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Narrator: OF ALL THE PLANETS IN
OUR SOLAR SYSTEM
NONE CAN SUPPORT COMPLEX
LIFE EXCEPT EARTH.
BUT THE CONDITIONS ON EARTH
WERE NOT ALWAYS SO SUITABLE
FOR LIFE
AND SCIENTISTS ARE WORKING
TO RECONSTRUCT
THE HISTORY OF TWO ESSENTIAL
REQUIREMENTS
WHICH MAKE THE PLANET
HABITABLE.
THE FIRST IS FREE OXYGEN IN
THE ATMOSPHERE.
THE OTHER IS A MODERATE AND
STABLE CLIMATE.
PALEONTOLOGIST ANDY KNOLL
HAS SPENT MUCH OF HIS CAREER
EXAMINING EARTH'S ROCK
RECORD
TO PIECE TOGETHER THE
HISTORY OF EARLY LIFE
AND THE RISE OF OXYGEN.
THERE'S THIS CLOSE WALTZ, IF
YOU WILL
BETWEEN THE HISTORY OF
EARTH'S PHYSICAL

ENVIRONMENTS
AND THE HISTORY OF LIFE.
Narrator: GEOLOGIST PAUL HOFFMAN
STUDIES THE TIME IN OUR PLANET'S HISTORY
WHEN THE CLIMATE WAS MUCH MORE EXTREME
A PERIOD CALLED THE SNOWBALL EARTH.
Hoffman: DURING THE MAXIMUM COLD OF THE SNOWBALL EARTH YOU HAVE AN EARTH THAT'S MORE LIKE MARS THAN IT IS LIKE EARTH.
Narrator: HOFFMAN IS SEEKING ANSWERS
TO HOW THE EARTH ENTERED THIS SNOWBALL
AND, MORE IMPORTANT FOR US HOW IT RETURNED TO WARMER CONDITIONS
AND HAS MAINTAINED A STABLE AND MODERATE CLIMATE.
BOTH OF THESE SCIENTISTS LOOK TO THE DEEP PAST
FOR CLUES TO THE PRESENT, ENRICHING OUR UNDERSTANDING OF THE ONE PLACE WE KNOW IN THE UNIVERSE
WHERE LIFE FLOURISHES -- EARTH, THE HABITABLE PLANET.

THE EARTH'S INCREDIBLE ARRAY OF DIFFERENT ANIMALS AND PLANTS
INCLUDING HUMANS, IS RELATIVELY NEW TO THIS PLANET.
FOSSILS CONTAINED IN THE EARTH'S VAST ROCK RECORD SHOW THAT THE FIRST ANIMALS EMERGED
AROUND 600 MILLION YEARS AGO
--
A MERE 15% OF EARTH'S 4.5-BILLION-YEAR HISTORY.
IT'S LIKELY THAT SIMPLE, SINGLE-CELLED ORGANISMS RULED ALONE FOR APPROXIMATELY 3 BILLION YEARS.

THE SAME ROCKS THAT DOCUMENT THIS EVOLUTION OF LIFE
PROVIDE INFORMATION ABOUT EARTH'S PHYSICAL ENVIRONMENT
CLUES TO HOW EARTH MANAGED TO CHANGE
FROM AN ALIEN WORLD OF SIMPLE MICROORGANISMS
TO A PLANET FILLED WITH COMPLEX LIFE.

ANDY KNOLL STUDIES THE EARLY PERIOD OF LIFE
THE FIRST 85% OF THE PLANET'S HISTORY.
Knoll: WHAT I REALLY WANT TO UNDERSTAND IS
WHEN ARE THERE PHYSICAL EVENTS
THAT INFLUENCE THE SUBSEQUENT COURSE OF EVOLUTION?
WHEN ARE THERE EVOLUTIONARY EVENTS
THAT FEED BACK ONTO A CHANGED WORLD?
AND IN ORDER TO MAKE THAT CONNECTION
WE REALLY WANT TO THINK ABOUT FOSSILS
NOT ONLY AS OBJECTS WITH SHAPE AND SIZE
AND SORT OF MECHANICAL FUNCTION
BUT WE WANT TO THINK ABOUT FOSSILS
AS CARRIERS OF PHYSIOLOGICAL INFORMATION
AND I THINK THAT'S A TYPE OF INFORMATION
THAT HAS BEEN UNDER APPRECIATED
IN CONSIDERATIONS OF OUR

