

1 02:48:18:28 02:48:22:11 Annenberg Media
 2 02:48:22:13 02:49:16:10 §
 3 02:49:16:12 02:49:17:25 EACH OF THESE OIL WELLS
 4 02:49:17:27 02:49:20:24 IS PRODUCING ABOUT
 100 BARRELS OF OIL EVERY DAY.
 5 02:49:20:26 02:49:22:09 OIL FROM WELLS LIKE THESE,
 6 02:49:22:11 02:49:24:09 HAS FUELED THE ENGINES
 AND ECONOMIES
 7 02:49:24:11 02:49:27:04 OF THE INDUSTRIALIZED WORLD
 FOR OVER A CENTURY.
 8 02:49:27:06 02:49:28:19 BUT FOR GEOLOGISTS,
 9 02:49:28:21 02:49:30:25 OIL WELLS SERVE AN EQUALLY
 IMPORTANT FUNCTION.
 10 02:49:30:27 02:49:33:24 THEY ACT AS VITAL WINDOWS
 TO THE EARTH'S INTERIOR.
 11 02:49:33:26 02:49:35:09 THERE ARE LIMITS, HOWEVER,
 12 02:49:35:11 02:49:37:24 TO HOW FAR THESE WINDOWS
 ALLOW US TO SEE.
 13 02:49:37:26 02:49:40:13 THESE WELLS ARE ABOUT
 A KILOMETER AND A HALF DEEP,
 14 02:49:40:15 02:49:42:14 AND THE DEEPEST OIL
 AND GAS WELLS
 15 02:49:42:16 02:49:45:08 PENETRATE THE EARTH'S CRUST
 TO ABOUT 8 KILOMETERS.
 16 02:49:45:10 02:49:47:18 THE WORLD'S DEEPEST WELL
 IS NOW BEING DRILLED
 17 02:49:47:20 02:49:49:03 IN THE SOVIET UNION.
 18 02:49:49:05 02:49:50:25 DESIGNED AS A SCIENTIFIC
 LABORATORY,
 19 02:49:50:27 02:49:53:09 IT HAS A PLANNED DEPTH
 OF 15 KILOMETERS,
 20 02:49:53:11 02:49:55:24 WHICH SEEMS DEEP
 UNTIL WE CONSIDER
 21 02:49:55:26 02:49:58:07 THAT THIS IS ONLY 1/4
 OF 1%
 22 02:49:58:09 02:50:00:25 OF THE DISTANCE
 TO THE CENTER OF THE EARTH.
 23 02:50:00:27 02:50:02:09 ALSO, DRILLING DEEP WELLS
 24 02:50:02:11 02:50:04:10 INVOLVES A TECHNOLOGICAL
 COMPLEXITY
 25 02:50:04:12 02:50:06:15 THAT RIVALS
 SPACE EXPLORATION.
 26 02:50:06:17 02:50:08:29 THE DEEP SOVIET WELL,
 FOR EXAMPLE,
 27 02:50:09:01 02:50:11:24 PENETRATES ROCKS
 AT PRESSURES 5,000 TIMES
 28 02:50:11:26 02:50:13:09 THAT OF THE EARTH'S SURFACE
 29 02:50:13:11 02:50:16:07 AND AT TEMPERATURES
 OF 300 DEGREES CENTIGRADE.
 30 02:50:16:09 02:50:18:07 ALTHOUGH PROGRESS
 IS BEING MADE,
 31 02:50:18:09 02:50:20:07 **ERE ARE TREMENDOUS**
 32 02:50:18:09 02:50:20:07 TECHNICAL OBSTACLES
 33 02:50:20:09 02:50:21:23 THAT MUST BE OVERCOME
 34 02:50:21:25 02:50:23:23 BEFORE WELLS LIKE THIS
 CAN BE EXTENDED

35 02:50:23:25 02:50:25:22 AND OFFER GEOLOGISTS
 A DIRECT VIEW
 36 02:50:25:24 02:50:27:08 OF THE EARTH'S INTERIOR.
 37 02:50:27:10 02:50:28:29 FORTUNATELY,
 THERE'S A GREAT DEAL
 38 02:50:29:01 02:50:31:06 WE CAN LEARN ABOUT
 THE EARTH'S INTERIOR
 39 02:50:31:08 02:50:33:07 WITHOUT HAVING TO SEE IT
 OR SAMPLE IT DIRECTLY.
 40 02:50:33:09 02:50:36:07 THIS BRANCH OF GEOLOGY--
 CALLED GEOPHYSICS--
 41 02:50:36:09 02:50:38:23 USES INDIRECT TECHNIQUES
 TO DEDUCE THE COMPOSITION
 42 02:50:38:25 02:50:41:23 AND BEHAVIOR OF
 THE INTERIOR OF THE EARTH.
 43 02:50:41:25 02:50:43:07 THESE METHODS INCLUDE
 44 02:50:43:09 02:50:45:07 STUDYING SEISMIC VIBRATIONS
 FROM EARTHQUAKES,
 45 02:50:45:09 02:50:48:06 ANALYZING VARIATIONS
 IN THE EARTH'S TEMPERATURE,
 46 02:50:48:08 02:50:49:22 MAGNETIC FIELD
 AND GRAVITY,
 47 02:50:49:24 02:50:52:06 AND USING LABORATORY
 AND COMPUTER MODELS
 48 02:50:52:08 02:50:55:08 TO SIMULATE CONDITIONS
 DEEP WITHIN THE EARTH.
 49 02:50:55:10 02:50:58:08 AND ALTHOUGH THESE DON'T
 TELL US EVERYTHING,
 50 02:50:58:10 02:51:00:22 THE INDIRECT APPROACH
 OF GEOPHYSICAL RESEARCH
 51 02:51:00:24 02:51:03:07 HAS PAINTED FOR US
 A REMARKABLY DETAILED PICTURE
 52 02:51:03:09 02:51:05:06 OF THE INTERIOR
 OF OUR PLANET.
 53 02:51:08:01 02:51:12:19 *AT 5:04 P.M.*
ON OCTOBER 17, 1989,
 54 02:51:12:21 02:51:16:14 *JUST 20 MINUTES BEFORE*
GAME THREE OF THE WORLD SERIES,
 55 02:51:16:16 02:51:19:04 *THE GROUND BENEATH*
THE SAN FRANCISCO BAY AREA
 56 02:51:19:06 02:51:21:18 *WAS CONVULSED*
BY A SEVERE EARTHQUAKE.
 57 02:51:27:20 02:51:29:01 [CAR ALARM]
 58 02:51:29:03 02:51:31:00 [EMERGENCY BELL]
 59 02:51:38:24 02:51:41:13 *THE DEATH TOLL WAS 63.*
 60 02:51:41:15 02:51:46:16 *THE DAMAGE--*
AN ESTIMATED \$6 BILLION.
 61 02:51:46:18 02:51:49:07 *BUT ALTHOUGH THEY CAN*
BE CATASTROPHIC,
 62 02:51:49:09 02:51:51:28 *BIG QUAKES PROVIDE*
VALUABLE INFORMATION
 63 02:51:52:00 02:51:55:05 *AS THEIR SHOCK WAVES*
RADIATE THROUGH THE EARTH.
 64 02:51:55:07 02:52:00:21 SEISMIC WAVES ARE
 LIKE SOUND WAVES IN AIR.
 65 02:52:00:23 02:52:03:28 THEY TRAVEL THROUGH

