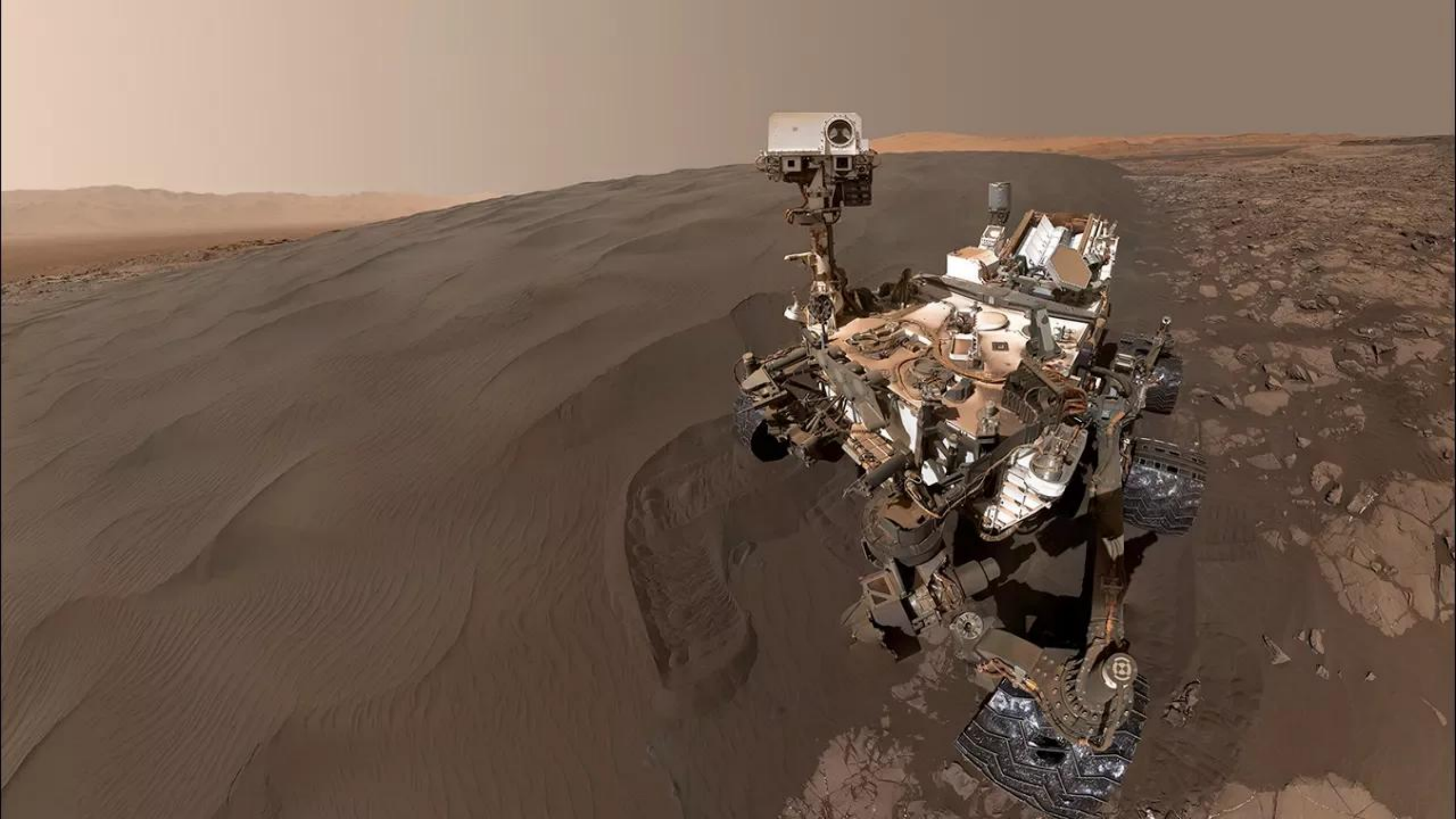

1
00:00:02,001 --> 00:00:03,770
>> Announcer: NASA's
Jet Propulsion

2
00:00:03,803 --> 00:00:07,173
Laboratory presents,
The von Karman Lecture:

3
00:00:07,206 --> 00:00:10,209
a series of talks by scientists
and engineers who are

4
00:00:10,242 --> 00:00:13,846
exploring our planet,
our solar system,

5
00:00:13,879 --> 00:00:16,015
and all that lies beyond.

6
00:00:16,048 --> 00:00:18,952
[cheerful music]

7
00:00:26,092 --> 00:00:27,994
>> Good evening,
ladies and gentlemen.

8
00:00:28,027 --> 00:00:29,162
How is everyone tonight?

9
00:00:29,195 --> 00:00:30,897
[audience members whoop]
[audience applauds]

10
00:00:30,930 --> 00:00:32,932
Yeah, cool. [laughs]

11
00:00:32,965 --> 00:00:34,200
Well, thank you, of
course, as always,

12
00:00:34,233 --> 00:00:36,836
for coming out to
join us tonight.

13
00:00:36,869 --> 00:00:38,905
Nearly five years
after it's amazing

14
00:00:38,938 --> 00:00:41,140
arrival at Mars,
the Curiosity Rover

15
00:00:41,173 --> 00:00:45,011
continues to reveal Mars
as a once habitable planet,

16
00:00:45,044 --> 00:00:46,913
showing that early in
the planet's history,

17
00:00:46,946 --> 00:00:48,848
generations of streams and lakes

18
00:00:48,881 --> 00:00:52,185
created landforms that
Curiosity explores today.

19
00:00:52,218 --> 00:00:53,853
Currently, the Rover is climbing

20
00:00:53,886 --> 00:00:55,822
through the foothills
of Mount Sharp,

21
00:00:55,855 --> 00:00:57,723
a three mile high
mountain formed from

22

00:00:57,756 --> 00:01:00,193
sediment brought in
by water and wind.

23
00:01:00,226 --> 00:01:02,095
Tonight, we have
two guests who will

24
00:01:02,128 --> 00:01:04,130
talk about the
challenges exploration

25
00:01:04,163 --> 00:01:06,732
with an aging robot,
the latest findings

26
00:01:06,765 --> 00:01:09,001
from the mission,
and what lies ahead.

27
00:01:09,034 --> 00:01:11,003
Our first guest is
Mr. Jim Erickson,

28
00:01:11,036 --> 00:01:15,074
who started working at JPL
in 1974 as a summer hire,

29
00:01:15,107 --> 00:01:19,745
and since there was always
something fun to do, never left.

30
00:01:19,778 --> 00:01:21,981
During his career at
JPL, he has worked on

31
00:01:22,014 --> 00:01:23,749
numerous space flight projects,

32
00:01:23,782 --> 00:01:25,852

including the Viking
mission to Mars,

33
00:01:25,885 --> 00:01:29,021
the Voyager mission to the
outer planets, Mars Observer,

34
00:01:29,054 --> 00:01:32,725
and he managed the Galileo
Project to the planet Jupiter.

35
00:01:32,758 --> 00:01:34,861
He then managed the
Mars Exploration Rovers,

36
00:01:34,894 --> 00:01:36,162
the Mars Reconnaissance Orbiter,

37
00:01:36,195 --> 00:01:37,864
the Deep Space
Networks and Mission

38
00:01:37,897 --> 00:01:39,866
Support and Planning
Program Office,

39
00:01:39,899 --> 00:01:42,935
and now, the Mars Science
Laboratory Curiosity Rover.

40
00:01:42,968 --> 00:01:44,203
He received his Bachelor
of Science degree

41
00:01:44,236 --> 00:01:46,906
from Harvey Mudd College in 1975

42
00:01:46,939 --> 00:01:50,143
and his MBA from West
Coast University in 1981.

43
00:01:50,176 --> 00:01:54,013
Tonight's second speaker
is Dr. Ashwin Vasavada,

44
00:01:54,046 --> 00:01:55,848
who is currently the
project scientist

45
00:01:55,881 --> 00:01:57,917
on the Mars Science
Laboratory Mission.

46
00:01:57,950 --> 00:02:00,019
He began working on the
mission 13 years ago,

47
00:02:00,052 --> 00:02:02,922
and two years ago took
over as the lead scientist.

48
00:02:02,955 --> 00:02:05,158
He has participated as a
scientific investigator

49
00:02:05,191 --> 00:02:07,026
on the the Lunar
Reconnaissance Orbiter,

50
00:02:07,059 --> 00:02:08,995
as well as the
Cassini and Galileo

51
00:02:09,028 --> 00:02:10,930
missions to the giant planets,

52
00:02:10,963 --> 00:02:12,165
specializing in
the understanding

53
00:02:12,198 --> 00:02:15,067
the environment of planetary
surfaces and atmospheres.

54
00:02:15,100 --> 00:02:17,803
He has a PhD in planetary
science from Caltech

55
00:02:17,836 --> 00:02:19,172
and a Bachelor of
Science degrees

56
00:02:19,205 --> 00:02:22,208
in Earth and space
science from UCLA.

57
00:02:22,241 --> 00:02:25,745
First up tonight, please help
me welcome, Mr. Jim Erickson.

58
00:02:25,778 --> 00:02:28,781
[audience applauds]

59
00:02:36,188 --> 00:02:38,991
>> Let me add a welcome
from the project as well,

60
00:02:39,024 --> 00:02:41,794
for everybody who
came out to see this.

61
00:02:41,827 --> 00:02:43,729
I'm sure you're
gonna be very happy

62
00:02:43,762 --> 00:02:45,932
to see what we're all gonna say.

63
00:02:45,965 --> 00:02:47,833

And let's get started.

64
00:02:47,866 --> 00:02:49,101
So, next slide.

65
00:02:49,134 --> 00:02:50,002
Oh.

66
00:02:50,035 --> 00:02:51,904
[audience laughs]

67
00:02:51,937 --> 00:02:53,006
First mistake.

68
00:02:56,208 --> 00:02:58,878
August 5th, or
August 6th depending

69
00:02:58,911 --> 00:03:01,781
on what time zone you
were in at the time.

70
00:03:01,814 --> 00:03:05,117
We landed, we confirmed
that we were down safely,

71
00:03:05,150 --> 00:03:07,787
and immediately
got pictures back,

72
00:03:07,820 --> 00:03:11,057
including a really nice
image of the target

73
00:03:11,090 --> 00:03:13,960
of Mount Sharp in
the background.

74
00:03:15,060 --> 00:03:17,029

And then of course,
it was obviously

75
00:03:17,062 --> 00:03:20,934
time to see where
Curiosity's gonna take us.

76
00:03:22,134 --> 00:03:24,871
Now, this is where we've been.

77
00:03:25,838 --> 00:03:27,039
This is the route from landing

78
00:03:27,072 --> 00:03:29,041
up at the top with the star,

79
00:03:29,074 --> 00:03:31,744
through our first stop
at Yellowknife Bay,

80
00:03:31,777 --> 00:03:34,914
and Ashwin will
talk about the rest.

81
00:03:34,947 --> 00:03:37,917
But there were some obstacles
that we had to overcome.

82
00:03:37,950 --> 00:03:40,019
You notice the Bagnold
Dunes which are

83
00:03:40,052 --> 00:03:44,056
the dark area with very
dangerous sand for a rover,

84
00:03:44,089 --> 00:03:46,826
and the fact that
we found out we had

85
00:03:46,859 --> 00:03:49,095
a lot of damage being
done to our wheels

86
00:03:49,128 --> 00:03:51,163
as we moved across the terrain.

87
00:03:51,196 --> 00:03:53,199
We figured out how
to deal with that,

88
00:03:53,232 --> 00:03:54,934
couldn't get rid of
it, but we figured out

89
00:03:54,967 --> 00:03:58,137
how to deal with it and
keep the mission going.

90
00:03:58,170 --> 00:04:00,072
And we continued,
and we continued,

91
00:04:00,105 --> 00:04:01,841
and we continued, and in fact,

92
00:04:01,874 --> 00:04:03,909
we're the fastest thing on Mars.

93
00:04:03,942 --> 00:04:08,014
We were able to drive 17
kilometers in only 1,790 days,

94
00:04:10,883 --> 00:04:14,754
which is a record for
any vehicle on Mars.

95
00:04:14,787 --> 00:04:16,922
[audience laughs]

96
00:04:16,955 --> 00:04:18,924
It's kind of a
small club though,

97
00:04:18,957 --> 00:04:21,160
yeah, you have to understand.

98
00:04:23,228 --> 00:04:26,065
And we weren't just driving.

99
00:04:26,098 --> 00:04:30,169
This is our vehicle, and
it has instruments galore.

100
00:04:32,838 --> 00:04:36,042
Ashwin will give you an
idea of what they do.

101
00:04:36,075 --> 00:04:37,910
We can actually do
a lot of fun things.

102
00:04:37,943 --> 00:04:41,047
We can drill, we can
scoop, we can deliver

103
00:04:41,080 --> 00:04:43,749
that kind of material
to a couple of

104
00:04:43,782 --> 00:04:46,919
analytical laboratories inside
the body of the vehicle.

105
00:04:46,952 --> 00:04:51,123
We've got a laser that
can actually vaporize rock

106

00:04:51,156 --> 00:04:53,826
and look at the spark
that you see there,

107
00:04:53,859 --> 00:04:57,029
and determine what's
in the material.

108
00:04:57,062 --> 00:04:59,832
So, it's a really cool device,

109
00:04:59,865 --> 00:05:04,103
and it is extremely
productive, and in fact,

110
00:05:04,136 --> 00:05:06,772
we are the most productive
vehicle on Mars.

111
00:05:06,805 --> 00:05:07,873
[audience laughs]

112
00:05:07,906 --> 00:05:11,043
We've got over 19.6
terabytes that are

113
00:05:11,076 --> 00:05:12,912
delivered to the
archive and available

114
00:05:12,945 --> 00:05:16,916
for the public and
scientists to look at.

115
00:05:16,949 --> 00:05:20,753
To put that in context,
I did a little Googling

116
00:05:20,786 --> 00:05:22,855
on the internet and

found out what the size

117
00:05:22,888 --> 00:05:24,857
of the iTunes music store was.

118
00:05:24,890 --> 00:05:28,795
And we are almost
20%, 19 point a bunch.

119
00:05:29,228 --> 00:05:31,197
So, that gives you some idea of

120
00:05:31,230 --> 00:05:35,034
exactly how much data that
we've actually delivered.

121
00:05:35,067 --> 00:05:37,837
Now, I'm not gonna
belabor the point.

122
00:05:37,870 --> 00:05:39,805
Let's start looking at the data,

123
00:05:39,838 --> 00:05:42,108
and for that, Dr. Vasavada.

124
00:05:42,141 --> 00:05:45,144
[audience applauds]

125
00:05:48,947 --> 00:05:51,050
[speaking away from mic]

126
00:05:51,083 --> 00:05:52,184
>> Hi, everybody.

127
00:05:52,217 --> 00:05:53,786
>> [Audience Members] Hi.
[laughs]

128
00:05:53,819 --> 00:05:55,755
>> I'm really excited
to tell you all about

129
00:05:55,788 --> 00:05:57,823
the last five years.

130
00:05:57,856 --> 00:06:01,827
We have, of course, a
really productive rover,

131
00:06:01,860 --> 00:06:04,029
a really amazing robot,
probably the most

132
00:06:04,062 --> 00:06:06,999
sophisticated robot
NASA's ever created.

133
00:06:07,032 --> 00:06:09,001
We had the honor
of seeing it launch

134
00:06:09,034 --> 00:06:11,036
off to Mars five years
ago and, actually,

135
00:06:11,069 --> 00:06:14,039
planning it for about
eight years before that,

136
00:06:14,072 --> 00:06:16,809
and then arrive five years ago,

137
00:06:16,842 --> 00:06:19,178
and now celebrating
this great milestone.

138
00:06:19,211 --> 00:06:22,181

So, there's actually
about, I don't know,

139
00:06:22,214 --> 00:06:25,184
six to 10 hours of
stuff I could tell you

140
00:06:25,217 --> 00:06:28,020
in the concise form of
everything the rover has done.

141
00:06:28,053 --> 00:06:29,955
So, I'm really
condensing it down to

142
00:06:29,988 --> 00:06:32,792
really what has
been the main story:

143
00:06:32,825 --> 00:06:35,127
why Curiosity was
sent to Mars by NASA

144
00:06:35,160 --> 00:06:36,996
and the scientific
community, and then

145
00:06:37,029 --> 00:06:38,764
everything that we've discovered

146
00:06:38,797 --> 00:06:41,033
that has informed that story.

147
00:06:42,234 --> 00:06:44,970
So, the story of
Curiosity really is about

148
00:06:45,003 --> 00:06:48,908
what we call habitability,
whether Mars ever offered

149
00:06:48,941 --> 00:06:51,043
the conditions that
could support life.

150
00:06:51,076 --> 00:06:52,978
That's why Curiosity
was sent to Mars,

151
00:06:53,011 --> 00:06:56,015
that's the place, and
that's the sort of role

152
00:06:56,048 --> 00:06:59,718
it performs in the larger
Mars Exploration Program,

153
00:06:59,751 --> 00:07:01,921
from figuring out if
Mars ever had water

154
00:07:01,954 --> 00:07:03,122
all the way to
figuring out if Mars

155
00:07:03,155 --> 00:07:05,858
ever had living things,
today or in the past.

156
00:07:05,891 --> 00:07:08,127
We're in the middle
there, figuring out,

157
00:07:08,160 --> 00:07:09,929
Curiosity was
launched knowing that

158
00:07:09,962 --> 00:07:13,132
there's water on Mars, and
we don't know there's life.

159
00:07:13,165 --> 00:07:16,802
So, Curiosity has been
asking the question:

160
00:07:16,835 --> 00:07:19,972
Did Mars ever offer a full
range of habitable conditions?

161
00:07:20,005 --> 00:07:23,209
Not just the water, but the
other things that life requires.

162
00:07:23,242 --> 00:07:26,912
And we have done a lot
of work in that respect,

163
00:07:26,945 --> 00:07:30,049
and I try to make the
case to you tonight

164
00:07:30,082 --> 00:07:31,150
of everything we've accomplished

165
00:07:31,183 --> 00:07:32,785
and how much we've
learned of just

166
00:07:32,818 --> 00:07:35,187
how habitable a planet Mars is.

167
00:07:35,220 --> 00:07:38,224
So, it starts all
the way back when,

168
00:07:39,224 --> 00:07:40,826
the scientific story at least,

169
00:07:40,859 --> 00:07:43,896

starts all the way
back when orbiters

170
00:07:43,929 --> 00:07:45,931
were orbiting Mars
and mapping the planet

171
00:07:45,964 --> 00:07:49,768
in preparation for sending
landed missions like Curiosity,

172
00:07:49,801 --> 00:07:52,771
and discovered a
crater, Gale Crater,

173
00:07:52,804 --> 00:07:54,807
that had a weird mountain
in the middle of it.

174
00:07:54,840 --> 00:07:56,175
And so, this is just
a nice illustration

175
00:07:56,208 --> 00:08:00,813
of Mars with an orbiter there,
Mars Reconnaissance Orbiter,

176
00:08:00,846 --> 00:08:03,782
which is one of the
current orbiters at Mars.

177
00:08:03,815 --> 00:08:05,150
The Gale Crater has
been actually mapped

178
00:08:05,183 --> 00:08:07,019
by three different missions.

179
00:08:07,052 --> 00:08:08,988
One of the things that

really made Gale Crater

180
00:08:09,021 --> 00:08:11,824
stand out was this mountain
in the middle of it.

181
00:08:11,857 --> 00:08:13,058
Craters, for
example on the Moon,

182
00:08:13,091 --> 00:08:15,895
of this size about a
hundred miles across,

183
00:08:15,928 --> 00:08:18,898
would not have a
large mound like that.

184
00:08:18,931 --> 00:08:20,165
They would just have maybe a

185
00:08:20,198 --> 00:08:23,002
central peak, a
very sharp mountain.

186
00:08:23,035 --> 00:08:25,871
And that exposed a
difference, of course,

187
00:08:25,904 --> 00:08:27,840
between the Moon and
Mars, that the Moon

188
00:08:27,873 --> 00:08:30,175
has no atmosphere, but
Mars, having an atmosphere,

189
00:08:30,208 --> 00:08:32,111
and even maybe
water in the past,

190
00:08:32,144 --> 00:08:35,014
can move stuff around, can
erode rock from one place

191
00:08:35,047 --> 00:08:37,983
and move dirt around, and
collect it somewhere else.

192
00:08:38,016 --> 00:08:40,986
That was a huge
discovery for the promise

193
00:08:41,019 --> 00:08:43,822
of doing geology on Mars because

194
00:08:43,855 --> 00:08:46,892
layered rock lends you a record,

195
00:08:46,925 --> 00:08:50,029
leaves a record behind that
you can explore on the ground

196
00:08:50,062 --> 00:08:52,965
with a virtual geologist
in the form of a rover.

