1 01:28:55:29 01:28:59:11 Annenberg Media
2 01:28:59:13 01:29:03:11 §
3 01:29:03:13 01:29:06:11 MADE POSSIBLE BY
SOUTHERN CALIFORNIA CONSORTIUM
4 01:29:48:27 01:29:49:29 THROUGHOUT HISTORY,
5 01:29:50:01 01:29:51:26 MOUNTAINS HAVE BEEN
DEEPLY EMBEDDED
6 01:29:51:28 01:29:53:08 IN THE HUMAN EXPERIENCE.
7 01:29:53:10 01:29:54:23 WE'VE WORSHIPPED THEM,
8 01:29:54:25 01:29:57:09 CREATED NATIONS
USING THEM AS BOUNDARIES,
9 01:29:57:11 01:29:59:24 STRIPPED THEM
OF VALUABLE RESOURCES,
10 01:29:59:26 01:30:01:08 AND RETURNED TO THEM
11 01:30:01:10 01:30:03:08 FOR INSPIRATION
AND RECREATION.
12 01:30:03:10 01:30:05:23 IF YOU ARE AT ALL CURIOUS
ABOUT THE EARTH,
13 01:30:05:25 01:30:08:08 YOU'VE PROBABLY WONDERED
WHY MOUNTAINS EXIST.
14 01:30:08:10 01:30:10:23 THIS QUESTION HAS INTRIGUED
EARTH SCIENTISTS
15 01:30:10:25 01:30:13:24 EVER SINCE THE EMERGENCE
OF GEOLOGY AS A SCIENCE
16 01:30:13:26 01:30:15:09 IN THE LATE 18th CENTURY.
17 01:30:15:11 01:30:17:08 THE MORE WE LEARN
ABOUT MOUNTAINS
18 01:30:17:10 01:30:18:23 AND WHAT THEY'RE MADE OF,
19 01:30:18:25 01:30:21:07 THE MORE FASCINATING
THIS QUESTION BECOMES.
20 01:30:21:09 01:30:22:23 MOST MOUNTAINS
ARE FORMING TODAY
21 01:30:22:25 01:30:24:08 IN TECTONICALLY
ACTIVE REGIONS
22 01:30:24:10 01:30:26:08 WHERE THE MOVEMENTS
OF PLATES
23 01:30:26:10 01:30:28:24 DEFORM THE ROCKS
OF THE EARTH'S LITHOSPHERE.
24 01:30:28:26 01:30:30:09 THEIR TREMENDOUS ENERGY
25 01:30:30:11 01:30:32:24 THAT'S EXPENDED IN THE
MOUNTAIN-BUILDING PROCESS
26 01:30:32:26 01:30:35:08 OFTEN HAS A PROFOUND EFFECT
ON THESE ROCKS.
27 01:30:35:10 01:30:38:08 THE GEOLOGIC EVENTS THAT
ACCOMPANY MOUNTAIN-BUILDING,
28 01:30:38:10 01:30:40:23 SUCH AS THE COLLISIONS
BETWEEN PLATES,
29 01:30:40:25 01:30:43:24 DEEP SUBSIDENCE OF PORTIONS
OF THE EARTH'S CRUST,
30 01:30:43:26 01:30:45:09 MOVING MASSES OF MAGMA,
31 01:30:45:11 01:30:48:24 AND THE DISPLACEMENT
OF ROCK BODIES
ALONG FAULT ZONES
32 01:30:48:26 01:30:51:08 FOCUS HEAT AND PRESSURE
ON THE ROCKS.
33 01:30:51:10 01:30:54:22 AS A RESULT, THESE ROCKS

ARE CHANGED DRAMATICALLY.

34 01:30:54:24 01:30:57:21 THIS PROCESS OF CHANGE
BY HEAT AND PRESSURE

35 01:30:57:23 01:30:59:06 IS CALLED METAMORPHISM--

36 01:30:59:08 01:31:02:06 A TERM DERIVED
FROM THE GREEK WORDS *META,*

37 01:31:02:08 01:31:03:22 WHICH MEANS CHANGE,

38 01:31:03:24 01:31:05:22 AND *MORPH,* MEANING FORM.

39 01:31:05:24 01:31:08:22 METAMORPHISM CHANGES
THE APPEARANCE OF ROCKS,

40 01:31:08:24 01:31:10:06 THEIR MINERAL COMPOSITION,

41 01:31:10:08 01:31:11:21 AND EVEN THEIR AGE

42 01:31:11:23 01:31:13:21 AS MEASURED BY
RADIOMETRIC DATING.

43 01:31:13:23 01:31:16:21 DURING METAMORPHISM,
ATOMS WITHIN THE ROCK

44 01:31:16:23 01:31:19:07 CAN DISLODGE THEMSELVES
FROM MINERAL LATTICES

45 01:31:19:09 01:31:20:07 AND MOVE ABOUT FREELY.

46 01:31:20:09 01:31:22:22 THIS ATOMIC RESHUFFLING

47 01:31:22:24 01:31:25:06 CAUSES EXISTING MINERALS
TO RECRYSTALLIZE

48 01:31:25:08 01:31:27:06 AND NEW MINERALS TO FORM.

49 01:31:27:08 01:31:31:06 THIS PROCESS ALSO RESETS
THE RADIOACTIVE CLOCK
WITHIN THE ROCK

50 01:31:31:08 01:31:33:18 TO THE TIME
OF METAMORPHISM.

51 01:31:33:20 01:31:37:07 METAMORPHISM CAN RESULT
IN COMPLEX STRUCTURES
AND RARE MINERALS

52 01:31:37:09 01:31:40:07 THAT MAKE THESE SOME OF
THE MOST BIZARRE-LOOKING

53 01:31:40:09 01:31:42:21 AND STRIKINGLY BEAUTIFUL
OF ALL CRUSTAL ROCKS.

54 01:31:42:23 01:31:44:06 BUT TO A GEOLOGIST,

55 01:31:44:08 01:31:46:21 THE REAL BEAUTY
OF METAMORPHIC ROCKS

56 01:31:46:23 01:31:48:21 IS THE INFORMATION
THEY CONTAIN

57 01:31:48:23 01:31:51:19 ABOUT TECTONIC PROCESSES
AND EARTH HISTORY.

58 01:31:55:06 01:31:58:05 *METAMORPHIC ROCKS*
CAN APPEAR IN MANY FORMS.

59 01:32:01:07 01:32:05:04 *FROM PLATEY, BLACK,*
FINE-GRAINED STONE,

60 01:32:05:06 01:32:07:04 *TO GRANITE-LIKE*
LAYERED ROCK,

61 01:32:07:06 01:32:09:19 *TO THE MARBLE*
USED BY SCULPTORS.