66 02:52:04:00 THE BODY OF THE EARTH
 02:52:07:20 FROM A SOURCE
 OF THE WAVES
 67 02:52:07:22 02:52:11:20 TO ALL POINTS WITHIN
 THE BODY OF THE EARTH.
 68 02:52:11:22 02:52:14:04 IT'S VERY SIMILAR
 TO MY TALKING
 69 02:52:14:06 02:52:16:20 AND THE WAVES THEN
 MOVING FROM MY MOUTH
 70 02:52:16:22 02:52:19:05 TO ALL POINTS
 IN THE ROOM.
 71 02:52:20:10 02:52:22:02 *LIKE SOUND WAVES*
IN THE AIR,
 72 02:52:22:04 02:52:24:19 *SEISMIC WAVES MOVE*
IN THREE DIMENSIONS,
 73 02:52:24:21 02:52:26:19 *FORMING SPHERICAL*
WAVE FRONTS
 74 02:52:26:21 02:52:29:03 *AS THEY PASS*
THROUGH OUR PLANET.
 75 02:52:32:26 02:52:35:07 *WHERE THE SEISMIC WAVES*
ENCOUNTER ROCK LAYERS
 76 02:52:35:09 02:52:36:22 *OF DIFFERING DENSITIES,*
 77 02:52:36:24 02:52:39:07 *THE WAVES REFLECT OFF*
THE BOUNDARIES
 78 02:52:39:09 02:52:40:20 *BETWEEN THE LAYERS,*
 79 02:52:40:22 02:52:44:03 *SIMILAR TO LIGHT*
REFLECTING OFF A MIRROR.
 80 02:52:44:05 02:52:46:18 *THESE WAVES ARE RECORDED*
ON SEISMOGRAPHS
 81 02:52:46:20 02:52:48:01 *DURING EARTHQUAKES,*
 82 02:52:48:03 02:52:50:17 *ALLOWING GEOPHYSICISTS*
TO SEE HOW LONG
 83 02:52:50:19 02:52:53:04 *THEY TAKE TO TRAVEL DOWN*
TO THE BOUNDARY,
 84 02:52:53:06 02:52:56:03 *REFLECT OFF IT,*
AND RETURN TO THE SURFACE.
 85 02:52:57:23 02:53:00:18 *FROM THE AMOUNT OF TIME*
NEEDED FOR THE ROUNDTRIP,
 86 02:53:00:20 02:53:03:03 *SCIENTISTS CAN CALCULATE*
THE DEPTH OF THE BOUNDARY
 87 02:53:03:05 02:53:06:03 *AND THUS LEARN MORE*
ABOUT THE DEEP STRUCTURE
 88 02:53:06:05 02:53:07:15 *OF THE EARTH.*
 89 02:53:08:23 02:53:11:18 SO, THE PRINCIPAL INFORMATION
 WE GET, THEN,
 90 02:53:11:20 02:53:15:03 ARE DISTANCES OF OBJECTS
 FROM THE SURFACE OF THE EARTH,
 91 02:53:15:05 02:53:18:01 AND THIS DEFINES
 THE GEOMETRY OF AN OBJECT.
 92 02:53:18:03 02:53:22:01 BECAUSE AS WE ILLUMINATE
 OR SHINE OUR SEISMIC WAVES
 93 02:53:22:03 02:53:24:16 ON DIFFERENT PARTS
 OF THE BODY,
 94 02:53:24:18 02:53:27:01 THOSE DIFFERENT PARTS
 MIGHT BE AT DIFFERENT DISTANCES
 95 02:53:27:03 02:53:29:02 FROM THE SURFACE

96 02:53:29:04 02:53:31:29 OF THE EARTH,
 AND, THEREFORE, WE'RE OUTLINING
 THE SHAPE OF THE BODY.
 97 02:53:33:03 02:53:34:17 *BUT NOT ALL SEISMIC ENERGY*
 98 02:53:34:19 02:53:37:16 *WILL BOUNCE OFF THE BOUNDARY*
BETWEEN ROCK LAYERS.
 99 02:53:37:18 02:53:41:01 *MUCH OF IT WILL PASS*
THROUGH THE BOUNDARY.
 100 02:53:41:03 02:53:43:15 *SINCE THE ROCK LAYERS*
DIFFER IN DENSITY,
 101 02:53:43:17 02:53:46:02 *THE VELOCITY AND DIRECTION*
OF THE WAVES
 102 02:53:46:04 02:53:48:17 *WILL CHANGE AS THEY CROSS*
THE BOUNDARY,
 103 02:53:48:19 02:53:51:16 *CAUSING THEM ONCE AGAIN*
TO BEHAVE LIKE LIGHT WAVES
 104 02:53:51:18 02:53:53:16 *AND TO BEND OR REFRACT*
 105 02:53:53:18 02:53:57:15 *AS THEY MOVE FROM ONE*
ROCK LAYER TO THE NEXT.
 106 02:54:00:29 02:54:02:17 *BY STUDYING*
THE TRAVEL TIMES
 107 02:54:02:19 02:54:05:17 *OF BOTH REFLECTED*
AND REFRACTED SEISMIC WAVES
 108 02:54:05:19 02:54:07:02 *FOLLOWING*
GREAT EARTHQUAKES,
 109 02:54:07:04 02:54:10:01 *GEOPHYSICISTS HAVE GRADUALLY*
PIECED TOGETHER
 110 02:54:10:03 02:54:12:22 *THE GENERAL STRUCTURE*
THROUGHOUT EARTH'S INTERIOR.
 111 02:54:14:09 02:54:17:04 *THERE'S HUNDREDS OF THOUSANDS*
OF EARTHQUAKES EVERY YEAR,
 112 02:54:17:06 02:54:19:24 *AND THERE'S THOUSANDS*
OF SEISMIC STATIONS
 113 02:54:19:26 02:54:21:09 *SCATTERED AROUND THE EARTH.*
 114 02:54:21:11 02:54:24:22 *SO, WE CONSTANTLY LISTEN*
FOR THESE EARTHQUAKES
 115 02:54:24:24 02:54:27:21 *AND CONSTANTLY PROCESS THEM*
THROUGH OUR SEISMIC STATIONS
 116 02:54:27:23 02:54:28:28 *AND THROUGH OUR COMPUTERS,*
 117 02:54:29:00 02:54:31:14 *AND SLOWLY WE'RE*
BUILDING UP AN IMAGE
 118 02:54:31:16 02:54:33:14 *OF WHAT ACTUALLY IS DOWN*
INSIDE THE EARTH,
 119 02:54:33:16 02:54:35:14 *BUILDING UP*
THREE-DIMENSIONAL IMAGES.
 120 02:54:35:16 02:54:36:29 *I SAY BUILDING UP*
 121 02:54:37:01 02:54:39:15 *BECAUSE IT'S VERY MUCH*
LIKE BUILDING UP AN IMAGE
 122 02:54:39:17 02:54:41:15 *ON A TELEVISION SCREEN.*
 123 02:54:41:17 02:54:45:14 *AS THE TELEVISION SCANNER*
SWEEPS ACROSS THE IMAGE,
 124 02:54:45:16 02:54:48:00 *YOU SLOWLY SEE WHAT IT IS*
YOU'RE LOOKING AT.
 125 02:54:50:06 02:54:53:19 *EARTHQUAKES AREN'T THE ONLY*
SOURCE OF SEISMIC WAVES.
 126 02:54:53:21 02:54:55:04 *PEOPLE SOMETIMES CREATE*

127 02:54:55:06 02:54:57:07 *THEIR OWN EARTH-SHAKING
DEVICES.*

128 02:54:59:01 02:55:00:14 [HENYEY]
SEISMIC WAVES

129 02:55:00:16 02:55:05:21 CAN BE GENERATED ARTIFICIALLY
AT THE EARTH'S SURFACE

130 02:55:05:23 02:55:07:26 BY EXPLOSIONS

131 02:55:07:28 02:55:12:26 OR BY DEVICES WHICH POUND
ON THE EARTH'S SURFACE,

132 02:55:12:28 02:55:17:14 AND THE WAVES, THEN,
TRANSFER THROUGH THE EARTH.

