

Iron Sulfide Minerals in Prebiotic Redox Chemistry

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1
00:00:12,799 --> 00:00:10,120

[Music]

2
00:00:15,939 --> 00:00:12,809

hi everybody it's very nice to be here

3
00:00:18,439 --> 00:00:15,949

in Mid Atlantic astrobiology community

4
00:00:21,070 --> 00:00:18,449

my tokus about iron sulphides and

5
00:00:23,960 --> 00:00:21,080

prebiotic products chemistry so I'm not

6
00:00:25,429 --> 00:00:23,970

that much interested in the origins of

7
00:00:27,859 --> 00:00:25,439

the polymers I'm interested in how the

8
00:00:29,990 --> 00:00:27,869

small molecules form complex reaction

9
00:00:33,530 --> 00:00:30,000

networks and how far I can push there

10
00:00:35,510 --> 00:00:33,540

how complex it can get probably all of

11
00:00:36,979 --> 00:00:35,520

you have heard about hydrothermal vents

12
00:00:39,560 --> 00:00:36,989

and the relevance for the origin of life

13
00:00:41,979 --> 00:00:39,570

basically we have hydrogen spring from

14

00:00:44,750 --> 00:00:41,989

the bottom of the ocean and the mixture

15

00:00:46,819 --> 00:00:44,760

contact of the hydrogen waters and see

16

00:00:48,979 --> 00:00:46,829

what it creates a stable redox potential

17

00:00:51,020 --> 00:00:48,989

and electrochemical gradient this one is

18

00:00:53,750 --> 00:00:51,030

used as a source of energy for by some

19

00:00:55,310 --> 00:00:53,760

of the oldest organisms on earth it's

20

00:00:57,080 --> 00:00:55,320

all hydrothermal vents that creates

21

00:00:59,240 --> 00:00:57,090

electrochemical potentials that

22

00:01:01,610 --> 00:00:59,250

basically feed some of the oldest

23

00:01:03,410 --> 00:01:01,620

archaea and bacteria on earth and they

24

00:01:06,230 --> 00:01:03,420

also also had been suggested as a

25

00:01:08,149 --> 00:01:06,240

possible source of energy and as a cold

26

00:01:09,830 --> 00:01:08,159

and icy worlds where there is not enough

27

00:01:12,380 --> 00:01:09,840

Sun radiation to do photosynthesis or

28

00:01:15,140 --> 00:01:12,390

not enough thermal energy to do other

29

00:01:17,330 --> 00:01:15,150

types of fractions so it's a very

30

00:01:19,490 --> 00:01:17,340

widespread source of energy and for the

31

00:01:21,530 --> 00:01:19,500

origin of life also people have noticed

32

00:01:23,060 --> 00:01:21,540

that a treat with metal sulphides which

33

00:01:25,039 --> 00:01:23,070

has structurally similar to iron

34

00:01:27,649 --> 00:01:25,049

sulphide cofactors fountain all the

35

00:01:29,690 --> 00:01:27,659

living cells and the structure of the

36

00:01:32,200 --> 00:01:29,700

hydrothermal vent chimneys it's

37

00:01:35,060 --> 00:01:32,210

basically the small compartments rich in

38

00:01:36,980 --> 00:01:35,070

transition metal sulfides and surrounded

39

00:01:39,380 --> 00:01:36,990

by the redox potentials that are more

40

00:01:41,539 --> 00:01:39,390

reducing in the insight and oxidizing on

41

00:01:44,300 --> 00:01:41,549

the outside and this looks very similar

42

00:01:46,370 --> 00:01:44,310

to how modern cells are organized so

43

00:01:48,319 --> 00:01:46,380

some people think that this small

44

00:01:51,859 --> 00:01:48,329

compartments could be the origin of the

45

00:01:53,810 --> 00:01:51,869

modern cells and this transition metals

46

00:01:55,399 --> 00:01:53,820

like a politically active and they can

47

00:01:57,440 --> 00:01:55,409

use this electrochemical energy to

48

