

Mylodon was the size of a white rhino: 5500 lbs and 10 ft tall. That's 500 times heavier than modern sloths!



Mylodon was named based on a jawbone found in Argentina by Charles Darwin while on the HMS Beagle expedition in 1832.

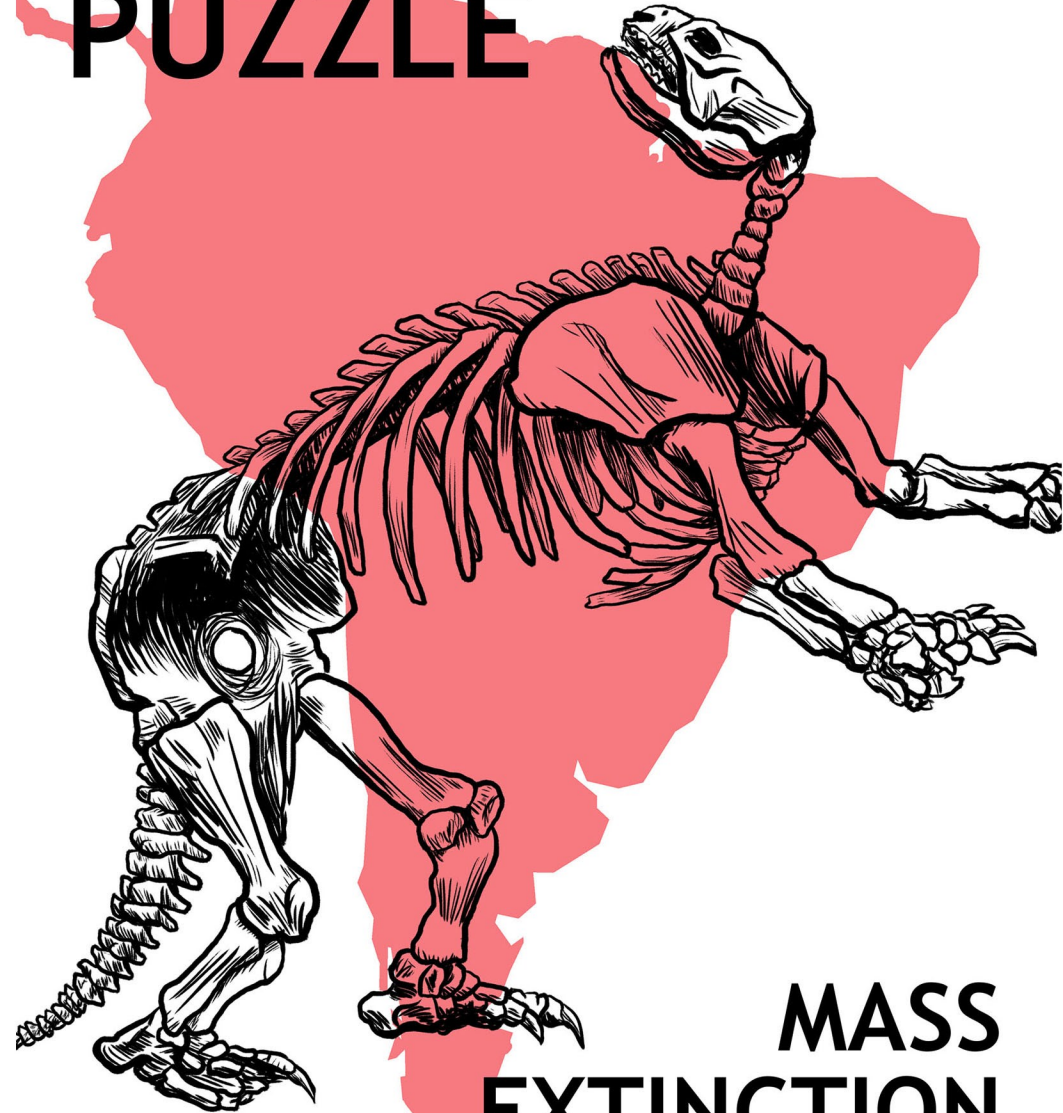


Mylodon had tough plates in its skin called osteoderms that would have made it hard to hunt.

Dr. Natalia Villavicencio participated in the Última Esperanza project as a Ph.D. student. Her work focused on improving the chronology of megafaunal extinction for some regions of South America using radiocarbon dating techniques to date little pieces of bone coming from extinct megafauna fossils. At the same time she developed regional analyses of the pattern of megafaunal extinction and its relation to human impacts and environmental changes (climate and vegetation) as in the case of the study of the record from Última Esperanza in Southern Patagonia.



A PLEISTOCENE PUZZLE



MASS EXTINCTION IN SOUTH AMERICA

A Pleistocene Puzzle: Extinction in South America

What's it about?

Follow the investigation of scientists Maria and Miguel as they solve a paleontological mystery. About 11,000 years ago, more than 80% of the large animal species in South America went extinct. Why did it happen? Maria and Miguel study an area in Chile called Última Esperanza. They discover many different lines of evidence that point to a warming climate and the arrival of humans as key causes of the extinctions. Today, life on earth also faces global warming and a growing human population. If action isn't taken, we may be witnessing the beginning of a modern mass extinction!

This comic is available online:

<http://www.ucmp.berkeley.edu/extinctioninsouthamerica/>

Also available in Spanish and Portuguese!

Drawings and text: Josh Frankel

Scientific and editorial advisors: Natalia Villavicencio, Emily Lindsey, Anthony Barnosky, Anna Thanukos

This comic was based on the research of a team of South and North American researchers and the following scientific paper:

Natalia A. Villavicencio, Emily L. Lindsey, Fabiana M. Martin, Luis A. Borrero, Patricio I. Moreno, Charles R. Marshall and Anthony D. Barnosky, 2015, Combination of humans, climate, and vegetation change triggered Late Quaternary megafauna extinction in the Última Esperanza region, southern Patagonia, Chile. *Ecography* 38:1–16.
http://ib.berkeley.edu/labs/barnosky/Villavicencio_et_al-2015-Ecography.pdf

Funding for this project was provided by the U.S. National Science Foundation Grant EAR-1148181.

Glossary

archaeology – the field that studies human cultures by investigating the stuff they left behind

artifact – an object made by a human

carnivore – animal that eats mainly other animals

extinction – an event in which the last members of a species die

fossil – any trace of a living thing (body part, burrow, footprint) preserved in the rock record

glacier – a huge mass of ice formed by compacted snow

herbivore – animal that eats mainly plants

ice age – a time in Earth's history when temperatures were lower and glaciers and ice sheets expanded

pollen – sex cells in plants that usually take the form of tiny grains of material

sediment – material like sand or soil that is moved and deposited by water or wind

