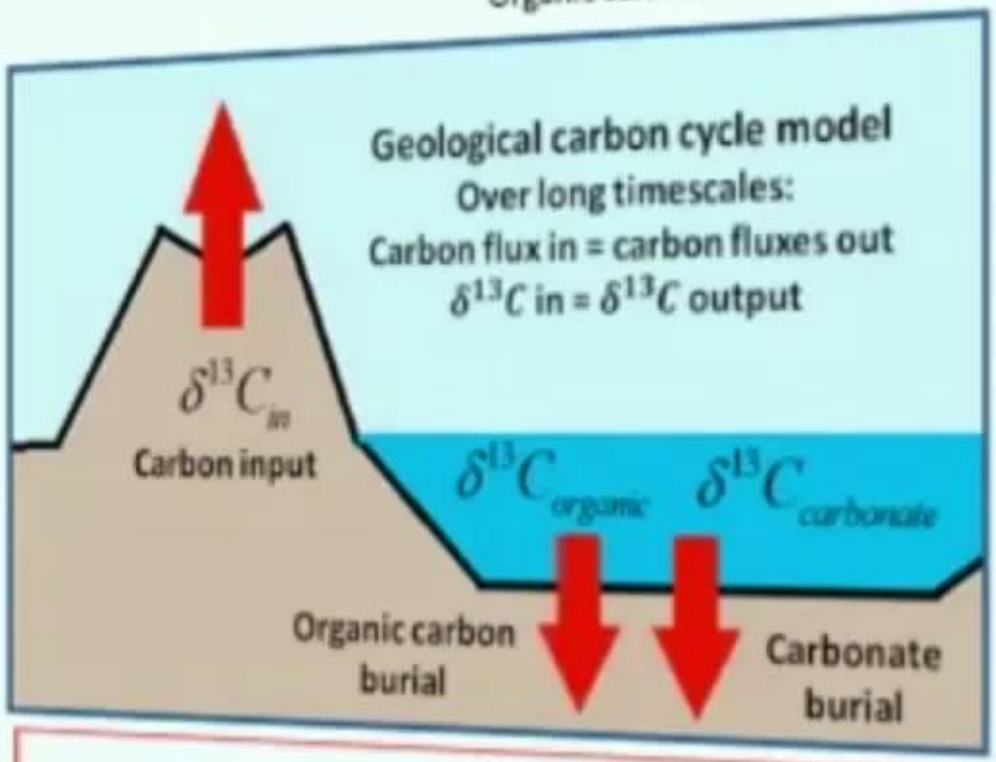
$$CO_2 + H_2O \rightarrow CH_2O + O_2$$

Organic carbon



$$f_{org} \cong \frac{organic\ burial\ (\frac{mol}{year})}{total\ carbon\ burial\ (\frac{mol}{year})} = \frac{\delta^{13}C_{in} - \delta^{13}C_{carb}}{\delta^{13}C_{org} - \delta^{13}C_{carb}}$$