PLANET'S HISTORY.
BUT I THINK IT'S REALLY THE KEYSTONE
THAT'S GOING TO ALLOW US TO HAVE A MUCH DEEPER UNDERSTANDING
OF HOW PHYSICAL AND BIOLOGICAL EVENTS HAVE INTERACTED
TO BRING US TO OUR PRESENT MOMENT.
Narrator: A CRUCIAL CHAPTER IN THE CHANGING PHYSIOLOGY OF LIFE
IS THE RISE OF OXYGEN, AS TOLD BY THE SIGNATURE TRACES
THAT SINGLE-CELLED ORGANISMS LEAVE BEHIND IN THE ROCK RECORD.
FIRST APPEARING ABOUT 2.5 BILLION YEARS AGO
OXYGEN CLIMBED TO ITS CURRENT LEVEL
APPROXIMATELY 580 MILLION YEARS AGO --
AROUND THE SAME TIME
THAT COMPLEX ANIMAL LIFE STARTED TO APPEAR.
Knoll: IT BECOMES PRETTY CLEAR FROM THE GEOLOGIC RECORD
THAT ANIMALS AND LARGE PLANTS WERE ESSENTIALLY

INTERCALATED
INTO A BIOLOGICAL WORLD THAT
WAS FULLY FUNCTIONING.
AND IN SOME WAYS
ANIMALS DON'T ADD THAT MUCH
TO THE FUNCTIONING OF THAT
WORLD.
SO, IF YOU ASK HISTORICALLY
WHAT UNDER PINS ECOSYSTEM
FUNCTION ON THIS PLANET
THE REAL WORKERS THAT MAKE
THIS PLANET FUNCTION
ARE THE BACTERIA.
NOW, WHY SHOULD WE EXPECT
THAT TINY, FRAGILE ORGANISMS
LIKE BACTERIA
SHOULD ACTUALLY LEAVE A
SIGNATURE
IN THE GEOLOGIC RECORD?
AND THE GOOD NEWS IS THAT
THEY LEAVE QUITE A SIGNATURE.
FOR EXAMPLE, THIS ROCK THAT
WE ARE LOOKING AT HERE
WAS DEPOSITED ABOUT 3 1/2
BILLION YEARS AGO
IN WHAT'S NOW SOUTH AFRICA.
AND, INTERESTINGLY
IT CARRIES PHYSICAL AND
CHEMICAL SIGNATURES OF
BIOLOGY.
IT'S PROBABLY A LITTLE BIT
DIFFICULT TO SEE

BUT THERE ARE SOME WAVYAND
BULBOUS LAMINATIONS
AND THOSE ARE FEATURES
CALLED STROMATOLITES.
Narrator: STROMATOLITES ARE
ROCK-LIKE STRUCTURES
USUALLY FORMED BY THE
TRAPPING, BINDING
AND CEMENTATION OF
SEDIMENTARY GRAINS BY MICRO
ORGANISMS.
DATING BACK 3.5 BILLION YEARS
THEY CONSTITUTE OUR EARLIEST
AND MOST PERVASIVE RECORD
OF LIFE ON EARTH.
I THINK IF YOU ONLY HAD THIS
ROCK TO WORK WITH
YOU MIGHT BE HESITANT
TO EVEN DISCUSS WHETHER IT
WAS EVIDENCE OF LIFE.
BUT WE CAN GOTO A NUMBER OF
PLACES TODAY
PLACES LIKE THE BAHAMAS,
WESTERN AUSTRALIA
WHERE STROMATOLITIC
STRUCTURES ARE FORMING
THAT CONNECT THIS VERY
ANCIENT ROCK WITH THE
PRESENT DAY
WHERE WE CAN ACTUALLY
OBSERVE THE PROCESSES
THAT LEAD TO THIS KIND OF

PATTERN.

Narrator: IT'S BELIEVED THAT MANY ANCIENT STROMATOLITES
WERE CREATED BY
CYANOBACTERIA
PHOTOSYNTHETIC
MICROORGANISMS THAT
PRODUCE OXYGEN
IMPLYING THAT THE CELLULAR MACHINERY FOR
PHOTOSYNTHESIS
AROSE EARLYIN THE PLANET'S HISTORY.
Knoll: THIS TELLS US THAT LIFE WAS PRESENT EARLY IN OUR PLANET'S HISTORY
BUT LET ME SHOW YOU ANOTHER ROCK --
ALSO 3 1/2 BILLION YEARS OLD
--FROM SOUTHERN AFRICA.
AND THIS ROCK LOOKS VERY DIFFERENT.
YOU CAN SEE HERE, IT'S BRIGHT RED
AND IT TURNS OUT THE BRIGHT RED IS IRON OXIDES.
AND IN GENERAL, THIS KIND OF BANDED, IRON-RICH ROCK
IS CALLED IRON FORMATION.
Narrator: THESE BANDED IRON FORMATIONS