00:02:00,620 --> 00:01:57,450

produce basic electro chemistry for

49

00:02:03,440 --> 00:02:00,630

example reduce CO_2 to small organic

50

00:02:05,149 --> 00:02:03,450

molecules in principle I'm not that

51
00:02:07,399 --> 00:02:05,159
interested about molecules that you can

52
00:02:09,559 --> 00:02:07,409
produce in the systems because apart

53
00:02:10,790 --> 00:02:09,569
from Socrates Asians other ways of

54
00:02:12,620 --> 00:02:10,800
producing organic molecule for example

55
00:02:14,330 --> 00:02:12,630
molecules from space

56
00:02:16,730 --> 00:02:14,340
what I'm interesting about how to use

57
00:02:18,620 --> 00:02:16,740
this electrochemical energy which is

58
00:02:20,450 --> 00:02:18,630
widely available on earth not only

59
00:02:22,550 --> 00:02:20,460
hydrogen events but in other settings to

60
00:02:24,590 --> 00:02:22,560
to run organic reactions to run a

61
00:02:26,570 --> 00:02:24,600
networks of organic reactions that

62
00:02:30,230 --> 00:02:26,580
gradually grow more complex and become

63
00:02:33,320 --> 00:02:30,240

something resembling living cell very

64

00:02:35,390 --> 00:02:33,330

basic idea how electrochemical cell

65

00:02:37,430 --> 00:02:35,400

works so if you use a repro chemical

66

00:02:39,590 --> 00:02:37,440

energy the easiest way to do it is by

67

00:02:41,900 --> 00:02:39,600

using the electrochemical cell you have

68

00:02:44,690 --> 00:02:41,910

a power source which in our case there

69

00:02:46,460 --> 00:02:44,700

wins then you need electrodes to run the

70

00:02:49,310 --> 00:02:46,470

reaction on the surface and conductive

71

00:02:52,310 --> 00:02:49,320

wires you can imagine some very basic

72

00:02:53,630 --> 00:02:52,320

setup with a small cavity around Federer

73

00:02:55,900 --> 00:02:53,640

moment you have traditional I'm

74

00:02:59,690 --> 00:02:55,910

oxidizing environment and you actually

75

00:03:01,280 --> 00:02:59,700

happen in a cavity reaches organic

76
00:03:02,060 --> 00:03:01,290
molecules on the surface of the minerals

77
00:03:05,300 --> 00:03:02,070
okay

78
00:03:08,840 --> 00:03:05,310
other conductive minerals yes it

79
00:03:11,120 --> 00:03:08,850
resulted actually if you put what

80
00:03:13,220 --> 00:03:11,130
immature in the inside of the heroine

81
00:03:15,410 --> 00:03:13,230
chimney is there very conductive and

82
00:03:18,020 --> 00:03:15,420
also most of the transition metal

83
00:03:20,810 --> 00:03:18,030
sulfides are conductive here I just

84
00:03:22,970 --> 00:03:20,820
focus on iron sulphides because similar

85
00:03:25,760 --> 00:03:22,980
to iron sulfur cofactors that we have

86
00:03:29,420 --> 00:03:25,770
and cells and also to keep the system

87
00:03:31,970 --> 00:03:29,430
simple so as you can see iron sulphides

88
00:03:34,610 --> 00:03:31,980

Makana white grey kite and purified are

89

00:03:36,560 --> 00:03:34,620

very conductive and pyrite depending on

90

00:03:39,020 --> 00:03:36,570

the structure can be conductor or semi

91

00:03:42,770 --> 00:03:39,030

conductor while metal oxides are not

92

00:03:44,600 --> 00:03:42,780

that conductive there is the most

93

00:03:48,080 --> 00:03:44,610

important part of electrochemical cell

94

00:03:49,760 --> 00:03:48,090

is an electrode actually the electrodes

95

00:03:51,560 --> 00:03:49,770

have to be electrically conductive so

96

00:03:53,240 --> 00:03:51,570

it's not a problem for them to exchange

97

00:03:55,550 --> 00:03:53,250

