Was the Early Earth Hot?

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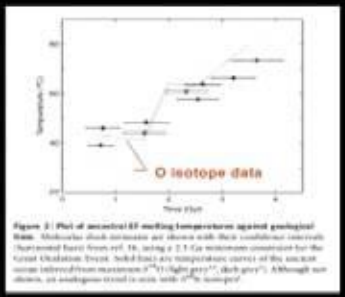
Palaeotemperature trend for Precambrian life inferred from resurrected proteins

Eric A. Gaucher[1], Sridhar Govindarajan[2] & Omjoy K. Ganesh[1]

Nature, Feb., 2008

- More recent work by this group proposes a detailed time scale for surface temperature evolution, based on two different molecular clock techniques
- Ancestral genes were synthesized and cloned into *E. coli* to allow them to be expressed as proteins
- Protein *melting points* were then measured in the lab



1
00:00:05,269 --> 00:00:03,350
okay so hello everybody and uh welcome

2
00:00:08,070 --> 00:00:05,279
to the university of washington's

3
00:00:10,150 --> 00:00:08,080
astrobiology seminar series

4
00:00:12,470 --> 00:00:10,160
today our distinguished speaker will be

5
00:00:13,669 --> 00:00:12,480
uh professor james casting of penn state

6
00:00:15,509 --> 00:00:13,679
university

7
00:00:16,470 --> 00:00:15,519
i'm going to give a little intro on on

8
00:00:19,070 --> 00:00:16,480
jim here

9
00:00:22,310 --> 00:00:19,080
jim got his ab at harvard university in

10
00:00:24,710 --> 00:00:22,320
1975 in chemistry and physics

11
00:00:27,029 --> 00:00:24,720
he did a master's in both physics and

12
00:00:29,189 --> 00:00:27,039
atmospheric chemistry in 1978 and then

13
00:00:33,270 --> 00:00:29,199

got his phd from the university of

14
00:00:35,670 --> 00:00:33,280
michigan in 1979 in atmospheric science

15
00:00:37,430 --> 00:00:35,680
he is very distinguished scientist he

16
00:00:40,389 --> 00:00:37,440
has been recently elected as a fellow of

17
00:00:42,150 --> 00:00:40,399
the american geophysical union in 2004

18
00:00:44,389 --> 00:00:42,160
and this year he was elected as a fellow

19
00:00:46,869 --> 00:00:44,399
of the geochemical society and of the

20
00:00:48,389 --> 00:00:46,879
american academy of arts and sciences as

21
00:00:49,990 --> 00:00:48,399
well

22
00:00:52,069 --> 00:00:50,000
jim has not only

23
00:00:53,590 --> 00:00:52,079
worked as an academic and a researcher

24
00:00:56,229 --> 00:00:53,600
but he's very active

25
00:00:57,590 --> 00:00:56,239
in helping nasa design some of his

26
00:00:59,590 --> 00:00:57,600
planetary missions in a particular

27
00:01:01,510 --> 00:00:59,600
terrestrial planet finder and he has

28
00:01:04,149 --> 00:01:01,520
served on the nasa terrestrial planet

29
00:01:05,990 --> 00:01:04,159
finder science working group the tpfc

30
00:01:08,230 --> 00:01:06,000
design and technology definition team

31
00:01:11,429 --> 00:01:08,240
which i worked with him on and also the

32
00:01:12,469 --> 00:01:11,439
nasa nsf exoplanet task force which

33
00:01:14,149 --> 00:01:12,479
sounds like it should come with a

34
00:01:15,590 --> 00:01:14,159
special uniform

35
00:01:17,670 --> 00:01:15,600
uh he is

36
00:01:18,789 --> 00:01:17,680
it does okay

37
00:01:20,469 --> 00:01:18,799
he's currently the distinguished

38
00:01:22,390 --> 00:01:20,479

professor of geosciences and meteorology

39
00:01:23,910 --> 00:01:22,400
at penn state university and in his

40
00:01:26,149 --> 00:01:23,920
spare time he works on the editorial

41
00:01:27,830 --> 00:01:26,159
board for astrobiology journal and as a

42
00:01:30,310 --> 00:01:27,840
member of the astrophysics subcommittee

43
00:01:33,109 --> 00:01:30,320
for the nasa advisory committee where he

44
00:01:34,710 --> 00:01:33,119
represents the interests of astrobiology

45
00:01:36,230 --> 00:01:34,720
for these large

46
00:01:37,990 --> 00:01:36,240
astrophysical missions that we hope to

47
00:01:40,230 --> 00:01:38,000
fly

48
00:01:42,149 --> 00:01:40,240
he works principally on the geophysical

49
00:01:43,510 --> 00:01:42,159
history of the earth focusing on climate

50
00:01:45,590 --> 00:01:43,520
and the evolution of planetary

51
00:01:50,389 --> 00:01:45,600
atmospheres and today he's going to talk

52
00:01:55,190 --> 00:01:52,710
okay thank you vicky and thank you all

53
00:01:57,030 --> 00:01:55,200
for inviting me out here i have been to

54
00:01:58,950 --> 00:01:57,040
the university of washington a couple of

55
00:01:59,830 --> 00:01:58,960
times before i think but not for quite a

56
00:02:01,429 --> 00:01:59,840
while

57
00:02:03,270 --> 00:02:01,439
i'm trying to remember the last time i

58
00:02:05,990 --> 00:02:03,280
was here i think it was maybe 10 years

59
00:02:09,109 --> 00:02:06,000
ago uh conway leovey who many of you may

60
00:02:10,790 --> 00:02:09,119
know invited me out i had known conway

61
00:02:13,110 --> 00:02:10,800
for a long time because he used to come

62
00:02:15,510 --> 00:02:13,120
down to nasa ames where i worked before

63
00:02:17,110 --> 00:02:15,520

i went to penn state he would come down

64
00:02:19,110 --> 00:02:17,120
and work with jim pollock and bob

65
00:02:21,430 --> 00:02:19,120
haverly there on on modeling mars

66
00:02:23,830 --> 00:02:21,440
climate so actually my contacts with

67
00:02:25,670 --> 00:02:23,840
university of washington go back a long

68
00:02:28,150 --> 00:02:25,680
ways uh

69
00:02:29,910 --> 00:02:28,160
the weather here is not the greatest

70
00:02:31,990 --> 00:02:29,920
today but let me tell you that in state

71
00:02:34,150 --> 00:02:32,000
college when i left yesterday it was 35

72
00:02:35,990 --> 00:02:34,160
degrees and raining so it's actually a

73
00:02:39,350 --> 00:02:36,000
pleasure to be out here on the

74
00:02:41,589 --> 00:02:39,360
relatively warm west coast

75
00:02:44,150 --> 00:02:41,599
what i want to talk today is about the

76
00:02:46,470 --> 00:02:44,160
uh the climate on the early earth some

77
00:02:48,710 --> 00:02:46,480
of you may have heard my my student or

78
00:02:51,110 --> 00:02:48,720
now postdoc sean goldman was here a

79
00:02:52,949 --> 00:02:51,120
month ago and he talked about sulfur

80
00:02:54,229 --> 00:02:52,959
photochemistry on the early earth and

81
00:02:56,630 --> 00:02:54,239
the sulfur mass independent

82
00:02:57,990 --> 00:02:56,640
fractionation problem i'm not going to

83
00:02:59,270 --> 00:02:58,000
do that because i didn't want to give

84
00:03:01,270 --> 00:02:59,280
the same talk that's probably what i

85
00:03:03,910 --> 00:03:01,280
would have talked about if sean hadn't

86
00:03:05,990 --> 00:03:03,920
but this is a topic that i'm also uh

87
00:03:08,390 --> 00:03:06,000
very interested in and

88
00:03:10,470 --> 00:03:08,400

uh there's people here that i've been

89
00:03:12,869 --> 00:03:10,480
already chatted with roger buick because

90
00:03:15,030 --> 00:03:12,879
roger out there there's roger up there

91
00:03:17,509 --> 00:03:15,040
uh in particular so i

92
00:03:19,509 --> 00:03:17,519
uh it's a very controversial issue and i

93
00:03:22,390 --> 00:03:19,519
i should say also that

94
00:03:23,430 --> 00:03:22,400
today i'm giving the talk here two days

95
00:03:25,589 --> 00:03:23,440
from now i'm going to go down to

96
00:03:27,270 --> 00:03:25,599
stanford where don lowe and norm sleep

97
00:03:29,270 --> 00:03:27,280
have been arguing about the climate of

98
00:03:32,949 --> 00:03:29,280
the early earth for the past five years

99
00:03:34,390 --> 00:03:32,959
or so maybe more than that so anyway i i

100
00:03:36,390 --> 00:03:34,400
thought this would be a good topic for

101
00:03:37,350 --> 00:03:36,400
both audiences

102
00:03:39,750 --> 00:03:37,360
just to

103
00:03:41,750 --> 00:03:39,760
introduce you here the the climate of

104
00:03:43,990 --> 00:03:41,760
the early earth obviously has varied

105
00:03:46,470 --> 00:03:44,000
with time sometimes it's been warmer

106
00:03:49,350 --> 00:03:46,480
sometimes it's been colder in general

107
00:03:51,750 --> 00:03:49,360
though we think that the early earth

108
00:03:53,190 --> 00:03:51,760
prior to now is usually warmer than it

109
00:03:55,509 --> 00:03:53,200
is today

110
00:03:57,910 --> 00:03:55,519
here's a slide that shows the

111
00:04:00,630 --> 00:03:57,920
temperatures and other events during the

112
00:04:03,750 --> 00:04:00,640
phanerozoic the last 540 million years

113
00:04:09,270 --> 00:04:07,270

we're in an ice age right now by by my

114
00:04:11,110 --> 00:04:09,280
definition of an ice age

115
00:04:13,910 --> 00:04:11,120
normally we think we're not in an ice

116
00:04:16,710 --> 00:04:13,920
age that was 10 20 000 years ago we're

117
00:04:19,189 --> 00:04:16,720
in interglacial between ice ages but

118
00:04:21,590 --> 00:04:19,199
from a long-term perspective there's ice

119
00:04:24,230 --> 00:04:21,600
on the on the poles and so we're in an

120
00:04:26,870 --> 00:04:24,240
ice age there has been ice on antarctica

121
00:04:29,270 --> 00:04:26,880
since about 35 million years ago so

122
00:04:31,510 --> 00:04:29,280
we've been in an ice age for the last uh

123
00:04:34,150 --> 00:04:31,520
35 million years and call it the

124
00:04:36,310 --> 00:04:34,160
pleistocene ice age or the late cenozoic

125
00:04:40,310 --> 00:04:36,320
ice age if you like

126
00:04:42,230 --> 00:04:40,320
prior to that the mesozoic era was warm

127
00:04:43,830 --> 00:04:42,240
for a long time this was the era when

128
00:04:45,270 --> 00:04:43,840
the dinosaurs were running around you

129
00:04:47,749 --> 00:04:45,280
probably know there were

130
00:04:49,749 --> 00:04:47,759
dinosaurs up in alaska north of the

131
00:04:51,990 --> 00:04:49,759
arctic circle there were alligators at

132
00:04:54,070 --> 00:04:52,000
crocodiles in siberia

133
00:04:56,790 --> 00:04:54,080
so we think the earth was considerably

134
00:04:59,189 --> 00:04:56,800
warmer than today at that time

135
00:05:01,510 --> 00:04:59,199
prior to that there was this long about

136
00:05:03,830 --> 00:05:01,520
80 million year long promo carboniferous

137
00:05:05,990 --> 00:05:03,840
ice age which was another sort of

138
00:05:07,909 --> 00:05:06,000

conventional ice age like the one that

139
00:05:09,749 --> 00:05:07,919
we're in right now where you get ice

140
00:05:11,110 --> 00:05:09,759
sheets at the poles that occasionally

141
00:05:13,749 --> 00:05:11,120
expand

142
00:05:17,189 --> 00:05:13,759
prior to that the uh most of the early

143
00:05:19,590 --> 00:05:17,199
paleozoic was warm uh this whole period

144
00:05:21,590 --> 00:05:19,600
here seems to be warm except there was

145
00:05:24,550 --> 00:05:21,600
an ice age pretty good pretty good one

146
00:05:26,870 --> 00:05:24,560
at the in the late ordovician where the

147
00:05:29,029 --> 00:05:26,880
continents became deeply glaciated but

148
00:05:31,510 --> 00:05:29,039
that's a weird one it lasted uh less

149
00:05:33,830 --> 00:05:31,520
than a million years it defines a single

150
00:05:36,790 --> 00:05:33,840
stage in the geologic record and it's in

151
00:05:39,029 --> 00:05:36,800
a period uh that is otherwise warm

152
00:05:40,950 --> 00:05:39,039
so that that one's a curious one these

153
00:05:43,029 --> 00:05:40,960
two the one that we're in right now and

154
00:05:45,029 --> 00:05:43,039
the promo carboniferous i would argue

155
00:05:47,749 --> 00:05:45,039
are probably caused by changes in

156
00:05:49,749 --> 00:05:47,759
atmospheric co2 you know the sun is

157
00:05:52,070 --> 00:05:49,759
slowly brightening that's not a huge

158
00:05:53,990 --> 00:05:52,080
factor in the phanerozoic but co2 goes

159
00:05:56,469 --> 00:05:54,000
up and down because it's controlled

160
00:05:59,029 --> 00:05:56,479
mostly by the carbonate silicate cycle

161
00:06:01,830 --> 00:05:59,039
and bob burner at yale has run models

162
00:06:04,309 --> 00:06:01,840
for many years that sort of explain the

163
00:06:06,550 --> 00:06:04,319

co2 variations based on motions of the

164
00:06:08,870 --> 00:06:06,560
continents and when you get lots of

165
00:06:11,029 --> 00:06:08,880
weathering and changes in seafood

166
00:06:14,150 --> 00:06:11,039
spreading rates

167
00:06:15,270 --> 00:06:14,160
if we go and look at the more

168
00:06:17,350 --> 00:06:15,280
vast

169
00:06:20,150 --> 00:06:17,360
expanse of earth history go back through

170
00:06:22,230 --> 00:06:20,160
geologic time the phanerozoic is now

171
00:06:24,710 --> 00:06:22,240
compressed up here at the top

172
00:06:26,550 --> 00:06:24,720
and the rest of this time back to four

173
00:06:28,790 --> 00:06:26,560
and a half billion years used to just be

174
00:06:31,029 --> 00:06:28,800
called the precambrian but of course we

175
00:06:32,830 --> 00:06:31,039
divide it subdivide it now into the

176
00:06:35,990 --> 00:06:32,840
adian and the archaean and the

177
00:06:37,909 --> 00:06:36,000
proterozoic eons

178
00:06:39,830 --> 00:06:37,919
at the end of the proterozoic just

179
00:06:42,309 --> 00:06:39,840
before the cambrian explosion there were

180
00:06:44,230 --> 00:06:42,319
some very deep glaciations at least two

181
00:06:45,909 --> 00:06:44,240
of them which many of you have probably

182
00:06:47,909 --> 00:06:45,919
heard about these are the ones that joe

183
00:06:49,909 --> 00:06:47,919
kershwink and paul hoffman have

184
00:06:51,830 --> 00:06:49,919
popularized as being snowball earth

185
00:06:53,670 --> 00:06:51,840
episodes i think they're right i think

186
00:06:55,909 --> 00:06:53,680
the earth probably was frozen over

187
00:06:57,670 --> 00:06:55,919
entirely at that point although maybe

188
00:06:59,430 --> 00:06:57,680

the ice was thin in the tropics so

189
00:07:01,270 --> 00:06:59,440
there's you've got to explain how the

190
00:07:04,309 --> 00:07:01,280
biota get through that

191
00:07:06,469 --> 00:07:04,319
i'm not going to talk about that today

192
00:07:08,710 --> 00:07:06,479
prior to that the most of the middle

193
00:07:11,029 --> 00:07:08,720
proterozoic was warm the earth was

194
00:07:13,270 --> 00:07:11,039
evidently ice free for

195
00:07:15,350 --> 00:07:13,280
almost a billion and a half years and

196
00:07:17,670 --> 00:07:15,360
that's probably real because the

197
00:07:19,510 --> 00:07:17,680
geologic record is relatively good

198
00:07:21,589 --> 00:07:19,520
during the proterozoic at least compared

199
00:07:23,430 --> 00:07:21,599
to the archaean

200
00:07:25,670 --> 00:07:23,440
i am going to talk about these two ice

201
00:07:28,790 --> 00:07:25,680
ages there's a very well documented ice

202
00:07:31,110 --> 00:07:28,800
age at 2.4 billion years or thereabouts

203
00:07:33,430 --> 00:07:31,120
which happens to correspond with the

204
00:07:35,830 --> 00:07:33,440
rise of atmospheric oxygen and that's a

205
00:07:37,909 --> 00:07:35,840
major theme of my talk today i don't

206
00:07:40,150 --> 00:07:37,919
think that that's an accident and so