FOUND ALL OVER THE WORLD
ARE FURTHER CLUES TO THE
EARLY HISTORY OF OXYGEN.
DATING AS FAR BACK AS 3.5
BILLION YEARS
THEY STOPPED FORMING
APPROXIMATELY 1.8 BILLION
YEARS AGO.
CONTINUALLY ENTERING THE
OCEAN THROUGH GEOTHERMAL
VENTS
IRON REMAINS DISSOLVED UNTIL
IT COMES INTO CONTACT WITH
OXYGEN.
THE BANDING OF IRON
FORMATIONS ON THIS ROCK
INDICATE THAT THERE WAS AN
IRON-RICH OCEAN
WITH LITTLE OR NO DISSOLVED
OXYGEN
AND THAT, AT SOME POINT, A
PULSE OF OXYGEN BECAME
AVAILABLE
OXIDIZING THE IRON AND
CAUSING IT TO SETTLE OUT OF
SOLUTION.
THIS KIND OF ROCK COULD NOT,
IN PRINCIPLE
FORM IN TODAY'S OCEANS
BECAUSE YOU CAN ONLY
TRANSPORT IRON THROUGH
OCEANS

WHEN THERE IS NO OXYGEN.
VERY LIKELY, WHAT CAUSED THIS IRON
TO CHANGE ITS CHEMICAL STATE
AND DROP OUT OF SOLUTION
WAS PHOTOSYNTHETIC BACTERIA.
SO, ROCKS LIKE THIS TELL US
THAT FOR THE FIRST HALF OF
OUR PLANET'S HISTORY
THERE WAS VERY LITTLE, IF ANY
FREE OXYGEN GAS IN THE
ATMOSPHERE AND OCEANS.
YOU AND I WOULDN'T HAVE
LASTED FIVE MINUTES ON THE
EARLY EARTH.
Narrator: SOME OF THE MOST
REVEALING CLUES
TO THE RISE OF OXYGEN
CAN ONLY BE UNCOVERED
THROUGH ORGANIC CHEMISTRY.
KNOLL'S COLLEAGUE,
BIOGEOCHEMIST ANN PEARSON
ANALYZES ANCIENT ROCKS
TO RECONSTRUCT THE BIOLOGY
AND ENVIRONMENT OF THIS ERA.
THE ORGANIC-RICH SEDIMENTARY ROCKS
THAT WE CAN SOMETIMES FIND,
SUCH AS THE EXAMPLE HERE
A LOT OF THIS ORGANIC MATTER
IS ACTUALLY RETAINED IN ITS

ORIGINAL FORM
WHICH MEANS THAT THE
MOLECULAR STRUCTURE OF THE
ROCK
HASN'T BEEN DESTROYED
EVEN THOUGH THIS ROCK IS WELL
OVER A BILLION YEARS OLD.
AND SO WE CAN IDENTIFY THE
KINDS OF ORGANISMS
THAT WERE PRESENT IN THE
SYSTEM
AND THOSE ORGANISMS TELL US
SOMETHING
ABOUT THE ENVIRONMENTAL
HISTORY OF THE SURFACE OF
THE PLANET.
Narrator: SOME OF THE
COMPOUNDS PEARSON LOOKS
FOR
ARE INDICATORSOF THE
EXISTENCE OF EUKARYOTES
OR ORGANISMS WITH A NUCLEUS
THE ANCIENT RELATIVES OF
TODAY'S ANIMALS AND PLANTS.
TO GAIN ACCESS TO THESE
COMPOUNDS
PEARSON EXTRACTS FATS, OR
LIPIDS, FROM THE ROCK SAMPLE.
ONCE THE LIPIDS ARE EXTRACTED
THEY ARE RUN THROUGH A MASS
SPECTROMETER
WHICH INDICATES WHAT KINDS OF

COMPOUNDS ARE IN THE SAMPLE.
Pearson: SO, WHEN WE LOOK AT A MIXED SAMPLE
AND IDENTIFY WHAT KINDS OF COMPOUNDS WE HAVE IN THE SAMPLE
SOMETIMES WE SEE A COMPOUND WITH A MASS SPECTRUM LIKE THIS
AND THIS IS THE MASS SPECTRUM OF A STEROL.
THE STEROL IS RELATED TO THE COMPOUND CHOLESTEROL
WHICH IS SOMETHING WE'RE FAMILIAR WITH.
AND ANY TIME WE SEE A STEROL, WE INTERPRET THAT
AS MEANING THERE WAS A EUKARYOTE IN THE SAMPLE.
AND THIS IS SIGNIFICANT
BECAUSE WE'RE ABLE TO THEN LOOK
FOR MOLECULAR FOSSILS OR BIOMARKERS
THAT RECORD EUKARYOTES
BEFORE EUKARYOTES BECAME BIG ENOUGH
TO LEAVE LARGE, MACROSCOPIC FOSSILS THAT WE CAN THEN SEE.
Narrator: BUT STEROLS DO MORE THAN TELL US WHAT KIND OF LIFE WAS PRESENT.

