

ASU ARIZONA STATE UNIVERSITY



Key Problem: Alteration

"Black" shale, Pilbara Craton, W. Australia



1
00:00:06,550 --> 00:00:04,150
well i see everybody got their clock set

2
00:00:10,070 --> 00:00:06,560
appropriately so uh no one showed up in

3
00:00:12,470 --> 00:00:10,080
her an hour uh earlier late this is carl

4
00:00:15,190 --> 00:00:12,480
pilcher broadcasting to you here from

5
00:00:17,349 --> 00:00:15,200
the temporary video con room at the car

6
00:00:19,510 --> 00:00:17,359
talk plaza excuse me at the nasa astro

7
00:00:21,429 --> 00:00:19,520
biology institute

8
00:00:23,830 --> 00:00:21,439
um

9
00:00:26,550 --> 00:00:23,840
and i am really really pleased to be

10
00:00:28,390 --> 00:00:26,560
able to introduce ariel lanbar uh to

11
00:00:30,550 --> 00:00:28,400
present the second

12
00:00:32,950 --> 00:00:30,560
nai director seminar

13
00:00:35,350 --> 00:00:32,960

uh of the new series

14

00:00:37,590 --> 00:00:35,360

uh ariel has been a member of the nai

15

00:00:40,229 --> 00:00:37,600

and a good friend since uh the nai's

16

00:00:42,310 --> 00:00:40,239

earliest days he has done a great deal

17

00:00:44,310 --> 00:00:42,320

of service to the nai and the

18

00:00:46,790 --> 00:00:44,320

astrobiology community as a whole in

19

00:00:49,190 --> 00:00:46,800

addition to his great research and most

20

00:00:50,549 --> 00:00:49,200

recently that service has taken the form

21

00:00:53,189 --> 00:00:50,559

of ariel

22

00:00:56,630 --> 00:00:53,199

taking the hopefully not too thankless

23

00:00:58,310 --> 00:00:56,640

job of being the chair of the

24

00:01:00,389 --> 00:00:58,320

science steering committee for the next

25

00:01:03,189 --> 00:01:00,399

astrobiology science conference and he's

26

00:01:06,070 --> 00:01:03,199

been doing a fabulous job

27

00:01:08,070 --> 00:01:06,080

ariel's work focuses on stable isotope

28

00:01:09,830 --> 00:01:08,080

geochemistry of non-traditional

29

00:01:11,109 --> 00:01:09,840

geochemical systems like iron and

30

00:01:12,950 --> 00:01:11,119

molybdenum

31

00:01:14,550 --> 00:01:12,960

and what he works on is understanding

32

00:01:16,630 --> 00:01:14,560

how earths and how earth and its

33

00:01:18,310 --> 00:01:16,640

biosphere have evolved through time

34

00:01:21,190 --> 00:01:18,320

particularly in the archaean and

35

00:01:23,030 --> 00:01:21,200

proterozoic and a few years ago he and

36

00:01:25,109 --> 00:01:23,040

andy noel wrote a particularly

37

00:01:28,070 --> 00:01:25,119

influential article that was published

38

00:01:30,710 --> 00:01:28,080

in science that focused attention on how

39

00:01:32,390 --> 00:01:30,720

unusual uh the chemistry of earth

40

00:01:35,109 --> 00:01:32,400

particularly earth's oceans may have

41

00:01:37,190 --> 00:01:35,119

been during earth's middle age

42

00:01:39,429 --> 00:01:37,200

about a billion to two billion years ago

43

00:01:41,429 --> 00:01:39,439

and if you haven't read that article i

44

00:01:44,469 --> 00:01:41,439

recommend it to you

45

00:01:47,429 --> 00:01:44,479

ariel got his bachelor's from harvard

46

00:01:49,429 --> 00:01:47,439

college in 1989 in his phd

47

00:01:51,910 --> 00:01:49,439

in geological and planetary sciences

48

00:01:53,590 --> 00:01:51,920

from caltech in 1996.