207
00:07:43,110 --> 00:07:40,160
either one of the either the rise of

208
00:07:46,870 --> 00:07:43,120
oxygen caused the ice age or vice versa

209
00:07:49,189 --> 00:07:46,880
the ice age caused the rise of oxygen

210
00:07:52,309 --> 00:07:49,199
the archaean in general now the geologic

211
00:07:54,070 --> 00:07:52,319
record gets pretty spotty as you go back

212
00:07:56,150 --> 00:07:54,080
earlier but

213
00:07:57,110 --> 00:07:56,160

we think it was probably warm however

214
00:08:00,150 --> 00:07:57,120
there's

215
00:08:03,430 --> 00:08:00,160
evidence for an ice age here at 2.8

216
00:08:05,510 --> 00:08:03,440
maybe to between 2.8 and 3 billion years

217
00:08:07,830 --> 00:08:05,520
and there may be ice

218
00:08:09,749 --> 00:08:07,840
even prior to that although it's not

219
00:08:10,550 --> 00:08:09,759
nothing has been published

220
00:08:12,309 --> 00:08:10,560
so

221
00:08:14,230 --> 00:08:12,319
that's important because the rest of

222
00:08:16,309 --> 00:08:14,240
this talk is

223
00:08:18,070 --> 00:08:16,319
well the next part of it is all these

224
00:08:21,270 --> 00:08:18,080
people who've been saying that the early

225
00:08:26,629 --> 00:08:24,150
so they in the last four or five years

226
00:08:28,469 --> 00:08:26,639
and in fact going back prior to that

227
00:08:30,950 --> 00:08:28,479
actually for the last 20 or 30 years

228
00:08:33,509 --> 00:08:30,960
there have been various people like paul

229
00:08:36,949 --> 00:08:33,519
canal at uh arizona state who have

230
00:08:39,190 --> 00:08:36,959
argued that the uh the early earth both

231
00:08:42,630 --> 00:08:39,200
in the archaean and the proterozoic was

232
00:08:45,269 --> 00:08:42,640
was actually quite high maybe 70 degrees

233
00:08:48,310 --> 00:08:45,279
60 to 70 degrees during the archaean in

234
00:08:51,430 --> 00:08:48,320
fact paul actually likes 85 degrees for

235
00:08:52,310 --> 00:08:51,440
the archaean if you press him on it

236
00:08:53,110 --> 00:08:52,320
why

237
00:08:55,110 --> 00:08:53,120
do

238
00:08:57,509 --> 00:08:55,120

people argue that the early earth was

239
00:09:00,230 --> 00:08:57,519
hot well a lot of it comes from isotope

240
00:09:03,829 --> 00:09:00,240
records and i'm going to just briefly go

241
00:09:06,070 --> 00:09:03,839
through uh some of the isotopic data

242
00:09:07,590 --> 00:09:06,080
if you look at the most recent ice age

243
00:09:09,750 --> 00:09:07,600
that we're in the pleistocene you know

244
00:09:11,590 --> 00:09:09,760
the glaciers have been coming and going

245
00:09:13,430 --> 00:09:11,600
we know most of what we know about that

246
00:09:15,030 --> 00:09:13,440
comes from oxygen isotopes and

247
00:09:16,470 --> 00:09:15,040
carbonates

248
00:09:17,430 --> 00:09:16,480
if you have

249
00:09:20,150 --> 00:09:17,440
more

250
00:09:22,550 --> 00:09:20,160
o18 in the carbonates that means that

251
00:09:25,350 --> 00:09:22,560
the climate is colder

252
00:09:27,590 --> 00:09:25,360
here's a delta o18 is a measure of

253
00:09:29,990 --> 00:09:27,600
relative to standard mean ocean water

254
00:09:32,949 --> 00:09:30,000
that's the relative amount of o 18 in

255
00:09:35,269 --> 00:09:32,959
carbonates as that gets higher than the

256
00:09:38,230 --> 00:09:35,279
climate is cold and as that gets lower

257
00:09:40,230 --> 00:09:38,240
the climate is warm today that happens

258
00:09:42,949 --> 00:09:40,240
because of two main things one is the

259
00:09:43,750 --> 00:09:42,959
buildup of ice on the poles which is low

260
00:09:45,829 --> 00:09:43,760
in

261
00:09:47,590 --> 00:09:45,839
018 and the other is that there's a

262
00:09:49,430 --> 00:09:47,600
fractionation between sea water and

263
00:09:50,389 --> 00:09:49,440

carbonates and the colder the water gets

264
00:09:52,150 --> 00:09:50,399
the more

265
00:09:53,430 --> 00:09:52,160
enriched the carbonates get in o

266
00:09:56,150 --> 00:09:53,440
eighteen

267
00:09:58,470 --> 00:09:56,160
well that that's not controversial or at

268
00:10:00,470 --> 00:09:58,480
least not very controversial on the the

269
00:10:01,990 --> 00:10:00,480
recent glacial interglacial time scale

270
00:10:04,150 --> 00:10:02,000
but if you try to go back even through

271
00:10:05,750 --> 00:10:04,160
the phanerozoic then it becomes

272
00:10:09,030 --> 00:10:05,760
controversial because there's a big

273
00:10:10,870 --> 00:10:09,040
trend in oxygen isotope data as john

274
00:10:12,790 --> 00:10:10,880
visor and graham shields and their

275
00:10:13,670 --> 00:10:12,800
collaborators have been arguing for many

276
00:10:16,069 --> 00:10:13,680
years

277
00:10:18,389 --> 00:10:16,079
this is visor's uh

278
00:10:21,350 --> 00:10:18,399
shields and visors

279
00:10:23,990 --> 00:10:21,360
oxygen isotope database from carbonates

280
00:10:26,069 --> 00:10:24,000
basically all their data going back from

281
00:10:28,790 --> 00:10:26,079
the present to three and a half billion

282
00:10:31,430 --> 00:10:28,800
years ago the dots are different data

283
00:10:33,269 --> 00:10:31,440
points and then this line is a drawn

284
00:10:35,670 --> 00:10:33,279
through the middle you can see that

285
00:10:37,829 --> 00:10:35,680
there's a very steep falloff you're

286
00:10:41,350 --> 00:10:37,839
going down towards lighter

287
00:10:43,190 --> 00:10:41,360
isotopically depleted carbonates

288
00:10:45,030 --> 00:10:43,200

much of the drop-off happens during the

289
00:10:47,910 --> 00:10:45,040
phanerozoic here and then it sort of

290
00:10:50,949 --> 00:10:47,920
levels out by the time you get that back

291
00:10:53,910 --> 00:10:50,959
to the archaean back in here the

292
00:10:56,949 --> 00:10:53,920
carbonates are at least 10 maybe 15 per

293
00:10:58,949 --> 00:10:56,959
mil lighter than they are today and that

294
00:11:01,350 --> 00:10:58,959
taken at face value that means high

295
00:11:04,230 --> 00:11:01,360
temperatures here's a

296
00:11:07,190 --> 00:11:04,240
calibration scale for how this works

297
00:11:08,470 --> 00:11:07,200
this is uh the delta o18 of calcite

298
00:11:09,829 --> 00:11:08,480
versus

299
00:11:12,550 --> 00:11:09,839
relative to the

300
00:11:14,150 --> 00:11:12,560
pd belluminite and this is temperature

301
00:11:16,230 --> 00:11:14,160
these are for different amounts of

302
00:11:19,269 --> 00:11:16,240
different concentrations of

303
00:11:20,630 --> 00:11:19,279
uh oxygen 18 and seawater i'm going to

304
00:11:22,470 --> 00:11:20,640
talk one of the variables here is

305
00:11:24,630 --> 00:11:22,480
whether seawater has remained constant

306
00:11:27,509 --> 00:11:24,640
but if you just stay up here at the top

307
00:11:29,670 --> 00:11:27,519
where seawater is at zero per ml on the

308
00:11:32,550 --> 00:11:29,680
on the small scale standard mean ocean

309
00:11:35,110 --> 00:11:32,560
water then it's sort of a linear almost

310
00:11:37,750 --> 00:11:35,120
a linear relationship and what about

311
00:11:40,710 --> 00:11:37,760
written 10 a change in 10 per ml in

312
00:11:44,230 --> 00:11:40,720
delta o 18 corresponds to a temperature

313
00:11:46,870 --> 00:11:44,240

increase of some 54 degrees celsius

314
00:11:49,910 --> 00:11:46,880
that's a lot so if the archaean really

315
00:11:52,150 --> 00:11:49,920
was 10 per ml lower in delta 018 if that

316
00:11:54,550 --> 00:11:52,160
was all temperature today the mean

317
00:11:56,550 --> 00:11:54,560
temperature is about 15 celsius so that

318
00:11:58,949 --> 00:11:56,560
would put you to about 70 c for the

319
00:12:01,269 --> 00:11:58,959
archaean

320
00:12:02,710 --> 00:12:01,279
all right now there's lots of criticisms

321
00:12:04,710 --> 00:12:02,720
to that uh

322
00:12:08,230 --> 00:12:04,720
what's the the main one the one that's

323
00:12:11,590 --> 00:12:08,240
been argued for a long time is that

324
00:12:13,829 --> 00:12:11,600
you may be affected by diagenesis when

325
00:12:16,629 --> 00:12:13,839
sediments carbonates in particular when

326
00:12:19,350 --> 00:12:16,639
they're deposited at the sea floor they

327
00:12:21,910 --> 00:12:19,360
can continue to exchange oxygen with

328
00:12:24,150 --> 00:12:21,920
seawater and as they get more deeply

329
00:12:27,190 --> 00:12:24,160
buried and warmed up but just by the

330
00:12:28,949 --> 00:12:27,200
geothermal gradient then the extra as

331
00:12:31,509 --> 00:12:28,959
long as the sea water is still in

332
00:12:34,230 --> 00:12:31,519
contact with the carbonates you can get

333
00:12:35,910 --> 00:12:34,240
exchange of isotopes and that tends to

334
00:12:37,990 --> 00:12:35,920
make the carbonates remember they're

335
00:12:39,670 --> 00:12:38,000
enriched in o-18 to begin with so that

336
00:12:42,310 --> 00:12:39,680
tends to deplete them and makes them

337
00:12:43,910 --> 00:12:42,320
isotopically lighter so this is what i

338
00:12:46,949 --> 00:12:43,920

always used to think that that whole

339
00:12:48,710 --> 00:12:46,959
oxygen isotope trend was just

340
00:12:51,110 --> 00:12:48,720
just diagenetic and therefore we could

341
00:12:52,710 --> 00:12:51,120
afford to ignore all those data which

342
00:12:55,910 --> 00:12:52,720
was very convenient because they're hard

343
00:12:57,910 --> 00:12:55,920
to explain if you don't ignore them

344
00:13:00,389 --> 00:12:57,920
however there's lots of people that have

345
00:13:01,509 --> 00:13:00,399
argued the opposite paul canal theon

346
00:13:02,470 --> 00:13:01,519
visor

347
00:13:04,629 --> 00:13:02,480
linda

348
00:13:07,030 --> 00:13:04,639
k mike arthur who's in our department at

349
00:13:09,110 --> 00:13:07,040
penn state lots of the you know

350
00:13:11,670 --> 00:13:09,120
carbonate the isotope g chemists have

351
00:13:13,829 --> 00:13:11,680
always argued that that's not the case

352
00:13:16,389 --> 00:13:13,839
now there's also evidence from silicon

353
00:13:19,269 --> 00:13:16,399
isotopes this paper by roberan chosidon

354
00:13:22,069 --> 00:13:19,279
from a couple years ago that seems to

355
00:13:26,310 --> 00:13:22,079
corroborate the oxygen isotope data and

356
00:13:29,670 --> 00:13:26,320
uh i will talk about that in a moment

357
00:13:31,670 --> 00:13:29,680
there is another explanation for the uh

358
00:13:33,750 --> 00:13:31,680
trend in the carbonates that is even

359
00:13:36,230 --> 00:13:33,760
more controversial and that's that the

360
00:13:37,910 --> 00:13:36,240
isotopic composition of seawater has

361
00:13:40,790 --> 00:13:37,920
changed with time

362
00:13:42,230 --> 00:13:40,800
now uh this is something that i've uh

363
00:13:44,150 --> 00:13:42,240

the last part of my talk will be

364
00:13:45,910 --> 00:13:44,160
concerned about this because i've

365
00:13:48,470 --> 00:13:45,920
now that i've gotten re-interested in

366
00:13:51,030 --> 00:13:48,480
the in the data i've ventured into this

367
00:13:53,590 --> 00:13:51,040
frame myself but there's a

368
00:13:55,990 --> 00:13:53,600
been a running debate for 30 or 40 years

369
00:13:58,069 --> 00:13:56,000
ever since oxygen isotopes

370
00:14:00,310 --> 00:13:58,079
were first measured as to whether the

371
00:14:01,910 --> 00:14:00,320
ocean stays constant and there's there

372
00:14:04,230 --> 00:14:01,920
are actually a lot of geochemists who

373
00:14:06,230 --> 00:14:04,240
would argue that that's the case i'm

374
00:14:08,389 --> 00:14:06,240
going to argue in this talk that it that

375
00:14:10,310 --> 00:14:08,399
it's not the case that the seawater

376
00:14:13,590 --> 00:14:10,320
changes with time

377
00:14:15,910 --> 00:14:13,600
however there is a and obviously if the

378
00:14:19,110 --> 00:14:15,920
ocean was isotopically lighter back in

379
00:14:20,870 --> 00:14:19,120
the past then you know that 10 ml change

380
00:14:23,110 --> 00:14:20,880
in the carbonates could just be due to a

381
00:14:25,430 --> 00:14:23,120
change of 10 per ml in seawater and have

382
00:14:27,829 --> 00:14:25,440
nothing to do with surface temperature

383
00:14:28,550 --> 00:14:27,839
however there's a way of checking this

384
00:14:31,110 --> 00:14:28,560
and

385
00:14:33,509 --> 00:14:31,120
that's uh comes from this very new

386
00:14:35,670 --> 00:14:33,519
technique which is uh from john eiler's

387
00:14:38,069 --> 00:14:35,680
group down at caltech he calls it the

388
00:14:41,030 --> 00:14:38,079

clumped isotope technique there's a

389
00:14:42,790 --> 00:14:41,040
paper by rosemary kame at owl in nature

390
00:14:44,949 --> 00:14:42,800
last year

391
00:14:46,790 --> 00:14:44,959
and what this is this is something i

392
00:14:48,310 --> 00:14:46,800
just learned about this from hearing

393
00:14:49,990 --> 00:14:48,320
john eiler talk at the goldschmidt

394
00:14:50,870 --> 00:14:50,000
conference in melbourne a couple years

395
00:14:54,069 --> 00:14:50,880
ago

396
00:14:56,790 --> 00:14:54,079
he's looking at carbonates again here

397
00:14:58,870 --> 00:14:56,800
but he's measuring

398
00:15:02,230 --> 00:14:58,880
measuring carbonates that have that are

399
00:15:05,350 --> 00:15:02,240
multiply substituted with rare isotopes

400
00:15:08,870 --> 00:15:05,360
so for instance here suppose you've got

401
00:15:11,590 --> 00:15:08,880
on this side here the normal carbonate

402
00:15:13,910 --> 00:15:11,600
has a carbon-12 and

403
00:15:17,110 --> 00:15:13,920
three o sixteens in it

404
00:15:20,550 --> 00:15:17,120
right but this carbonate here has both a

405
00:15:23,030 --> 00:15:20,560
carbon 13 and an oxygen 18 along with

406
00:15:25,590 --> 00:15:23,040
two of the normal o sixteens this is a

407
00:15:28,230 --> 00:15:25,600
very rare isotope very difficult to

408
00:15:31,269 --> 00:15:28,240
measure because you know that what the

409
00:15:33,590 --> 00:15:31,279
one percent of carbon is is

410
00:15:36,710 --> 00:15:33,600
c13 i think and about one or two percent

411
00:15:38,949 --> 00:15:36,720
of oxygen is o18 so this is it's very

412
00:15:39,750 --> 00:15:38,959
tricky to measure the concentration of

413
00:15:42,069 --> 00:15:39,760

this

414
00:15:45,829 --> 00:15:42,079
but here he's written out

415
00:15:47,910 --> 00:15:45,839
an equilibrium reaction this is 13 c

416
00:15:49,670 --> 00:15:47,920
o 3

417
00:15:52,710 --> 00:15:49,680
double minus plus

418
00:15:55,269 --> 00:15:52,720
this carbonate ion here has

419
00:15:58,069 --> 00:15:55,279
an o 18 in it and then they're reacting

420
00:16:00,230 --> 00:15:58,079
to form this one this is what uh eiler

421
00:16:02,389 --> 00:16:00,240
calls a clumped isotope he's got the

422
00:16:03,749 --> 00:16:02,399
both of the heavy isotopes in the same

423
