Andrew Knoll

The Proterozoic Eon: Life & Environments in Earth's Middle Age

1
00:00:00,160 --> 00:00:13,720
[Music]

2
00:00:19,160 --> 00:00:16,250
all of you in this room and I think

3
00:00:22,929 --> 00:00:19,170
actually every intelligent six-year-old

4
00:00:25,880 --> 00:00:22,939
knows that there is a record of life

5
00:00:28,130 --> 00:00:25,890
incorporated into sedimentary rocks the

6
00:00:31,009 --> 00:00:28,140
fossil record and we learn early that

7
00:00:34,639 --> 00:00:31,019
some time ago there were dinosaurs they

8
00:00:38,150 --> 00:00:34,649
were preceded by earlier tetrapod

9
00:00:40,549 --> 00:00:38,160
vertebrates that were preceded by fish

10
00:00:42,200 --> 00:00:40,559
and really intelligent six-year-olds

11
00:00:44,600 --> 00:00:42,210
note that there's also a record of

12
00:00:48,580 --> 00:00:44,610
marine life such as trilobite s-- and

13
00:00:53,330 --> 00:00:48,590

that this entire conventional record of

14
00:00:55,549 --> 00:00:53,340
tracks trails bones skeletons takes up

15
00:00:59,779 --> 00:00:55,559
what's called the phanerozoic era or the

16
00:01:02,330 --> 00:00:59,789
last 541 million years now if you look

17
00:01:05,149 --> 00:01:02,340
on the right the phanerozoic era is

18
00:01:07,520 --> 00:01:05,159
placed in the context of the geologic

19
00:01:09,859 --> 00:01:07,530
the age of the earth as a whole and

20
00:01:13,609 --> 00:01:09,869
we've heard a lot at this meeting about

21
00:01:18,109 --> 00:01:13,619
things that go on in the Hadean and

22
00:01:20,060 --> 00:01:18,119
Archaean eras that somehow must connect

23
00:01:22,550 --> 00:01:20,070
up to the things that people like Simon

24
00:01:25,280 --> 00:01:22,560
Conway Morris talked about which have

25
00:01:28,010 --> 00:01:25,290
their roots in in phanerozoic evolution

26
00:01:33,350 --> 00:01:28,020
and what connects those is the

27
00:01:35,090 --> 00:01:33,360
Proterozoic era and its record now there

28
00:01:37,429 --> 00:01:35,100
are two reasons why we might be

29
00:01:41,030 --> 00:01:37,439
interested in the Proterozoic one is for

30
00:01:43,160 --> 00:01:41,040
its own phenomenology this is an era

31
00:01:47,149 --> 00:01:43,170
nearly half of all recorded Earth

32
00:01:49,700 --> 00:01:47,159
history it begins or when it begins the

33
00:01:53,090 --> 00:01:49,710
earth basically has no oxygen in the

34
00:01:55,969 --> 00:01:53,100
atmosphere and has a biota made up of

35
00:01:58,700 --> 00:01:55,979
bacteria and archaea and by the time it

36
00:02:02,179 --> 00:01:58,710
ends we had a relatively oxygen-rich

37
00:02:04,520 --> 00:02:02,189
atmosphere that supports a biota that

38
00:02:07,760 --> 00:02:04,530

includes animals macroscopic seaweeds

39
00:02:09,410 --> 00:02:07,770
and the like between those both at the

40
00:02:12,080 --> 00:02:09,420
beginning and again toward the end of

41
00:02:12,590 --> 00:02:12,090
the Proterozoic era are as we heard

42
00:02:15,470 --> 00:02:12,600
yesterday

43
00:02:18,010 --> 00:02:15,480
they ice ages of a magnitude that is

44
00:02:23,720 --> 00:02:18,020
unknown over the last 500 million years

45
00:02:27,170 --> 00:02:23,730
also the emergence of eukaryotes as a

46
00:02:29,930 --> 00:02:27,180
major part of ecosystems so it's a rich

47
00:02:33,710 --> 00:02:29,940
record that I think one can look at for

48
00:02:36,980 --> 00:02:33,720
its own sake and at the same time it is

49
00:02:39,230 --> 00:02:36,990
a record that is much richer much more

50
00:02:41,480 --> 00:02:39,240
complete than the rather fragmentary

51
00:02:43,280 --> 00:02:41,490
record of the Archaean and therefore it

52
00:02:45,560 --> 00:02:43,290
can actually provide something of a

53
00:02:48,200 --> 00:02:45,570
template for thinking about how we might

54
00:02:51,380 --> 00:02:48,210
interpret the earlier record not to

55
00:02:54,410 --> 00:02:51,390
mention guide us in the exploration of

56
00:02:57,080 --> 00:02:54,420
sedimentary rocks on other planets now

57
00:02:59,830 --> 00:02:57,090
if the phanerozoic by definition and

58
00:03:03,080 --> 00:02:59,840
etymology is the record is the time of

59
00:03:06,140 --> 00:03:03,090
visible animals if we place that in the

60
00:03:08,360 --> 00:03:06,150
context of a molecular phylogeny and

61
00:03:10,610 --> 00:03:08,370
there's simply a notional phylogeny

62
00:03:14,690 --> 00:03:10,620
there and I understand that just about

63
00:03:16,670 --> 00:03:14,700

every note on this will be controversial

64
00:03:19,790 --> 00:03:16,680
to someone but I think everyone would

65
00:03:21,880 --> 00:03:19,800
agree that the animals that make up that

66
00:03:25,670 --> 00:03:21,890
conventional record of the phanerozoic

67
00:03:28,190 --> 00:03:25,680
constitute only the distal tips of one

68
00:03:31,100 --> 00:03:28,200
branch of the tree and that the deeper

69
00:03:34,280 --> 00:03:31,110
record and therefore the life that we

70
00:03:38,630 --> 00:03:34,290
might infer prior to the phanerozoic era

71
00:03:40,670 --> 00:03:38,640
is largely microbial so let's look at

72
00:03:44,540 --> 00:03:40,680
some sedimentary rocks from the

73
00:03:45,980 --> 00:03:44,550
proterozoic eon these are some rocks

74
00:03:48,320 --> 00:03:45,990
that when I was younger and fitter I

75
00:03:51,290 --> 00:03:48,330
worked on for a number of years these

76
00:03:53,900 --> 00:03:51,300
are carbonate rocks exposed in the

77
00:03:56,090 --> 00:03:53,910
Arctic island of Spitsbergen and what

78
00:03:59,060 --> 00:03:56,100
you're looking at there is about a

79
00:04:02,420 --> 00:03:59,070
thousand meters of carbonate rocks

80
00:04:05,930 --> 00:04:02,430
deposited between about 800 and 740

81
00:04:08,870 --> 00:04:05,940
million years ago there are no skeletons

82
00:04:11,990 --> 00:04:08,880
no bones no tracks or trails no evidence

83
00:04:13,910 --> 00:04:12,000
of animal life at all and so at this

84
00:04:16,190 --> 00:04:13,920
point the search for life becomes a

85
00:04:19,640 --> 00:04:16,200
practical one if we believe that the

86
00:04:22,280 --> 00:04:19,650
antecedent record was microbial should

87
00:04:25,340 --> 00:04:22,290
we expect the sedimentary rock record to

88
00:04:26,480 --> 00:04:25,350

preserve a tractable record of tiny

89
00:04:28,950 --> 00:04:26,490
micro or

90
00:04:31,830 --> 00:04:28,960
this also illustrates one of the

91
00:04:34,619 --> 00:04:31,840
advantages of essentially working out

92
00:04:37,019 --> 00:04:34,629
our rules of the game for exploring deep

93
00:04:40,379 --> 00:04:37,029
earth history that if you look at this

94
00:04:43,080 --> 00:04:40,389
pile of of carbonates if you would take

95
00:04:44,749 --> 00:04:43,090
all of the early Archaean carbonates

96
00:04:47,580 --> 00:04:44,759
that have ever been measured from

97
00:04:49,980 --> 00:04:47,590
basically everywhere in the world and

98
00:04:51,869 --> 00:04:49,990
stacked them on top of each other they

99
00:04:55,379 --> 00:04:51,879
would be about as thick as the little

100
00:04:57,659 --> 00:04:55,389
beige band right in the top of the black

101
00:05:00,570 --> 00:04:57,669
one at the corner of that picture so the

102
00:05:03,179 --> 00:05:00,580
record is indeed much richer and it is

103
00:05:06,089 --> 00:05:03,189
preserved rather differently so what do

104
00:05:08,760 --> 00:05:06,099
we see if we hone in on just one bed of

105
00:05:13,439 --> 00:05:08,770
those carbonates you can see here that

106
00:05:16,559 --> 00:05:13,449
there are these wavy laminated dolomite

107
00:05:18,420 --> 00:05:16,569
we know from just comparisons with the

108
00:05:21,119 --> 00:05:18,430
modern world where we can see processes

109
00:05:23,309 --> 00:05:21,129
in action that the kind of wavy textures

110
00:05:25,679 --> 00:05:23,319
that you see in that outcrop are

111
00:05:28,499 --> 00:05:25,689
generally associated with places where

112
00:05:30,420 --> 00:05:28,509
microbial mats interact with

113
00:05:33,990 --> 00:05:30,430

accumulating fine-grained carbonate

114
00:05:36,360 --> 00:05:34,000
sediments that tends to happen in

115
00:05:39,149 --> 00:05:36,370
coastal environments and we can see it

116
00:05:40,920 --> 00:05:39,159
in places like the Bahamas today if you

117
00:05:43,019 --> 00:05:40,930
look in the upper center of that picture

118
00:05:45,420 --> 00:05:43,029
you'll see something that's bowed up in

119
00:05:47,189 --> 00:05:45,430
the button-down parlance of geologists

120
00:05:49,760 --> 00:05:47,199
that's called a teepee structure and

121
00:05:52,320 --> 00:05:49,770
they tend to form in the super tidal

122
00:05:54,510 --> 00:05:52,330
environment that is the most landward

123
00:05:57,300 --> 00:05:54,520
and and most frequently exposed of

124
00:05:59,369 --> 00:05:57,310
coastal environments where evaporation

125
00:06:01,279 --> 00:05:59,379
causes precipitation of carbonate

126
00:06:04,139 --> 00:06:01,289
minerals and the pressure from that

127
00:06:06,959 --> 00:06:04,149
precipitation within pore waters causes

128
00:06:10,079 --> 00:06:06,969
beds to buckle so what we learn from

129
00:06:11,969 --> 00:06:10,089
this is first and foremost is that not

130
00:06:14,670 --> 00:06:11,979
only does the stacking of sedimentary

131
00:06:16,889 --> 00:06:14,680
rocks give us a record of time but

132
00:06:18,510 --> 00:06:16,899
physical and chemical features in those

133
00:06:20,730 --> 00:06:18,520
sedimentary rocks tell us something

134
00:06:22,740 --> 00:06:20,740
about environment so we actually have a

135
00:06:27,629 --> 00:06:22,750
time and space framework for thinking

136
00:06:30,629 --> 00:06:27,639
