Mesoarchean microbial iron shuttle model

O_2 O_2 O_2

FeOOH FeOOH

Suboxic conditions result in direct precipitation of Fe oxides in water column

1
00:00:11,870 --> 00:00:10,129
alright thanks for coming out guys so

2
00:00:14,420 --> 00:00:11,880
we're going to travel back to the mezzo

3
00:00:17,990 --> 00:00:14,430
archaean today but before we do I wanted

4
00:00:21,170 --> 00:00:18,000
to thank my funding sources which is the

5
00:00:22,940 --> 00:00:21,180
current na I can cycle the Lewis and

6
00:00:25,040 --> 00:00:22,950
Clark grant and the GSA graduate

7
00:00:27,979 --> 00:00:25,050
research grant I also like to thank my

8
00:00:29,510 --> 00:00:27,989
collaborators so I'm going to start

9
00:00:31,670 --> 00:00:29,520
today talking about the motivation

10
00:00:34,130 --> 00:00:31,680
behind my research but I'm going to go

11
00:00:36,620 --> 00:00:34,140
into background into the sumotori iron

12
00:00:38,930 --> 00:00:36,630
reduction I'm then I'm going to go into

13
00:00:40,840 --> 00:00:38,940

the approach behind my research and get

14
00:00:43,069 --> 00:00:40,850
some background to my field area and

15
00:00:45,830 --> 00:00:43,079
then I'll present some are an isotope

16
00:00:47,209 --> 00:00:45,840
data put it into context than the model

17
00:00:50,419 --> 00:00:47,219
and tie everything together with some

18
00:00:53,090 --> 00:00:50,429
implications and conclusions so the

19
00:00:55,430 --> 00:00:53,100
question driving my research is was

20
00:00:57,590 --> 00:00:55,440
there a chemical footprint of the

21
00:00:59,930 --> 00:00:57,600
sumotori iron reduction three billion

22
00:01:01,819 --> 00:00:59,940
years ago and I ask this question

23
00:01:05,149 --> 00:01:01,829
because the sumotori iron reduction is

24
00:01:09,230 --> 00:01:05,159
then has great astrobiological potential

25
00:01:12,260 --> 00:01:09,240
its electron acceptor iron is widespread

26
00:01:14,420 --> 00:01:12,270
in the solar system and this metabolism

27
00:01:18,110 --> 00:01:14,430
of the sumotori arm reduction is deeply

28
00:01:20,900 --> 00:01:18,120
rooted in the tree of life so let's move

29
00:01:23,870 --> 00:01:20,910
on to some background this equation

30
00:01:26,060 --> 00:01:23,880
right here is showing the matura RN

31
00:01:29,480 --> 00:01:26,070
reduction with the electron acceptor and

32
00:01:32,300 --> 00:01:29,490
blue and the electron donor in red so in

33
00:01:34,190 --> 00:01:32,310
this process you oxidize the organic

34
00:01:36,440 --> 00:01:34,200
matter at the same time that you reduce

35
00:01:40,040 --> 00:01:36,450
the ferric iron and this produces

36
00:01:42,230 --> 00:01:40,050
ferrous iron the purple boxes here are

37
00:01:44,810 --> 00:01:42,240
indicating the phyla that are capable to

38
00:01:46,670 --> 00:01:44,820

similar Tory I reduction so you can see

39
00:01:48,860 --> 00:01:46,680
that those phyla are deeply rooted and

40
00:01:53,690 --> 00:01:48,870
their present in both the bacterial and

41
00:01:56,060 --> 00:01:53,700
archaeal branches of life so how do we

42
00:01:58,130 --> 00:01:56,070
find dir in the rock record what

43
00:02:01,250 --> 00:01:58,140
fingerprints are there it basically

44
00:02:02,600 --> 00:02:01,260
boils down to isotopes and minerals so

45
00:02:05,150 --> 00:02:02,610
if you guys aren't familiar with iron

46
00:02:07,820 --> 00:02:05,160
isotopes we've got the notation here so

47
00:02:09,380 --> 00:02:07,830