00:16:05,430 --> 00:16:03,759
species here

424
00:16:07,910 --> 00:16:05,440
and the nice thing about this if you can

425
00:16:10,629 --> 00:16:07,920
measure the abundances of all all four

426
00:16:12,949 --> 00:16:10,639
of these species that that equilibrium

427
00:16:15,590 --> 00:16:12,959
depends on temperature cold temperatures

428
00:16:17,350 --> 00:16:15,600
favor the heavy the clumped isotope here

429
00:16:19,110 --> 00:16:17,360
and it's independent of the uh

430
00:16:21,189 --> 00:16:19,120
concentration of

431
00:16:23,110 --> 00:16:21,199
o 18 in seawater

432
00:16:24,949 --> 00:16:23,120
right so that's the real nice thing

433
00:16:26,629 --> 00:16:24,959
about it that gets you away from this

434
00:16:29,749 --> 00:16:26,639
question of whether sea water varies

435
00:16:34,710 --> 00:16:32,629
so the uh comedy adult paper came out by

436
00:16:36,550 --> 00:16:34,720
the way john visor was a co-author on

437
00:16:38,389 --> 00:16:36,560
this john is one of the people who's

438
00:16:40,870 --> 00:16:38,399

argued vociferously that seawater

439
00:16:43,350 --> 00:16:40,880
composition does change with time but

440
00:16:44,790 --> 00:16:43,360
eiler got him in and you know john has

441
00:16:46,949 --> 00:16:44,800
at least given in

442
00:16:50,150 --> 00:16:46,959
partly on this they've

443
00:16:52,550 --> 00:16:50,160
used this technique then to look at uh

444
00:16:55,269 --> 00:16:52,560
at ancient carbonates in a couple

445
00:16:58,189 --> 00:16:55,279
periods from the phanerozoic one is the

446
00:17:00,150 --> 00:16:58,199
carboniferous which is uh during that

447
00:17:02,069 --> 00:17:00,160
thermocarboniferous ice age when it's

448
00:17:03,829 --> 00:17:02,079
cold and another

449
00:17:05,590 --> 00:17:03,839
that's this sample right here and

450
00:17:07,669 --> 00:17:05,600
there's another sample from the early

451
00:17:10,470 --> 00:17:07,679
silurian when it's warm

452
00:17:12,870 --> 00:17:10,480
so that's these data here this is ocean

453
00:17:16,069 --> 00:17:12,880
temperature inferred from the clumped

454
00:17:17,110 --> 00:17:16,079
isotope technique the diamonds are their

455
00:17:19,350 --> 00:17:17,120
data

456
00:17:22,390 --> 00:17:19,360
here cold and the carboniferous warm in

457
00:17:24,870 --> 00:17:22,400
the early salarian this solid curve is

458
00:17:26,710 --> 00:17:24,880
bob burner's theoretical curve where

459
00:17:28,950 --> 00:17:26,720
he's running his carbon cycle model and

460
00:17:31,190 --> 00:17:28,960
trying to fit the climate and then this

461
00:17:33,110 --> 00:17:31,200
is uh i think this is

462
00:17:35,270 --> 00:17:33,120
vice or wallman's

463
00:17:36,710 --> 00:17:35,280

john vicer and klaus wallman's oxygen

464
00:17:38,870 --> 00:17:36,720
isotope curve where they're trying to

465
00:17:42,950 --> 00:17:38,880
let sea level uh see

466
00:17:44,230 --> 00:17:42,960
seawater isotopic composition vary

467
00:17:46,150 --> 00:17:44,240
over here

468
00:17:47,830 --> 00:17:46,160
what they once you've once you if you

469
00:17:50,950 --> 00:17:47,840
think you know the temperature you can

470
00:17:52,549 --> 00:17:50,960
then infer what seawater oxygen isotope

471
00:17:55,669 --> 00:17:52,559
composition is

472
00:17:57,830 --> 00:17:55,679
and here we are today at zero there the

473
00:18:00,150 --> 00:17:57,840
clumped isotope technique says that

474
00:18:01,190 --> 00:18:00,160
seawater hasn't changed by more than two

475
00:18:03,750 --> 00:18:01,200
per mil

476
00:18:05,669 --> 00:18:03,760
back to this uh back as

477
00:18:07,909 --> 00:18:05,679
as early as the uh

478
00:18:09,990 --> 00:18:07,919
the early silurian

479
00:18:12,630 --> 00:18:10,000
these this curve right here this solid

480
00:18:15,510 --> 00:18:12,640
curve is how jan viser thinks the

481
00:18:17,590 --> 00:18:15,520
seawater composition has varied and this

482
00:18:20,230 --> 00:18:17,600
lighter curve i think is klaus wallman's

483
00:18:22,070 --> 00:18:20,240
curve both of these they both models

484
00:18:25,110 --> 00:18:22,080
they assume that it varies

485
00:18:27,990 --> 00:18:25,120
so the point is is of the comma at our

486
00:18:31,029 --> 00:18:28,000
paper is that seawater hasn't changed by

487
00:18:33,669 --> 00:18:31,039
nearly enough to explain the uh oxygen

488
00:18:37,350 --> 00:18:33,679

isotope data meaning that it really was

489
00:18:39,909 --> 00:18:37,360
warm back in the early silurian

490
00:18:42,470 --> 00:18:39,919
and back to where we were

491
00:18:44,870 --> 00:18:42,480
that one of the the cold data point was

492
00:18:47,350 --> 00:18:44,880
during this ice age so that that uh

493
00:18:50,870 --> 00:18:47,360
makes sense the warm data point is from

494
00:18:53,270 --> 00:18:50,880
the it's between 443 and 423 million

495
00:18:55,270 --> 00:18:53,280
years ago so it's right here it's right

496
00:18:57,350 --> 00:18:55,280
after this late ordovician ice age but

497
00:19:00,310 --> 00:18:57,360
that as i said that ice age is an

498
00:19:01,830 --> 00:19:00,320
anomaly it's a very quick uh ice age

499
00:19:03,750 --> 00:19:01,840
that happened in the midst of an

500
00:19:06,390 --> 00:19:03,760
otherwise warm period

501
00:19:08,150 --> 00:19:06,400
and uh the clumped isotope data indicate

502
00:19:10,630 --> 00:19:08,160
that the temperatures here were

503
00:19:12,630 --> 00:19:10,640
something like 5 to 11 degrees celsius

504
00:19:13,590 --> 00:19:12,640
warmer than today

505
00:19:16,070 --> 00:19:13,600
so

506
00:19:18,150 --> 00:19:16,080
at any weight that

507
00:19:20,870 --> 00:19:18,160
that round has gone to those that think

508
00:19:22,470 --> 00:19:20,880
that seawater composition stays constant

509
00:19:24,549 --> 00:19:22,480
or more or less

510
00:19:26,310 --> 00:19:24,559
back to the oxygen isotope data the

511
00:19:29,110 --> 00:19:26,320
other thing that you can look at is

512
00:19:31,750 --> 00:19:29,120
cherts which are sio2

513
00:19:34,150 --> 00:19:31,760

uh church tend to be better preserved

514
00:19:36,390 --> 00:19:34,160
over longer time periods than carbonates

515
00:19:37,990 --> 00:19:36,400
are and so this is what paul canal has

516
00:19:40,710 --> 00:19:38,000
used for a long time he's measured

517
00:19:41,909 --> 00:19:40,720
oxygen isotopes in church and used this

518
00:19:44,470 --> 00:19:41,919
to infer

519
00:19:48,470 --> 00:19:44,480
things about pre-cambrian climates these

520
00:19:51,430 --> 00:19:48,480
are paul canales data from a 2005 review

521
00:19:52,789 --> 00:19:51,440
paper that he wrote this is dell o18 of

522
00:19:55,430 --> 00:19:52,799
the church

523
00:19:57,270 --> 00:19:55,440
and uh you can see that this is time

524
00:19:58,470 --> 00:19:57,280
going back to three and a half billion

525
00:20:00,549 --> 00:19:58,480
years ago

526
00:20:02,630 --> 00:20:00,559
uh what paul likes to do is he looks at

527
00:20:04,710 --> 00:20:02,640
there's a big spread in the data which

528
00:20:06,950 --> 00:20:04,720
come from all sorts of processes he

529
00:20:08,630 --> 00:20:06,960
likes to look at the upper envelope of

530
00:20:11,669 --> 00:20:08,640
the spread which paul would argue are

531
00:20:15,510 --> 00:20:11,679
the least altered least uh

532
00:20:17,590 --> 00:20:15,520
effect or the most representative of the

533
00:20:20,549 --> 00:20:17,600
ocean conditions and you can see that

534
00:20:23,110 --> 00:20:20,559
these also become lighter in o-18 as you

535
00:20:25,029 --> 00:20:23,120
go back then there's a big drop-off

536
00:20:27,350 --> 00:20:25,039
right around the archaean proterozoic

537
00:20:29,510 --> 00:20:27,360
boundary and then the archaean back here

538
00:20:30,789 --> 00:20:29,520

all the church are really light and this

539
00:20:32,710 --> 00:20:30,799
is what paul

540
00:20:34,789 --> 00:20:32,720
where these data have been around most

541
00:20:38,310 --> 00:20:34,799
of them for a long time this is where he

542
00:20:41,029 --> 00:20:38,320
gets his 70 degree archaean temperatures

543
00:20:43,430 --> 00:20:41,039
so that's the published uh figure there

544
00:20:46,710 --> 00:20:43,440
was a paper in gsa bulletin by paul

545
00:20:50,390 --> 00:20:46,720
knouth and don lowe in 2003 they

546
00:20:54,630 --> 00:20:50,400
published 70 degrees plus or minus 15 at

547
00:20:56,470 --> 00:20:54,640
about 3.3 billion years ago

548
00:20:58,470 --> 00:20:56,480
the carbonate data you know the

549
00:20:59,909 --> 00:20:58,480
carbonate data are not exactly the same

550
00:21:01,510 --> 00:20:59,919
because the biggest change in the

551
00:21:03,430 --> 00:21:01,520
carbonates actually occurs during the

552
00:21:05,990 --> 00:21:03,440
phanerozoic whereas the bigger change in

553
00:21:07,990 --> 00:21:06,000
the church occurs back uh between the

554
00:21:09,990 --> 00:21:08,000
archaean and the protozoa

555
00:21:12,310 --> 00:21:10,000
but the carbonate data

556
00:21:14,789 --> 00:21:12,320
say that uh ocean temperatures remained

557
00:21:16,789 --> 00:21:14,799
warm until fairly recently you know only

558
00:21:19,270 --> 00:21:16,799
400 million years ago

559
00:21:22,070 --> 00:21:19,280
so in fact this hypothesis predicts that

560
00:21:24,070 --> 00:21:22,080
the earth was warm all the way up until

561
00:21:26,870 --> 00:21:24,080
fairly recent history

562
00:21:28,470 --> 00:21:26,880
70 degrees in the archaean but still 55

563
00:21:32,070 --> 00:21:28,480

degrees or so at the beginning of the

564
00:21:33,750 --> 00:21:32,080
cambrian if you take it at face value

565
00:21:36,310 --> 00:21:33,760
now

566
00:21:37,990 --> 00:21:36,320
neither of those techniques

567
00:21:40,390 --> 00:21:38,000
neither of the carbonate techniques

568
00:21:41,909 --> 00:21:40,400
rules out diagenesis

569
00:21:43,750 --> 00:21:41,919
but

570
00:21:45,750 --> 00:21:43,760
you can also get

571
00:21:46,950 --> 00:21:45,760
you well you can have various factors

572
00:21:49,830 --> 00:21:46,960
that affect the

573
00:21:52,230 --> 00:21:49,840
the church but what has uh happened

574
00:21:53,830 --> 00:21:52,240
recently is that uh this paper that i

575
00:21:56,390 --> 00:21:53,840
mentioned at the outset by robert and

576
00:21:59,430 --> 00:21:56,400
chozidon they have looked at the silicon

577
00:22:01,990 --> 00:21:59,440
isotope composition of church normal

578
00:22:04,149 --> 00:22:02,000
silicon it's mostly silicon 28 but

579
00:22:07,270 --> 00:22:04,159
there's a certain amount of silicon 30

580
00:22:10,070 --> 00:22:07,280
in there and you can measure chert is

581
00:22:13,350 --> 00:22:10,080
sio2 so you can measure both its oxygen

582
00:22:15,270 --> 00:22:13,360
and silicon isotopic composition

583
00:22:19,110 --> 00:22:15,280
here's a plot

584
00:22:22,630 --> 00:22:19,120
of delta 30 s i in parts per mil versus

585
00:22:26,710 --> 00:22:22,640
age and it's kind of complicated because

586
00:22:29,750 --> 00:22:28,789
these authors would argue just ignore

587
00:22:31,270 --> 00:22:29,760
them

588
00:22:33,430 --> 00:22:31,280

and the reason is because at the

589
00:22:35,669 --> 00:22:33,440
beginning of the phanerozoic silica

590
00:22:37,669 --> 00:22:35,679
precipitating organisms evolved and that

591
00:22:38,710 --> 00:22:37,679
became a biological influence on the

592
00:22:42,070 --> 00:22:38,720
silicon

593
00:22:44,390 --> 00:22:42,080
cycle but prior to the beginning of the

594
00:22:46,470 --> 00:22:44,400
phanerozoic there were no such organisms

595
00:22:48,950 --> 00:22:46,480
so you had a lot more amorphous silica

596
00:22:51,430 --> 00:22:48,960
that built up in seawater and then

597
00:22:53,510 --> 00:22:51,440
there's a trend this is my red line

598
00:22:55,990 --> 00:22:53,520
going through here but there's a trend

599
00:22:59,270 --> 00:22:56,000
that silicon isotopes become

600
00:23:00,950 --> 00:22:59,280
lighter delta 30 s i is lighter as you

601
00:23:02,870 --> 00:23:00,960
go back in time

602
00:23:05,590 --> 00:23:02,880
and what they've then done on the right

603
00:23:06,390 --> 00:23:05,600
hand plot is they've plotted delta 30 s

604
00:23:10,149 --> 00:23:06,400
i

605
00:23:12,070 --> 00:23:10,159
versus delta o18 from the same data from

606
00:23:13,510 --> 00:23:12,080
the from the same church

607
00:23:15,750 --> 00:23:13,520
and you can see that there's a big

608
00:23:18,149 --> 00:23:15,760
scatter plot but you can draw a line

609
00:23:20,870 --> 00:23:18,159
through that the silicon isotopes

610
00:23:23,510 --> 00:23:20,880
correlate with the oxygen isotopes

611
00:23:25,590 --> 00:23:23,520
reasonably well and then

612
00:23:28,310 --> 00:23:25,600
these authors say that rules out

613
00:23:30,549 --> 00:23:28,320

diagenesis as a uh

614
00:23:34,230 --> 00:23:30,559
as a cause for the the variation in the

615
00:23:36,630 --> 00:23:34,240
silicon isotopes think about shirts or

616
00:23:39,190 --> 00:23:36,640
silica deposits they also connects if

617
00:23:40,630 --> 00:23:39,200
they have water flowing through them

618
00:23:42,950 --> 00:23:40,640
when they're down in the sediments they

619
00:23:45,270 --> 00:23:42,960
can exchange oxygen isotopes with the

620
00:23:47,669 --> 00:23:45,280
water but there's not enough silicon in

621
00:23:49,750 --> 00:23:47,679
the water to exchange silicon isotopes

622
00:23:52,870 --> 00:23:49,760
and so these are authors argue that the

623
00:23:54,230 --> 00:23:52,880
silica does silicon doesn't get reset

624
00:23:56,070 --> 00:23:54,240
and therefore the fact that it

625
00:23:57,990 --> 00:23:56,080
correlates with the oxygen means that

626
00:23:59,590 --> 00:23:58,000
not all of the oxygen data are getting

627
00:24:02,390 --> 00:23:59,600
reset either

628
00:24:04,230 --> 00:24:02,400
i think that's a reasonable argument but

629
00:24:06,549 --> 00:24:04,240
i mean this is one of the first papers

630
00:24:08,710 --> 00:24:06,559
that i've seen on silicon isotopes the

631
00:24:10,070 --> 00:24:08,720
fractionation in silicon isotopes by the

632
00:24:11,830 --> 00:24:10,080
way depend

633
00:24:14,549 --> 00:24:11,840
silica is coming out of the mid-ocean

634
00:24:17,510 --> 00:24:14,559
ridge hydrothermal vents it's either

635
00:24:18,870 --> 00:24:17,520
removed by precipitation on the basalts

636
00:24:21,350 --> 00:24:18,880
as it flows through the hydro

637
00:24:23,590 --> 00:24:21,360
hydrothermal vents or it's removed by a

638
00:24:26,149 --> 00:24:23,600

lot biologically

639
00:24:29,269 --> 00:24:26,159
or just from precipitation in

640
00:24:31,269 --> 00:24:29,279