species – a group of living things that interbreed with one another

Comprehension questions

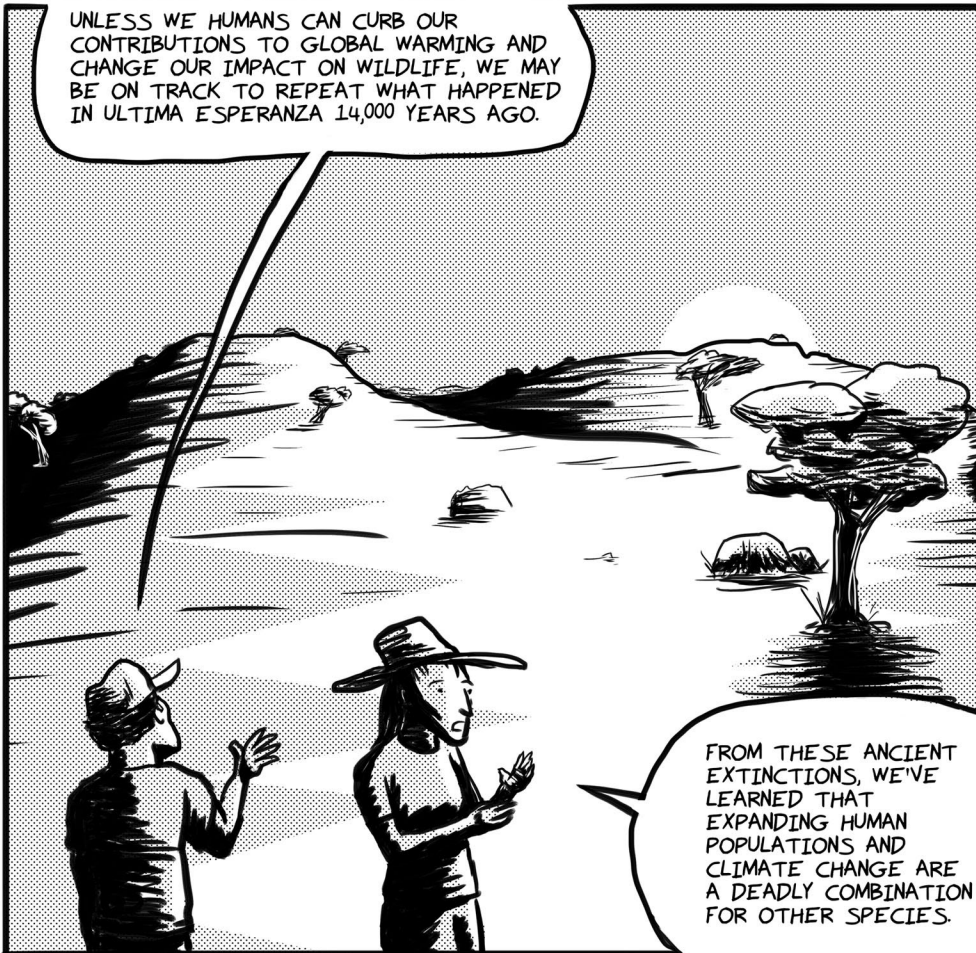
1. What question were the paleontologists Maria and Miguel trying to answer? Be as specific as possible.
2. Describe one potential hypothesis about the cause of the large animal extinction that was not supported by evidence. What evidence contradicted this hypothesis?
3. In this story, fossils are used to learn much more than just which species lived in Última Esperanza. List at least three things that the researchers learned from fossils other than what species they belonged to.
4. Describe at least three different lines of evidence that researchers used to figure out what the landscape of Última Esperanza was like at different points in time and what each line of evidence revealed.
5. Compare and contrast the explanations for the disappearance of carnivores and the disappearance of herbivores from Última Esperanza.



STUDYING PREHISTORIC EXTINCTIONS IS IMPORTANT BECAUSE IT GIVES US INSIGHT INTO ISSUES THAT WE FACE TODAY.



UNLESS WE HUMANS CAN CURB OUR CONTRIBUTIONS TO GLOBAL WARMING AND CHANGE OUR IMPACT ON WILDLIFE, WE MAY BE ON TRACK TO REPEAT WHAT HAPPENED IN ULTIMA ESPERANZA 14,000 YEARS AGO.



FROM THESE ANCIENT EXTINCTIONS, WE'VE LEARNED THAT EXPANDING HUMAN POPULATIONS AND CLIMATE CHANGE ARE A DEADLY COMBINATION FOR OTHER SPECIES.

A PLEISTOCENE PUZZLE

EXTINCTION IN SOUTH AMERICA



EARTH WASN'T ALWAYS LIKE IT IS TODAY.

ITS HISTORY IS MARKED BY TIMES OF EXTREME CHANGE.

FOR EXAMPLE, EARTH WENT THROUGH A SERIES OF ICE AGES DURING THE PLEISTOCENE EPOCH (FROM ABOUT 2.6 MILLION YEARS AGO UNTIL 11,700 YEARS AGO).



GLACIERS SPREAD DOWN FROM THE POLES AND THE MOUNTAINS AND THEN SHRANK AGAIN SEVERAL TIMES.

FOR ALL OF THAT TIME, BIG ANIMAL SPECIES SURVIVED DESPITE THE CHANGING CLIMATE.



BUT SOMETHING DIFFERENT HAPPENED AT THE END OF THE PLEISTOCENE...

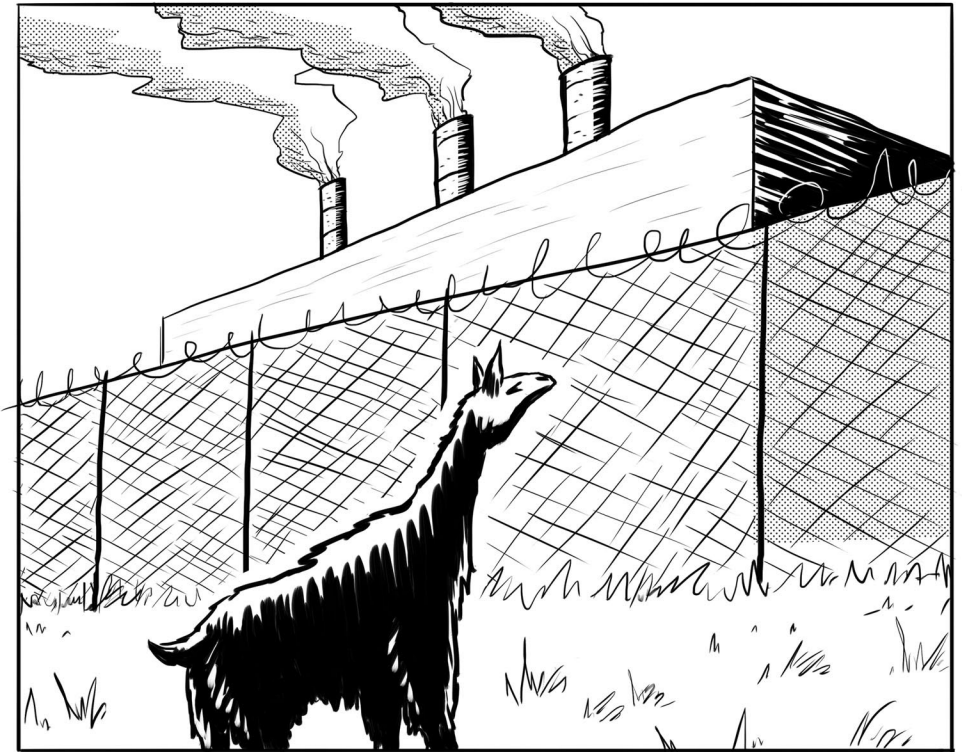
BIG ANIMAL SPECIES STARTED MYSTERIOUSLY DYING OUT.

AROUND HALF OF BIG ANIMAL SPECIES IN THE WORLD WENT EXTINCT. AND SOUTH AMERICA LOST MORE THAN ANY OTHER CONTINENT. MORE THAN 80% OF SOUTH AMERICAN SPECIES WEIGHING OVER ONE-HUNDRED POUNDS DISAPPEARED!

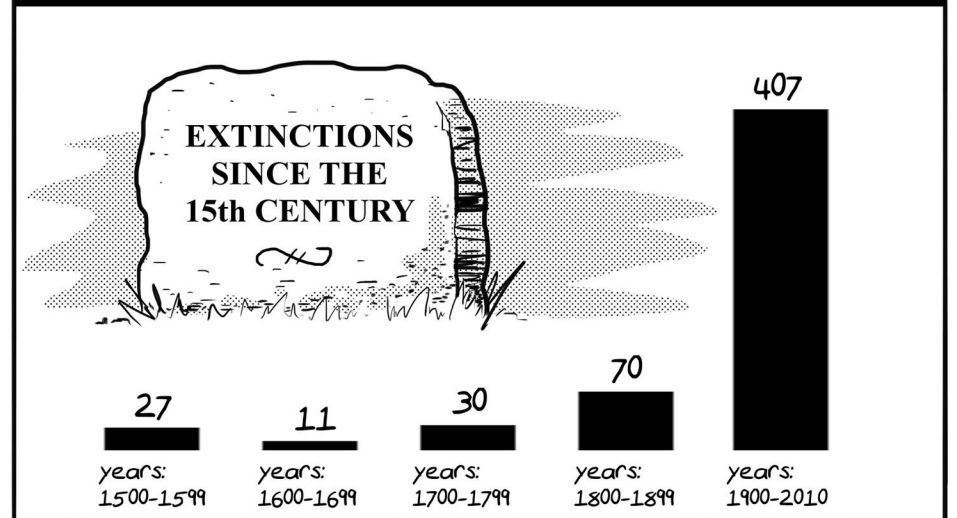
WHAT CAUSED THIS EXTINCTION? AND WHAT WAS GOING ON IN SOUTH AMERICA TO MAKE IT SO SEVERE?



