Difficulties arise

- To get around this, a density- dependent negative feedback function was introduced.
- However, the exact mechanism behind this feedback could not be identified
- Consequently, the thermodynamics of the model were re-examined

1
00:00:13,750 --> 00:00:09,580
alright as Tim mentioned now for

2
00:00:16,510 --> 00:00:13,760
something completely different so most

3
00:00:19,150 --> 00:00:16,520
of my work is focused on ecosystems and

4
00:00:21,250 --> 00:00:19,160
very cold subway tional environments

5
00:00:24,310 --> 00:00:21,260
which obviously are of interest to our

6
00:00:26,050 --> 00:00:24,320
community because they so far seem to be

7
00:00:28,180 --> 00:00:26,060
pretty good analogs for some of the

8
00:00:29,950 --> 00:00:28,190
potentially more habitable environments

9
00:00:32,619 --> 00:00:29,960
we might find throughout the rest of the

10
00:00:35,140 --> 00:00:32,629
solar system in particular I work with

11
00:00:38,380 --> 00:00:35,150
the ecosystem associated with blood

12
00:00:41,650 --> 00:00:38,390
falls which provides a very good case

13
00:00:43,840 --> 00:00:41,660

study mostly because you don't have to

14
00:00:46,630 --> 00:00:43,850
drill down into it in order to sample

15
00:00:48,819 --> 00:00:46,640
because you get this weird periodic

16
00:00:50,560 --> 00:00:48,829
upwelling from deep within the reservoir

17
00:00:52,780 --> 00:00:50,570
that brings the brine to the surface and

18
00:00:55,240 --> 00:00:52,790
then the brine because of the amount of

19
00:00:59,160 --> 00:00:55,250
dissolved iron and it oxidizes and turns

20
00:01:04,840 --> 00:01:02,920
so however the question I was hoping to

21
00:01:06,700 --> 00:01:04,850
tackle was what's powering this

22
00:01:08,529 --> 00:01:06,710
ecosystem it's clearly not

23
00:01:10,389 --> 00:01:08,539
photosynthetic because it's under about

24
00:01:12,130 --> 00:01:10,399
three kilometers of ice and to the best

25
00:01:15,029 --> 00:01:12,140
of I know under such no geothermal

26
00:01:17,980 --> 00:01:15,039
activity associated with that so but

27
00:01:19,510 --> 00:01:17,990
laws of thermodynamics tell us that's

28
00:01:23,889 --> 00:01:19,520
got to have some sort of external energy

29
00:01:26,859 --> 00:01:23,899
source and the way I just tackle this

30
00:01:30,400 --> 00:01:26,869
problem was building a model of it using

31
00:01:32,109 --> 00:01:30,410
vensim which is a free system dynamics

32
00:01:34,719 --> 00:01:32,119
modeling sweet system dynamics is a

33
00:01:38,589 --> 00:01:34,729
particular brand or school of modeling

34
00:01:40,480 --> 00:01:38,599
that focuses on how systems change over

35
00:01:43,960 --> 00:01:40,490
time and how their behavior fluctuates

36
00:01:45,609 --> 00:01:43,970
and roughly speaking this model and can

37
00:01:47,350 --> 00:01:45,619
be divided up into different sub

38
00:01:51,760 --> 00:01:47,360

components there's sort of a nutrient

39
00:01:53,440 --> 00:01:51,770
cycle and a metabolic cycle this is a

40
00:01:56,650 --> 00:01:53,450
very simplified schematic of the

41
00:01:58,600 --> 00:01:56,660
nutrient cycle we looked at three the be

42
00:02:00,880 --> 00:01:58,610
three primary nutrients carbon nitrogen

43
00:02:02,380 --> 00:02:00,890
phosphorus and they were basically just

44
00:02:04,870 --> 00:02:02,390
cycled around endlessly through a

45
00:02:06,639 --> 00:02:04,880
biological form which is the biomass

46
00:02:10,059 --> 00:02:06,649
died was converted into an inorganic

47
00:02:13,899 --> 00:02:10,069
form which then was either would either

48
00:02:15,699 --> 00:02:13,909
decay or was metabolized and convert it

49
00:02:17,300 --> 00:02:15,709
back into an inorganic form and then it

50
