1 01:29:27:18 01:29:31:00 Annenberg Media
2 01:29:31:02 01:30:23:15 §
3 01:30:23:17 01:30:24:27 A VOLCANIC ERUPTION
4 01:30:24:29 01:30:27:10 IS ONE OF THE MOST
AWE-INSPIRING SIGHTS
5 01:30:27:12 01:30:28:22 IN ALL OF NATURE.
6 01:30:28:24 01:30:31:06 BUT WHETHER AN ERUPTION
IS SUDDEN AND EXPLOSIVE,
7 01:30:31:08 01:30:32:22 SUCH AS MT. ST. HELEN'S,
8 01:30:32:24 01:30:34:08 OR MORE SUBDUED,
9 01:30:34:10 01:30:36:17 LIKE THE ERUPTIONS
OF KILAUEA IN HAWAII,
10 01:30:36:19 01:30:39:07 VOLCANIC ACTIVITY
IS NOT AN UNUSUAL EVENT.
11 01:30:39:09 01:30:42:06 VOLCANIC ERUPTIONS
ARE THE PULSE
OF GEOLOGIC ACTIVITY
12 01:30:42:08 01:30:43:22 IN THE EARTH'S INTERIOR.
13 01:30:43:24 01:30:45:08 THEY GRAPHICALLY
DEMONSTRATE
14 01:30:45:10 01:30:47:27 THAT GEOLOGIC PROCESSES
INSIDE THE EARTH
15 01:30:47:29 01:30:51:13 CAN HAVE A DIRECT IMPACT
HERE ON THE SURFACE.
16 01:30:51:15 01:30:53:28 THE LAVA THAT'S PRODUCED
DURING A VOLCANIC ERUPTION
17 01:30:54:00 01:30:56:13 IS, OF COURSE,
ROCK THAT MELTED
18 01:30:56:15 01:30:57:28 SOMEWHERE BENEATH
THE VOLCANO.
19 01:30:58:00 01:31:00:28 ROCK MELTS IN A VARIETY
OF GEOLOGIC SETTINGS
20 01:31:01:00 01:31:03:28 IN THE CRUST AND UPPER MANTLE
OF THE EARTH,
21 01:31:04:00 01:31:06:14 DEPENDING ON THE TEMPERATURE
AND PRESSURE CONDITIONS
22 01:31:06:16 01:31:09:14 AND ON THE COMPOSITION
AND WATER CONTENT OF THE ROCKS.
23 01:31:09:16 01:31:11:28 BUT LAVA REPRESENTS
ONLY A TINY PROPORTION
24 01:31:12:00 01:31:14:13 OF THE MAGMA THAT FORMS
WITHIN THE EARTH.
25 01:31:14:15 01:31:17:28 MOST OF THIS MAGMA
EITHER SEEPS
INTO VOIDS AND FRACTURES
26 01:31:18:00 01:31:20:00 WITHIN ROCKS
OF THE EARTH'S CRUST
27 01:31:20:02 01:31:24:00 OR IT RISES AND INTRUDES
INTO THE COOLER ROCKS ABOVE
28 01:31:24:02 01:31:26:13 AS ENORMOUS GLOBS
THAT REQUIRE THOUSANDS
29 01:31:26:15 01:31:28:27 OR EVEN MILLIONS OF YEARS
TO COOL.
30 01:31:28:29 01:31:31:27 IN FACT, MOST OF THE ROCK
OF THIS PLANET
31 01:31:31:29 01:31:33:27 WAS FORMED

FROM THE SLOW-COOLING

32 01:31:33:29 01:31:36:12 AND CRYSTALLIZATION OF MAGMA
DEEP UNDERGROUND.

33 01:31:36:14 01:31:39:23 THIS IS KNOWN
AS INTRUSIVE IGNEOUS ROCK.

34 01:31:39:25 01:31:43:24 *THE STUDY OF IGNEOUS ROCKS*
BEGAN IN THE 1780s,

35 01:31:43:26 01:31:45:09 *WHEN SCOTSMAN JAMES HUTTON*

36 01:31:45:11 01:31:47:10 *BECAME EMBROILED*
IN A CONTROVERSY

37 01:31:47:12 01:31:52:02 *WITH ANOTHER INFLUENTIAL*
GEOLOGIST, ABRAHAM WERNER.

38 01:31:52:04 01:31:54:01 *WERNER BELIEVED*
THAT THE EARTH

39 01:31:54:03 01:31:56:15 *WAS ONCE COVERED ENTIRELY*
BY A GREAT OCEAN

40 01:31:56:17 01:32:00:02 *FROM WHICH ALL ROCKS FORMED,*
STARTING WITH GRANITE.

41 01:32:00:04 01:32:02:21 *HUTTON DISAGREED.*

42 01:32:02:23 01:32:04:25 *IN EXPLORING THE HIGHLANDS*
OF SCOTLAND,

43 01:32:04:27 01:32:07:09 *HUTTON OBSERVED*
VEINS OF GRANITIC ROCK

44 01:32:07:11 01:32:10:00 *SLICING ACROSS*
SEDIMENTARY STRATA.

45 01:32:11:12 01:32:13:10 *HE REASONED*
THAT THE GRANITE

46 01:32:13:12 01:32:15:24 *MUST HAVE BEEN INJECTED*
INTO THE STRATA

47 01:32:15:26 01:32:17:12 *AS A MOLTEN LIQUID*

48 01:32:17:14 01:32:19:25 *AND NOT BEEN PRECIPITATED*
FROM A PRIMORDIAL SEA.

49 01:32:21:15 01:32:24:27 *HE MADE A LINK BETWEEN*
GRANITES FORMED AT DEPTH

50 01:32:24:29 01:32:26:26 *AND THE QUICKLY*
COOLING DEPOSITS

51 01:32:26:28 01:32:28:17 *OF ERUPTING VOLCANOES.*

52 01:32:31:04 01:32:33:18 *BOTH ARE PRODUCTS*
OF MOLTEN LIQUID,

53 01:32:33:20 01:32:35:18 *OR "MAGMA,"*
FROM EARTH'S INTERIOR.

54 01:32:35:20 01:32:37:03 *THANKS TO HUTTON,*

55 01:32:37:05 01:32:40:02 *GEOLOGISTS RECOGNIZED*
A NEW CLASS OF ROCKS

56 01:32:40:04 01:32:43:22 *CALLED IGNEOUS, LITERALLY*
"FIRE-FORMED ROCKS."

57 01:32:45:09 01:32:46:21 SOME OF THE ORIGINAL HEAT

58 01:32:46:23 01:32:49:06 THAT RESULTS
IN THE FORMATION OF MAGMA

59 01:32:49:08 01:32:52:05 COMES FROM THE ORIGINAL
FORMATION OF THE EARTH.

60 01:32:52:07 01:32:55:06 AS THE MATERIALS CAME TOGETHER
THAT FORM THE EARTH,

61 01:32:55:08 01:32:57:22 THEY PRODUCED AN ENORMOUS
AMOUNT OF COMPRESSION.

62 01:32:57:24 01:33:00:07 THAT WAS SOME

4 1/2 BILLION YEARS AGO.

63 01:33:00:09 01:33:02:06 BUT SOME OF THAT HEAT

64 01:33:02:08 01:33:04:21 STILL REMAINS IN
THE INTERIOR OF THE EARTH.

65 01:33:04:23 01:33:07:18 ANOTHER SOURCE IS FROM
RADIOACTIVE ISOTOPES.

66 01:33:07:20 01:33:09:27 POTASSIUM, THORIUM,
AND URANIUM

67 01:33:09:29 01:33:11:13 HAVE ALL CONTRIBUTED

68 01:33:11:15 01:33:13:22 AS A RESULT OF
RADIOACTIVE DECAY

69 01:33:13:24 01:33:15:08 TO HEATING OF THE EARTH,

70 01:33:15:10 01:33:17:22 PARTICULARLY IN THE EARLIER
HISTORY OF THE EARTH

71 01:33:17:24 01:33:20:13 WHEN THESE ISOTOPES
WERE MORE ABUNDANT.

72 01:33:20:15 01:33:21:27 NOW, THERE'S
ANOTHER CONTRIBUTION

73 01:33:21:29 01:33:24:11 THAT COMES
FROM THE TIDAL EFFECTS

74 01:33:24:13 01:33:25:26 OF THE SUN AND MOON.