WHICH BRINGS US TO THE PRESENT DAY, WHEN CLIMATE CHANGE AND HUMANS ARE TEAMING UP TO DISRUPT HABITATS MORE THAN EVER. HOW ARE MODERN MEGAFUNA FARING?



NOT SO HOT. THE REMAINING MEGAFUNA IN SOUTH AMERICA AND THE REST OF THE PLANET ARE UNDER INTENSE PRESSURE, AND EXTINCTION RATES ARE SKYROCKETING.



ALTHOUGH THE MEGAFAUNA OF ÚLTIMA ESPERANZA CO-EXISTED WITH HUMANS FOR A LONG TIME, THEIR NUMBERS PROBABLY BEGAN TO DWINDLE AS PEOPLE HUNTED THE HERBIVORES FOR FOOD AND COMPETED WITH THE CARNIVORES FOR RESOURCES.



THEN THROW IN CLIMATE CHANGE ON TOP OF THAT, WHICH RESULTED IN LESS OF THE VEGETATION THE HERBIVORES NEEDED TO EAT, AND THAT WAS THE END.



IF A SPECIES IS ALREADY VULNERABLE, IT DOESN'T TAKE MUCH TO PUSH IT OVER THE THRESHOLD TO EXTINCTION.

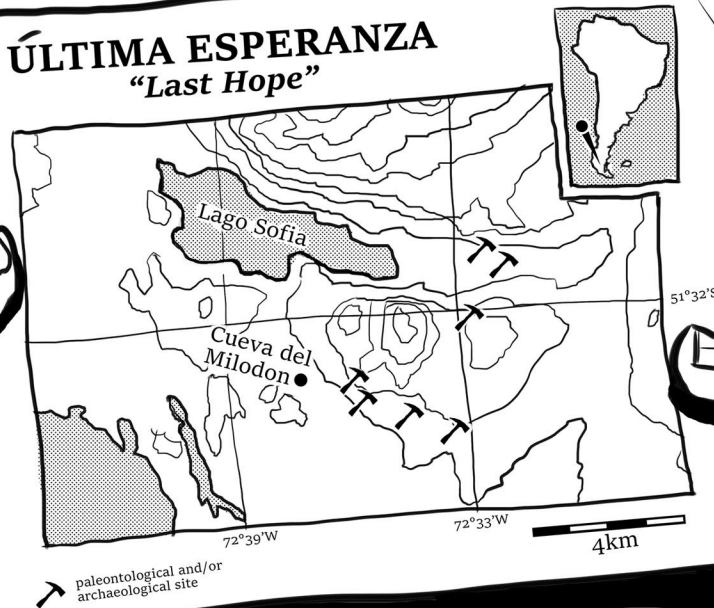
THAT'S WHAT MIGUEL AND I CAME TO ÚLTIMA ESPERANZA, CHILE TO FIND OUT!

MARIA AND I ARE PALEONTOLOGISTS – SCIENTISTS WHO STUDY FOSSILS TO LEARN WHAT LIFE WAS LIKE IN THE PAST. WE ARE WORKING AT ÚLTIMA ESPERANZA BECAUSE THE ROCK AND DIRT LAYERS HERE CONTAIN LOTS OF FOSSILS AND ARCHAEOLOGICAL REMAINS.



FOSSILS WILL HELP US FIND OUT MORE ABOUT WHAT THE PLEISTOCENE WAS LIKE IN THIS PART OF SOUTH AMERICA, AND HOPEFULLY GIVE US THE CLUES WE NEED TO SOLVE OUR EXTINCTION MYSTERY.

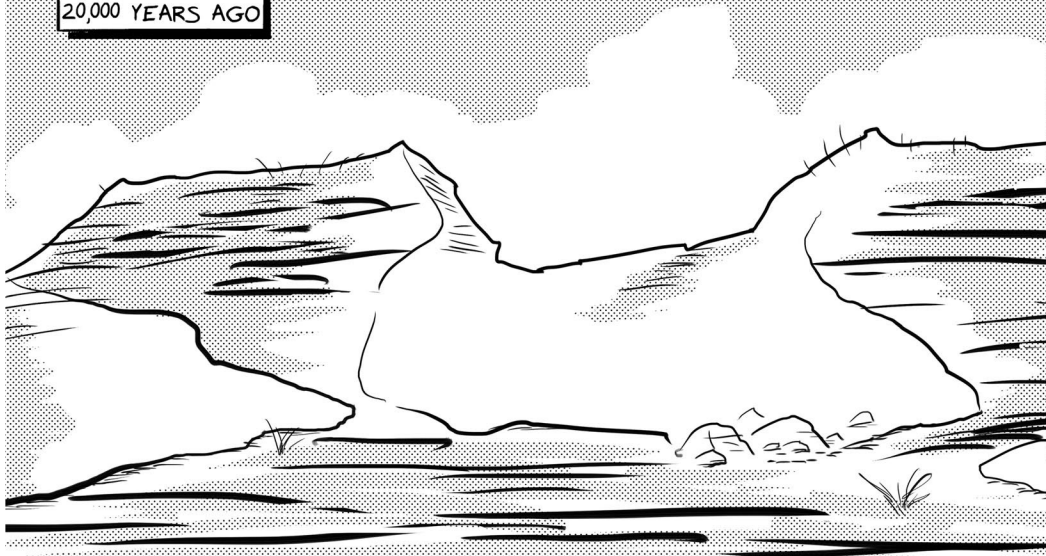
ÚLTIMA ESPERANZA “Last Hope”



OK, LET'S TURN BACK THE CLOCK AND SEE WHAT WAS HAPPENING HERE 20,000 YEARS AGO...



20,000 YEARS AGO



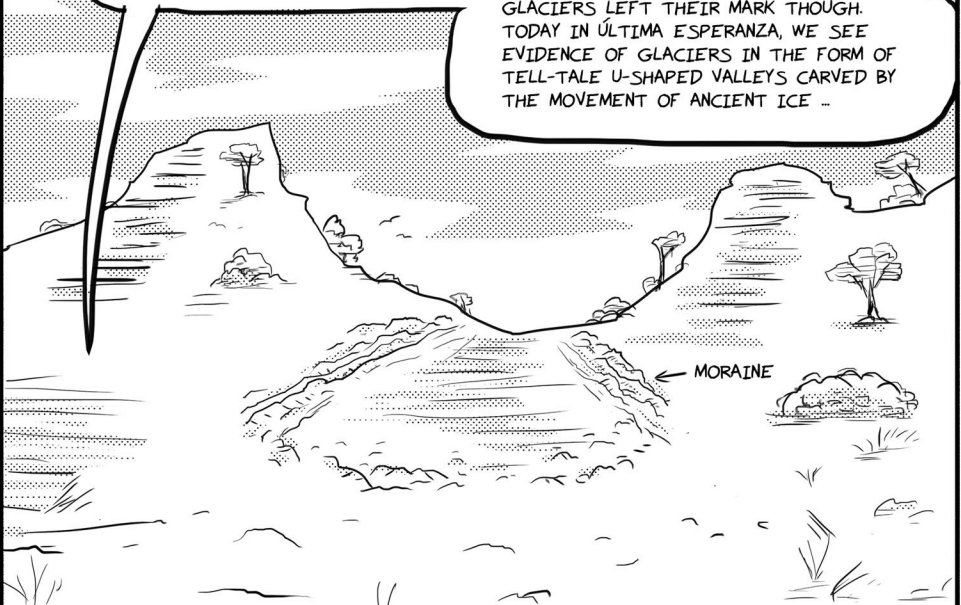
THEN, IN LESS THAN 3,000 YEARS 9 OF THOSE SPECIES DISAPPEARED.