about life now if you took a piece of

137
00:06:31,889 --> 00:06:30,639
that carbonate and just put it made a

138
00:06:34,379 --> 00:06:31,899

thin section and put it under a

139
00:06:36,209 --> 00:06:34,389
microscope all you would see was

140
00:06:37,619 --> 00:06:36,219
interlocking crystals of dolomite not

141
00:06:39,540 --> 00:06:37,629
particularly interesting to the

142
00:06:40,950 --> 00:06:39,550
paleontological high

143
00:06:43,410 --> 00:06:40,960
but if you went to those black

144
00:06:46,740 --> 00:06:43,420
concretions that you see in there

145
00:06:49,500 --> 00:06:46,750
those consist of silica sio2 or chert

146
00:06:51,420 --> 00:06:49,510
which formed soon after the deposition

147
00:06:53,820 --> 00:06:51,430
of the parent carbonates and actually

148
00:06:56,280 --> 00:06:53,830
grew within the sediments at the expense

149
00:06:58,950 --> 00:06:56,290
of carbonates in a way that actually

150
00:07:01,920 --> 00:06:58,960
preserves micron scale textures of the

151
00:07:04,500 --> 00:07:01,930
original sediment so if you take those

152
00:07:06,720 --> 00:07:04,510
shirts make thin sections put them under

153
00:07:09,020 --> 00:07:06,730
the microscope what you will see is what

154
00:07:11,010 --> 00:07:09,030
you see in the bottom which are well

155
00:07:13,710 --> 00:07:11,020
morphologically preserved micro fossils

156
00:07:16,740 --> 00:07:13,720
each cell like unit there is about 4

157
00:07:20,400 --> 00:07:16,750
microns in diameter so the good news is

158
00:07:22,950 --> 00:07:20,410
that we actually have mechanisms in the

159
00:07:25,310 --> 00:07:22,960
Proterozoic Eon that preserve in an

160
00:07:28,560 --> 00:07:25,320
identifiable intractable state a

161
00:07:30,750 --> 00:07:28,570
microfossil record and indeed when you

162
00:07:33,710 --> 00:07:30,760
look across different environments in

163
00:07:36,390 --> 00:07:33,720

this package of sedimentary rocks from

164
00:07:38,820 --> 00:07:36,400
Spitsbergen not only in solicit

165
00:07:41,280 --> 00:07:38,830
carbonates but in fine-grained solicit

166
00:07:43,050 --> 00:07:41,290
clastic rocks that is to say shales we

167
00:07:46,170 --> 00:07:43,060
find a variety of things that on the

168
00:07:48,510 --> 00:07:46,180
right-hand side are very similar to

169
00:07:51,210 --> 00:07:48,520
living cyanobacteria and on the

170
00:07:53,310 --> 00:07:51,220
left-hand side we see things such as on

171
00:07:55,950 --> 00:07:53,320
the left where we have a fragment of a

172
00:07:58,950 --> 00:07:55,960
macroscopic structure that's in acidic

173
00:08:02,550 --> 00:07:58,960
in in organization very likely green

174
00:08:04,350 --> 00:08:02,560
algal we have 100 micron tests very

175
00:08:06,840 --> 00:08:04,360
similar to those of different kinds of

176
00:08:08,490 --> 00:08:06,850
tests date and maybe we find cysts like

177
00:08:11,790 --> 00:08:08,500
we see in the lower centre that are

178
00:08:15,120 --> 00:08:11,800
about 500 microns in diameter so there

179
00:08:18,420 --> 00:08:15,130
is a micro fossil record a more

180
00:08:20,310 --> 00:08:18,430
conspicuous record turns out to be the

181
00:08:23,640 --> 00:08:20,320
record of stromatolites that most of you

182
00:08:25,590 --> 00:08:23,650
are familiar with the lower-left is sort

183
00:08:27,720 --> 00:08:25,600
of the Mecca Mecca for Precambrian

184
00:08:30,690 --> 00:08:27,730
paleontology that's Shark Bay in Western

185
00:08:34,380 --> 00:08:30,700
Australia where again in the modern

186
00:08:37,470 --> 00:08:34,390
world we can actually see the processes

187
00:08:40,940 --> 00:08:37,480
by which microbial mat communities

188
00:08:44,790 --> 00:08:40,950

interact with sediments to produce these

189
00:08:46,530 --> 00:08:44,800
upwardly doming laminated structures and

190
00:08:49,670 --> 00:08:46,540
on the right you can see stromatolites

191
00:08:51,540 --> 00:08:49,680
that were nucleated on just blocks

192
00:08:53,460 --> 00:08:51,550
exactly the way the Shark Bay

193
00:08:55,740 --> 00:08:53,470
stromatolite SAR

194
00:08:58,920 --> 00:08:55,750
and then accreted by the trappin binding

195
00:09:00,420 --> 00:08:58,930
and precipitation of sediments the

196
00:09:02,670 --> 00:09:00,430
suppressed associated with microbial

197
00:09:05,280 --> 00:09:02,680
mats and as you see in the cliff behind

198
00:09:08,100 --> 00:09:05,290
that skier there you sometimes see

199
00:09:10,410 --> 00:09:08,110
structures that are several meters high

200
00:09:12,900 --> 00:09:10,420
and and tens of meters thick which are

201
00:09:14,850 --> 00:09:12,910
actually biomes or reefs which are

202
00:09:17,280 --> 00:09:14,860
constructed by these microbial

203
00:09:19,590 --> 00:09:17,290
communities so again there's a there's a

204
00:09:23,310 --> 00:09:19,600
macroscopic conspicuous and widespread

205
00:09:25,560 --> 00:09:23,320
record of benthic microbial communities

206
00:09:27,750 --> 00:09:25,570
preserved in these stromatolites and

207
00:09:30,420 --> 00:09:27,760
then of course as we've heard a little

208
00:09:32,220 --> 00:09:30,430
bit about earlier in the meeting and and

209
00:09:35,070 --> 00:09:32,230
most of you know there are at least

210
00:09:37,470 --> 00:09:35,080
several chemical ways in which life can

211
00:09:40,730 --> 00:09:37,480
impart a fingerprint to sedimentary

212
00:09:42,960 --> 00:09:40,740
rocks there is an isotopic fractionation

213
00:09:47,160 --> 00:09:42,970

associated with autotrophic carbon

214
00:09:49,620 --> 00:09:47,170
fixation so that if you look at in the

215
00:09:53,430 --> 00:09:49,630
Bahamas today the carbon isotopic

216
00:09:54,570 --> 00:09:53,440
composition of carbonates and compare

217
00:09:57,780 --> 00:09:54,580
that with the carbon isotopic

218
00:10:00,180 --> 00:09:57,790
composition of biologically produced

219
00:10:02,520 --> 00:10:00,190
organic matter that is sedimented with

220
00:10:06,000 --> 00:10:02,530
those carbonates they will differ by

221
00:10:08,790 --> 00:10:06,010
about 25 parts per thousand or per mil

222
00:10:11,100 --> 00:10:08,800
and broadly speaking that kind of

223
00:10:14,370 --> 00:10:11,110
fractionation pattern between carbonates

224
00:10:16,440 --> 00:10:14,380
and and organic matter really

225
00:10:18,780 --> 00:10:16,450
characterizes the known the known

226
00:10:21,780 --> 00:10:18,790
sedimentary record so we can start to

227
00:10:23,670 --> 00:10:21,790
interrogate the microbiological carbon

228
00:10:26,720 --> 00:10:23,680
cycle in the Proterozoic one can do the

229
00:10:30,600 --> 00:10:26,730
same thing for for sulfur as well and

230
00:10:34,950 --> 00:10:30,610
indeed under certain conditions there

231
00:10:36,630 --> 00:10:34,960
are molecular fossils preserved DNA and

232
00:10:39,870 --> 00:10:36,640
RNA are too good to eat so they

233
00:10:42,960 --> 00:10:39,880
basically are not found in in rocks of

234
00:10:45,720 --> 00:10:42,970
this age but lipids can actually

235
00:10:49,400 --> 00:10:45,730
preserve so we have things like stair

236
00:10:52,920 --> 00:10:49,410
Eanes the geologically stable forms of

237
00:10:55,980 --> 00:10:52,930
sterols hope annoyed z' derived from

238
00:10:58,380 --> 00:10:55,990

bacteria and independently of the

239
00:11:01,920 --> 00:10:58,390
morphological record these can enhance

240
00:11:05,520 --> 00:11:01,930
our sense of microbial physiology and

241
00:11:07,079 --> 00:11:05,530
diversities in the Proterozoic so in

242
00:11:09,509 --> 00:11:07,089
rocks that are 750

243
00:11:12,179 --> 00:11:09,519
million years old we see a fairly

244
00:11:15,179 --> 00:11:12,189
extensive record associated with

245
00:11:17,129 --> 00:11:15,189
sedimentary rocks that have textures

246
00:11:20,369 --> 00:11:17,139
that in general we understand from

247
00:11:22,290 --> 00:11:20,379
looking at modern analogs if we just for

248
00:11:24,860 --> 00:11:22,300
a moment double the age and go back to

249
00:11:27,420 --> 00:11:24,870
things that are 1500 million years old

250
00:11:29,970 --> 00:11:27,430
these are some rocks in the upper left

251
00:11:33,150 --> 00:11:29,980
from northern Siberia and basically

252
00:11:36,030 --> 00:11:33,160
everything I just said about 750 million

253
00:11:39,889 --> 00:11:36,040
year old rocks holds for these there are

254
00:11:42,540 --> 00:11:39,899
microphones those are 10 micron bars

255
00:11:44,759 --> 00:11:42,550
some of which are comparable to sign of

256
00:11:47,160 --> 00:11:44,769
bacteria others of which appear to be

257
00:11:49,290 --> 00:11:47,170
eukaryotic there are carbon and sulfur

258
00:11:52,590 --> 00:11:49,300
isotopic signatures there are molecular

259
00:11:54,869 --> 00:11:52,600
biomarkers and there are stromatolites I

260
00:11:57,629 --> 00:11:54,879
like this picture in the lower left for

261
00:11:59,999 --> 00:11:57,639
two reasons one is that my field partner

262
00:12:02,280 --> 00:12:00,009
here a man named Misha samokov is

263
00:12:04,259 --> 00:12:02,290

precisely 2 meters tall when he has his

264
00:12:05,970 --> 00:12:04,269
hat on so he's a great guy to have in

265
00:12:08,129 --> 00:12:05,980
the field so that you can get him as a

266
00:12:10,290 --> 00:12:08,139
scale for any picture that you make and

267
00:12:13,769 --> 00:12:10,300
you if you look at that picture you

268
00:12:15,720 --> 00:12:13,779
might say to yourself oh I see that

269
00:12:18,689 --> 00:12:15,730
little bun in the center of the picture

270
00:12:21,059 --> 00:12:18,699
is a microbial bio herb and you're

271
00:12:23,900 --> 00:12:21,069
exactly right that's a little reef maybe

272
