EARTH-LIFE
SCIENCE
INSTITUTE

Shaunna Morrison

Mineral Evolution & Co-evolution with the Biosphere: Transition Element Availability Through Deep Time

1
00:00:00,720 --> 00:00:11,650
[Music]

2
00:00:15,620 --> 00:00:13,670
Thank You Donato and thank you all for

3
00:00:17,330 --> 00:00:15,630
being here I'm really excited to have

4
00:00:19,370 --> 00:00:17,340
the opportunity to talk to you about my

5
00:00:21,230 --> 00:00:19,380
work and the work of many of my

6
00:00:22,640 --> 00:00:21,240
colleagues and mineral evolution and the

7
00:00:28,819 --> 00:00:22,650
coevolution of the geosphere and

8
00:00:30,290 --> 00:00:28,829
biosphere and and much of the work

9
00:00:32,810 --> 00:00:30,300
you're going to be seeing here today is

10
00:00:35,780 --> 00:00:32,820
coming out of the Keck sponsored deep

11
00:00:38,060 --> 00:00:35,790
time data infrastructure project which

12
00:00:40,100 --> 00:00:38,070
has a great group of PI's including Bob

13
00:00:41,690 --> 00:00:40,110

Hazen and Peter Fox and also Paul

14
00:00:43,190 --> 00:00:41,700
Falkowski who's here today and is going

15
00:00:47,090 --> 00:00:43,200
to be giving us the keynote address

16
00:00:49,940 --> 00:00:47,100
tomorrow so one of the main aims of this

17
00:00:53,840 --> 00:00:49,950
project was to better understand the

18
00:00:57,560 --> 00:00:53,850
complex co-evolved amay data-driven

19
00:01:00,080 --> 00:00:57,570
perspective all too often

20
00:01:03,020 --> 00:01:00,090
biology and geology are treated very

21
00:01:04,999 --> 00:01:03,030
separately but as everyone here in this

22
00:01:08,390 --> 00:01:05,009
room well knows that's the wrong way to

23
00:01:10,999 --> 00:01:08,400
go about it because life evolved emerged

24
00:01:13,819 --> 00:01:11,009
and evolved in the presence of rocks and

25
00:01:17,539 --> 00:01:13,829
minerals and fluids and likewise life

26
00:01:19,730 --> 00:01:17,549
had a dramatic effect on the chemical

27
00:01:22,819 --> 00:01:19,740
landscape and therefore the geology and

28
00:01:24,770 --> 00:01:22,829
geochemistry of our planet so if you're

29
00:01:27,950 --> 00:01:24,780
more interested in this project you can

30
00:01:30,529 --> 00:01:27,960
certainly check out our website but the

31
00:01:32,989 --> 00:01:30,539
main goal of this project was to have a

32
00:01:35,179 --> 00:01:32,999
more holistic perspective of the

33
00:01:37,160 --> 00:01:35,189
evolution of our planet by integrating

34
00:01:39,739 --> 00:01:37,170
the large and growing geologic and

35
00:01:44,529 --> 00:01:39,749
biologic data resources in order to make

36
00:01:47,359 --> 00:01:44,539
discoveries that one field alone cannot

37
00:01:50,719 --> 00:01:47,369
so this project has been a particularly

38
00:01:53,510 --> 00:01:50,729

exciting for me as a mineralogist not a

39
00:01:55,910 --> 00:01:53,520
biologist as you will learn by my talk

40
00:01:58,699 --> 00:01:55,920
but it's been particularly exciting for

41
00:02:00,620 --> 00:01:58,709
me as a mineralogist because largely for

42
00:02:03,919 --> 00:02:00,630
a long time a neurology has been a very

43
00:02:06,199 --> 00:02:03,929
descriptive field we essentially go into

44
00:02:09,650 --> 00:02:06,209
the field or we synthesize minerals and

45
00:02:11,720 --> 00:02:09,660
we measure them and we describe them but

46
00:02:15,050 --> 00:02:11,730
we've largely for a while been somewhat

47
00:02:16,910 --> 00:02:15,060
removed from from geology and thinking

48
00:02:19,100 --> 00:02:16,920
about evolving systems and certainly far

49
00:02:21,290 --> 00:02:19,110
removed from life so it's been really

50
00:02:21,980 --> 00:02:21,300
exciting to me to see us go into a more

51
00:02:25,010 --> 00:02:21,990
predictive

52
00:02:28,610 --> 00:02:25,020
where we can do things like predict the

53
00:02:31,310 --> 00:02:28,620
number of missing mineral species using

54
00:02:33,070 --> 00:02:31,320
these mineral ecology studies we're also

55
00:02:36,230 --> 00:02:33,080
working on projects where we can

56
00:02:39,980 --> 00:02:36,240
pinpoint the specific location on

57
00:02:42,530 --> 00:02:39,990
Earth's surface of minerals and likewise

58
00:02:45,830 --> 00:02:42,540
of of knowing what minerals we expect to

59
00:02:47,180 --> 00:02:45,840
find at any specific location something

60
00:02:48,800 --> 00:02:47,190
that's going to be perhaps of more

61
00:02:51,370 --> 00:02:48,810
interest to everyone in this room is

62
00:02:54,050 --> 00:02:51,380
that we're also exploring the idea of

63
00:02:56,810 --> 00:02:54,060

earths mineral diversity and

64
00:02:58,310 --> 00:02:56,820
distribution as a planetary scale bio

65
00:03:00,740 --> 00:02:58,320
signature and I'm going to talk about

66
00:03:03,620 --> 00:03:00,750
that some more so we're not only making

67
00:03:05,270 --> 00:03:03,630
advances in mineralogy although I'm

68
00:03:07,430 --> 00:03:05,280
skewed towards that but we're also

69
00:03:09,200 --> 00:03:07,440
making advances and things like

70
00:03:14,660 --> 00:03:09,210
tectonics and the supercontinent cycles

71
00:03:17,300 --> 00:03:14,670
in paleo biology and in petrology so

72
00:03:19,010 --> 00:03:17,310
Eric asked us to think about some big

73
00:03:21,590 --> 00:03:19,020
questions that that we can address

74
00:03:25,400 --> 00:03:21,600
regarding this bridge between Earth and

75
00:03:27,950 --> 00:03:25,410
life so specifically the things I

76
00:03:29,750 --> 00:03:27,960
thought about where what do Earth's

77
00:03:30,980 --> 00:03:29,760
earliest environments look like that's

78
00:03:33,710 --> 00:03:30,990
something that we've been talking about

79
00:03:37,330 --> 00:03:33,720
a lot right then how do we actually

80
00:03:40,730 --> 00:03:37,340
tease out that information

81
00:03:45,530 --> 00:03:40,740
next do network topologies of minerals

82
00:03:48,170 --> 00:03:45,540
fossils proteins etc embed timelines now

83
00:03:51,320 --> 00:03:48,180
many of you geologists chemists

84
00:03:52,640 --> 00:03:51,330
your your a little bit more up on I'm

85
00:03:54,590 --> 00:03:52,650
sorry biologists in chemistry a little

86
00:03:57,020 --> 00:03:54,600
bit more up on using these kind of

87
00:03:59,150 --> 00:03:57,030
advanced analytical techniques geology

88
00:04:01,490 --> 00:03:59,160

is slowly trying to catch up with you so

89
00:04:04,010 --> 00:04:01,500
we're learning a lot now about embedded

90
00:04:06,800 --> 00:04:04,020
intrinsic time lines and and other

91
00:04:08,770 --> 00:04:06,810
features like chemistry and extinction

92
00:04:13,280 --> 00:04:08,780
events that we can get out of these

93
00:04:14,570 --> 00:04:13,290
analytical techniques next as I

94
00:04:16,400 --> 00:04:14,580
mentioned before is the mineral

95
00:04:18,470 --> 00:04:16,410
distribution that we're seeing on

96
00:04:20,180 --> 00:04:18,480
Earth's surface a planetary bio

97
00:04:24,640 --> 00:04:20,190
signature and can we use that in

98
00:04:27,440 --> 00:04:24,650
planetary evaluation and exploration and

99
00:04:29,960 --> 00:04:27,450
lastly and I really hope that this is

100
00:04:31,670 --> 00:04:29,970
true can geologic data reveal

101
00:04:36,010 --> 00:04:31,680
information about the emergence and

102
00:04:41,890 --> 00:04:38,620
so in my talk I'm going to stick to

103
00:04:42,850 --> 00:04:41,900
three topics the first is data resources

104
00:04:47,410 --> 00:04:42,860
I'm just going to go over that really

105
00:04:48,910 --> 00:04:47,420
quickly mineral evolution and mineral

106
00:04:52,090 --> 00:04:48,920
Network embedded features that we've

107
00:04:53,680 --> 00:04:52,100
been observing so first data resources

108
00:04:55,140 --> 00:04:53,690
just just to show you a few to give you

109
00:04:58,630 --> 00:04:55,150
some context of what we're working with

110
00:05:00,130 --> 00:04:58,640
the first is the rough project so this

111
00:05:02,680 --> 00:05:00,140
is one of the largest mineral databases

112
00:05:04,810 --> 00:05:02,690
and libraries in the world it's founded

113
00:05:07,690 --> 00:05:04,820

by my PhD advisor Bob Jones at the

114
00:05:09,820 --> 00:05:07,700
University of Arizona and it provides a

115
00:05:12,760 --> 00:05:09,830
set of very high quality

116
00:05:14,470 --> 00:05:12,770
spectral chemical and x-ray diffraction

117
00:05:17,800 --> 00:05:14,480
data in addition to some pictures and

118
00:05:20,530 --> 00:05:17,810
some references currently we have around

119
00:05:23,590 --> 00:05:20,540
3,500 distinct mineral species that we

120
00:05:28,090 --> 00:05:23,600
have characterized just for reference

121
00:05:29,980 --> 00:05:28,100
there are around 5300 so we've done over

122
00:05:33,430 --> 00:05:29,990
half and that number is continuing to

123
00:05:35,470 --> 00:05:33,440
grow right now we have over 10,000

124
00:05:37,990 --> 00:05:35,480
mineral species in the database in

125
00:05:39,640 --> 00:05:38,000
library and one of the great benefits of

126
00:05:40,900 --> 00:05:39,650
this is when you're looking at this

127
00:05:42,190 --> 00:05:40,910
chemical information and you're

128
00:05:45,130 --> 00:05:42,200
comparing it to the x-ray diffraction

129
00:05:46,780 --> 00:05:45,140
information you know that those those

130
00:05:49,330 --> 00:05:46,790
two pieces of information were gathered

131
00:05:51,760 --> 00:05:49,340
on the same sample as you know minerals

132
00:05:53,470 --> 00:05:51,770
show a lot of variation from from sample

133
00:05:55,780 --> 00:05:53,480
to sample aspect and it's certainly from

134
00:05:57,220 --> 00:05:55,790
location to location so it was important

135
00:05:59,080 --> 00:05:57,230
to us to make sure that we were

136