49

00:01:56,789 --> 00:01:53,600

he was on the faculty of the university

50

00:01:59,510 --> 00:01:56,799

of rochester for about six years before

51

00:02:02,310 --> 00:01:59,520

joining arizona state university

52

00:02:04,069 --> 00:02:02,320

where he is speaking to us uh from today

53

00:02:07,350 --> 00:02:04,079

and he's going to tell us

54

00:02:09,749 --> 00:02:07,360

about something that occurred just at

55

00:02:12,550 --> 00:02:09,759

the interface between the arcane and the

56

00:02:15,589 --> 00:02:12,560

paleo proterozoic a whiff of oxygen

57

00:02:17,830 --> 00:02:15,599

before the great oxidation event and

58

00:02:19,830 --> 00:02:17,840

ariel take it away

59

00:02:21,910 --> 00:02:19,840

thanks very much carl um i appreciate

60

00:02:22,790 --> 00:02:21,920

the generous introduction after all that

61

00:02:24,470 --> 00:02:22,800

um

62

00:02:26,150 --> 00:02:24,480

although most of my work has focused on

63

00:02:27,270 --> 00:02:26,160

iron and molybdenum isotopes at least a

64

00:02:29,190 --> 00:02:27,280

great deal of it you're not going to see

65

00:02:30,630 --> 00:02:29,200

any of that in this talk here

66

00:02:32,309 --> 00:02:30,640

in fact it's going to be almost an

67

00:02:34,150 --> 00:02:32,319

isotope-free zone except for a little

68

00:02:36,309 --> 00:02:34,160

bit of sulfur isotopes

69

00:02:38,949 --> 00:02:36,319

that we simply can't resist putting in

70

00:02:40,390 --> 00:02:38,959

um i want to uh stress at the outset of

71

00:02:41,350 --> 00:02:40,400

this talk although i'm giving it and

72

00:02:43,509 --> 00:02:41,360

although i'm going to be featuring

73

00:02:45,750 --> 00:02:43,519

primarily research results uh generated

74

00:02:47,670 --> 00:02:45,760

by by my research group um this has been

75

00:02:49,750 --> 00:02:47,680

part of a larger collaborative project

76

00:02:51,190 --> 00:02:49,760

involving a number of institutions um

77

00:02:53,830 --> 00:02:51,200

university of washington university of

78

00:02:55,830 --> 00:02:53,840

maryland uh uc riverside

79

00:02:57,670 --> 00:02:55,840

university of alberta and also mit and

80

00:02:59,430 --> 00:02:57,680

harvard have had a role in this and the

81

00:03:00,710 --> 00:02:59,440

geological survey of western australia

82

00:03:02,630 --> 00:03:00,720

so this is truly a collaborative

83

00:03:04,790 --> 00:03:02,640

international collaborative project

84

00:03:05,830 --> 00:03:04,800

that i'm going to be uh discussing i'm

85

00:03:09,830 --> 00:03:05,840

going to be presenting essentially some

86

00:03:12,070 --> 00:03:09,840

of the first results from that project

87

00:03:15,110 --> 00:03:12,080

uh what this research is all about

88

00:03:16,949 --> 00:03:15,120

is trying to better understand the rise

89

00:03:19,190 --> 00:03:16,959

of oxygen through time in the earth's

90

00:03:21,430 --> 00:03:19,200

atmosphere so what i'm showing you here

91

00:03:22,869 --> 00:03:21,440

and my apologies for the delivery here

92

00:03:24,390 --> 00:03:22,879

it's very awkward giving a talk at a

93

00:03:26,550 --> 00:03:24,400

computer screen so hopefully this will

94

00:03:27,750 --> 00:03:26,560

come off reasonably well um hopefully

95

00:03:30,149 --> 00:03:27,760

you can all see the pointer here what's

96

00:03:31,589 --> 00:03:30,159

shown here is uh it's a cartoon from a

97

00:03:33,830 --> 00:03:31,599

scientific american article by jim

98

00:03:36,630 --> 00:03:33,840

casting a number of years ago

99

00:03:38,550 --> 00:03:36,640

showing uh a sort of a general consensus

100

00:03:39,750 --> 00:03:38,560

concept of change in oxygen in the

101
00:03:41,990 --> 00:03:39,760
environment through time in the

102
00:03:44,710 --> 00:03:42,000
atmosphere through time

103
00:03:46,229 --> 00:03:44,720
the figure is notably vague on the

104
00:03:47,830 --> 00:03:46,239
y-axis where there are no units

105
00:03:50,229 --> 00:03:47,840
whatsoever

106
00:03:52,390 --> 00:03:50,239
which is somewhat reflective actually

107
00:03:53,990 --> 00:03:52,400
of the state of knowledge about oxygen

108
00:03:55,670 --> 00:03:54,000
through time in the earth's environment

109
00:03:57,830 --> 00:03:55,680
we know that today we have about 21

110
00:03:58,630 --> 00:03:57,840
percent but as we go back in time

111
00:04:00,309 --> 00:03:58,640
there's

112
00:04:02,149 --> 00:04:00,319
plenty of room for controversy even

113
00:04:03,990 --> 00:04:02,159

amongst those of us who are pretty

114

00:04:05,350 --> 00:04:04,000

convinced that oxygen was very low

115

00:04:07,350 --> 00:04:05,360

during the first half of history just

116

00:04:09,190 --> 00:04:07,360

what is low mean does low mean anoxic

117

00:04:10,789 --> 00:04:09,200

does low mean slightly oxix

118

00:04:12,229 --> 00:04:10,799

there's a very good reason that we don't

119

00:04:13,509 --> 00:04:12,239

have units here

120

00:04:15,990 --> 00:04:13,519

what we're going to focus on here is

121

00:04:18,629 --> 00:04:16,000

this major initial transition from this

122

00:04:19,990 --> 00:04:18,639

world of uh very low oxygen running

123

00:04:21,590 --> 00:04:20,000

through the first half of earth history

124

00:04:23,990 --> 00:04:21,600

roughly and then there was a sharp

125

00:04:25,990 --> 00:04:24,000

change uh this is this this is unitless

126

00:04:28,629 --> 00:04:26,000

but it's essentially a log axis making

127

00:04:31,350 --> 00:04:28,639

this change look uh very dramatic it was

128

00:04:33,110 --> 00:04:31,360

actually um in in

129

00:04:34,790 --> 00:04:33,120

linear terms a relatively small change

130

00:04:36,310 --> 00:04:34,800

but it was a change from a world with

131

00:04:37,830 --> 00:04:36,320

very little oxygen to a world with some

132

00:04:39,590 --> 00:04:37,840

appreciable fraction of the modern

133

00:04:41,030 --> 00:04:39,600

amount we believe

134

00:04:42,950 --> 00:04:41,040

so this is often referred to as the

135

00:04:44,150 --> 00:04:42,960

great oxidation event so we want to

136

00:04:45,590 --> 00:04:44,160

understand more about this event and

137

00:04:47,110 --> 00:04:45,600

i'll go into some more details about

138

00:04:48,390 --> 00:04:47,120

what we want to understand as we move

139

00:04:49,990 --> 00:04:48,400

along but that's the context of this

140

00:04:51,189 --> 00:04:50,000

talk we're trying to understand issues

141

00:04:52,070 --> 00:04:51,199

associated with the great oxidation

142

00:04:54,070 --> 00:04:52,080

event

143

00:04:55,909 --> 00:04:54,080

now there's been a lot of recent

144

00:04:57,270 --> 00:04:55,919

evolution on the topic of oxygen

145

00:04:59,510 --> 00:04:57,280

evolution

146

00:05:00,870 --> 00:04:59,520

and i list here a series of papers

147

00:05:02,629 --> 00:05:00,880

that

148

00:05:04,629 --> 00:05:02,639

have come out in the past year and a

149

00:05:07,189 --> 00:05:04,639

half or so um

150

00:05:08,550 --> 00:05:07,199

2006 and 2007 a number of them quite

151
00:05:11,110 --> 00:05:08,560
prominent uh

152
00:05:12,629 --> 00:05:11,120
in nature um and this is by way of

153
00:05:13,990 --> 00:05:12,639
illustrating this is a very vibrant area

154
00:05:15,990 --> 00:05:14,000
of research with a good deal of

155
00:05:17,430 --> 00:05:16,000
controversy particularly if uh you're

156
00:05:19,029 --> 00:05:17,440
interested in going into more detail

157
00:05:21,110 --> 00:05:19,039
than you'll see in this talk these two

158
00:05:21,990 --> 00:05:21,120
papers here by omoto at all and farquaad

159
00:05:23,909 --> 00:05:22,000
all

160
00:05:27,189 --> 00:05:23,919
battle back and forth

161
00:05:28,550 --> 00:05:27,199
about the earliest oxygen record

162
00:05:30,550 --> 00:05:28,560
um

163
00:05:32,070 --> 00:05:30,560

arguing about what was the archaean

164

00:05:34,150 --> 00:05:32,080

anoxic or not and what does that really

165

00:05:35,990 --> 00:05:34,160

mean

166

00:05:38,790 --> 00:05:36,000

so this work follows on the heels of

167

00:05:40,390 --> 00:05:38,800

much of these studies and what i'm going

168

00:05:42,230 --> 00:05:40,400

to focus on are two additional papers

169

00:05:44,469 --> 00:05:42,240

that aren't on that list

170

00:05:46,710 --> 00:05:44,479

that were published at the end of

171

00:05:48,310 --> 00:05:46,720

september in science

172

00:05:49,430 --> 00:05:48,320

one is titled the same as this talk a

173

00:05:51,110 --> 00:05:49,440

whiff of oxygen before the great

174

00:05:53,270 --> 00:05:51,120

oxidation event and the other a

175

00:05:55,270 --> 00:05:53,280

companion paper uh late arcane

176
00:05:58,310 --> 00:05:55,280
biospheric oxygenation and atmospheric

177
00:05:59,510 --> 00:05:58,320
evolution but led by jake kaufman uh and

178
00:06:00,550 --> 00:05:59,520
his colleagues at the university of

179
00:06:03,350 --> 00:06:00,560
maryland

180
00:06:04,790 --> 00:06:03,360
both of these studies uh uh

181
00:06:06,950 --> 00:06:04,800
the reason they're paired together is

182
00:06:09,430 --> 00:06:06,960
because they tell a complimentary story

183
00:06:11,350 --> 00:06:09,440
about a change in environmental

184
00:06:13,830 --> 00:06:11,360
oxygenation just before the great

185
00:06:14,870 --> 00:06:13,840
oxidation event

186
00:06:15,990 --> 00:06:14,880
and

187
00:06:18,150 --> 00:06:16,000
it's particularly appropriate to be

188
00:06:19,510 --> 00:06:18,160

talking about this at an nai director's

189

00:06:21,350 --> 00:06:19,520

seminar because

190

00:06:23,430 --> 00:06:21,360

this work is the outcome of the nasa

191

00:06:25,270 --> 00:06:23,440

astrobiology drilling program

192

00:06:27,510 --> 00:06:25,280

um some of you may not be aware that

193

00:06:30,469 --> 00:06:27,520

nasa has and the ass astrology institute

194

00:06:31,430 --> 00:06:30,479

has a drilling program but it does

195

00:06:32,150 --> 00:06:31,440

and

196

00:06:35,189 --> 00:06:32,160

the

197

00:06:37,189 --> 00:06:35,199

drilling rig that we're working with and

198

00:06:39,110 --> 00:06:37,199

the sort of uh samples that we are

199

00:06:42,710 --> 00:06:39,120

obtaining from this drilling program and

200

00:06:45,909 --> 00:06:42,720

this program over the in 2003 and 2004

201
00:06:48,309 --> 00:06:45,919
um generated uh 10 drill cores from

202
00:06:50,230 --> 00:06:48,319
western australia all focusing on the

203
00:06:52,230 --> 00:06:50,240
period of time before the rise of oxygen

204
00:06:53,590 --> 00:06:52,240
and various periods of various spans of

205
00:06:54,710 --> 00:06:53,600
time before that

206
00:06:56,469 --> 00:06:54,720
trying to get at various questions

207
00:06:58,150 --> 00:06:56,479
associated with that first great

208
00:06:59,270 --> 00:06:58,160
oxidation event

209
00:07:01,510 --> 00:06:59,280
the two papers i'm going to be

210
00:07:04,390 --> 00:07:01,520
discussing here in particular the i'm

211
00:07:06,230 --> 00:07:04,400
focusing on the whiff of oxygen paper um

212
00:07:08,309 --> 00:07:06,240
uh both are the represent the first

213
00:07:10,390 --> 00:07:08,319

results from the long core the one

214

00:07:13,029 --> 00:07:10,400

kilometer deep core that was drilled in

215

00:07:14,550 --> 00:07:13,039

2004 in the hammersley basin so the 10

216

00:07:16,469 --> 00:07:14,560

cores one of them in particular is what

217

00:07:17,830 --> 00:07:16,479

we're highlighting here in this study

218

00:07:20,070 --> 00:07:17,840

now

219

00:07:21,990 --> 00:07:20,080

by way of context you might ask well why

220

00:07:23,749 --> 00:07:22,000

is the nasa astrobiology institute in

221

00:07:26,469 --> 00:07:23,759

nasa more generally interested in

222

00:07:27,990 --> 00:07:26,479

drilling old rocks in western australia

223

00:07:29,430 --> 00:07:28,000

and why really there's interest in this

224

00:07:31,110 --> 00:07:29,440

oxygen question and for many of you this

225

00:07:32,790 --> 00:07:31,120

is this is obvious but for some this may

226

00:07:35,110 --> 00:07:32,800

not be especially for students so it's

227

00:07:36,629 --> 00:07:35,120

worth belaboring for just a moment so

228

00:07:38,629 --> 00:07:36,639

what you're seeing here is a cartoon of

229

00:07:41,990 --> 00:07:38,639

an extrasolar planet one of these hot

230

00:07:43,189 --> 00:07:42,000

jupiters these giant uh planets um

231

00:07:45,670 --> 00:07:43,199

close to their stars which are being

232

00:07:46,710 --> 00:07:45,680

discovered with regularity these days

233

00:07:48,390 --> 00:07:46,720

um

234

00:07:50,870 --> 00:07:48,400

amazingly we can actually sit here and

235

00:07:52,390 --> 00:07:50,880

say that uh to imagine a world like this

236

00:07:54,550 --> 00:07:52,400

is no longer an extraordinary thing

237

00:07:56,230 --> 00:07:54,560

because we know of many of them what is

238

00:07:58,230 --> 00:07:56,240

still extraordinary is this data here

239

00:08:00,309 --> 00:07:58,240

this is from a paper in nature this past

240

00:08:01,350 --> 00:08:00,319

year showing what i believe are the

241

00:08:03,029 --> 00:08:01,360

first

242

00:08:05,670 --> 00:08:03,039

uh spectroscopic data from the

243

00:08:07,909 --> 00:08:05,680

atmosphere of such an extrasolar planet

244

00:08:10,950 --> 00:08:07,919

and although these planets are very very

245

00:08:13,189 --> 00:08:10,960

unlikely to be hospitable to life

246

00:08:15,909 --> 00:08:13,199

this sort of data spectroscopic data

247

00:08:18,469 --> 00:08:15,919

from the atmospheres of uh extrasolar

248

00:08:20,629 --> 00:08:18,479

planets are likely in the next couple of

249

00:08:22,070 --> 00:08:20,639

decades to be obtained from planets that

250

00:08:23,670 --> 00:08:22,080

are much more like earth and hence

251
00:08:25,670 --> 00:08:23,680
planets that are more likely to support

252
00:08:26,790 --> 00:08:25,680
life and so the question before us is

253
00:08:29,029 --> 00:08:26,800
how would we go about looking for

254
00:08:30,790 --> 00:08:29,039
evidence of life on such planets what

255
00:08:33,589 --> 00:08:30,800
would what would constitute a planetary

256
00:08:36,310 --> 00:08:33,599
biosignature on an exoplanet and such a

257
00:08:38,230 --> 00:08:36,320
biosignature would be uh uh reflect

258
00:08:39,430 --> 00:08:38,240
would be something we can measure in the

259
00:08:41,750 --> 00:08:39,440
spectrum of the atmosphere of that

260
00:08:43,269 --> 00:08:41,760
planet that's the most uh

261
00:08:44,389 --> 00:08:43,279
first thing we're going to be able to do

262
00:08:46,630 --> 00:08:44,399
we hope

263
00:08:47,829 --> 00:08:46,640

and um oxygen features very prominently

264

00:08:50,870 --> 00:08:47,839

in that sort of discussion so what

265

00:08:55,509 --> 00:08:50,880

you're seeing here are uh a spectra in

266

00:08:57,350 --> 00:08:55,519

the infrared of venus earth and mars

267

00:08:58,630 --> 00:08:57,360

showing you uh the two things should

268

00:09:01,750 --> 00:08:58,640

jump out at you here from this figure

269

00:09:03,990 --> 00:09:01,760

one is that all these atmospheres show a

270

00:09:06,470 --> 00:09:04,000

pronounced carbon dioxide

271

00:09:07,750 --> 00:09:06,480

uh band which is which is a result of

272

00:09:09,910 --> 00:09:07,760

the fact that all these atmospheres have

273

00:09:11,509 --> 00:09:09,920

significant amounts of carbon dioxide

274

00:09:12,790 --> 00:09:11,519

but only earth shows that it shows this

275

00:09:14,949 --> 00:09:12,800

ozone feature

276

00:09:17,269 --> 00:09:14,959

an ozone is a byproduct of the

277

00:09:19,829 --> 00:09:17,279

photolysis of oxygen in a planetary

278

00:09:21,750 --> 00:09:19,839

atmosphere and to have ozone in amounts

279

00:09:23,990 --> 00:09:21,760

that you can detect like this from space

280

00:09:26,630 --> 00:09:24,000

is a reflection of the presence of large

281

00:09:29,030 --> 00:09:26,640

amounts of oxygen in

282

00:09:31,190 --> 00:09:29,040

the atmosphere of a planet and

283

00:09:32,870 --> 00:09:31,200

uh commonly it's it's believed and i'm

284

00:09:34,470 --> 00:09:32,880

not going to dispute this at all that if

285

00:09:36,389 --> 00:09:34,480

you have such large amounts of oxygen in

286

00:09:39,269 --> 00:09:36,399

the atmosphere of a planet you are

287

00:09:43,030 --> 00:09:39,279

seeing evidence of life on that planet

288

00:09:45,590 --> 00:09:43,040

and so as a result it if we want to uh

289

00:09:47,910 --> 00:09:45,600

uh develop such a concept of how we

290

00:09:50,710 --> 00:09:47,920

might look for life in uh

291

00:09:52,550 --> 00:09:50,720

beyond our solar system it behooves us

292

00:09:53,910 --> 00:09:52,560

to try to understand what controls the

293

00:09:56,389 --> 00:09:53,920

amount of oxygen in a planetary

294

00:09:58,230 --> 00:09:56,399

atmosphere if a planet has oxygenic

295

00:10:00,150 --> 00:09:58,240

photosynthesis will it

296

00:10:02,870 --> 00:10:00,160

will it inevitably evolve an oxygenated

297

00:10:04,550 --> 00:10:02,880

atmosphere that's a good question

298

00:10:06,470 --> 00:10:04,560

if um

299

00:10:08,310 --> 00:10:06,480

we look at lots of planets and don't see

300

00:10:09,110 --> 00:10:08,320

any oxygen what does that tell us about

301

00:10:10,870 --> 00:10:09,120

life

302

00:10:12,550 --> 00:10:10,880

um what are the odds that the planet

303

00:10:14,630 --> 00:10:12,560

that has oxygenic photosynthesis will

304

00:10:15,910 --> 00:10:14,640

evolve a 20 oxygen atmosphere like the

305

00:10:17,990 --> 00:10:15,920

earth these are all questions we don't

306

00:10:19,269 --> 00:10:18,000

really have answers to and if we want to

307

00:10:21,430 --> 00:10:19,279

understand them

308

00:10:23,670 --> 00:10:21,440

what we need to do is study the earth's

309

00:10:25,430 --> 00:10:23,680

past um given that this is the only

310

00:10:26,710 --> 00:10:25,440

planet that we really the only living

311

00:10:28,710 --> 00:10:26,720

planet that we really have to work with

312

00:10:29,910 --> 00:10:28,720

so uh this is what this is our natural

313

00:10:31,030 --> 00:10:29,920

laboratory

314

00:10:33,829 --> 00:10:31,040

so the question that we're going to

315

00:10:36,870 --> 00:10:33,839

focus on here is why why is there this

316

00:10:38,230 --> 00:10:36,880

rise of oxygen uh about 2.3 billion

317

00:10:40,310 --> 00:10:38,240

years ago

318

00:10:41,509 --> 00:10:40,320

in earth history

319

00:10:43,030 --> 00:10:41,519

we're not going to resolve that question

320

00:10:44,590 --> 00:10:43,040

but we're going to point the way towards

321

00:10:47,110 --> 00:10:44,600

the resolution

322

00:10:49,750 --> 00:10:47,120

hopefully so the simplest answer to that

323

00:10:51,509 --> 00:10:49,760

question that you might uh imagine

324

00:10:53,829 --> 00:10:51,519

is a biological explanation an

325

00:10:57,430 --> 00:10:53,839

evolutionary explanation if oxygenic

326

00:10:58,630 --> 00:10:57,440

photosynthesis is required uh to

327

00:11:01,269 --> 00:10:58,640

have large amounts of oxygen in the

328

00:11:03,269 --> 00:11:01,279

atmosphere then perhaps at 2.3 billion

329

00:11:05,670 --> 00:11:03,279

years ago or two point just a bit before

330

00:11:07,829 --> 00:11:05,680

that 2.4 billion years ago perhaps then

331

00:11:09,110 --> 00:11:07,839

that is the time when photosystem 2

332

00:11:11,509 --> 00:11:09,120

evolves and here's a picture of the

333

00:11:14,310 --> 00:11:11,519

oxygen evolving center of photosystem ii

334

00:11:16,150 --> 00:11:14,320

um and so perhaps this uh biochemistry

335

00:11:17,430 --> 00:11:16,160

evolves that point and rapidly proceeds

336

00:11:19,430 --> 00:11:17,440

to take over the world and make the

337

00:11:20,389 --> 00:11:19,440

planet an oxygenated and oxygenated

338

00:11:21,750 --> 00:11:20,399

world

339

00:11:23,829 --> 00:11:21,760

that is a view that you will certainly

340

00:11:26,310 --> 00:11:23,839

find in many textbooks it's a view that

341

00:11:29,350 --> 00:11:26,320

is strongly espoused by researchers like

342

00:11:31,350 --> 00:11:29,360

