

Take Home Messages



- High (+) Delta Values = Heavy Isotope Enrichment
- Isotopes Are Great Detective Tools
 - Temperature
 - Chemical Reactions
 - Precipitation
 - Many other magical things!

1
00:00:12,770 --> 00:00:08,540
I'm going to talk to you a bit today

2
00:00:15,320 --> 00:00:12,780
about the isotopic record of the geo

3
00:00:18,019 --> 00:00:15,330
biological record or the geochemical

4
00:00:21,620 --> 00:00:18,029
record somewhat what Lucy was talking

5
00:00:23,749 --> 00:00:21,630
about and I will preface this that I am

6
00:00:25,819 --> 00:00:23,759
by no means an expert in ice topic

7
00:00:28,580 --> 00:00:25,829
chemistry but I'm the best you've got

8
00:00:29,870 --> 00:00:28,590
for this one I'm talking so I will try

9
00:00:32,269 --> 00:00:29,880
to answer any questions that you have

10
00:00:35,330 --> 00:00:32,279
after this but some of the questions

11
00:00:37,069 --> 00:00:35,340
might best be kept for the speakers so

12
00:00:40,189 --> 00:00:37,079
this is actually going to be just a

13
00:00:43,189 --> 00:00:40,199

short talk since this is a huge sort of

14

00:00:44,930 --> 00:00:43,199

topic and it's essentially a detective

15

00:00:46,549 --> 00:00:44,940

story where you look at a signal and

16

00:00:49,610 --> 00:00:46,559

then you try to interpret it and figure

17

00:00:51,349 --> 00:00:49,620

out the best that you can make of it so

18

00:00:53,060 --> 00:00:51,359

I'm just going to familiarize you with

19

00:00:55,340 --> 00:00:53,070

the different types of isotopic

20

00:00:58,189 --> 00:00:55,350

fractionation and the terminology that

21

00:01:02,360 --> 00:00:58,199

she says it's quite often times foreign

22

00:01:05,870 --> 00:01:02,370

from what we are used to seeing so first

23

00:01:08,090 --> 00:01:05,880

things first just in case as sarah has

24

00:01:12,649 --> 00:01:08,100

pointed out earlier oh i guess i should

25

00:01:14,120 --> 00:01:12,659

be doing this to ya not everybody never

26
00:01:15,889 --> 00:01:14,130
assume that your audience knows exactly

27
00:01:19,639 --> 00:01:15,899
what you're talking about for the most

28
00:01:21,830 --> 00:01:19,649
basic stuff so just in case you don't

29
00:01:26,179 --> 00:01:21,840
know what an isotope is i'm just going

30
00:01:28,399 --> 00:01:26,189
to cover that quickly so when atoms are

31
00:01:30,679 --> 00:01:28,409
formed either through decay of other

32
00:01:34,370 --> 00:01:30,689
atoms or initially form that the

33
00:01:38,870 --> 00:01:34,380
creation of the atom back in the stellar

34
00:01:41,420 --> 00:01:38,880
day is of matter you can form atoms with

35
00:01:44,109 --> 00:01:41,430
the same number of protons but different

36
00:01:50,480 --> 00:01:44,119
neutrons and so here's an example of

37
00:01:52,399 --> 00:01:50,490
carbon all of these have six protons but

38
00:01:54,080 --> 00:01:52,409

they have different various numbers of

39

00:01:57,830 --> 00:01:54,090

neutrons and so you can get a carbon of

40

00:02:00,499 --> 00:01:57,840

a wait of 1208 of 13 or a mass of 14 and

41

00:02:02,649 --> 00:02:00,509

so you have three different Prime forms

42

00:02:06,910 --> 00:02:02,659

of carbon out there for example and

43

00:02:11,210 --> 00:02:06,920

carbon-12 and carbon-14 are stable as in

44

00:02:13,520 --> 00:02:11,220

they don't decay to other forms of atoms

45

00:02:17,420 --> 00:02:13,530

to lesser atoms on an appreciable time

46

00:02:19,880 --> 00:02:17,430

scale but carbon-14 is radioactive has a

47

00:02:22,960 --> 00:02:19,890

half-life of 5,700

48

00:02:28,130 --> 00:02:22,970

years so after if you have like a a

49

00:02:30,199 --> 00:02:28,140

pound or a mole of carbon 14 after fifty

50

00:02:32,059 --> 00:02:30,209

seven hundred and fifteen years you will

51
00:02:33,920 --> 00:02:32,069