00:06:01,470 --> 00:05:59,090
collecting all of this information on

137
00:06:05,260 --> 00:06:01,480
the same sample so it's all consistent

138
00:06:07,900 --> 00:06:05,270

as a part of the rough project we have

139
00:06:09,390 --> 00:06:07,910
the list of officially approved minerals

140
00:06:13,030 --> 00:06:09,400
from the International mineralogical

141
00:06:16,240 --> 00:06:13,040
Association and on this website you can

142
00:06:18,370 --> 00:06:16,250
you can search for specific phases if

143
00:06:19,720 --> 00:06:18,380
you'd like like I said there are around

144
00:06:21,160 --> 00:06:19,730
five thousand three hundred of those

145
00:06:23,290 --> 00:06:21,170
today of course that number is

146
00:06:26,560 --> 00:06:23,300
continuing to grow as we find more and

147
00:06:28,060 --> 00:06:26,570
more minerals you can also use the

148
00:06:29,260 --> 00:06:28,070
searchable chemical feature so if you're

149
00:06:31,030 --> 00:06:29,270
interested in finding minerals that

150
00:06:33,940 --> 00:06:31,040
specifically have a certain composition

151
00:06:37,990 --> 00:06:33,950
or don't have a specific element you can

152
00:06:40,450 --> 00:06:38,000
also search on these these tags here and

153
00:06:42,220 --> 00:06:40,460
there's a lot of information you can get

154
00:06:43,510 --> 00:06:42,230
to from there if you're interested what

155
00:06:45,820 --> 00:06:43,520
I specifically want to tell you about

156
00:06:46,870 --> 00:06:45,830
today though is the mineral evolution

157
00:06:49,670 --> 00:06:46,880
database so that's this button right

158
00:06:52,300 --> 00:06:49,680
here in this database was too

159
00:06:55,070 --> 00:06:52,310
a number of years ago by a Bob Hazen and

160
00:06:56,990 --> 00:06:55,080
what your what you see in this database

161
00:06:59,540 --> 00:06:57,000
and this is just a tiny glimpse of it it

162
00:07:01,520 --> 00:06:59,550
represents countless hours of literature

163
00:07:03,050 --> 00:07:01,530

review most of which has been done by

164
00:07:05,090 --> 00:07:03,060
Josh golden at the University of Arizona

165
00:07:08,689 --> 00:07:05,100
and a number of undergraduates that he's

166
00:07:11,390 --> 00:07:08,699
trained in this process and what we have

167
00:07:13,159 --> 00:07:11,400
here is is locality information so

168
00:07:15,680 --> 00:07:13,169
geologic localities and the minerals

169
00:07:18,260 --> 00:07:15,690
that occur there and often and the goal

170
00:07:20,779 --> 00:07:18,270
is to also have Ages associated with

171
00:07:24,439 --> 00:07:20,789
that so currently we have almost a

172
00:07:26,029 --> 00:07:24,449
million mineral locality pairs and we

173
00:07:28,790 --> 00:07:26,039
have over a hundred and twenty thousand

174
00:07:33,529 --> 00:07:28,800
mineral locality age data so that's

175
00:07:35,150 --> 00:07:33,539
quite a lot of data for for minerals the

176
00:07:38,240 --> 00:07:35,160
next website I like to mention is MnDOT

177
00:07:40,400 --> 00:07:38,250
org this is a crowd-sourced website that

178
00:07:41,659 --> 00:07:40,410
gives a geologic locations some

179
00:07:43,730 --> 00:07:41,669
interesting information about them but

180
00:07:46,219 --> 00:07:43,740
what we're really interested in is the

181
00:07:49,070 --> 00:07:46,229
fact that we can extract what minerals

182
00:07:50,540 --> 00:07:49,080
are present at that location right now

183
00:07:53,600 --> 00:07:50,550
they have around a three hundred

184
00:07:55,760 --> 00:07:53,610
thousand localities and about a million

185
00:07:58,250 --> 00:07:55,770
mineral locality pairs so we also have a

186
00:07:59,890 --> 00:07:58,260
lot of a lot of data coming from here

187
00:08:02,510 --> 00:07:59,900
now I mentioned that this was

188
00:08:04,610 --> 00:08:02,520

crowd-sourced then maybe this gives some

189
00:08:08,240 --> 00:08:04,620
of you pause it did me I was concerned

190
00:08:10,310 --> 00:08:08,250
about the accuracy of this data but as

191
00:08:12,909 --> 00:08:10,320
anyone who works with really large data

192
00:08:16,550 --> 00:08:12,919
set is from data sets are familiar

193
00:08:18,529 --> 00:08:16,560
errors tend to average out now of course

194
00:08:20,390 --> 00:08:18,539
while while we feel that we're working

195
00:08:22,070 --> 00:08:20,400
with big data for mineralogy we

196
00:08:24,499 --> 00:08:22,080
recognize that these numbers are not

197
00:08:27,170 --> 00:08:24,509
very big and compared to the statistics

198
00:08:29,469 --> 00:08:27,180
that are generally being done so it was

199
00:08:31,939 --> 00:08:29,479
really important for us to test that

200
00:08:34,909 --> 00:08:31,949
that the errors truly were being

201
00:08:36,980 --> 00:08:34,919
averaged out so I mentioned the mineral

202
00:08:40,130 --> 00:08:36,990
of missing mineral predictions we can do

203
00:08:42,709 --> 00:08:40,140
earlier so what we did was we ran that

204
00:08:44,089 --> 00:08:42,719
model on a mineral data set that was

205
00:08:46,250 --> 00:08:44,099
strictly taken from peer-reviewed

206
00:08:49,069 --> 00:08:46,260
literature so absolutely confirmed

207
00:08:52,430 --> 00:08:49,079
mineral occurrences and then we compared

208
00:08:53,900 --> 00:08:52,440
it to what we found with MnDOT and it

209
00:08:56,240 --> 00:08:53,910
turns out that they produced the same

210
00:08:59,269 --> 00:08:56,250
result even on relatively small subsets

211
00:09:01,069 --> 00:08:59,279
of the data so we're pretty confident in

212
00:09:02,020 --> 00:09:01,079
in using men debt although we're still

213
00:09:05,200 --> 00:09:02,030

certainly careful

214
00:09:08,680 --> 00:09:05,210
anything that we do the next one I like

215
00:09:11,200 --> 00:09:08,690
to mention quickly is Earth chem ran by

216
00:09:13,720 --> 00:09:11,210
a Kirsten Leonard at Lamont and this is

217
00:09:17,110 --> 00:09:13,730
a great geochemical database where you

218
00:09:20,830 --> 00:09:17,120
can get bulk chemistry trace elements

219
00:09:24,010 --> 00:09:20,840
and ages on a plethora of rocks it's

220
00:09:27,250 --> 00:09:24,020
been huge for our tectonic studies paleo

221
00:09:30,280 --> 00:09:27,260
bio DB drew Musante and Mike Meyer have

222
00:09:34,180 --> 00:09:30,290
really utilized this fossil network and

223
00:09:37,240 --> 00:09:34,190
have also contributed to it and with

224
00:09:38,920 --> 00:09:37,250
that I will get out of the resources and

225
00:09:40,510 --> 00:09:38,930
I'll talk a bit about mineral evolution

226
00:09:42,790 --> 00:09:40,520
I think a number of the people in this

227
00:09:44,110 --> 00:09:42,800
room are probably familiar with this

228
00:09:46,300 --> 00:09:44,120
idea and maybe you've heard Bob talk

229
00:09:47,800 --> 00:09:46,310
about it but I wanted to mention it

230
00:09:50,290 --> 00:09:47,810
today because I think it gives us a good

231
00:09:52,890 --> 00:09:50,300
framework for what what we're thinking

232
00:09:55,900 --> 00:09:52,900
about in this symposium

233
00:09:57,880 --> 00:09:55,910
so first mineral evolution focuses on

234
00:10:01,840 --> 00:09:57,890
changes in Earth's mineralogy

235
00:10:04,120 --> 00:10:01,850
through deep time now I know that I'll

236
00:10:05,890 --> 00:10:04,130
probably get the question about the term

237
00:10:07,570 --> 00:10:05,900
evolution so I just want to go ahead and

238
00:10:10,600 --> 00:10:07,580

say straight away I'm not referring to

239
00:10:12,880 --> 00:10:10,610
Darwinian evolution I'm using a much

240
00:10:15,370 --> 00:10:12,890
simpler definition of the word which is

241
00:10:18,880 --> 00:10:15,380
simply a system changing through time so

242
00:10:21,250 --> 00:10:18,890
that's what I mean and that change

243
00:10:22,600 --> 00:10:21,260
through time happens as a result of new

244
00:10:24,550 --> 00:10:22,610
minerals forming through a combination

245
00:10:27,220 --> 00:10:24,560
of chemical physical and biological

246
00:10:32,800 --> 00:10:27,230
processes that are different at each

247
00:10:35,020 --> 00:10:32,810
stage of planetary evolution so first in

248
00:10:36,760 --> 00:10:35,030
the earliest minerals once the

249
00:10:39,940 --> 00:10:36,770
supernovae cooled enough to start

250
00:10:43,240 --> 00:10:39,950
forming some very 9 Nano and micro scale

251
00:10:45,160 --> 00:10:43,250
grains of minerals we had about twelve

252
00:10:48,550 --> 00:10:45,170
distinct mineral species so things like

253
00:10:51,310 --> 00:10:48,560
diamond graphite moissanite just very

254
00:10:52,540 --> 00:10:51,320
few once things started to cool a little

255
00:10:55,110 --> 00:10:52,550
bit further and we're forming

256
00:11:00,400 --> 00:10:55,120
planetesimals we can get up to around 60

257
00:11:02,770 --> 00:11:00,410
minerals and then once our planet is

258
00:11:06,130 --> 00:11:02,780
finally cooled enough to form a very

259
00:11:09,400 --> 00:11:06,140
primitive crust we get up to around 500

260
00:11:11,890 --> 00:11:09,410
minerals through further igneous

261
00:11:14,620 --> 00:11:11,900
evolution and differentiation we can get

262
00:11:14,960 --> 00:11:14,630
up to a thousand and then with the onset

263
00:11:18,019 --> 00:11:14,970

of

264
00:11:21,410 --> 00:11:18,029
tectonics that helps us achieve 1500

265
00:11:23,449 --> 00:11:21,420
distinct mineral species so at this

266
00:11:26,329 --> 00:11:23,459
point we've gone up through about 2.5

267
00:11:28,850 --> 00:11:26,339
billion years of Earth history but I

268
00:11:31,730 --> 00:11:28,860
said earlier that there are 5,300

269
00:11:35,990 --> 00:11:31,740
mineral species today so what happened

270
00:11:38,449 --> 00:11:36,000
in between that 2.5 billion years and

271