WHAT HAPPENED?

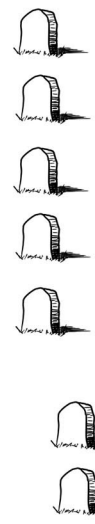
2016

BACK THEN THIS LANDSCAPE WAS COVERED WITH GLACIERS, WHICH DIDN'T START TO SHRINK UNTIL ABOUT 18,000 YEARS AGO.

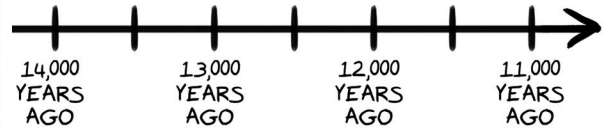
GLACIERS LEFT THEIR MARK THOUGH. TODAY IN ÚLTIMA ESPERANZA, WE SEE EVIDENCE OF GLACIERS IN THE FORM OF TELL-TALE U-SHAPED VALLEYS CARVED BY THE MOVEMENT OF ANCIENT ICE ...



... AS WELL AS MORAINES: RIDGES OF ROCK AND GRAVEL THAT ACCUMULATE ALONG EDGES OF GLACIERS.

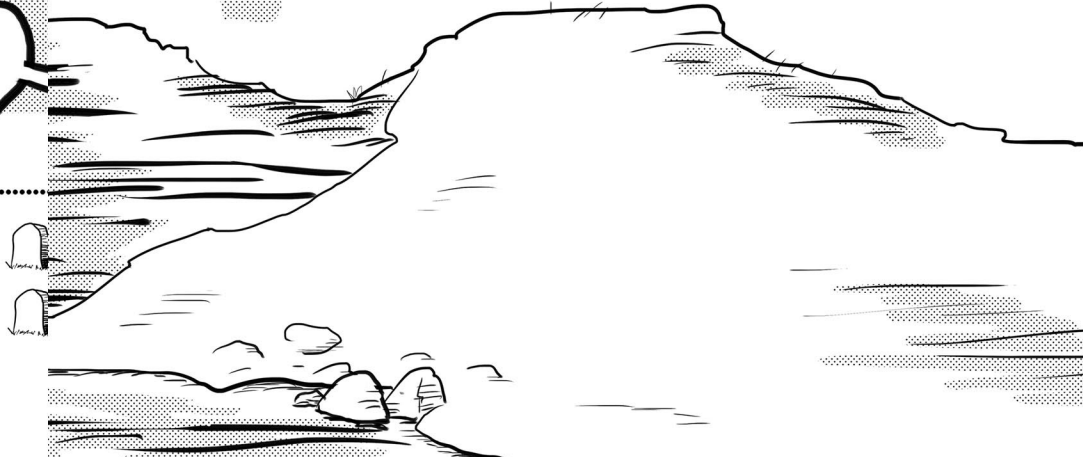
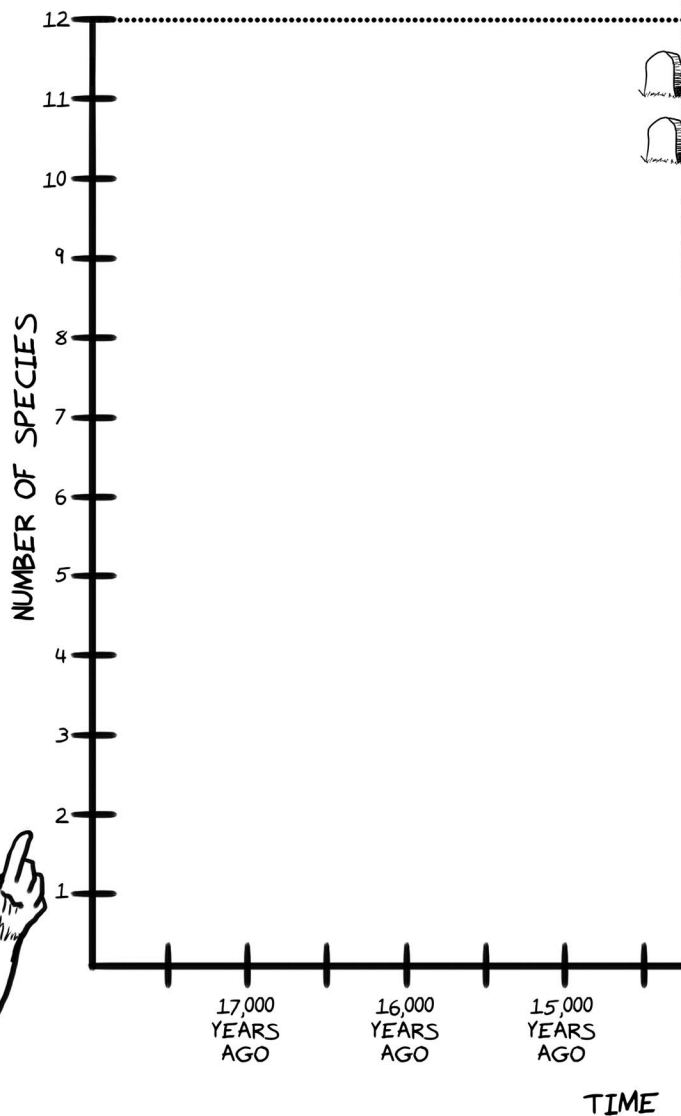


HUMANS HAPPENED. AND CLIMATE CHANGED.



SO, LET'S RECAP AND TAKE STOCK. FOR ABOUT 2 MILLION YEARS THE MEGAFUNA IN OUR STORY ROAMED SOUTH AMERICA, SURVIVING THROUGH MANY ICE AGES AND WARMING PERIODS.

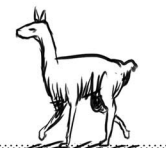
AT ÚLTIMA ESPERANZA 12 SPECIES RAPIDLY COLONIZED A NEWLY ICE-FREE AREA ABOUT 18,000 YEARS AGO.



MEANWHILE, HERE'S THE ROSTER OF BIG MAMMALS ROAMING THE CONTINENT BACK THEN. IMPRESSIVE, HUH?



Lama gracilis †



Lama guanicoe



Vicugna vicugna

SEVERAL SPECIES OF LLAMA



EXTINCT HOOFED MAMMAL WITH NO LIVING RELATIVES
Macrauchenia patachonica †



PLEISTOCENE SOUTH AMERICAN JAGUAR
Panthera onca mesembrina †



SHORT-FACED BEAR
Arctotherium †



SABER-TOOTHED CAT
Smilodon †



SOUTH AMERICAN HORSE
Hippidion saldiasi †



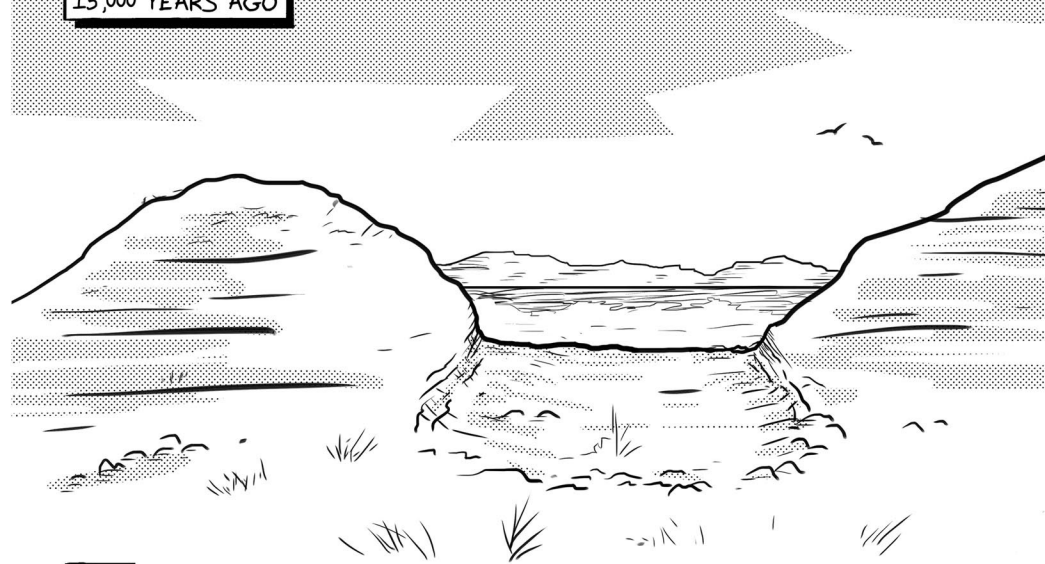
GIANT SLOTH
Mylodon darwini †

SCIENTISTS HAVE EXCAVATED FOSSILS OF ALL OF THESE CREATURES FROM THIS PART OF CHILE.