1
00:00:10,680 --> 00:00:09,000
yeah so i'm josh from the University of

2
00:00:12,600 --> 00:00:10,690
Washington and I'm going to be

3
00:00:15,330 --> 00:00:12,610
presenting some work I've done with my

4
00:00:19,710 --> 00:00:15,340
advisor David catling along with Roger

5
00:00:21,660 --> 00:00:19,720
Buick on the rise of oxygen and to

6
00:00:24,480 --> 00:00:21,670
motivate this I've put up Earth's

7
00:00:26,310 --> 00:00:24,490
reflectance spectrum not because this is

8
00:00:28,470 --> 00:00:26,320
what I do but because I think it

9
00:00:32,460 --> 00:00:28,480
illustrates quite nicely why thinking

10
00:00:33,720 --> 00:00:32,470
about the rise of oxygen is important so

11
00:00:37,680 --> 00:00:33,730
when you look at our spectrum you see

12
00:00:41,160 --> 00:00:37,690
really obvious other one absorption

13
00:00:43,139 --> 00:00:41,170

features from abundant biogenic

14
00:00:45,330 --> 00:00:43,149
atmospheric oxygen and you're

15
00:00:47,540 --> 00:00:45,340
potentially we could image terrestrial

16
00:00:51,600 --> 00:00:47,550
exoplanets and and see the same thing

17
00:00:54,090 --> 00:00:51,610
now on earth over the last few decades

18
00:00:56,639 --> 00:00:54,100
geologists and geochemists have put

19
00:00:59,220 --> 00:00:56,649
together this really good descriptive

20
00:01:01,500 --> 00:00:59,230
picture of the history of atmospheric

21
00:01:04,170 --> 00:01:01,510
oxygen and this is a different version

22
00:01:06,590 --> 00:01:04,180
of the figure that that Kevin showed and

23
00:01:09,870 --> 00:01:06,600
also is kind of a picture version of

24
00:01:11,700 --> 00:01:09,880
Briana's fame lab talk last night so we

25
00:01:13,940 --> 00:01:11,710
know that for the first couple of

26
00:01:16,170 --> 00:01:13,950
billion years of Earth history over here

27
00:01:19,289 --> 00:01:16,180
there was very little atmospheric oxygen

28
00:01:22,230 --> 00:01:19,299
then around sort of 2.4 2.5 it shot up

29
00:01:24,330 --> 00:01:22,240
to maybe one ten percent of modern

30
00:01:26,580 --> 00:01:24,340
levels were remained until a few hundred

31
00:01:29,820 --> 00:01:26,590
million years ago right increased again

32
00:01:32,940 --> 00:01:29,830
to genere modern levels now although

33
00:01:35,810 --> 00:01:32,950
this descriptive pizza is fairly well

34
00:01:39,980 --> 00:01:35,820
established the causes of the centuries

35
00:01:44,240 --> 00:01:39,990
are not particularly well understood and

36
00:01:47,249 --> 00:01:44,250
so I think if we want to go looking for

37
00:01:49,050 --> 00:01:47,259
oxygen biosignatures and exoplanets it's

38
00:01:50,550 --> 00:01:49,060

helpful to first to understand this we

39
00:01:52,109 --> 00:01:50,560
don't know for instance you know not

40
00:01:55,530 --> 00:01:52,119
only what caused this but as this is

41
00:01:57,030 --> 00:01:55,540
this kind of increase a general kind of

42
00:01:59,039 --> 00:01:57,040
behavior we would expect to see in all

43
00:02:01,649 --> 00:01:59,049
terrestrial planets with properties x y

44
00:02:03,389 --> 00:02:01,659
and z what determines the timing of this

45
00:02:05,340 --> 00:02:03,399
increase we don't know the answers to

46
00:02:07,889 --> 00:02:05,350
these questions so yeah i'm sure before

47
00:02:12,090 --> 00:02:07,899
we look for and interpret this i think

48
00:02:13,650 --> 00:02:12,100
it's helpful to understand this so so

49
00:02:16,910 --> 00:02:13,660
how might we do that how might we think

50
00:02:19,260 --> 00:02:16,920
about the cause of the rise of oxygen

