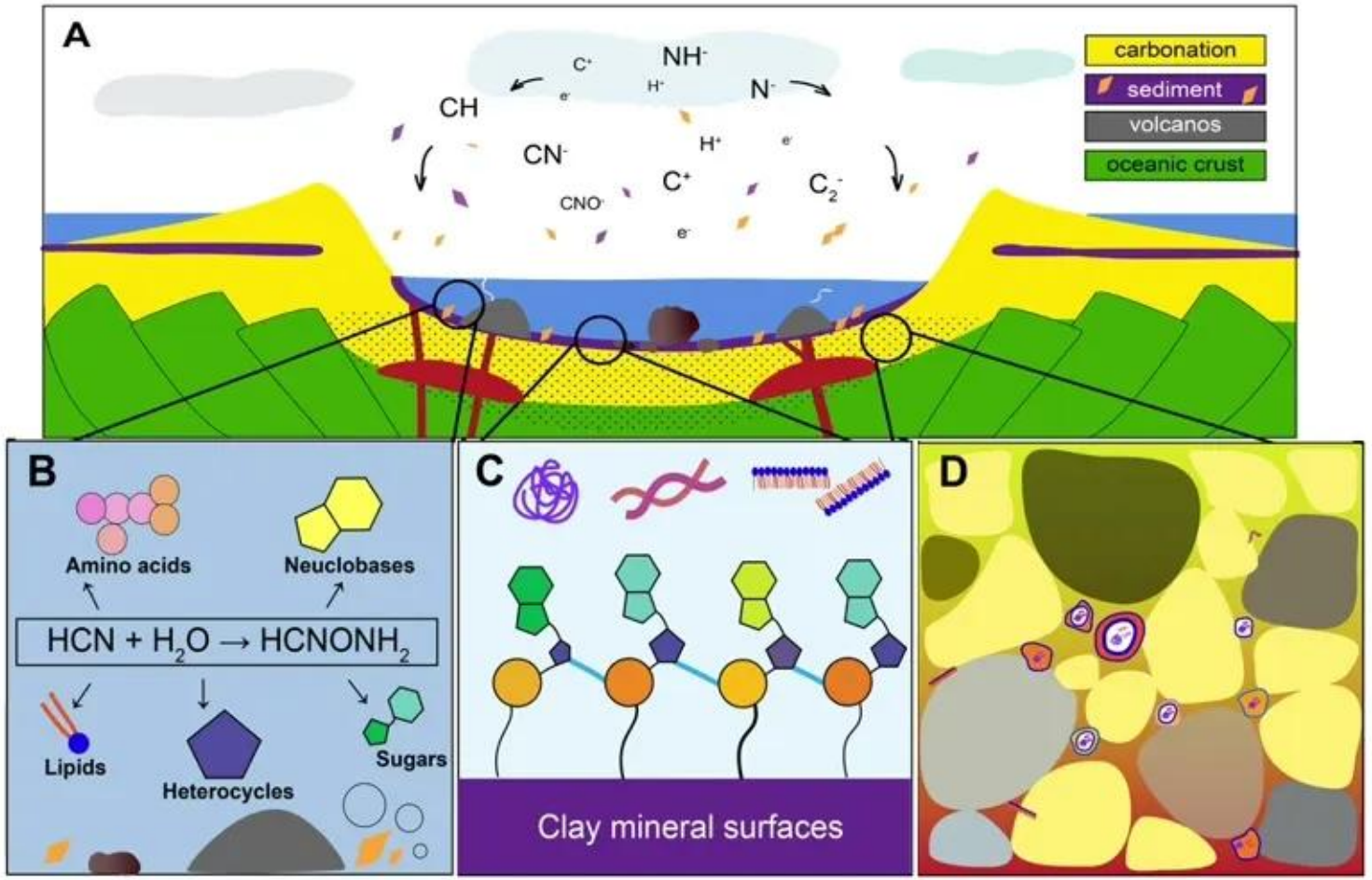
Heavy bombardments could have provided critical precursors, as well as optimal habitats and resources to support subsequent molecular evolution.