62 01:32:11:22 01:32:14:05 *ONE EXPLANATION*
WHY A WIDE VARIETY

63 01:32:14:07 01:32:15:20 *OF METAMORPHIC ROCKS EXISTS*

64 01:32:15:22 01:32:18:19 *IS SIMPLY THAT THERE ARE*
MANY DIFFERENT SEDIMENTARY

65 01:32:18:21 01:32:20:04 *AND IGNEOUS ROCKS,*

66 01:32:20:06 01:32:23:04 *EACH RESPONDING*
TO METAMORPHIC CONDITIONS
67 01:32:23:06 01:32:25:04 *IN ITS OWN UNIQUE WAY.*
68 01:32:28:07 01:32:31:05 *GEOLOGISTS*
USE THE TERM "PROTOLITH"
69 01:32:31:07 01:32:33:05 *TO REFER*
TO THE ORIGINAL ROCK
70 01:32:33:07 01:32:34:19 *EXISTING*
BEFORE METAMORPHISM.
71 01:32:34:21 01:32:39:04 *FOR EXAMPLE, LIMESTONE IS*
THE PROTOLITH OF MARBLE,
72 01:32:39:06 01:32:42:01 *ONE OF THE MOST COMMON*
METAMORPHIC ROCKS.
73 01:32:43:09 01:32:46:05 *AND BASALT,*
A VOLCANIC IGNEOUS ROCK
74 01:32:46:07 01:32:49:05 *IS THE PROTOLITH*
OF AMPHIBOLITE.
75 01:32:51:06 01:32:54:02 *BUT GEOLOGISTS HAVE FOUND*
MANY MORE TYPES
76 01:32:54:04 01:32:56:02 *OF METAMORPHIC ROCKS*
THAN PROTOLITHS,
77 01:32:56:04 01:32:59:02 *SO FACTORS OTHER THAN*
ORIGINAL COMPOSITION
78 01:32:59:04 01:33:03:18 *MUST ALSO PLAY A ROLE*
IN CREATING THESE ROCKS.
79 01:33:03:20 01:33:06:03 *STUDY OF*
GEOLOGIC STRUCTURES,
80 01:33:06:05 01:33:08:03 *SUCH AS FOLDS AND FAULTS,*
81 01:33:08:05 01:33:10:17 *SUGGESTS THAT THERE IS*
A WIDE RANGE
82 01:33:10:19 01:33:12:02 *OF PRESSURES*
AND TEMPERATURES
83 01:33:12:04 01:33:14:02 *INSIDE GROWING*
MOUNTAIN BELTS.
84 01:33:14:04 01:33:17:02 *QUITE LIKELY,*
THIS PLAYS A CRITICAL ROLE
85 01:33:17:04 01:33:21:03 *IN EXPLAINING VARIATIONS*
IN METAMORPHIC ROCKS.
86 01:33:21:05 01:33:24:03 *LABORATORY EXPERIMENTS*
HAVE HELPED GEOLOGISTS
87 01:33:24:05 01:33:26:17 *UNDERSTAND*
METAMORPHIC CONDITIONS.
88 01:33:30:04 01:33:33:09 THE CONDITION UNDER WHICH
METAMORPHISM OCCURS
89 01:33:33:11 01:33:36:18 IS BENEATH THE LEVEL
OF WEATHERING
AND SEDIMENTATION
90 01:33:36:20 01:33:39:03 TO FORM
THE SEDIMENTARY ROCKS,
91 01:33:39:05 01:33:43:17 GENERALLY AT TEMPERATURES
GREATER THAN 200 DEGREES
92 01:33:43:19 01:33:47:02 AND AT CONDITIONS
THAT DO NOT PRODUCE A MELT
93 01:33:47:04 01:33:49:17 SUCH AS GOES INTO
IGNEOUS ROCKS.
94 01:33:49:19 01:33:52:02 SO THE RANGE

IN TEMPERATURES
95 01:33:52:04 01:33:54:15 ARE ROUGHLY ABOUT
200 DEGREES "C"
96 01:33:54:17 01:33:56:16 TO ABOUT 800 DEGREES "C."
97 01:33:56:18 01:33:57:27 THEY OCCUR--
98 01:33:57:29 01:34:01:20 THE PROCESS AND FORMATION
OF THE ROCKS OCCUR AT DEPTHS
99 01:34:01:22 01:34:05:15 GENERALLY FROM
2 TO SEVERAL 10s
OF KILOMETERS IN DEPTH
100 01:34:05:17 01:34:08:14 BENEATH
THE EARTH'S SURFACE.
101 01:34:08:16 01:34:11:00 *AT THE SURFACE,*
WE ARE ACCUSTOMED
102 01:34:11:02 01:34:13:16 *TO THE PRESSURE OF THE AIR*
SURROUNDING US.
103 01:34:13:18 01:34:15:01 *WE DON'T NOTICE THE AIR*
104 01:34:15:03 01:34:19:00 *BECAUSE THE PRESSURE IS EQUAL*
ALL OVER OUR BODIES.
105 01:34:19:02 01:34:21:15 *DEEP UNDERGROUND, HOWEVER,*
106 01:34:21:17 01:34:24:00 *PRESSURE IS NOT*
EQUALLY APPLIED.
107 01:34:24:02 01:34:26:00 *ROCK CAN BE*
SQUEEZED STRONGLY
108 01:34:26:02 01:34:27:15 *WITH PRESSURE GREATEST*
109 01:34:27:17 01:34:30:01 *IN THE DIRECTION*
OF THE SQUEEZING.
110 01:34:30:03 01:34:32:16 *SOMETIMES,*
OPPOSING PRESSURE
111 01:34:32:18 01:34:35:15 *CAN BE APPLIED ON*
DIFFERENT PARTS OF A ROCK,
112 01:34:35:17 01:34:37:00 *CAUSING IT TO BEND*
113 01:34:37:02 01:34:40:15 *OR SHEAR APART LIKE*
A SLIDING DECK OF CARDS.
114 01:34:42:02 01:34:45:01 *WHETHER FROM SHEARING*
OR SIMPLE SQUEEZING,
115 01:34:45:03 01:34:46:16 *THE ROCK IS EXPERIENCING*
116 01:34:46:18 01:34:50:15 *WHAT GEOLOGISTS REFER TO*
AS DIRECTED PRESSURE
117 01:34:50:17 01:34:53:16 *OR DIRECTED STRESS.*
118 01:34:53:18 01:34:56:13 *THE STRUCTURE*
OF MANY METAMORPHIC ROCKS
119 01:34:56:15 01:35:00:09 *IS A RESULT*
OF DIRECTED PRESSURE.
120 01:35:00:11 01:35:02:28 *DIRECTED SHEAR STRESS,*
FOR EXAMPLE,
121 01:35:03:00 01:35:04:14 *HELPS EXPLAIN THE ORIGIN*
122 01:35:04:16 01:35:07:14 *OF A SPECTACULAR FORM*
OF CRYSTAL GROWTH.
123 01:35:09:16 01:35:12:28 *THESE SWIRLING IMAGES*
SUGGEST SEVERAL THINGS--
124 01:35:13:00 01:35:14:28 *A CLUSTER*
OF SPIRAL GALAXIES,
125 01:35:15:00 01:35:18:28 *THE CHINESE SYMBOL*
FOR YIN AND YANG.
126 01:35:19:00 01:35:21:29 *THEY ARE, IN FACT,*

SNOWBALL GARNETS.

127 01:35:22:01 01:35:23:14 *TO THE GEOLOGIST,*

128 01:35:23:16 01:35:26:13 *FROZEN SLICES*
OF METAMORPHISM IN ACTION.

129 01:35:29:00 01:35:31:13 *THE SWIRLING PATTERN*
IN A SNOWBALL GARNET

130 01:35:31:15 01:35:34:13 *IS FORMED BY PLANES*
OF TINY MINERAL INCLUSIONS

131 01:35:34:15 01:35:38:14 *THAT ARE SWALLOWED UP*
BY THE GARNET AS IT GROWS.

132 01:35:38:16 01:35:40:14 *SHEAR STRESS*
CAUSES THE GARNET

133 01:35:40:16 01:35:41:29 *TO ROTATE DURING GROWTH,*

134 01:35:42:01 01:35:44:28 *DISTORTING THE PLANES*
INTO SWIRLS.

135 01:35:48:00 01:35:50:28 *THE THREE-DIMENSIONAL FORM*
OF THE SWIRLING PATTERN

136 01:35:51:00 01:35:54:11 *CAN BE SHOWN BY MEANS*
OF A MULTI-RINGED MODEL.

137 01:35:54:13 01:35:57:27 *EACH RING*
REPRESENTS THE EDGE
OF A PLANE OF MINERALS

138 01:35:57:29 01:35:59:27 *INCORPORATED*
BY THE GROWING GARNET.

139 01:36:01:10 01:36:02:13 THESE ARE THE RINGS.

140 01:36:02:15 01:36:05:26 AND LET'S DO THAT PROCESS
AS IT GOES ON

141 01:36:05:28 01:36:07:11 SO WE CAN VISUALIZE IT.

142 01:36:07:13 01:36:09:26 FIRST, WE GROW
A LITTLE BIT OF GARNET,

143 01:36:09:28 01:36:11:26 THEN WE ROTATE THE RING.

