C: lateral view of specimens on block UBGD 32267; D: lateral view
1360 of specimens on block UBGD 32268; E–G: lateral and ventral views of specimens on block
1361 UBGD 32269; H: suture line of the complete specimen on UBGD 32269 at H = 18.8 mm.
1362 Black arrows indicate the position of the corresponding ventral view. Gu: *Gurleyites smithi*;
1363 He: *Hemiprionites typus*. Identification of the complete specimen on block UBGD 32269 (E–
1364 G) may be questionable as its overall shape, especially coiling, and ornamentation on inner
1365 whorls (bullate ribs visible on the umbilical margin) fit within the intraspecific variation of *G.*
1366 *smithi*, but the lack of ornamentation at later growth stages fits with *H. typus*. Its suture line
1367 (H) is also somewhat intermediate between *G. smithi* and *H. typus*. Scale bars: 10 mm, except
1368 H: 5 mm.

1369

1370 **Fig. 11.** A–P: *Anasibirites multiformis*. All specimens from bed BRC, Workman Wash, Utah,
1371 early late Smithian. A: UBGD 32270; B–C: lateral and ventral views of UBGD 32271; D:
1372 UBGD 32272; E: UBGD 32273; F–H: lateral and ventral views of UBGD 32274; I: UBGD
1373 32275; J–L: lateral and ventral views of UBGD 32276; M: UBGD 32277; N: UBGD 32278;
1374 O–P: lateral and ventral views of UBGD 32279. Black arrows indicate the position of the
1375 corresponding ventral view. Scale bars: 10 mm.

1376

1377 **Fig. 12.** A–I: *Hemiprionites walcottii*. A–B: lateral and ventral views of UBGD 32280; C–D:
1378 lateral and ventral views of UBGD 32281; E: UBGD 32282; F–G: lateral and ventral views of
1379 UBGD 32283; H–I: lateral and ventral views of UBGD 32284. J–S: *Hemiprionites typus*. J–
1380 K: lateral and ventral views of UBGD 32285; L–M: lateral and ventral views of UBGD
1381 32286; N: lateral view of UBGD 32287 (star indicates the minute depression visible near the
1382 ventrolateral margin); O: suture line of UBGD 32288 at H = 15.4 mm; P: lateral view of
1383 UBGD 32289; Q: lateral view of UBGD 32290; R–S: lateral and ventral views of UBGD
1384 32291. All specimens from bed BRC, Workman Wash, Utah, early late Smithian. Black
1385 arrows indicate the position of the corresponding ventral view. Scale bars: 10 mm, except O:
1386 5 mm.

1387

1388

1389 **Supplementary Figure A.** Scatter diagrams of H, W and U, and H/D, W/D and U/D for
1390 *Guodunites hooveri*. Open symbols indicate specimens from Rock Canyon, Arizona, and
1391 White Sage Wash, Utah (n = 12). Grey symbols indicate specimens from central and western
1392 Utah (data from Brayard et al., 2013; n = 56) and Palomino Ridge (data from Jattiot et al.,
1393 2017; n = 4).

1394

1395 **Supplementary Figure B.** Scatter diagrams of H, W and U, and H/D, W/D and U/D for
1396 *Gurleyites smithi*. Open symbols indicate specimens from bed BRC, Workman Wash, Utah,
1397 early late Smithian (n = 40). Grey symbols indicate specimens from Palomino Ridge (data
1398 from Jattiot et al., 2017; n = 7) and Crittenden Springs (Jenks and Brayard, 2018; n = 14),
1399 Nevada.

1400

1401 **Supplementary Figure C.** Box plots of U/D for *Gurleyites smithi* and *Hemiprionites typus*
1402 from the studied area and Nevada. Specimens from Nevada were sampled at Palomino Ridge
1403 (Jattiot et al., 2017) and Crittenden Springs (Jenks and Brayard, 2018).

1404

1405 **Supplementary Figure D.** Scatter diagrams of H, W and U, and H/D, W/D and U/D for
1406 *Anasibirites multiformis*. Open symbols indicate specimens from bed BRC, Workman Wash,
1407 Utah, early late Smithian (n = 14). Grey symbols indicate specimens from Palomino Ridge,
1408 Nevada (data from Jattiot et al., 2017; n = 54).

1409

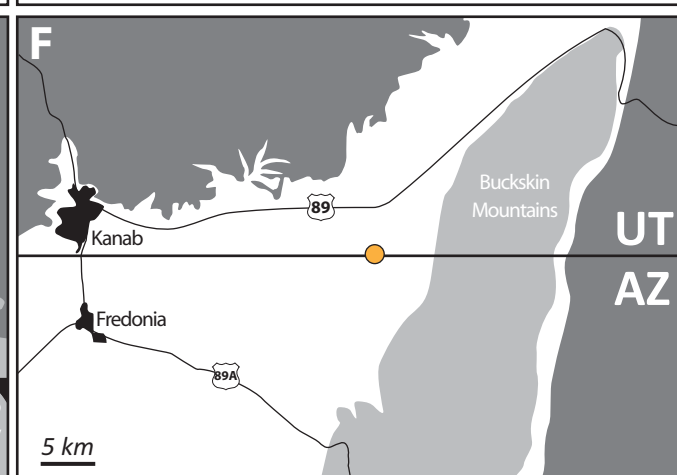
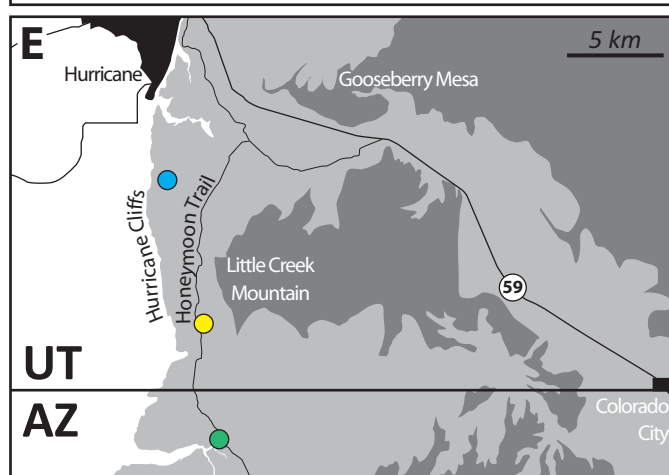
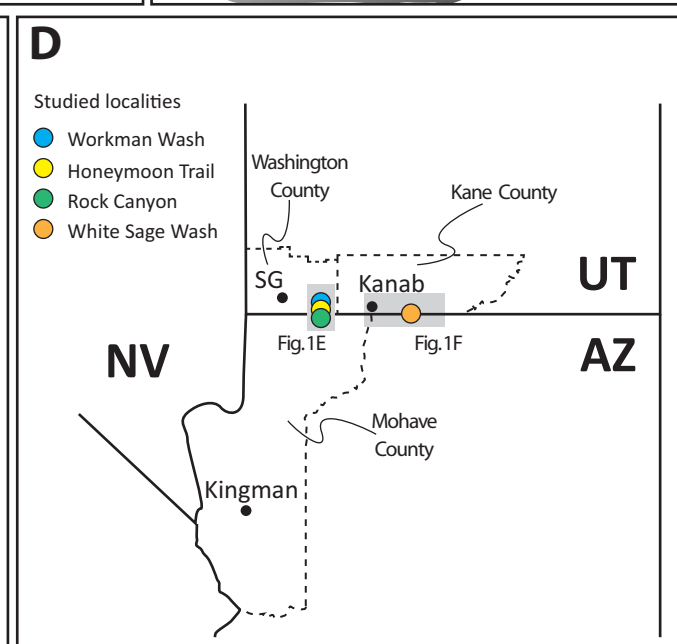
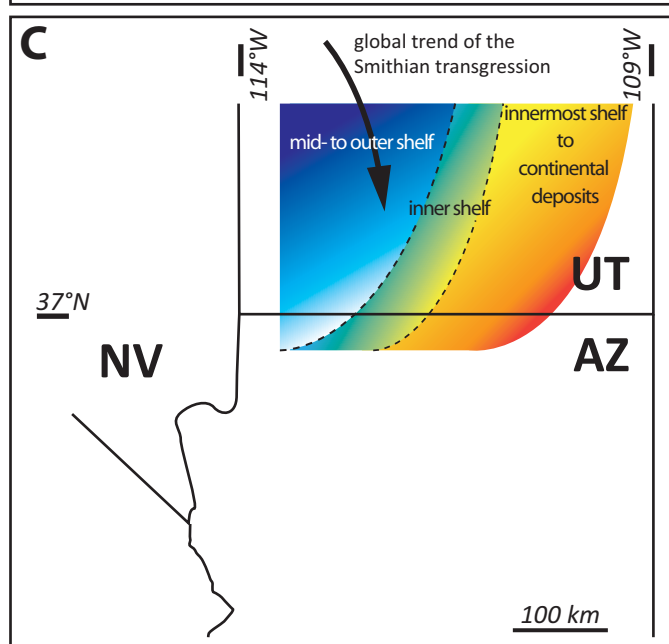
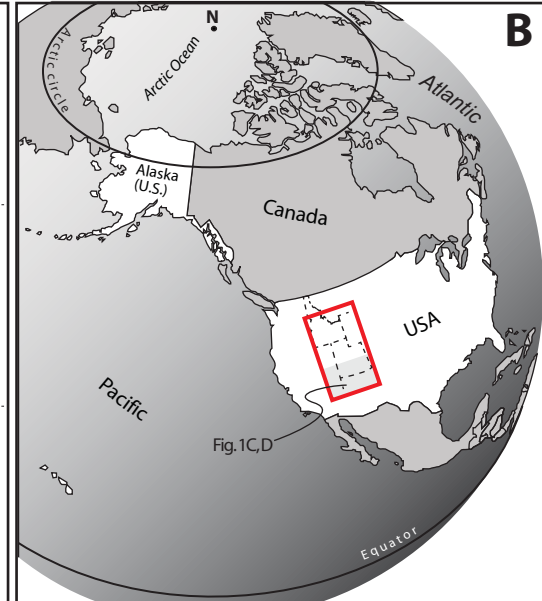
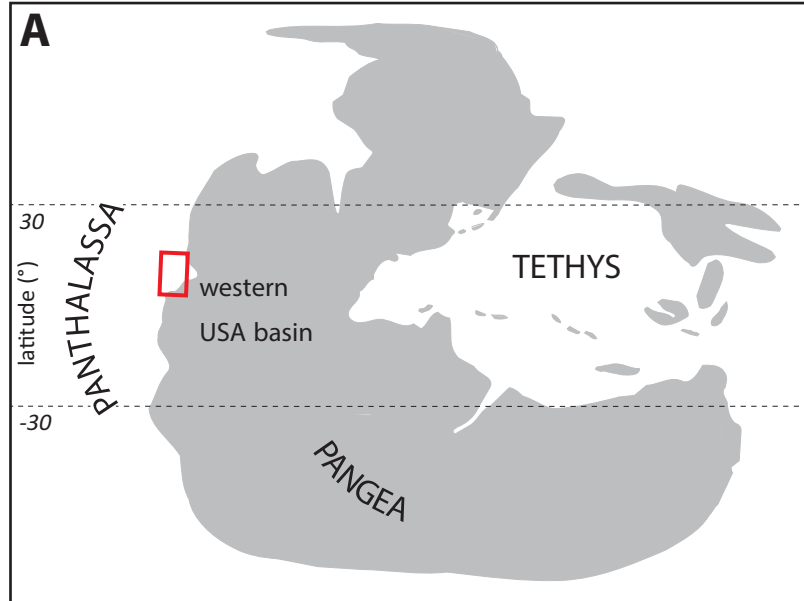
1410 **Supplementary Figure E.** Scatter diagrams of H, W and U, and H/D, W/D and U/D for
1411 *Hemiprionites typus*. Open symbols indicate specimens from bed BRC, Workman Wash,
1412 Utah, early late Smithian (n = 6). Grey symbols indicate specimens from Palomino Ridge
1413 (data from Jattiot et al., 2017; n = 58) and Crittenden Springs (data from Jenks and Brayard,
1414 2018; n = 23), Nevada.