00:12:26,280 --> 00:12:23,910
twice the side of size of this lectern

273
00:12:29,489 --> 00:12:26,290
but if you actually look at the surface

274
00:12:32,220 --> 00:12:29,499
on which Misha is standing it's it is a

275
00:12:34,290 --> 00:12:32,230
domed surface and it is part of a storm

276
00:12:37,470 --> 00:12:34,300
at oolitic biome that's probably about

277
00:12:40,949 --> 00:12:37,480
the size of this room and in fact the

278
00:12:43,350 --> 00:12:40,959
entire wall of rock behind Misha is part

279
00:12:45,600 --> 00:12:43,360
of a still larger biome that would be

280
00:12:47,400 --> 00:12:45,610
somewhat larger than this building so

281
00:12:49,769 --> 00:12:47,410
again we see that through the

282
00:12:52,819 --> 00:12:49,779
proterozoic eon microbial mat

283
00:12:56,400 --> 00:12:52,829
communities are largely surfacing

284
00:12:57,780 --> 00:12:56,410
environments from the the coastline all

285
00:13:00,660 --> 00:12:57,790
the way to the bottom of the photic zone

286
00:13:02,730 --> 00:13:00,670
and they can accrete structures that

287
00:13:07,590 --> 00:13:02,740
have dimensions equivalent to those of

288
00:13:09,239 --> 00:13:07,600

modern coral reefs now I'm not going to

289
00:13:12,079 --> 00:13:09,249
talk about the Archaean we've heard a

290
00:13:15,720 --> 00:13:12,089
lot about it except to say that this

291
00:13:18,619 --> 00:13:15,730
well-preserved record of life in

292
00:13:20,950 --> 00:13:18,629
Proterozoic rocks does provide us with

293
00:13:23,260 --> 00:13:20,960
something of a baseline

294
00:13:25,480 --> 00:13:23,270
that can help us to interpret the the

295
00:13:28,780 --> 00:13:25,490
deeper record so what you see here on

296
00:13:31,360 --> 00:13:28,790
the left are mr. Mehta likes that have

297
00:13:34,450 --> 00:13:31,370
been described by Abbie Elwood and

298
00:13:36,600 --> 00:13:34,460
others from the Pilbara region in

299
00:13:40,090 --> 00:13:36,610
Western Australia around

300
00:13:42,880 --> 00:13:40,100
2.3.4 excuse me billion years old and if

301
00:13:46,030 --> 00:13:42,890
you look at them the bottom half of the

302
00:13:48,910 --> 00:13:46,040
left-hand panel is very comforting you

303
00:13:50,560 --> 00:13:48,920
see these domed laminated structures

304
00:13:52,900 --> 00:13:50,570
that look much like the stromatolites

305
00:13:54,460 --> 00:13:52,910
we've just seen but it becomes a little

306
00:13:56,410 --> 00:13:54,470
more disconcerting when you continue

307
00:13:58,780 --> 00:13:56,420
upward and notice that the fabrics now

308
00:14:03,310 --> 00:13:58,790
become vertical what you're looking at

309
00:14:05,620 --> 00:14:03,320
are actually precipitated a sick euler

310
00:14:07,810 --> 00:14:05,630
aragonite crystals have precipitated on

311
00:14:11,290 --> 00:14:07,820
the sea floor this is an environment

312
00:14:14,350 --> 00:14:11,300
where carbonate was precipitating in

313
00:14:17,800 --> 00:14:14,360

remarkable fashion and we know from both

314
00:14:20,470 --> 00:14:17,810
today and proterozoic examples that when

315
00:14:23,590 --> 00:14:20,480
you have these high rates of carbonate

316
00:14:25,630 --> 00:14:23,600
precipitation you can make dough most

317
00:14:28,840 --> 00:14:25,640
laminated structures that are not

318
00:14:31,000 --> 00:14:28,850
templated by microbial mats so simply

319
00:14:33,430 --> 00:14:31,010
finding something that's Domo when the

320
00:14:35,590 --> 00:14:33,440
textures are precipitated is probably

321
00:14:37,270 --> 00:14:35,600
insufficient to declare victory and

322
00:14:39,070 --> 00:14:37,280
indeed when you look at the lower

323
00:14:40,240 --> 00:14:39,080
right-hand panel I mean that's but

324
00:14:43,180 --> 00:14:40,250
there's nothing that seems particularly

325
00:14:47,380 --> 00:14:43,190
biological about that is just a stacked

326
00:14:50,500 --> 00:14:47,390
set of precipitated carbonates on the

327
00:14:52,630 --> 00:14:50,510
other hand by looking at Proterozoic

328
00:14:54,750 --> 00:14:52,640
examples we find that if you go in and

329
00:14:58,060 --> 00:14:54,760
look microscopically at petrological

330
00:15:00,700 --> 00:14:58,070
textures you can sometimes find

331
00:15:03,940 --> 00:15:00,710
fingerprints of microbial mats and

332
00:15:07,540 --> 00:15:03,950
indeed when Abby and I and others looked

333
00:15:11,890 --> 00:15:07,550
at these in the in the these examples

334
00:15:14,290 --> 00:15:11,900
from the Pilbara we do see Petra logical

335
00:15:17,140 --> 00:15:14,300
evidence that there was at least a

336
00:15:19,030 --> 00:15:17,150
microbial influence on these but you

337
00:15:21,820 --> 00:15:19,040
really need to get at that level and

338
00:15:23,650 --> 00:15:21,830

that's a lesson from the Proterozoic how

339
00:15:25,810 --> 00:15:23,660
many at all have done similar things in

340
00:15:30,100 --> 00:15:25,820
rocks of comparable age from South

341
00:15:32,500 --> 00:15:30,110
Africa and indeed there's another thing

342
00:15:34,750 --> 00:15:32,510
that we can learn from the Proterozoic

343
00:15:37,110 --> 00:15:34,760
that can help us think about

344
00:15:40,829 --> 00:15:37,120
microstructures in the Archaean

345
00:15:43,180 --> 00:15:40,839
certainly the search image for

346
00:15:46,090 --> 00:15:43,190
exploration for microfossils in the

347
00:15:48,670 --> 00:15:46,100
Archaean comes from the success of

348
00:15:51,610 --> 00:15:48,680
finding microfossils incorporated in

349
00:15:53,620 --> 00:15:51,620
church in Proterozoic rocks on the other

350
00:15:55,990 --> 00:15:53,630
hand one thing we know from petrology

351
00:15:58,420 --> 00:15:56,000
and geochemistry is that many early

352
00:16:01,030 --> 00:15:58,430
Archaean shirts have been influenced by

353
00:16:04,120 --> 00:16:01,040
hydrothermal fluid flow and so we might

354
00:16:06,790 --> 00:16:04,130
want to ask is there an influence on the

355
00:16:09,400 --> 00:16:06,800
preserved textures of those rocks from

356
00:16:11,230 --> 00:16:09,410
hydrothermal activity and a way to

357
00:16:14,019 --> 00:16:11,240
evaluate that is to go into the

358
00:16:15,129 --> 00:16:14,029
Proterozoic where in general we have

359
00:16:18,370 --> 00:16:15,139
well-preserved

360
00:16:21,819 --> 00:16:18,380
fabrics and fossils and then look at

361
00:16:24,040 --> 00:16:21,829
local hydrothermal fluid flow and see

362
00:16:25,360 --> 00:16:24,050
what that does to the textures so what

363
00:16:29,650 --> 00:16:25,370

you're looking at in the lower right

364
00:16:33,400 --> 00:16:29,660
hand corner is a thin section of solicit

365
00:16:36,040 --> 00:16:33,410
I carbonate from some 740 million year

366
00:16:38,590 --> 00:16:36,050
old rocks in Canada if you look at the

367
00:16:40,840 --> 00:16:38,600
brown areas on the left and right they

368
00:16:44,259 --> 00:16:40,850
have textures which are very similar to

369
00:16:47,110 --> 00:16:44,269
those of early dye genetic charts in the

370
00:16:48,699 --> 00:16:47,120
Proterozoic in general but the white and

371
00:16:51,280 --> 00:16:48,709
purple areas that you see through the

372
00:16:53,769 --> 00:16:51,290
center of the slide are areas of

373
00:16:56,680 --> 00:16:53,779
concentrated hydrothermal fluid flow and

374
00:16:58,389 --> 00:16:56,690
within those all of the original

375
00:17:01,030 --> 00:16:58,399
textures of the church have been

376
00:17:04,270 --> 00:17:01,040
obliterated but as you see in the two

377
00:17:05,919 --> 00:17:04,280
panels of both that thin section that

378
00:17:09,159 --> 00:17:05,929
you both have the mobilization of

379
00:17:12,699 --> 00:17:09,169
organic mard matter and then it's it's

380
00:17:16,360 --> 00:17:12,709
recon dense ation forming 10 to 20 to 30

381
00:17:19,000 --> 00:17:16,370
micron steroidal micro structures now we

382
00:17:21,760 --> 00:17:19,010
know that there's fluid flow in the

383
00:17:25,630 --> 00:17:21,770
Archaean the upper panel on on the right

384
00:17:29,020 --> 00:17:25,640
shows organic matter condensing around a

385
00:17:31,480 --> 00:17:29,030
rhombohedral rhombohedral crystal and so

386
00:17:35,430 --> 00:17:31,490
we know that happens so the question is

387
00:17:38,320 --> 00:17:35,440
can we then make a judgment about

388
00:17:41,490 --> 00:17:38,330

whether what we're looking at in these

389
00:17:44,700 --> 00:17:41,500
very old roxas is associated with

390
00:17:48,140 --> 00:17:44,710
hydrothermal activity or maybe

391
00:17:50,030 --> 00:17:48,150
excitingly true biological remains and

392
00:17:51,620 --> 00:17:50,040
and I'm not saying that all things that

393
00:17:54,860 --> 00:17:51,630
have been reported as fossils in the

394
00:17:57,980 --> 00:17:54,870
Archaean are other than that it's just

395
00:18:00,049 --> 00:17:57,990
that there's probably one more loop we

396
00:18:03,770 --> 00:18:00,059
need to go through to have confidence

397
00:18:07,490 --> 00:18:03,780
and this is where that preservation of

398
00:18:08,690 --> 00:18:07,500
textures comes the the expectation at

399
00:18:12,350 --> 00:18:08,700
least for the work that we and others

400
00:18:14,510 --> 00:18:12,360
have done on hydrothermal alteration in

401
00:18:17,510 --> 00:18:14,520
the Proterozoic is that it will tend to

402
00:18:20,480 --> 00:18:17,520
obliterate textures so if on the Left

403
00:18:22,070 --> 00:18:20,490
where we're looking at rocks that are a

404
00:18:26,799 --> 00:18:22,080
little more than three billion years old

405
00:18:29,870 --> 00:18:26,809
from South Africa if you have preserved

406
00:18:31,790 --> 00:18:29,880
textures on a coarser scale and what

407