144 01:36:11:28 01:36:14:12 WE ROTATE THAT
AND GROW ANOTHER RING,

145 01:36:14:14 01:36:16:27 AND ROTATE IT
WITH THE RING INSIDE,

146 01:36:16:29 01:36:20:11 AND WE GROW ANOTHER RING
AND SO FORTH,

147 01:36:20:13 01:36:26:26 UNTIL WE DEVELOP BASICALLY
A SHAPE LIKE THIS.

148 01:36:29:14 01:36:32:27 WE HAVE A LITTLE PIT HERE,
A MOUND OVER HERE,

149 01:36:32:29 01:36:35:11 AND THE DIAMETER
OF ROTATION HERE.

150 01:36:35:13 01:36:38:11 WE CAN COMPARE THAT
WITH A REAL SPECIMEN,

151 01:36:38:13 01:36:40:11 WHICH IS OVER HERE.

152 01:36:40:13 01:36:44:10 THIS IS A REAL SPECIMEN
IN WHICH WE SEE

153 01:36:44:12 01:36:46:27 THE LITTLE PIT HERE,
THE MOUND HERE,

154 01:36:46:29 01:36:48:12 THE COMMON AXIS
THROUGH HERE,

155 01:36:48:14 01:36:50:26 AND IT SHOWS
THE SNOWBALL PATTERN.

156 01:36:50:28 01:36:53:25 WE CAN SEE
A CROSS-SECTION

OF A GARNET
157 01:36:53:27 01:36:56:24 THAT'S GROWING
CONSIDERABLY MORE
THAN THAT GARNET HAS,
158 01:36:56:26 01:36:59:09 SHOWING THAT ROTATION.
159 01:36:59:11 01:37:02:24 *DIRECTED STRESS*
INVOLVING COMPRESSION
160 01:37:02:26 01:37:04:09 *HELPS EXPLAIN THE ORIGIN*
161 01:37:04:11 01:37:06:25 *OF A VERY COMMON*
METAMORPHIC STRUCTURE.
162 01:37:06:27 01:37:09:10 *AS TEMPERATURE*
AND PRESSURE INCREASE,
163 01:37:09:12 01:37:13:24 *MINERALS RECOMBINE TO MAKE*
NEW, MORE STABLE MINERALS.
164 01:37:16:11 01:37:19:24 *THE MINERALS GROW*
IN THE DIRECTIONS
OF LOWEST PRESSURE,
165 01:37:19:26 01:37:22:10 *PERPENDICULAR*
TO THE DIRECTED STRESS.
166 01:37:22:12 01:37:24:10 *THIS RESULTS IN A LAYERING*
167 01:37:24:12 01:37:26:24 *WHICH GEOLOGISTS CALL*
"FOLIATION."
168 01:37:28:26 01:37:32:28 *SHEAR STRESS, TOO,*
CAN CAUSE FOLIATION.
169 01:37:33:00 01:37:34:09 I'LL HOLD A PIECE
170 01:37:34:11 01:37:37:10 OF A METAMORPHIC ROCK
WE CALL A MICA SCHIST.
171 01:37:37:12 01:37:39:10 WE CAN SEE
IT'S VERY LAYERED.
172 01:37:39:12 01:37:43:24 THAT LAYERING IS A PRESERVATION
OF A STRESS FIELD
173 01:37:43:26 01:37:46:09 GENERATED WITHIN A SUBDUCTION
ZONE ENVIRONMENT.
174 01:37:46:11 01:37:48:24 AS THE ROCK
IS RECRYSTALLIZED
175 01:37:48:26 01:37:51:09 UNDER GREAT PRESSURE
AND GREAT TEMPERATURE,
176 01:37:51:11 01:37:53:22 IT IS ALSO
RECORDING IN IT
177 01:37:53:24 01:37:56:19 THE INTENSITY
OF THE STRESS FIELD.
178 01:37:56:21 01:38:00:08 WE SEE STRESSES THAT HAD
TO BE IN SOME DIRECTION
179 01:38:00:10 01:38:02:01 TO HAVE PLANERIZED
THE MICAS,
180 01:38:02:03 01:38:03:19 FORMING THE MICA SCHIST.
181 01:38:03:21 01:38:07:07 *FOLIATED ROCKS*
ARE EASY ENOUGH TO SPOT,
182 01:38:07:09 01:38:09:07 *BUT ARE OFTEN*
TAKEN FOR GRANTED
183 01:38:09:09 01:38:10:22 *AT SOME COST.*
184 01:38:13:20 01:38:15:23 *CONSTRUCTING ROADS, DAMS,*
OR FOUNDATIONS
185 01:38:15:25 01:38:17:08 *ON SUCH ROCKS*
186 01:38:17:10 01:38:19:21 *CAN CREATE SEVERE PROBLEMS.*
187 01:38:19:23 01:38:25:00 THE PRODUCTION OF FOLIATION

WITHIN METAMORPHIC ROCKS

188 01:38:25:02 01:38:29:08 GIVES RISE TO THE SAME TYPE
OF STRUCTURAL HETEROGENEITY

189 01:38:29:10 01:38:30:23 AND WEAK DIRECTIONS

190 01:38:30:25 01:38:33:08 AS YOU FIND WITHIN
LANDSLIDE-PRONE,

191 01:38:33:10 01:38:35:08 FOR INSTANCE,
SEDIMENTARY ROCK.

192 01:38:35:10 01:38:39:07 ALTHOUGH WE CONSIDER
THESE BASEMENT ROCKS
TO BE QUITE STABLE,

193 01:38:39:09 01:38:43:05 IN REALITY,
SCHISTS CAN BE
VERY UNSTABLE.

194 01:38:43:07 01:38:46:05 MANY ENGINEERING FIRMS
THAT WERE WANTING
TO CONSTRUCT

195 01:38:46:07 01:38:50:06 EITHER HOUSES OR DAMS
OR OTHER CONSTRUCTIONS
ON METAMORPHIC ROCK

196 01:38:50:08 01:38:53:02 HAS TO TAKE
IN CONSIDERATION

197 01:38:53:04 01:38:55:22 THE FOLIATION
AND THE DIRECTION
OF THE FOLIATION

198 01:38:55:24 01:38:59:07 TO MAKE SURE
THAT IT ISN'T IN
AN UNSTABLE ORIENTATION,

199 01:38:59:09 01:39:01:23 WITH REGARDS
TO ANY ENGINEERED WORKS

200 01:39:01:25 01:39:04:08 THAT COULD BE
CONSTRUCTED ON IT.

201 01:39:06:25 01:39:08:22 *IN ADDITION*
TO DIRECTED STRESS,

202 01:39:08:24 01:39:10:22 *RISING TEMPERATURE*
WILL CAUSE MINERALS

203 01:39:10:24 01:39:13:07 *IN A METAMORPHIC ROCK*
TO REACT,

204 01:39:13:09 01:39:16:22 *FORMING NEW*
CRYSTAL LATTICES
AND MINERAL TYPES.

205 01:39:16:24 01:39:20:23 *THIS PROCESS,*
CALLED RECRYSTALLIZATION,

206 01:39:20:25 01:39:23:08 *GENERALLY CAUSES MINERALS*
TO GROW LARGER,

207 01:39:23:10 01:39:25:07 *DEVELOPING*
AN INTERLOCKING TEXTURE

208 01:39:25:09 01:39:27:22 *RESEMBLING THAT*
OF IGNEOUS ROCKS.