Ziqin (Grace) Ni zni@umd.edu University of Maryland, College Park

1
00:00:05,910 --> 00:00:03,189
this is grace and today i'm going to

2
00:00:08,990 --> 00:00:05,920
tell you a romantic story about making

3
00:00:12,070 --> 00:00:09,000
prebiotic organics from helium crust via

4
00:00:14,629 --> 00:00:12,080
hypervelocity impacts this research is

5
00:00:19,830 --> 00:00:14,639
funded by nasa fundamental laboratory

6
00:00:24,470 --> 00:00:22,230
so do you know that in the first few

7
00:00:28,870 --> 00:00:24,480
hundred million years after earth's

8
00:00:31,349 --> 00:00:28,880
birth from 4.1 to 3.8 billion years ago

9
00:00:33,830 --> 00:00:31,359
meteors comets and asteroids of

10
00:00:36,229 --> 00:00:33,840
different sizes heavily bombarded on

11
00:00:39,750 --> 00:00:36,239
earth's surface a period of time

12
00:00:42,150 --> 00:00:39,760
commonly referred as punitive late heavy

13
00:00:44,549 --> 00:00:42,160

bombardment

14
00:00:46,630 --> 00:00:44,559
these impact events are often considered

15
00:00:48,950 --> 00:00:46,640
being destructive to life

16
00:00:52,389 --> 00:00:48,960
at least we think

17
00:00:54,869 --> 00:00:52,399
dinosaurs are killed by impactors

18
00:00:56,389 --> 00:00:54,879
however re-examination of heavy

19
00:00:58,790 --> 00:00:56,399
bombardments yield different

20
00:01:01,189 --> 00:00:58,800
perspectives

21
00:01:03,750 --> 00:01:01,199
exogenous impactors may not only have

22
00:01:05,990 --> 00:01:03,760
seeded sterile earth with water and

23
00:01:08,230 --> 00:01:06,000
essential organics that originated in

24
00:01:10,710 --> 00:01:08,240
the outer space

25
00:01:12,870 --> 00:01:10,720
but also have enabled synthesis of new

26
00:01:15,510 --> 00:01:12,880
organic materials as they penetrate

27
00:01:17,510 --> 00:01:15,520
through the primitive atmosphere slammed

28
00:01:19,270 --> 00:01:17,520
into the ocean layer and collide with

29
00:01:21,590 --> 00:01:19,280
the crust

30
00:01:24,149 --> 00:01:21,600
imagine a juvenile earth without any

31
00:01:26,950 --> 00:01:24,159
organic materials carbon and nitrogen

32
00:01:30,310 --> 00:01:26,960
would have stayed as inorganic compounds

33
00:01:33,030 --> 00:01:30,320
and gotten recycled between atmosphere

34
00:01:35,109 --> 00:01:33,040
ocean crust and mantle

35
00:01:37,590 --> 00:01:35,119
though the specific mechanism remain

36
00:01:39,590 --> 00:01:37,600
controversial majority of the carbon and

37
00:01:42,230 --> 00:01:39,600
nitrogen in the mantle could have

38
00:01:44,789 --> 00:01:42,240

outgassed as carbon dioxide and nitrogen

39
00:01:47,749 --> 00:01:44,799
gas due to an early oxidation of the

40
00:01:50,550 --> 00:01:47,759
mantle and therefore creating a carbon

41
00:01:52,950 --> 00:01:50,560
dioxide and nitrogen dominated neutral

42
00:01:55,030 --> 00:01:52,960
atmosphere

43
00:01:57,749 --> 00:01:55,040
the composition of the primitive crust

44
00:02:00,230 --> 00:01:57,759
is likely ultramafic as suggested by

45
00:02:02,230 --> 00:02:00,240
remnants of comedians that formed

46
00:02:04,709 --> 00:02:02,240
billion years ago

47
00:02:06,950 --> 00:02:04,719
interaction of co2 with calcium and

48
00:02:09,589 --> 00:02:06,960
magnesium ions that dissolve from the

49