THEY PROVIDE EVIDENCE FOR ITS ENVIRONMENT.
THIS COMPLICATED MAZE OF LINES, CIRCLES, AND ARCHES
IS A ROAD MAP OF THE METABOLIC PATHWAYS OF LIVING CELLS
MOLECULAR BIOLOGISTS' CURRENT KNOWLEDGE
OF THE SEQUENCE OF REACTIONS INVOLVED IN CREATING COMPOUNDS
LIKE THE STEROLS IN PEARSON'S ROCK SAMPLE.
THE CHEMICAL PATHWAY FOR STEROLS
IS ON THE BOTTOM OF THIS CHART DOWN HERE
AND THE VERY FIRST STEP IN MAKING A STEROL
CONSISTS OF TAKING A PRECURS OR MOLECULE
AND ADDING OXYGEN, OR O2, TO IT.
SO, WHEN WE SEE THESE STEROLS IN THE ANCIENT ROCK RECORD
WE CAN INFER THAT THEY MUST HAVE BEEN FORMED BY THIS PATHWAY
THAT REQUIRES OXYGEN.
SO IN ADDITION TO BEING A GOOD

MARKER
FOR THE PRESENCE OF
EUKARYOTES
WE, ALSO, AT THE SAME TIME,
HAVE A TRACER, OR A RECORD
THAT THERE SHOULD HAVE BEEN
SOME AMOUNT OF OXYGEN, OR
O2
PRESENT IN THE OCEAN SYSTEM
OR IN THE ATMOSPHERE AT THAT
TIME.
AND SO THESE ARE GREAT
CLASSES OF BIOMARKER
MOLECULES
BECAUSE THEY CAN TELL US
SOMETHING
BOTH ABOUT THE BIOCHEMISTRY
OF THE SYSTEM
BECAUSE IT NEEDS OXYGEN, AND
ABOUT WHO LIVED THERE.
Narrator: ANCIENT ROCKS
LIKE THE 1.5-BILLION-YEAR-OLD
SHALE THAT PEARSON TESTED
SHOW A WORLD WITH VARIED LIFE
AND WITH SOME OXYGEN.
BUT THE CONDITIONS WERE FAR
FROM WHAT WE WOULD CALL
HABITABLE.
Knoll: IT'S STILL A DIFFERENT
WORLD.
IT STILL IS A WORLD WITH MUCH
LESS OXYGEN THAN WE HAVE

NOW
AND WE ARE FINDING OUT, YOU KNOW --
LITERALLY, EVEN AS WE'RE HAVING THIS CONVERSATION
DATA SETS ARE ACCUMULATING THAT TELL US --
REALLY FROM EVIDENCE FROM ALL OVER THE WORLD --
THAT THE FIRST ROCKS
THAT RECORD A WORLD THAT'S LIKE OUR OWN
OR AT LEAST SIMILAR TO OUR OWN
IN TERMS OF HAVING A LOT OF OXYGEN
WERE DEPOSITED ONLY ABOUT 580 MILLION YEARS AGO.
Narrator: SOON AFTER OXYGEN REACHED LEVELS
NEAR WHAT WE HAVE TODAY
THE FOSSIL RECORD SHOWS AN EXPLOSION
OF MANY DIFFERENT MOBILE, MACROSCOPIC ANIMALS --
THE BEGINNING OF A HABITABLE PLANET.
TO US, AT LEAST.
BUT HOW EARTH LEFT
ONE LONG-LIVED STATE THAT'S ALIEN TO US
AND TRANSFORMED TO ANOTHER

STATE THAT'S HABITABLE BY US
IS STILL BEING DEBATED.
Knoll: WHAT THAT MEANS
IS THAT THERE'S SOMETHING WE
DON'T KNOW
ABOUT OUR PLANET'S HISTORY
AND THEREFORE SOMETHING
THAT WE CAN STUDY
AND MAKE NEW DISCOVERIES.
IF WE UNDERSTOOD EVERYTHING
THERE WOULD BE NO POINT IN
BEING A SCIENTIST.
RATHER, SCIENTISTSGET UP IN
THE MORNING
BECAUSE THERE ARE IMPORTANT
QUESTIONS THAT WE CAN'T
ANSWER
AND THE SCIENTIFIC METHOD IS
DEVISING VERY RIGOROUS WAYS
OF TRYING TO ANSWER
QUESTIONS ABOUT WHAT WE
DON'T KNOW.

