



1  
00:00:00,790 --> 00:00:07,320

[Music]

2  
00:00:11,400 --> 00:00:08,700

[Applause]

3  
00:00:13,140 --> 00:00:11,410

I realized after submitting this

4  
00:00:15,420 --> 00:00:13,150

abstract this is a pretty difficult room

5  
00:00:17,519 --> 00:00:15,430

to tell something they don't know about

6  
00:00:19,350 --> 00:00:17,529

ice I'm going to tell you some things

7  
00:00:20,940 --> 00:00:19,360

I've been surprised to find out about

8  
00:00:23,400 --> 00:00:20,950

ice shells and environmental

9  
00:00:25,529 --> 00:00:23,410

considerations so this is work I've done

10  
00:00:28,950 --> 00:00:25,539

in support of two different projects one

11  
00:00:31,260 --> 00:00:28,960

is a JPL lead study called CRO which is

12  
00:00:33,780 --> 00:00:31,270

looking at full mission architectures

13  
00:00:35,280 --> 00:00:33,790

for accessing ice shell interiors and

14

00:00:38,130 --> 00:00:35,290

we're hoping to share the first results

15

00:00:40,860 --> 00:00:38,140

of that a TPS CDP s and a GU this fall

16

00:00:42,900 --> 00:00:40,870

so something to look forward to a quick

17

00:00:44,910 --> 00:00:42,910

plug there's going to be a session I'm

18

00:00:46,740 --> 00:00:44,920

Co convening not dissimilar to this one

19

00:00:48,330 --> 00:00:46,750

if the AG you fall meeting so if you

20

00:00:50,040 --> 00:00:48,340

think you have updates and you can

21

00:00:52,440 --> 00:00:50,050

already project them and put them in an

22

00:00:56,340 --> 00:00:52,450

abstract and submit it um might be a

23

00:00:58,350 --> 00:00:56,350

nice chance to meet in the other the

24

00:01:00,720 --> 00:00:58,360

other work they are that I've been

25

00:01:03,000 --> 00:01:00,730

supporting is honeybees slush proposal

26

00:01:05,219 --> 00:01:03,010

in sesame so I've listed a few

27

00:01:06,840 --> 00:01:05,229

co-authors here but really I've worked

28

00:01:10,279 --> 00:01:06,850

with probably 45 people between these

29

00:01:15,289 --> 00:01:13,200

so there's all the usual suspects this

30

00:01:20,219 --> 00:01:15,299

is something I stole out of a slush

31

00:01:21,539 --> 00:01:20,229

abstract or poster and it's tiny but you

32

00:01:23,130 --> 00:01:21,549

all know what these are others there's

33

00:01:24,960 --> 00:01:23,140

diurnal II activated cracks and deep

34

00:01:26,850 --> 00:01:24,970

faults and the potential for geologic

35

00:01:30,270 --> 00:01:26,860

stresses and lakes and salt lenses and

36

00:01:32,760 --> 00:01:30,280

acids and all the fun stuff and so I've

37

00:01:34,980 --> 00:01:32,770

said about trying to take a lot of these

38

00:01:36,719 --> 00:01:34,990

different abstract ideas to simplify

39

00:01:38,789 --> 00:01:36,729

them as much as possible and really look

40

00:01:43,490 --> 00:01:38,799

at how you can start to place system

41

00:01:45,870 --> 00:01:43,500

level capability constraints on them but

42

00:01:47,910 --> 00:01:45,880

yeah I noticed this when I uploaded my

43

00:01:53,460 --> 00:01:47,920

talk it's going to take forever for any

44

00:01:55,319 --> 00:01:53,470

animation to happen so I'll start by

45

00:01:57,620 --> 00:01:55,329

mentioning what's about to show up is

46

00:02:01,530 --> 00:01:57,630

Erin Leonard's geologic map I hope

47

00:02:02,730 --> 00:02:01,540

thinking about the the biggest tectonic

48

00:02:03,990 --> 00:02:02,740

worries when you go somewhere I'm only

49

00:02:05,429 --> 00:02:04,000

going to talk about your open this talk

50

00:02:08,509 --> 00:02:05,439

because it's 11 minutes and there's way

51  
00:02:12,120 --> 00:02:08,519  
