

1 Mid Jurassic (Late Callovian) dinoflagellate cysts from the Lotena Formation of the
2 Neuquén Basin, Argentina and their palaeogeographical significance

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17

18 **ABSTRACT**

19

20 The Lotena Formation from two localities, Picún Leufú and Portada Covunco, in the
21 Neuquén Basin of west-central Argentina was studied palynologically. The material
22 examined produced moderately diverse Late Callovian dinoflagellate cyst assemblages.

23 This age assignment is consistent with ammonite evidence. The dinoflagellate cyst
24 floras are reminiscent of the Middle Jurassic associations of northwest Europe and
25 surrounding areas. Marine palynomorphs typical of Australasia and the Arctic are

26 absent. The similarity with Europe is strongly suggestive of an open marine connection
27 between western Tethys and the Neuquén Basin during the Late Callovian. This is
28 interpreted as being via the Hispanic Corridor, with the palynofloras being passively
29 dispersed to the southwest by the circum-Tropical Marine Current. Earlier studies
30 indicate that this trans-Pangean equatorial seaway first began to allow biotic interchange
31 during the Mid Jurassic and this study proves that this open marine connection was
32 established by the Late Callovian. The similarities between the dinoflagellate cyst
33 assemblages of Europe and the Neuquén Basin are consistent with the distribution of
34 other marine fossils and the existence of geographically-continuous marine facies belts.

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36 Keywords: Lotena Formation; Mid Jurassic; dinoflagellate cysts; biostratigraphy;
37 palaeogeography; Argentina

38

39 **1. Introduction**

40

41 The palynofloras of the Lotena Formation of the Lotena Group from the
42 Neuquén Basin, Argentina have previously been studied by Volkheimer and
43 Quattrocchio, (1981), Quattrocchio and Sarjeant (1992), Martínez and Quattrocchio
44 (2003; 2004) and Zavala et al. (2003). The Lotena Formation is of Mid-Late Jurassic
45 age; more specifically Callovian-Oxfordian (Howell et al., 2005, fig. 3; Fig. 1). This
46 contribution represents a restudy of some of the material of Quattrocchio and Sarjeant
47 (1992) and Martínez and Quattrocchio (2004) (Fig. 2), and an interpretation of the
48 dinoflagellate cyst assemblages in terms of their detailed biostratigraphy and
49 palaeogeographical significance. Quattrocchio and Sarjeant (1992) is largely on
50 systematics and Martínez and Quattrocchio (2004) is mainly focused on palynofacies.

51 Global palaeogeographical aspects were not considered in detail by either Quattrocchio
52 and Sarjeant (1992) or Martínez and Quattrocchio (2004). The aims of this study are to
53 refine the biostratigraphy, and to compare the dinoflagellate cysts of the Lotena
54 Formation with coeval associations from other regions. Specifically, the latter goal
55 seeks to determine whether these marine palynofloras have closer affinities with the
56 western Tethys including the Subboreal Realm or with eastern Tethys/Australasia.

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58

59 **2. Geological Background**

60

61 The geological evolution of the Neuquén Basin was largely controlled by
62 tectonic events on the western margin of Gondwana. Following initial extensional
63 rifting during the Late Triassic, back-arc subsidence was initiated during the Early
64 Jurassic due to the development of a subduction zone (and an associated magmatic arc)
65 in western Gondwana. Thus, in western South America, subduction of Pacific oceanic
66 crust along the north-south trending continental margin of Chile and Argentina
67 accelerated significantly during the breakup of West and East Gondwana during the
68 Early Cretaceous. Andean subduction therefore took place under extensional conditions,
69 and was probably associated with negative trench roll-back. This led to the formation
70 of a magmatic arc along the Coast Ranges from southern Peru to central Chile and, to
71 the east, the Arequipa, Tarapacá and Neuquén extensional back arc basins (Mpodzis
72 and Ramos, 2008).

73 The Neuquén Basin is located immediately to the east of the Andes Mountains in
74 central western Argentina and eastern Chile between 31°S and 41°S (Figs. 1-3). It lies
75 within the Argentine provinces of La Pampa, Mendoza, Neuquén (from which it takes

76 its name) and Río Negro. The depocentre represents the southern end of the more
77 extensive Chilean Basin, is broadly triangular in outline, up to 700 km in a north-south
78 direction and covers over 150,000 km². The tectonic history of the Neuquén Basin
79 consists of synrift (Late Triassic-Early Jurassic), postrift/back-arc (Early Jurassic-Early
80 Cretaceous) and foreland stages (Howell et al., 2005, fig. 3). The basin fill is of Late
81 Triassic to Palaeocene age, and is between 4,000 and 7,000 m of heterolithic marine and
82 continental strata (Ramos, 1998; Howell et al., 2005). The majority of the Neuquén
83 Basin fill was deposited during the postrift phase; this comprises the Cuyo, Lotena and
84 Mendoza groups of Pliensbachian to Barremian age (Vergani et al., 1995; Howell et al.,
85 2005, fig. 3).