electrons with other molecules it

98

00:03:56,990 --> 00:03:55,560

doesn't cost them a lot of energy then

99

00:03:59,120 --> 00:03:57,000

they have to be chemically stable

100

00:04:00,380 --> 00:03:59,130

because you don't want your electrode to

101
00:04:02,810 --> 00:04:00,390
be dissolved in the middle of your

102
00:04:05,120 --> 00:04:02,820
reaction they have to be politically

103
00:04:07,310 --> 00:04:05,130
active this one is a bit less obvious

104
00:04:10,220 --> 00:04:07,320
what happens at naught if you have

105
00:04:12,350 --> 00:04:10,230
enough electrochemical energy not every

106
00:04:14,030 --> 00:04:12,360
surface will react with every redox

107
00:04:16,280 --> 00:04:14,040
molecule available there is a kinetic

108
00:04:19,280 --> 00:04:16,290
barrier which is the problem of the

109
00:04:22,039 --> 00:04:19,290
geometry and structures so there should

110
00:04:23,659 --> 00:04:22,049
be low kinetic barrier which transforms

111
00:04:25,280 --> 00:04:23,669
the reaction the surface has to be

112
00:04:26,270 --> 00:04:25,290
politically active for the specific

113
00:04:28,040 --> 00:04:26,280

molecules

114

00:04:30,920 --> 00:04:28,050

and also you would like a surface that

115

00:04:32,540 --> 00:04:30,930

is not especially reactive so the

116

00:04:34,460 --> 00:04:32,550

molecules once they reacted say go and

117

00:04:38,090 --> 00:04:34,470

solution to other things and don't stick

118

00:04:40,850 --> 00:04:38,100

to the surface how we can find this idea

119

00:04:42,860 --> 00:04:40,860

of mineral electrode basically we use a

120

00:04:44,210 --> 00:04:42,870

technique called cyclic voltammetry I

121

00:04:47,630 --> 00:04:44,220

don't know how many of you are familiar

122

00:04:49,610 --> 00:04:47,640

with it if you have a red extraction on

123

00:04:51,650 --> 00:04:49,620

the surface of the electron electrode

124

00:04:53,450 --> 00:04:51,660

you exchange electrons between the

125

00:04:56,590 --> 00:04:53,460

molecule and the surface and those

126

00:04:59,180 --> 00:04:56,600

results an electrical current you can

127

00:05:01,190 --> 00:04:59,190

adjust the electrical potential of the

128

00:05:03,830 --> 00:05:01,200

surface of your electrode and this new

129

00:05:05,900 --> 00:05:03,840

change the ratio of oxidizing to

130

00:05:08,660 --> 00:05:05,910

reducing molecules next to the electrode

131

00:05:11,030 --> 00:05:08,670

surface to adjust that you according to

132

00:05:12,650 --> 00:05:11,040

the Nernst equation you will have a

133

00:05:14,930 --> 00:05:12,660

current so you change the ratio you have

134

00:05:17,420 --> 00:05:14,940

more electrons in solution by slowly

135

00:05:18,800 --> 00:05:17,430

changing the products potential the

136

00:05:20,810 --> 00:05:18,810

surface of the electrode you will have

137

00:05:22,250 --> 00:05:20,820

electrical current this is a maximum

138

00:05:25,010 --> 00:05:22,260

around the electrical potential

139

00:05:26,360 --> 00:05:25,020

corresponding Tuesday electrical

140

00:05:29,090 --> 00:05:26,370

potential of the redox reaction of your

141

00:05:32,210 --> 00:05:29,100

interest so what we did we basically

142

00:05:34,670 --> 00:05:32,220

went to the museum ask to the minerals

143

00:05:36,380 --> 00:05:34,680

made some powder and made electro south

144

00:05:41,120 --> 00:05:36,390

of them intestines and interact with

145

00:05:42,620 --> 00:05:41,130