197
00:08:52,998 --> 00:08:56,068
So, here's Gale Crater,
a hundred miles across,

198
00:08:56,101 --> 00:08:58,804
and about three miles
deep, and there's

199
00:08:58,837 --> 00:09:01,173
the central peak that probably
formed with the impact,

200

00:09:01,206 --> 00:09:04,777
but all this stuff,
this is five kilometers,

201
00:09:04,810 --> 00:09:07,046
three miles high of layered rock

202
00:09:07,079 --> 00:09:09,748
that we can see from
orbit, discovered by

203
00:09:09,781 --> 00:09:11,216
the Mars Global
Surveyor, one of the

204
00:09:11,249 --> 00:09:14,787
initial orbiters in the
Mars Exploration Program,

205
00:09:14,820 --> 00:09:16,855
to consist of layered
rock that we think

206
00:09:16,888 --> 00:09:19,758
was brought in by water
or wind in the past,

207
00:09:19,791 --> 00:09:22,861
and leaving this very
important record for us today.

208
00:09:22,894 --> 00:09:24,196
The other things that
the later orbiters found,

209
00:09:24,229 --> 00:09:26,165
including the Mars
Reconnaissance Orbiter,

210
00:09:26,198 --> 00:09:28,067

which continues to
be our communications

211
00:09:28,100 --> 00:09:29,969
link back to Earth every day,

212
00:09:30,002 --> 00:09:31,837
that orbiter has a
scientific instrument

213
00:09:31,870 --> 00:09:34,773
that also found that these
layers change with height.

214
00:09:34,806 --> 00:09:36,742
As you go from the bottom
of the mound to the top,

215
00:09:36,775 --> 00:09:38,844
the minerals that are
in the rock change,

216
00:09:38,877 --> 00:09:41,814
the chemistry, the texture,
the look of the layers change,

217
00:09:41,847 --> 00:09:44,951
which also was just
very exciting news

218
00:09:46,151 --> 00:09:48,988
for the idea of being
able to land a rover here

219
00:09:49,021 --> 00:09:50,856
on the plains where
it's nice and safe,

220
00:09:50,889 --> 00:09:53,759
and driver over, and

then slowly ascend

221
00:09:53,792 --> 00:09:56,195
through these layers,
and read Mars' history

222
00:09:56,228 --> 00:09:58,897
like a book, page
by page, every layer

223
00:09:58,930 --> 00:10:01,066
being laid down
on top of the next

224
00:10:01,099 --> 00:10:04,837
as time advanced in
early Mars history.

225
00:10:04,870 --> 00:10:06,939
So, that kinda sets the context

226
00:10:06,972 --> 00:10:10,910
for why we chose this
particular landing site.

227
00:10:12,110 --> 00:10:13,912
Now, I'll just kinda
zoom in a little bit

228
00:10:13,945 --> 00:10:15,848
and show you where we are today.

229
00:10:15,881 --> 00:10:18,217
Here's Gale Crater again,
a really gorgeous picture,

230
00:10:18,250 --> 00:10:20,986
showing the mound here
again, the central peak,

231
00:10:21,019 --> 00:10:22,121
the hundred mile crater,

232
00:10:22,154 --> 00:10:23,956
a lot of dark sand
that's collected,

233
00:10:23,989 --> 00:10:26,959
that's probably modern sand
that's blowing around today.

234
00:10:26,992 --> 00:10:28,927
And you see this little
strip of dark sand,

235
00:10:28,960 --> 00:10:31,063
those are those dunes
that Jim mentioned.

236
00:10:31,096 --> 00:10:33,866
And here's where we chose
to do our field area.

237
00:10:33,899 --> 00:10:35,034
This is where we sent the rover,

238
00:10:35,067 --> 00:10:36,869
this is where we
plan to explore.

239
00:10:36,902 --> 00:10:38,203
And that map that Jim showed

240
00:10:38,236 --> 00:10:40,739
all fits in this
little box right here.

241
00:10:40,772 --> 00:10:43,809
So, here's that dark strip

of dunes that goes across.

242
00:10:43,842 --> 00:10:45,944
We landed out here
on the plains there,

243
00:10:45,977 --> 00:10:48,947
drove across the plains,
started climbing the mountain,

244
00:10:48,980 --> 00:10:51,216
this took about two years
to get to this point,

245
00:10:51,249 --> 00:10:54,119
after spending a lot of
time at Yellowknife Bay,

246
00:10:54,152 --> 00:10:55,854
where we made some
of our most important

247
00:10:55,887 --> 00:10:58,190
initial discovers,
reached the mountain here,

248
00:10:58,223 --> 00:10:59,792
and have spent about two years

249
00:10:59,825 --> 00:11:02,127
climbing to where we
are today at this star.

250
00:11:02,160 --> 00:11:04,096
And we're just about to ascend

251
00:11:04,129 --> 00:11:05,898
what's called the
Vera Rubin Ridge,

252
00:11:05,931 --> 00:11:07,766
a big ridge that
forms one of these

253
00:11:07,799 --> 00:11:09,201
major layers on the mountain.

254
00:11:09,234 --> 00:11:12,171
And then we'll get to a Clay
Unit and a Sulfate Unit.

255
00:11:12,204 --> 00:11:14,940
But most of the past
two or three years

256
00:11:14,973 --> 00:11:16,075
we've spent on the
mountain itself

257
00:11:16,108 --> 00:11:18,043
has been in this initial layers

258
00:11:18,076 --> 00:11:20,145
of the mountain called
the Murray Formation.

259
00:11:20,178 --> 00:11:21,914
It doesn't have
a fancy name like

260
00:11:21,947 --> 00:11:24,083
clay and sulfate
or hematite because

261
00:11:24,116 --> 00:11:26,752
we didn't know what it was made
out of when we landed there,

262
00:11:26,785 --> 00:11:28,120

so we just named it
after Bruce Murray,

263
00:11:28,153 --> 00:11:32,825
one of the founding planetary
scientists at Caltech.

264
00:11:32,858 --> 00:11:35,094
And so, we've been
spending all of

265
00:11:35,127 --> 00:11:36,829
our time here so
far, and we're about

266
00:11:36,862 --> 00:11:38,063
to get to the next layer.

267
00:11:38,096 --> 00:11:40,933
But now, keep your
eye on that map,

268
00:11:40,966 --> 00:11:43,068
we're now just about
to ascend the ridge,

269
00:11:43,101 --> 00:11:45,905
and this box here is this image

270
00:11:46,938 --> 00:11:49,908
from the Mars
Reconnaissance Orbiter.

271
00:11:49,941 --> 00:11:50,976
Yeah, look at that.

272
00:11:51,009 --> 00:11:52,978
That's Curiosity right there.

273

00:11:53,011 --> 00:11:56,048
Six feet across, and
you're looking down

274
00:11:56,081 --> 00:11:59,118
on Mars from 200 miles
above the surface.

275
00:11:59,151 --> 00:12:02,187
So, this is like looking
at a car on the freeway

276
00:12:02,220 --> 00:12:05,157
in San Diego from Los Angeles.

277
00:12:05,190 --> 00:12:07,159
So, we love the Mars
Reconnaissance Orbiter,

278
00:12:07,192 --> 00:12:09,828
not only for telling us
about Gale before we landed,

279
00:12:09,861 --> 00:12:11,830
but for sending our
data back every day.

280
00:12:11,863 --> 00:12:14,032
But it also continues
to watch over us

281
00:12:14,065 --> 00:12:16,769
and make sure we're still there.

282
00:12:16,802 --> 00:12:18,203
[laughs]

283
00:12:18,236 --> 00:12:19,972
So, I couldn't
resist throwing in

284
00:12:20,005 --> 00:12:22,107
a couple pictures of what
we've been doing lately,

285
00:12:22,140 --> 00:12:23,876
and then I'm gonna launch
into that big story

286
00:12:23,909 --> 00:12:26,779
about Mars' habitability
and climate.

287
00:12:26,812 --> 00:12:27,913
So, here's some sand dunes.

288
00:12:27,946 --> 00:12:29,948
This is when we're
actually crossing

289
00:12:29,981 --> 00:12:32,751
those big sand dunes
that Jim mentioned,

290
00:12:32,784 --> 00:12:34,153
we saw in that map.

291
00:12:34,186 --> 00:12:35,821
What I love about
this is not only

292
00:12:35,854 --> 00:12:39,825
because it's a selfie,
which our camera team

293
00:12:39,858 --> 00:12:41,026
learned how to take.

294
00:12:41,059 --> 00:12:43,128

They realized that a camera
on the end of your arm

295
00:12:43,161 --> 00:12:45,798
isn't good just for looking at

296
00:12:45,831 --> 00:12:47,966
the microscopic
details of the rocks

297
00:12:47,999 --> 00:12:49,835
and soils, like it
was designed to do,

298
00:12:49,868 --> 00:12:51,737
you can also raise it
up and look at yourself.

299
00:12:51,770 --> 00:12:53,005
[laughs]

300
00:12:53,038 --> 00:12:55,007
Thank all the
millennials for that tip.

301
00:12:55,040 --> 00:12:56,809
[audience laughs]

302
00:12:56,842 --> 00:12:59,978
But it actually takes
about 55 images,

303
00:13:00,011 --> 00:13:02,781
and 55 positions
of our arm because

304
00:13:02,814 --> 00:13:05,017
the camera isn't designed
to be a selfie camera.

305
00:13:05,050 --> 00:13:07,786
It's designed to be
very narrow angle.

306
00:13:07,819 --> 00:13:08,987
So, this was a lot
of work actually

307
00:13:09,020 --> 00:13:10,088
by all the people who did this.

308
00:13:10,121 --> 00:13:11,890
But you get these
spectacular pictures,

309
00:13:11,923 --> 00:13:14,059
and then you Photoshop out
the arm, and it goes away.

310
00:13:14,092 --> 00:13:16,862
[audience laughs]

311
00:13:16,895 --> 00:13:19,765
What's amazing about
this dune, to me,

312
00:13:19,798 --> 00:13:21,900
I mean, one of the
things that I just

313
00:13:21,933 --> 00:13:24,770
keep coming back to with
this mission and Mars,

314
00:13:24,803 --> 00:13:28,006
in fact, is just how
Earth like the planet is,

315
00:13:28,039 --> 00:13:29,107

especially when you bring really

316
00:13:29,140 --> 00:13:31,844
good cameras to Mars like this.

317
00:13:31,877 --> 00:13:33,979
You have to keep telling
yourself this wasn't

318
00:13:34,012 --> 00:13:38,116
taken in the desert, out
of Barstow or somewhere.

319
00:13:38,149 --> 00:13:40,919
One of the ways I can
try to prove that to you,

320
00:13:40,952 --> 00:13:42,955
actually, it's not a conspiracy,

321
00:13:42,988 --> 00:13:46,024
[everyone laughs]

322
00:13:46,057 --> 00:13:48,861
is that this dune,
what I love about it

323
00:13:48,894 --> 00:13:50,829
is it's so Earth
like in one sense.

324
00:13:50,862 --> 00:13:52,898
The wind is blowing just
like it is on Earth.

325
00:13:52,931 --> 00:13:55,834
The wind is picking
up debris and sand,

326

00:13:55,867 --> 00:13:57,803
and making that move
around just like

327
00:13:57,836 --> 00:13:59,037
sand does on Earth,
and sand piles

328
00:13:59,070 --> 00:14:01,106
up in dunes just like on Earth,

329
00:14:01,139 --> 00:14:03,909
and ripples form on the
sand just like on Earth.

330
00:14:03,942 --> 00:14:05,844
But one thing you will
never be able to see

331
00:14:05,877 --> 00:14:09,949
on Earth that's in this
picture are these wavy ripples.

332
00:14:11,149 --> 00:14:13,819
That wavelength of
ripple and that shape

333
00:14:13,852 --> 00:14:16,722
only forms in the thin
atmosphere of Mars.

334
00:14:16,755 --> 00:14:19,758
So, no Earth dune has
these little S shaped

335
00:14:19,791 --> 00:14:21,960
ripples that are about
three feet apart,

336
00:14:21,993 --> 00:14:25,931

and that is because has
this 1% thick atmosphere,

337
00:14:25,964 --> 00:14:27,833
and different physics applies,

338
00:14:27,866 --> 00:14:29,968
still similar physics
enough to form dunes,

339
00:14:30,001 --> 00:14:32,170
but different enough to
form different ripples.

340
00:14:32,203 --> 00:14:33,872
So, on this picture
you kinda see

341
00:14:33,905 --> 00:14:36,909
Earth and Mars,
which I really love.

342
00:14:38,009 --> 00:14:39,211
The Vera Rubin Ridge,
we're about to ascend,

343
00:14:39,244 --> 00:14:41,813
this is an eight
story wall of rock

344
00:14:41,846 --> 00:14:43,215
that we knew we had to cross to

345
00:14:43,248 --> 00:14:45,017
get higher up on the mountain.

346
00:14:45,050 --> 00:14:47,786
And we're currently driving
along the base of it

347
00:14:47,819 --> 00:14:49,121
taking all of these
wonderful pictures,

348
00:14:49,154 --> 00:14:52,791
and then looking for the
place where we can climb up.

349
00:14:52,824 --> 00:14:55,761
It's not too risky
because, another thing that

350
00:14:55,794 --> 00:14:57,162
the Mars Reconnaissance
Orbiter and other orbiters

351
00:14:57,195 --> 00:14:58,964
allow us to do is actually map

352
00:14:58,997 --> 00:15:00,165
the planet before we get there

353
00:15:00,198 --> 00:15:02,901
and make sure there is
a route we can climb up.

354
00:15:02,934 --> 00:15:04,937
So, we have a good idea
that there's a place

355
00:15:04,970 --> 00:15:07,940
that's just not
too steep so we can

356
00:15:09,007 --> 00:15:10,876
make it up this eight
story wall of rock

357
00:15:10,909 --> 00:15:12,811

and continue on up the mountain.

358
00:15:12,844 --> 00:15:13,946
But we're not there
yet, so we're on

359
00:15:13,979 --> 00:15:17,015
the wall part right now,
not the less steep part,

360
00:15:17,048 --> 00:15:20,018
and seeing what this
ridge is made out of.

361
00:15:20,051 --> 00:15:22,888
And again, the
questions we're asking

362
00:15:22,921 --> 00:15:25,924
start with geology
in most cases.

363
00:15:25,957 --> 00:15:27,893
Why is the ridge there?

364
00:15:27,926 --> 00:15:30,729
It's been flat for so long,
and why all of the sudden

365
00:15:30,762 --> 00:15:33,165
is there a eight
story wall of rock?

366
00:15:33,198 --> 00:15:34,132
Is there something
about the chemistry

367
00:15:34,165 --> 00:15:35,767
that may have changed?

368
00:15:35,800 --> 00:15:37,970
This ridge is called
the Vera Rubin Ridge

369
00:15:38,003 --> 00:15:40,172
after a pioneering
astronomer that

370
00:15:40,205 --> 00:15:42,207
inspired a lot of
our team members,

371
00:15:42,240 --> 00:15:47,012
but it's actually also
called the Hematite Unit

372
00:15:47,045 --> 00:15:48,914
or the Hematite Ridge because

373
00:15:48,947 --> 00:15:52,217
the ridge has this mineral
hematite, an iron oxide,

374
00:15:52,250 --> 00:15:55,053
iron that's combined
with oxygen,

375
00:15:55,086 --> 00:15:57,823
been oxygenated, or oxidized,

376
00:15:58,890 --> 00:16:01,793
and forms this reddish
mineral hematite.

377
00:16:01,826 --> 00:16:02,928
So, that's a clue.

378
00:16:02,961 --> 00:16:05,097
So, maybe there's

some process that

379
00:16:05,130 --> 00:16:07,165
brought iron in
from somewhere else.

380
00:16:07,198 --> 00:16:09,034
The iron was dissolved in water

381
00:16:09,067 --> 00:16:11,970
and hit the atmosphere at
this location of the ridge

382
00:16:12,003 --> 00:16:14,172
and got oxidized by
oxygen in the atmosphere.

383
00:16:14,205 --> 00:16:15,907
That's maybe a theory.

384
00:16:15,940 --> 00:16:17,909
There's a lot of other ways
this could've happened.

385
00:16:17,942 --> 00:16:19,945
We're trying to figure out
why the ridge is there,

386
00:16:19,978 --> 00:16:21,947
why the hematite's
concentrated there,

387
00:16:21,980 --> 00:16:23,115
and of course, what that means

388
00:16:23,148 --> 00:16:25,951
for the habitability
of ancient Mars.

389

00:16:25,984 --> 00:16:27,919
Here's another gorgeous
view of the Hematite Ridge,

390
00:16:27,952 --> 00:16:30,055
just from a couple weeks ago,

391
00:16:30,088 --> 00:16:32,824
and Mount Sharp
in the background.

392
00:16:32,857 --> 00:16:35,160
We're now seeing that
this ridge itself

393
00:16:35,193 --> 00:16:39,097
is composed of
extremely fine layers,

394
00:16:39,130 --> 00:16:42,734
and it was once buried,
and when it was buried

395
00:16:42,767 --> 00:16:44,202
it broke into all these chunks,

396
00:16:44,235 --> 00:16:48,006
and then ground water,
as it was buried,

397
00:16:48,039 --> 00:16:50,742
flowed through those fractures

398
00:16:50,775 --> 00:16:53,045
and precipitated these
whitish minerals,

399
00:16:53,078 --> 00:16:54,880
which are almost like
hard water deposits.

400
00:16:54,913 --> 00:16:56,214
They're dissolved
minerals in the water

401
00:16:56,247 --> 00:16:58,216
that then fill up the cracks.

402
00:16:58,249 --> 00:17:00,919
And so, this ridge just
has a lot to explore,

403
00:17:00,952 --> 00:17:02,020
and that's what we'll be doing

404
00:17:02,053 --> 00:17:04,122
the next three or four months.

405
00:17:04,155 --> 00:17:06,758
But let's get to the main event.

406
00:17:06,791 --> 00:17:07,959
That's sort of where
we've been doing,

407
00:17:07,992 --> 00:17:10,896
I didn't wanna start
with a bunch of slides

408
00:17:10,929 --> 00:17:13,999
that didn't include some
nice pictures at first.

409
00:17:14,032 --> 00:17:15,901
So, now we're gonna launch into

410
00:17:15,934 --> 00:17:17,769
a story about the
climate and habitability

411
00:17:17,802 --> 00:17:20,038
of Mars that will last
the rest of the talk.

412
00:17:20,071 --> 00:17:21,807
So, here's Earth and Mars.

413
00:17:21,840 --> 00:17:23,909
We love how beautiful
our planet is.

414
00:17:23,942 --> 00:17:26,144
But Mars is not too bad itself.

415
00:17:26,177 --> 00:17:29,981
It's about the relative
size compared to Earth,

416
00:17:30,014 --> 00:17:32,217
much farther away, of
course, than shown here.

417
00:17:32,250 --> 00:17:34,019
It has polar caps.

418
00:17:35,887 --> 00:17:38,723
Sometimes it's portrayed
like, "Does Mars have water?"

419
00:17:38,756 --> 00:17:41,126
We've known it's
had ice for decades,

420
00:17:41,159 --> 00:17:43,061
since the 1970s, 60s even.

421
00:17:43,094 --> 00:17:45,997
So, Mars has a ton of water,

it's just all frozen now.

422
00:17:46,030 --> 00:17:47,799
And the atmosphere's very thin,

423
00:17:47,832 --> 00:17:49,801
so it's actually too thin
to have liquid water.

424
00:17:49,834 --> 00:17:53,805
It would actually boil or
freeze almost at the same time

425
00:17:53,838 --> 00:17:56,074
in the very thin
atmosphere of Mars.

426
00:17:56,107 --> 00:17:57,742
But it does have
clouds, these little

427
00:17:57,775 --> 00:18:00,145
wispy watery water ice clouds.

428
00:18:00,178 --> 00:18:03,815
And so, today Mars isn't really

429
00:18:03,848 --> 00:18:05,117
a very appealing place for life.

430
00:18:05,150 --> 00:18:07,018
We've sort of accepted
that, even though

431
00:18:07,051 --> 00:18:09,888
we'd love to find if
there's any life on Mars.

432
00:18:09,921 --> 00:18:11,990

And today, unfortunately,
also extends

433
00:18:12,023 --> 00:18:13,825
back about three billion years.

434
00:18:13,858 --> 00:18:17,963
We think Mars had these same
dry and cold conditions.

435
00:18:19,230 --> 00:18:21,733
It's a little further out
from the sun than Earth,

436
00:18:21,766 --> 00:18:24,202
so it's quite cold for probably

437
00:18:24,235 --> 00:18:26,872
the last two or
three billion years.

438
00:18:26,905 --> 00:18:29,774
But maybe Mars, we
think, actually,

439
00:18:29,807 --> 00:18:31,910
was quite different
early in its history

440
00:18:31,943 --> 00:18:34,112
from the time it
formed, maybe after it

441
00:18:34,145 --> 00:18:37,015
initially cooled off until maybe

442
00:18:37,048 --> 00:18:39,050
a billion years after it formed.

443

00:18:39,083 --> 00:18:42,053
And we have evidence to cause us

444
00:18:42,086 --> 00:18:44,089
to think that it
was quite different.

445
00:18:44,122 --> 00:18:45,857
So, keep your eye
on Mars right now.

446
00:18:45,890 --> 00:18:47,226
This is pretty cool.

447
00:18:49,794 --> 00:18:50,929
Maybe it was like that.

448
00:18:50,962 --> 00:18:53,165
[laughs]

449
00:18:53,198 --> 00:18:55,800
This is probably the
best case scenario,

450
00:18:55,833 --> 00:18:56,868
I'll admit that, as a scientist,

451
00:18:56,901 --> 00:18:58,003
I have to be honest with you.