have half a pound or half a mole of

52
00:02:36,830 --> 00:02:33,930
carbon as it will have degraded to other

53
00:02:39,410 --> 00:02:36,840
products so primarily in the geochemical

54
00:02:42,260 --> 00:02:39,420
record since we're looking at timescales

55
00:02:44,720 --> 00:02:42,270
of 4 billion years and 3 billion years

56
00:02:48,680 --> 00:02:44,730
we're typically focused on the stable

57
00:02:50,840 --> 00:02:48,690
form of isotopes that we have the

58
00:02:52,400 --> 00:02:50,850
heavier isotopes are typically the less

59
00:02:55,699 --> 00:02:52,410
stable one so you're looking for the

60
00:03:02,660 --> 00:02:55,709
ones that mostly are near the mass of

61
00:03:04,880 --> 00:03:02,670
the the base Adam and the differences in

62
00:03:06,920 --> 00:03:04,890
the geologic record between the ratios

63
00:03:08,590 --> 00:03:06,930

of the assessee topes tells a lot about

64

00:03:13,250 --> 00:03:08,600

the environmental and biological

65

00:03:16,460 --> 00:03:13,260

conditions that we have so before we get

66

00:03:18,620 --> 00:03:16,470

into the talk I have to address this so

67

00:03:21,199 --> 00:03:18,630

there is a special sort of terminology

68

00:03:24,620 --> 00:03:21,209

that ice topic scientists use and it is

69

00:03:26,360 --> 00:03:24,630

this Delta notation and so if you look

70

00:03:28,670 --> 00:03:26,370

at any isotopic paper they're going to

71

00:03:31,580 --> 00:03:28,680

refer to the Delta values for their

72

00:03:34,610 --> 00:03:31,590

scopes and that is essentially you take

73

00:03:37,759 --> 00:03:34,620

however much of the heavier element is

74

00:03:40,130 --> 00:03:37,769

in this case carbon 13 and you find a

75

00:03:43,430 --> 00:03:40,140

ratio between carbon 13 and carbon to

76

00:03:46,610 --> 00:03:43,440

sample and then you subtract it from a

77

00:03:50,300 --> 00:03:46,620

ratio in a standard sample that has been

78

00:03:51,890 --> 00:03:50,310

established unilaterally so you always

79

00:03:53,720 --> 00:03:51,900

are comparing to the same value in the

80

00:03:56,270 --> 00:03:53,730

literature and then you divide that

81

00:03:59,030 --> 00:03:56,280

difference over that standard reference

82

00:04:02,560 --> 00:03:59,040

again and so you multiply it times a

83

00:04:06,110 --> 00:04:02,570

thousand and you get this Delta value

84

00:04:09,740 --> 00:04:06,120

and so this is reported as either Delta

85

00:04:12,560 --> 00:04:09,750

or per mil using this symbol which looks

86

00:04:14,020 --> 00:04:12,570

like a typo of a percentage symbol but

87

00:04:17,560 --> 00:04:14,030

that's actually what it looks like and

88

00:04:21,949 --> 00:04:17,570

so one percent of a composition of

89

00:04:25,010 --> 00:04:21,959

something is equal to 10 Delta or 10 per

90

00:04:27,230 --> 00:04:25,020

mil and apparently this is a point of

91

00:04:29,089 --> 00:04:27,240

contention among isotopic scientists

92

00:04:30,460 --> 00:04:29,099

that you refer to it as Delta or per

93

00:04:32,350 --> 00:04:30,470

meal instead of del

94

00:04:34,450 --> 00:04:32,360

apparently that's like nails on the

95

00:04:36,130 --> 00:04:34,460

chalkboard for a lot of people so

96

00:04:38,890 --> 00:04:36,140

they've actually I found this in my

97

00:04:41,440 --> 00:04:38,900

studies they have a they have this poem

98

00:04:43,900 --> 00:04:41,450

there once was a man from Cornell who

99

00:04:46,320 --> 00:04:43,910

pronounced every Delta as del but the

100

00:04:50,910 --> 00:04:46,330

spirit of Erie returned in a fury and

101
00:04:56,740 --> 00:04:50,920
transferred that fellow to hell so

102
00:04:58,540 --> 00:04:56,750
remember that Delta and per meal so the

103
00:05:00,340 --> 00:04:58,550
reference standards that I pointed out