00:11:41,389 --> 00:11:38,459
now to give us this more more than a

272
00:11:44,480 --> 00:11:41,399
three-fold increase in mineral diversity

273
00:11:45,460 --> 00:11:44,490
and the answer to that is his life

274
00:11:48,249 --> 00:11:45,470
happened

275
00:11:51,619 --> 00:11:48,259
oxygen 'ok photosynthesis specifically

276
00:11:54,650 --> 00:11:51,629
so as you're all familiar with here is a

277
00:11:58,160 --> 00:11:54,660
graph of the oxygen fugacity through

278
00:12:00,019 --> 00:11:58,170
time and we can see at 2.5 the great

279
00:12:03,079 --> 00:12:00,029
oxidation event we see this dramatic

280
00:12:04,670 --> 00:12:03,089
increase in atmospheric oxygen now this

281
00:12:06,949 --> 00:12:04,680
completely changed the chemical

282
00:12:10,160 --> 00:12:06,959
landscape of the surface of the earth

283
00:12:12,340 --> 00:12:10,170
and it had a profound effect on on the

284
00:12:14,420 --> 00:12:12,350
mineralogy so just to give an example

285
00:12:18,069 --> 00:12:14,430
here we're looking at copper minerals

286
00:12:20,720 --> 00:12:18,079
and the oxygen fugacity of our

287
00:12:23,299 --> 00:12:20,730
environment of our surface was right at

288
00:12:25,220 --> 00:12:23,309

this line prior to the rise of

289
00:12:26,360 --> 00:12:25,230
atmospheric oxygen and what you can see

290
00:12:28,100 --> 00:12:26,370
here is it would have been very

291
00:12:30,679 --> 00:12:28,110
difficult to have the widespread

292
00:12:34,579 --> 00:12:30,689
formation of copper 1 plus or copper 2

293
00:12:37,790 --> 00:12:34,589
plus mineral species in fact more than

294
00:12:40,610 --> 00:12:37,800
400 of the 700 known copper mineral

295
00:12:43,369 --> 00:12:40,620
species would not have formed in those

296
00:12:44,990 --> 00:12:43,379
pre goe conditions it also means that

297
00:12:49,460 --> 00:12:45,000
things like copper 2 plus would not have

298
00:12:51,799 --> 00:12:49,470
been available for life to utilize so if

299
00:12:55,970 --> 00:12:51,809
we look at the mineralogical record we

300
00:13:01,269 --> 00:12:55,980
see that that trend is confirmed here we

301
00:13:03,980 --> 00:13:01,279
have a max age on the axis on the x axis

302
00:13:07,730 --> 00:13:03,990
decreasing to the right and then on the

303
00:13:08,780 --> 00:13:07,740
y-axis we have mineral occurrences so we

304
00:13:11,210 --> 00:13:08,790
can think of this as sort of like

305
00:13:12,379 --> 00:13:11,220
abundance we don't have mineral

306
00:13:14,929 --> 00:13:12,389
abundances because this is actually very

307
00:13:18,980 --> 00:13:14,939
hard to estimate and determine although

308
00:13:20,809 --> 00:13:18,990
we are working on that basically mining

309
00:13:22,639 --> 00:13:20,819
companies know how much of their

310
00:13:25,309 --> 00:13:22,649
minerals they have but aside from things

311
00:13:27,230 --> 00:13:25,319
that are not economically important it's

312
00:13:28,080 --> 00:13:27,240
really hard to estimate no one's really

313
00:13:29,520 --> 00:13:28,090

studying that so

314
00:13:32,420 --> 00:13:29,530
right for now we're going to use the

315
00:13:35,870 --> 00:13:32,430
number of occurrences on Earth's surface

316
00:13:38,370 --> 00:13:35,880
also in the these blue bars represent

317
00:13:40,470 --> 00:13:38,380
copper 1 plus minerals and the green

318
00:13:42,750 --> 00:13:40,480
bars represent copper 2 plus minerals

319
00:13:43,980 --> 00:13:42,760
and what I'd like you to focus on there

320
00:13:46,650 --> 00:13:43,990
a number of things we can see here but

321
00:13:50,010 --> 00:13:46,660
what I'd like you to focus on is the

322
00:13:52,260 --> 00:13:50,020
relationship and the ratio between the

323
00:13:55,080 --> 00:13:52,270
green bars to the blue bars in other

324
00:13:57,000 --> 00:13:55,090
words the oxidized copper species to the

325
00:13:58,890 --> 00:13:57,010
reduced copper species so let's just

326
00:14:01,680 --> 00:13:58,900
zoom in a little bit and what I'd like

327
00:14:03,180 --> 00:14:01,690
to point out that as we see a rise in

328
00:14:05,970 --> 00:14:03,190
atmospheric oxygen we see a steady

329
00:14:07,980 --> 00:14:05,980
increase in that ratio of oxidized

330
00:14:09,750 --> 00:14:07,990
copper phases to reduced copper phases

331
00:14:12,900 --> 00:14:09,760
which is exactly what we should see

332
00:14:14,580 --> 00:14:12,910
right there are a number of other things

333
00:14:17,730 --> 00:14:14,590
you might notice here questions you

334
00:14:20,640 --> 00:14:17,740
might have for instance you know why are

335
00:14:24,090 --> 00:14:20,650
these bars so much lower and a lot of

336
00:14:26,160 --> 00:14:24,100
that has to do with erosional bias how

337
00:14:28,920 --> 00:14:26,170
to quantify erosional bias is a much

338
00:14:30,090 --> 00:14:28,930

more difficult question to answer and

339
00:14:33,060 --> 00:14:30,100
that's something that my colleague Chao

340
00:14:35,280 --> 00:14:33,070
you and Simone Runyan are working on

341
00:14:37,800 --> 00:14:35,290
trying to figure out how much of what

342
00:14:40,610 --> 00:14:37,810
we're seeing here is erosional bias and

343
00:14:43,220 --> 00:14:40,620
also you'll notice that we have Peaks

344
00:14:47,070 --> 00:14:43,230
associated with the supercontinent

345
00:14:49,170 --> 00:14:47,080
assemblies and if you this is a really

346
00:14:50,880 --> 00:14:49,180
fascinating thing to think about I'm not

347
00:14:52,380 --> 00:14:50,890
going to go into it today but my

348
00:14:53,900 --> 00:14:52,390
colleague Chelle you just had a paper

349
00:14:56,490 --> 00:14:53,910
come out in Nature communications

350
00:14:58,340 --> 00:14:56,500
looking at this thinking about pulses of

351
00:14:59,940 --> 00:14:58,350
mineralization associated with these

352
00:15:02,220 --> 00:14:59,950
supercontinent assemblies are

353
00:15:03,810 --> 00:15:02,230
specifically thinking about Rodinia

354
00:15:05,130 --> 00:15:03,820
because it turns out that the road

355
00:15:06,810 --> 00:15:05,140
Indian supercontinent behaves a little

356
00:15:09,870 --> 00:15:06,820
bit differently so if you're interested

357
00:15:11,790 --> 00:15:09,880
in that please check out his paper and

358
00:15:14,250 --> 00:15:11,800
if we look at the other first row

359
00:15:15,540 --> 00:15:14,260
transition elements we see a similar

360
00:15:18,300 --> 00:15:15,550
trend so we're looking at things like

361
00:15:20,250 --> 00:15:18,310
iron and manganese and and cobalt and

362
00:15:22,620 --> 00:15:20,260
we're seeing that these exhibit really

363
00:15:26,760 --> 00:15:22,630

similar trends to what we saw with

364
00:15:28,830 --> 00:15:26,770
copper we went as far as to generate

365
00:15:30,360 --> 00:15:28,840
these diagrams for the whole periodic

366
00:15:33,990 --> 00:15:30,370
table I don't expect you to be able to

367
00:15:35,400 --> 00:15:34,000
to see this and we found that by and

368
00:15:36,510 --> 00:15:35,410
large these trends are true of most

369
00:15:39,660 --> 00:15:36,520
elements there are some notable

370
00:15:40,650 --> 00:15:39,670
differences as you would expect and if

371
00:15:41,910 --> 00:15:40,660
anyone's interested in actually

372
00:15:44,970 --> 00:15:41,920
exploring this each one of these

373
00:15:49,610 --> 00:15:44,980
is a high-resolution PDF so I can send

374
00:15:51,780 --> 00:15:49,620
this to you just just let me know now

375
00:15:54,750 --> 00:15:51,790
obviously I care about minerals because

376
00:15:57,690 --> 00:15:54,760
I'm a mineralogist but but why should

377
00:16:00,329 --> 00:15:57,700
you care about minerals aside from them

378
00:16:03,689 --> 00:16:00,339
just being generally interesting they

379
00:16:06,240 --> 00:16:03,699
also provide ancient samples so we don't

380
00:16:08,040 --> 00:16:06,250
have direct samples of the DNA from

381
00:16:10,829 --> 00:16:08,050
earliest organisms right we don't have

382
00:16:13,230 --> 00:16:10,839
examples of we don't have direct samples

383
00:16:16,170 --> 00:16:13,240
of the aqueous chemistry from those time

384
00:16:18,210 --> 00:16:16,180
periods but what we do have are rocks

385
00:16:20,730 --> 00:16:18,220
and minerals that formed during those

386
00:16:24,090 --> 00:16:20,740
time periods and in their formation they

387
00:16:25,889 --> 00:16:24,100
tell us a lot about the conditions that

388
00:16:28,290 --> 00:16:25,899

were ongoing during that time the

389
00:16:30,840 --> 00:16:28,300
chemical temperature pressure conditions

390
00:16:32,430 --> 00:16:30,850
so we can tease out a lot of information

391
00:16:34,379 --> 00:16:32,440
about what was happening during the time

392
00:16:39,720 --> 00:16:34,389
periods of interest simply by looking at

393
00:16:41,180 --> 00:16:39,730
rocks and minerals so we we think will

394
00:16:42,870 --> 00:16:41,190
also be able to characterize a

395
00:16:44,639 --> 00:16:42,880
bioavailability of these elements

396
00:16:49,230 --> 00:16:44,649
through time for instance you know when

397
00:16:51,449 --> 00:16:49,240
copper two-plus became available and we

398
00:16:53,610 --> 00:16:51,459
hope that we can also relate this to the

399
00:16:55,290 --> 00:16:53,620
timing relate the timing of elemental

400
00:16:57,720 --> 00:16:55,300
availability to the emergence of

401
00:17:01,410 --> 00:16:57,730
biological functions I'd like to mention

402
00:17:03,870 --> 00:17:01,420
one paper here by Eli Moore and you'll

403
00:17:06,960 --> 00:17:03,880
notice some some names of people in the

404
00:17:09,329 --> 00:17:06,970
crowd here Donato and Paul a paper that

405
00:17:11,039 --> 00:17:09,339
is thinking along these lines and I

406
00:17:13,230 --> 00:17:11,049