209 01:39:30:09 01:39:31:15 *FOR EXAMPLE,*

210 01:39:31:17 01:39:33:07 *WHEN THE SEDIMENTARY ROCK*
LIMESTONE

211 01:39:33:09 01:39:36:08 *IS METAMORPHOSED BY HEAT*
INTO MARBLE,

212 01:39:36:10 01:39:39:22 *THE FINE GRAINS OF CALCITE*
IN THE ORIGINAL LIMESTONE

213 01:39:39:24 01:39:43:07 *RECRYSTALLIZE INTO*
LARGE CALCITE CRYSTALS,
214 01:39:43:09 01:39:45:22 *WHICH INTERLOCK*
TO GIVE THE EMERGING MARBLE
215 01:39:45:24 01:39:47:22 *A COARSE TEXTURE.*
216 01:39:52:07 01:39:53:21 *IN SOME CIRCUMSTANCES,*
217 01:39:53:23 01:39:56:06 *THE TEMPERATURE*
OF A DEEPLY BURIED ROCK
218 01:39:56:08 01:39:57:21 *CAN BECOME SO GREAT,*
219 01:39:57:23 01:39:59:20 *THE ROCK STARTS MELTING.*
220 01:39:59:22 01:40:01:05 *WHEN THIS HAPPENS,*
221 01:40:01:07 01:40:03:05 *A ROCK HAVING*
BOTH IGNEOUS
222 01:40:03:07 01:40:06:05 *AND METAMORPHIC FEATURES*
RESULTS.
223 01:40:06:07 01:40:09:20 *GEOLOGISTS CALL THESE*
INTERMEDIATE ROCK TYPES
224 01:40:09:22 01:40:12:06 *"MIGMATITES,"*
OR MIXED ROCKS.
225 01:40:14:23 01:40:16:20 *IN SOME MIGMATITES,*
226 01:40:16:22 01:40:18:20 *GEOLOGISTS FIND EVIDENCE*
FOR THE ORIGIN
227 01:40:18:22 01:40:21:20 *OF ONE OF EARTH'S*
MOST COMMON IGNEOUS ROCKS--
228 01:40:21:22 01:40:22:20 *GRANITE.*
229 01:40:24:22 01:40:26:21 *YET ANOTHER FACTOR*
MAY BE CRITICAL
230 01:40:26:23 01:40:28:21 *IN CREATING*
METAMORPHIC ROCKS.
231 01:40:28:23 01:40:30:21 *FOR MANY YEARS,*
GEOLOGISTS BELIEVED
232 01:40:30:23 01:40:33:20 *THAT THE OVERALL*
COMPOSITION OF A ROCK
233 01:40:33:22 01:40:35:20 *RARELY CHANGES*
DURING METAMORPHISM.
234 01:40:35:22 01:40:39:20 *HOWEVER, THIS IS NO LONGER*
ASSUMED TO BE THE CASE.
235 01:40:41:23 01:40:43:21 THE OTHER ASPECT
OF METAMORPHISM
236 01:40:43:23 01:40:46:06 AS A RESULT OF THESE
METAMORPHIC REACTIONS
237 01:40:46:08 01:40:49:05 IS THAT ROCKS UNDERGO
CHANGES IN COMPOSITION.
238 01:40:49:07 01:40:52:18 AND MAINLY,
THIS SHOWS UP
IN THE FORMATION
239 01:40:52:20 01:40:55:03 OF THE LIBERATION OF H2O
240 01:40:55:05 01:40:57:18 AND ITS DEPARTURE
FROM THE ROCKS.
241 01:40:57:20 01:41:01:18 THE ROCKS DRY OUT
IN VERY MUCH THE SAME WAY
242 01:41:01:20 01:41:05:01 THAT A FIRED POT
DEHYDRATES IN A KILN.
243 01:41:05:03 01:41:11:03 THE MAIN FEATURE OF
HIGHER TEMPERATURES,
FOR EXAMPLE,

244 01:41:11:05 01:41:14:03 IS TO CAUSE THE ROCK
TO UNDERGO
245 01:41:14:05 01:41:17:03 A LOSS OF CERTAIN
VOLATILE COMPONENTS.
246 01:41:17:05 01:41:18:19 IN MOST METAMORPHIC ROCKS,
247 01:41:18:21 01:41:23:19 THAT MEANS MAINLY
THE LOSS OF H2O AND CO2.
248 01:41:25:05 01:41:28:03 *FLUIDS ARE RELEASED*
NOT ONLY BY METAMORPHIC ROCKS
249 01:41:28:05 01:41:29:21 *AT HIGH TEMPERATURES,*
250 01:41:29:23 01:41:34:01 *BUT FROM MAGMAS INTRUDING*
THE METAMORPHIC ROCKS AS WELL.
251 01:41:34:03 01:41:37:19 *DURING MOUNTAIN-BUILDING,*
THE CRUST IN MANY PLACES
252 01:41:37:21 01:41:40:03 *IS SATURATED*
WITH MIGRATING FLUIDS.
253 01:41:40:05 01:41:42:18 *THESE ACCELERATE*
SOME CHEMICAL REACTIONS
254 01:41:42:20 01:41:45:03 *AND MAY STOP OTHERS.*
255 01:41:46:20 01:41:48:18 *SO, THE SPECTACULAR*
DIVERSITY
256 01:41:48:20 01:41:50:04 *OF METAMORPHIC ROCKS*
257 01:41:50:06 01:41:52:16 *IS CREATED BY*
THE NUMEROUS PROTOLITHS,
258 01:41:52:18 01:41:54:01 *THE PRESENCE OF FLUID,*
259 01:41:54:03 01:41:57:02 *AND THE WIDE RANGE OF*
TEMPERATURE AND PRESSURES
260 01:41:57:04 01:41:58:17 *POSSIBLE WITHIN THE EARTH.*
261 01:42:00:10 01:42:02:01 WHEN ROCKS ARE EXPOSED
262 01:42:02:03 01:42:04:16 TO THE HEAT AND PRESSURE
OF METAMORPHISM,
263 01:42:04:18 01:42:07:01 THEY UNDERGO CHANGES
BOTH IN TEXTURE
264 01:42:07:03 01:42:08:16 AND MINERAL CONTENT.
265 01:42:08:18 01:42:10:16 THE SPECIFIC CHANGES
THAT TAKE PLACE
266 01:42:10:18 01:42:12:17 DEPEND ON
A VARIETY OF FACTORS,
267 01:42:12:19 01:42:15:17 INCLUDING THE COMPOSITION
OF THE ORIGINAL ROCK--
268 01:42:15:19 01:42:17:01 CALLED THE PROTOLITH,
269 01:42:17:03 01:42:19:16 HOW MUCH HEAT AND PRESSURE
ARE APPLIED,
270 01:42:19:18 01:42:21:16 THE LENGTH OF TIME
OF METAMORPHISM,
271 01:42:21:18 01:42:23:29 AND WHETHER OR NOT
WATER IS PRESENT.
272 01:42:24:01 01:42:25:16 MOST METAMORPHIC ROCKS
273 01:42:25:18 01:42:28:02 FORM IN ONE OF TWO
GEOLOGIC SETTINGS.
274 01:42:28:04 01:42:30:02 THE FIRST
IS WHERE COLD ROCK
275 01:42:30:04 01:42:32:02 IS INTRUDED
BY A HOT MAGMA.
276 01:42:32:04 01:42:34:01 THIS IS CALLED
CONTACT METAMORPHISM,