452
00:18:58,036 --> 00:18:59,771
[laughs]

453
00:18:59,804 --> 00:19:02,941
This is like Mars with
a giant northern ocean,

454
00:19:02,974 --> 00:19:05,210
and a huge water

cycle with hurricanes.

455
00:19:05,243 --> 00:19:08,013
This is probably the
ultimate early Mars.

456
00:19:08,046 --> 00:19:10,949
It may have also been some less

457
00:19:10,982 --> 00:19:12,117
exciting version of this.

458
00:19:12,150 --> 00:19:14,085
But still very different,
where there was

459
00:19:14,118 --> 00:19:15,887
rivers, and there was lakes,

460
00:19:15,920 --> 00:19:17,055
and that's what I'll show you

461
00:19:17,088 --> 00:19:19,958
we found, in fact,
at Gale Crater.

462
00:19:19,991 --> 00:19:23,161
And so, here's some
of that evidence,

463
00:19:23,194 --> 00:19:26,765
for why, long before
Curiosity got there,

464
00:19:26,798 --> 00:19:28,099
we think that Mars did, in fact,

465
00:19:28,132 --> 00:19:32,137
have a lot more water

in the distant past.

466
00:19:32,170 --> 00:19:34,072
This is one of the
early pictures of Mars

467
00:19:34,105 --> 00:19:36,842
from probably the 1970s where,

468
00:19:38,009 --> 00:19:40,011
in the 60s, let me start there,

469
00:19:40,044 --> 00:19:43,014
JPL just a few years,
like a half a decade

470
00:19:43,047 --> 00:19:46,751
after Sputnik, JPL
already had a mission

471
00:19:46,784 --> 00:19:48,853
flying by Mars taking
the first pictures.

472
00:19:48,886 --> 00:19:52,991
And at that point, in 1965,
I think it was, Mariner 4,

473
00:19:54,792 --> 00:19:56,761
you're coming off
hundreds of years

474
00:19:56,794 --> 00:20:00,065
of history where there's
just ignorance about Mars.

475
00:20:00,098 --> 00:20:01,866
So, there was thought
that there still could

476
00:20:01,899 --> 00:20:05,203
be life on Mars, intelligent
life, plants, whatever,

477
00:20:05,236 --> 00:20:09,741
1965, all that excitement
with the spacecraft flying by,

478
00:20:09,774 --> 00:20:12,811
and the first pictures
were fuzzy pictures

479
00:20:12,844 --> 00:20:14,246
that just had craters.

480
00:20:17,048 --> 00:20:19,751
It disappointed a lot of
people, from what I hear.

481
00:20:19,784 --> 00:20:20,885
I wasn't even born yet.

482
00:20:20,918 --> 00:20:22,821
[laughs]

483
00:20:22,854 --> 00:20:25,023
But it had a lot of craters
that looked like the Moon.

484
00:20:25,056 --> 00:20:27,158
So, oh my gosh, Mars
is totally dead.

485
00:20:27,191 --> 00:20:28,860
But then just a few years later,

486
00:20:28,893 --> 00:20:29,995
pictures like this
started coming back

487
00:20:30,028 --> 00:20:32,831
from the follow up missions.

488
00:20:32,864 --> 00:20:34,199
These are craters
that made people think

489
00:20:34,232 --> 00:20:35,767
that maybe it was like the Moon,

490
00:20:35,800 --> 00:20:37,102
but look, between the craters on

491
00:20:37,135 --> 00:20:40,038
the plains there's
river systems.

492
00:20:40,071 --> 00:20:41,873
This is hard to get
around that water

493
00:20:41,906 --> 00:20:45,744
flowed around the surface,
and flowed downhill,

494
00:20:45,777 --> 00:20:46,978
and streams joined each other,

495
00:20:47,011 --> 00:20:49,114
just like they do on Earth,
and made bigger rivers,

496
00:20:49,147 --> 00:20:51,750
and they flowed for
sometimes hundreds of miles

497
00:20:51,783 --> 00:20:53,919
across the surface of Mars.

498
00:20:55,787 --> 00:20:58,189
A little later in history,
somewhat younger features

499
00:20:58,222 --> 00:20:59,991
get even more dramatic.

500
00:21:00,024 --> 00:21:02,027
So, these are actually channels,

501
00:21:02,060 --> 00:21:03,928
catastrophic flood channels.

502
00:21:03,961 --> 00:21:06,832
So, these channels
here are maybe

503
00:21:08,099 --> 00:21:10,869
several hundred feet
across, a quarter mile,

504
00:21:10,902 --> 00:21:12,037
a third of a mile wide.

505
00:21:12,070 --> 00:21:14,906
These channels can
be 50 miles wide,

506
00:21:14,939 --> 00:21:18,009
a hundred miles wide,
giant swaths of Mars

507
00:21:18,042 --> 00:21:20,011
where just huge amounts of water

508
00:21:20,044 --> 00:21:21,212
flowed across the
surface probably

509
00:21:21,245 --> 00:21:24,049
in catastrophic flows,
not over and over again,

510
00:21:24,082 --> 00:21:26,918
but just a huge flood, but
there's a lot of these.

511
00:21:26,951 --> 00:21:28,953
And so, something
dramatic happened

512
00:21:28,986 --> 00:21:31,923
at that point in Mars' history.

513
00:21:31,956 --> 00:21:33,825
And then we started
seeing pictures like this

514
00:21:33,858 --> 00:21:36,928
when we sent even more
sophisticated orbiters.

515
00:21:36,961 --> 00:21:39,798
This was discovered by
the Mars Global Surveyor

516
00:21:39,831 --> 00:21:42,134
in about the year 2000 I think.

517
00:21:44,135 --> 00:21:46,905
At the end of some of
these river networks,

518
00:21:46,938 --> 00:21:49,207
we call them valley networks,

519
00:21:49,240 --> 00:21:51,976

they empty into
craters like this,

520
00:21:52,009 --> 00:21:54,179
and where they empty, they
spread out into a fan.

521
00:21:54,212 --> 00:21:57,816
The sediment that's left
behind spreads out into a fan.

522
00:21:57,849 --> 00:22:00,852
People found these,
and after studying them

523
00:22:00,885 --> 00:22:03,755
and trying to disprove their
hypothesis about these,

524
00:22:03,788 --> 00:22:06,791
they're left with the idea
that these are deltas.

525
00:22:06,824 --> 00:22:08,159
So, a river flowed
into a crater,

526
00:22:08,192 --> 00:22:11,162
brought in a lot of
silty muddy water,

527
00:22:11,195 --> 00:22:13,064
met a standing body of water.

528
00:22:13,097 --> 00:22:14,199
That's the way you form a delta,

529
00:22:14,232 --> 00:22:17,869
like the Mississippi
going into the Gulf.

530
00:22:20,004 --> 00:22:22,974
The water causes the river
to suddenly slow down,

531
00:22:23,007 --> 00:22:25,143
and sediment drops out,
and it kinda spreads out,

532
00:22:25,176 --> 00:22:27,145
and you form this big
mound that's a delta

533
00:22:27,178 --> 00:22:28,847
with all these
different branches

534
00:22:28,880 --> 00:22:30,749
that the river
takes as it enters

535
00:22:30,782 --> 00:22:32,016
the standing body of water.

536
00:22:32,049 --> 00:22:33,151
So, this was evidence
that not only

537
00:22:33,184 --> 00:22:36,855
were there rivers, but
they lasted a long time

538
00:22:36,888 --> 00:22:38,923
to build up a giant
feature like this,

539
00:22:38,956 --> 00:22:43,094
and there were standing bodies
of water in these craters.

540
00:22:43,127 --> 00:22:46,731
So, here's sort of the history
of the climate of Mars.

541
00:22:46,764 --> 00:22:49,033
How did we get
from here to here?

542
00:22:49,066 --> 00:22:51,770
We started four and a
half billion years ago,

543
00:22:51,803 --> 00:22:52,904
and that geological era,

544
00:22:52,937 --> 00:22:54,205
because of all
these great features

545
00:22:54,238 --> 00:22:56,875
that look like they
were caused by water,

546
00:22:56,908 --> 00:22:59,911
we call that the
Noachian, like Noah.

547
00:22:59,944 --> 00:23:02,046
That's where the
valley networks are.

548
00:23:02,079 --> 00:23:03,882
So, this is like Jurassic Park,

549
00:23:03,915 --> 00:23:06,918
those ages Earth, we
have ages on Mars too.

550
00:23:06,951 --> 00:23:08,953

Not the Jurassic,
but the Noachian,

551
00:23:08,986 --> 00:23:10,789
Hesperian, and Amazonian.

552
00:23:10,822 --> 00:23:11,923
And the Noachian
is where you see

553
00:23:11,956 --> 00:23:14,159
the valley networks,
all those rivers.

554
00:23:14,192 --> 00:23:16,861
The Amazonian is the three
billion years to the present,

555
00:23:16,894 --> 00:23:19,831
where it's just wind and ice
really formed everything,

556
00:23:19,864 --> 00:23:21,866
not much liquid water anymore.

557
00:23:21,899 --> 00:23:23,168
And then the Hesperian
is kinda this

558
00:23:23,201 --> 00:23:25,737
mysterious time in Mars' history

559
00:23:25,770 --> 00:23:27,205
where there's not
as much evidence

560
00:23:27,238 --> 00:23:30,809
for long lived rivers, but
it's not quite dry yet,

561
00:23:30,842 --> 00:23:33,812
and you have these
catastrophic floods.

562
00:23:33,845 --> 00:23:35,880
What's the deal with those?

563
00:23:35,913 --> 00:23:37,215
And so, this is actually a

564
00:23:37,248 --> 00:23:40,152
quite interesting
time to explore.

565
00:23:41,252 --> 00:23:45,023
In terms of climate,
when you ask yourself

566
00:23:45,056 --> 00:23:47,158
what was necessary
for the climate system

567
00:23:47,191 --> 00:23:49,994
of Mars to be able to
form those features

568
00:23:50,027 --> 00:23:52,163
and to have a hydrologic cycle,

569
00:23:52,196 --> 00:23:55,934
for example, that could
supply rivers lakes.

570
00:23:55,967 --> 00:23:57,735
We've concluded, pretty much,

571
00:23:57,768 --> 00:24:00,205
as a scientific community,
that Mars was wet,

572
00:24:00,238 --> 00:24:01,973
hopefully you're
convinced of that,

573
00:24:02,006 --> 00:24:04,976
it's hard to deny all that
real geologic evidence,

574
00:24:05,009 --> 00:24:06,845
and maybe even warm.

575
00:24:06,878 --> 00:24:09,781
You could've had ice
that occasionally melted

576
00:24:09,814 --> 00:24:12,016
and formed these
rivers and lakes,

577
00:24:12,049 --> 00:24:13,818
but a much easier way to do that

578
00:24:13,851 --> 00:24:15,887
is you find some
way to heat up Mars,

579
00:24:15,920 --> 00:24:18,022
with a thicker atmosphere maybe,

580
00:24:18,055 --> 00:24:20,725
and then it's warm
enough to actually

581
00:24:20,758 --> 00:24:23,828
have a hydrologic cycle
with a humid atmosphere

582
00:24:23,861 --> 00:24:25,763

and evaporation from one place,

583
00:24:25,796 --> 00:24:27,031
and rain in another place.

584
00:24:27,064 --> 00:24:31,002
And then you really get a
very Earth like early Mars.

585
00:24:31,035 --> 00:24:32,971
There's problems
with this, actually,

586
00:24:33,004 --> 00:24:36,808
which make it all the
more fun to think about.

587
00:24:36,841 --> 00:24:40,011
And the same probably actually
is true for Earth, in fact.

588
00:24:40,044 --> 00:24:41,980
When you look at stars
across the universe,

589
00:24:42,013 --> 00:24:44,749
you come up with a
life cycle of stars,

590
00:24:44,782 --> 00:24:47,853
and they start
glowing less brightly,

591
00:24:49,854 --> 00:24:51,089
and as they get a little older,

592
00:24:51,122 --> 00:24:52,924
and they get into
their, I don't know,

593
00:24:52,957 --> 00:24:56,194
their teenage years, they
get very strong and bright,

594
00:24:56,227 --> 00:24:59,864
and there's a thing called
the faint young sun paradox

595
00:24:59,897 --> 00:25:02,800
where you have a lot
of water on Earth

596
00:25:02,833 --> 00:25:04,202
when the sun shouldn't
have been bright enough

597
00:25:04,235 --> 00:25:05,970
to allow it to be liquid.

598
00:25:06,003 --> 00:25:09,207
And the problem's
even worse at Mars,

599
00:25:09,240 --> 00:25:12,977
where the same fain
young sun existed

600
00:25:13,010 --> 00:25:15,947
a billion years
ago, only about 75%

601
00:25:15,980 --> 00:25:18,850
of the energy that
comes off the sun today

602
00:25:18,883 --> 00:25:22,020
was present in early
Mars and we, frankly,

603

00:25:22,053 --> 00:25:24,822
don't have any
climate models that

604
00:25:24,855 --> 00:25:28,793
take that sun and predict
a warm and wet Mars.

605
00:25:29,894 --> 00:25:32,864
So, this makes it
really fun for us

606
00:25:32,897 --> 00:25:34,966
on the Curiosity mission to find

607
00:25:34,999 --> 00:25:36,935
a lot of evidence,
which I'll show you,

608
00:25:36,968 --> 00:25:39,137
that says it was
probably warm and wet,

609
00:25:39,170 --> 00:25:41,906
and yet the people
who run climate models

610
00:25:41,939 --> 00:25:45,076
have no idea how
to make that work.

611
00:25:45,109 --> 00:25:48,179
See if you believe it. [laughs]

612
00:25:48,212 --> 00:25:49,914
So, what's cool about it is that

613
00:25:49,947 --> 00:25:51,983
Gale Crater is
right in Hesperian.

614
00:25:52,016 --> 00:25:53,952
So, the crater didn't even form

615
00:25:53,985 --> 00:25:55,853
'til about 3.8
billion years ago.

616
00:25:55,886 --> 00:25:57,989
So, we know that everything
Curiosity's seeing

617
00:25:58,022 --> 00:25:59,991
is from the Hesperian onward,

618
00:26:00,024 --> 00:26:02,193
and we think that
entire mountain formed

619
00:26:02,226 --> 00:26:05,196
and lasted a hundred
million years.

620
00:26:09,033 --> 00:26:12,904
So, from 3.8 to maybe
3.2 billion years ago

621
00:26:12,937 --> 00:26:15,106
is all the stuff you'll
see in our pictures

622
00:26:15,139 --> 00:26:17,775
other than the sand that's
blowing around today.

623
00:26:17,808 --> 00:26:20,044
But all the rock, all
the mountain parts

624

00:26:20,077 --> 00:26:22,847
are formed in this time period.

625
00:26:22,880 --> 00:26:24,148
So, we get to
explore this really

626
00:26:24,181 --> 00:26:28,786
interesting time and ask,
right here at the beginning,

627
00:26:28,819 --> 00:26:30,855
was Mars wet and warm?

628
00:26:30,888 --> 00:26:32,023
We can sort of infer what might

629
00:26:32,056 --> 00:26:33,891
have been the conditions here,

630
00:26:33,924 --> 00:26:36,928
and then we can ask, how long
did those conditions last?

631
00:26:36,961 --> 00:26:40,198
And what does it mean for
the possibility of life?

632
00:26:40,231 --> 00:26:41,966
I think that was my next slide.

633
00:26:41,999 --> 00:26:43,968
So, this is sort of where we are

634
00:26:44,001 --> 00:26:46,204
with the Curiosity
mission when we started.

635
00:26:46,237 --> 00:26:50,808

Mars was once wet and we
wanna know, was it also warm?

636
00:26:50,841 --> 00:26:52,944
And the specific
question, of course,

637
00:26:52,977 --> 00:26:57,849
that NASA charged us to
answer is, what is habitable?

638
00:26:57,882 --> 00:27:00,918
If there was ice and
it melted for a day,

639
00:27:00,951 --> 00:27:02,086
that's not really
that interesting

640
00:27:02,119 --> 00:27:05,757
for life and
habitability, because

641
00:27:05,790 --> 00:27:08,760
life can't evolve in 24 hours.

642
00:27:08,793 --> 00:27:10,995
But if we can find that
these wet conditions

643
00:27:11,028 --> 00:27:13,197
lasted for millions of years,

644
00:27:13,230 --> 00:27:16,134
tens of millions of
years, hopefully longer,

645
00:27:16,167 --> 00:27:20,772
that gives life a real chance
to do what it did on Earth.

646
00:27:21,839 --> 00:27:23,007
So, habitability.

647
00:27:23,040 --> 00:27:24,175
This is not Mars.

648
00:27:24,208 --> 00:27:26,077
[everyone laughs]

649
00:27:26,110 --> 00:27:29,147
This is one of the, for
us, less habitable places

650
00:27:29,180 --> 00:27:31,883
if you like spending
time in Death Valley,

651
00:27:31,916 --> 00:27:33,918
but perfectly habitable.

652
00:27:36,887 --> 00:27:39,090
When I give talks, and
there's eight year olds,

653
00:27:39,123 --> 00:27:41,759
I make them answer,
what is habitability?

654
00:27:41,792 --> 00:27:42,927
What conditions are required?

655
00:27:42,960 --> 00:27:44,729
But I won't make you answer.

656
00:27:44,762 --> 00:27:47,765
So, liquid water
is the first one.

657
00:27:47,798 --> 00:27:51,002
So, when we think of
what are the essential

658
00:27:51,035 --> 00:27:52,737
characteristics
of an environment

659
00:27:52,770 --> 00:27:56,040
that life can exist
in, liquid water

660
00:27:56,073 --> 00:27:57,175
is always the top of the list.

661
00:27:57,208 --> 00:27:58,843
Every life form we know on Earth

662
00:27:58,876 --> 00:28:01,045
requires liquid
water, and it actually

663
00:28:01,078 --> 00:28:03,047
requires not only liquid water,

664
00:28:03,080 --> 00:28:07,018
but liquid water that's
the right liquid water,

665
00:28:08,119 --> 00:28:11,856
not to acidic, not too
much dissolved in it,

666
00:28:13,157 --> 00:28:16,761
if it's too salty things don't
live, that sort of thing.

667
00:28:16,794 --> 00:28:18,896
So, we need to be a

little more sophisticated

668
00:28:18,929 --> 00:28:20,898
than just finding
evidence for liquid water.

669
00:28:20,931 --> 00:28:23,735
We need to ask,
what's the water like?

670
00:28:23,768 --> 00:28:25,770
The key chemical
ingredients for life,

671
00:28:25,803 --> 00:28:27,105
at least by analogy with Earth,

672
00:28:27,138 --> 00:28:29,107
we're not talking about
science fiction here,

673
00:28:29,140 --> 00:28:31,042
our best way of looking
for life on Mars

674
00:28:31,075 --> 00:28:33,845
is by analogy with us on Earth,

675
00:28:33,878 --> 00:28:36,214
and living things on
Earth share a lot of

676
00:28:36,247 --> 00:28:38,950
common characteristics in
terms of the chemistry.

677
00:28:38,983 --> 00:28:40,852
So carbon, hydrogen, oxygen,

678

00:28:40,885 --> 00:28:43,020
sulfur, phosphorus, nitrogen.

679
00:28:43,053 --> 00:28:45,823
There's five or six
elements, plus a few others,

680
00:28:45,856 --> 00:28:48,793
that are common
denominators for all of us,

681
00:28:48,826 --> 00:28:50,194
and bacteria, and
everything else.

682
00:28:50,227 --> 00:28:52,029
So, let's see if Mars had those

683
00:28:52,062 --> 00:28:54,966
to provide as raw
material for life.

684
00:28:54,999 --> 00:28:57,034
And then energy from metabolism.

685
00:28:57,067 --> 00:28:58,169
We all need sources of energy.

686
00:28:58,202 --> 00:29:00,071
We eat things who
eat other things,

687
00:29:00,104 --> 00:29:03,875
and eventually use the sun,
or something like that.

688
00:29:03,908 --> 00:29:05,777
There's a food chain
we're on the top of.

689
00:29:05,810 --> 00:29:07,912
On Mars, probably no food chain.

690
00:29:07,945 --> 00:29:09,180
If life ever existed,
it was probably

691
00:29:09,213 --> 00:29:13,785
just really basic life, and
so, it could use sunlight.

692
00:29:13,818 --> 00:29:15,019
But one of the
interesting things

693
00:29:15,052 --> 00:29:17,054
that we can look
for on Mars also

694
00:29:17,087 --> 00:29:19,891
is the way that certain
microbes on Earth

695
00:29:19,924 --> 00:29:22,160
can use chemistry for energy.

696
00:29:23,828 --> 00:29:25,963
You can dig down,
or you can somehow

697
00:29:25,996 --> 00:29:28,833
get a mile below the
surface of Earth,

698
00:29:28,866 --> 00:29:31,169
and find living microbes.

699
00:29:31,202 --> 00:29:33,738
Some of them are

actually able to use

700
00:29:33,771 --> 00:29:37,175
the chemical differences
between rocks at at that depth,

701
00:29:37,208 --> 00:29:39,043
there are minerals in the rocks,

702
00:29:39,076 --> 00:29:43,181
and create little batteries
between different chemicals

703
00:29:43,214 --> 00:29:47,952
and allow them to source
that energy to live.

