Marc Hirschmann

Accretion and retention of bio-essential elements during Earth's catastrophic early history

1
00:00:19,070 --> 00:00:17,060
I want to thank the organizers for the

2
00:00:21,220 --> 00:00:19,080
invitation to present these

3
00:00:23,150 --> 00:00:21,230
interdisciplinary conferences are always

4
00:00:24,650 --> 00:00:23,160
fascinating and I always learn a lot I

5
00:00:26,599 --> 00:00:24,660
didn't realize when I accepted the

6
00:00:28,759 --> 00:00:26,609
invitation just how much of the audience

7
00:00:31,009 --> 00:00:28,769
would actually be biologists as opposed

8
00:00:33,200 --> 00:00:31,019
to earth scientists and I've tried to

9
00:00:34,910 --> 00:00:33,210
make my talk as general as possible but

10
00:00:36,319 --> 00:00:34,920
it's 11 gives these sorts of talks to

11
00:00:39,729 --> 00:00:36,329
these sorts of audiences that one

12
00:00:41,840 --> 00:00:39,739
realizes the assumptions that are

13
00:00:43,970 --> 00:00:41,850

present in one's field that one doesn't

14
00:00:46,040 --> 00:00:43,980
always know that the rest of the world

15
00:00:51,889 --> 00:00:46,050
doesn't know about so hopefully I will

16
00:00:56,150 --> 00:00:51,899
be able to overcome that that barrier so

17
00:00:58,700 --> 00:00:56,160
the point of today's talk or is in part

18
00:01:01,189 --> 00:00:58,710
that our planet has fortunately of

19
00:01:03,979 --> 00:01:01,199
course a sufficient amount of bio

20
00:01:05,960 --> 00:01:03,989
essential elements but it is interesting

21
00:01:07,670 --> 00:01:05,970
and probably not coincidental that the

22
00:01:09,260 --> 00:01:07,680
bio essential elements are also those

23
00:01:11,060 --> 00:01:09,270
elements that are essential for

24
00:01:14,000 --> 00:01:11,070
habitability and in fact really

25
00:01:17,240 --> 00:01:14,010
habitability is probably more germane to

26
00:01:19,609 --> 00:01:17,250
what we're going to be talking about or

27
00:01:21,620 --> 00:01:19,619
what I'm going to be talking about the

28
00:01:23,210 --> 00:01:21,630
most of the talk is actually going to be

29
00:01:24,380 --> 00:01:23,220
about carbon and nitrogen with a little

30
00:01:25,969 --> 00:01:24,390
bit of hydrogen I'm welcome to say

31
00:01:27,920 --> 00:01:25,979
essentially nothing about sulfur and

32
00:01:29,480 --> 00:01:27,930
phosphorus but almost everything that I

33
00:01:32,450 --> 00:01:29,490
say applies to all of these elements

34
00:01:35,090 --> 00:01:32,460
which is to say that the presence of

35
00:01:37,219 --> 00:01:35,100
these elements on the planet is a

36
00:01:39,740 --> 00:01:37,229
product actually not of accretion really

37
00:01:41,390 --> 00:01:39,750
but of a depletion right the amount of

38
00:01:42,920 --> 00:01:41,400

material that was available in the solar

39
00:01:45,080 --> 00:01:42,930
system of all these elements was far

40
00:01:47,179 --> 00:01:45,090
greater than actually we have on the

41
00:01:50,749 --> 00:01:47,189
surface and it's the fact that the

42
00:01:53,300 --> 00:01:50,759
planet managed to save a little bit over

43
00:01:58,700 --> 00:01:53,310
the course of those that depletion that

44
00:02:00,770 --> 00:01:58,710
we have a habitable planet so we this is

45
00:02:02,959 --> 00:02:00,780
of course the blue planet and everybody

46
00:02:04,940 --> 00:02:02,969
looks at it and probably those of you

47
00:02:06,499 --> 00:02:04,950
who live on the surface think that

48
00:02:08,589 --> 00:02:06,509
there's a great deal of water in fact

49
00:02:11,270 --> 00:02:08,599
the earth has very little water

50
00:02:13,430 --> 00:02:11,280
two-thirds of the surface of the of the

51
00:02:13,880 --> 00:02:13,440
planet is covered by water but if you

52
00:02:15,350 --> 00:02:13,890
average

53
00:02:19,190 --> 00:02:15,360
it over the mass of the planet it's

54
00:02:21,650 --> 00:02:19,200
about 300 parts per million the for the

55
00:02:24,199 --> 00:02:21,660
most part this is a very very dry object

56
00:02:26,270 --> 00:02:24,209
but not totally dry if it were totally

57
00:02:27,770 --> 00:02:26,280
dry of course then we would be mercury

58
00:02:28,970 --> 00:02:27,780
or the moon or something like that and

59
00:02:32,780 --> 00:02:28,980
we wouldn't be having these

60
00:02:34,640 --> 00:02:32,790
conversations we wouldn't be here this

61
00:02:38,420 --> 00:02:34,650
the same is true actually even more so

62
00:02:41,300 --> 00:02:38,430
for carbon and nitrogen the supply that

63
00:02:43,550 --> 00:02:41,310

we have is sufficient but it is actually

64
00:02:45,640 --> 00:02:43,560
a very very small fraction of what was

65
00:02:50,240 --> 00:02:45,650
originally available in the solar system

66
00:02:52,250 --> 00:02:50,250
oops so this is a plot of the abundance

67
00:02:53,630 --> 00:02:52,260
of elements in the solar system or the

68
00:02:57,160 --> 00:02:53,640
abundance of the elements in the Sun

69
00:02:59,360 --> 00:02:57,170
it's essentially the same thing and

70
00:03:01,310 --> 00:02:59,370
normalized to the amount of silicon so

71
00:03:03,440 --> 00:03:01,320
10 to the 6th would be an equal amount

72
00:03:05,600 --> 00:03:03,450
of silicon and whatever element that's

73
00:03:08,449 --> 00:03:05,610
plotted here and it's of course a log

74
00:03:10,729 --> 00:03:08,459
scale and nitrogen isn't noted here but

75
00:03:12,170 --> 00:03:10,739
it's there the in fact the availability

76
00:03:15,080 --> 00:03:12,180
of the essential elements hydrogen

77
00:03:16,550 --> 00:03:15,090
carbon nitrogen oxygen in the solar

78
00:03:18,770 --> 00:03:16,560
system is far greater than that of

79
00:03:22,100 --> 00:03:18,780
silicon there's more of that stuff than

80
00:03:23,449 --> 00:03:22,110
there is rock if our planet was made of

81
00:03:27,410 --> 00:03:23,459
that then we would be something like

82
00:03:30,020 --> 00:03:27,420
Jupiter or or or or a star and we

83
00:03:32,990 --> 00:03:30,030
wouldn't have a habitable terrestrial

84
00:03:35,600 --> 00:03:33,000
planet so the initial availability is

85
00:03:36,949 --> 00:03:35,610
not the problem in fact it's going to or

86
00:03:38,780 --> 00:03:36,959
we're going to see that it's going to be

87
00:03:40,789 --> 00:03:38,790
the opposite the process of planet

88
00:03:44,930 --> 00:03:40,799

formation is a process of loss of these

89
00:03:46,610 --> 00:03:44,940
elements and saving just enough now what

90
00:03:48,289 --> 00:03:46,620
the problem of course is is I don't

91
00:03:51,740 --> 00:03:48,299
really know what just enough is and I

92
00:03:53,660 --> 00:03:51,750
maybe some of you do but it's clearly

93
00:03:55,819 --> 00:03:53,670
something similar to what we have within

94
00:03:59,240 --> 00:03:55,829
a couple orders of magnitude right Earth

95
00:04:01,280 --> 00:03:59,250
has just enough but what the band is too

96
00:04:04,660 --> 00:04:01,290
little or less than Earth or greater

97
00:04:07,220 --> 00:04:04,670
than Earth is I think an open question

98
00:04:08,840 --> 00:04:07,230
so here's another way of looking at this

99
00:04:10,130 --> 00:04:08,850
on a mug to use this slide again and

100
00:04:12,620 --> 00:04:10,140
again despite the fact that it's a

101
00:04:14,180 --> 00:04:12,630
little bit fuzzy so this is the

102
00:04:15,860 --> 00:04:14,190
abundance of carbon and this is the

103
00:04:18,199 --> 00:04:15,870
abundance of nitrogen relative to that

104
00:04:21,380 --> 00:04:18,209
of silicon in various solar system

105
00:04:23,570 --> 00:04:21,390
materials starting from the Sun or we

106
00:04:25,310 --> 00:04:23,580
could also look at beyond our solar

107
00:04:27,470 --> 00:04:25,320
system to the interstellar medium and

108
00:04:30,410 --> 00:04:27,480
see great abundances of carbon

109
00:04:32,630 --> 00:04:30,420
also nitrogen icy bodies

110
00:04:35,840 --> 00:04:32,640
undifferentiated bodies also have a

111
00:04:37,610 --> 00:04:35,850
great deal primitive building blocks of

112
00:04:39,830 --> 00:04:37,620
planets as represented by chondritic

113
00:04:41,570 --> 00:04:39,840

meteorites have certain proportions and

114
00:04:44,270 --> 00:04:41,580
then finally we get to earth and you'll

115
00:04:46,250 --> 00:04:44,280
notice that the scale on here is

116
00:04:48,620 --> 00:04:46,260
tremendous so if you want to think about

117
00:04:50,300 --> 00:04:48,630
it this way the earth has something like

118
00:04:52,880 --> 00:04:50,310
10 to the minus four of the original

119
00:04:54,950 --> 00:04:52,890
potential supply of carbon and about 10

120
00:04:57,770 --> 00:04:54,960
to the minus 5 of the original potential

121
00:04:59,990 --> 00:04:57,780
supply of nitrogen so the process of

122
00:05:02,300 --> 00:05:00,000
planet formation or actually first of

123
00:05:05,480 --> 00:05:02,310
all the process of rock formation going

124
00:05:07,340 --> 00:05:05,490
from dust and gas to Rakeem it simple

125
00:05:08,660 --> 00:05:07,350
rocky materials and then going from

126
00:05:11,090 --> 00:05:08,670
those simple rocky materials to

127
00:05:14,090 --> 00:05:11,100
assembling planets is a process of loss

128