think that some of this work could could

407
00:17:13,679 --> 00:17:13,240
contribute to to their work in the

408
00:17:14,909 --> 00:17:13,689
future

409
00:17:16,890 --> 00:17:14,919
and they're looking at the metal

410
00:17:18,329 --> 00:17:16,900
availability of microbial tablet

411
00:17:20,370 --> 00:17:18,339
metabolisms and essentially they

412
00:17:24,150 --> 00:17:20,380
reconstructed the history of this metal

413
00:17:26,760 --> 00:17:24,160

utilization by identifying links between

414
00:17:30,570 --> 00:17:26,770
redox state metal availability and

415
00:17:31,919 --> 00:17:30,580
metabolic pathways so this is something

416
00:17:35,039 --> 00:17:31,929
that we could hopefully help with in the

417
00:17:37,370 --> 00:17:35,049
future one other study I'd like to point

418
00:17:40,380 --> 00:17:37,380
out is by Jana Bromberg at Rutgers

419
00:17:43,260 --> 00:17:40,390
thinking about protein evolution so here

420
00:17:46,049 --> 00:17:43,270
she's constructed a network of the

421
00:17:48,990 --> 00:17:46,059
structural similarity of metal binding

422
00:17:50,430 --> 00:17:49,000
sites and what is interesting and

423
00:17:52,940 --> 00:17:50,440
striking here is despite the fact that

424
00:17:54,900 --> 00:17:52,950
she didn't actually include the the

425
00:17:56,730 --> 00:17:54,910
metal in the layout

426
00:17:59,790 --> 00:17:56,740
when you overlay it with the color you

427
00:18:02,640 --> 00:17:59,800
see this very distinct line from iron to

428
00:18:03,990 --> 00:18:02,650
manganese to copper and she thinks that

429
00:18:06,720 --> 00:18:04,000
this we're actually looking at a time

430
00:18:08,040 --> 00:18:06,730
line here but of course we're looking at

431
00:18:09,870 --> 00:18:08,050
a relative time line right we can say

432
00:18:13,020 --> 00:18:09,880
okay well iron came before manganese

433
00:18:14,970 --> 00:18:13,030
came before copper but I hope in better

434
00:18:16,950 --> 00:18:14,980
constraining the availability of these

435
00:18:19,260 --> 00:18:16,960
elements through geologic time that

436
00:18:22,710 --> 00:18:19,270
perhaps we could help her put some

437
00:18:25,110 --> 00:18:22,720
absolute ages on this rather than than

438
00:18:26,850 --> 00:18:25,120

just relative so we're working on that

439
00:18:31,890 --> 00:18:26,860
with her and hope that we'll be able to

440
00:18:34,050 --> 00:18:31,900
do that now the last section I'd like to

441
00:18:36,540 --> 00:18:34,060
talk about is some of our mineral

442
00:18:40,950 --> 00:18:36,550
networks and the embedded features that

443
00:18:42,870 --> 00:18:40,960
we've observed therein first we have a

444
00:18:45,060 --> 00:18:42,880
network here of copper minerals so each

445
00:18:46,830 --> 00:18:45,070
of these nodes represents a copper

446
00:18:48,210 --> 00:18:46,840
mineral species they're colored

447
00:18:50,450 --> 00:18:48,220
according to their chemistry so the

448
00:18:56,520 --> 00:18:50,460
presence or absence of sulfur and oxygen

449
00:18:58,980 --> 00:18:56,530
so the red phases are sulfides the blue

450
00:19:03,720 --> 00:18:58,990
are carbonates and oxides and the

451
00:19:05,340 --> 00:19:03,730
sulfates are in yellow the nodes are

452
00:19:07,110 --> 00:19:05,350
sized according to the number of their

453
00:19:09,990 --> 00:19:07,120
localities so again we can think of this

454
00:19:12,030 --> 00:19:10,000
kind of like abundance and the links are

455
00:19:13,650 --> 00:19:12,040
scaled inversely proportional to the

456
00:19:15,660 --> 00:19:13,660
frequency of a current so if they occur

457
00:19:17,610 --> 00:19:15,670
together often they are closer together

458
00:19:20,160 --> 00:19:17,620
if they occur together less often they

459
00:19:23,550 --> 00:19:20,170
are farther apart and so the thing that

460
00:19:26,930 --> 00:19:23,560
immediately pops out here is their high

461
00:19:29,810 --> 00:19:26,940
degree of partitioning on chemistry and

462
00:19:33,300 --> 00:19:29,820
in fact we can actually draw an oxygen

463
00:19:35,600 --> 00:19:33,310

fugacity line directly onto this network

464
00:19:38,280 --> 00:19:35,610
and and onto the data behind it and

465
00:19:40,380 --> 00:19:38,290
likewise a sulfur fugacity and we think

466
00:19:42,510 --> 00:19:40,390
there are a lot more bits of information

467
00:19:46,410 --> 00:19:42,520
that we can tease out of these networks

468
00:19:48,360 --> 00:19:46,420
mmm next here's a similar copper Network

469
00:19:50,760 --> 00:19:48,370
and here we're looking at a structural

470
00:19:53,250 --> 00:19:50,770
complexity this is work that has been a

471
00:19:56,370 --> 00:19:53,260
pioneered by Sergey cravat Jeff at the

472
00:19:59,100 --> 00:19:56,380
kola scientific institute for the

473
00:20:01,140 --> 00:19:59,110
russian academy of sciences and here he

474
00:20:03,240 --> 00:20:01,150
has come up with a method for

475
00:20:06,230 --> 00:20:03,250
quantifying the complexity of mineral

476
00:20:09,680 --> 00:20:06,240
crystal structures and reporting that in

477
00:20:11,390 --> 00:20:09,690
bits of information and this is

478
00:20:14,840 --> 00:20:11,400
particularly interesting because he

479
00:20:17,810 --> 00:20:14,850
hypothesizes that minerals began as very

480
00:20:19,370 --> 00:20:17,820
simple structures and over time became

481
00:20:21,169 --> 00:20:19,380
more and more complex so this is

482
00:20:24,220 --> 00:20:21,179
something we're working with him to try

483
00:20:27,560 --> 00:20:24,230
and think about is this is this true and

484
00:20:30,260 --> 00:20:27,570
so if we look here at this network you

485
00:20:33,740 --> 00:20:30,270
can see the very simple and the simple

486
00:20:36,380 --> 00:20:33,750
structures tend to cluster more or less

487
00:20:38,270 --> 00:20:36,390
in this area while the intermediate tend

488
00:20:40,669 --> 00:20:38,280

to cluster here so we can say more or

489
00:20:42,919 --> 00:20:40,679
less we're seeing there's a trend but

490
00:20:44,810 --> 00:20:42,929
what's interesting is that that logic

491
00:20:47,299 --> 00:20:44,820
seems to fall apart when we're talking

492
00:20:49,610 --> 00:20:47,309
about these more complex and the very

493
00:20:51,380 --> 00:20:49,620
complex phases you know things like clay

494
00:20:53,330 --> 00:20:51,390
minerals and stuff they tend to be just

495
00:20:55,040 --> 00:20:53,340
kind of interspersed throughout the

496
00:20:57,560 --> 00:20:55,050
network so I'm not sure what to make of

497
00:20:59,600 --> 00:20:57,570
that so it holds to a certain point and

498
00:21:05,630 --> 00:20:59,610
then we're losing it so this is a this

499
00:21:07,520 --> 00:21:05,640
is an ongoing study the second are the

500
00:21:10,580 --> 00:21:07,530
the last network that I would like to

501
00:21:11,510 --> 00:21:10,590
show you is that of carbon minerals and

502
00:21:13,160 --> 00:21:11,520
so here it's a slightly different

503
00:21:15,169 --> 00:21:13,170
network it's bipartite so we have two

504
00:21:19,010 --> 00:21:15,179
different types of nodes again the

505
00:21:21,140 --> 00:21:19,020
colored nodes are carbon minerals they

506
00:21:22,880 --> 00:21:21,150
are colored and sized in this case and

507
00:21:26,299 --> 00:21:22,890
according to their number of localities

508
00:21:28,580 --> 00:21:26,309
and the black nodes represent the carbon

509
00:21:30,530 --> 00:21:28,590
mineral localities on Earth's surface so

510
00:21:33,320 --> 00:21:30,540
for instance this is the Kola Peninsula

511
00:21:36,290 --> 00:21:33,330
and Russia where we have a lot of a lot

512
00:21:38,480 --> 00:21:36,300
of carbon mineral species and these

513
00:21:40,130 --> 00:21:38,490

nodes are sized according to their

514
00:21:44,570 --> 00:21:40,140
mineral diversity so if the black nodes

515
00:21:48,620 --> 00:21:44,580
larger it has more species and I bring

516
00:21:50,960 --> 00:21:48,630
this up to make two points one is that

517
00:21:52,730 --> 00:21:50,970
we can explore those planetary scale bio

518
00:21:56,120 --> 00:21:52,740
signatures that I was talking about

519
00:22:00,169 --> 00:21:56,130
earlier and on the second is to show you

520
00:22:01,970 --> 00:22:00,179
an embedded timeline so first let's look

521
00:22:04,220 --> 00:22:01,980
at the bio signatures so here we're

522
00:22:07,010 --> 00:22:04,230
seeing a graphical representation of the

523
00:22:09,380 --> 00:22:07,020
distribution and diversity of Carbon

524
00:22:10,940 --> 00:22:09,390
minerals if we if I were to show you one

525
00:22:13,130 --> 00:22:10,950
for all minerals on earth it would look

526
00:22:15,620 --> 00:22:13,140
quite similar to this and this

527
00:22:17,290 --> 00:22:15,630
distribution is conforms to a large

528
00:22:19,820 --> 00:22:17,300
number of rare events or ln re

529
00:22:24,110 --> 00:22:19,830
distribution

530
00:22:25,610 --> 00:22:24,120
by the fact that most minerals like Koza

531
00:22:27,529 --> 00:22:25,620
white which is a lanthanum carbon and

532
00:22:31,789 --> 00:22:27,539
actually found here in Japan are rare

533
00:22:35,060 --> 00:22:31,799
and only a very few of them are common

534
00:22:37,009 --> 00:22:35,070
things like calcite and aragonite and so

535
00:22:40,039 --> 00:22:37,019
in this distribution if we show it in a

536
00:22:41,600 --> 00:22:40,049
bar graph follows this trend right here

537
00:22:44,320 --> 00:22:41,610
and with this model we're actually able

538
00:22:46,970 --> 00:22:44,330

to create an accumulation curve and

539
00:22:49,310 --> 00:22:46,980
predict the number of missing carbon

540
00:22:51,669 --> 00:22:49,320
mineral species or whatever set of

541
00:22:54,649 --> 00:22:51,679