86 The strata of the Neuquén Basin are mostly shallow marine, related to a
87 prolonged connection with the palaeo-Pacific. However, marine influence was
88 periodically interrupted due to falls in sea-level (Mutti et al., 1994). These short-lived
89 periods of terrestrial deposition are normally indicated by regional-scale angular
90 unconformities which are indicative of tectonic overprints on eustatic changes.
91 Transgressive successions were deposited above these unconformities, indicating
92 progressive increases of accommodation space. The Lotena Group (Fig. 1) represents
93 the second oceanic incursion into the Neuquén Basin. The basal hiatus significantly
94 affected the overlying units (Zavala, 2002). This group largely comprises Middle
95 Callovian and Oxfordian siliciclastic units with subordinate carbonates and evaporites
96 (Fig. 3). The thickness of the Lotena Group is highly variable, ranging from as little as
97 several metres to 650 m in the Sierra de la Vaca Muerta (Zavala, 2005). It
98 unconformably overlies the continental and marine deposits of the Cuyo Group, and is
99 in turn overlain by the Mendoza Group (Fig. 1).

100 The Lotena Group in the Sierra de la Vaca Muerta and Covunco areas in the
101 southwest of the Neuquén Basin consists of six unconformity-bounded sequences. The
102 oldest of these, Sequence 1, comprises the red beds and evaporites of the Tábanos
103 Formation, and unconformably overlies the Cuyo Group with transgressive onlap. The
104 Lotena Formation is dominated by mudstone with subordinate evaporites, limestones
105 and sandstones: it comprises sequences 2 to 5. These are broadly similar and exhibit a
106 basal unit of confined shelfal sandstone lobes, which grade upwards into unconfined
107 shelfal sandstone lobes and carbonates. The basal confined shelfal sandstone lobes are
108 restricted to areas where the successions are thickest. The youngest Sequence (6) is
109 equivalent to the La Manga Formation and exhibits an irregular facies architecture
110 which truncates the underlying deposits. It is almost entirely composed of massive
111 carbonates that were deposited by turbidity currents. Facies analysis and mapping
112 indicate the reworking of older units. The Lotena Group in the Sierra de la Vaca Muerta
113 and adjacent areas probably accumulated in a tectonically unstable region. Sequences 4-
114 6 show a northward shift of their depocentres and widespread truncation along the
115 southern margins. The truncation may be related to intermittent uplift associated with
116 the syndimentary development of the Covunco anticline (Zavala, 2005).

117

118 **3. Material studied**

119

120 The three samples from the Lotena Formation analysed in this study are from the
121 southern part of the Neuquén Basin (Fig. 2). The slides are housed in the Laboratory of
122 Palynology, Universidad Nacional del Sur, Bahía Blanca, Argentina.

123

124 3.1. *Samples 2971 and 2970 from Puente del Arroyo Picún Leufú of Quattrocchio*
125 *and Sarjeant (1992)*

126

127 Samples 2971 and 2970 were collected by Dr. Wolfgang Volkheimer from a
128 prominent outcrop at the Puente del Arroyo Picún Leufú, where Nacional Route N40
129 crosses the Arroyo Picún Leufú, around 40 km south of Zapala (Fig. 2). At this locality,
130 the lower part of the Lotena Formation comprises 59 m of dark green mudstones with a
131 basal conglomerate (Quattrocchio and Sarjeant, 1992, fig. 4). The samples 2971 and
132 2970 are from 12 m and 34 m from the base of the lower conglomerate unit respectively
133 (Quattrocchio and Sarjeant, 1992, fig. 4). This mudstone-dominated unit has yielded the
134 ammonite *Rehmannia (Loczyceras) patagoniensis*, foraminifera and ostracods (Dellapé
135 et al., 1979). *Rehmannia (L.) patagoniensis* is present at the base of the succession and
136 is considered to be Mid to Late Callovian in age (Groeber et al., 1953, Stipanovic, 1969;
137 Riccardi et al., 1990). Riccardi (2008) stated that *R. (L.) patagoniensis* is indicative of
138 the Mid Callovian Jason and Coronatum chronozones.