1415

1416 **Supplementary Figure F.** Scatter diagrams of H, W and U, and H/D, W/D and U/D for
1417 *Hemiprionites walcottii*. Open symbols indicate specimens from bed BRC, Workman Wash,
1418 Utah, early late Smithian (n = 5). Grey symbols indicate specimens from Palomino Ridge
1419 (data from Jattiot et al., 2017; n = 26) and Crittenden Springs (data from Jenks and Brayard,
1420 2018; n = 2), Nevada.

1421

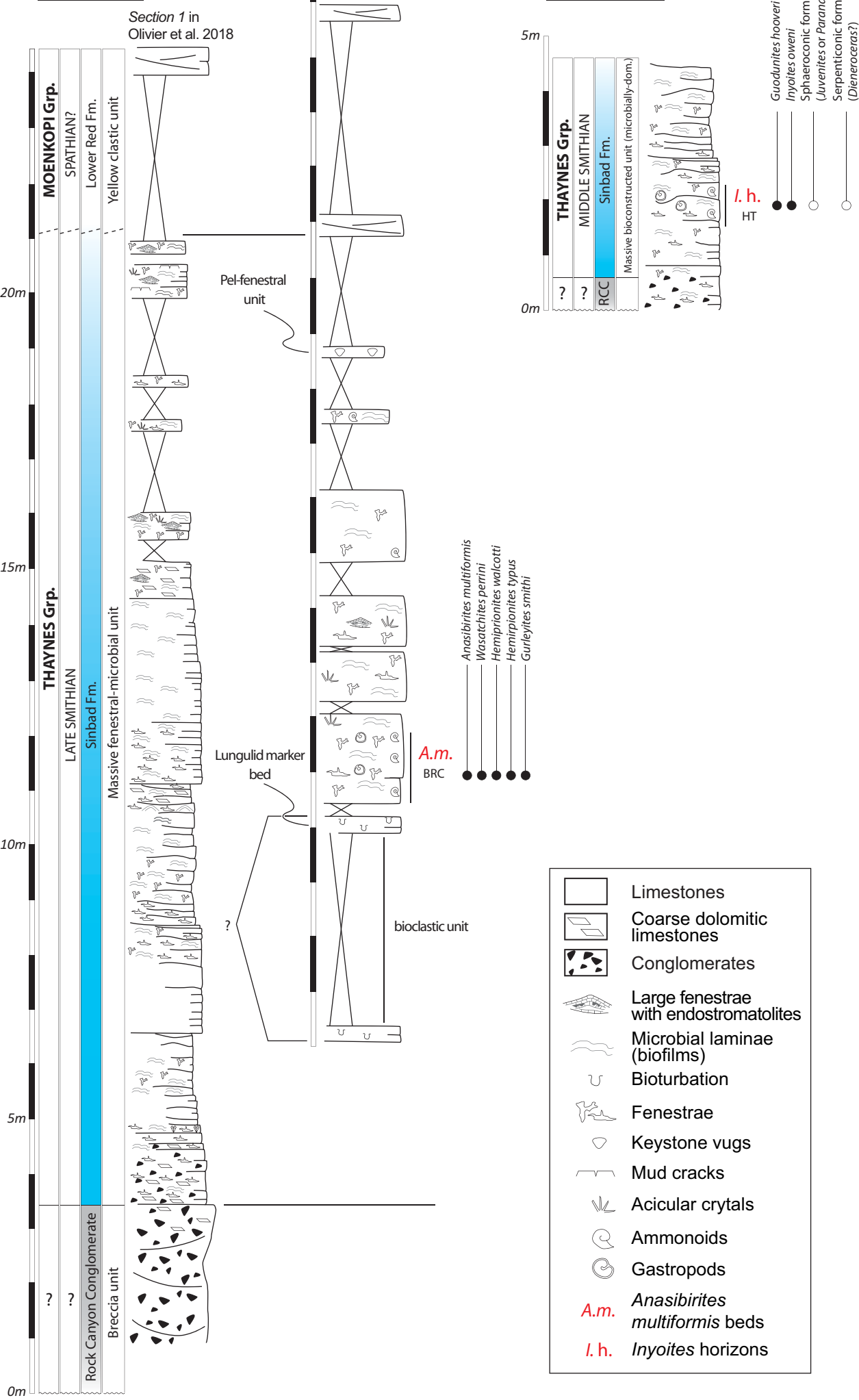
1422 **Supplementary Table A.** Measurements of some Smithian ammonoids from the studied area,
1423 central and southern Utah (data from Brayard et al., 2013) and Nevada (Palomino Ridge and
1424 Crittenden Springs; data from Jattiot et al., 2017 and Jenks and Brayard, 2018, respectively)
1425 (D: Diameter; H: whorl height; W: whorl width; U: umbilical diameter).