00:18:34,549 --> 00:18:31,800
you're looking at there is simply a

408
00:18:38,270 --> 00:18:34,559
shard of some laminated possibly matte

409
00:18:41,150 --> 00:18:38,280
material that actually contains eight to

410
00:18:43,490 --> 00:18:41,160
ten microns spheroids again I don't know

411
00:18:45,560 --> 00:18:43,500
that these are unequivocally fossils but

412
00:18:48,580 --> 00:18:45,570
at least they are in the context of

413
00:18:51,650 --> 00:18:48,590

preserved texture so again I think that

414
00:18:54,049 --> 00:18:51,660
the experience with better preserved

415
00:18:56,750 --> 00:18:54,059
materials in the Proterozoic can at

416
00:18:58,610 --> 00:18:56,760
least help us as we evaluate this

417
00:19:01,820 --> 00:18:58,620
precious but limited record of the

418
00:19:07,100 --> 00:19:01,830
Archaean now just a few words about

419
00:19:09,740 --> 00:19:07,110
cyanobacteria in the Proterozoic many of

420
00:19:12,020 --> 00:19:09,750
the sign and bacteria like fossils found

421
00:19:15,530 --> 00:19:12,030
in Proterozoic rocks seem to be

422
00:19:18,049 --> 00:19:15,540
generally similar to living sign of

423
00:19:20,360 --> 00:19:18,059
bacteria there are some populations that

424
00:19:23,299 --> 00:19:20,370
are very specifically similar so if you

425
00:19:25,700 --> 00:19:23,309
went to the Bahamas today and looked at

426
00:19:28,730 --> 00:19:25,710
who is these little concentric carbonate

427
00:19:31,520 --> 00:19:28,740
balls that accumulate in the in the

428
00:19:33,880 --> 00:19:31,530
tidal zone you would find that as we see

429
00:19:37,970 --> 00:19:33,890
in the lower right there they are

430
00:19:39,980 --> 00:19:37,980
festooned with endo lithic or boring

431
00:19:42,770 --> 00:19:39,990
sign a bacteria that basically burrow

432
00:19:46,669 --> 00:19:42,780
into them and live beneath the surface

433
00:19:48,950 --> 00:19:46,679
of the hood they are diverse they have

434
00:19:50,870 --> 00:19:48,960
for sign of bacteria rather complex

435
00:19:52,820 --> 00:19:50,880
developmental patterns they show

436
00:19:56,120 --> 00:19:52,830
evidence of behavior in the sense that

437
00:19:58,840 --> 00:19:56,130
today we can see things wrote down into

438
00:20:01,310 --> 00:19:58,850

the wood until they reach a point of

439
00:20:02,419 --> 00:20:01,320
light limitation and then they grow back

440
00:20:05,840 --> 00:20:02,429
up again we see

441
00:20:07,399 --> 00:20:05,850
same thing in the Proterozoic what we're

442
00:20:10,190 --> 00:20:07,409
looking at in the upper left is simply

443
00:20:12,980 --> 00:20:10,200
cross bedded who is there's a solicit I

444
00:20:15,259 --> 00:20:12,990
do it in the lower left and you can see

445
00:20:17,899 --> 00:20:15,269
that all around the surface it has these

446
00:20:20,450 --> 00:20:17,909
n dualistic structures one of which

447
00:20:22,609 --> 00:20:20,460
about a millimeter long from end to end

448
00:20:26,529 --> 00:20:22,619
is seen in the upper right and in this

449
00:20:29,299 --> 00:20:26,539
case we actually have several

450
00:20:31,700 --> 00:20:29,309
populations that are essentially

451
00:20:35,180 --> 00:20:31,710
indistinguishable from modern

452
00:20:39,350 --> 00:20:35,190
populations found in in who is today and

453
00:20:41,480 --> 00:20:39,360
so that we think this gives us a rare

454
00:20:44,090 --> 00:20:41,490
calibration point for looking at

455
00:20:46,730 --> 00:20:44,100
molecular clocks for example inside a

456
00:20:48,259 --> 00:20:46,740
bacteria and then there are these things

457
00:20:50,899 --> 00:20:48,269
in the upper right one thing that we

458
00:20:52,700 --> 00:20:50,909
find in rocks beginning around 1600

459
00:20:55,730 --> 00:20:52,710
million years ago are these sort of

460
00:20:58,519 --> 00:20:55,740
elongate cigar like structures that

461
00:21:02,779 --> 00:20:58,529
would be about 60 microns long they are

462
00:21:04,940 --> 00:21:02,789
very similar to the akan eats of gnostic

463
00:21:06,799 --> 00:21:04,950

alien sign of bacteria which some of you

464
00:21:09,049 --> 00:21:06,809
will know is the one clade of sign of

465
00:21:12,139 --> 00:21:09,059
bacteria that differentiates different

466
00:21:15,739 --> 00:21:12,149
cell types it has been suggested that

467
00:21:18,379 --> 00:21:15,749
maybe these are something else but one

468
00:21:21,350 --> 00:21:18,389
of the things that I think helps us to

469
00:21:23,690 --> 00:21:21,360
interpret these structures as achenes

470
00:21:26,299 --> 00:21:23,700
therefore again providing a calibration

471
00:21:29,389 --> 00:21:26,309
point for sign of bacterial evolution is

472
00:21:31,820 --> 00:21:29,399
that they are uniquely associated with

473
00:21:34,909 --> 00:21:31,830
very short cellular trichomes whose

474
00:21:36,950 --> 00:21:34,919
dimensions are precisely those of these

475
00:21:44,239 --> 00:21:36,960
achenes like structures that they're

476
00:21:46,940 --> 00:21:44,249
found among the the in the modern day

477
00:21:49,369 --> 00:21:46,950
when akka NEETs germinate they they form

478
00:21:52,159 --> 00:21:49,379
things called germ Ling's which are very

479
00:21:54,470 --> 00:21:52,169
short trichomes indistinguishable from

480
00:21:56,389 --> 00:21:54,480
these so again I think this tells us

481
00:22:00,109 --> 00:21:56,399
that by sixteen hundred million years

482
00:22:02,659 --> 00:22:00,119
ago we have gotten to the point of sign

483
00:22:04,220 --> 00:22:02,669
of bacterial diversification where we

484
00:22:07,310 --> 00:22:04,230
have those sign of bacteria that

485
00:22:09,200 --> 00:22:07,320
differentiate cell types there have been

486
00:22:11,930 --> 00:22:09,210
a number of sign of bacterial phylogeny

487
00:22:15,109 --> 00:22:11,940
x' published over the years this is just

488
00:22:15,620 --> 00:22:15,119

one from Betty sure Meister at Al what

489
00:22:18,500 --> 00:22:15,630
this

490
00:22:21,620 --> 00:22:18,510
jess is that the Proterozoic was a time

491
00:22:25,630 --> 00:22:21,630
when sign of bacterial diversity was

492
00:22:28,130 --> 00:22:25,640
unfolding and indeed I think that's very

493
00:22:31,700 --> 00:22:28,140
similar to the story we get from the

494
00:22:34,480 --> 00:22:31,710
fossil record in general moving then to

495
00:22:37,790 --> 00:22:34,490
eukaryotes again as all of you know

496
00:22:39,320 --> 00:22:37,800
eukaryotes are both genetically and and

497
00:22:42,860 --> 00:22:39,330
silent so they are structurally

498
00:22:45,980 --> 00:22:42,870
different from prokaryotes and so the

499
00:22:49,520 --> 00:22:45,990
question is can we actually document a

500
00:22:51,380 --> 00:22:49,530
record of eukaryotic evolution back

501
00:22:55,850 --> 00:22:51,390
through the Proterozoic to complement

502
00:22:58,100 --> 00:22:55,860
that of a bacteria and again the first

503
00:23:00,230 --> 00:22:58,110
question is practical that is when we

504
00:23:02,630 --> 00:23:00,240
find a micro fossil how can we tell

505
00:23:04,730 --> 00:23:02,640
whether it's eukaryotic it doesn't have

506
00:23:06,950 --> 00:23:04,740
a membrane bounded nucleus it doesn't

507
00:23:09,980 --> 00:23:06,960
have multiple linear chromosomes it

508
00:23:12,590 --> 00:23:09,990
doesn't have small subunit ribosomal RNA

509
00:23:17,330 --> 00:23:12,600
or any of these things all that

510
00:23:18,830 --> 00:23:17,340
preserves for the most part are walls so

511
00:23:20,060 --> 00:23:18,840
if you're a eukaryote that didn't make a

512
00:23:22,640 --> 00:23:20,070
cell wall if there's a fair chance

513
00:23:24,320 --> 00:23:22,650

you're only possibility of anything in

514
00:23:27,770 --> 00:23:24,330
the geologic record would be as a

515
00:23:29,660 --> 00:23:27,780
molecular staring microfossil so here's

516
00:23:33,050 --> 00:23:29,670
one example something called Shu useful

517
00:23:36,500 --> 00:23:33,060
idiom from 14 to 16 hundred million year

518
00:23:37,940 --> 00:23:36,510
old rocks in in China it's large about

519
00:23:40,340 --> 00:23:37,950
150 microns

520
00:23:42,380 --> 00:23:40,350
well that might prejudice you toward a

521
00:23:44,900 --> 00:23:42,390
eukaryotic interpretation it's not by

522
00:23:47,480 --> 00:23:44,910
itself definitive on the other hand

523
00:23:50,720 --> 00:23:47,490
these are festooned with regularly

524
00:23:53,030 --> 00:23:50,730
distributed processes and if you look at

525
00:23:56,120 --> 00:23:53,040
the cell wall particularly in the SEM in

526
00:23:58,490 --> 00:23:56,130
the lower right it basically consists of

527
00:24:02,570 --> 00:23:58,500
these tessellated plates and when you

528
00:24:05,960 --> 00:24:02,580
look at it in TEM work done by m9y el

529
00:24:09,620 --> 00:24:05,970
chavo here you can see a complexity of

530
00:24:12,140 --> 00:24:09,630
wall structure which is very similar to

531
00:24:17,030 --> 00:24:12,150
the complexity we see in eukaryotic

532
00:24:19,280 --> 00:24:17,040
cells very different from the micro

533
00:24:21,620 --> 00:24:19,290
structure that we would see and say sign

534
00:24:26,660 --> 00:24:21,630
of bacterial envelopes so I think

535
00:24:28,490 --> 00:24:26,670
together size wall complexity and and

536
00:24:29,480 --> 00:24:28,500
morphology tell us that this was a

537
00:24:32,330 --> 00:24:29,490
eukaryotic

538
00:24:34,280 --> 00:24:32,340

sell and just to quote Tom

539
00:24:36,590 --> 00:24:34,290
cavalier-smith a prominent protest

540
00:24:38,480 --> 00:24:36,600
ologists it says sis with spines

541
00:24:40,640 --> 00:24:38,490
articulate surface sculpturing would

542
00:24:43,130 --> 00:24:40,650