00:05:16,580 --> 00:05:14,100
and the key of course is is that the

129
00:05:19,310 --> 00:05:16,590
planet of interest the one that becomes

130
00:05:21,320 --> 00:05:19,320
the habitable planet it is the one that

131
00:05:23,060 --> 00:05:21,330
loses just the right amount doesn't lose

132
00:05:24,860 --> 00:05:23,070
too much because if you can lose four

133
00:05:27,140 --> 00:05:24,870
orders of magnitude why can't you lose

134
00:05:28,430 --> 00:05:27,150
six orders of magnitude or seven orders

135
00:05:32,630 --> 00:05:28,440
of magnitude that's of course what

136
00:05:34,820 --> 00:05:32,640
mercury probably did and so the loss may

137
00:05:38,270 --> 00:05:34,830
must be just the right amount and each

138
00:05:40,670 --> 00:05:38,280

of these processes from going from going

139
00:05:44,210 --> 00:05:40,680
from gas and dust to rocks is a lost

140
00:05:46,730 --> 00:05:44,220
process in the early solar nebula and

141
00:05:48,910 --> 00:05:46,740
then going from rocks to planetary

142
00:05:53,750 --> 00:05:48,920
differentiation is a second stage of

143
00:05:55,040 --> 00:05:53,760
loss so one way to think about it it's

144
00:05:58,130 --> 00:05:55,050
actually a bit of a deceptive way to

145
00:05:59,990 --> 00:05:58,140
think about it is that that the

146
00:06:02,420 --> 00:06:00,000
habitability of our planet depends on

147
00:06:04,580 --> 00:06:02,430
the amount of co2 on our atmosphere and

148
00:06:07,010 --> 00:06:04,590
of course our location relative to the

149
00:06:08,840 --> 00:06:07,020
Sun and we see tremendous variability

150
00:06:13,880 --> 00:06:08,850
just amongst our nearest neighbors

151
00:06:16,160 --> 00:06:13,890
between Venus Earth and Mars and this is

152
00:06:19,340 --> 00:06:16,170
at least apparently on the surface too

153
00:06:20,900 --> 00:06:19,350
much right it it isn't necessarily so

154
00:06:22,490 --> 00:06:20,910
that Venus has too much carbon but

155
00:06:24,950 --> 00:06:22,500
certainly Venus has too much carbon on

156
00:06:27,020 --> 00:06:24,960
its surface to be habitable and Mars has

157
00:06:28,880 --> 00:06:27,030
too little for its place in the solar

158
00:06:30,440 --> 00:06:28,890
system to be habitable at the moment

159
00:06:33,830 --> 00:06:30,450
although that may not have been true

160
00:06:35,600 --> 00:06:33,840
early in in solar system history one

161
00:06:37,700 --> 00:06:35,610
reason that this is deceptive is this is

162
00:06:39,530 --> 00:06:37,710
just a service inventory and in fact

163
00:06:41,270 --> 00:06:39,540

it's not just the surface inventory

164
00:06:42,680 --> 00:06:41,280
that's important it's also the

165
00:06:47,180 --> 00:06:42,690
inventory in the interior of a

166
00:06:49,310 --> 00:06:47,190
terrestrial planet so another way to

167
00:06:51,350 --> 00:06:49,320
look at this this plot or if plot

168
00:06:53,930 --> 00:06:51,360
similar to this was shown yesterday the

169
00:06:56,210 --> 00:06:53,940
so-called habitable zone which depends

170
00:06:58,220 --> 00:06:56,220
of course on the on this stellar

171
00:07:00,950 --> 00:06:58,230
luminosity of the particular star and

172
00:07:03,490 --> 00:07:00,960
the location of the planet relative to

173
00:07:07,550 --> 00:07:03,500
the star and we have Venus Earth and

174
00:07:10,490 --> 00:07:07,560
Mars there this plot of habitability is

175
00:07:12,140 --> 00:07:10,500
is really dependent on some assumptions

176
00:07:15,350 --> 00:07:12,150
about the availability of a greenhouse

177
00:07:18,080 --> 00:07:15,360
gas right it for example this line here

178
00:07:20,900 --> 00:07:18,090
is defined by the maximum saturation of

179
00:07:24,170 --> 00:07:20,910
co2 something like 40 atmospheres of co2

180
00:07:25,970 --> 00:07:24,180
I think if i recall correctly but that

181
00:07:27,440 --> 00:07:25,980
assumes that 40 atmospheres of co2 are

182
00:07:29,390 --> 00:07:27,450
available to the planet which actually

183
00:07:31,610 --> 00:07:29,400
is a fair amount of carbon considering

184
00:07:33,140 --> 00:07:31,620
that we have these hierarchies of loss

185
00:07:35,870 --> 00:07:33,150
that we don't know how far they're going

186
00:07:38,409 --> 00:07:35,880
to go so it isn't just a question of the

187
00:07:40,940 --> 00:07:38,419
solar luminosity in the location within

188
00:07:43,040 --> 00:07:40,950

within the step within the particular

189
00:07:44,900 --> 00:07:43,050
solar system but also the availability

190
00:07:49,040 --> 00:07:44,910
or the retention you can think about it

191
00:07:52,040 --> 00:07:49,050
either way of the of the greenhouse

192
00:07:54,560 --> 00:07:52,050
gases that allow for this band of

193
00:08:03,230 --> 00:07:54,570
habitability which of course is created

194
00:08:07,210 --> 00:08:03,240
by greenhouse gases so starting here and

195
00:08:10,550 --> 00:08:07,220
going to hear I have plotted the Earth's

196
00:08:12,680 --> 00:08:10,560
BSE this is where the earth scientist

197
00:08:15,140 --> 00:08:12,690
has to explain to the biologists this is

198
00:08:16,640 --> 00:08:15,150
simple bulk silicate earth right it's

199
00:08:18,350 --> 00:08:16,650
basically all of the earth except for

200
00:08:20,659 --> 00:08:18,360
its metallic portion and I have a

201
00:08:22,250 --> 00:08:20,669
certain concentration here and if I were

202
00:08:25,190 --> 00:08:22,260
to take that surface inventory that I

203
00:08:27,110 --> 00:08:25,200
showed you before the 400 ppm co2 in the

204
00:08:29,360 --> 00:08:27,120
atmosphere it wouldn't be nearly that or

205
00:08:31,219 --> 00:08:29,370
the one bar or point eight bars of

206
00:08:33,950 --> 00:08:31,229
nitrogen it wouldn't be nearly that most

207
00:08:35,899 --> 00:08:33,960
of this BS e is actually in the interior

208
00:08:39,820 --> 00:08:35,909
most of the volatiles and the earth

209
00:08:44,840 --> 00:08:43,250
so the right amount one thing will

210
00:08:46,579 --> 00:08:44,850
return to this in a moment but the right

211
00:08:49,730 --> 00:08:46,589
amount is not just the surface reservoir

212
00:08:51,230 --> 00:08:49,740
it's the reservoir in the battery if you

213
00:08:53,990 --> 00:08:51,240

will in the interior that replenishes

214
00:08:55,070 --> 00:08:54,000
the surface reservoir and also modulate

215
00:09:01,490 --> 00:08:55,080
the

216
00:09:06,320 --> 00:09:01,500
amount I don't know perhaps some of you

217
00:09:08,360 --> 00:09:06,330
do know it had better be the light

218
00:09:09,770 --> 00:09:08,370
amount earth must plot within the band

219
00:09:13,790 --> 00:09:09,780
of the right amount that's about all I

220
00:09:17,390 --> 00:09:13,800
dunno and of course it surely depends on

221
00:09:22,970 --> 00:09:17,400
things like radial distance and it is a

222
00:09:24,950 --> 00:09:22,980
product not of gain but of loss okay

223
00:09:26,390 --> 00:09:24,960
this plot comes again and again but I

224
00:09:31,550 --> 00:09:26,400
think I've already explained what i need

225
00:09:33,290 --> 00:09:31,560
to do for this particular whoops so yes

226
00:09:34,790 --> 00:09:33,300
alright so the point that I was

227
00:09:35,960 --> 00:09:34,800
beginning to make a moment ago that I'm

228
00:09:38,000 --> 00:09:35,970
going to return to is that this

229
00:09:41,000 --> 00:09:38,010
concentration here is not the

230
00:09:43,250 --> 00:09:41,010
concentration in the atmosphere or even

231
00:09:44,870 --> 00:09:43,260
on the surface but in the entire portion

232
00:09:48,920 --> 00:09:44,880
of the planet apart from that in the

233
00:09:51,890 --> 00:09:48,930
core there we go okay so just as an

234
00:09:53,750 --> 00:09:51,900
example for carbon and there are many

235
00:09:55,730 --> 00:09:53,760
different compilations like this I just

236
00:09:57,800 --> 00:09:55,740
happened to take this one because it's

237
00:09:59,990 --> 00:09:57,810
graphically interesting right the amount

238
00:10:01,880 --> 00:10:00,000

of carbon in the atmosphere is dwarfed

239
00:10:03,770 --> 00:10:01,890
by that which is in the oceans which is

240
00:10:06,740 --> 00:10:03,780
in turn dwarfed by that which is on the

241
00:10:10,340 --> 00:10:06,750
surface rocks such as lime stones and

242
00:10:12,050 --> 00:10:10,350
and so on which is in turn a small

243
00:10:16,400 --> 00:10:12,060
portion compared to that which is in the

244
00:10:19,610 --> 00:10:16,410
interior and what we find is first of

245
00:10:22,010 --> 00:10:19,620
all that um that that is that is this

246
00:10:23,470 --> 00:10:22,020
amount that the planet has and that that

247
00:10:26,840 --> 00:10:23,480
the planet apparently needs to operate

248
00:10:28,810 --> 00:10:26,850
and and and second of all that it's the

249
00:10:30,920 --> 00:10:28,820
exchanges between these which are

250
00:10:32,450 --> 00:10:30,930
intrinsically linked to plate tectonics

251
00:10:36,530 --> 00:10:32,460
which I think mark jelinek is going to

252
00:10:38,930 --> 00:10:36,540
talk about tomorrow that that allow for

253
00:10:40,580 --> 00:10:38,940
not just the beginning of a habitable

254
00:10:43,180 --> 00:10:40,590