iron isotopes are measured on relative

48
00:02:13,100 --> 00:02:09,390
to a standard which is the average

49
00:02:15,890 --> 00:02:13,110
igneous rocks iron 56 is the heavy

50
00:02:18,530 --> 00:02:15,900
isotope of iron and iron 54 is the light

51
00:02:19,309 --> 00:02:18,540
isotope so if you get a positive Delta

52
00:02:21,920 --> 00:02:19,319
50

53
00:02:24,530 --> 00:02:21,930
6-iron value that means you are enriched

54
00:02:26,629 --> 00:02:24,540
in the heavy isotope relative to igneous

55
00:02:28,640 --> 00:02:26,639
rocks and if you get a negative value

56
00:02:32,780 --> 00:02:28,650
that means you're depleted in the heavy

57
00:02:34,879 --> 00:02:32,790
isotope now this process it also enables

58
00:02:37,099 --> 00:02:34,889
the formation of certain minerals such

59
00:02:40,640 --> 00:02:37,109
as magnetite satellite and Vivian night

60
00:02:47,209 --> 00:02:40,650
so combining isotopes and minerals we

61
00:02:49,879 --> 00:02:47,219
can find dir in the rock record so for

62
00:02:52,399 --> 00:02:49,889
my study I did iron isotopes on whole

63
00:02:55,399 --> 00:02:52,409

rock samples microgel pyrite and

64
00:02:58,159 --> 00:02:55,409
magnetite separates these samples come

65
00:03:00,349 --> 00:02:58,169
from the mezzo archaean Witwatersrand

66
00:03:02,899 --> 00:03:00,359
supergroup and they represent a wide

67
00:03:07,509 --> 00:03:02,909
range of lithologies and depositional

68
00:03:10,189 --> 00:03:07,519
facies so where is the witwatersrand

69
00:03:12,709 --> 00:03:10,199
govardhan supergroup is part of the cat

70
00:03:15,470 --> 00:03:12,719
fall Cretan of South Africa and it's

71
00:03:17,899 --> 00:03:15,480
composed of the older West ran group and

72
00:03:20,990 --> 00:03:17,909
the younger more famous Central Rand

73
00:03:23,780 --> 00:03:21,000
group and Central Rand group is very

74
00:03:26,210 --> 00:03:23,790
famous because it's a it has lots of

75
00:03:28,729 --> 00:03:26,220
gold and but my samples are from the

76
00:03:30,409 --> 00:03:28,739
west rand group and we are lucky to get

77
00:03:32,179 --> 00:03:30,419
those samples because when they're

78
00:03:34,610 --> 00:03:32,189
trying to sample the central ran groups

79
00:03:36,499 --> 00:03:34,620
sometimes the drill cores went down too

80
00:03:38,929 --> 00:03:36,509
far and they accidentally sample the

81
00:03:42,740 --> 00:03:38,939
western group so I'm very thankful for

82
00:03:45,550 --> 00:03:42,750
that so there's a couple really

83
00:03:48,349 --> 00:03:45,560
fantastic aspects of the Western group

84
00:03:51,259 --> 00:03:48,359
the first is that it's experienced

85
00:03:53,479 --> 00:03:51,269
low-grade lo green show species

86
00:03:55,640 --> 00:03:53,489
metamorphism which sounds pretty scary

87
00:03:57,800 --> 00:03:55,650
to anyone that works with younger rocks

88
00:03:59,509 --> 00:03:57,810

or modern sediments but for the mezzo

89
00:04:03,619 --> 00:03:59,519
archaean it's pretty much the best we

90
00:04:06,050 --> 00:04:03,629
can hope for I these rocks represent a

91
00:04:09,949 --> 00:04:06,060
complete depositional Basin from just

92
00:04:11,890 --> 00:04:09,959
offshore to the starve shelf and these

93
00:04:14,959 --> 00:04:11,900
rocks have been used as evidence for

94
00:04:18,110 --> 00:04:14,969
atmospheric oxygen and that has come in

95
00:04:20,180 --> 00:04:18,120
the form of chromium isotopes selenium

96
00:04:24,379 --> 00:04:20,190
concentrations in pyrite and molybdenum