of a more amorphous silica in sea water

641
00:24:33,190 --> 00:24:31,279
and according to robert and shoshido

642
00:24:35,510 --> 00:24:33,200
fractionation occurs

643
00:24:37,590 --> 00:24:35,520
when it comes out by interacting with

644
00:24:39,430 --> 00:24:37,600
the basalts so the fractionation that

645
00:24:41,110 --> 00:24:39,440
you get depends on the temperature

646
00:24:44,630 --> 00:24:41,120
difference between the hydrothermal

647
00:24:45,990 --> 00:24:44,640
vents and seawater in their model

648
00:24:47,510 --> 00:24:46,000
i'm going to go through this kind of

649
00:24:48,549 --> 00:24:47,520
quickly because i've got a lot of things

650
00:24:50,870 --> 00:24:48,559
to say

651
00:24:52,630 --> 00:24:50,880
uh but that's

652
00:24:54,870 --> 00:24:52,640
that's the argument here and then what

653
00:24:56,789 --> 00:24:54,880
they've done is they uh

654
00:24:58,390 --> 00:24:56,799
they've plotted the silicon

655
00:25:00,870 --> 00:24:58,400
the temperatures from the silicon

656
00:25:02,549 --> 00:25:00,880
isotopes this is now age again going

657
00:25:05,430 --> 00:25:02,559
back to three and a half billion years

658
00:25:07,510 --> 00:25:05,440
ago the solid curve is the temperatures

659
00:25:09,909 --> 00:25:07,520
inferred from the oxygen isotopes in

660
00:25:11,510 --> 00:25:09,919
church this gray area here is the

661
00:25:14,230 --> 00:25:11,520
temperatures that they infer from the

662
00:25:16,230 --> 00:25:14,240
silicon isotopes and church they more or

663
00:25:18,549 --> 00:25:16,240

less agree although there's a lot of

664
00:25:20,789 --> 00:25:18,559
scatter in the silicon data but then

665
00:25:22,549 --> 00:25:20,799
they say this supports the idea that the

666
00:25:25,430 --> 00:25:22,559
early earth was hot

667
00:25:28,630 --> 00:25:25,440
and and may rule out diagenesis as being

668
00:25:31,190 --> 00:25:28,640
the cause of that variations okay so

669
00:25:33,269 --> 00:25:31,200
that's all geochemists and isotope stuff

670
00:25:34,470 --> 00:25:33,279
the biologists have been getting into

671
00:25:37,350 --> 00:25:34,480
this too

672
00:25:39,269 --> 00:25:37,360
and uh there's several recent papers

673
00:25:40,870 --> 00:25:39,279
saying that the biological record says

674
00:25:44,149 --> 00:25:40,880
the same thing

675
00:25:46,549 --> 00:25:44,159
this is not a new idea either uh here's

676
00:25:49,110 --> 00:25:46,559
a ribosomal rna tree how many people

677
00:25:52,070 --> 00:25:49,120
here have seen such a tree

678
00:25:53,669 --> 00:25:52,080
uh so this is washington so you all most

679
00:25:56,789 --> 00:25:53,679
of you have seen this this comes from

680
00:25:59,990 --> 00:25:56,799
looking doing sequencing of ribosomal

681
00:26:02,470 --> 00:26:00,000
rna or the dna analog thereof

682
00:26:05,830 --> 00:26:02,480
and you get the three domains of life

683
00:26:08,149 --> 00:26:05,840
the archaea the bacteria and the eukarya

684
00:26:11,269 --> 00:26:08,159
this is a way one way of looking deep

685
00:26:13,430 --> 00:26:11,279
into evolutionary history and what has

686
00:26:15,430 --> 00:26:13,440
been the root of the tree it's shown

687
00:26:16,950 --> 00:26:15,440
here is an unrooted tree but various

688
00:26:18,870 --> 00:26:16,960

arguments would place

689
00:26:20,549 --> 00:26:18,880
most biologists i think would place the

690
00:26:22,470 --> 00:26:20,559
root of the tree somewhere down near the

691
00:26:24,950 --> 00:26:22,480
base of the bacteria

692
00:26:27,430 --> 00:26:24,960
most of the most or all of the organisms

693
00:26:30,070 --> 00:26:27,440
near that root are hyperthermophiles

694
00:26:32,390 --> 00:26:30,080
that is organisms that live at

695
00:26:34,310 --> 00:26:32,400
preferred growth temperatures above 80

696
00:26:36,230 --> 00:26:34,320
celsius and that's been very

697
00:26:38,470 --> 00:26:36,240
controversial in the biological

698
00:26:42,149 --> 00:26:38,480
literature for a long time exactly what

699
00:26:47,590 --> 00:26:44,310
four years ago there was another paper

700
00:26:50,310 --> 00:26:47,600
that came out by eric uh gautier

701
00:26:52,310 --> 00:26:50,320
i haven't met eric but he's a

702
00:26:54,789 --> 00:26:52,320
was a member of steve benner's group at

703
00:26:56,710 --> 00:26:54,799
the university of florida and they

704
00:26:58,789 --> 00:26:56,720
looked at what they call resurrected

705
00:27:01,830 --> 00:26:58,799
proteins so they're now looking at

706
00:27:03,269 --> 00:27:01,840
different genes and in this paper what

707
00:27:05,029 --> 00:27:03,279
they did is they're looking at a

708
00:27:07,830 --> 00:27:05,039
particular

709
00:27:11,830 --> 00:27:07,840
gene set of genes that codes for this

710
00:27:13,510 --> 00:27:11,840
elongation factor protein eftu which i'm

711
00:27:15,590 --> 00:27:13,520
not a very good biologist so i don't

712
00:27:19,590 --> 00:27:15,600
even know what the tu stands for but

713
00:27:21,830 --> 00:27:19,600

this is the most common protein in

714
00:27:23,830 --> 00:27:21,840
in e coli which is you know the standard

715
00:27:25,909 --> 00:27:23,840
laboratory bacterium

716
00:27:29,029 --> 00:27:25,919
and it's these elongation factor

717
00:27:30,789 --> 00:27:29,039
proteins are present in in all organisms

718
00:27:32,789 --> 00:27:30,799
in large abundances so you can do

719
00:27:34,549 --> 00:27:32,799
comparisons with these

720
00:27:37,029 --> 00:27:34,559
what they've done then is they they do

721
00:27:40,230 --> 00:27:37,039
molecular phylogeny on this gene try to

722
00:27:41,430 --> 00:27:40,240
decide which protein sequences or the

723
00:27:44,470 --> 00:27:41,440
sequences

724
00:27:45,269 --> 00:27:44,480
uh which genes are common to the

725
00:27:48,149 --> 00:27:45,279
uh

726
00:27:49,590 --> 00:27:48,159
last common ancestor of these different

727
00:27:52,310 --> 00:27:49,600
existing

728
00:27:54,149 --> 00:27:52,320
bacteria and then they look at that

729
00:27:56,149 --> 00:27:54,159
protein and in this paper they just

730
00:27:58,789 --> 00:27:56,159
tried to estimate what the temperature

731
00:28:01,190 --> 00:27:58,799
stability of that protein was

732
00:28:04,470 --> 00:28:01,200
here in this upper graph they've looked

733
00:28:07,990 --> 00:28:04,480
at uh organisms that ren expand the

734
00:28:10,389 --> 00:28:08,000
range from mesophiles that live at 0 to

735
00:28:13,269 --> 00:28:10,399
40 degrees thermophiles that live from

736
00:28:15,830 --> 00:28:13,279
40 to 80 and hyper thermophiles so they

737
00:28:18,870 --> 00:28:15,840
basically all organisms

738
00:28:21,510 --> 00:28:18,880

and they found that if you do that the

739
00:28:24,230 --> 00:28:21,520
the two dark curves the yellow or the

740
00:28:25,430 --> 00:28:24,240
blue and the green are their

741
00:28:26,149 --> 00:28:25,440
estimated

742
00:28:27,750 --> 00:28:26,159
uh

743
00:28:31,110 --> 00:28:27,760
temperatures this is the melting

744
00:28:33,269 --> 00:28:31,120
temperature of the protein

745
00:28:36,070 --> 00:28:33,279
for these ancient organisms and this red

746
00:28:37,350 --> 00:28:36,080
curve that's thermos that's a that's a

747
00:28:40,149 --> 00:28:37,360
thermophilic

748
00:28:42,070 --> 00:28:40,159
existing bacteria so that if you look at

749
00:28:43,590 --> 00:28:42,080
all organisms with this technique you

750
00:28:46,470 --> 00:28:43,600
find out that they look like they have a

751
00:28:47,590 --> 00:28:46,480
thermophilic common ancestor in the

752
00:28:49,909 --> 00:28:47,600
bottom

753
00:28:51,990 --> 00:28:49,919
panel here they they've excluded

754
00:28:54,470 --> 00:28:52,000
present-day thermophilic organisms they

755
00:28:56,630 --> 00:28:54,480
just look at mesophiles organisms that

756
00:28:57,909 --> 00:28:56,640
live below 40 degrees

757
00:29:00,870 --> 00:28:57,919
and they've done the same type of

758
00:29:02,630 --> 00:29:00,880
analysis and they find that even modern

759
00:29:05,269 --> 00:29:02,640
day mesophiles appear to have a

760
00:29:08,950 --> 00:29:05,279
thermophilic ancestor so for instance e

761
00:29:10,389 --> 00:29:08,960
coli here is a mesophile which

762
00:29:13,350 --> 00:29:10,399
has a

763
00:29:16,789 --> 00:29:13,360

protein this elongation factor uh

764
00:29:18,870 --> 00:29:16,799
tends to melt at a at about 240 degrees

765
00:29:20,870 --> 00:29:18,880
or less or i guess that's the preferred

766
00:29:22,389 --> 00:29:20,880
growth temperature i'll probably garble

767
00:29:24,470 --> 00:29:22,399
this part because i'm not a very good

768
00:29:26,389 --> 00:29:24,480
biologist but that's the preferred

769
00:29:29,029 --> 00:29:26,399
growth temperature for e coli

770
00:29:31,590 --> 00:29:29,039
whereas the ancestor of e coli and other

771
00:29:34,870 --> 00:29:31,600
mesophiles had a preferred growth

772
00:29:37,110 --> 00:29:34,880
temperature around 55 celsius so that's

773
00:29:39,110 --> 00:29:37,120
sort of consistent well it's slightly

774
00:29:40,789 --> 00:29:39,120
different from what we just looked at on

775
00:29:43,350 --> 00:29:40,799
the last slide because the argument of

776
00:29:45,029 --> 00:29:43,360
this paper was the last common ancestor

777
00:29:47,830 --> 00:29:45,039
was a thermophile but not a

778
00:29:49,430 --> 00:29:47,840
hyperthermophile

779
00:29:51,350 --> 00:29:49,440
all right i had missed that paper when

780
00:29:54,149 --> 00:29:51,360
it came out but then i didn't miss this

781
00:29:56,230 --> 00:29:54,159
one this is one that came out same group

782
00:29:58,549 --> 00:29:56,240
or at least gaucher is still the first

783
00:30:00,950 --> 00:29:58,559
author this is just a from

784
00:30:02,789 --> 00:30:00,960
in nature in february of this year

785
00:30:05,029 --> 00:30:02,799
they're now looking at resurrected

786
00:30:07,909 --> 00:30:05,039
proteins and they're doing this uh more

787
00:30:10,230 --> 00:30:07,919
elaborately they actually

788
00:30:13,029 --> 00:30:10,240

figure out the pro the gene sequence for

789
00:30:16,230 --> 00:30:13,039
these ancient proteins they synthesize

790
00:30:19,510 --> 00:30:16,240
that gene and then they inject it into a

791
00:30:21,350 --> 00:30:19,520
e coli and the e coli produces the

792
00:30:23,110 --> 00:30:21,360
protein then they take that protein and

793
00:30:24,230 --> 00:30:23,120
measure its melting temperature in the

794
00:30:25,510 --> 00:30:24,240
lab

795
00:30:27,750 --> 00:30:25,520
and then they've

796
00:30:30,470 --> 00:30:27,760
done this for various organisms and they

797
00:30:32,950 --> 00:30:30,480
use molecular clocks they take published

798
00:30:35,029 --> 00:30:32,960
molecular clock estimates one of them by

799
00:30:37,029 --> 00:30:35,039
my colleague blair hedges at penn state

800
00:30:39,750 --> 00:30:37,039
where he's tried to place

801
00:30:41,750 --> 00:30:39,760
dates on the evolutionary time scale and

802
00:30:44,070 --> 00:30:41,760
they've they've got temperatures for

803
00:30:46,310 --> 00:30:44,080
organisms of different ages and here

804
00:30:48,549 --> 00:30:46,320
they've they've done these uh

805
00:30:50,310 --> 00:30:48,559
these dots with error bars are their

806
00:30:52,789 --> 00:30:50,320
biological estimate temperature

807
00:30:55,110 --> 00:30:52,799
estimates from resurrected proteins and

808
00:30:56,950 --> 00:30:55,120
they plotted that the the light curve

809
00:30:58,389 --> 00:30:56,960
these two light curves are different

810
00:31:00,310 --> 00:30:58,399
estimates of the temperature from the

811
00:31:02,549 --> 00:31:00,320
oxygen isotope data

812
00:31:05,269 --> 00:31:02,559
and so sure enough they their

813
00:31:07,350 --> 00:31:05,279

resurrected proteins fall on the same

814
00:31:08,149 --> 00:31:07,360
thing so

815
00:31:24,310 --> 00:31:08,159
the

816
00:31:26,070 --> 00:31:24,320
natural and physical sciences suggests

817
00:31:27,990 --> 00:31:26,080
that ancient life has continually

818
00:31:30,310 --> 00:31:28,000
adapted to changes in environmental

819
00:31:32,630 --> 00:31:30,320
temperatures throughout its evolutionary

820
00:31:34,789 --> 00:31:32,640
history in other words the whole

821
00:31:36,470 --> 00:31:34,799
biological evolutionary history of the

822
00:31:38,549 --> 00:31:36,480
earth is being driven by these

823
00:31:40,630 --> 00:31:38,559
constantly decreasing temperatures

824
00:31:42,149 --> 00:31:40,640
throughout geologic time

825
00:31:44,070 --> 00:31:42,159
and if

826
00:31:45,909 --> 00:31:44,080
my good colleague david schwartzman has

827
00:31:48,389 --> 00:31:45,919
written a book on this he actually wrote

828
00:31:50,950 --> 00:31:48,399
his book i think 15 years ago making the

829
00:31:53,509 --> 00:31:50,960
same argument that biological evolution

830
00:31:54,789 --> 00:31:53,519
is driven by a cooling temperature on

831
00:31:57,830 --> 00:31:54,799
the earth

832
00:31:59,590 --> 00:31:57,840
so i i don't agree with that and and i

833
00:32:01,110 --> 00:31:59,600
want to give you my reasons but what

834
00:32:02,870 --> 00:32:01,120
prompts the talk is that there's now

835
00:32:04,710 --> 00:32:02,880
this string of recent papers in the

836
00:32:07,029 --> 00:32:04,720
literature claiming that all the

837
00:32:09,190 --> 00:32:07,039
evidence point in that direction

838
00:32:11,269 --> 00:32:09,200

so let's think about it the way i think

839
00:32:13,509 --> 00:32:11,279
about it i'm a theoretician so let's

840
00:32:14,389 --> 00:32:13,519
think about it first from a theoretical

841
00:32:16,389 --> 00:32:14,399
standpoint

842
00:32:18,710 --> 00:32:16,399
we're pretty sure that the sun was less

843
00:32:21,830 --> 00:32:18,720
bright back in the past

844
00:32:24,230 --> 00:32:21,840
here's a published solar evolution curve

845
00:32:27,590 --> 00:32:24,240
an old one from douglas gough published

846
00:32:29,830 --> 00:32:27,600
in 1981 but it hasn't really changed

847
00:32:32,149 --> 00:32:29,840
very much since then the standard solar

848
00:32:33,430 --> 00:32:32,159
model is pretty much the same if you go

849
00:32:35,190 --> 00:32:33,440
back to four

850
00:32:37,350 --> 00:32:35,200
this is time running from four and a

851
00:32:40,230 --> 00:32:37,360
half billion years up to the present and

852
00:32:42,630 --> 00:32:40,240
this is solar luminosity relative today

853
00:32:44,789 --> 00:32:42,640
we're at one today the early sun was

854
00:32:46,789 --> 00:32:44,799
about 30 percent less luminous that's

855
00:32:48,870 --> 00:32:46,799
because it's converting hydrogen to

856
00:32:51,750 --> 00:32:48,880
helium in its core and as it does so the