planet but the steadiness of that

255
00:10:49,220 --> 00:10:43,190
habitable planet through various

256
00:10:54,720 --> 00:10:49,230
perturbations and in catastrophes so

257
00:10:58,199 --> 00:10:54,730
this whoops a little bit of

258
00:10:59,310 --> 00:10:58,209
slow there we go okay so this is for

259
00:11:01,290 --> 00:10:59,320
carbon I'm not going to show u

260
00:11:03,329 --> 00:11:01,300
equivalent maps for nitrogen and water

261
00:11:04,740 --> 00:11:03,339
but just a summary and actually we can

262
00:11:06,030 --> 00:11:04,750
skip the bottom portion of this plot

263
00:11:08,910 --> 00:11:06,040

just look at the top portion of this

264
00:11:12,240 --> 00:11:08,920
plot in fact for carbon water and

265
00:11:14,819 --> 00:11:12,250
nitrogen the reservoirs in the in the

266
00:11:16,620 --> 00:11:14,829
planet are not entirely on the surface

267
00:11:19,410 --> 00:11:16,630
its carbon that has the greatest amount

268
00:11:22,680 --> 00:11:19,420
of interior reservoir the amount of

269
00:11:24,569 --> 00:11:22,690
carbon in Earth's mantle is greatly

270
00:11:27,019 --> 00:11:24,579
exceeds that on the surface whereas

271
00:11:33,600 --> 00:11:27,029
those for water and nitrogen are

272
00:11:35,810 --> 00:11:33,610
approximately comparable I this is an

273
00:11:38,009 --> 00:11:35,820
example of something that you probably

274
00:11:40,740 --> 00:11:38,019
don't want me to step through in great

275
00:11:42,689 --> 00:11:40,750
detail the reason that i have this is

276
00:11:44,250 --> 00:11:42,699
that you may wonder how it is that we

277
00:11:45,930 --> 00:11:44,260
know what the concentrations of these

278
00:11:47,550 --> 00:11:45,940
elements are in the interior and the

279
00:11:49,170 --> 00:11:47,560
reason that we think we know it is

280
00:11:51,000 --> 00:11:49,180
because we have samples of the interior

281
00:11:53,670 --> 00:11:51,010
that comes from erupted volcanic

282
00:11:57,120 --> 00:11:53,680
products the salts that have preserved

283
00:11:59,639 --> 00:11:57,130
in them undie gas samples of melt that

284
00:12:01,290 --> 00:11:59,649
was made in the interior and we can look

285
00:12:04,439 --> 00:12:01,300
at the concentrations of things like

286
00:12:06,980 --> 00:12:04,449
carbon or water in these melts we can

287
00:12:10,710 --> 00:12:06,990
ratio them to trace elements such as

288
00:12:12,449 --> 00:12:10,720

barium niobium cerium and so on which we

289
00:12:13,949 --> 00:12:12,459
know very well the concentration of

290
00:12:15,629 --> 00:12:13,959
these in the earth because they're very

291
00:12:17,790 --> 00:12:15,639
steady their refractory lyssa file

292
00:12:19,860 --> 00:12:17,800
elements that are very very little

293
00:12:22,309 --> 00:12:19,870
between planetary objects and meteorites

294
00:12:25,620 --> 00:12:22,319
and so forth and from these ratios of

295
00:12:28,860 --> 00:12:25,630
carbon deberia more or water to cerium

296
00:12:31,139 --> 00:12:28,870
we can infer from these undie gas

297
00:12:35,819 --> 00:12:31,149
inclusions what the concentrations are

298
00:12:37,650 --> 00:12:35,829
in the interior and the reason that it's

299
00:12:40,230 --> 00:12:37,660
important or one of the reasons that

300
00:12:43,400 --> 00:12:40,240
it's important is not only are the these

301
00:12:46,019 --> 00:12:43,410
elements important for maintaining the

302
00:12:47,790 --> 00:12:46,029
our climate and and the atmosphere and

303
00:12:52,199 --> 00:12:47,800
so forth but they're also important for

304
00:12:55,500 --> 00:12:52,209
maintaining the dynamics of the interior

305
00:12:59,040 --> 00:12:55,510
so on the left here we have two

306
00:13:00,930 --> 00:12:59,050
different geodynamic models of how the

307
00:13:02,639 --> 00:13:00,940
strength of the lithosphere is affected

308
00:13:04,559 --> 00:13:02,649
either in the case where there's no

309
00:13:06,900 --> 00:13:04,569
water in the interior or in the cases

310
00:13:07,560 --> 00:13:06,910
where there is water in the material

311
00:13:09,690 --> 00:13:07,570
water

312
00:13:11,700 --> 00:13:09,700
greatly weakens rocks that allow strain

313
00:13:13,860 --> 00:13:11,710

localization it allows for the

314
00:13:16,620 --> 00:13:13,870
lithosphere the strong outer layer of

315
00:13:20,730 --> 00:13:16,630
the earth to break and that breakage is

316
00:13:24,150 --> 00:13:20,740
in fact the allowing plate tectonics to

317
00:13:25,680 --> 00:13:24,160
occur so without some amounts of

318
00:13:27,090 --> 00:13:25,690
volatile zin the interior we don't have

319
00:13:30,510 --> 00:13:27,100
plate tectonics and we don't have the

320
00:13:32,810 --> 00:13:30,520
recycling mechanisms that that allow for

321
00:13:35,640 --> 00:13:32,820
the planet to maintain its steady

322
00:13:37,470 --> 00:13:35,650
interior and exterior dynamics actually

323
00:13:39,830 --> 00:13:37,480
these two plots that make the same point

324
00:13:42,210 --> 00:13:39,840
so I don't really relate with them a

325
00:13:43,890 --> 00:13:42,220
really great example of why this is

326
00:13:46,560 --> 00:13:43,900
important is every once in a while of

327
00:13:49,170 --> 00:13:46,570
course the in the history of a planet

328
00:13:52,050 --> 00:13:49,180
there is a tendency for the climate to

329
00:13:53,910 --> 00:13:52,060
go haywire the most extreme examples of

330
00:13:56,760 --> 00:13:53,920
these are the so-called snowball earth

331
00:13:58,920 --> 00:13:56,770
events which happened twice in the

332
00:14:02,580 --> 00:13:58,930
Precambrian or at least twice in the

333
00:14:04,080 --> 00:14:02,590
Precambrian where the where the where

334
00:14:07,110 --> 00:14:04,090
the climate ran away and became

335
00:14:08,880 --> 00:14:07,120
effectively sealed off and the way that

336
00:14:11,520 --> 00:14:08,890
the planet escaped the snowball earth

337
00:14:13,260 --> 00:14:11,530
was the fact that even though weathering

338
00:14:16,140 --> 00:14:13,270

reactions shut down and all sorts of

339
00:14:17,640 --> 00:14:16,150
other reactions shut down so that so

340
00:14:19,200 --> 00:14:17,650
that the plan seemingly became

341
00:14:21,860 --> 00:14:19,210
permanently called the continued

342
00:14:24,780 --> 00:14:21,870
outgassing of co2 from the interior

343
00:14:26,970 --> 00:14:24,790
renewed the greenhouse and and and

344
00:14:29,970 --> 00:14:26,980
brought the earth out of the snowball

345
00:14:32,190 --> 00:14:29,980
event so in effect the interior

346
00:14:35,310 --> 00:14:32,200
volatiles allow for dynamics that

347
00:14:38,340 --> 00:14:35,320
recycle nutrients and so forth and they

348
00:14:41,790 --> 00:14:38,350
also serve as a battery to maintain the

349
00:14:47,670 --> 00:14:41,800
steadiness or the reasonable steadiness

350
00:14:49,290 --> 00:14:47,680
of of the planet's climate so I again I

351
00:14:51,630 --> 00:14:49,300
think Mark jelinek is going to talk more

352
00:14:53,780 --> 00:14:51,640
about this tomorrow so I won't say too

353
00:14:56,910 --> 00:14:53,790
much more but all of these elements

354
00:14:59,160 --> 00:14:56,920
carbon hydrogen nitrogen sulfur

355
00:15:00,990 --> 00:14:59,170
phosphorus are cycling from the interior

356
00:15:03,150 --> 00:15:01,000
to the exterior if the essential

357
00:15:06,270 --> 00:15:03,160
nutrients are being renewed this way the

358
00:15:09,450 --> 00:15:06,280
climate is being held more or less

359
00:15:11,640 --> 00:15:09,460
steady this way and so these volatile

360
00:15:16,830 --> 00:15:11,650
cycles are crucial to the habitability

361
00:15:20,970 --> 00:15:16,840
of the planet okay so how did we get

362
00:15:22,710 --> 00:15:20,980
here we got here starting from here into

363
00:15:24,569 --> 00:15:22,720

sets of processes one would be the

364
00:15:26,100 --> 00:15:24,579
formation of the rocks and then the

365
00:15:30,740 --> 00:15:26,110
other would be the formation from the

366
00:15:35,730 --> 00:15:30,750
rocks of the larger planetary bodies and

367
00:15:37,620 --> 00:15:35,740
so two essential kinds of primitive

368
00:15:39,960 --> 00:15:37,630
meteorites enstatite chondrites and

369
00:15:43,620 --> 00:15:39,970
carbonaceous chondrites illustrated here

370
00:15:48,240 --> 00:15:43,630
and here are our materials that been

371
00:15:50,400 --> 00:15:48,250
assembled from bits of dust and so on

372
00:15:51,689 --> 00:15:50,410
and the answer tight chondrites are

373
00:15:53,280 --> 00:15:51,699
generally thought to be inner solar

374
00:15:55,410 --> 00:15:53,290
system objects they're generally thought

375
00:15:57,600 --> 00:15:55,420
to be quite dry and volatile poor

376
00:16:00,240 --> 00:15:57,610
whereas the carbonaceous chondrites are

377
00:16:01,710 --> 00:16:00,250
thought to be outer not outer but middle

378
00:16:03,210 --> 00:16:01,720
solar system objects the outer solar

379
00:16:06,060 --> 00:16:03,220
system objects would be comments I

380
00:16:08,280 --> 00:16:06,070
suppose and the carbonaceous chondrites

381
00:16:10,319 --> 00:16:08,290
are thought to be rich in volatiles

382
00:16:11,850 --> 00:16:10,329
