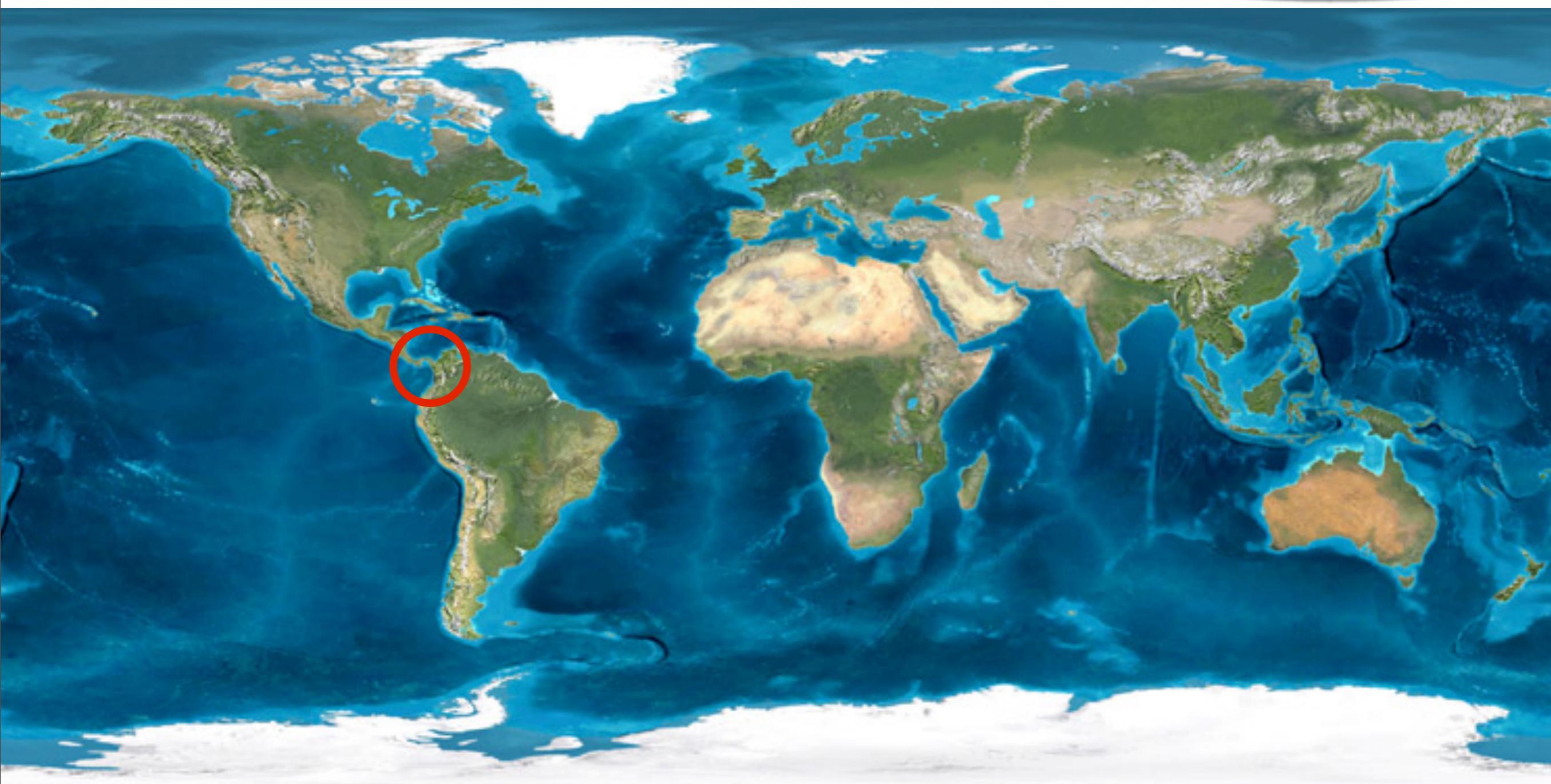
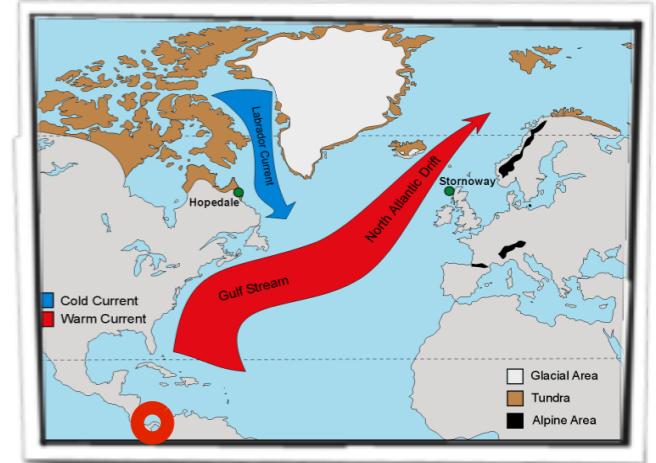




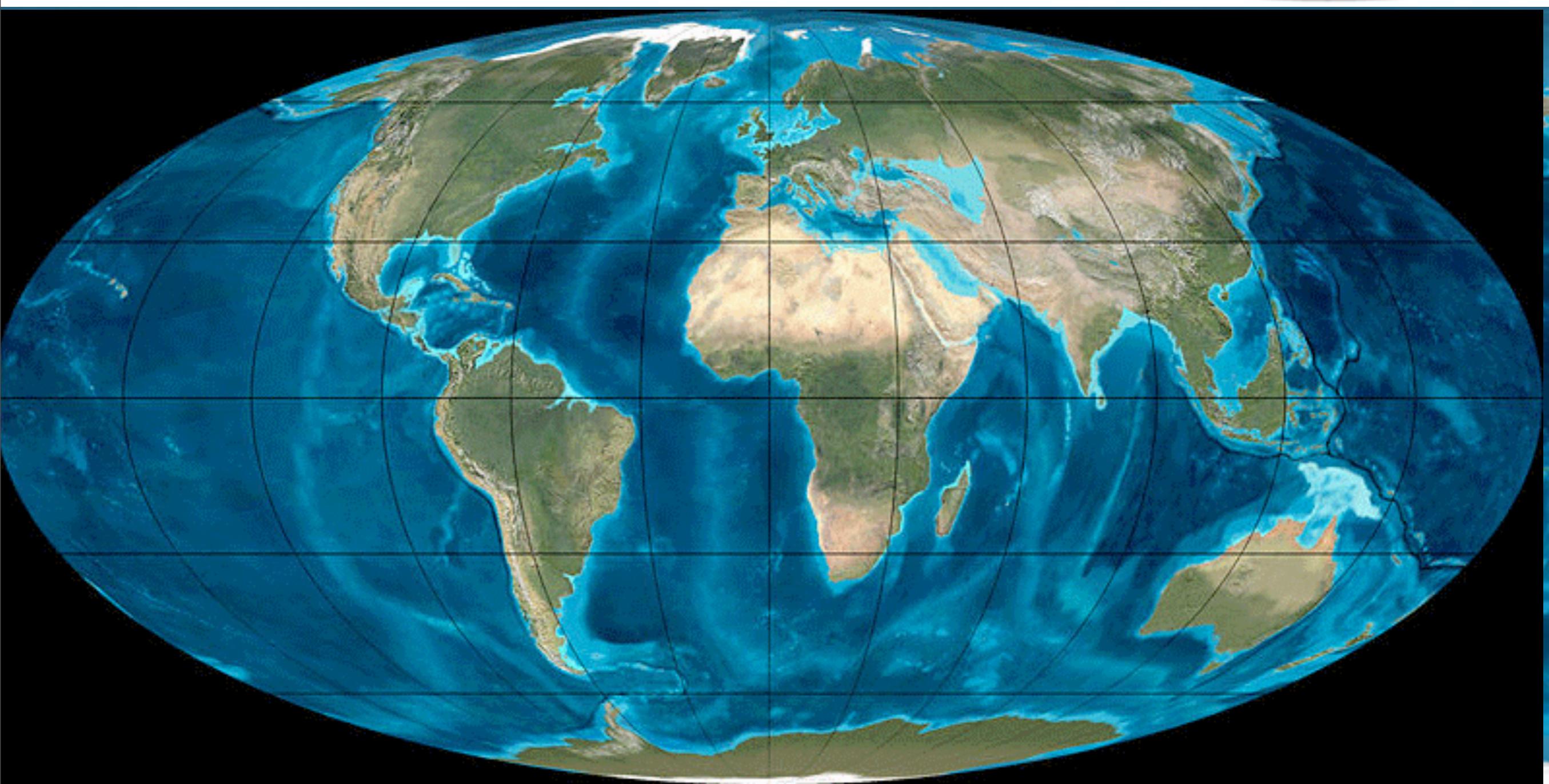
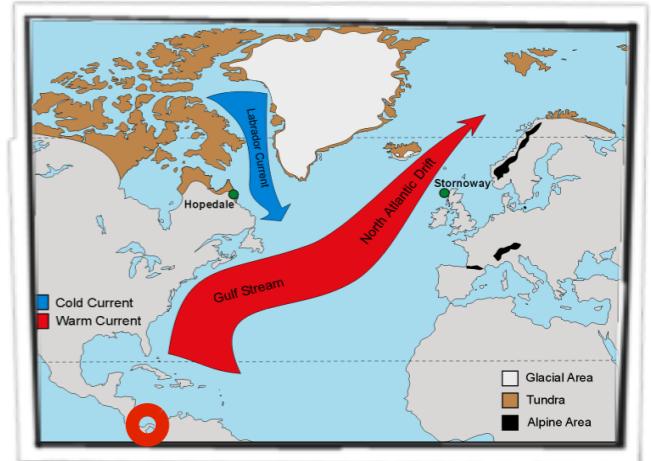
# Fossil Sharks

Catalina Pimiento

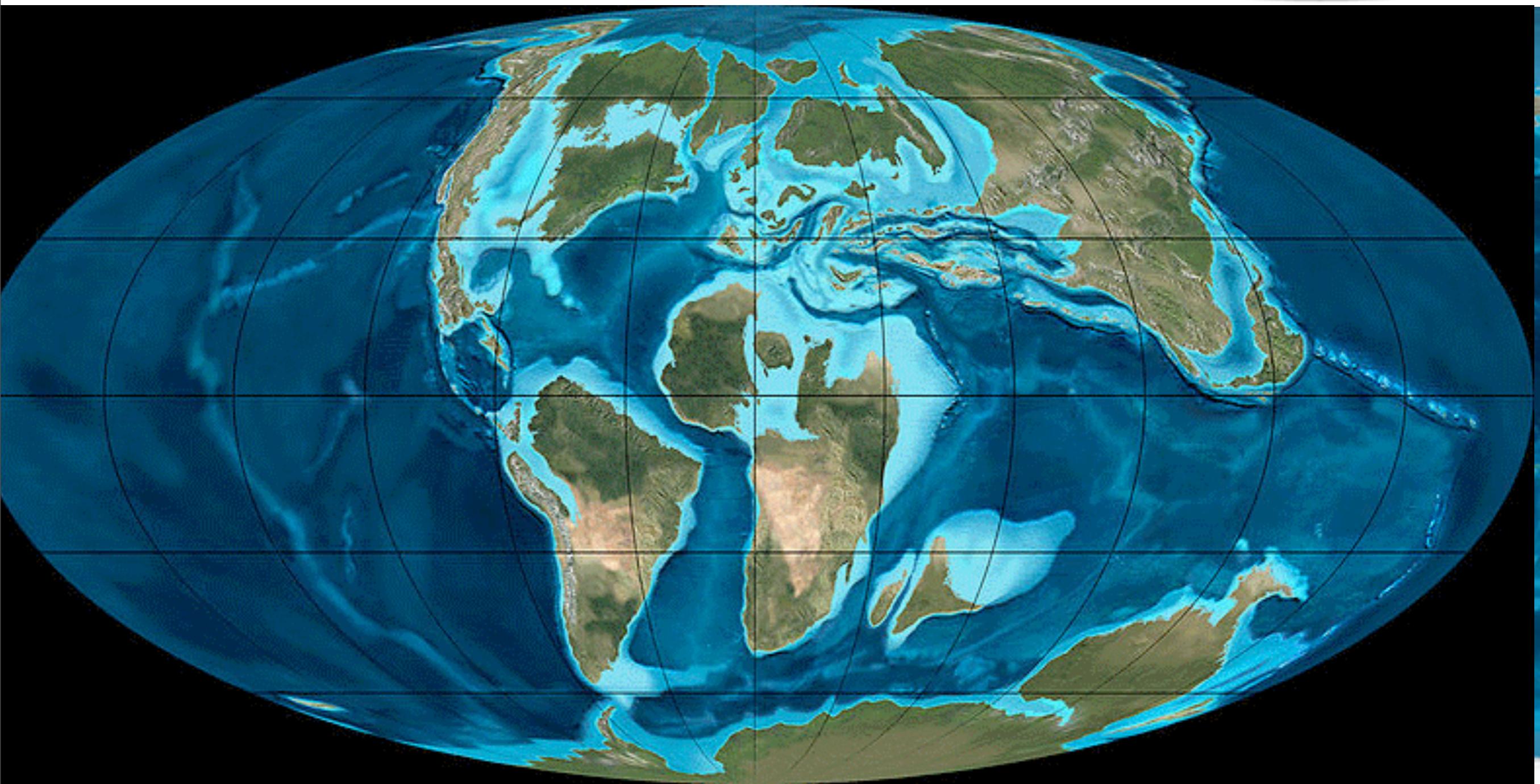
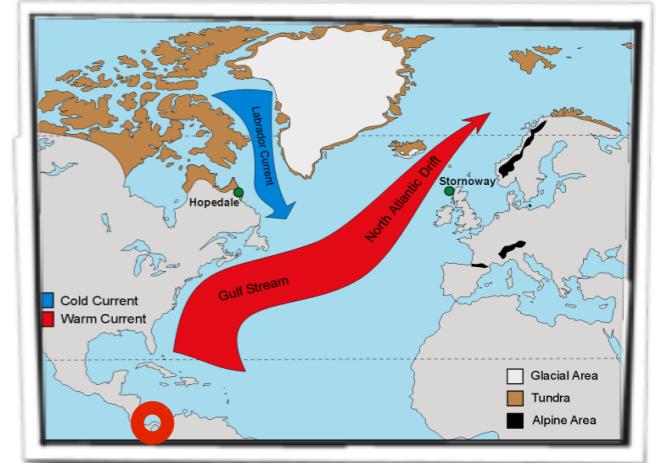
# ►the isthmus that changed the world