00:02:23,130 --> 00:02:17,310
would cycle around

51
00:02:25,290 --> 00:02:23,140
the metabolic cycle is a good deal a

52
00:02:28,680 --> 00:02:25,300
good deal but simpler at least it was at

53
00:02:30,720 --> 00:02:28,690
the start there is a good strong

54
00:02:34,020 --> 00:02:30,730
evidence for the cycling of sulfur from

55
00:02:35,699 --> 00:02:34,030
a oxidized form to sort of a not

56
00:02:37,650 --> 00:02:35,709
necessarily reduced form but usually

57
00:02:42,150 --> 00:02:37,660
elemental sulfur was assumed to be the

58
00:02:45,059 --> 00:02:42,160
primary intermediary form curiously

59
00:02:47,789 --> 00:02:45,069
enough for some reason from what can be

60
00:02:49,259 --> 00:02:47,799
told from the field data this cycle does

61
00:02:51,150 --> 00:02:49,269
not actually proceed all the way to

62
00:02:53,009 --> 00:02:51,160
hydrogen sulfide which is kind of unique

63
00:02:57,270 --> 00:02:53,019

they're not entirely sure why that

64
00:02:58,380 --> 00:02:57,280
happens anyhow and getting back to the

65
00:03:01,740 --> 00:02:58,390
original question it has been

66
00:03:03,690 --> 00:03:01,750
hypothesized that actually the major

67
00:03:05,729 --> 00:03:03,700
power source for this ecosystem is all

68
00:03:09,930 --> 00:03:05,739
that iron that I mentioned earlier that

69
00:03:12,930 --> 00:03:09,940
you're getting the mobilization of iron

70
00:03:15,500 --> 00:03:12,940
3 from the bedrock of the glacier as its

71
00:03:17,699 --> 00:03:15,510
scoured by glacial action and as

72
00:03:19,589 --> 00:03:17,709
consequently basically acts as a

73
00:03:25,129 --> 00:03:19,599
terminal electron acceptor for the

74
00:03:28,470 --> 00:03:25,139
cycling of sulfur and then just sort of

75
00:03:31,440 --> 00:03:28,480
ends up being dissolved in the water

76
00:03:33,270 --> 00:03:31,450
until it hits the air and oxidizers out

77
00:03:40,890 --> 00:03:33,280
or precipitates out after oxidizing

78
00:03:44,039 --> 00:03:40,900
rather so to actually do all the cycling

79
00:03:46,470 --> 00:03:44,049
we need some model organisms so for

80
00:03:48,839 --> 00:03:46,480
purpose of simplifying a what appears to

81
00:03:50,759 --> 00:03:48,849
be a relatively complicated ecosystem we

82
00:03:52,770 --> 00:03:50,769
just narrowed it down to two basic

83
00:03:55,620 --> 00:03:52,780
organisms the first is essentially the

84
00:03:57,900 --> 00:03:55,630
primary producer and that's based on the

85
00:04:00,030 --> 00:03:57,910
chemo Louth of trophic sulfur oxidizer

86
00:04:03,839 --> 00:04:00,040
Thea microsphere arctica which is a

87
00:04:06,120 --> 00:04:03,849
psycho file we pick that one because due

88
00:04:07,500 --> 00:04:06,130

to the based on Minetta genomic analysis

89
00:04:10,039 --> 00:04:07,510
they've done of the bacteria they've

90
00:04:13,050 --> 00:04:10,049
been able to isolate from the discharge

91
00:04:15,150 --> 00:04:13,060
something something that is very closely

92
00:04:18,060 --> 00:04:15,160
related to see you microsphere arctica

93
00:04:19,650 --> 00:04:18,070
appears to be the dominant species it's

94
00:04:22,620 --> 00:04:19,660
about forty percent of what they found

95
00:04:24,810 --> 00:04:22,630
so far and the second is a chemo organo

96
00:04:28,140 --> 00:04:24,820
trove sort of acts as a secondary

97
00:04:30,450 --> 00:04:28,150
consumer and maybe kind of a decomposer

98
00:04:32,249 --> 00:04:30,460
to try to vote as well

99
00:04:34,350 --> 00:04:32,259
which then reduces the sulfate and

100
00:04:37,200 --> 00:04:34,360
oxidizes the organic carbon so it

101
00:04:39,510 --> 00:04:37,210
completes the cycle that one is just

102
00:04:42,270 --> 00:04:39,520
based on sort of an amalgam of various

103
00:04:49,140 --> 00:04:42,280