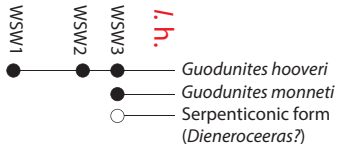
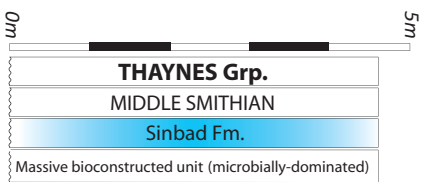


Workshop Wash

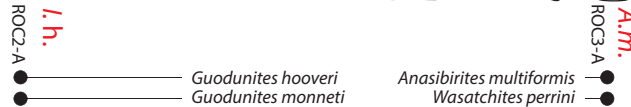
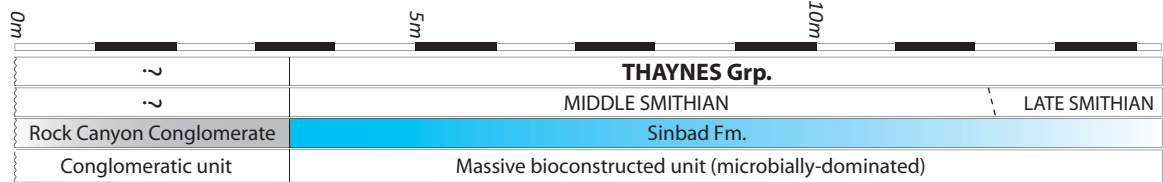
Section 3 in Olivier et al. 2018

Honeymoon Trail

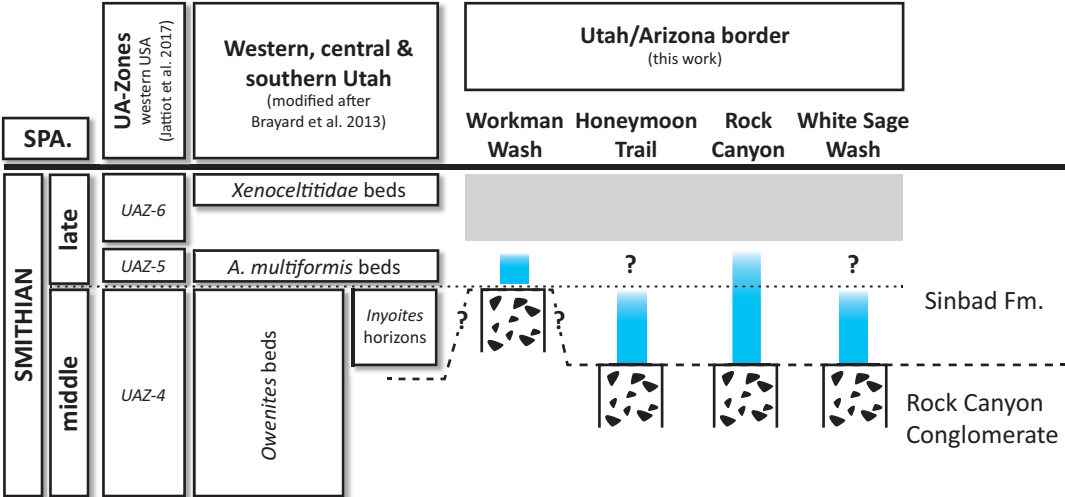


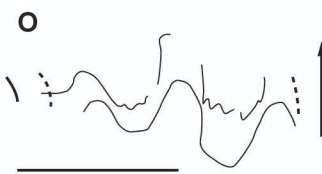
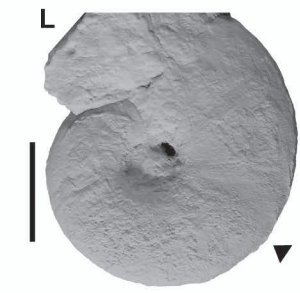
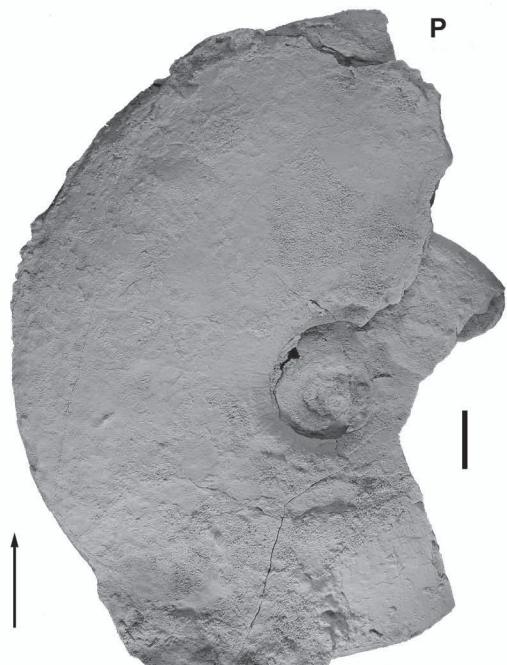
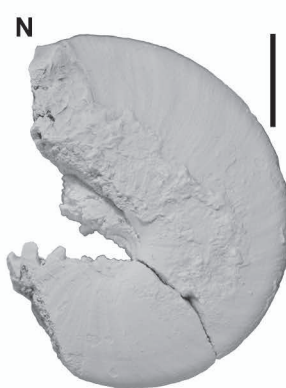
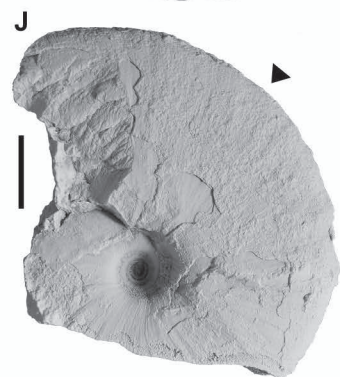
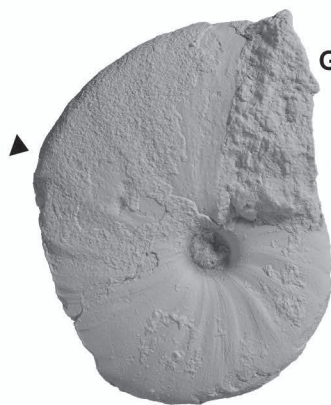
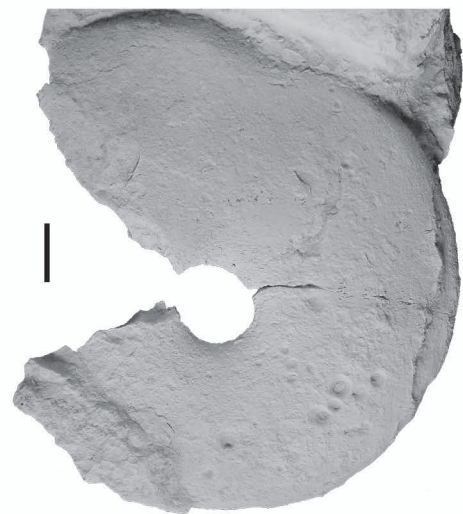
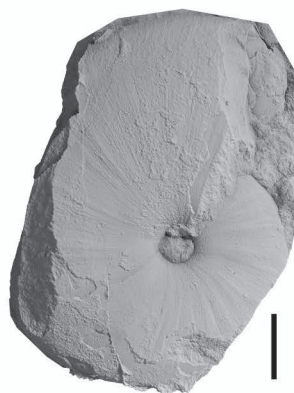
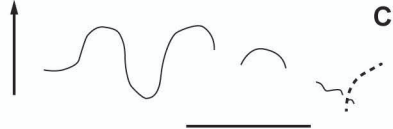
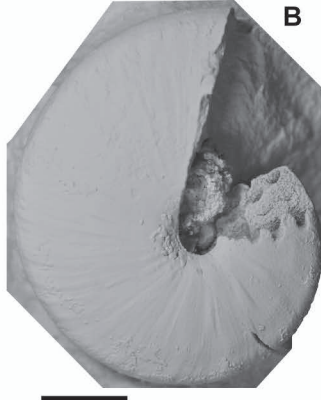
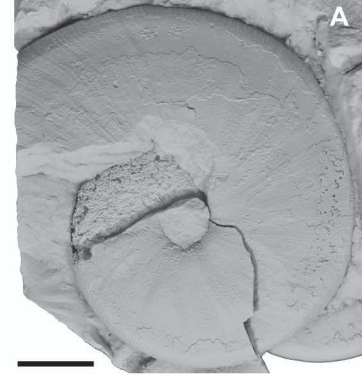