97
00:04:26,899 --> 00:04:24,389
isotopes so I say that we have this

98
00:04:33,100 --> 00:04:26,909
whole complete depositional Basin where

99
00:04:38,720 --> 00:04:36,800
so you can see here that this is a sort

100
00:04:40,280 --> 00:04:38,730
of model ocean basin and so we have

101
00:04:42,260 --> 00:04:40,290
samples from the braids approval depo

102
00:04:44,030 --> 00:04:42,270
phases which is just off shore and then

103
00:04:45,740 --> 00:04:44,040
slightly ensure the pro delta depth of

104
00:04:48,140 --> 00:04:45,750
faces and they should be considered

105
00:04:50,480 --> 00:04:48,150
proximal the transitional shelf would be

106
00:04:52,040 --> 00:04:50,490
intermediate and the outer shelf and

107
00:04:55,340 --> 00:04:52,050
starve shelf would be the distal

108
00:04:58,100 --> 00:04:55,350
depositional facies so let's look at

109
00:05:01,220 --> 00:04:58,110
some data this is showing iron isotopes

110
00:05:03,710 --> 00:05:01,230
plotted against tol iron concentrations

111
00:05:05,810 --> 00:05:03,720
which is normalized to Luminum and we

112
00:05:08,180 --> 00:05:05,820
normalized to aluminum because we want

113
00:05:11,810 --> 00:05:08,190

to look at iron enrichment beyond the

114
00:05:13,850 --> 00:05:11,820
trityl flux so the cooler blue colors

115
00:05:16,910 --> 00:05:13,860
are more proximal depositional facies

116
00:05:19,520 --> 00:05:16,920
and the more red warmer colors are the

117
00:05:21,620 --> 00:05:19,530
more distal depositional phases the

118
00:05:23,660 --> 00:05:21,630
diamonds are micro joule pyrite the

119
00:05:27,650 --> 00:05:23,670
circles are whole rocks and the squares

120
00:05:29,330 --> 00:05:27,660
are magnetite separates so we can see

121
00:05:30,950 --> 00:05:29,340
that as we move from the proximal part

122
00:05:32,930 --> 00:05:30,960
of the basin to the more distal part of

123
00:05:36,230 --> 00:05:32,940
basin we're getting enrichment in the

124
00:05:39,530 --> 00:05:36,240
iron contents so this line here is

125
00:05:42,050 --> 00:05:39,540
showing the iron concentration of the

126
00:05:43,700 --> 00:05:42,060
average our crust and to the left of

127
00:05:45,860 --> 00:05:43,710
this line we have mostly proximal

128
00:05:48,020 --> 00:05:45,870
samples which means they are depleted an

129
00:05:50,750 --> 00:05:48,030
iron relative to the average crust and

130
00:05:52,730 --> 00:05:50,760
on the right side we see the more distal

131
00:05:55,760 --> 00:05:52,740
samples and they are enriched in iron

132
00:05:57,140 --> 00:05:55,770
relative to the crust you can also see

133
00:05:59,090 --> 00:05:57,150
that the same time we have iron

134
00:06:03,950 --> 00:05:59,100
enrichment we're getting increasingly

135
00:06:06,830 --> 00:06:03,960
negative Delta 56 iron values and this

136
00:06:09,800 --> 00:06:06,840
line here is representing the average

137
00:06:11,720 --> 00:06:09,810
Delta 56 iron value of our key and crust

138
00:06:13,970 --> 00:06:11,730

so above the line we have mostly

139
00:06:15,680 --> 00:06:13,980
proximal samples which means that they

140
00:06:18,610 --> 00:06:15,690
are enriched in the heavy isotope of

141
00:06:22,160 --> 00:06:18,620
iron and then below this line we have

142
00:06:24,770 --> 00:06:22,170
the more negative Delta 56 samples the

143
00:06:26,900 --> 00:06:24,780
delt the distal depo faces and that

144
00:06:29,780 --> 00:06:26,910
means that they are depleted in the

145