51
00:02:21,060 --> 00:02:19,270
it's useful to kind of

52
00:02:23,250 --> 00:02:21,070
formalize our ignorance on the matter as

53
00:02:25,530 --> 00:02:23,260
it were by saying that the the time rate

54
00:02:27,690 --> 00:02:25,540
of change of the amount of oxygen in the

55
00:02:30,150 --> 00:02:27,700
atmosphere is equal to you know the

56
00:02:32,490 --> 00:02:30,160
source fluxes minus the sink fluxes and

57
00:02:33,990 --> 00:02:32,500
so obviously in this picture there are

58
00:02:35,670 --> 00:02:34,000
only two possible classes of

59
00:02:38,580 --> 00:02:35,680
explanations for the rise of oxygen

60
00:02:40,080 --> 00:02:38,590
either the source fluxes have to have

61
00:02:42,030 --> 00:02:40,090
increased at some point or the sink

62
00:02:44,160 --> 00:02:42,040
fluxes had to have decreased at some

63
00:02:49,110 --> 00:02:44,170

point to cause the imbalance that caused

64
00:02:52,680 --> 00:02:49,120
it to shoot up now in this talk I'm

65
00:02:55,440 --> 00:02:52,690
going to be focusing on whether or not

66
00:02:57,870 --> 00:02:55,450
an increase in the source flux can

67
00:03:00,050 --> 00:02:57,880
explain the rise of oxygen or more

68
00:03:02,130 --> 00:03:00,060
specifically where the changes in

69
00:03:05,960 --> 00:03:02,140
organic burial which I'll explain

70
00:03:09,570 --> 00:03:05,970
shortly can explain the rise of oxygen

71
00:03:11,340 --> 00:03:09,580
so and I should add that this fits into

72
00:03:13,470 --> 00:03:11,350
the isotope session because you get at

73
00:03:16,470 --> 00:03:13,480
organic burial through looking at carbon

74
00:03:18,210 --> 00:03:16,480
isotopes so how does this work well you

75
00:03:21,720 --> 00:03:18,220
will know how oxygen is made right

76
00:03:25,790 --> 00:03:21,730
plants cyanobacteria they take co2 and

77
00:03:30,360 --> 00:03:25,800
water produce reduced organic carbon and

78
00:03:33,000 --> 00:03:30,370
then give off oxygen however generally

79
00:03:36,060 --> 00:03:33,010
what happens is that when this organic

80
00:03:39,090 --> 00:03:36,070
carbon is respired or the organism dies

81
00:03:43,260 --> 00:03:39,100
and decomposes it gets reoxidized back

82
00:03:46,170 --> 00:03:43,270
to co2 and water and so photosynthesis

83
00:03:51,630 --> 00:03:46,180
does not increase atmospheric oxygen at

84
00:03:54,060 --> 00:03:51,640
all unless you bury this organic carbon

85
00:03:56,240 --> 00:03:54,070
in sediments permanently separating it

86
00:03:59,340 --> 00:03:56,250
from the surface thereby leaving behind

87
00:04:02,730 --> 00:03:59,350
one mole of oxygen for every mole of

88
00:04:05,100 --> 00:04:02,740

organic carbon you bury and so in this

89
00:04:06,360 --> 00:04:05,110
way the source flux of oxygen into the

90
00:04:08,220 --> 00:04:06,370
atmosphere which is what we're

91
00:04:10,860 --> 00:04:08,230
interested in for the rise of oxygen is

92
00:04:16,979 --> 00:04:10,870
exactly equal to the burial rate of

93
00:04:18,330 --> 00:04:16,989
organic carbon so to get at the oxygen

94
00:04:20,580 --> 00:04:18,340
source flux we need to understand the

95
00:04:23,190 --> 00:04:20,590
carbon cycle this is a really simple

96
00:04:25,860 --> 00:04:23,200
representation of the geological carbon

97
00:04:28,080 --> 00:04:25,870
cycle they've got carbon so these are is

98
00:04:28,840 --> 00:04:28,090
a fluxes of carbon and moles per year or

99
00:04:31,580 --> 00:04:28,850
whatever

100
00:04:35,240 --> 00:04:31,590
we've got some flux of carbon into the

101