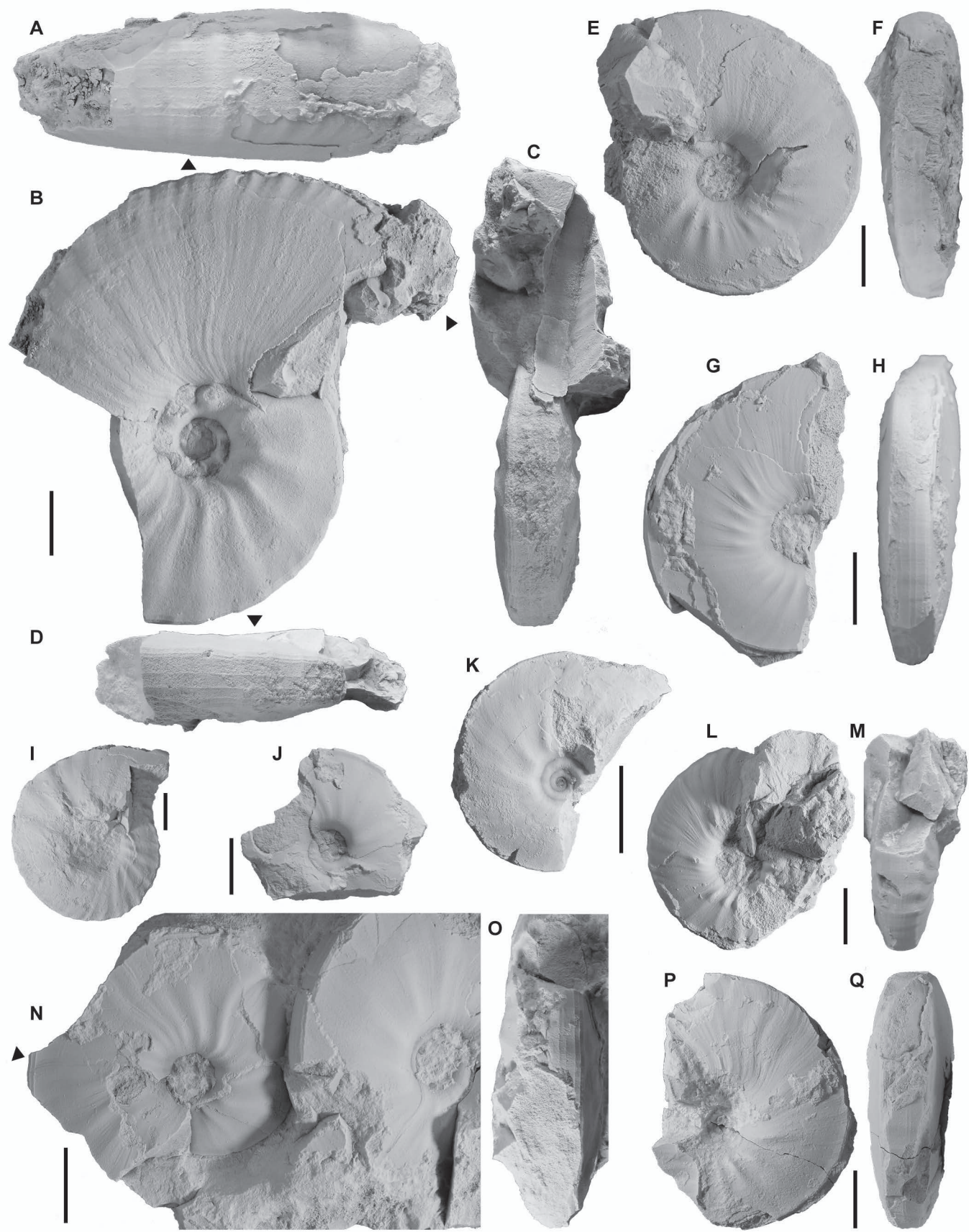
White Sage Wash

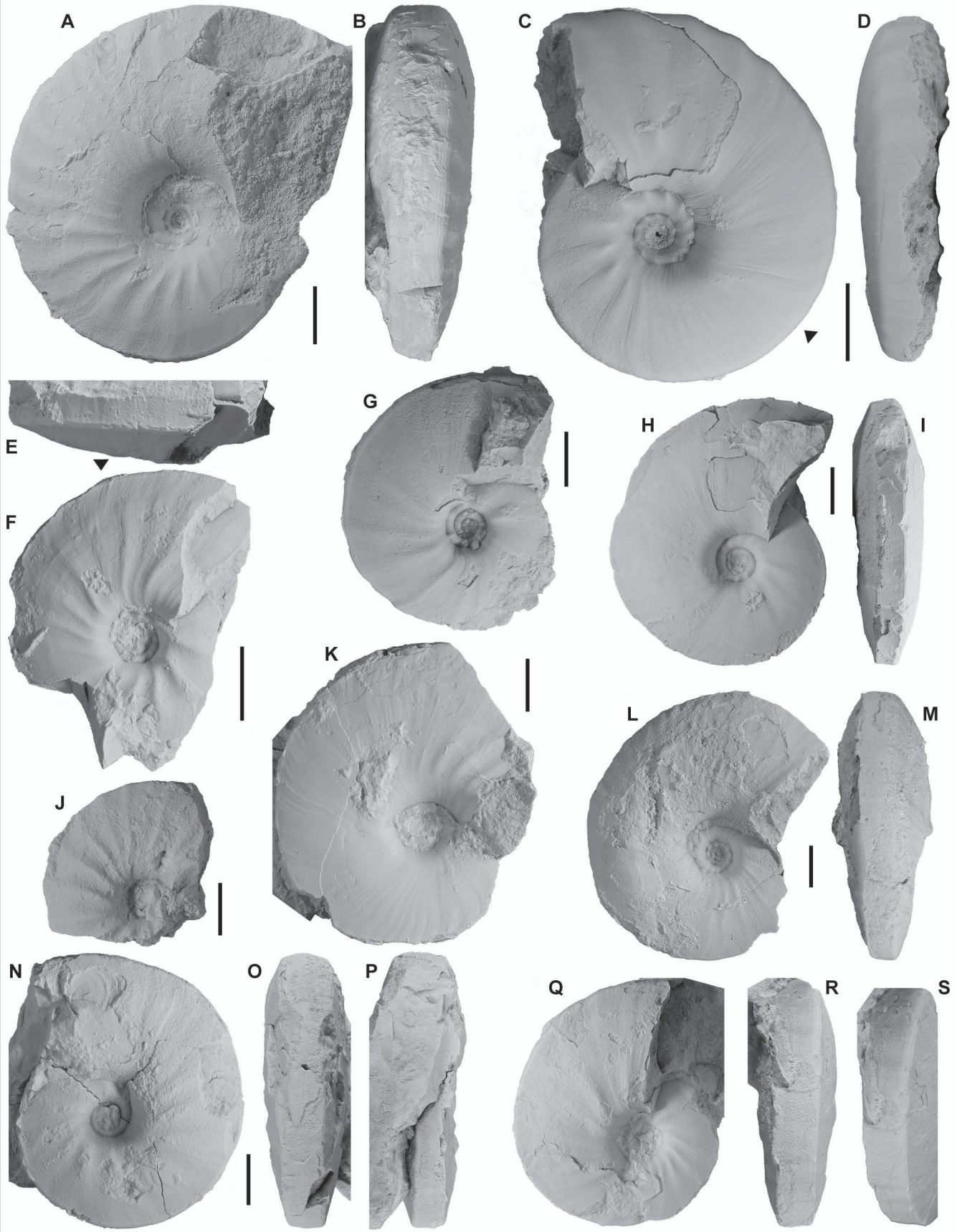


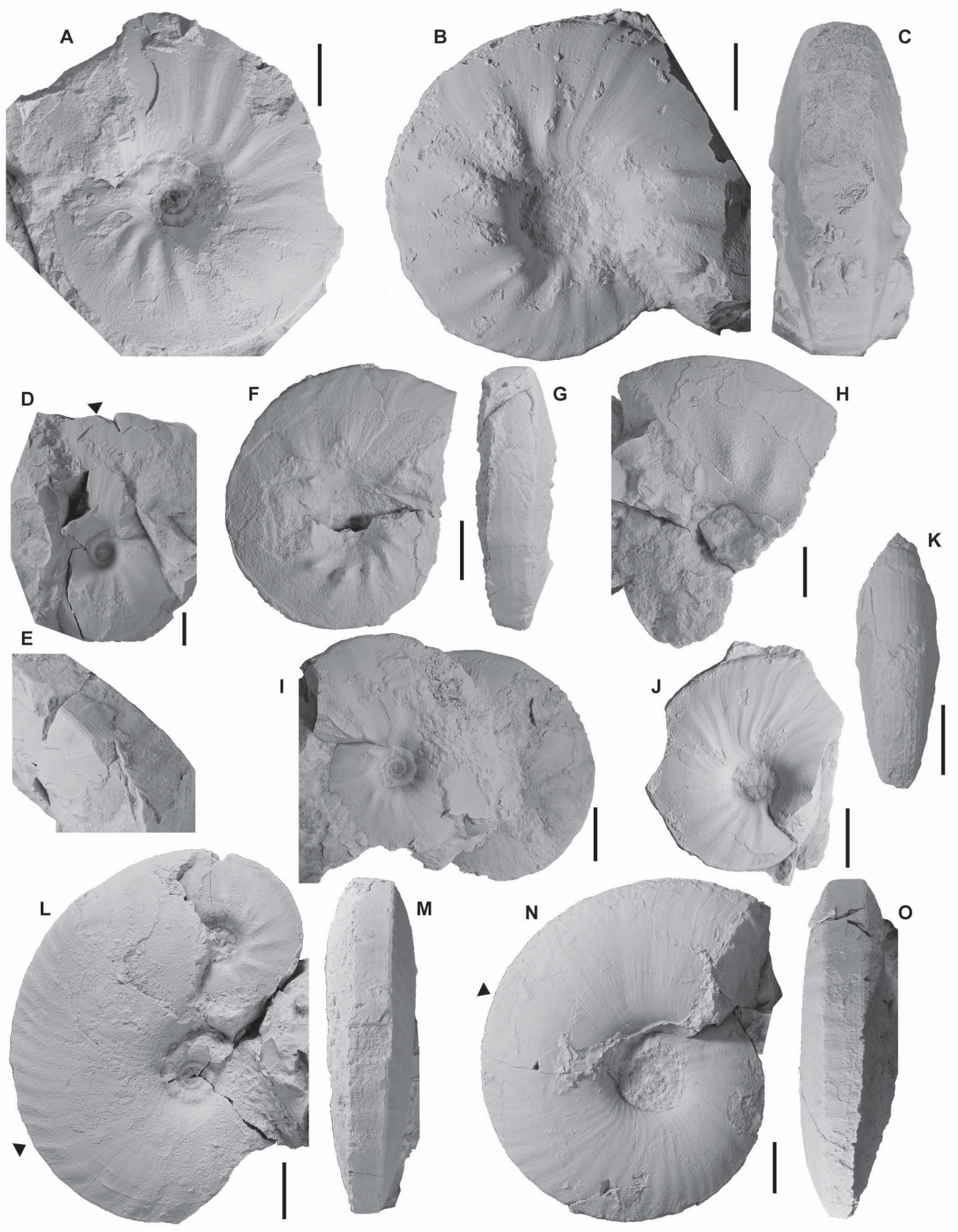
Rock Canyon

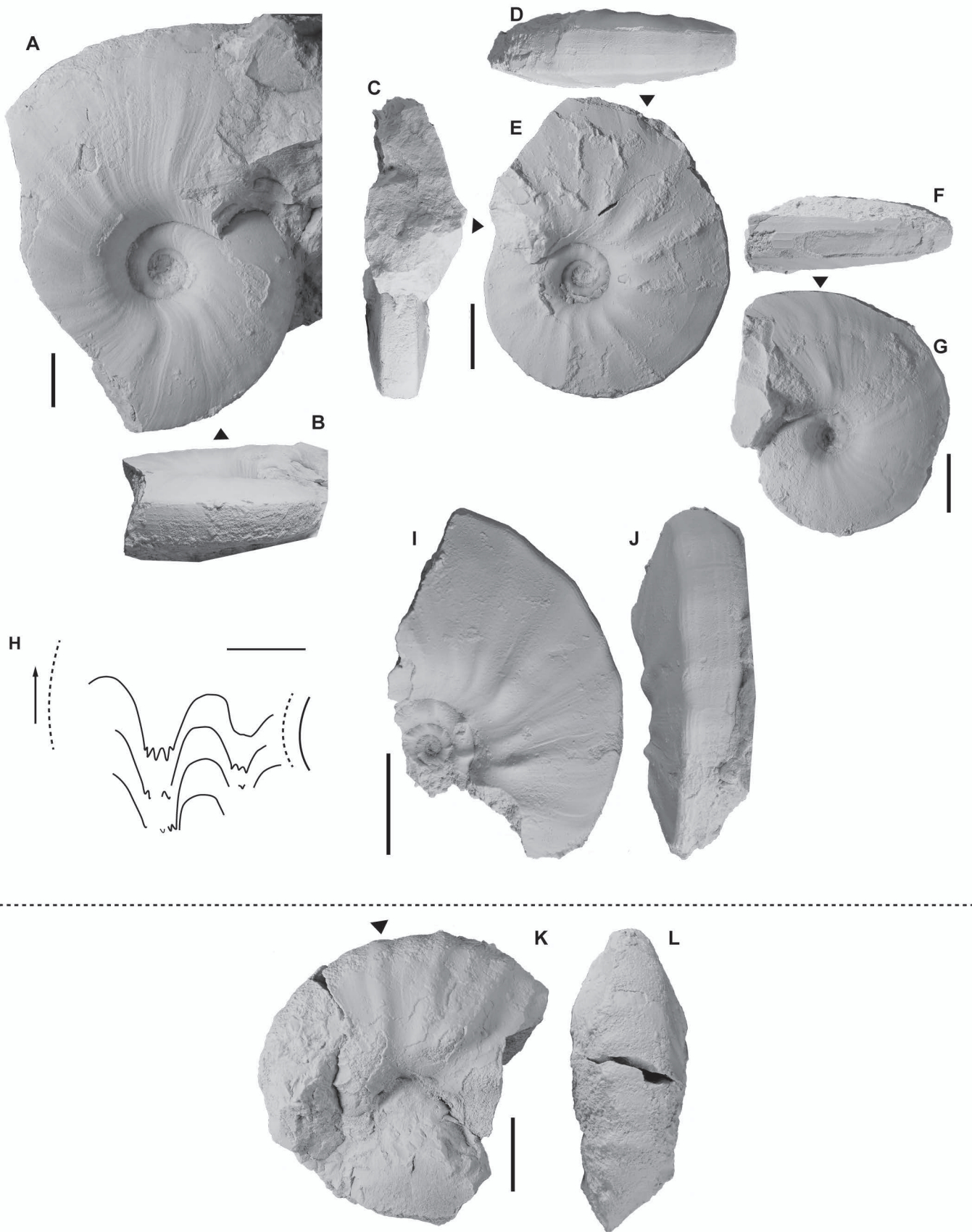


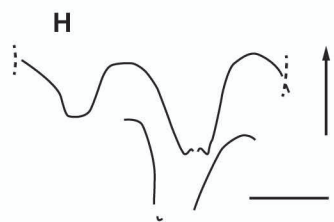