minerals are interested in in this case

542
00:22:56,750 --> 00:22:54,659
when we developed this data in January

543
00:23:00,320 --> 00:22:56,760
2015 there were four hundred and three

544
00:23:01,990 --> 00:23:00,330
known carbon species and we predicted

545
00:23:03,200 --> 00:23:02,000
that there were a hundred and forty-five

546
00:23:06,500 --> 00:23:03,210
missing

547
00:23:09,340 --> 00:23:06,510
Carbon minerals and if I can digress a

548
00:23:12,379 --> 00:23:09,350
little bit this actually spurred a

549
00:23:15,289 --> 00:23:12,389
citizen science project where called the

550
00:23:16,580 --> 00:23:15,299
carbon mineral challenge where called

551
00:23:18,799 --> 00:23:16,590
mineral collectors and scientists alike

552
00:23:21,680 --> 00:23:18,809
were encouraged to actually go and find

553
00:23:23,960 --> 00:23:21,690
these 145 missing Carbon minerals that

554
00:23:27,440 --> 00:23:23,970
project started in 2016 and as of last

555
00:23:29,870 --> 00:23:27,450
month they'd found 12 new carbon mineral

556
00:23:31,460 --> 00:23:29,880
species so that's nearly ten percent of

557
00:23:33,259 --> 00:23:31,470
what was predicted and a number of these

558
00:23:35,899 --> 00:23:33,269
species were actually directly predicted

559
00:23:38,330 --> 00:23:35,909
in the paper so it's been exciting to to

560
00:23:40,909 --> 00:23:38,340
see this actually happening and making

561
00:23:43,669 --> 00:23:40,919
predictions and they're happening so now

562
00:23:46,870 --> 00:23:43,679
if I can come back to this bio signature

563
00:23:49,490 --> 00:23:46,880

idea again we're seeing this graphical

564
00:23:52,399 --> 00:23:49,500
representation of the distribution of

565
00:23:57,680 --> 00:23:52,409
minerals and as I said before Earth has

566
00:23:59,750 --> 00:23:57,690
around 5,300 mineral species now if we

567
00:24:02,899 --> 00:23:59,760
look at other planetary bodies that we

568
00:24:05,990 --> 00:24:02,909
have a feel for their mineral diversity

569
00:24:08,330 --> 00:24:06,000
we don't find and granted that data is

570
00:24:10,549 --> 00:24:08,340
limited we don't find that they have

571
00:24:11,930 --> 00:24:10,559
quite this many in fact they usually

572
00:24:13,730 --> 00:24:11,940
have on the order of hundreds rather

573
00:24:16,250 --> 00:24:13,740
than on the order of thousands and they

574
00:24:18,710 --> 00:24:16,260
certainly don't have these extremely

575
00:24:21,049 --> 00:24:18,720
rare species you know it's more these

576
00:24:22,820 --> 00:24:21,059
things that are just quite common this

577
00:24:24,620 --> 00:24:22,830
is certainly true of Mars where we can

578
00:24:28,190 --> 00:24:24,630
look at meteorite data and we can look

579
00:24:30,919 --> 00:24:28,200
at Rover mission data and we found that

580
00:24:33,039 --> 00:24:30,929
you know it's certainly less than 500

581
00:24:34,840 --> 00:24:33,049
minerals and we don't have that

582
00:24:37,389 --> 00:24:34,850
large amount of rare mineral species

583
00:24:39,759 --> 00:24:37,399
this is also true of the moon where we

584
00:24:46,259 --> 00:24:39,769
have Apollo mission samples where we see

585
00:24:50,590 --> 00:24:46,269
around fewer than 350 mineral species so

586
00:24:52,779 --> 00:24:50,600
what we know that this distribution on

587
00:24:57,129 --> 00:24:52,789
earth happened as a result of the rise

588
00:25:00,009 --> 00:24:57,139

of atmospheric oxygen due to life now

589
00:25:02,680 --> 00:25:00,019
and we know that when we look at planets

590
00:25:06,849 --> 00:25:02,690
our bodies that presumably didn't have

591
00:25:09,849 --> 00:25:06,859
life or didn't have advanced life that

592
00:25:13,299 --> 00:25:09,859
they don't look like this so the idea is

593
00:25:16,539 --> 00:25:13,309
that perhaps this signature is a

594
00:25:18,340 --> 00:25:16,549
planetary scale bio signature we don't

595
00:25:19,419 --> 00:25:18,350
know if that's true but we tend to think

596
00:25:20,769 --> 00:25:19,429
that that is the case so that's

597
00:25:22,389 --> 00:25:20,779
something that we always have in the

598
00:25:24,129 --> 00:25:22,399
back of our mind when we're when we're

599
00:25:28,060 --> 00:25:24,139
doing these studies and hope to pursue

600
00:25:32,859 --> 00:25:28,070
that idea further so the last thing I

601
00:25:35,440 --> 00:25:32,869
would like to mention on this is that

602
00:25:38,409 --> 00:25:35,450
here we have it's the same copper is the

603
00:25:39,759 --> 00:25:38,419
same carbon bipartite Network but I've

604
00:25:40,989 --> 00:25:39,769
colored the nodes a little bit

605
00:25:43,810 --> 00:25:40,999
differently so you'll see here they're

606
00:25:47,409 --> 00:25:43,820
actually colored by age now so with red

607
00:25:50,560 --> 00:25:47,419
being the oldest moving into a blue

608
00:25:52,590 --> 00:25:50,570
being the youngest and you know you

609
00:25:54,789 --> 00:25:52,600
expect when you're looking at

610
00:25:57,330 --> 00:25:54,799
biologically evolving systems that there

611
00:26:00,190 --> 00:25:57,340
is certainly going to be a time line

612
00:26:01,720 --> 00:26:00,200
however I didn't necessarily expect when

613
00:26:03,369 --> 00:26:01,730

we were looking at mineralogical systems

614
00:26:05,619 --> 00:26:03,379
that we were going to see a time line

615
00:26:07,629 --> 00:26:05,629
however it's it's that's pretty clear

616
00:26:12,159 --> 00:26:07,639
you can see we start here in the centre

617
00:26:14,710 --> 00:26:12,169
of this locality you with the oldest red

618
00:26:17,049 --> 00:26:14,720
minerals moving up into orange and

619
00:26:19,229 --> 00:26:17,059
yellow and green finally out into blue

620
00:26:21,549 --> 00:26:19,239
on the outskirts so we have this nice

621
00:26:25,269 --> 00:26:21,559
timeline that essentially just fell out

622
00:26:30,039 --> 00:26:25,279
of this network and we weren't really

623
00:26:34,629 --> 00:26:30,049
expecting that so with that said Eric

624
00:26:40,080 --> 00:26:34,639
asked us to think about where we thought

625
00:26:44,890 --> 00:26:43,060
basically what I came up with is the

626
00:26:46,420 --> 00:26:44,900
fact that Earth's evolution has been

627
00:26:48,970 --> 00:26:46,430
in an intertwined succession of

628
00:26:52,510 --> 00:26:48,980
increasingly complex physical chemical

629
00:26:54,550 --> 00:26:52,520
and biological events so I hope that

630
00:26:56,350 --> 00:26:54,560
with this talk I've shown you that I

631
00:26:58,690 --> 00:26:56,360
think the key to understanding the

632
00:27:00,730 --> 00:26:58,700
complex history of our planet and other

633
00:27:02,710 --> 00:27:00,740
planetary bodies is the continued

634
00:27:05,380 --> 00:27:02,720
development and integration of

635
00:27:06,820 --> 00:27:05,390
cross-disciplinary data and expertise

636
00:27:10,720 --> 00:27:06,830
which is exactly what we've been doing

637
00:27:12,250 --> 00:27:10,730
with the Keck project and in fact we

638
00:27:15,850 --> 00:27:12,260

believe that so much that we've actually

639
00:27:19,690 --> 00:27:15,860
gone on to organize a another workshop

640
00:27:22,210 --> 00:27:19,700
if I may plug it now called the 4d

641
00:27:26,230 --> 00:27:22,220
workshop which is the deep time data

642
00:27:29,500 --> 00:27:26,240
driven discovery of the evolution of the

643
00:27:31,240 --> 00:27:29,510
earth and this in this workshop were

644
00:27:33,010 --> 00:27:31,250
bringing together a diverse group of

645
00:27:36,220 --> 00:27:33,020
geologists and biologists and data

646
00:27:43,030 --> 00:27:36,230
scientists from around the world to come

647
00:27:44,860 --> 00:27:43,040
in and to think about the sorry and come

648
00:27:47,320 --> 00:27:44,870
in to think about the emerging methods

649
00:27:49,600 --> 00:27:47,330
of data analysis and visualization than

650
00:27:52,420 --> 00:27:49,610
the how that can help us understand the

651
00:27:56,470 --> 00:27:52,430
past present and future of this evolving

652
00:27:58,540 --> 00:27:56,480
system so with that I would like to

653
00:28:01,710 --> 00:27:58,550
thank LC for inviting me to come and

654
00:28:04,270 --> 00:28:01,720
share my work with you today and to our

655
00:28:06,280 --> 00:28:04,280
sponsors and certainly to my

656
00:28:14,560 --> 00:28:06,290
collaborators who's a lot of work I

657
00:28:24,160 --> 00:28:17,570
questions yes I'll start with John in a

658
00:28:27,799 --> 00:28:24,170
good back thanks for that nice talk um

659
00:28:31,130 --> 00:28:27,809
wait when we see the plot of anything

660
00:28:33,680 --> 00:28:31,140
abundance with age particularly when we

661
00:28:36,260 --> 00:28:33,690
see things being more abundant in more

662
00:28:38,630 --> 00:28:36,270
recent times than in previous times

663
00:28:41,540 --> 00:28:38,640

there's two ways to interpret that data

664
00:28:44,210 --> 00:28:41,550
one is that it represents more recent

665
00:28:46,669 --> 00:28:44,220
production of those things on the other

666
00:28:49,010 --> 00:28:46,679
hand you could say well maybe this is a

667
00:28:51,020 --> 00:28:49,020
preservation artifact that it

668
00:28:55,570 --> 00:28:51,030
misrepresents that things that are older

669
00:28:57,950 --> 00:28:55,580
just didn't survive they decomposed and

670
00:29:01,160 --> 00:28:57,960
what I'd like to know is how do you

671
00:29:03,500 --> 00:29:01,170
separate these things because you know

672
00:29:06,580 --> 00:29:03,510
when you show the periodic table all

673
00:29:09,830 --> 00:29:06,590
those curves are increasing and it's I

674
00:29:11,900 --> 00:29:09,840
guess my my knoll hypothesis would be to

675
00:29:15,860 --> 00:29:11,910