00:04:37,760 --> 00:04:35,250
atmosphere ocean system co2 outcasts

102
00:04:40,010 --> 00:04:37,770
from volcanoes and then we've got carbon

103
00:04:42,380 --> 00:04:40,020
leaving the surface to the burial of

104
00:04:44,510 --> 00:04:42,390
organic carbon ie vista the stuff that's

105
00:04:51,770 --> 00:04:44,520
important for oxygen but also leaving as

106
00:04:54,560 --> 00:04:51,780
carbonates now life as we've heard

107
00:04:56,300 --> 00:04:54,570
fraction eats carbon during

108
00:04:59,120 --> 00:04:56,310
photosynthesis so each of these fluxes

109
00:05:01,910 --> 00:04:59,130
has a distinct isotopic signature and so

110
00:05:03,620 --> 00:05:01,920
i'm using this this Delta 13 c notation

111
00:05:05,600 --> 00:05:03,630
which is thankfully already been defined

112
00:05:07,100 --> 00:05:05,610
for me but if you don't remember that

113
00:05:10,700 --> 00:05:07,110

the definition you can just think of it

114
00:05:13,820 --> 00:05:10,710
as the ratio of rare heavy carbon 13

115
00:05:17,680 --> 00:05:13,830
atoms to abundant carbon-12 at and

116
00:05:19,760 --> 00:05:17,690
scaled in a totally counterintuitive way

117
00:05:21,620 --> 00:05:19,770
so what we can then say given these

118
00:05:24,290 --> 00:05:21,630
fluxes we can say over long time scales

119
00:05:26,030 --> 00:05:24,300
what goes in must equal what goes out so

120
00:05:28,160 --> 00:05:26,040
the input fluxes must balance the output

121
00:05:30,230 --> 00:05:28,170
fluxes and similarly the isotopic

122
00:05:31,940 --> 00:05:30,240
composition of what goes in must balance

123
00:05:34,010 --> 00:05:31,950
the isotopic composition and what goes

124
00:05:35,570 --> 00:05:34,020
out and I won't go through the math but

125
00:05:37,790 --> 00:05:35,580
it's it's really simple it's basically

126
00:05:40,430 --> 00:05:37,800
just two equations two unknowns and you

127
00:05:42,050 --> 00:05:40,440
get out this expression here which is

128
00:05:45,730 --> 00:05:42,060
which is really important so this tells

129
00:05:49,810 --> 00:05:45,740
you that if org which is defined as

130
00:05:53,960 --> 00:05:49,820
fractional organic barrel the amount of

131
00:05:57,470 --> 00:05:53,970
carbon that is buried as organic divided

132
00:06:00,200 --> 00:05:57,480
by the total carbon burial you can show

133
00:06:02,870 --> 00:06:00,210
using this kind of mass balance model

134
00:06:05,900 --> 00:06:02,880
that is equal to a function of purely

135
00:06:07,820 --> 00:06:05,910
the isotopes and so what this tells you

136
00:06:10,370 --> 00:06:07,830
then is that if you can go and measure

137
00:06:13,370 --> 00:06:10,380
the isotopic ratios of these various

138
00:06:15,560 --> 00:06:13,380

sorts and sync fluxes over time then

139
00:06:18,860 --> 00:06:15,570
that'll give you fractional organic

140
00:06:20,990 --> 00:06:18,870
burial over time which as I just

141
00:06:24,080 --> 00:06:21,000
explained gives you the oxygen source

142
00:06:25,580 --> 00:06:24,090
flux over time so isotopes give your

143
00:06:31,370 --> 00:06:25,590
organic burial gives your oxygen source

144
00:06:35,090 --> 00:06:31,380
slugs so people have been trying to do

145
00:06:38,030 --> 00:06:35,100
this for decades and we think that the

146
00:06:39,800 --> 00:06:38,040
isotopic composition of what goes in has

147
00:06:42,020 --> 00:06:39,810
been pretty much fixed so to figure out

148
00:06:42,800 --> 00:06:42,030
this thing you only have to know the

149
00:06:45,860 --> 00:06:42,810
isotopic

150
00:06:51,500 --> 00:06:45,870
