Mark Jellinek

The punctuated evolution & enigmatic resilience of plate tectonics: Novel controls on the dynamics & surprising longevity of Earth's habitability

1
00:00:00,160 --> 00:00:14,350
[Music]

2
00:00:18,620 --> 00:00:16,790
thanks Kristine I'll say that this is

3
00:00:21,230 --> 00:00:18,630
also my abstract then if you went

4
00:00:24,710 --> 00:00:21,240
looking for one if you actually found a

5
00:00:26,509 --> 00:00:24,720
different title part of it to do with me

6
00:00:28,759 --> 00:00:26,519
deciding what exactly to talk about and

7
00:00:32,030 --> 00:00:28,769
the breadth of this particular

8
00:00:35,510 --> 00:00:32,040
communities was one of the reason gave

9
00:00:37,069 --> 00:00:35,520
me pause as to what I wanted to cover so

10
00:00:38,720 --> 00:00:37,079
what I'm going to talk about is climate

11
00:00:40,270 --> 00:00:38,730
mantle coupling that was what I was

12
00:00:42,500 --> 00:00:40,280
asked to talk about but in particular

13
00:00:44,569 --> 00:00:42,510

the issue is how do you build and

14
00:00:47,660 --> 00:00:44,579
maintain an atmosphere and that really

15
00:00:50,720 --> 00:00:47,670
comes down to how volatile cycling work

16
00:00:53,569 --> 00:00:50,730
and how about a cycling works in terms

17
00:00:56,720 --> 00:00:53,579
of how much atmosphere you produce or

18
00:00:59,540 --> 00:00:56,730
maintain as a lot to do with whether

19
00:01:01,729 --> 00:00:59,550
habitability is even possible and so

20
00:01:02,959 --> 00:01:01,739
volatile cycling talk about there's a

21
00:01:04,820 --> 00:01:02,969
lot to do with whatever the tectonic

22
00:01:06,620 --> 00:01:04,830
regime of births or any other planet

23
00:01:08,960 --> 00:01:06,630
happens to be so how the planets thurs

24
00:01:10,670 --> 00:01:08,970
itself has a lot to do with whatever you

25
00:01:14,179 --> 00:01:10,680
keep an atmosphere whether we can have a

26
00:01:16,130 --> 00:01:14,189
habitable period and how dynamics that

27
00:01:18,469 --> 00:01:16,140
period is the habitability is not a

28
00:01:22,310 --> 00:01:18,479
state property of a planet it's very

29
00:01:24,170 --> 00:01:22,320
much transient in the exoplanet

30
00:01:26,149 --> 00:01:24,180
community this issue of habitable zone

31
00:01:28,880 --> 00:01:26,159
which that's the only time you'll hear

32
00:01:31,069 --> 00:01:28,890
me use that expression it's a big deal

33
00:01:33,410 --> 00:01:31,079
they look for it it's almost like a

34
00:01:35,690 --> 00:01:33,420
hunter looking for a target when I show

35
00:01:37,490 --> 00:01:35,700
you today is that there's any wrong way

36
00:01:41,960 --> 00:01:37,500
to think about that problem that's the

37
00:01:46,280 --> 00:01:41,970
way there is no habitable zone as a very

38
00:01:47,929 --> 00:01:46,290

dynamic property and Adam burrows is a

39
00:01:49,370 --> 00:01:47,939
review series of review papers on the

40
00:01:52,789 --> 00:01:49,380
sort of state of the world an exoplanet

41
00:01:56,780 --> 00:01:52,799
ology a couple of years ago and he kind

42
00:01:59,179 --> 00:01:56,790
of hinted at it in basically pointing

43
00:02:01,550 --> 00:01:59,189
the direction of out of inquiry into

44
00:02:03,109 --> 00:02:01,560
what is the what is the nature of

45
00:02:05,560 --> 00:02:03,119
planetary atmospheres and how do we use

46
00:02:08,600 --> 00:02:05,570
them to understand planetary interiors

47
00:02:10,790 --> 00:02:08,610
went with his paper was going okay so

48
00:02:12,110 --> 00:02:10,800
planets evolved over time then our

49
00:02:13,760 --> 00:02:12,120
atmosphere is evolved over time then

50
00:02:15,710 --> 00:02:13,770
habitability evolves over time

51
00:02:18,200 --> 00:02:15,720
so the idea that son or assistance for

52
00:02:22,430 --> 00:02:18,210
example is the major control is probably

53
00:02:26,450 --> 00:02:22,440
a misleading at the best of times okay

54
00:02:28,010 --> 00:02:26,460
in any event I'm going to be focusing on

55
00:02:31,790 --> 00:02:28,020
terrestrial planets and we have three of

56
00:02:36,380 --> 00:02:31,800
them at least for today Mars Earth and

57
00:02:38,690 --> 00:02:36,390
Venus and volatile cycling comes down to

58
00:02:41,690 --> 00:02:38,700
the sort of three things that enter one

59
00:02:44,780 --> 00:02:41,700
is what's a tectonic regime how does the

60
00:02:46,670 --> 00:02:44,790
tectonic regime and effect or mott or

61
00:02:52,250 --> 00:02:46,680
how is it modified by volcanism and

62
00:02:54,920 --> 00:02:52,260
weathering and then climate so again not

63
00:02:56,270 --> 00:02:54,930

again it gets in more detail break this

64
00:03:00,980 --> 00:02:56,280
out a little bit further there's a lot

65
00:03:05,840 --> 00:03:00,990
involved in each of these three each of

66
00:03:08,510 --> 00:03:05,850
those three I'll learn how to drive this

67
00:03:09,680 --> 00:03:08,520
at some point each of the three monikers

68
00:03:11,270 --> 00:03:09,690
the tectonic regime I'm going to be

69
00:03:13,700 --> 00:03:11,280
focusing on mantle stirring and

70
00:03:15,590 --> 00:03:13,710
structure story mostly stirring so what

71
00:03:18,590 --> 00:03:15,600
is the stirring style how does in

72
00:03:21,170 --> 00:03:18,600
gassing and outgassing work tectonic

73
00:03:24,320 --> 00:03:21,180
regime depends on planets resize a bit

74
00:03:26,000 --> 00:03:24,330
affected by and FX melting and volcanism

75
00:03:29,270 --> 00:03:26,010
where is the mantle melt how is that

76
00:03:31,880 --> 00:03:29,280
melt delivered to the surface stirrings

77
00:03:35,240 --> 00:03:31,890
affected by crust production where does

78
00:03:37,460 --> 00:03:35,250
that happen confident supercontinents it

79
00:03:40,370 --> 00:03:37,470
can add stiff bits to the top of the

80
00:03:41,840 --> 00:03:40,380
mantle which can introduce transients to

81
00:03:44,470 --> 00:03:41,850
the way the planet stores itself and

82
00:03:47,030 --> 00:03:44,480
also affect whether it can stir itself

83
00:03:48,800 --> 00:03:47,040
weathering regime weathering is not just

84
00:03:51,230 --> 00:03:48,810
about temperature it's about how do you

85
00:03:54,470 --> 00:03:51,240
turn rocks into clay in the first part

86
00:03:56,030 --> 00:03:54,480
is a mechanical one and the mechanics of

87
00:03:58,310 --> 00:03:56,040
weathering varies depending whether

88
00:04:00,350 --> 00:03:58,320

we're at subduction zones or it even at

89
00:04:03,800 --> 00:04:00,360
mid-ocean ridges seafloor weathering is

90
00:04:06,740 --> 00:04:03,810
for real but also happens in planets in

91
00:04:08,990 --> 00:04:06,750
continental interiors second part

92
00:04:12,170 --> 00:04:09,000
volcanism introduces greenhouse gases

93
00:04:13,640 --> 00:04:12,180
and aerosols statment sphere it's

94
00:04:15,140 --> 00:04:13,650
radiative properties it's a strong

95
00:04:18,190 --> 00:04:15,150
function of volcanism which is obviously

96
00:04:20,750 --> 00:04:18,200
tied to the way the mental melt

97
00:04:22,640 --> 00:04:20,760
weathering it is affected by volcanism

98
00:04:25,640 --> 00:04:22,650
again by the term by Vulcan is

99
00:04:27,500 --> 00:04:25,650
determining what rocks are around it if

100
00:04:29,720 --> 00:04:27,510
most of the volcanic rocks are basalt

101
00:04:32,000 --> 00:04:29,730
versus a granite then the weathering

102
00:04:34,730 --> 00:04:32,010
potentials become much well much

103
00:04:37,940 --> 00:04:34,740
different volcanism could introduce

104
00:04:40,370 --> 00:04:37,950
phases so aerosols are one kind of

105
00:04:41,600 --> 00:04:40,380
kindred Hayes's or aerosols it can

106
00:04:44,420 --> 00:04:41,610
introduce haze is particularly in a low

