
AbSciCon
2017
MESA, ARIZONA

1
00:00:12,250 --> 00:00:06,150
you

2
00:00:16,450 --> 00:00:14,070
[Music]

3
00:00:18,580 --> 00:00:16,460
so those nice introduction to a lot of

4
00:00:20,620 --> 00:00:18,590
the concepts that'll come up in this

5
00:00:23,679 --> 00:00:20,630
talk and we're kind of getting at the

6
00:00:26,710 --> 00:00:23,689
same issue but maybe from the opposite

7
00:00:28,630 --> 00:00:26,720
end so likewise the question that

8
00:00:30,160 --> 00:00:28,640
motivates this and lot of the stuff I

9
00:00:33,100 --> 00:00:30,170
like to think about research Rises and

10
00:00:34,990 --> 00:00:33,110
why are we here on our planet I mean not

11
00:00:36,930 --> 00:00:35,000
just those humans but us as you carry

12
00:00:40,330 --> 00:00:36,940
out these complex life forms that

13
00:00:42,490 --> 00:00:40,340

metabolize aerobic Li and so on and so

14
00:00:45,010 --> 00:00:42,500
forth am I aren't we just a planet full

15
00:00:46,690 --> 00:00:45,020
of single cellular you know bacteria and

16
00:00:49,420 --> 00:00:46,700
archaea like we were for maybe eight

17
00:00:51,069 --> 00:00:49,430
nine verse history so I'm going to

18
00:00:53,110 --> 00:00:51,079
approach this question sort of from a

19
00:00:54,850 --> 00:00:53,120
environmental standpoint its to say what

20
00:00:57,310 --> 00:00:54,860
are the environmental parameters that

21
00:00:59,229 --> 00:00:57,320
enable eukaryotes to persist on the

22
00:01:00,790 --> 00:00:59,239
surface of the earth today and then

23
00:01:02,770 --> 00:01:00,800
we'll look back and say okay what's the

24
00:01:07,090 --> 00:01:02,780
distribution of these your space and

25
00:01:09,130 --> 00:01:07,100
time in Earth's distant past so there's

26
00:01:10,900 --> 00:01:09,140
a variety of things you could look at as

27
00:01:13,270 --> 00:01:10,910
these parameters that we need to

28
00:01:16,029 --> 00:01:13,280
constrain we talked a lot about free

29
00:01:18,550 --> 00:01:16,039
oxygen for aerobic respiration but just

30
00:01:20,170 --> 00:01:18,560
like the last talk we were hearing a

31
00:01:22,359 --> 00:01:20,180
source of fixed nitrogen is really

32
00:01:25,450 --> 00:01:22,369
important for eukaryotes since they

33
00:01:26,770 --> 00:01:25,460
can't fix their own and so that's what

34
00:01:29,080 --> 00:01:26,780
I'll really be getting into in detail

35
00:01:30,190 --> 00:01:29,090
here just to give a little more

36
00:01:32,260 --> 00:01:30,200
background for those that weren't in the

37
00:01:33,850 --> 00:01:32,270
last talk all life as we know it at

38
00:01:37,600 --> 00:01:33,860

least needs nitrogen and a lot of it

39
00:01:40,090 --> 00:01:37,610
it's the most abundant sorry Adam

40
00:01:42,399 --> 00:01:40,100
after CH no so the bulk of your

41
00:01:44,319 --> 00:01:42,409
carbohydrates and so if it's scarce it

42
00:01:46,330 --> 00:01:44,329
becomes the rate limiting reactant sort

43
00:01:48,490 --> 00:01:46,340
of in the reaction that is life on the

44
00:01:50,260 --> 00:01:48,500
surface of the earth the thing is it's

45
00:01:51,520 --> 00:01:50,270
not scarce there's tons of nitrogen at

46
00:01:53,620 --> 00:01:51,530
the surface of the earth and we're

47
00:01:55,810 --> 00:01:53,630
always bathing in atmospheric n2 gas but

48
00:01:57,880 --> 00:01:55,820
this is pretty much inaccessible to you

49
00:01:58,569 --> 00:01:57,890
and I most organisms actually on the

50
00:02:00,639 --> 00:01:58,579