joe kershwin uh today um at least as of

343

00:11:32,790 --> 00:11:31,360

last week when i saw him at gsa

344

00:11:36,550 --> 00:11:32,800

um

345

00:11:38,150 --> 00:11:36,560

you can advance and it's and it's a

346

00:11:39,990 --> 00:11:38,160

reasonable hypothesis it's in fact a

347

00:11:41,509 --> 00:11:40,000

very difficult hypothesis to refute

348

00:11:43,750 --> 00:11:41,519

without going into the geologic record

349

00:11:44,949 --> 00:11:43,760

as we're going to try to do

350

00:11:46,310 --> 00:11:44,959

um

351
00:11:48,150 --> 00:11:46,320
most of the community though thinks it's

352
00:11:50,150 --> 00:11:48,160
probably not so simple

353
00:11:52,470 --> 00:11:50,160
and the reason for that is as follows i

354
00:11:56,069 --> 00:11:52,480
want to give you get across for you a at

355
00:11:57,590 --> 00:11:56,079
least a cartoon idea of why uh it's

356
00:12:00,150 --> 00:11:57,600
probably not as simple as just oxygen

357
00:12:02,550 --> 00:12:00,160
photosynthesis evolves and uh the planet

358
00:12:03,829 --> 00:12:02,560
becomes oxygenated

359
00:12:05,910 --> 00:12:03,839
so we're going to start just by thinking

360
00:12:08,629 --> 00:12:05,920
very simply the way a geochemist does

361
00:12:10,310 --> 00:12:08,639
about oxygenic photosynthesis what is it

362
00:12:11,670 --> 00:12:10,320
so uh if there are any biologists in the

363
00:12:13,269 --> 00:12:11,680

audience you'll be horrified by this but

364

00:12:14,710 --> 00:12:13,279

the way a geochemist thinks about oxygen

365

00:12:16,230 --> 00:12:14,720

with photosynthesis is that one takes

366

00:12:19,269 --> 00:12:16,240

co₂ and water

367

00:12:22,470 --> 00:12:19,279

and reacts them together and makes o₂

368

00:12:24,069 --> 00:12:22,480

and um here even if you're not a a

369

00:12:25,350 --> 00:12:24,079

life scientist this is just horrifying

370

00:12:27,110 --> 00:12:25,360

if you're an organic geochemist it's a

371

00:12:28,870 --> 00:12:27,120

horrifying thing to say that all organic

372

00:12:30,710 --> 00:12:28,880

carbon is ch₂o

373

00:12:33,110 --> 00:12:30,720

that's of course a gross simplification

374

00:12:34,710 --> 00:12:33,120

but to um

375

00:12:36,230 --> 00:12:34,720

to a first approximation if we're just

376

00:12:38,150 --> 00:12:36,240

thinking stoichiometrically of the ratio

377

00:12:41,190 --> 00:12:38,160

of carbon to hydrogen to oxygen this is

378

00:12:43,269 --> 00:12:41,200

the product of photosynthesis O_2 and

379

00:12:46,710 --> 00:12:43,279

quote unquote organic carbon

380

00:12:51,030 --> 00:12:46,720

in the stoichiometry CH_2O

381

00:12:54,710 --> 00:12:52,790

but there's also of course a back

382

00:12:56,629 --> 00:12:54,720

reaction which is very fortunate um it's

383

00:12:58,870 --> 00:12:56,639

what is allowing all of us to sit in our

384

00:13:01,750 --> 00:12:58,880

various rooms across the country and and

385

00:13:04,550 --> 00:13:01,760

watch this this uh uh seminar for better

386

00:13:06,470 --> 00:13:04,560

or worse um it's aerobic respiration the

387

00:13:08,310 --> 00:13:06,480

back reaction of O_2 with organic carbon

388

00:13:09,910 --> 00:13:08,320

to give you back co2 and water we are

389

00:13:11,509 --> 00:13:09,920

all all of us sitting in the room in the

390

00:13:12,870 --> 00:13:11,519

room in our rooms are doing this right

391

00:13:14,470 --> 00:13:12,880

now

392

00:13:16,069 --> 00:13:14,480

and this is a very efficient process

393

00:13:17,750 --> 00:13:16,079

such that almost all the oxygen that's

394

00:13:19,509 --> 00:13:17,760

produced per year in the biosphere is

395

00:13:22,069 --> 00:13:19,519

reconsumed by oxidation with organic

396

00:13:23,990 --> 00:13:22,079

carbon to give you back co2 and water

397

00:13:25,670 --> 00:13:24,000

so in a sense this is

398

00:13:27,190 --> 00:13:25,680

although obviously this is important

399

00:13:28,870 --> 00:13:27,200

because it's producing lots of oxygen

400

00:13:31,030 --> 00:13:28,880

this is this is very rapidly all

401
00:13:32,790 --> 00:13:31,040
consumed so it's not so simple on a

402
00:13:34,310 --> 00:13:32,800
geologic time scale it's not so simple

403
00:13:36,150 --> 00:13:34,320
to just look at oxygen photosynthesis

404
00:13:38,710 --> 00:13:36,160
and say aha if we have it then we have

405
00:13:40,550 --> 00:13:38,720
lots of oxygen in the atmosphere

406
00:13:43,990 --> 00:13:40,560
to it

407
00:13:48,470 --> 00:13:46,069
to a geochemist thinking about this

408
00:13:49,750 --> 00:13:48,480
requires thinking outside this fast box

409
00:13:51,670 --> 00:13:49,760
a little bit

410
00:13:52,629 --> 00:13:51,680
to the geochemist what uh needs to be

411
00:13:53,750 --> 00:13:52,639
considered

412
00:13:55,350 --> 00:13:53,760
is that

413
00:13:57,590 --> 00:13:55,360

on geologically relevant time scales

414

00:14:00,150 --> 00:13:57,600

there's a slow leakage out of this loop

415

00:14:01,750 --> 00:14:00,160

in the form of organic carbon being

416

00:14:03,110 --> 00:14:01,760

buried in sediments

417

00:14:04,470 --> 00:14:03,120

actually most of the organic carbon that

418

00:14:05,910 --> 00:14:04,480

makes it uh

419

00:14:07,670 --> 00:14:05,920

to be buried in sediments also gets

420

00:14:09,910 --> 00:14:07,680

re-oxidized by processes happening in

421

00:14:11,670 --> 00:14:09,920

sediments but a small fraction of that

422

00:14:13,350 --> 00:14:11,680

actually gets buried it's sequestered

423

00:14:15,189 --> 00:14:13,360

for geologically relevant periods of

424

00:14:17,750 --> 00:14:15,199

time um

425

00:14:19,350 --> 00:14:17,760

uh in in sediments particularly in the

426

00:14:21,189 --> 00:14:19,360

deep ocean

427

00:14:22,790 --> 00:14:21,199

um a consequence of this is that for

428

00:14:24,949 --> 00:14:22,800

every mole of organic carbon that one

429

00:14:27,509 --> 00:14:24,959

varies in sediments there is a mole of

430

00:14:29,590 --> 00:14:27,519

oxygen left behind in the atmosphere

431

00:14:31,430 --> 00:14:29,600

and to a geochemist thinking in long

432

00:14:33,509 --> 00:14:31,440

time scales this is the geologically

433

00:14:35,269 --> 00:14:33,519

relevant source quote unquote of oxygen

434

00:14:36,470 --> 00:14:35,279

to the atmosphere you need to have this

435

00:14:38,230 --> 00:14:36,480

going on in here you need to have the

436

00:14:40,310 --> 00:14:38,240

oxygen footage the synthesis to produce

437

00:14:41,670 --> 00:14:40,320

the oxygen but without some process like

438

00:14:43,750 --> 00:14:41,680

this bearing organic carbon you're not

439

00:14:46,230 --> 00:14:43,760

going to have build up of of oxygen in

440

00:14:47,590 --> 00:14:46,240

the atmosphere over time scales that are

441

00:14:49,509 --> 00:14:47,600

relevant to us when we think in terms of

442

00:14:52,710 --> 00:14:49,519

hundreds of millions of years

443

00:14:54,389 --> 00:14:52,720

of course that this is all a cycle and

444

00:14:57,269 --> 00:14:54,399

so there is a back reaction of that

445

00:14:59,030 --> 00:14:57,279

oxygen with reduced gases from volcanoes

446

00:15:01,189 --> 00:14:59,040

with dissolved reductance in seawater

447

00:15:03,509 --> 00:15:01,199

with reduced compounds iron ii plus and

448

00:15:05,269 --> 00:15:03,519

other materials in igneous rocks and and

449

00:15:08,069 --> 00:15:05,279

sediments when these when these buried

450

00:15:10,150 --> 00:15:08,079

organic sediments um uh are exhumed

451

00:15:11,670 --> 00:15:10,160

which in some cases they are

452

00:15:13,590 --> 00:15:11,680

you have then the opportunity for those

453

00:15:15,269 --> 00:15:13,600

sediments to re-react with oxygen but

454

00:15:16,710 --> 00:15:15,279

all these processes happen slowly there

455

00:15:19,590 --> 00:15:16,720

are they operate on geological time

456

00:15:21,590 --> 00:15:19,600

scales but to a geoscientist then the

457

00:15:23,750 --> 00:15:21,600

the rise of oxygen and the controls on

458

00:15:25,269 --> 00:15:23,760

oxygen are in part about oxygen

459

00:15:27,829 --> 00:15:25,279

photosynthesis but they're just as much

460

00:15:29,430 --> 00:15:27,839

about the balance between this flux

461

00:15:31,910 --> 00:15:29,440

which is really about this flux down

462

00:15:34,470 --> 00:15:31,920

here versus the rate of consumption of

463

00:15:36,470 --> 00:15:34,480

oxygen by reductance that that become

464

00:15:38,550 --> 00:15:36,480

exposed on geologically meaningful time

465

00:15:40,870 --> 00:15:38,560

scales so it's this balance that becomes

466

00:15:42,870 --> 00:15:40,880

very important if you are a

467

00:15:45,509 --> 00:15:42,880

geoscientist and one way you can think

468

00:15:47,509 --> 00:15:45,519

about this um i apologize for the typo

469

00:15:48,790 --> 00:15:47,519

up here there shouldn't be a b up there

470

00:15:50,550 --> 00:15:48,800

is you could sort of divide these two

471

00:15:53,030 --> 00:15:50,560

views into a supply side view and a

472

00:15:54,870 --> 00:15:53,040

demand side view so the supply side view

473

00:15:57,030 --> 00:15:54,880

is that oxygenic photosynthesis evolves

474

00:15:59,350 --> 00:15:57,040

at 2.4 or 2.3 billion years ago and

475

00:16:00,870 --> 00:15:59,360

rapidly takes over the planet

476

00:16:02,310 --> 00:16:00,880

the demand side view is that oxygen

477

00:16:04,389 --> 00:16:02,320

photosynthesis

478

00:16:06,310 --> 00:16:04,399

has to evolve by that time but may have

479

00:16:08,470 --> 00:16:06,320

evolved much much earlier and that

480

00:16:10,230 --> 00:16:08,480

oxygen takes over only when the oxic

481

00:16:12,470 --> 00:16:10,240

sources this production of oxygen the

482

00:16:13,910 --> 00:16:12,480

net production of oxygen overwhelms the

483

00:16:15,749 --> 00:16:13,920

reducing sinks

484

00:16:19,030 --> 00:16:15,759

which may be as much because of a change

485

00:16:22,069 --> 00:16:19,040

in the reflux of reductance μ m as it may

486

00:16:23,269 --> 00:16:22,079

be because of a rise in oxygen

487

00:16:25,189 --> 00:16:23,279

production

488

00:16:26,949 --> 00:16:25,199

so this is a more complicated picture

489

00:16:29,509 --> 00:16:26,959

and in particular from an evolutionary

490

00:16:31,269 --> 00:16:29,519

standpoint this demand side picture uh

491

00:16:33,269 --> 00:16:31,279

allows for the possibility that oxygenic

492

00:16:34,949 --> 00:16:33,279

photosynthesis is extremely ancient it

493

00:16:37,030 --> 00:16:34,959

could you know hypothetically could date

494

00:16:37,829 --> 00:16:37,040

back to very shortly after the origin of

495

00:16:40,710 --> 00:16:37,839

life

496

00:16:42,870 --> 00:16:40,720

which could be 3.8 billion years ago

497

00:16:44,389 --> 00:16:42,880

so these are very these two views have

498

00:16:47,110 --> 00:16:44,399

very different consequences for how

499

00:16:48,389 --> 00:16:47,120

early oxygen photosynthesis might exist

500

00:16:50,230 --> 00:16:48,399

as i said before it's very hard to

501
00:16:51,430 --> 00:16:50,240
differentiate between these hypotheses

502
00:16:52,870 --> 00:16:51,440
but one of the simplest ways you can

503
00:16:55,030 --> 00:16:52,880
think of to differentiate between them

504
00:16:57,430 --> 00:16:55,040
is to search for evidence of oxygen in

505
00:16:59,030 --> 00:16:57,440
the record before 2.4 or 2.3 billion

506
00:17:01,269 --> 00:16:59,040
years ago before the great rise of

507
00:17:04,069 --> 00:17:01,279
oxygen if you find evidence of oxygen in

508
00:17:05,510 --> 00:17:04,079
that earlier record then you have a if

509
00:17:07,590 --> 00:17:05,520
at least if it's in amounts that are

510
00:17:09,750 --> 00:17:07,600
larger than what can easily be made by

511
00:17:10,870 --> 00:17:09,760
non-biological processes then you have

512
00:17:14,309 --> 00:17:10,880
an argument

513
00:17:16,069 --> 00:17:14,319

for this demand side point of view

514

00:17:18,150 --> 00:17:16,079

now of course there have been many uh

515

00:17:19,350 --> 00:17:18,160

studies over the years that have

516

00:17:21,590 --> 00:17:19,360

provided data that people have

517

00:17:24,309 --> 00:17:21,600

interpreted in terms as indicating

518

00:17:25,750 --> 00:17:24,319

evidence of oxygen uh in the fir during

519

00:17:27,350 --> 00:17:25,760

the first half of earth history at least

520

00:17:29,830 --> 00:17:27,360

in in some amounts

521

00:17:31,190 --> 00:17:29,840

um so the most classic ex

522

00:17:32,789 --> 00:17:31,200

line of evidence that you'll find is the

523

00:17:34,710 --> 00:17:32,799

presence of banded iron formations in

524

00:17:36,070 --> 00:17:34,720

the archaean and paleo-protzoa but

525

00:17:37,990 --> 00:17:36,080

particularly here in the archaean

526

00:17:40,150 --> 00:17:38,000

geological record so abandon iron

527

00:17:41,750 --> 00:17:40,160

formations are these massive deposits of

528

00:17:43,110 --> 00:17:41,760

iron oxide

529

00:17:44,630 --> 00:17:43,120

another line of evidence that has become

530

00:17:45,430 --> 00:17:44,640

very much in vogue in the last decade or

531

00:17:48,230 --> 00:17:45,440

so

532

00:17:49,990 --> 00:17:48,240

are particularly organic biomarkers

533

00:17:52,630 --> 00:17:50,000

that for example those biomarkers that

534

00:17:54,549 --> 00:17:52,640

are indicative of the

535

00:17:56,230 --> 00:17:54,559

argued by many people and i think agreed

536

00:17:58,630 --> 00:17:56,240

to by most to be indicative of the

537

00:18:01,430 --> 00:17:58,640

presence of eukaryotes which require

538

00:18:02,870 --> 00:18:01,440

oxygen for some of their biochemistry

539

00:18:04,310 --> 00:18:02,880

in the early record

540

00:18:06,870 --> 00:18:04,320

the trouble with these and these are

541

00:18:08,230 --> 00:18:06,880

both fine lines of of evidence

542

00:18:10,390 --> 00:18:08,240

and i'm not trying to argue against any

543

00:18:12,150 --> 00:18:10,400

of them is that they have they have

544

00:18:13,750 --> 00:18:12,160

they're controversial so in the case of

545

00:18:15,350 --> 00:18:13,760

organic biomarkers as i just said while

546

00:18:17,190 --> 00:18:15,360

most of the community i think accepts

547

00:18:19,510 --> 00:18:17,200

the validity of the of the data that's

548

00:18:21,190 --> 00:18:19,520

been produced to date um there is great

549

00:18:22,870 --> 00:18:21,200

concern including by some of the authors

550

00:18:24,630 --> 00:18:22,880

of some of the most notable studies

551

00:18:26,710 --> 00:18:24,640

about the possibility of contamination

552

00:18:28,870 --> 00:18:26,720

of ancient sediments um from which some

553

00:18:31,669 --> 00:18:28,880

of these spectacular molecules have been

554

00:18:33,510 --> 00:18:31,679

extracted um so although this is this is

555

00:18:36,549 --> 00:18:33,520

a great line of evidence it's not

556

00:18:38,070 --> 00:18:36,559

without its its criticisms and flaws um

557

00:18:39,990 --> 00:18:38,080

or at least challenges and so you'd like

558

00:18:42,549 --> 00:18:40,000

to have other lines of evidence banded

559

00:18:44,470 --> 00:18:42,559

our information similarly uh you can

560

00:18:46,310 --> 00:18:44,480

produce banana formations of course by

561

00:18:48,390 --> 00:18:46,320

taking iron two plus in the oceans and

562

00:18:50,549 --> 00:18:48,400

oxidizing it with o2 to make iron three

563

00:18:53,430 --> 00:18:50,559

plus which precipitates out to make iron

564

00:18:54,950 --> 00:18:53,440

hydroxides so they you can take these as

565

00:18:56,310 --> 00:18:54,960

evidence of oxygen but there are at

566

00:18:59,270 --> 00:18:56,320

least two other mechanisms which have

567

00:19:01,430 --> 00:18:59,280

not been uh refuted despite some efforts

568

00:19:02,630 --> 00:19:01,440

to do so um some experimental efforts to

569

00:19:05,029 --> 00:19:02,640

do so

570

00:19:06,710 --> 00:19:05,039

which can alternatively produce

571

00:19:08,549 --> 00:19:06,720

massive deposit of iron oxide without

572

00:19:11,110 --> 00:19:08,559

having oxygen around one of these

573

00:19:12,870 --> 00:19:11,120

methods is by photo oxidation so

574

00:19:15,029 --> 00:19:12,880

ultraviolet light can react with iron

575

00:19:16,390 --> 00:19:15,039

two plus to form iron three plus and

576

00:19:18,310 --> 00:19:16,400

laboratory experiments show that that's

577

00:19:21,029 --> 00:19:18,320

rapid enough that it can account for at

578

00:19:22,549 --> 00:19:21,039

least some banded iron formations um and

579

00:19:25,190 --> 00:19:22,559

more in vogue in recent years is the

580

00:19:27,270 --> 00:19:25,200

notion of an oxygenic photosynthesis

581

00:19:29,029 --> 00:19:27,280

photosynthesis by bacteria that that

582

00:19:31,190 --> 00:19:29,039

instead of using water as an electron

583

00:19:33,350 --> 00:19:31,200

donor use iron two plus as an electron

584

00:19:36,230 --> 00:19:33,360

donor and such bacteria instead of

585

00:19:38,390 --> 00:19:36,240

producing oxygen produce iron three plus

586

00:19:42,310 --> 00:19:38,400

as the oxidized waste product

587

00:19:44,630 --> 00:19:42,320

and such bacteria were were a concept uh

588

00:19:46,150 --> 00:19:44,640

uh when i was first studying about this

589

00:19:47,830 --> 00:19:46,160

20 years ago or so

590

00:19:49,909 --> 00:19:47,840

um but in the last decade they've been

591

00:19:52,390 --> 00:19:49,919

discovered to actually exist and they

592

00:19:54,950 --> 00:19:52,400

oxidize iron at a rate fast enough to

593

00:19:56,630 --> 00:19:54,960

also account for banded iron formations

594

00:19:58,150 --> 00:19:56,640

so although both these lines of evidence

595

00:19:59,669 --> 00:19:58,160

are quite reasonable neither of them

596

00:20:01,510 --> 00:19:59,679

is incontrovertible so you'd like to

597

00:20:03,350 --> 00:20:01,520

have additional lines of evidence to

598

00:20:06,470 --> 00:20:03,360

work with and this is typically the case

599

00:20:08,870 --> 00:20:06,480

when you study earth history that uh you

600

00:20:10,390 --> 00:20:08,880

are in a deductive mode of reasoning and

601
00:20:11,270 --> 00:20:10,400
you know you rarely find a smoking

602
00:20:16,230 --> 00:20:11,280
bullet

603
00:20:17,909 --> 00:20:16,240
smoking gun

604
00:20:20,070 --> 00:20:17,919
and you're left trying to accumulate

605
00:20:21,270 --> 00:20:20,080
lines of evidence and hope that if you

606
00:20:22,390 --> 00:20:21,280
find multiple lines of evidence that

607
00:20:23,830 --> 00:20:22,400
point in the same direction that the

608
00:20:26,870 --> 00:20:23,840
cumulative weight of those lines even

609
00:20:28,230 --> 00:20:26,880
though none is perfectly solid is um

610
00:20:30,470 --> 00:20:28,240
convincing to

611
00:20:32,470 --> 00:20:30,480
what one hopes is two sigma confidence

612
00:20:34,870 --> 00:20:32,480
so what we're going to talk about today

613
00:20:37,270 --> 00:20:34,880

is uh the use of redox sensitive

614

00:20:39,430 --> 00:20:37,280

transition metals as a tool to look at

615

00:20:40,950 --> 00:20:39,440

changes in oxygenation through time and

616

00:20:42,310 --> 00:20:40,960

this is not a new idea i learned about

617

00:20:45,029 --> 00:20:42,320

it uh from a book that dick holland

618

00:20:47,110 --> 00:20:45,039

wrote in 1984 and i don't know that the

619

00:20:48,789 --> 00:20:47,120

idea even was unique to dick at that

620

00:20:50,230 --> 00:20:48,799

time so this is an old idea but it

621

00:20:51,750 --> 00:20:50,240

hasn't really been applied all that much

622

00:20:53,590 --> 00:20:51,760

and not at the level of detail and

623

00:20:55,350 --> 00:20:53,600

systematic investigation that we've been

624

00:20:56,789 --> 00:20:55,360

able to do with this astrobiology drill

625

00:20:58,390 --> 00:20:56,799

core

626

00:21:00,630 --> 00:20:58,400

um this figure is meant to get across

627

00:21:02,470 --> 00:21:00,640

the basic concept though so why why what

628

00:21:04,950 --> 00:21:02,480

elements we're focusing on we're going

629

00:21:06,549 --> 00:21:04,960

to focus a lot on the element molybdenum