107
00:04:47,090 --> 00:04:44,430
oxygen world so volcanic out products

108
00:04:48,620 --> 00:04:47,100
can lead to the formation of black gazes

109
00:04:51,140 --> 00:04:48,630
of white haze is all kinds of things

110
00:04:54,280 --> 00:04:51,150
which affect the climate which in turn

111
00:04:56,900 --> 00:04:54,290
affects the potential / habitability

112
00:05:00,350 --> 00:04:56,910
cross production obvious that enters

113
00:05:02,120 --> 00:05:00,360

into albedo and that has a big effect on

114
00:05:05,230 --> 00:05:02,130
what the average surface temperature on

115
00:05:08,050 --> 00:05:05,240
earth is and how that varies in space

116
00:05:10,040 --> 00:05:08,060
okay it involves like and climate

117
00:05:12,140 --> 00:05:10,050
obviously climate depends on surface

118
00:05:14,090 --> 00:05:12,150
temperature there's all kinds of

119
00:05:15,140 --> 00:05:14,100
feedbacks albedo depends on surface

120
00:05:18,200 --> 00:05:15,150
temperature depends on whether we have

121
00:05:19,520 --> 00:05:18,210
lights so they have rocks weathering

122
00:05:20,420 --> 00:05:19,530
again so whether in gear certainly

123
00:05:24,470 --> 00:05:20,430
depends on temperature precipitation

124
00:05:25,760 --> 00:05:24,480
rates so what you know weathering it's a

125
00:05:27,620 --> 00:05:25,770
a function of precipitation rates

126
00:05:29,390 --> 00:05:27,630
whether you get precipitation depends on

127
00:05:30,710 --> 00:05:29,400
whether you're making mountains and

128
00:05:32,300 --> 00:05:30,720
where those mountains are are they in

129
00:05:35,120 --> 00:05:32,310
the tropics are they in high latitude

130
00:05:37,730 --> 00:05:35,130
and so on it's the point of this anyway

131
00:05:40,670 --> 00:05:37,740
it's indicates that the ball will

132
00:05:44,510 --> 00:05:40,680
slightly mating that governs Earth's

133
00:05:46,460 --> 00:05:44,520
climate or any planet's climate involves

134
00:05:48,140 --> 00:05:46,470
a number of different things that are

135
00:05:49,490 --> 00:05:48,150
very tightly coupled and also complex

136
00:05:53,630 --> 00:05:49,500
there's lots of opportunities for

137
00:05:55,940 --> 00:05:53,640
feedback sand and rich behaviors the

138
00:05:58,610 --> 00:05:55,950

idea of thinking about habitability or

139
00:06:01,700 --> 00:05:58,620
habitable zone I think the idea thinking

140
00:06:04,610 --> 00:06:01,710
about habitable zone is sort of very I

141
00:06:06,710 --> 00:06:04,620
would say to restricted thinking about

142
00:06:07,940 --> 00:06:06,720
all these these three main controls on

143
00:06:10,310 --> 00:06:07,950
and gassing and outgassing and

144
00:06:11,810 --> 00:06:10,320
atmospheric stability the issue is do we

145
00:06:13,280 --> 00:06:11,820
get habitability that's what the

146
00:06:18,350 --> 00:06:13,290
question were interested in how long

147
00:06:20,330 --> 00:06:18,360
does it last and I guess for the purpose

148
00:06:23,960 --> 00:06:20,340
of this symposium to what extent does

149
00:06:26,080 --> 00:06:23,970
that enable habitants as well okay some

150
00:06:28,610 --> 00:06:26,090
issues that enter into the style of

151
00:06:30,500 --> 00:06:28,620
volatile cycling so I'm going to be sort

152
00:06:33,710 --> 00:06:30,510
of focusing mostly on mantle stirring

153
00:06:35,240 --> 00:06:33,720
how that works planetary formation so

154
00:06:37,010 --> 00:06:35,250
how much what is the budget of heat

155
00:06:38,810 --> 00:06:37,020
producing elements in the mantle or

156
00:06:40,400 --> 00:06:38,820
where are the heat producing elements at

157
00:06:40,970 --> 00:06:40,410
the top of the mantle that is bottom the

158
00:06:45,080 --> 00:06:40,980
mantle

159
00:06:47,360 --> 00:06:45,090
stuck in the core planetary age internal

160
00:06:49,580 --> 00:06:47,370
temperature of the mantles we'll talk

161
00:06:51,950 --> 00:06:49,590
about a bit there's a lot to do with the

162
00:06:55,310 --> 00:06:51,960
positive the potential for a given

163
00:06:57,110 --> 00:06:55,320

tectonic regime and age has a lot to do

164
00:06:59,570 --> 00:06:57,120
is well the strength of radiogenic

165
00:07:02,270 --> 00:06:59,580
heating so young planets of different

166
00:07:04,520 --> 00:07:02,280
heating rates than old planets a big one

167
00:07:08,630 --> 00:07:04,530
history what is the history of tectonic

168
00:07:10,310 --> 00:07:08,640
deformation tectonic motion it turns out

169
00:07:12,500 --> 00:07:10,320
that the evolutionary path the planet

170
00:07:15,020 --> 00:07:12,510
takes depends on where it's been it like

171
00:07:16,250 --> 00:07:15,030
humans that gets in that way that's

172
00:07:19,900 --> 00:07:16,260
depending on how we spend our teenage

173
00:07:24,110 --> 00:07:19,910
years we end up as a professor or not

174
00:07:26,590 --> 00:07:24,120
and on my teenage years I can say nobody

175
00:07:28,580 --> 00:07:26,600
would have guessed I'd be a professor

176
00:07:30,170 --> 00:07:28,590
most of what I'm going to show you the

177
00:07:32,090 --> 00:07:30,180
tectonic particularly with the tectonic

178
00:07:33,830 --> 00:07:32,100
regimes you get plate tectonics not

179
00:07:37,000 --> 00:07:33,840
plate tectonics something in between all

180
00:07:41,390 --> 00:07:37,010
those solutions are usually permitted

181
00:07:43,700 --> 00:07:41,400
say that again Mars Venus are solutions

182
00:07:45,380 --> 00:07:43,710
for an evolutionary paths are almost

183
00:07:47,300 --> 00:07:45,390
equally plausible the beginning of

184
00:07:50,920 --> 00:07:47,310
Earth's time that an earth end up the

185
00:07:53,660 --> 00:07:50,930
way it is is not a foregone conclusion

186
00:07:55,040 --> 00:07:53,670
tectonic resilience so earth ended up in

187
00:07:57,500 --> 00:07:55,050
a plate tectonic regime and managed to

188
00:08:00,380 --> 00:07:57,510

stay there that is a kind of amazing

189
00:08:04,130 --> 00:08:00,390
thing so what controls the resilience of

190
00:08:06,230 --> 00:08:04,140
that particular attractor okay if you

191
00:08:07,880 --> 00:08:06,240
broad questions so you can read faster

192
00:08:11,480 --> 00:08:07,890
that I'm good you can read faster that

193
00:08:13,910 --> 00:08:11,490
I'm going to say but yeah but you're

194
00:08:16,940 --> 00:08:13,920
beyond my talk is sort of partly for

195
00:08:18,590 --> 00:08:16,950
discussion so is the habitability that

196
00:08:22,670 --> 00:08:18,600
has left it so long a natural

197
00:08:27,050 --> 00:08:22,680
consequence of Earth's or current

198
00:08:29,660 --> 00:08:27,060
tectonic regime is our current earth

199
00:08:33,260 --> 00:08:29,670
some product or somehow related to an

200
00:08:34,940 --> 00:08:33,270
early crisis impact history or impact

201
00:08:36,980 --> 00:08:34,950
erosion a pledge which will do a thought

202
00:08:38,900 --> 00:08:36,990
experiment related to that so do the

203
00:08:40,219 --> 00:08:38,910
very initial conditions enter into where

204
00:08:44,030 --> 00:08:40,229
we are now and how does that how does

205
00:08:46,520 --> 00:08:44,040
that work is our current tectonic regime

206
00:08:48,800 --> 00:08:46,530
and climatic resilience product of the

207
00:08:50,990 --> 00:08:48,810
way we started in how we evolved along

208
00:08:52,910 --> 00:08:51,000
that path so is the memory of the

209
00:08:55,240 --> 00:08:52,920
beginning of plate tectonics for example

210
00:08:57,829 --> 00:08:55,250
or the way in which the first

211
00:09:01,639 --> 00:08:57,839
solidified the rheological structure

212
00:09:03,650 --> 00:09:01,649
that emerged from that has that played a

213
00:09:06,769 --> 00:09:03,660