75 01:33:25:28 01:33:28:02 AS A RESULT
OF THESE TIDES,

76 01:33:28:04 01:33:30:16 THE EARTH IS BEING
CONSTANTLY SQUEEZED AND FLEXED,

77 01:33:30:18 01:33:33:01 AND THAT TENDS
TO BUILD UP SOME HEAT

78 01:33:33:03 01:33:35:00 IN THE EARTH'S INTERIOR
AS WELL.

79 01:33:36:05 01:33:37:18 *THE ASCENT OF MAGMA*

80 01:33:37:20 01:33:39:28 *IS A PROCESS*
CALLED "INTRUSION."

81 01:33:40:00 01:33:41:28 *IF THE MAGMA COOLS*
UNDERGROUND,

82 01:33:42:00 01:33:43:15 *IT FORMS AN INTRUSIVE,*

83 01:33:43:17 01:33:47:09 *SOMETIMES CALLED "PLUTONIC,"*
IGNEOUS ROCK.

84 01:33:47:11 01:33:49:15 *IF IT ERUPTS*
AT THE SURFACE,

85 01:33:49:17 01:33:53:00 *THE IGNEOUS ROCK IS CALLED*
"EXTRUSIVE," OR VOLCANIC.

86 01:33:54:29 01:33:56:13 *JAMES HUTTON*
STUDIED GRANITE

87 01:33:56:15 01:33:59:10 *BECAUSE IT IS AMONG*
THE COMMON PLUTONIC ROCKS

88 01:33:59:12 01:34:00:20 *OF SCOTLAND,*

89 01:34:00:22 01:34:02:26 *BUT WORLDWIDE,*
THERE ARE, IN FACT,

90 01:34:02:28 01:34:05:25 *MANY TYPES*
OF PLUTONIC ROCKS.

91 01:34:05:27 01:34:08:28 *THOSE THAT CONTAIN*
ABUNDANT IRON AND MAGNESIUM

92 01:34:09:00 01:34:11:14 *ARE CALLED "MAFIC" ROCKS*
BY GEOLOGISTS.

93 01:34:11:16 01:34:13:25 *GABBRO IS AN EXAMPLE.*

94 01:34:15:11 01:34:18:08 *"FELSIC" ROCKS,*

SUCH AS GRANITE,

95 01:34:18:10 01:34:21:14 *CONTAIN ABUNDANT SILICA*
AND ALUMINA.

96 01:34:21:16 01:34:24:24 *FINALLY, MANY IGNEOUS ROCKS*
ARE ESSENTIALLY MIXTURES

97 01:34:24:26 01:34:26:25 *OF MAFIC*
AND FELSIC COMPOSITIONS.

98 01:34:26:27 01:34:30:19 *THESE ARE KNOWN AS THE*
"INTERMEDIATE" IGNEOUS ROCKS.

99 01:34:30:21 01:34:33:19 *DIORITE IS ONE OF THE MOST*
ABUNDANT EXAMPLES.

100 01:34:34:29 01:34:36:25 *EACH OF THESE*
PLUTONIC ROCKS

101 01:34:36:27 01:34:38:24 *HAS A COMPOSITIONALLY*
IDENTICAL COUNTERPART

102 01:34:38:26 01:34:41:12 *IN VOLCANIC ROCKS.*

103 01:34:41:14 01:34:43:11 *BUT ALTHOUGH*
THEY MAY BE MADE

104 01:34:43:13 01:34:44:27 *OF EXACTLY*
THE SAME MATERIAL,

105 01:34:44:29 01:34:46:17 *THEIR TEXTURES*
ARE VERY DIFFERENT.

106 01:34:46:19 01:34:49:05 *THIS CAN ONLY BE*
DUE TO THE FACT

107 01:34:49:07 01:34:52:23 *THAT EACH COOLS AND HARDENS*
UNDER DIFFERENT CONDITIONS.

108 01:34:54:15 01:34:57:10 *LABORATORY STUDIES INDICATE*
THAT IF THE MOLTEN ROCK

109 01:34:57:12 01:34:58:25 *COOLS TOO QUICKLY,*

110 01:34:58:27 01:35:00:26 *CRYSTALS ARE*
UNABLE TO FORM

111 01:35:00:28 01:35:03:24 *SINCE THE INDIVIDUAL ATOMS*
IN THE MELT

112 01:35:03:26 01:35:06:12 *DON'T HAVE ENOUGH TIME*
TO BUILD CRYSTAL LATTICES.

113 01:35:09:02 01:35:12:01 *IF THE MOLTEN ROCK*
COOLS SLOWLY, HOWEVER,

114 01:35:12:03 01:35:15:04 *CRYSTALS WILL ULTIMATELY FORM*
THROUGHOUT THE MAGMA.

115 01:35:15:06 01:35:18:04 *AND THE MORE SLOWLY*
THE MAGMA COOLS,

116 01:35:18:06 01:35:20:18 *THE LARGER*
THE CRYSTALS WILL GROW.

117 01:35:24:09 01:35:27:06 THIS DIKE FORMED
WHEN A HOT, ANDESITIC MAGMA

118 01:35:27:08 01:35:30:12 WELLED UP INTO A FRACTURE
IN THIS GNEISS.

119 01:35:30:14 01:35:31:28 AS THE MAGMA COOLED,

120 01:35:32:00 01:35:34:19 IT TRANSFERRED HEAT
INTO THE SURROUNDING GNEISS.

121 01:35:34:21 01:35:36:19 HEAT TRANSFER
WAS, OF COURSE,

122 01:35:36:21 01:35:38:19 MORE RAPID HERE
AT THE CONTACT,

123 01:35:38:21 01:35:42:03 RESULTING IN THE GNEISS
BEING COOKED BY THE MAGMA HEAT.

124 01:35:42:05 01:35:44:20 BECAUSE CRYSTAL SIZE
IN IGNEOUS ROCKS
125 01:35:44:22 01:35:47:12 IS A GOOD INDICATOR
OF RELATIVE COOLING RATE,
126 01:35:47:14 01:35:49:27 WE CAN ALSO SEE
THAT THE MAGMA ITSELF
127 01:35:49:29 01:35:51:26 COOLED MORE QUICKLY
AT THE CONTACT.
128 01:35:51:28 01:35:53:27 THE SMALLER CRYSTALS
AT THE CONTACT
129 01:35:53:29 01:35:56:27 TELL US THAT THE MAGMA
COOLED MORE QUICKLY THERE
130 01:35:56:29 01:36:00:05 THAN HERE AT THE CENTER,
WHERE THE CRYSTALS ARE LARGER.
131 01:36:01:09 01:36:02:21 *BASED UPON TEXTURE,*
132 01:36:02:23 01:36:04:18 *GEOLOGISTS INFER*
THAT GRANITES CRYSTALLIZE
133 01:36:04:20 01:36:08:16 *FROM MAGMA COOLING SLOWLY*
DEEP UNDERGROUND.
134 01:36:10:13 01:36:12:25 *IN CONTRAST,*
RHYOLITES FORM
135 01:36:12:27 01:36:15:26 *FROM MAGMA THAT COOLS*
SLOWLY AT FIRST,
136 01:36:15:28 01:36:18:11 *ALLOWING A SMALL AMOUNT*
OF THE LARGER CRYSTALS
137 01:36:18:13 01:36:20:02 *CALLED "PHENOCRYSTS"*
TO DEVELOP.
138 01:36:20:04 01:36:23:17 *THEN IT COOLS QUICKLY*
AS A RESULT OF AN ERUPTION,
139 01:36:23:19 01:36:25:09 *STOPPING CRYSTAL GROWTH*
ALTOGETHER.
140 01:36:27:03 01:36:29:02 TEXTURES THAT RESULT
IN THE CRYSTALLIZATION
141 01:36:29:04 01:36:30:06 OF THOSE MINERALS
142 01:36:30:08 01:36:31:17 TELLS US
ABOUT THE CONDITIONS
143 01:36:31:19 01:36:33:03 UNDER WHICH
THAT ROCK FORMED.
144 01:36:33:05 01:36:37:11 SOME ROCKS HAVE
VERY LARGE CRYSTALS
145 01:36:37:13 01:36:39:26 THAT ARE EASILY VISIBLE
TO THE NAKED EYE.
146 01:36:39:28 01:36:42:02 WE CALL THAT
A "PHANERITIC" TEXTURE.
147 01:36:42:04 01:36:44:16 YOUR EVERYDAY GRANITE
HAS A PHANERITIC TEXTURE,
148 01:36:44:18 01:36:47:01 AND THAT SHOWS
THAT THAT ROCK
149 01:36:47:03 01:36:49:03 HAD TO CRYSTALLIZE
AT SOME DEPTH,
150 01:36:49:05 01:36:51:18 SEVERAL KILOMETERS DOWN
IN THE EARTH'S CRUST.
151 01:36:51:20 01:36:54:02 THAT ROCK REPRESENTS
A DIFFERENT TIME,
152 01:36:54:04 01:36:56:17 AND IT'S EXPOSED
NOW AT THE SURFACE