133 02:55:17:16 02:55:22:27 THIS IS VERY SIMILAR
TO X-RAYS, FOR EXAMPLE,

134 02:55:22:29 02:55:25:06 AND WHEN WE X-RAY
A HUMAN BODY,

135 02:55:25:08 02:55:27:29 THE X-RAYS, INSTEAD OF BEING
DESTRUCTIVE TO THE BODY,

136 02:55:28:01 02:55:30:24 ARE USED AS
A SOURCE OF ENERGY

137 02:55:30:26 02:55:33:28 WHICH CAN PENETRATE
TO THE INTERIOR OF THE BODY

138 02:55:34:00 02:55:37:12 AND THEN SCATTER OR REFLECT
OFF BONES OR INTERNAL ORGANS

139 02:55:37:14 02:55:40:26 AND THEN CAN BE, UH...

140 02:55:40:28 02:55:42:26 DOCUMENTED ON A FILM

141 02:55:42:28 02:55:45:12 OR SOME OTHER KIND
OF SENSOR,

142 02:55:45:14 02:55:47:28 AND WE CAN SEE
THE INTERIOR OF THE BODY.

143 02:55:48:00 02:55:50:13 SIMILARLY, WE SEE
THE INTERIOR OF THE EARTH

144 02:55:50:15 02:55:53:02 FROM THE INFORMATION
THAT COMES BACK

145 02:55:53:04 02:55:54:15 FROM SEISMIC WAVES.

146 02:55:56:23 02:55:58:27 *BASED ON SEISMOLOGICAL
RESEARCH,*

147 02:55:58:29 02:56:01:27 *GEOPHYSICISTS HAVE DEDUCED
THAT THE EARTH'S INTERIOR*

148 02:56:01:29 02:56:05:09 *IS DIVIDED INTO
THREE LAYERS.*

149 02:56:05:11 02:56:08:09 *THE CRUST--
A THIN SKIN AT THE SURFACE.*

150 02:56:08:11 02:56:11:10 *THE MANTLE--
A THICK SHELL OF ROCK*

151 02:56:11:12 02:56:15:01 *BENEATH THE CRUST WHICH
EXTENDS DOWN TO THE CORE,*

152 02:56:15:03 02:56:16:16 *A CENTRAL SPHERE*

153 02:56:16:18 02:56:19:16 *ROUGHLY HALF THE DIAMETER
OF THE PLANET.*

154 02:56:19:18 02:56:23:11 *THE EARTH'S CRUST ITSELF
OCCURS IN TWO VARIETIES--*

155 02:56:23:13 02:56:27:11 *CONTINENTAL CRUST, WHICH FORMS
ALL THE LARGE LAND MASSES,*

156 02:56:27:13 02:56:28:26 *AND OCEANIC CRUST*

157 02:56:28:28 02:56:32:02 *THAT UNDERLIES ALL
THE GREAT OCEAN BASINS.*

158 02:56:33:11 02:56:34:25 *AN IMPORTANT DISTINCTION*
 159 02:56:34:27 02:56:36:25 *BETWEEN THESE TWO TYPES*
 OF CRUST
 160 02:56:36:27 02:56:38:24 *IS THAT THEY'RE MOSTLY*
 MADE UP
 161 02:56:38:26 02:56:40:25 *OF DIFFERENT KINDS*
 OF ROCK.
 162 02:56:40:27 02:56:43:11 *GRANITIC ROCK IS TYPICAL*
 OF CONTINENTS,
 163 02:56:43:13 02:56:47:17 *WHILE BASALT PREDOMINATES*
 IN OCEAN BASINS.
 164 02:56:47:19 02:56:51:15 *ALSO THE CONTINENTS*
 ARE SOMEWHAT THICKER
 THAN IN THE OCEANS.
 165 02:56:51:17 02:56:53:10 *THE CONTINENTS*
 ARE BETWEEN
 166 02:56:53:12 02:56:56:11 *ABOUT 25 AND 40*
 KILOMETERS THICK.
 167 02:56:56:13 02:56:57:27 *THE OCEANIC CRUST*
 168 02:56:57:29 02:57:01:24 *IS SOMETHING BETWEEN*
 5 AND 10 KILOMETERS
 THICK.
 169 02:57:01:26 02:57:04:09 *THE CONTINENTAL*
 CRUST
 170 02:57:04:11 02:57:08:10 *IS MADE UP*
 OF MATERIALS
 171 02:57:08:12 02:57:11:11 *WHICH HAVE BEEN*
 SWEPT TOGETHER
 172 02:57:11:13 02:57:15:10 *DURING*
 DYNAMIC PROCESSES
 ON THE EARTH.
 173 02:57:15:12 02:57:17:24 *THEY INCLUDE*
 IGNEOUS ROCKS
 174 02:57:17:26 02:57:22:04 *FROM VOLCANIC*
 AND MAGMATIC EVENTS,
 175 02:57:22:06 02:57:23:26 *SEDIMENTARY ROCKS*
 176 02:57:23:28 02:57:26:27 *THAT HAVE BEEN*
 PUSHED IN
 FROM THE OCEANS,
 177 02:57:26:29 02:57:28:12 *AND*
 METAMORPHIC ROCKS
 178 02:57:28:14 02:57:32:10 *WHICH HAVE BEEN*
 MODIFIED BY HEAT
 AND PRESSURE
 179 02:57:32:12 02:57:36:05 *AS THEY'VE BEEN*
 TAKEN TO DEPTHS
 ON THE CONTINENTS
 180 02:57:36:07 02:57:37:27 *INTO THE EARTH'S*
 INTERIOR
 181 02:57:37:29 02:57:40:07 *AND THEN*
 REGURGITATED AGAIN.
 182 02:57:40:09 02:57:43:05 *THE CHEMISTRY*
 OF CONTINENTS
 AS A RESULT
 183 02:57:43:07 02:57:44:20 *IS VERY COMPLEX.*
 184 02:57:44:22 02:57:46:06 *BUT BY AND LARGE,*

185 02:57:46:08 02:57:49:04 MUCH OF THE CRUST
IS COMPOSED
OF SILICATES,

186 02:57:49:06 02:57:51:23 PRIMARILY OF
ALUMINUM, POTASSIUM,

187 02:57:51:25 02:57:55:06 CALCIUM,
WITH SOME IRON
AND MAGNESIUM.

188 02:57:56:22 02:57:59:24 THE OCEANIC CRUST
IS A BIT MORE
PRIMITIVE

189 02:57:59:26 02:58:02:26 THAN THE CONTINENTAL
CRUST, MORE UNIFORM.

190 02:58:02:28 02:58:05:24 WE BELIEVE
IT'S LARGELY IRON

191 02:58:05:26 02:58:07:09 AND MAGNESIUM
SILICATES.

192 02:58:07:11 02:58:09:27 IT HAS SOME
STRUCTURE TO IT,

193 02:58:09:29 02:58:14:00 BUT MUCH
LESS STRUCTURE
THAN THE CONTINENTS.

194 02:58:17:09 02:58:19:09 *ALTHOUGH AS A GENERAL RULE*

195 02:58:19:11 02:58:21:09 *OUR KNOWLEDGE*
OF THE EARTH'S INTERIOR

196 02:58:21:11 02:58:22:23 *COMES FROM INDIRECT*
EVIDENCE,

197 02:58:22:25 02:58:24:11 *THERE ARE SOME EXCEPTIONS.*

198 02:58:26:02 02:58:28:24 *OCCASIONALLY ERUPTING LAVA*
WILL CARRY WITH IT

199 02:58:28:26 02:58:30:08 *FRAGMENTS OF ROCK*

200 02:58:30:10 02:58:32:28 *TORN FROM THE WALLS*
OF VOLCANIC CONDUITS.

201 02:58:33:00 02:58:35:07 *THESE ARE KNOWN*
AS XENOLITHS

202 02:58:35:09 02:58:37:09 *OR FOREIGN ROCKS.*

203 02:58:37:11 02:58:39:23 *SOME XENOLITHS COME*
FROM THE MANTLE.