104
00:05:02,470 --> 00:05:00,350
before this is what's been established

105
00:05:04,540 --> 00:05:02,480
in the geochemical community and if I

106
00:05:08,230 --> 00:05:04,550
mistaken you can take it up with the

107
00:05:12,160 --> 00:05:08,240
either Wikipedia or the isotope

108
00:05:13,660 --> 00:05:12,170
geochemistry this afternoon but the

109
00:05:18,490 --> 00:05:13,670
reference standards for the carbon

110
00:05:25,500 --> 00:05:18,500
ratios come from this Vienna peedee

111
00:05:27,790 --> 00:05:25,510
belemnite all right from South Carolina

112
00:05:30,130 --> 00:05:27,800
nitrogen they just fixed it to our

113
00:05:34,090 --> 00:05:30,140

current ratio of nitrogen in the

114

00:05:39,550 --> 00:05:34,100

atmosphere hydrogen and oxygen since the

115

00:05:42,159 --> 00:05:39,560

ocean is a great sort of bulk bulk area

116

00:05:44,620 --> 00:05:42,169

its ratio does not change much so they

117

00:05:48,100 --> 00:05:44,630

fixed that standard to the modern mean

118

00:05:49,810 --> 00:05:48,110

ocean water value and sulfur this one's

119

00:05:52,210 --> 00:05:49,820

always a bit intriguing to me and I wish

120

00:05:55,810 --> 00:05:52,220

I knew why they fix it to this meteorite

121

00:05:58,750 --> 00:05:55,820

sample from Canyon Diablo oh it must be

122

00:06:00,730 --> 00:05:58,760

a popular one or there might be some

123

00:06:04,750 --> 00:06:00,740

legitimate scientific reason for it but

124

00:06:06,219 --> 00:06:04,760

that is what that is fixed to so there

125

00:06:07,960 --> 00:06:06,229

are three different types of

126

00:06:11,140 --> 00:06:07,970

fractionation that I'm going to touch

127

00:06:13,120 --> 00:06:11,150

upon here the first one is equilibrium

128

00:06:15,100 --> 00:06:13,130

fractionation since when you're looking

129

00:06:17,320 --> 00:06:15,110

at samples in the rock they'll have

130

00:06:18,730 --> 00:06:17,330

different ratios and in order to

131

00:06:20,290 --> 00:06:18,740

understand how they get to that ratios

132

00:06:22,420 --> 00:06:20,300

you have to understand the processes

133

00:06:25,240 --> 00:06:22,430

that go into fractionating them between

134

00:06:28,150 --> 00:06:25,250

the heavy and the lighter isotopes so

135

00:06:30,070 --> 00:06:28,160

equilibrium fractionation fractionation

136

00:06:32,860 --> 00:06:30,080

involves separation of the isotopes

137

00:06:35,290 --> 00:06:32,870

based upon an equilibrium process so if

138

00:06:37,480 --> 00:06:35,300

you have a chemical reaction going in

139

00:06:39,730 --> 00:06:37,490

some water in there exchanging atoms

140

00:06:43,029 --> 00:06:39,740

between them there might be a tendency

141

00:06:43,690 --> 00:06:43,039

for one of the size of the equilibrium

142

00:06:45,880 --> 00:06:43,700

reaction to

143

00:06:49,510 --> 00:06:45,890

scavenge up the heavier isotopes for

144

00:06:51,280 --> 00:06:49,520

example and so you will see a definite

145

00:06:55,690 --> 00:06:51,290

signature between the heavy and the

146

00:06:57,460 --> 00:06:55,700

light products and reactants in this

147

00:07:00,240 --> 00:06:57,470

reaction based upon just equilibrium

148

00:07:02,670 --> 00:07:00,250

processes and this is dependent upon

149

00:07:04,690 --> 00:07:02,680

larger atoms the heavier isotopes

150

00:07:07,360 --> 00:07:04,700

typically have a decrease in the

151

00:07:09,070 --> 00:07:07,370

vibrational energy and so that affects

152

00:07:11,350 --> 00:07:09,080

what side of the equilibrium equation

153

00:07:14,980 --> 00:07:11,360

they'll show up a pond and so an example

154

00:07:16,750 --> 00:07:14,990

of this not one hundred percent of the

155

00:07:19,900 --> 00:07:16,760

time but a lot of the time is water

156

00:07:22,450 --> 00:07:19,910