Narrator: ADDING TO THIS
MYSTERY
IS THE FACT THAT, DURING THE
FINAL RISE OF OXYGEN
THERE WERE RADICAL
WORLDWIDE CLIMATE-CHANGING
EVENTS.

IN THE COUNTRY OF NAMIBIA

EXPOSED ROCK FACES SUGGEST
PROCESSES 600 MILLION YEARS
AGO
THAT CREATED AN UNIMAGINABLE
WORLD
BRINGING NEW MEANING TO THE
TERM "ICE AGE,"
WHERE GLACIERS FLOWED
WORLDWIDE
AND THE TROPICS WERE MORE
LIKE THE POLES --
A TIME KNOWN AS THE SNOWBALL
EARTH.
Hoffman: DURING THE MAXIMUM
COLD OF THE SNOWBALL EARTH
THE MEAN ANNUAL GLOBAL
TEMPERATURE
IS MINUS-50 DEGREES CELSIUS.
THE OCEAN IS FROZEN OVER
AND SO YOU HAVE A
SOLID-SURFACE PLANET.
SO YOU NOW HAVE AN EARTH
THAT'S MORE LIKE MARS
THAN IT IS LIKE EARTH.
Narrator: GEOLOGIST PAUL
HOFFMAN'S RESEARCH
CENTERS ON THE QUESTION OF
WHAT HAPPENED
TO CREATE THIS PLANETARY
DEEP FREEZE
A FREEZE THAT OPENS A LOT OF
QUESTIONS

ABOUT HOW THE EARTH
MAINTAINS A HABITABLE CLIMATE
EVEN TODAY.
Hoffman: THIS ONLY REALLY
BECAME A QUESTION
IN THE MIDDLE OF THE 20th
CENTURY
WHEN PEOPLE REALIZED
THAT OVER THE 5 BILLION YEARS
OF OUR SOLAR SYSTEM
SOLAR RADIANT ENERGY HAS
INCREASED BY ALMOST 30%.
SO IT'S SURPRISING, THEREFORE,
THAT THE GEOLOGICAL EVIDENCE
INDICATES THAT THE SURFACE
TEMPERATURE OF THE EARTH
HASN'T CHANGED VERY MUCH
OVER AT LEAST 3 1/2 BILLION
YEARS.
SO THAT MEANS THAT THERE
MUST BE SOMETHING INTERNAL
TO THE EARTH
THAT IS SELF-ADJUSTING SO THAT
THE EARTH
ALWAYS MAINTAINS A STABLE
TEMPERATURE --
NOT UNCHANGING, BUT LIMITED IN
THE AMOUNT OF CHANGE
DESPITE THIS LARGE INCREASE IN
SOLAR RADIATION.
Narrator: THE EARTH'S ABILITY TO
SELF-ADJUST ITS TEMPERATURE

IS LINKED TO CARBON DIOXIDE
A GREENHOUSE GAS WHICH
CAPTURES HEAT
THAT WOULD NORMALLY RADIATE
TO OUTER SPACE
AND SENDS IT BACK TO THE
SURFACE.
THE MORE CARBON DIOXIDE IN
THE ATMOSPHERE
THE WARMER THE SURFACE
TEMPERATURE.
Hoffman: IT WORKS IN THE
FOLLOWING WAY.
CARBON DIOXIDE IS EMITTED TO
THE ATMOSPHERE
PRIMARILY FROM VOLCANIC
ACTIVITY.
CARBON DIOXIDE IS CONSUMED
BY ROCK DECOMPOSITION.
GEOLOGISTS CALL THIS PROCESS
WEATHERING.
AND THAT PROCESS CONSUMES
CARBON DIOXIDE.
THE CARBON DIOXIDE GETS
DISSOLVED
IN GROUNDWATER AND RIVER
WATER
IS DEPOSITED AS SEDIMENT INTO
THE OCEAN
AND ULTIMATELY SINKS BACK
INTO THE MANTLE
THROUGH THE PLATE-TECTONIC

PROCESS CALLED SUBDUCTION.
IT GETS HEATED UP
AND DECARBONATION REACTIONS
TAKE PLACE.
AND IT'S CONVERTED BACK INTO
CO2
WHICH COMES BACK OUT OF
VOLCANOES.
AND THAT'S THE SORT OF
COMPLETE CYCLE
THE GEOLOGICAL CYCLE, OF
CARBON.
Narrator: THIS GEOLOGICAL
CYCLING OF CARBON
FROM THE EARTH'S INTERIOR TO
THE ATMOSPHERE ACTS AS A
THERMOSTAT
MAINTAINING A STABLE CLIMATE
ON THE PLANET.
THE WAY THE THERMOSTAT
WORKS IS THE WEATHERING
REACTIONS
ARE THEMSELVES DEPENDENT ON
TEMPERATURE.
SO, IF THE EARTH GOT WARMER
FOR ANY REASON
THERE WOULD BE MORE WATER
VAPOR IN THE ATMOSPHERE
AND THEREFORE THERE WOULD
BE MORE RAIN.
AND MORE RAIN MEANS THE
WEATHERING RATES WOULD GO