630

00:21:08,149 --> 00:21:06,559

which i don't pick just because it's a

631

00:21:11,270 --> 00:21:08,159

little bit of a tongue twister

632

00:21:12,789 --> 00:21:11,280

i also don't pick it because uh

633

00:21:14,549 --> 00:21:12,799

the joke i like to tell is that for

634

00:21:15,750 --> 00:21:14,559

those of you who are douglas adams fans

635

00:21:17,669 --> 00:21:15,760

if you've read the hitchhiker's guide to

636

00:21:18,950 --> 00:21:17,679

the galaxy um you know that the answer

637

00:21:20,230 --> 00:21:18,960

to life the universe and everything is

638

00:21:22,549 --> 00:21:20,240

42

639

00:21:24,950 --> 00:21:22,559

and uh the atomic number of molybdenum

640

00:21:26,070 --> 00:21:24,960

is indeed 42. so it makes good sense to

641

00:21:27,110 --> 00:21:26,080

be obsessed with molybdenum for that

642

00:21:28,950 --> 00:21:27,120

reason but that's actually not the

643

00:21:31,110 --> 00:21:28,960

reason we're focusing on it the reason

644

00:21:32,950 --> 00:21:31,120

geochemically that molybdenum is a

645

00:21:34,310 --> 00:21:32,960

entertaining element to work with or a

646

00:21:35,830 --> 00:21:34,320

uh

647

00:21:37,669 --> 00:21:35,840

a good element to work with is because

648

00:21:39,190 --> 00:21:37,679

as a very contrasting behavior as a

649

00:21:42,230 --> 00:21:39,200

function of environmental redox

650

00:21:44,149 --> 00:21:42,240

chemistry it has a switch-like behavior

651
00:21:46,230 --> 00:21:44,159
as it has been uh described in the

652
00:21:47,830 --> 00:21:46,240
literature so this this figure is meant

653
00:21:49,190 --> 00:21:47,840
to get this concept across so what

654
00:21:51,590 --> 00:21:49,200
you're seeing here is a profile of

655
00:21:53,190 --> 00:21:51,600
molybdenum concentration in the black

656
00:21:54,710 --> 00:21:53,200
sea which is the type locality on the

657
00:21:57,110 --> 00:21:54,720
modern planet that you go to if you want

658
00:21:58,870 --> 00:21:57,120
to look at strongly contrasting redox

659
00:22:01,029 --> 00:21:58,880
behavior so the surface waters of the

660
00:22:03,110 --> 00:22:01,039
black sea are oxygenated the deep waters

661
00:22:04,630 --> 00:22:03,120
of the black sea have very little oxygen

662
00:22:06,310 --> 00:22:04,640
and have in fact a large amount of

663
00:22:07,909 --> 00:22:06,320

hydrogen sulfide very reducing

664

00:22:09,830 --> 00:22:07,919

environment

665

00:22:11,590 --> 00:22:09,840

and molybdenum shows a very sharply

666

00:22:13,190 --> 00:22:11,600

contrasting behavior as a go you go

667

00:22:15,909 --> 00:22:13,200

across this transition the so-called

668

00:22:16,950 --> 00:22:15,919

redox cline so why is that

669

00:22:19,350 --> 00:22:16,960

the reason for that is that in

670

00:22:21,110 --> 00:22:19,360

oxygenated waters molybdenum is highly

671

00:22:23,110 --> 00:22:21,120

unreactive it's present as the molybdate

672

00:22:26,549 --> 00:22:23,120

anion

673

00:22:28,070 --> 00:22:26,559

which is a highly unreactive uh uh ion

674

00:22:29,510 --> 00:22:28,080

such that molybdenum has a very long

675

00:22:31,110 --> 00:22:29,520

residence time in the modern oceans

676
00:22:32,310 --> 00:22:31,120
about eight hundred thousand years and

677
00:22:34,149 --> 00:22:32,320
in fact it's the most abundant

678
00:22:35,990 --> 00:22:34,159
transition metal in the modern oceans

679
00:22:38,230 --> 00:22:36,000
because this molybdate ion is so

680
00:22:39,669 --> 00:22:38,240
unreactive so even aluminum is by far

681
00:22:40,870 --> 00:22:39,679
not an abundant element in the crust it

682
00:22:42,149 --> 00:22:40,880
turns out to be the most abundant

683
00:22:43,350 --> 00:22:42,159
transition metal in the oceans because

684
00:22:45,590 --> 00:22:43,360
of its

685
00:22:47,270 --> 00:22:45,600
great stability uh chemical stability

686
00:22:49,510 --> 00:22:47,280
when in the when

687
00:22:50,710 --> 00:22:49,520
fully oxygenated

688
00:22:52,470 --> 00:22:50,720

however when molybdenum gets into a

689

00:22:54,789 --> 00:22:52,480

reducing environment the chemistry

690

00:22:56,470 --> 00:22:54,799

changes very sharply what happens is

691

00:22:59,430 --> 00:22:56,480

actually not a redox reaction to first

692

00:23:02,070 --> 00:22:59,440

order but a substitution of sulfurs for

693

00:23:04,470 --> 00:23:02,080

oxygens around this molybdenum six plus

694

00:23:05,590 --> 00:23:04,480

uh uh

695

00:23:07,190 --> 00:23:05,600

center

696

00:23:09,270 --> 00:23:07,200

and to form these guys which are

697

00:23:10,630 --> 00:23:09,280

referred to as oxy thiomalipdates and

698

00:23:12,149 --> 00:23:10,640

these are very particle reactive and

699

00:23:13,190 --> 00:23:12,159

hence gets scavenged out of the water

700

00:23:15,270 --> 00:23:13,200

column

701
00:23:17,029 --> 00:23:15,280
and in uh

702
00:23:19,270 --> 00:23:17,039
ocean basins the

703
00:23:20,630 --> 00:23:19,280
um dominant form of particulate matter

704
00:23:23,110 --> 00:23:20,640
that's raining down for this stuff to

705
00:23:24,230 --> 00:23:23,120
stick to are organic carbon particles

706
00:23:26,149 --> 00:23:24,240
and hence you have an affinity of

707
00:23:27,430 --> 00:23:26,159
molybdenum for organic carbon in these

708
00:23:28,549 --> 00:23:27,440
kind of environments so the molybdenum

709
00:23:30,549 --> 00:23:28,559
gets removed from the water and it's

710
00:23:33,590 --> 00:23:30,559
getting removed by being scrubbed out

711
00:23:36,149 --> 00:23:33,600
onto organic carbon particles

712
00:23:39,190 --> 00:23:36,159
um so the upshot is that molybdenum uh

713
00:23:40,549 --> 00:23:39,200

is abundant in oxygenated seawater it it

714

00:23:42,710 --> 00:23:40,559

is not going to be so abundant in sea

715

00:23:44,710 --> 00:23:42,720

water if that's not oxygenated and as

716

00:23:46,470 --> 00:23:44,720

we'll talk about also aluminum will tend

717

00:23:48,070 --> 00:23:46,480

to accumulate in sedimentary

718

00:23:49,270 --> 00:23:48,080

environments that are full of hydrogen

719

00:23:50,549 --> 00:23:49,280

sulfide

720

00:23:51,830 --> 00:23:50,559

that accumulated waters that are full of

721

00:23:54,789 --> 00:23:51,840

hydrogen sulfide those will tend to

722

00:23:56,470 --> 00:23:54,799

concentrate molybdenum

723

00:23:57,750 --> 00:23:56,480

in addition molybdenum rhenium is

724

00:23:59,909 --> 00:23:57,760

another element with very similar

725

00:24:01,510 --> 00:23:59,919

behavior and to some degree uranium

726

00:24:02,830 --> 00:24:01,520

although as we'll talk about uranium is

727

00:24:05,350 --> 00:24:02,840

not quite

728

00:24:07,750 --> 00:24:05,360

identical so the concept underlying this

729

00:24:09,350 --> 00:24:07,760

application is isn't very simple

730

00:24:11,990 --> 00:24:09,360

the idea here is that on a world where

731

00:24:13,430 --> 00:24:12,000

you have oxygen if oxygen is present

732

00:24:15,430 --> 00:24:13,440

then molybdenum can accumulate in the

733

00:24:16,710 --> 00:24:15,440

oceans and it does so in through several

734

00:24:19,110 --> 00:24:16,720

steps that are oxygen sensitive the

735

00:24:20,390 --> 00:24:19,120

first step is weathering of molybdenum

736

00:24:22,630 --> 00:24:20,400

carrying minerals on the continents

737

00:24:24,870 --> 00:24:22,640

which are mostly sulfide minerals so

738

00:24:26,789 --> 00:24:24,880

those are very reactive with oxygen so

739

00:24:28,230 --> 00:24:26,799

molybdenum sulfides and igneous rocks

740

00:24:29,430 --> 00:24:28,240

will weather in the presence of oxygen

741

00:24:31,269 --> 00:24:29,440

releasing their molybdenum to river

742

00:24:32,789 --> 00:24:31,279

waters if there's a lot of oxygen around

743

00:24:35,190 --> 00:24:32,799

then that molybdenum becomes malibate

744

00:24:36,470 --> 00:24:35,200

and is highly soluble and unreactive and

745

00:24:38,390 --> 00:24:36,480

it gets delivered to the oceans where it

746

00:24:40,470 --> 00:24:38,400

can accumulate and that can happen on

747

00:24:42,310 --> 00:24:40,480

land it can also happen uh

748

00:24:44,149 --> 00:24:42,320

in a submarine setting where you have

749

00:24:46,070 --> 00:24:44,159

submarine basalts where again you have

750

00:24:47,510 --> 00:24:46,080

sulfides that contain molybdenum and

751
00:24:49,190 --> 00:24:47,520
rhenium

752
00:24:51,029 --> 00:24:49,200
and the chemistry of those is going to

753
00:24:52,310 --> 00:24:51,039
be sensitive to oxygen it will release

754
00:24:54,149 --> 00:24:52,320
their molybdenum into this into the

755
00:24:55,590 --> 00:24:54,159
water in the presence of oxygen

756
00:24:56,710 --> 00:24:55,600
on the other hand if oxygen is absent

757
00:24:58,870 --> 00:24:56,720
then you have a very different story

758
00:25:00,070 --> 00:24:58,880
then this flux is turned off essentially

759
00:25:01,909 --> 00:25:00,080
because the weathering rates of the

760
00:25:04,149 --> 00:25:01,919
sulfide minerals carrying these elements

761
00:25:06,310 --> 00:25:04,159
on land are very very slow

762
00:25:07,909 --> 00:25:06,320
um and the um

763
00:25:09,669 --> 00:25:07,919

the minerals will be much more robust

764

00:25:11,590 --> 00:25:09,679

against weathering the solubility of

765

00:25:12,630 --> 00:25:11,600

molybdenum will be lower in in waters

766

00:25:14,149 --> 00:25:12,640

they won't be able to accumulate in the

767

00:25:15,590 --> 00:25:14,159

oceans as much and so you'll have a

768

00:25:18,390 --> 00:25:15,600

world with much less molybdenum in the

769

00:25:20,070 --> 00:25:18,400

oceans so the the amount of molybdenum

770

00:25:22,070 --> 00:25:20,080

and rhenium and to some degree uranium

771

00:25:26,070 --> 00:25:22,080

in the oceans in these two scenarios is

772

00:25:30,630 --> 00:25:27,590

and where you would go to look for that

773

00:25:32,710 --> 00:25:30,640

um let me skip this slide um is in

774

00:25:34,710 --> 00:25:32,720

anoxic environments like the sediments

775

00:25:37,510 --> 00:25:34,720

beneath the modern black sea

776

00:25:39,110 --> 00:25:37,520

um those are the places where um

777

00:25:40,549 --> 00:25:39,120

molybdenum is going to get is going to

778

00:25:42,390 --> 00:25:40,559

accumulate from sea water if there is

779

00:25:44,710 --> 00:25:42,400

molybdenum in the sea water to

780

00:25:45,990 --> 00:25:44,720

uh to accumulate so if you go to the

781

00:25:47,029 --> 00:25:46,000

modern black sea you'll find there's a

782

00:25:50,230 --> 00:25:47,039

good amount of molybdenum in the

783

00:25:51,750 --> 00:25:50,240

sediments beneath that basin uh because

784

00:25:54,070 --> 00:25:51,760

although this is an anoxic base and it's

785

00:25:56,310 --> 00:25:54,080

in contact with a very large oxygenated

786

00:25:57,990 --> 00:25:56,320

ocean which is chock full of molybdenum

787

00:25:59,029 --> 00:25:58,000

if such a basin however formed in the

788

00:26:00,549 --> 00:25:59,039

archaean

789

00:26:01,909 --> 00:26:00,559

um

790

00:26:03,269 --> 00:26:01,919

and if in the archaean there was very

791

00:26:04,549 --> 00:26:03,279

little oxygen in the environ in the

792

00:26:05,990 --> 00:26:04,559

environment you would expect there to be

793

00:26:07,750 --> 00:26:06,000

very little molybdenum in the oceans of

794

00:26:09,430 --> 00:26:07,760

that time and the sediments accumulating

795

00:26:11,830 --> 00:26:09,440

in such a basin in the archaean would

796

00:26:14,630 --> 00:26:11,840

probably be relatively low in molybdenum

797

00:26:16,230 --> 00:26:14,640

that's the basic concept here

798

00:26:17,669 --> 00:26:16,240

and in fact if we go to a number of

799

00:26:20,230 --> 00:26:17,679

modern basins what you're seeing here is

800

00:26:22,870 --> 00:26:20,240

the molybdenum concentration versus a

801
00:26:24,310 --> 00:26:22,880
parameter called toc which is just an

802
00:26:26,310 --> 00:26:24,320
abbreviation to confuse you this is

803
00:26:27,430 --> 00:26:26,320
total organic carbon remember i said

804
00:26:28,950 --> 00:26:27,440
there should be an affinity between

805
00:26:30,549 --> 00:26:28,960
molybdenum and organic carbon and

806
00:26:32,390 --> 00:26:30,559
sediments and so you can go to number of

807
00:26:33,190 --> 00:26:32,400
modern basins here's the black sea the

808
00:26:35,990 --> 00:26:33,200
from the

809
00:26:37,990 --> 00:26:36,000
barn fjord karyako basin the sonic inlet

810
00:26:40,310 --> 00:26:38,000
these are these are very well studied

811
00:26:41,750 --> 00:26:40,320
modern anoxic basins and you can see

812
00:26:43,830 --> 00:26:41,760
that they all each one of them shows

813
00:26:45,909 --> 00:26:43,840

this trend each one is a different slope

814

00:26:48,070 --> 00:26:45,919

but each one shows a trend of molybdenum

815

00:26:50,149 --> 00:26:48,080

versus organic carbon and the amount of

816

00:26:51,430 --> 00:26:50,159

molybdenum in these sediments and these

817

00:26:53,029 --> 00:26:51,440

are in the sediments underneath these

818

00:26:54,470 --> 00:26:53,039

the waters in these basins and the

819

00:26:56,390 --> 00:26:54,480

amount of molybdenum in these sediments

820

00:26:58,230 --> 00:26:56,400

is very high compared to average crustal

821

00:27:00,230 --> 00:26:58,240

abundances so molybdenum the average

822

00:27:02,149 --> 00:27:00,240

crust is around a part per million by

823

00:27:03,830 --> 00:27:02,159

weight um and the sediments in these

824

00:27:05,350 --> 00:27:03,840

kind of basins you're talking about tens

825

00:27:07,430 --> 00:27:05,360

to even hundreds of parts per million of

826

00:27:08,950 --> 00:27:07,440

molybdenum and the reason for that again

827

00:27:10,310 --> 00:27:08,960

just to stress this is that these kind

828

00:27:11,990 --> 00:27:10,320

of environments these anoxic

829

00:27:14,710 --> 00:27:12,000

environments are environments in which

830

00:27:16,789 --> 00:27:14,720

molybdenum that is abundant in sea water

831

00:27:18,149 --> 00:27:16,799

um uh there are environments in which

832

00:27:20,070 --> 00:27:18,159

molybdenum which is abundant in seawater

833

00:27:21,269 --> 00:27:20,080

becomes destabilized and gets scrubbed

834

00:27:23,350 --> 00:27:21,279

out into sediment so these are the kind

835

00:27:24,789 --> 00:27:23,360

of places you go to look for evidence

836

00:27:26,870 --> 00:27:24,799

that you had oceans with lots of

837

00:27:28,070 --> 00:27:26,880

molybdenum in them so today we have an

838

00:27:29,350 --> 00:27:28,080

ocean with lots of molybdenum and

839

00:27:31,510 --> 00:27:29,360

sediments in these environments are then

840

00:27:32,789 --> 00:27:31,520

very rich in molybdenum

841

00:27:34,470 --> 00:27:32,799

um

842

00:27:37,029 --> 00:27:34,480

now you can go back so these kind of

843

00:27:38,549 --> 00:27:37,039

sediments then if you if you let them

844

00:27:40,230 --> 00:27:38,559

get buried and altered through time turn

845

00:27:41,750 --> 00:27:40,240

into the kind of rocks that refer to as

846

00:27:46,470 --> 00:27:41,760

black shales

847

00:27:48,230 --> 00:27:46,480

the geologic past for example in the

848

00:27:49,830 --> 00:27:48,240

devonian where these have been very well

849

00:27:51,350 --> 00:27:49,840

studied and look at the trend of

850

00:27:54,389 --> 00:27:51,360

molybdenum versus organic carbon in

851
00:27:57,110 --> 00:27:54,399
devonian black shales you find that that

852
00:27:58,549 --> 00:27:57,120
that trend is very similar to the range

853
00:28:00,310 --> 00:27:58,559
of

854
00:28:02,870 --> 00:28:00,320
values that you find in these modern

855
00:28:04,710 --> 00:28:02,880
sediments so this is telling us first of

856
00:28:05,830 --> 00:28:04,720
all that the devonian the bulk oceans

857
00:28:06,870 --> 00:28:05,840
probably had a lot of molybdenum and

858
00:28:08,389 --> 00:28:06,880
hence there was probably a fair amount

859
00:28:10,389 --> 00:28:08,399
of oxygen around even though there are

860
00:28:11,830 --> 00:28:10,399
lots of black shales from that time

861
00:28:13,669 --> 00:28:11,840
but the other thing it's the main point

862
00:28:15,510 --> 00:28:13,679
i want to drive home is that we see in

863
00:28:17,110 --> 00:28:15,520

modern sedimentary systems this

864

00:28:19,110 --> 00:28:17,120

relationship between molybdenum organic

865

00:28:21,590 --> 00:28:19,120

carbon and these molybdenum enrichments

866

00:28:23,269 --> 00:28:21,600

and we see these also in devonian um

867

00:28:24,950 --> 00:28:23,279

black shale so we can go back to back in

868

00:28:25,990 --> 00:28:24,960

time to rocks that are hundreds of

869

00:28:27,830 --> 00:28:26,000

millions or

870

00:28:30,310 --> 00:28:27,840

millions of years old and see something

871

00:28:31,909 --> 00:28:30,320

very similar to what we find in modern

872

00:28:33,590 --> 00:28:31,919

bases that gives us confidence that we

873

00:28:35,430 --> 00:28:33,600

are kind of on to what's going on here

874

00:28:37,350 --> 00:28:35,440

that we have a handle on it

875

00:28:39,190 --> 00:28:37,360

ariel would you just say how long ago

876

00:28:41,190 --> 00:28:39,200

the devonian was

877

00:28:44,230 --> 00:28:41,200

uh it's a few well i'm not sure exactly

878

00:28:49,029 --> 00:28:44,240

these these samples it's about on the

879

00:28:51,350 --> 00:28:49,830

so

880

00:28:53,590 --> 00:28:51,360

um to

881

00:28:54,870 --> 00:28:53,600

assess this a little bit um so it's

882

00:28:56,549 --> 00:28:54,880

nowhere near as old as what we're go

883

00:28:57,750 --> 00:28:56,559

where we're going but it's a period of

884

00:28:59,990 --> 00:28:57,760

time has been very well studied with

885

00:29:01,269 --> 00:29:00,000

respect to the chemistry of of black

886

00:29:03,830 --> 00:29:01,279

shales so

887

00:29:04,950 --> 00:29:03,840

it's sort of the ancient analog of the

888

00:29:06,630 --> 00:29:04,960

modern black sea which has been very

889

00:29:09,190 --> 00:29:06,640

well studied for the chemistry of these

890

00:29:11,510 --> 00:29:09,200

redox sensitive metals

891

00:29:14,950 --> 00:29:11,520

so um we've actually used this sort of

892

00:29:17,909 --> 00:29:14,960

tool in a in a gross sense already

893

00:29:19,750 --> 00:29:17,919

in studies shown here this is a paper by

894

00:29:21,430 --> 00:29:19,760

um clint scott who's a student of tim

895

00:29:23,269 --> 00:29:21,440

lines at uc riverside who's been

896

00:29:25,190 --> 00:29:23,279

compiling data both from the literature

897

00:29:27,110 --> 00:29:25,200

and published already previously

898

00:29:28,789 --> 00:29:27,120

published data on the lived in black

899

00:29:30,389 --> 00:29:28,799

shales through time

900

00:29:32,230 --> 00:29:30,399

and there are complexities here that i i

901
00:29:34,710 --> 00:29:32,240
don't want to go into but the basic

902
00:29:36,389 --> 00:29:34,720
concept here is that um if you look at

903
00:29:37,830 --> 00:29:36,399
molybdenum and black shales through time

904
00:29:39,190 --> 00:29:37,840
you indeed see

905
00:29:40,950 --> 00:29:39,200
a uh

906
00:29:42,149 --> 00:29:40,960
sort of secular changes in the archaean

907
00:29:45,430 --> 00:29:42,159
you generally see very low

908
00:29:46,389 --> 00:29:45,440
concentrations of molybdenum um uh you

909
00:29:48,389 --> 00:29:46,399
know

910
00:29:50,630 --> 00:29:48,399
one to ten ppm sort of values are are

911
00:29:52,789 --> 00:29:50,640
typical then you go into the proteozoic

912
00:29:54,789 --> 00:29:52,799
and you see higher you see some olympic

913
00:29:56,470 --> 00:29:54,799

enrichments but there's nowhere near as

914

00:29:58,950 --> 00:29:56,480

spectacular as what you see in the

915

00:30:00,470 --> 00:29:58,960

phanerozoic and the more modern record

916

00:30:03,350 --> 00:30:00,480

so if you recall that cartoon i showed

917

00:30:04,630 --> 00:30:03,360

you the three stages of oxygen evolution

918

00:30:06,230 --> 00:30:04,640

and that figure the axis ran the other

919

00:30:08,470 --> 00:30:06,240

way my apologies that these axes flip

920

00:30:09,830 --> 00:30:08,480