big part in letting leading earth to

214
00:09:10,610 --> 00:09:06,779
where it is and as finally that what are

215
00:09:12,110 --> 00:09:10,620
the big links between the mantle dynamic

216
00:09:15,680 --> 00:09:12,120
controls on the probability for

217
00:09:17,990 --> 00:09:15,690
habitability inhabitants inhabitants

218
00:09:19,610 --> 00:09:18,000
themselves and I'll show you an example

219
00:09:21,620 --> 00:09:19,620
of the time to do the thought experiment

220
00:09:24,110 --> 00:09:21,630
I want to do but one question is to what

221
00:09:28,190 --> 00:09:24,120
extent is long period tectonically

222
00:09:30,110 --> 00:09:28,200
driven changes in climate impose

223
00:09:33,139 --> 00:09:30,120
environmental stresses that are

224
00:09:35,720 --> 00:09:33,149
expressed in the biological record and

225
00:09:39,199 --> 00:09:35,730
we'll look at one example in a moment

226
00:09:42,319 --> 00:09:39,209
but what to do today is talk a bit about

227
00:09:43,759 --> 00:09:42,329
how you write this problem down so what

228
00:09:45,920 --> 00:09:43,769
are the some of the underlying mechanics

229
00:09:47,569 --> 00:09:45,930
that go into thinking about the tectonic

230
00:09:49,819 --> 00:09:47,579
regime of a planet the weights thurs

231
00:09:52,850 --> 00:09:49,829
itself the major control and in gassing

232
00:09:54,259 --> 00:09:52,860
and outgassing and then we're going to

233
00:10:00,100 --> 00:09:54,269
do three thought experiments I hope to

234
00:10:02,960 --> 00:10:00,110
get through to the first is a simple one

235
00:10:05,600 --> 00:10:02,970
if we beat up we throw rocks at Earth

236
00:10:08,060 --> 00:10:05,610
early right after the magma ocean

237
00:10:09,829 --> 00:10:08,070
finished solidifying assuming is a bit

238
00:10:11,870 --> 00:10:09,839

of crust on top you lose that crust of

239
00:10:13,759 --> 00:10:11,880
space you lose some heat production does

240
00:10:15,230 --> 00:10:13,769
that put earth on an evolutionary path

241
00:10:17,630 --> 00:10:15,240
that is more likely to end up and the

242
00:10:20,930 --> 00:10:17,640
regime we're in now as opposed to say

243
00:10:23,480 --> 00:10:20,940
Venus what we're not going to talk about

244
00:10:24,680 --> 00:10:23,490
but it's interesting to think about if

245
00:10:27,319 --> 00:10:24,690
anyone's interested in talking about a

246
00:10:29,329 --> 00:10:27,329
can offline but this is a huge one so

247
00:10:31,220 --> 00:10:29,339
intermittent transient super continental

248
00:10:32,509 --> 00:10:31,230
cycles lock up the earth we're going to

249
00:10:33,920 --> 00:10:32,519
shipping to show you a simulation of one

250
00:10:37,610 --> 00:10:33,930
in just a minute they lock up the way

251
00:10:39,439 --> 00:10:37,620
there are stirs itself and the question

252
00:10:41,420 --> 00:10:39,449
is can they drive climatic crises like

253
00:10:44,600 --> 00:10:41,430
snowball earth and the answer is yes

254
00:10:48,019 --> 00:10:44,610
they can at least we have models that do

255
00:10:49,910 --> 00:10:48,029
that and at least in the cryogenic the

256
00:10:51,740 --> 00:10:49,920
last snowball earth produced a

257
00:10:54,139 --> 00:10:51,750
biological opportunity to show you in

258
00:10:57,050 --> 00:10:54,149
just a moment you want to hope we do do

259
00:10:59,150 --> 00:10:57,060
I hope I do get to is the more

260
00:11:00,500 --> 00:10:59,160
interesting one I think for sort of the

261
00:11:03,470 --> 00:11:00,510
general picture for how its retro

262
00:11:07,699 --> 00:11:03,480
planets work which is how resilient is

263
00:11:08,690 --> 00:11:07,709

the climate climate of earth to time

264
00:11:10,640 --> 00:11:08,700
dependence and

265
00:11:13,670 --> 00:11:10,650
tecktonik regime that is evident in

266
00:11:14,900 --> 00:11:13,680
proxy data I'm going to show you all

267
00:11:16,490 --> 00:11:14,910
right the first thing I'm not going to

268
00:11:18,920 --> 00:11:16,500
talk about just because it's interesting

269
00:11:22,220 --> 00:11:18,930
to think about so time on the x-axis

270
00:11:26,030 --> 00:11:22,230
here so this is 1.6 billion years ago

271
00:11:27,530 --> 00:11:26,040
this is now and what you're looking at

272
00:11:29,870 --> 00:11:27,540
the blue bar if you can't read it this

273
00:11:31,070 --> 00:11:29,880
is snowball earth this is about 740

274
00:11:34,310 --> 00:11:31,080
million years that's six hundred and

275
00:11:35,210 --> 00:11:34,320
five million years at the other end and

276
00:11:37,250 --> 00:11:35,220
what you're looking at a few different

277
00:11:40,460 --> 00:11:37,260
lines the Blue is the rise of oxygen

278
00:11:42,620 --> 00:11:40,470
Green is total biomass so billion years

279
00:11:44,060 --> 00:11:42,630
up until the end of the cryogen you in

280
00:11:47,120 --> 00:11:44,070
the world was dominated by single-cell

281
00:11:49,850 --> 00:11:47,130
dudes they had a good time right they

282
00:11:51,320 --> 00:11:49,860
ran the show four billion years the end

283
00:11:54,580 --> 00:11:51,330
of the melt out which by the way

284
00:11:56,930 --> 00:11:54,590
happened during the break up of Rodinia

285
00:11:59,060 --> 00:11:56,940
five million years is about how long it

286
00:12:01,850 --> 00:11:59,070
took for the essential diversity we see

287
00:12:04,060 --> 00:12:01,860
now to begin to emerge five million

288
00:12:06,770 --> 00:12:04,070

years after billion years of stability

289
00:12:09,050 --> 00:12:06,780
the question that we don't have time to

290
00:12:12,080 --> 00:12:09,060
talk about is to what extent did the

291
00:12:14,480 --> 00:12:12,090
formation and breakup of rodinia affect

292
00:12:17,540 --> 00:12:14,490
climate and effect structure of the

293
00:12:18,830 --> 00:12:17,550
oceans possibly to give rise to the

294
00:12:21,230 --> 00:12:18,840
environmental stresses that may have

295
00:12:22,790 --> 00:12:21,240
given rise to this change whether it's

296
00:12:24,170 --> 00:12:22,800
an instability or an expression of by

297
00:12:29,630 --> 00:12:24,180
stability I don't know but it's

298
00:12:31,880 --> 00:12:29,640
interesting okay do you plate tectonics

299
00:12:32,900 --> 00:12:31,890
to earth smoothly continuously okay

300
00:12:35,090 --> 00:12:32,910
raise your hand if you think you think

301
00:12:38,060 --> 00:12:35,100
they do say select onyx is always taught

302
00:12:41,600 --> 00:12:38,070
as being a slow gradual thing so who the

303
00:12:46,460 --> 00:12:41,610
students in here raise your hand all

304
00:12:50,270 --> 00:12:46,470
just one student in here okay who's not

305
00:12:53,000 --> 00:12:50,280
a student in here all right everyone

306
00:12:54,350 --> 00:12:53,010
who's not raising their hand so how does

307
00:12:56,210 --> 00:12:54,360
this place iconic stir the earth

308
00:13:01,760 --> 00:12:56,220
smoothly I just I got a laser pointer

309
00:13:08,300 --> 00:13:01,770
pointing right at you know I was behind

310
00:13:10,040 --> 00:13:08,310
you that's it you you are now but ok but

311
00:13:15,320 --> 00:13:10,050
displace tectonic stir it stir it stir

312
00:13:16,850 --> 00:13:15,330
the earth smoothly and continuously he's

313
00:13:18,480 --> 00:13:16,860

the professor right now I don't want to

314
00:13:20,590 --> 00:13:18,490
answer the question

315
00:13:23,710 --> 00:13:20,600
alright you got to move on otherwise

316
00:13:26,350 --> 00:13:23,720
Christine will get to me so the answer

317
00:13:29,950 --> 00:13:26,360
is it's interesting right that's another

318
00:13:31,630 --> 00:13:29,960
professor Li answer four billion years

319
00:13:34,150 --> 00:13:31,640