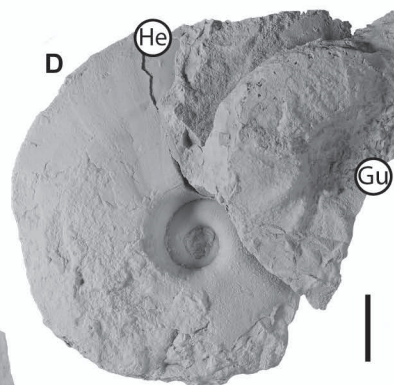
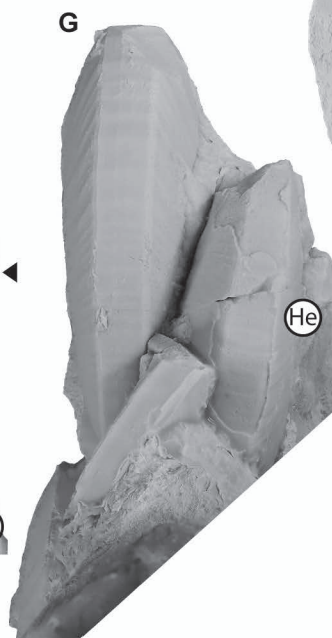
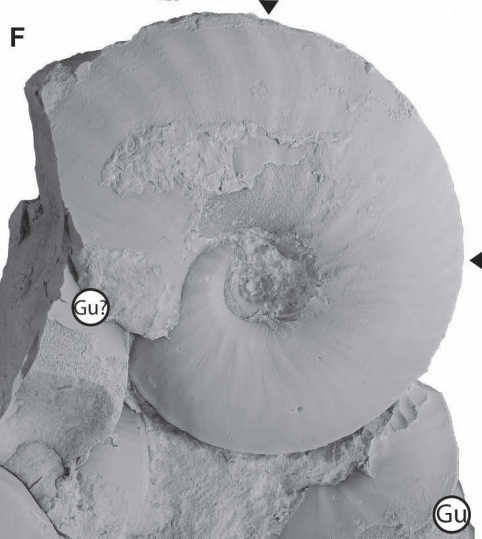
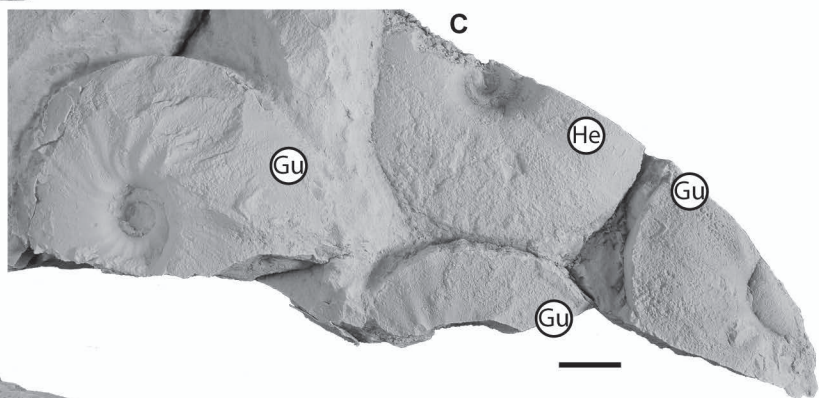
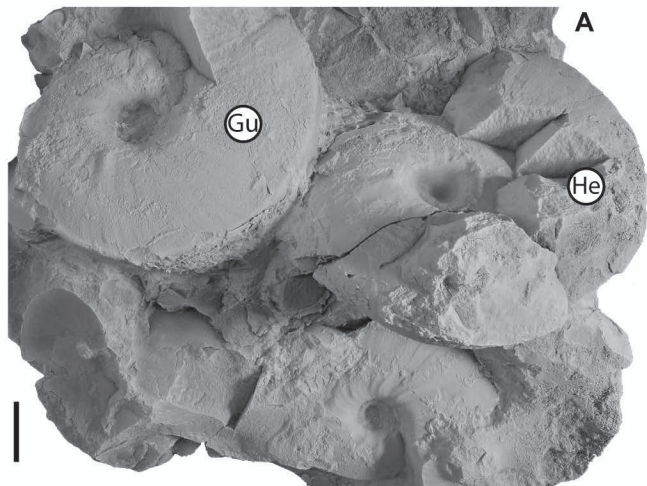


