AbSciCon 2019

1
00:00:00,790 --> 00:00:07,320
[Music]

2
00:00:11,860 --> 00:00:09,299
[Applause]

3
00:00:13,629 --> 00:00:11,870
what I'm gonna be talking about today is

4
00:00:17,080 --> 00:00:13,639
some work that we've been trying to do

5
00:00:19,750 --> 00:00:17,090
to look at how we might be able to

6
00:00:24,370 --> 00:00:19,760
distinguish the identity of different

7
00:00:26,620 --> 00:00:24,380
carbon fixation pathways in deep time so

8
00:00:28,660 --> 00:00:26,630
I mean we care about this right because

9
00:00:30,849 --> 00:00:28,670
not only are we taking carbon dioxide

10
00:00:34,120 --> 00:00:30,859
and converting it to biomass but it has

11
00:00:36,370 --> 00:00:34,130
to do with energetics material transfer

12
00:00:39,340 --> 00:00:36,380
and perhaps more importantly the

13
00:00:41,350 --> 00:00:39,350

Lindemann style trophic dynamics of the

14
00:00:43,720 --> 00:00:41,360
global biosphere at the time and one of

15
00:00:46,300 --> 00:00:43,730
the things that you can do to identify

16
00:00:48,850 --> 00:00:46,310
which autotrophic pathway may actually

17
00:00:52,420 --> 00:00:48,860
be fixing carbon is by looking at the

18
00:00:54,610 --> 00:00:52,430
ratios of carbon-13 to carbon-12 it

19
00:00:57,730 --> 00:00:54,620
turns out that due to the tension

20
00:00:59,890 --> 00:00:57,740
between equilibrium isotope effects and

21
00:01:03,070 --> 00:00:59,900
enzymatically controlled kinetic isotope

22
00:01:05,649 --> 00:01:03,080
effects you will end up with at the end

23
00:01:08,550 --> 00:01:05,659
of this process biomass that's enriched

24
00:01:11,980 --> 00:01:08,560
in the light isotope of carbon and

25
00:01:13,960 --> 00:01:11,990
leaving behind carbon dioxide that is

26
00:01:18,510 --> 00:01:13,970
enriched in the heavy isotope of carbon

27
00:01:21,570 --> 00:01:18,520
okay so how do we actually get at this

28
00:01:24,790 --> 00:01:21,580
effect and how do we use it to identify

29
00:01:27,100 --> 00:01:24,800
different carbon fixation pathways well

30
00:01:29,200 --> 00:01:27,110
one of the things that gave me a great

31
00:01:33,040 --> 00:01:29,210
pleasure to here is that I'm gonna be

32
00:01:35,820 --> 00:01:33,050
talking before Jody who has one of what

33
00:01:39,070 --> 00:01:35,830
I think the most crystal-clear

34
00:01:41,830 --> 00:01:39,080
presentations on how you actually can go

35
00:01:44,350 --> 00:01:41,840
out into the environment and figure out

36
00:01:46,690 --> 00:01:44,360
from the carbon isotopic composition of

37
00:01:48,460 --> 00:01:46,700
dissolve co2 or its counterpart

38
00:01:51,010 --> 00:01:48,470

dissolved bicarbonate and then the

39
00:01:53,560 --> 00:01:51,020
carbon isotopic composition of primary

40
00:01:55,899 --> 00:01:53,570
biomass in here a particulate organic

41
00:01:58,660 --> 00:01:55,909
carbon and figure out from the isotopic

42
00:02:00,880 --> 00:01:58,670
difference there the isotope

43
00:02:02,950 --> 00:02:00,890
fractionation associated with primary

44
00:02:04,390 --> 00:02:02,960
production and if you go and read this

45
00:02:06,580 --> 00:02:04,400
paper one of the amazing things about

46
00:02:08,410 --> 00:02:06,590
this data set is that if you correct for

47
00:02:10,539 --> 00:02:08,420
nitrate and you correct for temperature

48
00:02:12,570 --> 00:02:10,549
you're left with the temporal signal

49
00:02:17,199 --> 00:02:12,580