face of the earth

51
00:02:04,660 --> 00:02:00,649
since it's very energetically costly to

52
00:02:06,670 --> 00:02:04,670
break that triple and N bond so that

53
00:02:08,830 --> 00:02:06,680
means that all eukaryotes rely on a

54
00:02:10,539 --> 00:02:08,840
source of nitrogen that's fixed by other

55
00:02:15,280 --> 00:02:10,549
organisms and that's only done by a few

56
00:02:17,199 --> 00:02:15,290
clades of prokaryotes so just to put

57
00:02:18,940 --> 00:02:17,209
that simply these prokaryotes apply the

58
00:02:20,170 --> 00:02:18,950
nitrogen for the whole biosphere and if

59
00:02:22,630 --> 00:02:20,180
you want to look at this then in terms

60
00:02:24,070 --> 00:02:22,640
of a cycle what we can see then is if

61
00:02:26,559 --> 00:02:24,080
you start with nitrogen the atmosphere

62
00:02:29,319 --> 00:02:26,569
first gets fixed into biomass by

63
00:02:31,199 --> 00:02:29,329

prokaryotes and only when they die in

64
00:02:33,160 --> 00:02:31,209
their biomass ckets respired does this

65
00:02:35,649 --> 00:02:33,170
nitrogen then get released into the

66
00:02:37,750 --> 00:02:35,659
environment as the ammonium ion this can

67
00:02:41,619 --> 00:02:37,760
be assimilated into biological tissues

68
00:02:43,839 --> 00:02:41,629
and so if you were to see this is how

69
00:02:45,759 --> 00:02:43,849
the nation cycle would operate on a more

70
00:02:47,259 --> 00:02:45,769
or less anaerobic world where this

71
00:02:48,849 --> 00:02:47,269
ammonium is the dominant ion in the

72
00:02:50,020 --> 00:02:48,859
water column but as soon as you

73
00:02:52,929 --> 00:02:50,030
introduce a little bit of oxygen

74
00:02:55,390 --> 00:02:52,939
actually then that changes nitrate

75
00:02:57,849 --> 00:02:55,400
instead is the more stable ion and so

76
00:03:01,059 --> 00:02:57,859
nitrification will occur sorry again

77
00:03:03,339 --> 00:03:01,069
where ammonium then gets nitrified into

78
00:03:04,780 --> 00:03:03,349
nitrate and this is the form of nitrogen

79
00:03:06,490 --> 00:03:04,790
that eukaryotes really like to

80
00:03:09,220 --> 00:03:06,500
assimilate today and that they rely on

81
00:03:11,559 --> 00:03:09,230
for their nitrogen needs so that's a

82
00:03:14,349 --> 00:03:11,569
similar Tauri metabolism you can also in

83
00:03:16,750 --> 00:03:14,359
locally subbox akin vironment s-- you

84
00:03:18,309 --> 00:03:16,760
get dissimilatory reduction of nitrate

85
00:03:20,379 --> 00:03:18,319
which is denitrification this pathway

86
00:03:22,780 --> 00:03:20,389
here and that closes the loop on the

87
00:03:23,949 --> 00:03:22,790
aerobic nitrogen cycle so the question

88
00:03:25,720 --> 00:03:23,959

we really want to ask them looking back

89
00:03:27,460 --> 00:03:25,730
through time is when did aerobic

90
00:03:29,170 --> 00:03:27,470
nitrogen cycling occur through space and

91
00:03:31,990 --> 00:03:29,180
time in the oceans through first past

92
00:03:34,569 --> 00:03:32,000
since this is presumed to be critical

93
00:03:36,520 --> 00:03:34,579
for the distribution of eukaryotes today

94
00:03:38,259 --> 00:03:36,530
and the way we do that is by using

95
00:03:40,149 --> 00:03:38,269
nitrogen isotopes or at least a large

96
00:03:42,159 --> 00:03:40,159
part of the work is done using nitrogen

97
00:03:44,379 --> 00:03:42,169
isotopes because each of these pathways

98
00:03:45,759 --> 00:03:44,389
has a characteristic fractionation which

99
00:03:48,849 --> 00:03:45,769