204 02:58:42:25 02:58:44:07 *IN OTHER PLACES,*

205 02:58:44:09 02:58:46:08 *HUGE SLICES OF MANTLE ROCK*

206 02:58:46:10 02:58:48:07 *HAVE BEEN BROUGHT*
TO THE SURFACE

207 02:58:48:09 02:58:49:23 *BY TECTONIC ACTIVITY*

208 02:58:49:25 02:58:52:23 *ATTACHED TO PIECES*
OF SEA FLOOR CRUST.

209 02:58:54:07 02:58:58:00 *THESE UNUSUAL ROCK SLICES*
ARE CALLED OPHIOLITES.

210 02:58:58:02 02:59:00:23 AN OPHIOLITE IS
A SEQUENCE OF ROCKS

211 02:59:00:25 02:59:02:07 THAT GEOLOGISTS
INTERPRET

212 02:59:02:09 02:59:06:22 AS BEING A CROSS-SECTION
THROUGH THE OCEANIC CRUST,

213 02:59:06:24 02:59:09:21 THE PART OF THE EARTH'S CRUST
THAT UNDERLIES THE OCEANS.

214 02:59:09:23 02:59:11:09 IT'S A SEQUENCE OF ROCKS

215 02:59:11:11 02:59:13:19 THAT MIGHT BE
 3 TO 5 KILOMETERS THICK.
 216 02:59:13:21 02:59:17:22 THE BOTTOM-MOST LAYERS
 CONSIST OF ROCKS
 LIKE THESE BEHIND US,
 217 02:59:17:24 02:59:20:20 WHICH ARE ROCKS
 OF THE EARTH'S MANTLE
 218 02:59:20:22 02:59:23:21 COMPOSED OF MINERALS
 RICH IN IRON
 AND MAGNESIUM.
 219 02:59:23:23 02:59:28:07 MOVING UP THROUGH
 THE 3 TO 4 KILOMETER
 THICK SECTION,
 220 02:59:28:09 02:59:31:29 YOU MOVE INTO ROCKS
 CALLED GABBROS
 221 02:59:32:01 02:59:34:08 WHICH ARE RICHER
 IN SILICA THAN THESE,
 222 02:59:34:10 02:59:37:06 AND THEN FINALLY TO ROCKS
 WHICH ARE THOUGHT TO BE
 223 02:59:37:08 02:59:40:20 THE ROCKS THAT FORM
 THE ACTUAL FLOOR
 OF THE OCEAN,
 224 02:59:40:22 02:59:43:07 ROCKS THAT WERE EITHER
 ERUPTED VOLCANICALLY
 225 02:59:43:09 02:59:46:01 OR DEPOSITED AS SEDIMENTS
 ON THE OCEAN FLOOR.
 226 02:59:47:10 02:59:50:05 OPHIOLITES ARE OF SPECIAL
 INTEREST TO GEOLOGISTS
 227 02:59:50:07 02:59:53:05 BECAUSE THEY ARE
 THE EASIEST WAY TO SEE
 228 02:59:53:07 02:59:55:02 INTO THE EARTH'S MANTEL.
 229 02:59:55:04 02:59:59:02 THE CRUST OF THE OCEANS
 IS MUCH THINNER
 230 02:59:59:04 03:00:00:18 THAN THE CRUST
 ON THE CONTINENTS.
 231 03:00:00:20 03:00:02:03 ON A CONTINENT,
 232 03:00:02:05 03:00:05:21 YOU'D HAVE TO BE SEEING
 60 TO 70 KILOMETERS DEEP
 233 03:00:05:23 03:00:07:21 IN ORDER TO GET TO MANTLE,
 234 03:00:07:23 03:00:09:06 WHEREAS UNDER
 THE OCEAN FLOOR,
 235 03:00:09:08 03:00:12:06 THE MANTLE LIES 3 TO 4
 TO 5 KILOMETERS
 236 03:00:12:08 03:00:14:19 BELOW THE TOP
 OF THE OCEANIC CRUST.
 237 03:00:14:21 03:00:18:03 SO, OPHIOLITES,
 WHEN THEY ARE EXPOSED
 AS THIS ONE IS,
 238 03:00:18:05 03:00:19:20 ARE A CHANCE
 FOR GEOLOGISTS
 239 03:00:19:22 03:00:23:05 TO PEEK DOWN
 3-4 KILOMETERS DEEP
 IN THE EARTH
 240 03:00:23:07 03:00:26:04 AND ACTUALLY BE LOOKING
 AT THE MANTLE.
 241 03:00:27:12 03:00:29:28 SO, APART

242 03:00:30:00 03:00:32:25 FROM SOME XENOLITHS,
 WALKING ACROSS A COMPLETE
 OPHIOLITE SECTION
 243 03:00:32:27 03:00:35:04 IS THE ONLY OTHER WAY
 GEOLOGISTS HAVE
 244 03:00:35:06 03:00:38:05 OF DIRECTLY VIEWING ROCK
 FROM EARTH'S MANTLE.
 245 03:00:47:21 03:00:50:03 I HAVE COME
 A QUARTER MILE
 246 03:00:50:05 03:00:51:19 FROM OUR LAST STOP
 247 03:00:51:21 03:00:54:05 IN THE LOWER PART
 OF THE OPHIOLITE.
 248 03:00:54:07 03:00:56:05 THERE ROCKS
 LOOK LIKE THIS--
 249 03:00:56:07 03:00:58:05 DARK BECAUSE
 THEY ARE RICH
 250 03:00:58:07 03:01:00:19 IN THE MINERALS OLIVINE
 AND PYROXENE,
 251 03:01:00:21 03:01:02:16 WHICH ARE TYPICAL
 OF THE EARTH'S MANTLE.
 252 03:01:02:18 03:01:07:00 THE ROCKS
 I'M STANDING ON NOW
 ARE LIGHTER-COLORED,
 253 03:01:07:02 03:01:08:29 PRIMARILY BECAUSE
 THEY ARE RICH
 254 03:01:09:01 03:01:10:14 IN THE MINERAL FELDSPAR,
 255 03:01:10:16 03:01:12:07 THE WHITE MINERAL
 IN THIS ROCK.
 256 03:01:12:09 03:01:14:05 IN COMING
 THE QUARTER MILE,
 257 03:01:14:07 03:01:16:27 I HAVE WALKED
 FROM THE EARTH'S MANTLE
 258 03:01:16:29 03:01:18:10 INTO THE EARTH'S CRUST.
 259 03:01:19:14 03:01:21:01 WHILE
 OPHIOLITE OUTCROPPINGS
 260 03:01:21:03 03:01:23:17 ARE A RICH
 GEOLOGICAL FIND,
 261 03:01:23:19 03:01:25:05 THEY ARE RARE
 262 03:01:25:07 03:01:28:18 AND ONLY PROVIDE A VIEW
 OF THE UPPERMOST MANTLE,
 263 03:01:28:20 03:01:30:05 SO SEISMOLOGICAL RESEARCH
 264 03:01:30:07 03:01:33:03 REMAINS THE PRIMARY TOOL
 GEOPHYSICISTS USE TO STUDY
 265 03:01:33:05 03:01:35:22 THE DEEP INTERIOR
 OF THE EARTH.
 266 03:01:37:04 03:01:39:17 GEOLOGISTS DIVIDE
 THE SEISMIC WAVES
 267 03:01:39:19 03:01:42:01 THAT TRAVEL THROUGH
 THE EARTH'S INTERIOR
 268 03:01:42:03 03:01:44:03 INTO TWO BASIC TYPES--
 269 03:01:44:05 03:01:49:18 PRIMARY OR "P" WAVES
 AND SECONDARY OR "S" WAVES.
 270 03:01:49:20 03:01:52:17 A "P" WAVE
 IS A COMPRESSIONAL WAVE
 271 03:01:52:19 03:01:54:17 THAT MAKES THE ROCK VIBRATE
 272 03:01:54:19 03:01:57:07 PARALLEL TO THE DIRECTION