that may have something to do with

50
00:02:18,940 --> 00:02:17,209
enhanced co2 access as time has

51
00:02:20,680 --> 00:02:18,950
increased okay

52
00:02:23,770 --> 00:02:20,690
so one of the things though that we have

53
00:02:27,460 --> 00:02:23,780
to worry about is that rocks are not

54
00:02:31,270 --> 00:02:27,470
biomass and dissolved co2 so how do we

55
00:02:33,550 --> 00:02:31,280
go from the dissolve co2 carbon isotopic

56
00:02:35,620 --> 00:02:33,560
composition the composition of biomass

57
00:02:37,630 --> 00:02:35,630
and figure out something from the

58
00:02:39,550 --> 00:02:37,640
geologic record well the way we do we do

59
00:02:41,949 --> 00:02:39,560
is we approach it in this sort of haze

60
00:02:44,020 --> 00:02:41,959
diagram since we've got the carbon

61
00:02:46,240 --> 00:02:44,030
isotopic composition of these different

62
00:02:48,400 --> 00:02:46,250
compounds on the Left axis here is what

63
00:02:51,009 --> 00:02:48,410

we want this difference between dissolve

64
00:02:52,990 --> 00:02:51,019
co2 and biomass but we have to be

65
00:02:55,960 --> 00:02:53,000
concerned with the temperature dependent

66
00:02:58,420 --> 00:02:55,970
isotopic fractionation associated with

67
00:03:02,130 --> 00:02:58,430
carbonate speciation we have to be

68
00:03:05,590 --> 00:03:02,140
concerned with the mineral logic

69
00:03:07,780 --> 00:03:05,600
associated fractionation associated with

70
00:03:09,580 --> 00:03:07,790
the different precipitation of carbonate

71
00:03:11,289 --> 00:03:09,590
minerals and then of course there's

72
00:03:13,059 --> 00:03:11,299
going to be some small but important

73
00:03:15,280 --> 00:03:13,069
fractionation associated with the

74
00:03:19,120 --> 00:03:15,290
reworking of primary biomass into

75
00:03:21,729 --> 00:03:19,130
sedimentary total organic carbon okay so

76
00:03:24,940 --> 00:03:21,739
one of the things is that what does this

77
00:03:27,940 --> 00:03:24,950
record of mineral carbon isotopic

78
00:03:30,940 --> 00:03:27,950
compositions and total organic carbon

79
00:03:33,220 --> 00:03:30,950
isotopic compositions look like in deep

80
00:03:35,680 --> 00:03:33,230
time one of the things that were very

81
00:03:38,830 --> 00:03:35,690
fortunate for is that there was recently

82
00:03:41,110 --> 00:03:38,840
an incredible statistical reanalysis of

83
00:03:43,660 --> 00:03:41,120
the carbon isotope record in deep time

84
00:03:45,940 --> 00:03:43,670
and the carbon isotope record in deep

85
00:03:47,470 --> 00:03:45,950
time it turns out has two distinct types

86
00:03:48,819 --> 00:03:47,480
of States there's going to be the

87
00:03:51,690 --> 00:03:48,829
intervals that we're going to ignore

88
00:03:54,099 --> 00:03:51,700

here so called transitional intervals

89
00:03:56,199 --> 00:03:54,109
associated with climatic upheavals and

90
00:03:58,210 --> 00:03:56,209
non steady-state behavior in the carbon

91
00:04:00,460 --> 00:03:58,220
cycle but we're going to be focusing

92
00:04:03,039 --> 00:04:00,470
instead on these non transitional

93
00:04:05,949 --> 00:04:03,049
intervals largely the phanerozoic middle

94
00:04:08,349 --> 00:04:05,959
Proterozoic and back in time so what we

95
00:04:11,710 --> 00:04:08,359
want to do is we want to invert this

96
00:04:14,440 --> 00:04:11,720
haze diagram then and go from the carbon

97