position of carbonate and organic carbon

151
00:06:53,510 --> 00:06:51,510
and so here's the the data this is a

152
00:06:59,030 --> 00:06:53,520
compilation I put together from various

153
00:07:02,360 --> 00:06:59,040
other compilations the carbonates are in

154
00:07:05,030 --> 00:07:02,370
red organics in blue this is over Earth

155
00:07:10,090 --> 00:07:05,040
history and this is that strange Delta

156
00:07:12,620 --> 00:07:10,100
13c measurement of the isotopic ratios

157
00:07:14,659 --> 00:07:12,630
most authors who have looked at this

158
00:07:16,909 --> 00:07:14,669
this kind of data have basically said

159
00:07:19,430 --> 00:07:16,919
well it looks like they've both been

160
00:07:22,580 --> 00:07:19,440
pretty much constant over Earth history

161
00:07:24,379 --> 00:07:22,590
and so therefore everything on the right

162
00:07:27,260 --> 00:07:24,389
hand side of this equation is a constant

163
00:07:29,629 --> 00:07:27,270

as a function of time there for organic

164
00:07:32,690 --> 00:07:29,639
burial is a constant as a function of

165
00:07:34,610 --> 00:07:32,700
time therefore the oxygen source flux is

166
00:07:37,640 --> 00:07:34,620
a constant as a function of time

167
00:07:40,520 --> 00:07:37,650
therefore you cannot explain the rise of

168
00:07:41,930 --> 00:07:40,530
oxygen by an increase in this it must

169
00:07:44,420 --> 00:07:41,940
have been a decrease in some of the sink

170
00:07:46,550 --> 00:07:44,430
fluxes that caused the rise of oxygen on

171
00:07:48,380 --> 00:07:46,560
earth that's the most popular

172
00:07:50,810 --> 00:07:48,390
interpretation but there have been a few

173
00:07:54,950 --> 00:07:50,820
papers that have tried to draw the lines

174
00:07:56,480 --> 00:07:54,960
through this data and they've done this

175
00:07:58,790 --> 00:07:56,490
for one reason or another either

176
00:08:03,350 --> 00:07:58,800
invoking other kind of carbon cycle

177
00:08:04,909 --> 00:08:03,360
processes or biases and preservation but

178
00:08:07,159 --> 00:08:04,919
even without those complications there's

179
00:08:08,990 --> 00:08:07,169
a fair amount of spread in this data set

180
00:08:11,300 --> 00:08:09,000
and so it's not obvious the extent to

181
00:08:14,000 --> 00:08:11,310
which the isotopes really constrain

182
00:08:16,310 --> 00:08:14,010
organic burial and so what I've been

183
00:08:19,310 --> 00:08:16,320
trying to do is a fairly rigorous

184
00:08:21,770 --> 00:08:19,320
statistical analysis of this data set to

185
00:08:26,029 --> 00:08:21,780
try and determine exactly how well if

186
00:08:27,379 --> 00:08:26,039
org is as constrained and so I won't go

187
00:08:29,779 --> 00:08:27,389
through all the details other than to

188
00:08:31,730 --> 00:08:29,789

say I took a sort of shotgun approach to

189
00:08:33,920 --> 00:08:31,740
statistics just applying a whole bunch

190
00:08:35,930 --> 00:08:33,930
of different methodologies hoping to

191
00:08:37,820 --> 00:08:35,940
derive robust conclusions that don't

192
00:08:40,190 --> 00:08:37,830
depend too much on the specific

193
00:08:42,230 --> 00:08:40,200
methodology so here's one one of those

194
00:08:43,790 --> 00:08:42,240
techniques our regression method similar

195
00:08:47,030 --> 00:08:43,800
to what you might use in climate science

196
00:08:48,260 --> 00:08:47,040
say to determine to what extent is there

197
00:08:50,510 --> 00:08:48,270
a significant increase in global

198
00:08:52,370 --> 00:08:50,520
temperature over some time spent given

199
00:08:54,620 --> 00:08:52,380