organic molecules our first idea was to

146

00:05:44,450 --> 00:05:42,630

use small organic molecules that are

147

00:05:46,909 --> 00:05:44,460

usually used and metabolic first

148

00:05:48,310 --> 00:05:46,919

scenarios such as small peptides in

149

00:05:51,650 --> 00:05:48,320

carboxylic acids

150

00:05:53,240 --> 00:05:51,660

acetamide and nothing happened and then

151

00:05:55,670 --> 00:05:53,250

we thought that actually it's not the

152

00:05:58,190 --> 00:05:55,680

way how it's done insulating cells in

153

00:06:00,830 --> 00:05:58,200

living cells small molecules do not

154

00:06:03,190 --> 00:06:00,840

react directly with iron sulphide

155

00:06:08,060 --> 00:06:03,200

cofactors they usually react with other

156

00:06:10,370 --> 00:06:08,070

radical factors and common is there four

157

00:06:14,540 --> 00:06:10,380

types of relics cofactors NADH is

158

00:06:16,490 --> 00:06:14,550

nicotinamide cytochromes Flavians and

159

00:06:18,170 --> 00:06:16,500

qui notes and if you look at the

160

00:06:20,690 --> 00:06:18,180

structure of the queenan's they seem to

161

00:06:22,790 --> 00:06:20,700

be some of the oldest molecules known as

162

00:06:24,320 --> 00:06:22,800

the universe there they have been

163

00:06:26,300 --> 00:06:24,330

detected and interstellar clouds

164

00:06:28,340 --> 00:06:26,310

actually just stole this picture of

165

00:06:31,730 --> 00:06:28,350

Queen Anne's in space from NASA website

166

00:06:33,650 --> 00:06:31,740

and there also can be easily produced

167

00:06:35,180 --> 00:06:33,660

from polycyclic aromatic hydrocarbons

168

00:06:37,410 --> 00:06:35,190

which is the most common source of

169

00:06:41,550 --> 00:06:37,420

carbon on earth

170

00:06:44,670 --> 00:06:41,560

I mix it with water our eyes and

171

00:06:47,430 --> 00:06:44,680

basically radiating it so we can be

172

00:06:50,180 --> 00:06:47,440

almost sure that early Earth's had lot

173

00:06:53,550 --> 00:06:50,190

of Queen oats or at least some queen and

174

00:06:56,220 --> 00:06:53,560

also if you look at electron transport

175

00:06:58,110 --> 00:06:56,230

chain which people argue that the

176
00:07:01,080 --> 00:06:58,120
hydrothermal vent small cavities as an

177
00:07:04,110 --> 00:07:01,090
analog of how it works in most of the

178
00:07:06,660 --> 00:07:04,120
cells is that you have a series of iron

179
00:07:09,150 --> 00:07:06,670
sulfur factors which is the small little

180
00:07:10,800 --> 00:07:09,160
globes that transport the electrons to

181
00:07:12,620 --> 00:07:10,810
the Queen on and then the Queen and nice

182
00:07:16,500 --> 00:07:12,630
electrons to cytochrome or two other

183
00:07:19,290 --> 00:07:16,510
organic molecules so this fragment of

184
00:07:21,750 --> 00:07:19,300
metal sulfur cluster given electrons to

185
00:07:24,840 --> 00:07:21,760
Queen on its highly conserved across all

186
00:07:27,120 --> 00:07:24,850
domains of life and finally all living

187
00:07:29,400 --> 00:07:27,130
organism especially bacteria archaea and

188
00:07:31,530 --> 00:07:29,410

plants still use Queen Anne's a lot for

189

00:07:33,770 --> 00:07:31,540

chemical communication you can find

190

00:07:36,930 --> 00:07:33,780

queen anne's that relics cofactors

191

00:07:39,260 --> 00:07:36,940

bacteria use twins for respiration a lot

192

00:07:42,090 --> 00:07:39,270

of bacteria in the absence of oxygen

193

00:07:45,900 --> 00:07:42,100

actually use electrons as final electron