† = extinct by the end of the Pleistocene

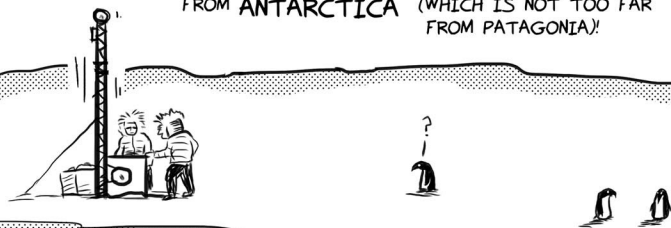


15,000 YEARS AGO

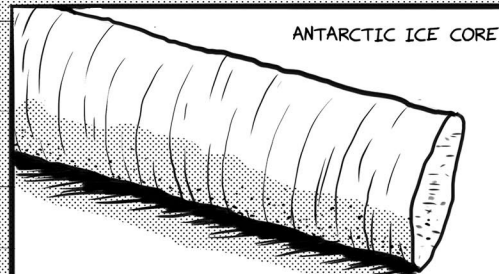
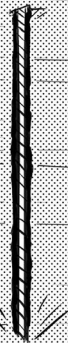


2016

THE ICE MELTED AS THE CLIMATE WARMED AND GRASSES RECLAIMED THE LAND. BUT HOW DO WE KNOW WHAT TEMPERATURE IT WAS 15,000 YEARS AGO? THE EVIDENCE COMES FROM ANTARCTICA (WHICH IS NOT TOO FAR FROM PATAGONIA!)



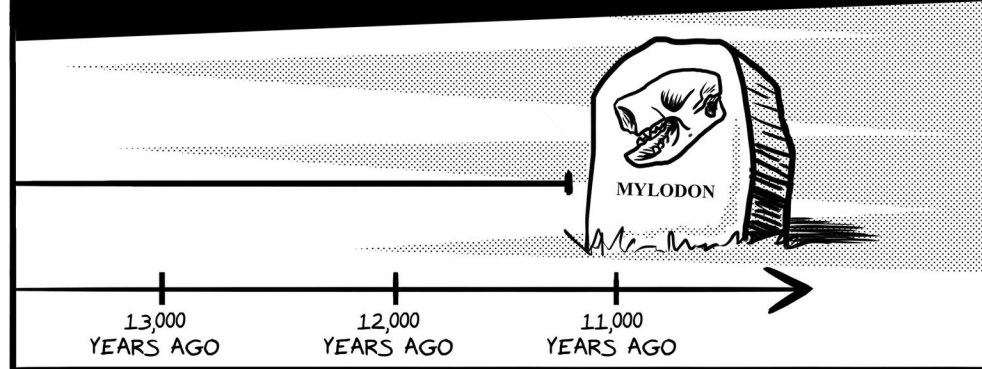
IF WE DRILL DEEP ENOUGH INTO ANTARCTIC GLACIERS, WE EVENTUALLY COME TO LAYERS OF ICE DATING BACK TO THE PLEISTOCENE!



ANTARCTIC ICE CORE

THE YEARLY DRY AND SNOWY SEASONS LEAVE COMPACTED LAYERS IN THE ICE, SO WE CAN JUST COUNT LAYERS STARTING FROM THE TOP TO FIND THE AGE OF THE ICE WE ARE STUDYING.

MYLODON, THE LAST LARGE GRAZER IN THE REGION, FINALLY WENT EXTINCT.

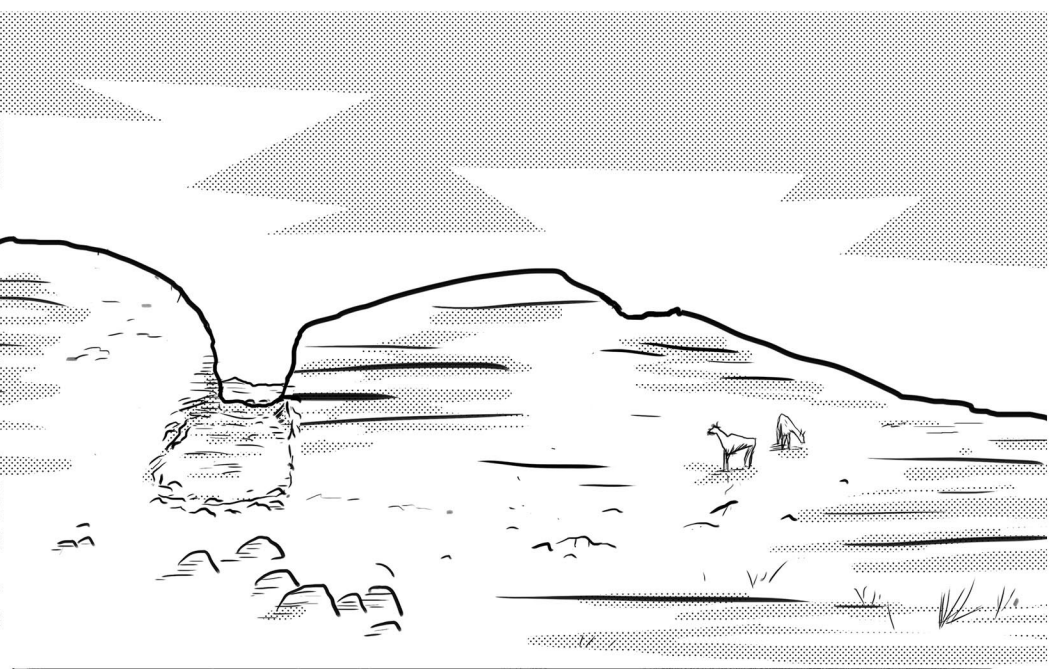


WE HAVE EXCELLENT EVIDENCE OF MYLODON'S DIET IN THE FORM OF FOSSILIZED DUNG, CALLED COPROLITES. MYLODON ATE GRASS, AND WITHOUT THE GRASSLAND THEY DISAPPEARED.





11,000 YEARS AGO



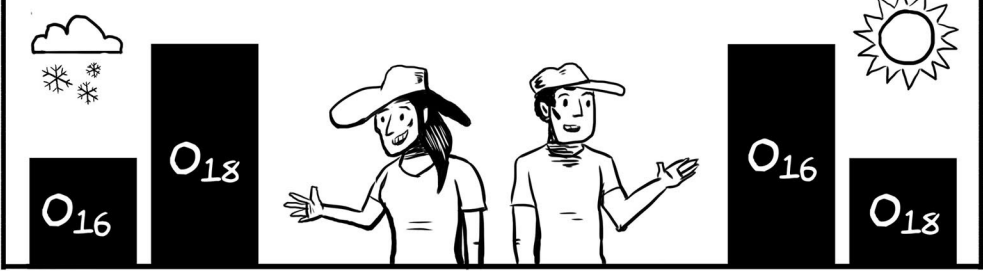
2016

BY 11,000 YEARS AGO THE ENTIRE LANDSCAPE HAD COMPLETELY TRANSFORMED INTO NOTHOFAGUS FOREST.