139

140 3.2. *Sample 1525 from Portada Covunco of Martínez and Quattrocchio (2004)*

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142 Sample 1525 of Martínez and Quattrocchio (2004) is by far the most
143 palynologically productive of the three horizons studied by Martínez and Quattrocchio
144 (2004) from the Lotena Formation of the Portada Covunco section, around 20 km from
145 Zapala (Fig. 2). Here the formation is approximately 220 m thick and corresponds to
146 units 2 and 3 of Zavala et al. (2002). The sample is a massive dark grey mudstone from
147 Unit 2. No ammonites have been recorded from the Lotena Formation of the Portada
148 Covunco section. However, the underlying Lajas Formation of the Cuyo Group has

149 yielded the ammonite *Eurycephalites cf. vergarensis*, which is characteristic of the
150 Vergarensis Chronozone, which is of Early Callovian age (Riccardi et al., 1989; 1990;
151 Riccardi, 2008).

152

153 **4. Description of the palynomorph assemblages**

154

155 The three samples restudied here yielded moderately abundant palynomorph
156 associations. The species recorded, and others discussed herein, are listed in Appendix
157 1; their distribution and abundances are recorded in Table 1. A selection of
158 dinoflagellate cysts are illustrated in Plate I. The assemblages are dominated by pollen
159 grains with lesser proportions of dinoflagellate cysts. The pollen genus *Classopollis* is
160 prominent; other pollen taxa recorded include the saccate forms *Alisporites* spp.,
161 *Araucariacites* spp. and *Callialasporites* spp. (Table 1). The dominance of *Classopollis*
162 is indicative of arid conditions. This is especially the case for samples 2971 and 2970
163 from Puente del Arroyo Picún Leufú, which is more proximal than Portada Covunco
164 (Martinez and Quattrocchio, 2004; Table 1). *Classopollis* was produced by
165 representatives of the Cheirolepidaceae, and the parent plants were thermophylic and
166 xerophytic. They preferred dry coastal regions (Pocock and Jansonius, 1961; Srivastava,
167 1976), which is consistent with the palaeolatitudinal position of the Neuquén Basin
168 during the Jurassic (Smith et al., 1994). Miscellaneous microplankton, including
169 acritarchs and prasinophytes, and pteridophyte spores are also present in relatively
170 minor proportions. This palynomorph spectrum is indicative of an offshore shelfal
171 depositional setting.

172

173 **5. Biostratigraphy**

174

175 5.1. Samples 2971 and 2970 from Puente del Arroyo Picún Leufú of Quattrocchio and
176 Sarjeant (1992)

177

178 The dinoflagellate cyst assemblages in samples 2971 and 2970 (see Table 1) are
179 entirely consistent with a Callovian age when compared to European assemblages. The
180 prominence of *Nannoceratopsis pellucida* in 2971, together with the presence of forms
181 such as *Chytroisphaeridia chytroeides*, *Ellipsoidictyum gochtii*, *Gonyaulacysta*
182 *jurassica* subsp. *adecta*, *Meiourogonyaux* sp., *Mendicodinium groenlandicum*,
183 *Pareodinia ceratophora*, *Sentusidinium* spp. and *Tubotuberella dangeardii* is typical of
184 the Callovian of northwest Europe and adjacent areas (e.g. Riding, 1982; 1987a; 2005;
185 Berger, 1986; Smelror, 1988a;b; Prauss, 1989; Feist-Burkhardt and Wille, 1992;
186 Smelror and Below, 1992; Poulsen, 1996; Riding and Thomas, 1997). The presence of
187 *Limbodinium absidatum* and *Wanaea acollaris* in sample 2971 refines this assessment
188 to the Late Callovian. *Limbodinium absidatum* is confined to the Late Callovian-Early
189 Oxfordian interval (Athleta to Coronatum chronozones) (Riding 1987b; Riding and
190 Thomas, 1992). The range top of *Wanaea acollaris* is within the Late Callovian
191 (Riding, 1984); the few, sporadic reports of this species in the Early Oxfordian are
192 thought to represent contamination (Riding and Thomas, 1997). No exclusively
193 Oxfordian markers such as *Leptodinium* spp. and *Systematophora* spp. were observed.
194 The presence of *Ambonosphaera? staffinensis* in the Callovian is unusual; the range of
195 this species is Mid Oxfordian to Early Cretaceous (Poulsen and Riding, 1992, fig. 2).

196 A single specimen of *Protobatioladinium* cf. *P. lindiensis* Schrank 2005 was
197 recorded in sample 2971. *Protobatioladinium lindiensis* was originally described from
198 the Tithonian of Tanzania, and similar forms are present in the Bathonian-Ryazanian

199 interval of Europe and Israel (Schrank, 2005). *Dissiliodinium volkheimeri* is confined to
200 the Southern Hemisphere. It was recorded from the Bathonian and Callovian of offshore
201 northwestern Australia by Mantle (2009a). Quattrocchio and Sarjeant (1992, p. 70)
202 stated that *Dissiliodinium volkheimeri* is conspecific with *Dissiliodinium* sp. (no
203 antapical node) of Helby et al. (1987), from the Bajocian-Bathonian of Australia.
204 However, this contention is not supported here because *Dissiliodinium volkheimeri* has
205 a thin autophragm and has extremely low-relief ornamentation. By contrast,
206 *Dissiliodinium* sp. (no antapical node) of Helby et al. (1987) has an irregular reticulate
207 ornamentation and is smaller. *Endoscrinium* cf. *E. galeritum* 1967 subsp. *reticulatum* is
208 apparently endemic to the Neuquén Basin.