00:02:11,270 --> 00:02:09,599
ultramafic minerals can soon form

50
00:02:13,990 --> 00:02:11,280
secondary carbonates

51
00:02:16,390 --> 00:02:14,000
in the pore space and fracture zones as

52
00:02:19,830 --> 00:02:16,400
suggested by the laboratory experiments

53
00:02:22,470 --> 00:02:19,840
and also the video showing you here

54
00:02:25,190 --> 00:02:22,480
extensive synthetization can introduce

55
00:02:27,670 --> 00:02:25,200
nitrogen in the form of ammonia ions to

56
00:02:30,150 --> 00:02:27,680
substitute potassium in the clay

57
00:02:32,470 --> 00:02:30,160
minerals that present in the hydrous

58
00:02:34,710 --> 00:02:32,480
ultramafic rocks

59
00:02:37,350 --> 00:02:34,720
this process could have been extremely

60
00:02:38,550 --> 00:02:37,360
efficient on early earth considering

61
00:02:40,710 --> 00:02:38,560
elevated

62
00:02:43,270 --> 00:02:40,720
volcanic outgassing rates and the more

63
00:02:45,990 --> 00:02:43,280

vigorous hydrothermal circulation driven

64
00:02:48,630 --> 00:02:46,000
by a higher surface heat flow

65
00:02:50,949 --> 00:02:48,640
consequently a considerable amount of

66
00:02:53,589 --> 00:02:50,959
carbon and nitrogen could have been

67
00:02:55,990 --> 00:02:53,599
accumulated in the early earth's crust a

68
00:02:58,390 --> 00:02:56,000
hidden reservoir that have never been

69
00:03:00,949 --> 00:02:58,400
considered as a significant source of

70
00:03:03,589 --> 00:03:00,959
carbon and nitrogen to form prebiotic

71
00:03:05,830 --> 00:03:03,599
organics

72
00:03:08,470 --> 00:03:05,840
in this study we really want to know if

73
00:03:10,710 --> 00:03:08,480
we could synthesize prebiotic organics

74
00:03:13,830 --> 00:03:10,720
using inorganic carbon and nitrogen in

75
00:03:18,869 --> 00:03:13,840
the crust via hypervelocity impact if we

76
00:03:23,430 --> 00:03:20,949
to answer these questions we simulate

77
00:03:26,470 --> 00:03:23,440
hypervelocity impact plasma environment

78
00:03:29,990 --> 00:03:26,480
using high power post laser ablation

79
00:03:32,630 --> 00:03:30,000
we use q-switch laser at 1064 nanometer

80
00:03:34,869 --> 00:03:32,640
under a minimum laser energy 70

81
00:03:36,229 --> 00:03:34,879
millijoule and a pulse width of 9

82
00:03:38,390 --> 00:03:36,239
nanoseconds

83
00:03:40,550 --> 00:03:38,400
this laser enabled irradiance greater

84
00:03:42,550 --> 00:03:40,560
than gigawatts per centimeter square

85
00:03:45,190 --> 00:03:42,560
sufficient to generate the thermodynamic

86
00:03:48,550 --> 00:03:45,200
plasma state of silica vapor generated

87
00:03:50,550 --> 00:03:48,560
by collision of two prosodic bodies

88
00:03:53,350 --> 00:03:50,560

the laser system was steered and

89
00:03:56,550 --> 00:03:53,360
irradiated on the sample pallet

90
00:03:59,270 --> 00:03:56,560
we performed all experiments at 10 to

91
00:04:01,429 --> 00:03:59,280
the -5 pascal of the chamber pressure in

92
00:04:05,670 --> 00:04:01,439
order to mitigate the interference from

93
00:04:07,830 --> 00:04:05,680
ambient carbon dioxide and nitrogen gas

94
00:04:10,949 --> 00:04:07,840
ions form in the plasma but then

95
00:04:13,270 --> 00:04:10,959
extracted and accommodated by ion optics

96
00:04:17,270 --> 00:04:13,280
and sent to quadruple mass spectrometer