around in that figure

921

00:30:11,510 --> 00:30:09,840

back in time was there and the modern

922

00:30:13,269 --> 00:30:11,520

was over here and this figure we flipped

923

00:30:15,510 --> 00:30:13,279

it the other way here's the archaean and

924

00:30:17,830 --> 00:30:15,520

here's the modern but you can see that

925

00:30:19,750 --> 00:30:17,840

as in that cartoon there's a three sort

926

00:30:21,190 --> 00:30:19,760

of suggestion of a three-stage story

927

00:30:23,029 --> 00:30:21,200

here which is what you would expect that

928

00:30:25,110 --> 00:30:23,039

if oxygen really went from very low to

929

00:30:26,630 --> 00:30:25,120

intermediate to high then molybdenum and

930

00:30:27,990 --> 00:30:26,640

sediments would go from very low to

931

00:30:29,269 --> 00:30:28,000

immediate to high and indeed we see

932

00:30:30,470 --> 00:30:29,279

something like that with with some

933

00:30:32,549 --> 00:30:30,480

complexities that we're not going to

934

00:30:34,070 --> 00:30:32,559

discuss in this talk here but this sort

935

00:30:35,830 --> 00:30:34,080

of the fact that we can see this sort of

936

00:30:37,190 --> 00:30:35,840

thing in the ancient record gives us

937

00:30:38,870 --> 00:30:37,200

good confidence that in again that

938

00:30:41,110 --> 00:30:38,880

indeed we are on to something when it

939

00:30:43,510 --> 00:30:41,120

comes to using molybdenum and sediments

940

00:30:44,950 --> 00:30:43,520

through time as a proxy for oxygen in

941

00:30:48,149 --> 00:30:44,960

the environment

942

00:30:49,750 --> 00:30:48,159

as we're going to talk about uh in in uh

943

00:30:51,669 --> 00:30:49,760

in a couple minutes with the data that

944

00:30:53,190 --> 00:30:51,679

we're showing that we're obtaining now

945

00:30:55,750 --> 00:30:53,200

we're finding evidence of

946

00:30:57,430 --> 00:30:55,760

short-lived variations μm in molybdenum

947

00:31:00,470 --> 00:30:57,440

uh possibly short-lived variations of

948

00:31:03,350 --> 00:31:00,480

molybdenum even in the archaean μm which

949

00:31:04,630 --> 00:31:03,360

is the big story here so as we'll get to

950

00:31:05,830 --> 00:31:04,640

so if you want to study this sort of

951
00:31:07,669 --> 00:31:05,840
thing you need to find the right kind of

952
00:31:09,510 --> 00:31:07,679
sediments we've said you want these so

953
00:31:11,190 --> 00:31:09,520
called black shales these sediments are

954
00:31:12,230 --> 00:31:11,200
black because they're full of organic

955
00:31:14,310 --> 00:31:12,240
carbon

956
00:31:16,070 --> 00:31:14,320
and here's a nice picture of one of the

957
00:31:17,590 --> 00:31:16,080
drill core samples that we've worked on

958
00:31:19,909 --> 00:31:17,600
this is the kind of thing that you want

959
00:31:21,190 --> 00:31:19,919
nice as we say in the business juicy

960
00:31:23,510 --> 00:31:21,200
black shales

961
00:31:25,590 --> 00:31:23,520
also they contain these beautiful pyrite

962
00:31:27,029 --> 00:31:25,600
nodules and laminations these are iron

963
00:31:28,470 --> 00:31:27,039

sulfides

964

00:31:29,830 --> 00:31:28,480

that form in reduced environments this

965

00:31:31,590 --> 00:31:29,840

is what you want

966

00:31:33,190 --> 00:31:31,600

this kind of material

967

00:31:35,190 --> 00:31:33,200

the reason that drilling becomes very

968

00:31:36,549 --> 00:31:35,200

important uh that and the reason

969

00:31:38,549 --> 00:31:36,559

something like astrobiology drilling

970

00:31:40,070 --> 00:31:38,559

program has been so critical

971

00:31:41,830 --> 00:31:40,080

is because what you find at the surface

972

00:31:43,190 --> 00:31:41,840

is very typically altered it's usually

973

00:31:44,710 --> 00:31:43,200

not quite as bad as this picture but

974

00:31:46,710 --> 00:31:44,720

this is a fun picture to show the

975

00:31:48,389 --> 00:31:46,720

extreme of what can happen so in western

976
00:31:50,630 --> 00:31:48,399
australia where you have rocks of the

977
00:31:51,909 --> 00:31:50,640
appropriate antiquity and of the

978
00:31:53,590 --> 00:31:51,919
appropriate very low grade of

979
00:31:55,110 --> 00:31:53,600
metamorphism which is critical for this

980
00:31:57,029 --> 00:31:55,120
kind of work

981
00:31:58,630 --> 00:31:57,039
you unfortunately also have pervasive

982
00:31:59,669 --> 00:31:58,640
oxidative weathering of the surface

983
00:32:01,750 --> 00:31:59,679
environment

984
00:32:03,830 --> 00:32:01,760
water over time flows through rocks if

985
00:32:05,830 --> 00:32:03,840
that water has oxygen in it

986
00:32:07,830 --> 00:32:05,840
then you start to oxidize whatever's in

987
00:32:10,710 --> 00:32:07,840
the rocks so what you're seeing here is

988
00:32:13,110 --> 00:32:10,720

a picture of what uh in a drill core is

989

00:32:14,549 --> 00:32:13,120

a nice black shale but an outcrop or

990

00:32:16,470 --> 00:32:14,559

it's been exposed for we don't know how

991

00:32:19,509 --> 00:32:16,480

long um

992

00:32:21,669 --> 00:32:19,519

uh in outcrop it's weathered to pieces

993

00:32:22,789 --> 00:32:21,679

uh the it's not black at all it's white

994

00:32:24,230 --> 00:32:22,799

because the organic carbon has

995

00:32:27,029 --> 00:32:24,240

essentially been oxidized it's been

996

00:32:28,230 --> 00:32:27,039

ashed effectively chemically slowly um

997

00:32:30,870 --> 00:32:28,240

but it's analogous to what would happen

998

00:32:32,710 --> 00:32:30,880

if you stuck that sample in in a furnace

999

00:32:34,630 --> 00:32:32,720

and burned all the organic carbon it's

1000

00:32:36,630 --> 00:32:34,640

just been a very slow burn

1001
00:32:37,990 --> 00:32:36,640
so naturally this kind of rock is not

1002
00:32:39,909 --> 00:32:38,000
all that useful for the sort of thing

1003
00:32:41,590 --> 00:32:39,919
that we're after uh because the redox

1004
00:32:44,149 --> 00:32:41,600
sensitive metals like molybdenum that

1005
00:32:45,509 --> 00:32:44,159
were in here will no longer be in their

1006
00:32:47,750 --> 00:32:45,519
primary

1007
00:32:48,870 --> 00:32:47,760
abundances so drilling becomes very

1008
00:32:50,630 --> 00:32:48,880
important

1009
00:32:52,789 --> 00:32:50,640
so the astrobiology drilling program as

1010
00:32:54,950 --> 00:32:52,799
i said drilled 10 drill cores of various

1011
00:32:57,669 --> 00:32:54,960
depths at various periods of time in

1012
00:32:59,350 --> 00:32:57,679
western australia in 2003 and 2004 this

1013
00:33:01,350 --> 00:32:59,360

is a picture here of roger buick who was

1014

00:33:03,990 --> 00:33:01,360

the mastermind behind this hammersley

1015

00:33:06,470 --> 00:33:04,000

basin drill corps um he's pointing both

1016

00:33:08,230 --> 00:33:06,480

to western australia which is where the

1017

00:33:11,029 --> 00:33:08,240

hammersley basin and the the pildora

1018

00:33:13,830 --> 00:33:11,039

craton is and to our drill core so this

1019

00:33:15,990 --> 00:33:13,840

particular cord this is number nine uh

1020

00:33:18,149 --> 00:33:16,000

of the ten cores and was drilled in this

1021

00:33:19,830 --> 00:33:18,159

location here

1022

00:33:22,310 --> 00:33:19,840

now this project in some ways was rather

1023

00:33:23,990 --> 00:33:22,320

star-crossed initially um

1024

00:33:25,750 --> 00:33:24,000

first of all took quite a long time for

1025

00:33:27,350 --> 00:33:25,760

it to evolve it evolved initially as an

1026

00:33:28,789 --> 00:33:27,360

outgrowth of the

1027

00:33:31,909 --> 00:33:28,799

early earth focus group which was

1028

00:33:35,190 --> 00:33:31,919

created when barry blumberg uh the

1029

00:33:37,590 --> 00:33:35,200

former director of the nai um asked for

1030

00:33:40,070 --> 00:33:37,600

the nai teams to propose ideas for

1031

00:33:41,750 --> 00:33:40,080

astrobiology missions and he had in mind

1032

00:33:43,269 --> 00:33:41,760

of course space missions but a few of us

1033

00:33:44,870 --> 00:33:43,279

got together and proposed the idea of a

1034

00:33:46,549 --> 00:33:44,880

mission to the early earth

1035

00:33:47,990 --> 00:33:46,559

and so was born the focus group and so

1036

00:33:48,950 --> 00:33:48,000

eventually was born this particular

1037

00:33:50,070 --> 00:33:48,960

project

1038

00:33:52,230 --> 00:33:50,080

and as you can see there was a long

1039

00:33:54,470 --> 00:33:52,240

gestation and finally we began to be

1040

00:33:55,509 --> 00:33:54,480

able to analyze things in 2006. but as i

1041

00:33:56,710 --> 00:33:55,519

said this project was somewhat

1042

00:33:58,149 --> 00:33:56,720

star-crossed

1043

00:33:59,669 --> 00:33:58,159

and i'll explain why because it's kind

1044

00:34:01,669 --> 00:33:59,679

of an amusing story of how science

1045

00:34:03,190 --> 00:34:01,679

really works

1046

00:34:05,269 --> 00:34:03,200

so here's the stratigraphy that we were

1047

00:34:08,950 --> 00:34:05,279

pursuing we were going after the last

1048

00:34:11,510 --> 00:34:08,960

250 million years of the archaean

1049

00:34:14,149 --> 00:34:11,520

and in particular the big focus was to

1050

00:34:15,750 --> 00:34:14,159

study these sediments down here these

1051

00:34:17,909 --> 00:34:15,760

very old black shales that date back to

1052

00:34:19,669 --> 00:34:17,919

around 2.7 billion years ago which are

1053

00:34:21,909 --> 00:34:19,679

particular interest because these are

1054

00:34:23,589 --> 00:34:21,919

the sediments from which

1055

00:34:25,349 --> 00:34:23,599

biomarker evidence

1056

00:34:28,069 --> 00:34:25,359

which constitutes the earliest evidence

1057

00:34:30,069 --> 00:34:28,079

of eukaryotes comes from so these are

1058

00:34:32,470 --> 00:34:30,079

very important rocks and there's great

1059

00:34:33,589 --> 00:34:32,480

desire to sample them again and the need

1060

00:34:36,230 --> 00:34:33,599

reason to say that they need to be

1061

00:34:38,310 --> 00:34:36,240

sampled again is because the biomarker

1062

00:34:40,149 --> 00:34:38,320

evidence that had what has been uh that

1063

00:34:42,389 --> 00:34:40,159

was produced um in a landmark paper in

1064

00:34:44,710 --> 00:34:42,399

1999 by jochen brox and roger summons

1065

00:34:45,829 --> 00:34:44,720

and roger buick um those samples had

1066

00:34:47,349 --> 00:34:45,839

been um

1067

00:34:49,270 --> 00:34:47,359

had not been obtained in a pristine

1068

00:34:51,030 --> 00:34:49,280

manner with respect to contamination had

1069

00:34:52,950 --> 00:34:51,040

not been stored in a manner to avoid

1070

00:34:54,950 --> 00:34:52,960

contamination and so there's been

1071

00:34:57,670 --> 00:34:54,960

controversy uh ever since the results

1072

00:34:59,990 --> 00:34:57,680

were were first announced as to whether

1073

00:35:01,430 --> 00:35:00,000

or not the biomarkers extracted from

1074

00:35:02,550 --> 00:35:01,440

those rocks were really indigenous to

1075

00:35:04,390 --> 00:35:02,560

the rocks

1076

00:35:05,910 --> 00:35:04,400

great care was taken to try to confirm

1077

00:35:07,990 --> 00:35:05,920

that that was indeed the case but there

1078

00:35:10,069 --> 00:35:08,000

remains lingering controversy about it

1079

00:35:11,750 --> 00:35:10,079

so it was great desire to to resample

1080

00:35:13,270 --> 00:35:11,760

those rocks to sample them fresh and to

1081

00:35:15,109 --> 00:35:13,280

drill in a way that would be free of

1082

00:35:16,630 --> 00:35:15,119

contamination

1083

00:35:18,230 --> 00:35:16,640

so that was the primary goal of this

1084

00:35:19,510 --> 00:35:18,240

project to go after those biomarkers and

1085

00:35:21,430 --> 00:35:19,520

to also look at the environment at that

1086

00:35:22,870 --> 00:35:21,440

time and along the way to also look at

1087

00:35:25,030 --> 00:35:22,880

the environment and biomarkers

1088

00:35:26,950 --> 00:35:25,040

throughout this last 250 million years

1089

00:35:28,950 --> 00:35:26,960

of the archaean leading leading up to

1090

00:35:31,910 --> 00:35:28,960

the rise of oxygen the great oxidation

1091

00:35:33,510 --> 00:35:31,920

event as it turns out we had two major

1092

00:35:36,150 --> 00:35:33,520

problems um

1093

00:35:37,829 --> 00:35:36,160

the first problem is that uh in the end

1094

00:35:39,750 --> 00:35:37,839

the the drillers on this project

1095

00:35:42,630 --> 00:35:39,760

insisted on using a hydrocarbon-based

1096

00:35:44,230 --> 00:35:42,640

drilling fluid despite our protestations

1097

00:35:45,750 --> 00:35:44,240

the flu that they chose to use was

1098

00:35:48,150 --> 00:35:45,760

something that should have been fairly

1099

00:35:49,990 --> 00:35:48,160

molecularly well characterized so that

1100

00:35:51,589 --> 00:35:50,000

we could uh cope with it but it turns

1101

00:35:54,630 --> 00:35:51,599

out to be a much messier material than

1102

00:35:55,990 --> 00:35:54,640

had been hoped um roger summons is still

1103

00:35:58,390 --> 00:35:56,000

fairly optimistic that he'll be able to

1104

00:35:59,910 --> 00:35:58,400

pull biomarker data out of here but it's

1105

00:36:02,150 --> 00:35:59,920

much proven to be much harder and more

1106

00:36:03,589 --> 00:36:02,160

complicated than expected so that was

1107

00:36:06,069 --> 00:36:03,599

problem number one

1108

00:36:07,990 --> 00:36:06,079

problem number two is that um

1109

00:36:09,430 --> 00:36:08,000

uh we didn't actually get down to the

1110

00:36:11,270 --> 00:36:09,440

stratigraphy in the end

1111

00:36:12,470 --> 00:36:11,280

because the location where we were

1112

00:36:13,990 --> 00:36:12,480

forced to drill

1113

00:36:16,150 --> 00:36:14,000

was turned out not to be the ideal

1114

00:36:17,430 --> 00:36:16,160

location and i say force because

1115

00:36:19,990 --> 00:36:17,440

you don't have free reign to drill

1116

00:36:22,390 --> 00:36:20,000

wherever you want to in the pilbara

1117

00:36:23,910 --> 00:36:22,400

aboriginal groups have their claims over

1118

00:36:26,470 --> 00:36:23,920

this land and you have to negotiate with

1119

00:36:28,390 --> 00:36:26,480

them to find the place that is uh where

1120

00:36:29,990 --> 00:36:28,400

they will permit you to drill and so the

1121

00:36:31,750 --> 00:36:30,000

ideal location for this drilling turned

1122

00:36:33,990 --> 00:36:31,760

out not to be the ideal location from

1123

00:36:35,109 --> 00:36:34,000

their perspective um and we were hopeful

1124

00:36:36,470 --> 00:36:35,119

that the location that we finally

1125

00:36:37,829 --> 00:36:36,480

settled on would work but as it turns

1126

00:36:39,750 --> 00:36:37,839

out what happened is that in that

1127

00:36:41,510 --> 00:36:39,760

location this unit here the whitney

1128

00:36:43,430 --> 00:36:41,520

formation was stratigraphically

1129

00:36:44,790 --> 00:36:43,440

thickened by about a factor of two and

1130

00:36:46,069 --> 00:36:44,800

so that although we drilled about a

1131

00:36:47,750 --> 00:36:46,079

kilometer we never actually got through

1132

00:36:49,750 --> 00:36:47,760

this stratigraphy here

1133

00:36:52,550 --> 00:36:49,760

so our initial take on this project was

1134

00:36:56,790 --> 00:36:52,560

oh my god what a what a colossal

1135

00:36:58,870 --> 00:36:56,800

failure um and we decided to to uh to

1136

00:37:00,790 --> 00:36:58,880

forge ahead nonetheless and our our

1137

00:37:02,470 --> 00:37:00,800

notion was to focus all our attention on

1138

00:37:05,510 --> 00:37:02,480

this last period of time on this unit

1139

00:37:07,670 --> 00:37:05,520

here called the mount mcrae shale um

1140

00:37:09,349 --> 00:37:07,680

uh and to look at the environment in

1141

00:37:10,390 --> 00:37:09,359

biology at that time

1142

00:37:12,069 --> 00:37:10,400

so that's what we're going to do here as

1143

00:37:14,310 --> 00:37:12,079

i walk you through the data so this

1144

00:37:15,670 --> 00:37:14,320

mount mcrae shale is a classic archaean

1145

00:37:18,550 --> 00:37:15,680

black shale

1146

00:37:19,990 --> 00:37:18,560

archaean

1147

00:37:21,910 --> 00:37:20,000

um

1148

00:37:23,190 --> 00:37:21,920

and uh it's been known for years and

1149

00:37:24,550 --> 00:37:23,200

studied in various ways for years but

1150

00:37:27,670 --> 00:37:24,560

never with the detail we're going to go

1151
00:37:28,710 --> 00:37:27,680
into here and so here in in detail is is

1152
00:37:30,069 --> 00:37:28,720
the piece of the core that we're looking

1153
00:37:31,670 --> 00:37:30,079
at here it's about 100 meters worth of

1154
00:37:33,670 --> 00:37:31,680
drill core and when you look at it in

1155
00:37:35,670 --> 00:37:33,680
detail it's not all black shale there

1156
00:37:38,310 --> 00:37:35,680
are actually two black shale units

1157
00:37:40,310 --> 00:37:38,320
within here the so-called s1 unit and s2

1158
00:37:42,069 --> 00:37:40,320
unit and we further subdivide the s1

1159
00:37:43,829 --> 00:37:42,079
unit into two subunits we'll mention to

1160
00:37:45,109 --> 00:37:43,839
talk about that a little bit more

1161
00:37:47,030 --> 00:37:45,119
so we decided to focus a lot of

1162
00:37:48,950 --> 00:37:47,040
attention on these black shale units to

1163
00:37:51,589 --> 00:37:48,960

see what we could learn in particular

1164

00:37:53,990 --> 00:37:51,599

with respect to paleo redox

1165

00:37:55,829 --> 00:37:54,000

um so i apologize the masking here

1166

00:37:57,589 --> 00:37:55,839

doesn't seem to have translated to webex

1167

00:37:58,950 --> 00:37:57,599

all that perfectly but hopefully this

1168

00:38:00,470 --> 00:37:58,960

will come out okay

1169

00:38:02,230 --> 00:38:00,480

um so what you're seeing here is that

1170

00:38:04,390 --> 00:38:02,240

drill core the depths and the

1171

00:38:05,750 --> 00:38:04,400

lithologies the kind of rocks and here

1172

00:38:07,589 --> 00:38:05,760

you see going to see them you're going

1173

00:38:09,430 --> 00:38:07,599

to see the molybdenum concentration in

1174

00:38:11,510 --> 00:38:09,440

parts per million and then here and here

1175

00:38:13,030 --> 00:38:11,520

the molybdenum enrichment factor which

1176

00:38:14,230 --> 00:38:13,040

is essentially a way of comparing the

1177

00:38:16,390 --> 00:38:14,240

molybdenum

1178

00:38:17,589 --> 00:38:16,400

and and here the rhenium concentrations

1179

00:38:19,109 --> 00:38:17,599

in the sediment

1180

00:38:21,109 --> 00:38:19,119

to those in the average continental

1181

00:38:22,630 --> 00:38:21,119

crust so a value of one is the same as

1182

00:38:24,230 --> 00:38:22,640

average continental crust and an

1183

00:38:25,510 --> 00:38:24,240

enhancement from that is a deviation

1184

00:38:27,670 --> 00:38:25,520

away from

1185

00:38:29,190 --> 00:38:27,680

above average crust

1186

00:38:32,870 --> 00:38:29,200

so when we look at the lower part here

1187

00:38:35,270 --> 00:38:32,880

this s2 unit what do we find in s2 we

1188

00:38:36,870 --> 00:38:35,280

find very low values of molybdenum very

1189

00:38:39,670 --> 00:38:36,880

low molybdenum enrichment factors and

1190

00:38:41,349 --> 00:38:39,680

very low rhenium enrichment factors

1191

00:38:43,030 --> 00:38:41,359

it looks very much like these black

1192

00:38:44,950 --> 00:38:43,040

shales although as we'll see they have a

1193

00:38:47,829 --> 00:38:44,960

good amount of organic carbon

1194

00:38:49,030 --> 00:38:47,839

enough that in uh the phanerozoic if you

1195

00:38:51,270 --> 00:38:49,040

found such rocks you'd find them

1196

00:38:52,790 --> 00:38:51,280

spectacularly enriched in aluminum um in

1197

00:38:54,550 --> 00:38:52,800

this case they're not at all enriched in

1198

00:38:56,470 --> 00:38:54,560

molybdenum um and the simplest

1199

00:38:58,710 --> 00:38:56,480

interpretation this as we'll come back

1200

00:39:00,390 --> 00:38:58,720

to again is that the oceans in which

1201
00:39:02,390 --> 00:39:00,400
these sediments accumulated probably had

1202
00:39:03,990 --> 00:39:02,400
relatively little organic i probably had

1203
00:39:05,190 --> 00:39:04,000
relatively little molybdenum dissolved

1204
00:39:06,950 --> 00:39:05,200
in them

1205
00:39:09,430 --> 00:39:06,960
as we move up though into the upper part