704
00:29:47,985 --> 00:29:49,120
So, we can look
for those similar

705
00:29:49,153 --> 00:29:51,923
types of sources
of energy on Mars

706
00:29:51,956 --> 00:29:54,893
if life may have
been underground.

707
00:29:55,993 --> 00:29:57,094
And then how do we
look for all this?

708
00:29:57,127 --> 00:29:58,896
How do we study habitability?

709
00:29:58,929 --> 00:30:01,766
Jim did a great job of
describing the rover.

710
00:30:01,799 --> 00:30:05,870
We love the laser, it's the
most fun experiment to run.

711
00:30:10,074 --> 00:30:13,911
The way that we get at
the habitability issues,

712
00:30:13,944 --> 00:30:16,214
and the chemical ingredients
necessary for life,

713
00:30:16,247 --> 00:30:18,883
and the raw material,
and all those things,

714
00:30:18,916 --> 00:30:22,019
in the most in depth way
is through our drill,

715
00:30:22,052 --> 00:30:24,088
which we place against
a rock and drill powder,

716
00:30:24,121 --> 00:30:25,890
and deliver it to
two laboratories

717
00:30:25,923 --> 00:30:27,892
that are built in the
front of the rover.

718
00:30:27,925 --> 00:30:30,828
So, this was a real
feat for the people

719
00:30:30,861 --> 00:30:32,930
who designed and built the rover

720

00:30:32,963 --> 00:30:35,900
to actually fit in laboratories.

721
00:30:35,933 --> 00:30:37,835
These are laboratories
that would fill

722
00:30:37,868 --> 00:30:40,972
a better part of a
university office,

723
00:30:41,005 --> 00:30:44,008
in a geology department
at a university.

724
00:30:44,041 --> 00:30:46,744
This is a mass spectrometer and

725
00:30:46,777 --> 00:30:50,147
a gas chromatograph, and a
tunable laser spectrometer.

726
00:30:50,180 --> 00:30:52,750
Probably spread it
out over a huge room

727
00:30:52,783 --> 00:30:54,151
in a university, but
you shrink it down,

728
00:30:54,184 --> 00:30:57,722
you miniaturize it, you
stuff it all in a canister

729
00:30:57,755 --> 00:30:59,957
about the size of an
old microwave oven,

730
00:30:59,990 --> 00:31:01,993
and you gold plate

it 'cause it's cool,

731
00:31:02,026 --> 00:31:04,795
[everyone laughs]

732
00:31:04,828 --> 00:31:06,831
and then you carefully
put it in the rover.

733
00:31:06,864 --> 00:31:08,766
And so, this is one of
our main laboratories

734
00:31:08,799 --> 00:31:12,970
call SAM, sample analysis at
Mars, everything's an acronym,

735
00:31:13,003 --> 00:31:16,073
and 650 yard of wiring,
ovens that heat up

736
00:31:16,106 --> 00:31:18,142
the rock and soil to
a thousand degrees,

737
00:31:18,175 --> 00:31:20,144
and decompose it, degrade it so

738
00:31:20,177 --> 00:31:23,781
the gasses come off
and we can study them.

739
00:31:23,814 --> 00:31:26,217
Some of our most nerve wracking

740
00:31:26,250 --> 00:31:30,087
mechanisms on the rover,
100,000 RPM vacuum pumps

741

00:31:30,120 --> 00:31:32,723
which you can never maintain.

742
00:31:32,756 --> 00:31:36,828
You send them to Mars, and
you hope they keep working.

743
00:31:37,995 --> 00:31:40,765
We get nervous about
sending any motors to Mars,

744
00:31:40,798 --> 00:31:44,035
even simple motors,
but 100,000 RPM pumps,

745
00:31:45,102 --> 00:31:46,837
they're still working.

746
00:31:46,870 --> 00:31:49,774
[audience laughs]

747
00:31:49,807 --> 00:31:52,243
So, here, we landed
five years ago

748
00:31:53,877 --> 00:31:56,013
at, actually, 10:30 tonight is

749
00:31:56,046 --> 00:31:58,883
when we all gathered here at JPL

750
00:31:59,984 --> 00:32:02,153
with about, I think, a
thousand other people

751
00:32:02,186 --> 00:32:04,989
to listen helplessly, actually,

752
00:32:05,022 --> 00:32:08,092

as Curiosity sent back signals

753
00:32:08,125 --> 00:32:12,830
14 minutes old as it
descended to the surface.

754
00:32:12,863 --> 00:32:14,799
I'd show you the
movie, it's super fun,

755
00:32:14,832 --> 00:32:17,201
but go watch it online
if you wanna relive it.

756
00:32:17,234 --> 00:32:19,771
[laughs]

757
00:32:20,904 --> 00:32:24,041
These are the scour marks from

758
00:32:24,074 --> 00:32:27,078
the rocket engines
that were on a little

759
00:32:27,111 --> 00:32:30,047
jet pack that lowered
the rover to the surface.

760
00:32:30,080 --> 00:32:31,849
They actually led to one of our

761
00:32:31,882 --> 00:32:35,086
first major discoveries about
climate and habitability.

762
00:32:35,119 --> 00:32:37,154
This is Mount Sharp,
those are those dunes.

763

00:32:37,187 --> 00:32:39,090
So, we landed quite far away,

764
00:32:39,123 --> 00:32:41,792
and since then have
traversed across those dunes

765
00:32:41,825 --> 00:32:44,762
and climbed a little
ways up the mountain.

766
00:32:44,795 --> 00:32:46,097
But here are those scour marks.

767
00:32:46,130 --> 00:32:50,001
We looked up close,
just days after landing.

768
00:32:50,034 --> 00:32:52,770
About a month after
landing we got to this site

769
00:32:52,803 --> 00:32:54,739
where we found these,
what looked like

770
00:32:54,772 --> 00:32:58,109
upturned pieces of
sidewalk, and it turned out

771
00:32:58,142 --> 00:33:00,845
that they were a rock
called a conglomerate.

772
00:33:00,878 --> 00:33:02,947
That's a rock made out
of a bunch of other rock

773
00:33:02,980 --> 00:33:07,085
that's cemented together,

just like a sidewalk actually.

774
00:33:08,185 --> 00:33:11,188
As the rock was falling apart,

775
00:33:11,221 --> 00:33:15,059
after a few billion
years of sitting there,

776
00:33:15,092 --> 00:33:16,727
the pebbles that were coming out

777
00:33:16,760 --> 00:33:17,995
were all distinctly rounded.

778
00:33:18,028 --> 00:33:19,764
You can see that.

779
00:33:19,797 --> 00:33:22,733
And that is something
that doesn't happen

780
00:33:22,766 --> 00:33:25,736
too easily in the natural world.

781
00:33:25,769 --> 00:33:28,939
When rocks break they are
very sharp and jagged.

782
00:33:28,972 --> 00:33:31,742
But if they're rolling around,

783
00:33:31,775 --> 00:33:35,012
in a stream for example,
for 10 miles or so,

784
00:33:35,045 --> 00:33:37,081
you can round them
like is seen here.

785
00:33:37,114 --> 00:33:39,817
So, we already had this really

786
00:33:39,850 --> 00:33:42,219
visceral evidence that
we were traversing

787
00:33:42,252 --> 00:33:45,923
across an ancient streambed
just a month after landing.

788
00:33:45,956 --> 00:33:47,858
And we thought that
might be the case

789
00:33:47,891 --> 00:33:50,161
from outlines of
an ancient river

790
00:33:50,194 --> 00:33:53,197
that we could see
near our landing site.

791
00:33:53,230 --> 00:33:54,999
But this is really
the first time

792
00:33:55,032 --> 00:33:56,967
that we've been on
the surface of Mars,

793
00:33:57,000 --> 00:33:59,070
with our own robotic eyes,

794
00:33:59,103 --> 00:34:03,074
seeing something that
we can all relate too,

795

00:34:03,107 --> 00:34:07,211
rounded pebbles on the
bottom of a streambed.

796
00:34:07,244 --> 00:34:09,980
We then drover over
to Yellowknife Bay.

797
00:34:10,013 --> 00:34:12,850
So, here's Mount Sharp.

798
00:34:12,883 --> 00:34:14,051
This is one of our
gorgeous images

799
00:34:14,084 --> 00:34:15,986
from our navigation
cameras which are

800
00:34:16,019 --> 00:34:18,055
grayscale black
and white cameras.

801
00:34:18,088 --> 00:34:21,025
This is our arm
deployed at the surface.

802
00:34:21,058 --> 00:34:23,861
We're about to drill here.

803
00:34:23,894 --> 00:34:27,731
You'll notice how dramatic
the scenery has changed.

804
00:34:27,764 --> 00:34:29,166
In the image you
saw before there was

805
00:34:29,199 --> 00:34:31,735
a bunch of gravel,

little rocks everywhere.

806
00:34:31,768 --> 00:34:34,839
Now, we're in these
big slabs of rock.

807
00:34:34,872 --> 00:34:36,140
What attracted us
to this site is,

808
00:34:36,173 --> 00:34:38,109
again, from looking at
the orbital pictures

809
00:34:38,142 --> 00:34:40,077
thinking that that
stream might have

810
00:34:40,110 --> 00:34:43,781
led to an ancient
lake at one point.

811
00:34:43,814 --> 00:34:46,050
And when we got here,
at the site of this

812
00:34:46,083 --> 00:34:48,752
what we though might have
been an ancient lake,

813
00:34:48,785 --> 00:34:50,888
the rocks all of the sudden
turn into these big slabs

814
00:34:50,921 --> 00:34:53,791
of very fine grain material.

815
00:34:53,824 --> 00:34:55,860
And so far, that
was really good news

816
00:34:55,893 --> 00:34:58,762
for the fact that it could
actually be lake deposits.

817
00:34:58,795 --> 00:35:02,199
And so, of course, we
wanted to drill it.

818
00:35:02,232 --> 00:35:05,903
I love these pictures
of our drill holes.

819
00:35:05,936 --> 00:35:08,806
The drill hole's
only a dime size,

820
00:35:08,839 --> 00:35:11,209
to give you a
sense of the scale.

821
00:35:12,876 --> 00:35:14,078
This is one of my
favorite pictures

822
00:35:14,111 --> 00:35:16,747
of the whole mission just
'cause how cool it is.

823
00:35:16,780 --> 00:35:18,782
We drilled this
hole, and we took a

824
00:35:18,815 --> 00:35:20,885
picture of it from about
seven feet off the ground,

825
00:35:20,918 --> 00:35:22,052
looking at a dime
sized drill hole,

826
00:35:22,085 --> 00:35:23,921
so we have great cameras.

827
00:35:23,954 --> 00:35:25,156
And then we shot
it with the laser,

828
00:35:25,189 --> 00:35:27,091
[mimics laser shots]

829
00:35:27,124 --> 00:35:29,160
again, from seven
feet off the ground

830
00:35:29,193 --> 00:35:31,962
into a dime sized
drill hole to see

831
00:35:31,995 --> 00:35:35,199
if the composition changed
with the depth of the drill.

832
00:35:35,232 --> 00:35:39,103
And then we saw this
gorgeous mineral vein,

833
00:35:39,136 --> 00:35:41,205
which is, again, that sort
of hard water deposit stuff,

834
00:35:41,238 --> 00:35:43,107
calcium sulfate
which probably was

835
00:35:43,140 --> 00:35:46,844
ground water flowing through
the rock after it hardened.

836

00:35:46,877 --> 00:35:49,113
This is also one of
my favorite pictures.

837
00:35:49,146 --> 00:35:51,982
You get to see my favorite
pictures of Mars tonight,

838
00:35:52,015 --> 00:35:54,852
in the five year
anniversary talk.

839
00:35:54,885 --> 00:35:56,120
What I love about
this one is that

840
00:35:56,153 --> 00:36:00,758
we took it with our own light
in the middle of the night.

841
00:36:00,791 --> 00:36:03,794
All the other pictures
of Mars you'll see

842
00:36:03,827 --> 00:36:07,765
are falsely, or as
best as we can do,

843
00:36:07,798 --> 00:36:09,833
corrected to remove
the orange glow

844
00:36:09,866 --> 00:36:11,769
of all the dust in
Mars' atmosphere.

845
00:36:11,802 --> 00:36:14,838
So, if you just snap a picture
on Mars, it's very orange.

846

00:36:14,871 --> 00:36:16,073
But we try to color correct them

847
00:36:16,106 --> 00:36:18,108
so that human eyes
can sort of better

848
00:36:18,141 --> 00:36:20,811
understand what's going
on without all the orange.

849
00:36:20,844 --> 00:36:22,046
But this one is a real picture.

850
00:36:22,079 --> 00:36:25,883
Because the glow of the
orange sky is gone at night.

851
00:36:25,916 --> 00:36:29,019
And when you bring a
LED, your own flash,

852
00:36:29,052 --> 00:36:33,924
with you on the camera, this
is the real color of Mars.

853
00:36:33,957 --> 00:36:36,060
And so, what was cool is that
we drilled into the rock,

854
00:36:36,093 --> 00:36:39,830
and the material inside
the rock wasn't red,

855
00:36:39,863 --> 00:36:43,767
which is true of most of
the oxidized parts of Mars.

856
00:36:43,800 --> 00:36:44,902
It was actually gray.

857
00:36:44,935 --> 00:36:46,937
So, that was great
evidence that this

858
00:36:46,970 --> 00:36:49,206
material hadn't been
exposed to a lot

859
00:36:49,239 --> 00:36:50,941
of harsh conditions
like other parts

860
00:36:50,974 --> 00:36:53,110
of Mars that had been
oxidized and weathered,

861
00:36:53,143 --> 00:36:56,880
and may actually
preserve evidence

862
00:36:56,913 --> 00:37:00,017
of the conditions
from a long time ago.

863
00:37:00,050 --> 00:37:01,752
So, again, fine grain material,

864
00:37:01,785 --> 00:37:04,121
and we analyzed it
in our laboratories,

865
00:37:04,154 --> 00:37:08,759
and we found an ancient
lake based on the geology.

866
00:37:09,826 --> 00:37:12,029
We found fresh water
based on the minerals

867
00:37:12,062 --> 00:37:13,897
that were in that drill hole.

868
00:37:13,930 --> 00:37:15,199
We found clay minerals
in particular,

869
00:37:15,232 --> 00:37:17,935
phyllosilicates
that form when water

870
00:37:17,968 --> 00:37:19,937
interacts with rock,
but not just any water,

871
00:37:19,970 --> 00:37:22,072
water that's not too acidic.

872
00:37:22,105 --> 00:37:25,843
We found not too many salts
dissolved in that rock.

873
00:37:25,876 --> 00:37:29,780
So, the water was basically
fresh water available for life.

874
00:37:29,813 --> 00:37:32,116
And we found the key
chemical ingredients of life.

875
00:37:32,149 --> 00:37:33,917
We found carbon, and
nitrogen, and oxygen,

876
00:37:33,950 --> 00:37:35,886
and sulfur, and
phosphorus, and nitrogen

877
00:37:35,919 --> 00:37:37,721

in the form of nitrates.

878
00:37:37,754 --> 00:37:38,989
That's actually a
nutrient for life,

879
00:37:39,022 --> 00:37:41,792
a form of nitrogen
that life can use.

880
00:37:41,825 --> 00:37:43,027
And we found organic molecules.

881
00:37:43,060 --> 00:37:45,062
We found simple
organic molecules.

882
00:37:45,095 --> 00:37:48,198
Not like DNA quite
yet, but we found

883
00:37:48,231 --> 00:37:50,734
organic molecules
that, at least,

884
00:37:50,767 --> 00:37:53,237
showed that Mars
had already become

885
00:37:54,971 --> 00:37:57,007
to naturally, probably,
assemble larger

886
00:37:57,040 --> 00:38:00,010
molecules out of carbon,
and hydrogen, and oxygen.

887
00:38:00,043 --> 00:38:01,979
And those molecules,
very importantly,

888
00:38:02,012 --> 00:38:05,115
survived three billion years
sitting in these rocks.

889
00:38:05,148 --> 00:38:07,951
So, in future missions
when we go look for life,

890
00:38:07,984 --> 00:38:09,920
or return samples
back from Earth,

891
00:38:09,953 --> 00:38:11,188
this is one of our main
findings from the mission,

892
00:38:11,221 --> 00:38:14,892
is that we have hope
that even old rocks

893
00:38:14,925 --> 00:38:16,894
have preserved
that evidence that

894
00:38:16,927 --> 00:38:20,164
we can bring back
and study on Earth.

895
00:38:20,197 --> 00:38:23,867
Okay, so, I gotta keep this from

896
00:38:23,900 --> 00:38:26,937
going into the three
hour version of the talk.

897
00:38:26,970 --> 00:38:28,205
So, I'm gonna speed up.

898

00:38:28,238 --> 00:38:30,974
But this is a
little map of Mars,

899
00:38:31,007 --> 00:38:33,844
of the mission really,
in sort of profile.

900
00:38:33,877 --> 00:38:35,846
We landed out here
on Yellowknife Bay,

901
00:38:35,879 --> 00:38:40,117
we drove across the
plains, and that's sort of

902
00:38:40,150 --> 00:38:41,852
where we spent the
first two years.

903
00:38:41,885 --> 00:38:44,121
I got just a couple pictures
of what we found there.

904
00:38:44,154 --> 00:38:46,757
Another one of my
favorite pictures.

905
00:38:46,790 --> 00:38:49,093
We came across this
amazing landscape

906
00:38:49,126 --> 00:38:53,130
where the fine grain
muddy, mudstone we call it,

907
00:38:54,197 --> 00:38:57,168
the lake bed deposits
had gone away,

908

00:38:58,235 --> 00:39:00,170
and the gravel had gone
away, and there was

909
00:39:00,203 --> 00:39:04,141
this amazing set of these
linear beds of sandstone.

910
00:39:04,174 --> 00:39:06,944
So, now not mud,
but bigger particles

911
00:39:06,977 --> 00:39:09,246
of sand that had formed slabs.

912
00:39:10,981 --> 00:39:12,216
And you can see all
the slabs are kind of

913
00:39:12,249 --> 00:39:16,820
tilted away from you
towards Mount Sharp.

914
00:39:16,853 --> 00:39:19,056
And this was, again, studied,

915
00:39:19,089 --> 00:39:20,791
we tried to come up
with a lot of ways

916
00:39:20,824 --> 00:39:22,760
of explaining this,
and as good scientists,

917
00:39:22,793 --> 00:39:25,028
tried to prove ourselves
wrong in each case,

918
00:39:25,061 --> 00:39:28,098
and the hypothesis that survived

919
00:39:28,131 --> 00:39:30,768
was that this was a river delta.

920
00:39:30,801 --> 00:39:33,904
And so, we now had
seen a river bed,

921
00:39:33,937 --> 00:39:37,842
a streambed, we had seen
the lake bed of a lake

922
00:39:38,909 --> 00:39:40,944
in Yellowknife Bay,
and now we find

923
00:39:40,977 --> 00:39:42,146
the interface between those two,

924
00:39:42,179 --> 00:39:45,082
where a river meets a
lake, it forms a delta.

925
00:39:45,115 --> 00:39:47,084
And it forms the
delta out of sand,

926
00:39:47,117 --> 00:39:50,120
that's the particular
size of particles

927
00:39:50,153 --> 00:39:52,890
that first gets dumped
out of the water

928
00:39:52,923 --> 00:39:55,726
when a flowing
river hits a lake.

929

00:39:55,759 --> 00:39:59,863
And so, this made kind of an
amazing prediction though.

930
00:39:59,896 --> 00:40:03,033
It suggested that
there was a giant lake

931
00:40:03,066 --> 00:40:07,171
that probably filled in much
of the area in this picture.

932
00:40:08,839 --> 00:40:11,742
In fact, what's not
obvious form this picture,

933
00:40:11,775 --> 00:40:14,044
but everything sort of
goes higher and higher.

934
00:40:14,077 --> 00:40:18,182
So, there's a delta here, and
then all this rock above it.

935
00:40:18,215 --> 00:40:19,783
So, that doesn't quite work.

936
00:40:19,816 --> 00:40:21,018
How do you have a
lake in front of you

937
00:40:21,051 --> 00:40:23,854
when the mountain is
climbing up in front of you,

938
00:40:23,887 --> 00:40:26,123
unless the mountain wasn't there

939
00:40:26,156 --> 00:40:29,126
when the lakes were there,

and instead the mountain

940
00:40:29,159 --> 00:40:31,995
itself is some
remnant of lake beds

941
00:40:32,028 --> 00:40:35,098
that were built
successively over time.

942
00:40:35,131 --> 00:40:38,936
So, that was sort of
a crazy hypothesis,

943
00:40:38,969 --> 00:40:41,171
but we had to go
test it, of course.

944
00:40:41,204 --> 00:40:43,207
As we got to the
mountain, the prediction

945
00:40:43,240 --> 00:40:45,943
was we would find
lake bed sediments,

946
00:40:45,976 --> 00:40:50,113
like at Yellowknife Bay,
but in the mountain itself.

947
00:40:50,146 --> 00:40:52,182
And that's what we
found, remarkably.

948
00:40:52,215 --> 00:40:54,818
We got to the base
of the mountain,

949
00:40:54,851 --> 00:40:58,188
and we found these very

thin repetitive layers,

950
00:40:58,221 --> 00:41:00,157
two millimeters, three
millimeters thick,

951
00:41:00,190 --> 00:41:02,926
hundreds, and hundreds,
and hundreds of them.