species since no one particular species

104
00:04:51,659 --> 00:04:49,150
seemed to dominate the population so as

105
00:04:53,430 --> 00:04:51,669
this is going along quite happily we're

106
00:04:55,080 --> 00:04:53,440
making the model more sophisticated more

107
00:04:58,860 --> 00:04:55,090
detailed and then we start running into

108
00:05:02,879 --> 00:04:58,870
difficulties specifically the population

109
00:05:05,670 --> 00:05:02,889
is not stable of neither the heterotroph

110
00:05:08,879 --> 00:05:05,680
King Morgan otro for the sulfur oxidizer

111
00:05:11,460 --> 00:05:08,889
as either you tend to see two patterns

112
00:05:14,100 --> 00:05:11,470
of behavior either the population would

113
00:05:15,659 --> 00:05:14,110

crash right at startup and nothing would

114
00:05:17,790 --> 00:05:15,669
happen for the rest of the simulation

115
00:05:21,450 --> 00:05:17,800
that's usually when the death rate was

116
00:05:24,810 --> 00:05:21,460
relatively high or it would grow very

117
00:05:28,710 --> 00:05:24,820
slowly peak overshoot and then crash

118
00:05:30,420 --> 00:05:28,720
very slowly and that was when the death

119
00:05:32,520 --> 00:05:30,430
rate was very low either way you ended

120
00:05:34,770 --> 00:05:32,530
up with essentially no population by the

121
00:05:36,420 --> 00:05:34,780
end of the model which given that this

122
00:05:37,920 --> 00:05:36,430
particular ecosystem is thought to have

123
00:05:40,890 --> 00:05:37,930
been isolated for three to five million

124
00:05:42,480 --> 00:05:40,900
years is probably not accurate since if

125
00:05:43,800 --> 00:05:42,490
that were the case there wouldn't be any

126
00:05:46,950 --> 00:05:43,810
good system at this point at least

127
00:05:48,629 --> 00:05:46,960
that's the thinking so just to give you

128
00:05:51,390 --> 00:05:48,639
some examples this is what happens with

129
00:05:53,939 --> 00:05:51,400
high death rate and it's just dies start

130
00:05:56,370 --> 00:05:53,949
up and then with low death rate you get

131
00:05:59,580 --> 00:05:56,380
this really nice peak and then falls off

132
00:06:02,909 --> 00:05:59,590
to zero as the nutrients become too

133
00:06:04,469 --> 00:06:02,919
scarce so originally to get around this

134
00:06:07,529 --> 00:06:04,479
we introduced density-dependent negative

135
00:06:10,050 --> 00:06:07,539
feedback functions which basically is a

136
00:06:11,969 --> 00:06:10,060
modeling jargon term for an effect that

137
00:06:14,180 --> 00:06:11,979
acts on the population in this

138
00:06:16,350 --> 00:06:14,190

particular case on the mortality either

139
00:06:19,379 --> 00:06:16,360
increasing the death rate or decreasing

140
00:06:21,149 --> 00:06:19,389
the growth rate which increases

141
00:06:22,860 --> 00:06:21,159
proportional to the population so the

142
00:06:26,790 --> 00:06:22,870
dense of the population the stronger

143
00:06:28,260 --> 00:06:26,800
this effect is which works however we

144
00:06:30,499 --> 00:06:28,270
got some reviewer comments most notably

145
00:06:33,240 --> 00:06:30,509
from christopher k who pointed out that

146
00:06:35,360 --> 00:06:33,250
this is probably a bit too complicated

147
00:06:37,499 --> 00:06:35,370
especially since we can't actually

148
00:06:40,290 --> 00:06:37,509
identify any mechanism that could be

149
00:06:42,149 --> 00:06:40,300
responsible so in the spirit of Occam's

150
00:06:43,570 --> 00:06:42,159
razor we decided okay let's go back and

151
00:06:45,339 --> 00:06:43,580
let's simplify things

152
00:06:49,240 --> 00:06:45,349
and we went back to the third on i'm at

153
00:06:51,490 --> 00:06:49,250
dynamics so originally the metabolic

154
00:06:53,140 --> 00:06:51,500