too much to talk about in icy satellites

52  
00:02:13,710 --> 00:02:12,130  
but one result of Erin's work mapping

53  
00:02:15,360 --> 00:02:13,720  
Europa and thinking about the geologic

54  
00:02:16,710 --> 00:02:15,370  
history has been that the geologic

55  
00:02:19,170 --> 00:02:16,720  
evolution has changed over time

56  
00:02:21,599 --> 00:02:19,180  
she found that in Europa's earliest

57  
00:02:22,320 --> 00:02:21,609  
period so that's the first period down

58  
00:02:26,850 --> 00:02:22,330  
here at the bottom

59  
00:02:28,710 --> 00:02:26,860  
on the x-axis so the today is this third

60  
00:02:31,110 --> 00:02:28,720  
period on the x-axis you have all the

61  
00:02:32,850 --> 00:02:31,120  
different kinds of units and what she

62  
00:02:34,770 --> 00:02:32,860  
found is that if you look at the blue

63  
00:02:36,720 --> 00:02:34,780

the very first thing to form on Europa

64

00:02:38,250 --> 00:02:36,730

were global regional Plains so large

65

00:02:40,830 --> 00:02:38,260

scale deformation everywhere and that

66

00:02:43,230 --> 00:02:40,840

transition to bands which are still

67

00:02:45,360 --> 00:02:43,240

large but more local features his

68

00:02:48,630 --> 00:02:45,370

transition to chaos which are relatively

69

00:02:52,320 --> 00:02:48,640

local and also cracks and craters so the

70

00:02:54,360 --> 00:02:52,330

the geology has really changed from

71

00:02:55,950 --> 00:02:54,370

widely distributed high stress

72

00:02:57,300 --> 00:02:55,960

requirement tectonics the more locally

73

00:03:00,030 --> 00:02:57,310

distributed cracks that can form at

74

00:03:01,500 --> 00:03:00,040

lower stresses and so I just had a paper

75

00:03:03,300 --> 00:03:01,510

out in Icarus where I look at sort of

76

00:03:06,000 --> 00:03:03,310

the stresses and forces available on

77

00:03:07,560 --> 00:03:06,010

Europa to deform it today and my primary

78

00:03:09,720 --> 00:03:07,570

anxieties for drilling through an ice

79

00:03:11,610 --> 00:03:09,730

shell lie in diurnal active cracks and

80

00:03:15,570 --> 00:03:11,620

I'm not as worried about deep interior

81

00:03:17,640 --> 00:03:15,580

faults so the most impressive thing I do

82

00:03:18,690 --> 00:03:17,650

are these movies of ice shells and so of

83

00:03:22,980 --> 00:03:18,700

course I'm going to show them in every

84

00:03:25,560 --> 00:03:22,990

talk I give this is showing an ice shell

85

00:03:26,420 --> 00:03:25,570

falling out from 50 kilometers to a

86

00:03:29,670 --> 00:03:26,430

present-day

87

00:03:31,620 --> 00:03:29,680

ice shell thickness for an estimate of

88

00:03:33,660 --> 00:03:31,630

interior silicate heat generation and

89

00:03:35,280 --> 00:03:33,670

internal tidal heating and on the left

90

00:03:37,290 --> 00:03:35,290

the red stuff is stiff and the blue

91

00:03:38,729 --> 00:03:37,300

stuff is convecting and in the middle

92

00:03:41,240 --> 00:03:38,739

and tracking the historical freezing

93

00:03:43,920 --> 00:03:41,250

rate which relates to salt composition

94

00:03:46,110 --> 00:03:43,930

and on the right is the age that the ice

95

00:03:47,520 --> 00:03:46,120

froze in just one quick thing I want to

96

00:03:49,410 --> 00:03:47,530

mention here is that when you actually

97

00:03:51,210 --> 00:03:49,420

simulate convection on top of an ocean

98

00:03:52,199 --> 00:03:51,220

with fully temperature dependent

99

00:03:54,000 --> 00:03:52,209

parameters it can look much different

100

00:03:57,090 --> 00:03:54,010

than the convection models you're used

101  
00:03:59,130 --> 00:03:57,100  
to especially because the stagnant lids

102  