condensation so if you have a room at

157

00:07:24,400 --> 00:07:22,460

one hundred percent humidity and juror

158

00:07:26,980 --> 00:07:24,410

and you have some water droplets that

159

00:07:29,200 --> 00:07:26,990

form it is freely exchanging between the

160

00:07:31,960 --> 00:07:29,210

water moisture in the atmosphere and the

161

00:07:33,670 --> 00:07:31,970

water moisture on the surface and so the

162

00:07:35,380 --> 00:07:33,680

heavy isotopes in the drops that are

163

00:07:37,510 --> 00:07:35,390

forming as long as that one hundred

164

00:07:39,970 --> 00:07:37,520

percent humidity is maintained will

165

00:07:41,890 --> 00:07:39,980

precipitate more readily and so the

166

00:07:46,630 --> 00:07:41,900

water and those droplets will be heavier

167

00:07:48,430 --> 00:07:46,640

than the water in the air a second type

168

00:07:51,730 --> 00:07:48,440

of fractionation is kinetic

169

00:07:53,890 --> 00:07:51,740

fractionation and so this is the other

170

00:07:56,920 --> 00:07:53,900

type of processes that occur during non

171

00:08:01,120 --> 00:07:56,930

equilibrium conditions and so that would

172

00:08:03,970 --> 00:08:01,130

be if you had wind blowing through that

173

00:08:08,200 --> 00:08:03,980

previous experiment and it wasn't 100%

174

00:08:11,190 --> 00:08:08,210

heute humid anymore and you're going to

175

00:08:13,210 --> 00:08:11,200

get still some water condensation or

176

00:08:15,550 --> 00:08:13,220

actually let's look at this in the

177

00:08:18,580 --> 00:08:15,560

reverse manner sorry as I have done here

178

00:08:20,770 --> 00:08:18,590

evaporation is typically a process so

179

00:08:23,530 --> 00:08:20,780

you'll have water that has reached a

180

00:08:27,120 --> 00:08:23,540

high enough temperature to kick up some

181

00:08:30,220 --> 00:08:27,130

of the water into water vapor and that

182

00:08:32,260 --> 00:08:30,230

the heavier elements will be left behind

183

00:08:34,480 --> 00:08:32,270

and the lighter elements are

184

00:08:37,990 --> 00:08:34,490

preferentially kicked into the water

185

00:08:40,330 --> 00:08:38,000

vapor and then wind blows through and it

186

00:08:42,550 --> 00:08:40,340

blows out those lighter elements making

187

00:08:44,350 --> 00:08:42,560

it a non equilibrium condition which

188

00:08:46,450 --> 00:08:44,360

then encourages more of the lighter

189

00:08:49,440 --> 00:08:46,460

elements to come into the air and then

190

00:08:51,880 --> 00:08:49,450

pulled away so that's an example of a

191

00:08:55,240 --> 00:08:51,890

kinetic fractionation process and

192

00:08:55,710 --> 00:08:55,250

another major thing here is biological

193

00:08:57,540 --> 00:08:55,720

process

194

00:08:59,400 --> 00:08:57,550

these are typically not at equilibrium

195

00:09:01,259 --> 00:08:59,410

so they're driven in one direction and

196

00:09:04,710 --> 00:09:01,269

have a very hard time going backwards

197

00:09:10,259 --> 00:09:04,720

and so you see a large preference for

198

00:09:12,300 --> 00:09:10,269

lighter isotopes in biological processes

199

00:09:16,259 --> 00:09:12,310

and this is one of the major line of

200

00:09:18,480 --> 00:09:16,269

evidence that they look at for the bio

201
00:09:20,280 --> 00:09:18,490
signatures that Lucy was talking about

202
00:09:23,059 --> 00:09:20,290
before if you see something that looks

203
00:09:26,610 --> 00:09:23,069
like life you can take an ice etobicoke

204
00:09:29,309 --> 00:09:26,620
from it and see if it's if it

205
00:09:31,550 --> 00:09:29,319
corresponds to the environment of what

206
00:09:34,769 --> 00:09:31,560
you would expect or if it's enriched in

207
00:09:38,569 --> 00:09:34,779
light isotopes or if it's enriched in

208
00:09:41,069 --> 00:09:38,579