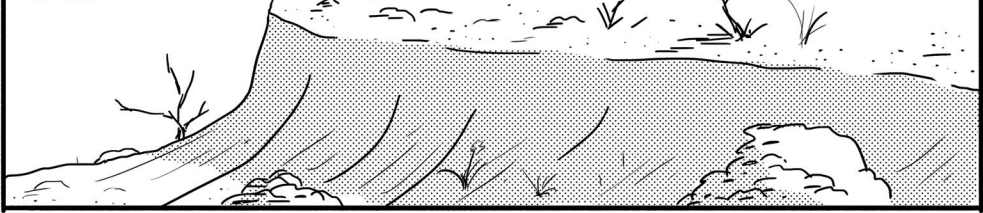
BOG AND LAKE CORE SAMPLES FROM AROUND THIS TIME SHOW AN INCREASE IN CHARCOAL ASSOCIATED WITH FOREST FIRES.



NEXT, WE MEASURE THE RATIO OF TWO VARIETIES OF OXYGEN ATOM IN THIS OLD ICE: O_{16} AND O_{18} . DURING WARMER PERIODS LESS OF THE HEAVIER O_{18} GETS LOCKED IN THE ICE. PRECISE MEASUREMENT OF THIS RATIO FROM ANTARCTIC ICE CORES TELLS US THE TEMPERATURE IN NEARBY PATAGONIA DURING THE PLEISTOCENE SO WE KNOW THAT 15,000 YEARS AGO, IT WAS WARMING UP!



AND AS IT WARMED, ALL OF THAT MELTED ICE FORMED A BIG LAKE. THE EVIDENCE CAN BE SEEN IN FLAT TERRACES IN TODAY'S LANDSCAPE. THE TERRACES WERE ERODED BY WAVES AT THE WATER'S EDGE WHEN THE LAKE WAS AT DIFFERENT LEVELS.



15,000 YEARS AGO

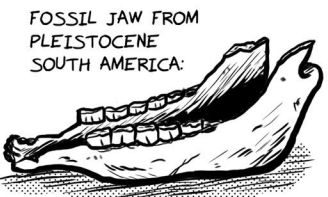


2016

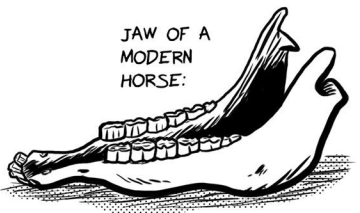


LUSH PLAINS ATTRACTED GRAZERS: LLAMAS, VICUNAS, AND GIANT GROUND SLOTHS ... AS WELL AS PANTHERS AND SABER-TOOTHED CATS THAT WERE HUNTING THEM!

WE KNOW THESE SPECIES WERE THERE BECAUSE WE COMPARED THE SHAPES OF FOSSIL BONES TO OTHER PREVIOUSLY-IDENTIFIED FOSSILS AND TO THE BONES OF RELATED ANIMALS. THE FOSSILS FOUND IN ÚLTIMA ESPERANZA MATCH THE BONES OF WELL-KNOWN SPECIES GIVING A CLEAR PICTURE OF THE ANIMALS THEY CAME FROM.

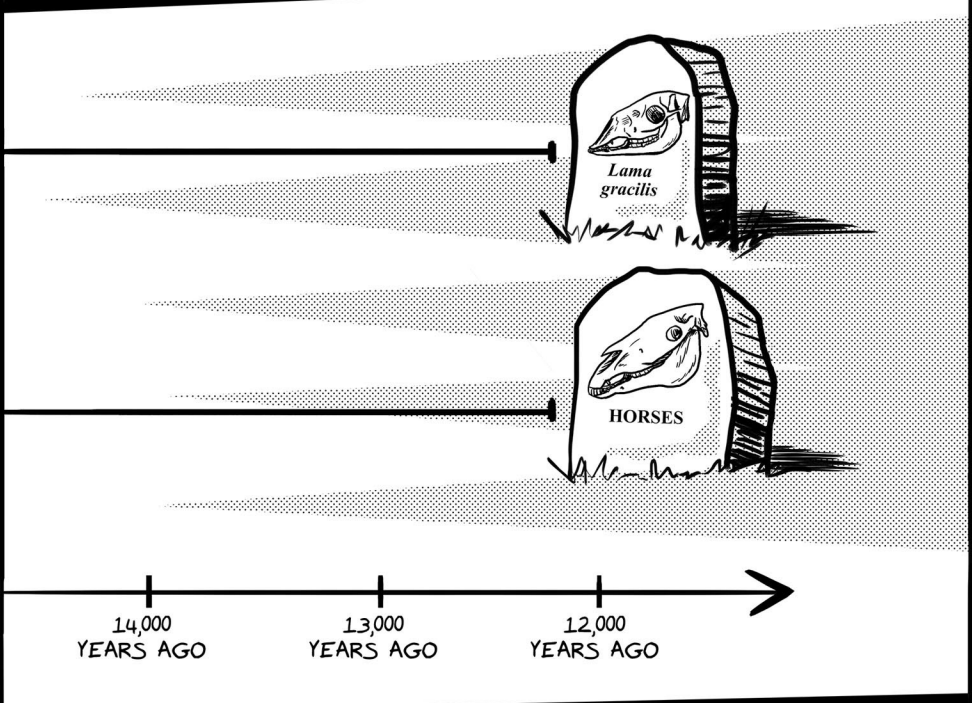


FOSSIL JAW FROM PLEISTOCENE SOUTH AMERICA:



JAW OF A MODERN HORSE:

THERE'S STILL SOME GRASSLAND, BUT THE REDUCTION IN HABITAT COMBINED WITH HUNTING BY HUMANS MAY HAVE BEEN TOO MUCH FOR GRAZERS LIKE HORSES AND LLAMAS.



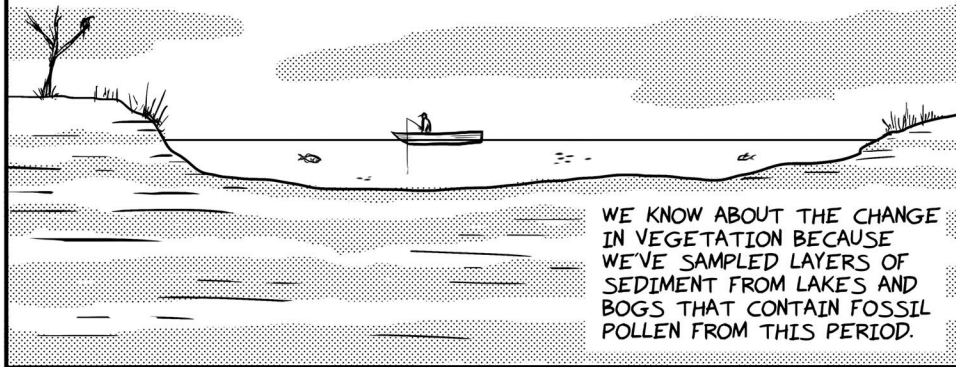
THIS IS WHEN THEY DISAPPEAR FROM THE FOSSIL RECORD.

11,200 YEARS AGO



2016

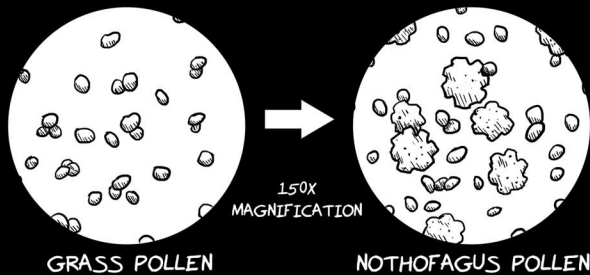
AS THE CLIMATE CONTINUED WARMING, PATAGONIA GOT WETTER AND MORE TREES STARTED TO GROW IN THE AREA.