have been studied quite a bit and just

100
00:03:50,759 --> 00:03:48,859
to sum up lots of work very quickly the

101
00:03:53,110 --> 00:03:50,769
processes of nitrogen fixation

102
00:03:55,569 --> 00:03:53,120
remineralization and nitrification in

103
00:03:57,539 --> 00:03:55,579
the modern environment at least in part

104
00:03:59,740 --> 00:03:57,549
relatively small isotopic fractionation

105
00:04:02,800 --> 00:03:59,750
when compared with this denitrification

106
00:04:05,199 --> 00:04:02,810
flux which can exert really large

107
00:04:06,939 --> 00:04:05,209
kinetic isotopic fractionation so it

108
00:04:08,770 --> 00:04:06,949
removes lighter nitrogen to the

109
00:04:11,589 --> 00:04:08,780
atmosphere which carries a negative

110
00:04:14,740 --> 00:04:11,599
Delta 59 value meaning what's left will

111
00:04:17,080 --> 00:04:14,750
have to be positive by mass balance so

112
00:04:18,699 --> 00:04:17,090
just again as a guiding principle we

113
00:04:20,920 --> 00:04:18,709

sort of think that if you were to scoop

114
00:04:22,749 --> 00:04:20,930
up biomass that's in mud being deposited

115
00:04:25,140 --> 00:04:22,759
in the bottom of the ocean and it falls

116
00:04:27,850 --> 00:04:25,150
between maybe minus 2 plus 2 per mil

117
00:04:30,219 --> 00:04:27,860
relative to 0 which is the atmospheric

118
00:04:32,890 --> 00:04:30,229
baseline that would be indicative of a

119
00:04:35,200 --> 00:04:32,900
fixation dominated ecosystem or maybe an

120
00:04:37,360 --> 00:04:35,210
anaerobic ecosystem whereas

121
00:04:39,279 --> 00:04:37,370
in order to get these more elevated

122
00:04:42,600 --> 00:04:39,289
values at least in general it's often

123
00:04:44,529 --> 00:04:42,610
because of aerobic nitrogen cycle so

124
00:04:45,850 --> 00:04:44,539
like I said that's been used as a

125
00:04:48,040 --> 00:04:45,860
guiding principle to answer this

126
00:04:50,740 --> 00:04:48,050
question and people have done a lot of

127
00:04:52,270 --> 00:04:50,750
work trying to look at that in ancient

128
00:04:54,520 --> 00:04:52,280
sedimentary rock so I'm plotting this

129
00:04:56,020 --> 00:04:54,530
data here everything that's been

130
00:04:58,090 --> 00:04:56,030
published from bulk marine sedimentary

131
00:04:59,650 --> 00:04:58,100
rocks through geologic time with this

132
00:05:02,080 --> 00:04:59,660
grave and then being what we would

133
00:05:04,420 --> 00:05:02,090
consider our anaerobic nitrogen fixation

134
00:05:06,370 --> 00:05:04,430
window and so if you look on the right

135
00:05:08,320 --> 00:05:06,380
side of the screen and the Archaean the

136
00:05:10,810 --> 00:05:08,330
limited data we do have seem to plot

137
00:05:14,260 --> 00:05:10,820
close to this atmospheric value and then

138
00:05:17,170 --> 00:05:14,270

the first significant enrichment you see

139
00:05:18,400 --> 00:05:17,180
in Delta 59 comes right around what we

140
00:05:20,260 --> 00:05:18,410
would independently constrained to be

141
00:05:22,930 --> 00:05:20,270
the great oxidation event in the

142
00:05:23,499 --> 00:05:22,940
earliest paleo Proterozoic so that makes

143
00:05:25,810 --> 00:05:23,509
sense

144
00:05:27,790 --> 00:05:25,820
qualitatively but the first thing we

145
00:05:30,610 --> 00:05:27,800
wanted to do in this study is fill this

146
00:05:33,010 --> 00:05:30,620
fairly large temporal gap in this record

147
00:05:34,270 --> 00:05:33,020
in the immediate aftermath of the goe

148