857
00:32:54,870 --> 00:32:51,760
core becomes denser it shrinks and heats

858
00:32:57,909 --> 00:32:54,880
up and the fusion reactions go faster

859
00:33:00,070 --> 00:32:57,919
just to calibrate here at 3.3 billion

860
00:33:02,710 --> 00:33:00,080
years ago that's when enough and low

861
00:33:05,750 --> 00:33:02,720
think it was 70 degrees celsius the sun

862
00:33:08,149 --> 00:33:05,760
at that point was about 77 as bright as

863
00:33:10,070 --> 00:33:08,159

it is today so you have to have a big

864
00:33:12,789 --> 00:33:10,080
greenhouse effect and really over

865
00:33:14,310 --> 00:33:12,799
compensate for this uh decrease in solar

866
00:33:16,950 --> 00:33:14,320
luminosity

867
00:33:18,549 --> 00:33:16,960
uh what are the most likely gases for

868
00:33:20,389 --> 00:33:18,559
causing the greenhouse effect on the

869
00:33:21,990 --> 00:33:20,399
early earth i think sean goldman

870
00:33:24,310 --> 00:33:22,000
probably talked some about this so i'm

871
00:33:25,430 --> 00:33:24,320
going to be rather brief about it co2 is

872
00:33:27,669 --> 00:33:25,440
one of them

873
00:33:30,070 --> 00:33:27,679
the big greenhouse gases today are co2

874
00:33:31,830 --> 00:33:30,080
and water vapor co2 is largely

875
00:33:34,310 --> 00:33:31,840
controlled by the carbonate silicate

876
00:33:35,669 --> 00:33:34,320
cycle shown here co2 comes out of

877
00:33:37,909 --> 00:33:35,679
volcanoes

878
00:33:39,190 --> 00:33:37,919
it's consumed by silicate weathering on

879
00:33:41,669 --> 00:33:39,200
the continents and then there's

880
00:33:43,750 --> 00:33:41,679
carbonate precipitation in the oceans

881
00:33:45,430 --> 00:33:43,760
the carbonates get dragged down and they

882
00:33:47,990 --> 00:33:45,440
get heated up

883
00:33:50,389 --> 00:33:48,000
and they undergo metamorphism so co2 is

884
00:33:52,310 --> 00:33:50,399
cycling through here if the early earth

885
00:33:55,509 --> 00:33:52,320
was colder than the weathering would

886
00:33:57,669 --> 00:33:55,519
slow down so volcanic co2 would build up

887
00:34:00,789 --> 00:33:57,679
so there is a mechanism for

888
00:34:02,389 --> 00:34:00,799

forcing co2 to build up if when the sun

889
00:34:04,630 --> 00:34:02,399
was less bright this is something that

890
00:34:07,590 --> 00:34:04,640
i've worked on for a long time

891
00:34:09,349 --> 00:34:07,600
if volcanism was faster on the early

892
00:34:11,349 --> 00:34:09,359
earth because the interior was hotter

893
00:34:13,750 --> 00:34:11,359
then you'd expect more co2 to come out

894
00:34:15,829 --> 00:34:13,760
of volcanoes so you you might i mean

895
00:34:17,669 --> 00:34:15,839
there's reasons to think that co2 could

896
00:34:19,750 --> 00:34:17,679
have been quite high

897
00:34:22,069 --> 00:34:19,760
but then you can do the types of things

898
00:34:24,710 --> 00:34:22,079
that that we do we build climate models

899
00:34:27,750 --> 00:34:24,720
you can say okay well uh suppose the

900
00:34:30,310 --> 00:34:27,760
archaean earth was 70 degrees at 3.3

901
00:34:31,109 --> 00:34:30,320
billion years how much co2 would that

902
00:34:33,430 --> 00:34:31,119
take

903
00:34:35,669 --> 00:34:33,440
well that's a that's a doable problem so

904
00:34:37,829 --> 00:34:35,679
we take our climate model which we've

905
00:34:41,510 --> 00:34:37,839
carefully constructed and deconstructed

906
00:34:43,909 --> 00:34:41,520
over the past 20 years and we put in co2

907
00:34:45,669 --> 00:34:43,919
this is a one-dimensional climate model

908
00:34:47,909 --> 00:34:45,679
what we call a radiative convective

909
00:34:49,829 --> 00:34:47,919
climate model where you average out

910
00:34:51,589 --> 00:34:49,839
temperatures over the earth that's

911
00:34:53,349 --> 00:34:51,599
probably just fine when you're going to

912
00:34:55,750 --> 00:34:53,359
a dense co2 atmosphere because the

913
00:34:57,190 --> 00:34:55,760

latitudinal gradients would be rather

914
00:34:59,349 --> 00:34:57,200
small

915
00:35:03,030 --> 00:34:59,359
we run that model for

916
00:35:03,910 --> 00:35:03,040
77 solar luminosity and these curves

917
00:35:06,950 --> 00:35:03,920
here

918
00:35:11,190 --> 00:35:06,960
this is the co2 partial pressure in bars

919
00:35:12,870 --> 00:35:11,200
on this axis today we're at 300 ppms

920
00:35:15,750 --> 00:35:12,880
a little higher than that or about 3

921
00:35:17,670 --> 00:35:15,760
times 10 to the minus 4 bars down here

922
00:35:19,990 --> 00:35:17,680
this is going up to ten bars on the

923
00:35:21,910 --> 00:35:20,000
right these curves are for different

924
00:35:23,349 --> 00:35:21,920
amounts of methane and don't pay too

925
00:35:24,950 --> 00:35:23,359
much attention to those because we

926
00:35:27,109 --> 00:35:24,960
recently found a problem with the

927
00:35:29,190 --> 00:35:27,119
methane part and so the the methane

928
00:35:30,870 --> 00:35:29,200
greenhouse was overestimated in this

929
00:35:32,710 --> 00:35:30,880
model

930
00:35:36,550 --> 00:35:32,720
if you want to get to

931
00:35:39,510 --> 00:35:36,560
70 degrees celsius that's about 340

932
00:35:41,349 --> 00:35:39,520
a little over 340 kelvin

933
00:35:44,230 --> 00:35:41,359
according to these calculations if you

934
00:35:47,510 --> 00:35:44,240
had a thousand ppms of methane you would

935
00:35:49,270 --> 00:35:47,520
need about three bars of co2 and we as i

936
00:35:51,270 --> 00:35:49,280
said we actually overestimated the

937
00:35:53,510 --> 00:35:51,280
methane greenhouse effect so probably

938
00:35:55,670 --> 00:35:53,520

need more than three bars of co2 in

939
00:35:58,069 --> 00:35:55,680
order to get to be that warm

940
00:36:00,470 --> 00:35:58,079
that by itself is not impossible uh it

941
00:36:03,109 --> 00:36:00,480
depends how you think the the carbonate

942
00:36:04,790 --> 00:36:03,119
silica cycle ran on the early earth as i

943
00:36:06,870 --> 00:36:04,800
said different people have different

944
00:36:09,190 --> 00:36:06,880
ideas about that norm normsleep and

945
00:36:10,950 --> 00:36:09,200
kevin's only think all the earth's co2

946
00:36:13,829 --> 00:36:10,960
was in the mantle at that time and so it

947
00:36:15,910 --> 00:36:13,839
was really cold

948
00:36:18,310 --> 00:36:15,920
recently sean goldman may have showed

949
00:36:20,310 --> 00:36:18,320
this slide we've redone climate

950
00:36:23,190 --> 00:36:20,320
calculations this is for a slightly

951
00:36:26,470 --> 00:36:23,200
later period in the late archaean 2.8

952
00:36:28,470 --> 00:36:26,480
billion years so luminosity is 80 of

953
00:36:30,230 --> 00:36:28,480
present we found that we've been

954
00:36:31,589 --> 00:36:30,240
overestimating the methane greenhouse

955
00:36:33,510 --> 00:36:31,599
effect just because the absorption

956
00:36:36,069 --> 00:36:33,520
coefficients were stuck in the wrong

957
00:36:37,990 --> 00:36:36,079
wavelength bin so we fixed that

958
00:36:40,630 --> 00:36:38,000
but then we also put in some additional

959
00:36:42,710 --> 00:36:40,640
things there's there's ethane in this

960
00:36:44,710 --> 00:36:42,720
model that we can predict from this form

961
00:36:47,030 --> 00:36:44,720
photochemically from the methane and

962
00:36:49,270 --> 00:36:47,040
there are hydrocarbon particles and if

963
00:36:51,750 --> 00:36:49,280

you get the methane to co2 ratio

964
00:36:53,589 --> 00:36:51,760
anywhere near one then you start even

965
00:36:55,470 --> 00:36:53,599
above a few tenths you start forming

966
00:36:57,990 --> 00:36:55,480
hydrocarbon particles and those give you

967
00:37:01,109 --> 00:36:58,000
anti-greenhouse cooling and so when we

968
00:37:03,750 --> 00:37:01,119
put that all in and just try to

969
00:37:06,390 --> 00:37:03,760
make the bring the earth above freezing

970
00:37:07,750 --> 00:37:06,400
at the lake in the later ken we find

971
00:37:09,750 --> 00:37:07,760
that you need

972
00:37:12,630 --> 00:37:09,760
well here's a plausible radar key on

973
00:37:15,030 --> 00:37:12,640
earth here this has a few a few

974
00:37:18,550 --> 00:37:15,040
hundredths of a bar of co2 and a

975
00:37:19,990 --> 00:37:18,560
temperature today's temperature is 288 k

976
00:37:21,349 --> 00:37:20,000
on this scale

977
00:37:23,589 --> 00:37:21,359
so

978
00:37:26,069 --> 00:37:23,599
you can you can still warm the earth

979
00:37:28,390 --> 00:37:26,079
with co2 and methane but you don't get

980
00:37:29,510 --> 00:37:28,400
as much warming out of the methane as we

981
00:37:31,990 --> 00:37:29,520
had uh

982
00:37:33,510 --> 00:37:32,000
found earlier the co2 greenhouse effects

983
00:37:35,270 --> 00:37:33,520
have not changed

984
00:37:37,589 --> 00:37:35,280
the reason i put this up here is that if

985
00:37:39,910 --> 00:37:37,599
you if you eliminate the methane the

986
00:37:42,870 --> 00:37:39,920
temperatures will drop still by

987
00:37:45,589 --> 00:37:42,880
12 or 15 degrees c so this is a good way

988
00:37:47,510 --> 00:37:45,599

of getting that glaciation when oxygen

989
00:37:50,310 --> 00:37:47,520
goes up

990
00:37:52,870 --> 00:37:50,320
all right so to get to that point almost

991
00:37:55,430 --> 00:37:52,880
all of us agree that oxygen went up at

992
00:37:57,349 --> 00:37:55,440
2.4 billion years except for my

993
00:37:58,550 --> 00:37:57,359
colleague hiroshimoto who still doesn't

994
00:38:01,109 --> 00:37:58,560
agree with that

995
00:38:02,310 --> 00:38:01,119
and sean sean talked about it i'm just

996
00:38:05,990 --> 00:38:02,320
going to

997
00:38:08,310 --> 00:38:06,000
show you a little bit of the evidence

998
00:38:12,150 --> 00:38:08,320
remember this is this there's an ice age

999
00:38:14,470 --> 00:38:12,160
here right when oxygen goes up

1000
00:38:16,390 --> 00:38:14,480
the standard geologic evidence for the

1001
00:38:18,390 --> 00:38:16,400
rise of oxygen there's a lot of

1002
00:38:20,470 --> 00:38:18,400
different things most suggested

1003
00:38:23,430 --> 00:38:20,480
originally by preston cloud way back in

1004
00:38:25,589 --> 00:38:23,440
the late 60s and early 70s

1005
00:38:27,430 --> 00:38:25,599
dick holland who's retired from harvard

1006
00:38:29,829 --> 00:38:27,440
now worked on this problem for a long

1007
00:38:31,670 --> 00:38:29,839
time so this is one of his slides

1008
00:38:33,750 --> 00:38:31,680
without going through it the red boxes

1009
00:38:36,150 --> 00:38:33,760
are evidence of high oxygen the blue

1010
00:38:38,310 --> 00:38:36,160
boxes are evidence for low oxygen

1011
00:38:40,790 --> 00:38:38,320
there's a big change in this figure

1012
00:38:42,550 --> 00:38:40,800
somewhere around 2.2 billion years the

1013
00:38:44,829 --> 00:38:42,560

age dates have gotten a little better

1014
00:38:51,030 --> 00:38:44,839
since then so that might be should be

1015
00:38:54,150 --> 00:38:51,040
2.4 red beds this is uh oxidized iron in

1016
00:38:56,550 --> 00:38:54,160
soils and cliffs it's mostly

1017
00:38:59,750 --> 00:38:56,560
the mineral hematite they come in around

1018
00:39:02,230 --> 00:38:59,760
2.2 so that's evidence for high oxygen

1019
00:39:04,950 --> 00:39:02,240
uranium ores it's all the same reduced

1020
00:39:06,710 --> 00:39:04,960
uranium mineral uraninite but there's

1021
00:39:09,430 --> 00:39:06,720
two different types there's detrital

1022
00:39:12,069 --> 00:39:09,440
uraninite and uh uraninite that

1023
00:39:15,190 --> 00:39:12,079
precipitated out of seawater this the

1024
00:39:16,950 --> 00:39:15,200
trido uranonite was weathered out of the

1025
00:39:19,270 --> 00:39:16,960
parent rock and carried down and

1026
00:39:21,349 --> 00:39:19,280
deposited in sediments without ever

1027
00:39:23,750 --> 00:39:21,359
oxidizing so that's considered to be

1028
00:39:26,069 --> 00:39:23,760
evidence of low oxygen and there's also

1029
00:39:28,950 --> 00:39:26,079
detrital pyrite and ciderite which are

1030
00:39:30,630 --> 00:39:28,960
other minerals so those have been with

1031
00:39:33,990 --> 00:39:30,640
standard arguments for a change in

1032
00:39:35,990 --> 00:39:34,000
oxygen at about 2.2

1033
00:39:40,230 --> 00:39:36,000
if you then looked at the geologic

1034
00:39:41,430 --> 00:39:40,240
record one of the places where the this

1035
00:39:44,069 --> 00:39:41,440
late

1036
00:39:47,349 --> 00:39:44,079
early proterozoic glaciation paleo

1037
00:39:49,190 --> 00:39:47,359
proterezo glaciation it's called is well

1038
00:39:52,069 --> 00:39:49,200

preserved it's in the huronian super

1039
00:39:54,790 --> 00:39:52,079
group north just north of lake huron

1040
00:39:57,270 --> 00:39:54,800
it's in southern canada was mapped by a

1041
00:39:59,750 --> 00:39:57,280
canadian geologist named stu roscoe back

1042
00:40:02,630 --> 00:39:59,760
in the late 60s and

1043
00:40:06,390 --> 00:40:02,640
this sequence goes it's bounded in age

1044
00:40:08,390 --> 00:40:06,400
by 2.2 billion years at the top and 2.45

1045
00:40:10,950 --> 00:40:08,400
billion years at the bottom there's

1046
00:40:13,430 --> 00:40:10,960
three glacial diamictites in here the

1047
00:40:16,230 --> 00:40:13,440
gauganda the bruce and the ramsay lake

1048
00:40:18,390 --> 00:40:16,240
below the bottom most one in this

1049
00:40:20,950 --> 00:40:18,400
matanenda formation you find detrital

1050
00:40:23,349 --> 00:40:20,960
uranonite and pyrite and above the

1051
00:40:25,349 --> 00:40:23,359
gauganda in the lorraine formation

1052
00:40:29,030 --> 00:40:25,359
that's a red bed formation

1053
00:40:32,069 --> 00:40:29,040
so roscoe pointed out way back 40 years

1054
00:40:34,150 --> 00:40:32,079
ago or so that hmm this this to him was

1055
00:40:36,230 --> 00:40:34,160
the first set of glaciations in earth

1056
00:40:37,190 --> 00:40:36,240
history said isn't that interesting that

1057
00:40:39,829 --> 00:40:37,200
happened

1058
00:40:41,430 --> 00:40:39,839
right at the same time as oxygen went up

1059
00:40:43,109 --> 00:40:41,440
because preston cloud had already

1060
00:40:44,950 --> 00:40:43,119
published his theory of the rise of

1061
00:40:47,030 --> 00:40:44,960
oxygen by that time

1062
00:40:49,510 --> 00:40:47,040
and roscoe didn't have an explanation

1063
00:40:51,270 --> 00:40:49,520

for that but if you believe the methane

1064
00:40:53,349 --> 00:40:51,280
greenhouse story then it actually makes

1065
00:40:56,069 --> 00:40:53,359
sense because when oxygen goes up

1066
00:40:57,510 --> 00:40:56,079
methane goes down you lose 10 or 15

1067
00:40:59,510 --> 00:40:57,520
degrees of warming so it's not

1068
00:41:01,829 --> 00:40:59,520
surprising that earth went into a

1069
00:41:03,990 --> 00:41:01,839