WE KNOW ABOUT THE CHANGE IN VEGETATION BECAUSE WE'VE SAMPLED LAYERS OF SEDIMENT FROM LAKES AND BOGS THAT CONTAIN FOSSIL POLLEN FROM THIS PERIOD.

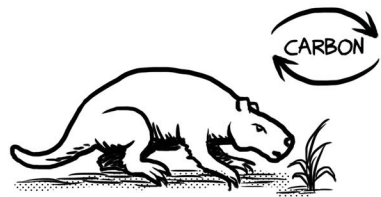


AT FIRST MOST OF THE POLLEN WAS FROM GRASSES. BUT AROUND 11,200 YEARS AGO THERE WAS AN INCREASE IN NOTHOFAGUS (BEECH TREE) POLLEN ABUNDANCE.



HOW DO WE KNOW THE AGE OF THESE FOSSILS? WE USE A CLEVER TECHNIQUE CALLED RADIOCARBON DATING.

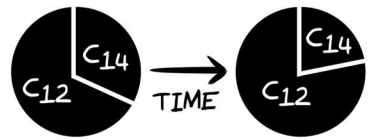
1. LIVING ANIMAL EXCHANGES CARBON WITH ITS ENVIRONMENT, INCLUDING SMALL AMOUNTS OF RADIOACTIVE CARBON (C_{14}).



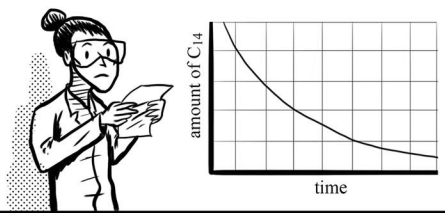
2. WHEN THE ANIMAL DIES, THAT EXCHANGE STOPS. THE DEAD ANIMAL DOESN'T TAKE IN NEW C_{14} .



3. OVER TIME, C_{14} DECAYS AT A CONSISTENT RATE SO THE RATIO OF C_{14} TO REGULAR CARBON (C_{12}) DECREASES.

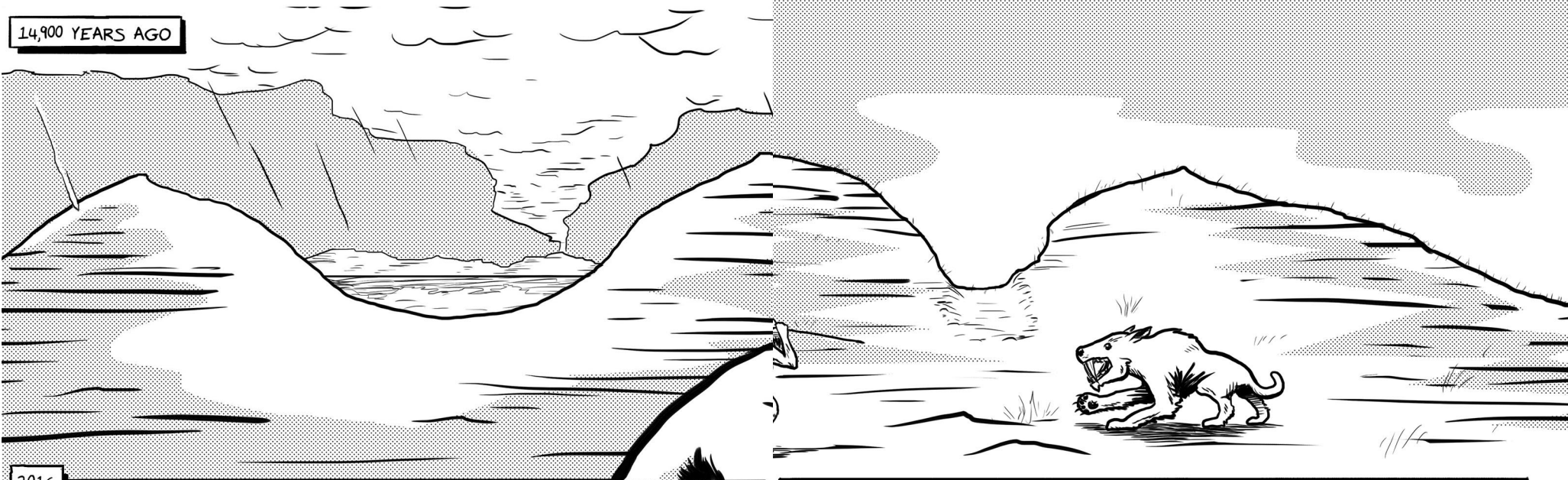


4. SCIENTISTS MEASURE THE RATIO OF C_{14} TO C_{12} IN A FOSSIL TO FIND OUT HOW LONG IT'S BEEN SINCE THE ANIMAL DIED.



RADIOCARBON DATES TELL US WHEN DIFFERENT ANIMALS WERE LIVING IN ÚLTIMA ESPERANZA, AND WHEN THEY SEEM TO BE GONE. THE LATEST DATES WE HAVE ON VICUNA FOSSILS IN THIS REGION, FOR INSTANCE, ARE ABOUT 15,000 YEARS AGO. VICUNAS PROBABLY MOVED OUT OF ÚLTIMA ESPERANZA BECAUSE THE CLIMATE WAS GETTING TOO WARM FOR THEIR TASTE, BUT THEY DIDN'T GO EXTINCT -- THEY ARE STILL LIVING IN THE HIGH ANDES MOUNTAINS TODAY!

14,900 YEARS AGO



2016

THE RECLUS VOLCANO 100KM NORTHWEST OF ÚLTIMA ESPERANZA ERUPTED 14,900 YEARS AGO, COVERING THE LANDSCAPE IN VOLCANIC DEBRIS.



WHEN WE LOOK AT LAYERS OF SEDIMENT FROM THIS TIME WE SEE THIS BAND OF ASH SPEWED FROM THE RECLUS ERUPTION.

MAYBE THE CARNIVORES DIED OUT BECAUSE OF COMPETITION WITH THE NEWLY-ARRIVED HUMANS WHY DO WE THINK THAT HUMANS EAT MEAT TOO. UPON ARRIVAL, THEY BEGAN HUNTING THE SAME LARGE HERBIVORES THAT HAD PREVIOUSLY FED ONLY THE PANTHERS AND SABRE-CATS.



WE'VE FOUND BONES OF HORSES AND MYLODON SHOWING CUT MARKS FROM HUMAN TOOLS AND BURNING FROM COOKING FIRES. AND WE'VE FOUND BONES FROM THOSE SAME PREY SPECIES IN LARGE CARNIVORE DENS. HUMANS AND BIG CATS COMPETED FOR THE SAME FOOD RESOURCES, SO AS HUMAN POPULATIONS GREW, LARGE CARNIVORE POPULATIONS MAY HAVE DECLINED.

ALSO, WE KNOW FROM MODERN EXPERIENCE THAT HUMANS USUALLY TRY TO KILL OR DRIVE AWAY PREDATORS WE THINK COULD ATTACK US OR THE ANIMALS WE EAT.