277 01:42:34:03 01:42:37:16 AND ITS EFFECTS ARE CONFINED
TO A SMALL AREA.
278 01:42:37:18 01:42:41:01 THE OTHER SETTING IS AT
A CONVERGENT PLATE MARGIN,
279 01:42:41:03 01:42:43:02 WHERE THE MOTIONS
OF THE PLATES
280 01:42:43:04 01:42:45:17 GENERATES METAMORPHIC
CONDITIONS OVER WIDE AREAS,
281 01:42:45:19 01:42:48:16 IN PLACES COVERING THOUSANDS
OF SQUARE KILOMETERS.
282 01:42:48:18 01:42:52:01 THIS IS KNOWN
AS REGIONAL METAMORPHISM.
283 01:42:52:03 01:42:53:29 *ONE OF THE MAIN DIFFERENCES*
284 01:42:54:01 01:42:56:29 *BETWEEN CONTACT*
AND REGIONAL METAMORPHISM
285 01:42:57:01 01:42:59:28 *IS THAT TEMPERATURE*
IS THE PREDOMINANT CAUSE
286 01:43:00:01 01:43:02:14 *OF CONTACT METAMORPHISM,*
287 01:43:02:16 01:43:04:15 *WHEREAS*
REGIONAL METAMORPHISM
288 01:43:04:17 01:43:08:14 *INVOLVES BOTH TEMPERATURE*
AND PRESSURE.
289 01:43:08:16 01:43:12:15 THE CHEMICAL CHANGES
THAT ACCOMPANY
CONTACT METAMORPHISM,
290 01:43:12:17 01:43:13:29 ESPECIALLY OF MARBLES,
291 01:43:14:01 01:43:17:14 IS SEEN ON
THIS HAND-SIZED SAMPLE
OF A CONTACT.
292 01:43:17:16 01:43:19:00 ON THE LEFT SIDE
293 01:43:19:02 01:43:21:15 IS AN INTRUSIVE
IGNEOUS ROCK,
294 01:43:21:17 01:43:24:22 A TONALITE
THAT CAME INTO CONTACT
295 01:43:24:24 01:43:26:29 WITH A LIMESTONE.
296 01:43:27:01 01:43:28:29 THE LIMESTONE
WAS HEATED UP,
297 01:43:29:01 01:43:31:29 AND AT THE SAME TIME
THERE WERE ELEMENTS
298 01:43:32:01 01:43:33:29 THAT LEFT BOTH
CHEMICAL ELEMENTS--
299 01:43:34:01 01:43:37:15 THAT LEFT
THE INTRUSIVE ROCK
INTO THE MARBLE,
300 01:43:37:17 01:43:40:00 AND THEN ELEMENTS
THAT LEFT THE MARBLE
301 01:43:40:02 01:43:42:29 AND WENT INTO
THE INTRUSIVE ROCK.
302 01:43:43:01 01:43:46:29 THE MATERIAL LEAVING
THE INTRUSIVE ROCK
303 01:43:47:01 01:43:51:15 CONSISTED OF SOME IRON,
ALUMINUM, AND SILICON,
304 01:43:51:17 01:43:56:13 WHICH WENT
TO FORM GARNETS--
THE BROWN MATERIAL HERE.
305 01:43:56:15 01:43:59:13 SILICA CONTINUED IN

FURTHER INTO THE MARBLE

306 01:43:59:15 01:44:01:27 THAN DID
THE OTHER TWO ELEMENTS,

307 01:44:01:29 01:44:04:27 RESULTING IN
A LAYER OF THE MINERAL
WOLLASTONITE,

308 01:44:04:29 01:44:07:09 WHICH IS
A CALCIUM SILICATE.

309 01:44:07:11 01:44:10:28 THIS IS A GOOD EXAMPLE
OF A WELL-LAYERED ROCK

310 01:44:11:00 01:44:13:13 PRODUCED BY
REGIONAL METAMORPHISM

311 01:44:13:15 01:44:15:28 IN THE SO-CALLED
AMPHIBOLITE FACIES.

312 01:44:16:00 01:44:18:12 IT CONSISTS OF
ALTERNATING LAYERS--

313 01:44:18:14 01:44:21:12 THE LIGHT OF QUARTZITE,

314 01:44:21:14 01:44:23:27 AND OF DARK,
A MICA SCHIST

315 01:44:23:29 01:44:27:28 BEARING THE ALUMINUM SILICATE
MINERAL SILLAMANITE.

316 01:44:28:00 01:44:30:28 AT FIRST, YOU'D THINK THESE
ARE RELIC SEDIMENTARY BEDS,

317 01:44:31:00 01:44:32:00 BUT THEY'RE NOT.

318 01:44:32:02 01:44:33:12 THEY'VE BEEN
STRUCTURALLY TRANSPOSED

319 01:44:33:14 01:44:34:27 FROM SEDIMENTARY BEDS

320 01:44:34:29 01:44:38:27 INTO TECTONICALLY BOUNDED
LAYERS.

321 01:44:38:29 01:44:42:21 HERE YOU CAN SEE TWO OF
THE BIOTITE-RICH LAYERS

322 01:44:42:23 01:44:45:28 COMING TOGETHER
TO CONSTITUTE
A SINGLE LAYER.

323 01:44:46:00 01:44:51:11 SO THERE HAS BEEN A GREAT DEAL
OF DIRECTED SHEAR PRESSURE

324 01:44:51:13 01:44:52:26 THROUGH THIS ROCK

325 01:44:52:28 01:44:56:10 THAT HAS PRODUCED
THIS WELL-LAYERED
ASPECT TO IT.

326 01:44:59:12 01:45:01:25 METAMORPHISM HAS BEEN
COMPARED TO COOKING.

327 01:45:01:27 01:45:04:11 THE DISH
THAT YOU WIND UP WITH

328 01:45:04:13 01:45:06:11 DEPENDS ON YOUR
STARTING INGREDIENTS

329 01:45:06:13 01:45:08:11 AND THE WAY YOU COOK THEM.

330 01:45:08:13 01:45:10:10 LIKEWISE, LABORATORY
EXPERIMENTS HAVE SHOWN

331 01:45:10:12 01:45:12:10 THAT THE COMPOSITION
OF ROCKS

332 01:45:12:12 01:45:14:25 CHANGES VERY LITTLE
DURING METAMORPHISM.

333 01:45:14:27 01:45:17:10 BUT AS TEMPERATURE
AND PRESSURE INCREASE,

334 01:45:17:12 01:45:19:26 THE ATOMS WITHIN THE ROCK

BECOME MOBILE

335 01:45:19:28 01:45:22:11 AND RECOMBINE
TO FORM NEW MINERALS.

336 01:45:22:13 01:45:24:11 THESE EXPERIMENTS
HAVE ALSO SHOWN

337 01:45:24:13 01:45:26:25 THAT THE VARIOUS
METAMORPHIC MINERALS,

338 01:45:26:27 01:45:29:10 OR ASSEMBLAGES OF MINERALS
FOUND TOGETHER,

339 01:45:29:12 01:45:31:10 FORM ONLY WITHIN
SPECIFIC RANGES

340 01:45:31:12 01:45:32:25 OF TEMPERATURE
AND PRESSURE.

341 01:45:32:27 01:45:36:11 SO GEOLOGISTS
CAN USE MINERALS
AND METAMORPHIC ROCKS

342 01:45:36:13 01:45:38:11 AS PRESSURE GAUGES
AND THERMOMETERS

343 01:45:38:13 01:45:39:26 TO UNDERSTAND
THE CONDITIONS

344 01:45:39:28 01:45:42:17 UNDER WHICH METAMORPHISM
TOOK PLACE.

345 01:45:42:19 01:45:44:25 THIS AN EXAMPLE
OF HOW MINERALS ARE USED

346 01:45:44:27 01:45:47:10 TO INTERPRET
THE METAMORPHISM OF BASALT,

347 01:45:47:12 01:45:50:25 THE ROCK THAT MAKES UP
THE OCEAN BASIN'S CRUST.

348 01:45:50:27 01:45:53:08 PRESSURE ON THE CHART
INCREASES DOWNWARD

349 01:45:53:10 01:45:56:09 AND TEMPERATURE
INCREASES TO THE RIGHT.

350 01:45:56:11 01:45:59:24 THIS IS A PIECE
OF UNMETAMORPHOSED BASALT,

351 01:45:59:26 01:46:01:23 WHICH FORMED
AT THE EARTH'S SURFACE.

352 01:46:01:25 01:46:04:08 THIS ROCK WOULD PLOT HERE
ON OUR CHART

353 01:46:04:10 01:46:07:12 AT RELATIVELY LOW
TEMPERATURE AND PRESSURE.

354 01:46:07:14 01:46:09:23 AS BASALT IS METAMORPHOSED

355 01:46:09:25 01:46:12:24 TO DIFFERENT COMBINATIONS
OF TEMPERATURE AND PRESSURE,

356 01:46:12:26 01:46:15:09 ITS MINERAL COMPOSITION
CHANGES

357 01:46:15:11 01:46:18:08 AS THE ROCK REEQUILIBRATES
TO ITS NEW CONDITION.

358 01:46:18:10 01:46:20:08 THESE ZONES ON THE CHART

359 01:46:20:10 01:46:22:08 ARE CALLED
METAMORPHIC FACIES.