00:06:31,550 --> 00:06:29,790
heavy isotope relative to the crust so

146
00:06:34,160 --> 00:06:31,560
this inverse correlation between the

147
00:06:36,650 --> 00:06:34,170
iron concentration and the iron isotope

148
00:06:38,570 --> 00:06:36,660
values has been seen before in modern

149
00:06:40,640 --> 00:06:38,580
environments and it's indicative of

150
00:06:43,820 --> 00:06:40,650
something called a benthic iron shuttle

151
00:06:46,250 --> 00:06:43,830
or microbial iron shuttle

152
00:06:49,490 --> 00:06:46,260
so this work was pioneered by silca

153
00:06:52,880 --> 00:06:49,500
sever minh and in her 2008 study on the

154
00:06:55,910 --> 00:06:52,890
black sea they found that I sitaki light

155
00:06:58,070 --> 00:06:55,920
iron was being produced on the shelf by

156
00:07:00,980 --> 00:06:58,080
microbes and this light iron was

157
00:07:03,800 --> 00:07:00,990
preferentially removed and deposited

158
00:07:06,530 --> 00:07:03,810
entrapped in the more distal deep basin

159
00:07:09,500 --> 00:07:06,540
this meant that a residual heavy pool of

160
00:07:12,410 --> 00:07:09,510
iron was left on the shelf now another

161
00:07:15,140 --> 00:07:12,420
important aspect of the study is that it

162
00:07:17,180 --> 00:07:15,150
required a redox boundary in order to

163
00:07:20,210 --> 00:07:17,190

trap the benthic iron flux through the

164
00:07:22,550 --> 00:07:20,220
microbial iron flux and in fact every

165
00:07:26,060 --> 00:07:22,560
study that I've come across of microbial

166
00:07:28,400 --> 00:07:26,070
iron shuttle requires a redox boundary

167
00:07:30,440 --> 00:07:28,410
in order to get that inverse correlation

168
00:07:33,890 --> 00:07:30,450
between iron concentration and iron

169
00:07:35,960 --> 00:07:33,900
isotopes so this is modern environment

170
00:07:39,190 --> 00:07:35,970
study how does this apply to the measure

171
00:07:42,530 --> 00:07:39,200
can and this is where it gets fun so

172
00:07:45,200 --> 00:07:42,540
we've got a model and the first part of

173
00:07:47,660 --> 00:07:45,210
the model is we need food for the

174
00:07:50,990 --> 00:07:47,670
dissymmetry iron reducing bacteria and

175
00:07:53,210 --> 00:07:51,000
so because other papers have come out

176
00:07:54,950 --> 00:07:53,220
suggesting that oxygen was present in

177
00:07:56,450 --> 00:07:54,960
this mess rocky atmosphere I'm

178
00:07:58,730 --> 00:07:56,460
suggesting that there is a redox

179
00:08:01,130 --> 00:07:58,740
stratified water column with oxic

180
00:08:04,520 --> 00:08:01,140
surface waters on top and anoxic

181
00:08:08,110 --> 00:08:04,530
ferruginous waters below so iron would

182
00:08:12,200 --> 00:08:08,120
precipitate and go to the shelf and

183
00:08:16,430 --> 00:08:12,210
these ferric iron would be reduced by

184
00:08:19,880 --> 00:08:16,440
the dir bacteria and a produce I stop

185
00:08:21,890 --> 00:08:19,890
relight iron now this isotope cool iron

186
00:08:24,830 --> 00:08:21,900
would be preferentially removed and

187
00:08:26,780 --> 00:08:24,840
trapped below the redox climb and this

188
00:08:29,090 --> 00:08:26,790

would leave the heavy iron isotopes on

189
00:08:31,640 --> 00:08:29,100
the shelf this is why we have the more

190
00:08:33,590 --> 00:08:31,650
heavy iron isotopes on the shelf and

191
00:08:37,790 --> 00:08:33,600
they get increasingly light as we

192
00:08:39,920 --> 00:08:37,800
increase the distance from the shelf so

193
00:08:42,170 --> 00:08:39,930