the tendency of time series data to kind

200
00:08:55,910 --> 00:08:54,630
of correlate with itself so you fit this

201
00:08:58,639 --> 00:08:55,920
sort of model to the

202
00:09:01,430 --> 00:08:58,649
you fit a trend to the carbonates you

203
00:09:03,079 --> 00:09:01,440
fit a trend to the organics you generate

204
00:09:05,629 --> 00:09:03,089
uncertainties in a kind of Monte Carlo

205
00:09:07,970 --> 00:09:05,639
way you plug that in and you get out a

206
00:09:10,129 --> 00:09:07,980
change in organic burial fraction

207
00:09:12,470 --> 00:09:10,139
organic burial over Earth history with

208
00:09:15,410 --> 00:09:12,480
uncertainties and so if you do that you

209
00:09:18,079 --> 00:09:15,420
get something looks like this this is a

210
00:09:20,509 --> 00:09:18,089
probability distribution for the change

211
00:09:23,449 --> 00:09:20,519
in F or fractional organic burial the

212
00:09:26,449 --> 00:09:23,459
percentage changing it over the rock

213
00:09:28,449 --> 00:09:26,459

record and so what you see is that you

214
00:09:31,280 --> 00:09:28,459
know with ninety-five percent confidence

215
00:09:32,750 --> 00:09:31,290
the change is anywhere from very little

216
00:09:35,720 --> 00:09:32,760
all the way up to a hundred percent

217
00:09:38,240 --> 00:09:35,730
increase of doubling this is a very

218
00:09:42,860 --> 00:09:38,250
broad confidence interval 0 to 100

219
00:09:45,710 --> 00:09:42,870
percent you can kind of do the same

220
00:09:47,720 --> 00:09:45,720
thing with with different methodologies

221
00:09:49,460 --> 00:09:47,730
so rather than impose a regression you

222
00:09:51,500 --> 00:09:49,470
just take the the organic data in this

223
00:09:52,579 --> 00:09:51,510
case the crosses you smooth it out with

224
00:09:54,319 --> 00:09:52,589
some algorithm that gives you

225
00:09:55,670 --> 00:09:54,329
uncertainties do the same for the

226
00:09:58,430 --> 00:09:55,680
carbonates smooth it out get

227
00:10:00,259 --> 00:09:58,440
uncertainties plug goes into your

228
00:10:02,150 --> 00:10:00,269
equation get out if all over time this

229
00:10:04,280 --> 00:10:02,160
is fraction organic burial over Earth

230
00:10:05,600 --> 00:10:04,290
history with uncertainties and you

231
00:10:07,310 --> 00:10:05,610
basically had a similar kind of answer

232
00:10:09,530 --> 00:10:07,320
there are subtle differences depending

233
00:10:12,139 --> 00:10:09,540
on how you do the methodology but you

234
00:10:14,060 --> 00:10:12,149
get a similar look and distribution so

235
00:10:18,889 --> 00:10:14,070
what does this mean then for the rise of

236
00:10:22,639 --> 00:10:18,899
oxygen well if you take the lower end of

237
00:10:24,829 --> 00:10:22,649
our confidence interval then you can

238
00:10:27,439 --> 00:10:24,839

show using fairly simple flux arguments

239
00:10:28,970 --> 00:10:27,449
that whatever you do this isn't enough

240
00:10:30,920 --> 00:10:28,980
to explain the rise of oxygen at a

241
00:10:33,620 --> 00:10:30,930
twenty percent increase in organic

242
00:10:35,360 --> 00:10:33,630
burial will not cause a rise of oxygen

243
00:10:38,480 --> 00:10:35,370
you need a decrease in some of the sink

244
00:10:39,800 --> 00:10:38,490
flux flux is but if you take the upper

245
00:10:42,050 --> 00:10:39,810
end of our confidence interval one

246
00:10:44,780 --> 00:10:42,060
hundred percent increase in f org over

247
00:10:46,670 --> 00:10:44,790
Earth history then then yeah if you make

248
00:10:48,769 --> 00:10:46,680
certain assumptions about the absolute