cycle had been kind of crudely done

155
00:06:56,740 --> 00:06:53,150
because we didn't really have a lot of

156
00:06:58,629 --> 00:06:56,750
information but then we decided you know

157
00:06:59,890 --> 00:06:58,639
what let's just and they're also a bunch

158
00:07:02,050 --> 00:06:59,900
of different metabolic pathways that

159
00:07:03,999 --> 00:07:02,060
could be chosen but we decided okay

160
00:07:06,850 --> 00:07:04,009
let's just pick one that seems likely

161
00:07:10,540 --> 00:07:06,860
and model that explicitly in the amount

162
00:07:13,990 --> 00:07:10,550
and the ego system simulation so for the

163
00:07:16,689 --> 00:07:14,000

sulfur oxidizers we did this oxidation

164
00:07:19,659 --> 00:07:16,699
of elemental sulfur using iron 3 is a

165
00:07:24,520 --> 00:07:19,669
electron acceptor producing sulfate iron

166
00:07:27,490 --> 00:07:24,530
2 and some hydrogen protons not under

167
00:07:29,260 --> 00:07:27,500
institute conditions provides 160 4.5

168
00:07:31,719 --> 00:07:29,270
kilojoules per mole per two electron

169
00:07:33,369 --> 00:07:31,729
produced and then for the purposes

170
00:07:37,300 --> 00:07:33,379
modeling we assumed this is going to be

171
00:07:39,519 --> 00:07:37,310
used for the fixation of inorganic

172
00:07:41,679 --> 00:07:39,529
carbon which is represented by the

173
00:07:43,719 --> 00:07:41,689
reduction of inorganic carbon acetate

174
00:07:47,950 --> 00:07:43,729
which requires 142 kilojoules per mole

175
00:07:49,869 --> 00:07:47,960
in situations for the chemo granite

176
00:07:52,629 --> 00:07:49,879
roast its kind of running it in reverse

177
00:07:55,390 --> 00:07:52,639
you have acetate plus sulfate solver

178
00:07:58,990 --> 00:07:55,400
gets reduced the state gets oxidized

179
00:08:01,420 --> 00:07:59,000
this is notably a lot less energetic

180
00:08:03,899 --> 00:08:01,430
only produces 19.6 kilojoules per mole

181
00:08:06,459 --> 00:08:03,909
per electron and Institute conditions

182
00:08:08,499 --> 00:08:06,469
which may explain why there are any

183
00:08:12,610 --> 00:08:08,509
aren't anywhere near as many of these

184
00:08:16,959 --> 00:08:12,620
organisms in the reservoir based on

185
00:08:20,920 --> 00:08:16,969
metagenomic analysis and that worked

186
00:08:22,869 --> 00:08:20,930
that made it stable which allowed us for

187
00:08:25,360 --> 00:08:22,879
create this nice-looking baseline model

188
00:08:26,890 --> 00:08:25,370

where it plateaus and stays stable and

189
00:08:29,439 --> 00:08:26,900
you can do sensitivity tests and see how

190
00:08:33,250 --> 00:08:29,449
resilient it is and it also suggests

191
00:08:35,860 --> 00:08:33,260
that iren ultimately is the limiting

192
00:08:39,219 --> 00:08:35,870
element or limiting nutrient for this

193
00:08:41,139 --> 00:08:39,229
ecosystem which for astrobiologists

194
00:08:45,519 --> 00:08:41,149
probably isn't that big of a thing but

195
00:08:47,620 --> 00:08:45,529
most of the ecology literature is this

196
00:08:49,240 --> 00:08:47,630
is a bit unusual because most

197
00:08:52,720 --> 00:08:49,250
psychologists are used to dealing with

198
00:08:54,579 --> 00:08:52,730
more mundane terrestrial ecosystems

199
00:08:56,590 --> 00:08:54,589
where energy is basically assumed to be

200
00:08:56,820 --> 00:08:56,600
free because they have photosynthesis so

201
00:08:58,470 --> 00:08:56,830
there

202
00:09:00,060 --> 00:08:58,480
usually concerned with nutrient

203
00:09:02,430 --> 00:09:00,070
limitation so the idea of an energy

204
00:09:06,390 --> 00:09:02,440
limited one is actually kind of new and

205
00:09:10,170 --> 00:09:06,400
at least in the ecology literature and

206
00:09:12,240 --> 00:09:10,180
to test this out it's assumed that the