952
00:41:02,959 --> 00:41:05,762
You can form those
by wind, for example

953
00:41:05,795 --> 00:41:08,765
blowing around sand or
blowing around dust,

954
00:41:08,798 --> 00:41:10,200
but when you do that,
you tend to form

955
00:41:10,233 --> 00:41:14,037
more wavy beds that,
you follow one layer

956
00:41:14,070 --> 00:41:16,006
and it kinda ends and
then another one starts,

957
00:41:16,039 --> 00:41:17,941
it's called cross bedding.

958
00:41:17,974 --> 00:41:19,877
These, you can
follow these layers

959
00:41:19,910 --> 00:41:23,146
for a long ways across
the entire surface,

960
00:41:23,179 --> 00:41:26,016
and it's very consistent
with very slow

961
00:41:26,049 --> 00:41:29,786
sedimentation inside a
standing body of water,

962
00:41:29,819 --> 00:41:32,956
where it's calm water, the lake
floor just goes on forever,

963
00:41:32,989 --> 00:41:35,792
and you just deposit
a very thin layer,

964
00:41:35,825 --> 00:41:37,995
year after year,
decade after decade,

965
00:41:38,028 --> 00:41:40,764
and you build up
years and years,

966
00:41:40,797 --> 00:41:45,102
and decades, and eons of
time in these deposits.

967
00:41:45,135 --> 00:41:46,904
So, we found this at the base of

968
00:41:46,937 --> 00:41:48,038
the mountain, and
then, of course,

969
00:41:48,071 --> 00:41:50,140
wanted to figure out how
much of the mountain,

970
00:41:50,173 --> 00:41:52,876
how long does this story go on?

971
00:41:52,909 --> 00:41:55,779
How long did the lakes last?

972
00:41:55,812 --> 00:41:57,147
So, that's what we did.

973
00:41:57,180 --> 00:41:59,016
We got to the mountain here,

974
00:41:59,049 --> 00:42:00,817
and then we were in
the Murray Formation,

975
00:42:00,850 --> 00:42:03,787
this main first
layer of the mountain

976
00:42:03,820 --> 00:42:05,722
that we've been in
for the entire time,

977
00:42:05,755 --> 00:42:07,791
up until about a month from now,

978
00:42:07,824 --> 00:42:10,861
when we actually climb
the Hematite Unit.

979
00:42:10,894 --> 00:42:13,764
We first had to drive
across some obstacles.

980
00:42:13,797 --> 00:42:16,133
One of them was called
the Stimson formation,

981
00:42:16,166 --> 00:42:18,001
which is another
geologic term we use

982
00:42:18,034 --> 00:42:21,038
for a bunch of sandstone
that probably came in,

983
00:42:21,071 --> 00:42:24,074
we think, later, and
it just is sort of

984
00:42:24,107 --> 00:42:26,777
a younger thing we have
to sort of drive around

985
00:42:26,810 --> 00:42:30,147
to continue to find
more lake bed deposits.

986
00:42:30,180 --> 00:42:32,115
Here's what it looked like
as we were driving across

987
00:42:32,148 --> 00:42:34,217
towards the higher
parts of the mountain.

988
00:42:34,250 --> 00:42:37,721
This is one, I say it again,
one of my favorite pictures.

989
00:42:37,754 --> 00:42:39,790
And the reason it
is, in this case,

990
00:42:39,823 --> 00:42:41,925
is because it shows
such great variety

991
00:42:41,958 --> 00:42:44,995
of all the materials
that we studied.

992
00:42:46,196 --> 00:42:48,865
There's the gravel, there
are these dark rocks

993
00:42:48,898 --> 00:42:50,734
that is one of the
more mysterious things.

994
00:42:50,767 --> 00:42:53,003
We don't really understand
these very dark rocks.

995
00:42:53,036 --> 00:42:55,806
They're kinda rare, but here
there's a bunch of them.

996
00:42:55,839 --> 00:42:57,975
There's the sand that
we've studied many times.

997
00:42:58,008 --> 00:42:59,776
There's the mudstone,
the lake bed

998
00:42:59,809 --> 00:43:01,712
deposits that look like this.

999
00:43:01,745 --> 00:43:05,749
There's sandstone that came
later, the Stimson formation,

1000
00:43:05,782 --> 00:43:08,185
that forms these
mesas and buttes.

1001

00:43:08,218 --> 00:43:10,754
And then there's the
rounded domes here

1002
00:43:10,787 --> 00:43:12,789
of the Sulfate Unit that's
higher up on the mountain

1003
00:43:12,822 --> 00:43:15,092
that we'll maybe get
to in a year or two,

1004
00:43:15,125 --> 00:43:18,796
and then the upper
parts of Mount Sharp.

1005
00:43:19,896 --> 00:43:20,931
And here's what
it looks like when

1006
00:43:20,964 --> 00:43:23,900
we're at the interface
between the mud

1007
00:43:23,933 --> 00:43:27,804
of the lakes and the sand
of the Stimson formation.

1008
00:43:27,837 --> 00:43:30,107
And we got a really good
look at the Stimson here,

1009
00:43:30,140 --> 00:43:32,175
which is the sandstone
that came later.

1010
00:43:32,208 --> 00:43:34,177
And actually, this is the
site where we learned,

1011

00:43:34,210 --> 00:43:36,146
where pieced
together the history

1012
00:43:36,179 --> 00:43:37,981
of did it actually come later,

1013
00:43:38,014 --> 00:43:41,852
and we did that at what's
called a geological contact,

1014
00:43:41,885 --> 00:43:44,087
kind of a word that probably
makes immediate sense to you,

1015
00:43:44,120 --> 00:43:46,156
where two things
touch, they contact.

1016
00:43:46,189 --> 00:43:48,125
And that's one thing
where you can learn

1017
00:43:48,158 --> 00:43:52,763
about how one episode of forming
rocks turned into another

1018
00:43:54,164 --> 00:43:55,899
by looking at their interface.

1019
00:43:55,932 --> 00:43:58,201
So, we spent a lot of time in
this area called Marias Pass

1020
00:43:58,234 --> 00:44:00,804
studying the details
of this interface

1021
00:44:00,837 --> 00:44:04,808
and figuring out that the

mudstone form eroded away,

1022
00:44:04,841 --> 00:44:06,977
then sand blew in by the wind,

1023
00:44:07,010 --> 00:44:11,081
this wasn't formed in water at
all, and sand dunes built up,

1024
00:44:11,114 --> 00:44:13,050
and then those dunes
turned into rock

1025
00:44:13,083 --> 00:44:17,721
and left these amazing
sandstone formations behind.

1026
00:44:17,754 --> 00:44:21,725
And if you think those
are pretty, look at these.

1027
00:44:21,758 --> 00:44:23,960
These are just
amazing landscape,

1028
00:44:23,993 --> 00:44:27,164
like you're in Utah, or
Arizona, or somewhere.

1029
00:44:27,197 --> 00:44:28,799
These are the Murray Buttes.

1030
00:44:28,832 --> 00:44:29,900
And here's all the
lake bed mudstone

1031
00:44:29,933 --> 00:44:31,168
that we continue to see over and

1032

00:44:31,201 --> 00:44:33,070
over again as we
climb the mountain,

1033
00:44:33,103 --> 00:44:34,971
and then the later
sandstone came in.

1034
00:44:35,004 --> 00:44:38,208
You can imagine that all
these were once connected.

1035
00:44:38,241 --> 00:44:41,778
There was a whole thick
layer of sand that blew in,

1036
00:44:41,811 --> 00:44:44,881
and then was buried
and turned into rock.

1037
00:44:44,914 --> 00:44:46,983
And now most of
it, 90% of it has

1038
00:44:47,016 --> 00:44:49,820
been eroded away and blow away,

1039
00:44:49,853 --> 00:44:52,723
and you just leave these
impressive towers behind.

1040
00:44:52,756 --> 00:44:55,058
And the towers sort
of protected by this

1041
00:44:55,091 --> 00:44:57,828
capping rock that
protects it from

1042
00:44:57,861 --> 00:45:00,097

erosion and slowly
blocks fall off.

1043
00:45:00,130 --> 00:45:02,966
If you come 10,000
years from now,

1044
00:45:02,999 --> 00:45:04,067
it'll be a little smaller,

1045
00:45:04,100 --> 00:45:08,105
and a million years from
now, it might be gone.

1046
00:45:08,138 --> 00:45:11,875
So then, we really
got to the good stuff

1047
00:45:11,908 --> 00:45:15,746
when we passed through
the Stimson formation

1048
00:45:15,779 --> 00:45:16,947
and we got to where the mountain

1049
00:45:16,980 --> 00:45:19,182
just starts taking
off in elevation.

1050
00:45:19,215 --> 00:45:23,053
So, we've been climbing
now for the past few years

1051
00:45:23,086 --> 00:45:27,791
through the bulk of the Murray
Formation, almost 600 feet.

1052
00:45:27,824 --> 00:45:29,760
This offered the
opportunity for us

1053
00:45:29,793 --> 00:45:32,929
to kind of change our approach.

1054
00:45:32,962 --> 00:45:34,164
The variety sort of went away.

1055
00:45:34,197 --> 00:45:36,833
There was not the buttes
anymore, and the sandstone.

1056
00:45:36,866 --> 00:45:38,735
It was just all mudstone.

1057
00:45:38,768 --> 00:45:40,937
And so, we fame up
with a process of

1058
00:45:40,970 --> 00:45:43,740
every once in a while
just drilling regularly.

1059
00:45:43,773 --> 00:45:46,143
Every 25 meters we said
we're gonna drill a hole

1060
00:45:46,176 --> 00:45:48,211
and build up a record of how the

1061
00:45:48,244 --> 00:45:50,781
Murray Formation
changed over time.

1062
00:45:50,814 --> 00:45:52,749
Because if it was all lakes,

1063
00:45:52,782 --> 00:45:54,084
maybe the lakes
changed over time.

1064
00:45:54,117 --> 00:45:57,220
Maybe they came and went,
maybe their chemistry changed,

1065
00:45:57,253 --> 00:45:59,756
and their habitability
conditions changed.

1066
00:45:59,789 --> 00:46:01,958
So, let's just
build up a record.

1067
00:46:01,991 --> 00:46:03,827
And that's what this shows.

1068
00:46:03,860 --> 00:46:06,830
We've now drilled
15 times on Mars,

1069
00:46:06,863 --> 00:46:08,865
and we've scooped
up sand and analyzed

1070
00:46:08,898 --> 00:46:10,834
in our laboratories four times.

1071
00:46:10,867 --> 00:46:11,968
And these are all
the drill holes

1072
00:46:12,001 --> 00:46:14,938
that we drilled in
the Murray Formation.

1073
00:46:14,971 --> 00:46:17,174
And you can see there's a lot
of variety, even to your eye.

1074

00:46:17,207 --> 00:46:18,842
Some of it is the less weathered

1075
00:46:18,875 --> 00:46:20,977
oxidized material that's grayer.

1076
00:46:21,010 --> 00:46:23,980
Others, it's distinctly
red like most

1077
00:46:24,013 --> 00:46:27,150
of Mars appears because
it's more oxidized.

1078
00:46:27,183 --> 00:46:29,219
And so, by drilling successively

1079
00:46:29,252 --> 00:46:32,022
as we climb through the
Murray every 25 meters,

1080
00:46:32,055 --> 00:46:33,190
we can see that
the environmental

1081
00:46:33,223 --> 00:46:35,759
conditions were
actually changing.

1082
00:46:35,792 --> 00:46:40,564
And we, of course, wanted to
understand what that meant

1083
00:46:40,597 --> 00:46:43,901
for the prospects for
life and habitability.

1084
00:46:45,001 --> 00:46:47,103
So, I won't go through all this,

1085
00:46:47,136 --> 00:46:48,872
but this is sort
of one of the ways

1086
00:46:48,905 --> 00:46:52,075
that we visualize the
data as a science team.

1087
00:46:52,108 --> 00:46:53,810
These pie charts represent the

1088
00:46:53,843 --> 00:46:56,746
different minerals
that are in the rocks.

1089
00:46:56,779 --> 00:46:58,815
And so, out here
on Yellowknife Bay

1090
00:46:58,848 --> 00:47:00,951
there's a lot of green,
those are the clay minerals,

1091
00:47:00,984 --> 00:47:03,153
the ones that really are
the definitive evidence

1092
00:47:03,186 --> 00:47:05,789
for water interacting
with rock in a lake,

1093
00:47:05,822 --> 00:47:09,092
and fresh water, and
less acidic water.

1094
00:47:09,125 --> 00:47:11,161
Then we got to the
base of Mount Sharp,

1095

00:47:11,194 --> 00:47:14,965
and we still had clays, we
still had the lake bed deposits,

1096
00:47:14,998 --> 00:47:16,967
but we started seeing
a bunch of this

1097
00:47:17,000 --> 00:47:21,838
red pie slice which is hematite,
which is this iron oxide.

1098
00:47:21,871 --> 00:47:26,209
And so, the conditions
that were very un-oxidized,

1099
00:47:26,242 --> 00:47:30,780
not too harshly weathering
back at Yellowknife bay,

1100
00:47:30,813 --> 00:47:33,884
seemed to have gotten
a little harsher,

1101
00:47:33,917 --> 00:47:36,186
so to speak, more
weathering, more oxidation,

1102
00:47:36,219 --> 00:47:38,121
even though the clays were still

1103
00:47:38,154 --> 00:47:40,824
there and the lake
was still there.

1104
00:47:40,857 --> 00:47:43,126
And as we got even higher,
even the hematite went away,

1105
00:47:43,159 --> 00:47:46,763

and even some of the basic rock
forming minerals went away,

1106
00:47:46,796 --> 00:47:50,800
and this drill hole
itself was just left with

1107
00:47:50,833 --> 00:47:52,068
one of the basic parts of a rock

1108
00:47:52,101 --> 00:47:55,138
which is silica, and
not too much else.

1109
00:47:55,171 --> 00:47:57,941
And so, what was
beautiful about this

1110
00:47:57,974 --> 00:48:01,011
is we had some patterns that
we could try to explain,

1111
00:48:01,044 --> 00:48:04,881
interpret by environmental
conditions changing over time,

1112
00:48:04,914 --> 00:48:06,016
'cause each one of
these drill holes

1113
00:48:06,049 --> 00:48:09,052
is higher than the
next by 25 meters.

1114
00:48:09,085 --> 00:48:12,822
And I'll focus on how we
have two explanations.

1115
00:48:12,855 --> 00:48:15,959
It's a nice friendly

competition in the science team.

1116
00:48:15,992 --> 00:48:18,128
We have a lot of
data, and we have two

1117
00:48:18,161 --> 00:48:20,130
different models to explain it.

1118
00:48:20,163 --> 00:48:22,198
And then as we got even higher,

1119
00:48:22,231 --> 00:48:26,937
we saw this very different
looking combination of minerals,

1120
00:48:26,970 --> 00:48:28,204
and then we saw
three drill holes

1121
00:48:28,237 --> 00:48:30,173
that were almost
identical to each other,

1122
00:48:30,206 --> 00:48:32,142
and suggested that
conditions actually

1123
00:48:32,175 --> 00:48:36,112
weren't changing to much in
that part of the mountain.

1124
00:48:36,145 --> 00:48:39,116
So, briefly, one
idea that explains

1125
00:48:41,117 --> 00:48:43,987
the clays and the
hematite down here

1126
00:48:44,020 --> 00:48:46,189
at the base of this
30 foot section

1127
00:48:46,222 --> 00:48:48,792
of rock we drilled three times,

1128
00:48:48,825 --> 00:48:50,927
these are a little tighter
space than 25 meters,

1129
00:48:50,960 --> 00:48:54,030
we drilled three times
in a row right here,

1130
00:48:54,063 --> 00:48:58,735
is that the lakes were there,
the deposited sediment,

1131
00:48:58,768 --> 00:49:02,672
and then ground water later
on flowed through these rocks,

1132
00:49:02,705 --> 00:49:04,074
and it was slightly acidic,

1133
00:49:04,107 --> 00:49:07,044
and it dissolved
with acid some of

1134
00:49:08,778 --> 00:49:10,981
the parts of the
rock and minerals

1135
00:49:11,014 --> 00:49:13,917
and delivered them
down to these areas.

1136
00:49:13,950 --> 00:49:15,051

So, we see more hematite,

1137
00:49:15,084 --> 00:49:17,020
we see more trace
metals down here,

1138
00:49:17,053 --> 00:49:19,155
and we see a lot of
these are just depleted

1139
00:49:19,188 --> 00:49:22,125
of a lot of their initial
minerals and chemicals.

1140
00:49:22,158 --> 00:49:24,027
So, that was one model.

1141
00:49:24,060 --> 00:49:25,895
Another model that
does a pretty good

1142
00:49:25,928 --> 00:49:27,931
job also of explaining
the same data,

1143
00:49:27,964 --> 00:49:30,900
so it's fun to have
these competing ideas,

1144
00:49:30,933 --> 00:49:32,969
is that there was a lake,

1145
00:49:33,002 --> 00:49:35,105
or a series of lakes
really on Mars,

1146
00:49:35,138 --> 00:49:39,776
that had different amounts
of oxygen dissolved in it.

1147
00:49:39,809 --> 00:49:40,977
I didn't know this on Earth,

1148
00:49:41,010 --> 00:49:44,748
but maybe some of you
are fisher people,

1149
00:49:44,781 --> 00:49:49,185
and there's more oxygen
near the shore of a lake,

1150
00:49:49,218 --> 00:49:51,921
and when you get deeper
water, there's less oxygen,

1151
00:49:51,954 --> 00:49:53,790
and so a lot of stuff
lives in the more

1152
00:49:53,823 --> 00:49:55,825
oxygenated part of the
upper surface of the lake

1153
00:49:55,858 --> 00:49:57,927
where it mixes with
the atmosphere.

1154
00:49:57,960 --> 00:49:59,996
And the same thing would
be expected on Mars

1155
00:50:00,029 --> 00:50:01,965
if the lakes were kind of placid

1156
00:50:01,998 --> 00:50:03,900
and not overturning too much,

1157
00:50:03,933 --> 00:50:06,870
you'd get more oxygen in the

near shore part of the lake,

1158
00:50:06,903 --> 00:50:09,139
and deeper down, less oxidant.

1159
00:50:11,207 --> 00:50:12,942
Either caused by
ultraviolet light

1160
00:50:12,975 --> 00:50:16,079
or oxygen directly mixing
in from the atmosphere.

1161
00:50:16,112 --> 00:50:18,748
And so, you might find
that if we drilled

1162
00:50:18,781 --> 00:50:21,985
in a rock that was once part
of a near shore environment,

1163
00:50:22,018 --> 00:50:23,953
you'd have more
hematite, and you'd have

1164
00:50:23,986 --> 00:50:27,124
more of those oxygen
enhanced minerals.

1165
00:50:28,958 --> 00:50:30,760
And if you drill
a hole that once

1166
00:50:30,793 --> 00:50:32,028
was in the deep part of a lake,

1167
00:50:32,061 --> 00:50:35,165
you might see that
change to the other

1168
00:50:35,198 --> 00:50:38,001
classes of minerals that we
found in the other holes.

1169
00:50:38,034 --> 00:50:39,736
So, this does a pretty good job

1170
00:50:39,769 --> 00:50:42,072
of explaining the
mineralogy, the chemistry,

1171
00:50:42,105 --> 00:50:44,207
and fits in the
lake hypothesis too.

1172
00:50:44,240 --> 00:50:47,877
So, now it's just left to really

1173
00:50:47,910 --> 00:50:49,179
gather more data,
and think through,

1174
00:50:49,212 --> 00:50:50,980
and really see
which one of these

1175
00:50:51,013 --> 00:50:53,149
ends up winning the day.

1176
00:50:53,182 --> 00:50:55,952
So, to finish up our
exploration of the Murray,

1177
00:50:55,985 --> 00:50:58,221
a couple more
interesting things.

1178
00:50:58,254 --> 00:51:00,924
This was a really

cool find for us,

1179
00:51:00,957 --> 00:51:04,027
a picture of mud
cracks on ancient Mars.

1180
00:51:04,060 --> 00:51:06,196
This is a slab of rock
about two feet across,

1181
00:51:06,229 --> 00:51:07,797
and it really was striking.

1182
00:51:07,830 --> 00:51:09,966
We hadn't seen anything
that looked like this

1183
00:51:09,999 --> 00:51:11,201
when we came across
it, where you have

1184
00:51:11,234 --> 00:51:12,969
these little
rectangular patterns

1185
00:51:13,002 --> 00:51:16,172
all over this rock, just
maybe an inch across each,

1186
00:51:16,205 --> 00:51:18,908
and very angular patterns.

1187
00:51:18,941 --> 00:51:20,844
It really struck a
lot of the geologists

1188
00:51:20,877 --> 00:51:24,914
on our team immediately
as desiccation cracks,

1189
00:51:24,947 --> 00:51:28,151
cracks that form
like in a drying pond

1190
00:51:28,184 --> 00:51:30,086
in the middle of
summer on Earth.

1191
00:51:30,119 --> 00:51:32,021
The waters goes away,
the mud's left behind,

1192
00:51:32,054 --> 00:51:33,923
you get these, we've
probably all seen it,

1193
00:51:33,956 --> 00:51:36,059
these little square
blocks of mud.