ago now these are a bunch of different

320
00:13:36,220 --> 00:13:34,160
proxies for internal and external

321
00:13:39,670 --> 00:13:36,230
dynamic or integral solid body dynamics

322
00:13:42,760 --> 00:13:39,680
to the way the earthworks going to kill

323
00:13:44,920 --> 00:13:42,770
it no maybe the first plot plate

324
00:13:46,870 --> 00:13:44,930
velocities this is apparent plate

325
00:13:49,990 --> 00:13:46,880
velocity so using paleo magnetic data

326
00:13:52,570 --> 00:13:50,000
and ages to get it relative motions

327
00:13:53,890 --> 00:13:52,580
between plates and what you see is to go

328
00:13:55,690 --> 00:13:53,900
back through time and there are peaks

329
00:13:58,180 --> 00:13:55,700
there were plate where relative motions

330
00:14:00,010 --> 00:13:58,190
are fast and slow paleo magnetic

331
00:14:01,780 --> 00:14:00,020
intensity John's probably talked to a

332
00:14:04,360 --> 00:14:01,790
number of you guys about this the dipole

333
00:14:06,780 --> 00:14:04,370
moment is varied a lot in time and it

334
00:14:09,430 --> 00:14:06,790
has almost killed the laser pointer

335
00:14:11,350 --> 00:14:09,440
high-low high-low those that those

336
00:14:16,150 --> 00:14:11,360
variations are getting more robust to

337
00:14:17,620 --> 00:14:16,160
not less as time goes on passive margin

338
00:14:22,930 --> 00:14:17,630

longevity who knows what a passive

339
00:14:28,210 --> 00:14:22,940
margin is two people three people ok

340
00:14:30,370 --> 00:14:28,220
what's the fasted margin John okay it's

341
00:14:33,340 --> 00:14:30,380
boring nothing much nothing much happens

342
00:14:38,470 --> 00:14:33,350
okay we're passive margin longevity is

343
00:14:43,360 --> 00:14:38,480
long often metamorphic gradients well

344
00:14:45,910 --> 00:14:43,370
when passive margin sorry is long often

345
00:14:49,540 --> 00:14:45,920
metamorphic gradients are well Louis

346
00:14:50,830 --> 00:14:49,550
compared to the peak because the data is

347
00:14:54,520 --> 00:14:50,840
sort of interesting so where you have

348
00:14:55,840 --> 00:14:54,530
nothing happening you don't have a lot

349
00:14:57,220 --> 00:14:55,850
basically that the gradients through

350
00:14:58,990 --> 00:14:57,230
confidence are very low we have a lot

351
00:15:01,390 --> 00:14:59,000
happening types of marginal entities

352
00:15:03,760 --> 00:15:01,400
it's very low we have steep metamorphic

353
00:15:06,040 --> 00:15:03,770
gradients so in this particular case

354
00:15:08,230 --> 00:15:06,050
there's lots of heat transfer confidence

355
00:15:09,700 --> 00:15:08,240
are getting beat up form destructed lots

356
00:15:11,860 --> 00:15:09,710
of heat transfer through the continents

357
00:15:15,220 --> 00:15:11,870
for no passive margin they're getting

358
00:15:18,100 --> 00:15:15,230
eaten up all right so the evolution of

359
00:15:19,840 --> 00:15:18,110
Earth's confidence or because it gives

360
00:15:24,370 --> 00:15:19,850
us Wilson cycles with it they don't

361
00:15:26,140 --> 00:15:24,380
exist yet is increases and decreases in

362
00:15:27,940 --> 00:15:26,150
passive margin lunge Avenue take telling

363
00:15:31,020 --> 00:15:27,950

us about periods where the earth is very

364
00:15:32,350 --> 00:15:31,030
very active tectonic Lee and we're isn't

365
00:15:34,090 --> 00:15:32,360
commodious

366
00:15:36,280 --> 00:15:34,100
leave alone magnesium so people talk

367
00:15:37,810 --> 00:15:36,290
about the Earth's mantle getting warmer

368
00:15:39,310 --> 00:15:37,820
back through time and magnesium being a

369
00:15:42,400 --> 00:15:39,320
proxy well yeah it's high back through

370
00:15:44,620 --> 00:15:42,410
that but it oscillates if you look down

371
00:15:47,259 --> 00:15:44,630
at what's called Ozzie and depletion

372
00:15:50,470 --> 00:15:47,269
ages which rotana qualifies it's a way

373
00:15:52,420 --> 00:15:50,480
of dating when you build crayons the

374
00:15:55,329 --> 00:15:52,430
production of crayons the oldest part of

375
00:15:57,160 --> 00:15:55,339
continents again it happens in Peaks

376
00:16:01,030 --> 00:15:57,170
whole bunch is built three billion years

377
00:16:06,850 --> 00:16:01,040
ago then two etc so the picture here is

378
00:16:11,759 --> 00:16:06,860
time dependent thank you the time

379
00:16:17,800 --> 00:16:15,970
so this is another data another example

380
00:16:19,449 --> 00:16:17,810
of that time dependent so this is this

381
00:16:22,420 --> 00:16:19,459
is now now that's three and a half

382
00:16:25,840 --> 00:16:22,430
billion years ago the colored bar is are

383
00:16:28,259 --> 00:16:25,850
the ages of gold deposits who thinks

384
00:16:30,699 --> 00:16:28,269
about gold deposits in this room anybody

385
00:16:33,280 --> 00:16:30,709
one person all right mark karishma

386
00:16:35,230 --> 00:16:33,290
thinks about gold deposits to see you go

387
00:16:37,870 --> 00:16:35,240
back through time is the production of

388
00:16:41,439 --> 00:16:37,880

gold is periodic or not periodic but

389
00:16:43,150 --> 00:16:41,449
intermittent superposed on to that this

390
00:16:46,900 --> 00:16:43,160
line in the background or zircon ages

391
00:16:49,090 --> 00:16:46,910
these are these are mother through cons

392
00:16:51,610 --> 00:16:49,100
form at about 800 degrees in Granite's

393
00:16:54,639 --> 00:16:51,620
so they're tracking they are related to

394
00:16:56,230 --> 00:16:54,649
the production of granite which are how

395
00:16:58,240 --> 00:16:56,240
confident switcher parts of confidences

396
00:17:01,389 --> 00:16:58,250
they form so the related to core

397
00:17:03,850 --> 00:17:01,399
complexes and so on so we're looking at

398
00:17:06,460 --> 00:17:03,860
is the production of crust happening

399
00:17:08,199 --> 00:17:06,470
also in time dependent ways gold

400
00:17:11,010 --> 00:17:08,209
deposits Utah independent crust happens

401
00:17:14,280 --> 00:17:11,020
time-dependent waves what about climate

402
00:17:16,720 --> 00:17:14,290
subject to what I'm talking about today

403
00:17:18,159 --> 00:17:16,730
so one of the biggest mysteries is you

404
00:17:20,350 --> 00:17:18,169
go back through time as you know the

405
00:17:22,299 --> 00:17:20,360
cryogenic and snowball earth is here 600

406
00:17:25,650 --> 00:17:22,309
million years ago to 742 they're about

407
00:17:27,880 --> 00:17:25,660
the one background 2.3 is hotly debated

408
00:17:31,360 --> 00:17:27,890
one of the big mysteries is why the

409
00:17:34,530 --> 00:17:31,370
earth did not have profound glaciation

410
00:17:37,539 --> 00:17:34,540
early on when the Sun is weak alright so

411
00:17:39,310 --> 00:17:37,549
episodic tectonics is somehow modulated

412
00:17:41,560 --> 00:17:39,320
Earth's climate to produce glaciation

413
00:17:44,730 --> 00:17:41,570

only relatively recently episodic

414
00:17:46,560 --> 00:17:44,740
behavior anyway early

415
00:17:49,470 --> 00:17:46,570
all right is the time dependence of

416
00:17:53,130 --> 00:17:49,480
surprise now again the beginning said

417
00:17:55,290 --> 00:17:53,140
okay the way volatile cycling works the

418
00:17:58,350 --> 00:17:55,300
major control is how does the mantle

419
00:18:01,350 --> 00:17:58,360
stir it gases into itself and leave and

420
00:18:04,590 --> 00:18:01,360
relieve them so to make this point we're

421
00:18:06,710 --> 00:18:04,600
going to watch a movie and this is a

422
00:18:09,120 --> 00:18:06,720
numerical analyst view of the current

423
00:18:12,290 --> 00:18:09,130
continental distribution so I guess this

424
00:18:14,880 --> 00:18:12,300
is for Tobias well basically Africa

425
00:18:16,440 --> 00:18:14,890
highly pixelated so the first three