97
00:04:22,150 --> 00:04:19,509
each of our sample pallets contain a

98
00:04:23,670 --> 00:04:22,160
source of carbon which is carbonate here

99
00:04:26,070 --> 00:04:23,680
and a source of nitrogen from

100
00:04:30,469 --> 00:04:26,080
nitrogenous salt they can either be

101
00:04:34,790 --> 00:04:30,479
sodium nitrate or ammonium chloride

102
00:04:36,870 --> 00:04:34,800
heavy labeled materials are also used

103
00:04:39,110 --> 00:04:36,880
a quadruple mass spectrometer measures

104
00:04:40,870 --> 00:04:39,120
the nominal mass of the ions and their

105
00:04:42,950 --> 00:04:40,880
intensity

106
00:04:45,110 --> 00:04:42,960
recombination of carbon and nitrogen

107
00:04:48,230 --> 00:04:45,120
that released from the both reactants

108
00:04:52,790 --> 00:04:48,240
allowed the formation of cyanide ions cn

109
00:04:58,070 --> 00:04:55,270
when the ablation target was prepared

110
00:05:00,230 --> 00:04:58,080
using a single isotopic labeled material

111
00:05:03,590 --> 00:05:00,240
the mass of recombination ions will

112
00:05:05,990 --> 00:05:03,600
shift from 26 to 27.

113
00:05:09,270 --> 00:05:06,000

when both of the reactants are labeled

114
00:05:11,110 --> 00:05:09,280
the mass station will shift to 28.

115
00:05:12,870 --> 00:05:11,120
this migration of the peaks as a

116
00:05:15,590 --> 00:05:12,880
function of the input materials

117
00:05:17,909 --> 00:05:15,600
reinforce that carbon and nitrogen atoms

118
00:05:21,909 --> 00:05:17,919
stand from the solid starting material

119
00:05:24,070 --> 00:05:21,919
in the plasma plume to form new species

120
00:05:26,230 --> 00:05:24,080
here are four mass spectrum observed

121
00:05:28,550 --> 00:05:26,240
from the simulation experiments using

122
00:05:30,310 --> 00:05:28,560
calcium carbonate and ammonium chlorides

123
00:05:32,870 --> 00:05:30,320
as starting materials

124
00:05:35,189 --> 00:05:32,880
each spectrum is a summation of 20 skins

125
00:05:36,790 --> 00:05:35,199
and the y-axis is normalized to the

126
00:05:40,070 --> 00:05:36,800
total number of

127
00:05:42,310 --> 00:05:40,080
ions detected in each spectrum

128
00:05:44,710 --> 00:05:42,320
the background of each spectrum has been

129
00:05:47,110 --> 00:05:44,720
identified using stepwise baseline

130
00:05:49,270 --> 00:05:47,120
regression and subtracted from the raw

131
00:05:51,830 --> 00:05:49,280
spectrum

132
00:05:55,749 --> 00:05:51,840
in the label 3 experiment we observe the

133
00:05:58,629 --> 00:05:55,759
recombination of cn and cno at mass 26

134
00:06:01,270 --> 00:05:58,639
and 42 respectively

135
00:06:03,590 --> 00:06:01,280
as we start to label a single reactant

136
00:06:07,189 --> 00:06:03,600
we start to observe the peak shifted to

137
00:06:09,430 --> 00:06:07,199
mass 27 and 43

138
00:06:12,629 --> 00:06:09,440

when both of the reactants were heavy

139
00:06:14,469 --> 00:06:12,639
labeled we detect peaks at mass 28 and

140
00:06:16,870 --> 00:06:14,479
44.

141
00:06:19,590 --> 00:06:16,880
we repeat similar experiments using

142
00:06:22,870 --> 00:06:19,600
calcium carbonate and sodium nitrate and

143
00:06:24,550 --> 00:06:22,880
observe comparable mass peaks at mass 26

144
00:06:27,189 --> 00:06:24,560
and 42.