360 01:46:22:10 01:46:25:08 EACH FACIES IS DEFINED
BY THE FORMATION

361 01:46:25:10 01:46:27:24 DURING METAMORPHISM
OF A PARTICULAR MINERAL

362 01:46:27:26 01:46:29:24 OR MINERAL ASSEMBLAGE.

363 01:46:29:26 01:46:32:24 FOR EXAMPLE, THIS IS

A METAMORPHOSED BASALT
364 01:46:32:26 01:46:34:23 CONTAINING
THE MINERAL AMPHIBOLE.
365 01:46:34:25 01:46:37:08 AMPHIBOLE FORMS
AT A TEMPERATURE
366 01:46:37:10 01:46:40:23 BETWEEN 450
AND 700 DEGREES CENTIGRADE,
367 01:46:40:25 01:46:42:08 AND AT A PRESSURE
368 01:46:42:10 01:46:45:24 CORRESPONDING TO A DEPTH
OF AT LEAST 6 KILOMETERS.
369 01:46:45:26 01:46:47:09 THIS METAMORPHOSED BASALT
370 01:46:47:11 01:46:49:08 WOULD PLOT HERE
ON THE CHART
371 01:46:49:10 01:46:52:06 IN THE AMPHIBOLITE FACIES.
372 01:46:54:08 01:46:56:06 THIS IS
A METAMORPHOSED BASALT
373 01:46:56:08 01:46:59:06 THAT CONTAINS ZEOLITES,
ANOTHER MINERAL GROUP,
374 01:46:59:08 01:47:03:08 AND IT PLOTS HERE
IN THE ZEOLITE FACIES.
375 01:47:03:10 01:47:04:22 THE ZEOLITE FACIES
376 01:47:04:24 01:47:07:07 CORRESPONDS TO LESS INTENSE
METAMORPHIC CONDITIONS
377 01:47:07:09 01:47:09:21 THAN DOES
THE AMPHIBOLITE FACIES,
378 01:47:09:23 01:47:11:06 SO ROCKS
CONTAINING ZEOLITES
379 01:47:11:08 01:47:14:19 ARE SAID TO BE OF
LOWER METAMORPHIC GRADE.
380 01:47:14:21 01:47:18:06 METAMORPHISM IS A PROCESS
OF PROGRESSIVE CHANGE.
381 01:47:18:08 01:47:21:22 AS ROCK ARE EXPOSED
TO HIGHER TEMPERATURES
AND PRESSURES,
382 01:47:21:24 01:47:24:22 THEY'RE ALTERED
IN A PREDICTABLE MANNER.
383 01:47:24:24 01:47:27:06 AS THE INTENSITY
OF METAMORPHISM INCREASES,
384 01:47:27:08 01:47:29:06 THE ROCKS BECOME HARDER
385 01:47:29:08 01:47:30:21 AND MORE COARSELY
CRYSTALLINE,
386 01:47:30:23 01:47:33:21 AND DEVELOP SPECIAL
METAMORPHIC TEXTURES.
387 01:47:33:23 01:47:36:22 GEOLOGISTS REFER TO
PROGRESSIVE METAMORPHISM
388 01:47:36:24 01:47:39:22 AS AN INCREASE
IN METAMORPHIC GRADE
389 01:47:39:24 01:47:41:07 FROM LOW TO HIGH.
390 01:47:41:09 01:47:44:06 THE BEST WAY TO SEE
THIS PATTERN OF CHANGE
391 01:47:44:08 01:47:47:06 IS TO BEGIN WITH
AN UNMETAMORPHOSED PROTOLITH
392 01:47:47:08 01:47:48:21 AND WATCH IT CHANGE
393 01:47:48:23 01:47:51:24 AS THE INTENSITY
OF METAMORPHISM INCREASES.
394 01:47:51:26 01:47:55:20 *GEOLOGISTS CAN SEE*

HOW PARTICULAR ROCK TYPES

395 01:47:55:22 01:47:57:20 *UNDERGO PROGRESSIVE METAMORPHISM*

396 01:47:57:22 01:48:00:05 *BY TRACING WIDESPREAD ROCK FORMATIONS*

397 01:48:00:07 01:48:03:04 *FROM AREAS WHERE NO METAMORPHISM HAS OCCURRED,*

398 01:48:03:06 01:48:06:04 *INTO AREAS WHERE METAMORPHISM IS EXTREME.*

399 01:48:09:10 01:48:11:04 IF OUR STARTING MATERIAL

400 01:48:11:06 01:48:13:11 IS LIKE A CLAYSTONE LIKE THIS,

401 01:48:13:13 01:48:14:27 AS SEDIMENTARY ROCK,

402 01:48:14:29 01:48:16:12 RELATIVELY LUMINOUS RICH.

403 01:48:16:14 01:48:18:19 ON HEATING THIS UNDER THE LOW PART

404 01:48:18:21 01:48:20:04 OF THE REGIONAL METAMORPHISM,

405 01:48:20:06 01:48:23:04 WE DEVELOP A VERY LAYERED

406 01:48:23:06 01:48:25:19 FINE-LINEARED ROCK CALLED A SLATE.

407 01:48:25:21 01:48:28:05 IT DOESN'T HAVE ANY RECOGNIZABLE MINERALS

408 01:48:28:07 01:48:30:20 BECAUSE THEY HAVEN'T GROWN LARGE ENOUGH,

409 01:48:30:22 01:48:33:05 BUT DUE TO THE GROWTH OF NEW MINERALS

410 01:48:33:07 01:48:35:04 AND OF THE DIRECTED PRESSURE,

411 01:48:35:06 01:48:38:04 WE END UP WITH A WELL-FOLIATED ROCK,

412 01:48:38:06 01:48:41:04 POSSIBLE TO CLEAVE INTO REGULAR THIN LAYERS.

413 01:48:41:06 01:48:43:04 WITH INCREASED TEMPERATURE AND PRESSURE

414 01:48:43:06 01:48:44:20 AT THE SLATE,

415 01:48:44:22 01:48:47:20 IT'S TRANSFORMED INTO A SLIGHTLY HIGHER GRADE ROCK

416 01:48:47:22 01:48:49:20 WHICH IS CALLED A PHYLLITE.

417 01:48:49:22 01:48:52:04 THIS ROCK HAS A LINEAR STRUCTURE

418 01:48:52:06 01:48:55:04 AS WELL AS TO THE FOLIATED STRUCTURE

419 01:48:55:06 01:48:57:19 THAT IT IS SLIGHTLY DIFFERENT IN LUSTER

420 01:48:57:21 01:49:00:20 DUE TO THE LARGER MICA-SIZED CRYSTALS.

421 01:49:00:22 01:49:03:20 AS THE TEMPERATURE AND PRESSURE INCREASE FURTHER,

422 01:49:03:22 01:49:05:05 WE DEVELOP A SCHIST.