probably have required both an ending

543
00:24:45,049 --> 00:24:43,140
endomembrane system and a cytoskeleton

544
00:24:47,540 --> 00:24:45,059
the most fundamental features of the

545
00:24:50,030 --> 00:24:47,550
eukaryotic cell and I think that's right

546
00:24:52,880 --> 00:24:50,040
and that gives us confidence that a that

547
00:24:55,880 --> 00:24:52,890
we're looking at a eukaryote and also

548
00:24:58,430 --> 00:24:55,890
that preservable features of eukaryotes

549
00:25:01,130 --> 00:24:58,440
can actually allow us to make some

550
00:25:03,140 --> 00:25:01,140
inferences about features of cell

551
00:25:05,330 --> 00:25:03,150
biology that are not well preserved

552
00:25:08,419 --> 00:25:05,340
again that particular fossil is over

553
00:25:11,120 --> 00:25:08,429
fourteen hundred million years old now

554
00:25:13,490 --> 00:25:11,130
I'm gonna skip through the next thing

555
00:25:17,299 --> 00:25:13,500
because I already hear the hoofbeats of

556
00:25:20,150 --> 00:25:17,309
the end of time coming up I did want to

557
00:25:22,040 --> 00:25:20,160
say that with Emmanuel we've published a

558
00:25:23,750 --> 00:25:22,050
paper on some fourteen to fifteen

559
00:25:27,650 --> 00:25:23,760
hundred million year old rocks from

560
00:25:29,720 --> 00:25:27,660
northern Australia and these are have a

561
00:25:31,940 --> 00:25:29,730
moderate diversity of things that we

562
00:25:38,630 --> 00:25:31,950
think are eukaryotic they are not easy

563
00:25:40,549 --> 00:25:38,640

to place follow genetically but because

564
00:25:42,950 --> 00:25:40,559
of some of the forms we think we can

565
00:25:45,380 --> 00:25:42,960
identify some of them as being hospital

566
00:25:49,100 --> 00:25:45,390
for example as opposed to photosynthetic

567
00:25:51,320 --> 00:25:49,110
we know that we can see evidence of cell

568
00:25:53,270 --> 00:25:51,330
differentiation I think people sometimes

569
00:25:55,070 --> 00:25:53,280
think that cell differentiation is the

570
00:25:58,070 --> 00:25:55,080
special province of multicellular

571
00:25:59,750 --> 00:25:58,080
organisms but most eukaryotic organisms

572
00:26:02,560 --> 00:25:59,760
differentiate different cells during

573
00:26:06,640 --> 00:26:02,570
their life cycle and we do see cysts

574
00:26:09,040 --> 00:26:06,650
just zip through that we start seeing

575
00:26:10,880 --> 00:26:09,050
through the work of Nick Butterfield

576
00:26:13,820 --> 00:26:10,890
things that we can actually identify

577
00:26:16,250 --> 00:26:13,830
follow genetically by about ten hundred

578
00:26:20,330 --> 00:26:16,260
and fifty million years ago these I

579
00:26:22,760 --> 00:26:20,340
think are well interpreted as a red

580
00:26:25,490 --> 00:26:22,770
algae which tell us that not only have

581
00:26:27,560 --> 00:26:25,500
brown groups come into existence within

582
00:26:29,480 --> 00:26:27,570
the eukaryotes at this time but

583
00:26:34,100 --> 00:26:29,490
photosynthesis has come to them simple

584
00:26:38,169 --> 00:26:34,110
multicellularity has come to them they

585
00:26:41,270 --> 00:26:38,179
just keep going through this

586
00:26:45,500 --> 00:26:41,280
interestingly although we have a record

587
00:26:51,860 --> 00:26:48,430
at least sixteen hundred million years

588
00:26:55,100 --> 00:26:51,870

when we look at the biomarker record

589
00:26:56,900 --> 00:26:55,110
here from the work of yep and brock's we

590
00:27:01,870 --> 00:26:56,910
find that there's not much record of

591
00:27:06,110 --> 00:27:01,880
eukaryotic sin the form of of lipid

592
00:27:09,260 --> 00:27:06,120
biomarkers indeed again from this mezzo

593
00:27:11,570 --> 00:27:09,270
protein or middle Proterozoic basin we

594
00:27:14,299 --> 00:27:11,580
have evidence that most of the primary

595
00:27:15,890 --> 00:27:14,309
production was bacterial and indeed in

596
00:27:18,650 --> 00:27:15,900
this particular basin at this particular

597
00:27:22,280 --> 00:27:18,660
time the lower part of the photic zone

598
00:27:25,520 --> 00:27:22,290
was an toxic because we see biomarkers

599
00:27:27,220 --> 00:27:25,530
that are made by green and purple sulfur

600
00:27:31,640 --> 00:27:27,230
bacteria

601
00:27:33,980 --> 00:27:31,650
now although eukaryotes originated early

602
00:27:36,500 --> 00:27:33,990
about eight hundred million years ago we

603
00:27:39,680 --> 00:27:36,510
see a major diversification with new

604
00:27:42,710 --> 00:27:39,690
types of fossils like these vase shape

605
00:27:45,590 --> 00:27:42,720
tests we start seeing scales of the type

606
00:27:48,350 --> 00:27:45,600
that so you might associate with a

607
00:27:50,200 --> 00:27:48,360
couple of the four heads today we see an

608
00:27:54,200 --> 00:27:50,210
increase in the diversity of

609
00:27:56,090 --> 00:27:54,210
multicellular and seen acidic types we

610
00:27:59,230 --> 00:27:56,100
see an increase in the diversity of

611
00:28:03,080 --> 00:27:59,240
cysts and other types and one might ask

612
00:28:06,350 --> 00:28:03,090
why halfway through the history of

613
00:28:09,799 --> 00:28:06,360

eukaryotes do we see this difference and

614
00:28:11,690 --> 00:28:09,809
let me suggest an ecological argument

615
00:28:14,600 --> 00:28:11,700
and you can take this for what it's what

616
00:28:17,150 --> 00:28:14,610
it's worth but many people think that

617
00:28:19,490 --> 00:28:17,160
there's at least an ecological component

618
00:28:21,620 --> 00:28:19,500
to the driving of diversification of

619
00:28:26,450 --> 00:28:21,630
animals in the Cambrian that is

620
00:28:29,720 --> 00:28:26,460
associated with carnivorous and so if

621
00:28:33,260 --> 00:28:29,730
there were a significant uptick in the

622
00:28:35,360 --> 00:28:33,270
ecological importance of protists in

623
00:28:38,990 --> 00:28:35,370
eukaryotes that eat other eukaryotes

624
00:28:44,240 --> 00:28:39,000
that might drive much of what we see in

625
00:28:47,000 --> 00:28:44,250
the in in the neoproterozoic and indeed

626
00:28:49,250 --> 00:28:47,010
when you do a sort of character analysis

627
00:28:50,930 --> 00:28:49,260
with phylogeny x' it's pretty clear that

628
00:28:53,419 --> 00:28:50,940
eukaryotes that make their living

629
00:28:55,940 --> 00:28:53,429
largely by eating other eukaryotes fika

630
00:28:58,549 --> 00:28:55,950
trophic lis are derived groups of

631
00:29:00,350 --> 00:28:58,559
alekhya ler clock ages suggest an origin

632
00:29:04,340 --> 00:29:00,360
around at least in the neoproterozoic

633
00:29:06,259 --> 00:29:04,350
and certainly fossils these vase shape

634
00:29:09,310 --> 00:29:06,269
fossils which are abundant in rocks

635
00:29:12,620 --> 00:29:09,320
beginning around 750 million years ago

636
00:29:14,960 --> 00:29:12,630
clearly made by things like test date

637
00:29:17,899 --> 00:29:14,970
and maybe today some of their modern

638
00:29:21,560 --> 00:29:17,909

relatives are in fact eukaryote eaters

639
00:29:24,110 --> 00:29:21,570
and one can guess a that the reason you

640
00:29:26,899 --> 00:29:24,120
have a test is for protection and B

641
00:29:30,500 --> 00:29:26,909
there's actually evidence of predation

642
00:29:32,539 --> 00:29:30,510
on these things also we find beginning

643
00:29:35,930 --> 00:29:32,549
in rocks of this age that we start

644
00:29:39,470 --> 00:29:35,940
seeing scales indeed these scales

645
00:29:41,810 --> 00:29:39,480
described by Phoebe Cohen are probably

646
00:29:46,789 --> 00:29:41,820
the most diverse eukaryotic fossils

647
00:29:49,460 --> 00:29:46,799
before animals and again while we can't

648
00:29:51,919 --> 00:29:49,470
pin them down follow genetically there

649
00:29:54,950 --> 00:29:51,929
is reason to think that they might serve

650
00:29:58,009 --> 00:29:54,960
the the role of protection against other

651
00:30:00,159 --> 00:29:58,019
protists and then finally one can think

652
00:30:03,200 --> 00:30:00,169
of multicellularity as a defense and

653
00:30:05,990 --> 00:30:03,210
just to argue this one more point that

654
00:30:08,810 --> 00:30:06,000
I'll finish there's a wonderful paper

655
00:30:12,680 --> 00:30:08,820
some years ago in which people had were

656
00:30:13,820 --> 00:30:12,690
growing single-celled algae in culture

657
00:30:15,049 --> 00:30:13,830
you can grow these for a million

658
00:30:18,350 --> 00:30:15,059
generation they're always be

659
00:30:21,230 --> 00:30:18,360
single-celled you put in a eukaryotic

660
00:30:23,299 --> 00:30:21,240
predator and within 10 to 20 generations

661
00:30:25,070 --> 00:30:23,309
they're obligate Lea multicellular and

662
00:30:27,080 --> 00:30:25,080
they will stay multicellular even if you

663
00:30:30,440 --> 00:30:27,090

remove the predator and the reason for

664
00:30:32,840 --> 00:30:30,450
that is that when you stay attached

665
00:30:36,500 --> 00:30:32,850
after cell division you can't get eaten

666
00:30:38,480 --> 00:30:36,510
so there may be something that since

667
00:30:40,940 --> 00:30:38,490
molecular clocks suggest that animals

668
00:30:42,950 --> 00:30:40,950
are taking shape on this timescale maybe

669
00:30:46,100 --> 00:30:42,960
that has something to do with it last

670
00:30:49,159 --> 00:30:46,110
point there's a conundrum here in that

671
00:30:51,710 --> 00:30:49,169
we think that eukaryotes existed early

672
00:30:54,529 --> 00:30:51,720
we have evidence that photosynthesis

673
00:30:57,169 --> 00:30:54,539
came to eukaryotes fairly early yet if

674
00:30:59,810 --> 00:30:57,179
you look at the biomarker record it

675
00:31:03,379 --> 00:30:59,820
looks like eukaryotes are only becoming

676
00:31:06,590 --> 00:31:03,389