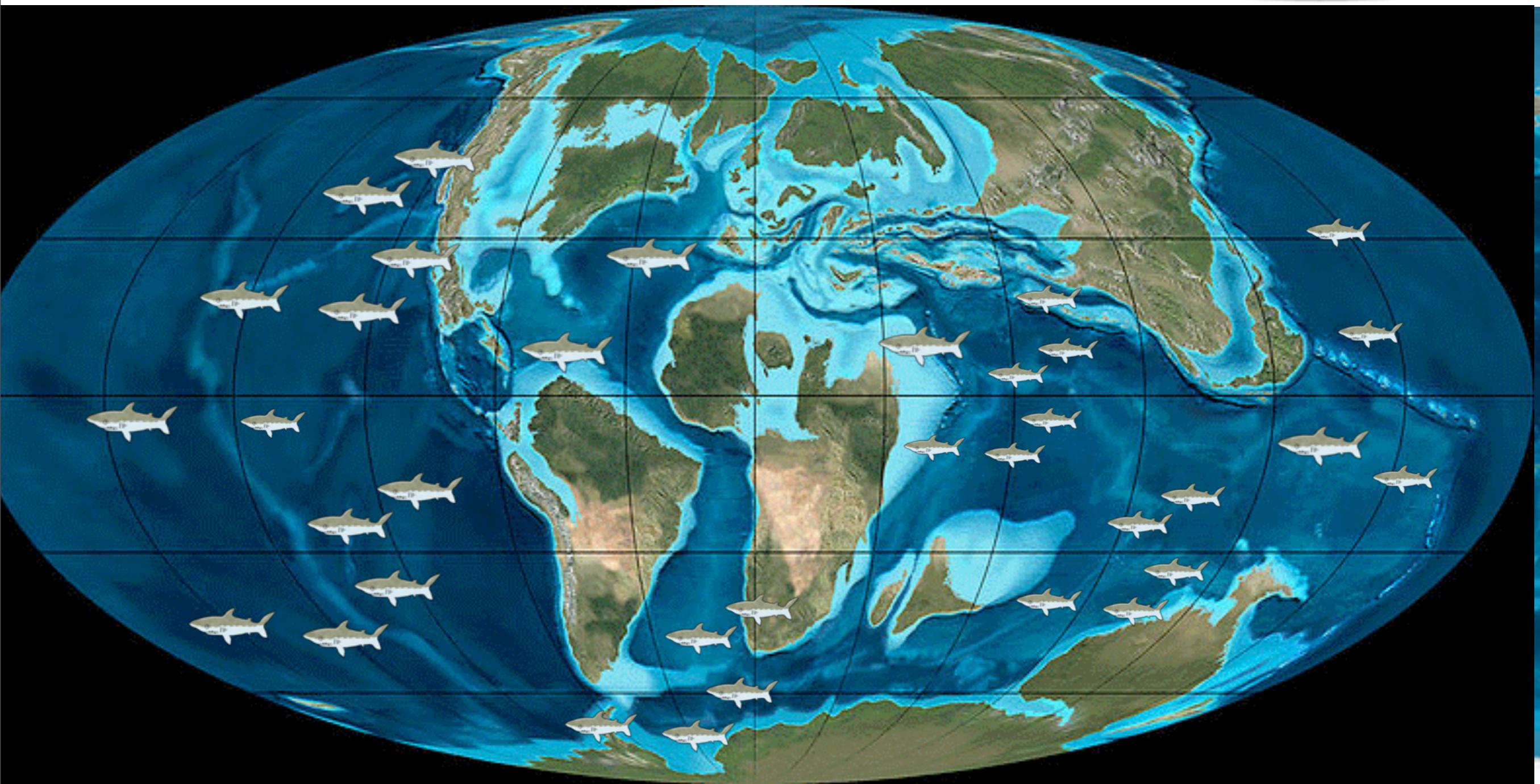
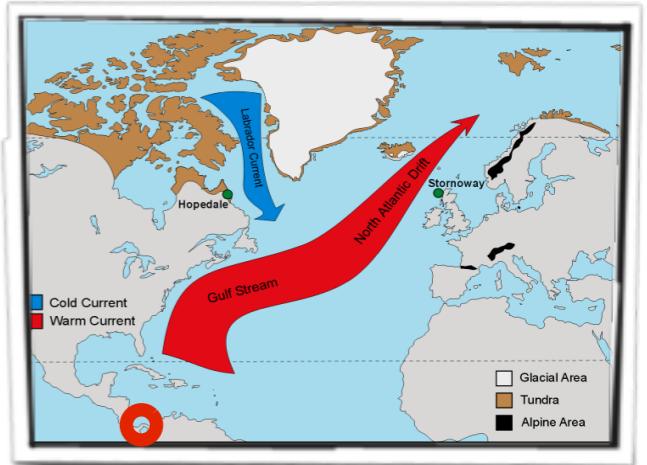
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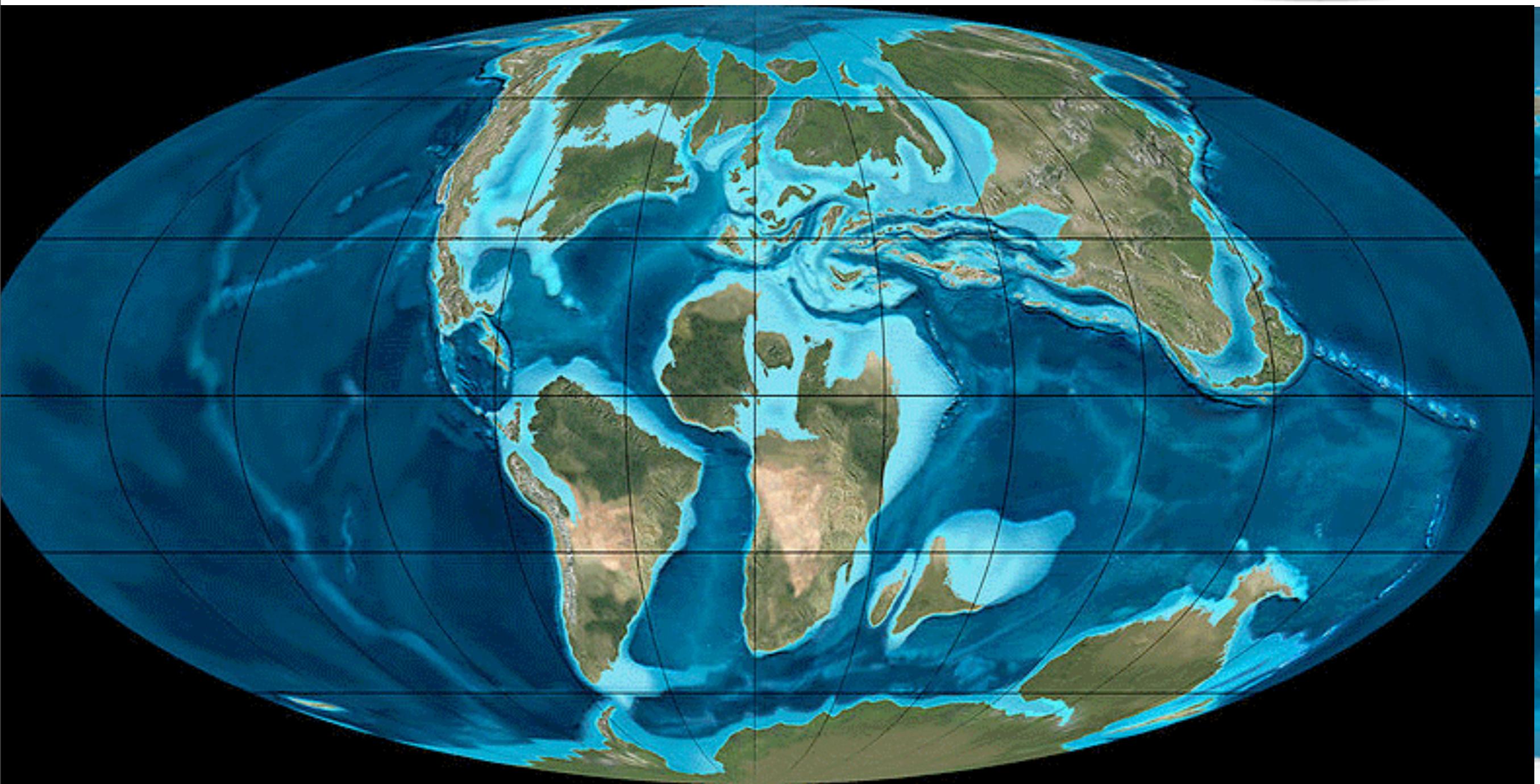
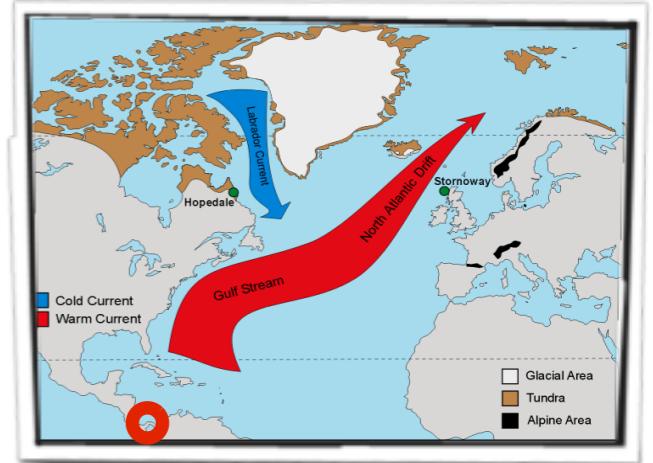
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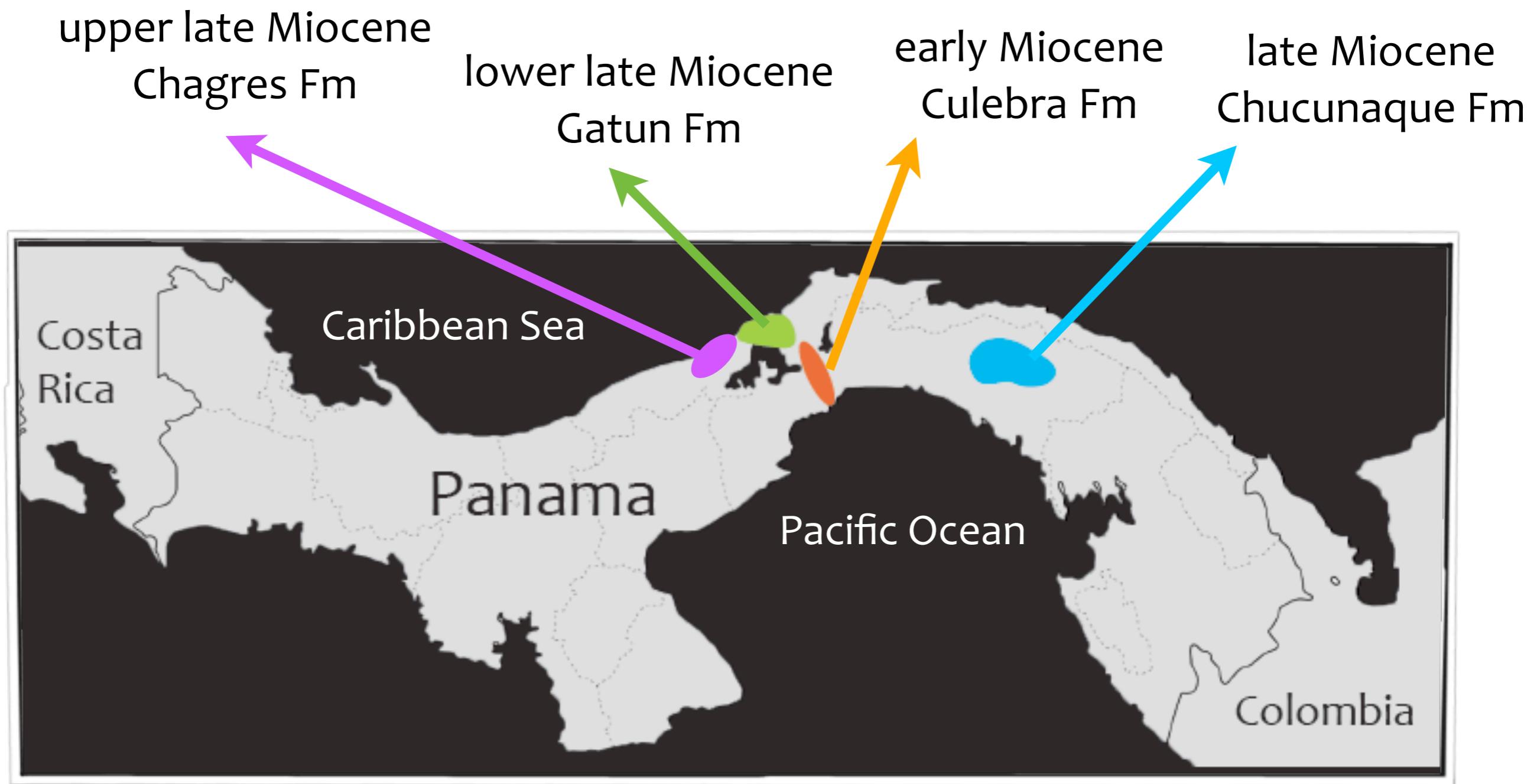
# ►the isthmus that changed the world