00:05:36,219 --> 00:05:34,280
for a few hundred million years

149
00:05:38,050 --> 00:05:36,229
especially considering this has recently

150
00:05:40,600 --> 00:05:38,060
been proposed as a time where oxygen may

151
00:05:43,300 --> 00:05:40,610
have overshot equilibrium values and

152
00:05:45,040 --> 00:05:43,310
been fairly high on a few hundred

153
00:05:46,270 --> 00:05:45,050
million year timescale and this could

154
00:05:49,180 --> 00:05:46,280
have been a critical time for eukaryotic

155
00:05:51,250 --> 00:05:49,190
evolution so we went ahead and did that

156
00:05:53,260 --> 00:05:51,260
thanks to our collaborator Andre Becker

157
00:05:55,600 --> 00:05:53,270
we were able to get samples spanning a

158
00:05:57,610 --> 00:05:55,610
large geographic extent so for multiple

159
00:06:00,939 --> 00:05:57,620
continents and filling in this temporal

160
00:06:04,180 --> 00:06:00,949
gap and just to quickly flash the data

161
00:06:06,010 --> 00:06:04,190
up there into this old previous plot you

162
00:06:08,020 --> 00:06:06,020
can see that they are less corroborate

163
00:06:10,930 --> 00:06:08,030

the story based on the pre-existing data

164
00:06:12,040 --> 00:06:10,940
which is that from the goe onwards for a

165
00:06:15,100 --> 00:06:12,050
few hundred million years you have

166
00:06:17,499 --> 00:06:15,110
values persistently above this fixation

167
00:06:19,330 --> 00:06:17,509
window or in a qualitative sense you

168
00:06:22,629 --> 00:06:19,340
have a signal of aerobic nitrogen

169
00:06:24,850 --> 00:06:22,639
cycling so if we were to keep the just

170
00:06:26,649 --> 00:06:24,860
sort of the canonical view of this we

171
00:06:28,450 --> 00:06:26,659
could just stop there and say in a

172
00:06:29,950 --> 00:06:28,460
qualitative sense that this might be

173
00:06:31,600 --> 00:06:29,960
indicative of greater nitrate

174
00:06:32,950 --> 00:06:31,610
availability and that could have played

175
00:06:35,770 --> 00:06:32,960
a role in the evolution of eukaryotes

176
00:06:37,659 --> 00:06:35,780
but the thing I want to start to get

177
00:06:40,060 --> 00:06:37,669
into here and just sort of looking

178
00:06:41,620 --> 00:06:40,070
forward is asking this question can we

179
00:06:45,459 --> 00:06:41,630
get more quantitative information from

180
00:06:46,750 --> 00:06:45,469
this record so maybe starting humbly

181
00:06:48,040 --> 00:06:46,760
with this we're going to use a very

182
00:06:50,080 --> 00:06:48,050
simple ice

183
00:06:51,550 --> 00:06:50,090
to a box model view of this which is

184
00:06:54,219 --> 00:06:51,560
going to be the same as the nitrogen

185
00:06:56,080 --> 00:06:54,229
cycle as I outlined at the beginning so

186
00:06:58,149 --> 00:06:56,090
just walk through it we trace nitrogen

187
00:07:00,850 --> 00:06:58,159
from the atmosphere that gets fixed in

188
00:07:03,070 --> 00:07:00,860

the ocean by nitrogen fixers when they

189
00:07:04,689 --> 00:07:03,080
die a very small percentage of that gets

190
00:07:06,580 --> 00:07:04,699
buried in marine sediments but most

191
00:07:08,439 --> 00:07:06,590
actually gets remineralized

192
00:07:11,680 --> 00:07:08,449
and then if there's any oxygen in the

193
00:07:13,360 --> 00:07:11,690
ocean nitrified into nitrate and so that

194
00:07:15,790 --> 00:07:13,370
becomes your surface ocean nitrate pool

195
00:07:17,140 --> 00:07:15,800
and there's other ways on the modern

196
00:07:18,520 --> 00:07:17,150