1206
00:39:11,109 --> 00:39:09,440
of the unit we see the beginning of an

1207
00:39:12,710 --> 00:39:11,119
enrichment in molybdenum concentrations

1208
00:39:14,550 --> 00:39:12,720
and enrichment factors and rhenium

1209
00:39:16,470 --> 00:39:14,560
enrichment factors as well getting up to

1210
00:39:17,990 --> 00:39:16,480
molybdenum concentrations of around 40

1211
00:39:19,430 --> 00:39:18,000
parts per million

1212
00:39:21,109 --> 00:39:19,440
that's a

1213
00:39:24,150 --> 00:39:21,119

a respectable amount of molybdenum it's

1214

00:39:25,990 --> 00:39:24,160

it's lower than um equivalent black

1215

00:39:27,109 --> 00:39:26,000

shale that you might find in the younger

1216

00:39:28,550 --> 00:39:27,119

record

1217

00:39:30,710 --> 00:39:28,560

but it is

1218

00:39:33,109 --> 00:39:30,720

still quite uh

1219

00:39:34,550 --> 00:39:33,119

it's quite unusual for the archaean

1220

00:39:35,750 --> 00:39:34,560

what we see here is more typical of

1221

00:39:37,750 --> 00:39:35,760

what's been seen in our keen black

1222

00:39:39,349 --> 00:39:37,760

shales this is really quite unusual

1223

00:39:41,030 --> 00:39:39,359

and as we go further up we see that

1224

00:39:42,870 --> 00:39:41,040

these concentrations die away the

1225

00:39:44,390 --> 00:39:42,880

enrichment factors die away but they

1226

00:39:46,550 --> 00:39:44,400

never quite get back to the original

1227

00:39:47,990 --> 00:39:46,560

values right you have to look at in some

1228

00:39:49,829 --> 00:39:48,000

detail but the enrichment factors here

1229

00:39:51,349 --> 00:39:49,839

are all substantially higher than one

1230

00:39:52,710 --> 00:39:51,359

whereas down here they're barely higher

1231

00:39:54,950 --> 00:39:52,720

than one if at all

1232

00:39:56,870 --> 00:39:54,960

um so there's some change in the system

1233

00:39:59,589 --> 00:39:56,880

when you compare the region down below

1234

00:40:01,270 --> 00:39:59,599

to the region up above

1235

00:40:02,870 --> 00:40:01,280

now before we get too excited we might

1236

00:40:04,069 --> 00:40:02,880

want to ask ourselves how do we know

1237

00:40:06,310 --> 00:40:04,079

that what we're seeing here in terms of

1238

00:40:08,310 --> 00:40:06,320

variations is actually primary how do we

1239

00:40:09,829 --> 00:40:08,320

know it's indigenous to the rocks

1240

00:40:11,829 --> 00:40:09,839

of course as i mentioned before fluids

1241

00:40:13,589 --> 00:40:11,839

passed through rocks these

1242

00:40:15,589 --> 00:40:13,599

rocks have had around uh two and a half

1243

00:40:18,310 --> 00:40:15,599

billion years to um

1244

00:40:19,910 --> 00:40:18,320

to be altered um and so how do you know

1245

00:40:21,829 --> 00:40:19,920

this molybdenum enrichment is not the

1246

00:40:23,750 --> 00:40:21,839

result of metals coming in much later

1247

00:40:25,109 --> 00:40:23,760

after deposition

1248

00:40:27,109 --> 00:40:25,119

and the way we go after that is by

1249

00:40:29,829 --> 00:40:27,119

looking at the rhenium osmium

1250

00:40:31,190 --> 00:40:29,839

geochronological system

1251

00:40:33,589 --> 00:40:31,200

and the idea here is that this is the

1252

00:40:35,910 --> 00:40:33,599

geochronometer the rhenium 187 decays to

1253

00:40:37,109 --> 00:40:35,920

osmium 187 with a half life of around 42

1254

00:40:38,390 --> 00:40:37,119

billion years

1255

00:40:39,750 --> 00:40:38,400

so we can do is we can take these

1256

00:40:41,750 --> 00:40:39,760

sediments particularly the ones that are

1257

00:40:44,230 --> 00:40:41,760

rich in rhenium

1258

00:40:46,390 --> 00:40:44,240

and we can see if they fall along a nice

1259

00:40:48,710 --> 00:40:46,400

isochron we can see if we get a

1260

00:40:49,990 --> 00:40:48,720

geologically meaningful age and the idea

1261

00:40:51,670 --> 00:40:50,000

here is that if we come up with a nice

1262

00:40:53,430 --> 00:40:51,680

isochron and a good age we've got we've

1263

00:40:54,550 --> 00:40:53,440

done two things one is that we've got a

1264

00:40:56,390 --> 00:40:54,560

better constraint on the age of these

1265

00:40:57,990 --> 00:40:56,400

rocks than we had before which is

1266

00:41:00,230 --> 00:40:58,000

valuable as we'll see

1267

00:41:01,430 --> 00:41:00,240

and in addition it provides a test for

1268

00:41:03,109 --> 00:41:01,440

alteration

1269

00:41:05,750 --> 00:41:03,119

because if you get a nice isochrone and

1270

00:41:07,349 --> 00:41:05,760

a geologically meaningful age

1271

00:41:08,630 --> 00:41:07,359

and by geologically meaningful i mean an

1272

00:41:10,790 --> 00:41:08,640

age that's consistent with what we think

1273

00:41:13,589 --> 00:41:10,800

the age of this rock is a priori from

1274

00:41:14,950 --> 00:41:13,599

other constraints um then it's likely

1275

00:41:17,109 --> 00:41:14,960

that the rhenium enrichment that we're

1276

00:41:19,670 --> 00:41:17,119

seeing here is indeed primary if on the

1277

00:41:21,829 --> 00:41:19,680

other hand that rhenium came in you know

1278

00:41:24,309 --> 00:41:21,839

a hundred hundreds of millions of years

1279

00:41:26,150 --> 00:41:24,319

later when this uh region was subject to

1280

00:41:27,910 --> 00:41:26,160

some alteration or another then you

1281

00:41:30,950 --> 00:41:27,920

would expect to get a very unreasonable

1282

00:41:35,109 --> 00:41:30,960

age if if you get a a nice isochron at

1283

00:41:37,910 --> 00:41:35,119

all so this is a great um test of the

1284

00:41:39,750 --> 00:41:37,920

primacy of this signal

1285

00:41:41,510 --> 00:41:39,760

and this work was done by brian kendall

1286

00:41:43,270 --> 00:41:41,520

and rob kreiser at university of alberta

1287

00:41:45,030 --> 00:41:43,280

brian was actually a visiting student at

1288

00:41:46,710 --> 00:41:45,040

asu learning how to work with molybdenum

1289

00:41:48,309 --> 00:41:46,720

isotopes when we were studying these

1290

00:41:50,309 --> 00:41:48,319

rocks and he asked if he could take some

1291

00:41:51,349 --> 00:41:50,319

samples back to geranium osmium on

1292

00:41:53,589 --> 00:41:51,359

because that's what he'd been doing for

1293

00:41:55,349 --> 00:41:53,599

the bulk of his phd thesis and this is

1294

00:41:56,470 --> 00:41:55,359

the data that he produced which

1295

00:41:58,230 --> 00:41:56,480

none of us suspected we could get

1296

00:41:59,990 --> 00:41:58,240

something so nice so here you're seeing

1297

00:42:03,270 --> 00:42:00,000

the osmium isotopes versus rhenium

1298

00:42:05,910 --> 00:42:03,280

osmium this is a classic uh iso uh way

1299

00:42:07,430 --> 00:42:05,920

of plotting a geochronologic data

1300

00:42:09,750 --> 00:42:07,440

and you're seeing and here you see the

1301
00:42:11,510 --> 00:42:09,760
various data points they form an array

1302
00:42:13,270 --> 00:42:11,520
because we've sampled what branded is

1303
00:42:15,190 --> 00:42:13,280
sampled

1304
00:42:16,950 --> 00:42:15,200
at different distances along the core in

1305
00:42:18,390 --> 00:42:16,960
order to get an array of

1306
00:42:19,910 --> 00:42:18,400
parent-to-daughter ratios which is

1307
00:42:21,430 --> 00:42:19,920
essential for building an isochrone this

1308
00:42:23,190 --> 00:42:21,440
way so these numbers correspond to

1309
00:42:25,829 --> 00:42:23,200
different depths in the core

1310
00:42:28,630 --> 00:42:25,839
um across about

1311
00:42:30,470 --> 00:42:28,640
15 meters or so of depth

1312
00:42:32,710 --> 00:42:30,480
which which spans that rhenium

1313
00:42:34,309 --> 00:42:32,720

enrichment interval and what you see is

1314

00:42:36,230 --> 00:42:34,319

they follow along a very nice array they

1315

00:42:37,430 --> 00:42:36,240

define a very tight isocon corresponding

1316

00:42:40,550 --> 00:42:37,440

to an age

1317

00:42:44,870 --> 00:42:40,560

of uh 2501 million years plus or minus

1318

00:42:46,390 --> 00:42:44,880

8.2 very very nice and tight isocron

1319

00:42:47,829 --> 00:42:46,400

and this falls very nicely within the

1320

00:42:49,190 --> 00:42:47,839

other constraints that exist for the age

1321

00:42:50,470 --> 00:42:49,200

of this section we knew it was around

1322

00:42:52,550 --> 00:42:50,480

two and a half billion years ago we knew

1323

00:42:54,390 --> 00:42:52,560

it was before the great oxidation event

1324

00:42:57,030 --> 00:42:54,400

and now we know quite clearly it's it's

1325

00:42:58,470 --> 00:42:57,040

almost smack dab at the archaean

1326
00:43:00,710 --> 00:42:58,480
protozoa boundary that's commonly

1327
00:43:02,390 --> 00:43:00,720
defined at 2.5 billion years ago

1328
00:43:04,630 --> 00:43:02,400
um so this is a spectacular conformation

1329
00:43:06,550 --> 00:43:04,640
both the age of this of this

1330
00:43:07,430 --> 00:43:06,560
sequence of rocks and of the fact that

1331
00:43:12,390 --> 00:43:07,440
um

1332
00:43:13,990 --> 00:43:12,400
metal variations we're seeing here are

1333
00:43:15,589 --> 00:43:14,000
primary to the rock they're not some

1334
00:43:17,589 --> 00:43:15,599
sort of alteration

1335
00:43:18,870 --> 00:43:17,599
product

1336
00:43:20,550 --> 00:43:18,880
now to get a little more sophisticated

1337
00:43:21,829 --> 00:43:20,560
in how we interpret the data

1338
00:43:23,589 --> 00:43:21,839

if you recall before we looked at a

1339

00:43:25,589 --> 00:43:23,599

bunch of modern sedimentary environments

1340

00:43:27,349 --> 00:43:25,599

i plotted molybdenum concentration

1341

00:43:29,910 --> 00:43:27,359

versus organic carbon content in

1342

00:43:31,349 --> 00:43:29,920

sediments so we can do the same here

1343

00:43:33,190 --> 00:43:31,359

and the reason to do this is because the

1344

00:43:34,790 --> 00:43:33,200

absolute molybdenum concentration may

1345

00:43:36,630 --> 00:43:34,800

vary as a function of the organic carbon

1346

00:43:38,550 --> 00:43:36,640

content in the rock so just looking at

1347

00:43:39,829 --> 00:43:38,560

the molybdenum concentration alone is

1348

00:43:41,829 --> 00:43:39,839

only seeing part of the story and you

1349

00:43:44,150 --> 00:43:41,839

could be fooled um looking at these

1350

00:43:45,589 --> 00:43:44,160

trends is is a bit more solid

1351
00:43:47,190 --> 00:43:45,599
so here's molybdenum versus total

1352
00:43:48,710 --> 00:43:47,200
organic carbon

1353
00:43:50,630 --> 00:43:48,720
this is the field defined by the modern

1354
00:43:52,710 --> 00:43:50,640
anoxic basins and also this devonian

1355
00:43:55,270 --> 00:43:52,720
trend these uh uh

1356
00:43:56,950 --> 00:43:55,280
paleozoic black shales

1357
00:43:58,870 --> 00:43:56,960
and what you see here here's the data

1358
00:44:01,510 --> 00:43:58,880
from this s2 unit the lower unit the

1359
00:44:03,109 --> 00:44:01,520
unit has very little molybdenum and it

1360
00:44:04,950 --> 00:44:03,119
it has actually although it's much less

1361
00:44:06,390 --> 00:44:04,960
organic carbon than the upper unit so

1362
00:44:07,829 --> 00:44:06,400
the axis we're down here around values

1363
00:44:09,670 --> 00:44:07,839

of five this is actually a quite high

1364

00:44:11,829 --> 00:44:09,680

amount of organic carbon for uh for a

1365

00:44:13,990 --> 00:44:11,839

sedimentary rock this is a black shale

1366

00:44:15,510 --> 00:44:14,000

and in the younger record if you saw a

1367

00:44:16,950 --> 00:44:15,520

rock with five percent organic carbon

1368

00:44:18,710 --> 00:44:16,960

you'd have molybdenum concentrations

1369

00:44:20,390 --> 00:44:18,720

that are way up here

1370

00:44:22,069 --> 00:44:20,400

um however that's not what we have in

1371

00:44:23,829 --> 00:44:22,079

this s2 unit we have a very shallow

1372

00:44:25,190 --> 00:44:23,839

slope here in other words even as the

1373

00:44:27,750 --> 00:44:25,200

organic carbon content was varying

1374

00:44:29,990 --> 00:44:27,760

around from from uh two to two percent

1375

00:44:32,069 --> 00:44:30,000

to six or seven percent the aluminum

1376

00:44:34,150 --> 00:44:32,079

concentration was staying very low

1377

00:44:36,150 --> 00:44:34,160

and this says to us that that during

1378

00:44:37,270 --> 00:44:36,160

this period of time these sedum the

1379

00:44:38,710 --> 00:44:37,280

water column that these sediments

1380

00:44:41,030 --> 00:44:38,720

accumulated in look very different from

1381

00:44:43,190 --> 00:44:41,040

the water column of younger sediments

1382

00:44:45,270 --> 00:44:43,200

younger analogous sediments in the sense

1383

00:44:46,710 --> 00:44:45,280

of having much less molybdenum content

1384

00:44:48,470 --> 00:44:46,720

in the water column

1385

00:44:50,550 --> 00:44:48,480

as you go into the s1 unit as i

1386

00:44:51,910 --> 00:44:50,560

mentioned we subdivided in we split it

1387

00:44:53,990 --> 00:44:51,920

in half and each half has a slightly

1388

00:44:55,990 --> 00:44:54,000

different trend but each half has a

1389

00:44:58,550 --> 00:44:56,000

quite respectable trend considering the

1390

00:44:59,990 --> 00:44:58,560

antiquity of these rocks

1391

00:45:01,109 --> 00:45:00,000

the correlation coefficients are quite

1392

00:45:02,150 --> 00:45:01,119

reasonable

1393

00:45:04,790 --> 00:45:02,160

and you can see that these trends

1394

00:45:06,710 --> 00:45:04,800

actually approach those of modern anoxic

1395

00:45:08,790 --> 00:45:06,720

basins they're lower

1396

00:45:10,150 --> 00:45:08,800

but they are they do approach them

1397

00:45:11,510 --> 00:45:10,160

so what we're seeing here it looks like

1398

00:45:13,829 --> 00:45:11,520

is a transition from a world in which

1399

00:45:15,829 --> 00:45:13,839

the oceans had very little molybdenum to

1400

00:45:17,990 --> 00:45:15,839

a world in which uh it's very hard to

1401

00:45:19,270 --> 00:45:18,000

explain these data unless the water

1402

00:45:22,150 --> 00:45:19,280

column in which these sediments

1403

00:45:23,670 --> 00:45:22,160

accumulated had a appreciable amount of

1404

00:45:25,589 --> 00:45:23,680

molybdenum dissolved in it that's the

1405

00:45:27,589 --> 00:45:25,599

only way you can get these relationships

1406

00:45:29,030 --> 00:45:27,599

as far as we understand right now so it

1407

00:45:31,030 --> 00:45:29,040

looks like we have a transition from one

1408

00:45:33,430 --> 00:45:31,040

world to another world as we go from

1409

00:45:34,870 --> 00:45:33,440

this array to either of these arrays

1410

00:45:36,150 --> 00:45:34,880

there may be a slight change between

1411

00:45:37,589 --> 00:45:36,160

these two

1412

00:45:39,270 --> 00:45:37,599

and we could discuss that a bit i don't

1413

00:45:40,870 --> 00:45:39,280

want to pin too much on that

1414

00:45:41,990 --> 00:45:40,880

but clearly this world was different

1415

00:45:44,630 --> 00:45:42,000

from this world with respect to the

1416

00:45:46,630 --> 00:45:44,640

molybdenum content of the oceans

1417

00:45:48,309 --> 00:45:46,640

and arguably it's certainly a reasonable

1418

00:45:50,390 --> 00:45:48,319

interpretation to say that that change

1419

00:45:51,910 --> 00:45:50,400

in aluminum concentrations reflects a

1420

00:45:53,910 --> 00:45:51,920

change in the oxidation state of the

1421

00:45:55,430 --> 00:45:53,920

environment which could be well be due

1422

00:45:56,550 --> 00:45:55,440

to change the amount of oxygen in the

1423

00:45:58,550 --> 00:45:56,560

environment

1424

00:46:00,069 --> 00:45:58,560

we can argue nuances of that but that's

1425

00:46:02,150 --> 00:46:00,079

certainly a reasonable story and so the

1426
00:46:04,630 --> 00:46:02,160
notion would be that we we have captured

1427
00:46:07,349 --> 00:46:04,640
here at 2.5 billion years ago a

1428
00:46:09,190 --> 00:46:07,359
transition from a situation in which the

1429
00:46:10,470 --> 00:46:09,200
oceans were very low in molybdenum

1430
00:46:12,309 --> 00:46:10,480
because the environment was very low in

1431
00:46:14,790 --> 00:46:12,319
oxygen to a world in which there was

1432
00:46:16,790 --> 00:46:14,800
perhaps more oxygen available

1433
00:46:19,589 --> 00:46:16,800
now i should stress that i've presented

1434
00:46:20,790 --> 00:46:19,599
this all so far in terms of a world and

1435
00:46:23,190 --> 00:46:20,800
we really don't know that we're looking

1436
00:46:24,470 --> 00:46:23,200
at one location at one period of time

1437
00:46:26,870 --> 00:46:24,480
it's quite possible that what we're

1438
00:46:28,710 --> 00:46:26,880

seeing is a very local phenomenon you

1439

00:46:29,670 --> 00:46:28,720

could imagine a a

1440

00:47:22,550 --> 00:46:29,680

a

1441

00:47:24,470 --> 00:47:22,560

oxygen present in the environment even

1442

00:47:27,349 --> 00:47:24,480

if only locally

1443

00:47:29,349 --> 00:47:27,359

2.5 billion years ago which is 100

1444

00:47:31,349 --> 00:47:29,359

million years or so before

1445

00:47:32,870 --> 00:47:31,359

the great oxidation event really takes

1446

00:47:34,470 --> 00:47:32,880

off

1447

00:47:35,829 --> 00:47:34,480

now you might ask how much oxygen are we

1448

00:47:36,630 --> 00:47:35,839

talking about how much do we need to do

1449

00:47:37,910 --> 00:47:36,640

this

1450

00:47:39,510 --> 00:47:37,920

and there they're

1451

00:47:40,710 --> 00:47:39,520

that's that's a very hard thing to get a

1452

00:47:42,470 --> 00:47:40,720

handle on

1453

00:47:44,390 --> 00:47:42,480

um but we go we've gone about it in this

1454

00:47:45,670 --> 00:47:44,400

way um this it's the simplest thing

1455

00:47:47,190 --> 00:47:45,680

about the only thing that we can do

1456

00:47:49,430 --> 00:47:47,200

easily right now

1457

00:47:51,349 --> 00:47:49,440

we can ask ourselves if if molybdenum

1458

00:47:55,510 --> 00:47:51,359

and rhenium are carried in sulfide

1459

00:47:57,430 --> 00:47:55,520

minerals like like iron pyrite here

1460

00:47:58,790 --> 00:47:57,440

we can ask ourselves how much oxygen do

1461

00:48:00,870 --> 00:47:58,800

we need to start to change the

1462

00:48:02,309 --> 00:48:00,880

weathering behavior of these minerals

1463

00:48:03,910 --> 00:48:02,319

how much oxygen

1464

00:48:06,470 --> 00:48:03,920

do we need to start liberating lots of

1465

00:48:08,470 --> 00:48:06,480

molybdenum uranium from igneous rocks if

1466

00:48:09,510 --> 00:48:08,480

the molybdenum are present in the form

1467

00:48:11,990 --> 00:48:09,520

of

1468

00:48:15,109 --> 00:48:12,000

molybdenum sulfides or molybdenum and

1469

00:48:16,950 --> 00:48:15,119

rhenium associated with pyrite or other

1470

00:48:18,470 --> 00:48:16,960

sulfide minerals

1471

00:48:19,750 --> 00:48:18,480

and this is fool's gold so i suppose we

1472

00:48:21,349 --> 00:48:19,760

should be careful that we aren't on a

1473

00:48:22,710 --> 00:48:21,359

fool's errand than doing this but it's

1474

00:48:24,870 --> 00:48:22,720

something we can at least try to do to

1475

00:48:26,470 --> 00:48:24,880

get a handle on how much oxygen

1476

00:48:28,870 --> 00:48:26,480

it turns out there are very few studies

1477

00:48:30,549 --> 00:48:28,880

of the rate of weathering of sulfides as

1478

00:48:33,109 --> 00:48:30,559

a function of the amount of oxygen but

1479

00:48:34,470 --> 00:48:33,119

there is one study from the early 1990s

1480

00:48:35,829 --> 00:48:34,480

by williamson and rinstead that looks

1481

00:48:38,390 --> 00:48:35,839

pretty good that other workers in the

1482

00:48:39,750 --> 00:48:38,400

field have also made use of

1483

00:48:41,670 --> 00:48:39,760

so they looked at the weathering rate of

1484

00:48:43,670 --> 00:48:41,680

pyrite as a function of oxygen and from

1485

00:48:46,309 --> 00:48:43,680

from the the function that they derived

1486

00:48:47,430 --> 00:48:46,319

you can make a plot like this

1487

00:48:48,710 --> 00:48:47,440

which is which is answering the

1488

00:48:50,470 --> 00:48:48,720

following question

1489

00:48:52,390 --> 00:48:50,480

let's imagine that i have a pyrite

1490

00:48:55,750 --> 00:48:52,400

nodule that's a pyrite a grain that's

1491

00:48:57,270 --> 00:48:55,760

about 100 microns in size a pyrite cube

1492

00:48:59,270 --> 00:48:57,280