# ►the isthmus that changed the world



## ► Miocene fossil shark localities

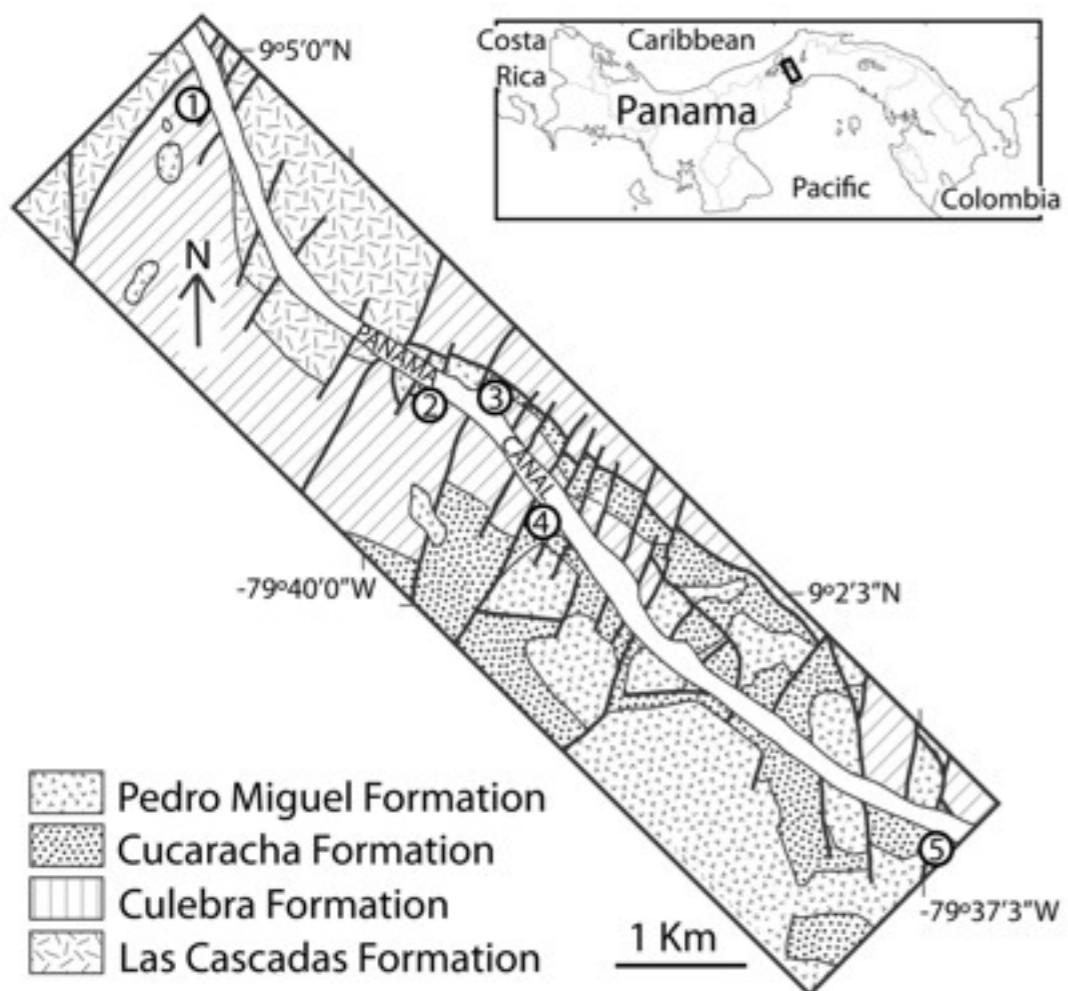


## ► Miocene fossil shark localities

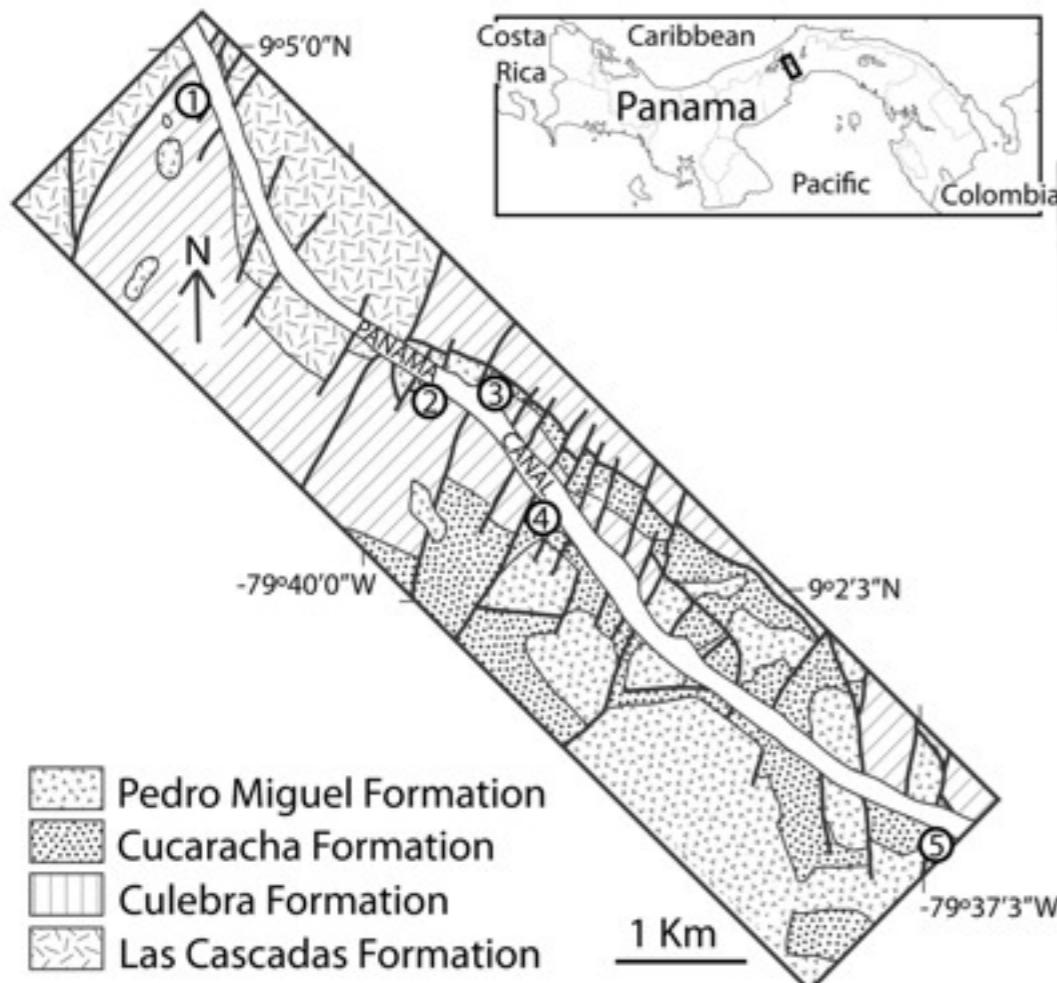




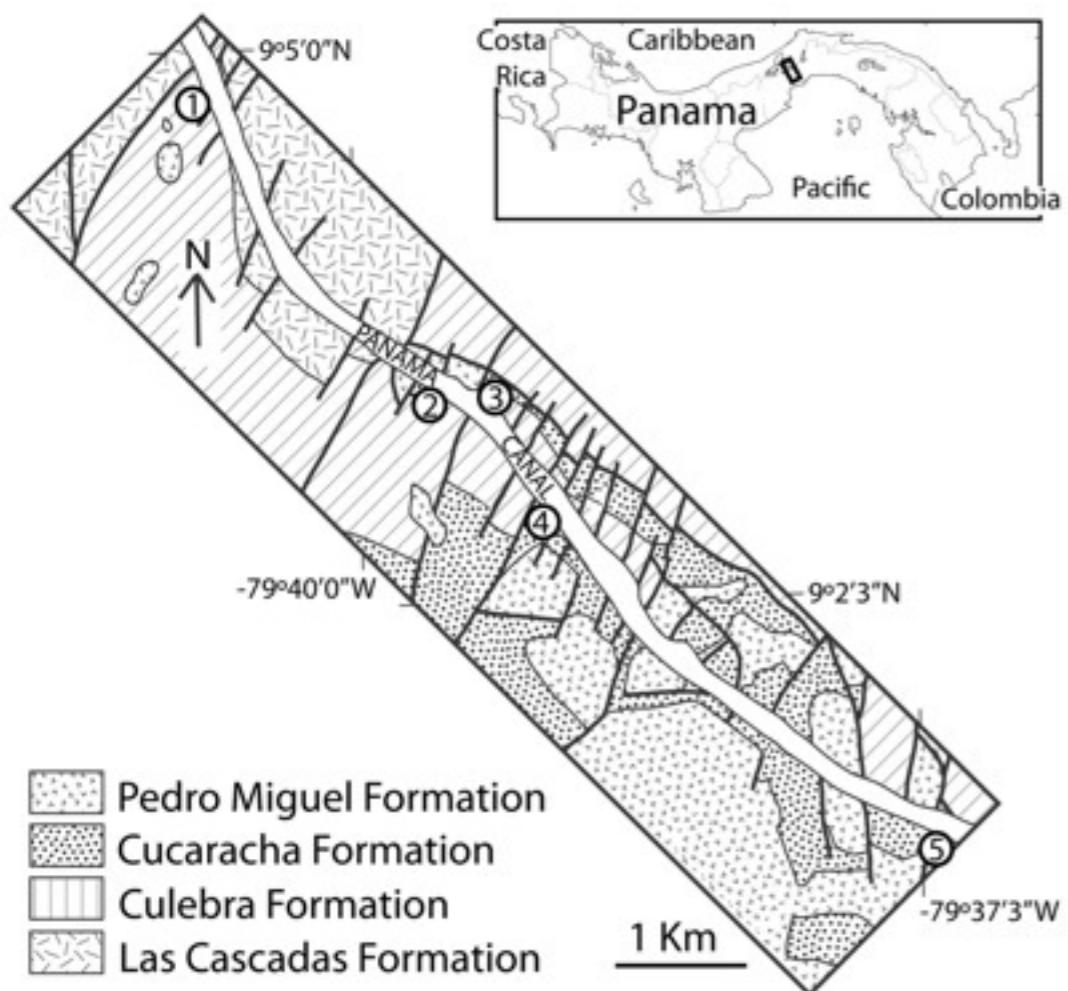
# ►early Miocene Culebra Formation



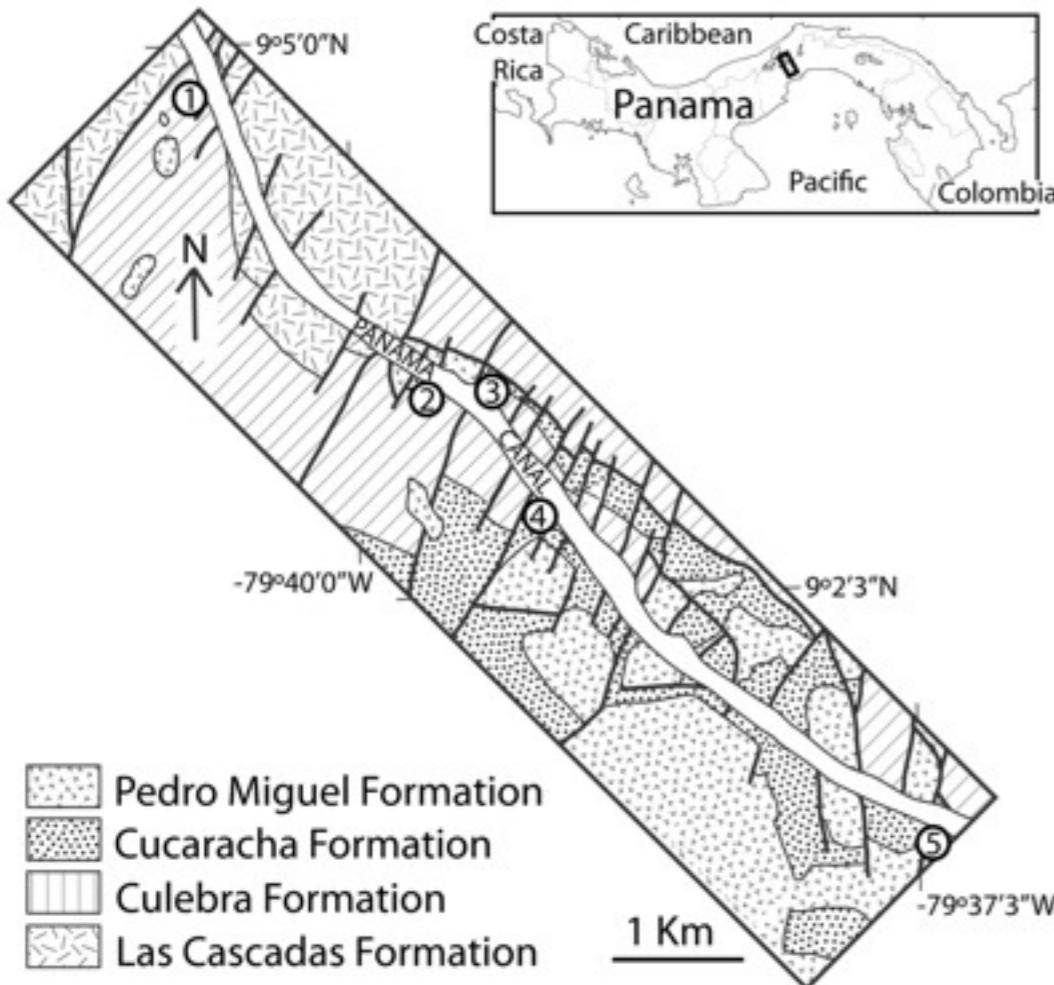
# ►early Miocene Culebra Formation



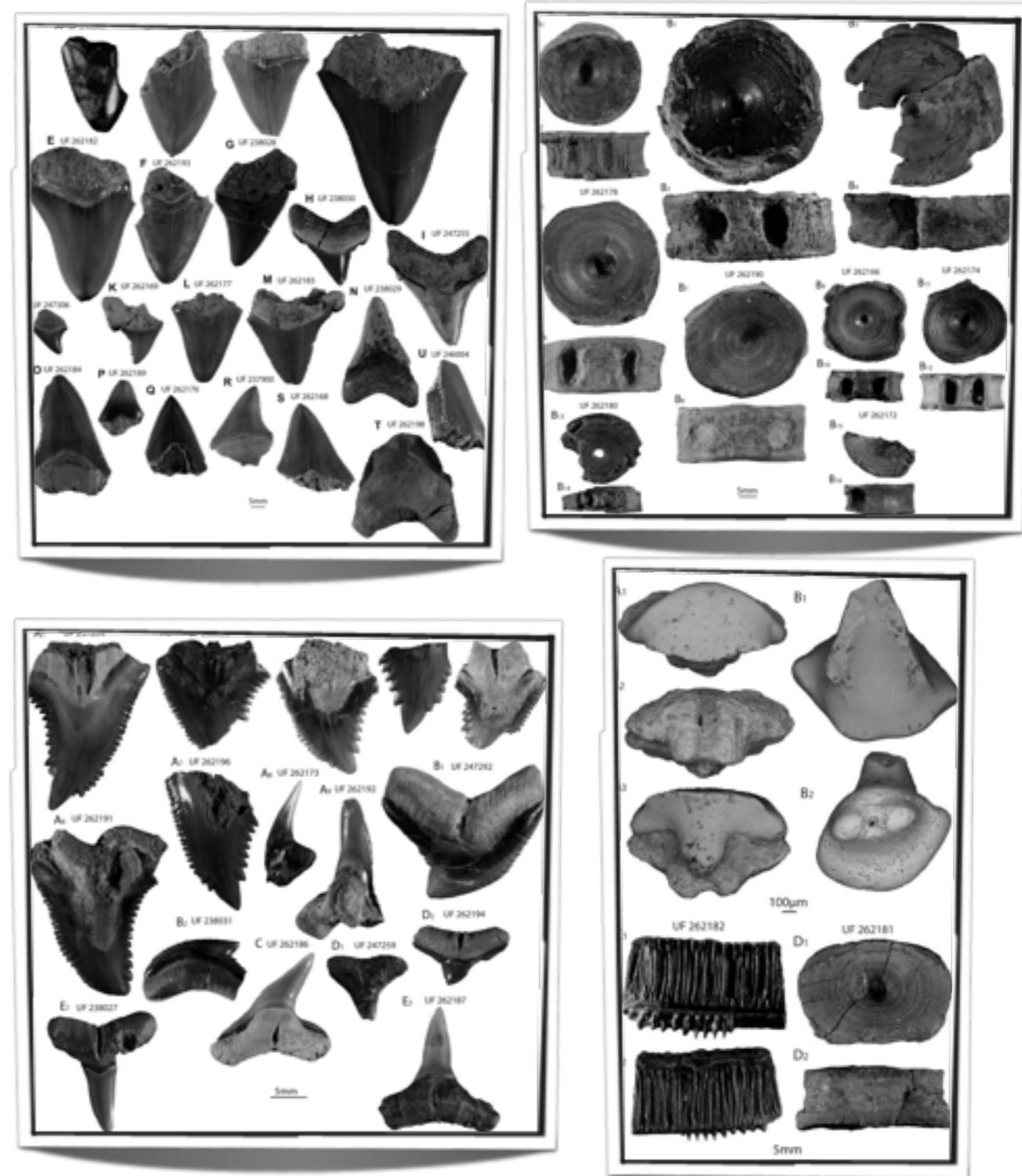
# ►early Miocene Culebra Formation



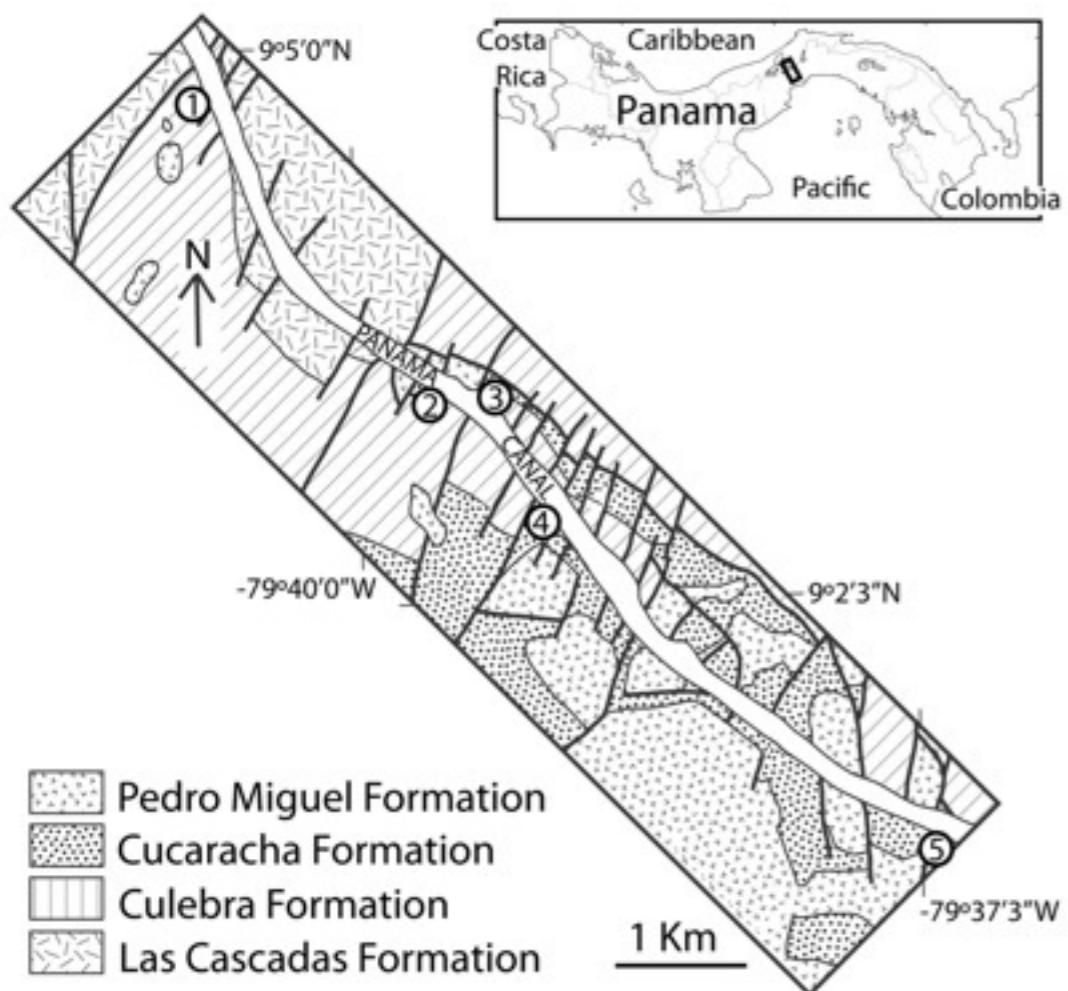
# ►early Miocene Culebra Formation



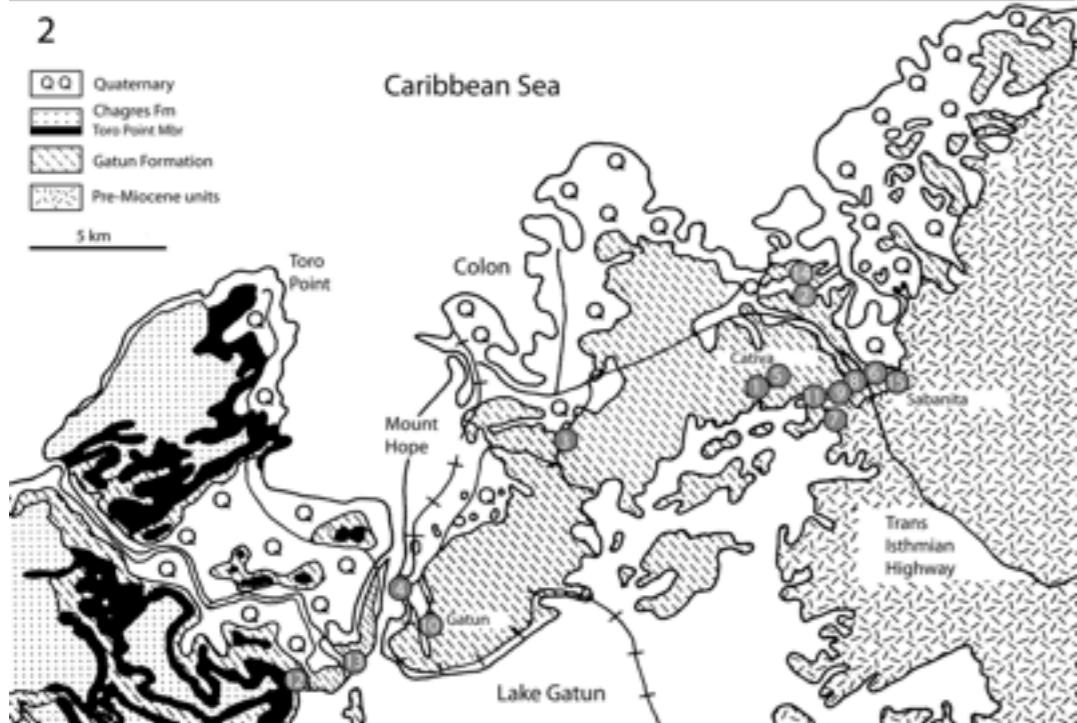
Pedro Miguel Formation  
 Cucaracha Formation  
 Culebra Formation  
 Las Cascadas Formation