153 01:36:56:19 01:36:59:02 ONLY DUE TO LATER
TECTONIC ACTIVITY.
154 01:36:59:04 01:37:01:17 OTHER IGNEOUS ROCKS
CRYSTALLIZE NEAR THE SURFACE.
155 01:37:01:19 01:37:03:02 VOLCANIC ROCKS,
FOR EXAMPLE,
156 01:37:03:04 01:37:06:19 RECORD A VERY RAPID
CRYSTALLIZATION
157 01:37:06:21 01:37:08:19 OF THE SAME KIND OF MAGMA,
158 01:37:08:21 01:37:11:19 BUT AS THE CRYSTALLIZATION
BECOMES MORE RAPID,
159 01:37:11:21 01:37:14:18 THE CRYSTALS ARE FORCED
TO BE SMALLER AND SMALLER,
160 01:37:14:20 01:37:17:18 BECOMING EVENTUALLY APHANITIC,
OR INVISIBLE TO THE EYE,
161 01:37:17:20 01:37:19:04 ARE EVEN FASTER.
162 01:37:19:06 01:37:21:20 THE MINERALS DON'T
HAVE TIME TO GROW,
163 01:37:21:22 01:37:24:18 AND THE RESULT
IS VOLCANIC GLASS,
WHICH WE CALL "OBSIDIAN."
164 01:37:24:20 01:37:28:02 ALSO, WE'RE LEARNING TO READ
TEXTURES FROM THE ROCK,
165 01:37:28:04 01:37:31:24 AND WE LEARN THE CONDITION
UNDER WHICH IT FORMS.
166 01:37:33:12 01:37:35:11 *BY STUDYING*
THE CRYSTAL TEXTURES
167 01:37:35:13 01:37:37:11 *OF IGNEOUS ROCKS,*
GEOLOGISTS HAVE DISCOVERED
168 01:37:37:13 01:37:40:10 *THAT NOT ALL MINERALS*
FORM FROM A MAGMA
169 01:37:40:12 01:37:42:25 *AT THE SAME TIME*
AND TEMPERATURE.
170 01:37:42:27 01:37:45:09 *RATHER, MAGMA CRYSTALLIZES*
ONE OR TWO MINERAL TYPES
171 01:37:45:11 01:37:47:13 *AT A TIME.*
172 01:37:48:20 01:37:50:06 *THE EARLY-FORMING CRYSTALS,*
173 01:37:50:08 01:37:52:22 *THOSE THAT CAN WITHSTAND*
HIGHER TEMPERATURES,
174 01:37:52:24 01:37:54:21 *SUCH AS PLAGIOCLASE*
OR OLIVINE,
175 01:37:54:23 01:37:56:06 *PRESERVE*
SYMMETRICAL SHAPES
176 01:37:56:08 01:37:58:08 *THAT COULD*
ONLY HAVE RESULTED
177 01:37:58:10 01:38:01:27 *FROM THE CRYSTAL FORMATION*
TAKING PLACE IN A LIQUID.
178 01:38:05:09 01:38:06:22 *LATER-FORMING CRYSTALS,*
179 01:38:06:24 01:38:10:04 *SUCH AS POTASSIUM FELDSPAR*
AND QUARTZ,
180 01:38:10:06 01:38:11:19 *EXHIBIT IRREGULAR SHAPES,*
181 01:38:11:21 01:38:13:18 *INDICATING THAT*
THEY CRYSTALLIZED LAST
182 01:38:13:20 01:38:15:17 *FROM SMALL COMPARTMENTS*
OF LIQUID
183 01:38:15:19 01:38:17:03 *CONFINED IN THE SPACES*

184 01:38:17:05 01:38:20:02 *REMAINING BETWEEN*
THE EARLY-FORMING CRYSTALS.
185 01:38:24:07 01:38:27:20 *LAB WORK BY NORMAN BOWEN*
AND OTHER EXPERIMENTALISTS
186 01:38:27:22 01:38:30:03 *HAS GIVEN US*
PRECISE INFORMATION
187 01:38:30:05 01:38:33:04 *ABOUT HOW MAGMA*
CRYSTALLIZES.
188 01:38:33:06 01:38:35:21 *BOWEN CALLED THE SEQUENCE*
OF MINERAL CRYSTALLIZATION
189 01:38:35:23 01:38:38:13 *IN MAGMA*
A "REACTION SERIES."
190 01:38:39:19 01:38:41:29 *THIS IS BECAUSE*
AS MAGMA COOLS,
191 01:38:42:01 01:38:44:29 *EARLY-FORMING MINERALS*
MAY REACT WITH THE MAGMA
192 01:38:45:01 01:38:48:01 *TO FORM NEW MINERALS*
AT LOWER TEMPERATURES.
193 01:38:48:03 01:38:52:14 *SOME MINERALS REACT*
CONTINUOUSLY WITH THE MAGMA
194 01:38:52:16 01:38:55:05 *AND SO ARE CONSTANTLY*
UNDERGOING CHANGE.
195 01:38:56:15 01:38:58:14 *OTHERS REACT*
DISCONTINUOUSLY,
196 01:38:58:16 01:39:01:20 *THAT IS, ONLY AT CERTAIN*
SPECIFIC TEMPERATURES.
197 01:39:03:26 01:39:05:25 THE FIRST MINERALS
TO CRYSTALLIZE
198 01:39:05:27 01:39:07:10 ARE THE CALCIUM
PLAGIOCLASES,
199 01:39:07:12 01:39:09:24 WHICH WOULD CRYSTALLIZE
UP ABOUT 1,100,
200 01:39:09:26 01:39:12:24 A LITTLE MORE THAN
1,100 DEGREES CELSIUS.
201 01:39:12:26 01:39:16:05 ALONG WITH
THE CALCIC PLAGIOCLASES,
202 01:39:16:07 01:39:19:05 WE'D EXPECT TO FIND
CRYSTALLIZATION OF MINERALS
203 01:39:19:07 01:39:20:09 LIKE OLIVINE.
204 01:39:20:11 01:39:22:06 BUT AS
THE TEMPERATURE FALLS,
205 01:39:22:08 01:39:24:28 DIFFERENT MINERALS
BEGIN TO CRYSTALLIZE.
206 01:39:25:00 01:39:27:28 IN FACT, SOME
OF THE EARLIER MINERALS
207 01:39:28:00 01:39:30:12 BEGIN TO CONVERT
INTO SOME OF THE MINERALS
208 01:39:30:14 01:39:31:24 THAT CRYSTALLIZE
AT LOWER TEMPERATURES.
209 01:39:31:26 01:39:33:21 AND IN THE
DISCONTINUOUS SERIES,
210 01:39:33:23 01:39:37:18 WE SEE OLIVINE
BEING DOMINATED THEN
211 01:39:37:20 01:39:39:10 AND OVERTAKEN BY PYROXENE,
212 01:39:39:12 01:39:43:24 PYROXENE BEING CHANGED
INTO HORNBLENDE,