194

00:07:48,180 --> 00:07:45,910

acceptors and also quorum sensing agents

195

00:07:50,190 --> 00:07:48,190

they are wound signals and plants and

196

00:07:52,290 --> 00:07:50,200

the neurotransmitters in higher animals

197

00:07:57,360 --> 00:07:52,300

so this is the Queen Anne that we still

198

00:08:01,200 --> 00:07:57,370

have in our body we tasted our minerals

199

00:08:03,960 --> 00:08:01,210

against Queen Anne's so the result was

200

00:08:05,790 --> 00:08:03,970

somewhat surprising metal sulfides

201

00:08:08,550 --> 00:08:05,800

usually used in prebiotic chemistry

202

00:08:09,930 --> 00:08:08,560

studies i reduced cofactors because

203

00:08:12,540 --> 00:08:09,940

they're more conductive more reactive

204

00:08:14,640 --> 00:08:12,550

such as my King arrived grain diet in

205

00:08:16,710 --> 00:08:14,650

parrot Alec but none of them was

206

00:08:18,330 --> 00:08:16,720

reactive with Queen Anne's actually the

207

00:08:21,570 --> 00:08:18,340

one food and water they would start

208

00:08:23,220 --> 00:08:21,580

slowly to decompose pirate was very

209

00:08:26,040 --> 00:08:23,230

reactive with all the Queens that we

210

00:08:28,320 --> 00:08:26,050

tested and the surprising thing was that

211

00:08:31,200 --> 00:08:28,330

parrot was actually more reactive than

212

00:08:34,740 --> 00:08:31,210

commercially available electrodes made

213

00:08:37,170 --> 00:08:34,750

of platinum or carbon as you can see

214

00:08:40,050 --> 00:08:37,180

here to be complicated but the relics

215

00:08:41,430 --> 00:08:40,060

potential between for oxidation and

216

00:08:43,680 --> 00:08:41,440

reduction of molecule called

217

00:08:45,960 --> 00:08:43,690

hydroquinone so pirates the difference

218

00:08:47,070 --> 00:08:45,970

between two peaks it's smaller than for

219

00:08:49,200 --> 00:08:47,080

glassy carbon electrode

220

00:08:50,460 --> 00:08:49,210

meaning that it requires less energy you

221

00:08:53,130 --> 00:08:50,470

can also see

222

00:08:55,110 --> 00:08:53,140

there is more current going through

223

00:08:57,540 --> 00:08:55,120

pirate electrons through glassy carbon

224

00:08:59,970 --> 00:08:57,550

electrode showing the direction is much

225

00:09:02,910 --> 00:08:59,980

faster so we actually found an electrode

226

00:09:04,920 --> 00:09:02,920

made of stones which works better than

227

00:09:06,990 --> 00:09:04,930

commercial available purified electrodes

228

00:09:10,500 --> 00:09:07,000

which is an interesting saying probably

229

00:09:12,240 --> 00:09:10,510

not realised origin of life they also

230

00:09:15,270 --> 00:09:12,250

interested how the reaction work about

231

00:09:17,100 --> 00:09:15,280

kinetic what we did we change the speed

232

00:09:19,230 --> 00:09:17,110

with which we change the rex potential

233

00:09:22,290 --> 00:09:19,240

and it causes increase in the current

234

00:09:23,730 --> 00:09:22,300

and if this increase is proportional to

235

00:09:25,230 --> 00:09:23,740

the square root of the change if the

236

00:09:27,720 --> 00:09:25,240

rate the physics potential it means that

237

00:09:29,370 --> 00:09:27,730

reaction is diffusion controlled what we

238

00:09:31,050 --> 00:09:29,380

saw is that most of the oxidation of

239

00:09:32,760 --> 00:09:31,060

Queenan so by diffusion controlled so

240

00:09:35,400 --> 00:09:32,770

Queenan will take the electrons and go

241

00:09:37,170 --> 00:09:35,410