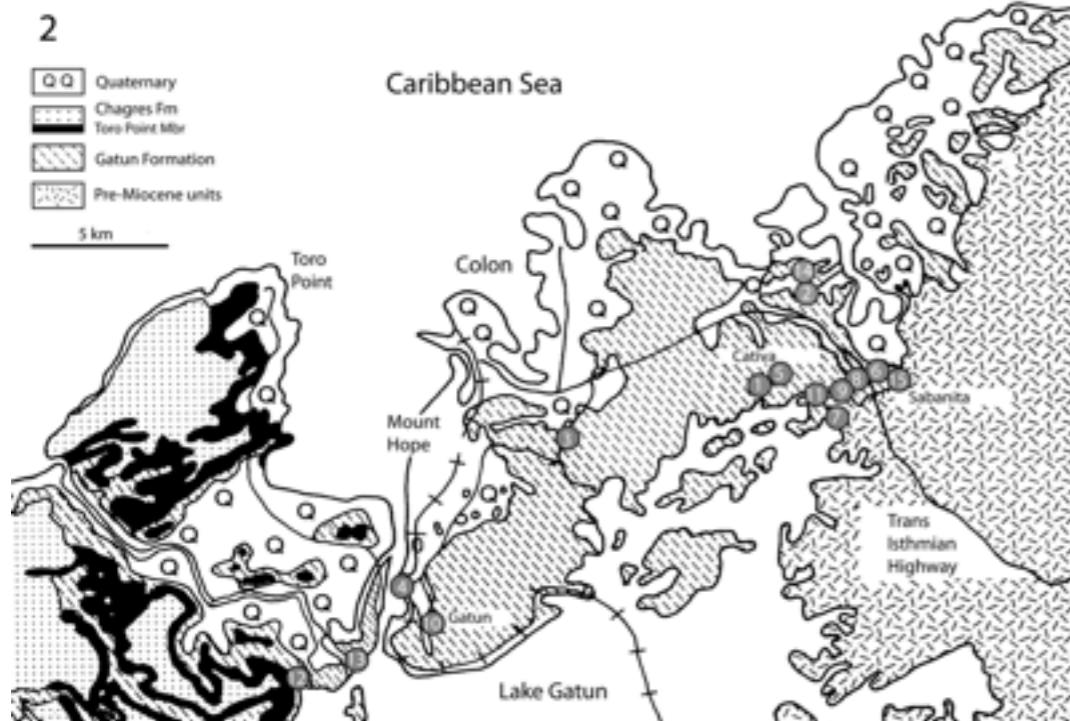
# ►early Miocene Culebra Formation



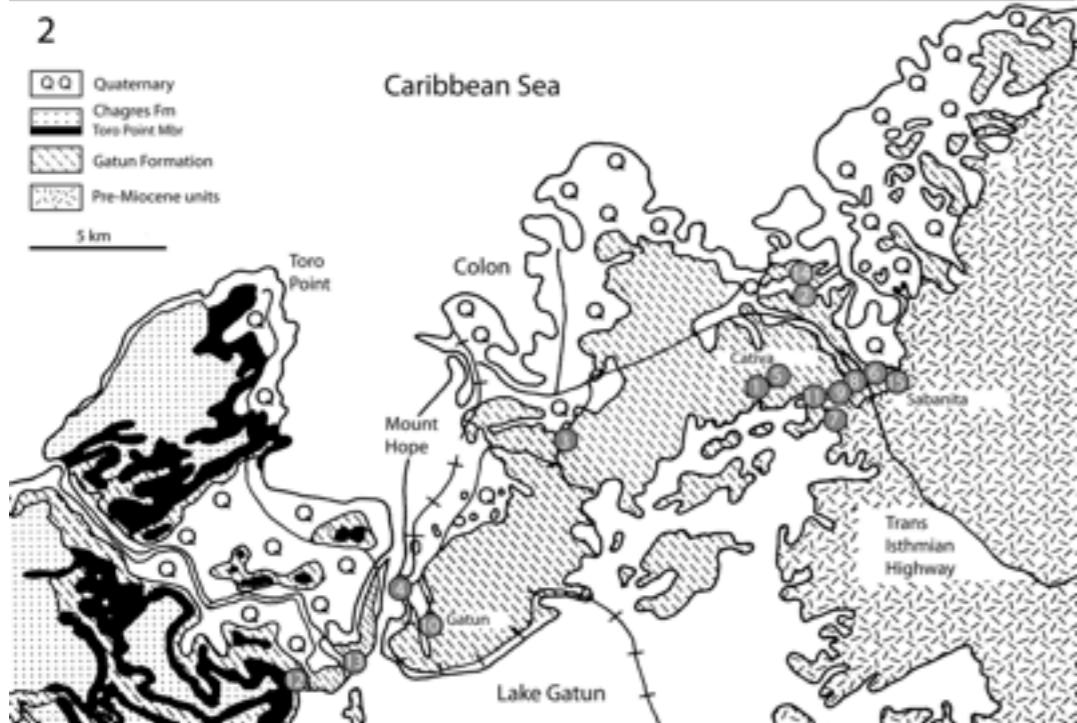
# ►late Miocene Gatun Formation



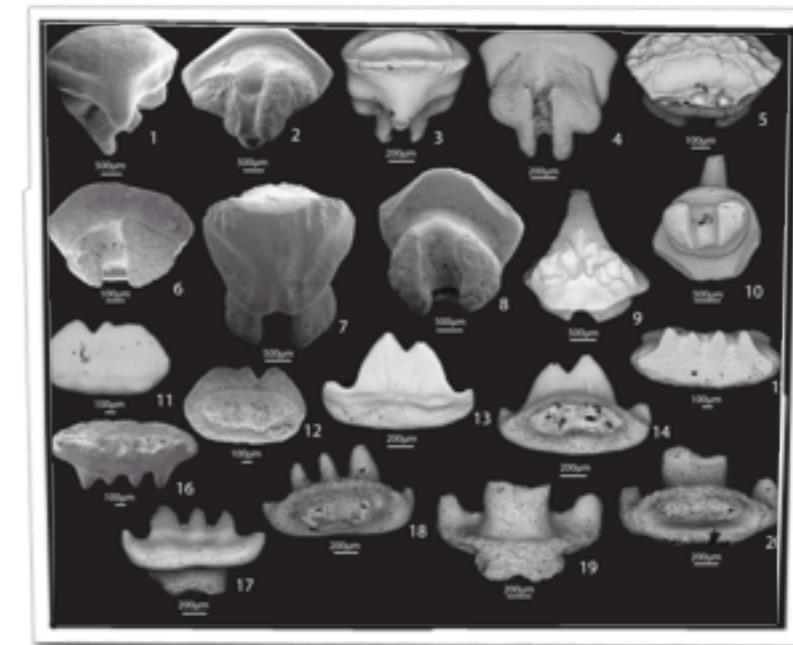
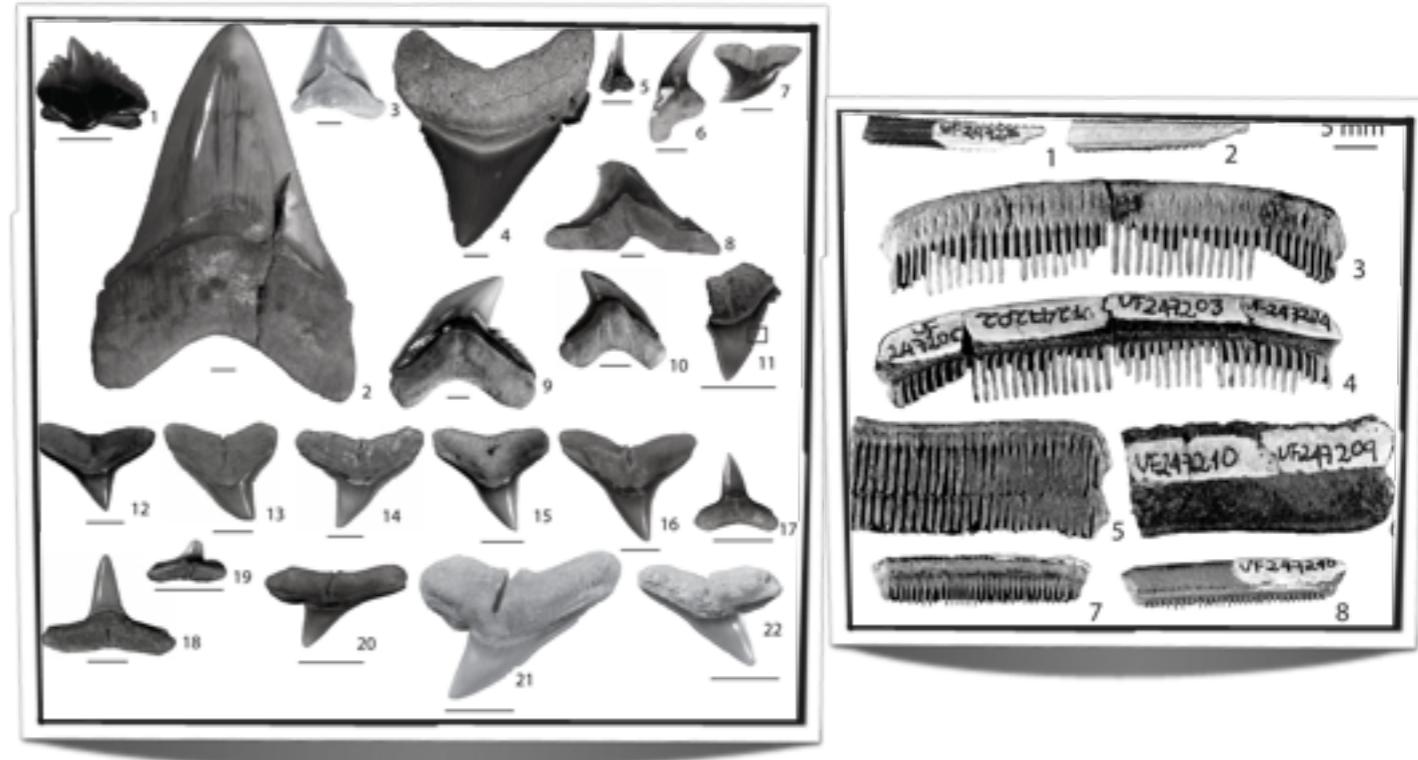
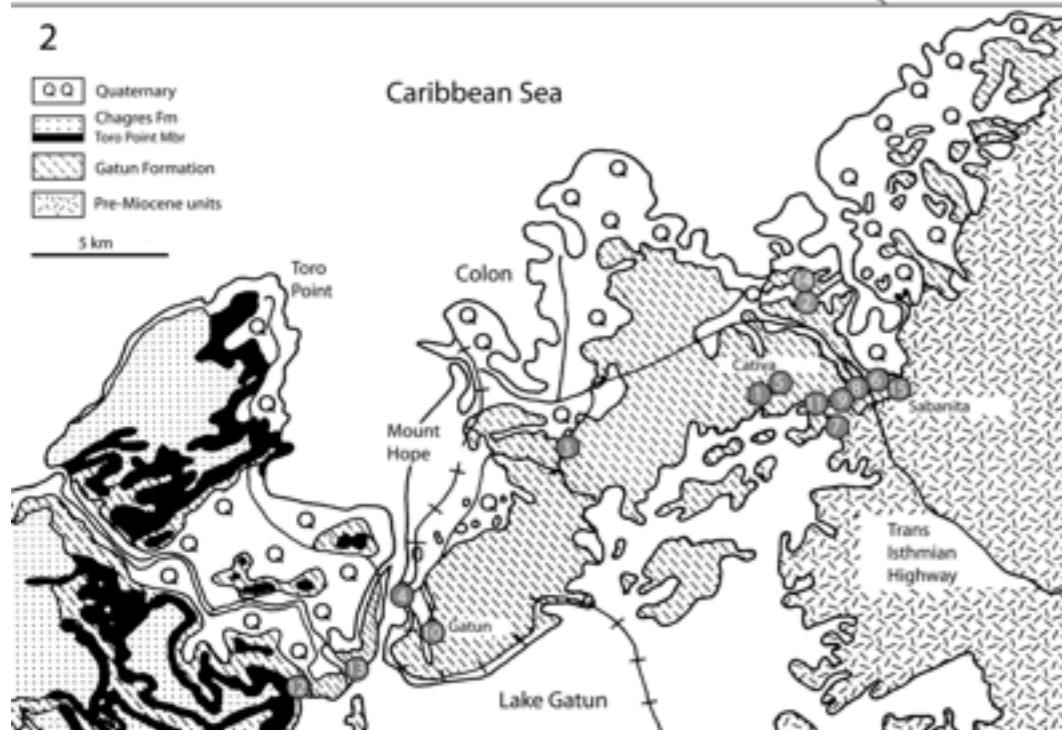
# ►late Miocene Gatun Formation