because they formed outside of the snow

383
00:16:13,860 --> 00:16:11,860
line where there were lots of Isis

384
00:16:15,300 --> 00:16:13,870
available to react with the rocks and

385
00:16:18,000 --> 00:16:15,310
the answer type chondrites are thought

386
00:16:19,439 --> 00:16:18,010
to be volatile depleted but if you look

387
00:16:21,420 --> 00:16:19,449
on this plot you'll see that the

388
00:16:23,610 --> 00:16:21,430

enstatite chondrites have orders of

389
00:16:26,100 --> 00:16:23,620
magnitude more carbon and nitrogen than

390
00:16:28,050 --> 00:16:26,110
that then our planet so it isn't just

391
00:16:30,030 --> 00:16:28,060
the rock formation in the interior of

392
00:16:31,769 --> 00:16:30,040
the solar system that depletes the

393
00:16:35,100 --> 00:16:31,779
system the process of planet formation

394
00:16:37,439 --> 00:16:35,110
is also a depletion process B op beyond

395
00:16:38,970 --> 00:16:37,449
this how is it that the answer type

396
00:16:40,379 --> 00:16:38,980
contracts have so much carbon and

397
00:16:43,650 --> 00:16:40,389
nitrogen when they formed in the inner

398
00:16:46,319 --> 00:16:43,660
solar system good question so here's a

399
00:16:49,139 --> 00:16:46,329
sort of a and I don't think we know the

400
00:16:52,920 --> 00:16:49,149
answer to it actually so here's sort of

401
00:16:54,840 --> 00:16:52,930
a map of broadly speaking in the outer

402
00:16:56,670 --> 00:16:54,850
solar system beyond the frost line where

403
00:16:59,670 --> 00:16:56,680
there are lots of Isis the carbonaceous

404
00:17:03,900 --> 00:16:59,680
chondrites and other icy bodies form and

405
00:17:06,449 --> 00:17:03,910
it is possible for rocks to react with

406
00:17:08,939 --> 00:17:06,459
water and carbon Isis and so forth and

407
00:17:10,439 --> 00:17:08,949
to gain volatiles that can later be

408
00:17:12,240 --> 00:17:10,449
delivered to the interior of the solar

409
00:17:14,549 --> 00:17:12,250
system but also here where it's supposed

410
00:17:17,400 --> 00:17:14,559
to be too hot too hot for Isis to form

411
00:17:20,939 --> 00:17:17,410
the enstatite chondrites gain carbon and

412
00:17:23,970 --> 00:17:20,949
nitrogen there are two answers to this

413
00:17:26,039 --> 00:17:23,980

one well the two partial answers to this

414
00:17:28,409 --> 00:17:26,049
one is is that the carbon and nitrogen

415
00:17:30,240 --> 00:17:28,419
are actually probably not carried in

416
00:17:32,070 --> 00:17:30,250
Isis but they're probably carried in

417
00:17:34,320 --> 00:17:32,080
much more refractory materials

418
00:17:34,860 --> 00:17:34,330
refractory organics that form not by

419
00:17:39,120 --> 00:17:34,870
equilibria

420
00:17:42,750 --> 00:17:39,130
reactions but by by by various kinetic

421
00:17:44,970 --> 00:17:42,760
processes this plot just to focus on

422
00:17:47,490 --> 00:17:44,980
this plot here this is a kinetic model

423
00:17:48,990 --> 00:17:47,500
by Bergen at all a group that i'm

424
00:17:52,440 --> 00:17:49,000
involved with from the University of

425
00:17:54,450 --> 00:17:52,450
Michigan showing the amount of carbon as

426
00:17:56,040 --> 00:17:54,460
a function of radial distance that is

427
00:17:59,130 --> 00:17:56,050
actually contained within refractory

428
00:18:00,450 --> 00:17:59,140
carbon there are probably many such

429
00:18:04,799 --> 00:18:00,460
compounds but mostly in these

430
00:18:08,340 --> 00:18:04,809
calculations these are pahs and so first

431
00:18:09,960 --> 00:18:08,350
of all out here the temperatures of

432
00:18:11,490 --> 00:18:09,970
condensation temperatures of these

433
00:18:14,060 --> 00:18:11,500
refractory organics effectively are

434
00:18:16,590 --> 00:18:14,070
hundreds of degrees greater than that of

435
00:18:18,930 --> 00:18:16,600
water right so first of all they may

436
00:18:21,150 --> 00:18:18,940
form closer into the solar system and

437
00:18:23,730 --> 00:18:21,160
then second of all also radio mixing

438
00:18:25,650 --> 00:18:23,740

between interior and exterior or

439
00:18:27,600 --> 00:18:25,660
exterior and interior portions of the

440
00:18:31,980 --> 00:18:27,610
solar system may bring such materials

441
00:18:38,160 --> 00:18:31,990
into the inner solar system so that gets

442
00:18:40,169 --> 00:18:38,170
us more or less to to hear but also it's

443
00:18:43,350 --> 00:18:40,179
important I or I just mentioned radial

444
00:18:45,299 --> 00:18:43,360
mixing water is probably better studied

445
00:18:50,340 --> 00:18:45,309
than carbon and nitrogen we already know

446
00:18:52,049 --> 00:18:50,350
that if we posit that the early solar

447
00:18:56,700 --> 00:18:52,059
system consisted of essentially dry

448
00:18:58,830 --> 00:18:56,710
object in the interior and icy bodies in

449
00:19:00,960 --> 00:18:58,840
the exterior that just the dynamics of

450
00:19:05,190 --> 00:19:00,970
accretion lead to radial mixing which

451
00:19:07,650 --> 00:19:05,200
bring the fair portion of the icy bodies

452
00:19:09,480 --> 00:19:07,660
into the interior and so if one runs an

453
00:19:12,299 --> 00:19:09,490
accretion model such as this one ends up

454
00:19:14,669 --> 00:19:12,309
with planets that in the interior that

455
00:19:16,620 --> 00:19:14,679
have had delivered great amounts of

456
00:19:18,120 --> 00:19:16,630
water now notice by the way this is a

457
00:19:19,860 --> 00:19:18,130
log scale here you may not be able to

458
00:19:21,840 --> 00:19:19,870
read these numbers 10 to the minus 3 10

459
00:19:24,840 --> 00:19:21,850
to the minus 2 this sort of process

460
00:19:27,750 --> 00:19:24,850
leads to planets that are far more water

461
00:19:31,620 --> 00:19:27,760
rich by at least an order of magnitude

462
00:19:34,260 --> 00:19:31,630
then we actually observe in certainly an

463
00:19:36,360 --> 00:19:34,270

earthen and obviously the other planets

464
00:19:38,580 --> 00:19:36,370
so there isn't any problem bringing the

465
00:19:40,140 --> 00:19:38,590
volatile in there were already what's it

466
00:19:42,060 --> 00:19:40,150
for carbon and nitrogen there wasn't the

467
00:19:43,320 --> 00:19:42,070
problems of all souls being there in the

468
00:19:44,880 --> 00:19:43,330
inner solar system in the first place

469
00:19:48,030 --> 00:19:44,890
because they're in the enstatite Condren

470
00:19:48,810 --> 00:19:48,040
so there is no problem in accreting all

471
00:19:53,659 --> 00:19:48,820
these material

472
00:19:56,820 --> 00:19:53,669
22 growing planets the the depletion is

473
00:19:59,159 --> 00:19:56,830
partial in that oh you know I'm okay for

474
00:20:01,620 --> 00:19:59,169
time still right the the depletion is

475
00:20:03,269 --> 00:20:01,630
partial in the formation of the rocks

476
00:20:05,970 --> 00:20:03,279
but a lot of the depletion actually has

477
00:20:09,120 --> 00:20:05,980
to take place in the stage of planet

478
00:20:13,049 --> 00:20:09,130
formation so that's where we're going to

479
00:20:14,249 --> 00:20:13,059
go from here to here one of the

480
00:20:17,279 --> 00:20:14,259
interesting things that was actually

481
00:20:19,019 --> 00:20:17,289
noted very prominently in a paper in the

482
00:20:21,499 --> 00:20:19,029
geochemical literature by bernard marty

483
00:20:25,919 --> 00:20:21,509
a few years ago is that this process of

484
00:20:28,379 --> 00:20:25,929
planet formation and and and delivery of

485
00:20:31,080 --> 00:20:28,389
volatiles not only delivers volatile in

486
00:20:33,450 --> 00:20:31,090
a depleted state but the depletion is

487
00:20:34,980 --> 00:20:33,460
differential that is to say that the

488
00:20:37,080 --> 00:20:34,990

amount of water that's delivered or

489
00:20:38,850 --> 00:20:37,090
maybe I shouldn't use delivered the

490
00:20:40,259 --> 00:20:38,860
amount of water that's retained the

491
00:20:41,669 --> 00:20:40,269
amount of carbon that's retained in the

492
00:20:43,889 --> 00:20:41,679
amount of nitrogen that's retained in

493
00:20:45,930 --> 00:20:43,899
the planet does not simply look like

494
00:20:47,730 --> 00:20:45,940
taking a carbonaceous chondrite are

495
00:20:50,909 --> 00:20:47,740
taking a building block and reducing

496
00:20:54,629 --> 00:20:50,919
amount it's it's volatile concentration

497
00:20:56,310 --> 00:20:54,639
some elements are depleted more more

498
00:20:59,190 --> 00:20:56,320
severely than others and in particular

499
00:21:01,080 --> 00:20:59,200
nitrogen is very strongly depleted

500
00:21:04,409 --> 00:21:01,090
interestingly it's even more depleted

501
00:21:07,049 --> 00:21:04,419
than a non reactive gases like neon or

502
00:21:10,139 --> 00:21:07,059
argon something that we have yet to

503
00:21:12,779 --> 00:21:10,149
explain whoops this rather complicated

504
00:21:15,570 --> 00:21:12,789
plot is basically the same information

505
00:21:17,340 --> 00:21:15,580
with just a lot more examples in it here

506
00:21:19,710 --> 00:21:17,350
is the bulk silicate earth in terms of

507
00:21:23,240 --> 00:21:19,720
its carbon nitrogen ratio here are all

508
00:21:25,080 --> 00:21:23,250
different kinds of primitive meteorites

