

# 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.

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Arnaud Brayard, Nicolas Olivier, Emmanuelle Vennin, James F. Jenks, Kevin G. Bylund, et al.. 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.. Global and Planetary Change, 2020, 192, pp.103251. 10.1016/j.gloplacha.2020.103251 . hal-02883322

## HAL Id: hal-02883322 https://hal.science/hal-02883322

Submitted on 22 Oct 2020

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1	New middle and late Smithian ammonoid faunas from the Utah/Arizona
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- 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:

Smithian, Early Triassic, Ammonoids, Utah, Arizona, Biostratigraphy, Transgressionregression cycle

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- 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 and preservation of the fossil record is to be analyzed and interpreted (Brett, 1995; 62 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; Hag and Al-Oahtani, 2005; Hag, 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

the southern part of the western USA basin during the early-middle Smithian (Fig. 1C), 76 followed by a marked regression near the Smithian/Spathian boundary (Paull and Paull, 1993, 77 1997; Lucas et al., 2007b; Brayard et al., 2013). However, the southern-most boundary of the 78 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 (e.g., Paull and Paull, 1993; Lucas et al., 2007b) from several localities in southern Utah. 82 83 These organisms served for instance to characterize local open marine conditions, but the 84 associated timescale was poorly constrained. Newly-found Smithian ammonoid faunas near the Utah/Arizona border allow us to determine 85 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

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

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

177

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

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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.

However, internal recrystallization is common, making the collection and preparation of thesespecimens 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

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

206 The second southern Utah site studied herein is located along a  $\sim$ 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 Invoites 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

channelized conglomerates filling large incised valleys. This site serves as a type section for

this formation (Reeside and Bassler, 1922; Nielson, 1991). Overlying microbial deposits of

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

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

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#### 251 5.1. Biostratigraphical significance of sampled ammonoids

252

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

257 Invoites oweni was found at a single locality, Honeymoon Trail, indicating the presence of the 258 late middle Smithian Invoites 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 *Invoites* 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. (2017). Although rare, Guodunites also occurs in late middle Smithian assemblages of the 264 265 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).

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

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

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#### 281 5.2. Richness and abundance of sampled ammonoids

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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 Invoites 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).

The unusual very low richness of late middle Smithian ammonoid assemblages in the southwestern-most part of the basin can be explained by the shallow seas in this area (mostly peritidal settings) that may have been favorable to only a few taxa. Jattiot et al. (2018) has already pointed out that the distribution of middle Smithian ammonoids within the western USA basin was highly contrasted, both in terms of abundance and richness, according to north-south and south-north gradients. These authors emphasized the role of the terrigenous 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. Late Smithian ammonoid assemblages include highly cosmopolitan taxa (Brayard et al., 2006, 314 315 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

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

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

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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

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

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

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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 Invoites 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 epicontinental sea likely persisted in the area near the Utah/Arizona border for a period less 363 364 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

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  $\delta^{18}$ O conodont data analyzed by conventional gas isotope ratio mass spectrometry (Sun et al., 2012; Romano et al., 2013). Nevertheless, recently published  $\delta^{18}$ O conodont data 382 383 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

environmental perturbations such as changes in carbon and sulfur cycles (Payne, 2004;

Horacek et al., 2007b; Galfetti et al., 2007; Song et al., 2014; Zhang et al., 2015; Stebbins et

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

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 Invoites, 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.

3) The biostratigraphical constraints obtained for the Sinbad Fm. demonstrate that thesouthern-most extent of the Smithian sea in the southwestern-most part of the western USA

basin is further south than previously realized, reaching northern Arizona and eastern KaneCounty, 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 (Invoites 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-
- 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).

572	<b>Discussion:</b> Two additional <i>Inyoites</i> species ( <i>I. beaverensis</i> and <i>I. stokesi</i> ) 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.
- 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 *Gurlevites* 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 of Gurleyites smithi. Since G. smithi is the type species of Gurleyites and has priority, 655 656 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 Gurlevites, and by Tozer (1971) who synonymized Gurlevites 660 with Anasibirites. In 1930, Spath erected the new genus Arctoprionites for Goniodiscus 661 nodosus from Spitsbergen (Frebold, 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 Gurlevites 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 why it also should not be placed within the genus Gurleyites. Spath (1934) erected three 666 667 additional prionitid taxa from Spitsbergen, i.e., Gurlevites 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

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

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

The observed spiral lines on the venter and on the flanks are a newly observed ornamental
feature indicating that *Gurleyites*, similar to another Prionitidae, *Hemiprionites* (e.g., Jattiot et
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 *Gurlevites 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

species, thus also supporting a possible close phylogenetic link between *Anasibirites* and *Gurleyites*. This resemblance between both genera, found in a few *Gurleyites* specimens, was
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.
- 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.
- v 2010 *Wasatchites perrini* Stephen et al., fig. 7c.
- v 2013 Wasatchites perrini Brayard et al., p. 191, figs. 13d, 59a-k.
- v 2017 *Wasatchites perrini* Jattiot and Bucher in Jattiot et al., p. 28, figs. 13d, 59a-k.
- 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.