1194
00:51:36,092 --> 00:51:38,928
And this is what
it would look like

1195
00:51:38,961 --> 00:51:41,164
if the layer above
this rock layer

1196
00:51:41,197 --> 00:51:45,001
had all those cracks and
sort of left their imprint,

1197
00:51:45,034 --> 00:51:46,769
'cause you see these as ridges.

1198
00:51:46,802 --> 00:51:48,071
So, it's almost like
a Plaster of Paris

1199

00:51:48,104 --> 00:51:50,840
imprint of mud cracks.

1200
00:51:50,873 --> 00:51:53,810
And they were confined
to this thin red layer.

1201
00:51:53,843 --> 00:51:55,111
We measured the angles and the

1202
00:51:55,144 --> 00:51:56,779
geometries of all these cracks

1203
00:51:56,812 --> 00:51:58,748
and compared them to
mud cracks on Earth.

1204
00:51:58,781 --> 00:51:59,983
And it turned out,
again, that this was

1205
00:52:00,016 --> 00:52:03,753
the best scientific
explanation for this rock.

1206
00:52:03,786 --> 00:52:06,122
All that's very
academic, but then

1207
00:52:06,155 --> 00:52:08,124
I think about this,
and it's just amazing.

1208
00:52:08,157 --> 00:52:10,760
'Cause to me, it's
not a dinosaur,

1209
00:52:10,793 --> 00:52:12,028
we'd love to find a dinosaur,

1210
00:52:12,061 --> 00:52:15,832
but if you're a
geologist, this is getting

1211
00:52:17,133 --> 00:52:19,769
close to finding like
the dinosaur footprint.

1212
00:52:19,802 --> 00:52:23,907
We're looking at like a day
or a week on ancient Mars.

1213
00:52:25,007 --> 00:52:26,809
You're looking at
there was a lake,

1214
00:52:26,842 --> 00:52:30,079
and one day the lake dried
up, and the mud cracked,

1215
00:52:30,112 --> 00:52:32,849
and then we're looking at it
three billion years later.

1216
00:52:32,882 --> 00:52:36,953
You know, it's just kind
of mind blowing, in a way.

1217
00:52:38,054 --> 00:52:39,989
And so, this was
evidence now that

1218
00:52:40,022 --> 00:52:42,892
the lakes didn't last forever.

1219
00:52:42,925 --> 00:52:44,928
In fact, the higher we
got on the mountain,

1220

00:52:44,961 --> 00:52:47,063
we started seeing
more things like this

1221
00:52:47,096 --> 00:52:50,133
where the lakes actually
disappeared every now and then.

1222
00:52:50,166 --> 00:52:52,969
So, that's interesting.

1223
00:52:53,002 --> 00:52:54,737
So, we're beginning to see maybe

1224
00:52:54,770 --> 00:52:56,206
a twist in the
plot of the history

1225
00:52:56,239 --> 00:52:59,042
of Mount Sharp and Gale Crater,

1226
00:53:01,177 --> 00:53:03,880
and yet after this
we've seen more

1227
00:53:03,913 --> 00:53:05,748
of those continuous
thin layers again.

1228
00:53:05,781 --> 00:53:07,951
So, the lakes came
back, but we think now,

1229
00:53:07,984 --> 00:53:11,120
for the past maybe
third of the 600 feet

1230
00:53:11,153 --> 00:53:13,756
of Mount Sharp we've explored,

1231
00:53:13,789 --> 00:53:16,192
that the upper third is
a lot more intermittent

1232
00:53:16,225 --> 00:53:18,928
than the bottom two thirds.

1233
00:53:18,961 --> 00:53:23,066
But if your hopes for
ancient life are waning,

1234
00:53:23,099 --> 00:53:26,202
I will cheer you
up again because

1235
00:53:26,235 --> 00:53:28,905
after all those lakes went away,

1236
00:53:28,938 --> 00:53:32,809
even the ones that came and
went, all this stuff was buried,

1237
00:53:32,842 --> 00:53:35,178
and turned into
rock, and fractured,

1238
00:53:35,211 --> 00:53:38,014
and the fractures are
just everywhere we look,

1239
00:53:38,047 --> 00:53:40,116
they're filled with
this calcium sulfate.

1240
00:53:40,149 --> 00:53:43,920
So, that means even after the
lakes dried up at the surface,

1241
00:53:43,953 --> 00:53:46,189

there was still ground water
flowing through the ground

1242
00:53:46,222 --> 00:53:48,958
and bringing chemicals
from one place to another,

1243
00:53:48,991 --> 00:53:52,095
dissolving calcium and
sulfate over one place,

1244
00:53:52,128 --> 00:53:54,130
filling cracks and
leaving these little

1245
00:53:54,163 --> 00:53:57,767
fins of calcium sulfate
for us to find today.

1246
00:53:57,800 --> 00:54:01,004
So, the history of
water in Gale Crater

1247
00:54:01,037 --> 00:54:03,106
isn't just confined to the lake,

1248
00:54:03,139 --> 00:54:06,042
but also as long as
the ground water lasted

1249
00:54:06,075 --> 00:54:10,880
after the environment at the
surface may hae been too dry.

1250
00:54:10,913 --> 00:54:13,816
So, in the future, we're
gonna keep climbing.

1251
00:54:13,849 --> 00:54:15,084
We still got a lot to do.

1252
00:54:15,117 --> 00:54:19,055
We are now at the Hematite
Ridge which is this wall.

1253
00:54:19,088 --> 00:54:21,991
So, we're actually down
here now with the rover.

1254
00:54:22,024 --> 00:54:24,127
We're gonna ascend the
wall and go over it,

1255
00:54:24,160 --> 00:54:28,231
get into a big unit of clay
that's still further up.

1256
00:54:29,799 --> 00:54:31,034
So, the amazing
thing is all the clay

1257
00:54:31,067 --> 00:54:35,071
that we found so far
wasn't visible from space,

1258
00:54:35,104 --> 00:54:37,206
from the instruments on the
Mars Reconnaissance Orbiter

1259
00:54:37,239 --> 00:54:40,143
that can detect
clays from space.

1260
00:54:40,176 --> 00:54:41,878
We don't know why
exactly that is,

1261
00:54:41,911 --> 00:54:43,212
but we discovered them because

1262
00:54:43,245 --> 00:54:45,114
we were there and
we're able to drill.

1263
00:54:45,147 --> 00:54:48,084
But the clays here
are a bright signal

1264
00:54:48,117 --> 00:54:50,987
up to space that there's
clays in these rocks.

1265
00:54:51,020 --> 00:54:52,722
So, we've been
waiting to get to this

1266
00:54:52,755 --> 00:54:56,159
clay are since before landing,
since we picked this site.

1267
00:54:56,192 --> 00:54:57,794
So, it's gonna be
very exciting for

1268
00:54:57,827 --> 00:54:59,896
us to get there and
see what it means

1269
00:54:59,929 --> 00:55:03,900
for another possible
lake environment.

1270
00:55:03,933 --> 00:55:07,036
So, to wrap up here,
here we are with

1271
00:55:07,069 --> 00:55:10,206
the story of climate and
habitability on Mars.

1272
00:55:10,239 --> 00:55:12,075
Mars was once wet.

1273
00:55:12,108 --> 00:55:13,109
Was it warm?

1274
00:55:14,110 --> 00:55:15,778
I think it's quite likely,

1275
00:55:15,811 --> 00:55:17,180
and the reason we think that is,

1276
00:55:17,213 --> 00:55:19,882
in spite of the faint
young sun paradox,

1277
00:55:19,915 --> 00:55:23,153
is that the lakes were
there for so long,

1278
00:55:26,756 --> 00:55:28,124
and they were so continuous,

1279
00:55:28,157 --> 00:55:29,992
that it's very had
to explain them

1280
00:55:30,025 --> 00:55:32,929
by the other creative ideas that

1281
00:55:32,962 --> 00:55:35,164
scientists have had
of how you can get

1282
00:55:35,197 --> 00:55:39,769
the rivers and floods in a
permanently cold environment.

1283

00:55:40,903 --> 00:55:43,806
You have to have, like
a volcano goes off,

1284
00:55:43,839 --> 00:55:46,175
and makes gasses in
the atmosphere that

1285
00:55:46,208 --> 00:55:48,911
temporarily create a warm planet

1286
00:55:48,944 --> 00:55:51,147
for a hundred years
or a thousand years,

1287
00:55:51,180 --> 00:55:54,016
or you have a
meteorite hit and also

1288
00:55:54,049 --> 00:55:57,153
create a temporary atmosphere,

1289
00:55:57,186 --> 00:55:59,856
or you have seasonal
ice that occasionally

1290
00:55:59,889 --> 00:56:01,858
trickles out a
little bit of water.

1291
00:56:01,891 --> 00:56:04,994
None of those really can support

1292
00:56:05,027 --> 00:56:07,964
the amount of water
we see that would

1293
00:56:07,997 --> 00:56:10,833
be required to build
up all these layers,

1294
00:56:10,866 --> 00:56:13,870
which are 30 miles
of lake sediments

1295
00:56:15,070 --> 00:56:18,074
that build up hundreds and
hundreds of feet thick.

1296
00:56:18,107 --> 00:56:20,009
So, you have to have
a lot of flowing water

1297
00:56:20,042 --> 00:56:22,812
to deliver that sand, to
deliver that sediment.

1298
00:56:22,845 --> 00:56:26,816
And then if you just
take rough calculations

1299
00:56:26,849 --> 00:56:28,050
of how long it would
take to build up

1300
00:56:28,083 --> 00:56:32,088
600 feet of lake bed deposits
based on analogy with Earth,

1301
00:56:32,121 --> 00:56:35,792
it's probably millions to
tens of millions of years.

1302
00:56:35,825 --> 00:56:38,861
So, that's not a lot of time
in the billion years sense,

1303
00:56:38,894 --> 00:56:41,798
but it's a lot of
time to explain,

1304
00:56:42,998 --> 00:56:46,135
unless you had a humid
atmosphere that was stable,

1305
00:56:46,168 --> 00:56:49,105
like a stable warm
early climate of Mars.

1306
00:56:49,138 --> 00:56:52,876
And so, I think the
legacy of the mission,

1307
00:56:53,976 --> 00:56:56,179
one of the legacies
besides the main one,

1308
00:56:56,212 --> 00:56:59,048
which of habitability,
is gonna be that

1309
00:56:59,081 --> 00:57:01,150
we threw a wrench
into our understanding

1310
00:57:01,183 --> 00:57:03,786
of the climate of
Mars by showing that

1311
00:57:03,819 --> 00:57:07,757
in the Hesperian it
remained warm and wet,

1312
00:57:07,790 --> 00:57:11,861
and quite likely, Mars had a
pretty good hydrologic system.

1313
00:57:13,128 --> 00:57:14,163
I just said that.

1314
00:57:14,196 --> 00:57:16,032
[everyone laughs]

1315
00:57:16,065 --> 00:57:18,134
And so, what's next then?

1316
00:57:20,202 --> 00:57:22,905
Curiosity's doing great.

1317
00:57:22,938 --> 00:57:24,740
She's getting a little older.

1318
00:57:24,773 --> 00:57:25,875
Things are starting
to break a little bit,

1319
00:57:25,908 --> 00:57:27,043
but we still got
a lot ahead of us,

1320
00:57:27,076 --> 00:57:28,978
and we think we still
got, I don't know,

1321
00:57:29,011 --> 00:57:31,948
three, four, five
years of great science

1322
00:57:31,981 --> 00:57:34,917
ahead at the Clay Unit,
the Hematite Ridge,

1323
00:57:34,950 --> 00:57:37,753
the sulfates beyond,
and we'll complete

1324
00:57:37,786 --> 00:57:40,957
the story of the climb
in the Hesperian.

1325
00:57:43,192 --> 00:57:45,795
Based on the chemistry
of all that water

1326
00:57:45,828 --> 00:57:49,799
and the fact that we
found organic molecules,

1327
00:57:49,832 --> 00:57:51,868
it's synonymous to
us with habitability.

1328
00:57:51,901 --> 00:57:53,870
So, not only did
water last millions

1329
00:57:53,903 --> 00:57:56,205
of tens of millions of years,
but habitable conditions,

1330
00:57:56,238 --> 00:57:58,140
more importantly,
lasted that long.

1331
00:57:58,173 --> 00:57:59,876
And that's the
kind of time scale

1332
00:57:59,909 --> 00:58:01,944
that life can really
begin to make use of

1333
00:58:01,977 --> 00:58:04,113
in terms of originating on Mars,

1334
00:58:04,146 --> 00:58:05,848
or being delivered
somewhere else

1335
00:58:05,881 --> 00:58:09,986
and evolving and surviving on
Mars, and spreading on Mars.

1336
00:58:10,019 --> 00:58:12,021
And combine that with
our third contribution,

1337
00:58:12,054 --> 00:58:13,823
it think, of this
mission, which is

1338
00:58:13,856 --> 00:58:15,057
finding organic
molecules that have

1339
00:58:15,090 --> 00:58:17,894
been preserved for
three billion years,

1340
00:58:17,927 --> 00:58:22,098
that really sets up
this good looking rover,

1341
00:58:22,131 --> 00:58:24,834
'cause it's based on Curiosity.

1342
00:58:24,867 --> 00:58:26,769
This is the Mars 2020 rover,

1343
00:58:26,802 --> 00:58:28,838
which looks a lot
like Curiosity,

1344
00:58:28,871 --> 00:58:32,942
but will actually be sent to
Mars to seek signs of life.

1345
00:58:34,043 --> 00:58:36,813

This was planned,
optimistically,

1346
00:58:37,246 --> 00:58:39,949
hoping that Curiosity would find

1347
00:58:39,982 --> 00:58:41,851
that Mars was once habitable and

1348
00:58:41,884 --> 00:58:45,087
capable of preserving
signs of life.

1349
00:58:45,120 --> 00:58:48,791
And now that we have shown
that that's possible,

1350
00:58:48,824 --> 00:58:51,093
this mission is our
best chance for actually

1351
00:58:51,126 --> 00:58:53,162
determining if life
ever took hold,

1352
00:58:53,195 --> 00:58:54,997
both by the
instruments it carries

1353
00:58:55,030 --> 00:58:57,033
with it to Mars to
explore an environment

1354
00:58:57,066 --> 00:58:58,935
that we think is
habitable, and by

1355
00:58:58,968 --> 00:59:00,736
collecting samples that one day

1356
00:59:00,769 --> 00:59:02,738
we might be able to
return back to Earth

1357
00:59:02,771 --> 00:59:06,776
and study in the best
laboratories on Earth.

1358
00:59:06,809 --> 00:59:08,010
Yeah, that's kinda where we are,

1359
00:59:08,043 --> 00:59:10,179
and thank you very much.

1360
00:59:10,212 --> 00:59:13,216
[audience applauds]

1361
00:59:27,863 --> 00:59:30,166
So, with that, Jim and I
would love to take questions

1362
00:59:30,199 --> 00:59:32,768
for 10 minutes or so.

1363
00:59:32,801 --> 00:59:36,039
Please use the
microphones, and fire away.

1364
00:59:37,773 --> 00:59:40,810
[audience murmuring]

1365
00:59:46,081 --> 00:59:47,049
>> Audience member:
You guys ready?

1366
00:59:47,082 --> 00:59:48,150
>> Sure.

1367

00:59:48,183 --> 00:59:49,986
>> So what'd you guys
do with the wheels?

1368
00:59:50,019 --> 00:59:52,822
[laughs]

1369
00:59:52,855 --> 00:59:53,923
>> Okay, we did a lot of things.

1370
00:59:53,956 --> 00:59:55,791
The first thing was
to really test them

1371
00:59:55,824 --> 00:59:58,894
to find out what was
going on on Mars.

1372
00:59:58,927 --> 01:00:03,733
We spent a lot of money
buying brand new wheels

1373
01:00:03,766 --> 01:00:05,935
and destroying them
with the kinds of things

1374
01:00:05,968 --> 01:00:07,136
that we thought
might actually be

1375
01:00:07,169 --> 01:00:09,171
what's contributing
to the damage,

1376
01:00:09,204 --> 01:00:12,208
characterizing it,
and then basically

1377
01:00:12,241 --> 01:00:14,944
building models

as to how we could

1378
01:00:14,977 --> 01:00:16,946
drive in this kind of a terrain,

1379
01:00:16,979 --> 01:00:18,748
how far we would be able to go,

1380
01:00:18,781 --> 01:00:20,216
how much damage
we would get if we

1381
01:00:20,249 --> 01:00:24,787
ran on the really sharp
jagged stuff versus the sand.

1382
01:00:24,820 --> 01:00:27,023
And then we sort of
keep that in mind

1383
01:00:27,056 --> 01:00:28,824
whenever we make decisions about

1384
01:00:28,857 --> 01:00:31,994
what routes to take to
avoid the worse stuff,

1385
01:00:32,027 --> 01:00:36,932
but sometimes the good science
is where the rough stuff is.

1386
01:00:36,965 --> 01:00:38,901
So, we make those
kinds of trades.

1387
01:00:38,934 --> 01:00:41,170
In addition, we
actually built software

1388

01:00:41,203 --> 01:00:45,007
that allows the
rover drive softer.

1389
01:00:45,040 --> 01:00:47,877
Specifically it's
called traction control,

1390
01:00:47,910 --> 01:00:50,746
and it basically
says if one wheel is

1391
01:00:50,779 --> 01:00:54,050
going over a rock,
everybody else slows down

1392
01:00:54,083 --> 01:00:58,020
so it doesn't get pushing
that one wheel into the rock.

1393
01:00:58,053 --> 01:01:01,057
And that looks like
it's working quite well.

1394
01:01:01,090 --> 01:01:02,658
And so, that's
another thing that's

1395
01:01:02,691 --> 01:01:04,860
gonna stretch out the
life of the wheels.

1396
01:01:04,893 --> 01:01:08,764
Right now we have enough
life in these wheels

1397
01:01:08,797 --> 01:01:10,032
that we're gonna
be able to get to

1398

01:01:10,065 --> 01:01:13,035
the top of where we wanna
investigate on Mount Sharp

1399
01:01:13,068 --> 01:01:16,772
with margin, and
that's a good thing,

1400
01:01:16,805 --> 01:01:18,841
and we'll see what
happens afterwards.

1401
01:01:18,874 --> 01:01:21,077
And already, people are
talking and think about

1402
01:01:21,110 --> 01:01:22,878
traction control mark two,

1403
01:01:22,911 --> 01:01:25,882
and make it even
better and softer.

1404
01:01:28,117 --> 01:01:32,021
>> I have two questions
about the soil.

1405
01:01:32,054 --> 01:01:36,726
I understand there's quite
a bit of radiation on Mars.

1406
01:01:36,759 --> 01:01:39,128
The first question
is, do we know

1407
01:01:40,863 --> 01:01:44,200
whether the soil, or any of
the soil you've analyzed,

1408
01:01:45,801 --> 01:01:48,871

could support life
like the astronaut

1409
01:01:50,172 --> 01:01:54,110
in the Martian movie
raising potatoes?

1410
01:01:54,143 --> 01:01:56,245
And the second question is,

1411
01:01:57,980 --> 01:02:01,150
do we know whether
we could make glass

1412
01:02:01,183 --> 01:02:05,855
out of the soil to use as
radiation shielding window?

1413
01:02:08,223 --> 01:02:10,826
>> The first question,
I think one of the

1414
01:02:10,859 --> 01:02:13,930
challenges is the
soil does have a lot

1415
01:02:15,030 --> 01:02:17,900
of this chemical
perchlorate in it.

1416
01:02:17,933 --> 01:02:19,835
Maybe you've even seen
some recent news reports

1417
01:02:19,868 --> 01:02:22,905
about how perchlorate
was considered

1418
01:02:22,938 --> 01:02:25,207
a bad thing for

current life on Mars,

1419
01:02:25,240 --> 01:02:28,944
and maybe even worse when
it's irradiated by UV light.

1420
01:02:28,977 --> 01:02:30,813
So, when you have
soil, the problem is

1421
01:02:30,846 --> 01:02:32,114
it gets a lot of the perchlorate

1422
01:02:32,147 --> 01:02:33,816
and it has a lot
of surface area,

1423
01:02:33,849 --> 01:02:35,951
so it gets a lot of
ultraviolet light,

1424
01:02:35,984 --> 01:02:37,186
may not be the best.

1425
01:02:37,219 --> 01:02:40,723
But you could drill
a lot of holes

1426
01:02:40,756 --> 01:02:44,894
in that nice gray rock that
has the less altered stuff,

1427
01:02:44,927 --> 01:02:47,797
and maybe make some
soil out of that.

1428
01:02:47,830 --> 01:02:51,100
I'm not an expert in this,
but that's just my two cents.

1429
01:02:51,133 --> 01:02:53,169
And your second question,

1430
01:02:54,770 --> 01:02:55,838
what was the second
question again?

1431
01:02:55,871 --> 01:02:56,939
>> Audience Member:
Making glass.

1432
01:02:56,972 --> 01:02:58,941
>> Oh yeah, I suspect
that's possible

1433
01:02:58,974 --> 01:03:00,209
like it is on Earth
because a lot of

1434
01:03:00,242 --> 01:03:03,012
the rocks are made out
of very similar chemicals

1435
01:03:03,045 --> 01:03:06,048
and minerals as on
Earth, including silica.