OF ITS MOVEMENT.
273 03:01:57:09 03:01:59:16 SINCE IT
IS A VERY FAST WAVE,
274 03:01:59:18 03:02:00:29 TRAVELING THROUGH ROCK
275 03:02:01:01 03:02:03:03 AT BETWEEN 4 AND
7 KILOMETERS PER SECOND,
276 03:02:03:05 03:02:06:17 THE "P" WAVE
IS THE FIRST WAVE TO ARRIVE
277 03:02:06:19 03:02:09:22 AT A RECORDING STATION
FOLLOWING AN EARTHQUAKE.
278 03:02:09:24 03:02:12:17 AN "S" WAVE,
ON THE OTHER HAND,
279 03:02:12:19 03:02:14:04 HAS A SHEERING MOTION
280 03:02:14:06 03:02:18:00 THAT MAKES THE ROCK VIBRATE
PERPENDICULAR TO ITS PATH.
281 03:02:18:02 03:02:20:16 THIS MOVEMENT
SLOWS THE "S" WAVE
282 03:02:20:18 03:02:24:16 SO THAT IT TRAVELS AT 2
TO 5 KILOMETERS PER SECOND,
283 03:02:24:18 03:02:27:15 OR ABOUT HALF THE SPEED
OF THE "P" WAVE.
284 03:02:27:17 03:02:29:15 THIS IS WHY "S" WAVES
285 03:02:29:17 03:02:32:28 ARRIVE AS SECONDARY WAVES
AT THE EARTH'S SURFACE.
286 03:02:34:07 03:02:35:26 THERE IS ANOTHER
IMPORTANT DIFFERENCE
287 03:02:35:28 03:02:38:10 BETWEEN "P" WAVES
AND "S" WAVES.
288 03:02:38:12 03:02:41:09 ALTHOUGH BOTH CAN PASS
THROUGH SOLID ROCK,
289 03:02:41:11 03:02:42:25 ONLY "P" WAVES
290 03:02:42:27 03:02:46:14 CAN ALSO PASS THROUGH
GASES AND LIQUIDS.
291 03:02:46:16 03:02:47:29 AS GEOPHYSICISTS
PROBE DEEPER
292 03:02:48:01 03:02:49:16 INTO THE EARTH'S INTERIOR,
293 03:02:49:18 03:02:53:01 THE PROPERTIES OF THE TWO
TYPES OF SEISMIC WAVES
294 03:02:53:03 03:02:55:16 PROVIDE CLUES
ABOUT WHAT THE CORE
295 03:02:55:18 03:02:58:02 OF THIS PLANET
MUST BE LIKE.
296 03:03:00:17 03:03:02:14 WHEN A LARGE EARTHQUAKE
OCCURS,
297 03:03:02:16 03:03:04:15 SEISMOGRAPH STATIONS
AROUND THE WORLD
298 03:03:04:17 03:03:08:01 RECORD THE ARRIVALS
OF ITS "P" AND "S" WAVES,
299 03:03:08:03 03:03:10:16 BUT FOR STATIONS SLIGHTLY
MORE THAN HALF THE DISTANCE
300 03:03:10:18 03:03:13:16 AROUND THE EARTH
FROM THE QUAKE'S FOCUS,
301 03:03:13:18 03:03:15:14 "P" WAVES ARE NOT RECORDED.
302 03:03:15:16 03:03:18:29 THIS REGION IS CALLED
THE "P" WAVE SHADOW ZONE.
303 03:03:19:01 03:03:20:28 AT ALMOST

304 03:03:21:00 *THE OPPOSITE POINT*
 03:03:24:07 *ON THE EARTH'S SURFACE,*
 305 03:03:26:10 *THE "P" WAVES REAPPEAR.*
 03:03:27:24 *THE SHADOW ZONE EXISTS*
 306 03:03:27:26 *BECAUSE THE WAVES*
ARE REFRACTED
 307 03:03:29:25 *AS THEY PASS*
THROUGH THE BOUNDARY
 308 03:03:32:00 *BETWEEN THE MANTLE*
AND CORE
 309 03:03:33:19 *AND ARE DIVERTED*
FROM THEIR ORIGINAL PATHS.
 310 03:03:41:00 *THE "S" WAVES LEAVE*
A MUCH LARGER SHADOW ZONE
 311 03:03:44:14 *BECAUSE NONE OF THEM*
PASSES THROUGH THE CORE.
 312 03:03:49:02 *GIVEN THAT "S" WAVES*
CANNOT TRAVERSE LIQUIDS,
 313 03:03:52:00 *IT SEEMS PROBABLE*
 314 03:03:53:18 *THAT AT LEAST PART OF*
THE EARTH'S CORE IS LIQUID.
 315 03:03:56:20 *IN FACT, THE WAY*
THE SEISMIC WAVES
 316 03:03:59:19 *PASS THROUGH THE CORE*
 317 03:04:01:04 *TELLS US THAT IT CONSISTS*
OF TWO PARTS--
 318 03:04:04:04 *A LIQUID OUTER CORE*
AND A SOLID INNER CORE.
 319 03:04:09:03 *STUDY OF EARTH'S INTERIOR*
SUGGESTS THAT THIS CORE
 320 03:04:11:29 *IS COMPOSED MOSTLY OF IRON*
 321 03:04:14:05 *COMBINED*
WITH SMALLER AMOUNTS
 322 03:04:16:12 *OF LIGHTER ELEMENTS.*
 323 03:04:18:13 *SEISMIC STUDIES*
AREN'T THE ONLY WAY
 324 03:04:20:27 *OF UNLOCKING THE SECRETS*
OF THE DEEP EARTH.
 325 03:04:23:29 *GEOPHYSICS PROVIDES*
OTHER TECHNIQUES AS WELL.
 326 03:04:27:28 *GRAVITY IS ANOTHER TYPE*
OF INDIRECT EVIDENCE
 327 03:04:30:28 *GEOPHYSICISTS USE TO LEARN*
ABOUT THE EARTH'S INTERIOR.
 328 03:04:33:28 *THE FORCE OF GRAVITY*
BETWEEN TWO OBJECTS
 329 03:04:36:12 *DEPENDS ON THE OBJECTS' MASS*
 330 03:04:38:14 *AND THE DISTANCE*
BETWEEN THEM.
 331 03:04:39:28 *THE GREATER THE MASS*
OF EITHER OBJECT
 332 03:04:42:14 *OR THE CLOSER*
THEY ARE TOGETHER,
 333 03:04:44:28 *THE STRONGER THE*
GRAVITATIONAL ATTRACTION.
 334 03:04:46:27 *FOR EXAMPLE,*