00:04:16,870 --> 00:04:14,450
isotopic composition of sedimentary

98
00:04:18,670 --> 00:04:16,880
carbonate minerals the carbon isotopic

99
00:04:21,279 --> 00:04:18,680
composition of sedimentary organic

100
00:04:24,879 --> 00:04:21,289
carbon and go through a procedure that

101
00:04:27,430 --> 00:04:24,889
allows us to extract to the best of our

102
00:04:30,850 --> 00:04:27,440
ability the isotopic difference between

103
00:04:31,510 --> 00:04:30,860
dissolve co2 in primary biomass in deep

104
00:04:35,920 --> 00:04:31,520
time

105
00:04:39,999 --> 00:04:35,930
so it turns out that this technique was

106
00:04:41,650 --> 00:04:40,009
developed by Sarah Hurley a postdoc I'm

107
00:04:43,600 --> 00:04:41,660
fortunate enough to be working with and

108
00:04:45,309 --> 00:04:43,610
what it happens as we go like this let's

109
00:04:48,520 --> 00:04:45,319
look at a histogram for a certain time

110
00:04:50,830 --> 00:04:48,530
period of the isotopic composition of

111
00:04:52,620 --> 00:04:50,840
carbon eight carbon and what Sara

112
00:04:55,629 --> 00:04:52,630
realized is that if you do an agnostic

113
00:04:58,089 --> 00:04:55,639

resampling of the isotopic effects

114
00:05:00,420 --> 00:04:58,099
associated with carbonate mineral

115
00:05:02,670 --> 00:05:00,430
precipitation the temperature derived

116
00:05:05,649 --> 00:05:02,680
isotopic effects associated with

117
00:05:08,469 --> 00:05:05,659
carbonate speciation what you can end up

118
00:05:11,469 --> 00:05:08,479
with is you can end up with a frequency

119
00:05:13,930 --> 00:05:11,479
distribution of the Delta 13c carbon

120
00:05:15,490 --> 00:05:13,940
isotopic composition of dissolved co2

121
00:05:18,270 --> 00:05:15,500
for the time period that you're

122
00:05:21,249 --> 00:05:18,280
interested similarly if you take the

123
00:05:23,830 --> 00:05:21,259
isotopic distribution associated with

124
00:05:26,700 --> 00:05:23,840
sedimentary organic carbon and run it

125
00:05:28,870 --> 00:05:26,710
through a random resampling looking at a

126
00:05:32,920 --> 00:05:28,880
distribution that might have something

127
00:05:36,610 --> 00:05:32,930
to do with how or primary biomass is

128
00:05:39,339 --> 00:05:36,620
fractionated during microbial reworking

129
00:05:41,589 --> 00:05:39,349
you can end up with a frequency

130
00:05:44,260 --> 00:05:41,599
distribution of the carbon isotopic

131
00:05:46,959 --> 00:05:44,270
composition of biomass in deep time

132
00:05:48,850 --> 00:05:46,969
combining these two effectively just

133
00:05:51,370 --> 00:05:48,860
taking their difference gives you a

134
00:05:54,010 --> 00:05:51,380
frequency distribution of the so called

135
00:05:56,469 --> 00:05:54,020
epsilon P for primary productivity

136
00:05:59,800 --> 00:05:56,479
epsilon for a difference in Delta values

137
00:06:02,409 --> 00:05:59,810
that then may tell you something about

138
00:06:07,480 --> 00:06:02,419

what carbon fixation pathways were

139
00:06:11,680 --> 00:06:07,490
operating in deep time okay so when

140
00:06:15,339 --> 00:06:11,690
Sarah did this with the non transitional

141
00:06:18,370 --> 00:06:15,349
intervals in the carbon isotope record

142
00:06:21,010 --> 00:06:18,380
what she returned was the following type

143
00:06:22,930 --> 00:06:21,020
of distributions if we start over here

144
00:06:24,939 --> 00:06:22,940
something centered at about 50 million