509
00:21:26,610 --> 00:21:25,090
carbonaceous chondrites ordinary

510
00:21:29,070 --> 00:21:26,620
chondrite dennis too tight chondrites

511
00:21:30,960 --> 00:21:29,080
and there are a few exceptions but for

512
00:21:32,759 --> 00:21:30,970
the most end although it you'll notice

513
00:21:34,289 --> 00:21:32,769

that some of these exceptions have to do

514
00:21:37,740 --> 00:21:34,299
with who's reporting it rather than what

515
00:21:41,159 --> 00:21:37,750
the objects are because the because of

516
00:21:42,899 --> 00:21:41,169
analytical challenges but almost all of

517
00:21:44,669 --> 00:21:42,909
the primitive objects have low carbon

518
00:21:45,869 --> 00:21:44,679
nitrogen ratio whereas the bulk silicate

519
00:21:47,820 --> 00:21:45,879
or if there's a high carbon nitrogen

520
00:21:50,430 --> 00:21:47,830
ratio so this is telling us something

521
00:21:51,869 --> 00:21:50,440
about the depletion process that is

522
00:21:53,070 --> 00:21:51,879
differential and that's and that

523
00:21:57,450 --> 00:21:53,080
different elements are going to behave

524
00:21:59,340 --> 00:21:57,460
differently so one of the great

525
00:22:01,760 --> 00:21:59,350
catastrophic events of course is blow

526
00:22:04,370 --> 00:22:01,770
off of the atmosphere by impacts

527
00:22:06,260 --> 00:22:04,380
small and large and we know this

528
00:22:08,360 --> 00:22:06,270
occurred the whole process of assembling

529
00:22:11,060 --> 00:22:08,370
a planet to the series of ever larger

530
00:22:15,590 --> 00:22:11,070
energy events perhaps culminating in the

531
00:22:18,220 --> 00:22:15,600
in the moon-forming impact that that was

532
00:22:20,450 --> 00:22:18,230
sufficient to melt the entire Earth and

533
00:22:22,580 --> 00:22:20,460
these impacts of course have the

534
00:22:24,800 --> 00:22:22,590
possibility the likelihood that they

535
00:22:27,020 --> 00:22:24,810
will blow off whatever primitive early

536
00:22:29,210 --> 00:22:27,030
atmosphere the planet has accreted and

537
00:22:31,100 --> 00:22:29,220
there's also the possibility that this

538
00:22:33,650 --> 00:22:31,110

can be differential for example again de

539
00:22:36,980 --> 00:22:33,660
a knob a ten years ago now 12 years ago

540
00:22:38,870 --> 00:22:36,990
pointed out that if there's a impact to

541
00:22:41,810 --> 00:22:38,880
a planet that already has a liquid water

542
00:22:43,460 --> 00:22:41,820
ocean and a co2 nitrogen atmosphere that

543
00:22:45,560 --> 00:22:43,470
that the atmosphere can be lost

544
00:22:48,680 --> 00:22:45,570
differentially to the ocean and that

545
00:22:50,510 --> 00:22:48,690
that may explain why a ratio that I

546
00:22:53,150 --> 00:22:50,520
haven't yet shown you but it's the same

547
00:22:57,530 --> 00:22:53,160
as before that that the carbon is lost

548
00:22:58,970 --> 00:22:57,540
preferentially to the water in in the

549
00:23:04,090 --> 00:22:58,980
bulk silicate ER it's as compared to

550
00:23:07,700 --> 00:23:04,100
it's likely building blocks the other

551
00:23:10,000 --> 00:23:07,710
catastrophic event is core formation so

552
00:23:14,870 --> 00:23:10,010
the atmospheric loss and core formation

553
00:23:17,330 --> 00:23:14,880
we knew 150 years ago in fact as soon as

554
00:23:20,600 --> 00:23:17,340
the advent of of industrial steel that

555
00:23:22,400 --> 00:23:20,610
that that iron metal loves all of the

556
00:23:25,040 --> 00:23:22,410
bio essential elements all of them

557
00:23:28,670 --> 00:23:25,050
carbon nitrogen hydrogen sulfur

558
00:23:31,040 --> 00:23:28,680
phosphorus if it were up to the metal it

559
00:23:32,660 --> 00:23:31,050
would steal all of the material that we

560
00:23:34,460 --> 00:23:32,670
have on the surface that that is bio

561
00:23:37,010 --> 00:23:34,470
essential and also that we need from

562
00:23:39,670 --> 00:23:37,020
habitability so core formation has the

563
00:23:44,690 --> 00:23:39,680

possibility of robbing the surface of

564
00:23:50,600 --> 00:23:44,700
much most all of the bioavailable

565
00:23:54,020 --> 00:23:50,610
element quantifying this is actually for

566
00:23:56,120 --> 00:23:54,030
in geologically plausible conditions is

567
00:23:58,610 --> 00:23:56,130
actually a project that the community

568
00:23:59,990 --> 00:23:58,620
has taken on fairly recently we tend to

569
00:24:01,910 --> 00:24:00,000
think about this in terms of a very

570
00:24:04,040 --> 00:24:01,920
relatively simple parameter called the

571
00:24:05,780 --> 00:24:04,050
partition coefficient the D which is

572
00:24:08,420 --> 00:24:05,790
experimentally the concentration of

573
00:24:10,040 --> 00:24:08,430
carbon that is in the metal alloy as

574
00:24:12,200 --> 00:24:10,050
compared to the silicate that both

575
00:24:15,440 --> 00:24:12,210
ultimately going to form the mantle and

576
00:24:18,500 --> 00:24:15,450
D gas to form the surface reservoirs

577
00:24:21,230 --> 00:24:18,510
and values for carbon tend to be 10 to

578
00:24:23,299 --> 00:24:21,240
the 2 or greater the concentration of

579
00:24:25,370 --> 00:24:23,309
carbon in the metal is a hundred or a

580
00:24:28,360 --> 00:24:25,380
thousand or ten thousand times greater

581
00:24:30,860 --> 00:24:28,370
than that which is in the silicate and

582
00:24:32,360 --> 00:24:30,870
for nitrogen actually it varies as a

583
00:24:34,129 --> 00:24:32,370
function of I haven't told you what this

584
00:24:36,350 --> 00:24:34,139
parameter is on the x-axis but it's

585
00:24:39,230 --> 00:24:36,360
basically the oxidation state of the

586
00:24:41,600 --> 00:24:39,240
system from oxidized to reduced and

587
00:24:43,519 --> 00:24:41,610
nitrogens behavior depends on that but

588
00:24:46,370 --> 00:24:43,529

under most plausible conditions it to

589
00:24:51,710 --> 00:24:46,380
greatly concentrates in the alloy as

590
00:24:54,889 --> 00:24:51,720
compared to the silicate so core

591
00:24:57,620 --> 00:24:54,899
formation is going to take much of the

592
00:24:59,810 --> 00:24:57,630
carbon much of the nitrogen atmospheric

593
00:25:02,990 --> 00:24:59,820
loss is going to is going to

594
00:25:06,560 --> 00:25:03,000
quantitatively remove materials from the

595
00:25:09,019 --> 00:25:06,570
surface when it occurs and we can think

596
00:25:14,269 --> 00:25:09,029
about the formation of early reservoirs

597
00:25:18,680 --> 00:25:14,279
as a magma ocean losing metal to the

598
00:25:21,019 --> 00:25:18,690
interior and losing gas to the to this

599
00:25:22,700 --> 00:25:21,029
to the atmosphere which has the

600
00:25:26,289 --> 00:25:22,710
potential for loss the only thing that

601
00:25:28,460 --> 00:25:26,299
is likely to be retained over time

602
00:25:33,799 --> 00:25:28,470
available to the eventual surface is

603
00:25:35,840 --> 00:25:33,809
that which is in the silicate and so

604
00:25:38,360 --> 00:25:35,850
this is controlled by the solubility of

605
00:25:41,570 --> 00:25:38,370
the materials the solubility of carbon

606
00:25:44,960 --> 00:25:41,580
or or or support carbon monoxide or

607
00:25:47,169 --> 00:25:44,970
nitrogen or or or ammonia and the

608
00:25:50,629 --> 00:25:47,179
partitioning between the silicate and

609
00:25:52,789 --> 00:25:50,639
and the alloy and one can make a map for

610
00:25:56,000 --> 00:25:52,799
the different elements of their relative

611
00:25:59,120 --> 00:25:56,010
propensity to be either in the mantle or

612
00:26:00,980 --> 00:25:59,130
the atmosphere this mantle or the

613
00:26:02,600 --> 00:26:00,990

atmosphere or the mantle or the core

614
00:26:05,060 --> 00:26:02,610
depending on these different parameters

615
00:26:07,610 --> 00:26:05,070
and what one finds is is that for

616
00:26:11,389 --> 00:26:07,620
example carbon loves to be in the core

617
00:26:13,490 --> 00:26:11,399
or the atmosphere it hardly stays in the

618
00:26:15,440 --> 00:26:13,500
silicate as well the other extreme would

619
00:26:18,830 --> 00:26:15,450
be water which has great solubility in

620
00:26:23,269 --> 00:26:18,840
the silicate another way to look at that

621
00:26:24,919 --> 00:26:23,279
is is this way where again the amount

622
00:26:27,350 --> 00:26:24,929
that's retained in the silicate portion

623
00:26:29,120 --> 00:26:27,360
of the earth is minimal for carbon and

624
00:26:32,830 --> 00:26:29,130
maximal for water and inter

625
00:26:34,910 --> 00:26:32,840
for nitrogen this is the differential

626
00:26:38,990 --> 00:26:34,920
retention that I was talking about

627
00:26:40,310 --> 00:26:39,000
before that we see evidence for I will

628
00:26:44,210 --> 00:26:40,320
skip this because the belt is already

629
00:26:47,450 --> 00:26:44,220
wrong however these processes are too

630
00:26:48,920 --> 00:26:47,460
potent I said that there is a loss

631
00:26:52,910 --> 00:26:48,930
process and in fact there is a loss

632
00:26:55,850 --> 00:26:52,920
process and this loss process if one

633
00:26:58,160 --> 00:26:55,860
allows it to occur with either with

634
00:27:00,380 --> 00:26:58,170
atmospheric loss or without atmospheric

635
00:27:02,660 --> 00:27:00,390