Measurements: Sampled specimens are all fragmented, preventing measurements. Estimated
 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 more broadly rounded venter at all growth stages, the mid-flank position of its tubercles, and 780 781 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

**Remark:** Jattiot et al. (2016) provided a comprehensive review of the taxonomy of the
various iconic late Smithian *Anasibirites* species. We follow the conclusions of this work and
thus do not include the complete description and synonymy list for each sampled species.
Reader should refer to Jattiot et al. (2016) for complete synonymy lists (see also our remarks
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
007	incusarements. See Supplementary Fig. D and Supplementary Table 1. Estimated
810	maximal size: ~10 cm (Jattiot et al., 2016).
810 811	maximal size: ~10 cm (Jattiot et al., 2016).
<ul><li>810</li><li>811</li><li>812</li></ul>	<ul><li>maximal size: ~10 cm (Jattiot et al., 2016).</li><li>Discussion: This species is abundant within the studied area, but is mainly represented by</li></ul>
<ul><li>810</li><li>811</li><li>812</li><li>813</li></ul>	<ul> <li>maximal size: ~10 cm (Jattiot et al., 2016).</li> <li>Discussion: This species is abundant within the studied area, but is mainly represented by small-sized specimens, generally &lt; 4 cm (Fig. 11). As shown by Jattiot et al. (2016), the</li> </ul>
<ul> <li>810</li> <li>811</li> <li>812</li> <li>813</li> <li>814</li> </ul>	<ul> <li>maximal size: ~10 cm (Jattiot et al., 2016).</li> <li>Discussion: This species is abundant within the studied area, but is mainly represented by small-sized specimens, generally &lt; 4 cm (Fig. 11). As shown by Jattiot et al. (2016), the occurrence of megastriae mimicking the intercalation of strong ribs only on the inner whorls</li> </ul>
<ul> <li>810</li> <li>811</li> <li>812</li> <li>813</li> <li>814</li> <li>815</li> </ul>	<ul> <li>maximal size: ~10 cm (Jattiot et al., 2016).</li> <li>Discussion: This species is abundant within the studied area, but is mainly represented by small-sized specimens, generally &lt; 4 cm (Fig. 11). As shown by Jattiot et al. (2016), the occurrence of megastriae mimicking the intercalation of strong ribs only on the inner whorls (often &lt;20 mm) is essential for distinguishing <i>A. kingianus</i> from <i>A. multiformis</i>. The latter</li> </ul>
<ul> <li>810</li> <li>811</li> <li>812</li> <li>813</li> <li>814</li> <li>815</li> <li>816</li> </ul>	<ul> <li>maximal size: ~10 cm (Jattiot et al., 2016).</li> <li>Discussion: This species is abundant within the studied area, but is mainly represented by small-sized specimens, generally &lt; 4 cm (Fig. 11). As shown by Jattiot et al. (2016), the occurrence of megastriae mimicking the intercalation of strong ribs only on the inner whorls (often &lt;20 mm) is essential for distinguishing <i>A. kingianus</i> from <i>A. multiformis</i>. The latter display weaker and denser megastriae throughout ontogeny. <i>A. multiformis</i> is also less</li> </ul>
<ul> <li>810</li> <li>811</li> <li>812</li> <li>813</li> <li>814</li> <li>815</li> <li>816</li> <li>817</li> </ul>	<ul> <li>maximal size: ~10 cm (Jattiot et al., 2016).</li> <li>Discussion: This species is abundant within the studied area, but is mainly represented by small-sized specimens, generally &lt; 4 cm (Fig. 11). As shown by Jattiot et al. (2016), the occurrence of megastriae mimicking the intercalation of strong ribs only on the inner whorls (often &lt;20 mm) is essential for distinguishing <i>A. kingianus</i> from <i>A. multiformis</i>. The latter display weaker and denser megastriae throughout ontogeny. <i>A. multiformis</i> is also less variable with a generally more compressed whorl and near isometric growth. <i>A. multiformis</i> is</li> </ul>
<ul> <li>810</li> <li>811</li> <li>812</li> <li>813</li> <li>814</li> <li>815</li> <li>816</li> <li>817</li> <li>818</li> </ul>	<ul> <li>maximal size: ~10 cm (Jattiot et al., 2016).</li> <li>Discussion: This species is abundant within the studied area, but is mainly represented by small-sized specimens, generally &lt; 4 cm (Fig. 11). As shown by Jattiot et al. (2016), the occurrence of megastriae mimicking the intercalation of strong ribs only on the inner whorls (often &lt;20 mm) is essential for distinguishing <i>A. kingianus</i> from <i>A. multiformis</i>. The latter display weaker and denser megastriae throughout ontogeny. <i>A. multiformis</i> is also less variable with a generally more compressed whorl and near isometric growth. <i>A. multiformis</i> is much more abundant than <i>A. kingianus</i> in the western USA basin (Jattiot et al., 2016; Jenks)</li> </ul>
<ul> <li>810</li> <li>811</li> <li>812</li> <li>813</li> <li>814</li> <li>815</li> <li>816</li> <li>817</li> <li>818</li> <li>819</li> </ul>	maximal size: ~10 cm (Jattiot et al., 2016). <b>Discussion:</b> This species is abundant within the studied area, but is mainly represented by small-sized specimens, generally < 4 cm ( <b>Fig. 11</b> ). As shown by Jattiot et al. (2016), the occurrence of megastriae mimicking the intercalation of strong ribs only on the inner whorls (often <20 mm) is essential for distinguishing <i>A. kingianus</i> from <i>A. multiformis</i> . The latter display weaker and denser megastriae throughout ontogeny. <i>A. multiformis</i> is also less variable with a generally more compressed whorl and near isometric growth. <i>A. multiformis</i> is much more abundant than <i>A. kingianus</i> in the western USA basin (Jattiot et al., 2016; Jenks and Brayard, 2018). <i>Anasibirites</i> is an iconic genus utilized worldwide to define the base of
<ul> <li>810</li> <li>811</li> <li>812</li> <li>813</li> <li>814</li> <li>815</li> <li>816</li> <li>817</li> <li>818</li> <li>819</li> <li>820</li> </ul>	<ul> <li>maximal size: ~10 cm (Jattiot et al., 2016).</li> <li>Discussion: This species is abundant within the studied area, but is mainly represented by small-sized specimens, generally &lt; 4 cm (Fig. 11). As shown by Jattiot et al. (2016), the occurrence of megastriae mimicking the intercalation of strong ribs only on the inner whorls (often &lt;20 mm) is essential for distinguishing <i>A. kingianus</i> from <i>A. multiformis</i>. The latter display weaker and denser megastriae throughout ontogeny. <i>A. multiformis</i> is also less variable with a generally more compressed whorl and near isometric growth. <i>A. multiformis</i> is much more abundant than <i>A. kingianus</i> in the western USA basin (Jattiot et al., 2016; Jenks and Brayard, 2018). <i>Anasibirites</i> is an iconic genus utilized worldwide to define the base of the late Smithian (e.g., Brühwiler et al., 2010), as it shows a highly cosmopolitan distribution</li> </ul>