145
00:06:27,580 --> 00:06:24,949
years ago going back to something about

146
00:06:30,670 --> 00:06:27,590
250 million years ago what you can see

147
00:06:33,700 --> 00:06:30,680
is a slight increase in the most

148
00:06:35,709 --> 00:06:33,710
frequent value of carbon isotope

149
00:06:38,350 --> 00:06:35,719
fractionation by the dominant primary

150
00:06:40,390 --> 00:06:38,360
producers at that time though there are

151
00:06:42,310 --> 00:06:40,400
a number of evolutionary events that may

152
00:06:44,620 --> 00:06:42,320
be associated with this it's also

153
00:06:44,890 --> 00:06:44,630
possible that what you're looking at is

154
00:06:47,680 --> 00:06:44,900
CIN

155
00:06:50,590 --> 00:06:47,690
we the effect of the gross long-term

156
00:06:53,620 --> 00:06:50,600
increase in co2 as we go back through

157
00:06:56,439 --> 00:06:53,630
the phanerozoic and as co2 increases

158
00:06:59,590 --> 00:06:56,449
what you end up with is you end up with

159
00:07:02,140 --> 00:06:59,600
less of a more efficient operation of

160
00:07:03,820 --> 00:07:02,150
the carbon co2 concentrating mechanisms

161
00:07:06,700 --> 00:07:03,830
that are associated with these organisms

162
00:07:10,029 --> 00:07:06,710
leading to a larger fractionation we're

163
00:07:11,920 --> 00:07:10,039

going to focus next on two intervals for

164
00:07:14,680 --> 00:07:11,930
a case study the case study one is this

165
00:07:16,480 --> 00:07:14,690
mid Proterozoic interval and what we

166
00:07:19,120 --> 00:07:16,490
want to do is we want to ask the

167
00:07:21,790 --> 00:07:19,130
following question was the middle

168
00:07:24,760 --> 00:07:21,800
Proterozoic actually the age of

169
00:07:26,939 --> 00:07:24,770
cyanobacteria what I'm showing here is a

170
00:07:30,850 --> 00:07:26,949
diagram that has a bunch of different

171
00:07:35,320 --> 00:07:30,860
compilations of oxygen levels from today

172
00:07:37,000 --> 00:07:35,330
back to the early archaea and shown here

173
00:07:40,120 --> 00:07:37,010
is of course the great oxidation

174
00:07:43,450 --> 00:07:40,130
oxidation interval but also shown down

175
00:07:46,540 --> 00:07:43,460
here in green are some indications both

176
00:07:49,420 --> 00:07:46,550
from geochemistry and also from micro

177
00:07:52,000 --> 00:07:49,430
fossils of cyanobacterial oxygenic

178
00:07:56,320 --> 00:07:52,010
photosynthesis and then on this side of

179
00:08:00,520 --> 00:07:56,330
the diagram some information from

180
00:08:02,890 --> 00:08:00,530
molecular clocks from micro fossil

181
00:08:06,219 --> 00:08:02,900
evidence and from biomarker evidence for

182
00:08:08,950 --> 00:08:06,229
a primary production global primary

183
00:08:11,560 --> 00:08:08,960
biospheric primary production dominated

184
00:08:14,290 --> 00:08:11,570
by algae and what we're asking is in

185
00:08:16,570 --> 00:08:14,300
this mid Proterozoic interval wasn't

186
00:08:19,659 --> 00:08:16,580
really an age of cyanobacteria can we

187
00:08:22,000 --> 00:08:19,669
use this technique to say okay the

188
00:08:24,490 --> 00:08:22,010

primary producer at this time which it

189
00:08:26,529 --> 00:08:24,500
seems like it was was a sign of

190
00:08:31,719 --> 00:08:26,539
bacterial population or was it something

191
00:08:34,120 --> 00:08:31,729
else so one of the things that is a

192
00:08:37,350 --> 00:08:34,130