important in the phytoplankton about 700

677
00:31:09,440 --> 00:31:06,600
and about 700 million years ago and

678
00:31:09,800 --> 00:31:09,450
again I think ecological modeling can

679
00:31:12,230 --> 00:31:09,810
help

680
00:31:16,780 --> 00:31:12,240
on the right is an interesting diagram

681
00:31:20,120 --> 00:31:16,790
and what it shows is that if you look at

682
00:31:22,250 --> 00:31:20,130
basically population size which is what

683
00:31:27,410 --> 00:31:22,260
we're really looking at on the x-axis

684
00:31:31,130 --> 00:31:27,420
and just look at the arms right size is

685
00:31:33,020 --> 00:31:31,140
on the x-axis and population numbers on

686
00:31:36,130 --> 00:31:33,030
on there sorry

687
00:31:39,890 --> 00:31:36,140
body size on the left on the y-axis

688
00:31:44,180 --> 00:31:39,900

numbers on on the on the right at low

689
00:31:47,750 --> 00:31:44,190
nutrient levels small cells always win

690
00:31:49,370 --> 00:31:47,760
and so today in the lowest nutrient

691
00:31:51,830 --> 00:31:49,380
levels of the oceans sign of bacteria

692
00:31:53,870 --> 00:31:51,840
dominate primary production and it may

693
00:31:56,390 --> 00:31:53,880
well be that the reason sign of bacteria

694
00:31:58,640 --> 00:31:56,400
dominate primary production in through

695
00:32:01,820 --> 00:31:58,650
most of the Proterozoic is that nutrient

696
00:32:03,440 --> 00:32:01,830
levels are very low independently of any

697
00:32:05,980 --> 00:32:03,450
paleontological evidence there's a

698
00:32:08,750 --> 00:32:05,990
evidence for a change in phosphate

699
00:32:11,500 --> 00:32:08,760
availability beginning in the later in

700
00:32:14,750 --> 00:32:11,510
the Oh Proterozoic and what will happen

701
00:32:16,760 --> 00:32:14,760
ecologically if you add nutrients you

702
00:32:19,340 --> 00:32:16,770
increase the population size of the sign

703
00:32:21,770 --> 00:32:19,350
of bacteria but only to the point where

704
00:32:25,370 --> 00:32:21,780
they become controlled by grazers and at

705
00:32:30,220 --> 00:32:25,380
that point larger size classes can grow

706
00:32:32,930 --> 00:32:30,230
in so it may be that the reason that

707
00:32:34,750 --> 00:32:32,940
eukaryotic algae become important only

708
00:32:39,200 --> 00:32:34,760
toward the end of the Proterozoic is

709
00:32:41,030 --> 00:32:39,210
that nutrient status is changing in in

710
00:32:45,200 --> 00:32:41,040
the oceans and that has a further

711
00:32:48,650 --> 00:32:45,210
consequence because once you replace or

712
00:32:51,020 --> 00:32:48,660
add larger cells at the base of the food

713
00:32:53,390 --> 00:32:51,030

chain to the smaller ones you end up

714
00:32:55,910 --> 00:32:53,400
distributing more energy and biomass

715
00:32:58,010 --> 00:32:55,920
higher in the food web so it may be

716
00:33:01,880 --> 00:32:58,020
there at least one component of the

717
00:33:06,080 --> 00:33:01,890
riddle for why animals radiate when they

718
00:33:08,330 --> 00:33:06,090
do is that the changing nature of the

719
00:33:12,010 --> 00:33:08,340
primary producers in ecosystems is

720
00:33:15,330 --> 00:33:12,020
actually making more energy and biomass

721
00:33:18,269 --> 00:33:15,340
available for larger organisms of

722
00:33:22,680 --> 00:33:18,279
of food webs so with that then let me

723
00:33:24,899 --> 00:33:22,690
just end punchlines life and environment

724
00:33:28,169 --> 00:33:24,909
are recorded over a four billion year

725
00:33:29,759 --> 00:33:28,179
history of the earth and that they seem

726
00:33:33,330 --> 00:33:29,769
to be closely intertwined throughout

727
00:33:34,919 --> 00:33:33,340
that history the Proterozoic is a world

728
00:33:36,629 --> 00:33:34,929
that is both biologically an

729
00:33:40,320 --> 00:33:36,639
environmentally distinct from what

730
00:33:44,129 --> 00:33:40,330
became for and after and importantly

731
00:33:46,499 --> 00:33:44,139
that Proterozoic rocks provide maybe our

732
00:33:49,409 --> 00:33:46,509
best template for thinking about how to

733
00:33:52,230 --> 00:33:49,419
interpret the deeper rock record and

734
00:33:53,970 --> 00:33:52,240
also provide a guide for the exploration

735
00:34:00,659 --> 00:33:53,980
of sedimentary rocks on Mars and

736
00:34:08,159 --> 00:34:00,669
elsewhere so thank you very much thank

737
00:34:11,030 --> 00:34:08,169
you very much for a beautiful talk in

738
00:34:13,710 --> 00:34:11,040

the final resort there are quite a few

739
00:34:16,169 --> 00:34:13,720
mass extinctions and I'm wondering

740
00:34:18,149 --> 00:34:16,179
during the 2000 million years of the

741
00:34:19,169 --> 00:34:18,159
Proterozoic weather there's if are there

742
00:34:21,319 --> 00:34:19,179
any sediment layers that are

743
00:34:23,280 --> 00:34:21,329
well-preserved enough and nor

744
00:34:25,230 --> 00:34:23,290
chronologically ordered that you can

745
00:34:32,309 --> 00:34:25,240
test or try to see if there were any

746
00:34:35,129 --> 00:34:32,319
mass extinctions there's at least one

747
00:34:37,859 --> 00:34:35,139
case we can make we people talked

748
00:34:40,559 --> 00:34:37,869
yesterday about these global glaciation

749
00:34:43,099 --> 00:34:40,569
something called snowball Earth's one

750
00:34:48,540 --> 00:34:43,109
that begins actually rather precisely at

751
00:34:50,190 --> 00:34:48,550
716 million years ago ends about 660

752
00:34:53,399 --> 00:34:50,200
million years ago and then a second

753
00:34:56,700 --> 00:34:53,409
shorter lived one that ends 635 million

754
00:35:01,319 --> 00:34:56,710
years ago if you look at the nature of

755
00:35:04,130 --> 00:35:01,329
the eukaryotic biota before the earlier

756
00:35:08,069 --> 00:35:04,140
of those ice ages you have this

757
00:35:10,400 --> 00:35:08,079
relatively rich diversity of a variety

758
00:35:14,880 --> 00:35:10,410
of eukaryotic clades

759
00:35:17,430 --> 00:35:14,890
very few of which actually make it

760
00:35:20,130 --> 00:35:17,440
through the glaciations now we know that

761
00:35:23,040 --> 00:35:20,140
some eukaryotic clades did because

762
00:35:25,349 --> 00:35:23,050
there's reason to believe that some of

763
00:35:27,350 --> 00:35:25,359

the diversity that radiates after the

764
00:35:29,120 --> 00:35:27,360
ice ages has its roots

765
00:35:31,580 --> 00:35:29,130
in this earlier diversification of

766
00:35:34,070 --> 00:35:31,590
eukaryotes but at the species and genus

767
00:35:36,350 --> 00:35:34,080
level not much makes it through those

768
00:35:40,730 --> 00:35:36,360
ice ages so that's our that's our our

769
00:35:42,950 --> 00:35:40,740
one best look at mass extinction now for

770
00:35:45,320 --> 00:35:42,960
prokaryotes bacteria it's it's a little

771
00:35:46,910 --> 00:35:45,330
bit different in that those tell my

772
00:35:49,640 --> 00:35:46,920
students you can brush your teeth in the

773
00:35:52,970 --> 00:35:49,650
morning and kill 99% of the bacteria in

774
00:35:55,520 --> 00:35:52,980
your mouth but by evening your teeth

775
00:35:56,810 --> 00:35:55,530
will be filmed again so it's it's I

776
00:36:00,640 --> 00:35:56,820
think it's a it's a it's a different

777
00:36:02,930 --> 00:36:00,650
order of exercise to try and drive

778
00:36:05,390 --> 00:36:02,940
bacteria to extinction and we certainly

779
00:36:08,540 --> 00:36:05,400
see no evidence of it so when people say

780
00:36:10,370 --> 00:36:08,550
that the Permian Triassic extinction was

781
00:36:11,750 --> 00:36:10,380
the largest ever that's probably not

782
00:36:14,960 --> 00:36:11,760
true because of the one you just

783
00:36:18,080 --> 00:36:14,970
described well you know it's very hard

784
00:36:20,360 --> 00:36:18,090
to quantify what's going going on so how

785
00:36:22,010 --> 00:36:20,370
I sometimes write about the remote

786
00:36:24,260 --> 00:36:22,020
Triassic and I need to be able to say

787
00:36:27,050 --> 00:36:24,270
it's the largest mass extinction ever so

788
00:36:37,130 --> 00:36:27,060

I'll stick to that story the extent to

789
00:36:46,240 --> 00:36:37,140
which is true we simply don't know any

790
00:36:51,140 --> 00:36:48,590
how much of this shift from

791
00:36:53,900 --> 00:36:51,150
cyanobacteria to eukaryotic algae could

792
00:36:56,510 --> 00:36:53,910
be a result of increased availability of

793
00:36:59,270 --> 00:36:56,520
fixed nitrogen well I guess one of the

794
00:37:01,940 --> 00:36:59,280
questions is it could be important in an

795
00:37:05,140 --> 00:37:01,950
area and I wrote about this some years

796
00:37:07,670 --> 00:37:05,150
ago in in some ways I think that

797
00:37:10,490 --> 00:37:07,680
nitrogen nitrogen may prove to be a

798
00:37:12,890 --> 00:37:10,500
responder here I mean there is evidence

799
00:37:16,070 --> 00:37:12,900
based on nitrogen isotopes that at least

800
00:37:18,500 --> 00:37:16,080
in shallow water environments there was

801
00:37:22,160 --> 00:37:18,510
some nitrate available as you go

802
00:37:24,700 --> 00:37:22,170
offshore nitrogen isotopes indicate a

803
00:37:27,410 --> 00:37:24,710
greater role for nitrogen fixation and

804
00:37:28,450 --> 00:37:27,420
certainly one of the things I didn't

805
00:37:32,270 --> 00:37:28,460
have time to talk about but

806
00:37:35,420 --> 00:37:32,280
environmentally in literally every

807
00:37:40,010 --> 00:37:35,430
Proterozoic Basin but one within the

808
00:37:42,440 --> 00:37:40,020
range of of basin depths recorded in

809
00:37:44,450 --> 00:37:42,450
sedimentary basins which is really only

810
00:37:47,990 --> 00:37:44,460
you know a couple hundred meters at best

811
00:37:52,400 --> 00:37:48,000
you capture the transition from object'