209 The Late Callovian age of sample 2971, 12 m from the base of the succession,
210 inferred from the presence of *Limbodinium absidatum* and *Wanaea acollaris* is
211 consistent with the occurrence of the Mid to Late Callovian ammonite *Rehmannia*
212 (*Loczyceras*) *patagoniensis* in the lowermost bed. This suggests that the majority of the
213 succession at Puente del Arroyo, Picún Leufú is of Late Callovian age.

214

215 5.2. Sample 1525 from Portada Covunco of Martínez and Quattrocchio (2004)

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217 The relatively low diversity dinoflagellate cyst assemblage in sample 1525 is
218 also consistent with the Callovian Stage. *Gonyaulacysta jurassica* subsp. *adecta* is
219 prominent, and *Chytroeisphaeridia chytroeides*, ?*Meiourogonyaulax* sp.,
220 *Mendicodinium groenlandicum* and *Rynchodiniopsis cladophora* are also present. This
221 association is typical of the Callovian of the Northern Hemisphere (e.g. Riding and
222 Thomas, 1992; 1997; Riding et al., 1999; Riding, 2005). The presence of *Scriniodinium*
223 *crystallinum* refines this assessment to no older than Late Callovian. The range of

224 *Scriniodinium crystallinum* in the Northern Hemisphere is Late Callovian to earliest
225 Kimmeridgian (Riding, 1987a; Riding and Fensome, 2002). The questionable
226 specimens of *Liesbergia liesbergensis*, *Trichodinium scarburghensis* and *Wanaea* sp.
227 also support a Late Callovian age assessment. *Liesbergia liesbergensis* is indicative of
228 the Mid Callovian to earliest Oxfordian interval of Europe (Berger, 1986; Riding,
229 2005). *Trichodinium scarburghensis* is characteristic of the Late Callovian to Mid
230 Oxfordian (Riding and Thomas 1992). ?*Wanaea* sp. has a spinose paracingular crest,
231 hence is similar to forms such as the Late Callovian to Early Oxfordian marker *Wanaea*
232 *thysanota* (see Riding and Helby, 2001a). No marker species with range bases within
233 the Oxfordian such as *Endoscrinium luridum*, *Glossodinium dimorphum*,
234 *Gonyaulacysta jurassica* subsp. *jurassica* and *Wanaea fimbriata* were recorded.

235

236 **6. The provincialism of Jurassic dinoflagellate cysts**

237

238 Because dinoflagellates are planktonic, their cysts can potentially have wide
239 biogeographical distributions. In the Jurassic several prominent Mid-Late Jurassic
240 species, such as *Gonyaulacysta jurassica*, *Nannoceratopsis pellucida* and
241 *Scriniodinium crystallinum*, are known to be distributed globally. However, many other
242 taxa appear to be restricted to northwest Europe/western Tethys, eastern
243 Tethys/Australasia and the Arctic region (Norris, 1975). The Australasian biotic
244 province is especially well-differentiated, having many endemic taxa (Helby et al.,
245 1987; Riding and Ioannides, 1996). Typically in the Arctic/Boreal region, there is a
246 mixture of widely-distributed Northern Hemisphere forms and endemic high latitude
247 taxa (Brideaux and Fisher, 1976; Davies, 1983; Smelror and Below, 1992. Riding et al.,
248 1999).

249 At certain times during the Jurassic, such as the Bathonian and the
250 Kimmeridgian/Tithonian, it is possible to distinguish distinct Boreal (Arctic) and
251 western Tethyan (Euro-Atlantic) provinces within the Northern Hemisphere (Riding et
252 al., 1985; 1999; Riding and Ioannides, 1996). This marked provincialism was most
253 likely due to a number of factors including lithofacies control, nutrient levels, ocean
254 currents, salinity, seasonality (i.e. winter darkness) and temperature. One of the most
255 important factors, however, was likely to have been the presence or absence of open
256 marine connections. Organic cyst-producing dinoflagellates prefer shelfal environments
257 (Wall et al., 1977). Therefore during periods of high sea levels, when extensive areas of
258 continental shelf are flooded, dinoflagellates are passively dispersed over very wide
259 areas. The Callovian and Oxfordian interval was a time of rising and relatively high sea
260 levels (Ager, 1981; Haq et al., 1987). Consequently, dinoflagellate cyst associations are
261 extremely similar in taxonomic spectrum and relative proportions in this interval
262 throughout the equatorial, middle and high latitudes throughout the Americas, the Arctic
263 and western Tethys (Johnson and Hills, 1973; Jain et al. 1986; Garg et al., 1987;
264 Smelror, 1988a,b; Thusu et al., 1988; Conway, 1990; Poulsen, 1996; Riding et al., 1999;
265 Ibrahim et al., 2002). This situation suggests significant levels of ocean current activity
266 at this time. Such is the relative uniformity of Callovian-Oxfordian dinoflagellate cyst
267 assemblages throughout much of the Northern Hemisphere, the Australasian
268 phytoplankton province represents a major biotal contrast (Riding and Helby, 2001b;
269 Mantle, 2005; 2009a,b).