426
00:18:17,760 --> 00:18:16,450
movies are different ways of looking at

427
00:18:19,500 --> 00:18:17,770
continents who's the pit plate

428
00:18:22,790 --> 00:18:19,510
boundaries horizontal velocities and

429
00:18:24,840 --> 00:18:22,800
strain rates bottom is heat transfer

430
00:18:27,660 --> 00:18:24,850
temperature this is plates going down

431
00:18:29,490 --> 00:18:27,670
and plumes rising so each of these

432
00:18:32,280 --> 00:18:29,500
simulations the middle is the core it's

433
00:18:35,430 --> 00:18:32,290
hot the top is cold there's a mustiness

434
00:18:37,680 --> 00:18:35,440
fear and the plates are strong just want

435
00:18:41,460 --> 00:18:37,690
you to watch the movie thinking about

436
00:18:43,380 --> 00:18:41,470
the fact that it's all outgassing

437
00:18:46,260 --> 00:18:43,390
atmospheric production is all about

438
00:18:47,910 --> 00:18:46,270

stirring if you look at the interior

439
00:18:50,610 --> 00:18:47,920
mantle everywhere you see an upwelling

440
00:18:52,799 --> 00:18:50,620
that is where volcanism is happening

441
00:18:54,510 --> 00:18:52,809
crustal production you can see in the

442
00:18:55,350 --> 00:18:54,520
confidence and in the response of the

443
00:18:58,169 --> 00:18:55,360
plates there's an inherent

444
00:19:00,510 --> 00:18:58,179
time-dependent what we're looking at now

445
00:19:03,360 --> 00:19:00,520
is confident slowly forming up to form a

446
00:19:04,710 --> 00:19:03,370
supercontinent if they bounced around

447
00:19:06,450 --> 00:19:04,720
they wandered around until they locked

448
00:19:09,090 --> 00:19:06,460
up and they get stuck here now this is a

449
00:19:11,610 --> 00:19:09,100
billion years of Earth history in a few

450
00:19:14,010 --> 00:19:11,620
seconds but the key thing here is that

451
00:19:15,930 --> 00:19:14,020
in this particular simulation which is

452
00:19:18,570 --> 00:19:15,940
relatively high end in terms of what's

453
00:19:20,370 --> 00:19:18,580
in it including plates a fairly complex

454
00:19:21,870 --> 00:19:20,380
rheology and just letting the earth do

455
00:19:29,220 --> 00:19:21,880
what it does is it in here in time

456
00:19:33,590 --> 00:19:29,230
dependence okay now so basic mechanics

457
00:19:37,320 --> 00:19:33,600
so mantle stirring a volatile exchange

458
00:19:39,780 --> 00:19:37,330
comes down to breaking plates and moving

459
00:19:45,270 --> 00:19:39,790
them around start with so look at two

460
00:19:47,580 --> 00:19:45,280
concepts first is to break a plate if

461
00:19:49,290 --> 00:19:47,590
you imagine growing a math growing a

462
00:19:51,049 --> 00:19:49,300
mantle at the end of the magma ocean

463
00:19:53,760 --> 00:19:51,059

period and having a little sphere on top

464
00:19:56,159 --> 00:19:53,770
and forming a drip beneath it to break a

465
00:19:58,050 --> 00:19:56,169
plate flow into the drip forming beneath

466
00:20:00,690 --> 00:19:58,060
a plate

467
00:20:03,090 --> 00:20:00,700
are lit this year has to pull down on

468
00:20:05,100 --> 00:20:03,100
that plate enough or strongly enough to

469
00:20:08,340 --> 00:20:05,110
actually break it so what matters is how

470
00:20:10,880 --> 00:20:08,350
fast the drip is going and how viscous

471
00:20:13,740 --> 00:20:10,890
it is so this particular case the drip

472
00:20:16,620 --> 00:20:13,750
has a newtonian rheology looks like this

473
00:20:17,970 --> 00:20:16,630
and have to outdo you a yield stress the

474
00:20:20,280 --> 00:20:17,980
yield stress depends on a number of

475
00:20:22,170 --> 00:20:20,290
things depends on how many balls with

476
00:20:24,360 --> 00:20:22,180
the volatile budget is what and what the

477
00:20:27,570 --> 00:20:24,370
lithosphere is actually made of and then

478
00:20:28,770 --> 00:20:27,580
the speed of the drip also matters so

479
00:20:31,680 --> 00:20:28,780
this particular picture which is

480
00:20:33,510 --> 00:20:31,690
relatively naive if the drip falls down

481
00:20:35,280 --> 00:20:33,520
it can break a plate well let me get

482
00:20:39,210 --> 00:20:35,290
plate tectonics to start and we can go

483
00:20:41,040 --> 00:20:39,220
from one plate to more than one well the

484
00:20:46,320 --> 00:20:41,050
key issue is how big is this viscous

485
00:20:48,510 --> 00:20:46,330
stress sorry more interesting and deeper

486
00:20:49,950 --> 00:20:48,520
picture is to realize that as you pull

487
00:20:52,350 --> 00:20:49,960
down on the plate we do some deformation

488
00:20:54,240 --> 00:20:52,360

at the top so as soon as we have

489
00:20:56,130 --> 00:20:54,250
deformation to top there's topography

490
00:20:58,740 --> 00:20:56,140
here that this area's higher than this

491
00:21:01,430 --> 00:20:58,750
and so there are lateral differences in

492
00:21:03,750 --> 00:21:01,440
hydrostatic pressures this topography is

493
00:21:06,780 --> 00:21:03,760
enabling lithosphere that's over here to

494
00:21:08,430 --> 00:21:06,790
try and slow in to fill the gap so

495
00:21:09,900 --> 00:21:08,440
there's one restoring force interest of

496
00:21:12,810 --> 00:21:09,910
problems we pull down on this at some

497
00:21:14,640 --> 00:21:12,820
rate there's a rate at which flows

498
00:21:18,000 --> 00:21:14,650
little sphere into that gap is trying to

499
00:21:19,500 --> 00:21:18,010
anneal the boundary these dash lines are

500
00:21:22,140 --> 00:21:19,510
an attempt to show you the other part

501
00:21:23,910 --> 00:21:22,150
which is micro structural damage as the

502
00:21:26,310 --> 00:21:23,920
plate pulls down a little sphere and

503
00:21:28,740 --> 00:21:26,320
changes the fabric there's memory of

504
00:21:31,860 --> 00:21:28,750
that fabric so the two other issues that

505
00:21:34,110 --> 00:21:31,870
enter is well are we pulling down on

506
00:21:36,330 --> 00:21:34,120
this fast enough to keep this plate

507
00:21:37,920 --> 00:21:36,340
boundary open before it heals itself and

508
00:21:39,480 --> 00:21:37,930
that could dependent the healing rake

509
00:21:42,900 --> 00:21:39,490
it's been a temperature composition

510
00:21:45,780 --> 00:21:42,910
volatiles in history and what is the

511
00:21:48,180 --> 00:21:45,790
memory of this damage so we're

512
00:21:49,920 --> 00:21:48,190
introducing damage and how does that

513
00:21:53,670 --> 00:21:49,930

affect the way that the mantle moves are

514
00:21:56,730 --> 00:21:53,680
the mantle about beyond that okay so

515
00:21:59,220 --> 00:21:56,740
very quickly overview of some of the

516
00:22:00,750 --> 00:21:59,230
basics so stagnant lid one plate planets

517
00:22:02,460 --> 00:22:00,760
happen where the pull down stress the

518
00:22:05,010 --> 00:22:02,470
convective stress is less than those a

519
00:22:07,440 --> 00:22:05,020
spheric yield stress basically drips

520
00:22:09,630 --> 00:22:07,450
can't pull down and break it the

521
00:22:11,270 --> 00:22:09,640
convective stress declines with

522
00:22:12,560 --> 00:22:11,280
increasing mantle temperatures the more

523
00:22:15,650 --> 00:22:12,570
heat production for example we have in

524
00:22:17,120 --> 00:22:15,660
here the less this is if the stress that

525
00:22:19,220 --> 00:22:17,130
we're pulling down with it equals the

526
00:22:21,770 --> 00:22:19,230
yield stress well then we're and we can

527
00:22:24,860 --> 00:22:21,780
go either way so this is a sort of basic

528
00:22:26,420 --> 00:22:24,870
condition for an episodic regime if the

529
00:22:27,980 --> 00:22:26,430
convective stress is bigger than a yield

530
00:22:29,600 --> 00:22:27,990
stress and we can maintain it that way

531
00:22:33,050 --> 00:22:29,610
then in principle we can have a plate