00:04:01,890 --> 00:03:59,140  
above convection cells can be much

103  
00:04:03,270 --> 00:04:01,900  
higher proportion of the ice shell that

104  
00:04:05,070 --> 00:04:03,280  
means that you're going to be in colder

105  
00:04:07,290 --> 00:04:05,080  
stiffer ice for longer with the

106  
00:04:09,210 --> 00:04:07,300  
potential for fracture porosity and

107  
00:04:12,720 --> 00:04:09,220  
spend less time in the convecting regime

108  
00:04:16,440 --> 00:04:12,730  
near the melting temperature and so if

109  
00:04:18,409 --> 00:04:16,450  
you plot I took bar and showmen out of

110  
00:04:20,430 --> 00:04:18,419  
the europa book and you often see this

111  
00:04:21,990 --> 00:04:20,440  
parameterization of the convective ice

112  
00:04:24,780 --> 00:04:22,000  
shell thermal structure the black line

113  
00:04:25,800 --> 00:04:24,790

if you plot what convective ice shell

114

00:04:27,540 --> 00:04:25,810

thermal structures might look like

115

00:04:33,150 --> 00:04:27,550

they're much closer to something like a

116

00:04:36,000 --> 00:04:33,160

conductive show there are regimes where

117

00:04:38,310 --> 00:04:36,010

I can freeze out ice shells

118

00:04:41,310 --> 00:04:38,320

to steady-state modern values and one

119

00:04:43,590 --> 00:04:41,320

thing to mention here is that all of

120

00:04:45,180 --> 00:04:43,600

this purple stuff are areas where there

121

00:04:46,980 --> 00:04:45,190

is entrained partial melt that doesn't

122

00:04:49,470 --> 00:04:46,990

immediately drain out and so you can

123

00:04:51,330 --> 00:04:49,480

find regimes where you have a slushy ice

124

00:04:53,190 --> 00:04:51,340

ocean interface if you're thinking about

125

00:04:54,870 --> 00:04:53,200

getting all the way into the water you

126

00:04:56,190 --> 00:04:54,880

might have difficulty detecting a sharp

127

00:04:57,420 --> 00:04:56,200

boundary at the ice ocean interface and

128

00:05:03,360 --> 00:04:57,430

when you get there it might not be

129

00:05:06,450 --> 00:05:03,370

mechanically intact um another issue

130

00:05:07,920 --> 00:05:06,460

with conductive shells so this is really

131

00:05:09,620 --> 00:05:07,930

difficult to see but on the y-axis is

132

00:05:13,650 --> 00:05:09,630

depth through a 15 kilometer shell and

133

00:05:16,620 --> 00:05:13,660

on the x-axis is porosity so I built a

134

00:05:19,470 --> 00:05:16,630

shell with 20% initial porosity and then

135

00:05:21,330 --> 00:05:19,480

I let it bake for a thousand years up to

136

00:05:23,760 --> 00:05:21,340

65 million years which is the current

137

00:05:25,320 --> 00:05:23,770

surface age of Europa one thing you

138

00:05:27,300 --> 00:05:25,330

notice that even if you pick a really

139

00:05:29,910 --> 00:05:27,310

high starting porosity you tend to

140

00:05:32,340 --> 00:05:29,920

maintain high porosity in about the

141

00:05:34,200 --> 00:05:32,350

upper half of a conductive ice shell so

142

00:05:36,420 --> 00:05:34,210

the issue here is I don't know what

143

00:05:38,190 --> 00:05:36,430

porosity Yorubas ice shell froze at but

144

00:05:40,230 --> 00:05:38,200

it sure is fractured in a fracture

145

00:05:41,670 --> 00:05:40,240

porosity is relatively high and has been

146

00:05:44,790 --> 00:05:41,680

throughout its history it can be

147

00:05:46,500 --> 00:05:44,800

retained over geologic time so porosity

148

00:05:47,910 --> 00:05:46,510

is more than about five percent are

149

00:05:49,440 --> 00:05:47,920

going to keep you connected to the

150

00:05:51,870 --> 00:05:49,450

vacuum and those might not just be a

151

00:05:54,300 --> 00:05:51,880