glaciation

1070
00:41:06,230 --> 00:41:04,000
but there's other ways to explain that

1071
00:41:09,430 --> 00:41:06,240
and so that

1072
00:41:12,390 --> 00:41:09,440
the first way is that the rise of oxygen

1073
00:41:13,750 --> 00:41:12,400
causes the glaciation the second way you

1074
00:41:17,510 --> 00:41:13,760
can invert that and you can say the

1075
00:41:20,470 --> 00:41:17,520
glaciation cause the rise of oxygen that

1076
00:41:23,589 --> 00:41:20,480
logically is also self-consistent

1077
00:41:26,150 --> 00:41:23,599
this has been published by uh low entice

1078
00:41:28,550 --> 00:41:26,160
in pre-cambrian research last year so

1079
00:41:31,349 --> 00:41:28,560
their argument is that cyanobacteria had

1080
00:41:33,750 --> 00:41:31,359
evolved cyanobacteria are the organisms

1081
00:41:35,430 --> 00:41:33,760
that produce the first oxygen they have

1082
00:41:37,910 --> 00:41:35,440
most of them have a maximum growth

1083
00:41:40,069 --> 00:41:37,920
temperature of 60 degrees there's one

1084
00:41:43,109 --> 00:41:40,079
species which name i forget right now

1085
00:41:44,630 --> 00:41:43,119
that can live up to 72 or 73 degrees

1086
00:41:46,230 --> 00:41:44,640
celsius

1087
00:41:47,750 --> 00:41:46,240
they're studied in places like

1088
00:41:50,470 --> 00:41:47,760

yellowstone where you have these hot

1089
00:41:52,790 --> 00:41:50,480
spring pools and so in the low entice

1090
00:41:55,030 --> 00:41:52,800
model they say well the archaean was 60

1091
00:41:57,190 --> 00:41:55,040
or 70 degrees when the temperatures

1092
00:41:59,430 --> 00:41:57,200
finally got down low enough for

1093
00:42:02,950 --> 00:41:59,440
cyanobacteria to thrive then they

1094
00:42:06,390 --> 00:42:02,960
produced a lot of oxygen and that

1095
00:42:09,349 --> 00:42:06,400
caused the rise of oxygen right

1096
00:42:12,150 --> 00:42:09,359
so here's a figure from their paper

1097
00:42:13,910 --> 00:42:12,160
that does this this is time running from

1098
00:42:17,109 --> 00:42:13,920
three and a half to two billion years

1099
00:42:19,750 --> 00:42:17,119
ago the solid curve is co2 in their

1100
00:42:22,950 --> 00:42:19,760
model and so in order they have to have

1101
00:42:24,790 --> 00:42:22,960
everything driven by co2 that methane

1102
00:42:27,430 --> 00:42:24,800
also varies but that's really not that

1103
00:42:30,470 --> 00:42:27,440
important in their model so here back in

1104
00:42:32,230 --> 00:42:30,480
the arc early archaean co2 was high

1105
00:42:34,309 --> 00:42:32,240
notice that there's no real numbers on

1106
00:42:36,630 --> 00:42:34,319
this scale but we just looked at that

1107
00:42:38,710 --> 00:42:36,640
you need three bars of co2 or more to

1108
00:42:40,150 --> 00:42:38,720
make it hot back then

1109
00:42:42,630 --> 00:42:40,160
then

1110
00:42:44,230 --> 00:42:42,640
the continents start to grow and that's

1111
00:42:46,710 --> 00:42:44,240
plausible they we know there was a lot

1112
00:42:50,150 --> 00:42:46,720
of continental growth along here that

1113
00:42:53,030 --> 00:42:50,160

sucked down co2 by silicate weathering

1114
00:42:54,790 --> 00:42:53,040
co if co2 got low the temperatures

1115
00:42:57,190 --> 00:42:54,800
dropped they agree that there's a

1116
00:43:00,150 --> 00:42:57,200
glaciation around three billion years or

1117
00:43:01,990 --> 00:43:00,160
so then i oh this is where i always

1118
00:43:03,829 --> 00:43:02,000
forget this part of the story they ran

1119
00:43:05,190 --> 00:43:03,839
out of continents to weather or

1120
00:43:08,710 --> 00:43:05,200
something and so

1121
00:43:12,470 --> 00:43:08,720
uh co2 went back up in the later ken

1122
00:43:14,950 --> 00:43:12,480
back up to 60 or 70 degrees then

1123
00:43:17,109 --> 00:43:14,960
co2 dropped again for some reason and

1124
00:43:19,430 --> 00:43:17,119
that causes the rise of oxygen at that

1125
00:43:22,230 --> 00:43:19,440
point so you can do this whole thing by

1126
00:43:23,910 --> 00:43:22,240
having co2 go up and down but even

1127
00:43:26,150 --> 00:43:23,920
though i read this paper recently i

1128
00:43:29,349 --> 00:43:26,160
can't remember anything except for the

1129
00:43:32,150 --> 00:43:29,359
first reason why it changes maybe

1130
00:43:33,990 --> 00:43:32,160
somebody here remembers that

1131
00:43:36,790 --> 00:43:34,000
so any of the the problem with that is

1132
00:43:37,990 --> 00:43:36,800
you have to really you need huge swings

1133
00:43:40,470 --> 00:43:38,000
if you're going to drive the whole

1134
00:43:42,950 --> 00:43:40,480
climate by co2 you need huge swings to

1135
00:43:45,430 --> 00:43:42,960
make it warm you need three or more bars

1136
00:43:47,270 --> 00:43:45,440
of co2 to get down to glacial conditions

1137
00:43:49,030 --> 00:43:47,280
you've got to be well below one bar you

1138
00:43:51,349 --> 00:43:49,040

probably need to be down to a few tenths

1139
00:43:53,670 --> 00:43:51,359
of a bar so it's got to be going up and

1140
00:43:55,589 --> 00:43:53,680
down and it's doing it multiple times

1141
00:43:57,270 --> 00:43:55,599
and if you find any other evidence for

1142
00:43:59,750 --> 00:43:57,280
glaciation in the archaean then you

1143
00:44:02,069 --> 00:43:59,760
would have to do it yet again

1144
00:44:04,309 --> 00:44:02,079
so that's you know i'm a theoretician

1145
00:44:05,750 --> 00:44:04,319
that's difficult for us theoreticians to

1146
00:44:07,109 --> 00:44:05,760
explain

1147
00:44:09,109 --> 00:44:07,119
if you go

1148
00:44:11,190 --> 00:44:09,119
if you have three but another thing that

1149
00:44:13,589 --> 00:44:11,200
is testable from the geologic record is

1150
00:44:14,950 --> 00:44:13,599
if you had three bars of co2 and 70

1151
00:44:17,750 --> 00:44:14,960
degrees celsius

1152
00:44:20,870 --> 00:44:17,760
rain water would be both hot and very

1153
00:44:23,430 --> 00:44:20,880
acidic because three bars of co2 is 10

1154
00:44:26,230 --> 00:44:23,440
000 times the current concentration the

1155
00:44:28,470 --> 00:44:26,240
ph of rain water drops about a log one

1156
00:44:31,910 --> 00:44:28,480
unit for every factor of 100 increase in

1157
00:44:34,230 --> 00:44:31,920
co2 so this three bar atmosphere at 70

1158
00:44:37,750 --> 00:44:34,240
degrees c the ph of rain water instead

1159
00:44:39,670 --> 00:44:37,760
of being 5.7 it'd be 3.7 and that would

1160
00:44:41,910 --> 00:44:39,680
really weather the heck out of anything

1161
00:44:43,510 --> 00:44:41,920
that was exposed to it and then if you

1162
00:44:45,990 --> 00:44:43,520
look in the literature there's arguments

1163
00:44:48,550 --> 00:44:46,000

as to whether that weathering was going

1164
00:44:51,670 --> 00:44:48,560
on at that rate norm sleep and don lowe

1165
00:44:55,430 --> 00:44:51,680
have been publishing published arguments

1166
00:44:57,270 --> 00:44:55,440
about that uh in the past few years

1167
00:44:58,470 --> 00:44:57,280
okay so i'm not going to take a side on

1168
00:45:01,190 --> 00:44:58,480
that although

1169
00:45:04,069 --> 00:45:01,200
i i don't think that dick collins if you

1170
00:45:05,030 --> 00:45:04,079
read his 84 book he also cites evidence

1171
00:45:06,870 --> 00:45:05,040
in there he doesn't think that

1172
00:45:09,510 --> 00:45:06,880
weathering in the archaean was all that

1173
00:45:11,190 --> 00:45:09,520
rapid compared to today

1174
00:45:13,589 --> 00:45:11,200
all right well then this brings me to

1175
00:45:15,190 --> 00:45:13,599
the last part of the talk here if you

1176
00:45:17,670 --> 00:45:15,200
i'm going to argue that the temperature

1177
00:45:20,069 --> 00:45:17,680
was not hot but then you have to how do

1178
00:45:22,390 --> 00:45:20,079
you explain the oxygen and silicon

1179
00:45:24,150 --> 00:45:22,400
isotope data which are sitting around

1180
00:45:25,990 --> 00:45:24,160
there and if you can't explain them then

1181
00:45:28,150 --> 00:45:26,000
you've got a problem

1182
00:45:30,790 --> 00:45:28,160
so let's think about what controls the

1183
00:45:33,750 --> 00:45:30,800
oxygen isotope composition of seawater

1184
00:45:35,750 --> 00:45:33,760
was very nice paper by carlos muellenbox

1185
00:45:38,950 --> 00:45:35,760
and bob clayton

1186
00:45:40,950 --> 00:45:38,960
back in the mid-1970s clayton of course

1187
00:45:43,109 --> 00:45:40,960
is the famous geochemist who was one of

1188
00:45:46,470 --> 00:45:43,119

the first people to measure oxygen

1189
00:45:48,309 --> 00:45:46,480
isotopes and meteorites and so he's a

1190
00:45:50,790 --> 00:45:48,319
big star in the field

1191
00:45:52,950 --> 00:45:50,800
they publish what i think is still you

1192
00:45:55,270 --> 00:45:52,960
know what is still the accepted

1193
00:45:57,670 --> 00:45:55,280
explanation for what controls the oxygen

1194
00:46:00,150 --> 00:45:57,680
isotope composition of seawater it's

1195
00:46:02,069 --> 00:46:00,160
mostly controlled by cycling of water

1196
00:46:03,109 --> 00:46:02,079
through the mid-ocean ridge hydrothermal

1197
00:46:05,990 --> 00:46:03,119
vents

1198
00:46:08,550 --> 00:46:06,000
and the way this works is that the sea

1199
00:46:10,630 --> 00:46:08,560
water if we if we work on a small scale

1200
00:46:12,790 --> 00:46:10,640
standard standard mean ocean water sea

1201
00:46:16,230 --> 00:46:12,800
water is at zero per mil

1202
00:46:19,190 --> 00:46:16,240
basalts are at about 5.7 per ml

1203
00:46:22,230 --> 00:46:19,200
and uh this is these are data from owned

1204
00:46:24,630 --> 00:46:22,240
in a mule and box science 93 paper

1205
00:46:27,670 --> 00:46:24,640
they're looking at an ophelite which is

1206
00:46:29,109 --> 00:46:27,680
a preserved section of oceanic crust

1207
00:46:32,470 --> 00:46:29,119
going down

1208
00:46:34,150 --> 00:46:32,480
from zero to five kilometers this is uh

1209
00:46:35,990 --> 00:46:34,160
they argue is they're they're looking at

1210
00:46:37,670 --> 00:46:36,000
the the effects of one of these

1211
00:46:40,470 --> 00:46:37,680
hydrothermal weathering systems

1212
00:46:42,470 --> 00:46:40,480
hydrothermal circulation systems

1213
00:46:45,190 --> 00:46:42,480

at high temperatures deep within the

1214
00:46:47,190 --> 00:46:45,200
vents the seawater is trying to come to

1215
00:46:50,230 --> 00:46:47,200
the same isotopic composition of the

1216
00:46:52,950 --> 00:46:50,240
rock so that the sea water is getting

1217
00:46:54,309 --> 00:46:52,960
heavier because it's extracting o-18

1218
00:46:56,550 --> 00:46:54,319
from the rock

1219
00:46:59,349 --> 00:46:56,560
at low temperatures in the upper parts

1220
00:47:01,589 --> 00:46:59,359
there then you're depositing uh

1221
00:47:03,430 --> 00:47:01,599
exchanging of

1222
00:47:06,790 --> 00:47:03,440
oxygen isotopes with the rock and the

1223
00:47:09,030 --> 00:47:06,800
oxy o18 goes back into the basalts so

1224
00:47:12,150 --> 00:47:09,040
the upper the upper portions of the

1225
00:47:13,990 --> 00:47:12,160
ophiolite are enriched in o-18 and the

1226
00:47:16,710 --> 00:47:14,000
lower portions of the ophiolite are

1227
00:47:18,790 --> 00:47:16,720
depleted in o-18 and it's this bow this

1228
00:47:20,230 --> 00:47:18,800
is more important there's also exchange

1229
00:47:22,230 --> 00:47:20,240
that occurs during continental

1230
00:47:24,470 --> 00:47:22,240
weathering but the water fluxes through

1231
00:47:28,230 --> 00:47:24,480
the mid-ocean ridges are so large that

1232
00:47:30,790 --> 00:47:28,240
that's what dominates the uh the budget

1233
00:47:32,710 --> 00:47:30,800
now and and then these same authors then

1234
00:47:35,190 --> 00:47:32,720
have argued that this process has been

1235
00:47:36,950 --> 00:47:35,200
going on plate tectonics has been going

1236
00:47:39,589 --> 00:47:36,960
on throughout the year's history

1237
00:47:41,430 --> 00:47:39,599
therefore seawater isotopic composition

1238
00:47:42,630 --> 00:47:41,440

doesn't change with time that's the

1239
00:47:44,069 --> 00:47:42,640
argument

1240
00:47:45,990 --> 00:47:44,079
but

1241
00:47:47,910 --> 00:47:46,000
that's only true if the vent systems

1242
00:47:50,309 --> 00:47:47,920
operated the same way in the past as

1243
00:47:52,390 --> 00:47:50,319
they do today and so you have to ask

1244
00:47:54,630 --> 00:47:52,400
whether or not that's the case

1245
00:47:57,030 --> 00:47:54,640
well as i mentioned at the outset we've

1246
00:48:00,150 --> 00:47:57,040
been working on this and wrote a paper

1247
00:48:02,309 --> 00:48:00,160
in epsl a couple of years ago giving one

1248
00:48:04,790 --> 00:48:02,319
suggested reason for why things might

1249
00:48:07,510 --> 00:48:04,800
change maybe plate tectonics hasn't

1250
00:48:09,349 --> 00:48:07,520
always been operating the same as today

1251
00:48:11,030 --> 00:48:09,359
one thing that we another point that we

1252
00:48:12,550 --> 00:48:11,040
all agree with i think this one there's

1253
00:48:14,630 --> 00:48:12,560
no dissenters

1254
00:48:16,790 --> 00:48:14,640
geothermal heat flow was higher in the

1255
00:48:18,870 --> 00:48:16,800
past because there was more there were

1256
00:48:20,950 --> 00:48:18,880
more radioactive elements in the crust

1257
00:48:23,190 --> 00:48:20,960
and mantle giving off more heat there's

1258
00:48:25,430 --> 00:48:23,200
also more energy left over from

1259
00:48:27,829 --> 00:48:25,440
accretion so there's more

1260
00:48:29,910 --> 00:48:27,839
geothermal heat coming out

1261
00:48:31,990 --> 00:48:29,920
then you get how does that affect plate

1262
00:48:33,510 --> 00:48:32,000
tectonics here the models are all over

1263
00:48:35,510 --> 00:48:33,520

the place

1264
00:48:37,670 --> 00:48:35,520
i'm going to quote a model here by

1265
00:48:39,589 --> 00:48:37,680
eldridge morris but norm sleep has a

1266
00:48:41,190 --> 00:48:39,599
model plate tectonics model that

1267
00:48:43,030 --> 00:48:41,200
predicts the same thing

1268
00:48:44,950 --> 00:48:43,040
both of these models say that the

1269
00:48:47,109 --> 00:48:44,960
oceanic crust would have been thicker in

1270
00:48:48,790 --> 00:48:47,119
the past because the heat is getting you

1271
00:48:51,510 --> 00:48:48,800
would get a greater depth of partial

1272
00:48:53,910 --> 00:48:51,520
melting at the ridges and um

1273
00:48:56,230 --> 00:48:53,920
because of the increased heat flow so in

1274
00:48:58,309 --> 00:48:56,240
in eldridge moore's model the oceanic

1275
00:49:00,870 --> 00:48:58,319
crust today is about seven or eight

1276
00:49:02,470 --> 00:49:00,880
kilometers thick but as you go back into

1277
00:49:05,109 --> 00:49:02,480
the archaean

1278