away into other sinks the only one that

242

00:09:38,700 --> 00:09:37,180

had little bit precipitation was the

243

00:09:41,580 --> 00:09:38,710

Queen and called hydroquinone which is

244

00:09:43,950 --> 00:09:41,590

known to polymerize spontaneously so it

245

00:09:48,330 --> 00:09:43,960

didn't perform were so that usually

246

00:09:49,740 --> 00:09:48,340

performs in solution and then we tested

247

00:09:52,500 --> 00:09:49,750

the reaction over more than hundred

248

00:09:54,000 --> 00:09:52,510

cycles and the electrode was stable so

249

00:09:55,320 --> 00:09:54,010

there actually can go over and over and

250

00:09:59,280 --> 00:09:55,330

over and over again we don't create

251
00:10:02,220 --> 00:09:59,290
intermediates or side products so

252
00:10:04,680 --> 00:10:02,230
finally we found our ideal electorate

253
00:10:07,140 --> 00:10:04,690
and it's one of the most common minerals

254
00:10:09,630 --> 00:10:07,150
on earth reacted with one of the most

255
00:10:11,340 --> 00:10:09,640
common organic molecules on earth which

256
00:10:11,670 --> 00:10:11,350
makes it highly plausible for the origin

257
00:10:14,940 --> 00:10:11,680
of life

258
00:10:17,400 --> 00:10:14,950
it's conductive it's stable it's active

259
00:10:19,370 --> 00:10:17,410
and the surface doesn't stick to the

260
00:10:22,260 --> 00:10:19,380
molecules of our interest

261
00:10:24,120 --> 00:10:22,270
this was more experimental and kinetic

262
00:10:27,660 --> 00:10:24,130
consideration what about thermodynamics

263
00:10:31,710 --> 00:10:27,670

if we think about redox reactions found

264

00:10:34,560 --> 00:10:31,720

in biology they actually occur in pretty

265

00:10:37,650 --> 00:10:34,570

narrow redox potential which is more or

266

00:10:39,930 --> 00:10:37,660

less between minus hundred and minus 300

267

00:10:42,950 --> 00:10:39,940

millivolt and you can see that if you

268

00:10:47,100 --> 00:10:42,960

compare the redox potentials necessary

269

00:10:50,400 --> 00:10:47,110

with to perform organic reactions in the

270

00:10:53,340 --> 00:10:50,410

cell this region of stability of iron

271

00:10:56,280 --> 00:10:53,350

minerals this is a pirate overlaps with

272

00:10:59,440 --> 00:10:56,290

pretty much all the organic redox

273

00:11:01,990 --> 00:10:59,450

reaction need for the cell you can argue

274

00:11:04,780 --> 00:11:02,000

actually the composition of the seawater

275

00:11:06,280 --> 00:11:04,790

and early Earth was different and so the

276

00:11:09,760 --> 00:11:06,290

stability of the mineral was different

277

00:11:11,680 --> 00:11:09,770

and if you can but still tire to be less

278

00:11:14,410 --> 00:11:11,690

stable compared to more reduced iron

279

00:11:16,570 --> 00:11:14,420

sulphides in the absence of oxygen and

280

00:11:18,670 --> 00:11:16,580

at low sulfur concentration on the ocean

281

00:11:21,280 --> 00:11:18,680

but the stability it still have to

282

00:11:23,560 --> 00:11:21,290

basically overlap with all the organic

283

00:11:27,400 --> 00:11:23,570

reactions that we know all that we need

284

00:11:29,560 --> 00:11:27,410

to construct this up and I'm not sure if

285

00:11:32,050 --> 00:11:29,570

you recognize this guy he's basically

286

00:11:33,910 --> 00:11:32,060

one of the fathers of biochemistry who

287

00:11:35,260 --> 00:11:33,920

basically is responsible for half of the

288

00:11:38,590 --> 00:11:35,270

things you've written the back to mr.