complicating factor in this is that all

193
00:08:39,969 --> 00:08:37,360
extant cyanobacteria have a co2

194
00:08:42,610 --> 00:08:39,979
concentrating mechanism probably the

195
00:08:45,100 --> 00:08:42,620
most famous bacterial organelle is known

196
00:08:48,010 --> 00:08:45,110
as the carboxy zone it's where cyanosis

197
00:08:51,160 --> 00:08:48,020
today have their Rubisco have all their

198
00:08:53,860 --> 00:08:51,170
carbonic anhydrase they bring in bicarb

199
00:08:55,990 --> 00:08:53,870
it gets converted through the activity

200
00:08:58,690 --> 00:08:56,000
of carbonic anhydrase to carbon dioxide

201
00:09:00,280 --> 00:08:58,700
right at the site of carbon fixation

202
00:09:02,920 --> 00:09:00,290
and what you can do is you can overcome

203
00:09:04,810 --> 00:09:02,930
some of the catalytic inefficiency of

204
00:09:08,350 --> 00:09:04,820
Rubisco in that way and there have been

205
00:09:10,710 --> 00:09:08,360
a whole bunch of different estimates for

206
00:09:13,000 --> 00:09:10,720
when the cyanobacterial co2

207
00:09:15,280 --> 00:09:13,010
concentrating mechanism may have come

208
00:09:19,540 --> 00:09:15,290
into play and what it is usually

209
00:09:21,970 --> 00:09:19,550
associated with is drops in carbon

210
00:09:24,340 --> 00:09:21,980
dioxide levels it makes sense if carbon

211
00:09:27,220 --> 00:09:24,350
dioxide levels fall you would expect

212
00:09:31,510 --> 00:09:27,230
that a co2 concentrating mechanism would

213
00:09:35,740 --> 00:09:31,520

be developed so we decided to test this

214
00:09:39,610 --> 00:09:35,750
and Sarah in the lab was able to create

215
00:09:42,240 --> 00:09:39,620
a carboxy zone this mutant of the

216
00:09:51,400 --> 00:09:42,250
wild-type cyanobacterium Senate caucus

217
00:09:53,920 --> 00:09:51,410
7002 and these green fluorescence images

218
00:09:58,150 --> 00:09:53,930
show the distribution of Rubisco in

219
00:10:01,870 --> 00:09:58,160
these mutant cyanobacteria she grew them

220
00:10:04,330 --> 00:10:01,880
under different co2 levels and it turns

221
00:10:06,370 --> 00:10:04,340
out that they're a high carbon requiring

222
00:10:08,580 --> 00:10:06,380
mutant which means that growing them at

223
00:10:10,840 --> 00:10:08,590
very low co2 levels is very difficult

224
00:10:12,910 --> 00:10:10,850
fortunately though it's a relatively

225
00:10:14,950 --> 00:10:12,920
simple system to model where you just

226
00:10:16,990 --> 00:10:14,960
have co2 diffusing into the site of

227
00:10:19,150 --> 00:10:17,000
carbon fixation so we were able to model

228
00:10:23,380 --> 00:10:19,160
what might happen at lower co2 levels

229
00:10:26,590 --> 00:10:23,390
even at relatively low co2 levels what

230
00:10:30,300 --> 00:10:26,600
you can see is that the range of carbon

231
00:10:33,990 --> 00:10:30,310
isotopes that are produced by these

232
00:10:37,690 --> 00:10:34,000
potentially physiologically ancestral

233
00:10:41,380 --> 00:10:37,700
cyanobacteria does not cover more than

234
00:10:44,050 --> 00:10:41,390
about 30% of the epsilon primary

235
00:10:47,080 --> 00:10:44,060
productivity range that we see in the

236
00:10:49,450 --> 00:10:47,090
middle Proterozoic so what happens when

237
00:10:52,120 --> 00:10:49,460
you just take a wild-type cyanobacterium

238
00:10:54,100 --> 00:10:52,130

and grow it again under different co2

239
00:10:56,650 --> 00:10:54,110