270

271 **7. Palaeogeographical significance of the dinoflagellate cyst assemblages**

272

273 The dinoflagellate cyst associations from samples 2971, 2970 and 1525 are of
274 moderate to low diversity, and are strongly reminiscent of the Late Callovian floras of
275 the Northern Hemisphere. For example, the previous reports of *Ambonosphaera?*
276 *staffinensis*, *Ellipsoidictyum gochti*, *Limbodinium absidatum*, *Rynchodiniopsis*
277 *cladophora* and *Wanaea acollaris* are all from Europe, North America and adjacent
278 regions (e.g. Johnson and Hills, 1973; Feist-Burkhardt and Wille, 1992; Riding and
279 Thomas, 1992; Riding et al., 1999). By contrast, *Chytroeisphaeridia chytroeides*,
280 *Mendicodinium groenlandicum*, *Nannoceratopsis pellucida*, *Pareodinia ceratophora*,
281 *Scriniodinium crystallinum* and *Tubotuberella dangeardii* are global in distribution
282 (Davey, 1987; Helby et al., 1987, Mantle, 2009a,b). The only species apparently
283 confined to the Southern Hemisphere is *Dissiliodinium volkheimeri*. This form has been
284 recorded from the Neuquén Basin and offshore northwestern Australia (Quattrocchio
285 and Sarjeant, 1992; Mantle, 2009a). *Dissiliodinium* is a relatively morphologically
286 simple genus and the majority of the species were described from the Northern
287 Hemisphere. This implies that *Dissiliodinium volkheimeri* may not be confined to the
288 Southern Hemisphere. A single specimen of *Protobatioladinium* cf. *P. lindiensis* was
289 recorded from sample 2971 (Plate I, fig. 8). *Protobatioladinium lindiensis* was
290 described from the Tithonian of Tanzania, East Africa by Schrank (2005). This species
291 apparently has a wide distribution; similar forms have been recorded from the
292 Bathonian to Ryazanian of Europe (Schrank, 2005, p. 72). *Endoscrinium* cf. *E.*
293 *galeritum* subsp. *reticulatum* (Plate I, fig. 14) is prominent in sample 2971 (Table 1);
294 this morphotype appears to be confined to the Neuquén Basin.

295 Significantly, no taxa of exclusively Australasian affinity were observed in this
296 study. In the Callovian of Australasia, several characteristic and endemic species are
297 present including *Endoscrinium kempiae*, *Meiourogonyaulax penitabulata*,

298 *Nannoceratopsis reticulata*, *Paragonyaulacysta helbyi*, *Ternia balmei*, *Voodooia*
299 *tabulata*, *Wanaea digitata*, *Woodinia pedis* and others (Davey, 1987; Helby et al., 1987;
300 1988; Riding and Helby, 2001b; Mantle, 2005; 2009a,b). None of these taxa, and other
301 endemic Austral forms, have been recorded from the Lotena Formation of the Neuquén
302 Basin. Hence, due to the lack of Australasian elements, this assemblage is consistent
303 with a strong marine connection with the Euro-Atlantic province to the north. This
304 strongly implies that the Neuquén Basin was isolated from eastern Gondwana in terms
305 of biotal exchange during the Callovian. Australasian dinoflagellate cysts could not
306 have been passively dispersed westwards across the middle latitudes into the Neuquén
307 Basin via trans-Pacific routes due to the wide geographical extent of this deep ocean
308 basin, and the active subduction zone immediately to the west of the Americas (Fig. 4).
309 Similarly, latitudinal and palaeotemperature barriers would probably have prevented
310 dispersal from Australasia to South America around the southern margin of Gondwana
311 (i.e. Australia and Antarctica) via the Southern Gondwanan Seaway (Hallam, 1983; Fig.
312 4).