532
00:22:34,430 --> 00:22:33,060
tectonic regime convective stresses are

533
00:22:39,050 --> 00:22:34,440
very sensitive temperatures I've

534
00:22:42,500 --> 00:22:39,060
mentioned and yield stresses are very

535
00:22:48,980 --> 00:22:42,510
sensitive to the volatile budget okay

536
00:22:52,040 --> 00:22:48,990
now more modern view the problem with

537
00:22:54,020 --> 00:22:52,050
earth is that a direction matters in

538
00:22:56,090 --> 00:22:54,030

terms of how we do those experiments of

539
00:23:00,230 --> 00:22:56,100
breaking and getting plates to grow and

540
00:23:01,910 --> 00:23:00,240
break this is a sort of beautiful the

541
00:23:05,480 --> 00:23:01,920
end of a beautiful PhD by Matt Weller

542
00:23:07,340 --> 00:23:05,490
and what this is is it not it's non

543
00:23:09,380 --> 00:23:07,350
dimensional internal heating rate on the

544
00:23:10,700 --> 00:23:09,390
y-axis and a yield stress on the left so

545
00:23:13,700 --> 00:23:10,710
this is the strength of plates and if I

546
00:23:16,220 --> 00:23:13,710
choose one and we do an experiment where

547
00:23:18,800 --> 00:23:16,230
I ask the question if I begin in a

548
00:23:25,130 --> 00:23:18,810
stagette lid regime in this case and I

549
00:23:28,390 --> 00:23:25,140
increase it the internal heating rate or

550
00:23:31,040 --> 00:23:28,400
I move up in internal heating rates paid

551
00:23:35,960 --> 00:23:31,050
the transition to stagette lid if I

552
00:23:39,350 --> 00:23:35,970
begin here and go up happens down here

553
00:23:40,970 --> 00:23:39,360
if I begin the same experiment at high

554
00:23:46,120 --> 00:23:40,980
heating rates and decrease the heating

555
00:23:50,690 --> 00:23:48,500
the regime diagram here is we've got

556
00:23:53,480 --> 00:23:50,700
several different modes stag and lead

557
00:23:56,950 --> 00:23:53,490
one plate plate tectonics multimode is

558
00:23:59,660 --> 00:23:56,960
both plates and not plates are possible

559
00:24:03,230 --> 00:23:59,670
if I choose the lithospheric yield

560
00:24:07,280 --> 00:24:03,240
stress and I increase I move up the

561
00:24:08,780 --> 00:24:07,290
internal heating rate the transition or

562
00:24:10,670 --> 00:24:08,790
the earth or where the transition from

563
00:24:12,440 --> 00:24:10,680

stagette lid to multiple multimode

564
00:24:13,880 --> 00:24:12,450
behavior happens happens at a different

565
00:24:16,040 --> 00:24:13,890
location internal heating rate space

566
00:24:18,950 --> 00:24:16,050
then if I run the experiment the other

567
00:24:21,860 --> 00:24:18,960
way so there's a directionality to this

568
00:24:26,500 --> 00:24:21,870
a bit of hysteresis to look at it

569
00:24:31,580 --> 00:24:29,540
and I in terms of a bi of stability

570
00:24:33,950 --> 00:24:31,590
diagram so up here we've got a number of

571
00:24:35,420 --> 00:24:33,960
things going on so one is the condition

572
00:24:37,460 --> 00:24:35,430
that we're going to play with the

573
00:24:40,460 --> 00:24:37,470
tectonic States a stagette lid and plate

574
00:24:42,740 --> 00:24:40,470
tectonics and a convective vigor so but

575
00:24:44,780 --> 00:24:42,750
again with no plate tectonics and I go

576
00:24:50,780 --> 00:24:44,790
this way I can be in either plate

577
00:24:56,510 --> 00:24:50,790
tectonic or a stagnant lid regime what

578
00:24:57,800 --> 00:24:56,520
the simulations jet what's the point

579
00:25:00,470 --> 00:24:57,810
what the plot shows we don't project

580
00:25:03,470 --> 00:25:00,480
this back down onto a surface at the

581
00:25:08,540 --> 00:25:03,480
bottom is if I begin in a stagnant lid

582
00:25:12,910 --> 00:25:08,550
regime and I change the experimental

583
00:25:14,960 --> 00:25:12,920
condition let's say increase well we do

584
00:25:28,760 --> 00:25:14,970
going to change things let's just look

585
00:25:32,420 --> 00:25:28,770
at surface temperature okay so great all

586
00:25:34,430 --> 00:25:32,430
right let me yeah okay so one of the

587
00:25:37,700 --> 00:25:34,440
ways we can turn plate tectonics off is

588
00:25:40,640 --> 00:25:37,710

by making the surface need to come back

589
00:25:42,320 --> 00:25:40,650
to this cartoon one of the ways we can

590
00:25:45,370 --> 00:25:42,330
close up plate boundaries is by making

591
00:25:47,750 --> 00:25:45,380
the surface warm so if I turn if I

592
00:25:50,570 --> 00:25:47,760
increase the surface temperature the

593
00:25:53,090 --> 00:25:50,580
planet to greenhouse forces we increase

594
00:25:56,330 --> 00:25:53,100
the client we change the temperature of

595
00:25:58,640 --> 00:25:56,340
Earth's surface by say 10 or 50 or

596
00:25:59,990 --> 00:25:58,650
hundred degrees by greenhouse forcing we

597
00:26:01,610 --> 00:26:00,000
make the top of the little sphere more

598
00:26:05,510 --> 00:26:01,620
runny and we have a better chance of

599
00:26:06,830 --> 00:26:05,520
annealing that particular boundary if we

600
00:26:09,380 --> 00:26:06,840
go it look they're looking at this

601
00:26:13,130 --> 00:26:09,390
particular situation if we begin in a

602
00:26:17,270 --> 00:26:13,140
stagette lid regime which is this red

603
00:26:18,560 --> 00:26:17,280
dot and I go I decrease the surface

604
00:26:20,240 --> 00:26:18,570
temperatures so in principle I'm

605
00:26:22,130 --> 00:26:20,250
increasing the ability to keep a plate

606
00:26:25,700 --> 00:26:22,140
boundary open but you can see is we

607
00:26:27,890 --> 00:26:25,710
never actually get out if I begin in a

608
00:26:30,800 --> 00:26:27,900
plate tectonic regime and I increase the

609
00:26:33,500 --> 00:26:30,810
surface temperature we get it an easy

610
00:26:35,600 --> 00:26:33,510
way we get a transition to stagnant lit

611
00:26:38,000 --> 00:26:35,610
so what the point here is to show is

612
00:26:38,440 --> 00:26:38,010
that depending on which way we begin if

613
00:26:41,830 --> 00:26:38,450

it begin

614
00:26:43,870 --> 00:26:41,840
stagnant lid it's not super easy to get

615
00:26:45,550 --> 00:26:43,880
out again in plate tectonic village we

616
00:26:47,500 --> 00:26:45,560
can we can get into a one plate regime

617
00:26:59,700 --> 00:26:47,510
but it's very difficult to get back from

618
00:27:01,630 --> 00:26:59,710
them okay now it's time we go all right

619
00:27:06,700 --> 00:27:01,640
so quickly a couple of thought

620
00:27:09,100 --> 00:27:06,710
experiments so first one is what happens

621
00:27:10,870 --> 00:27:09,110
to reduce the heat production in earth a

622
00:27:13,180 --> 00:27:10,880
little bit by pelting it with rocks

623
00:27:14,980 --> 00:27:13,190
early so this is basically making the

624
00:27:20,200 --> 00:27:14,990
mantle temperature on average a little

625
00:27:21,580 --> 00:27:20,210
bit colder if we begin in this

626
00:27:26,650 --> 00:27:21,590
particular case if you begin with a

627
00:27:29,110 --> 00:27:26,660
condor it explan attends to want to be

628
00:27:32,140 --> 00:27:29,120
in a stagette lid regime and we reduce

629
00:27:33,610 --> 00:27:32,150
the amount of heat production an amount

630
00:27:35,230 --> 00:27:33,620
that corresponds to losing what is

631
00:27:38,770 --> 00:27:35,240
essentially to modern inventory of

632
00:27:40,870 --> 00:27:38,780
continental heat production there is a

633
00:27:46,690 --> 00:27:40,880
greater probability to end up in a

634
00:27:51,760 --> 00:27:46,700
multi-mode regime right so the early the

635
00:27:55,630 --> 00:27:51,770
early of a the early erosion of of Earth

636
00:27:59,260 --> 00:27:55,640
by rocks essentially by big rocks makes

637
00:28:00,610 --> 00:27:59,270
it more likely to end up in a regime

638
00:28:04,060 --> 00:28:00,620