surface problem these high porosity

152

00:05:55,830 --> 00:05:54,310

could extend to depth and persist over

153

00:06:00,890 --> 00:05:55,840

geologic time so you might have

154

00:06:06,360 --> 00:06:05,190

if I make a relationship between salt

155

00:06:08,430 --> 00:06:06,370

content and an ice shell and it's

156

00:06:10,820 --> 00:06:08,440

freezing rate you can see all these

157

00:06:13,440 --> 00:06:10,830

weird structures start to form when you

158

00:06:16,670 --> 00:06:13,450

begin to make ice shells it's because

159

00:06:18,780 --> 00:06:16,680

you start to get a small wave length

160

00:06:21,570 --> 00:06:18,790

compositional convection from salts in

161

00:06:23,820 --> 00:06:21,580

addition to the thermal convection in

162

00:06:26,820 --> 00:06:23,830

the ice and what this can actually do is

163

00:06:29,820 --> 00:06:26,830

it can produce lateral and horizontal

164

00:06:34,200 --> 00:06:29,830

heterogeneity s and salt content they

165

00:06:35,430 --> 00:06:34,210

could build salt hazards into different

166

00:06:36,780 --> 00:06:35,440

parts of the ice shell that would be

167

00:06:38,250 --> 00:06:36,790

difficult to detect through remote

168

00:06:46,320 --> 00:06:38,260

sensing which could average over these

169

00:06:48,690 --> 00:06:46,330

lengths so one interesting thing to

170

00:06:49,500 --> 00:06:48,700

think about is if you assume the ocean

171

00:06:51,840 --> 00:06:49,510

is an earth so

172

00:06:55,170 --> 00:06:51,850

the ice shell on average has to be that

173

00:06:56,460 --> 00:06:55,180

salinity or less and so it's possible

174

00:06:59,250 --> 00:06:56,470

that you're going to encounter some

175

00:07:00,960 --> 00:06:59,260

where we are up to 25 kilograms of salt

176  
00:07:02,640 --> 00:07:00,970  
for every meter that you drill so if you

177  
00:07:04,350 --> 00:07:02,650  
have a 50 centimeter wide probe that's a

178  
00:07:06,750 --> 00:07:04,360  
couple centimeters of salt for every

179  
00:07:10,260 --> 00:07:06,760  
meter and so if you start to pick the

180  
00:07:13,980 --> 00:07:10,270  
the geologic object of interest to you

181  
00:07:15,210 --> 00:07:13,990  
if it's a hundred meters tall a lake or

182  
00:07:18,030 --> 00:07:15,220  
something that you want to freeze out

183  
00:07:20,010 --> 00:07:18,040  
then you could be talking several meters

184  
00:07:24,510 --> 00:07:20,020  
of salt lenses that you would have to

185  
00:07:27,450 --> 00:07:24,520  
cut through and the reason I make that

186  
00:07:29,310 --> 00:07:27,460  
comparison is I get asked a lot what

187  
00:07:31,950 --> 00:07:29,320  
happens if you hit a meteorite or

188  
00:07:35,220 --> 00:07:31,960

something and I wanted to compare the

189

00:07:37,950 --> 00:07:35,230

amount of antigenic non ice material to

190

00:07:39,660 --> 00:07:37,960

potential exogenic nice material so one

191

00:07:41,910 --> 00:07:39,670

way to back at the envelope that is you

192

00:07:46,170 --> 00:07:41,920

can take this Alvarado study from 2008

193

00:07:48,000 --> 00:07:46,180

where they simulate a bunch of I'm gonna

194

00:07:49,860 --> 00:07:48,010

start with stuff from IO so they

195

00:07:52,590 --> 00:07:49,870

simulate impacts on IO and how lowa

196

00:07:54,180 --> 00:07:52,600

ejected might end up on Europa they look

197

00:07:58,290 --> 00:07:54,190

at the distribution of Io material on

198

00:08:00,440 --> 00:07:58,300

the surface and find that there's a

199

00:08:02,880 --> 00:08:00,450

dependence on both latitude and

200

00:08:05,100 --> 00:08:02,890

longitude of that material distribution

201  