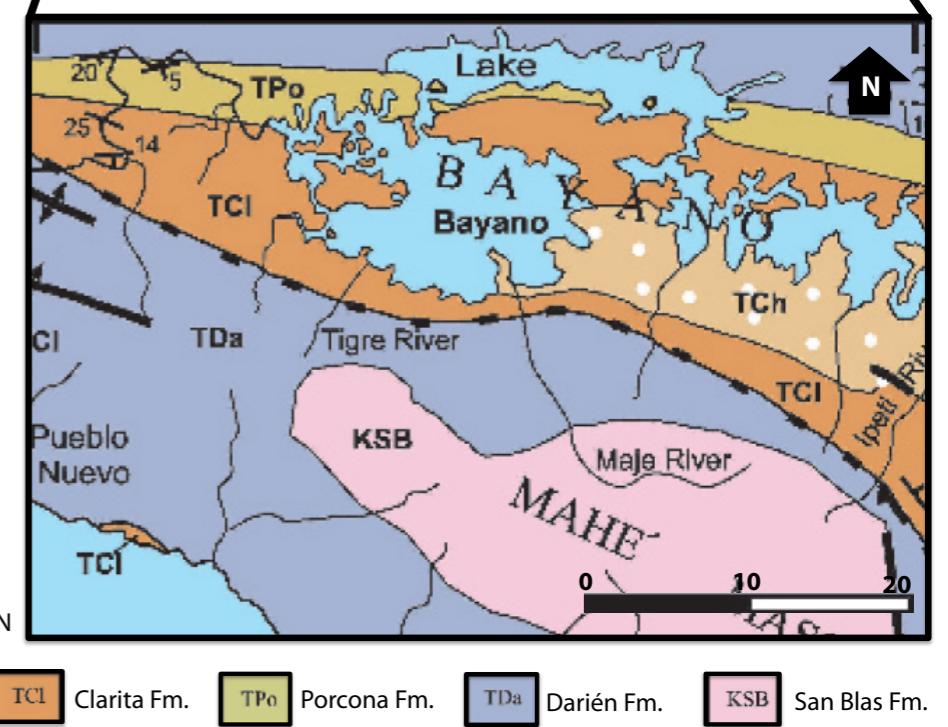
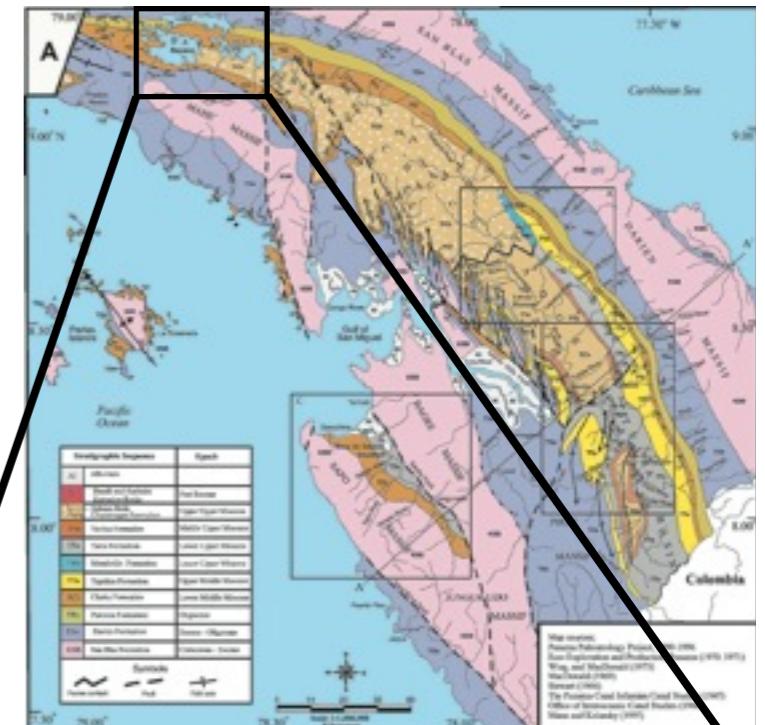
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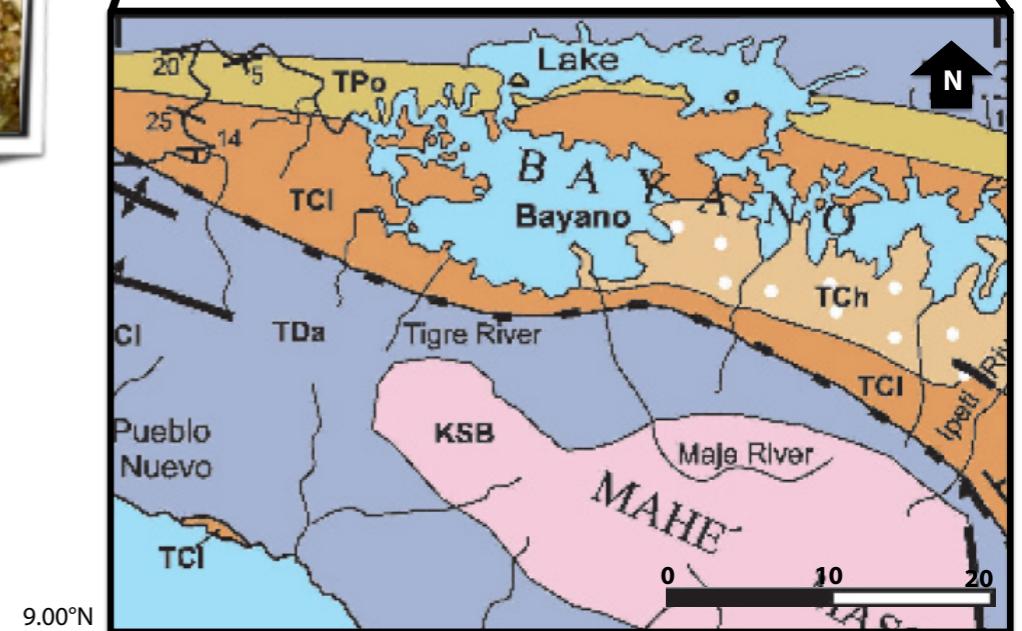
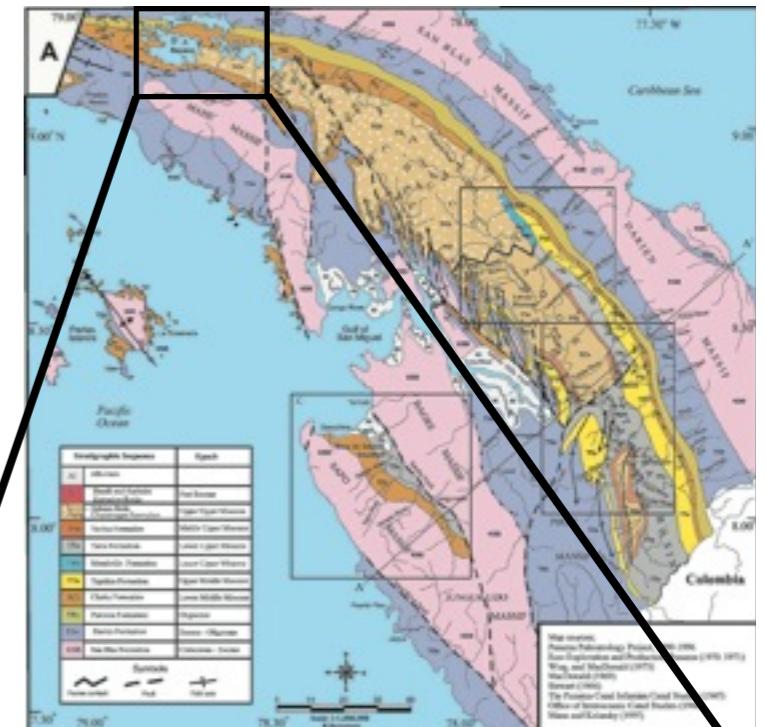
# ►late Miocene Gatun Formation



# ►late Miocene Chucunaque Formation

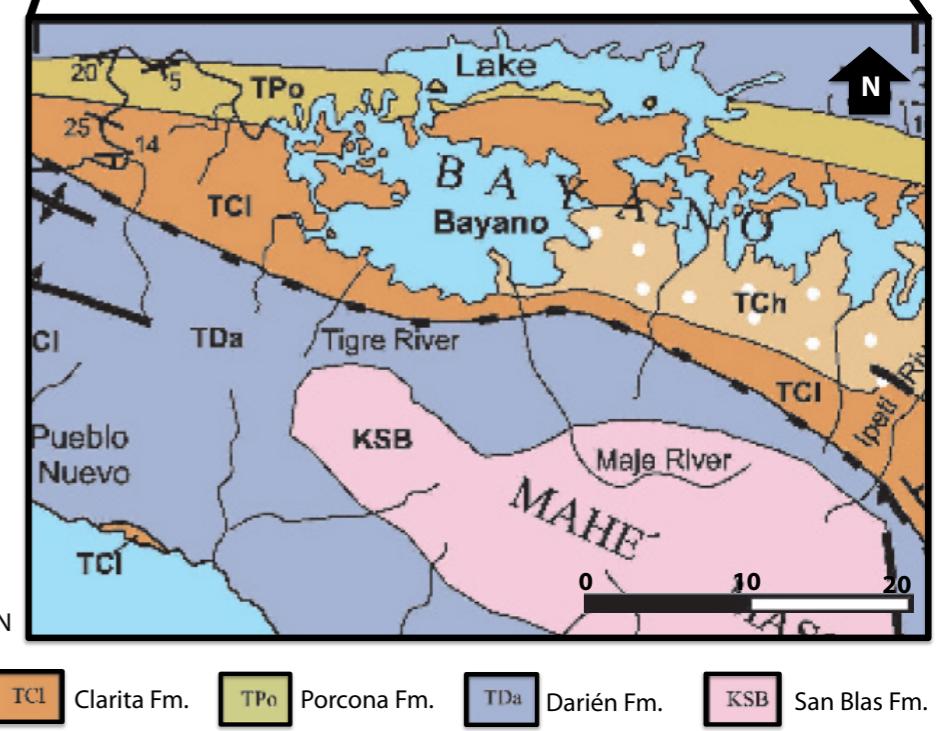
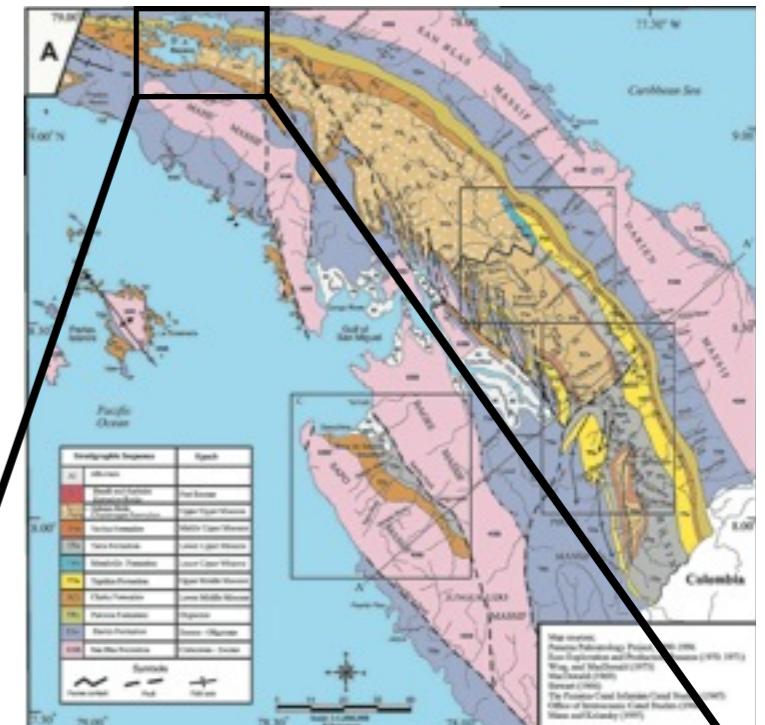


# ►late Miocene Chucunaque Formation

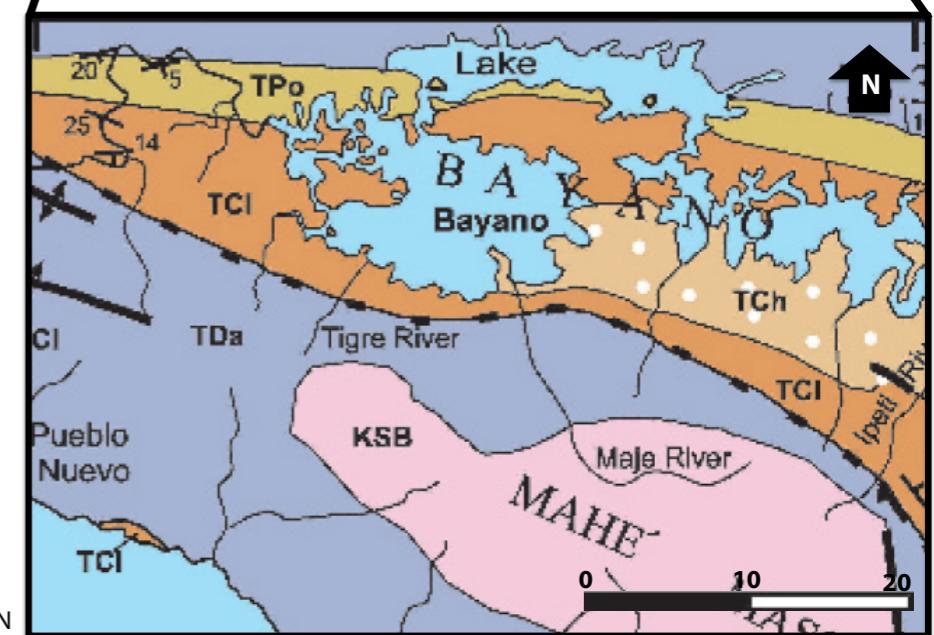
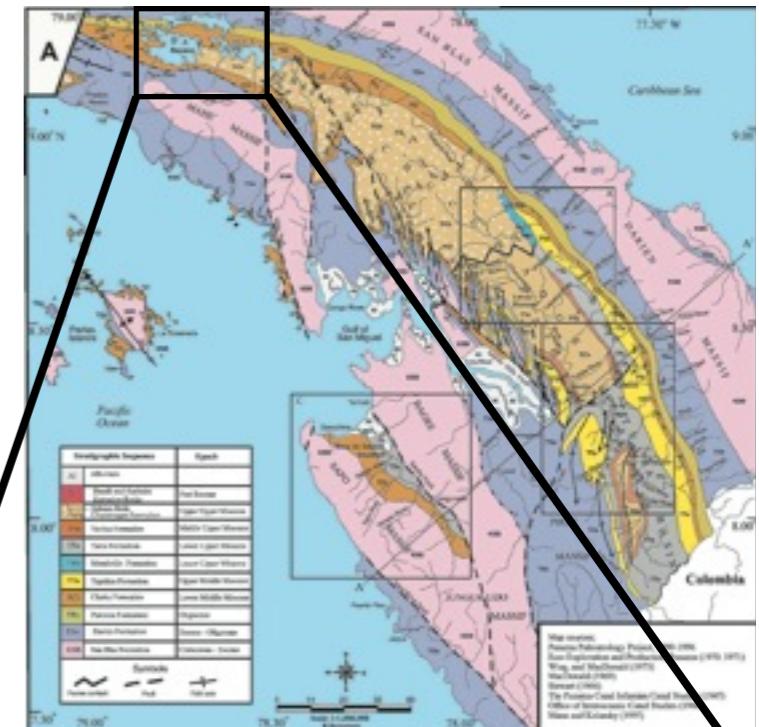


TCl Clarita Fm. TPo Porconia Fm. TDa Darién Fm. KSB San Blas Fm.

# ►late Miocene Chucunaque Formation



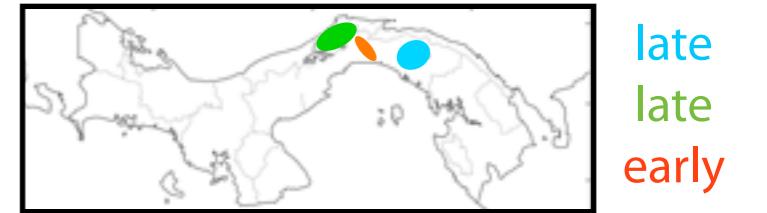
# ►late Miocene Chucunaque Formation



TCI Clarita Fm. TPo Porconia Fm. TDa Darién Fm. KSB San Blas Fm.

Coates et al. 2004

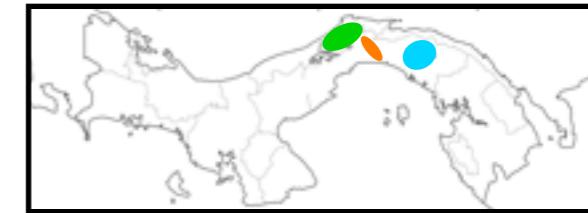
## ► Miocene shark faunas: Biodiversity



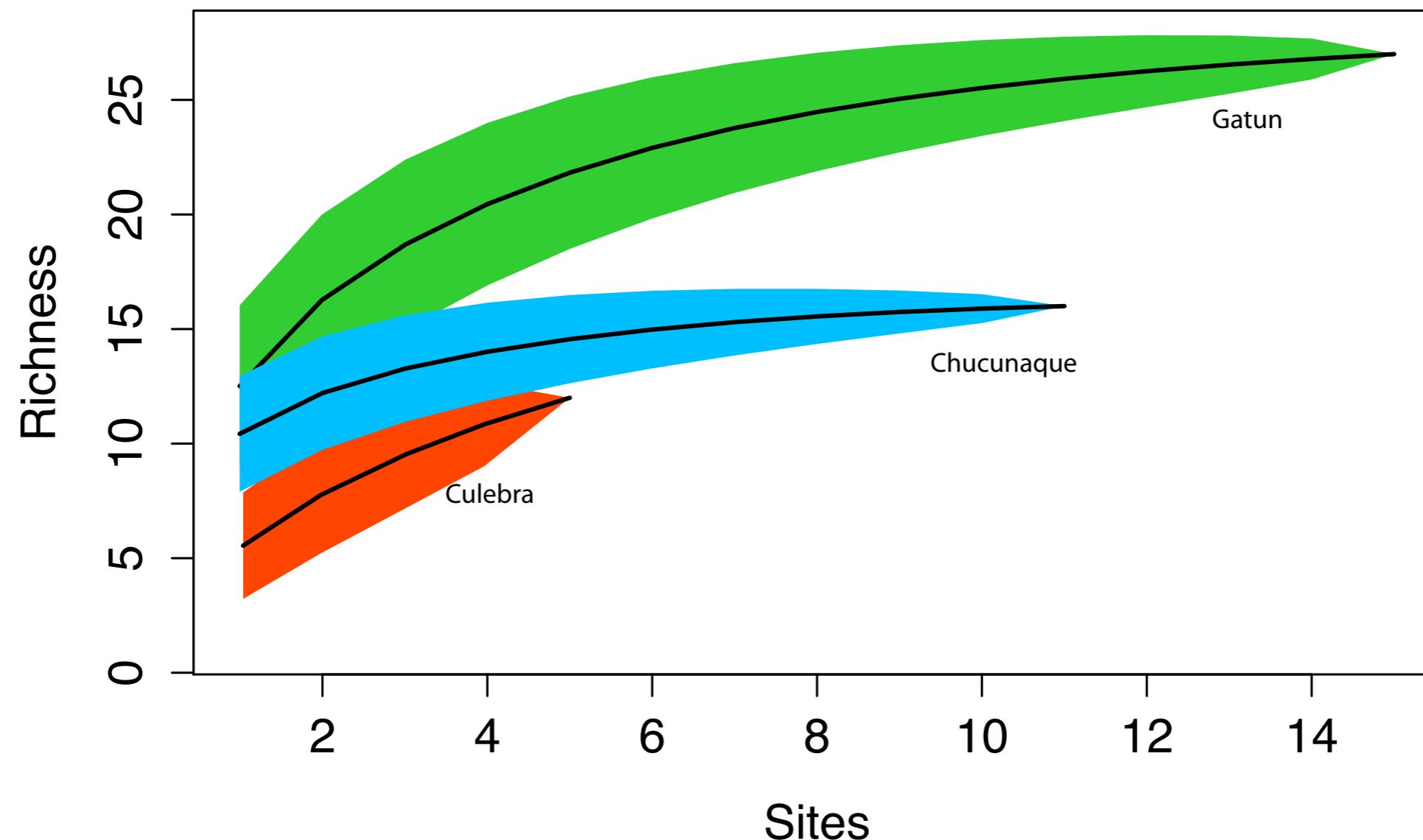
At least 32 taxa so far...