where plate tectonics is it leaves

639
00:28:07,420 --> 00:28:04,070
possible we do the other experiments

640
00:28:09,010 --> 00:28:07,430
begin in this world and we began in a

641
00:28:10,270 --> 00:28:09,020
plate tectonic regime and we increase

642
00:28:12,940 --> 00:28:10,280
the heat production towards something

643
00:28:14,800 --> 00:28:12,950
like chondritic we're more likely to be

644
00:28:18,630 --> 00:28:14,810
in a stagnant later once or one play

645
00:28:21,280 --> 00:28:18,640
planet world so the idea here is that

646
00:28:24,190 --> 00:28:21,290
the style of stirring the choice of

647
00:28:26,550 --> 00:28:24,200
planet makes it depends in this case on

648
00:28:32,230 --> 00:28:26,560
what how strong the conductive stresses

649
00:28:34,320 --> 00:28:32,240
and that depends a bit on the

650
00:28:40,510 --> 00:28:34,330
collisional history early all right

651
00:28:42,280 --> 00:28:40,520
quick one I promise all right so next

652
00:28:44,230 --> 00:28:42,290
thing is what happens we take we so you

653
00:28:47,590 --> 00:28:44,240
know the the data set I showed the

654
00:28:49,510 --> 00:28:47,600
beginning this one basically said all

655
00:28:51,910 --> 00:28:49,520
right earth plenty of Earth's first

656
00:28:52,360 --> 00:28:51,920
three billion years certainly was

657
00:28:54,540 --> 00:28:52,370
dynamic

658
00:28:56,710 --> 00:28:54,550
be very active very time-dependent

659
00:28:58,690 --> 00:28:56,720
question is how resilient was Earth's

660
00:29:03,130 --> 00:28:58,700
climate through that period as Earth was

661
00:29:06,070 --> 00:29:03,140
figuring itself out as it was evolving

662
00:29:07,720 --> 00:29:06,080
to go back in time evolving from what we

663
00:29:10,060 --> 00:29:07,730

have sort of continuous plate tectonics

664
00:29:12,400 --> 00:29:10,070
something that looks more spasmodic what

665
00:29:15,570 --> 00:29:12,410
are the consequences one way to do this

666
00:29:19,299 --> 00:29:15,580
is to perturb a thermal history model so

667
00:29:21,340 --> 00:29:19,309
what this is is this is now this is back

668
00:29:23,350 --> 00:29:21,350
in time it's a thermal history history

669
00:29:24,790 --> 00:29:23,360
calculation for earth with some other

670
00:29:27,280 --> 00:29:24,800
stuff on it so the black line is the

671
00:29:29,080 --> 00:29:27,290
evolution of mantle temperature as we go

672
00:29:31,780 --> 00:29:29,090
back in time Earth's plates choose

673
00:29:34,600 --> 00:29:31,790
different shapes different platforms and

674
00:29:38,799 --> 00:29:34,610
the amount is the way in which it cools

675
00:29:41,080 --> 00:29:38,809
changes so black is did the temperature

676
00:29:43,180 --> 00:29:41,090
of the mantle the outgassing rates are

677
00:29:44,740 --> 00:29:43,190
in the heavy red line so the heavy line

678
00:29:47,710 --> 00:29:44,750
this is just assuming markers and

679
00:29:49,330 --> 00:29:47,720
solidus is right and the dash red line

680
00:29:51,250 --> 00:29:49,340
is assuming that marker Sherman solid is

681
00:29:54,160 --> 00:29:51,260
his right and his student Raj Das Gupta

682
00:29:56,500 --> 00:29:54,170
'he's outgassing efficiency is correct

683
00:29:59,020 --> 00:29:56,510
so outgassing changes back through time

684
00:30:00,610 --> 00:29:59,030
because d carbonation is better so we

685
00:30:01,900 --> 00:30:00,620
can choose a period perturb it so we

686
00:30:06,310 --> 00:30:01,910
take the mantle temperature and now

687
00:30:07,810 --> 00:30:06,320
introduce an episodic component to it we

688
00:30:10,660 --> 00:30:07,820

can ask the question what is the pco2

689
00:30:13,120 --> 00:30:10,670
that emerges from that bc 2 depends on

690
00:30:16,120 --> 00:30:13,130
the volcanic flux and the weathering

691
00:30:18,490 --> 00:30:16,130
regime the weathering rate not just show

692
00:30:19,419 --> 00:30:18,500
you a couple solutions and then i'll

693
00:30:23,080 --> 00:30:19,429
finish we're going to look at a couple

694
00:30:25,840 --> 00:30:23,090
plots that look like this so this is a

695
00:30:30,480 --> 00:30:25,850
zonal energy balance model and so you

696
00:30:39,010 --> 00:30:30,490
can look at greenhouse forcing all right

697
00:30:43,670 --> 00:30:41,390
alright so we're going to put ur bit and

698
00:30:45,920 --> 00:30:43,680
win a North Christine for ten seconds so

699
00:30:47,980 --> 00:30:45,930
the three to three different possible

700
00:30:50,990 --> 00:30:47,990
solutions ice-free snowball earth

701
00:30:52,430 --> 00:30:51,000
partially glaciated earth this is where

702
00:30:54,380 --> 00:30:52,440
we start if we introduce that

703
00:30:57,350 --> 00:30:54,390
perturbation and under current Earth's

704
00:31:00,200 --> 00:30:57,360
current mantle temperature as you can

705
00:31:01,820 --> 00:31:00,210
see as we go through the hot period we

706
00:31:03,140 --> 00:31:01,830
head towards an i3 earth we don't

707
00:31:05,000 --> 00:31:03,150
approach the green on green house run

708
00:31:07,400 --> 00:31:05,010
away does it go through the cold period

709
00:31:11,990 --> 00:31:07,410
we must make more glaciers not super

710
00:31:15,020 --> 00:31:12,000
interesting we go at 3.5 billion years

711
00:31:22,010 --> 00:31:15,030
the answer is potentially a lot more

712
00:31:25,460 --> 00:31:22,020
interesting being that at 3.5 billion

713
00:31:30,290 --> 00:31:25,470

years we entered we essentially begin in

714
00:31:32,540 --> 00:31:30,300
a frozen planet this is a 3.5 billion

715
00:31:34,460 --> 00:31:32,550
with beginning to frozen planet if we

716
00:31:36,170 --> 00:31:34,470
wanted to plant it up we can actually

717
00:31:37,520 --> 00:31:36,180
achieve partial glaciation could

718
00:31:39,740 --> 00:31:37,530
actually end up all the way up over here

719
00:31:41,210 --> 00:31:39,750
if we cool the planet back down when we

720
00:31:46,280 --> 00:31:41,220
just make a frozen planted a lot more

721
00:31:48,110 --> 00:31:46,290
frozen in the Precambrian world which

722
00:31:50,680 --> 00:31:48,120
has got it which is a water world the

723
00:31:53,750 --> 00:31:50,690
albedo is that mostly the water planet

724
00:31:57,380 --> 00:31:53,760
the interesting thing here is if we

725
00:32:00,050 --> 00:31:57,390
increase the outgassing or increase the

726
00:32:02,330 --> 00:32:00,060
outgassing or decrease the outgassing we

727
00:32:04,700 --> 00:32:02,340
never answer a pen glacial earth alright

728
00:32:07,070 --> 00:32:04,710
so precambrian world being warm at least

729
00:32:09,590 --> 00:32:07,080
with our our simulations is not a

730
00:32:12,800 --> 00:32:09,600
surprise it's been a few more than 10

731
00:32:15,770 --> 00:32:12,810
seconds yes okay all right just finish

732
00:32:18,110 --> 00:32:15,780
volatile cycling try to put too much

733
00:32:19,880 --> 00:32:18,120
into this but basically the crux is

734
00:32:23,200 --> 00:32:19,890
vample stirring how does in gassing and

735
00:32:26,690 --> 00:32:23,210
outgassing work how does it in turn make

736
00:32:27,770 --> 00:32:26,700
govern the atmospheric stability how

737
00:32:30,050 --> 00:32:27,780
does that affect the radiative

738
00:32:32,900 --> 00:32:30,060

properties of the atmosphere and what is

739
00:32:36,380 --> 00:32:32,910
the likelihood and duration of habitable

740
00:32:38,000 --> 00:32:36,390
periods in terms of earth we can bounce

741
00:32:41,750 --> 00:32:38,010
it and out of snowballs but we don't

742
00:32:43,460 --> 00:32:41,760
seem to do much more than that all right

743
00:32:46,590 --> 00:32:43,470
thank you all right let's thank our

744
00:32:50,740 --> 00:32:48,090
[Applause]