one direction then it's indicative of a

209
00:09:43,230 --> 00:09:41,079
biological process and so that's some of

210
00:09:46,860 --> 00:09:43,240
the things that they've used for some of

211
00:09:49,590 --> 00:09:46,870
the rock samples from Greenland from 3.6

212
00:09:51,210 --> 00:09:49,600
billion years ago as to try to support

213
00:09:54,840 --> 00:09:51,220

the evidence that the samples they're

214

00:09:57,809 --> 00:09:54,850

looking at our from living matter and so

215

00:10:01,100 --> 00:09:57,819

all of this together in a nice pretty

216

00:10:05,040 --> 00:10:01,110

diagram so if you look at the ocean as a

217

00:10:06,840 --> 00:10:05,050

base value of zero percent so that's our

218

00:10:09,420 --> 00:10:06,850

reference material and you're looking at

219

00:10:13,129 --> 00:10:09,430

the oxygen the heavy oxygen as it goes

220

00:10:16,470 --> 00:10:13,139

throughout the year environmental system

221

00:10:19,019 --> 00:10:16,480

it first starts with the evaporation

222

00:10:20,670 --> 00:10:19,029

lighter isotopes evaporate and so

223

00:10:23,759 --> 00:10:20,680

suddenly you have the clouds up there

224

00:10:26,269 --> 00:10:23,769

that are at negative ten Delta or

225

00:10:29,639 --> 00:10:26,279

negative 10 per mil and so you now have

226

00:10:32,910 --> 00:10:29,649

clouds that are isotopically lighter

227

00:10:36,660 --> 00:10:32,920

than the ocean then when they head over

228

00:10:38,879 --> 00:10:36,670

the land you it starts to rain you

229

00:10:44,460 --> 00:10:38,889

preferentially rain the heavier isotopes

230

00:10:48,150 --> 00:10:44,470

and so now you get it's only negative

231

00:10:52,730 --> 00:10:48,160

three per mil now and the water vapor up

232

00:10:56,549 --> 00:10:52,740

here is then negative 15 per mil and so

233

00:11:00,480 --> 00:10:56,559

you get lighter elements down here which

234

00:11:03,119 --> 00:11:00,490

is at the same time enhancing the water

235

00:11:05,189 --> 00:11:03,129

that's left behind then you can get

236

00:11:08,129 --> 00:11:05,199

evaporation returning it to the system

237

00:11:09,300 --> 00:11:08,139

which helps to make it lighter again in

238

00:11:10,860 --> 00:11:09,310

the vapor passes

239

00:11:14,190 --> 00:11:10,870

I'm you can cross over some mountain

240

00:11:17,700 --> 00:11:14,200

ridges and the subsequent precipitation

241

00:11:21,750 --> 00:11:17,710

then changes the ratio again so you do

242

00:11:23,490 --> 00:11:21,760

get you can track how the fractionation

243

00:11:26,280 --> 00:11:23,500

changes throughout this ecological

244

00:11:28,800 --> 00:11:26,290

system and it tells you some evidence

245

00:11:30,780 --> 00:11:28,810

where the water came from what happened

246

00:11:32,490 --> 00:11:30,790

to it along the way it just leaves them

247

00:11:34,560 --> 00:11:32,500

signal behind that you can put your

248

00:11:37,890 --> 00:11:34,570

detective hat on and help to figure out

249

00:11:39,660 --> 00:11:37,900

what is going on the last type of

250

00:11:42,329 --> 00:11:39,670

isotope fractionation I'm going to talk

251
00:11:45,300 --> 00:11:42,339
about is mass independent and so this is

252
00:11:48,180 --> 00:11:45,310
stuff that's not the the kinetic isotope

253
00:11:52,290 --> 00:11:48,190
of fractionation that I talked about

254
00:11:55,560 --> 00:11:52,300
before or the the unidirectional one so

255
00:12:01,260 --> 00:11:55,570
this is not based upon mass for the

256
00:12:03,150 --> 00:12:01,270
fractionation so this oh it's not based

257
00:12:05,480 --> 00:12:03,160
upon the mass so it doesn't scale

258
00:12:07,710 --> 00:12:05,490
linearly like it did with the

259
00:12:10,950 --> 00:12:07,720
equilibrium and kinetic fractionation

260
00:12:12,960 --> 00:12:10,960