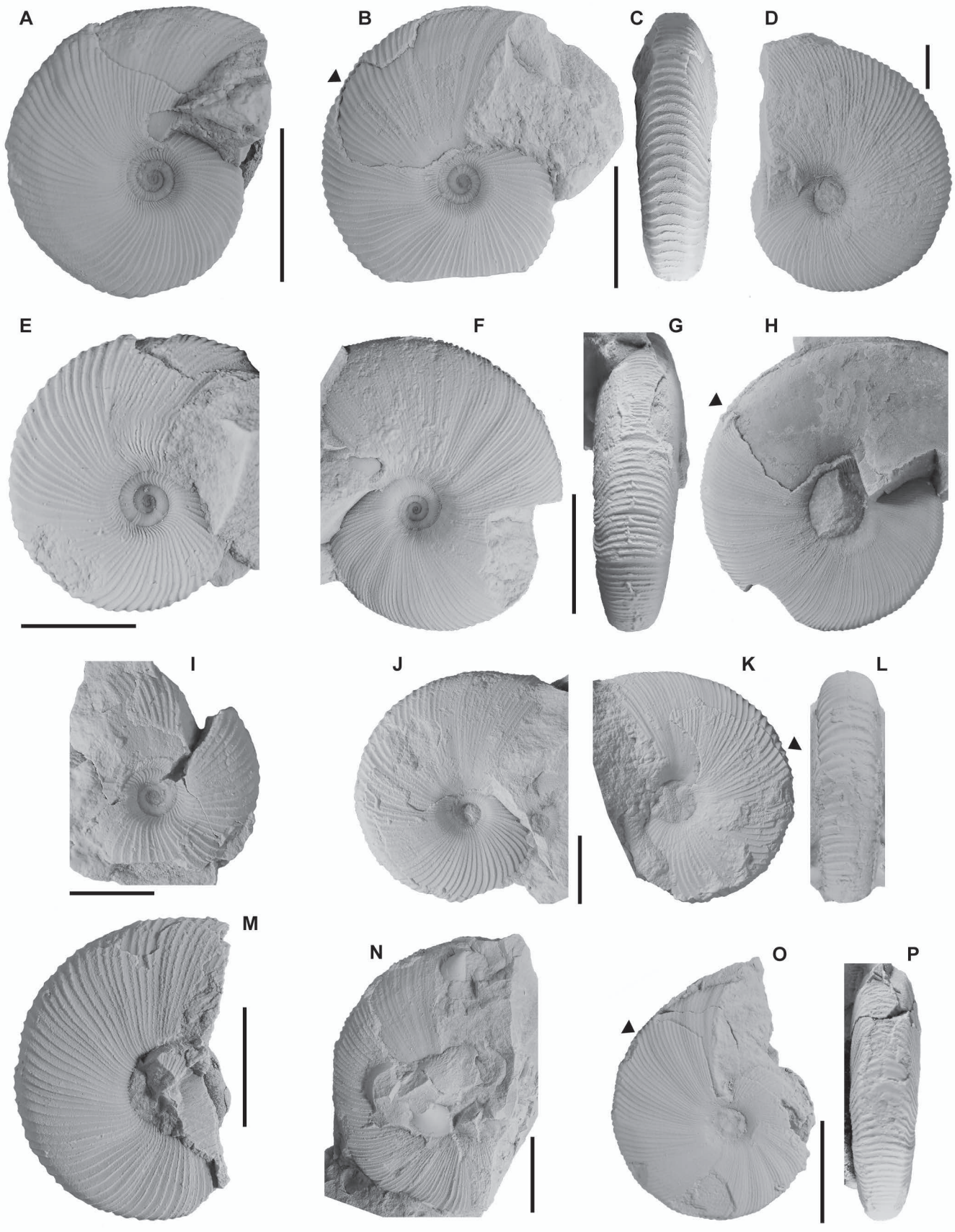


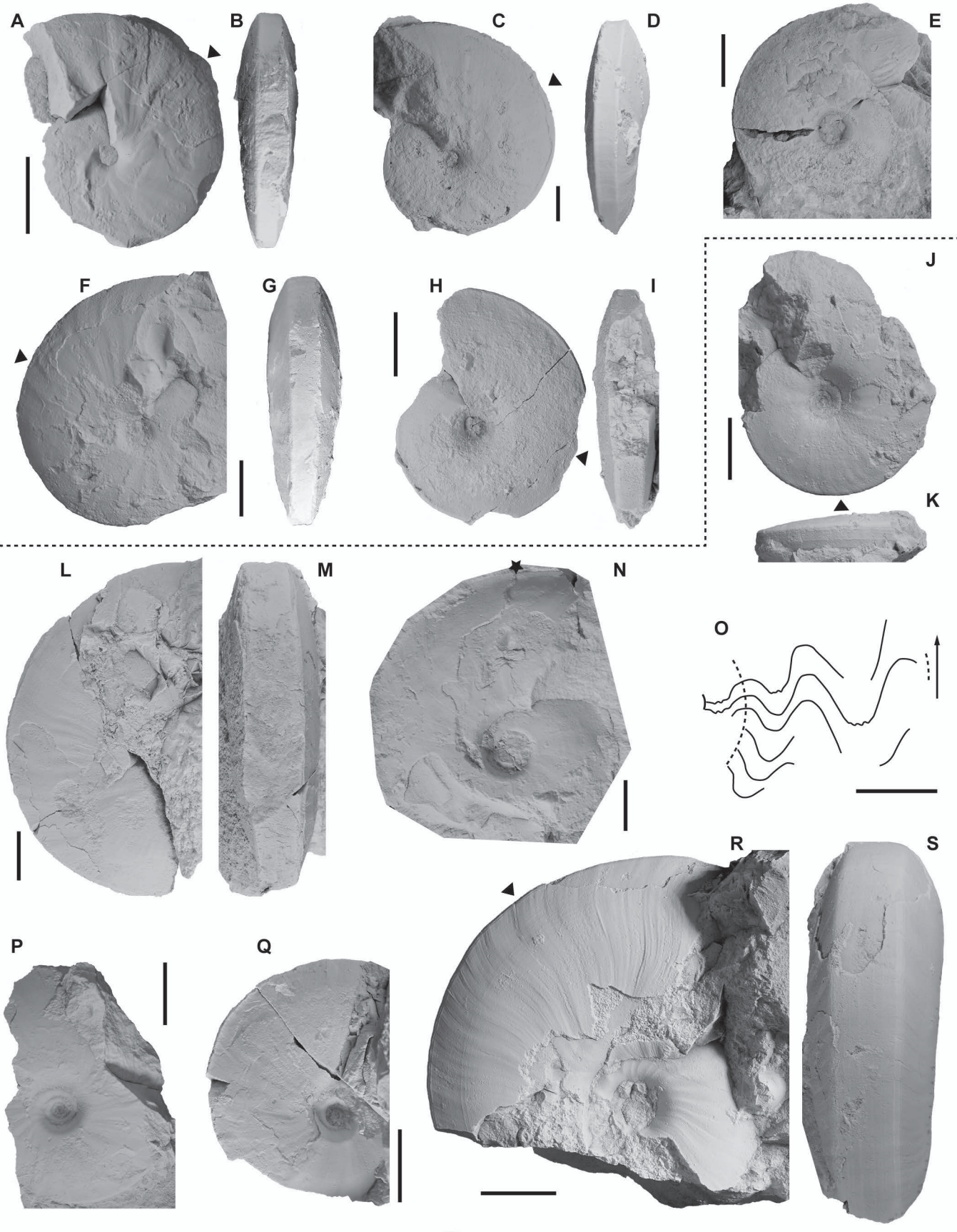






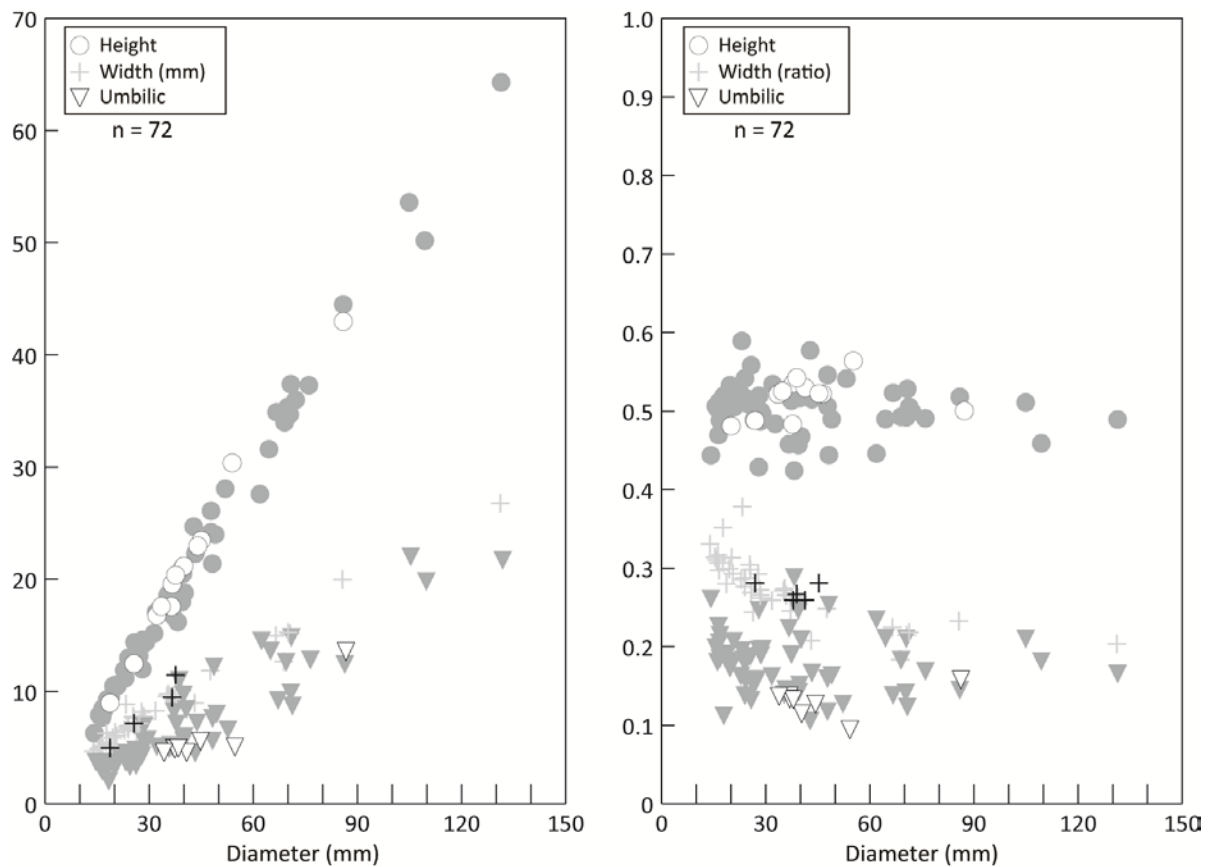






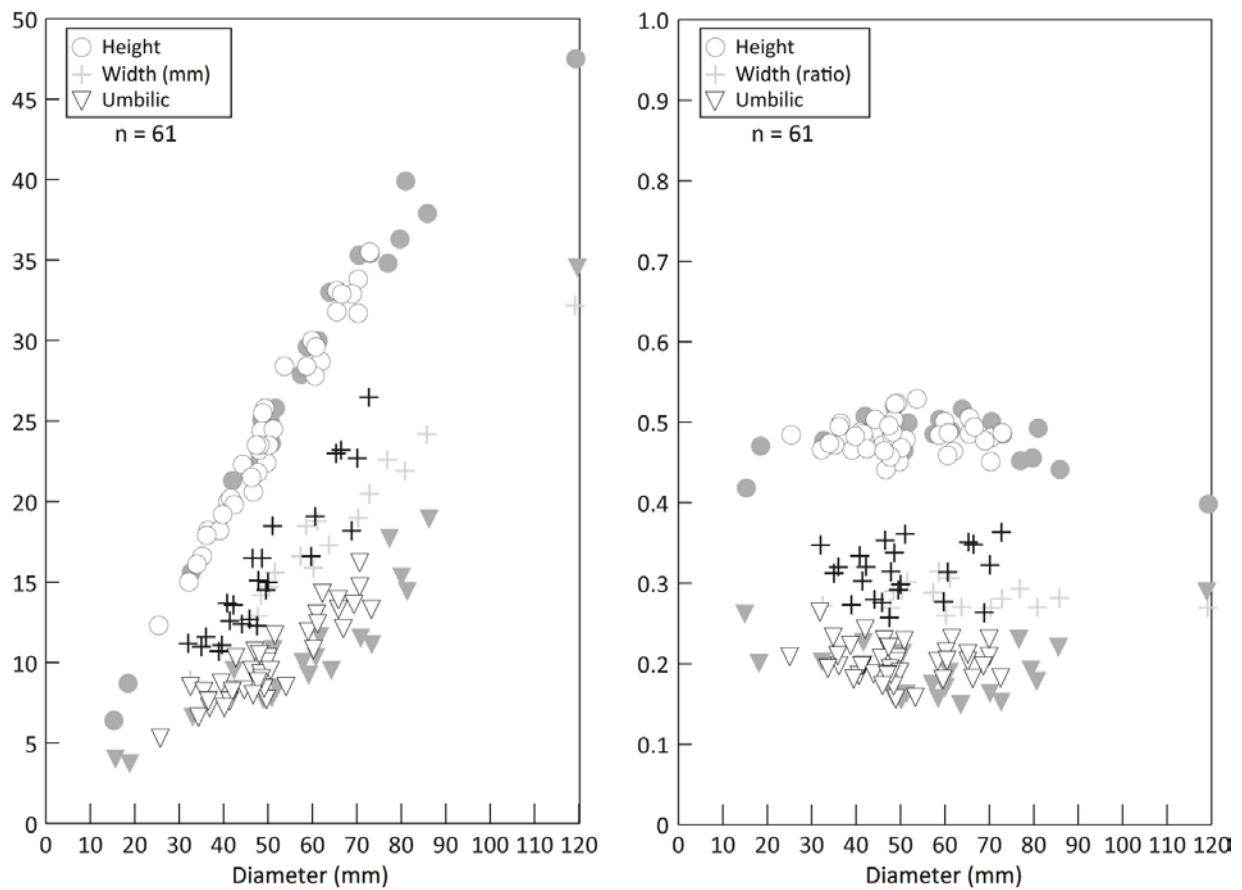
New middle and late Smithian ammonoid faunas from the Utah/Arizona border: new evidence for calibrating Early Triassic transgressive-regressive trends and paleobiogeographical signals in the western USA basin – Brayard et al.

Suppl. Fig. A. Scatter diagrams of H, W and U, and H/D, W/D and U/D for *Guodunites hooveri*. Open symbols indicate specimens from Rock Canyon, Arizona, and White Sage Wash, Utah (n = 12). Grey symbols indicate specimens from central and western Utah (data from Brayard et al., 2013; n = 56) and Palomino Ridge (data from Jattiot et al., 2017; n = 4).