Only 4 are extinct

# ► Miocene shark faunas: Biodiversity

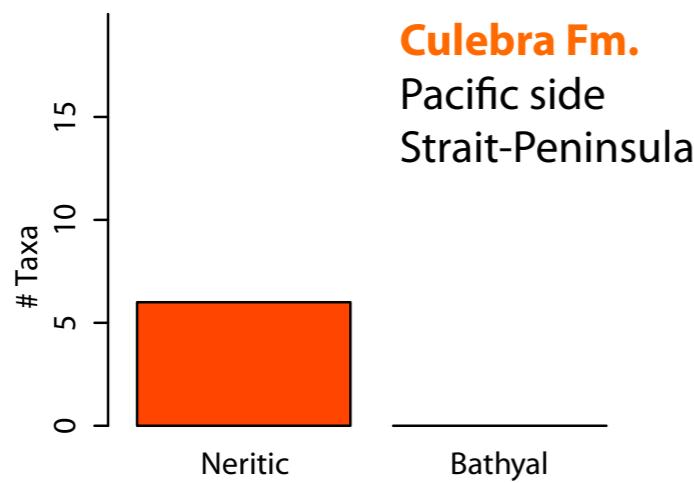
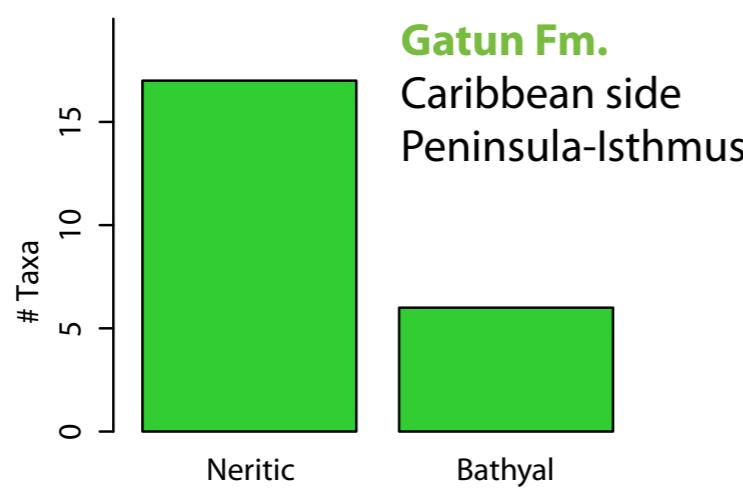
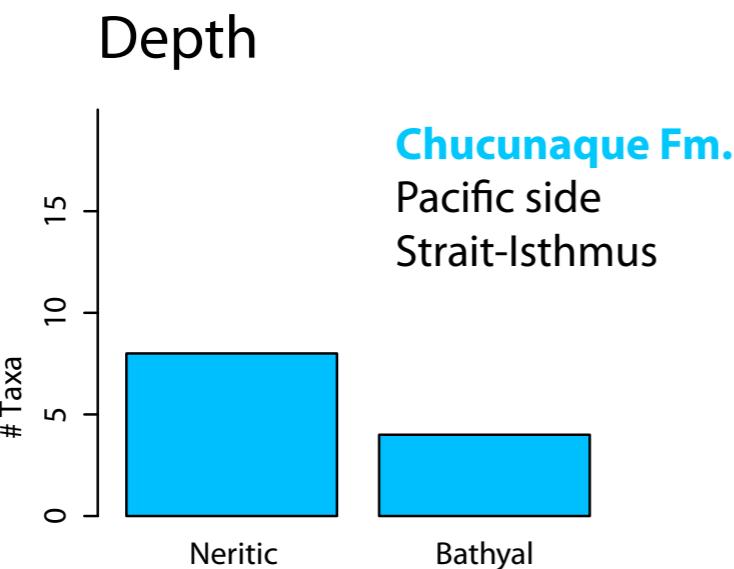
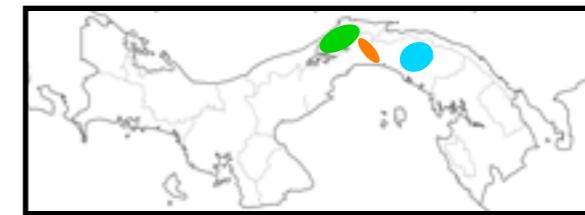


At least 32 taxa so far...  
Only 4 are extinct

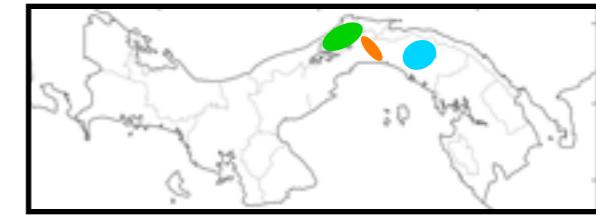


late  
late  
early

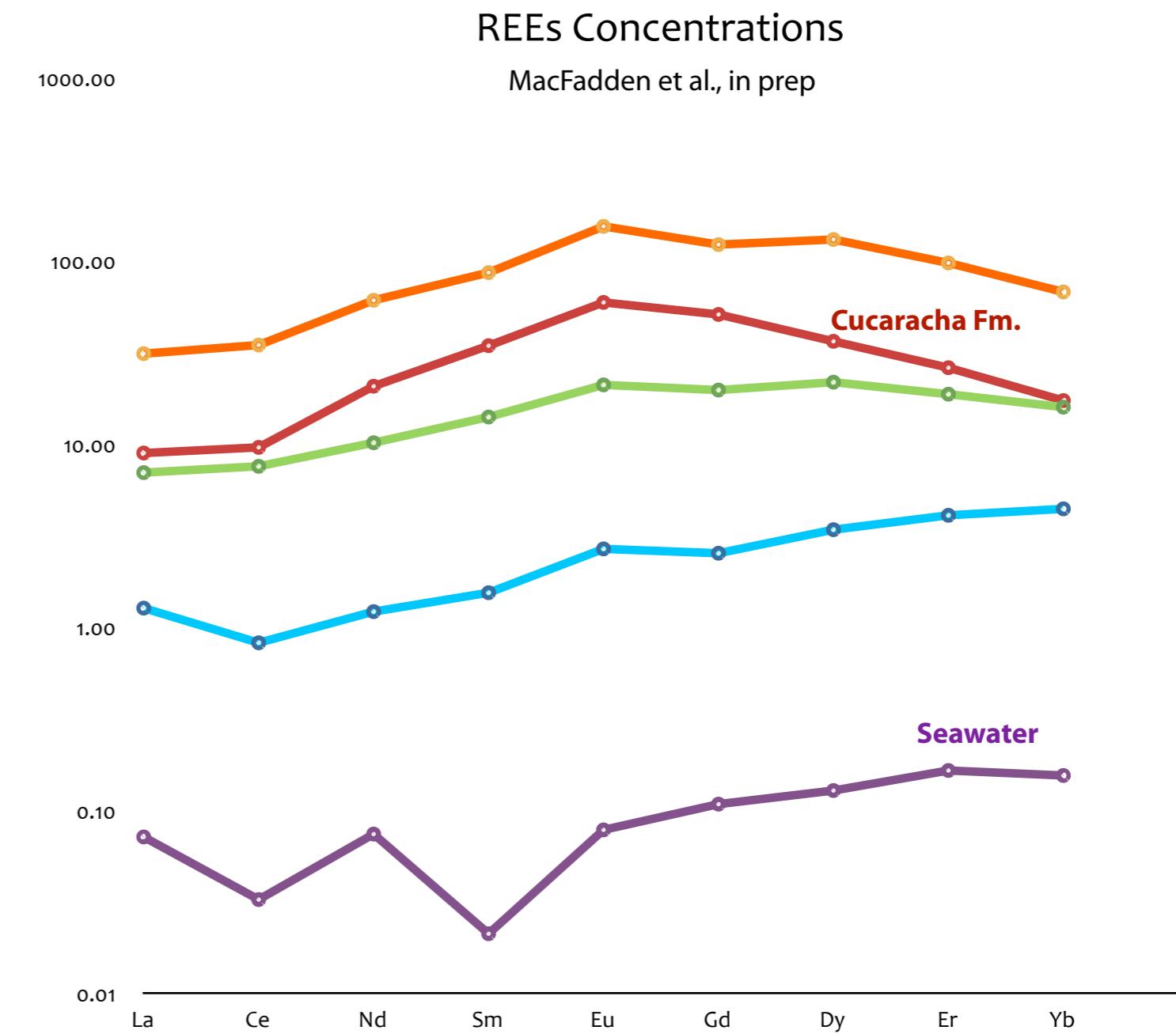
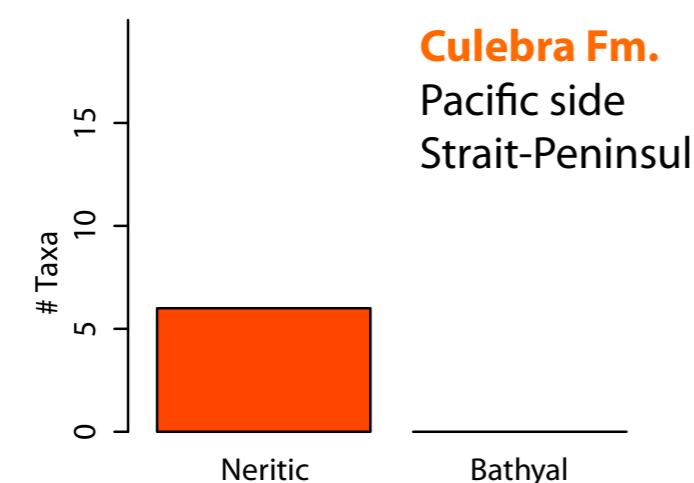
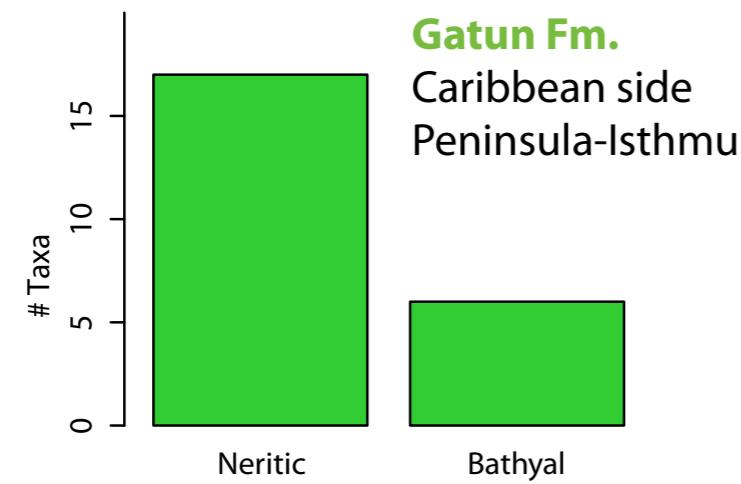
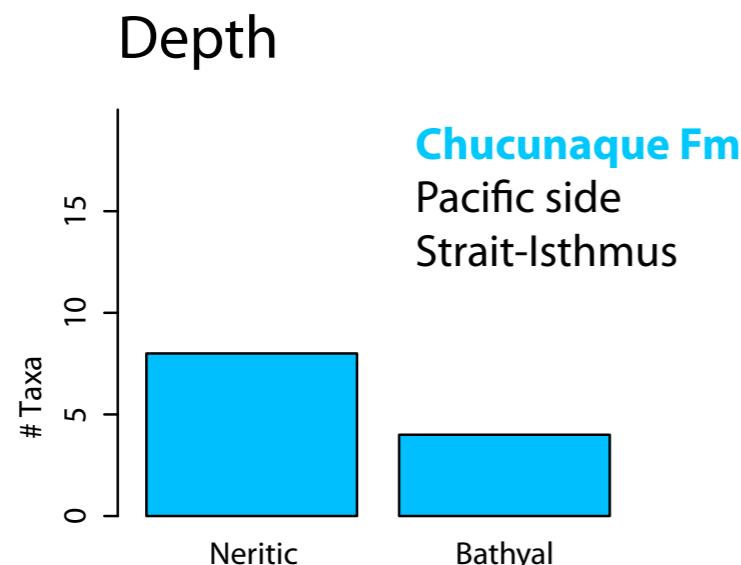
# ► Miocene shark faunas: Environment



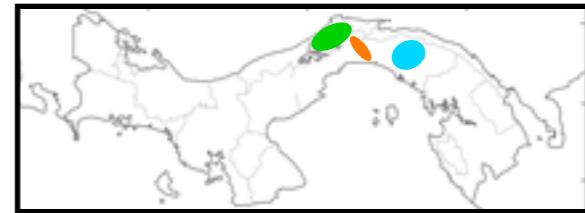
# ► Miocene shark faunas: Environment



late  
late  
early



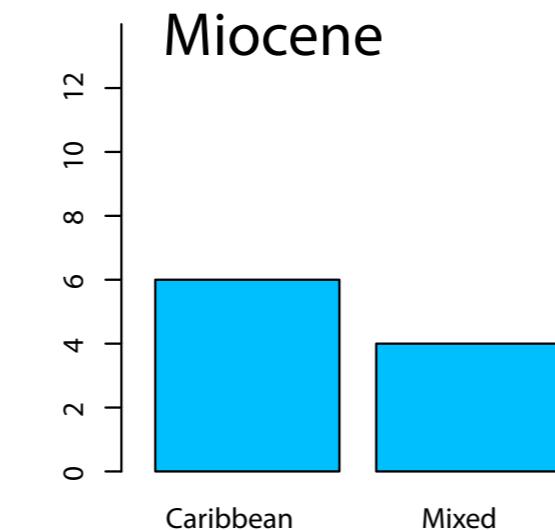
# ► Miocene shark faunas: Biogeography



late  
late  
early

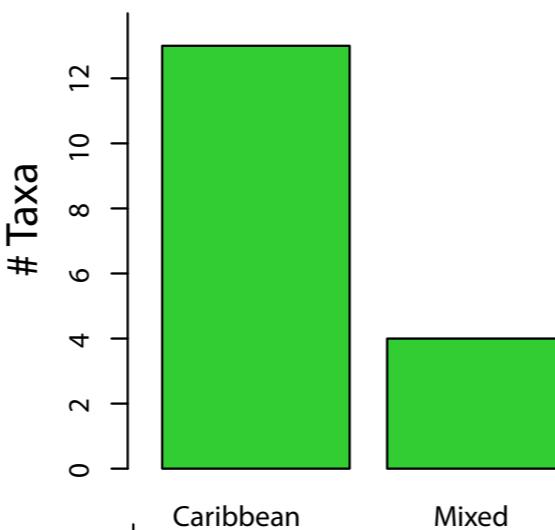
## Chucunaque Fm.

Pacific side  
Strait-Isthmus



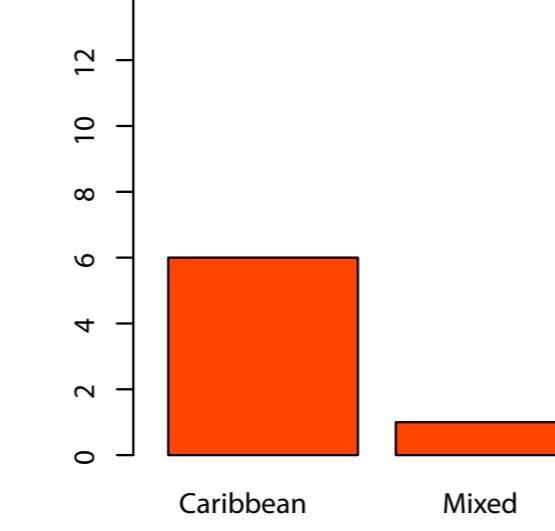
## Gatun Fm.