313 Similarly, characteristically Arctic/Boreal Callovian dinoflagellate cyst taxa
314 such as *Evansia dalei*, *Evansia perireticulata*, *Paragonyaulacysta calloviensis* and
315 *Paragonyaulacysta retiphragmata* have not been observed in the Neuquén Basin. These
316 species were cold-adapted Arctic forms (e.g. Johnson and Hills 1973; Dörhöfer and
317 Davies 1980; Smelror and Below, 1992). The absence of these forms indicates that
318 potential southerly dispersal routes via the high northerly palaeolatitudes into the
319 Hispanic Corridor were not viable for cyst-forming dinoflagellates.

320 In the western Tethys (i.e. eastern North America and North Africa) Jurassic
321 biotas, including dinoflagellate cysts, were markedly different from their counterparts
322 from southeastern Tethys (Australasia, eastern Asia and northeast India). Central

323 southern Tethys (i.e. East Africa, India and Madagascar) appears to have supported a
324 mixed assemblage, with both European and Austral dinoflagellate cysts being present
325 (e.g. Jiang et al. 1992, Garg et al. 2003, Msaky, 2007). During the Triassic and Jurassic,
326 the Tethys circumglobal current (TCC) flowed westwards in the tropics and north-south
327 currents during such greenhouse intervals tended to be relatively weak (Bush, 1997).
328 Thus, the westward flow of the TCC would have potentially been responsible for the
329 dispersal of planktonic organisms from eastern to western Tethys during the Mesozoic.
330 Despite this, endemic Australasian dinoflagellate cyst taxa have not been observed west
331 of East Africa. Interruptions in shelfal seas, water stratification and/or other constraints
332 apparently prevented the westward dispersal of Austral dinoflagellate cysts during the
333 Jurassic. Aberhan (2001) discussed bidirectional (seasonal) biotic exchange across the
334 Hispanic Corridor during the Mid Jurassic driven by the establishment of a
335 megamonsoonal ocean circulation.

336 The characteristically European affinity of the Callovian dinoflagellate cysts
337 from the Lotena Formation of the Neuquén Basin is entirely consistent with the
338 palaeogeography inferred from other fossil groups. The Hispanic Corridor or Caribbean
339 Seaway represented a relatively narrow open marine connection from western Tethys
340 southwestwards across Central America into western South America in the Mid and
341 Late Jurassic (e.g. Hallam, 1983, fig. 1; Irurralde-Vinent, 2003, fig. 1; 2006, fig. 1; Fig.
342 4). This seaway first opened during the Early Jurassic (Aberhan, 2001), and would have
343 allowed the free interchange of marine biotas between the western Tethys and the
344 Neuquén Basin from the Mid and Late Jurassic (Bathonian to Oxfordian). Contiguous
345 shallow marine siliciclastic facies were present throughout the Hispanic Corridor during
346 the Oxfordian (Irurralde-Vinent, 2003). This study strongly indicates that this open
347 seaway was present during the Late Callovian (Fig. 4). Some studies have stated that

348 this connection was not fully established until the Late Jurassic (e.g. Irurralde-Vinent,
349 2006, fig. 2). Previously, Pangea represented a major barrier to free movement of
350 marine waters and biotas in the equatorial region. Van de Schootbrugge et al. (2005)
351 postulated that the possible opening of the Hispanic Corridor may have caused the
352 radiation in cyst-forming dinoflagellates during the Early Jurassic (Late Sinemurian and
353 Late Pliensbachian). The passive dispersal facilitated by the opening of this seaway
354 were probably driven westwards through the Hispanic Corridor on the circum-Tropical
355 Marine Current (Parrish, 1992; Irurralde-Vinent, 2006), and interchanged with the
356 Neuquén Basin via the western margin of South America. However, it is also possible
357 that some marine connections were present between South America and Africa via the
358 Mozambique Corridor (Longshaw and Griffiths, 1983, fig. 4).

359 Musacchio (1979; 1981) reported diverse associations of benthonic foraminifera
360 and ostracods from the Lotena Formation. The foraminifera are cosmopolitan, and are
361 similar to coeval faunas from northern Europe. This is consistent with a marine
362 connection via the Hispanic Corridor. Boomer and Ballent (1996) concluded that the
363 similarities between Early to Mid Jurassic marine ostracod faunas from southwest
364 Britain, North Africa and the Neuquén Basin indicate westward migration into the
365 eastern part of the Tethys along the Hispanic Corridor as opposed to via the
366 Tethyan/Pacific seaway. This biotic evidence for a marine connection between further
367 north in the Chilean Basin and into North America, and the Neuquén Basin is consistent
368 with the configuration of shallow marine facies belts. In the Neuquén Basin, the area of
369 Callovian marine deposition is surrounded by coastal and continental deposits, with
370 definite closure towards the south (Zavala, 2005, fig. 1; Fig. 3).