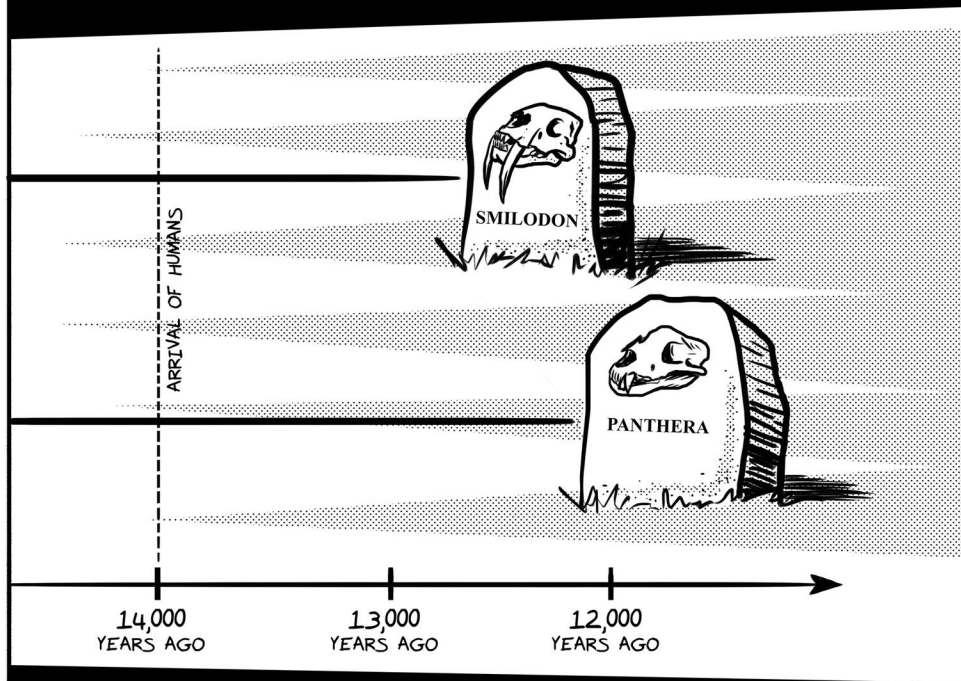


14,000 YEARS AGO



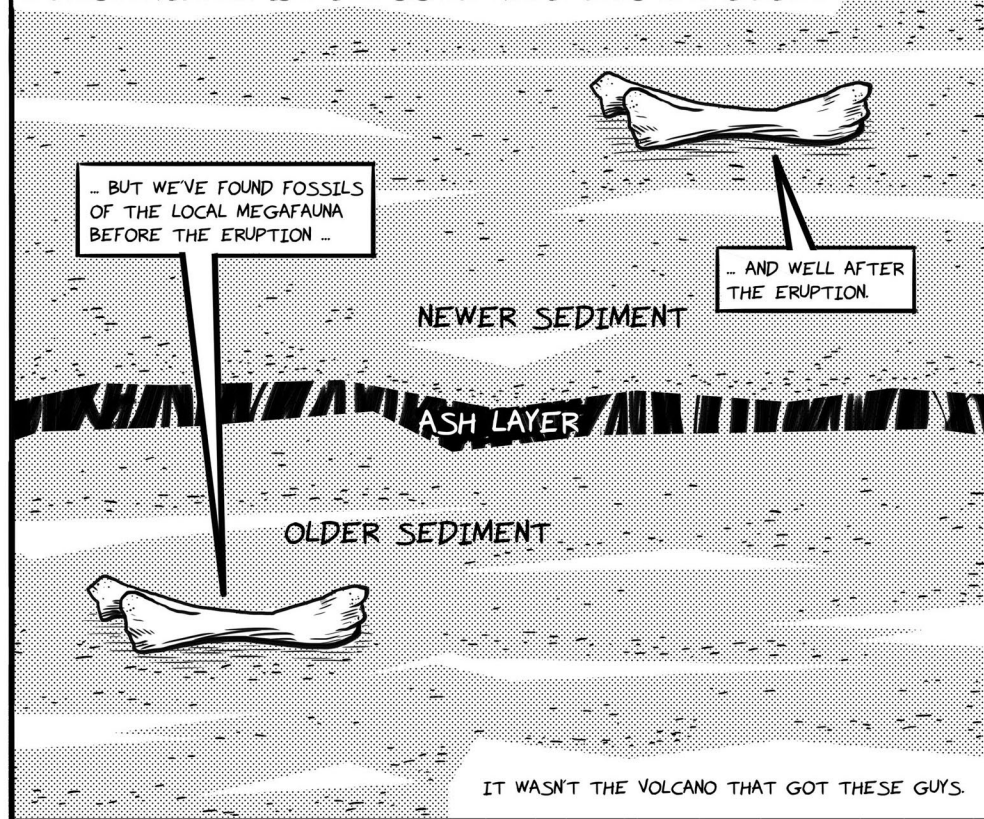
2016

AFTER HUMANS ARRIVED, THE FIRST MEGAFaUNA SPECIES TO DIE OUT WERE THE LARGE CARNIVORES—PANTHERS AND SABRE-TOOTH CATS BUT HUMANS CO-EXISTED WITH THESE OTHER PREDATORS FOR NEARLY 2000 YEARS. SO WHY DID THE BIG CATS DIE OUT?



WE CAN LEARN WHEN A SPECIES GOES EXTINCT BY DATING THE MOST RECENT OCCURRENCE OF THE FOSSILS. OF COURSE, WE PROBABLY DON'T HAVE THE FOSSIL OF THE LAST INDIVIDUAL THAT EVER LIVED, BUT THIS STILL GIVES US A PRETTY GOOD IDEA OF WHEN THESE ANIMALS WENT EXTINCT.

DID THE VOLCANO CAUSE LOCAL EXTINCTIONS AT ÚLTIMA ESPERANZA? A CATASTROPHIC EVENT IS A LIKELY SUSPECT WHEN IT COMES TO EXTINCTION ...

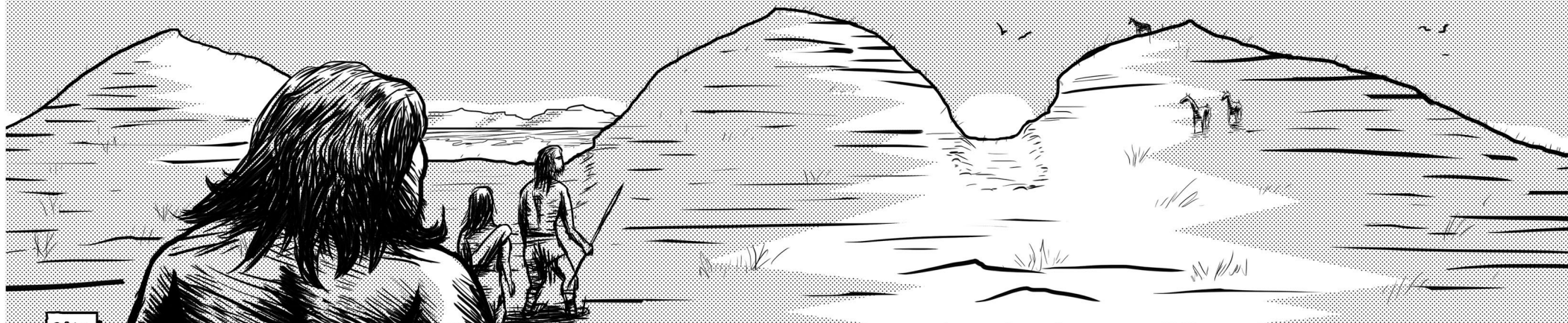


... BUT WE'VE FOUND FOSSILS OF THE LOCAL MEGAFaUNA BEFORE THE ERUPTION ...

... AND WELL AFTER THE ERUPTION.

IT WASN'T THE VOLCANO THAT GOT THESE GUYS.

14,000 YEARS AGO

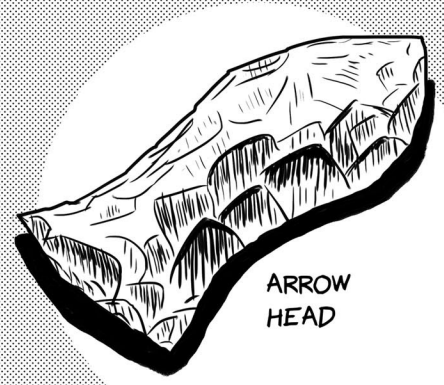


2016

HERE'S WHERE HUMANS ENTER THE STORY. THEY SHOWED UP AROUND 14,000 YEARS AGO AND SOON BEGAN LEAVING LOTS OF EVIDENCE FOR US TO FIND!



ARCHAEOLOGICAL SITES IN THE AREA HAVE YIELDED HUMAN REMAINS, ARTIFACTS, AND OTHER EVIDENCE OF HUMAN HABITATION.



ARROW HEAD



CHUNK OF BURNT BONE FOUND NEAR A HEARTH

ONCE AGAIN, WE USED CARBON DATING TO PUT A DATE TO ALL OF THIS EVIDENCE.