earth to get nitrate into the surface

197
00:07:21,100 --> 00:07:18,530
ocean you can get it delivered by rivers

198
00:07:23,260 --> 00:07:21,110
and through atmospheric deposition we

199
00:07:24,159 --> 00:07:23,270
could modulate these in the Precambrian

200
00:07:25,689 --> 00:07:24,169
if we think that they were less

201
00:07:27,279 --> 00:07:25,699
effective but the truth is they're

202
00:07:30,879 --> 00:07:27,289
really minor fluxes compared to the

203
00:07:33,159 --> 00:07:30,889
fixation flux so then from your surface

204
00:07:34,869 --> 00:07:33,169
ocean nitrate pool you have two possible

205
00:07:36,399 --> 00:07:34,879
outputs either the burial again which is

206
00:07:38,649 --> 00:07:36,409
a very small percentage of total or

207
00:07:42,640 --> 00:07:38,659
denitrification which more or less

208
00:07:44,830 --> 00:07:42,650
balances nitrogen fixation so the thing

209
00:07:47,260 --> 00:07:44,840
we need to focus on here is that as you

210
00:07:50,800 --> 00:07:47,270
can see there's two types or two places

211
00:07:53,559 --> 00:07:50,810
of denitrification that occurs in the

212
00:07:55,059 --> 00:07:53,569
modern ocean so there's a greatly

213
00:07:56,769 --> 00:07:55,069

self-explanatory water column

214
00:07:58,480 --> 00:07:56,779
denitrification which occurs in the

215
00:08:00,749 --> 00:07:58,490
water column or sedimentary which occurs

216
00:08:02,740 --> 00:08:00,759
in the poor waters of Suboxone sediments

217
00:08:03,939 --> 00:08:02,750
the reason we have to distinguish

218
00:08:05,620 --> 00:08:03,949
between the two is that they actually

219
00:08:07,480 --> 00:08:05,630
have really different isotopic effects

220
00:08:08,950 --> 00:08:07,490
so I mentioned before there's a large

221
00:08:11,350 --> 00:08:08,960
kinetic isotope effect in the water

222
00:08:12,820 --> 00:08:11,360
column the thing with sediments is that

223
00:08:14,740 --> 00:08:12,830
they're thought to be diffusion limited

224
00:08:16,529 --> 00:08:14,750
systems and so you could imagine if you

225
00:08:18,580 --> 00:08:16,539
bring nitrate into a pore that's

226
00:08:20,769 --> 00:08:18,590
thermodynamically favorable for nitrate

227
00:08:22,719 --> 00:08:20,779
reduction you'd exhaust it all reacted

228
00:08:26,019 --> 00:08:22,729
completely and you get no corresponding

229
00:08:28,570 --> 00:08:26,029
isotope effect and so you can use either

230
00:08:32,139 --> 00:08:28,580
a top down isotope mass balance approach

231
00:08:34,860 --> 00:08:32,149
or a flux estimate approach to actually

232
00:08:36,610 --> 00:08:34,870
try to pin down how much each of these

233
00:08:38,819 --> 00:08:36,620
fluxes contributes to the total

234
00:08:41,980 --> 00:08:38,829
denitrification flux in the modern ocean

235
00:08:43,569 --> 00:08:41,990
and best estimates are somewhere on the

236
00:08:46,300 --> 00:08:43,579
order of a one to three ratio of water

237
00:08:48,730 --> 00:08:46,310
column to sedimentary denitrification so

238
00:08:50,500 --> 00:08:48,740

if you take that sort of box back to the

239
00:08:52,720 --> 00:08:50,510
envelope calculation and then just do

240
00:08:56,230 --> 00:08:52,730
the isotope mass balance it correspond

241
00:08:57,910 --> 00:08:56,240
to a surface ocean nitrate isotopic

242
00:09:01,330 --> 00:08:57,920
composition or something like plus five

243
00:09:04,360 --> 00:09:01,340
or six per mil so this is all

244
00:09:07,210 --> 00:09:04,370