one of the remaining question is what

194
00:08:45,170 --> 00:08:42,180
minerals are the reservoirs for the

195
00:08:47,390 --> 00:08:45,180
benthic iron flux I address this

196
00:08:49,520 --> 00:08:47,400
question by doing normative calculations

197
00:08:53,030 --> 00:08:49,530
based on bulk element data and iron

198
00:08:56,660 --> 00:08:53,040
speciation data and so you can see that

199
00:08:57,150 --> 00:08:56,670
the green represents a silicate as the

200
00:08:59,639 --> 00:08:57,160
iron bear

201
00:09:02,730 --> 00:08:59,649
in face the red it would indicate

202
00:09:05,369 --> 00:09:02,740
magnetite the blue pyrite and then the

203
00:09:07,379 --> 00:09:05,379
purple hematite and as we move from the

204
00:09:10,139 --> 00:09:07,389
proximal to the more distal part of the

205
00:09:12,720 --> 00:09:10,149
basin we're having seen an increasing

206
00:09:14,999 --> 00:09:12,730
proportion of magnetite and this leads

207
00:09:16,860 --> 00:09:15,009
us to hypothesize that it's magnetite is

208
00:09:20,189 --> 00:09:16,870
the main reservoir for the benefit iron

209
00:09:21,809 --> 00:09:20,199
flux you can also see that the size of

210
00:09:23,429 --> 00:09:21,819
the pie chart is increasing as we're

211
00:09:25,710 --> 00:09:23,439
moving to the distal basin and that

212
00:09:28,410 --> 00:09:25,720
represents iron enrichment but it's not

213
00:09:31,530 --> 00:09:28,420

just iron that's being enriched this a

214
00:09:33,629 --> 00:09:31,540
trend also holds for manganese manganese

215
00:09:35,119 --> 00:09:33,639
is increasing as we go from the proximal

216
00:09:37,889 --> 00:09:35,129
to the distal part of the basin and

217
00:09:40,040 --> 00:09:37,899
another previous study on the banded

218
00:09:43,499 --> 00:09:40,050
iron formations of the starved shelf of

219
00:09:45,990 --> 00:09:43,509
these rocks found that manganese was

220
00:09:47,730 --> 00:09:46,000
anomalously enriched compared to all

221
00:09:53,360 --> 00:09:47,740
other banded iron formations of the

222
00:09:56,400 --> 00:09:53,370
archaean so if we plot iron isotopes

223
00:09:58,170 --> 00:09:56,410
against manganese concentrations you can

224
00:10:00,660 --> 00:09:58,180
see that we have an inverse correlation

225
00:10:03,210 --> 00:10:00,670
here as well where we have increasing

226
00:10:05,759 --> 00:10:03,220
manganese content and that corresponds

227
00:10:08,759 --> 00:10:05,769
with more and more light iron isotope

228
00:10:11,790 --> 00:10:08,769
values so this leads me to hypothesize

229
00:10:14,699 --> 00:10:11,800
that manganese is hitching a ride on the

230
00:10:17,550 --> 00:10:14,709
microbial iron shuttle so manganese is

231
00:10:19,740 --> 00:10:17,560
being shuttled as well so to tie

232
00:10:22,139 --> 00:10:19,750
everything together we see an inverse

233
00:10:24,269 --> 00:10:22,149
correlation between the iron content and

234
00:10:27,660 --> 00:10:24,279
the iron isotopes which is indicative of

235
00:10:29,340 --> 00:10:27,670
microbial iron shuttle and the inverse

236
00:10:31,470 --> 00:10:29,350
correlation between iron isotopes a

237
00:10:34,949 --> 00:10:31,480
manganese content is suggesting that

238
00:10:37,410 --> 00:10:34,959

manganese is being shuttled as well the

239
00:10:39,480 --> 00:10:37,420
iron enrichment is corresponding to an

240
00:10:41,549 --> 00:10:39,490
increasing proportion of magnetite in

241
00:10:44,090 --> 00:10:41,559
the samples and this study is