213 01:39:43:26 01:39:45:20 HORNBLENDE INTO BIOTITE.
214 01:39:45:22 01:39:49:18 AND THERE'S A CONVERSION,
USUALLY JUST A PAIR OF MINERALS
215 01:39:49:20 01:39:52:17 AS WE GO TO LOWER
AND LOWER TEMPERATURES.
216 01:39:52:19 01:39:55:17 THE LOW-TEMPERATURE MINERALS
IN BOWEN'S REACTION SERIES
217 01:39:55:19 01:39:58:08 CONSIST ALSO
OF PLAGIOCLASES.
218 01:39:58:10 01:39:59:22 THE CONTINUOUS SERIES
219 01:39:59:24 01:40:02:08 CHANGES FROM
THE CALCIUM-RICH PLAGIOCLASE
220 01:40:02:10 01:40:04:09 TO THE SODIUM-RICH
PLAGIOCLASES.
221 01:40:04:11 01:40:06:23 AS WE GET DOWN
TO TEMPERATURES
222 01:40:06:25 01:40:08:24 OF 800, 700 DEGREES CELSIUS,
223 01:40:08:26 01:40:11:08 WE HAVE MORE SODIC-RICH
PLAGIOCLASES.
224 01:40:11:10 01:40:16:20 WE HAVE MINERALS LIKE
K-FELDSPARS, BIOTITE,
225 01:40:16:22 01:40:19:07 MUSCOVITE, AND QUARTZ
CRYSTALLIZING.
226 01:40:19:09 01:40:21:23 THESE ARE THE MORE
FELSIC CONSTITUENTS
227 01:40:21:25 01:40:23:20 IN BOWEN'S REACTION SERIES.
228 01:40:25:03 01:40:27:26 *THE ACTUAL TEMPERATURES*
AT WHICH MAGMA FORMS
229 01:40:27:28 01:40:29:12 *OR CRYSTALLIZES*
230 01:40:29:14 01:40:32:02 *ARE INFLUENCED GREATLY*
BY ITS WATER CONTENT.
231 01:40:32:04 01:40:34:21 *IN GENERAL, THE GREATER*
THE WATER CONTENT,
232 01:40:34:23 01:40:36:13 *THE LOWER THE TEMPERATURES.*
233 01:40:38:26 01:40:40:24 *BY SHOWING*
THAT MAGMA CRYSTALLIZES
234 01:40:40:26 01:40:42:24 *IN A PIECEMEAL FASHION,*
235 01:40:42:26 01:40:46:12 *BOWEN PROVIDED AN EXPLANATION*
FOR WHY PLUTONIC ROCKS
236 01:40:46:14 01:40:48:27 *CONTAIN SO MANY TYPES*
OF CRYSTALS
237 01:40:48:29 01:40:50:22 *AND VOLCANOES SO FEW.*
238 01:40:50:24 01:40:54:11 *BUT BOWEN'S WORK HAS OTHER*
IMPORTANT IMPLICATIONS.
239 01:40:55:28 01:40:58:25 *IT SUGGESTS THAT DIFFERENT*
KINDS OF IGNEOUS ROCKS
240 01:40:58:27 01:41:01:14 *CAN FORM FROM A SINGLE*
PARENT MAGMA.
241 01:41:02:23 01:41:05:11 BOWEN DEVELOPED THE SERIES
242 01:41:05:13 01:41:08:26 IN RESPONSE TO THE IDEA
OF WHAT WAS THE ORIGIN--
243 01:41:08:28 01:41:10:25 WHAT IS THE ORIGIN
OF GRANITE?
244 01:41:10:27 01:41:14:00 HE FELT THAT ALL MAGMAS
245 01:41:14:02 01:41:17:06 ORIGINALLY STARTED OUT
AS BASALTIC MATERIAL.

246 01:41:17:08 01:41:20:27 BUT THROUGH A PROCESS
OF DIFFERENTIATION,
247 01:41:20:29 01:41:22:27 THE MAGMA EVOLVED
AND CHANGED.
248 01:41:22:29 01:41:25:19 THE EARLY
CRYSTALLIZING MATERIALS--
249 01:41:25:21 01:41:27:04 THE MATERIALS
THAT WOULD CRYSTALLIZE
250 01:41:27:06 01:41:28:19 AT HIGHER TEMPERATURE--
251 01:41:28:21 01:41:30:08 WOULD TEND TO
SETTLE OUT
252 01:41:30:10 01:41:32:07 OR BECOME SEPARATED
IN SOME WAY
253 01:41:32:09 01:41:33:22 FROM THE MAGMA.
254 01:41:33:24 01:41:35:22 THIS PROCESS IS CALLED
"DIFFERENTIATION,"
255 01:41:35:24 01:41:38:16 AND IT DEMONSTRATES
HOW A MAGMA MIGHT EVOLVE
256 01:41:38:18 01:41:40:03 SO THAT YOU CAN CHANGE
257 01:41:40:05 01:41:42:17 FROM WHAT WAS ORIGINALLY
A MAFIC MAGMA
258 01:41:42:19 01:41:44:02 INTO A FELSIC MAGMA
259 01:41:44:04 01:41:48:01 CONSISTING OF
THE LOWER MELTING MINERALS.
260 01:41:49:17 01:41:51:15 *GEOLOGISTS FIND EVIDENCE*
OF DIFFERENTIATION
261 01:41:51:17 01:41:54:08 *PRESERVED IN MANY*
PLUTONIC ROCKS.
262 01:41:54:10 01:41:57:13 *FOR EXAMPLE,*
SOME INTRUSIONS ARE LAYERED
263 01:41:57:15 01:42:00:29 *DUE TO SETTLING OUT OF*
EARLY-FORMING MAFIC MINERALS.
264 01:42:01:01 01:42:02:14 *AS THESE MINERALS*
265 01:42:02:16 01:42:04:29 *LEFT THE UPPER PART*
OF THE MAGMA BODY,
266 01:42:05:01 01:42:08:19 *ONLY FELSIC MINERALS*
WERE LEFT TO CRYSTALLIZE THERE.
267 01:42:08:21 01:42:12:11 *AT VOLCANOES, THE COMPOSITION*
OF LAVA AND ASH
268 01:42:12:13 01:42:13:28 *MAY CHANGE IN TIME,*
269 01:42:14:00 01:42:17:02 *REFLECTING DIFFERENTIATION*
IN THE MAGMA UNDERNEATH.
270 01:42:19:15 01:42:22:06 THE EFFECT OF COOLING RATE,
WATER CONTENT,
271 01:42:22:08 01:42:23:20 AND MAGMA COMPOSITION
272 01:42:23:22 01:42:26:19 ON THE RESULTING TEXTURE
OF INTRUSIVE IGNEOUS ROCKS
273 01:42:26:21 01:42:29:04 CAN BE INVESTIGATED
IN A MORE COMPLETE
274 01:42:29:06 01:42:30:19 AND QUANTITATIVE WAY
275 01:42:30:21 01:42:32:05 USING LABORATORY
EXPERIMENTS.
276 01:42:32:07 01:42:35:06 A LAB ALONE CANNOT RECREATE
THE GEOLOGIC PROCESSES
277 01:42:35:08 01:42:37:20 THAT CAUSE A MAGMA TO FORM.
278 01:42:37:22 01:42:40:20 THESE PROCESSES OPERATE DEEP

WITHIN THE EARTH'S INTERIOR,
279 01:42:40:22 01:42:43:20 AND THEY ARE USUALLY TIED
TO TECTONIC PROCESSES
280 01:42:43:22 01:42:46:06 AND THE MOVEMENT OF PLATES.
281 01:42:48:09 01:42:49:16 IGNEOUS ACTIVITY
282 01:42:49:18 01:42:51:22 IS DIRECTLY RELATED
TO PLATE TECTONICS.
283 01:42:51:24 01:42:55:07 OCEAN RIDGES,
ZONES OF SPREADING
284 01:42:55:09 01:42:56:22 IN THE EARTH'S OCEANS
285 01:42:56:24 01:42:59:21 IS DUE TO THE UPWELLING
OF MOLTEN MAGMA
286 01:42:59:23 01:43:02:23 DERIVED FROM PARTIAL MELTING
IN THE MANTLE.
287 01:43:02:25 01:43:05:08 IN MELTING MANTLE,
THE RESULT IS A MAGMA
288 01:43:05:10 01:43:07:23 THAT WILL CRYSTALLIZE
TO FORM BASALT,
289 01:43:07:25 01:43:10:22 AND THAT'S WHY BASALT
IS THE DOMINANT ROCK TYPE
290 01:43:10:24 01:43:12:21 OF OCEAN RIDGES,
OF OCEAN ISLANDS,
291 01:43:12:23 01:43:14:06 AND OCEAN CRUST.
292 01:43:14:08 01:43:15:22 AT SUBDUCTION ZONES,
293 01:43:15:24 01:43:17:07 THAT OCEAN CRUST
IS SUBDUCTED,
294 01:43:17:09 01:43:21:01 TAKEN BACK DOWN TO
EARTH'S MANTLE AND IS HEATED.
295 01:43:21:03 01:43:23:00 IT THEN IS PARTIAL MELTED,
296 01:43:23:02 01:43:25:29 AND MAGMA RISING
FROM THAT PARTIAL MELT
297 01:43:26:01 01:43:28:13 RISES TO FORM
THE GREAT VOLCANOES
298 01:43:28:15 01:43:30:19 ABOVE THE RIM OF FIRE.
299 01:43:31:23 01:43:33:06 *PARTICULAR TYPES OF MAGMA*
300 01:43:33:08 01:43:35:05 *ARE ASSOCIATED*
WITH SPECIFIC TYPES
301 01:43:35:07 01:43:36:25 *OF PLATE BOUNDARIES.*
302 01:43:38:09 01:43:40:06 PLATE TECTONIC THEORY
303 01:43:40:08 01:43:44:28 EXPLAINS WHY WE HAVE
MAGMAS ON THE SEA FLOOR,
304 01:43:45:00 01:43:46:13 WHICH ARE VERY DIFFERENT
305 01:43:46:15 01:43:48:20 FROM MAGMAS THAT FORM
ON CONTINENTS.
306 01:43:48:22 01:43:51:04 THE MAGMAS ON THE SEA FLOOR
307 01:43:51:06 01:43:53:19 ARE ENRICHED
IN IRON AND MAGNESIUM,
308 01:43:53:21 01:43:56:21 TENDING TO BE ON THE
BALSALTIC SIDE OF THE SCALE,
309 01:43:56:23 01:43:58:05 HIGHER-TEMPERATURE MINERALS
310 01:43:58:07 01:44:00:14 IN ACCORDANCE WITH
BOWEN'S REACTION SERIES.
311 01:44:00:16 01:44:02:28 IN SUBDUCTION ZONES,
312 01:44:03:00 01:44:06:25 RELATIVELY COOL, WET ROCKS
ON THE SEA FLOOR,
313 01:44:06:27 01:44:09:00 SEA FLOOR LITHOSPHERE,