UP
AND SO CARBON DIOXIDE WOULD BE CONSUMED AT A FASTER RATE.
AND SO THAT WOULD ULTIMATELY LEAD TO A NEW STABLE CLIMATE PERHAPS AT A SLIGHTLY HIGHER TEMPERATURE.
SIMILARLY, IF THE EARTH COOLED DOWN FOR SOME REASON
WHAT WOULD HAPPEN IS
THAT WEATHERING RATES OVERALL WOULD GET SLOWER.
AND SO IF THE VOLCANIC OUTGASSING RATE STAYED THE SAME
CARBON DIOXIDE WOULD START TO ACCUMULATE IN THE ATMOSPHERE
AND THAT WOULD COUNTERACT THE COOLING
AND WOULD TEND TO STABILIZE THE CLIMATE AGAIN
NOT AT EXACTLY THE SAME TEMPERATURE AS BEFORE
BUT IT WOULD PREVENT A RUNAWAY COOLING OR WARMING.
Narrator: EVEN WITH THE GLOBAL THERMOSTAT
THAT'S BUILT INTO THE CARBON CYCLE
EVIDENCE OF SEVERAL PAST ICE

AGES
CAN BE FOUND IN ANCIENT
GLACIAL DEPOSITS AROUND THE
WORLD.
IN SQUANTUM, MASSACHUSETTS,
HOFFMAN SHOWS US FEATURES
WHICH REVEAL A PARTIAL ICE
AGE ABOUT 580 MILLION YEARS
AGO.
Hoffman: WELL, WHAT WE SEE
HERE
IS A COMPLETELY DISORGANIZED
MIXTURE
OF CLAY AND SILT AND SAND AND
STONES AND BOULDERS
THAT HAVE ALL BEEN CHURNED
AND RUBBED TOGETHER
DUE TO GLACIAL ACTION.
SO, IF YOU LOOK UNDERNEATH
ANY ACTIVE GLACIER
YOU SEE THIS BED OF MUCK
THAT'S FULL OF STONES AND
BOULDERS AND WHAT NOT
THAT'S GETTING DRAGGED
ALONG BY THE FLOWING ICE
OVERTOP
AND IT'S A VERY DISTINCTIVE KIND
OF DEPOSIT.
IT LOOKS LIKE IT JUST GOT
DUMPED OUT OF A CEMENT MIXER
OKAY, AND THAT INDICATES THAT
THERE WERE NO WAVES OR

CURRENTS
INVOLVED IN THE DEPOSITION OF THIS MATERIAL.
THIS IS SOMETHING THAT WAS JUST CHURNING EVERYTHING TOGETHER
AND THE ONLY PROCESS OF TRANSPORT
THAT OPERATES IN THAT WAY
IS TRANSPORT BENEATH A FLOWING GLACIER.
Narrator: IN ADDITION
TO INDICATING THE PRESENCE OF GLACIERS
THE ROCKS CAN ALSO REVEAL
WHEN THOSE GLACIERS STARTED TO RECEDE
AND THE PLANET STARTED GETTING WARMER.
THIS IS SHOWN BY LAMINATIONS, OR LAYERS.
SO, WHAT I'M LOOKING FOR HERE
IS A LAYER OF STRATIFIED MATERIAL.
OKAY, SO, THIS IS MASSIVE TILL.
IT'S SOMEWHAT CHURNED-UP.
THIS IS STILL PRETTY MASSIVE,
AND IT'S MASSIVE UP THERE.
BUT, OKAY, NOW, HERE WE GO.
SO, THIS IS MASSIVE.
A LITTLE BIT OF PEBBLE LAYERS HERE.