335 03:04:49:13 03:04:52:27 OCEAN TIDES ARE PRODUCED
 BY THE GRAVITATIONAL PULL
 OF THE SUN AND MOON.
 336 03:04:52:29 03:04:54:27 HOWEVER,
 EVEN THOUGH THE SUN
 337 03:04:54:29 03:04:57:12 IS 25 MILLION TIMES
 MORE MASSIVE THAN THE MOON,
 338 03:04:57:14 03:05:00:26 THE MOON'S EFFECT ON TIDES
 IS TWICE AS GREAT
 339 03:05:00:28 03:05:03:02 BECAUSE IT'S CLOSER
 TO THE EARTH.
 340 03:05:03:04 03:05:05:02 THE INSTRUMENT
 THAT GEOPHYSICISTS USE
 341 03:05:05:04 03:05:07:11 TO MEASURE
 THE FORCE OF GRAVITY
 342 03:05:07:13 03:05:08:27 IS CALLED A GRAVIMETER.
 343 03:05:08:29 03:05:10:25 THIS DEVICE
 IS INCREDIBLY SENSITIVE,
 344 03:05:10:27 03:05:12:12 CAPABLE OF
 DETECTING VARIATIONS
 345 03:05:12:14 03:05:14:12 IN THE FORCE OF GRAVITY
 346 03:05:14:14 03:05:16:24 AS TINY AS 1 PART
 IN 100 MILLION.
 347 03:05:16:26 03:05:18:24 ON EARTH,
 CHANGES IN GRAVITY
 348 03:05:18:26 03:05:23:03 ARE OFTEN DUE TO VARIATIONS
 IN THE MASS OF THE ROCK
 349 03:05:23:05 03:05:24:20 IN THE EARTH'S INTERIOR.
 350 03:05:24:22 03:05:27:19 FOR EXAMPLE, THE EARTH'S
 MANTLE ROCK IS DENSER
 351 03:05:27:21 03:05:29:05 AND THEREFORE MORE MASSIVE
 352 03:05:29:07 03:05:31:25 THAN THE CRUSTAL ROCK
 OF THE EARTH.
 353 03:05:31:27 03:05:34:10 IN AREAS WHERE THE MANTLE
 IS UNUSUALLY THICK,
 354 03:05:34:12 03:05:37:19 THERE ARE UNUSUALLY HIGH
 GRAVITY READINGS.
 355 03:05:37:21 03:05:39:20 *GRAVIMETERS*
HAVE ALSO PROVE USEFUL
 356 03:05:39:22 03:05:42:20 *IN DETECTING HIGH-DENSITY*
IRON ORE DEPOSITS
 357 03:05:42:22 03:05:46:23 *AND LOW-DENSITY BODIES*
OF SALT HIDDEN FROM VIEW.
 358 03:05:46:25 03:05:48:25 *AT THE HEART*
OF A GRAVIMETER
 359 03:05:48:27 03:05:51:24 *IS A SPRING WITH A WEIGHT*
ATTACHED TO ITS END.
 360 03:05:51:26 03:05:53:24 *THE STRONGER THE PULL*
OF GRAVITY,
 361 03:05:53:26 03:05:56:08 *THE MORE THE SPRING*
IS EXTENDED.
 362 03:05:58:08 03:06:00:20 *THIS EXTENSION,*
A FUNCTION OF GRAVITY,
 363 03:06:00:22 03:06:03:04 *IS ACCURATELY MEASURED*
BY THE GRAVIMETER.
 364 03:06:05:27 03:06:07:25 MAGNETISM PROVIDES MORE

397 03:07:37:07 03:07:39:05 *THAT A LINK EXISTS BETWEEN ELECTRICITY AND MAGNETISM.*
 398 03:07:39:07 03:07:41:05 *ENGLISH SCIENTIST MICHAEL FARADAY*
 399 03:07:41:07 03:07:45:10 *INVENTED A DEVICE THAT ILLUSTRATED THIS PRINCIPLE.*
 400 03:07:45:12 03:07:48:25 *AS AN ELECTRIC CURRENT IS PASSED THROUGH A WIRE,*
 401 03:07:48:27 03:07:51:12 *A MAGNETIC FIELD IS GENERATED.*
 402 03:07:51:14 03:07:54:05 *THE WIRE MOVES IN A CIRCLE,*
 403 03:07:54:07 03:07:56:20 *FOLLOWING THE SHAPE OF THE FIELD.*
 404 03:07:56:22 03:07:59:05 *THE SAME PRINCIPLE CAN BE OBSERVED*
 405 03:07:59:07 03:08:00:23 *USING IRON FILINGS.*
 406 03:08:02:10 03:08:05:06 *AN ELECTRIC CURRENT GENERATES A MAGNETIC FIELD*
 407 03:08:05:08 03:08:07:21 *CAUSING THE FILINGS TO ORIENT THEMSELVES*
 408 03:08:07:23 03:08:10:10 *TOWARDS INVISIBLE NORTH AND SOUTH POLES.*
 409 03:08:12:22 03:08:14:19 *FARADAY WENT ON TO DISCOVER*
 410 03:08:14:21 03:08:17:05 *THAT MOVING A MAGNET THROUGH A COIL*
 411 03:08:17:07 03:08:18:19 *GENERATES AN ELECTRIC CURRENT.*
 412 03:08:20:22 03:08:22:05 *FARADAY'S OBSERVATIONS*
 413 03:08:22:07 03:08:25:05 *ARE THE BASIS OF OUR MODERN VIEWS*
 414 03:08:25:07 03:08:27:12 *ABOUT EARTH'S MAGNETIC FIELD.*
 415 03:08:27:14 03:08:29:26 *WE KNOW THE EARTH'S MAGNETIC FIELD*
 416 03:08:29:28 03:08:31:25 *ORIGINATES DEEP IN THE EARTH.*
 417 03:08:31:27 03:08:33:11 *WE THINK IT ORIGINATES*
 418 03:08:33:13 03:08:36:01 *IN THE OUTER CORE OF THE EARTH.*
 419 03:08:36:03 03:08:37:17 *THE BASIC IDEA*
 420 03:08:37:19 03:08:41:03 *IS THAT THE OUTER PART OF THE EARTH'S CORE*
 421 03:08:41:05 03:08:43:05 *IS A FLUID--*
 422 03:08:43:07 03:08:46:19 *MOLTEN IRON-- WITH SOME LIGHT ELEMENT ALLOYED IN,*
 423 03:08:46:21 03:08:48:20 *POSSIBLY SILICON OR OXYGEN.*
 424 03:08:48:22 03:08:51:09 *BECAUSE IT'S A LIQUID METAL,*
 425 03:08:51:11 03:08:53:24 *IT CAN MOVE EASILY*
 426 03:08:53:26 03:08:56:06 *AND IT CAN CONDUCT ELECTRICITY.*
 427 03:08:56:08 03:09:00:05 *HEAT COMING FROM DEEPER*

428 03:09:00:07 IN THE EARTH'S CORE
 03:09:02:05 PRODUCES
 429 03:09:02:07 CONVECTION CURRENTS
 03:09:03:19 OR FLUID MOTIONS,
 430 03:09:03:21 03:09:05:19 WHICH THEN
 HAS THE EFFECT
 431 03:09:05:21 03:09:10:06 OF MOVING AN
 ELECTRICAL CONDUCTOR--
 THE METALLIC FLUID--
 432 03:09:10:08 03:09:11:21 THROUGH
 A MAGNETIC FIELD.
 433 03:09:11:23 03:09:14:05 WHEN YOU MOVE
 A CONDUCTING SUBSTANCE
 434 03:09:14:07 03:09:15:18 THROUGH
 A MAGNETIC FIELD,
 435 03:09:15:20 03:09:17:18 YOU GENERATE
 ELECTRICAL CURRENTS,
 436 03:09:17:20 03:09:19:25 WHICH THEN GENERATE
 MAGNETIC FIELDS.
 437 03:09:21:06 03:09:24:03 SO, A SELF-SUSTAINED
 ELECTROMAGNETIC CYCLE,
 438 03:09:24:05 03:09:25:19 THOUGH FAR FROM STEADY,
 439 03:09:25:21 03:09:28:06 IS ACTIVE
 DEEP INSIDE EARTH.
 440 03:09:29:20 03:09:31:04 ON OCCASION,
 441 03:09:31:06 03:09:33:18 AN ASTONISHING LIGHT SHOW
 TRIGGERED BY THE SUN
 442 03:09:33:20 03:09:36:03 REVEALS PARTS OF
 THE MAGNETIC FIELD
 443 03:09:36:05 03:09:37:17 SURROUNDING OUR PLANET.
 444 03:09:40:05 03:09:43:04 FROM THE SURFACE OF
 THE SUN, A CONSTANT FLOW
 445 03:09:43:06 03:09:45:04 OF ELECTRICALLY
 CHARGED PARTICLES--
 446 03:09:45:06 03:09:47:04 KNOWN AS THE SOLAR WIND--
 447 03:09:47:06 03:09:48:20 ENTERS SPACE.
 448 03:09:48:22 03:09:51:03 THE SOLAR WIND IS
 MOSTLY DEFLECTED FROM EARTH
 449 03:09:51:05 03:09:53:05 BY OUR PLANET'S
 MAGNETIC FIELD.
 450 03:09:55:01 03:09:56:14 BUT NEAR THE POLES,
 451 03:09:56:16 03:09:58:14 THESE PARTICLES
 ARE DRAWN MAGNETICALLY
 452 03:09:58:16 03:10:00:19 TOWARD EARTH'S SURFACE.
 453 03:10:00:21 03:10:04:04 AS THEY HIT THE ATMOSPHERE,
 THEY CAUSE GASES TO GLOW
 454 03:10:04:06 03:10:05:18 AND FORM
 SHIMMERING CURTAINS
 455 03:10:05:20 03:10:08:03 OF RED, WHITE,
 AND GREEN LIGHTS,
 456 03:10:08:05 03:10:10:02 WHICH WE CALL THE AURORA.
 457 03:10:10:04 03:10:12:03 WHEN SOLAR FLARES OCCUR,
 458 03:10:12:05 03:10:14:19 THE AURORA ARE
 ESPECIALLY SPECTACULAR,
 459 03:10:14:21 03:10:18:22 BECAUSE CHARGED PARTICLES
 BOMBARD EARTH'S ATMOSPHERE