242
00:10:47,100 --> 00:10:44,100
particularly exciting because it is the

243
00:10:49,439 --> 00:10:47,110
oldest record of microbial iron shuttle

244
00:10:51,749 --> 00:10:49,449
that we have and it shows that the

245
00:10:53,850 --> 00:10:51,759
sumotori iron reduction was a left of

246
00:10:57,600 --> 00:10:53,860
basin-wide footprint three billion years

247
00:11:00,389 --> 00:10:57,610
ago so this implies that there is an

248
00:11:02,720 --> 00:11:00,399
active iron cycling microbial community

249
00:11:05,370 --> 00:11:02,730
and the redox stratified ocean and

250
00:11:09,569 --> 00:11:05,380
lastly i think this emphasizes the

251
00:11:10,980 --> 00:11:09,579
importance of using basin-wide samples

252
00:11:13,139 --> 00:11:10,990
to address basin

253
00:11:15,180 --> 00:11:13,149
research questions because if I had only

254
00:11:17,699 --> 00:11:15,190
sampled the proximal part of the basin

255
00:11:20,670 --> 00:11:17,709
argc heavy iron eyes took values and

256
00:11:22,440 --> 00:11:20,680
think maybe some iron was oxidized if I

257
00:11:24,630 --> 00:11:22,450
only sampled the distal part of the

258
00:11:27,090 --> 00:11:24,640
basin or just seeing negative iron eyes

259
00:11:28,440 --> 00:11:27,100
took values and think there's dir there

260
00:11:31,470 --> 00:11:28,450
and that would be the end of the story

261
00:11:33,090 --> 00:11:31,480
it was only with the complete basin that

262
00:11:35,460 --> 00:11:33,100
I could be able to piece together a

263
00:11:49,500 --> 00:11:35,470

model of a mezzo archaean iron shuttle

264
00:11:52,380 --> 00:11:49,510
so with that are there any questions so

265
00:11:55,110 --> 00:11:52,390
you mentioned how you're moving the

266
00:11:57,870 --> 00:11:55,120
ferrous iron from the surface ocean into

267
00:12:00,030 --> 00:11:57,880
the deep ocean so if the surface ocean

268
00:12:02,670 --> 00:12:00,040
is oxidized in the deep ocean is reduced

269
00:12:05,400 --> 00:12:02,680
or an toxic I guess or dis oxic

270
00:12:08,730 --> 00:12:05,410
depending on you want to freeze it how

271
00:12:11,070 --> 00:12:08,740
are you getting the ferrous iron through

272
00:12:13,170 --> 00:12:11,080
the oxygen and then immobilizing it in

273
00:12:15,720 --> 00:12:13,180
the deep ocean that's an excellent

274
00:12:18,000 --> 00:12:15,730
question so there's multiple ways that

275
00:12:19,920 --> 00:12:18,010
or there's multiple different transport

276
00:12:21,660 --> 00:12:19,930
mechanisms that have been invoked in the

277
00:12:23,699 --> 00:12:21,670
literature for microbial iron shuttles

278
00:12:27,000 --> 00:12:23,709
the first would be a ferrous ion

279
00:12:30,300 --> 00:12:27,010
traveling along the redox klein and then

280
00:12:32,910 --> 00:12:30,310
going down below another one of via the

281
00:12:34,440 --> 00:12:32,920
iron is transported by ligands and that

282
00:12:37,170 --> 00:12:34,450
would be able to travel through the

283
00:12:39,329 --> 00:12:37,180
octopus waters that way and the last is

284
00:12:41,730 --> 00:12:39,339
that the bed the garrn flux is being

285
00:12:45,420 --> 00:12:41,740
transported as a solid a nanoparticulate

286
00:12:48,180 --> 00:12:45,430
solid and that is on what I favor but it

287
00:12:50,100 --> 00:12:48,190
requires that all of the benthic iron

288
00:12:52,650 --> 00:12:50,110

flux is oxidized if you're going to

289
00:12:58,710 --> 00:12:52,660
preserve that heavy the light iron