145
00:06:29,749 --> 00:06:27,199
the peak shifted with the application of

146
00:06:32,390 --> 00:06:29,759
isotopic doped reactants

147
00:06:37,110 --> 00:06:32,400
we also observe an o2 as the

148
00:06:39,430 --> 00:06:37,120
decomposition product from nitrate salts

149
00:06:41,430 --> 00:06:39,440
in the meantime we realize accumulation

150
00:06:44,390 --> 00:06:41,440
of ions in the chamber that has been

151
00:06:47,270 --> 00:06:44,400
detected in the mass spectrum such as

152
00:06:50,629 --> 00:06:47,280
chlorine in the nitrate experiment

153
00:06:52,790 --> 00:06:50,639
despite multiple sources of signals both

154
00:06:55,909 --> 00:06:52,800
ammonium chloride and sodium nitrate

155
00:06:58,550 --> 00:06:55,919
experiments distinguish cn and cno from

156
00:07:00,550 --> 00:06:58,560
other potential isobaric interfaces

157
00:07:02,790 --> 00:07:00,560
providing confidence that the source of

158
00:07:06,070 --> 00:07:02,800
carbon and nitrogen are derived from the

159
00:07:10,469 --> 00:07:08,469
to provide complementary insights into

160
00:07:12,790 --> 00:07:10,479
the chemical and physical process

161
00:07:15,830 --> 00:07:12,800
associated with bombardments that may

162
00:07:18,790 --> 00:07:15,840
affect organic synthesis we explored a

163
00:07:20,710 --> 00:07:18,800

second method to simulate hypervelocity

164
00:07:23,189 --> 00:07:20,720
impact environment

165
00:07:24,309 --> 00:07:23,199
we used physical bombardment of carbon

166
00:07:28,150 --> 00:07:24,319
60

167
00:07:30,950 --> 00:07:28,160
bucket balls on nitrogen-rich substrate

168
00:07:35,189 --> 00:07:30,960
having labeled carbon 13 bucket ball was

169
00:07:38,230 --> 00:07:35,199
ionized accelerated and bombarded on an

170
00:07:41,029 --> 00:07:38,240
ammonium nitrate substrate at velocity

171
00:07:44,150 --> 00:07:41,039
greater than 70 kilometer per second

172
00:07:48,790 --> 00:07:44,160
the ions generated were detected by a

173
00:07:56,550 --> 00:07:52,629
we observed isotopic labeled cn and cno

174
00:07:59,589 --> 00:07:56,560
peaks at mass 27 and 43 respectively

175
00:08:02,230 --> 00:07:59,599
when heavily labeled carbon 13

176
00:08:06,469 --> 00:08:02,240
60 bucket ball

177
00:08:10,309 --> 00:08:06,479
bombarded on ammonia nitrate target

178
00:08:13,029 --> 00:08:10,319
the isotopic labeled material are used

179
00:08:17,909 --> 00:08:13,039
then we observe migration of the peak to

180
00:08:21,990 --> 00:08:20,230
the significant peaks at the other mass

181
00:08:26,070 --> 00:08:22,000
station were observed during the

182
00:08:28,790 --> 00:08:26,080
experiment due to the presence of 20

183
00:08:31,589 --> 00:08:28,800
carbon 12 contamination sourced from the

184
00:08:37,509 --> 00:08:34,550
the cn and cmo yielded at mass station

185
00:08:39,829 --> 00:08:37,519
28 and 44 nonetheless represent

186
00:08:42,389 --> 00:08:39,839
recombination products from the labeled

187
00:08:45,670 --> 00:08:42,399
input material

188
00:08:48,310 --> 00:08:45,680

we compared and contrast the yield of cn

189
00:08:50,870 --> 00:08:48,320
and cno between reduced nitrogen in

190
00:08:52,470 --> 00:08:50,880
ammonia and oxidized nitrogen in the

191
00:08:54,470 --> 00:08:52,480
nitrate form

192
00:08:56,470 --> 00:08:54,480
the arrow bar represents two standard

193
00:08:58,230 --> 00:08:56,480