423 01:49:05:07 01:49:07:26 THIS IS
A GARNET SCHIST
424 01:49:07:28 01:49:09:11 WITH LARGE
GARNET CRYSTALS.
425 01:49:09:13 01:49:10:26 LOTS OF WHITE MICA.
426 01:49:10:28 01:49:12:19 VERY COARSE CRYSTALS.
427 01:49:12:21 01:49:14:04 THIS WOULD BE FORMED
428 01:49:14:06 01:49:16:05 AT QUITE HIGH
METAMORPHIC GRADE.
429 01:49:16:07 01:49:18:05 AT A HIGHER
METAMORPHIC GRADE
430 01:49:18:07 01:49:21:05 THAT YOU
CONSTITUTE A GNEISS
431 01:49:21:07 01:49:24:04 WHERE YOU START HAVING
MINERALS SEGREGATE
432 01:49:24:06 01:49:25:19 INTO DEFINITE LAYERS.
433 01:49:29:21 01:49:32:20 *IF METAMORPHIC ROCKS*
FORM INSIDE THE EARTH
434 01:49:32:22 01:49:34:20 *AS TEMPERATURES*
AND PRESSURES RISE,
435 01:49:34:22 01:49:37:05 *WHY AREN'T THEY*
UNMETAMORPHOSED
436 01:49:37:07 01:49:40:04 *AS TEMPERATURES*
AND PRESSURES
FALL BACK DOWN?
437 01:49:42:06 01:49:44:04 *IN PART,*
THIS IS BECAUSE
438 01:49:44:06 01:49:46:04 *LOSS OF FLUIDS*
DURING METAMORPHISM
439 01:49:46:06 01:49:47:23 *MAKES IT IMPOSSIBLE*
440 01:49:47:25 01:49:51:05 *FOR CERTAIN*
CHEMICAL REACTIONS
TO REVERSE THEMSELVES.
441 01:49:51:07 01:49:53:03 *ALSO, AS TEMPERATURES DROP,*
442 01:49:53:05 01:49:56:18 *IONS CANNOT MIGRATE EASILY*
THROUGH THE ROCK,
443 01:49:56:20 01:49:59:02 *SO MINERALS WILL NOT*
RECRYSTALLIZE.
444 01:50:02:04 01:50:04:02 *SO, IN MOST*
METAMORPHIC ROCKS,
445 01:50:04:04 01:50:06:17 *GEOLOGISTS FIND*
A PRESERVED RECORD
446 01:50:06:19 01:50:08:18 *OF THE GREATEST*
TEMPERATURES AND PRESSURES
447 01:50:08:20 01:50:11:18 *OCCURRING DURING*
CRUSTAL DEFORMATION.
448 01:50:11:20 01:50:15:02 *WITH THE DEVELOPMENT*
OF PLATE TECTONICS THEORY,
449 01:50:15:04 01:50:17:02 *THE TEMPERATURE*
AND PRESSURE CHANGES
450 01:50:17:04 01:50:20:02 *GEOLOGISTS HAVE LONG SEEN*
IN METAMORPHIC ROCKS,
451 01:50:20:04 01:50:22:28 *FINALLY BEGAN*
TO MAKE SENSE.
452 01:50:23:00 01:50:26:03 FOR MANY YEARS, GEOLOGISTS
HAVE BEEN ABLE TO RELATE

453 01:50:26:05 01:50:29:03 INDIVIDUAL FACIES
TO THE PRESSURE AND
TEMPERATURE CONDITIONS
454 01:50:29:05 01:50:30:17 OF METAMORPHISM,
455 01:50:30:19 01:50:32:17 BUT THEY HAD
NO SATISFACTORY EXPLANATION
456 01:50:32:19 01:50:35:17 FOR THE GEOLOGIC PROCESSES
THAT FROM METAMORPHIC ROCKS.
457 01:50:35:19 01:50:39:02 THAT IS, UNTIL THE THEORY
OF PLATE TECTONICS EMERGED.
458 01:50:39:04 01:50:40:19 ONE GOOD EXAMPLE
459 01:50:40:21 01:50:44:03 IS THIS RELATIVELY RARE
METAMORPHIC ROCK
CALLED BLUESCHIST.
460 01:50:44:05 01:50:45:18 EXPERIMENTAL WORK HAD SHOWN
461 01:50:45:20 01:50:47:02 THAT THE MINERALS
IN BLUESCHIST
462 01:50:47:04 01:50:50:24 FORM UNDER VERY UNUSUAL
METAMORPHIC CONDITIONS.
463 01:50:50:26 01:50:53:00 THESE CONDITIONS ARE
A PRESSURE RANGE
464 01:50:53:02 01:50:57:00 EQUIVALENT TO A DEPTH
OF 15-30 KILOMETERS
IN THE CRUST,
465 01:50:57:02 01:50:59:00 AND A VERY COOL TEMPERATURE,
466 01:50:59:02 01:51:01:16 ONLY 200-400 DEGREES
CENTIGRADE.
467 01:51:01:18 01:51:03:16 THAT'S THE APPROXIMATE
COOKING TEMPERATURE
468 01:51:03:18 01:51:06:04 OF A KITCHEN OVEN
OR TOASTER.
469 01:51:06:06 01:51:09:00 AT A DEPTH
OF 15-30 KILOMETERS,
470 01:51:09:02 01:51:12:00 THE TEMPERATURE'S NORMALLY
ABOUT TWICE AS HOT,
471 01:51:12:02 01:51:14:15 500-750 DEGREES CENTIGRADE.
472 01:51:14:17 01:51:17:16 THE ONLY WAY THAT ROCKS
CAN BE METAMORPHOSED
473 01:51:17:18 01:51:19:01 TO BLUESCHIST FACIES
474 01:51:19:03 01:51:23:00 IS TO BE QUICKLY SHOVED
DOWN TO THOSE EXTREME DEPTHS
475 01:51:23:02 01:51:25:00 AND RAPIDLY BROUGHT BACK UP
476 01:51:25:02 01:51:27:15 BEFORE THE ROCKS
HAVE TIME TO HEAT UP.
477 01:51:27:17 01:51:30:00 THAT'S EXACTLY WHAT HAPPENS
WHERE TWO TECTONIC PLATES
478 01:51:30:02 01:51:32:16 ARE COLLIDING
IN A SUBDUCTION ZONE.
479 01:51:32:18 01:51:34:16 IN FACT,
BLUESCHIST-BEARING ROCKS
480 01:51:34:18 01:51:37:01 NORMALLY OCCUR
IN LONG LINEAR ZONES
481 01:51:37:03 01:51:40:15 THAT MARK ANCIENT PLATE
SUBDUCTION BOUNDARIES.
482 01:51:42:02 01:51:44:15 *METAMORPHIC ROCKS*
PROVIDE GEOLOGISTS

483 01:51:44:17 01:51:46:15 *WITH THE MOST*
COMPLETE PICTURE
484 01:51:46:17 01:51:48:15 *OF TEMPERATURES*
AND PRESSURES DEVELOPED
485 01:51:48:17 01:51:50:16 *WHEN PLATES COLLIDE.*
486 01:51:50:18 01:51:52:00 *IN ADDITION,*
487 01:51:52:02 01:51:54:29 *THESE ROCKS CONTAIN OTHER*
FUNDAMENTAL INFORMATION.
488 01:51:57:02 01:51:58:15 *IN THE METAMORPHIC REGIONS*
489 01:51:58:17 01:52:00:28 *OF THE NORTHEASTERN*
UNITED STATES, FOR EXAMPLE,
490 01:52:01:00 01:52:03:13 *SNOWBALL GARNETS PRESERVE*
AN IMPORTANT RECORD
491 01:52:03:15 01:52:06:13 *OF THE BUILDING OF*
THE APPALACHIAN MOUNTAINS.
492 01:52:09:03 01:52:12:29 *BY COMPARING THE AMOUNT*
OF RUBIDIUM ISOTOPE DECAY
493 01:52:13:01 01:52:16:13 *AT THE CENTER*
OF THESE GARNETS
RELATIVE TO THEIR MARGINS,
494 01:52:16:15 01:52:20:28 *GEOLOGISTS CAN DETERMINE*
HOW FAST THE CRYSTALS GROW.
495 01:52:21:00 01:52:22:13 THE GARNETS IN VERMONT
496 01:52:22:15 01:52:25:25 TOOK ABOUT 1O,
1O 1/2 MILLION
YEARS TO GROW,
497 01:52:25:27 01:52:29:29 AND IS CORRESPONDENT
TO A GROWTH RATE
498 01:52:30:01 01:52:34:28 OF ROUGHLY A FEW
ATOMIC DIAMETERS
PER YEAR.
499 01:52:35:00 01:52:39:13 TO GIVE YOU SOME COMPARISON
OF WHAT THAT MIGHT BE
500 01:52:39:15 01:52:43:29 IN TERMS THAT MIGHT BE MORE
IN A HUMAN REFERENCE FRAME,
501 01:52:44:01 01:52:47:13 THAT CORRESPONDS TO
ABOUT A MILLIONTH AS FAST
502 01:52:47:15 01:52:53:11 AS THE DIAMETER
OF AN ORDINARY TREE
MIGHT GROW,
503 01:52:53:13 01:52:56:09 SO IT'S
A VERY SLOW PROCESS.
504 01:52:56:11 01:52:58:11 *THE VERMONT GARNETS*
505 01:52:58:13 01:53:01:27 *BEGAN GROWING ABOUT*
380 MILLION YEARS AGO.
506 01:53:01:29 01:53:04:12 *AS THE CONTINENTS*
OF EURASIA AND AFRICA
507 01:53:04:14 01:53:05:27 *DRIFTED TOWARD THE AMERICAS*
508 01:53:05:29 01:53:08:26 *TO FORM THE SUPERCONTINENT*
OF PANGAEA.
509 01:53:11:28 01:53:13:26 *THE CONVERGENCE*
OF THE PLATES
510 01:53:13:28 01:53:15:26 *GRADUALLY*
HEAVED UP THE ROCKS
511 01:53:15:28 01:53:17:27 *OF NORTHEASTERN*
NORTH AMERICA