levels well what happens is you produce

240
00:10:59,950 --> 00:10:56,660
a range of carbon isotope values that

241
00:11:01,780 --> 00:10:59,960
covers 95% of the middle protozoic

242
00:11:05,320 --> 00:11:01,790
epsilon primary productivity

243
00:11:10,180 --> 00:11:05,330
distribution suggesting then that one of

244
00:11:11,950 --> 00:11:10,190
the simplest interpretations of the

245
00:11:14,260 --> 00:11:11,960
middle Proterozoic

246
00:11:17,320 --> 00:11:14,270
primary productivity record is that

247
00:11:19,269 --> 00:11:17,330
cyanobacteria with a carbon can't see

248
00:11:22,950 --> 00:11:19,279
you too concentrating mechanism for the

249
00:11:25,630 --> 00:11:22,960
dominant primary producer at this time

250
00:11:28,389 --> 00:11:25,640
great so what I'm gonna do now is I'm

251
00:11:31,510 --> 00:11:28,399
gonna speed into the second case study

252
00:11:34,300 --> 00:11:31,520
which is looking in very deep time and

253
00:11:36,519 --> 00:11:34,310
saying okay what might this carbon

254
00:11:39,850 --> 00:11:36,529
isotope fractionation distribution mean

255
00:11:41,260 --> 00:11:39,860
there's some similarity here between

256
00:11:43,750 --> 00:11:41,270
what you see in the middle Proterozoic

257
00:11:46,930 --> 00:11:43,760
and what you see in the early Archaean

258
00:11:49,449 --> 00:11:46,940
and in fact that may be used to say okay

259
00:11:51,460 --> 00:11:49,459
the same carbon fixation pathways were

260
00:11:52,990 --> 00:11:51,470
an operation at this time what we

261
00:11:56,260 --> 00:11:53,000
decided to do is a thought experiment

262
00:11:59,380 --> 00:11:56,270
and working with some colleagues at BU

263
00:12:02,560 --> 00:11:59,390

Daniel se gray and Josh Gould furred we

264
00:12:08,220 --> 00:12:02,570
decided to look at what might

265
00:12:10,660 --> 00:12:08,230
potentially happen if you created a

266
00:12:12,340 --> 00:12:10,670
endergonic and biomass capable

267
00:12:15,519 --> 00:12:12,350
metabolism from a simple set of

268
00:12:18,570 --> 00:12:15,529
potential prebiotic seed compounds shown

269
00:12:21,820 --> 00:12:18,580
down here acetate carbon dioxide 4 made

270
00:12:24,280 --> 00:12:21,830
hydrogen sulfide and some others and so

271
00:12:26,320 --> 00:12:24,290
essentially what Daniel and Josh did is

272
00:12:33,430 --> 00:12:26,330
they went ahead and they led to a

273
00:12:35,440 --> 00:12:33,440
network expansion associated with this

274
00:12:37,420 --> 00:12:35,450
metabolism and they were able to show

275
00:12:39,579 --> 00:12:37,430
that not only was it endergonic it was

276
00:12:40,870 --> 00:12:39,589
capable of producing biomass and what we

277
00:12:44,970 --> 00:12:40,880
wanted to know is what's the carbon

278
00:12:47,590 --> 00:12:44,980
isotopic consequences of this expansion

279
00:12:50,220 --> 00:12:47,600
so it turns out the carbon isotope

280
00:12:54,220 --> 00:12:50,230
fractionation is both incredibly

281
00:12:59,680 --> 00:12:54,230
confusing but at some level relatively

282
00:13:02,560 --> 00:12:59,690
straightforward so it depends on two

283
00:13:04,600 --> 00:13:02,570
things primarily one the nearest

284
00:13:07,240 --> 00:13:04,610
neighbors that the carbon atom is bonded

285
00:13:09,340 --> 00:13:07,250
to and then the nearest neighbors to

286
00:13:11,650 --> 00:13:09,350
those nearest neighbors and so what a

287