460 03:10:18:24 03:10:21:01 ACROSS
THE HIGHER LATITUDES.

461 03:10:23:11 03:10:25:09 ALTHOUGH THE EARTH'S
MAGNETIC FIELD

462 03:10:25:11 03:10:28:01 IS SIMILAR TO THAT
OF A BAR MAGNET,

463 03:10:28:03 03:10:29:15 THERE'S ONE
IMPORTANT DIFFERENCE--

464 03:10:29:17 03:10:31:12 THE STRENGTH
OF THE EARTH'S FIELD

465 03:10:31:14 03:10:32:27 VARIES CONSIDERABLY
OVER TIME.

466 03:10:32:29 03:10:35:06 THE EARTH'S FIELD
HAS DECREASED IN STRENGTH

467 03:10:35:08 03:10:38:01 ABOUT 5% OVER
THE LAST 150 YEARS.

468 03:10:38:03 03:10:41:01 ROCKS CAN ALSO HAVE
A MAGNETIC FIELD,

469 03:10:41:03 03:10:43:01 BUT THEIR MAGNETISM
IS PERMANENT.

470 03:10:43:03 03:10:46:01 IRON-RICH ROCKS THAT
HAVE BEEN STRONGLY HEATED

471 03:10:46:03 03:10:49:00 BECOME MAGNETIZED BY
THE EARTH'S MAGNETIC FIELD.

472 03:10:49:02 03:10:50:17 WHEN THE ROCK COOLS,

473 03:10:50:19 03:10:52:11 THAT MAGNETISM
IS LOCKED IN,

474 03:10:52:13 03:10:54:17 BECOMING A PERMANENT PART
OF THE ROCK,

475 03:10:54:19 03:10:56:02 AND BECAUSE IT'S PERMANENT,

476 03:10:56:04 03:10:58:01 MAGNETIZED ROCKS
OF DIFFERENT AGES

477 03:10:58:03 03:11:00:27 ARE ACTUALLY RECORDS
OF THE EARTH'S MAGNETISM

478 03:11:00:29 03:11:02:10 THROUGHOUT GEOLOGIC TIME.

479 03:11:02:12 03:11:04:11 WHEN A ROCK IS MAGNETIZED,

480 03:11:04:13 03:11:06:12 ITS MAGNETIC FIELD
IS ALIGNED

481 03:11:06:14 03:11:08:26 TO THE MAGNETIC
NORTH POLE OF THE EARTH,

482 03:11:08:28 03:11:11:16 SIMILAR TO THE WAY
A COMPASS NEEDLE POINTS

483 03:11:11:18 03:11:13:02 TO MAGNETIC NORTH.

484 03:11:13:04 03:11:15:15 THIS ALIGNMENT,
CALLED MAGNETIC POLARITY,

485 03:11:15:17 03:11:17:29 IS ALSO PERMANENT
IN MAGNETIZED ROCKS.

486 03:11:18:01 03:11:19:14 IN THE EARLY 1900s,

487 03:11:19:16 03:11:22:29 GEOPHYSICISTS STUDYING
LAVA FLOWS IN FRANCE

488 03:11:23:01 03:11:24:14 MADE A STARTLING DISCOVERY.

489 03:11:24:16 03:11:28:04 THE LAVAS AND THE BAKED
SOILS UNDERNEATH THEM

490 03:11:28:06 03:11:30:25 WERE BOTH
PERMANENTLY MAGNETIZED,

491 03:11:30:27 03:11:32:09 AND THEIR MAGNETIC POLARITY

492 03:11:32:11 03:11:33:23 WAS IDENTICAL
 IN ORIENTATION.
 493 03:11:33:25 03:11:36:28 BUT THAT ORIENTATION
 WAS EXACTLY OPPOSITE
 494 03:11:37:00 03:11:38:14 THAT OF THE EARTH.
 495 03:11:38:16 03:11:41:29 THAT IS THE MAGNETIC
 NORTH POLE OF THE ROCKS
 496 03:11:42:01 03:11:46:16 POINTED TOWARD THE MAGNETIC
 SOUTH POLE OF THE EARTH.
 497 03:11:46:18 03:11:49:13 THIS OBSERVATION WAS
 THE FIRST CLEAR EVIDENCE
 498 03:11:49:15 03:11:52:13 THAT THE MAGNETIC FIELD
 OF THE EARTH
 499 03:11:52:15 03:11:53:26 COMPLETELY REVERSES ITSELF.
 500 03:11:56:01 03:11:58:14 DURING A TIME
 OF NORMAL POLARITY,
 501 03:11:58:16 03:12:01:15 MAGNETIC LINES OF FORCE
 LEAVE THE EARTH
 502 03:12:01:17 03:12:02:29 NEAR THE SOUTH POLE
 503 03:12:03:01 03:12:06:14 AND RE-ENTER THE EARTH
 NEAR THE NORTH POLE.
 504 03:12:07:18 03:12:09:00 DURING REVERSED POLARITY,
 505 03:12:09:02 03:12:11:24 LINES OF FORCE
 RUN THE OTHER WAY,
 506 03:12:11:26 03:12:13:23 GOING FROM NORTH TO SOUTH.
 507 03:12:13:25 03:12:15:06 IN OTHER WORDS,
 508 03:12:15:08 03:12:18:08 THE MAGNETIC POLES
 SWITCH PLACES.
 509 03:12:18:10 03:12:19:28 MANY ROCKS CONTAIN A RECORD
 510 03:12:20:00 03:12:21:12 OF THE STRENGTH
 AND DIRECTION
 511 03:12:21:14 03:12:23:13 OF THE EARTH'S
 MAGNETIC FIELD
 512 03:12:23:15 03:12:26:12 THAT EXISTED WHEN
 THE ROCKS WERE FORMED.
 513 03:12:26:14 03:12:29:07 HERE IN THE MOJAVE DESERT
 OF CALIFORNIA,
 514 03:12:29:09 03:12:33:08 GEOLOGIST SCOTT BOGUE
 DRILLS FOR CORES OF LAVA,
 515 03:12:33:10 03:12:36:07 WHICH ARE KEYS
 TO OUR MAGNETIC PAST.
 516 03:12:39:15 03:12:42:27 LAVA FLOWS OF DIFFERING
 AGES PRESERVE EVIDENCE
 517 03:12:42:29 03:12:45:27 OF A NUMBER OF PREVIOUS
 MAGNETIC REVERSALS.
 518 03:12:45:29 03:12:47:26 THEY ARE LIKE
 TAPE RECORDINGS
 519 03:12:47:28 03:12:50:12 OF PREHISTORIC
 MAGNETIC BEHAVIOR.
 520 03:12:50:14 03:12:53:13 THE STUDY OF THESE
 ANCIENT MAGNETIC FIELDS
 521 03:12:53:15 03:12:55:27 IS CALLED PALEOMAGNETISM.
 522 03:12:55:29 03:12:57:13 WE CAN SAY SOMETHING
 523 03:12:57:15 03:13:00:12 ABOUT ANCIENT MAGNETIC
 FIELDS OF THE EARTH
 524 03:13:00:14 03:13:03:12 BECAUSE OF THE RECORD