loss for even small amounts of metal

636
00:27:04,910 --> 00:27:02,670
transiting into the core one ends up

637
00:27:07,450 --> 00:27:04,920
with ratios of carbon nitrogen carbon

638
00:27:10,640 --> 00:27:07,460

hydrogen and so forth starting from

639
00:27:12,470 --> 00:27:10,650
chondritic materials that are much more

640
00:27:18,140 --> 00:27:12,480
extreme than what we observe in the bulk

641
00:27:20,420 --> 00:27:18,150
silicate earth what's the solution to

642
00:27:22,010 --> 00:27:20,430
this the solution to this is something

643
00:27:24,280 --> 00:27:22,020
that was referred to yesterday and the

644
00:27:27,230 --> 00:27:24,290
discussions is the so-called late veneer

645
00:27:30,280 --> 00:27:27,240
after the catastrophic the largest

646
00:27:32,690 --> 00:27:30,290
catastrophic events of core formation

647
00:27:34,430 --> 00:27:32,700
atmospheric blow-off associated with the

648
00:27:36,860 --> 00:27:34,440
moon-forming impact and so forth of

649
00:27:38,510 --> 00:27:36,870
course accretion continued not nearly as

650
00:27:40,970 --> 00:27:38,520
much accretion but a small amount and

651
00:27:47,740 --> 00:27:40,980
that accretion added chondritic like

652
00:27:52,850 --> 00:27:50,630
we know this occurred accretion models

653
00:27:59,590 --> 00:27:52,860
of course can't possibly stop with the

654
00:28:03,260 --> 00:27:59,600
last final slide climatic of climactic

655
00:28:07,520 --> 00:28:03,270
climatic and climactic are it's tempting

656
00:28:10,880 --> 00:28:07,530
to say 111 means the other climactic

657
00:28:14,630 --> 00:28:10,890
events I and and so depending on when

658
00:28:18,110 --> 00:28:14,640
those last large impacts occurred we

659
00:28:20,570 --> 00:28:18,120
expect something like 10 to the minus 3

660
00:28:22,970 --> 00:28:20,580
10 to the minus 2 even as much as 10 to

661
00:28:25,430 --> 00:28:22,980
the minus one of the mass of the earth

662
00:28:29,680 --> 00:28:25,440
to continue to accrete we know that this

663
00:28:31,970 --> 00:28:29,690

occurred according to the metals the

664
00:28:33,770 --> 00:28:31,980
metals that love to go into the course

665
00:28:34,970 --> 00:28:33,780
in rafal elements like platinum and so

666
00:28:37,190 --> 00:28:34,980
forth those of you who like precious

667
00:28:40,460 --> 00:28:37,200
metal jewelry would wish that our late

668
00:28:42,499 --> 00:28:40,470
veneer would have been greater and so

669
00:28:45,589 --> 00:28:42,509
some amount was added afterwards and

670
00:28:50,829 --> 00:28:45,599
some amount also added other sidra five

671
00:28:56,930 --> 00:28:53,869
however the fact that there is this

672
00:28:59,419 --> 00:28:56,940
differential concentration compared to

673
00:29:02,269 --> 00:28:59,429
late veneer like materials compared to

674
00:29:05,389 --> 00:29:02,279
meteoritic materials shows us that the

675
00:29:07,489 --> 00:29:05,399
sum of the of the bioavailable elements

676
00:29:10,099 --> 00:29:07,499
the sum of the habitable important

677
00:29:12,680 --> 00:29:10,109
elements is some combination between

678
00:29:15,619 --> 00:29:12,690
that material that was processed through

679
00:29:17,930 --> 00:29:15,629
the core forming and atmospheric loss

680
00:29:21,019 --> 00:29:17,940
processes and something added back we

681
00:29:23,539 --> 00:29:21,029
actually need both we need we need early

682
00:29:25,519 --> 00:29:23,549
delivery and processing in the in the in

683
00:29:27,529 --> 00:29:25,529
these catastrophes and then we need

684
00:29:30,439 --> 00:29:27,539
material added afterwards otherwise we

685
00:29:31,399 --> 00:29:30,449
would have to extreme barium first of

686
00:29:33,139 --> 00:29:31,409
all we wouldn't have enough of these

687
00:29:34,699 --> 00:29:33,149
elements and second of all the

688
00:29:40,369 --> 00:29:34,709

fractionation between them would be more

689
00:29:43,299 --> 00:29:40,379
extreme than what we observe okay so the

690
00:29:45,949 --> 00:29:43,309
one that is most extreme in terms of its

691
00:29:48,169 --> 00:29:45,959
magma ocean remnant is hydrogen there's

692
00:29:49,909 --> 00:29:48,179
much more hydrogen than there is the

693
00:29:52,399 --> 00:29:49,919
other elements and it's the one that's

694
00:29:54,859 --> 00:29:52,409
most soluble in the silicate so it's the

695
00:29:58,219 --> 00:29:54,869
one that's retained by the planet these

696
00:30:01,129 --> 00:29:58,229
probably carbon nitrogen sulfur were

697
00:30:03,829 --> 00:30:01,139
probably delivered after in small

698
00:30:06,919 --> 00:30:03,839
amounts after these catastrophic events

699
00:30:08,839 --> 00:30:06,929
whether or not this nitrogen depletion

700
00:30:11,239 --> 00:30:08,849
is owing to the fact that things were

701
00:30:13,489 --> 00:30:11,249
delivered that lost nitrogen in ways

702
00:30:15,680 --> 00:30:13,499
that we don't see in contradict

703
00:30:17,479 --> 00:30:15,690
meteorites is one possibility another

704
00:30:19,909 --> 00:30:17,489
possibility is that there was an

705
00:30:21,319 --> 00:30:19,919
additional process of late loss of a

706
00:30:28,539 --> 00:30:21,329
low-temperature atmosphere which would

707
00:30:33,439 --> 00:30:31,129
it isn't that we gained these elements

708
00:30:40,879 --> 00:30:33,449
it's that we lost them by just the right

709
00:30:43,459 --> 00:30:40,889
amount but the supply to hot inner solar

710
00:30:45,409 --> 00:30:43,469
system planets is is far greater than

711
00:30:47,059 --> 00:30:45,419
what we actually see in other words it

712
00:30:48,769 --> 00:30:47,069
isn't just that we were born in the

713
00:30:50,509 --> 00:30:48,779

inner solar system which was volatile

714
00:30:54,379 --> 00:30:50,519
depleted the process of planet formation

715
00:30:56,190 --> 00:30:54,389
expelled much much of the volatile and

716
00:30:58,200 --> 00:30:56,200
then the fractionation is

717
00:31:00,299 --> 00:30:58,210
is both core formation in atmospheric

718
00:31:02,100 --> 00:31:00,309
loss and the final inventory is a

719
00:31:03,779 --> 00:31:02,110
combination of early delivered elements

720
00:31:05,789 --> 00:31:03,789
in lace veneer and this isn't on the

721
00:31:08,310 --> 00:31:05,799
conclusion but i do want to return to

722
00:31:11,759 --> 00:31:08,320
the point that i made at the outset

723
00:31:13,830 --> 00:31:11,769
which is we would like to know what the

724
00:31:16,519 --> 00:31:13,840
right amount of these elements are in

725
00:31:19,639 --> 00:31:16,529
order to operate a planet that has

726
00:31:22,710 --> 00:31:19,649
steady internal dynamics and also steady

727
00:31:24,240 --> 00:31:22,720
habitable climate and apart from the

728
00:31:25,830 --> 00:31:24,250
fact that Earth is within the window i'm

729
00:31:40,440 --> 00:31:25,840
not sure we know what that window is

730
00:31:42,810 --> 00:31:40,450
thank you questions could you comment on

731
00:31:45,269 --> 00:31:42,820
to what extent should we be looking only

732
00:31:47,250 --> 00:31:45,279
at elements in its atomic form versus

733
00:31:49,470 --> 00:31:47,260
its molecular structures because often

734
00:31:51,690 --> 00:31:49,480
the fractionation seems to be dependent

735
00:31:53,879 --> 00:31:51,700
on the kind of molecules these carbon

736
00:31:57,269 --> 00:31:53,889
nitrogen oxygen sulfur phosphorus form

737
00:32:00,269 --> 00:31:57,279
in minerals how much of a dependence is

738
00:32:03,539 --> 00:32:00,279

it in terms of loss or depletion on a

739
00:32:05,159 --> 00:32:03,549
planet on yeah of course most of the

740
00:32:06,899 --> 00:32:05,169
processes that I'm talking about in

741
00:32:08,490 --> 00:32:06,909
terms of planet formation or very high

742
00:32:09,840 --> 00:32:08,500
temperature processing so all the

743
00:32:12,450 --> 00:32:09,850
molecules that would be thinking about

744
00:32:14,129 --> 00:32:12,460
are quite simple but depending on for

745
00:32:16,830 --> 00:32:14,139
example the oxidation state whether or

746
00:32:20,759 --> 00:32:16,840
not we have n2 or NH 3 whether or not we

747
00:32:22,740 --> 00:32:20,769
have co co 2 or ch4 that's how simple we

748
00:32:25,259 --> 00:32:22,750
are in terms of the kinds of molecules

749
00:32:27,659 --> 00:32:25,269
that may be present the all of these

750
00:32:29,519 --> 00:32:27,669
parameters that are that I'm examining

751
00:32:31,409 --> 00:32:29,529
whether it be partitioning or solubility

752
00:32:33,180 --> 00:32:31,419
depend very strongly on that so that so

753
00:32:34,860 --> 00:32:33,190
that's quite important the only place

754
00:32:37,289 --> 00:32:34,870
where anything more complex may be

755
00:32:40,850 --> 00:32:37,299
involved would be in the other portion

756
00:32:43,889 --> 00:32:40,860
of the process going from dust grains to

757
00:32:45,720 --> 00:32:43,899
say chondritic meteorites are or their

758
00:32:49,769 --> 00:32:45,730
equivalent where the formation of

759
00:32:50,850 --> 00:32:49,779
various refractory organics will have a

760
00:32:53,070 --> 00:32:50,860
lot to do with their preservation

761
00:33:04,120 --> 00:32:53,080