Caribbean side  
Peninsula-Isthmus

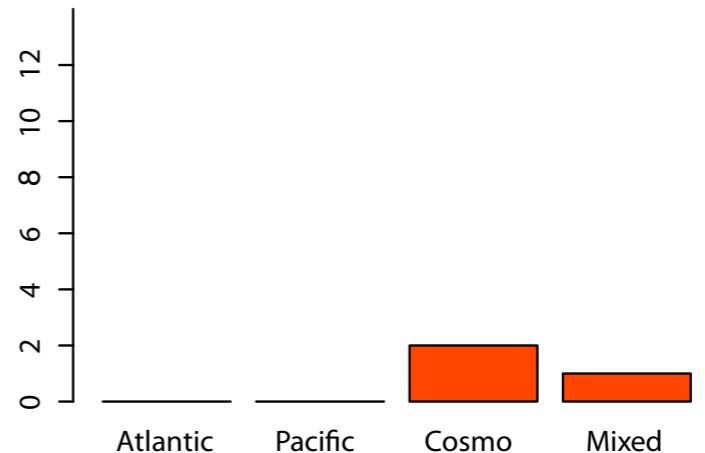
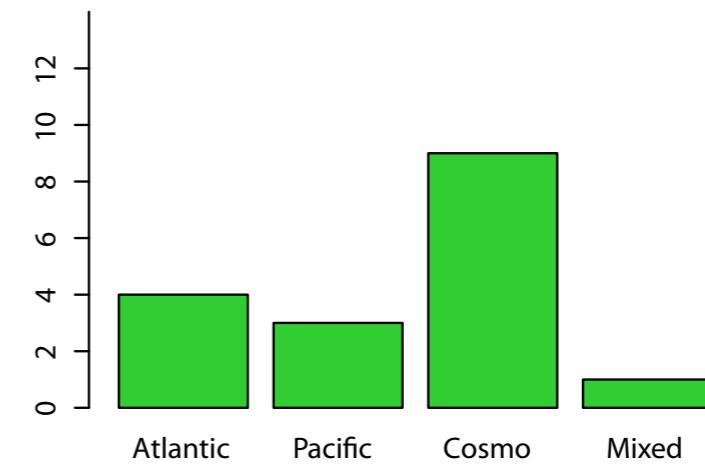
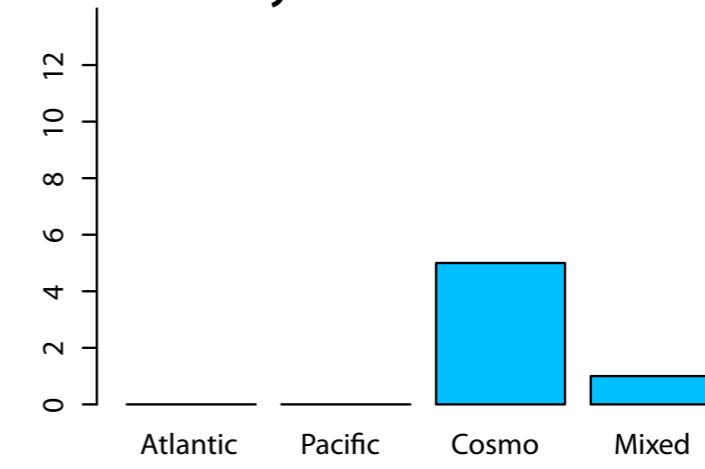


## Culebra Fm.

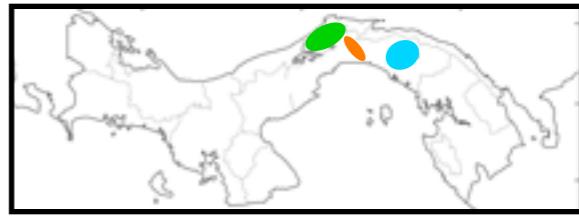
Pacific side  
Strait-Peninsula



## Today



# ► Miocene shark faunas: Biogeography



late  
late  
early

Miocene

Today

Largest marine predator of  
all time

# ►Megalodon



# ►nursery area for Megalodon



Pimienta et al. 2010

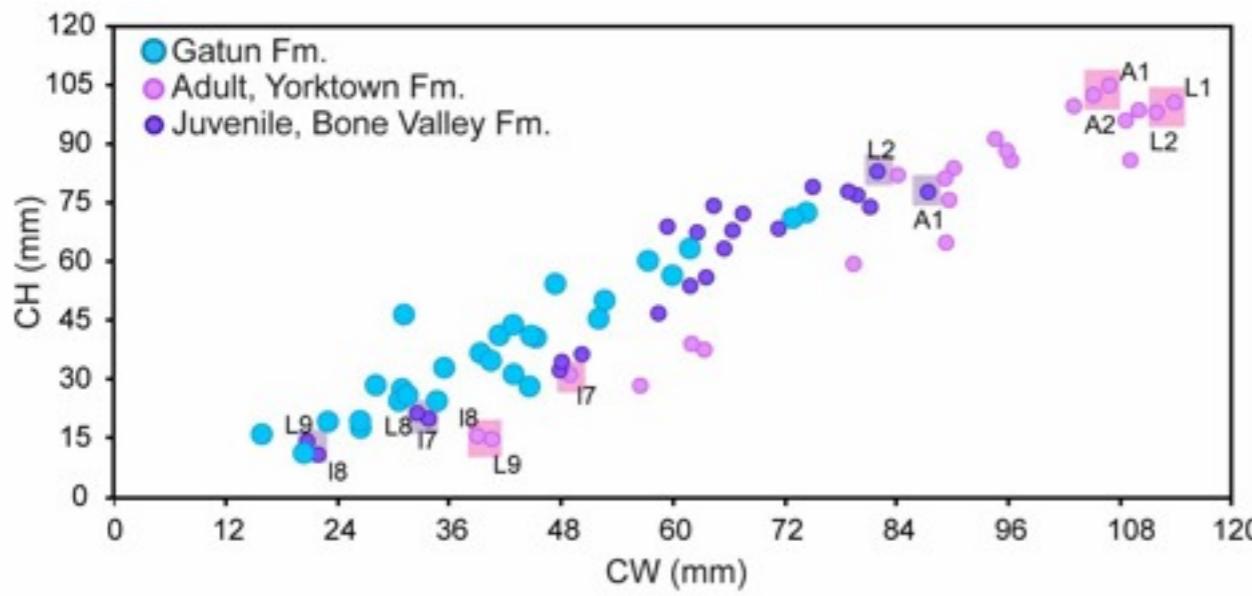
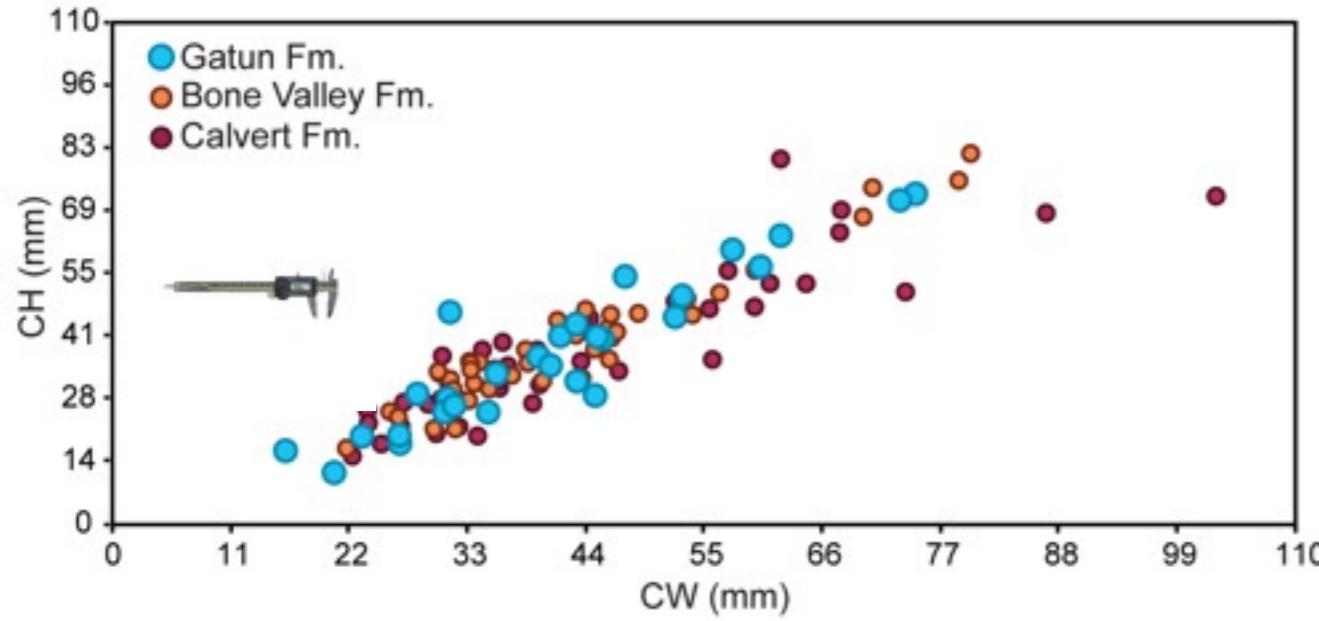


# Nursery Habitats

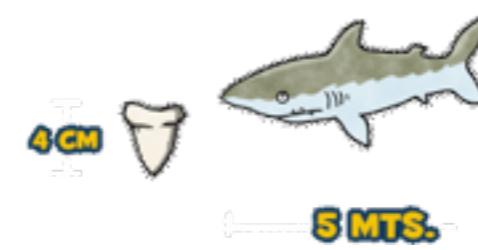


- \* Essential habitats for sharks survival
- \* Juveniles y neonates
- \* Food + Protection = Productive + Shallow waters