interpret those purely espresso vation

676
00:29:18,110 --> 00:29:15,870
artifacts not as production so how do

677
00:29:19,970 --> 00:29:18,120
you go about doing that well I would

678
00:29:22,820 --> 00:29:19,980
love to know how to do that as well

679
00:29:24,320 --> 00:29:22,830
so we're certainly looking for

680
00:29:25,610 --> 00:29:24,330
collaborators and people who have ideas

681
00:29:27,380 --> 00:29:25,620
on that so if you're interested in

682
00:29:30,350 --> 00:29:27,390
helping us explore that we would love to

683
00:29:32,419 --> 00:29:30,360
as I mentioned my colleague Cal U and

684
00:29:34,850 --> 00:29:32,429
aunt Simone Runyan at Carnegie are

685
00:29:37,730 --> 00:29:34,860
actively working on trying to quantify

686
00:29:40,810 --> 00:29:37,740
that so in addition to having this

687
00:29:42,620 --> 00:29:40,820
erosional bias this preservation bias

688
00:29:43,549 --> 00:29:42,630

through time you know we're losing

689
00:29:51,470 --> 00:29:43,559
things

690
00:29:53,630 --> 00:29:51,480
soluble that we see you know we see this

691
00:29:55,070 --> 00:29:53,640
huge increase in them likely they

692
00:29:56,750 --> 00:29:55,080
certainly were forming back then but you

693
00:29:58,010 --> 00:29:56,760
will never see them so it's not even a

694
00:29:59,870 --> 00:29:58,020
matter of what we've lost all of that

695
00:30:01,400 --> 00:29:59,880
rock it's a matter of their their

696
00:30:01,970 --> 00:30:01,410
soluble so they're just going to

697
00:30:04,130 --> 00:30:01,980
disappear

698
00:30:05,900 --> 00:30:04,140
so it's so there are a lot of things

699
00:30:08,799 --> 00:30:05,910
that have to be considered

700
00:30:12,110 --> 00:30:08,809
certainly that general upward trend is

701
00:30:14,270 --> 00:30:12,120
largely the results of erosional bias

702
00:30:16,340 --> 00:30:14,280
and so it's important for us to think

703
00:30:18,200 --> 00:30:16,350
about how you know were these more

704
00:30:20,840 --> 00:30:18,210
oxidized phases more effective than the

705
00:30:22,690 --> 00:30:20,850
reduced phases that's that's certainly

706
00:30:25,730 --> 00:30:22,700
important when thinking about this trend

707
00:30:27,080 --> 00:30:25,740
so yeah it's a great question and I

708
00:30:29,860 --> 00:30:27,090
would love to have a better and

709
00:30:34,820 --> 00:30:29,870
than that but where we're working on it

710
00:30:38,840 --> 00:30:34,830
okay okay next my question is related to

711
00:30:42,110 --> 00:30:38,850
Jones Christians for example Ariake on

712
00:30:45,380 --> 00:30:42,120
dogs its occupies all the Archaean looks

713
00:30:49,430 --> 00:30:45,390

like green and eastern robbers it's a

714
00:30:53,150 --> 00:30:49,440
three point eight to about say four

715
00:30:57,800 --> 00:30:53,160
billion Red Cross occupy only 0.01

716
00:31:00,140 --> 00:30:57,810
percent among the total landmass so it's

717
00:31:05,090 --> 00:31:00,150
really small so that therefore next

718
00:31:08,330 --> 00:31:05,100
question is how to deconstruct the

719
00:31:11,180 --> 00:31:08,340
mineral distribution switches so one

720
00:31:15,170 --> 00:31:11,190
idea is that all of those rocks is a

721
00:31:17,140 --> 00:31:15,180
kind of accretionary complex so the

722
00:31:21,160 --> 00:31:17,150
ecclesia complex mean the fragments of

723
00:31:23,990 --> 00:31:21,170
oceanic crust and also trench turbidite

724
00:31:27,140 --> 00:31:24,000
so that therefore this is that we call

725
00:31:29,660 --> 00:31:27,150
pacific type organ it's quite different

726
00:31:34,010 --> 00:31:29,670
you know much bigger George Green it's

727
00:31:36,140 --> 00:31:34,020
like okay continental continents formed

728
00:31:39,950 --> 00:31:36,150
by subduction just granitic rocks and

729
00:31:43,400 --> 00:31:39,960
also passive much like of North America

730
00:31:46,460 --> 00:31:43,410
is of New York so completely different

731
00:31:50,630 --> 00:31:46,470
set of blocks between completely

732
00:31:52,100 --> 00:31:50,640
different kind of minerals right so that

733
00:31:56,000 --> 00:31:52,110
therefore my recommendation is you

734
00:32:00,140 --> 00:31:56,010
should first okay to make a database you

735
00:32:03,400 --> 00:32:00,150
should first to put intermediate up exam

736
00:32:07,880 --> 00:32:03,410
table type what kind of orogenic belts

737
00:32:11,300 --> 00:32:07,890
and formed by what kind of process so

738
00:32:14,080 --> 00:32:11,310

that okay this one method how to extend

739
00:32:16,820 --> 00:32:14,090
and we are very much in the Hadean docs

740
00:32:21,560 --> 00:32:16,830
Hadean Docs is completely absent only us

741
00:32:25,130 --> 00:32:21,570
now but it must be present okay if it is

742
00:32:29,000 --> 00:32:25,140
Kamat yet form that mid-oceanic ridge

743
00:32:31,430 --> 00:32:29,010
ever it's because due to high mantle

744
00:32:34,220 --> 00:32:31,440
potential temperature so therefore

745
00:32:37,310 --> 00:32:34,230
vassals at hydrolysis have done work at

746
00:32:40,910 --> 00:32:37,320
all because completely different set of

747
00:32:44,450 --> 00:32:40,920
blocks in the Hadean so the ha

748
00:32:46,850 --> 00:32:44,460
to estimate the minerals and also the

749
00:32:49,250 --> 00:32:46,860
mineral abundance and others and also

750
00:32:50,300 --> 00:32:49,260
water interactions completely different

751
00:32:57,770 --> 00:32:50,310
okay

752
00:33:00,650 --> 00:32:57,780
question WA our advice is the localized

753
00:33:03,440 --> 00:33:00,660
environment is completely different for

754
00:33:06,860 --> 00:33:03,450
example oxygen in ocean and atmosphere

755
00:33:11,660 --> 00:33:06,870
even today Mount of the volcano is

756
00:33:16,480 --> 00:33:11,670
bustles okay froze to involve the okay

757
00:33:19,300 --> 00:33:16,490
trees and then you will have native iron

758
00:33:22,280 --> 00:33:19,310
even under extremely you know oxygen

759
00:33:25,570 --> 00:33:22,290
atmosphere environments so that

760
00:33:29,170 --> 00:33:25,580
therefore you should carefully classify

761
00:33:33,410 --> 00:33:29,180
the mode of occurrence and the process

762
00:33:36,650 --> 00:33:33,420
you know if available data so that they

763
00:33:39,530 --> 00:33:36,660

have these two global or local and also

764
00:33:42,410 --> 00:33:39,540
what kind of urgent wells understand and

765
00:33:46,250 --> 00:33:42,420
the gold is hidden so how do you

766
00:33:47,930 --> 00:33:46,260
estimate this mine yeah I really

767
00:33:50,630 --> 00:33:47,940
appreciate that and and you're really

768
00:33:52,280 --> 00:33:50,640
touching on the complexity of what we're

769
00:33:54,560 --> 00:33:52,290
up against here when we're dealing with

770
00:33:57,440 --> 00:33:54,570
I'm not having often you know direct

771
00:33:58,940 --> 00:33:57,450
access to these samples and I really

772
00:34:02,270 --> 00:33:58,950
appreciate your comments that's very

773
00:34:04,400 --> 00:34:02,280
insightful thank you so my question is

774
00:34:05,840 --> 00:34:04,410
the first is a bit of a silly questions

775
00:34:09,730 --> 00:34:05,850
we've barely scratched the surface

776
00:34:12,080 --> 00:34:09,740
literally of Mars and the moon so it was

777
00:34:13,930 --> 00:34:12,090
founded bit striking the numbers are you

778
00:34:19,010 --> 00:34:13,940
safe so low such low numbers for both

779
00:34:21,380 --> 00:34:19,020
bodies so it may take a while we're

780
00:34:22,850 --> 00:34:21,390
still finding twelve minerals until last

781
00:34:24,650 --> 00:34:22,860
month on the earth so is it possible

782
00:34:28,370 --> 00:34:24,660
that we just haven't sampled enough up

783
00:34:32,200 --> 00:34:28,380
there and relatedly if those are the

784
00:34:35,480 --> 00:34:32,210
numbers then may the such mineral poor

785
00:34:39,080 --> 00:34:35,490
state of Mars barely basically prove

786
00:34:41,180 --> 00:34:39,090
that it never had life well you know so

787
00:34:43,340 --> 00:34:41,190
I actually work on the the Mars Science

788
00:34:47,780 --> 00:34:43,350

Laboratory Curiosity rover and one of

789
00:34:49,550 --> 00:34:47,790
the questions that we often get is so

790
00:34:50,570 --> 00:34:49,560
was there life on why is there life or

791
00:34:51,919 --> 00:34:50,580
you know do you know when you're not

792
00:34:54,790 --> 00:34:51,929
just you're just not telling us you know

793
00:34:57,550 --> 00:34:54,800
these sorts of things and and what

794
00:34:59,200 --> 00:34:57,560
I tend to think is this lack of mineral

795
00:35:03,000 --> 00:34:59,210
diversity that we're seeing with the

796
00:35:06,190 --> 00:35:03,010
chemin x-ray diffraction instrument

797
00:35:09,850 --> 00:35:06,200
could indicate that we didn't have

798
00:35:13,330 --> 00:35:09,860
advanced life on Mars now could we have

799
00:35:15,430 --> 00:35:13,340
had some some more basic life perhaps I

800
00:35:17,920 --> 00:35:15,440
don't know enough to to say whether or

801
00:35:28,570 --> 00:35:17,930
not that is true but I tend to think

802
00:35:29,830 --> 00:35:28,580
that right right so yeah so I I tend to

803
00:35:31,870 --> 00:35:29,840
say when people asked me if there was

804
00:35:34,200 --> 00:35:31,880
life on Mars I tend to say no which is

805
00:35:37,090 --> 00:35:34,210
kind of a bit of a bummer and perhaps

806
00:35:38,800 --> 00:35:37,100
some of my Mars colleagues might not

807
00:35:41,860 --> 00:35:38,810
like for me to say that so maybe don't

808
00:35:45,820 --> 00:35:41,870
air that part but I tend to think that

809
00:35:47,410 --> 00:35:45,830
that there wasn't but I absolutely could

810
00:35:50,110 --> 00:35:47,420
be wrong and I'm totally open to other

811
00:35:54,250 --> 00:35:50,120