00:08:07,320 --> 00:08:05,110  
and so something I've done is you can

202  
00:08:12,290 --> 00:08:07,330  
build probability maps of where IO

203  
00:08:14,790 --> 00:08:12,300  
materials going to land so this is

204  
00:08:17,100 --> 00:08:14,800  
yellow is more likely to have material

205  
00:08:18,140 --> 00:08:17,110  
deposited on it and blue is not so there

206  
00:08:19,980 --> 00:08:18,150  
can be latitudinal and longitudinal

207  
00:08:21,440 --> 00:08:19,990  
dependencies in the amount of non ice

208  
00:08:24,060 --> 00:08:21,450  
material you might have to drill through

209  
00:08:25,830 --> 00:08:24,070  
and you can look at total fluxes from

210  
00:08:27,540 --> 00:08:25,840  
IOT Europa and start to think about how

211  
00:08:30,870 --> 00:08:27,550  
much over 65 million years you could

212  
00:08:32,940 --> 00:08:30,880  
accumulate so for example if you have a

213  
00:08:34,110 --> 00:08:32,950

50 centimeter diameter drill because you

214

00:08:35,969 --> 00:08:34,120

want to stick a nuclear reactor or

215

00:08:38,100 --> 00:08:35,979

something in it you only have to deal

216

00:08:40,620 --> 00:08:38,110

with about 10 kilograms of non ice

217

00:08:42,630 --> 00:08:40,630

material every kilometer you drill if

218

00:08:44,610 --> 00:08:42,640

you're going with a finless RTG or

219

00:08:47,040 --> 00:08:44,620

stripping out your GPA chess breaks from

220

00:08:49,350 --> 00:08:47,050

the RTG you can get thinner and you have

221

00:08:51,270 --> 00:08:49,360

to deal with less material even if you

222

00:08:53,820 --> 00:08:51,280

include primary impacts on Europa from

223

00:08:55,950 --> 00:08:53,830

other bodies these numbers are still

224

00:08:57,750 --> 00:08:55,960

extremely small about a thousandth of

225

00:09:02,540 --> 00:08:57,760

what you have to worry about with salt

226

00:09:07,009 --> 00:09:05,329

and so one fun thing is you can think

227

00:09:08,750 --> 00:09:07,019

about what happens if every projectile

228

00:09:10,790 --> 00:09:08,760

that hits Europa is broken up into the

229

00:09:13,400 --> 00:09:10,800

worst size pieces so pieces on the scale

230

00:09:15,740 --> 00:09:13,410

of your drill that's not how the

231

00:09:17,930 --> 00:09:15,750

universe works but even if it were in

232

00:09:21,110 --> 00:09:17,940

that worst case you only have about a 1%

233

00:09:23,750 --> 00:09:21,120

chance for a 10 centimeter borehole of

234

00:09:26,180 --> 00:09:23,760

hitting an object that is the same size

235

00:09:29,240 --> 00:09:26,190

as your drill or bigger and you only

236

00:09:31,430 --> 00:09:29,250

have about a point six percent chance if

237

00:09:33,980 --> 00:09:31,440

it's 50 centimeters and of course in a

238

00:09:36,259 --> 00:09:33,990

reality you tend to create many many

239

00:09:37,819 --> 00:09:36,269

more small objects on an impact than you

240

00:09:39,170 --> 00:09:37,829

retain large objects and so this is

241

00:09:40,699 --> 00:09:39,180

going to skew further to the left and I

242

00:09:42,500 --> 00:09:40,709

think the chances of really having to

243

00:09:45,319 --> 00:09:42,510

worry about more than just the

244

00:09:52,370 --> 00:09:45,329

occasional dust in the ice from exogenic

245

00:09:56,360 --> 00:09:52,380

material is pretty low so for me the the

246

00:09:58,250 --> 00:09:56,370

primary things the our driving system

247

00:10:01,160 --> 00:09:58,260

capability definition is I really worry

248

00:10:03,110 --> 00:10:01,170

about title shear stresses especially on

249

00:10:06,290 --> 00:10:03,120

tethers I think Kate and her team are

250