314 01:44:09:02 01:44:10:15 ARE SUBDUCTED
UNDER CONTINENTS,
315 01:44:10:17 01:44:13:22 AND BECAUSE OF THE PRESENCE
OF SO MUCH WATER,
316 01:44:13:24 01:44:15:28 MELTING BEGINS
AT A LOW TEMPERATURE.
317 01:44:16:00 01:44:18:14 THUS A PARTIAL MELTING
TAKES PLACE,
318 01:44:18:16 01:44:22:14 AND WE TEND TO GET ROCKS
THAT ARE HIGHER IN SILICA
319 01:44:22:16 01:44:24:28 ASSOCIATED WITH
SUBDUCTION ZONES,
320 01:44:25:00 01:44:28:17 HENCE ANDESITE VOLCANOES
IN SOUTH AMERICA,
321 01:44:28:19 01:44:31:01 RATHER THAN
THE BASALTIC TYPE ROCKS
322 01:44:31:03 01:44:33:28 IN THE MID-OCEANIC RIDGES.
323 01:44:35:24 01:44:37:07 *AT CONVERGENT*
PLATE BOUNDARIES,
324 01:44:37:09 01:44:40:22 *ANDESITE AND ITS PLUTONIC*
EQUIVALENT DIORITE
325 01:44:40:24 01:44:43:22 *ARE AMONG THE MOST COMMON*
IGNEOUS ROCKS.
326 01:44:43:24 01:44:45:07 *BUT GEOLOGISTS*
ARE UNCERTAIN
327 01:44:45:09 01:44:47:27 *OF HOW THEIR*
PARENT MAGMA FORMS.
328 01:44:49:08 01:44:52:05 WE THINK THAT
MUCH OF THE MAGMA
329 01:44:52:07 01:44:54:21 DEVELOPS AS A RESULT
OF MELTING OF BASALT
330 01:44:54:23 01:44:56:06 FROM THE UPPER PART
331 01:44:56:08 01:44:58:05 OF THE DESCENDING
LITHOSPHERIC PLATE.
332 01:44:58:07 01:45:00:07 THERE MAY ALSO BE COMPONENTS
333 01:45:00:09 01:45:02:27 THAT ARE DERIVED FROM
THE MARINE SEDIMENTS
334 01:45:02:29 01:45:05:05 THAT MAY ALSO BE
CARRIED DOWN.
335 01:45:05:07 01:45:08:22 THESE MARINE SEDIMENTS
MAY HAVE INTERSTITIAL WATER
336 01:45:08:24 01:45:10:23 THAT CAN ALSO
CONTRIBUTE TO
337 01:45:10:25 01:45:13:08 AND BECOME DISSOLVED
IN THE MAGMA.
338 01:45:13:10 01:45:16:02 THERE MAY BE SUBSTANTIAL
AMOUNTS OF SERPENTINE
339 01:45:16:04 01:45:18:17 THAT ARE BEING BROUGHT DOWN
WITH THE BASALT.
340 01:45:18:19 01:45:20:02 THESE ARE HYDRATED MINERALS
341 01:45:20:04 01:45:22:03 AND COULD ALSO
CONTRIBUTE WATER.
342 01:45:22:05 01:45:24:15 THE PRESENCE OF WATER
IS SIGNIFICANT
343 01:45:24:17 01:45:27:16 BECAUSE IT HELPS TO
BRING ABOUT A FLUXING

344 01:45:27:18 01:45:30:00 OF THE REMAINING AMOUNT
OF MATERIAL.
345 01:45:30:02 01:45:31:15 IT LOWERS THE MELTING POINT,
346 01:45:31:17 01:45:33:29 AND IT HELPS
IN THE FORMATION OF MAGMA.
347 01:45:34:01 01:45:37:00 AS THIS MAGMA MOVES UP
TOWARDS THE SURFACE,
348 01:45:37:02 01:45:38:29 IS IT BASALTIC
IN COMPOSITION?
349 01:45:39:01 01:45:40:16 IS IT MORE FELSIC?
350 01:45:40:18 01:45:43:25 WE AREN'T COMPLETELY CERTAIN
OF THE NATURE OF THE MAGMA.
351 01:45:43:27 01:45:46:26 AS THIS MAGMA MOVES UP
TOWARDS THE SURFACE,
352 01:45:46:28 01:45:49:27 IT ENCOUNTERS THE BASE
OF THE EARTH'S CRUST,
353 01:45:49:29 01:45:52:12 MAINLY MADE UP
OF FELSIC CONSTITUENTS.
354 01:45:52:14 01:45:54:12 THESE ARE LOWER
MELTING MATERIAL.
355 01:45:54:14 01:45:57:29 AS WE LOOK AT BOWEN'S
REACTION SERIES,
356 01:45:58:01 01:46:01:01 WE SEE THAT THESE MINERALS
FROM THE CONTINENTAL CRUST
357 01:46:01:03 01:46:03:17 ARE REALLY
THE LOW MELTING MATERIALS,
358 01:46:03:19 01:46:06:02 SO THEY ARE VERY LIKELY
TO BECOME INCORPORATED
359 01:46:06:04 01:46:07:22 INTO THE MAGMA.
360 01:46:07:24 01:46:11:21 *IN FACT, PARTIAL MELTING*
OF CONTINENTAL CRUST,
361 01:46:11:23 01:46:14:03 *MANTLE,*
AND SUBDUCTING SLABS
362 01:46:14:05 01:46:15:17 *PROBABLY ALL CONTRIBUTE*
363 01:46:15:19 01:46:18:16 *TO THE FORMATION*
OF ANDESITE AND DIORITE.
364 01:46:18:18 01:46:21:17 *BUT THESE AREN'T*
THE ONLY IGNEOUS ROCKS
365 01:46:21:19 01:46:24:00 *THAT FORM AT CONVERGENT*
PLATE BOUNDARIES.
366 01:46:24:02 01:46:25:21 *MANY OTHER TYPES*
ALSO OCCUR.
367 01:46:27:12 01:46:29:10 *PARTIAL MELTING*
IN THE MANTLE,
368 01:46:29:12 01:46:31:27 *TRIGGERED BY UPWELLING*
ASSOCIATED WITH SUBDUCTION,
369 01:46:31:29 01:46:34:01 *WILL FORM BASALTIC MAGMA.*
370 01:46:35:24 01:46:38:21 *THIS MAGMA MAY COLLECT,*
COOL, AND HARDEN
371 01:46:38:23 01:46:40:20 *AT THE BASE OF THE CRUST.*
372 01:46:42:07 01:46:44:11 IN SOME CASES, THOUGH,
373 01:46:44:13 01:46:47:11 THE MAGMA MAY MOVE RAPIDLY
UP TOWARDS THE SURFACE,
374 01:46:47:13 01:46:49:21 STILL A BASALTIC
COMPOSITION,
375 01:46:49:23 01:46:53:21 AND ERUPT AS A BASALTIC LAVA

AT THE EARTH'S SURFACE.

376 01:46:53:23 01:46:57:05 IF IT'S HELD FOR SOME TIME
WITHIN THE EARTH'S CRUST,

377 01:46:57:07 01:46:59:12 ASSIMILATION MAY TAKE PLACE,

378 01:46:59:14 01:47:01:12 WHERE LARGE AMOUNTS
OF THE CRUST

379 01:47:01:14 01:47:04:12 MAY BE MELTED AND INCORPORATED
INTO THIS MAGMA

380 01:47:04:14 01:47:07:26 SO THAT IT BECOMES HIGHER
IN FELSIC CONSTITUENTS.