- 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.
- v p 2008 *Hemiprionites* cf. *H. butleri* Brayard and Bucher, p. 58, pl. 29, figs 1, 4, 7 only,
  text- fig. 50.
- 843 2012b *Hemiprionites typus* Brühwiler and Bucher, p. 103, figs. 89A-AH.
- 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 <i>Hemiprionites</i> 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: <i>H. typus</i> 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 <i>H. typus</i> partly overlaps with <i>Gurleyites smithi</i> , 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).

894	<b>Description:</b> See taxonomic revision of <i>Hemiprionites</i> 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	
909	Acknowledgements
910	This work is a contribution to the ANR project AFTER (ANR-13-JS06-0001-01) and was
911	also supported by the French "Investissements d'Avenir" program, project ISITE-BFC (ANR-
912	15-IDEX-03). The final version of this paper benefited from constructive reviews by Spencer
913	Lucas and two anonymous referees. S. Ritter (BYU) shared some locality data (HT). We
914	thank G. Caravaca, T. Hurd and P. Guenser for their help in the field. The studied sections are
915	located on US public land under the stewardship of the Bureau of Land Management (BLM)
916	of the US Department of the Interior; access to these lands is gratefully acknowledged.
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

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

1305

Fig. 4. Temporal extent of the deposition of the Sinbad Fm. at each studied locality as
determined by newly-found ammonoid assemblages. See Fig. 1 for abbreviations. The gray
shaded area corresponds to the end of the marine deposits of the Sinbad Fm. The age for the
base of the Sinbad Fm. at WW remains tentative because late middle Smithian ammonoids
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

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

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

1329



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

Fig. 9. A–J: *Gurleyites smithi*. All specimens from bed BRC, Workman Wash, Utah, early
late Smithian. A–B: lateral and ventral views of UBGD 32261; C–E: apertural, ventral and
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 BRC, Workman Wash, Utah, early late Smithian. A–B: lateral and ventral views of specimens 1358 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; He: Hemiprionites typus. Identification of the complete specimen on block UBGD 32269 (E-1363 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.

1377 **Fig. 12**. A–I: *Hemiprionites walcotti*. 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 UBGD 32289; Q: lateral view of UBGD 32290; R-S: lateral and ventral views of UBGD 1383 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

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- 1388

Supplementary Figure 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).

1394

Supplementary Figure 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.

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 walcotti. 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

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



























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).


**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.



**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).



**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).



**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.



**Suppl. Fig. F.** Scatter diagrams of H, W and U, and H/D, W/D and U/D for *Hemiprionites walcotti*. 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.