# ►nursery area for Megalodon



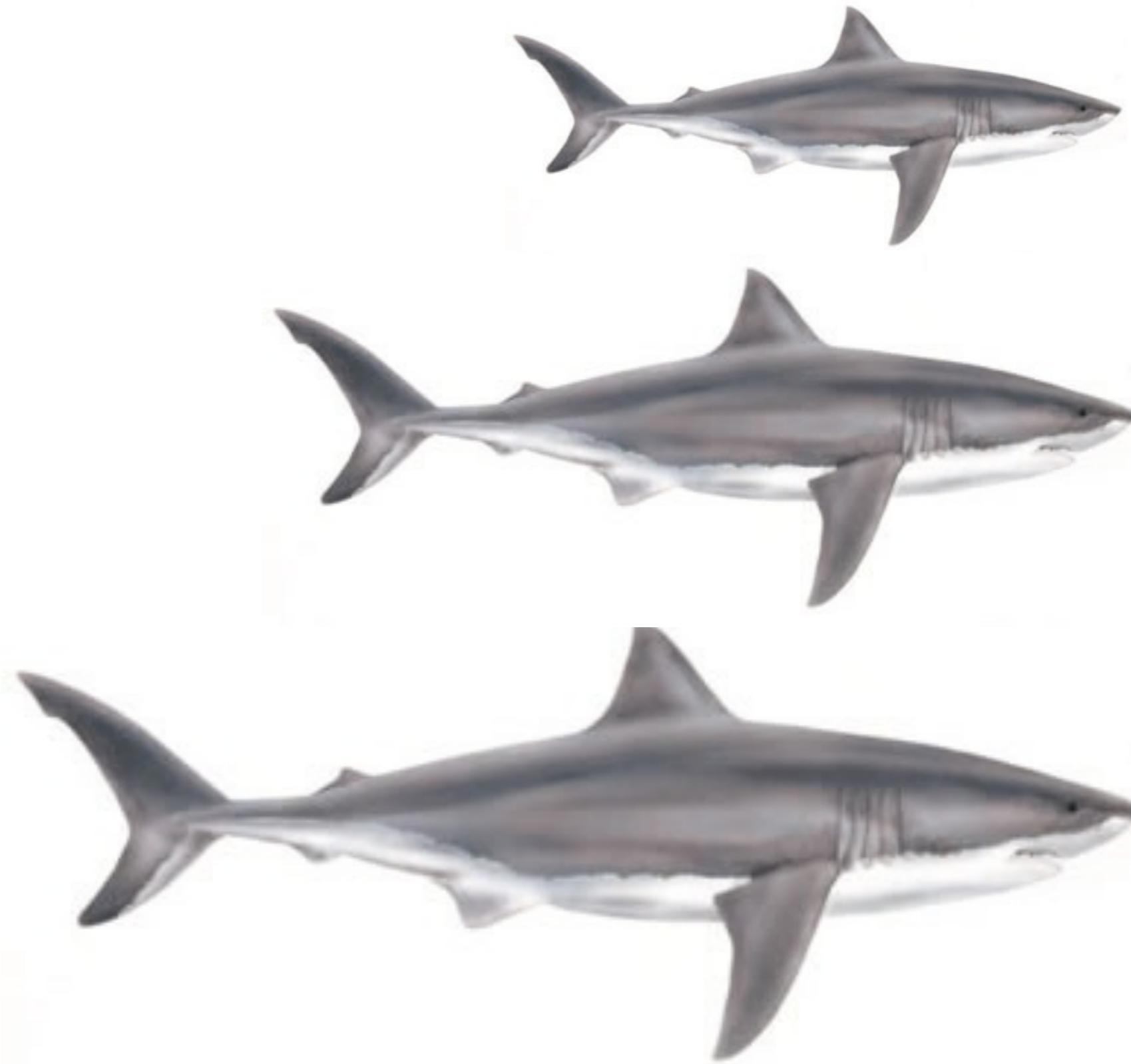
White Shark



Megalodon



# ►future plans



body size

— Geologic Time —

# ►future plans

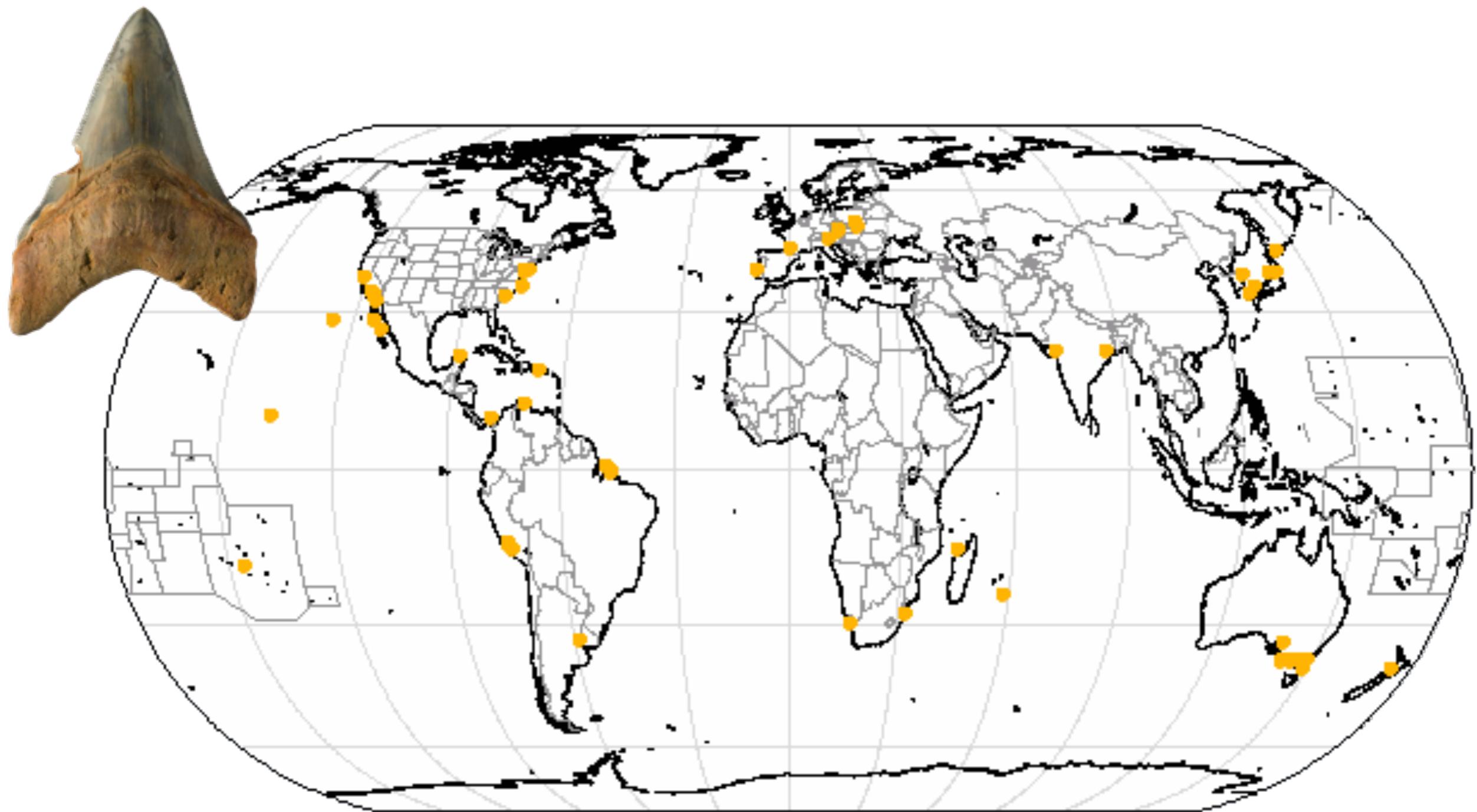
body size

# ►future plans

body size

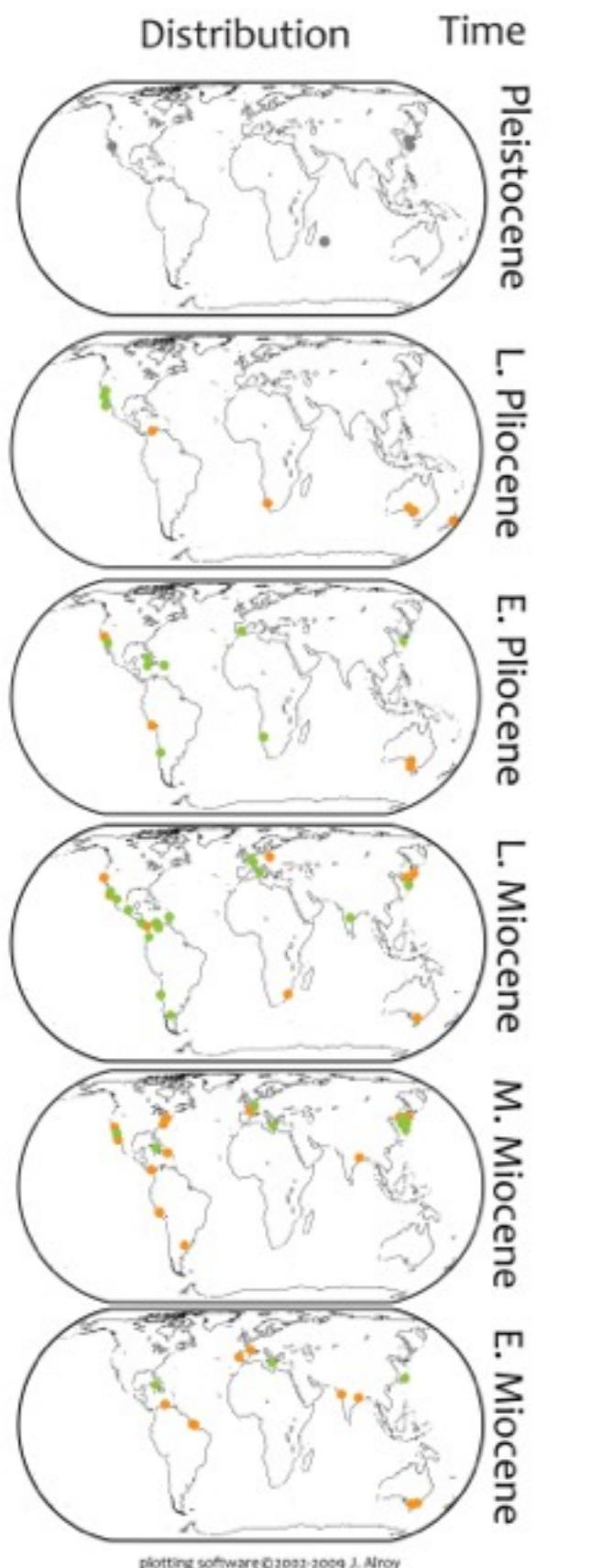
Ocean	Lat.	Country	Formation	Age	Collection
Atlantic	Central	Venezuela	Cantaure	E. Miocene (18Ma)	Various
	North	US (MA)	Calvert	M. Miocene (14Ma)	USNMNH
	North	US (VA)	St. Marys	M. Miocene (14Ma)	FLMNH
	North	US (NC)	Pungo River	L. Miocene (12Ma)	USNMNH
	South	Argentina	Paraná	M. Miocene (12Ma)	NHM BsAs/La Plata
	Central	Panama	Gatun	L. Miocene (10Ma)	FLMNH
	North	US (NC)	Yorktown	E. Pliocene (6Ma)	USNMNH
	North	US (FL)	Bone Valley	E. Pliocene (5Ma)	FLMNH
	Central	Venezuela	Paraguaná	L. Pliocene (3.5Ma)	Various
Pacific	North	USA (CA)	Rosarito	E. Miocene (18Ma)	SDNHM
	North	USA (CA)	Temblor	M. Miocene (14Ma)	UCMP, SDNHM
	South	Peru	Pisco (Ica)	M. Miocene (12Ma)	NHM Lima
	South	Peru	Pisco (El Jahuay)	L. Miocene (10Ma)	NHM Lima
	North	USA (CA)	St.Margarita, St.Mateo	L. Miocene (10Ma)	UCMP, SDNHM
	South	Peru	Pisco (Sud Sacaco)	L. Miocene (7Ma)	NHM Lima
	South	Chile	Bahía Inglesa	L. Miocene (7Ma)	NHM Santiago
	South	Chile	Bahía Inglesa	E. Pliocene (4Ma)	NHM Santiago
	Central	Ecuador	Onzole	E. Pliocene (4Ma)	British Mus.
Indian	Central	Australia	Batesford, Gippsland	E. Miocene (18Ma)	Victoria Mus.
	Central	Australia	Port Campbell	M. Miocene (11Ma)	Victoria Mus.
	Central	Australia	Black Rock	L. Miocene (8Ma)	Victoria Mus.
	Central	Australia	Whaler's Bluff, Loxton Sand	E. Pliocene (4Ma)	Victoria Mus.
	Central	Australia	Grange Burn, Cameron Inlet	L. Pliocene (3.5Ma)	Victoria Mus.

# geographic distribution size in deep time



plotting software 2002-2012 J. Alroy

# patterns of extinction

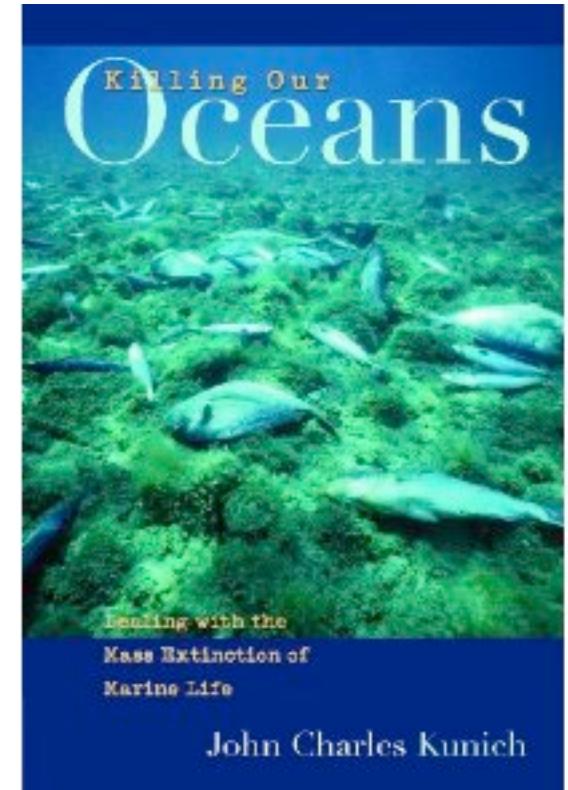
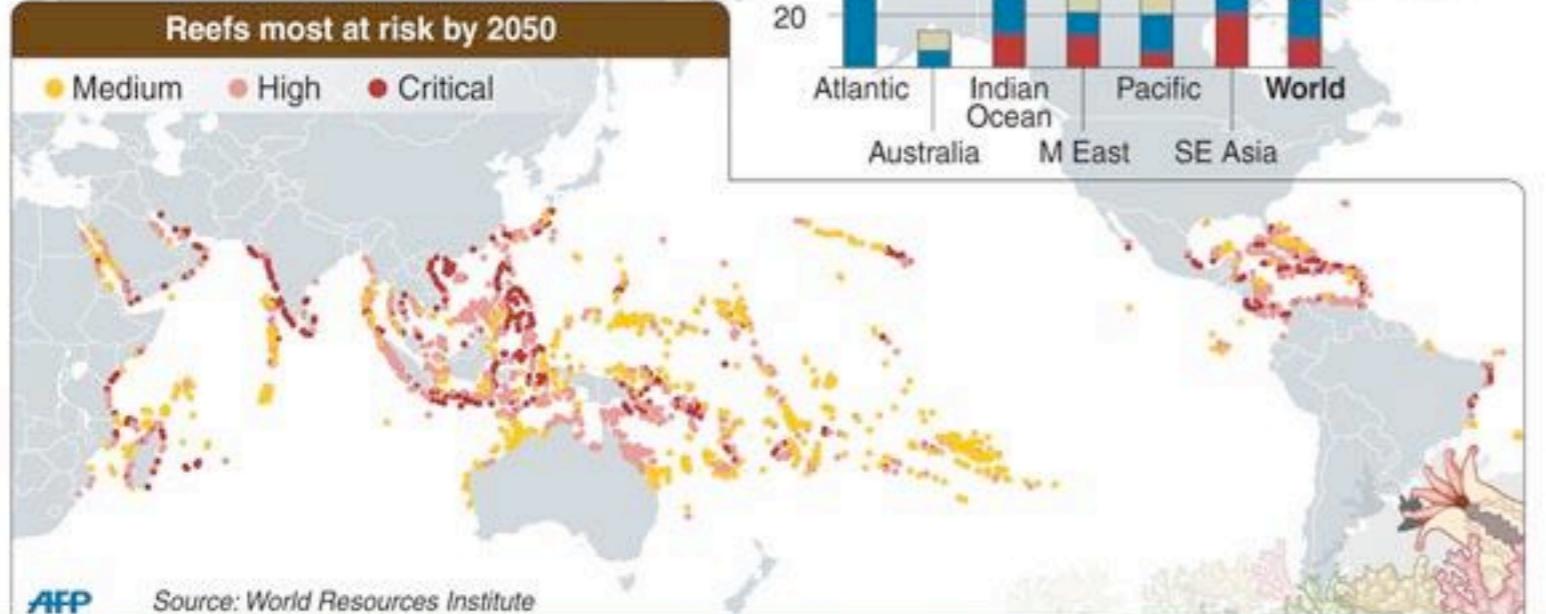


- What are the patterns of Megalodon extinction?
  - ✓ Distribution
- Why Megalodon became extinct?
  - ✓ Climate
  - ✓ Oceanography
  - ✓ Preys
  - ✓ Competitors

# why is this important?

## Reefs at risk

Overfishing, coastal development and pollution pose the most direct threats to the world's coral reefs



A monk seal is resting on a sandy beach, facing towards the right. The background shows a clear blue ocean and some low-lying vegetation.

A monk seal is swimming in clear blue water, surrounded by various coral reef structures. The seal is facing towards the left.

## DO MONK SEALS HAVE A PRAYER?

By Bruce Walsh

In Hawaii, scientists and conservationists are trying to stave off the extinction of one of the world's most critically endangered marine mammals.

through a strategy game of conservation

**For generations, Hawaiians have called the monk seal "Endohausen," or "dog running in the rough sea," a name this critically endangered marine mammal has certainly earned. Scientists and volunteers who now keep vigil over the seals are trying to outmaneuver the species' extinction in a rapidly changing and sometimes hostile environment by using a range of tactics, including relocating seals to where they predict will be safer shores.**

The Endohausen, also known as Hawaiian monk seals, which once roamed the waters of the 1,300-island Hawaiian archipelago, are thought to have disappeared from the main islands about 100 years ago. Today, the few hundred seals that remain are restricted to the remote, outer islands of the Hawaiian chain.

The last 100 years have seen a dramatic increase in the number of monk seals, especially in the last 20 years.

Today, the monk seal population is estimated at around 1,200 individuals.

Monk seals are highly intelligent animals, and their ability to adapt to changing environments makes them

more successful than many other marine mammals. They are able to survive in a variety of environments, from shallow coastal waters to deep oceanic waters, and can even live in freshwater streams.

Monk seals are also very adaptable to changes in their environment. For example, they can switch from a diet of fish to a diet of squid, or even switch from a diet of squid to a diet of fish, depending on what is available.

Monk seals are also very good at avoiding predators. They are able to swim quickly and maneuver easily, which allows them to escape from predators like sharks and killer whales.

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**IN SEARCH OF SAFER SHORES**

Monk seals are the most

endangered marine mammals in the world, and their numbers have declined sharply in recent years.

Scientists believe that the decline is due to a combination of factors, including habitat loss, predation by sharks, and disease.

One of the most significant factors is habitat loss, as monk seals rely on specific types of coastal habitats for breeding and raising their young.

Sharks are another threat, as monk seals are often preyed upon by large sharks like tiger sharks and hammerheads.

Finally, disease is believed to play a role in the decline, particularly in the form of leptospirosis, a bacterial infection that can cause respiratory problems and death.

Given the severity of the problem, conservation efforts have been focused on identifying and protecting key habitats for monk seals, as well as monitoring populations and addressing threats like shark predation and disease.

While these efforts are important, it is also crucial to address the underlying causes of monk seal decline, such as habitat loss and predation by sharks.

Overall, the future of monk seals remains uncertain, but through continued research and conservation efforts, there is hope for their survival.

Monk seals are a unique and fascinating part of the marine ecosystem, and their survival is crucial for the health and well-being of the planet.

As we work to protect these amazing animals, let us remember that every action we take, no matter how small, can make a difference in their survival.

Let's do our part to ensure that monk seals continue to grace our oceans for generations to come.

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# Implications: Conservation

Approximately 17% of sharks and their relatives are threatened, an additional 13% are considered Near Threatened, and a high proportion (47%) are Data Deficient. IUCN 2010

## Trophic Downgrading of Planet Earth

James A. Estes,<sup>1\*</sup> John Terborgh,<sup>2</sup> Justin S. Brashares,<sup>3</sup> Mary E. Power,<sup>4</sup> Joel Berger,<sup>5</sup> William J. Bond,<sup>6</sup> Stephen R. Carpenter,<sup>7</sup> Timothy E. Essington,<sup>8</sup> Robert D. Holt,<sup>9</sup> Jeremy B. C. Jackson,<sup>10</sup> Robert J. Marquis,<sup>11</sup> Lauri Oksanen,<sup>12</sup> Tarja Oksanen,<sup>13</sup> Robert T. Paine,<sup>14</sup> Ellen K. Pikitch,<sup>15</sup> William J. Ripple,<sup>16</sup> Stuart A. Sandin,<sup>10</sup> Marten Scheffer,<sup>17</sup> Thomas W. Schoener,<sup>18</sup> Jonathan B. Shurin,<sup>19</sup> Anthony R. E. Sinclair,<sup>20</sup> Michael E. Soulé,<sup>21</sup> Risto Virtanen,<sup>22</sup> David A. Wardle<sup>23</sup>

Until recently, large apex consumers were ubiquitous across the globe and had been for millions of years. The loss of these animals may be humankind's most pervasive influence on nature. Although such losses are widely viewed as an ethical and aesthetic problem, recent research reveals extensive cascading effects of their disappearance in marine, terrestrial, and freshwater ecosystems worldwide. This empirical work supports long-standing theory about the role of top-down forcing in ecosystems but also highlights the unanticipated impacts of trophic cascades on processes as diverse as the dynamics of disease, wildfire, carbon sequestration, invasive species, and biogeochemical cycles. These findings emphasize the urgent need for interdisciplinary research to forecast the effects of trophic downgrading on process, function, and resilience in global ecosystems.

Science (2011)

TREE (2010)

... the geohistorical record is a natural laboratory from which we can address the responses of species to environmental changes, helping us to understand which species will be most sensitive and what kinds of responses will be most common.

Review

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## Conservation paleobiology: putting the dead to work

Gregory P. Dietl<sup>1</sup> and Karl W. Flessa<sup>2</sup>

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<sup>2</sup> Department of Geosciences, University of Arizona, Tucson, AZ 85721, USA

# **Training the next generation of scientist: Education and Outreach**

# ►website for kids

**TIBURONES FÓSILES EN PANAMÁ**  
 FOSSIL SHARKS IN PANAMA

Smithsonian Tropical Research Institute

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# ►classroom activities

**SCIENCE SAMPLER**

**Fossil sharks: Learning from and about the past**

by Catalina Pimiento and Rose M. Pringle

Have you ever felt the excitement of school-aged children as they observe fossils in a museum? Children are usually enthusiastic to learn about prehistoric remains or fossils of both plants and animals. Recent studies on preferences in museums have revealed that children are fascinated by fossil sharks—the remains of sharks that inhabited the oceans of the past (MacFadden 2006). This has created new opportunities to connect informal science learning at museums to public school science curricula. By studying fossil sharks, children learn about the composition of ancient faunas and the geologic changes that have occurred in the Earth's history. A study of fossil sharks can be tied to numerous important areas of natural (Earth) sciences such as geology, geography, and paleontology. Studies of fossil sharks can also be connected to science, technology, engineering, and mathematics (STEM) topics, such as evidence for evolution and climate change in the past.

In this article, we describe a series of science activities for middle school students that focuses on the study of fossil sharks through an examination of the morphological characteristics of their teeth by using models, drawings, and websites. The activities presented are intended to guide students toward an understanding of timescales and fossils as providing important evidence of how life and environmental conditions have changed over time.

The activities are presented in three sections. In the first section, students will learn general concepts of fossils and identify fossil-shark species based

on the morphological characteristics of their teeth. In this section, students will conclude that fossil sharks can be found on land, even though sharks are marine animals. Experiences in Section 2 will allow students to discover for themselves that the Earth is dynamic and continents are in constant dynamic movement. This will help students to understand how it is possible to find the remains of sharks on land. Finally, in the last section, students will explore the dimension of geologic time and will integrate the knowledge and skills learned in the first two sections.

**FIGURE 1** Sample of fossil shark teeth collected in Panama and Florida

FLORIDA MUSEUM OF NATURAL HISTORY/AMNH/SMITHSONIAN TROPICAL RESEARCH INSTITUTE

Pimiento and Pringle 2011

**¿CÓMO SON LOS DIENTES DE LOS TIBURONES?**

Coia del Educador

Luz Helena Oviedo  
Catalina Pimiento

Smithsonian Tropical Research Institute

Oviedo and Pimiento 2011

# ►undergraduate course

Introduction to the Paleontology of Panama, Class 2012



►undergraduate course

# ►undergraduate course



Blended course



Screenshot of a Moodle course page titled "Conceptos básicos". The page contains text, images, and links related to basic concepts in paleontology.



Screenshot of a blog post titled "El apasionante mundo de la paleontología". The post discusses the exciting world of paleontology, featuring images of fossils and geological specimens.