812
00:37:54,650 --> 00:37:52,410
anoxic water masses so most of the

813
00:37:58,030 --> 00:37:54,660

Proterozoic appears to be this fairly

814
00:38:02,360 --> 00:37:58,040
thin veneer probably tens of meters of

815
00:38:04,040 --> 00:38:02,370
oxic waters beneath an anoxic oxygen

816
00:38:06,320 --> 00:38:04,050
minimum zone and there's no question

817
00:38:08,810 --> 00:38:06,330
that that's a perfect conditions for

818
00:38:12,320 --> 00:38:08,820
actually destroying nitrogen and we get

819
00:38:15,620 --> 00:38:12,330
back to the environment so yes at low

820
00:38:17,620 --> 00:38:15,630
nitrogen particularly offshore one might

821
00:38:19,730 --> 00:38:17,630
favor cyanobacteria

822
00:38:22,820 --> 00:38:19,740
one of the things that I think will

823
00:38:25,520 --> 00:38:22,830
build up nitrate availability in the

824
00:38:28,850 --> 00:38:25,530
oceans is simply as you create a more

825
00:38:31,370 --> 00:38:28,860
oxic redox profile and that I think is

826
00:38:32,810 --> 00:38:31,380
ultimately driven by phosphorus so yes

827
00:38:35,180 --> 00:38:32,820
it's important but yes it's not

828
00:38:42,510 --> 00:38:35,190
independent of what's going on with

829
00:38:48,160 --> 00:38:45,730
do you see any changes in the physiology

830
00:38:52,360 --> 00:38:48,170
or the shapes of eukaryotic like its

831
00:38:55,300 --> 00:38:52,370
protists at the Joey well we don't have

832
00:38:59,830 --> 00:38:55,310
any the oldest fossil evidence that we

833
00:39:01,480 --> 00:38:59,840
have for eukaryotes is about between

834
00:39:04,480 --> 00:39:01,490
sixteen hundred and sixteen hundred and

835
00:39:06,190 --> 00:39:04,490
fifty million million years ago now

836
00:39:08,500 --> 00:39:06,200
having said that one has to be honest

837
00:39:10,210 --> 00:39:08,510
and say that the the quality of the

838
00:39:13,120 --> 00:39:10,220

record per se just gets worse and worse

839
00:39:15,940 --> 00:39:13,130
as you go go backward through time but

840
00:39:18,310 --> 00:39:15,950
no we have there prokaryotes and well

841
00:39:21,510 --> 00:39:18,320
firfer prokaryotes well I think what

842
00:39:24,280 --> 00:39:21,520
happens that is very different is that

843
00:39:27,700 --> 00:39:24,290
to the extent that sign of bacteria

844
00:39:30,610 --> 00:39:27,710
existed in the Archaean earth their

845
00:39:33,160 --> 00:39:30,620
population sizes and oxygen fluxes

846
00:39:35,950 --> 00:39:33,170
associated with those were insufficient

847
00:39:40,870 --> 00:39:35,960
to essentially titrate out all the sinks

848
00:39:43,990 --> 00:39:40,880
for oxygen what happens at the goe is

849
00:39:47,290 --> 00:39:44,000
that again because of oxygen produced by

850
00:39:49,990 --> 00:39:47,300
sign of bacteria you end up oxygenating

851
00:39:51,910 --> 00:39:50,000
the surface ocean and atmosphere and

852
00:39:53,500 --> 00:39:51,920
that that shows I think an important

853
00:39:57,600 --> 00:39:53,510
thing that saina bacteria end up being

854
00:40:01,300 --> 00:39:57,610
ecosystem engineers in that through that

855
00:40:04,420 --> 00:40:01,310
process associated with the oxygen they

856
00:40:08,560 --> 00:40:04,430
produce you basically produce photic

857
00:40:10,990 --> 00:40:08,570
zones in which the alternative electron

858
00:40:14,050 --> 00:40:11,000
donors things like sulphide and ferrous

859
00:40:16,420 --> 00:40:14,060
iron are simply no longer there so I

860
00:40:19,890 --> 00:40:16,430
think that's the big difference then is

861
00:40:23,710 --> 00:40:19,900
sign of bacteria either go from being

862
00:40:26,560 --> 00:40:23,720
absent or a smaller part of ecosystems

863
00:40:28,210 --> 00:40:26,570

to being dominant primary producers and

864
00:40:31,260 --> 00:40:28,220
of course we don't see this in the

865
00:40:33,340 --> 00:40:31,270
fossil record but as once you get

866
00:40:36,810 --> 00:40:33,350
metabolically significant amounts of

867
00:40:40,390 --> 00:40:36,820
oxygen and in the atmosphere then you

868
00:40:43,480 --> 00:40:40,400
dramatically expand respiratory

869
00:40:45,700 --> 00:40:43,490
capabilities chemoautotrophs abilities

870
00:40:49,320 --> 00:40:45,710
biosynthetic capabilities and I think

871
00:40:51,610 --> 00:40:49,330
you see you see some evidence of that in

872
00:40:53,260 --> 00:40:51,620
phylogeny but not directly

873
00:40:55,030 --> 00:40:53,270
in the fossil record but as an

874
00:40:56,560 --> 00:40:55,040
extinction event do you think it Trump's

875
00:40:58,750 --> 00:40:56,570
the one that you just described you know

876
00:41:01,720 --> 00:40:58,760
lynn margulis bless her soul always used

877
00:41:04,870 --> 00:41:01,730
to talk I think unfortunately about the

878
00:41:07,630 --> 00:41:04,880
the oxygen Holocaust and she had this

879
00:41:09,880 --> 00:41:07,640
sense that basically the world was full

880
00:41:12,820 --> 00:41:09,890
of anaerobes and as oxygen comes up they

881
00:41:15,270 --> 00:41:12,830
all die actually what they all did was

882
00:41:17,170 --> 00:41:15,280
went a millimeter beneath the surface

883
00:41:20,230 --> 00:41:17,180
where there's still an toxic

884
00:41:22,840 --> 00:41:20,240
environments so III tend to think of the

885
00:41:25,330 --> 00:41:22,850
goe as expanding the ecological

886
00:41:27,400 --> 00:41:25,340
amplitude not simply changing it in a

887
00:41:37,590 --> 00:41:27,410
way that fundamentally drives most

888
00:41:40,480 --> 00:41:37,600

earlier life out of existence is

889
00:41:43,240 --> 00:41:40,490
basically to our scenario and you have

890
00:41:45,940 --> 00:41:43,250
continually than the kind of work and I

891
00:41:49,840 --> 00:41:45,950
have let your papers from your vantage

892
00:41:51,940 --> 00:41:49,850
and my question as a I'm geologist and

893
00:41:54,520 --> 00:41:51,950
we have worked over the world it's more

894
00:41:57,970 --> 00:41:54,530
than 100 localities over 30 years and

895
00:42:01,360 --> 00:41:57,980
then the Archaean is a kind of know

896
00:42:03,910 --> 00:42:01,370
segment dialogues in the area so that

897
00:42:07,750 --> 00:42:03,920
therefore in your opinion ok quite a few

898
00:42:09,580 --> 00:42:07,760
amounts of nutrients provided and the

899
00:42:14,050 --> 00:42:09,590
fire's work with emergence of huge

900
00:42:14,530 --> 00:42:14,060
animals because large amounts of cement

901
00:42:18,040 --> 00:42:14,540
airlocks

902
00:42:21,130 --> 00:42:18,050
appeared that's fine and then probably

903
00:42:24,400 --> 00:42:21,140
the assail bacteria produce oxygen and

904
00:42:27,820 --> 00:42:24,410
oxygen pumped have been very productive

905
00:42:31,390 --> 00:42:27,830
so the used mentioned okay itself as

906
00:42:36,930 --> 00:42:31,400
high as long low oxygen intermediate and

907
00:42:43,180 --> 00:42:36,940
high oxygen so there is the okay then

908
00:42:48,340 --> 00:42:43,190
life change very simple one progeria

909
00:42:54,340 --> 00:42:48,350
right and then endosymbiont and then we

910
00:42:58,150 --> 00:42:54,350
are multiple architecture including

911
00:43:02,050 --> 00:42:58,160
everything right so that okay i my

912
00:43:05,320 --> 00:43:02,060
question is what is the most important

913
00:43:08,320 --> 00:43:05,330

environmental pressure to change

914
00:43:13,420 --> 00:43:08,330
the system of life okay that's a very

915
00:43:15,580 --> 00:43:13,430
good question and I I think I moved over

916
00:43:18,130 --> 00:43:15,590
a slide bite from a review of Tim

917
00:43:20,170 --> 00:43:18,140
Lyons's papers quickly but other people

918
00:43:22,420 --> 00:43:20,180
have shown similar things that I think

919
00:43:26,650 --> 00:43:22,430
that most of us would agree that before

920
00:43:29,110 --> 00:43:26,660
the goe o - tensions were very very low

921
00:43:31,390 --> 00:43:29,120
ten to the minus five PA L or something

922
00:43:34,530 --> 00:43:31,400
like that that you permanently have a

923
00:43:36,700 --> 00:43:34,540
transition to a world that at least has

924
00:43:40,960 --> 00:43:36,710
something like a few percent of today's

925
00:43:43,630 --> 00:43:40,970
oxygen levels in the Proterozoic and

926
00:43:45,310 --> 00:43:43,640
that persists it's usually shown as a

927
00:43:47,110 --> 00:43:45,320
straight line but that's a line of

928
00:43:49,090 --> 00:43:47,120
ignorance it could go up and down we

929
00:43:53,560 --> 00:43:49,100
don't don't really know what's going on

930
00:43:56,440 --> 00:43:53,570
but all the sedimentary geochemical

931
00:44:01,240 --> 00:43:56,450
indicators tell us that we are moving to

932
00:44:04,450 --> 00:44:01,250