381 01:47:10:08 01:47:11:21 AND THESE
FELSIC CONSTITUENTS

382 01:47:11:23 01:47:13:07 THEN INCREASE THE VISCOSITY

383 01:47:13:09 01:47:17:10 SO THAT THE MAGMA DOESN'T
SO EASILY MOVE UP TO THE SURFACE

384 01:47:17:12 01:47:18:25 TO ERUPT AS A VOLCANO,

385 01:47:18:27 01:47:20:25 BUT INSTEAD,
IT LODGES ITSELF

386 01:47:20:27 01:47:23:25 WITHIN THE CRUST OF THE EARTH
AS A PLUTON.

387 01:47:25:16 01:47:27:28 *PLUTONS, HUGE MASSES*
OF IGNEOUS ROCK,

388 01:47:28:00 01:47:30:28 *ALSO FORM WHEN*
CONTINENTAL CRUST AND SEDIMENT

389 01:47:31:00 01:47:32:14 *ARE PARTIALLY MELTED*

390 01:47:32:16 01:47:36:01 *BY THE HEAT*
OF RISING MAFIC MAGMAS.

391 01:47:36:03 01:47:38:08 *THE MOLTEN*
CONTINENTAL MATERIAL

392 01:47:38:10 01:47:41:07 *COOLS TO FORM ONE OF*
THE MOST CHARACTERISTIC ROCKS

393 01:47:41:09 01:47:44:05 *OF CONVERGENT PLATE*
BOUNDARIES--GRANITE.

394 01:47:46:01 01:47:48:13 *MAGMA RISES*
FROM THE EARTH'S INTERIOR

395 01:47:48:15 01:47:50:13 *BECAUSE IT IS BUOYANT,*

396 01:47:50:15 01:47:53:16 *THAT IS, LESS DENSE*
THAN THE ROCK MATERIAL
SURROUNDING IT.

397 01:47:55:03 01:47:57:01 *IT ASCENDS IN SEVERAL WAYS.*

398 01:47:57:03 01:47:59:04 *AT DIVERGENT*
PLATE BOUNDARIES,

399 01:47:59:06 01:48:01:19 *MAGMA SIMPLY*
FILLS UP THE SPACES

400 01:48:01:21 01:48:04:04 *OPENED AS THE CRUST*
IS PULLED APART.

401 01:48:05:19 01:48:07:28 *BY CONTRAST, AT CONVERGENT*
PLATE BOUNDARIES,

402 01:48:08:00 01:48:10:25 *ROCK ENCLOSING*
A MAGMA BODY

403 01:48:10:27 01:48:14:14 *MAY BE PUSHED ASIDE*
AS THE MAGMA PASSES THROUGH IT.

404 01:48:16:28 01:48:20:11 *OR THE MAGMA MAY FRACTURE*
THE OVERLYING COUNTRY ROCK

405 01:48:20:13 01:48:22:20 *THROUGH A PROCESS*
CALLED "STOPING."

406 01:48:24:03 01:48:26:01 *BITS OF FRACTURED COUNTRY ROCK*
407 01:48:26:03 01:48:28:00 *SINK INTO THE MAGMA CHAMBER,*
408 01:48:28:02 01:48:31:00 *WHERE THEY MAY BE PRESERVED UPON COOLING*
409 01:48:31:02 01:48:33:14 *IN THE FORM OF FRAGMENTS CALLED "XENOLITHS."*
410 01:48:36:05 01:48:37:18 *IN PART,*
411 01:48:37:20 01:48:40:09 *MAGMA MAY EVEN MELT ITS WAY THROUGH THE CRUST,*
412 01:48:40:11 01:48:43:14 *INCREASING IN VOLUME AND CHANGING IN COMPOSITION.*
413 01:48:45:09 01:48:47:24 *ONCE FORMED, IGNEOUS INTRUSIONS*
414 01:48:47:26 01:48:50:25 *ARE CLASSIFIED ACCORDING TO THEIR GEOMETRIC SHAPES*
415 01:48:50:27 01:48:52:21 *AND OVERALL SIZE.*
416 01:48:52:23 01:48:54:08 *SMALL, COMMON INTRUSIONS*
417 01:48:54:10 01:48:56:15 *POSSESSING SHEET-LIKE SHAPES*
418 01:48:56:17 01:48:59:00 *THAT CUT ACROSS THE BEDDING OR FABRIC*
419 01:48:59:02 01:49:01:29 *OF PRE-EXISTING ROCKS ARE CALLED "DIKES."*
420 01:49:03:08 01:49:05:05 *"SILLS" ARE RELATED TO DIKES,*
421 01:49:05:07 01:49:08:15 *BUT INSTEAD OF CUTTING ACROSS STRATA AS DIKES DO,*
422 01:49:08:17 01:49:11:02 *SILLS INTRUDE BETWEEN LAYERS,*
423 01:49:11:04 01:49:14:14 *FORMING SHEETS PARALLEL TO THE STRATA.*
424 01:49:14:16 01:49:18:03 *A LACCOLITH IS A SHALLOW, SILL-LIKE STRUCTURE*
425 01:49:18:05 01:49:21:03 *THAT BULGES UPWARDS IN ITS CENTRAL PORTION,*
426 01:49:21:05 01:49:23:07 *OFTEN CAUSING A HUMP OR GENTLE RISE*
427 01:49:23:09 01:49:25:03 *IN THE OVERLYING CRUST.*
428 01:49:26:12 01:49:27:26 *THE LARGEST INTRUSIONS,*
429 01:49:27:28 01:49:30:24 *TYPICALLY HAVING THE SHAPE OF SPHEROIDAL BLOBS,*
430 01:49:30:26 01:49:32:10 *ARE THE PLUTONS.*
431 01:49:32:12 01:49:35:15 *THESE RANGE FROM MASSES CALLED "STOCKS,"*
432 01:49:35:17 01:49:39:11 *WHICH CROP OUT OVER AREAS TENS OF SQUARE KILOMETERS,*
433 01:49:39:13 01:49:40:26 *TO GIGANTIC INTRUSIONS*
434 01:49:40:28 01:49:44:00 *EXPOSED OVER HUNDREDS OF SQUARE KILOMETERS.*
435 01:49:45:24 01:49:49:29 *GEOLOGISTS CALL THESE HUGE PLUTONS "BATHOLITHS."*
436 01:49:51:13 01:49:53:11 *PLUTONS OFTEN RISE IN GROUPS,*
437 01:49:53:13 01:49:55:12 *SO A BATHOLITH*

CAN, IN FACT,

438 01:49:55:14 01:49:58:12 *BE COMPOSED OF MANY PLUTONS MERGED TOGETHER.*

439 01:49:59:29 01:50:01:14 WATCHING A LAVA LAMP

440 01:50:01:16 01:50:03:28 CAN GIVE US A GOOD DEAL OF INSIGHT

441 01:50:04:00 01:50:05:29 INTO THE WAY A BATHOLITH FORMS.

442 01:50:06:01 01:50:08:28 WHEN ROCKS MELT IN THE LITHOSPHERE OF THE EARTH,

443 01:50:09:00 01:50:11:22 THE MAGMA BEGINS TO RISE BECAUSE IT'S LESS DENSE

444 01:50:11:24 01:50:13:09 THAN THE SURROUNDING ROCK,

445 01:50:13:11 01:50:14:24 JUST AS THESE BUOYANT BLOBS

446 01:50:14:26 01:50:16:15 RISE THROUGH THE SURROUNDING OIL

447 01:50:16:17 01:50:19:00 WHEN THE BASE OF THE LAMP IS HEATED.

448 01:50:19:02 01:50:20:15 AS THE BUBBLES OF MAGMA

449 01:50:20:17 01:50:22:28 MAKE THEIR WAY TOWARD THE EARTH'S SURFACE,

450 01:50:23:00 01:50:24:18 THEY EXPAND AND PACK TOGETHER,

451 01:50:24:20 01:50:26:04 COALESCING AND COOLING

452 01:50:26:06 01:50:29:03 INTO A HUGE MASS OF PLUTONIC IGNEOUS ROCK.