hypotheses so to get at what you

812
00:35:56,740 --> 00:35:54,260
initially said yes perhaps we just

813
00:35:59,860 --> 00:35:56,750

haven't found it yet but for instance on

814
00:36:02,260 --> 00:35:59,870
on Mars it's very likely that you know

815
00:36:04,960 --> 00:36:02,270
we don't there's not much evidence for

816
00:36:06,400 --> 00:36:04,970
granite crust formation or you know

817
00:36:09,150 --> 00:36:06,410
certainly plate tectonics and things

818
00:36:11,800 --> 00:36:09,160
like that so the likelihood of

819
00:36:13,780 --> 00:36:11,810
generating quite as many mineral species

820
00:36:16,750 --> 00:36:13,790
is automatically diminished from that

821
00:36:19,000 --> 00:36:16,760
standpoint but still you know if we're

822
00:36:21,010 --> 00:36:19,010
thinking about life dramatically making

823
00:36:22,930 --> 00:36:21,020
these chemical niches I would expect to

824
00:36:25,810 --> 00:36:22,940
see a much higher number than what we

825
00:36:27,010 --> 00:36:25,820
have we only have a few Rover missions

826
00:36:29,290 --> 00:36:27,020
that have gone we only have a few

827
00:36:32,080 --> 00:36:29,300
Martian meteorites so it's an it's a big

828
00:36:33,700 --> 00:36:32,090
planet and likewise the moon is also

829
00:36:36,580 --> 00:36:33,710
really large so I think we need way more

830
00:36:39,160 --> 00:36:36,590
exploration before we can say anything

831
00:36:41,260 --> 00:36:39,170
definitive about that perhaps would be

832
00:36:43,600 --> 00:36:41,270
also interesting to know how much of the

833
00:36:44,980 --> 00:36:43,610
minerals are exposed to the surface it

834
00:36:48,580 --> 00:36:44,990
is accessible to those techniques

835
00:36:51,970 --> 00:36:48,590
compared to what in a reality is down so

836
00:36:57,760 --> 00:36:51,980
we have calleb and then and then I'll

837
00:36:59,260 --> 00:36:57,770
come back still a minute you didn't

838
00:37:02,050 --> 00:36:59,270

throw it at me

839
00:37:04,330 --> 00:37:02,060
so I think this is wonderful that and

840
00:37:05,770 --> 00:37:04,340
this may be a very difficult question to

841
00:37:07,270 --> 00:37:05,780
answer but I'd be interested to know

842
00:37:09,370 --> 00:37:07,280
your thoughts on it so one of the things

843
00:37:11,530 --> 00:37:09,380
that strikes me is that when we talk

844
00:37:15,820 --> 00:37:11,540
about bio signatures whether it's Earth

845
00:37:17,980 --> 00:37:15,830
Mars wherever we don't have a

846
00:37:19,510 --> 00:37:17,990
particularly good calibration as much as

847
00:37:23,200 --> 00:37:19,520
we don't know what a purely abiotic

848
00:37:25,270 --> 00:37:23,210
earth would be with neurologically after

849
00:37:28,120 --> 00:37:25,280
four billion years neither do we know

850
00:37:30,370 --> 00:37:28,130
what a purely abiotic Mars should look

851
00:37:32,710 --> 00:37:30,380
like I don't know what the answer to

852
00:37:34,900 --> 00:37:32,720
that is I wonder if you had any insight

853
00:37:37,300 --> 00:37:34,910
whether there's some way in mining the

854
00:37:38,859 --> 00:37:37,310
data looking at persistent ratios of

855
00:37:42,760 --> 00:37:38,869
particular minerals whether there's some

856
00:37:44,380 --> 00:37:42,770
clue to what a purely abiotic planetary

857
00:37:47,859 --> 00:37:44,390
and terrestrial type planet would look

858
00:37:49,359 --> 00:37:47,869
like after billions of years yeah I mean

859
00:37:52,240 --> 00:37:49,369
I think it depends on the pathways that

860
00:37:55,210 --> 00:37:52,250
you think that the planet went in as far

861
00:37:57,430 --> 00:37:55,220
as its chemical environment but yeah I

862
00:37:59,470 --> 00:37:57,440
mean you you know many of these minerals

863
00:38:01,720 --> 00:37:59,480

that forms that many of these five

864
00:38:04,300 --> 00:38:01,730
thousand you know this huge boom could

865
00:38:06,280 --> 00:38:04,310
have formed a biotic lees a number of

866
00:38:08,650 --> 00:38:06,290
them couldn't have so the first order

867
00:38:11,050 --> 00:38:08,660
step is to actually just remove anything

868
00:38:14,320 --> 00:38:11,060
that could not have formed without the

869
00:38:17,349 --> 00:38:14,330
direct presence of life we still have a

870
00:38:20,140 --> 00:38:17,359
huge number so that doesn't really help

871
00:38:21,790 --> 00:38:20,150
answer that question you can make some

872
00:38:24,220 --> 00:38:21,800
assumption you know you can cut it off

873
00:38:25,840 --> 00:38:24,230
at plate tectonics and say okay well but

874
00:38:27,460 --> 00:38:25,850
that doesn't really make sense right

875
00:38:28,630 --> 00:38:27,470
because the the chemistry of the planet

876
00:38:31,020 --> 00:38:28,640
is going to continue to evolve and

877
00:38:33,660 --> 00:38:31,030
you're gonna create new chemical niches

878
00:38:36,490 --> 00:38:33,670
so you're right that's a very difficult

879
00:38:39,070 --> 00:38:36,500
question and well it's one that we think

880
00:38:41,920 --> 00:38:39,080
about a lot but I don't have a good

881
00:38:44,349 --> 00:38:41,930
answer for thank you hello I phoned your

882
00:38:46,210 --> 00:38:44,359
talk absolutely fascinating um one of

883
00:38:48,849 --> 00:38:46,220
the questions I had was I found it

884
00:38:50,590 --> 00:38:48,859
interesting that there was a great rise

885
00:38:53,380 --> 00:38:50,600
in mineral oxidation at the onset of the

886
00:38:55,510 --> 00:38:53,390
Cambrian and have you guys looked into

887
00:38:58,599 --> 00:38:55,520
any historical bioturbation data for

888
00:39:01,180 --> 00:38:58,609

mineral exposure on in terms of mass

889
00:39:04,420 --> 00:39:01,190
extinction events because if there's

890
00:39:07,510 --> 00:39:04,430
boring creatures that go in go under the

891
00:39:09,010 --> 00:39:07,520
oceanic I guess crustal surface then

892
00:39:11,260 --> 00:39:09,020
does that mean that there's more mineral

893
00:39:14,589 --> 00:39:11,270
exposure creating more oxidation for

894
00:39:17,859 --> 00:39:14,599
yeah sure I mean in general you're going

895
00:39:20,650 --> 00:39:17,869
to get oxidized material within the

896
00:39:24,609 --> 00:39:20,660
first you know a few kilometers of the

897
00:39:27,370 --> 00:39:24,619
crust relatively quickly through abiotic

898
00:39:29,620 --> 00:39:27,380
processes but I certainly think that

899
00:39:30,870 --> 00:39:29,630
biotic processes could influence that I

900
00:39:33,010 --> 00:39:30,880
mean they definitely changed the

901
00:39:35,410 --> 00:39:33,020
mineralogical landscape of any

902
00:39:37,570 --> 00:39:35,420
environment then in fact I didn't show

903
00:39:40,270 --> 00:39:37,580
it today but I had my colleagues drew

904
00:39:42,160 --> 00:39:40,280
Musante and Mike Meyer that I put up

905
00:39:46,900 --> 00:39:42,170
there have done a lot of work and in

906
00:39:48,160 --> 00:39:46,910
thinking about paleo biology so if you

907
00:39:49,150 --> 00:39:48,170
want to see me afterwards I can show you

908
00:39:50,980 --> 00:39:49,160
a lot of the work that they've been

909
00:39:52,630 --> 00:39:50,990
doing we've got some cool manuscripts

910
00:39:56,770 --> 00:39:52,640
that maybe they won't mind if I share

911
00:39:58,660 --> 00:39:56,780
with you so I would like to ask about

912
00:40:02,640 --> 00:39:58,670
the connection between your talk and

913
00:40:06,010 --> 00:40:02,650

Everett Chuck's talk so you showed this

914
00:40:10,329 --> 00:40:06,020
increasing that mineral diversity how

915
00:40:12,579 --> 00:40:10,339
does that relate to the way that life is

916
00:40:14,829 --> 00:40:12,589
solving Earth's problem in terms of the

917
00:40:18,430 --> 00:40:14,839
thermodynamics so in other words how

918
00:40:22,540 --> 00:40:18,440
does that show that in a sense the life

919
00:40:24,220 --> 00:40:22,550
is helping the planet approach some more

920
00:40:26,890 --> 00:40:24,230
equilibrium state than initially if you

921
00:40:29,339 --> 00:40:26,900
have something to say about that yeah so

922
00:40:32,320 --> 00:40:29,349
essentially life is creating these

923
00:40:33,750 --> 00:40:32,330
widely varying chemical niches right all

924
00:40:36,430 --> 00:40:33,760
over the place they're making it very

925
00:40:38,620 --> 00:40:36,440
strange chemically and that's actually

926
00:40:40,390 --> 00:40:38,630
what's creating these environments for

927
00:40:42,220 --> 00:40:40,400
these different minerals to form that's

928
00:40:45,700 --> 00:40:42,230
what's creating this huge mineral

929
00:40:47,950 --> 00:40:45,710
diversity so aside from that I'm not

930
00:40:49,510 --> 00:40:47,960
sure that I can really directly relate

931
00:40:51,220 --> 00:40:49,520
it to Everett's talk although he's

932
00:40:52,900 --> 00:40:51,230
raising his hand so I think he might be

933
00:40:54,339 --> 00:40:52,910
able to do that so I would love to hear

934
00:40:56,859 --> 00:40:54,349
what whatever it has to say about that

935
00:40:59,260 --> 00:40:56,869
so I've got to Everett and then we have

936
00:41:04,510 --> 00:40:59,270
two last question and we need to move on

937
00:41:07,450 --> 00:41:04,520
I think there's a major difference and

938
00:41:11,800 --> 00:41:07,460

that your what a lot of what you see is

939
00:41:14,829 --> 00:41:11,810
driven by photosynthetic oxidation of

940
00:41:17,980 --> 00:41:14,839
the Earth's surface and that is a

941
00:41:20,859 --> 00:41:17,990
different thermodynamic state than what

942
00:41:23,130 --> 00:41:20,869
I was talking about where I was I was

943
00:41:24,910 --> 00:41:23,140
talking about what the planet provides

944
00:41:28,830 --> 00:41:24,920
chemically it hasn't

945
00:41:31,990 --> 00:41:28,840