this is based on photochemical and spin

261
00:12:16,530 --> 00:12:12,970
forbidden reactions and so you'll see

262
00:12:18,810 --> 00:12:16,540
some signals that are left behind due to

263
00:12:20,310 --> 00:12:18,820

the isotopic fractionation that is not

264

00:12:21,960 --> 00:12:20,320

covered by the previous forms that i

265

00:12:23,990 --> 00:12:21,970

mentioned and i'll get to a picture in

266

00:12:29,490 --> 00:12:24,000

just a second that will be quite

267

00:12:31,079 --> 00:12:29,500

informative but one of the best things

268

00:12:33,900 --> 00:12:31,089

that they use to track this with is

269

00:12:36,750 --> 00:12:33,910

sulfur isotopes and so when you look at

270

00:12:39,440 --> 00:12:36,760

a graph like this so this is a display

271

00:12:41,850 --> 00:12:39,450

of sulfur isotope fractionation

272

00:12:45,180 --> 00:12:41,860

throughout the Earth's geologic history

273

00:12:48,360 --> 00:12:45,190

and if you look at this you can see a

274

00:12:51,420 --> 00:12:48,370

giant scatter plot over here and then

275

00:12:54,180 --> 00:12:51,430

suddenly it all evens out it is level

276

00:12:57,150 --> 00:12:54,190

for the past two and a half billion

277

00:13:00,090 --> 00:12:57,160

years and see I hope if you're a

278

00:13:02,520 --> 00:13:00,100

scientist or anybody and look at this

279

00:13:05,630 --> 00:13:02,530

you could be like something has happened

280

00:13:08,370 --> 00:13:05,640

there let's figure out what that is and

281

00:13:12,360 --> 00:13:08,380

so this corresponds to the great

282

00:13:14,220 --> 00:13:12,370

oxygenate oxygenation event which the

283

00:13:16,590 --> 00:13:14,230

oxygen reacts with the sulfur in the

284

00:13:18,840 --> 00:13:16,600

isotope to create sulfates and the

285

00:13:21,570 --> 00:13:18,850

sulfate reducing bacteria then

286

00:13:22,240 --> 00:13:21,580

essentially fixes this isotopic ratio

287

00:13:24,760 --> 00:13:22,250

after

288

00:13:26,710 --> 00:13:24,770

but before that it does have the oxygen

289

00:13:29,770 --> 00:13:26,720

to react with and nothing essentially

290

00:13:31,180 --> 00:13:29,780

scavenges out so you see this what

291

00:13:33,550 --> 00:13:31,190

appears to be random sort of

292

00:13:35,980 --> 00:13:33,560

fractionation that's going on so you can

293

00:13:38,020 --> 00:13:35,990

track the isotopic record and see really

294

00:13:39,580 --> 00:13:38,030

great things that help to tell us about

295

00:13:43,330 --> 00:13:39,590

what's happened in the history of the

296

00:13:45,130 --> 00:13:43,340

Earth's geologic record and so the main

297

00:13:48,130 --> 00:13:45,140

take-home point and I will let you

298

00:13:50,170 --> 00:13:48,140

choose your geek of choice whether you

299

00:13:53,290 --> 00:13:50,180

want fringe or buffy the vampire slayer

300

00:13:56,440 --> 00:13:53,300

is you get to put on your detective hat

301

00:13:59,920 --> 00:13:56,450

and use it to figure out what this

302

00:14:02,590 --> 00:13:59,930

record is telling you and so the high

303

00:14:05,560 --> 00:14:02,600

Delta values equal heavy isotope liquid

304

00:14:07,660 --> 00:14:05,570

nourishment and anything else that you

305

00:14:10,480 --> 00:14:07,670

see different with the isotopic record

306

00:14:12,070 --> 00:14:10,490

could be because of the temperature the

307

00:14:14,650 --> 00:14:12,080

different chemical reactions that have

308

00:14:18,370 --> 00:14:14,660

been happening precipitation or other

309

00:14:21,130 --> 00:14:18,380

processes that scientists are currently

310

00:14:22,420 --> 00:14:21,140

discovering but it's a great tool you

311

00:14:25,090 --> 00:14:22,430

just have to spend a lot of time and

312

00:14:28,810 --> 00:14:25,100

figure out why the ratios are the way