that's sort of a typical size you might

1493

00:49:02,230 --> 00:48:59,280

find in a igneous rock

1494

00:49:04,150 --> 00:49:02,240

and let's ask how long in years will

1495

00:49:06,790 --> 00:49:04,160

that pyrite grain last

1496

00:49:08,470 --> 00:49:06,800

um when exposed to oxygen

1497

00:49:09,589 --> 00:49:08,480

to oxygenated waters where the oxygen in

1498

00:49:11,430 --> 00:49:09,599

the atmosphere is at these different

1499

00:49:13,109 --> 00:49:11,440

partial pressures

1500

00:49:14,309 --> 00:49:13,119

and what you do if you use if you look

1501

00:49:16,390 --> 00:49:14,319

at their paper and use their functions

1502

00:49:18,230 --> 00:49:16,400

you obtain a line like this

1503

00:49:19,910 --> 00:49:18,240

and the message here is that even with

1504

00:49:21,910 --> 00:49:19,920

very low amounts of oxygen 10 to the

1505

00:49:24,230 --> 00:49:21,920

minus 5 or even 10 to the minus 6 of the

1506

00:49:26,390 --> 00:49:24,240

present atmospheric level

1507

00:49:27,829 --> 00:49:26,400

that pyrite grain is going to fall apart

1508

00:49:30,790 --> 00:49:27,839

is going to dissolve to nothing within

1509

00:49:32,390 --> 00:49:30,800

10 to 100 000 years which geologically

1510

00:49:35,349 --> 00:49:32,400

speaking in a weathering context is

1511

00:49:37,270 --> 00:49:35,359

fairly fast fairly fast so the idea here

1512

00:49:39,510 --> 00:49:37,280

is that you don't need very much oxygen

1513

00:49:41,190 --> 00:49:39,520

to cause pyrite grains of this size to

1514

00:49:42,710 --> 00:49:41,200

weather very rapidly much more rapidly

1515

00:49:44,870 --> 00:49:42,720

than they did before

1516

00:49:46,150 --> 00:49:44,880

and so this is why we suspect um that

1517

00:49:47,430 --> 00:49:46,160

the amount of oxygen that we need to

1518

00:49:48,710 --> 00:49:47,440

explain this is actually very small

1519

00:49:50,950 --> 00:49:48,720

that's why we talk about this in terms

1520

00:49:53,270 --> 00:49:50,960

of a width of oxygen we're not talking

1521

00:49:55,270 --> 00:49:53,280

about a 2.5 billion years of shift to an

1522

00:49:57,510 --> 00:49:55,280

oxygenated planet we're not talking

1523

00:49:59,430 --> 00:49:57,520

about a percent of the modern oxygen

1524

00:50:00,470 --> 00:49:59,440

level let alone something uh close to

1525

00:50:04,069 --> 00:50:00,480

the modern oxygen level we're talking

1526

00:50:05,829 --> 00:50:04,079

about something very small um but um but

1527

00:50:08,069 --> 00:50:05,839

more than what was there before because

1528

00:50:09,750 --> 00:50:08,079

before this this excursion to metal

1529

00:50:13,030 --> 00:50:09,760

concentration it looks like there was

1530

00:50:14,710 --> 00:50:13,040

little or no uh uh even even less oxygen

1531

00:50:17,430 --> 00:50:14,720

around if we can infer from this

1532

00:50:18,470 --> 00:50:17,440

molybdenum proxy

1533

00:50:20,470 --> 00:50:18,480

and a little bit of strengthening of

1534

00:50:21,990 --> 00:50:20,480

this idea comes from looking at the

1535

00:50:23,829 --> 00:50:22,000

uranium as well as the rhenium and

1536

00:50:25,510 --> 00:50:23,839

molybdenum so i've mentioned uranium

1537

00:50:27,589 --> 00:50:25,520

several times as we've gone along here

1538

00:50:28,870 --> 00:50:27,599

i've said it's similar to molybdenum but

1539

00:50:29,910 --> 00:50:28,880

i've always hedged that and said it's a

1540

00:50:31,190 --> 00:50:29,920

little different

1541

00:50:32,470 --> 00:50:31,200

and and

1542

00:50:34,069 --> 00:50:32,480

as you can see here when we actually

1543

00:50:35,750 --> 00:50:34,079

look at the uranium

1544

00:50:37,510 --> 00:50:35,760

through this drill core

1545

00:50:38,950 --> 00:50:37,520

at high resolution

1546

00:50:40,150 --> 00:50:38,960

we don't see anything like the feature

1547

00:50:42,150 --> 00:50:40,160

that we see in molybdenum and rhenium

1548

00:50:43,670 --> 00:50:42,160

abundances somehow the uranium is

1549

00:50:46,069 --> 00:50:43,680

behaving differently

1550

00:50:47,510 --> 00:50:46,079

and we're we think we hypothesize anyway

1551

00:50:49,510 --> 00:50:47,520

that the story here has to do with the

1552

00:50:50,950 --> 00:50:49,520

fact that the oxygen level is very low

1553

00:50:52,309 --> 00:50:50,960

and the fact that uranium rhenium and

1554

00:50:53,589 --> 00:50:52,319

molybdenum actually have some

1555

00:50:55,109 --> 00:50:53,599

differences in their chemistry when

1556

00:50:56,870 --> 00:50:55,119

oxygen is very low

1557

00:50:59,109 --> 00:50:56,880

one of the primary differences is the

1558

00:51:01,430 --> 00:50:59,119

carrier mineral of these metals in

1559

00:51:02,950 --> 00:51:01,440

igneous rocks so as i said molybdenum

1560

00:51:04,950 --> 00:51:02,960

and rhenium are found in sulfide

1561

00:51:07,349 --> 00:51:04,960

minerals which are very susceptible to

1562

00:51:08,790 --> 00:51:07,359

oxidative weathering uranium though in

1563

00:51:10,710 --> 00:51:08,800

igneous rocks is primarily found in

1564

00:51:12,069 --> 00:51:10,720

feldspars and zircons and various

1565

00:51:14,549 --> 00:51:12,079

minerals that are not nearly as

1566

00:51:16,069 --> 00:51:14,559

susceptible to oxygen so if you imagine

1567

00:51:18,230 --> 00:51:16,079

a world where there's very little oxygen

1568

00:51:20,390 --> 00:51:18,240

around essentially anoxic

1569

00:51:22,710 --> 00:51:20,400

and then you introduce a whiff of oxygen

1570

00:51:24,870 --> 00:51:22,720

um quote unquote 10 to the minus 5 or of

1571

00:51:26,950 --> 00:51:24,880

the modern level something like that

1572

00:51:28,549 --> 00:51:26,960

you will start to oxidize sulfides you

1573

00:51:29,990 --> 00:51:28,559

will significantly perturb the

1574

00:51:31,750 --> 00:51:30,000

molybdenum and rhenium budgets of the

1575

00:51:33,910 --> 00:51:31,760

ocean but you won't significantly

1576

00:51:36,710 --> 00:51:33,920

perturb the uranium budget of the ocean

1577

00:51:37,829 --> 00:51:36,720

um either locally or globally and that's

1578

00:51:39,030 --> 00:51:37,839

one of the ways that uranium is

1579

00:51:40,870 --> 00:51:39,040

different from living and uranium there

1580

00:51:41,990 --> 00:51:40,880

are other ways that also factor in in

1581

00:51:43,829 --> 00:51:42,000

the same way

1582

00:51:45,510 --> 00:51:43,839

that all point in the direction of of

1583

00:51:47,589 --> 00:51:45,520

arguing that we have evidence of a small

1584

00:51:49,109 --> 00:51:47,599

amount of oxygen enough to perturb these

1585

00:51:50,950 --> 00:51:49,119

elements budgets but not enough to

1586

00:51:51,990 --> 00:51:50,960

perturb the uranium budget and somewhere

1587

00:51:53,030 --> 00:51:52,000

in here if we could get more

1588

00:51:54,230 --> 00:51:53,040

quantitative about these various

1589

00:51:55,430 --> 00:51:54,240

weathering rates of minerals we could

1590

00:51:57,190 --> 00:51:55,440

probably actually put a much tighter

1591

00:51:58,390 --> 00:51:57,200

constraint than what i've done so far on

1592

00:52:00,630 --> 00:51:58,400

the amount of oxygen that might have

1593

00:52:02,309 --> 00:52:00,640

been around

1594

00:52:04,069 --> 00:52:02,319

and i'd be remiss if i didn't stress

1595

00:52:06,150 --> 00:52:04,079

that what's it the message from the

1596

00:52:07,349 --> 00:52:06,160

companion paper kaufman at all as i

1597

00:52:09,430 --> 00:52:07,359

mentioned there's two papers published

1598

00:52:10,549 --> 00:52:09,440

in science at the end of september one

1599

00:52:12,630 --> 00:52:10,559

focus on the metals that's what i've

1600

00:52:14,390 --> 00:52:12,640

dwelt on here the other paper focuses on

1601
00:52:15,829 --> 00:52:14,400
mass independent sulfur isotopes which

1602
00:52:17,829 --> 00:52:15,839
are a

1603
00:52:19,910 --> 00:52:17,839
an hour plus lecture unto themselves so

1604
00:52:21,270 --> 00:52:19,920
i can't do this justice

1605
00:52:23,109 --> 00:52:21,280
but for those who are familiar with this

1606
00:52:25,589 --> 00:52:23,119
i want to point out that the sulfur

1607
00:52:28,230 --> 00:52:25,599
isotopes also show

1608
00:52:30,390 --> 00:52:28,240
distinct changes that couple very nicely

1609
00:52:32,790 --> 00:52:30,400
to what we're seeing with the metals

1610
00:52:35,750 --> 00:52:32,800
so here's plotted this two parameters

1611
00:52:38,230 --> 00:52:35,760
the cap delta 33 sulfur versus the uh

1612
00:52:39,270 --> 00:52:38,240
delta 34 sulfur again i'm not going to

1613
00:52:41,990 --> 00:52:39,280

explain this because it would take an

1614

00:52:44,710 --> 00:52:42,000

hour to do so but notice that the down

1615

00:52:47,190 --> 00:52:44,720

here the data fall along a well-defined

1616

00:52:49,349 --> 00:52:47,200

array here this is in the lower unit

1617

00:52:50,710 --> 00:52:49,359

this lower black shell unit

1618

00:52:52,230 --> 00:52:50,720

the data follow along this this

1619

00:52:53,910 --> 00:52:52,240

well-defined array

1620

00:52:56,549 --> 00:52:53,920

but when you go up to the upper black

1621

00:52:58,309 --> 00:52:56,559

shell units something that that that

1622

00:53:01,030 --> 00:52:58,319

the data

1623

00:53:03,109 --> 00:53:01,040

array changes markedly the array you see

1624

00:53:05,750 --> 00:53:03,119

down here is typical of what's seen in

1625

00:53:07,990 --> 00:53:05,760

archaeal uh sediments this is very

1626
00:53:09,910 --> 00:53:08,000
unusual and the simplest explanation if

1627
00:53:12,390 --> 00:53:09,920
you follow through all the the details

1628
00:53:14,309 --> 00:53:12,400
of logic um the simple explanation for

1629
00:53:16,790 --> 00:53:14,319
this transition is that there is a turn

1630
00:53:18,309 --> 00:53:16,800
on from here to here of an oxidative

1631
00:53:19,750 --> 00:53:18,319
part of the sulfur cycle that we start

1632
00:53:21,430 --> 00:53:19,760
to oxidize

1633
00:53:22,630 --> 00:53:21,440
reduce sulfur compounds in the surface

1634
00:53:24,069 --> 00:53:22,640
ocean

1635
00:53:26,069 --> 00:53:24,079
to make

1636
00:53:28,069 --> 00:53:26,079
sulfate which can then again be

1637
00:53:30,230 --> 00:53:28,079
re-reduced in a reducing basin to give

1638
00:53:33,270 --> 00:53:30,240

us this particular isotopic signal it's

1639

00:53:35,030 --> 00:53:33,280

a slightly complicated story um but uh

1640

00:53:36,790 --> 00:53:35,040

and so i'm not i can't possibly go into

1641

00:53:38,470 --> 00:53:36,800

it here but suffice to say there's a big

1642

00:53:39,750 --> 00:53:38,480

change here and this the most

1643

00:53:42,390 --> 00:53:39,760

straightforward interpretation although

1644

00:53:43,990 --> 00:53:42,400

it is not a simple interpretation

1645

00:53:46,069 --> 00:53:44,000

in and of itself is that this is

1646

00:53:48,950 --> 00:53:46,079

consistent with this change in oxidation

1647

00:53:51,829 --> 00:53:48,960

state in the environment

1648

00:53:53,829 --> 00:53:51,839

you can also plot the capital delta 36

1649

00:53:55,270 --> 00:53:53,839

against capital delta 33 these are two

1650

00:53:56,470 --> 00:53:55,280

mass independent signatures plotted

1651
00:53:58,230 --> 00:53:56,480
against each other

1652
00:54:00,309 --> 00:53:58,240
and you see that in the lower unit the

1653
00:54:01,670 --> 00:54:00,319
data fall along this array here

1654
00:54:02,950 --> 00:54:01,680
and the upper unit they follow along at

1655
00:54:03,910 --> 00:54:02,960
this array with a somewhat different

1656
00:54:05,510 --> 00:54:03,920
slope

1657
00:54:07,030 --> 00:54:05,520
and this is indicative of some sort of

1658
00:54:09,510 --> 00:54:07,040
change in the atmospheric chemistry of

1659
00:54:11,829 --> 00:54:09,520
sulfur that we don't fully understand um

1660
00:54:13,510 --> 00:54:11,839
but it is it is certainly suggestive it

1661
00:54:16,470 --> 00:54:13,520
well it's indicative of some sort of

1662
00:54:18,710 --> 00:54:16,480
change in in atmospheric chemistry um

1663
00:54:19,910 --> 00:54:18,720

which may well uh couple with the notion

1664

00:54:22,470 --> 00:54:19,920

of there being a little bit of oxygen

1665

00:54:24,549 --> 00:54:22,480

around changing the the speciation of

1666

00:54:27,109 --> 00:54:24,559

gases in the atmosphere the final thing

1667

00:54:29,030 --> 00:54:27,119

to take away from this figure is the the

1668

00:54:30,390 --> 00:54:29,040

axis over here so so over here we're

1669

00:54:32,390 --> 00:54:30,400

looking at the lower and upper unit in

1670

00:54:34,630 --> 00:54:32,400

the mount mcrae shale this western

1671

00:54:36,069 --> 00:54:34,640

australian black shale

1672

00:54:37,670 --> 00:54:36,079

but the data that i've shown you here

1673

00:54:39,990 --> 00:54:37,680

are actually a compilation that includes

1674

00:54:44,470 --> 00:54:40,000

data from our drill core as well as data

1675

00:54:47,510 --> 00:54:45,910

and um

1676

00:54:49,990 --> 00:54:47,520

what you see is that the two data sets

1677

00:54:51,510 --> 00:54:50,000

on both these basins both

1678

00:54:53,510 --> 00:54:51,520

both the south african basin and the

1679

00:54:55,589 --> 00:54:53,520

western australian basin show the same

1680

00:54:58,069 --> 00:54:55,599

sort of trends and that is at least

1681

00:54:59,430 --> 00:54:58,079

suggestive of um

1682

00:55:01,510 --> 00:54:59,440

the effects we're seeing not being

1683

00:55:03,430 --> 00:55:01,520

simply in one small isolated basin but

1684

00:55:04,790 --> 00:55:03,440

perhaps being global now there's debate

1685

00:55:06,069 --> 00:55:04,800

about this because it's not entirely

1686

00:55:07,910 --> 00:55:06,079

clear that these two basins one in

1687

00:55:10,390 --> 00:55:07,920

western australia one in south africa

1688

00:55:11,589 --> 00:55:10,400

were actually uh very far apart two and

1689

00:55:13,349 --> 00:55:11,599

a half billion years ago they may have

1690

00:55:15,430 --> 00:55:13,359

been part of one large basin at that

1691

00:55:17,349 --> 00:55:15,440

time um but it's what you got to work

1692

00:55:19,430 --> 00:55:17,359

with so it's it's where it's it's what

1693

00:55:20,790 --> 00:55:19,440

you look at and it's lee suggested that

1694

00:55:23,030 --> 00:55:20,800

there could have been a more widespread

1695

00:55:24,309 --> 00:55:23,040

effect than uh than you might otherwise

1696

00:55:25,430 --> 00:55:24,319

think

1697

00:55:27,750 --> 00:55:25,440

so to take us back to our initial

1698

00:55:30,309 --> 00:55:27,760

motivation here's our cartoon of oxygen

1699

00:55:32,390 --> 00:55:30,319

in the environment through time um

1700

00:55:34,790 --> 00:55:32,400

uh the sort of canonical story that most

1701

00:55:36,470 --> 00:55:34,800

people will uh uh

1702

00:55:38,150 --> 00:55:36,480

recite you who are who are knowledgeable

1703

00:55:39,829 --> 00:55:38,160

about the field and what we think we

1704

00:55:42,470 --> 00:55:39,839

find here is that so here's the the

1705

00:55:45,109 --> 00:55:42,480

great oxidation event um starting around

1706

00:55:46,470 --> 00:55:45,119

2.4 and really taking off around 2.3 um

1707

00:55:49,750 --> 00:55:46,480

what we think is that we have evidence

1708

00:55:51,910 --> 00:55:49,760

now of a whiff of oxygen at 2.5 billion

1709

00:55:53,349 --> 00:55:51,920

years ago here at this point in time and

1710

00:55:56,069 --> 00:55:53,359

you put this together with the biomarker

1711

00:55:59,190 --> 00:55:56,079

evidence in the fifths

1712

00:56:01,270 --> 00:55:59,200

and you start to start to have increased

1713

00:56:02,230 --> 00:56:01,280

confidence in the notion that oxygen may

1714

00:56:04,549 --> 00:56:02,240

well have been present in the

1715

00:56:06,470 --> 00:56:04,559

environment uh well before the great

1716

00:56:08,630 --> 00:56:06,480

oxidation event and we think we've also

1717

00:56:09,829 --> 00:56:08,640

here developed a novel strategy for

1718

00:56:11,670 --> 00:56:09,839

going about looking for evidence of that

1719

00:56:13,190 --> 00:56:11,680

oxygen we very much like to look at

1720

00:56:14,789 --> 00:56:13,200

other sediments of greater antiquity and

1721

00:56:17,349 --> 00:56:14,799

see how far back this particular

1722

00:56:18,710 --> 00:56:17,359

signature might go

1723

00:56:20,150 --> 00:56:18,720

and the final thought i want to leave

1724

00:56:22,470 --> 00:56:20,160

you with is that as we think more and

1725

00:56:24,150 --> 00:56:22,480

more and get get better data and data as

1726
00:56:25,910 --> 00:56:24,160
we have now at high temporal resolution

1727
00:56:28,950 --> 00:56:25,920
looking at high resolution in the drill

1728
00:56:31,030 --> 00:56:28,960
core through time in the archaean i

1729
00:56:34,150 --> 00:56:31,040
think we probably need to start to shift

1730
00:56:36,470 --> 00:56:34,160
our vision of um of

1731
00:56:38,390 --> 00:56:36,480
of what the debate is all about when we

1732
00:56:40,470 --> 00:56:38,400
talk about oxygen in the ancient

1733
00:56:42,230 --> 00:56:40,480
environment the archaean environment the

1734
00:56:44,470 --> 00:56:42,240
debate is often depicted in a cartoon

1735
00:56:46,630 --> 00:56:44,480
fashion between those who argue for an

1736
00:56:48,870 --> 00:56:46,640
anoxic world and those who argue for an

1737
00:56:50,390 --> 00:56:48,880
oxygenated world

1738
00:56:52,309 --> 00:56:50,400

if you read the papers carefully even

1739

00:56:54,230 --> 00:56:52,319

between partisans in that debate you see

1740

00:56:56,390 --> 00:56:54,240

that it's actually not so simple that

1741

00:56:58,069 --> 00:56:56,400

that anoxic never really means no oxygen

1742

00:56:59,589 --> 00:56:58,079

or rarely means no oxygen it can mean

1743

00:57:01,270 --> 00:56:59,599

but not necessarily

1744

00:57:02,549 --> 00:57:01,280

and those who argue for an oxygenated

1745

00:57:03,750 --> 00:57:02,559

environment often are talking about

1746

00:57:05,190 --> 00:57:03,760

something that is a percent of the

1747

00:57:07,990 --> 00:57:05,200

modern or maybe even a bit less has

1748

00:57:09,910 --> 00:57:08,000

oxygenated but but but that's in detail

1749

00:57:11,510 --> 00:57:09,920

if you step back the argument often is

1750

00:57:13,190 --> 00:57:11,520

is between those who say lots of oxygen

1751
00:57:14,390 --> 00:57:13,200
and those who say none and i think in

1752
00:57:16,390 --> 00:57:14,400
the archaean we need to have a somewhat

1753
00:57:17,589 --> 00:57:16,400
more sophisticated view of things and

1754
00:57:19,190 --> 00:57:17,599
and i'm trying to embody that here in

1755
00:57:20,230 --> 00:57:19,200
this figure here so this is a picture

1756
00:57:23,670 --> 00:57:20,240
not of the r key and this is of the

1757
00:57:26,150 --> 00:57:23,680
modern or the recent um from zero to

1758
00:57:29,190 --> 00:57:26,160
650 000 years ago you're looking here at

1759
00:57:31,750 --> 00:57:29,200
data of carbon dioxide and methane in

1760
00:57:33,829 --> 00:57:31,760
antarctic ice cores right so we know

1761
00:57:35,670 --> 00:57:33,839
very well from the modern that these

1762
00:57:36,789 --> 00:57:35,680
gases are trace gases in the modern

1763
00:57:38,870 --> 00:57:36,799

environment

1764

00:57:40,710 --> 00:57:38,880

um present parts per million and parts

1765

00:57:41,829 --> 00:57:40,720

per billion concentrations in the in the

1766

00:57:43,589 --> 00:57:41,839

atmosphere

1767

00:57:45,270 --> 00:57:43,599

and they're variable

1768

00:57:47,990 --> 00:57:45,280

right now you wouldn't say that the

1769

00:57:49,990 --> 00:57:48,000

modern atmosphere is amethanic

1770

00:57:51,510 --> 00:57:50,000

um but the amount of methane is indeed

1771

00:57:53,030 --> 00:57:51,520

very low but it's there's enough there

1772

00:57:55,349 --> 00:57:53,040

that we actually worry about it quite a

1773

00:57:58,069 --> 00:57:55,359

bit and you wouldn't say that the modern

1774

00:57:59,430 --> 00:57:58,079

atmosphere is devoid of carbon dioxide

1775

00:58:01,109 --> 00:57:59,440

even though it's present as a fairly

1776

00:58:02,549 --> 00:58:01,119