00:10:08,300 --> 00:10:06,300

doing great work looking at how diurnal

251  
00:10:12,050 --> 00:10:08,310  
flexing of real tethers might cause them

252  
00:10:13,850 --> 00:10:12,060  
to break if the ice shell was formed

253  
00:10:15,470 --> 00:10:13,860  
with significant fracture porosity it

254  
00:10:17,480 --> 00:10:15,480  
could have retained that porosity and

255  
00:10:19,160 --> 00:10:17,490  
that means you can remain connected to

256  
00:10:20,540 --> 00:10:19,170  
the vacuum for significant depths so you

257  
00:10:22,160 --> 00:10:20,550  
might not just have to build pressure

258  
00:10:24,620 --> 00:10:22,170  
caps near the surface you might have to

259  
00:10:26,449 --> 00:10:24,630  
build them the whole way and it may be

260  
00:10:28,430 --> 00:10:26,459  
that only a small proportion of the ice

261  
00:10:29,870 --> 00:10:28,440  
shell is convecting especially if you're

262  
00:10:31,130 --> 00:10:29,880  
aiming for a 15 kilometer ice shell

263  
00:10:34,250 --> 00:10:31,140

there's probably very little ductile

264

00:10:36,440 --> 00:10:34,260

portion there's very poor constraints on

265

00:10:39,199 --> 00:10:36,450

composition in general including how and

266

00:10:40,519 --> 00:10:39,209

where salt is distributed and so trying

267

00:10:41,960 --> 00:10:40,529

to think about the physical processes

268

00:10:44,510 --> 00:10:41,970

that drive that which is something a lot

269

00:10:48,050 --> 00:10:44,520

of people in this room do is extremely

270

00:10:50,389 --> 00:10:48,060

useful for planning purposes in that

271

00:10:52,130 --> 00:10:50,399

really the dangers from exogenic nice

272

00:10:54,260 --> 00:10:52,140

Arda nice material are pretty trivial

273

00:10:55,400 --> 00:10:54,270

compared to the amount of soluble not

274

00:10:56,710 --> 00:10:55,410

ice material you're going to have to

275

00:10:59,360 --> 00:10:56,720

deal with as you go through an Ice Show

276

00:11:00,680 --> 00:10:59,370

and among the many other things I don't

277

00:11:03,199 --> 00:11:00,690

have time to talk about there's the

278

00:11:04,310 --> 00:11:03,209

potential for sublimating salt lags on

279

00:11:06,530 --> 00:11:04,320

the surface that you're going to have to

280

00:11:08,000 --> 00:11:06,540

break through clathrates if they're

281

00:11:09,500 --> 00:11:08,010

stable in your opus ice shell could be a

282

00:11:12,170 --> 00:11:09,510

large problem they're a large problem in

283

00:11:13,699 --> 00:11:12,180

terrestrial drilling and also small

284

00:11:16,150 --> 00:11:13,709

scale variations in your melt jacket

285

00:11:17,830 --> 00:11:16,160

volume if you have small changes in the

286

00:11:18,910 --> 00:11:17,840

or in the volume of your melt jacket or

287

00:11:22,140 --> 00:11:18,920

the amount of heat you're putting into

288

00:11:24,130 --> 00:11:22,150

or out of your drill you can result in

289

00:11:25,930 --> 00:11:24,140

perturbations in the volume of that

290

00:11:27,970 --> 00:11:25,940

cavity and if you're in the elastic part

291

00:11:29,470 --> 00:11:27,980

of the ice you can have significant

292

00:11:31,090 --> 00:11:29,480

instantaneous pressure changes that

293

00:11:33,280 --> 00:11:31,100

could fracture ice it could force your

294

00:11:34,840 --> 00:11:33,290

melt jacket outwards into the ice or if

295

00:11:38,740 --> 00:11:34,850

you under pressure you can destabilize

296

00:11:39,700 --> 00:11:38,750

that melt cavity and so these are the

297

00:11:41,410 --> 00:11:39,710

things I'm worried about

298

00:11:44,830 --> 00:11:41,420

you're free to worry about other things