00:49:06,549 --> 00:49:05,119
the crust could have been 20 to 25

1279
00:49:09,190 --> 00:49:06,559
kilometers thick

1280
00:49:11,670 --> 00:49:09,200
and then plate tectonics itself might

1281
00:49:13,589 --> 00:49:11,680
operate very differently in particular

1282
00:49:15,829 --> 00:49:13,599
this thick oceanic crust is still

1283
00:49:18,069 --> 00:49:15,839
lighter than the underlying mantle and

1284
00:49:20,549 --> 00:49:18,079
so it should float isostatically and it

1285
00:49:22,309 --> 00:49:20,559
should displace seawater

1286
00:49:25,190 --> 00:49:22,319
and that would mean that the mid-ocean

1287
00:49:26,950 --> 00:49:25,200
ridges would be less deeply submerged

1288
00:49:29,109 --> 00:49:26,960

than they are today

1289
00:49:30,549 --> 00:49:29,119
well why does that matter

1290
00:49:32,630 --> 00:49:30,559
it turns out

1291
00:49:34,710 --> 00:49:32,640
and this is something that john bross i

1292
00:49:37,510 --> 00:49:34,720
think has worked out on here out at

1293
00:49:39,910 --> 00:49:37,520
university of washington in many of the

1294
00:49:41,589 --> 00:49:39,920
mid-ocean ridge vent systems the water

1295
00:49:44,069 --> 00:49:41,599
going through those vents is in what we

1296
00:49:45,589 --> 00:49:44,079
call the super convective regime you may

1297
00:49:48,150 --> 00:49:45,599
know that the water coming out of a

1298
00:49:49,910 --> 00:49:48,160
typical black smoker at least on a

1299
00:49:52,790 --> 00:49:49,920
fast spreading ridge is coming out right

1300
00:49:54,710 --> 00:49:52,800
near the critical point for seawater

1301
00:49:56,710 --> 00:49:54,720
and so that means that below that you're

1302
00:49:58,950 --> 00:49:56,720
in the supercritical regime where the

1303
00:49:59,750 --> 00:49:58,960
heat transport properties of water are

1304
00:50:03,270 --> 00:49:59,760
very

1305
00:50:06,710 --> 00:50:03,280
this is a graph that i actually made a

1306
00:50:08,950 --> 00:50:06,720
long time ago that graphs a combination

1307
00:50:10,069 --> 00:50:08,960
of seawater parameters that go into heat

1308
00:50:12,309 --> 00:50:10,079
transport

1309
00:50:16,549 --> 00:50:12,319
alpha is the coefficient of thermal

1310
00:50:18,309 --> 00:50:16,559
expansion rho is density cp is the

1311
00:50:21,030 --> 00:50:18,319
specific heat of constant pressure of

1312
00:50:22,710 --> 00:50:21,040
water and nu is the kinematic viscosity

1313
00:50:25,270 --> 00:50:22,720

if you combine these things and make a

1314
00:50:27,510 --> 00:50:25,280
contour map you see that

1315
00:50:29,990 --> 00:50:27,520
going pressure in bars

1316
00:50:32,950 --> 00:50:30,000
from 0 to 600 and temperature from 0 to

1317
00:50:34,549 --> 00:50:32,960
600 you see that things peak here's the

1318
00:50:36,950 --> 00:50:34,559
critical point this is done for pure

1319
00:50:39,750 --> 00:50:36,960
water the critical point is that 220

1320
00:50:43,670 --> 00:50:39,760
bars and 3 7

1321
00:50:46,150 --> 00:50:43,680
374 celsius so right here and so the uh

1322
00:50:48,150 --> 00:50:46,160
the vents if you just follow an adiabat

1323
00:50:50,470 --> 00:50:48,160
down there it's going right through this

1324
00:50:51,910 --> 00:50:50,480
supercritical regime this is something

1325
00:50:54,390 --> 00:50:51,920
if you look at the literature on this

1326
00:50:56,630 --> 00:50:54,400
there's a whole big literature that goes

1327
00:50:58,630 --> 00:50:56,640
back 20 or 30 years people

1328
00:51:01,349 --> 00:50:58,640
oceanographers pointing out that that's

1329
00:51:03,670 --> 00:51:01,359
very special properties and what we did

1330
00:51:05,990 --> 00:51:03,680
is just a simple 1d

1331
00:51:08,470 --> 00:51:06,000
analysis that says

1332
00:51:10,549 --> 00:51:08,480
suppose you reduce the uh the depth

1333
00:51:13,030 --> 00:51:10,559
above the mid-ocean ridges then you

1334
00:51:14,549 --> 00:51:13,040
can't get into that supercritical regime

1335
00:51:16,549 --> 00:51:14,559
water won't be as effective at

1336
00:51:18,390 --> 00:51:16,559
transporting out the heat and therefore

1337
00:51:21,349 --> 00:51:18,400
the hydrothermal penetration depth

1338
00:51:22,549 --> 00:51:21,359

actually would have to be much shallower

1339
00:51:24,630 --> 00:51:22,559
um

1340
00:51:27,510 --> 00:51:24,640
so for instance if you go down along an

1341
00:51:30,069 --> 00:51:27,520
adiabat within the vents here and graph

1342
00:51:31,829 --> 00:51:30,079
this water properties parameter it peaks

1343
00:51:34,150 --> 00:51:31,839
at the critical point and then goes back

1344
00:51:36,150 --> 00:51:34,160
down and this was what our 1d model

1345
00:51:37,829 --> 00:51:36,160
predicts on hydrothermal penetration

1346
00:51:40,790 --> 00:51:37,839
depth that

1347
00:51:42,549 --> 00:51:40,800
when when you have a

1348
00:51:45,510 --> 00:51:42,559
shallowly submerged ridges the

1349
00:51:46,950 --> 00:51:45,520
penetration would be not nearly as deep

1350
00:51:49,030 --> 00:51:46,960
and so you wouldn't have that high

1351
00:51:51,349 --> 00:51:49,040
temperature interaction zone between the

1352
00:51:53,190 --> 00:51:51,359
water and the basalts and that will then

1353
00:51:55,349 --> 00:51:53,200
change the balance that is uh

1354
00:51:58,309 --> 00:51:55,359
controlling the isotopic composition of

1355
00:52:00,870 --> 00:51:58,319
seawater i'm going through this too fast

1356
00:52:02,950 --> 00:52:00,880
to do it in detail but the the basic

1357
00:52:05,270 --> 00:52:02,960
point here is that you can think of

1358
00:52:06,549 --> 00:52:05,280
plausible changes that will that will

1359
00:52:08,230 --> 00:52:06,559
change the you know even though you've

1360
00:52:10,790 --> 00:52:08,240
got the same mechanism controlling

1361
00:52:12,790 --> 00:52:10,800
seawater isotopic composition if you

1362
00:52:16,069 --> 00:52:12,800
change the boundary conditions on it

1363
00:52:17,270 --> 00:52:16,079

then you can get very different results

1364
00:52:19,990 --> 00:52:17,280
there's a couple other things if you've

1365
00:52:21,990 --> 00:52:20,000
got shallower water it'll boil in the

1366
00:52:24,309 --> 00:52:22,000
vent systems and the brine is enriched

1367
00:52:26,230 --> 00:52:24,319
in o-18 and that will be interacting

1368
00:52:28,870 --> 00:52:26,240
with the rock whereas the isotopically

1369
00:52:29,750 --> 00:52:28,880
light lighter vapor escapes

1370
00:52:32,309 --> 00:52:29,760
so

1371
00:52:34,950 --> 00:52:32,319
know we argued in this paper then that

1372
00:52:36,950 --> 00:52:34,960
you can still reproduce the the what you

1373
00:52:39,190 --> 00:52:36,960
see in the ophelites it doesn't

1374
00:52:42,549 --> 00:52:39,200
necessarily mean that seawater isotopic

1375
00:52:43,670 --> 00:52:42,559
composition has been the same

1376
00:52:45,430 --> 00:52:43,680
finally the

1377
00:52:48,309 --> 00:52:45,440
last point you also have to be able to

1378
00:52:50,390 --> 00:52:48,319
explain silicon isotope data but

1379
00:52:52,870 --> 00:52:50,400
remember the silicon isotope data in the

1380
00:52:54,790 --> 00:52:52,880
robaran chosidon paper are determined

1381
00:52:56,390 --> 00:52:54,800
that fractionation is determined by the

1382
00:52:57,750 --> 00:52:56,400
difference between the temperatures

1383
00:53:00,549 --> 00:52:57,760
within the vent systems and the

1384
00:53:02,230 --> 00:53:00,559
temperature of seawater in their model

1385
00:53:03,990 --> 00:53:02,240
they assume that the vent systems were

1386
00:53:06,470 --> 00:53:04,000
the same temperatures today and sea

1387
00:53:08,630 --> 00:53:06,480
water was much warmer thereby reducing

1388
00:53:10,309 --> 00:53:08,640

the temperature difference in our model

1389
00:53:12,470 --> 00:53:10,319
we assumed the sea water was the same

1390
00:53:14,710 --> 00:53:12,480
temperatures today but the vent systems

1391
00:53:17,190 --> 00:53:14,720
were much cooler and that reduced it

1392
00:53:19,270 --> 00:53:17,200
goes the same direction so arguably the

1393
00:53:21,109 --> 00:53:19,280
same mechanism could explain the silicon

1394
00:53:22,870 --> 00:53:21,119
isotope data

1395
00:53:25,030 --> 00:53:22,880
all right

1396
00:53:27,030 --> 00:53:25,040
so that let me leave you then

1397
00:53:28,390 --> 00:53:27,040
that's a lot of stuff in a short period

1398
00:53:31,510 --> 00:53:28,400
of time but i'll leave you then with

1399
00:53:34,230 --> 00:53:31,520
some speculative conclusions uh i think

1400
00:53:36,390 --> 00:53:34,240
it's unlikely in spite of all that

1401
00:53:39,349 --> 00:53:36,400
isotopic and biological data i think

1402
00:53:41,430 --> 00:53:39,359
it's unlikely that that model is correct

1403
00:53:42,390 --> 00:53:41,440
we think the early earth was

1404
00:53:47,270 --> 00:53:42,400
more

1405
00:53:49,589 --> 00:53:47,280
partially because the sun was less cold

1406
00:53:51,190 --> 00:53:49,599
the biological data you know rather than

1407
00:53:52,870 --> 00:53:51,200
representing the temperature of the

1408
00:53:55,750 --> 00:53:52,880
entire earth maybe that just means that

1409
00:53:57,670 --> 00:53:55,760
organisms migrated from predominantly

1410
00:54:00,470 --> 00:53:57,680
hot springs environments to a more

1411
00:54:02,870 --> 00:54:00,480
general cooler environment

1412
00:54:05,990 --> 00:54:02,880
are these large multiball

1413
00:54:08,150 --> 00:54:06,000

oscillations in co2 are hard to explain

1414
00:54:10,710 --> 00:54:08,160
the paleo proterozoic glaciations are

1415
00:54:13,430 --> 00:54:10,720
nicely explained by the rise of oxygen

1416
00:54:15,190 --> 00:54:13,440
and the loss of methane and then finally

1417
00:54:17,190 --> 00:54:15,200
there's still a lot of disagreement on

1418
00:54:19,270 --> 00:54:17,200
this so my main purpose in giving this

1419
00:54:21,829 --> 00:54:19,280
talk is just to raise these issues and

1420
00:54:32,309 --> 00:54:21,839
see if any of you have ideas on how to

1421
00:54:32,319 --> 00:54:40,390
questions for jim

1422
00:54:44,390 --> 00:54:41,990
roger

1423
00:54:46,470 --> 00:54:44,400
is there any way of independently

1424
00:54:48,230 --> 00:54:46,480
measuring um

1425
00:54:50,710 --> 00:54:48,240
the temperature of

1426
00:54:53,910 --> 00:54:50,720
archaean hydrothermal system

1427
00:54:57,990 --> 00:54:53,920
that doesn't rely on oxygen isotopes

1428
00:55:09,109 --> 00:54:59,750
maybe you can use

1429
00:55:13,750 --> 00:55:10,710
that's recently been discovered at

1430
00:55:16,549 --> 00:55:13,760
issuer to measure both penetration depth

1431
00:55:18,069 --> 00:55:16,559
and temperature of the water

1432
00:55:19,829 --> 00:55:18,079
right that's a that's a very good

1433
00:55:21,990 --> 00:55:19,839
question i mean and this is something

1434
00:55:23,589 --> 00:55:22,000
that i looked into carefully because i

1435
00:55:26,150 --> 00:55:23,599
was worried when we were writing this

1436
00:55:27,990 --> 00:55:26,160
paper that just such data might exist

1437
00:55:29,910 --> 00:55:28,000
somewhere that you know if you have a

1438
00:55:31,990 --> 00:55:29,920

mineral assembly suppose you find an

1439
00:55:34,069 --> 00:55:32,000
ophelite and you see some mineral

1440
00:55:37,270 --> 00:55:34,079
assemblage out there that you know for

1441
00:55:40,549 --> 00:55:37,280
sure what temperature it came out at

1442
00:55:43,190 --> 00:55:40,559
then you can test the model and as far

1443
00:55:45,589 --> 00:55:43,200
as i'm aware this has not been done i

1444
00:55:47,270 --> 00:55:45,599
mean i've i've certain i'm not really in

1445
00:55:48,950 --> 00:55:47,280
this field but i've searched as well as

1446
00:55:50,950 --> 00:55:48,960
i can and i had a big email

1447
00:55:52,230 --> 00:55:50,960
correspondence with carlos muellenbox

1448
00:55:55,270 --> 00:55:52,240
and paul canal

1449
00:55:57,270 --> 00:55:55,280
last fall and bob gregory and you know i

1450
00:55:59,670 --> 00:55:57,280
don't think you know i i've not been

1451
00:56:01,829 --> 00:55:59,680
shown any data from the ophelites or

1452
00:56:04,549 --> 00:56:01,839
anywhere else that really

1453
00:56:05,990 --> 00:56:04,559
constrain that interaction temperature

1454
00:56:07,589 --> 00:56:06,000
so i think they've been over

1455
00:56:09,270 --> 00:56:07,599
interpreting their data they're simply

1456
00:56:12,150 --> 00:56:09,280
assuming the same interaction

1457
00:56:15,670 --> 00:56:12,160
temperature and and that's you know that

1458
00:56:19,910 --> 00:56:15,680
really then fixes the result

1459
00:56:23,349 --> 00:56:21,430
what was the early temperature if it

1460
00:56:24,710 --> 00:56:23,359
wasn't 75 what would you guess the

1461
00:56:26,710 --> 00:56:24,720
temperature was

1462
00:56:28,789 --> 00:56:26,720
i was just chatting with roger about

1463
00:56:30,950 --> 00:56:28,799

this there there is a published estimate

1464
00:56:33,510 --> 00:56:30,960
you can use uh the pr

1465
00:56:36,230 --> 00:56:33,520
gypsum apparently evaporated well

1466
00:56:38,309 --> 00:56:36,240
precipitated back in the archaean and

1467
00:56:39,750 --> 00:56:38,319
this is something that roger published

1468
00:56:40,549 --> 00:56:39,760
many years ago

1469
00:56:46,470 --> 00:56:40,559
uh

1470
00:56:50,789 --> 00:56:48,630
it started off life as gypsum and the

1471
00:56:53,270 --> 00:56:50,799
published uh that gives an upper limit

1472
00:56:55,990 --> 00:56:53,280
on temperature the published upper limit

1473
00:56:57,829 --> 00:56:56,000
was 60 degrees but you and david

1474
00:57:00,549 --> 00:56:57,839
cattling have looked at this more

1475
00:57:02,470 --> 00:57:00,559
recently and it depends on salinity and

1476
00:57:04,789 --> 00:57:02,480
and so actually i mean what would you

1477
00:57:06,470 --> 00:57:04,799
say roger what what's the uh

1478
00:57:08,549 --> 00:57:06,480
what is the gypsum

1479
00:57:10,549 --> 00:57:08,559
20

1480
00:57:12,549 --> 00:57:10,559
all right so this is i had actually

1481
00:57:14,470 --> 00:57:12,559
forgotten that before i came out here

1482
00:57:16,230 --> 00:57:14,480
and i was chatting with roger earlier if

1483
00:57:18,630 --> 00:57:16,240
you believe that gypsum argument then

1484
00:57:20,470 --> 00:57:18,640
that may be able to constrain

1485
00:57:22,470 --> 00:57:20,480
if you know if the temperature is below

1486
00:57:25,990 --> 00:57:22,480
20 it can't be much below 20 or you'll

1487
00:57:27,990 --> 00:57:26,000
go glacial we're at 15 today 15 degrees

1488
00:57:29,430 --> 00:57:28,000

c global average today and it's a

1489
00:57:31,270 --> 00:57:29,440
glacial climate

1490
00:57:33,030 --> 00:57:31,280