289

00:11:41,350 --> 00:11:38,600

textbook he cut is covered citric acid

290

00:11:43,540 --> 00:11:41,360

cycle he showed how ATP is necessary for

291

00:11:45,790 --> 00:11:43,550

muscle contraction he also his character

292

00:11:47,350 --> 00:11:45,800

that's called the chitin and he spent a

293

00:11:49,900 --> 00:11:47,360

lot of time sink in how the simple

294

00:11:52,330 --> 00:11:49,910

chemical reactions lead to life

295

00:11:55,360 --> 00:11:52,340

what he said that Queen Anne seem to

296

00:11:57,640 --> 00:11:55,370

play a most important role in cell life

297

00:11:59,290 --> 00:11:57,650

and future knowledge of the properties

298

00:12:02,700 --> 00:11:59,300

might bring us closer to the

299

00:12:04,360 --> 00:12:02,710

understanding of the leading state so

300

00:12:06,820 --> 00:12:04,370

this is it for now

301

00:12:09,250 --> 00:12:06,830

I want to thank professor Devlin who

302

00:12:11,710 --> 00:12:09,260

doesn't mind me having side projects and

303

00:12:14,200 --> 00:12:11,720

my previous supervisors a terrible judge

304

00:12:16,150 --> 00:12:14,210

my test images as a loss and her

305

00:12:18,510 --> 00:12:16,160

Authority's initiative who paid for an

306

00:12:27,450 --> 00:12:18,520

issue like full paid my postdocs other

307

00:12:27,460 --> 00:12:36,860

[Applause]

308

00:12:41,329 --> 00:12:39,210

thank you um could you put the slide up

309

00:12:44,300 --> 00:12:41,339

where you have a comparison of the

310

00:12:47,910 --> 00:12:44,310

cyclic voltammogram of the different

311

00:12:49,620 --> 00:12:47,920

iron yes now the one before that where

312

00:12:53,490 --> 00:12:49,630

you show you so that pirate was more

313

00:12:55,889 --> 00:12:53,500

active okay yeah that's interesting

314

00:12:59,699 --> 00:12:55,899

because when you cleave pyrite or you

315

00:13:02,280 --> 00:12:59,709

crush it the termination is not FES to

316

00:13:04,769 --> 00:13:02,290

it so that the surface of pyrite is not

317

00:13:09,329 --> 00:13:04,779

pyrite so I'm wondering it's more like

318

00:13:11,009 --> 00:13:09,339

FES so I was wondering you know have you

319

00:13:14,130 --> 00:13:11,019

really looked carefully at what is the

320

00:13:16,730 --> 00:13:14,140

electrode surface itself is that I would

321

00:13:20,340 --> 00:13:16,740

be surprised if it's FES 2 terminating

322

00:13:22,710 --> 00:13:20,350

50 extra I mean videotex rate of the

323

00:13:29,340 --> 00:13:22,720

bulk material but not of the entire

324

00:13:31,199 --> 00:13:29,350

surface well in this case I don't it's a

325

00:13:34,769 --> 00:13:31,209

good thing to look at I think perceive

326

00:13:37,519 --> 00:13:34,779

what is say geometry FPS will be more

327

00:13:40,889 --> 00:13:37,529

relevant I guess to iron sulfur clusters

328

00:13:47,850 --> 00:13:40,899

but in terms of materials I mean I don't

329

00:13:49,199 --> 00:13:47,860

know it's a good question but still it

330

00:13:49,590 --> 00:13:49,209

would be something in between say

331

00:13:52,259 --> 00:13:49,600

awesome

332

00:13:59,660 --> 00:13:52,269

yeah it is I mean in the FES looks like

333

00:14:03,210 --> 00:13:59,670

it works pretty well to talk wonder Oh

334

00:14:05,189 --> 00:14:03,220

America American NY right they all look

335

00:14:08,400 --> 00:14:05,199

the same so extra did I mean machina

336

00:14:10,470 --> 00:14:08,410

white in water in the potential range

337

00:14:12,509 --> 00:14:10,480

which is like Christmas to perpetuate

338

00:14:15,990 --> 00:14:12,519

which of the cells it starts to

339

00:14:18,240 --> 00:14:16,000

decompose and syllable eyes and pirate

340

00:14:20,400 --> 00:14:18,250

what we literally the first scans that

341

00:14:24,300 --> 00:14:20,410

we did stabilizes the surface is due to

342

00:14:25,889 --> 00:14:24,310

different to the other scans but so I'm

343

00:14:27,360 --> 00:14:25,899

not sure how change the surface probably

344

00:14:31,050 --> 00:14:27,370

we need to do more surface

345

00:14:32,610 --> 00:14:31,060

characterization for that okay so we

346

00:14:34,390 --> 00:14:32,620

need to move to the next figure I think