207
00:09:13,980 --> 00:09:12,250
irons being we don't know how rapidly

208
00:09:16,590 --> 00:09:13,990
the iron 3 is being mobilized from the

209
00:09:19,620 --> 00:09:16,600
bedrock so we played around with that

210
00:09:22,020 --> 00:09:19,630
order burying it by about an order of

211
00:09:24,990 --> 00:09:22,030
magnitude and sure enough that leads to

212
00:09:26,250 --> 00:09:25,000
a directly proportional change in the

213
00:09:29,400 --> 00:09:26,260

amount of biomass and in the

214
00:09:31,920 --> 00:09:29,410
productivity so so far this is looking

215
00:09:34,050 --> 00:09:31,930
pretty consistent and lastly sort of the

216
00:09:35,160 --> 00:09:34,060
implications for astrobiology as I

217
00:09:38,820 --> 00:09:35,170
mentioned some of these may not be that

218
00:09:41,340 --> 00:09:38,830
surprising flux of available energy is a

219
00:09:43,560 --> 00:09:41,350
major limiting factor for population

220
00:09:45,360 --> 00:09:43,570
growth perhaps more so at least in this

221
00:09:46,680 --> 00:09:45,370
case in the flux of nutrients because

222
00:09:48,990 --> 00:09:46,690
there are some limiting nutrients

223
00:09:51,320 --> 00:09:49,000
notably phosphorus in this ecosystem but

224
00:09:54,530 --> 00:09:51,330
they apparently weren't limiting enough

225
00:09:57,240 --> 00:09:54,540
to keep instability from happening and

226
00:09:58,800 --> 00:09:57,250
sort of a suggestion to in addition to

227
00:10:00,240 --> 00:09:58,810
fall the water if all the elements we

228
00:10:01,980 --> 00:10:00,250
probably ought to consider follow the

229
00:10:05,820 --> 00:10:01,990
energy as well in terms of looking for

230
00:10:18,530 --> 00:10:05,830
habitability so yeah there you go any

231
00:10:27,780 --> 00:10:18,540
questions any questions for Thompson ok

232
00:10:29,700 --> 00:10:27,790
keep making me go all the way um so I'm

233
00:10:32,250 --> 00:10:29,710
sorry if this comes from a little bit of

234
00:10:35,490 --> 00:10:32,260
ignorance of both nice geochemistry and

235
00:10:38,220 --> 00:10:35,500
biology Blake yesterday there was a

236
00:10:40,590 --> 00:10:38,230
poster looking at sulfur and its

237
00:10:42,690 --> 00:10:40,600
oxidation in with respect to the great

238
00:10:50,190 --> 00:10:42,700

oxidation event and some other talks

239
00:10:52,050 --> 00:10:50,200
about it and your system uses sulfur and

240
00:10:58,050 --> 00:10:52,060
oxygen and all that sort of fixation

241
00:10:59,820 --> 00:10:58,060
stuff is your a system something that

242
00:11:02,190 --> 00:10:59,830
would be old enough to have had

243
00:11:05,790 --> 00:11:02,200
implications and something like the

244
00:11:07,500 --> 00:11:05,800
great accident oh um probably not this

245
00:11:10,550 --> 00:11:07,510
is the system is only about three to

246
00:11:13,980 --> 00:11:10,560
five million years old it was formed

247
00:11:15,480 --> 00:11:13,990
during basically uplifted pocket of

248
00:11:19,950 --> 00:11:15,490
seawater that got eventually got frozen

249
00:11:22,890 --> 00:11:19,960
over so probably not i don't i mean it

250
00:11:26,910 --> 00:11:22,900
is a totally anaerobic system or anoxic

251
00:11:29,790 --> 00:11:26,920
system rather but i don't know i

252
00:11:32,310 --> 00:11:29,800
honestly don't know enough about the

253
00:11:33,960 --> 00:11:32,320
sort of great the prebiotic or early

254
00:11:35,730 --> 00:11:33,970
Earth literature to really competently

255
00:11:38,790 --> 00:11:35,740
say this is a good analog it's certainly

256
00:11:41,190 --> 00:11:38,800
worth looking into but I can't say from

257
00:11:42,330 --> 00:11:41,200
authority that this is something we

258
00:11:49,080 --> 00:11:42,340
should really be looking for for