so that would say that temperatures

1491
00:57:34,870 --> 00:57:33,040
would have been

1492
00:57:40,390 --> 00:57:34,880
like today or maybe just a little bit

1493
00:57:43,990 --> 00:57:41,750
so you mentioned the the carbon and

1494
00:57:47,109 --> 00:57:44,000
silicon site that's sort of enshrined in

1495
00:57:49,750 --> 00:57:47,910
but

1496
00:57:51,349 --> 00:57:49,760
i guess i don't understand how if you

1497
00:57:52,549 --> 00:57:51,359
believe that the carbon silicon cycle is

1498
00:57:55,109 --> 00:57:52,559
happening

1499
00:57:57,670 --> 00:57:55,119
why would you have three bars of co2 at

1500
00:57:59,349 --> 00:57:57,680
such a warm temperature that

1501
00:58:02,309 --> 00:57:59,359
by invoking the carbon and silicon cycle

1502
00:58:03,030 --> 00:58:02,319
draw down co2 to more clement levels

1503
00:58:04,630 --> 00:58:03,040
well

1504
00:58:06,309 --> 00:58:04,640
in that picture that i showed you the

1505
00:58:08,549 --> 00:58:06,319
silicate weathering is happening on the

1506
00:58:10,950 --> 00:58:08,559
continents so suppose the continents

1507
00:58:13,430 --> 00:58:10,960
were much smaller early on jim walker

1508
00:58:15,750 --> 00:58:13,440
published a model like this back in 19

1509
00:58:18,069 --> 00:58:15,760
mid 1980s so he said consider an ocean

1510
00:58:19,670 --> 00:58:18,079
covered earth where it is and he said

1511
00:58:21,589 --> 00:58:19,680
let's let's say that the amount of

1512
00:58:25,589 --> 00:58:21,599
carbon at earth's surface is the same as

1513
00:58:27,910 --> 00:58:25,599

today about 60 or 80 bars of co2

1514
00:58:30,069 --> 00:58:27,920
in that case it can only be removed by

1515
00:58:32,150 --> 00:58:30,079
weathering of the sea floor

1516
00:58:33,670 --> 00:58:32,160
and so jim did a little back of the en

1517
00:58:35,589 --> 00:58:33,680
he thought that process was very

1518
00:58:37,910 --> 00:58:35,599
inefficient and he concluded that you'd

1519
00:58:39,430 --> 00:58:37,920
get 10 bars of co2 in the atmosphere in

1520
00:58:41,430 --> 00:58:39,440
steady state

1521
00:58:44,789 --> 00:58:41,440
now since that time kevin's only and

1522
00:58:46,630 --> 00:58:44,799
norm sleep have written a paper in jgr

1523
00:58:48,710 --> 00:58:46,640
they add something to it they think you

1524
00:58:50,549 --> 00:58:48,720
know they argue pretty convincingly that

1525
00:58:52,549 --> 00:58:50,559
carbon is being exchanged between the

1526
00:58:55,190 --> 00:58:52,559
crust and the mantle and so in their

1527
00:58:57,270 --> 00:58:55,200
model the co2 forms carbonate veins in

1528
00:58:59,589 --> 00:58:57,280
the ocean and those carbonate veins are

1529
00:59:01,589 --> 00:58:59,599
subducted into the mantle so they think

1530
00:59:03,270 --> 00:59:01,599
that all the sea most of the co2 was

1531
00:59:05,109 --> 00:59:03,280
originally an earth

1532
00:59:06,870 --> 00:59:05,119
mantle and they argue that the early

1533
00:59:09,109 --> 00:59:06,880
earth was cold

1534
00:59:11,270 --> 00:59:09,119
so you know my take home

1535
00:59:13,190 --> 00:59:11,280
view of that is that from a theoretical

1536
00:59:14,870 --> 00:59:13,200
standpoint you can get almost any answer

1537
00:59:16,710 --> 00:59:14,880
you want depending on the assumptions

1538
00:59:20,069 --> 00:59:16,720

that you make i don't think any of the

1539
00:59:21,829 --> 00:59:20,079
arguments are particularly strong

1540
00:59:23,910 --> 00:59:21,839
the problem with with theirs actually is

1541
00:59:25,109 --> 00:59:23,920
that they they they say that you know

1542
00:59:27,670 --> 00:59:25,119
you would be

1543
00:59:29,670 --> 00:59:27,680
uh very cold in fact you'd be snowball

1544
00:59:31,349 --> 00:59:29,680
earth that cuts off the atmosphere from

1545
00:59:33,510 --> 00:59:31,359
the ocean so there's no way to get the

1546
00:59:35,270 --> 00:59:33,520
ocean if you have subaerial volcanoes

1547
00:59:37,670 --> 00:59:35,280
there's no way to get the co2 down to

1548
00:59:44,150 --> 00:59:37,680
the sea floor so you have to do a couple

1549
00:59:44,160 --> 00:59:54,150
christmas

1550
00:59:57,670 --> 00:59:56,630
right so what we do for for water clouds

1551
00:59:58,950 --> 00:59:57,680
is we

1552
01:00:01,030 --> 00:59:58,960
we we

1553
01:00:04,069 --> 01:00:01,040
we don't exactly neglect them we put

1554
01:00:05,750 --> 01:00:04,079
them at the surface because we're

1555
01:00:08,230 --> 01:00:05,760
clouds are very important part of the

1556
01:00:10,390 --> 01:00:08,240
climate in fact there's a literature out

1557
01:00:12,470 --> 01:00:10,400
there if you go look people suggesting

1558
01:00:14,549 --> 01:00:12,480
that you can solve the faint young sun

1559
01:00:16,789 --> 01:00:14,559
problem by just having lower cloudiness

1560
01:00:18,630 --> 01:00:16,799
on the early earth you know the sun was

1561
01:00:21,270 --> 01:00:18,640
30 percent less bright early in the

1562
01:00:23,670 --> 01:00:21,280
earth's history earth's albedo is about

1563
01:00:26,069 --> 01:00:23,680

30 percent and most of that is clouds so

1564
01:00:28,069 --> 01:00:26,079
then if you have no clouds on the early

1565
01:00:29,430 --> 01:00:28,079
earth that exactly compensates for the

1566
01:00:31,589 --> 01:00:29,440
faint young sun

1567
01:00:33,510 --> 01:00:31,599
but then you get to this question though

1568
01:00:35,109 --> 01:00:33,520
if temperatures were warm and if the

1569
01:00:37,750 --> 01:00:35,119
most of the earth's surface was covered

1570
01:00:39,270 --> 01:00:37,760
by water how could there not be clouds

1571
01:00:42,549 --> 01:00:39,280
uh you know i just don't think that

1572
01:00:44,789 --> 01:00:42,559
that's a self-consistent answer if you

1573
01:00:46,230 --> 01:00:44,799
want to do better than this then you

1574
01:00:48,230 --> 01:00:46,240
know so we put the cloud layer at the

1575
01:00:50,069 --> 01:00:48,240
ground we tune the climate model so that

1576
01:00:52,549 --> 01:00:50,079
we get the right answer for present

1577
01:00:54,630 --> 01:00:52,559
earth we tune the surface albedo which

1578
01:00:56,710 --> 01:00:54,640
which simulates a cloud layer and then

1579
01:00:59,109 --> 01:00:56,720
we just hold that fixed as we go back in

1580
01:01:00,870 --> 01:00:59,119
time essentially assuming zero cloud

1581
01:01:02,230 --> 01:01:00,880
feedback

1582
01:01:03,990 --> 01:01:02,240
and so it depends what you think the

1583
01:01:05,589 --> 01:01:04,000
early if the early earth was cold then

1584
01:01:07,270 --> 01:01:05,599
cloudiness might have been less but if

1585
01:01:11,109 --> 01:01:07,280
it was warmer than today i don't see how

1586
01:01:15,829 --> 01:01:13,589
i'm trying to imagine the biology

1587
01:01:17,910 --> 01:01:15,839
side you only have the one liner there

1588
01:01:19,589 --> 01:01:17,920

so is the idea that the life was

1589
01:01:21,750 --> 01:01:19,599
huddling around the

1590
01:01:23,510 --> 01:01:21,760
warm places

1591
01:01:25,589 --> 01:01:23,520
and then only

1592
01:01:28,150 --> 01:01:25,599
was forced to adapt

1593
01:01:29,829 --> 01:01:28,160
when things got cooler

1594
01:01:31,430 --> 01:01:29,839
well you know i went over the biology

1595
01:01:33,589 --> 01:01:31,440
part pretty quickly because i don't know

1596
01:01:34,710 --> 01:01:33,599
how to explain that there's been the you

1597
01:01:36,870 --> 01:01:34,720
know

1598
01:01:39,670 --> 01:01:36,880
the argument about hyperthermals in the

1599
01:01:41,349 --> 01:01:39,680
rna tree has been around for a long time

1600
01:01:43,670 --> 01:01:41,359
and there's been a whole literature of

1601
01:01:47,030 --> 01:01:43,680
people trying to one explanation for

1602
01:01:49,670 --> 01:01:47,040
that is that it's uh just survive you

1603
01:01:51,190 --> 01:01:49,680
you had life originated at cooler

1604
01:01:53,750 --> 01:01:51,200
temperatures but then you had a giant

1605
01:01:56,309 --> 01:01:53,760
impact and uh raised temperatures and

1606
01:01:59,510 --> 01:01:56,319
only the therma hyper thermophilic

1607
01:02:00,390 --> 01:01:59,520
organisms lived through the giant impact

1608
01:02:03,670 --> 01:02:00,400
right

1609
01:02:05,510 --> 01:02:03,680
but this latest one with the the gaucher

1610
01:02:08,470 --> 01:02:05,520
thing with the biological you know the

1611
01:02:10,069 --> 01:02:08,480
resurrected proteins and the molecular

1612
01:02:12,069 --> 01:02:10,079
clock dating

1613
01:02:13,270 --> 01:02:12,079

i'm not the best person to address that

1614
01:02:15,910 --> 01:02:13,280
although i know there are a lot of

1615
01:02:18,549 --> 01:02:15,920
people who don't like molecular clocks

1616
01:02:19,670 --> 01:02:18,559
and so you can go after that

1617
01:02:21,589 --> 01:02:19,680
i i

1618
01:02:22,870 --> 01:02:21,599
my colleague you know blair hedges at

1619
01:02:24,549 --> 01:02:22,880
penn state is one of the people that

1620
01:02:26,150 --> 01:02:24,559
does these things and

1621
01:02:28,150 --> 01:02:26,160
you know so you can go after that part

1622
01:02:30,069 --> 01:02:28,160
of the argument i kind of like the

1623
01:02:31,670 --> 01:02:30,079
resurrected protein thing it was really

1624
01:02:33,109 --> 01:02:31,680
clever and i you know

1625
01:02:34,549 --> 01:02:33,119
could hardly believe when i read the

1626
01:02:36,230 --> 01:02:34,559
details that you know how they're

1627
01:02:38,069 --> 01:02:36,240
actually doing that recreating the

1628
01:02:40,470 --> 01:02:38,079
proteins and measuring their melting

1629
01:02:45,829 --> 01:02:40,480
point temperatures

1630
01:02:45,839 --> 01:02:52,750
is anybody here want to explain that for

1631
01:03:01,030 --> 01:02:55,829
us is it easy to maintain high levels of

1632
01:03:04,309 --> 01:03:02,870
well no that's that's actually i didn't

1633
01:03:06,549 --> 01:03:04,319
give that part but

1634
01:03:08,230 --> 01:03:06,559
when oxygen is low then that's exactly

1635
01:03:10,150 --> 01:03:08,240
what we do with our photochemical model

1636
01:03:11,510 --> 01:03:10,160
if you put in the same flux of methane

1637
01:03:13,510 --> 01:03:11,520
that you have today

1638
01:03:15,829 --> 01:03:13,520

you get the the lifetime of methane is

1639
01:03:17,589 --> 01:03:15,839
about a thousand times longer so you get

1640
01:03:19,670 --> 01:03:17,599
instead of one part per million you get

1641
01:03:21,510 --> 01:03:19,680
a thousand parts per million

1642
01:03:24,069 --> 01:03:21,520
and then i had a phd student a few years

1643
01:03:26,870 --> 01:03:24,079
ago pushkar karecha who did some simple

1644
01:03:28,630 --> 01:03:26,880
ecological models of the the archaean

1645
01:03:30,150 --> 01:03:28,640
and anaerobic archaean ocean we think

1646
01:03:31,670 --> 01:03:30,160
that methanogens would be living

1647
01:03:33,990 --> 01:03:31,680
throughout the water column and in

1648
01:03:36,069 --> 01:03:34,000
sediments and we we constructed a little

1649
01:03:38,150 --> 01:03:36,079
model and we're able to show to my

1650
01:03:39,750 --> 01:03:38,160
satisfaction that the fluxes of methane

1651
01:03:41,910 --> 01:03:39,760
coming out of that would be sort of

1652
01:03:43,109 --> 01:03:41,920
within a factor of three of the present

1653
01:03:44,870 --> 01:03:43,119
value

1654
01:03:46,789 --> 01:03:44,880
so no i mean one of the reasons we

1655
01:03:48,630 --> 01:03:46,799
believe in the methane greenhouse is not

1656
01:03:51,270 --> 01:03:48,640
because we need the methane it's just

1657
01:03:53,270 --> 01:03:51,280
hard to avoid the methane

1658
01:03:56,630 --> 01:03:53,280
only way to avoid it is if methanogens

1659
01:03:58,230 --> 01:03:56,640
evolve very late in evolutionary history

1660
01:04:02,710 --> 01:03:58,240
which there are some supporters of that

1661
01:04:07,990 --> 01:04:06,950
oh what would 75 uh see earth be like in

1662
01:04:09,750 --> 01:04:08,000
terms of

1663
01:04:13,349 --> 01:04:09,760

albedo you know

1664
01:04:22,630 --> 01:04:14,309
rain

1665
01:04:24,630 --> 01:04:22,640
very close no it's not enormous this was

1666
01:04:26,230 --> 01:04:24,640
it's about the same as today

1667
01:04:28,789 --> 01:04:26,240
and this is something that i didn't

1668
01:04:29,670 --> 01:04:28,799
realize dick holland educated me on this

1669
01:04:32,549 --> 01:04:29,680
uh

1670
01:04:34,470 --> 01:04:32,559
some time ago the the amount of rainfall

1671
01:04:37,109 --> 01:04:34,480
is limited by the amount of sunlight

1672
01:04:39,670 --> 01:04:37,119
that hits the ocean surface so you know

1673
01:04:42,470 --> 01:04:39,680
today about half the energy of the

1674
01:04:44,390 --> 01:04:42,480
sunlight that hits the surface goes into

1675
01:04:45,190 --> 01:04:44,400
evaporation of seawater

1676
01:04:47,190 --> 01:04:45,200
and

1677
01:04:49,190 --> 01:04:47,200
thus you know there's no way you can

1678
01:04:51,029 --> 01:04:49,200
increase the amount of evaporation by

1679
01:04:52,390 --> 01:04:51,039
more than a factor of two compared to

1680
01:04:54,390 --> 01:04:52,400
today

1681
01:04:56,309 --> 01:04:54,400
regardless of how hot it is

1682
01:04:58,710 --> 01:04:56,319
now you can ask how do you how do you

1683
01:05:00,470 --> 01:04:58,720
resolve that well the evaporation rate

1684
01:05:03,829 --> 01:05:00,480
is a function of three things one is

1685
01:05:05,029 --> 01:05:03,839
temperature the uh relative humidity and

1686
01:05:09,190 --> 01:05:05,039
wind speed

1687
01:05:10,870 --> 01:05:09,200
because that's hard to know but what

1688
01:05:13,109 --> 01:05:10,880

happens if you had a three bar

1689
01:05:15,029 --> 01:05:13,119
atmosphere or a 10 bar co2 atmosphere

1690
01:05:17,029 --> 01:05:15,039
the temperature would be very high

1691
01:05:18,950 --> 01:05:17,039
but the evaporation rate is constrained

1692
01:05:20,950 --> 01:05:18,960
by energy balance and therefore the

1693
01:05:23,109 --> 01:05:20,960
relative humidity would rise to the

1694
01:05:24,710 --> 01:05:23,119
point where evaporation was cut down to

1695
01:05:26,870 --> 01:05:24,720
about its present rate

1696
01:05:29,510 --> 01:05:26,880
i think that argument is right

1697
01:05:32,789 --> 01:05:29,520
so is arizona not houston

1698
01:05:34,870 --> 01:05:32,799
yeah it's it's surprisingly well it's no

1699
01:05:37,270 --> 01:05:34,880
it's not arizona it's human right but

1700
01:05:38,630 --> 01:05:37,280
it's not raining that that much in terms

1701
01:05:39,829 --> 01:05:38,640
of uh

1702
01:05:41,589 --> 01:05:39,839
volume

1703
01:05:50,230 --> 01:05:41,599
because there just is enough energy to

1704
01:05:52,549 --> 01:05:51,109
okay