been calibrated with the modern ocean so

245
00:09:09,250 --> 00:09:07,220
what we really got thinking then is okay

246
00:09:11,260 --> 00:09:09,260
the modern ocean is quite a bit

247
00:09:12,910 --> 00:09:11,270
different from the Precambrian if you

248
00:09:15,820 --> 00:09:12,920
consider that water combi nitrification

249
00:09:17,290 --> 00:09:15,830
is 1/4 of the total output despite the

250
00:09:19,390 --> 00:09:17,300
fact that it has to occur in oxygen

251
00:09:22,000 --> 00:09:19,400
minimum zone which are a negligible

252
00:09:24,280 --> 00:09:22,010
fraction of the ocean volume today that

253
00:09:25,750 --> 00:09:24,290
is really a testimony to the rapid

254
00:09:27,790 --> 00:09:25,760
kinetics or the faster rate of

255
00:09:29,500 --> 00:09:27,800
denitrification in the water column as

256
00:09:32,740 --> 00:09:29,510
opposed to in these sedimentary poor

257
00:09:37,210 --> 00:09:32,750
waters which are much vaster volume but

258
00:09:38,470 --> 00:09:37,220
not correspondingly vast reflux and so

259
00:09:40,300 --> 00:09:38,480
we thought that is well what if you

260
00:09:43,690 --> 00:09:40,310
cranked the ocean to Precambrian levels

261
00:09:45,190 --> 00:09:43,700
of maybe approaching 100% anoxia then

262
00:09:48,400 --> 00:09:45,200
presumably this number will start to

263
00:09:50,170 --> 00:09:48,410

reach 100% and that has implications yes

264
00:09:53,770 --> 00:09:50,180
for isotope mass balance but maybe also

265
00:09:55,870 --> 00:09:53,780
for the rate of nitrogen loss so just to

266
00:09:59,380 --> 00:09:55,880
flip through the things that model is

267
00:10:01,180 --> 00:09:59,390
showing us when we did that this is the

268
00:10:04,570 --> 00:10:01,190
total outputs from that surface ocean

269
00:10:06,340 --> 00:10:04,580
nitrate box so it's burial sedimentary

270
00:10:08,050 --> 00:10:06,350
and water column denitrification burial

271
00:10:10,780 --> 00:10:08,060
again it's really small less than 1% of

272
00:10:14,070 --> 00:10:10,790
the total output in the modern ocean if

273
00:10:16,900 --> 00:10:14,080
you just tie it to 25 and 75 balance

274
00:10:19,960 --> 00:10:16,910
just based on the literature then if you

275
00:10:21,550 --> 00:10:19,970
crank it towards 100% anoxia you'll see

276
00:10:24,900 --> 00:10:21,560
that water combi nitrification does

277
00:10:27,130 --> 00:10:24,910
approach 100 percent of the outputs and

278
00:10:29,740 --> 00:10:27,140
correspondingly then with this we just

279
00:10:31,510 --> 00:10:29,750
keep the same x-axis here the total rate

280
00:10:34,810 --> 00:10:31,520
of nitrogen removal this is our just

281
00:10:37,360 --> 00:10:34,820
scaled to modern is 1 will also increase

282
00:10:40,330 --> 00:10:37,370
just due to the greater rate of water

283
00:10:41,560 --> 00:10:40,340
column denitrification so if we keep

284
00:10:44,260 --> 00:10:41,570
this as a simple model we're not

285
00:10:46,000 --> 00:10:44,270
changing anything else you increase this

286
00:10:47,920 --> 00:10:46,010
output flux and basically you're not

287
00:10:49,750 --> 00:10:47,930
bearing as much biomass that's from

288
00:10:50,830 --> 00:10:49,760

nitrate assimilating organisms or

289
00:10:53,080 --> 00:10:50,840
another way to think of it is there's

290
00:10:56,050 --> 00:10:53,090
not enough nitrate left around to fuel

291
00:10:58,210 --> 00:10:56,060
those organisms and so you can see this

292