371

372 **8. Conclusions**

373

374 The Lotena Formation of the Neuquén Basin, Argentina yields low-moderate
375 diversity dinoflagellate cyst assemblages indicative of a Late Callovian age by
376 comparison with northwest Europe. No Australasian or Boreal forms were observed,
377 and the floras of the Lotena Formation are extremely reminiscent of coeval Eurasian
378 assemblages. This means that there must have been an open marine connection between
379 Europe (and adjacent areas) and the Neuquén Basin via the circum-Tropical Marine
380 Current through the Hispanic Corridor during the Late Callovian. Prior to the Mid
381 Jurassic, there was no permanent ‘trans-Pangean’ equatorial seaway which allowed
382 biotal interchange. This conclusion is consistent with evidence from shallow marine
383 facies belts and other fossil groups including foraminifera and ostracods.

384 A more comprehensive study of the Lotena Formation at localities such as
385 Puente del Arroyo Picún Leufú and Portada Covunco should be undertaken. This should
386 allow a significant refinement of Callovian/Oxfordian biostratigraphy and
387 palaeogeographical interpretations.

388

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390

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399

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630

631

632 Appendix 1.

633 An alphabetical list of palynomorphs identified below generic level in the
634 Lotena Formation of the Neuquén Basin, and discussed in the text and/or Table 1, with
635 author citations arranged in three groups. The taxa not recorded in this study, but
636 mentioned in the text are asterisked. References to the dinoflagellate cyst author
637 citations can be found in Fensome and Williams (2004).

638

639 **Pollen**

- 640 *Araucariacites australis* Cookson 1947
- 641 *Microcachryidites castellanosii* Menendez 1968
- 642 *Vitreisporites pallidus* (Reissinger 1938) Nilsson 1958
- 643
- 644 **Spore**
- 645 *Retitriletes austroclavatidites* (Cookson 1953) Döring et al. 1963
- 646
- 647 **Dinoflagellate cysts**
- 648 *Ambonosphaera? staffinensis* (Gitmez 1970) Poulsen & Riding 1992
- 649 *Chytroeisphaeridia chytroeides* (Sarjeant 1962) Downie & Sarjeant 1965
- 650 *Dissiliodinium volkheimeri* Quattrocchio & Sarjeant 1992
- 651 *Ellipsoidictyum gochtii* Fensome 1979
- 652 *Endoscrinium* cf. *E. galeritum* (Deflandre 1939) Vozzhennikova 1967 subsp.
- 653 *reticulatum* (Klement 1960) Górká 1970
- 654 **Endoscrinium kempiae* (Stover & Helby 1987) Lentin & Williams 1989
- 655 **Endoscrinium luridum* (Deflandre 1939) Gocht 1970
- 656 **Evansia dalei* (Smelror & Århus 1989) Below 1990
- 657 **Evansia perireticulata* (Århus et al. 1989) Lentin & Williams 1993
- 658 **Glossodinium dimorphum* Ioannides et al. 1977
- 659 *Gonyaulacysta jurassica* (Deflandre 1939) Norris & Sarjeant 1965 subsp. *adecta*
- 660 Sarjeant 1982
- 661 **Gonyaulacysta jurassica* (Deflandre 1939) Norris & Sarjeant 1965 subsp. *jurassica*
- 662 (autonym)
- 663 *Liesbergia liesbergensis* Berger 1986
- 664 *Limbodinium absidatum* (Drugg 1978) Riding 1987

- 665 **Meiourogonyaulax penitabulata* Riding & Helby 2001
- 666 *Mendicodinium groenlandicum* (Pocock & Sarjeant 1972) Davey 1979
- 667 *Nannoceratopsis pellucida* Deflandre 1939
- 668 **Nannoceratopsis reticulata* Mantle 2005
- 669 **Paragonyaulacysta calloviensis* Johnson & Hills 1973
- 670 **Paragonyaulacysta helbyi* Mantle 2009
- 671 **Paragonyaulacysta retiphragmata* Dörhöfer & Davies 1980
- 672 *Pareodinia ceratophora* Deflandre 1947
- 673 *Protobatioladinium* cf. *P. lindiensis* Schrank 2005
- 674 *Rynchodiniopsis cladophora* (Deflandre 1939) Below 1981
- 675 *Scriniodinium crystallinum* (Deflandre 1939) Klement 1960
- 676 **Ternia balmei* Helby & Stover 1987
- 677 *Trichodinium scarburghensis* (Sarjeant 1964) Williams et al. 1993
- 678 *Tubotuberella dangeardii* (Sarjeant 1968) Stover & Evitt 1978
- 679 **Voodooia tabulata* Riding & Helby 2001
- 680 *Wanaea acollaris* Dodekova 1975
- 681 **Wanaea fimbriata* Sarjeant 1961
- 682 **Wanaea digitata* Cookson & Eisenack 1958
- 683 **Woodinia pedis* Riding & Helby 2001