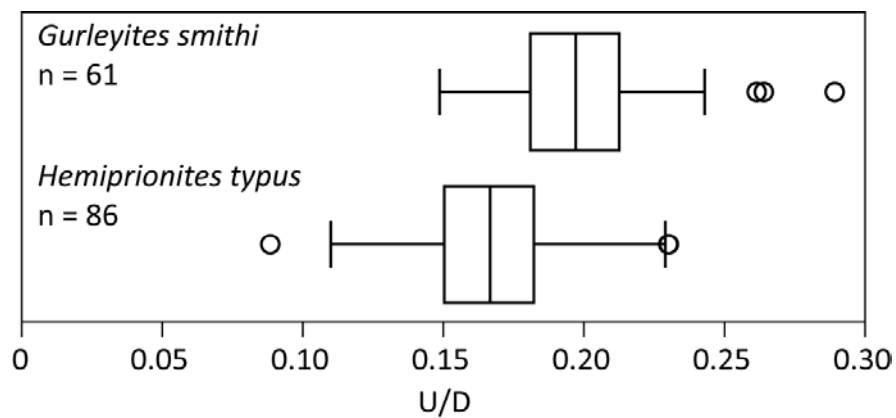
New middle and late Smithian ammonoid faunas from the Utah/Arizona border: new evidence for calibrating Early Triassic transgressive-regressive trends and paleobiogeographical signals in the western USA basin – Brayard et al.

Suppl. Fig. B. Scatter diagrams of H, W and U, and H/D, W/D and U/D for *Gurleyites smithi*. Open symbols indicate specimens from bed BRC, Workman Wash, Utah, early late Smithian (n = 40). Grey symbols indicate specimens from Palomino Ridge (data from Jattiot et al., 2017; n = 7) and Crittenden Springs (Jenks and Brayard, 2018; n = 14), Nevada.