1436
01:03:06,081 --> 01:03:07,083
>> Thank you.

1437
01:03:08,917 --> 01:03:10,853
>> First of all, thank you
guys so much for what you do.

1438
01:03:10,886 --> 01:03:13,989
It's just such an amazing
thing that everybody does here.

1439
01:03:14,022 --> 01:03:15,925

Yes ma'am, thank you.

1440
01:03:15,958 --> 01:03:17,726
Thank you guys for
what you do here.

1441
01:03:17,759 --> 01:03:19,094
It's such an amazing thing.

1442
01:03:19,127 --> 01:03:20,830
I have two questions.

1443
01:03:20,863 --> 01:03:22,765
Elon Musk just released a paper

1444
01:03:22,798 --> 01:03:27,169
about his general idea
about how to get to Mars.

1445
01:03:27,202 --> 01:03:29,205
So, I wanted to see if you guys,

1446
01:03:29,238 --> 01:03:31,874
number one, do you work
directly at all with him,

1447
01:03:31,907 --> 01:03:34,076
or just share data, and
what you thought about that.

1448
01:03:34,109 --> 01:03:36,045
And then the second
question was about

1449
01:03:36,078 --> 01:03:38,814
how you send commands
to the rover.

1450
01:03:38,847 --> 01:03:42,084

'Cause I know it's not
an instantaneous process.

1451
01:03:42,117 --> 01:03:44,119
Do you stack up a whole
series of commands

1452
01:03:44,152 --> 01:03:45,888
that they have to be
in certain orders?

1453
01:03:45,921 --> 01:03:48,724
Do things have to move
before another thing?

1454
01:03:48,757 --> 01:03:50,125
If commands get there
late, could it mess up?

1455
01:03:50,158 --> 01:03:51,861
I'm sure, that's stuff.

1456
01:03:51,894 --> 01:03:53,062
So, thank you guys
again for all that,

1457
01:03:53,095 --> 01:03:54,830
and I'll take my question away.

1458
01:03:54,863 --> 01:03:55,731
Thanks.

1459
01:03:55,764 --> 01:03:56,966
[audience laughs]

1460
01:03:56,999 --> 01:03:59,034
>> You wanna tackle Elon?

1461
01:03:59,067 --> 01:03:59,969

>> You can take the first one.

1462
01:04:00,002 --> 01:04:01,904
>> Oh.
[laughs]

1463
01:04:01,937 --> 01:04:03,939
Okay, there's several ways that

1464
01:04:03,972 --> 01:04:07,910
JPL is involved with
Elon Musk's organization.

1465
01:04:08,977 --> 01:04:11,180
Among other things,
for helping him

1466
01:04:11,213 --> 01:04:13,115
to understand the
kinds of navigation

1467
01:04:13,148 --> 01:04:16,819
that we do to get to
Mars, and providing

1468
01:04:18,220 --> 01:04:19,955
information for him on how he's

1469
01:04:19,988 --> 01:04:22,725
gonna have to do
some of that as well.

1470
01:04:22,758 --> 01:04:25,027
And clearly, if he's able to do

1471
01:04:26,228 --> 01:04:27,963
what he would like
to do, which is to

1472

01:04:27,996 --> 01:04:30,766
start sending
spacecraft and landing

1473
01:04:30,799 --> 01:04:34,036
them on Mars in the
next few years actually,

1474
01:04:34,069 --> 01:04:36,805
we might end up
being a customer for

1475
01:04:36,838 --> 01:04:40,009
providing some payloads
that he could transport.

1476
01:04:40,042 --> 01:04:42,211
We're always
interested in options.

1477
01:04:42,244 --> 01:04:43,879
So, that's some of the things

1478
01:04:43,912 --> 01:04:46,015
that we're thinking
about with that.

1479
01:04:46,048 --> 01:04:47,783
Anything else?

1480
01:04:47,816 --> 01:04:51,187
>> No, I can talk about
operations real quick.

1481
01:04:53,755 --> 01:04:56,125
Everything you said
is basically, yes.

1482
01:04:56,158 --> 01:04:59,161
So, we send up a series

of commands ever day.

1483
01:04:59,194 --> 01:05:01,764
Mars has about
seven to 22 minutes,

1484
01:05:01,797 --> 01:05:05,000
I think, is the
range of waiting time

1485
01:05:05,033 --> 01:05:08,871
for signals at the speed
of light to get to Mars.

1486
01:05:08,904 --> 01:05:12,775
And so, if you were to say,
"turn the rover right,"

1487
01:05:12,808 --> 01:05:15,044
15 minutes later
the rover gets that,

1488
01:05:15,077 --> 01:05:17,112
it turns right, and
then 15 minutes later

1489
01:05:17,145 --> 01:05:19,782
you get the response
that, "I turned right."

1490
01:05:19,815 --> 01:05:21,951
A horrible way to
operate a rover on Mars.

1491
01:05:21,984 --> 01:05:24,053
And so, we actually send
up one full days worth

1492
01:05:24,086 --> 01:05:26,789
of commands every single day.

1493
01:05:26,822 --> 01:05:28,824
Well, actually, now
five days a week,

1494
01:05:28,857 --> 01:05:32,094
and a three day set of
commands on the weekend.

1495
01:05:32,127 --> 01:05:35,197
And the rover is
built to execute

1496
01:05:35,230 --> 01:05:36,966
all those commands on its own,

1497
01:05:36,999 --> 01:05:39,168
and knows how to
check a lot of things

1498
01:05:39,201 --> 01:05:40,903
for its own safety to make sure

1499
01:05:40,936 --> 01:05:44,840
the humans hadn't told
it to do anything stupid.

1500
01:05:44,873 --> 01:05:46,909
We also do a lot of
checking of everything

1501
01:05:46,942 --> 01:05:50,813
on Earth before we ever
send it, of course.

1502
01:05:50,846 --> 01:05:54,951
Yeah, everything you said
about, there is a gap where,

1503

01:05:57,185 --> 01:05:59,121
we send up a full
days worth of commands

1504
01:05:59,154 --> 01:06:00,856
when the sun is rising on Mars,

1505
01:06:00,889 --> 01:06:01,924
when the sun is setting on Mars,

1506
01:06:01,957 --> 01:06:03,726
the rover sends back its data,

1507
01:06:03,759 --> 01:06:06,095
and we use that data
to plan the next day.

1508
01:06:06,128 --> 01:06:08,931
But something could've
happened over night,

1509
01:06:08,964 --> 01:06:10,733
and our new commands
get up there,

1510
01:06:10,766 --> 01:06:14,136
and now the rover, if
something's gone wrong,

1511
01:06:14,169 --> 01:06:15,938
when it receives our
commands that were

1512
01:06:15,971 --> 01:06:18,941
built on assuming
everything was fine.

1513
01:06:18,974 --> 01:06:21,810
But it's also smart enough
to know how to handle that.

1514
01:06:21,843 --> 01:06:23,212
And then it would tell
us it's in trouble

1515
01:06:23,245 --> 01:06:25,247
at its next opportunity.

1516
01:06:26,882 --> 01:06:29,018
Of course, the most
challenging part

1517
01:06:29,051 --> 01:06:31,820
is that Mars has a 24
and a half hour day,

1518
01:06:31,853 --> 01:06:33,222
so we can never
quite stay in sync

1519
01:06:33,255 --> 01:06:36,825
with the Mars
sunrise and sunset.

1520
01:06:36,858 --> 01:06:37,926
We actually get out of phase

1521
01:06:37,959 --> 01:06:39,728
with Mars every
three weeks or so,

1522
01:06:39,761 --> 01:06:43,032
and then back in phase
three weeks later.

1523
01:06:43,065 --> 01:06:45,968
>> Hi, regarding
the alpha particle

1524

01:06:48,036 --> 01:06:52,041
X-ray function on the
spectrometer on Curiosity.

1525
01:06:53,875 --> 01:06:57,813
Has it located any
additional information

1526
01:06:57,846 --> 01:07:01,117
in regard to perhaps
locating a new mineral?

1527
01:07:03,819 --> 01:07:07,723
>> That's one of our
real useful instruments.

1528
01:07:07,756 --> 01:07:09,091
We sort of have a
pattern that we use,

1529
01:07:09,124 --> 01:07:11,093
where we first drive
and take pictures,

1530
01:07:11,126 --> 01:07:12,995
and if something in the
pictures is real interesting,

1531
01:07:13,028 --> 01:07:14,096
we'll approach it
with the rover,

1532
01:07:14,129 --> 01:07:16,098
get out the arm,
and then place this

1533
01:07:16,131 --> 01:07:18,133
alpha particle
X-ray spectrometer,

1534

01:07:18,166 --> 01:07:22,104
which emits alpha
particles and X-rays,

1535
01:07:22,137 --> 01:07:27,009
and then reads the X-ray, the
X-ray's emitted by the rock.

1536
01:07:27,042 --> 01:07:28,177
And that's actually
a nice technique

1537
01:07:28,210 --> 01:07:31,046
to figure out what the
rock is made out of.

1538
01:07:31,079 --> 01:07:33,082
And if that is looking good,

1539
01:07:33,115 --> 01:07:35,851
then only we would spend
the effort on drilling it.

1540
01:07:35,884 --> 01:07:38,020
And so, most of
the rocks on Mars

1541
01:07:38,053 --> 01:07:40,956
are very similar to rocks
you'd find on Earth.

1542
01:07:40,989 --> 01:07:42,791
Mars and Earth
formed in a similar

1543
01:07:42,824 --> 01:07:43,892
part of the solar system,

1544
01:07:43,925 --> 01:07:45,961
they're sister

planets in that sense.

1545
01:07:45,994 --> 01:07:49,064
But we have found,
not with the APXS,

1546
01:07:49,097 --> 01:07:52,768
but with our X-ray
diffractometer,

1547
01:07:52,801 --> 01:07:55,737
which actually shines
X-rays through rock powder,

1548
01:07:55,770 --> 01:07:57,206
and makes a little
rainbow pattern

1549
01:07:57,239 --> 01:08:01,009
like a diffraction pattern,
like light through a prism,

1550
01:08:01,042 --> 01:08:03,812
and we found a mineral on Mars

1551
01:08:03,845 --> 01:08:06,148
that no one expected to
be there called tridymite,

1552
01:08:06,181 --> 01:08:10,052
which is a crystalline
form of silica in rocks.

1553
01:08:10,085 --> 01:08:11,887
It's quite rare on Earth,

1554
01:08:11,920 --> 01:08:14,924
and indicates that
on Mars there was

1555
01:08:15,957 --> 01:08:18,127
a lot more evolution
of the magmas

1556
01:08:18,160 --> 01:08:20,762
under the surface
than we ever expected.

1557
01:08:20,795 --> 01:08:23,031
It's kind of a mineral
that only forms

1558
01:08:23,064 --> 01:08:25,968
when there's been
circulating magma

1559
01:08:26,001 --> 01:08:27,136
interacting with
water and things

1560
01:08:27,169 --> 01:08:30,038
for quite a long time instead of

1561
01:08:30,071 --> 01:08:32,941
the more pristine
basaltic minerals

1562
01:08:32,974 --> 01:08:35,043
that most of Mars
is made out of.

1563
01:08:35,076 --> 01:08:36,845
>> Thank you, good lecture.

1564
01:08:36,878 --> 01:08:38,247
>> Ashwin: Thank you.

1565
01:08:41,249 --> 01:08:43,852
>> I was wondering

with the 2020 rover,

1566
01:08:43,885 --> 01:08:45,754
what's the plan
for sample return?

1567
01:08:45,787 --> 01:08:47,122
You mentioned if we
can get them back,

1568
01:08:47,155 --> 01:08:49,958
or something like that.

1569
01:08:49,991 --> 01:08:53,929
>> Okay, sample return
is a lecture in its own.

1570
01:08:55,830 --> 01:08:58,100
But put it the following way.

1571
01:08:58,133 --> 01:09:01,837
It looks like, right now, that
with the technology we have,

1572
01:09:01,870 --> 01:09:05,774
it's going to be a
three part journey.

1573
01:09:05,807 --> 01:09:06,975
We're gonna have
to break it into

1574
01:09:07,008 --> 01:09:09,878
three different
missions, so to speak.

1575
01:09:09,911 --> 01:09:11,747
The first of which is to find

1576

01:09:11,780 --> 01:09:13,949
the right things on the planet,

1577
01:09:13,982 --> 01:09:18,187
take samples, and get them
ready to be brought back.

1578
01:09:18,220 --> 01:09:20,122
Once we've done that,
we have a vehicle

1579
01:09:20,155 --> 01:09:24,993
that collects them, puts
them inside a little rocket

1580
01:09:25,026 --> 01:09:27,930
or some other similar technique,

1581
01:09:27,963 --> 01:09:31,033
and gets it up into Mars orbit.

1582
01:09:31,066 --> 01:09:34,036
And then the third leg
is to go to Mars orbit,

1583
01:09:34,069 --> 01:09:36,939
capture them safely,
both in terms of

1584
01:09:36,972 --> 01:09:39,808
protecting the samples, but also

1585
01:09:40,976 --> 01:09:44,813
making sure that the
vehicle that is gonna

1586
01:09:44,846 --> 01:09:47,149
bring it back isn't
contaminated by the samples

1587
01:09:47,182 --> 01:09:50,219
and the exterior
of that vehicle,

1588
01:09:50,252 --> 01:09:53,222
or return capsule,
or anything else

1589
01:09:53,255 --> 01:09:57,826
isn't contaminated by the
surface of Mars, so to speak,

1590
01:09:57,859 --> 01:09:59,728
and then bring
that back to Earth.

1591
01:09:59,761 --> 01:10:03,131
And then we have the ability
to study these samples,

1592
01:10:03,164 --> 01:10:06,068
not only with the
latest scientific

1593
01:10:06,101 --> 01:10:07,936
instruments at the time,

1594
01:10:07,969 --> 01:10:10,105
but keep them in storage
for new and better

1595
01:10:10,138 --> 01:10:14,910
techniques that might be
developed in the future.

1596
01:10:14,943 --> 01:10:18,814
>> So, is that three
mission thing you described

1597

01:10:18,847 --> 01:10:21,783
part of the 2020 plan,
or is that something

1598
01:10:21,816 --> 01:10:24,153
that comes later when available,

1599
01:10:25,820 --> 01:10:28,156
when funds are available.
>> Right now 2020's,

1600
01:10:28,189 --> 01:10:31,126
one of their goals
is to prove out

1601
01:10:31,159 --> 01:10:34,763
the encapsulation,
the sample handling,

1602
01:10:37,032 --> 01:10:40,836
storage, and deposition
for the future.

1603
01:10:40,869 --> 01:10:43,138
Now, whether those
particular samples

1604
01:10:43,171 --> 01:10:46,775
that were cored and
contained with 2020

1605
01:10:48,877 --> 01:10:50,846
are gonna be the
ones that return,

1606
01:10:50,879 --> 01:10:53,915
or whether this
precursor mission

1607
01:10:53,948 --> 01:10:55,884

is really a precursor,
and there will be

1608
01:10:55,917 --> 01:10:57,986
more and better ones
that are in the future

1609
01:10:58,019 --> 01:11:01,723
to get other samples in
other areas, we don't know.

1610
01:11:01,756 --> 01:11:05,894
But right now 2020's job is to
prove that this can be done.

1611
01:11:08,963 --> 01:11:10,032
>> Hello.

1612
01:11:10,065 --> 01:11:13,168
Do you see any
potential applications

1613
01:11:13,201 --> 01:11:16,772
of swarm robotics
to Mars Exploration?

1614
01:11:16,805 --> 01:11:18,740
And if so, what would
be they key benefits

1615
01:11:18,773 --> 01:11:20,242
and the key challenges?

1616
01:11:21,976 --> 01:11:24,112
>> Swarm robotics, do you
know anything about that?

1617
01:11:24,145 --> 01:11:27,949
>> I'm afraid the
concept of swarm robotics

1618
01:11:27,982 --> 01:11:30,085
is kind of too far
out there for us to

1619
01:11:30,118 --> 01:11:32,220
really plan a mission on it.

1620
01:11:32,253 --> 01:11:34,756
We usually tend to make use of

1621
01:11:34,789 --> 01:11:38,794
very well defined, well
understood technologies.

1622
01:11:41,029 --> 01:11:44,032
It takes a lot of proof to make

1623
01:11:44,065 --> 01:11:45,200
sure that we can do something,

1624
01:11:45,233 --> 01:11:48,003
to get that into
the latest mission.

1625
01:11:48,036 --> 01:11:50,906
So, it might be a while.

1626
01:11:50,939 --> 01:11:53,942
>> Thank you.
>> In a similar vein though,

1627
01:11:53,975 --> 01:11:55,877
[speaking away from mic]

1628
01:11:55,910 --> 01:11:59,014
>> I was just gonna
say, to end that

1629
01:11:59,047 --> 01:12:01,150
on a slightly positive note,

1630
01:12:04,119 --> 01:12:06,088
we're thinking, at
least, about trying

1631
01:12:06,121 --> 01:12:08,824
to fly a helicopter with
the Mars 2020 mission,

1632
01:12:08,857 --> 01:12:11,126
which would have
the advantage of

1633
01:12:11,159 --> 01:12:13,128
scouting out ahead of the rover

1634
01:12:13,161 --> 01:12:15,997
and looking for potential places

1635
01:12:16,030 --> 01:12:17,733
that the rover might travers,

1636
01:12:17,766 --> 01:12:19,201
getting some advanced imagery,

1637
01:12:19,234 --> 01:12:21,770
advanced chemical
information perhaps,

1638
01:12:21,803 --> 01:12:24,005
and of course, as
Jim was saying,

1639
01:12:24,038 --> 01:12:26,908
just learning how to do that.

1640

01:12:26,941 --> 01:12:29,778
Curiosity's the third
generation rover on Mars,

1641
01:12:29,811 --> 01:12:32,781
and we went from the shoebox
sized rover, to the golf cart,

1642
01:12:32,814 --> 01:12:36,051
to the car sized rover
in three generations.

1643
01:12:36,084 --> 01:12:38,019
But we gotta start somewhere,
and the helicopter,

1644
01:12:38,052 --> 01:12:41,189
a single helicopter learning
how to fly that on Mars

1645
01:12:41,222 --> 01:12:43,125
is the start of what
could end up being

1646
01:12:43,158 --> 01:12:45,794
a nice swarm of vehicles later.

1647
01:12:45,827 --> 01:12:46,895
>> Okay, we'll take
two more questions

1648
01:12:46,928 --> 01:12:47,996
from the microphone
and then move

1649
01:12:48,029 --> 01:12:51,066
to then move to
the other centers.

1650
01:12:51,099 --> 01:12:53,769

>> Well, I have a
real estate question.

1651
01:12:53,802 --> 01:12:57,205
I don't know if it's fitting
to ask to scientists,

1652
01:12:57,238 --> 01:12:58,840
but who owns Mars?

1653
01:12:58,873 --> 01:13:00,742
Are we gonna fight over this?

1654
01:13:00,775 --> 01:13:01,877
Number one.

1655
01:13:01,910 --> 01:13:04,780
And number two, so it's obvious

1656
01:13:05,814 --> 01:13:09,785
there was water before,
but it's gone now.

1657
01:13:09,818 --> 01:13:13,789
So, are we hoping that
we can transplant water,

1658
01:13:16,224 --> 01:13:19,161
or make water
appear, or make water

1659
01:13:19,194 --> 01:13:20,729
because we wanna live there?

1660
01:13:20,762 --> 01:13:21,863
Is that po--
>> Yeah.

1661
01:13:21,896 --> 01:13:24,132

>> That's no possible,
we can't make water

1662
01:13:24,165 --> 01:13:26,067
on a dry planet, is there?

1663
01:13:26,100 --> 01:13:28,904
>> So, start with who owns Mars.

1664
01:13:30,839 --> 01:13:32,140
I can't give you the
legal definition,

1665
01:13:32,173 --> 01:13:33,775
there probably is one.

1666
01:13:33,808 --> 01:13:36,111
But a good analogy to
think about with Mars,

1667
01:13:36,144 --> 01:13:39,781
and even the Moon, and other
planets, is Antarctica.

1668
01:13:39,814 --> 01:13:41,850
So, no country owns Antarctica,

1669
01:13:41,883 --> 01:13:45,220
but we agree among nations
to treat it in a certain way,

1670
01:13:45,253 --> 01:13:47,923
and to do science there, and
not interfere with each other

1671
01:13:47,956 --> 01:13:49,157
that are doing science there,

1672
01:13:49,190 --> 01:13:51,827

and not plant a flag there
and claim it for yourself.

1673
01:13:51,860 --> 01:13:54,095
So, that's the sort
of working model

1674
01:13:54,128 --> 01:13:56,198
that we would have
for planets as well.

1675
01:13:56,231 --> 01:13:58,900
Until long time
from now when people

1676
01:13:58,933 --> 01:14:01,703
are actually putting
civilizations there,

1677
01:14:01,736 --> 01:14:03,672
as it's a scientific
target, we would

1678
01:14:03,705 --> 01:14:06,074
treat it like we currently
treat Antarctica.

1679
01:14:06,107 --> 01:14:07,909
>> So, are we the
only country who

1680
01:14:07,942 --> 01:14:09,978
sent a robot over there?