AND THEN, WOW, LOOK AT THIS.
THIS IS ALL BEAUTIFULLY
LAMINATED AND STRIATED.
SO, FROM HERE RIGHT UP TO
THERE IS AN INTERVAL
IN WHICH YOU CAN SEE ALL THIS
DELICATE, LITTLE LAMINATION.
SO, THIS WASN'T DEPOSITED
UNDERNEATH ICE.
THIS HAD TO HAVE BEEN
DEPOSITED UNDERNEATH WATER.
BUT IF YOU LOOK CLOSELY
THERE ARE STONES
THAT ARE SCATTERED ALL
THROUGH HERE.
THERE'S A BIG ONE.
OH, THERE'S A BEAUTY RIGHT
OVER THERE.
LOOK AT THIS ONE. HERE'S A
ROUND STONE OF GRANITE.
ANOTHER LITTLE ONE THERE.
THERE'S ONE.
AND THEY'RE JUST SITTING IN
THIS FINE, LAMINATED SILT AND
MUD.
OKAY, SO THIS FINELY LAMINATED
STUFF MUST HAVE BEEN
DEPOSITED
JUST BY SLOW SETTLING IN VERY
CALM WATER --
A FINE-GRAIN MATERIAL.
AND SO THE PROBLEM IS, HOW DO

THESE OUTSIZED STONES GET THERE?
AND SO THE ALMOST ONLY WAY YOU COULD IMAGINE THESE STONES COMING
IS FROM HAVING BEEN FLOATING IN ICE.
AND THEN AS THE ICE MELTS
THE STONES DROP DOWN OUT OF THE ICEBERGS
AND, PLUNK, PLOP DOWN ON THE SEAFLOOR.
AND SO THIS INTERVAL HERE REPRESENTS A RETREAT OF THE ICE.
Narrator: FEATURES LIKE THOSE FOUND IN SQUANTUM
ARE ALSO FOUND IN NAMIBIA, SHOWING A PERIOD OF GLACIATION
APPROXIMATELY 600 MILLION YEARS AGO
FOLLOWED BY A WARMING PERIOD, WHERE THE GLACIERS MELTED AWAY.
Hoffman: THE REASON WHY THE ROCKS ARE SO INTERESTING THERE
IS THAT WE KNOW THAT NAMIBIA WAS THE WARMEST PART OF THE OCEAN AT THAT TIME
OR ONE OF THE WARMEST PARTS,

AND IT WAS GLACIATED.
AND NOT ONLY WAS IT GLACIATED. THERE WERE NO MOUNTAINS THERE.
THESE ARE NOT MOUNTAIN GLACIERS.
THESE WERE GLACIERS THAT FORMED AT SEA LEVEL
IN THE WARMEST PART OF THE OCEAN.
OKAY, SO, THERE YOU'RE FRONT AND CENTER
WITH THE MAIN PARADOX OF THESE GLACIATIONS --
THAT YOU HAD GLACIERS AT SEA LEVEL
IN THE WARMEST PARTS OF THE WORLD
WHICH IMPLIES THAT THE REST OF THE WORLD
WAS GLACIATED, AS WELL.
Narrator: EVIDENCE FOR TWO DISTINCT SNOWBALL PERIODS
ONE 710 MILLION YEARS AGO
AND ANOTHER 635 MILLION YEARS AGO
IS FOUND NOT JUST IN THE GLACIAL DEPOSITS OF NAMIBIA
BUT IN GLACIAL DEPOSITS WORLDWIDE.
THROUGH PALEOMAGNETIC TESTING

THESE DEPOSITS HAVE ALL BEEN PLACED NEAR THE EQUATOR
PAINTING THE PICTURE OF A SNOWBALL EARTH
WHERE ALL OF THE CONTINENTS ARE IN THE TROPICS.
AT THIS POINT, ALL OF THE LAND ON THE PLANET
WOULD BE WHERE IT IS WARMEST AND WETTEST
LEADING TO MORE WEATHERING.
THIS ELEVATED WEATHERING
WOULD ABSORB MORE AND MORE CARBON DIOXIDE OVER TIME
COOLING THE EARTH.
AS TEMPERATURES GET COLDER
THE AREA OF ICE AND SNOW AT THE POLES
BECOMES GREATER AND GREATER.
THE EXPANSES OF ICE AT THE POLES
WILL INCREASE THE PLANET'S REFLECTIVITY, OR ALBEDO
COOLING IT EVEN MORE.
Hoffman: SO, PRESUMABLY
THE AREA THAT'S COVERED BY ICE AND SNOW GETS GREATER.
AND AS A RESULT, THE ALBEDO BECOMES HIGHER.
MORE OF THE RADIATION IS BEING REFLECTED

LESS IS BEING ABSORBED
AND SO THERE'S AN ADDITIONAL COOLING EFFECT.
AND SO, THEREFORE, THE FEEDBACK BECOMES STRONGER AND STRONGER
AND THERE BECOMES A POINT WHERE THE FEEDBACK IS SELF-SUSTAINING.
YOU CAN'T STOP IT. THAT'S THE TIPPING POINT.
AND ONCE YOU GO BEYOND THAT POINT
THE ADVANCE OF THE ICE WOULD OCCUR VERY RAPIDLY
AND THE ENTIRE TROPICAL OCEAN
WHICH IS HALF THE SURFACE AREA OF THE EARTH
WOULD BECOME ICE-COVERED IN A MATTER OF MONTHS TO YEARS.
SO THAT WOULD BE A CATASTROPHIC ADVANCE OF THE ICE
IN THE FINAL STAGES.
OKAY, SO THERE'S AN INSTABILITY.
THERE'S A TIPPING POINT
BEYOND WHICH THE ICE CAN'T BE STOPPED.
Narrator: BUT IF OUR PLANET FELL INTO A DEEP FREEZE