trace constituent

1777

00:58:04,150 --> 00:58:02,559

it's even though it's trace it's still

1778

00:58:06,470 --> 00:58:04,160

significant in its impact on the

1779

00:58:08,150 --> 00:58:06,480

environment and i think that oxygen in

1780

00:58:10,549 --> 00:58:08,160

the archaean is probably somewhat of the

1781

00:58:12,390 --> 00:58:10,559

same thing i i think we we need to open

1782

00:58:13,990 --> 00:58:12,400

our minds to the possibility anyway that

1783

00:58:16,309 --> 00:58:14,000

oxygenic photosynthesis might be quite

1784

00:58:18,470 --> 00:58:16,319

ancient um that oxygen that other

1785

00:58:21,109 --> 00:58:18,480

factors beyond the evolution of oxygen

1786

00:58:23,510 --> 00:58:21,119

oxygen photosynthesis kept oxygen low

1787

00:58:25,430 --> 00:58:23,520

for a billion years or more

1788

00:58:26,870 --> 00:58:25,440

and that during that time oxygen behave

1789

00:58:29,190 --> 00:58:26,880

in the atmosphere very much as methane

1790

00:58:31,589 --> 00:58:29,200

and co2 do now that was present in low

1791

00:58:33,109 --> 00:58:31,599

amounts in variable amounts amounts that

1792

00:58:34,390 --> 00:58:33,119

may have been very highly variable

1793

00:58:36,069 --> 00:58:34,400

geographically

1794

00:58:37,829 --> 00:58:36,079

but it was there and some of the debates

1795

00:58:39,349 --> 00:58:37,839

we have between various proxies may not

1796

00:58:41,349 --> 00:58:39,359

be nearly as black and white as we like

1797

00:58:43,829 --> 00:58:41,359

to think it may well be that the amount

1798

00:58:45,589 --> 00:58:43,839

of oxygen bounces around um

1799

00:58:46,870 --> 00:58:45,599

too low to trip one proxy but high

1800

00:58:49,349 --> 00:58:46,880

enough to trip another and then back and

1801
00:58:51,270 --> 00:58:49,359
forth and back and forth and i suspect

1802
00:58:52,870 --> 00:58:51,280
that as we dig deeper and deeper into

1803
00:58:55,430 --> 00:58:52,880
the archaean record we'll emerge with a

1804
00:58:58,309 --> 00:58:55,440
picture somewhat like this of oxygen is

1805
00:59:01,270 --> 00:58:58,319
a biogenic trace gas bouncing around um

1806
00:59:04,710 --> 00:59:01,280
uh various values always low but but

1807
00:59:06,789 --> 00:59:04,720
often but uh often present

1808
00:59:08,950 --> 00:59:06,799
and uh i'll leave you with just a set of

1809
00:59:10,309 --> 00:59:08,960
conclusions i won't walk through them um

1810
00:59:11,589 --> 00:59:10,319
other than to say that we have in

1811
00:59:12,870 --> 00:59:11,599
progress a number of other studies that

1812
00:59:14,789 --> 00:59:12,880
haven't gone into here because there's

1813
00:59:16,390 --> 00:59:14,799

simply no time we're looking at iron

1814

00:59:17,750 --> 00:59:16,400

isotope data we're looking at libnam and

1815

00:59:18,710 --> 00:59:17,760

other isotopes i want to stress in

1816

00:59:20,390 --> 00:59:18,720

particular i should have mentioned this

1817

00:59:21,349 --> 00:59:20,400

the outset that almost all the metal

1818

00:59:22,710 --> 00:59:21,359

data you've seen here have been

1819

00:59:25,670 --> 00:59:22,720

generated by

1820

00:59:28,390 --> 00:59:25,680

my phd student yun dwan and uh

1821

00:59:30,069 --> 00:59:28,400

co-workers here at asu gail arnold no

1822

00:59:32,710 --> 00:59:30,079

longer asu but recent until recently at

1823

00:59:34,549 --> 00:59:32,720

asu and gwyneth gordon and jun is also

1824

00:59:36,390 --> 00:59:34,559

working as part of her thesis on iron

1825

00:59:38,069 --> 00:59:36,400

isotopes and libido isotopes which show

1826

00:59:39,750 --> 00:59:38,079

variations that i'm not comfortable

1827

00:59:41,829 --> 00:59:39,760

sharing in a very public forum like this

1828

00:59:43,829 --> 00:59:41,839

yet but show variations that are quite

1829

00:59:45,589 --> 00:59:43,839

uh sympathetic with the story that i've

1830

00:59:47,349 --> 00:59:45,599

been uh outlining for you up to this

1831

00:59:48,230 --> 00:59:47,359

point so we're looking at other proxies

1832

00:59:49,829 --> 00:59:48,240

we're starting to look at other

1833

00:59:51,349 --> 00:59:49,839

locations in more detail look at that

1834

00:59:53,910 --> 00:59:51,359

south african base in more detail from

1835

00:59:55,510 --> 00:59:53,920

metal content and uh the story so the

1836

00:59:58,150 --> 00:59:55,520

story that you've heard today i think is

1837

00:59:59,589 --> 00:59:58,160

just the first of a richer story to come

1838

01:00:02,549 --> 00:59:59,599

so thanks i'll be glad to take any

1839

01:00:02,559 --> 01:00:06,870

okay ariel thank you very much

1840

01:00:12,470 --> 01:00:10,150

for a great talk and a very clear one uh

1841

01:00:14,309 --> 01:00:12,480

would anybody around the net who has

1842

01:00:15,990 --> 01:00:14,319

questions please raise your hand on

1843

01:00:17,829 --> 01:00:16,000

webex and while you're doing that

1844

01:00:19,750 --> 01:00:17,839

there's a question here at nai central

1845

01:00:21,030 --> 01:00:19,760

from david morrison

1846

01:00:23,109 --> 01:00:21,040

hi there ariel

1847

01:00:24,230 --> 01:00:23,119

thanks very much um

1848

01:00:25,430 --> 01:00:24,240

now i can tell who that is in that

1849

01:00:26,309 --> 01:00:25,440

little picture there

1850

01:00:28,870 --> 01:00:26,319

right

1851

01:00:33,349 --> 01:00:28,880

uh i'm curious about this the period of

1852

01:00:35,109 --> 01:00:33,359

time between 2.5 and 2.3 or so you

1853

01:00:37,750 --> 01:00:35,119

talked about why you couldn't go lower

1854

01:00:39,990 --> 01:00:37,760

in this drill car but is there data from

1855

01:00:42,390 --> 01:00:40,000

the drill car to indicate whether this

1856

01:00:44,630 --> 01:00:42,400

whiff stays around goes up and down or

1857

01:00:45,829 --> 01:00:44,640

whatever in the subsequent uh 200

1858

01:00:47,829 --> 01:00:45,839

million years

1859

01:00:50,789 --> 01:00:47,839

sure sure well this drill core we can't

1860

01:00:51,829 --> 01:00:50,799

really go much much younger

1861

01:00:53,670 --> 01:00:51,839

we're basically looking at the upper

1862

01:00:54,870 --> 01:00:53,680

part that we can that we can work on it

1863

01:00:56,470 --> 01:00:54,880

was it

1864

01:00:58,390 --> 01:00:56,480

that's just the nature of this core

1865

01:01:00,150 --> 01:00:58,400

these there is a south african drill

1866

01:01:01,990 --> 01:01:00,160

core project um

1867

01:01:03,829 --> 01:01:02,000

uh funded by a private foundation the

1868

01:01:05,510 --> 01:01:03,839

agron foundation which actually more or

1869

01:01:08,069 --> 01:01:05,520

less starts where this core leaves off

1870

01:01:10,390 --> 01:01:08,079

and works its way up in time and that's

1871

01:01:11,990 --> 01:01:10,400

what we're eager to dig into in part um

1872

01:01:14,710 --> 01:01:12,000

the story gets a bit more complicated

1873

01:01:17,670 --> 01:01:14,720

because that south african core is

1874

01:01:18,870 --> 01:01:17,680

is from uh a different faces this the

1875

01:01:20,630 --> 01:01:18,880

sediments there were laid down in

1876

01:01:22,390 --> 01:01:20,640

shallower water and so whether those are

1877

01:01:24,470 --> 01:01:22,400

the right whether they provide the right

1878

01:01:26,309 --> 01:01:24,480

kind of environment for sequestering

1879

01:01:27,670 --> 01:01:26,319

molybdenum in the same way so whether we

1880

01:01:29,109 --> 01:01:27,680

could be comparing apples and apples

1881

01:01:30,630 --> 01:01:29,119

apples and oranges is not clear but

1882

01:01:32,549 --> 01:01:30,640

that's that's one of the directions

1883

01:01:34,069 --> 01:01:32,559

we're going in um within this core

1884

01:01:35,829 --> 01:01:34,079

though i mean it is

1885

01:01:37,109 --> 01:01:35,839

you know we look let me find the right

1886

01:01:40,230 --> 01:01:37,119

figure here

1887

01:01:42,150 --> 01:01:40,240

that's this one i want so as i i tried

1888

01:01:43,990 --> 01:01:42,160

to stress but it's worth um

1889

01:01:45,990 --> 01:01:44,000

stressing again so so you look at these

1890

01:01:47,109 --> 01:01:46,000

data and you see this this this

1891

01:01:49,109 --> 01:01:47,119

excursion

1892

01:01:50,950 --> 01:01:49,119

and um it's very tempting especially

1893

01:01:52,549 --> 01:01:50,960

when you use a word like with to imagine

1894

01:01:54,150 --> 01:01:52,559

that this is a transient phenomenon and

1895

01:01:56,390 --> 01:01:54,160

i even i even said that at the outset

1896

01:01:58,150 --> 01:01:56,400

that it might be transient and it might

1897

01:01:59,670 --> 01:01:58,160

be somewhat transient but if you look at

1898

01:02:00,789 --> 01:01:59,680

this in detail

1899

01:02:03,109 --> 01:02:00,799

i tried to stress before i'm going to

1900

01:02:04,470 --> 01:02:03,119

stress it again the malignant enrichment

1901
01:02:06,390 --> 01:02:04,480
factors

1902
01:02:07,589 --> 01:02:06,400
here are very very low

1903
01:02:11,430 --> 01:02:07,599
up here

1904
01:02:13,190 --> 01:02:11,440
they're not as high as they are here but

1905
01:02:14,870 --> 01:02:13,200
they're not so low it looks like there

1906
01:02:16,710 --> 01:02:14,880
was molybdenum in the environment in the

1907
01:02:19,589 --> 01:02:16,720
aqueous environment here more so than

1908
01:02:21,510 --> 01:02:19,599
there was down here so and if you look

1909
01:02:22,950 --> 01:02:21,520
at the molybdenum um to organic carbon

1910
01:02:24,069 --> 01:02:22,960
ratio

1911
01:02:25,190 --> 01:02:24,079
here

1912
01:02:26,390 --> 01:02:25,200
as i mentioned i don't want to make too

1913
01:02:27,270 --> 01:02:26,400

much of it but

1914

01:02:29,510 --> 01:02:27,280

um

1915

01:02:31,990 --> 01:02:29,520

you go from this unit at the very bottom

1916

01:02:33,589 --> 01:02:32,000

to this here this is the lower part of

1917

01:02:34,390 --> 01:02:33,599

the upper unit where the big excursion

1918

01:02:36,710 --> 01:02:34,400

happens

1919

01:02:38,150 --> 01:02:36,720

and then as you go up you you settle

1920

01:02:39,670 --> 01:02:38,160

down into this slope here which is a

1921

01:02:41,430 --> 01:02:39,680

little shallower but it's still much

1922

01:02:42,630 --> 01:02:41,440

steeper than what's down here this is a

1923

01:02:44,870 --> 01:02:42,640

more sophisticated way of saying the

1924

01:02:46,870 --> 01:02:44,880

same thing that what comes after that

1925

01:02:48,870 --> 01:02:46,880

excursion is still different than what

1926

01:02:50,710 --> 01:02:48,880

came before and and what we say in the

1927

01:02:52,150 --> 01:02:50,720

paper is that this may well have been we

1928

01:02:54,950 --> 01:02:52,160

may all be seeing an irreversible

1929

01:02:56,230 --> 01:02:54,960

transition of some sort here um

1930

01:02:58,630 --> 01:02:56,240

uh so

1931

01:03:00,230 --> 01:02:58,640

you know bets are off but but it's quite

1932

01:03:01,670 --> 01:03:00,240

possible that that's what what we're

1933

01:03:04,789 --> 01:03:01,680

seeing here is

1934

01:03:09,190 --> 01:03:06,549

yeah that's great but it still tells me

1935

01:03:11,270 --> 01:03:09,200

you need more data in those uh couple of

1936

01:03:14,549 --> 01:03:11,280

hundred million years before this

1937

01:03:14,559 --> 01:03:19,029

we need more drilling

1938

01:03:19,039 --> 01:03:22,230

penn state has a question

1939

01:03:26,710 --> 01:03:25,270

yeah hi hi ariel this is jim casting i i

1940

01:03:31,510 --> 01:03:26,720

like your story

1941

01:03:34,069 --> 01:03:31,520

wondering about the implications when

1942

01:03:37,190 --> 01:03:34,079

you talk about a whiff of oxygen there

1943

01:03:39,990 --> 01:03:37,200

you compared oxygen in the uh reduced

1944

01:03:42,710 --> 01:03:40,000

archaean atmosphere to methane in the ox

1945

01:03:45,109 --> 01:03:42,720

in the present oxygenic atmosphere

1946

01:03:46,870 --> 01:03:45,119

it's it's a good analogy in some way i

1947

01:03:48,549 --> 01:03:46,880

think but on the other hand there's a

1948

01:03:50,549 --> 01:03:48,559

significant difference and that's that

1949

01:03:52,150 --> 01:03:50,559

today you've got oxygen and ozone so a

1950

01:03:54,630 --> 01:03:52,160

good uv screen

1951

01:03:57,190 --> 01:03:54,640

back then if you didn't then

1952

01:04:00,230 --> 01:03:57,200

the photolysis rates are much faster and

1953

01:04:02,230 --> 01:04:00,240

so the lifetime of oxygen in a methane

1954

01:04:04,309 --> 01:04:02,240

rich atmosphere is much shorter than the

1955

01:04:06,549 --> 01:04:04,319

lifetime of methane in an oxygen-rich

1956

01:04:09,109 --> 01:04:06,559

atmosphere so i guess the difference in

1957

01:04:12,309 --> 01:04:09,119

my mind is that it's hard to have a very

1958

01:04:14,549 --> 01:04:12,319

low level level of oxygen like one one

1959

01:04:16,470 --> 01:04:14,559

ppm or something like that that's that's

1960

01:04:18,309 --> 01:04:16,480

a global signal it'll just be a plume

1961

01:04:20,470 --> 01:04:18,319

and i i think your whiff may actually be

1962

01:04:23,109 --> 01:04:20,480

bigger than you think

1963

01:04:25,190 --> 01:04:23,119

uh it could be or i mean i mean much of

1964

01:04:26,309 --> 01:04:25,200

the unless i'm wrong much of the logic

1965

01:04:28,549 --> 01:04:26,319

you just presented is in a sort of

1966

01:04:30,069 --> 01:04:28,559

steady state sense and you mentioned

1967

01:04:32,309 --> 01:04:30,079

plumes at the end so you could imagine

1968

01:04:33,990 --> 01:04:32,319

that you have a world where you have

1969

01:04:35,910 --> 01:04:34,000

plumes and wax of oxygen that aren't

1970

01:04:37,829 --> 01:04:35,920

very long-lived but they do get around

1971

01:04:39,349 --> 01:04:37,839

not globally perhaps but in the regional

1972

01:04:40,710 --> 01:04:39,359

sense and maybe that's what we're seeing

1973

01:04:42,870 --> 01:04:40,720

uh i don't know i mean like like all

1974

01:04:45,109 --> 01:04:42,880

analogies um you know it's poetry and

1975

01:04:46,470 --> 01:04:45,119

it's imperfect and i leave it to

1976

01:04:48,069 --> 01:04:46,480

those who think more deeply about the

1977

01:04:48,870 --> 01:04:48,079

atmospheric physics and chemistry to

1978

01:04:51,029 --> 01:04:48,880

really

1979

01:04:53,990 --> 01:04:51,039

dig into it but

1980

01:04:55,990 --> 01:04:54,000

but but the major point

1981

01:04:57,910 --> 01:04:56,000

we talked about this in our seminar here

1982

01:04:59,670 --> 01:04:57,920

last week and and uh you know the

1983

01:05:02,710 --> 01:04:59,680

question is what do you need to weather

1984

01:05:03,829 --> 01:05:02,720

molybdenum molybdenum which i can't say

1985

01:05:06,309 --> 01:05:03,839

properly

1986

01:05:08,470 --> 01:05:06,319

right but maybe maybe you do need a

1987

01:05:10,870 --> 01:05:08,480

global signal in which case maybe it's a

1988

01:05:13,270 --> 01:05:10,880

pretty big puff of oxygen

1989

01:05:14,470 --> 01:05:13,280

maybe maybe what we really need is is uh

1990

01:05:16,710 --> 01:05:14,480

well we need more drilling as david

1991

01:05:18,549 --> 01:05:16,720

alluded to but we also uh we need more

1992

01:05:19,910 --> 01:05:18,559

experimental work you know the amount of

1993

01:05:22,789 --> 01:05:19,920

experimental work that goes on that

1994

01:05:24,870 --> 01:05:22,799

actually tries to tie to archaean and

1995

01:05:26,950 --> 01:05:24,880

protozoa geochemistry is very small and

1996

01:05:28,150 --> 01:05:26,960

that's you know it would be nice to

1997

01:05:29,829 --> 01:05:28,160

to revisit the kind of thing that

1998

01:05:32,870 --> 01:05:29,839

williamson and rimstep did with with

1999

01:05:33,589 --> 01:05:32,880

pyrite um but with uh with more sulfides

2000

01:05:42,630 --> 01:05:33,599

and

2001

01:05:46,390 --> 01:05:44,309

ariel i've got a question that's a

2002

01:05:47,910 --> 01:05:46,400

little far afield and i'd encourage

2003

01:05:48,950 --> 01:05:47,920

other people to raise their hands on

2004

01:05:51,349 --> 01:05:48,960

webex

2005

01:05:54,470 --> 01:05:51,359

to ask questions as well

2006

01:05:57,029 --> 01:05:54,480

and that is that there has been work

2007

01:05:58,870 --> 01:05:57,039

particularly by dave dimaray's group

2008

01:06:00,470 --> 01:05:58,880

including dave and tori holler and brad

2009

01:06:02,710 --> 01:06:00,480

beabout about

2010

01:06:04,750 --> 01:06:02,720

the role that the production of reduced

2011

01:06:07,589 --> 01:06:04,760

gases may have played somewhat

2012

01:06:10,150 --> 01:06:07,599

counter-intuitively in oxidizing earth's

2013

01:06:12,069 --> 01:06:10,160

atmosphere in that these microbial

2014

01:06:14,470 --> 01:06:12,079

communities that exist today and

2015

01:06:16,549 --> 01:06:14,480

presumably existed uh in this time

2016

01:06:18,069 --> 01:06:16,559

period two and a half billion years ago

2017

01:06:19,430 --> 01:06:18,079

they were putting out oxygen during the

2018

01:06:21,990 --> 01:06:19,440

daytime but they were putting out

2019

01:06:23,829 --> 01:06:22,000

hydrogen and methane at night and that

2020

01:06:25,589 --> 01:06:23,839

hydrogen and methane goes up to the top

2021

01:06:28,230 --> 01:06:25,599

of the atmosphere the hydrogen escapes

2022

01:06:30,950 --> 01:06:28,240

and you have a net oxidation so

2023

01:06:33,990 --> 01:06:30,960

what do you think might be

2024

01:06:36,230 --> 01:06:34,000

the contribution or the balance between

2025

01:06:38,789 --> 01:06:36,240

the oxidation of the atmosphere by the

2026

01:06:41,750 --> 01:06:38,799

loss of hydrogen to space

2027

01:06:44,630 --> 01:06:41,760

versus the photosynthetic production of

2028

01:06:48,630 --> 01:06:44,640

molecular oxygen

2029

01:06:49,990 --> 01:06:48,640

um so you want a quantitative answer

2030

01:06:52,390 --> 01:06:50,000

any kind of answer you want to try

2031

01:06:53,829 --> 01:06:52,400

giving i i don't even have a qualitative

2032

01:06:55,430 --> 01:06:53,839

feel i mean i mean the loss of hydrogen

2033

01:06:57,990 --> 01:06:55,440

to space and you know there's a lot of

2034

01:07:00,069 --> 01:06:58,000

ideas you know lee comp is here online a

2035

01:07:01,910 --> 01:07:00,079

lot of good ideas leave an author of of

2036

01:07:05,430 --> 01:07:01,920

one of the better ones um

2037

01:07:07,349 --> 01:07:05,440

uh uh of what actually was changing to

2038

01:07:08,950 --> 01:07:07,359

cause a change of oxygen um the one

2039

01:07:11,829 --> 01:07:08,960

thing that we do know goes on is loss of

2040

01:07:14,470 --> 01:07:11,839

hydrogen to space right and so um that's

2041

01:07:16,150 --> 01:07:14,480

one that we can't avoid but

2042

01:07:17,589 --> 01:07:16,160

to actually try to quantify the relative

2043

01:07:19,430 --> 01:07:17,599

importance

2044

01:07:22,069 --> 01:07:19,440

i you know of the various policies

2045

01:07:24,150 --> 01:07:22,079

involved you know

2046

01:07:32,230 --> 01:07:24,160

tough problem maybe lee would like to

2047

01:07:35,109 --> 01:07:33,670

i think jim's the one who might want to

2048

01:07:37,190 --> 01:07:35,119

comment on that

2049

01:07:39,750 --> 01:07:37,200

i have a potential postdoc who wants to

2050

01:07:41,990 --> 01:07:39,760

work on that problem yeah

2051

01:07:43,430 --> 01:07:42,000

colin goldberg

2052

01:07:47,190 --> 01:07:43,440

so crawl for a little bit of money you

2053

01:07:47,200 --> 01:07:53,910

okay i hear you

2054

01:07:59,029 --> 01:07:56,870

okay we're going once going twice for

2055

01:08:02,630 --> 01:07:59,039

asking ariel questions or continuing

2056

01:08:06,549 --> 01:08:04,870

okay ariel i guess we will thank you

2057

01:08:12,069 --> 01:08:06,559

again for a great talk

2058

01:08:18,070 --> 01:08:14,789

okay remember the next director seminar

2059

01:08:20,309 --> 01:08:18,080

is i think four weeks from today

2060

01:08:22,070 --> 01:08:20,319

december 3rd and it will be by jeff

2061

01:08:25,669 --> 01:08:22,080

marcy and we're going to be hearing

2062

01:08:29,510 --> 01:08:25,679

about low mass extra solar planets so