a world with more completely oxic radix

933
00:44:07,030 --> 00:44:04,460
profiles about the time that animals

934
00:44:09,550 --> 00:44:07,040
come in so yes I think there is a

935
00:44:12,430 --> 00:44:09,560
history of increasing oxygen there's a

936
00:44:16,750 --> 00:44:12,440
paper just came out by two geologists in

937
00:44:21,760 --> 00:44:16,760
the United States John Husson and I'm

938
00:44:25,120 --> 00:44:21,770

just blanking on Ola shut Shannon Peters

939
00:44:26,800 --> 00:44:25,130
in which they actually argue what may be

940
00:44:29,740 --> 00:44:26,810
similar to what your thinking is that

941
00:44:32,140 --> 00:44:29,750
you simply have more erosion and more

942
00:44:34,660 --> 00:44:32,150
sediments in the phanerozoic than you

943
00:44:37,660 --> 00:44:34,670
did earlier and that's what drives this

944
00:44:40,180 --> 00:44:37,670
oxygen change I think the problem is we

945
00:44:43,600 --> 00:44:40,190
know that there is a decay curve that

946
00:44:46,300 --> 00:44:43,610
the older the sedimentary unit the more

947
00:44:49,360 --> 00:44:46,310
likely it has been eroded so I think

948
00:44:52,080 --> 00:44:49,370
that it I would agree with previous

949
00:44:55,180 --> 00:44:52,090
speakers that you probably have less

950
00:44:57,220 --> 00:44:55,190
exposed landmass and at least much of of

951
00:44:59,950 --> 00:44:57,230
the Archaean and that may change

952
00:45:02,710 --> 00:44:59,960
nutrient levels I think the difference

953
00:45:06,280 --> 00:45:02,720
in preserved sediments between the

954
00:45:10,960 --> 00:45:06,290
Proterozoic and phanerozoic may well be

955
00:45:13,200 --> 00:45:10,970
a question of preservation so to get at

956
00:45:16,450 --> 00:45:13,210
your question then the what people have

957
00:45:18,190 --> 00:45:16,460
stopped doing is saying why was there 1

958
00:45:21,190 --> 00:45:18,200
percent of today's levels

959
00:45:24,870 --> 00:45:21,200
in the Proterozoic or I say stop saying

960
00:45:26,920 --> 00:45:24,880
why did oxygen change at these two

961
00:45:29,319 --> 00:45:26,930
junctures at the beginning end of the

962
00:45:31,300 --> 00:45:29,329
Proterozoic but rather say what

963
00:45:34,300 --> 00:45:31,310

conditions would actually maintain a

964
00:45:36,700 --> 00:45:34,310
long-term steady state of these three

965
00:45:39,579 --> 00:45:36,710
different types and again that that

966
00:45:42,089 --> 00:45:39,589
appears to go perhaps more than anything

967
00:45:45,880 --> 00:45:42,099
else it's a nutrient availability

968
00:45:47,470 --> 00:45:45,890
especially phosphorus and the important

969
00:45:51,099 --> 00:45:47,480
thing that's becoming clearer and

970
00:45:53,859 --> 00:45:51,109
clearer is that in a world where anoxic

971
00:45:57,520 --> 00:45:53,869
water masses are rich in ferrous iron

972
00:46:00,730 --> 00:45:57,530
there are important sinks for phosphate

973
00:46:04,000 --> 00:46:00,740
that marine geochemists haven't thought

974
00:46:06,520 --> 00:46:04,010
about until recently soil chemists knew

975
00:46:08,050 --> 00:46:06,530
about these thirty years ago but marine

976
00:46:11,230 --> 00:46:08,060
chemists are just starting

977
00:46:14,220 --> 00:46:11,240
sorry to interrupt but sorry my final

978
00:46:18,670 --> 00:46:14,230
important question is the why life

979
00:46:23,020 --> 00:46:18,680
selected okay at the side for example 1

980
00:46:26,770 --> 00:46:23,030
million bigger for pre-k Eukarya and

981
00:46:30,010 --> 00:46:26,780
another 1 million and two bigger that is

982
00:46:33,849 --> 00:46:30,020
us but multiple assemblage of many

983
00:46:36,400 --> 00:46:33,859
different ok organisms I understand the

984
00:46:39,579 --> 00:46:36,410
question that I I driving horse yeah I I

985
00:46:43,599 --> 00:46:39,589
think there are example is there there

986
00:46:45,880 --> 00:46:43,609
are diffusion plays a very important

987
00:46:48,250 --> 00:46:45,890
role on amending the size of organisms

988
00:46:50,589 --> 00:46:48,260

and I think bacteria are largely small

989
00:46:52,690 --> 00:46:50,599
because of diffusion and the nature

990
00:46:55,240 --> 00:46:52,700
there's their cytosol

991
00:46:57,040 --> 00:46:55,250
eukaryotes which have a different

992
00:46:59,470 --> 00:46:57,050
internal architecture can be somewhat

993
00:47:01,980 --> 00:46:59,480
larger but are still diffusion limited

994
00:47:04,960 --> 00:47:01,990
the nice thing about animals at least

995
00:47:06,849 --> 00:47:04,970
once you start climbing the animal tree

996
00:47:11,559 --> 00:47:06,859
is that they have to have structures

997
00:47:13,660 --> 00:47:11,569
that essentially get around the limits

998
00:47:17,079 --> 00:47:13,670
of diffusion ever you I'm usually the

999
00:47:19,589 --> 00:47:17,089
most oxidized oh I think in some ways

1000
00:47:24,640 --> 00:47:19,599
it's it's then the relationship between

1001
00:47:27,960 --> 00:47:24,650
the physiological capabilities of an

1002
00:47:30,360 --> 00:47:27,970
organism they're related to size and

1003
00:47:33,840 --> 00:47:30,370
essentially the amount of

1004
00:47:36,150 --> 00:47:33,850
oxygen which in turn actually does go

1005
00:47:39,300 --> 00:47:36,160
back to things like phosphorus

1006
00:47:40,680 --> 00:47:39,310
availability so it's it's it's not us at

1007
00:47:42,710 --> 00:47:40,690
least I don't think there's a simple

1008
00:47:46,650 --> 00:47:42,720
magic wand but I think it's this

1009
00:47:59,090 --> 00:47:46,660
interconnectedness that goes from really

1010
00:48:02,060 --> 00:47:59,100
physiology to tectonics thank you okay

1011
00:48:05,730 --> 00:48:02,070
it's a related question to the

1012
00:48:07,400 --> 00:48:05,740
phosphorus story you just suggested so

1013
00:48:09,360 --> 00:48:07,410

one implication of that is that

1014
00:48:12,570 --> 00:48:09,370
continental weathering rates may have

1015
00:48:14,310 --> 00:48:12,580
been constant for a million years which

1016
00:48:17,580 --> 00:48:14,320
is interesting to think about yeah it

1017
00:48:19,110 --> 00:48:17,590
really is and again when you look at the

1018
00:48:20,820 --> 00:48:19,120
Tim Lyons curve and you showed something

1019
00:48:25,170 --> 00:48:20,830
like it

1020
00:48:26,730 --> 00:48:25,180
it shows the atmosphere being you know

1021
00:48:27,570 --> 00:48:26,740
having a constant composition for a

1022
00:48:30,000 --> 00:48:27,580
billion years

1023
00:48:34,140 --> 00:48:30,010
we don't know that that's true all we

1024
00:48:37,890 --> 00:48:34,150
know is that it never dipped below back

1025
00:48:40,620 --> 00:48:37,900
into a atmospheric anoxia and it never

1026
00:48:44,820 --> 00:48:40,630
reached a state where you essentially

1027
00:48:47,400 --> 00:48:44,830
eliminated all of the subsurface an

1028
00:48:50,400 --> 00:48:47,410
toxic water masses but that means it

1029
00:48:52,770 --> 00:48:50,410
probably varies within a certain level

1030
00:48:56,790 --> 00:48:52,780
so yeah it could be what I don't

1031
00:48:59,000 --> 00:48:56,800
understand just that the the pro the

1032
00:49:03,270 --> 00:48:59,010
middle of the part of the Proterozoic

1033
00:49:07,020 --> 00:49:03,280
where the carbon isotopic curve is is

1034
00:49:08,670 --> 00:49:07,030
flat which is odd where you have and you

1035
00:49:12,360 --> 00:49:08,680
know more about this and I do an toxic

1036
00:49:17,070 --> 00:49:12,370
and orogenic Granite's odd structures

1037
00:49:20,340 --> 00:49:17,080
and petrology sometimes called the

1038
00:49:22,620 --> 00:49:20,350

boring billion you know what's really

1039
00:49:26,370 --> 00:49:22,630
going what fundamentally I don't think I

1040
00:49:28,380 --> 00:49:26,380
understand the tectonics of that portion

1041
00:49:31,140 --> 00:49:28,390
of Earth history but it does seem to be

1042
00:49:33,780 --> 00:49:31,150
at least qualitatively somewhat distinct

1043
00:49:37,320 --> 00:49:33,790
from the phanerozoic tectonics that we

1044
00:49:41,110 --> 00:49:37,330
understand and earlier stuff that's the

1045
00:49:44,590 --> 00:49:43,460
so let's thank the speaker again thank

1046
00:49:47,240 --> 00:49:44,600
you much

1047
00:49:49,850 --> 00:49:47,250
[Applause]

1048
00:49:51,950 --> 00:49:49,860
before closing decision we'll make an

1049
00:49:55,550 --> 00:49:51,960
announcement for the poster presenters

1050
00:49:58,100 --> 00:49:55,560
please remove your posters during this

1051
00:50:01,520 --> 00:49:58,110
next coffee break because so that we can

1052
00:50:02,960 --> 00:50:01,530
clean that room so let's thank the

1053
00:50:06,770 --> 00:50:02,970
speaker again and thank you very much