512 01:53:17:29 01:53:20:12 *TO CREATE THE APPALACHIAN MOUNTAIN RANGE,*

513 01:53:20:14 01:53:23:11 *PUSHING THE ROCKS INTO HUGE FLAT-LYING FOLDS*

514 01:53:23:13 01:53:24:26 *CALLED "NAPPES."*

515 01:53:28:13 01:53:31:11 *BURIED DEEP INSIDE THESE GIANT FOLDS OF ROCK,*

516 01:53:31:13 01:53:33:12 *TINY GARNET CRYSTALS*

517 01:53:33:14 01:53:35:12 *ECHO THE TWISTING AND CONTORTING*

518 01:53:35:14 01:53:36:27 *GOING ON AROUND THEM.*

519 01:53:36:29 01:53:40:11 *ROTATING AND SPIRALING BETWEEN 20 AND 30 DEGREES*

520 01:53:40:13 01:53:42:11 *EVERY MILLION YEARS.*

521 01:53:44:28 01:53:48:02 THE BEAUTY ABOUT THE GARNETS IN VERMONT

522 01:53:48:04 01:53:51:09 IS THAT THE ONES WE MEASURED WERE SNOWBALL GARNETS,

523 01:53:51:11 01:53:54:25 AND SO WE GET SOME OTHER USEFUL INFORMATION

524 01:53:54:27 01:53:58:02 FROM THE GARNETS STUDIED IN VERMONT.

525 01:53:58:04 01:54:01:24 THAT INFORMATION TELLS US HOW FAST THE ROCKS WERE DEFORMING.

526 01:54:01:26 01:54:05:09 IN OTHER WORDS, HOW FAST THE GARNETS WERE ROTATING.

527 01:54:05:11 01:54:09:10 THAT TELLS US HOW FAST THE ROCKS AROUND THE GARNETS

528 01:54:09:12 01:54:12:10 THAT WERE CAUSING THAT ROTATION WERE DEFORMING.

529 01:54:12:12 01:54:16:27 THAT IS SOMETHING THAT HAS NEVER BEEN MEASURED BEFORE.

530 01:54:16:29 01:54:18:09 IT'S OF CONSIDERABLE INTEREST

531 01:54:18:11 01:54:20:24 FOR PEOPLE STUDYING TECTONISM,

532 01:54:20:26 01:54:23:09 BECAUSE WE'RE ACTUALLY MEASURING THE RATES

533 01:54:23:11 01:54:25:25 AT WHICH THE ROCKS GET FOLDED,

534 01:54:25:27 01:54:30:25 AND THAT'S ANOTHER FACTOR WE'RE INTERESTED IN.

535 01:54:32:13 01:54:36:09 *LIKE A TINY BLACK BOX FLIGHT RECORDER IN AN AIRPLANE*

536 01:54:36:11 01:54:39:09 *OR A TRIP ODOMETER IN A CAR,*

537 01:54:39:11 01:54:41:09 *A SNOWBALL GARNET PROVIDES GEOLOGISTS*

538 01:54:41:11 01:54:44:10 *WITH A CRYSTALLINE LOG*

OF PLATE COLLISION

539 01:54:44:12 01:54:47:24 *AND MOUNTAIN-BUILDING*
SPANNING MILLIONS OF YEARS.

540 01:54:50:26 01:54:52:07 METAMORPHISM
IS A FUNDAMENTAL

541 01:54:52:09 01:54:54:07 ROCK-FORMING PROCESS
ON EARTH.

542 01:54:54:09 01:54:58:07 ABOUT 15% OF ALL CONTINENTAL
CRUST EXPOSED AT THE SURFACE

543 01:54:58:09 01:55:00:07 IS COMPOSED
OF METAMORPHIC ROCKS,

544 01:55:00:09 01:55:02:23 AND MUCH OF
THE OCEANIC CRUST

545 01:55:02:25 01:55:05:23 IS METAMORPHOSED
TO A LOW GRADE
AS IT FORMS.

546 01:55:05:25 01:55:08:22 JUST AS FOSSILS ARE A RECORD
OF LIFE THROUGH TIME,

547 01:55:08:24 01:55:10:07 METAMORPHIC ROCKS ARE USED

548 01:55:10:09 01:55:12:07 TO STUDY THE HISTORY
OF THE EARTH.

549 01:55:12:09 01:55:14:22 THEY ALLOW US TO RECONSTRUCT
THE MOVEMENTS OF PLATES

550 01:55:14:24 01:55:16:07 THAT NO LONGER EXIST,

551 01:55:16:09 01:55:18:08 AND TO STUDY
MOUNTAIN RANGES

552 01:55:18:10 01:55:20:11 THAT HAVE
LONG SINCE WORN AWAY.

553 01:55:20:13 01:55:22:08 LIKE THE OPENING
OF NEW OCEANS,

554 01:55:22:10 01:55:23:22 THE MOVEMENT
OF CONTINENTS,

555 01:55:23:24 01:55:26:07 AND THE CREATION
OF MOUNTAIN RANGES,

556 01:55:26:09 01:55:29:07 METAMORPHISM
IS A CONSEQUENCE
OF PLATE TECTONICS.

557 01:55:29:09 01:55:31:22 THE RISE IN TEMPERATURE
AND PRESSURE

558 01:55:31:24 01:55:33:07 THAT MAKES
METAMORPHISM POSSIBLE

559 01:55:33:09 01:55:35:23 IS ALMOST ALWAYS LINKED
TO PLATE MOVEMENT

560 01:55:35:25 01:55:37:08 AND MOUNTAIN-BUILDING.

561 01:55:37:10 01:55:40:07 THE COLLISIONS
AND INTRUSIONS
AND FAULT ZONES

562 01:55:40:09 01:55:41:22 THAT METAMORPHOSE THE ROCKS

563 01:55:41:24 01:55:44:19 ARE CONCENTRATED
AT PLATE MARGINS.

564 01:55:44:21 01:55:47:07 AS ROCKS ARE DEPRESSED
TO GREAT DEPTH,

565 01:55:47:09 01:55:49:22 SAY 10s OF KILOMETERS
IN A SUBDUCTION ZONE,

566 01:55:49:24 01:55:51:20 OR PLACED UNDER
THE GREAT COMPRESSION

567 01:55:51:22 01:55:53:05 OF A CONTINENTAL COLLISION,
568 01:55:53:07 01:55:55:21 METAMORPHIC CONDITIONS
CAN BECOME SO INTENSE
569 01:55:55:23 01:55:58:06 THAT THE ROCKS
BEGIN TO MELT.
570 01:55:58:08 01:56:01:05 THE MAGMA RISES BUOYANTLY
TOWARD THE SURFACE,
571 01:56:01:07 01:56:04:05 SETTING THE STAGE FOR
THE FORMATION OF NEW ROCKS
572 01:56:04:07 01:56:05:20 AND NEW METAMORPHIC
TRANSFORMATIONS.
573 01:56:05:22 01:56:07:20 WHEN WE STUDY
METAMORPHIC ROCKS,
574 01:56:07:22 01:56:09:20 WE ARE SEEING
A BRIEF GLIMPSE
575 01:56:09:22 01:56:12:21 OF THIS CYCLE OF ROCK
FORMATION AND CHANGE,
576 01:56:12:23 01:56:16:20 A CYCLE THAT'S AS OLD
AS THE EARTH ITSELF.
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