through processes of metamorphism and

762
00:33:10,250 --> 00:33:07,550
yeah you mentioned that the bio

763
00:33:14,060 --> 00:33:10,260

essential elements are 0 files yes and

764
00:33:16,640 --> 00:33:14,070
then you you like comparing bulk silicon

765
00:33:18,170 --> 00:33:16,650
earth but not bulk earth you then came

766
00:33:20,600 --> 00:33:18,180
to some conclusions about the late

767
00:33:23,600 --> 00:33:20,610
veneer but it seems to me that if you

768
00:33:28,550 --> 00:33:23,610
don't instead of using BSE you use BS

769
00:33:30,980 --> 00:33:28,560
bulk earth unpardonable yes if you had

770
00:33:33,320 --> 00:33:30,990
used be e then you could at least to the

771
00:33:34,910 --> 00:33:33,330
extent that we know about the how many

772
00:33:36,320 --> 00:33:34,920
of these essential elements are in the

773
00:33:39,590 --> 00:33:36,330
core i know that's not very well known

774
00:33:41,510 --> 00:33:39,600
but we know a little bit and if we if

775
00:33:43,280 --> 00:33:41,520
you included that in the analysis you

776
00:33:45,200 --> 00:33:43,290
could say something a little bit more

777
00:33:46,790 --> 00:33:45,210
constraining about the late veneer for

778
00:33:48,950 --> 00:33:46,800
example maybe there are so many of these

779
00:33:50,240 --> 00:33:48,960
these elements the bio essential element

780
00:33:51,530 --> 00:33:50,250
in the core that you wouldn't even need

781
00:33:56,060 --> 00:33:51,540
elite veneer to explain some of the

782
00:34:00,470 --> 00:33:56,070
anomalies you see perhaps the guiding

783
00:34:02,270 --> 00:34:00,480
assumption in what I was telling you is

784
00:34:04,280 --> 00:34:02,280
that once things go to the core they

785
00:34:06,620 --> 00:34:04,290
stay there which is to say that they're

786
00:34:08,210 --> 00:34:06,630
not any longer available to be sampled

787
00:34:10,520 --> 00:34:08,220
by the surface or the mantle and so

788
00:34:12,050 --> 00:34:10,530

forth we don't know what those values

789
00:34:13,909 --> 00:34:12,060
are very well so when we look at the

790
00:34:16,370 --> 00:34:13,919
bulk silicate earth what we're looking

791
00:34:18,860 --> 00:34:16,380
at is the mantle the and the surface and

792
00:34:20,659 --> 00:34:18,870
so forth the late veneer sort of by

793
00:34:23,240 --> 00:34:20,669
definition is that material which is

794
00:34:26,960 --> 00:34:23,250
added after the closure or the effective

795
00:34:29,480 --> 00:34:26,970
closure of exchange with the core so I

796
00:34:31,040 --> 00:34:29,490
don't know that knowing the bulk earth

797
00:34:33,200 --> 00:34:31,050
would tell us much about the late veneer

798
00:34:35,480 --> 00:34:33,210
it would tell us a lot about the feeding

799
00:34:37,720 --> 00:34:35,490
zone of the original materials that were

800
00:34:40,280 --> 00:34:37,730
added to the earth enstatite chondrites

801
00:34:45,100 --> 00:34:40,290
carbonaceous chondrites and so on and it

802
00:34:48,470 --> 00:34:47,419
something that I haven't quantified for

803
00:34:50,390 --> 00:34:48,480
you I've just told you that they're both

804
00:34:52,070 --> 00:34:50,400
important is that there's the processes

805
00:34:55,040 --> 00:34:52,080
of core formation and also atmospheric

806
00:34:57,470 --> 00:34:55,050
loss and unless we know those two we

807
00:35:00,230 --> 00:34:57,480
don't necessarily know what the original

808
00:35:02,000 --> 00:35:00,240
supply was because one is still in the

809
00:35:07,310 --> 00:35:02,010
system hard to know the bulk earth and

810
00:35:09,650 --> 00:35:07,320
the other is lost yeah thanks that

811
00:35:11,600 --> 00:35:09,660
really beautiful talk I just maybe

812
00:35:12,740 --> 00:35:11,610
there's a little bit outside of what

813
00:35:16,730 --> 00:35:12,750

you're comfortable with but could you

814
00:35:17,620 --> 00:35:16,740
give us your best estimate of scenarios

815
00:35:19,269 --> 00:35:17,630
for the atmosphere

816
00:35:21,490 --> 00:35:19,279
of the earth between three point eight

817
00:35:23,700 --> 00:35:21,500
and four billion years ago yeah that is

818
00:35:26,740 --> 00:35:23,710
outside of what I was talking about but

819
00:35:31,240 --> 00:35:26,750
but but one thing that something that I

820
00:35:33,160 --> 00:35:31,250
skipped that I think is there we go that

821
00:35:37,299 --> 00:35:33,170
I think is very interesting is it's

822
00:35:39,099 --> 00:35:37,309
generally assumed just ad hoc that that

823
00:35:42,370 --> 00:35:39,109
the early Earth looked on the like the

824
00:35:43,990 --> 00:35:42,380
earliest earth the magma ocean earth

825
00:35:46,569 --> 00:35:44,000
look like the left hand side of this

826
00:35:48,700 --> 00:35:46,579
diagram which I actually think there's

827
00:35:50,620 --> 00:35:48,710
some inconsistency to that which is that

828
00:35:52,390 --> 00:35:50,630
they have a magma ocean and iron metal

829
00:35:54,999 --> 00:35:52,400
and then the atmosphere ought to be co2

830
00:35:58,480 --> 00:35:55,009
and h2o right highly reduced quite

831
00:36:00,370 --> 00:35:58,490
oxidized and it's equally plausible that

832
00:36:01,660 --> 00:36:00,380
the early Earth I don't have nitrogen

833
00:36:03,730 --> 00:36:01,670
here but that the early Earth's

834
00:36:09,730 --> 00:36:03,740
atmosphere the very first atmosphere was

835
00:36:11,589 --> 00:36:09,740
reduced coh to methane and and so on the

836
00:36:14,109 --> 00:36:11,599
density of this atmosphere of course in

837
00:36:15,819 --> 00:36:14,119
the magma ocean stages tens of bars or

838
00:36:18,269 --> 00:36:15,829

hundreds of bars or something like that

839
00:36:20,259 --> 00:36:18,279
Matt cannot have lasted right the

840
00:36:22,210 --> 00:36:20,269
weathering processes and whatever

841
00:36:24,279 --> 00:36:22,220
whatever else must have drawn down most

842
00:36:27,670 --> 00:36:24,289
of the carbon but I would say that the

843
00:36:29,170 --> 00:36:27,680
starting condition would have to be well

844
00:36:30,940 --> 00:36:29,180
no I wouldn't say what have to be could

845
00:36:34,779 --> 00:36:30,950
easily have been something like this and

846
00:36:36,249 --> 00:36:34,789
the transition to what you're talking

847
00:36:37,900 --> 00:36:36,259
about what you think is old but i think

848
00:36:41,859 --> 00:36:37,910
is like hundreds of million years after

849
00:36:43,210 --> 00:36:41,869
this i I think we don't know very much

850
00:36:45,789 --> 00:36:43,220
about and it would it would be

851
00:36:48,370 --> 00:36:45,799
interesting to know one thing that we do

852
00:36:50,620 --> 00:36:48,380
seem to know is that this is that the

853
00:36:52,539 --> 00:36:50,630
rocks on the surface don't reflect this

854
00:36:54,609 --> 00:36:52,549
highly reduced condition going all the

855
00:36:57,220 --> 00:36:54,619
way back to 3.8 to 4 billion years which

856
00:36:59,589 --> 00:36:57,230
is to say that some oxidation process

857
00:37:02,319 --> 00:36:59,599
occurred probably hydrogen loss but

858
00:37:06,069 --> 00:37:02,329
there are other ideas yeah it seems like

859
00:37:08,079 --> 00:37:06,079
I learned a funky it seems like a lot of

860
00:37:10,120 --> 00:37:08,089
the processes should be dependent on the

861
00:37:12,099 --> 00:37:10,130
size of scientism you know obviously

862
00:37:14,319 --> 00:37:12,109
surface area to volume ratio and

863
00:37:15,730 --> 00:37:14,329

atmospheric loss and differentiation so

864
00:37:18,970 --> 00:37:15,740
nuts wondering if you'd taken that into

865
00:37:20,380 --> 00:37:18,980
account in your calculation oh so you're

866
00:37:26,380 --> 00:37:20,390
talking about the planet or the planet

867
00:37:28,569 --> 00:37:26,390
Esmil yeah we do take that into account

868
00:37:30,940 --> 00:37:28,579
in terms of planets but in terms of

869
00:37:31,630 --> 00:37:30,950
differentiation to planetesimals this is

870
00:37:35,350 --> 00:37:31,640
something that we're

871
00:37:36,760 --> 00:37:35,360
beginning to get to at least in in in my

872
00:37:38,440 --> 00:37:36,770
research with collaborators which is

873
00:37:41,920 --> 00:37:38,450
that the material delivered to the

874
00:37:43,510 --> 00:37:41,930
planet is not largely chondritic

875
00:37:45,550 --> 00:37:43,520
meteorites but it's probably largely

876
00:37:47,980 --> 00:37:45,560
planetesimals that had been processed on

877
00:37:50,170 --> 00:37:47,990
small bodies on 100 kilometer or 300

878
00:37:53,140 --> 00:37:50,180
kilometers size bodies and the

879
00:37:55,840 --> 00:37:53,150
metamorphism that occurs on that the the

880
00:37:57,190 --> 00:37:55,850
maturation if you will of the carbon and

881
00:37:58,840 --> 00:37:57,200
nitrogen in the hydrogen and the

882
00:38:01,690 --> 00:37:58,850
diversity of materials that are

883
00:38:03,070 --> 00:38:01,700
delivered no we're not taking that into

884
00:38:10,030 --> 00:38:03,080
account and that might be a very large

885
00:38:13,870 --> 00:38:10,040
part of the story I have a two brave

886
00:38:15,880 --> 00:38:13,880
question first I like the argument in

887
00:38:19,060 --> 00:38:15,890
the process of forming climbing say the