terms of chemical energy sources it's a

946
00:41:33,790 --> 00:41:32,000
it's a different there's a serious

947
00:41:37,060 --> 00:41:33,800
thermodynamic consequence to drawing

948
00:41:40,720 --> 00:41:37,070
your box to also include the Sun or at

949
00:41:42,880 --> 00:41:40,730
least solar photons and as a result then

950
00:41:44,440 --> 00:41:42,890
what we're familiar with at the surface

951
00:41:46,180 --> 00:41:44,450
of the earth especially walking around

952
00:41:50,290 --> 00:41:46,190
the continents is a lot of

953
00:41:54,280 --> 00:41:50,300
disequilibrium generation by life but

954
00:41:58,030 --> 00:41:54,290
that's because of cheating and grabbing

955
00:42:01,150 --> 00:41:58,040
those photons and working uphill and

956
00:42:03,130 --> 00:42:01,160
producing dreadful conditions like a 20%

957
00:42:05,800 --> 00:42:03,140
oxygen atmosphere where you know that's

958
00:42:08,860 --> 00:42:05,810
a horrible place to live yeah extreme

959
00:42:10,840 --> 00:42:08,870
conditions like that so there's there is

960
00:42:13,150 --> 00:42:10,850
a there is a difference it's a but it's

961
00:42:18,790 --> 00:42:13,160
a different there's major consequences

962
00:42:20,440 --> 00:42:18,800
once photo trophy begins I'm getting

963
00:42:28,330 --> 00:42:20,450

that pull that's one question before you

964
00:42:30,580 --> 00:42:28,340
are not coming back thanks nice talk I'd

965
00:42:33,040 --> 00:42:30,590
said - I guess fundamental questions for

966
00:42:34,960 --> 00:42:33,050
how you analyze your data and one of

967
00:42:37,450 --> 00:42:34,970
them has to do with the threshold the

968
00:42:40,120 --> 00:42:37,460
heavy mineral was just simple presence

969
00:42:42,700 --> 00:42:40,130
of absence in terms of any abundance of

970
00:42:44,980 --> 00:42:42,710
the mineral and when you plot it on the

971
00:42:46,690 --> 00:42:44,990
networks and also for drawing the

972
00:42:49,780 --> 00:42:46,700
connections between two minerals

973
00:42:51,250 --> 00:42:49,790
I assume it's like colocation but like

974
00:42:54,010 --> 00:42:51,260
can you talk a little bit more in detail

975
00:42:56,020 --> 00:42:54,020
about how you made that cutoff for if

976
00:42:56,980 --> 00:42:56,030
two minerals were co-located or not yes

977
00:43:00,250 --> 00:42:56,990
absolutely

978
00:43:01,330 --> 00:43:00,260
so to answer the first question and both

979
00:43:02,500 --> 00:43:01,340
of those questions are something we

980
00:43:05,440 --> 00:43:02,510
think about a lot and their actual

981
00:43:09,220 --> 00:43:05,450
there's significant problems in handling

982
00:43:11,710 --> 00:43:09,230
our data so firstly ideally we would

983
00:43:14,050 --> 00:43:11,720
have abundant information right I would

984
00:43:15,040 --> 00:43:14,060
know exactly how much pyrite by volume

985
00:43:17,080 --> 00:43:15,050
by weight well however you want to

986
00:43:20,140 --> 00:43:17,090
measure it is on Earth's surface but we

987
00:43:21,730 --> 00:43:20,150
don't know that information we have

988
00:43:23,890 --> 00:43:21,740

somewhat of an idea for economically

989
00:43:25,300 --> 00:43:23,900
significant things but we don't for

990
00:43:29,500 --> 00:43:25,310
things that mining companies don't care

991
00:43:31,810 --> 00:43:29,510
about so for now we are basically if

992
00:43:34,540 --> 00:43:31,820
MnDOT or if a or if a piece of

993
00:43:37,960 --> 00:43:34,550
peer-reviewed literature says that this

994
00:43:38,170 --> 00:43:37,970
is a geologic locality we're calling

995
00:43:41,770 --> 00:43:38,180
that

996
00:43:46,990 --> 00:43:41,780
was one crystal there but it could be

997
00:43:49,570 --> 00:43:47,000
that there was a ton there so that is a

998
00:43:51,610 --> 00:43:49,580
big flaw and using the number of

999
00:43:53,860 --> 00:43:51,620
localities instead of abundance and

1000
00:43:56,400 --> 00:43:53,870
that's something that we we're trying to

1001
00:43:58,860 --> 00:43:56,410
get past but it's a really big hurdle

1002
00:44:01,540 --> 00:43:58,870
and oh and co-occurrence so

1003
00:44:03,430 --> 00:44:01,550
co-occurrence is if if they were cited

1004
00:44:06,100 --> 00:44:03,440
by the literature as having occurred and

1005
00:44:08,710 --> 00:44:06,110
the essentially the same geologic unit

1006
00:44:11,050 --> 00:44:08,720
geologic setting which there is some

1007
00:44:12,910 --> 00:44:11,060
variation there and that's something we

1008
00:44:15,370 --> 00:44:12,920
have to think about very carefully with

1009
00:44:17,290 --> 00:44:15,380
with each sample which is why that

1010
00:44:19,960 --> 00:44:17,300
mineral evolution database when I said

1011
00:44:21,820 --> 00:44:19,970
it represented countless hours I really

1012
00:44:25,060 --> 00:44:21,830
mean countless hours Josh golden has

1013
00:44:27,430 --> 00:44:25,070

spent oh I think it's about six years

1014
00:44:29,140 --> 00:44:27,440
now maybe a little bit more working on

1015
00:44:31,450 --> 00:44:29,150
that database and for him that means

1016
00:44:33,130 --> 00:44:31,460
painstakingly going through every piece

1017
00:44:36,370 --> 00:44:33,140
of literature that he could possibly

1018
00:44:38,800 --> 00:44:36,380
find and really understanding the

1019
00:44:41,350 --> 00:44:38,810
geology behind the statements that are

1020
00:44:45,490 --> 00:44:41,360
being made in that literature so it's

1021
00:44:47,320 --> 00:44:45,500
not a perfect system but so Shauna it's

1022
00:44:49,000 --> 00:44:47,330
not necessarily a question for you but

1023
00:44:51,850 --> 00:44:49,010
maybe you and Everett and others in the

1024
00:44:54,970 --> 00:44:51,860
room Dante can Neal and another others

1025
00:44:56,800 --> 00:44:54,980
have painstakingly tried to understand

1026
00:44:58,950 --> 00:44:56,810
whether there's been a net oxidation of

1027
00:45:02,350 --> 00:44:58,960
the crust and mantle through time and

1028
00:45:05,100 --> 00:45:02,360
using chromium vanadium others the

1029
00:45:08,800 --> 00:45:05,110
valence states of these hasn't changed

1030
00:45:13,330 --> 00:45:08,810
so there clearly is superabundant

1031
00:45:14,920 --> 00:45:13,340
amount of reductant within the mantle it

1032
00:45:17,230 --> 00:45:14,930
begs the question then do you really

1033
00:45:20,110 --> 00:45:17,240
care whether you have to go half a

1034
00:45:22,930 --> 00:45:20,120
kilometer into mars or just scratch the

1035
00:45:24,610 --> 00:45:22,940
surface because you're looking at the

1036
00:45:27,400 --> 00:45:24,620
surface manifestation of mineral

1037
00:45:31,330 --> 00:45:27,410
evolution really so it's this thin skin

1038
00:45:34,000 --> 00:45:31,340

right so that makes life a lot easier

1039
00:45:36,430 --> 00:45:34,010
for you if you can you can adjust off' I

1040
00:45:38,110 --> 00:45:36,440
that with and especially because mantle

1041
00:45:42,550 --> 00:45:38,120
convection is virtually nil on Mars

1042
00:45:44,260 --> 00:45:42,560
today so I mean I don't know if you have

1043
00:45:46,620 --> 00:45:44,270
thoughts about this but more

1044
00:45:50,050 --> 00:45:46,630
fundamentally I guess more profoundly is

1045
00:45:52,090 --> 00:45:50,060
why hasn't the mantle changed or at

1046
00:45:54,280 --> 00:45:52,100
least the upper portion of the mantle

1047
00:45:57,610 --> 00:45:54,290
we can sample changed in terms of redox

1048
00:46:00,370 --> 00:45:57,620
state through time so your fundamental

1049
00:46:01,630 --> 00:46:00,380
question I think maybe Everett wants to

1050
00:46:03,430 --> 00:46:01,640
think about that I don't want to try to

1051
00:46:05,950 --> 00:46:03,440
I don't want to try to touch that but in

1052
00:46:08,680 --> 00:46:05,960
thinking about Mars yes that's exactly

1053
00:46:11,560 --> 00:46:08,690
my line of thinking is likely when we're

1054
00:46:13,450 --> 00:46:11,570
just looking at the surface where we can

1055
00:46:15,910 --> 00:46:13,460
do pretty much a direct comparison to

1056
00:46:17,590 --> 00:46:15,920
what I'm showing here for on earth I

1057
00:46:19,900 --> 00:46:17,600
mean on earth obviously we know a lot

1058
00:46:21,640 --> 00:46:19,910
more about the the mantle minerals but

1059
00:46:24,130 --> 00:46:21,650
as you pointed out we find that that

1060
00:46:26,920 --> 00:46:24,140
extreme diversity is actually located in

1061
00:46:30,040 --> 00:46:26,930
our crust so yes absolutely

1062
00:46:31,810 --> 00:46:30,050
now why the mantle hasn't dramatically

1063
00:46:32,890 --> 00:46:31,820

changed as a result of this this is

1064
00:46:35,410 --> 00:46:32,900
something that a lot of people are

1065
00:46:37,690 --> 00:46:35,420
thinking about right and yeah I don't

1066
00:46:39,460 --> 00:46:37,700
have a good answer for that I if someone

1067
00:46:52,240 --> 00:46:39,470
does I would love to hear it ever it has

1068
00:46:55,780 --> 00:46:52,250
something to say life has had a profound

1069
00:46:58,180 --> 00:46:55,790
impact on the atmosphere and a

1070
00:47:04,870 --> 00:46:58,190
negligible impact on the oxidation state

1071
00:47:10,780 --> 00:47:04,880
of mantle Mantle's big lifes wimpy sorry

1072
00:47:13,720 --> 00:47:10,790
about that well it's not yeah get over

1073
00:47:17,170 --> 00:47:13,730
it let's not also let's be careful to

1074
00:47:30,880 --> 00:47:17,180
not equate life and photosynthesis

1075
00:47:45,820 --> 00:47:30,890
somehow in our thinking here yeah but

1076
00:48:05,030 --> 00:47:49,700
the well the mass of the mantel is

1077
00:48:07,230 --> 00:48:05,040
pretty profound well less thanks you're

1078
00:48:10,700 --> 00:48:07,240
the son I never at the gate

1079
00:48:30,440 --> 00:48:10,710
[Applause]