HOW DID IT EVER ESCAPE?
THE ESCAPE IS PLATE TECTONICS
AND, IN PARTICULAR
THE WAY PLATE TECTONICS
DRIVES THE CARBON CYCLE.
IF A SNOWBALL OCCURRED
WEATHERING RATES WOULD BE
EXTREMELY SLOW
BUT PLATE TECTONICS WOULD
CONTINUE.
SO VOLCANOES CONTINUE TO
PUMP CO2 INTO THE OCEAN
WATER
AND INTO THE ATMOSPHERE.
SO WHAT HAPPENS IS THAT
SLOWLY, OVER TIME
THE CARBON DIOXIDE
AND MAYBE OTHER GREENHOUSE
GASES IN THE ATMOSPHERE
BUILD UP AND CREATE A
STRONGER AND STRONGER
GREENHOUSE EFFECT.
AND ULTIMATELY, ACCORDING TO
THEORY
THE GREENHOUSE EFFECT DUE
TO THE ACCUMULATION OF
CARBON DIOXIDE
BECOMES SO STRONG THAT IT'S
ABLE TO COUNTERACT
THE HIGH ALBEDO OF THE
ICE-COVERED EARTH
AND PRECIPITATE WHAT IS

BELIEVED TO BE A VIOLENT DEGLACIATION
OR MELTDOWN, OF ALL THE ICE
UNDER THE INFLUENCE OF AN ENORMOUSLY ELEVATED
CARBON-DIOXIDE LOAD IN THE ATMOSPHERE.
Narrator: THE TIMING OF THESE RADICALLY DIFFERENT CLIMATES
OCCURS INTRIGUINGLY CLOSE TO THE BEGINNING
OF WHAT IS KNOWN AS THE CAMBRIAN EXPLOSION
WHEN COMPLEX LIFE ON EARTH BEGAN.
THIS CLOSENESS IN TIMING HAS LED TO QUESTIONS
ABOUT THE POSSIBILITY THAT THE SNOWBALL EARTH
AND ITS GREENHOUSE AFTERMATH MAY HAVE BEEN
SOMEHOW LINKED
TO THE SUDDEN APPEARANCE OF MANY NEW KINDS OF ANIMALS
IN THE FOSSIL RECORD.
Hoffman: THERE WERE STRESSES ASSOCIATED WITH THE GLACIATION.
THERE WERE OBVIOUSLY STRESSES
ASSOCIATED WITH THE GREENHOUSE AFTERMATH.

SO YOU COULD IMAGINE THAT
THAT WOULD BE AN
ENVIRONMENT
IN WHICH THERE WOULD BE
STRONG, SELECTIVE PRESSURE
AND, THEREFORE, THAT MIGHT BE
AN INCENTIVE
FOR EVOLUTIONARY CHANGE.
BUT THE ARRIVAL OF
MULTICELLULAR ANIMALS
IS NOT JUST A CHANGE.
THIS IS A BIOLOGICAL
INNOVATION.
THIS IS A CHANGE TO A WORLD IN
WHICH YOU HAD ORGANISMS
WHICH ACHIEVED A LEVEL OF
COMPLEXITY AND BEHAVIOR
THAT HAD NEVER BEEN SEEN
PREVIOUSLY.
WE DON'T HAVE ANY IDEA AT THIS
POINT
WHY A SNOWBALL GLACIATION
AND ITS GREENHOUSE
AFTERMATH
MIGHT HAVE CREATED A
CIRCUMSTANCE
THAT WOULD HAVE BEEN
SELECTIVELY FAVORABLE
FOR THIS GREAT CHANGE IN THE
COURSE OF BIOLOGICAL
EVOLUTION
BUT THE COINCIDENCE IN TIMING

IS TANTALIZING.
Narrator: WHILE THE QUESTION
OF HOW COMPLEX LIFE EMERGED
ON OUR PLANET PERSISTS
THE WORK OF SCIENTISTS LIKE
PAUL HOFFMAN AND ANDY KNOLL
BRINGS US CLOSER TO THE
ANSWER
SHEDDING LIGHT NOT JUST ON
HOW EARTH BECAME HABITABLE
BUT ON HOW IT REMAINS
HABITABLE TODAY.

[BIRDS SQUAWKING]

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