deviation of the eos from four

194
00:09:00,470 --> 00:08:58,240
experiments

195
00:09:03,190 --> 00:09:00,480
the observation suggests that cyanide

196
00:09:05,910 --> 00:09:03,200
ions can be produced via hypervelocity

197
00:09:09,110 --> 00:09:05,920
impacts at a similar rate irrespective

198
00:09:12,230 --> 00:09:09,120
of the redux states of the substrate

199
00:09:14,389 --> 00:09:12,240
the two-fold difference in yields of cmo

200
00:09:16,630 --> 00:09:14,399
suggests that reduced nitrogen in

201
00:09:22,389 --> 00:09:16,640
ammonium form is more efficient at

202
00:09:25,910 --> 00:09:24,310
with the both experiments we have

203
00:09:28,230 --> 00:09:25,920
demonstrated the capability of

204
00:09:30,470 --> 00:09:28,240
synthesizing prebiotic organics via

205
00:09:32,870 --> 00:09:30,480
hypervelocity impacts using source of

206
00:09:35,350 --> 00:09:32,880
carbon and nitrogen from the crust

207
00:09:37,910 --> 00:09:35,360
the next question is how much prebiotic

208
00:09:39,590 --> 00:09:37,920
organics could we have synthesized

209
00:09:42,070 --> 00:09:39,600
to address these questions let's

210
00:09:44,470 --> 00:09:42,080
estimate the total reservoir size i mean

211
00:09:46,870 --> 00:09:44,480
the crustal residual size of carbon and

212
00:09:52,790 --> 00:09:46,880
nitrogen available for the organic

213
00:09:57,430 --> 00:09:54,949

spontaneous sequestration of carbon

214
00:10:00,389 --> 00:09:57,440
dioxide into the ultramafic oceanic

215
00:10:02,389 --> 00:10:00,399
crust and ejecta could have stored a

216
00:10:03,509 --> 00:10:02,399
significant amount of carbonate on the

217
00:10:05,670 --> 00:10:03,519
surface

218
00:10:08,230 --> 00:10:05,680
the crust alone could have trapped 3

219
00:10:11,030 --> 00:10:08,240
times 10 to the 21st moles of carbon

220
00:10:12,870 --> 00:10:11,040
dioxide based on the box model of global

221
00:10:15,990 --> 00:10:12,880
carbon dioxide cycling through

222
00:10:21,110 --> 00:10:18,550
abiotic fixation of nitrogen gas to

223
00:10:24,550 --> 00:10:21,120
nitrogenous salts is the rate limiting

224
00:10:27,430 --> 00:10:24,560
steps and has to rely on energetic

225
00:10:29,350 --> 00:10:27,440
process such as lightening in atmosphere

226
00:10:31,030 --> 00:10:29,360
or chemical reducing agents near

227
00:10:33,590 --> 00:10:31,040
hydrothermal vents

228
00:10:35,750 --> 00:10:33,600
assume an average 5 times 10 to the 10

229
00:10:38,310 --> 00:10:35,760
moles nitrogen gas is converted into

230
00:10:41,030 --> 00:10:38,320
nitrogenous salts per year the crustal

231
00:10:44,310 --> 00:10:41,040
budget of nitrogen is estimated to be 10

232
00:10:49,030 --> 00:10:46,550
assume all materials are distributed

233
00:10:51,269 --> 00:10:49,040
evenly on the earth's surface we could

234
00:10:54,310 --> 00:10:51,279
have a surface concentration of carbon

235
00:10:58,829 --> 00:10:54,320
and nitrogen as 10 to the 13 or 10 to

236
00:11:01,750 --> 00:10:58,839
the 10 moles per cubic kilometers

237
00:11:04,710 --> 00:11:01,760
respectively the mass of the ejecta that

238
00:11:06,790 --> 00:11:04,720

shocked to vaporize is under orders of

239
00:11:09,430 --> 00:11:06,800
six times the mass of the incoming

240
00:11:10,870 --> 00:11:09,440
impactors that traveled at 20 kilometer

241
00:11:13,750 --> 00:11:10,880