745
00:32:52,960 --> 00:32:50,750
so I guess we have a short time for

746
00:32:59,770 --> 00:32:52,970
questions and you can catch mark maybe

747
00:33:02,320 --> 00:32:59,780
at the poster and coffee breaks yes yes

748
00:33:05,320 --> 00:33:02,330
could you go back one slide please sure

749
00:33:07,000 --> 00:33:05,330
now that spot on the left is a little

750
00:33:09,280 --> 00:33:07,010
for example just the blue lines where we

751
00:33:11,560 --> 00:33:09,290
talked about snowball events now there's

752
00:33:14,590 --> 00:33:11,570
a lot more structure unless billion

753
00:33:16,600 --> 00:33:14,600
years then there is previously yes and I

754
00:33:18,730 --> 00:33:16,610
assume that that's a selection effect

755
00:33:20,500 --> 00:33:18,740
but can you make any comments about that

756
00:33:22,150 --> 00:33:20,510
for example of that what's called the

757
00:33:24,370 --> 00:33:22,160
boring billion I guess what is nothing

758
00:33:25,870 --> 00:33:24,380
there now did a lot happen and we just

759
00:33:30,480 --> 00:33:25,880
can't see it because of selection of X

760
00:33:36,610 --> 00:33:32,740
well I don't think you'd get away from

761
00:33:37,840 --> 00:33:36,620
the problem of selection or bias as you

762
00:33:43,750 --> 00:33:37,850
go back to the archaean because I love

763
00:33:46,290 --> 00:33:43,760

rocks around however in the rotten in

764
00:33:48,880 --> 00:33:46,300
the ark any exposed archaean rocks

765
00:33:51,640 --> 00:33:48,890
proterozoic and are key and rocks to be

766
00:33:53,290 --> 00:33:51,650
in years and before there's only one

767
00:33:55,630 --> 00:33:53,300
period this one a particular that has

768
00:34:01,420 --> 00:33:55,640
reliable glacial deposits in it snowdrop

769
00:34:04,000 --> 00:34:01,430
stones no evidence of cap carbonate like

770
00:34:06,040 --> 00:34:04,010
sequences that are that are common that

771
00:34:09,060 --> 00:34:06,050
a common indicators of rapid melt you

772
00:34:12,250 --> 00:34:09,070
know melt outs from snowball solutions

773
00:34:15,000 --> 00:34:12,260
but to know there are no reliable

774
00:34:18,100 --> 00:34:15,010
glacial glacial features in any rocks

775
00:34:19,870 --> 00:34:18,110
certainly before I mean this guy is

776
00:34:24,520 --> 00:34:19,880
hotly contested this is paul Hoffman's

777
00:34:26,110 --> 00:34:24,530
figure before 2.5 is you know basically

778
00:34:29,500 --> 00:34:26,120
all glacial features before that are

779
00:34:31,240 --> 00:34:29,510
questions into Bay right but it look

780
00:34:32,770 --> 00:34:31,250
could it be lots and lots and lots of

781
00:34:34,750 --> 00:34:32,780
structure there as much on the right

782
00:34:39,820 --> 00:34:34,760
side of this plot is on the left no no

783
00:34:43,360 --> 00:34:39,830
no so to produce this these two periods

784
00:34:45,160 --> 00:34:43,370
took lots and lots of Matt you know you

785
00:34:46,960 --> 00:34:45,170
know first you have to identify all the

786
00:34:49,180 --> 00:34:46,970
rocks from the planets that are within

787
00:34:51,760 --> 00:34:49,190
that age group in there and Mackenzie

788
00:34:53,890 --> 00:34:51,770

mountains in Canada in Africa and in

789
00:34:57,690 --> 00:34:53,900
Australia and in those the question you

790
00:34:59,880 --> 00:34:57,700
ask is what is the aerial fraction that

791
00:35:02,880 --> 00:34:59,890
cords evidence of notches glaciers but

792
00:35:04,650 --> 00:35:02,890
rapid deglaciation you have to be able

793
00:35:08,760 --> 00:35:04,660
to demonstrate that the glaciation was

794
00:35:10,530 --> 00:35:08,770
also at the equator and there's

795
00:35:11,640 --> 00:35:10,540
directional paleo magnetic data here

796
00:35:16,770 --> 00:35:11,650
that allows you to do that more

797
00:35:18,930 --> 00:35:16,780
convincingly but there's lots of rocks

798
00:35:21,690 --> 00:35:18,940
that is thought to be at high latitude

799
00:35:27,540 --> 00:35:21,700
at this at these periods with no

800
00:35:30,180 --> 00:35:27,550
evidence of glaciation okay not true I'm

801
00:35:32,640 --> 00:35:30,190
not going to make dumb but I'm spouting

802
00:35:42,270 --> 00:35:32,650
the party line that so not true what is

803
00:35:45,180 --> 00:35:42,280
your this one is yes I'm not argh so I'm

804
00:35:47,550 --> 00:35:45,190
not arguing at 2.3 you said the whole

805
00:35:50,579 --> 00:35:47,560
thing wasn't not another potential one

806
00:35:53,900 --> 00:35:50,589
at 3.5 that Martian do it published

807
00:35:56,370 --> 00:35:53,910
about a year ago very clear drop stones

808
00:35:58,500 --> 00:35:56,380
no evidence of the camp but we don't

809
00:36:00,690 --> 00:35:58,510
really know if the camp carbonate would

810
00:36:03,260 --> 00:36:00,700
form under the conditions of an archaeon

811
00:36:06,690 --> 00:36:03,270
ocean the chemistry is different I

812
00:36:08,910 --> 00:36:06,700
chemistry is different so but so the

813
00:36:10,980 --> 00:36:08,920

drop stones there are there is there is

814
00:36:15,089 --> 00:36:10,990
what looks like a good glacial thing in

815
00:36:19,520 --> 00:36:15,099
the Barbican at about 3.5 clear drop

816
00:36:23,579 --> 00:36:19,530
stones barbed units no striated doubles

817
00:36:26,160 --> 00:36:23,589
but you don't always get those true

818
00:36:27,540 --> 00:36:26,170
enough but we don't see is continuous

819
00:36:30,630 --> 00:36:27,550
evidence of glaciation all the way

820
00:36:33,569 --> 00:36:30,640
through this period but even partial but

821
00:36:36,450 --> 00:36:33,579
you know the record is not commensurate

822
00:36:38,790 --> 00:36:36,460
to that full stop we don't have a

823
00:36:46,339 --> 00:36:38,800
continuous record of our key in time the

824
00:36:58,970 --> 00:36:46,349
way we do with a finer look good when I

825
00:37:06,690 --> 00:37:03,569
okay baby I mean if you'd like to

826
00:37:09,450 --> 00:37:06,700
discuss a Grover but is no percentage of

827
00:37:11,480 --> 00:37:09,460
our TM specifically they are changing

828
00:37:14,450 --> 00:37:11,490
all to occupy only 20

829
00:37:17,510 --> 00:37:14,460
% of another continent and if we go back

830
00:37:20,000 --> 00:37:17,520
ari Eric Ian it's a distant one percent

831
00:37:22,330 --> 00:37:20,010
but I'm not arguing with that but so the

832
00:37:24,560 --> 00:37:22,340
model solutions that that we have

833
00:37:25,609 --> 00:37:24,570
admitted partial glaciation through the

834
00:37:27,830 --> 00:37:25,619
hope through that whole theory about

835
00:37:29,650 --> 00:37:27,840
their product is positive at least one

836
00:37:32,240 --> 00:37:29,660
oh yeah I wouldn't argue that there's

837
00:37:34,270 --> 00:37:32,250
the surprising thing in its period is it

838
00:37:37,730 --> 00:37:34,280

is not global glaciation the whole time

839
00:37:40,340 --> 00:37:37,740
right so if i did a climate model

840
00:37:42,500 --> 00:37:40,350
without considering the geodynamic

841
00:37:44,660 --> 00:37:42,510
control on volcanic outgassing and

842
00:37:46,130 --> 00:37:44,670
weathering we would have us we would

843
00:37:47,930 --> 00:37:46,140
have a snowball solution for the first

844
00:37:50,900 --> 00:37:47,940
billion years of Earth's life if I

845
00:37:52,820 --> 00:37:50,910
include weathering and now casting at

846
00:37:54,620 --> 00:37:52,830
this controlled by mantle stirring we

847
00:37:56,180 --> 00:37:54,630
get partial I solutions and I don't

848
00:38:05,480 --> 00:37:56,190
think that's inconsistent with either of

849
00:38:08,390 --> 00:38:05,490
the two comments all right any more

850
00:38:12,680 --> 00:38:08,400
questions we seem to still have a bit of

851
00:38:14,270 --> 00:38:12,690
time but all right well then we'll go

852
00:38:18,270 --> 00:38:14,280
ahead and move on to the next Hut thank