00:11:00,940 --> 00:10:58,220
born out then and the outputs for bulk

293
00:11:03,490 --> 00:11:00,950
sedimentary delta 15 n values where if

294
00:11:05,740 --> 00:11:03,500
you tie it to the modern value of about

295
00:11:07,930 --> 00:11:05,750
plus 5 if you were to crank the ocean a

296
00:11:10,600 --> 00:11:07,940
little more anoxic you get faster

297
00:11:12,280 --> 00:11:10,610
nitrate reduction in the water column a

298
00:11:14,020 --> 00:11:12,290
little more isotopic enrichment but

299
00:11:15,060 --> 00:11:14,030
there comes a tipping point where you

300
00:11:17,400 --> 00:11:15,070
remove

301
00:11:18,660 --> 00:11:17,410
nitrates so effectively that you don't

302
00:11:21,060 --> 00:11:18,670
leave much behind for nitrate

303
00:11:24,750 --> 00:11:21,070
assimilating organisms or in other words

304
00:11:27,030 --> 00:11:24,760
if you're in this dominantly anoxic

305
00:11:29,040 --> 00:11:27,040
portion of the plot then you're

306
00:11:30,510 --> 00:11:29,050
dominated by nitrogen fixing organisms

307
00:11:32,370 --> 00:11:30,520
as most of your biomass and you could be

308
00:11:36,990 --> 00:11:32,380
competitively excluding eukaryotes that

309
00:11:38,070 --> 00:11:37,000
rely on the dissolved nitrate so finally

310
00:11:39,510 --> 00:11:38,080
what does this mean then for the

311
00:11:42,150 --> 00:11:39,520
evolution of complex life on earth what

312
00:11:43,980 --> 00:11:42,160
was the trajectory we think it took so

313
00:11:45,150 --> 00:11:43,990

I've taken the data from that first data

314
00:11:48,540 --> 00:11:45,160
plot and just been them now by

315
00:11:50,850 --> 00:11:48,550
individual formation then put a trend

316
00:11:53,190 --> 00:11:50,860
through it it seems that this transition

317
00:11:55,110 --> 00:11:53,200
from nitrogen fixation to nitrate

318
00:11:57,510 --> 00:11:55,120
assimilation dominated ecosystems

319
00:11:58,710 --> 00:11:57,520
occurred around the goe and then it was

320
00:12:02,370 --> 00:11:58,720
sustained for a few hundred million

321
00:12:04,610 --> 00:12:02,380
years immediately following that so the

322
00:12:06,360 --> 00:12:04,620
question is was this a necessary and

323
00:12:08,070 --> 00:12:06,370
sufficient or necessary but not

324
00:12:10,680 --> 00:12:08,080
sufficient condition for the evolution

325
00:12:12,870 --> 00:12:10,690
of eukaryotes so the but it plotted here

326
00:12:14,550 --> 00:12:12,880
is the first compelling body fossil

327
00:12:17,310 --> 00:12:14,560
evidence for eukaryotic organisms which

328
00:12:18,449 --> 00:12:17,320
from the later paleo Proterozoic and if

329
00:12:20,100 --> 00:12:18,459
we were to take that to be the earliest

330
00:12:21,990 --> 00:12:20,110
occurrence then there would seem to be

331
00:12:24,060 --> 00:12:22,000
some temporal gap where either there's a

332
00:12:26,760 --> 00:12:24,070
biological or other environmental hurdle

333
00:12:29,340 --> 00:12:26,770
in the way of their evolution whereas

334
00:12:31,050 --> 00:12:29,350
perhaps with just the poor preservation

335
00:12:33,930 --> 00:12:31,060
of these sorts of fossils in deep time

336
00:12:35,010 --> 00:12:33,940
we're missing an earlier occurrence of

337
00:12:36,389 --> 00:12:35,020
these and so distinguishing between

338
00:12:37,740 --> 00:12:36,399

those two I think is important to

339
00:12:39,900 --> 00:12:37,750
understand what are the factors that

340
00:12:42,240 --> 00:12:39,910
ultimately control the emergence of