1681
01:14:10,011 --> 01:14:12,814
>> No, right now
we're the only country

1682
01:14:12,847 --> 01:14:14,917
that successfully landed.

1683
01:14:16,251 --> 01:14:19,788
There have been
orbiters from Europe,

1684
01:14:20,955 --> 01:14:22,958
from Russia, from India,

1685
01:14:24,025 --> 01:14:25,794
and I think China
has one on the way,

1686
01:14:25,827 --> 01:14:27,162
and the UAE has one on the way.

1687
01:14:27,195 --> 01:14:29,064
So, it's quite a few nations.

1688
01:14:29,097 --> 01:14:31,166
I'm probably forgetting some.

1689
01:14:31,199 --> 01:14:34,069
And then, in terms of water,

1690
01:14:34,102 --> 01:14:37,005
there is a lot of ice on
Mars, it's up near the poles.

1691
01:14:37,038 --> 01:14:39,975
So, more water than you
could ever make use of.

1692
01:14:40,008 --> 01:14:42,010
I think if you spread
it around Mars,

1693
01:14:42,043 --> 01:14:45,780
it would be 30
feet deep of water

1694
01:14:45,813 --> 01:14:46,915
covering the entire planet.

1695
01:14:46,948 --> 01:14:48,984
That's how much water's
trapped in the poles.

1696
01:14:49,017 --> 01:14:51,152
So, you could make
plenty of water up there.

1697
01:14:51,185 --> 01:14:52,988
But if you want it
near the equator,

1698
01:14:53,021 --> 01:14:55,957
Mars also has a tiny bit
of water in the atmosphere,

1699
01:14:55,990 --> 01:14:58,193
and you could just slowly get
that out of the atmosphere.

1700
01:14:58,226 --> 01:15:01,963
There's also water in
rocks, like clay minerals

1701
01:15:01,996 --> 01:15:06,001
actually have water in
their atomic structure,

1702
01:15:06,034 --> 01:15:08,069
and so you could find a way
to extract that water as well,

1703
01:15:08,102 --> 01:15:11,172
so all these things would
be looked at for astronauts.

1704
01:15:11,205 --> 01:15:13,174
>> And one more,
which is there are

1705
01:15:13,207 --> 01:15:16,011
some ancient buried
glaciers that

1706
01:15:16,044 --> 01:15:17,846
are up at the mid latitudes.

1707
01:15:17,879 --> 01:15:21,950
Not at the equator, not at the
poles, but kind of between.

1708
01:15:23,051 --> 01:15:25,220
And they might be a very
useful source of water

1709
01:15:25,253 --> 01:15:28,924
that's a little more
manageable to get to

1710
01:15:28,957 --> 01:15:32,060
than way up at the
north and south poles.

1711
01:15:32,093 --> 01:15:34,195
>> So, you're saying
it's possible.

1712
01:15:34,228 --> 01:15:35,730
[audience laughs]

1713
01:15:35,763 --> 01:15:36,865
>> Jim: Sure, yeah.

1714
01:15:36,898 --> 01:15:38,867
>> We might be able to

live there with water.

1715
01:15:38,900 --> 01:15:39,902
>> Jim: Yes.

1716
01:15:41,903 --> 01:15:44,773
>> Thank you. [laughs]

1717
01:15:44,806 --> 01:15:45,907
I think she wants to go.

1718
01:15:45,940 --> 01:15:48,977
[audience laughs]

1719
01:15:49,010 --> 01:15:51,847
>> So, if it was
very likely that

1720
01:15:52,914 --> 01:15:56,151
there was some sort
of life on Mars,

1721
01:15:56,184 --> 01:15:58,153
what type of life would it be?

1722
01:15:58,186 --> 01:16:01,156
Would it be single
celled organisms,

1723
01:16:01,189 --> 01:16:05,059
or more advanced animals
or plants like fish?

1724
01:16:08,196 --> 01:16:11,833
>> It depends how long life
had a chance to evolve,

1725
01:16:11,866 --> 01:16:14,936
and what Mars offered

in terms of niches

1726
01:16:14,969 --> 01:16:16,137
for it to evolve into.

1727
01:16:16,170 --> 01:16:18,907
At this point having
mapped the planet

1728
01:16:18,940 --> 01:16:21,977
very rigorously from
orbit, and having seen

1729
01:16:22,010 --> 01:16:25,046
a lot, not a lot, having seen
a tiny amount of the planet

1730
01:16:25,079 --> 01:16:29,751
in great detail from, I
think, seven landers now,

1731
01:16:29,784 --> 01:16:31,886
the idea that we're
gonna one day come across

1732
01:16:31,919 --> 01:16:34,222
plants or footprints of
dinosaurs or something,

1733
01:16:34,255 --> 01:16:36,958
probably has faded
away at this point.

1734
01:16:36,991 --> 01:16:41,063
But the microbes are by far the
dominant life form on Earth.

1735
01:16:42,196 --> 01:16:45,934
We mean nothing in terms
of the biomass of Earth.

1736
01:16:45,967 --> 01:16:48,103
So, there's a
great potential for

1737
01:16:48,136 --> 01:16:51,840
life to have evolved
and been vigorous

1738
01:16:51,873 --> 01:16:54,943
on Mars as microbes
for a long time,

1739
01:16:54,976 --> 01:16:56,077
as it was on Earth for the first

1740
01:16:56,110 --> 01:16:59,948
few billion years
of life on Earth.

1741
01:16:59,981 --> 01:17:03,818
>> Okay, let's go to
the other centers.

1742
01:17:03,851 --> 01:17:06,955
>> Okay, these are from the web.

1743
01:17:06,988 --> 01:17:09,090
>> Oh, from the web, okay.

1744
01:17:09,123 --> 01:17:11,192
>> Diego, hi Diego,
asks, "What are the

1745
01:17:11,225 --> 01:17:14,863
"top theories of
where the water went?"

1746
01:17:17,131 --> 01:17:18,967

The top theories of
where the water went

1747
01:17:19,000 --> 01:17:21,870
all have to do
with the way Mars,

1748
01:17:23,838 --> 01:17:25,173
it's sort of a Cinderella issue.

1749
01:17:25,206 --> 01:17:27,776
Is that the right analogy?

1750
01:17:27,809 --> 01:17:28,877
>> Audience Member: Three Bears.

1751
01:17:28,910 --> 01:17:30,045
>> Three Bears,
thank you, she knows,

1752
01:17:30,078 --> 01:17:32,781
Goldilocks, wrong
fictional character.

1753
01:17:32,814 --> 01:17:33,948
[audience laughs]

1754
01:17:33,981 --> 01:17:38,086
Yeah, a Little Mermaid.
[everyone laughs]

1755
01:17:39,921 --> 01:17:41,189
Not too hot, too cold, all that,

1756
01:17:41,222 --> 01:17:42,857
but in the case
of Mars and Earth,

1757
01:17:42,890 --> 01:17:44,893

it's the size of Mars.

1758
01:17:44,926 --> 01:17:46,895
Mars, as you saw in
that initial picture,

1759
01:17:46,928 --> 01:17:49,764
is about a third
the size of Earth.

1760
01:17:49,797 --> 01:17:51,733
That means it has
more surface area

1761
01:17:51,766 --> 01:17:54,102
compared to its internal volume.

1762
01:17:55,169 --> 01:17:57,005
And planets that have
more surface area

1763
01:17:57,038 --> 01:18:00,742
give off relatively more
heat, and they cool faster.

1764
01:18:00,775 --> 01:18:01,910
So, earlier in Mars' history,

1765
01:18:01,943 --> 01:18:04,012
its crust thickened and cooled,

1766
01:18:04,045 --> 01:18:06,181
and that probably
led to its magnetic

1767
01:18:06,214 --> 01:18:09,818
field turning off
earlier than Earth's did.

1768

01:18:09,851 --> 01:18:11,853
Earth's hasn't turned
off yet, actually.

1769
01:18:11,886 --> 01:18:14,989
So, once you cool the crust and

1770
01:18:15,022 --> 01:18:17,859
turn off the magnetic field,
you leave the atmosphere

1771
01:18:17,892 --> 01:18:21,963
vulnerable to the solar wind
stripping it away over time.

1772
01:18:21,996 --> 01:18:24,833
And also, because Mars is
just physically smaller,

1773
01:18:24,866 --> 01:18:26,935
its gravity is less
strong, and the atmosphere

1774
01:18:26,968 --> 01:18:31,072
can actually be lost due
to being lost to space,

1775
01:18:31,105 --> 01:18:33,041
because the gravity's
not strong enough.

1776
01:18:33,074 --> 01:18:34,209
So, there's a few
theories like that

1777
01:18:34,242 --> 01:18:36,010
that would all lead
us to believe that

1778
01:18:36,043 --> 01:18:39,013

Mars' atmosphere over
time has gone away.

1779
01:18:39,046 --> 01:18:40,882
And in fact, there's a
mission called Maven,

1780
01:18:40,915 --> 01:18:42,751
which is an orbit
at Mars right now,

1781
01:18:42,784 --> 01:18:46,187
that's actually been
showing that, even today,

1782
01:18:46,220 --> 01:18:47,889
Mars' atmosphere
is being lost by

1783
01:18:47,922 --> 01:18:49,824
the solar wind
through this process,

1784
01:18:49,857 --> 01:18:52,060
and you can calculate how
fast it's being lost today,

1785
01:18:52,093 --> 01:18:54,729
and figure out that over time,

1786
01:18:54,762 --> 01:18:57,866
this theory actually
holds up quite well.

1787
01:18:57,899 --> 01:19:01,903
>> Okay, the next one is
from The Coffee Enthusiast,

1788
01:19:01,936 --> 01:19:04,739
and he asks, "Is it

possible that Mount Sharp

1789
01:19:04,772 --> 01:19:07,008
"was caused by
volcanic activity,

1790
01:19:07,041 --> 01:19:10,879
"or has it been entirely
from sedimentary deposits?"

1791
01:19:10,912 --> 01:19:12,013
>> Good question.

1792
01:19:12,046 --> 01:19:15,216
So, we haven't found any
evidence from volcanism.

1793
01:19:15,249 --> 01:19:19,154
The tridymite, actually
I'd mentioned earlier,

1794
01:19:19,187 --> 01:19:21,956
can be found around
volcanoes on Earth,

1795
01:19:21,989 --> 01:19:25,927
but so far there's not
vents, no lava flows,

1796
01:19:25,960 --> 01:19:28,730
no fissures where magma
would come out of,

1797
01:19:28,763 --> 01:19:30,031
that we found
anywhere near there.

1798
01:19:30,064 --> 01:19:34,836
And plus, the layers themselves
are very flat on Mars,

1799
01:19:34,869 --> 01:19:37,038
whereas a volcano,
if you all made one

1800
01:19:37,071 --> 01:19:39,174
in your science fair
project, they come out,

1801
01:19:39,207 --> 01:19:41,209
and you get layers
that sort of conform

1802
01:19:41,242 --> 01:19:43,077
to the shape of the
mound instead of

1803
01:19:43,110 --> 01:19:45,814
being flat like
you sliced a cake.

1804
01:19:45,847 --> 01:19:48,883
And so, the Gale, at
least the bottom part

1805
01:19:48,916 --> 01:19:51,820
of Mount Sharp where we
are is the cake model,

1806
01:19:51,853 --> 01:19:54,956
and the upper part is
not the volcano model,

1807
01:19:54,989 --> 01:19:56,191
but it's also not layered.

1808
01:19:56,224 --> 01:19:58,827
It's just massive,
it's just thick.

1809
01:19:58,860 --> 01:20:01,830
And so, we think that could
just be wind blown dust

1810
01:20:01,863 --> 01:20:05,900
that came in and just
made a big thick layer.

1811
01:20:05,933 --> 01:20:08,870
>> This is the
interesting question.

1812
01:20:08,903 --> 01:20:11,172
Jeff asks, "What has surprised

1813
01:20:11,205 --> 01:20:14,075
"you most during this mission?"

1814
01:20:14,108 --> 01:20:17,012
And I'll take a
crack at it first.

1815
01:20:18,246 --> 01:20:20,949
I always like to be interested
in the science that happens,

1816
01:20:20,982 --> 01:20:24,219
but that's more fair to
leave that for Ashwin.

1817
01:20:24,252 --> 01:20:26,054
The things that
have surprised me

1818
01:20:26,087 --> 01:20:28,223
are things that have
happened on the vehicle,

1819
01:20:28,256 --> 01:20:30,959

and how well we've
been able to respond

1820
01:20:30,992 --> 01:20:32,193
to the challenges
that we've gotten

1821
01:20:32,226 --> 01:20:35,129
with the flight team,
basically, solving

1822
01:20:35,162 --> 01:20:37,198
everything we've
been thrown at yet.

1823
01:20:37,231 --> 01:20:40,802
Now, we've got one problem
we're currently working,

1824
01:20:40,835 --> 01:20:43,805
which has to do with the
drill not working quite right.

1825
01:20:43,838 --> 01:20:45,206
And we're, I think,
well on the way

1826
01:20:45,239 --> 01:20:46,908
to solving that
to the point where

1827
01:20:46,941 --> 01:20:49,744
we're gonna be able
to drill again fairly,

1828
01:20:49,777 --> 01:20:52,180
fairly soon, where
fairly is in months,

1829
01:20:52,213 --> 01:20:54,249

not years, and not weeks.

1830
01:20:58,219 --> 01:21:00,121
It is one thing
that JPL does well,

1831
01:21:00,154 --> 01:21:02,090
and it's one thing that
JPL's people does well,

1832
01:21:02,123 --> 01:21:05,059
is deal with the
problem that they have,

1833
01:21:05,092 --> 01:21:07,929
and get the most
science from a vehicle,

1834
01:21:07,962 --> 01:21:11,032
run it into the ground, get
everything you can from it,

1835
01:21:11,065 --> 01:21:13,935
so you don't end up
leaving a perfectly

1836
01:21:13,968 --> 01:21:17,071
good rover on the
surface 'cause you were

1837
01:21:17,104 --> 01:21:19,040
trying to baby it too much.

1838
01:21:19,073 --> 01:21:20,242
You wear it out.

1839
01:21:22,143 --> 01:21:24,112
>> Yeah, I should
probably have prepared

1840
01:21:24,145 --> 01:21:27,148
answers for these
kinds of questions.

1841
01:21:27,181 --> 01:21:29,150
I don't know if
there's any one thing

1842
01:21:29,183 --> 01:21:31,019
that surprised me,
but one thing that

1843
01:21:31,052 --> 01:21:34,022
certainly comes to
mind is just how

1844
01:21:35,256 --> 01:21:39,261
abundant the evidence for
lakes and water has been.

1845
01:21:40,962 --> 01:21:42,997
We were really nervous
about going to Gale Crater

1846
01:21:43,030 --> 01:21:44,933
because we haven't been
to Mars a whole lot,

1847
01:21:44,966 --> 01:21:48,770
and it could've
been a strike out.

1848
01:21:48,803 --> 01:21:51,205
Those of us who were
championing Gale Crater

1849
01:21:51,238 --> 01:21:53,074
as a landing site
had to convince a lot

1850
01:21:53,107 --> 01:21:55,944
of other scientists that it
was the right place to go,

1851
01:21:55,977 --> 01:21:58,212
largely because it
contained the record.

1852
01:21:58,245 --> 01:22:00,715
And so, the argument
that won the day

1853
01:22:00,748 --> 01:22:02,984
is it's gonna tell you
a lot of Mars' history.

1854
01:22:03,017 --> 01:22:04,919
The problem is, a
lot of Mars' history

1855
01:22:04,952 --> 01:22:07,855
couldn't all been boring,
and blown in by wind,

1856
01:22:07,888 --> 01:22:09,791
and no water involved.

1857
01:22:09,824 --> 01:22:10,892
We had good reason, of course,

1858
01:22:10,925 --> 01:22:13,061
to think that water was there.

1859
01:22:13,094 --> 01:22:15,196
From the day we found the
rounded pebbles 'til today,

1860
01:22:15,229 --> 01:22:17,031
it's just been

water, water, water.

1861
01:22:17,064 --> 01:22:19,033
And that's been really wonderful

1862
01:22:19,066 --> 01:22:22,036
to learn about
ancient Mars that way.

1863
01:22:22,069 --> 01:22:23,204
I think our last
online question,

1864
01:22:23,237 --> 01:22:26,107
Finding Freedom asks,
"How are the images

1865
01:22:26,140 --> 01:22:29,077
"processed to make the
sky appear blue on Mars?"

1866
01:22:29,110 --> 01:22:31,813
Yeah, I mentioned that
a little bit earlier.

1867
01:22:31,846 --> 01:22:33,014
We cheat a little bit.

1868
01:22:33,047 --> 01:22:35,016
The sky is kind
of salmon colored.

1869
01:22:35,049 --> 01:22:38,219
There's all this
dust in the air that,

1870
01:22:38,252 --> 01:22:42,223
and it's sort of orangy
dust, the color of Mars dust,

1871
01:22:42,256 --> 01:22:45,093
and it tints everything orange.

1872
01:22:45,126 --> 01:22:48,830
And so, when you just snap
a picture with our cameras,

1873
01:22:48,863 --> 01:22:53,001
you get an orange sky and
a very orange set of rocks.

1874
01:22:53,034 --> 01:22:55,103
We basically use
something similar

1875
01:22:55,136 --> 01:22:58,006
to a white balance
function on Photoshop

1876
01:22:58,039 --> 01:23:02,877
where we can re-tint the colors
and remove the orange cast,

1877
01:23:02,910 --> 01:23:05,113
and make it appear
more like it would look

1878
01:23:05,146 --> 01:23:07,115
if those same rocks
were on Earth.

1879
01:23:07,148 --> 01:23:10,218
And we do that to
allow our geologists

1880
01:23:12,086 --> 01:23:16,157
to use their sort of
subconscious skillset.

1881

01:23:16,190 --> 01:23:17,859
We have geologists on our team

1882
01:23:17,892 --> 01:23:19,894
who've spent their
life walking around

1883
01:23:19,927 --> 01:23:23,231
very similar rocks in
the deserts on Earth.

1884
01:23:26,901 --> 01:23:28,903
It helps their
intuition when they

1885
01:23:28,936 --> 01:23:31,039
see rocks and
minerals in the colors

1886
01:23:31,072 --> 01:23:32,206
that they see them on Earth.

1887
01:23:32,239 --> 01:23:34,809
So, that's why we do that.

1888
01:23:36,944 --> 01:23:38,079
Final question?

1889
01:23:39,113 --> 01:23:40,015
No?

1890
01:23:41,048 --> 01:23:43,117
Okay, we got one.

1891
01:23:43,150 --> 01:23:45,887
>> Go to the microphone please.

1892
01:23:47,188 --> 01:23:48,056
>> Audience Member: Hi, Ash.

1893
01:23:48,089 --> 01:23:49,157
>> Hi.

1894
01:23:49,190 --> 01:23:51,993
>> Well, you mentioned
about tridymite.

1895
01:23:52,026 --> 01:23:53,127
Have you considered
the fact that

1896
01:23:53,160 --> 01:23:55,196
when silica is amorphous and is

1897
01:23:55,229 --> 01:23:58,099
deposited amorphous
like it is from fluids,

1898
01:23:58,132 --> 01:24:00,034
that it can also devitrify into

1899
01:24:00,067 --> 01:24:03,938
cristobalite and tridymite
like with in petrified wood,

1900
01:24:03,971 --> 01:24:06,974
or in snowflake
obsidian for example,

1901
01:24:07,007 --> 01:24:08,943
that you don't actually
need the high temperatures

1902
01:24:08,976 --> 01:24:11,779
to get the tridymite, which
would be more compatible with

1903
01:24:11,812 --> 01:24:14,749

the low temperature formation
of your phyllosilicates.

1904
01:24:14,782 --> 01:24:15,850
>> Thank you very.

1905
01:24:15,883 --> 01:24:16,951
I am not the expert on
the tridymite discovery,

1906
01:24:16,984 --> 01:24:19,854
but I will bring that
back to the team.

1907
01:24:19,887 --> 01:24:22,023
[laughs]

1908
01:24:22,056 --> 01:24:24,125
A real life geologist.

1909
01:24:24,158 --> 01:24:25,827
>> Audience Member:
How 'bout we do lunch?

1910
01:24:25,860 --> 01:24:27,762
>> Sure. [laughs]

1911
01:24:27,795 --> 01:24:30,998
Okay, well, we wanna thank
you on behalf of the,

1912
01:24:31,031 --> 01:24:32,800
actually, since this is
the five year anniversary

1913
01:24:32,833 --> 01:24:35,203
in the, literally
thousands, 3,000,

1914

01:24:35,236 --> 01:24:38,806
4,000, 5,000 people
who helped develop MSL,

1915
01:24:38,839 --> 01:24:42,076
the Mars Science Laboratory
and Curiosity since 2003 or so,

1916
01:24:42,109 --> 01:24:45,046
and the 500 scientists
around the world

1917
01:24:45,079 --> 01:24:48,950
in seven or eight different
countries who operate it today,

1918
01:24:48,983 --> 01:24:51,219
and the about 200 people at JPL

1919
01:24:51,252 --> 01:24:53,221
who keep the rover
going every day,

1920
01:24:53,254 --> 01:24:56,757
we wanna thank you all for
coming, and keep watching.