00:13:14,470 --> 00:13:11,660
colleague Chris butch was able to do was

288
00:13:17,530 --> 00:13:14,480

take this full set hundreds of different

289
00:13:22,620 --> 00:13:17,540
compounds and actually calculate what

290
00:13:25,060 --> 00:13:22,630
the isotopic fractionation would be as

291
00:13:32,210 --> 00:13:25,070
this explained

292
00:13:35,660 --> 00:13:32,220
happens okay and here shown on the left

293
00:13:39,439 --> 00:13:35,670
is the iterations here are two images of

294
00:13:41,509 --> 00:13:39,449
that epsilon primary productivity on the

295
00:13:43,730 --> 00:13:41,519
top the number of compounds in the

296
00:13:45,470 --> 00:13:43,740
network is shown linearly on the bottom

297
00:13:47,720 --> 00:13:45,480
we've got it plotted versus the log

298
00:13:49,400 --> 00:13:47,730
number of networks allowed number of

299
00:13:51,650 --> 00:13:49,410
compounds in the network this one is

300
00:13:54,800 --> 00:13:51,660
easier to see the differences the early

301
00:13:58,490 --> 00:13:54,810
networks are shown here in blue and in

302
00:14:00,759 --> 00:13:58,500
red but as the network increases in

303
00:14:03,620 --> 00:14:00,769
diversity and potentially in complexity

304
00:14:08,199 --> 00:14:03,630
isotope fractionation actually goes the

305
00:14:12,110 --> 00:14:08,209
other way it is narrowing up and

306
00:14:14,120 --> 00:14:12,120
approaching a single mode at about 18

307
00:14:21,610 --> 00:14:14,130
per mil for the difference between

308
00:14:24,139 --> 00:14:21,620
dissolve co2 and biomass so what's the

309
00:14:27,050 --> 00:14:24,149
reason behind this it turns out that

310
00:14:28,519 --> 00:14:27,060
when you count the bonds and the bonding

311
00:14:30,470 --> 00:14:28,529
partners that are involved in this as

312
00:14:35,240 --> 00:14:30,480
Chris has done here what you see is that

313
00:14:37,220 --> 00:14:35,250

as the network expands your overall

314
00:14:39,009 --> 00:14:37,230
bonding environment is getting more

315
00:14:42,170 --> 00:14:39,019
reduced you're seeing a lot more

316
00:14:44,689 --> 00:14:42,180
carbon-carbon bonds and carbon hydrogen

317
00:14:46,819 --> 00:14:44,699
bonds and here what I've shown is the

318
00:14:49,160 --> 00:14:46,829
distribution of Chris's chemo

319
00:14:51,740 --> 00:14:49,170
informatics prediction along with the

320
00:14:53,210 --> 00:14:51,750
early Archaean distribution and though

321
00:14:55,759 --> 00:14:53,220
they're not exactly the same there may

322
00:14:57,949 --> 00:14:55,769
be some kinetic effects here and less

323
00:15:00,230 --> 00:14:57,959
equilibrium effects here one thing

324
00:15:02,780 --> 00:15:00,240
that's very clear is that an epsilon

325
00:15:05,030 --> 00:15:02,790
primary productivity of around 18 per

326
00:15:07,639 --> 00:15:05,040
mil or 20 per mil a'somethin that would

327
00:15:10,400 --> 00:15:07,649
have been in the past associated with

328
00:15:13,460 --> 00:15:10,410
say the carbon fixation by the Calvin

329
00:15:15,620 --> 00:15:13,470
cycle may simply reflect the development

330
00:15:18,439 --> 00:15:15,630
in these networks of aliphatic

331
00:15:20,420 --> 00:15:18,449
carbon-carbon bond okay I'll leave you

332
00:15:22,699 --> 00:15:20,430
now with what we know what we think we

333
00:15:26,009 --> 00:15:22,709
know and what we want to know and thanks

334
00:15:27,280 --> 00:15:26,280
you