453 01:50:29:05 01:50:32:07 A COMPOSITE IGNEOUS INTRUSION LIKE THIS

454 01:50:32:09 01:50:35:00 CAN BE IMMENSE, ENCOMPASSING TENS,

455 01:50:35:02 01:50:37:15 OR IN THE CASE OF A BATHOLITH,

456 01:50:37:17 01:50:39:08 SEVERAL HUNDRED INDIVIDUAL PLUTONS.

457 01:50:39:10 01:50:41:09 WHEN EROSION EVENTUALLY STRIPS AWAY

458 01:50:41:11 01:50:44:10 THE SEVERAL KILOMETERS OF ROCK COVERING THE BATHOLITH,

459 01:50:44:12 01:50:45:25 THE MASS OF PLUTONIC ROCK

460 01:50:45:27 01:50:48:17 REMAINS AS AN ELONGATE MOUNTAIN RANGE.

461 01:50:48:19 01:50:50:01 PLUTONIC ROCKS ARE COMPOSED

462 01:50:50:03 01:50:53:00 OF A TIGHTLY INTERGROWN MASS OF CRYSTALS,

463 01:50:53:02 01:50:56:01 WHICH IS USUALLY MORE RESISTANT TO WEATHERING

464 01:50:56:03 01:50:58:04 THAN THE SEDIMENTARY AND METAMORPHIC ROCKS

465 01:50:58:06 01:51:00:04 WHICH SURROUND THE MAGMATIC INTRUSION.

466 01:51:00:06 01:51:01:18 GEOLOGISTS USE BATHOLITHS

467 01:51:01:20 01:51:04:19 TO TRY TO UNDERSTAND THE TECTONIC HISTORY

468 01:51:04:21 01:51:06:05 OF THE EARTH'S CRUST.

469 01:51:06:07 01:51:09:03 THE SIERRA NEVADA BATHOLITH

HERE IN EASTERN CALIFORNIA
470 01:51:09:05 01:51:11:26 IS AN EXCELLENT EXAMPLE.
471 01:51:11:28 01:51:13:25 THE HUNDREDS
OF INDIVIDUAL PLUTONS
472 01:51:13:27 01:51:16:10 WHICH MAKE UP THIS
BATHOLITHIC MOUNTAIN RANGE
473 01:51:16:12 01:51:18:25 REPRESENT A SERIES
OF MAGMATIC INTRUSIONS
474 01:51:18:27 01:51:21:18 THAT BEGAN ABOUT
200 MILLION YEARS AGO
475 01:51:21:20 01:51:24:08 AND CONTINUED OVER THE NEXT
120 MILLION YEARS.
476 01:51:24:10 01:51:26:08 MOST OF THIS PLUTONIC ROCK
477 01:51:26:10 01:51:28:19 IS CHEMICALLY VERY SIMILAR
TO ANDESITE,
478 01:51:28:21 01:51:31:04 A VOLCANIC ROCK
THAT'S FOUND FORMING
479 01:51:31:06 01:51:34:12 IN CONTINENTAL VOLCANIC ARCS,
SUCH AS THE ANDES.
480 01:51:34:14 01:51:37:03 THESE ARCS EXIST
BECAUSE OCEANIC CRUST
481 01:51:37:05 01:51:40:11 IS BEING SUBDUCTED
BENEATH THE EDGE OF A CONTINENT.
482 01:51:40:13 01:51:42:28 PARTIAL MELTING
OF THE DOWN-GOING ROCKS
483 01:51:43:00 01:51:44:13 GENERATES
THE ANDESITIC MAGMA,
484 01:51:44:15 01:51:48:15 WHICH RISES IN BUOYANT PLUMES
TO FEED THE VOLCANOES
485 01:51:48:17 01:51:51:12 OR TO BECOME PART
OF THE BATHOLITH BELOW.
486 01:51:51:14 01:51:53:26 SO THE OVERALL STRUCTURE
AND COMPOSITION
487 01:51:53:28 01:51:55:14 OF THE SIERRAN
PLUTONIC ROCKS
488 01:51:55:16 01:51:58:29 TELLS US THAT THIS IS
A DEEPLY ERODED MAGMATIC ARC
489 01:51:59:01 01:52:02:03 WHICH FORMED ALONG
AN ANCIENT SUBDUCTION MARGIN.
490 01:52:03:14 01:52:05:25 *THE STUDY OF ANCIENT*
IGNEOUS ROCKS
491 01:52:05:27 01:52:08:09 *HAS NOT ONLY PROVIDED*
A WEALTH OF INFORMATION
492 01:52:08:11 01:52:09:24 *CONCERNING PAST*
TECTONIC PROCESSES,
493 01:52:09:26 01:52:12:09 *IT HAS REVEALED MUCH*
ABOUT THE EVOLUTION
494 01:52:12:11 01:52:13:29 *OF EARTH'S CRUST.*
495 01:52:15:19 01:52:19:18 *ONE ANCIENT TYPE*
OF IGNEOUS ROCK IS "KOMATIITE,"
496 01:52:19:20 01:52:21:03 *A RARE CLASS OF BASALT*
497 01:52:21:05 01:52:23:02 *FORMED FROM MUCH HIGHER*
TEMPERATURES
498 01:52:23:04 01:52:26:09 *THAN THE HOTTEST*
BASALT LAVAS KNOWN TODAY.
499 01:52:26:11 01:52:27:24 *KOMATIITES*

SUGGEST THE EARTH

500 01:52:27:26 01:52:30:21 *ONCE HAD*
A MUCH WARMER INTERIOR.

501 01:52:32:22 01:52:35:23 *"ANORTHOSITE" IS ANOTHER*
KIND OF ROCK

502 01:52:35:25 01:52:37:24 *THAT IS RELATIVELY*
RARE ON EARTH

503 01:52:37:26 01:52:39:09 *AND ALMOST*
ENTIRELY EMBEDDED

504 01:52:39:11 01:52:40:27 *IN ANCIENT PLUTONIC BELTS*

505 01:52:40:29 01:52:44:07 *CUTTING ACROSS THE OLDER*
PORTIONS OF THE CONTINENTS.

506 01:52:46:07 01:52:48:13 *ANORTHOSITE MAY BE RARE*
ON EARTH,

507 01:52:48:15 01:52:50:27 *BUT IT IS THE PRIMARY*
TYPE OF ROCK

508 01:52:50:29 01:52:52:13 *FOUND IN THE HIGHLANDS*

509 01:52:52:15 01:52:55:17 *OF OUR NEAREST NEIGHBOR*
IN SPACE--THE MOON.

510 01:52:57:01 01:52:59:14 WHEN THE ASTRONAUTS
CAME BACK FROM THE MOON,

511 01:52:59:16 01:53:01:14 THEY BROUGHT BACK SAMPLES
OF A KIND OF ROCK

512 01:53:01:16 01:53:02:22 CALLED ANORTHOSITE.

513 01:53:02:24 01:53:05:20 APPARENTLY IT'S VERY COMMON
ON THE MOON,

514 01:53:05:22 01:53:08:17 BUT IT'S RELATIVELY RARE
HERE ON EARTH.

515 01:53:08:19 01:53:11:16 I HAVE AN EXAMPLE
OF AN ANORTHOSITE HERE.

516 01:53:11:18 01:53:14:07 THIS IS FROM
THE SAN GABRIEL MOUNTAINS.

517 01:53:14:09 01:53:16:22 IT SEEMS TO REPRESENT
A BODY OF ROCK

518 01:53:16:24 01:53:18:21 THAT WAS FORMED
AT GREAT DEPTH

519 01:53:18:23 01:53:20:06 IN THE EARTH'S INTERIOR.

520 01:53:20:08 01:53:22:06 IT MAY HAVE STARTED OUT

521 01:53:22:08 01:53:24:12 AS A ROCK OF
BASALTIC COMPOSITION,

522 01:53:24:14 01:53:26:03 A MAGMA
OF BASALTIC COMPOSITION,

523 01:53:26:05 01:53:29:18 BUT IT WAS HELD AT GREAT DEPTH
FOR A LONG TIME--

524 01:53:29:20 01:53:32:03 LONG ENOUGH THAT THE CRYSTALS
HAD AN OPPORTUNITY

525 01:53:32:05 01:53:33:20 TO GROW VERY LARGE.

526 01:53:33:22 01:53:36:20 THIS IS MADE UP
OF EXTREMELY LARGE CRYSTALS.

527 01:53:36:22 01:53:40:12 IT WAS EVIDENTLY
UNDER TREMENDOUS PRESSURE

528 01:53:40:14 01:53:42:13 AT THAT DEPTH AS WELL,

529 01:53:42:15 01:53:43:28 AND SO THIS MAGMA

530 01:53:44:00 01:53:46:29 HAS UNDERGONE AN EXTREME AMOUNT
OF DIFFERENTIATION.