525 03:13:03:14 THEY LEAVE IN ROCKS,
 03:13:06:26 AND MANY ROCKS
 BECOME MAGNETIZED
 526 03:13:06:28 03:13:08:13 WHEN THEY ARE FORMED
 527 03:13:08:15 03:13:10:28 OR SOMETIME
 AFTER THEY ARE FORMED.
 528 03:13:11:00 03:13:12:12 WHEN THEY
 BECOME MAGNETIZED,
 529 03:13:12:14 03:13:13:28 THEY BECOME MAGNETIZED
 530 03:13:14:00 03:13:16:11 PARALLEL TO THE EARTH'S
 MAGNETIC FIELD
 531 03:13:16:13 03:13:17:24 AT THAT TIME,
 532 03:13:17:26 03:13:20:18 SO IF YOU CAN
 COLLECT A ROCK SAMPLE,
 533 03:13:20:20 03:13:22:12 MEASURE WHICH WAY
 IT'S MAGNETIZED,
 534 03:13:22:14 03:13:24:24 AND DETERMINE WHEN
 IT WAS MAGNETIZED,
 535 03:13:24:26 03:13:26:10 THEN YOU CAN LEARN
 536 03:13:26:12 03:13:28:14 ABOUT THE ORIENTATION
 OF THE MAGNETIC FIELD
 537 03:13:28:16 03:13:30:12 AT THAT TIME
 IN THE PAST.
 538 03:13:31:27 03:13:33:11 *SCIENTISTS GENERALLY AGREE*
 539 03:13:33:13 03:13:36:09 *THAT THE EARTH'S MAGNETIC*
FIELD REVERSES ITSELF
 540 03:13:36:11 03:13:39:23 *ON THE AVERAGE OF ONCE*
EVERY 500,000 YEARS.
 541 03:13:39:25 03:13:42:15 *WIDESPREAD EVIDENCE*
SUGGESTS
 542 03:13:42:17 03:13:45:21 *THAT THE LAST REVERSAL*
OCCURRED 700,000 YEARS AGO,
 543 03:13:45:23 03:13:47:22 *BUT THERE*
IS ALSO SOME EVIDENCE
 544 03:13:47:24 03:13:50:05 *THAT AS MANY*
AS A DOZEN REVERSALS
 545 03:13:50:07 03:13:52:10 *MAY HAVE OCCURRED*
SINCE THAT TIME.
 546 03:13:52:12 03:13:55:08 WE KNOW THAT
 IN GENERAL TERMS,
 547 03:13:55:10 03:13:56:21 DURING
 A MAGNETIC REVERSAL,
 548 03:13:56:23 03:13:58:09 THE FIELD INTENSITY
 DECREASES
 549 03:13:58:11 03:14:01:05 TO 10 OR 20%
 OF ITS NORMAL VALUE.
 550 03:14:01:07 03:14:02:20 SO AT SOME POINT
 551 03:14:02:22 03:14:05:21 AS THE EARTH WERE
 ENTERING A REVERSAL,
 552 03:14:05:23 03:14:08:17 THERE WOULD
 BE A DECREASE
 IN FIELD INTENSITY.
 553 03:14:08:19 03:14:10:01 WE KNOW BY COMPARING
 554 03:14:10:03 03:14:12:02 THE MAGNETIC
 FIELD STRENGTH TODAY
 555 03:14:12:04 03:14:14:23 TO MEASUREMENTS

OF THE MAGNETIC FIELD
 556 03:14:14:25 03:14:16:22 160 YEARS AGO
 557 03:14:16:24 03:14:18:23 THAT THE EARTH'S
 MAGNETIC FIELD
 558 03:14:18:25 03:14:21:07 IS CURRENTLY
 DECREASING IN STRENGTH.
 559 03:14:21:09 03:14:24:08 IT'S DECREASED
 ABOUT 5% SINCE 1832.
 560 03:14:24:10 03:14:25:23 SO SOME HAVE CLAIMED
 561 03:14:25:25 03:14:27:23 THAT THE EARTH'S
 MAGNETIC FIELD
 562 03:14:27:25 03:14:30:22 MAY BE ENTERING
 A REVERSAL RIGHT NOW.
 563 03:14:35:24 03:14:38:24 THE DISCOVERY THAT
 THE EARTH'S MAGNETIC FIELD
 564 03:14:38:26 03:14:41:09 IS TURNED OFF BRIEFLY
 DURING A REVERSAL
 565 03:14:41:11 03:14:42:23 RAISES SOME
 PROFOUND QUESTIONS.
 566 03:14:42:25 03:14:45:23 HOW LONG IS THE EARTH
 WITHOUT A MAGNETIC FIELD?
 567 03:14:45:25 03:14:47:23 HOW DOES A REVERSAL
 AFFECT ANIMALS
 568 03:14:47:25 03:14:50:07 WHO DEPEND ON THE EARTH'S
 MAGNETIC FIELD
 569 03:14:50:09 03:14:52:09 FOR NAVIGATION
 DURING MIGRATIONS?
 570 03:14:52:11 03:14:54:09 DOES THE LOSS
 IN FIELD STRENGTH
 571 03:14:54:11 03:14:55:24 CAUSE AN INCREASE
 572 03:14:55:26 03:14:57:24 IN POTENTIALLY DEADLY
 SOLAR RADIATION?
 573 03:14:57:26 03:15:00:08 LINKING GRAVITY, MAGNETISM,
 AND SEISMICITY
 574 03:15:00:10 03:15:02:23 WITH THE GEOLOGIC HISTORY
 OF THE EARTH
 575 03:15:02:25 03:15:05:08 ARE GOALS
 OF GEOPHYSICAL RESEARCH.
 576 03:15:05:10 03:15:07:07 BY CREATIVELY USING
 INDIRECT EVIDENCE,
 577 03:15:07:09 03:15:09:24 THESE EARTH SCIENTISTS
 PROBE THE EARTH'S INTERIOR
 578 03:15:09:26 03:15:12:24 FOR KNOWLEDGE OF ITS
 STRUCTURE AND COMPOSITION
 579 03:15:12:26 03:15:14:21 AND TO LOCATE
 VALUABLE STORES
 580 03:15:14:23 03:15:16:22 OF NATURAL RESOURCES
 AS WELL.
 581 03:15:16:24 03:15:18:22 GEOPHYSICS
 HAS FOREVER CHANGED
 582 03:15:18:24 03:15:21:06 OUR SIMPLE MODEL OF
 A THREE-LAYERED EARTH.
 583 03:15:21:08 03:15:23:06 WITHOUT HAVING
 ACTUALLY SEEN IT,
 584 03:15:23:08 03:15:25:21 WE KNOW THAT
 THE INTERIOR OF THE EARTH

585 03:15:25:23 03:15:27:21 IS REMARKABLY COMPLEX
IN ITS STRUCTURE
586 03:15:27:23 03:15:29:22 AND COMPOSITION
AND BEHAVIOR.
587 03:15:29:24 03:15:31:22 UNDERSTANDING
THAT COMPLEXITY
588 03:15:31:24 03:15:33:21 WILL ULTIMATELY
YIELD EXPLANATIONS
589 03:15:33:23 03:15:36:06 FOR THE ORIGIN
OF THE EARTH
590 03:15:36:08 03:15:38:06 AND FOR THE TECTONIC FORCES
591 03:15:38:08 03:15:40:05 THAT CONTINUOUSLY
CHANGE ITS FACE.
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