684

685 **Display material captions:**

686

687 Fig. 1. A generalised lithological log of the succession in the Neuquén Basin (right hand
 688 side), modified from Zavala (2005). The Lotena Group, which includes the Lotena
 689 Formation, is highlighted. The upper left inset map illustrates the location of the

690 Neuquén Basin. The lower left inset map illustrates the detailed extent of the Neuquén
691 Basin.

692

693 Fig. 2. The locations of the Portada Covunco and Picún Leufú sections from where the
694 samples of the Lotena Formation studied herein were collected.

695

696 Fig. 3. The location of the Neuquén Basin, in central western Argentina and eastern
697 Chile with a palaeogeographical reconstruction of this depocentre during the Late
698 Callovian and Early Oxfordian (modified from Legarreta and Uliana, 1999).

699

700 Fig. 4. A palaeogeographical map of the world for the Oxfordian (161.2-155.7 Ma),
701 immediately following the Callovian (164.7-161.2 Ma), modified after Iturralde-Vinent
702 (2003). The continuously open nature of the Hispanic Corridor indicates the potential
703 for biotal exchange between the western Tethys and the eastern Pacific oceans.
704 Specifically, it is postulated that dinoflagellate cysts could have dispersed through the
705 Hispanic Corridor during the Callovian. Note that shallow marine siliciclastic facies
706 belts adjacent to continental areas extended from the western Tethys, through the
707 Hispanic Corridor, to the Neuquén Basin.

708

709 Table 1. The numbers of palynomorphs counted in the three samples studied. An 'X'
710 denotes a form which was recorded outside of the main count. Biostratigraphically-
711 significant dinoflagellate cysts are in bold font. A question mark (?) indicates equivocal
712 material.

713

714 Plate I

715 A selection of dinoflagellate cysts from the Upper Callovian part of the Lotena
716 Formation of Puente del Arroyo Picún Leufú and Portada Covunco, in the Neuquén
717 Basin, west-central Argentina. The sample number, slide number and England Finder
718 (EF) coordinate are given for each specimen. All samples, slides and figured specimens
719 are housed in the collections of the Laboratory of Palynology, Universidad Nacional del
720 Sur, Bahía Blanca, Argentina. The scale bars all represent 10 µm. UNSP = Universidad
721 Nacional del Sur- Palynology. PC = Portada Covunco. PL = Picún Leufú.

722

723 1, 5. *Gonyaulacysta jurassica* (Deflandre 1939) Norris & Sarjeant 1965 subsp. *adecta*
724 Sarjeant 1982. 1 – sample/slide UNSP PC 1525/b, EF Y54/2. 5 – sample/slide UNSP
725 PC 1525/b, EF T68/3.

726 2. *Scriniodinium crystallinum* (Deflandre 1939) Klement 1960. Sample/slide UNSP PC
727 1525/c, EF M9/2.

728 3, 4. *Nannoceratopsis pellucida* Deflandre 1939. 3 – sample/slide UNSP PL 2971/7, EF
729 N50. 4 – sample/slide UNSP PL 2971/3, EF R50/1.

730 6. *Pareodinia ceratophora* Deflandre 1947. Sample/slide UNSP PL 2971/4, EF V32/4.

731 7. *Tubotuberella dangeardii* (Sarjeant 1968) Stover & Evitt 1978. Sample/slide UNSP
732 PL 2971/7, EF J39/1.

733 8. *Protobatioladinium* cf. *P. lindiensis* Schrank 2005. Sample/slide UNSP PL 2971/3,
734 EF Q47/3.

735 9. *Limbodinium absidatum* (Drugg 1978) Riding 1987. Sample/slide UNSP PL 2971/7,
736 EF B48/1.

737 10, 11. *Wanaea acollaris* Dodekova 1975. 10 – sample/slide UNSP PL 2971/2, EF
738 Q43/1. 11 – sample/slide UNSP PL 2971/7, EF S50/4.

- 739 12. *Rynchodiniopsis cladophora* (Deflandre 1939) Below 1981. Sample/slide UNSP PC
740 1525/d, EF H18/2.
- 741 13. *Chytroeisphaeridia chytroeides* (Sarjeant 1962) Downie & Sarjeant 1965.
742 Sample/slide UNSP PC 1525/b, EF R66/2.
- 743 14. *Endoscrinium* cf. *E. galeritum* (Deflandre 1939) Vozzhennikova 1967 subsp.
744 *reticulatum* (Klement 1960) Górká 1970. Sample/slide UNSP PL 2971/7, EF T44/2.
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