531 01:53:47:01 01:53:48:13 THAT IS TO SAY,

532 01:53:48:15 01:53:51:28 THERE WAS A SEPARATION
OF THE CRYSTALS FROM THE MELT.
533 01:53:52:00 01:53:53:13 APPARENTLY THESE CRYSTALS
534 01:53:53:15 01:53:55:27 SETTLED TO THE BOTTOM
OF THE CHAMBER
535 01:53:55:29 01:53:58:12 WHERE THEY BECAME ALMOST
PURELY MADE UP
536 01:53:58:14 01:54:00:13 OF THIS ONE KIND OF CRYSTAL.
537 01:54:00:15 01:54:01:27 IT'S A CALCIUM-RICH
PLAGIOCLASE,
538 01:54:01:29 01:54:03:29 AND THE KIND OF ROCK
539 01:54:04:01 01:54:06:13 MADE ALMOST EXCLUSIVELY
OF THIS PLAGIOCLASE
540 01:54:06:15 01:54:09:26 IS CALLED, AS I SAY,
ANORTHOSITE.
541 01:54:09:28 01:54:11:26 I HAVE ANOTHER EXAMPLE HERE,
542 01:54:11:28 01:54:14:04 ALSO FROM THE SAN GABRIEL
MOUNTAINS,
543 01:54:14:06 01:54:17:19 THAT GIVES US AN IDEA
OF HOW THIS DIFFERENTIATION
544 01:54:17:21 01:54:19:03 MAY HAVE PROCEEDED.
545 01:54:19:05 01:54:20:19 THE CRYSTALS GREW LARGE.
546 01:54:20:21 01:54:22:20 WE CAN ALMOST
IMAGINE THE MAGMA
547 01:54:22:22 01:54:24:19 SURROUNDING THEM
IN THIS AREA HERE
548 01:54:24:21 01:54:26:19 AND THE CRYSTALS
SETTLING DOWN.
549 01:54:26:21 01:54:28:21 THESE ARE SINGLE
LARGE CRYSTALS.
550 01:54:28:23 01:54:31:23 YOU CAN TELL
BY THEIR UNIFORM SHAPE
551 01:54:31:25 01:54:33:08 AND THE STRAIGHT SIDES.
552 01:54:33:10 01:54:35:23 LARGE CRYSTALS GROWING
IN WHAT WAS MOLTEN ROCK
553 01:54:35:25 01:54:36:22 SURROUNDING IT.
554 01:54:36:24 01:54:38:07 THESE CRYSTALS THEN SETTLED
555 01:54:38:09 01:54:40:07 TO THE BOTTOM
OF THE CHAMBER.
556 01:54:40:09 01:54:42:22 THIS SAMPLE IS OVER
A BILLION YEARS OLD.
557 01:54:42:24 01:54:45:16 THE OTHER KNOWN ANORTHOSITES
ARE VERY OLD AS WELL.
558 01:54:46:20 01:54:47:24 *THE PRESENCE*
559 01:54:47:26 01:54:49:01 *OF VERY ANCIENT*
ANORTHOSITE,
560 01:54:49:03 01:54:51:00 *BOTH ON EARTH*
AND THE MOON,
561 01:54:51:02 01:54:52:15 *SUGGEST THAT*
THESE WORLDS
562 01:54:52:17 01:54:55:16 *MAY ONCE HAVE BEEN*
MORE SIMILAR IN COMPOSITION.
563 01:54:57:14 01:54:59:26 *BUT EARTH'S INTERIOR,*
STILL GEOLOGICALLY ALIVE,
564 01:54:59:28 01:55:04:02 *HAS ALLOWED OUR PLANET*
TO CONTINUE EVOLVING...

565 01:55:04:04 01:55:07:04 *WHILE THE MOON,*
NOW GEOLOGICALLY DEAD,
566 01:55:07:06 01:55:09:22 *REMAINS THE SAME.*
567 01:55:09:24 01:55:13:20 *INDEED, THE FORMATION, ASCENT,*
AND COOLING OF MAGMA
568 01:55:13:22 01:55:16:20 *IS ONE OF THE MOST SIGNIFICANT*
AGENTS OF CHANGE
569 01:55:16:22 01:55:18:12 *IN EARTH'S VAST INTERIOR.*
570 01:55:20:02 01:55:21:15 THROUGHOUT GEOLOGIC TIME,
571 01:55:21:17 01:55:24:13 THE GREAT HEAT GENERATED
WITHIN THE EARTH'S INTERIOR
572 01:55:24:15 01:55:26:13 HAS CAUSED ROCKS TO MELT.
573 01:55:26:15 01:55:27:27 MOST OF THE EARTH
574 01:55:27:29 01:55:30:12 IS COMPOSED OF
INTRUSIVE IGNEOUS ROCKS.
575 01:55:30:14 01:55:33:10 THE CONTINENTS ARE LARGELY
MASSES OF GRANITIC ROCK
576 01:55:33:12 01:55:35:25 BENEATH A THIN BLANKET
OF SOIL AND SEDIMENT.
577 01:55:35:27 01:55:39:00 OCEANIC CRUST
IS MOSTLY GABBRO,
578 01:55:39:02 01:55:41:00 COATED WITH BASALT
AND MUD.
579 01:55:41:02 01:55:43:14 EVEN THE ROCKS
OF THE EARTH'S MANTLE
580 01:55:43:16 01:55:45:13 WERE FORMED FROM
THE SLOW COOLING
581 01:55:45:15 01:55:46:28 OF ULTRAMAFIC MAGMAS.
582 01:55:47:00 01:55:49:21 AND SO FAR, EVIDENCE
FROM THE INTERIOR PLANETS
583 01:55:49:23 01:55:51:05 OF OUR SOLAR SYSTEM
584 01:55:51:07 01:55:55:08 INDICATE THAT THEY, TOO,
FORMED IN A SIMILAR WAY.
585 01:55:55:10 01:55:57:24 GEOLOGISTS CAN'T STUDY
IGNEOUS INTRUSIONS DIRECTLY,
586 01:55:57:26 01:56:00:24 BUT BY ANALYZING THE MINERALS
WITHIN THESE ROCKS
587 01:56:00:26 01:56:02:25 AND MAPPING THEIR
PHYSICAL RELATIONSHIPS,
588 01:56:02:27 01:56:05:20 EARTH SCIENTISTS ARE GAINING
AN INTIMATE UNDERSTANDING
589 01:56:05:22 01:56:07:20 OF THE EVOLUTION
OF THE LITHOSPHERE.
590 01:56:07:22 01:56:10:27 RESEARCH INTO INTRUSIVE
IGNEOUS PROCESSES
591 01:56:10:29 01:56:13:15 IS NOW MORE IMPORTANT
AND INTERESTING THAN EVER.
592 01:56:13:17 01:56:16:15 FOR EXAMPLE, IT'S USED
IN DETERMINING THE LOCATION
593 01:56:16:17 01:56:19:14 OF METALLIC ORES,
PRECIOUS METALS AND GEMS,
594 01:56:19:16 01:56:21:00 FOR INTERPRETING
THE COMPLEXITIES
595 01:56:21:02 01:56:22:16 OF PLATE TECTONICS,
596 01:56:22:18 01:56:25:03 AND IN STUDYING
THE HISTORY OF OTHER PLANETS

597 01:56:25:05 01:56:27:00 SIMILAR TO OUR OWN.
598 01:56:27:02 01:56:28:15 INTRUSIVE IGNEOUS ROCKS
599 01:56:28:17 01:56:31:16 REMIND US THAT A GREAT DEAL
OF GEOLOGIC ACTIVITY
600 01:56:31:18 01:56:34:16 TAKES PLACE IN A VAST,
UNSEEN ARENA.
601 01:56:34:18 01:56:36:17 THERE IN THE EARTH'S
INTERIOR,
602 01:56:36:19 01:56:41:00 MAGMA CONTINUES TO FORM
AND MOVE ABOUT AND CRYSTALLIZE,
603 01:56:41:02 01:56:44:15 SETTING THE STAGE FOR THE GROWTH
OF THE OCEAN BASINS,
604 01:56:44:17 01:56:45:23 THE CONTINENTS,
605 01:56:45:25 01:56:47:16 AND THE MOUNTAIN RANGES
OF THE FUTURE.
606 01:56:49:21 01:56:52:19 CAPTIONING MADE POSSIBLE BY
SOUTHERN CALIFORNIA CONSORTIUM
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