249
00:10:52,550 --> 00:10:48,779
fluxes that are plausible then you can

250
00:10:54,199 --> 00:10:52,560
get out a rise of oxygen so basically

251
00:10:56,360 --> 00:10:54,209
what this analysis shows is that given

252
00:10:58,639 --> 00:10:56,370
the uncertainty in the change in organic

253
00:11:01,160 --> 00:10:58,649
burial over of history we simply cannot

254
00:11:04,939 --> 00:11:01,170
say whether the rise of oxygen was

255
00:11:07,519 --> 00:11:04,949
caused by increased source flux so

256
00:11:08,860 --> 00:11:07,529
that's the basic conclusion I was going

257
00:11:11,140 --> 00:11:08,870
to talk about

258
00:11:14,670 --> 00:11:11,150
more complex carbon cycle model but I

259
00:11:17,140 --> 00:11:14,680
think I'll just skip out of that because

260
00:11:20,290 --> 00:11:17,150
yeah so that's the basic conclusion the

261
00:11:22,329 --> 00:11:20,300
isotopes don't constrain the source flux

262
00:11:26,400 --> 00:11:22,339
of oxygen and so to to make progress

263
00:11:28,660 --> 00:11:26,410

here we somehow need better better

264
00:11:31,720 --> 00:11:28,670
isotope data the better represents the

265
00:11:33,100 --> 00:11:31,730
global average with less spread yes I'll

266
00:11:34,450 --> 00:11:33,110
just open up for questions and if you

267
00:11:35,590 --> 00:11:34,460
want to know more also this should

268
00:11:37,570 --> 00:11:35,600
appear in the American Journal of

269
00:11:56,190 --> 00:11:37,580
science some time for the end of the

270
00:12:02,950 --> 00:11:59,200
nas which is a question but I think some

271
00:12:06,880 --> 00:12:02,960
support to your argument I'm surprised

272
00:12:10,030 --> 00:12:06,890
you didn't mention the sharp rise in the

273
00:12:13,480 --> 00:12:10,040
Delta 13 C values around the time of the

274
00:12:17,190 --> 00:12:13,490
great oxidation event since it's

275
00:12:20,680 --> 00:12:17,200
believed that that rise in the carbonate

276
00:12:23,380 --> 00:12:20,690
the carbonate carbon isotope values is

277
00:12:26,199 --> 00:12:23,390
related to an increase in the burial of

278
00:12:29,320 --> 00:12:26,209
organic carbon and it's coincident with

279
00:12:31,150 --> 00:12:29,330
the great oxidation event yeah so where

280
00:12:33,269 --> 00:12:31,160
are we now so this is what you're

281
00:12:40,360 --> 00:12:33,279
talking about right this ad the

282
00:12:44,380 --> 00:12:40,370
amalgamation of all the data yeah yeah

283
00:12:47,110 --> 00:12:44,390
yeah yeahs 2.3 there's definitely an

284
00:12:50,050 --> 00:12:47,120
increase in the isotopes of carbon which

285
00:12:51,550 --> 00:12:50,060
which could be attributed to well the

286
00:12:52,690 --> 00:12:51,560
increased organic burial could be part

287
00:12:54,160 --> 00:12:52,700
of the explanation for the rise of

288
00:12:56,140 --> 00:12:54,170

oxygen but could also be a consequence

289
00:12:58,329 --> 00:12:56,150
of the Roses of oxygen right answer this

290
00:13:01,480 --> 00:12:58,339
question about the timing and I think it

291
00:13:03,370 --> 00:13:01,490
seems to be coming after the rise of

292
00:13:05,320 --> 00:13:03,380
oxygen as determined by the self enough

293
00:13:07,900 --> 00:13:05,330
signal so i don't know if that is really

294
00:13:11,769 --> 00:13:07,910
supports the idea that enhanced organic

295
00:13:14,350 --> 00:13:11,779
burial cause the rise of oxygen the

296
00:13:17,290 --> 00:13:14,360
great oxidation event is well-timed but

297
00:13:24,530 --> 00:13:17,300
the carbon isotope excursion is not well