per second

242
00:11:15,509 --> 00:11:13,760
given the projected mass frequency of

243
00:11:16,710 --> 00:11:15,519
impactors during the late heavy

244
00:11:19,430 --> 00:11:16,720
bombardment

245
00:11:22,310 --> 00:11:19,440
we calculate the mass of impactors that

246
00:11:24,870 --> 00:11:22,320
are above the threshold impactor size to

247
00:11:26,790 --> 00:11:24,880
penetrate an ocean layer and generate

248
00:11:28,710 --> 00:11:26,800
sufficient ejecta

249
00:11:31,430 --> 00:11:28,720
the estimated total

250
00:11:33,670 --> 00:11:31,440
of 3 times 10 to the 8 cubic kilometer

251
00:11:36,310 --> 00:11:33,680
of cluster material could have been

252
00:11:39,350 --> 00:11:36,320
vaporized from the crust

253
00:11:41,910 --> 00:11:39,360
if 0.1 mole percent of the vaporized

254
00:11:44,310 --> 00:11:41,920
carbon and the nitrogen recombined and

255
00:11:46,470 --> 00:11:44,320
condensed as organic the continent and

256
00:11:49,910 --> 00:11:46,480
oceanic crust could have generated a

257
00:11:52,550 --> 00:11:49,920
total of 10 to the 15 and 10 to the 18

258
00:11:54,550 --> 00:11:52,560
moles of organics during the 300 million

259
00:11:56,629 --> 00:11:54,560
years of heavy bombardment

260
00:11:59,269 --> 00:11:56,639
this is equivalent to an organic

261
00:12:01,910 --> 00:11:59,279
production rate 10 to the 7 to 10 to the

262
00:12:04,230 --> 00:12:01,920
10 moles per year at least four orders

263
00:12:07,269 --> 00:12:04,240

magnitude higher than the previous

264
00:12:10,949 --> 00:12:07,279
estimate of organic production rate via

265
00:12:13,990 --> 00:12:10,959
atmospheric shock in neutral condition

266
00:12:16,069 --> 00:12:14,000
the story does not end here after newly

267
00:12:18,629 --> 00:12:16,079
combined organics were rained down to

268
00:12:20,470 --> 00:12:18,639
the crater they could have reacted with

269
00:12:23,190 --> 00:12:20,480
water and catalytic

270
00:12:25,350 --> 00:12:23,200
substrates near the crater basin to form

271
00:12:27,750 --> 00:12:25,360
molecular building blocks such as amino

272
00:12:29,430 --> 00:12:27,760
acids nuclear bases

273
00:12:32,710 --> 00:12:29,440
clay minerals formed due to the

274
00:12:34,949 --> 00:12:32,720
post-impact synthetization plus red dry

275
00:12:37,430 --> 00:12:34,959
cycling could have promoted the

276
00:12:40,509 --> 00:12:37,440
absorption of a comprehensive

277
00:12:43,190 --> 00:12:40,519
panel of monomers and facilitate

278
00:12:45,590 --> 00:12:43,200
self-assembly of molecules

279
00:12:47,750 --> 00:12:45,600
interstitial pore space and fractures

280
00:12:49,750 --> 00:12:47,760
near the crater surface could have

281
00:12:53,190 --> 00:12:49,760
offered the optimal habitats to

282
00:12:54,310 --> 00:12:53,200
concentrate polymerized carbonic organic

283
00:12:56,710 --> 00:12:54,320
compounds

284
00:12:59,829 --> 00:12:56,720
and showing them from harmful uv

285
00:13:01,430 --> 00:12:59,839
radiation and successive impact events

286
00:13:04,069 --> 00:13:01,440
on the surface

287
00:13:06,389 --> 00:13:04,079
because of these reasons hypervelocity

288
00:13:10,150 --> 00:13:06,399

impacts could have been an invaluable

289
00:13:12,550 --> 00:13:10,160
mechanism to live its emergence on earth

290
00:13:14,629 --> 00:13:12,560
and this is great i hope you enjoy my