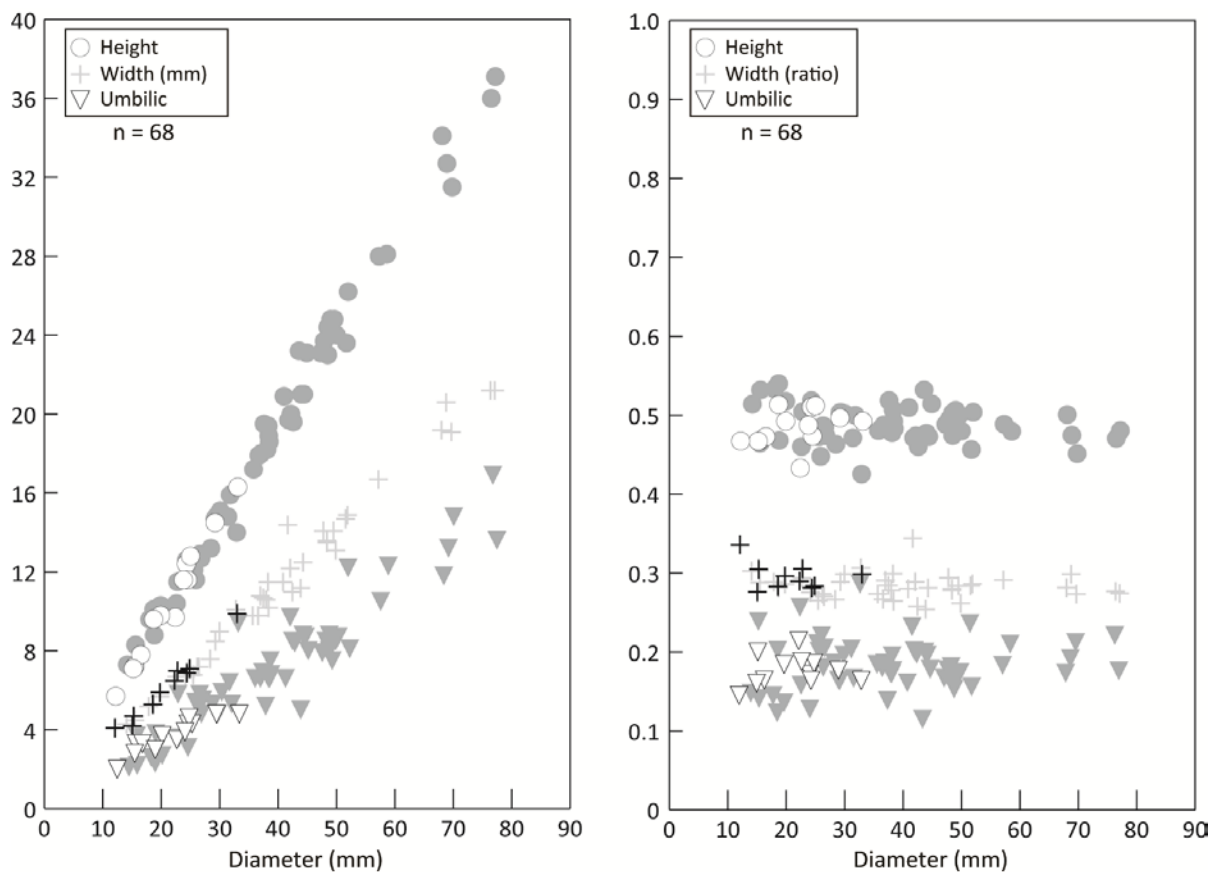
New middle and late Smithian ammonoid faunas from the Utah/Arizona border: new evidence for calibrating Early Triassic transgressive-regressive trends and paleobiogeographical signals in the western USA basin – Brayard et al.

Suppl. Fig. C. Box plots of U/D for *Gurleyites smithi* and *Hemiprionites typus* from the studied area and Nevada. Specimens from Nevada were sampled at Palomino Ridge (Jattiot et al., 2017) and Crittenden Springs (Jenks and Brayard, 2018).



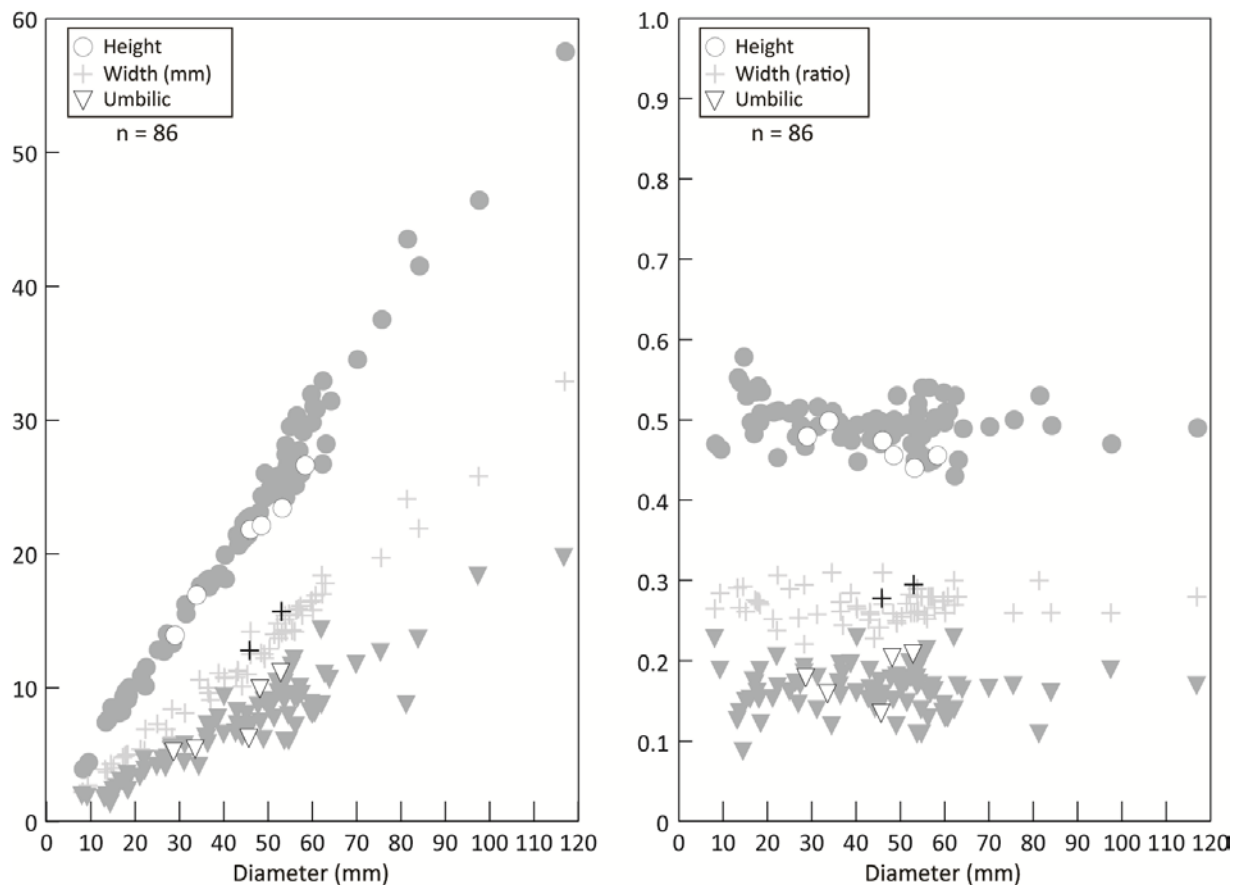
New middle and late Smithian ammonoid faunas from the Utah/Arizona border: new evidence for calibrating Early Triassic transgressive-regressive trends and paleobiogeographical signals in the western USA basin – Brayard et al.

Suppl. Fig. D. Scatter diagrams of H, W and U, and H/D, W/D and U/D for *Anasibirites multiformis*. Open symbols indicate specimens from bed BRC, Workman Wash, Utah, early late Smithian (n = 14). Grey symbols indicate specimens from Palomino Ridge, Nevada (data from Jattiot et al., 2017; n = 54).



New middle and late Smithian ammonoid faunas from the Utah/Arizona border: new evidence for calibrating Early Triassic transgressive-regressive trends and paleobiogeographical signals in the western USA basin – Brayard et al.

Suppl. Fig. E. Scatter diagrams of H, W and U, and H/D, W/D and U/D for *Hemiprionites* *typus*. Open symbols indicate specimens from bed BRC, Workman Wash, Utah, early late Smithian (n = 6). Grey symbols indicate specimens from Palomino Ridge (data from Jattiot et al., 2017; n = 58) and Crittenden Springs (data from Jenks and Brayard, 2018; n = 23), Nevada.



New middle and late Smithian ammonoid faunas from the Utah/Arizona border: new evidence for calibrating Early Triassic transgressive-regressive trends and paleobiogeographical signals in the western USA basin – Brayard et al.

Suppl. Fig. F. Scatter diagrams of H, W and U, and H/D, W/D and U/D for *Hemiprionites walcottii*. Open symbols indicate specimens from bed BRC, Workman Wash, Utah, early late Smithian (n = 5). Grey symbols indicate specimens from Palomino Ridge (data from Jattiot et al., 2017; n = 26) and Crittenden Springs (data from Jenks and Brayard, 2018; n = 2), Nevada.