888
00:38:21,880 --> 00:38:19,070

process of losing volatiles so if we

889
00:38:24,910 --> 00:38:21,890
just focus on the tablet of the

890
00:38:28,900 --> 00:38:24,920
volatiles let's talk about later on

891
00:38:31,120 --> 00:38:28,910
linear of supply so in addition to the

892
00:38:34,540 --> 00:38:31,130
highly eccentric higher things like a

893
00:38:38,920 --> 00:38:34,550
distance in yo leo are there any other

894
00:38:41,560 --> 00:38:38,930
sectors are also of importance to the

895
00:38:46,060 --> 00:38:41,570
temptation of volatiles and these

896
00:38:49,540 --> 00:38:46,070
factors can be also quantifiable and my

897
00:38:51,300 --> 00:38:49,550
second question is you as you mentioned

898
00:38:56,200 --> 00:38:51,310
with the economy of the solar system

899
00:38:58,750 --> 00:38:56,210
from rocky body gasps body and eyes

900
00:39:02,770 --> 00:38:58,760
abilities outer world so I'm wondering

901
00:39:04,810 --> 00:39:02,780
if the economy of likeable or universal

902
00:39:07,750 --> 00:39:04,820
for our other planet or system of

903
00:39:09,760 --> 00:39:07,760
certain clinical system Thanks well I

904
00:39:12,010 --> 00:39:09,770
think I know the answer to your second

905
00:39:15,340 --> 00:39:12,020
question I'm not sure I know how to

906
00:39:17,230 --> 00:39:15,350
respond to your first question of course

907
00:39:20,140 --> 00:39:17,240
actually there's a plot that isn't in

908
00:39:21,490 --> 00:39:20,150
here of the composition of stars but I

909
00:39:23,050 --> 00:39:21,500
think many of you are familiar with it

910
00:39:25,540 --> 00:39:23,060
they're more oxygen rich stars and

911
00:39:27,820 --> 00:39:25,550
carbon rich stars and that will have a

912
00:39:31,300 --> 00:39:27,830
considerable effect on the on the

913
00:39:33,450 --> 00:39:31,310

volatile chemistry of the of the dust

914
00:39:36,550 --> 00:39:33,460
and the gas around those stars but

915
00:39:37,990 --> 00:39:36,560
certainly so this is the interstellar

916
00:39:40,210 --> 00:39:38,000
medium here certainly in terms of the

917
00:39:43,330 --> 00:39:40,220
absolute abundance of things like carbon

918
00:39:45,580 --> 00:39:43,340
and nitrogen and obviously hydrogen it

919
00:39:46,990 --> 00:39:45,590
is generally true that any solar

920
00:39:51,190 --> 00:39:47,000
system that is making terrestrial

921
00:39:54,130 --> 00:39:51,200
planets must be shedding those elements

922
00:39:55,810 --> 00:39:54,140
in the process whether they shed them in

923
00:39:58,600 --> 00:39:55,820
the same way that our solar system has I

924
00:40:00,790 --> 00:39:58,610
don't know and I'm not sure I know how

925
00:40:04,120 --> 00:40:00,800
to answer your first question you're

926
00:40:05,530 --> 00:40:04,130
asking whether or not in addition to

927
00:40:07,720 --> 00:40:05,540
heliocentric distance there are other

928
00:40:17,260 --> 00:40:07,730
important variables that affect the lost

929
00:40:19,360 --> 00:40:17,270
processes yeah and and was that question

930
00:40:27,340 --> 00:40:19,370
directed at our solar system or more

931
00:40:29,800 --> 00:40:27,350
generally well there's a certain

932
00:40:31,300 --> 00:40:29,810
stochastic aspect to it right so one

933
00:40:33,520 --> 00:40:31,310
thing that's really important to our

934
00:40:35,530 --> 00:40:33,530
planet apparently is the occurrence of

935
00:40:38,650 --> 00:40:35,540
giant impacts or the frequency of giant

936
00:40:41,650 --> 00:40:38,660
impact and so you know a planet like

937
00:40:45,130 --> 00:40:41,660
Mars which is an embryo which didn't

938
00:40:46,690 --> 00:40:45,140

suffer any truly giant impacts would

939
00:40:49,900 --> 00:40:46,700
certainly have a different loss history

940
00:40:51,490 --> 00:40:49,910
than Earth it has a different history

941
00:40:53,640 --> 00:40:51,500
also because of its heliocentric

942
00:40:55,810 --> 00:40:53,650
distance but the difference between

943
00:40:57,970 --> 00:40:55,820
planets that are effectively embryos

944
00:40:59,350 --> 00:40:57,980
that form very quickly you know Mars is

945
00:41:01,600 --> 00:40:59,360
thought to have formed within the first

946
00:41:03,310 --> 00:41:01,610
couple of million years of the solar

947
00:41:04,770 --> 00:41:03,320
system history as opposed to larger

948
00:41:07,780 --> 00:41:04,780
planets which have this more protracted

949
00:41:09,640 --> 00:41:07,790
impact in accretion history like Earth

950
00:41:14,980 --> 00:41:09,650
and Venus that's that's an important

951
00:41:17,020 --> 00:41:14,990
difference you said in the beginning of

952
00:41:19,840 --> 00:41:17,030
your talk that the tectonics is

953
00:41:23,350 --> 00:41:19,850
essential for the renewal of elements

954
00:41:25,810 --> 00:41:23,360
yes so what do you think about is it

955
00:41:27,850 --> 00:41:25,820
important for the origin of life or the

956
00:41:29,560 --> 00:41:27,860
maintenance of life and what about early

957
00:41:32,140 --> 00:41:29,570
Earth before bit tectonics and what

958
00:41:34,900 --> 00:41:32,150
about math yeah I think I'll let mark

959
00:41:36,370 --> 00:41:34,910
answer that tomorrow I i don't think

960
00:41:38,980 --> 00:41:36,380
that plate tectonics is essential for

961
00:41:40,720 --> 00:41:38,990
the origin of life I don't think it's

962
00:41:42,850 --> 00:41:40,730
necessarily important for the

963
00:41:45,040 --> 00:41:42,860

maintenance of life but I do think it's

964
00:41:46,780 --> 00:41:45,050
important for the maintenance of

965
00:41:51,010 --> 00:41:46,790
habitability and I think the counter

966
00:41:53,220 --> 00:41:51,020
example is Mars if life Mars appears to

967
00:41:57,280 --> 00:41:53,230
have been habitable early in its history

968
00:42:00,479 --> 00:41:57,290
it appears to have what whether or not

969
00:42:03,370 --> 00:42:00,489
it had life I guess I defer to

970
00:42:05,890 --> 00:42:03,380
others about but definitely the

971
00:42:09,209 --> 00:42:05,900
steadiness of our climate and our

972
00:42:12,519 --> 00:42:09,219
habitability is intrinsically limited

973
00:42:14,259 --> 00:42:12,529
intrinsically related to plate tectonics

974
00:42:18,880 --> 00:42:14,269
I would assert but i think that mark is

975
00:42:21,249 --> 00:42:18,890
going to address this tomorrow true all

976
00:42:24,130 --> 00:42:21,259
right thank you great thought a lot to

977
00:42:25,569 --> 00:42:24,140
think about one question is in the near

978
00:42:27,999 --> 00:42:25,579
the end we are talking mentioned there

979
00:42:29,829 --> 00:42:28,009
is a possible late loss of a nitrogen

980
00:42:34,449 --> 00:42:29,839
from low temperature animals here yes

981
00:42:37,449 --> 00:42:34,459
and and I like to hear you to talk more

982
00:42:39,669 --> 00:42:37,459
about that and if that was a case oh

983
00:42:43,599 --> 00:42:39,679
where is that isotopic fractionation

984
00:42:45,370 --> 00:42:43,609
Sigma signature okay so it depends on

985
00:42:47,229 --> 00:42:45,380
the on the light I did I wasn't very

986
00:42:49,269 --> 00:42:47,239
specific about what that late loss was

987
00:42:51,309 --> 00:42:49,279
if the late loss was something like

988
00:42:53,589 --> 00:42:51,319

hydrodynamic escape then there would be

989
00:42:55,059 --> 00:42:53,599
a very strong isotopic signature but it

990
00:42:59,229 --> 00:42:55,069
actually wasn't what I was thinking

991
00:43:03,039 --> 00:42:59,239
about there's a recent paper by slick

992
00:43:04,929 --> 00:43:03,049
ting at all that suggests that not giant

993
00:43:07,929 --> 00:43:04,939
impacts but small impacts are much more

994
00:43:10,150 --> 00:43:07,939
ablative than we previously thought and

995
00:43:14,019 --> 00:43:10,160
and if the loss was by ablation then

996
00:43:15,519 --> 00:43:14,029
first of all we wouldn't expect a that

997
00:43:18,039 --> 00:43:15,529
we wouldn't expect an isotopic

998
00:43:19,299 --> 00:43:18,049
fractionation and second of all then we

999
00:43:20,650 --> 00:43:19,309
need to think about the late veneer

1000
00:43:22,809 --> 00:43:20,660
differently because the whole idea of

1001
00:43:26,079 --> 00:43:22,819
the late veneer is is that small impacts

1002
00:43:27,939 --> 00:43:26,089
add volatile to the planet but if if if

1003
00:43:29,620 --> 00:43:27,949
the ablation is very efficient in some

1004
00:43:31,599 --> 00:43:29,630
of those small impacts in some fraction

1005
00:43:33,880 --> 00:43:31,609
of the small impact then the late veneer

1006
00:43:36,549 --> 00:43:33,890
itself is both in addition and a loss

1007
00:43:38,829 --> 00:43:36,559
process and has the possibility of a

1008
00:43:41,410 --> 00:43:38,839
fractionation not of isotopes but of

1009
00:43:42,849 --> 00:43:41,420
different elements depending on their

1010
00:43:47,650 --> 00:43:42,859
persistence in the atmosphere or

1011
00:43:50,259 --> 00:43:47,660
deposition and solid okay so we need to

1012
00:43:52,100 --> 00:43:50,269
wrap up for lunch we thank the speakers

1013
00:43:55,320 --> 00:43:52,110

this morning once more

1014
00:44:07,720 --> 00:43:55,330
[Applause]