341
00:12:43,949 --> 00:12:42,250
complex life and other planets and then

342
00:12:46,470 --> 00:12:43,959
lastly I'll close just by saying that

343
00:12:47,940 --> 00:12:46,480
the retraction of these aerobic

344
00:12:49,530 --> 00:12:47,950
environments in the mid Proterozoic

345
00:12:51,630 --> 00:12:49,540
could perhaps help explain why

346
00:12:52,949 --> 00:12:51,640
eukaryotes may have emerged earlier but

347
00:12:54,840 --> 00:12:52,959
did not take on their dominant

348
00:12:57,300 --> 00:12:54,850
ecological aspect until the later

349
00:12:58,560 --> 00:12:57,310
Precambrian when these conditions return

350
00:13:02,069 --> 00:12:58,570
and then have stayed for the last

351
00:13:09,190 --> 00:13:02,079
several hundred million years so with

352
00:13:18,110 --> 00:13:12,320
thanks very much we have time for a

353
00:13:21,170 --> 00:13:18,120
question using scooch over hey Rick stop

354
00:13:22,670 --> 00:13:21,180
so one of the things that you encounter

355
00:13:24,530 --> 00:13:22,680
when you build a model like this you end

356
00:13:26,480 --> 00:13:24,540
up having to ramp the nitrogen cycle up

357
00:13:30,290 --> 00:13:26,490
to really high nitrogen fixation race

358
00:13:31,550 --> 00:13:30,300
something like ten times modern to

359
00:13:34,250 --> 00:13:31,560
support the very high denitrification

360
00:13:35,570 --> 00:13:34,260
loss as they go on have you looked

361
00:13:38,480 --> 00:13:35,580
you're thought much about that do you

362
00:13:40,070 --> 00:13:38,490
think a notion with 1,400 teragrams of

363
00:13:43,900 --> 00:13:40,080

your nitrogen fixation is totally

364
00:13:46,040 --> 00:13:43,910
reasonable no so we didn't try to

365
00:13:50,140 --> 00:13:46,050
correspondingly increase the amount of

366
00:13:52,190 --> 00:13:50,150
nitrogen fixation to allow a total

367
00:13:53,810 --> 00:13:52,200
nitrogen loss rate that is that much

368
00:13:56,900 --> 00:13:53,820
absolutely higher than today it's just

369
00:13:58,820 --> 00:13:56,910
those so if you basically in this simple

370
00:14:01,100 --> 00:13:58,830
run of it set nitrogen fixation at a

371
00:14:03,530 --> 00:14:01,110
constant we didn't tamper with that and

372
00:14:06,080 --> 00:14:03,540
so it's all relative to that baseline

373
00:14:08,090 --> 00:14:06,090
but if we had been planning on doing is

374
00:14:09,770 --> 00:14:08,100
ultimately running it with that time

375
00:14:11,390 --> 00:14:09,780
component so we just solved it in steady

376
00:14:13,910 --> 00:14:11,400
state or basically we've set a nitrogen

377
00:14:14,990 --> 00:14:13,920
fixation rate and it could be higher or

378
00:14:19,750 --> 00:14:15,000
lower than today

379
00:14:26,390 --> 00:14:24,470
so yes yeah in that scenario what we had

380
00:14:27,620 --> 00:14:26,400
been thinking would be the ultimate way

381
00:14:29,870 --> 00:14:27,630
to constrain it

382
00:14:31,430 --> 00:14:29,880
this is unable to tease out whether

383
00:14:32,750 --> 00:14:31,440
nitrogen versus foster should Alton

384
00:14:34,460 --> 00:14:32,760
Utley be the thing that's limiting

385
00:14:36,500 --> 00:14:34,470
productivity so in a sense we just tie a

386
00:14:39,200 --> 00:14:36,510
total productivity prescribed that based

387
00:14:44,030 --> 00:14:39,210
on phosphorus availability is - the main

388
00:14:45,269 --> 00:14:44,040

goal of it all simple thank you very

389
00:14:45,770 --> 00:14:45,279
much