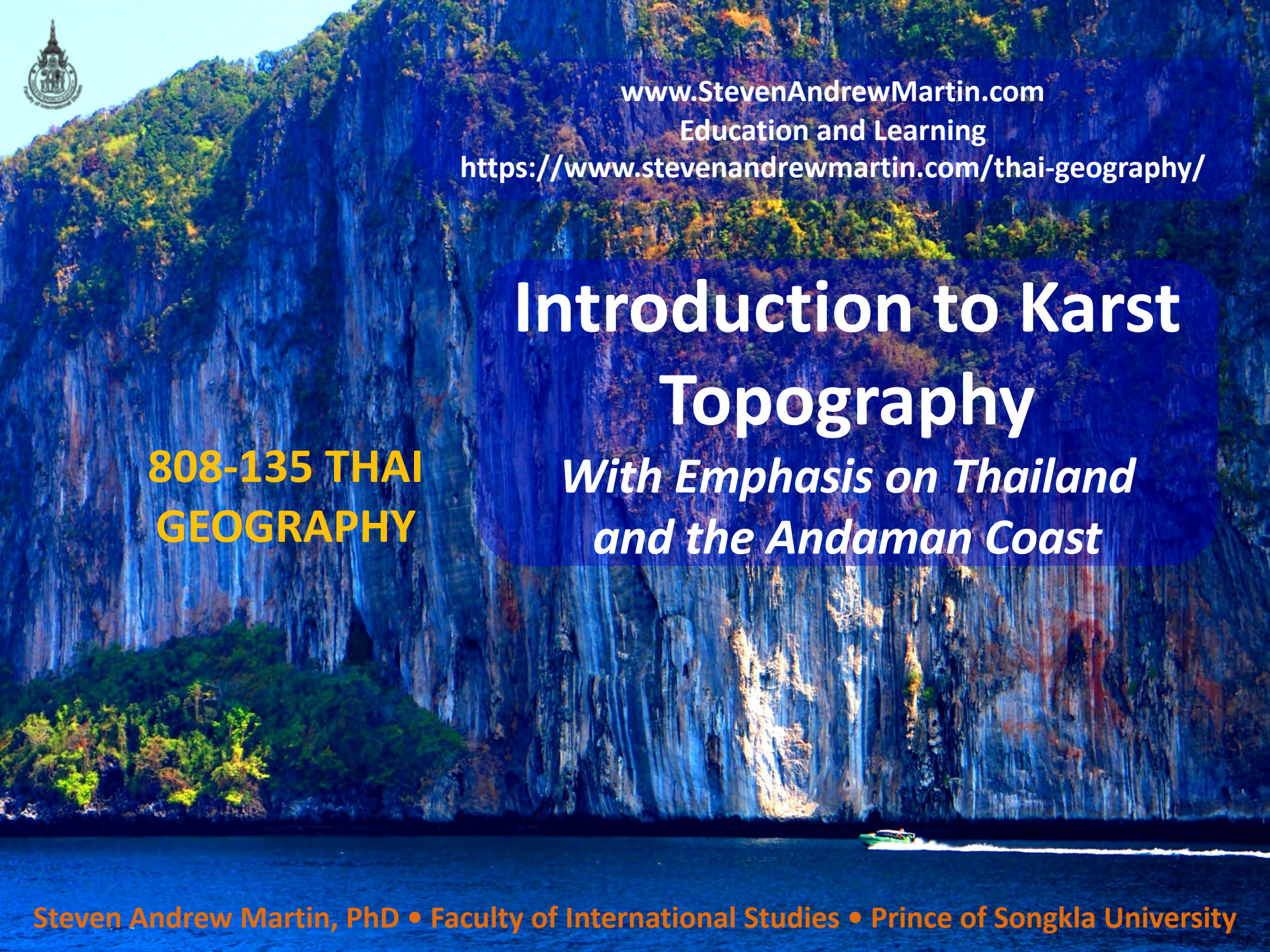

www.StevenAndrewMartin.com
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Introduction to Karst Topography

With Emphasis on Thailand and the Andaman Coast

808-135 THAI GEOGRAPHY

Steven Andrew Martin, PhD • Faculty of International Studies • Prince of Songkla University

“Haystack” Karst Towers, Phangnga Bay, Krabi, Thailand

Hypothetical sea level

60 mya (Cretaceous)

(+ or –) 100 - 300 meters

“Fossilized coral reef cut into shapes by the action of water over millions of years”

Dr. Raymond Ritchie

Phi Phi Leh Island
Photo by Steven Martin

The characteristic feature of topography of the Thai Peninsula is the limestone karst mountains formed of Permian Ratburi Limestone and to a lesser extent Ordovician-Devonian Satun Group limestone (Ridd, 2011)

LECTURE OUTLINE (80 Slides)

1. Introduction to Karst Topography
2. Introduction to Limestone
3. Review of Thai Geologic History
4. Karst Processes
5. Karst Regions
6. Karst Landscapes in Thailand
7. Karst Topography of the Andaman Coast
8. Review and Concluding Thoughts
9. References and Academic Resources
10. Glossary

Karst *noun*

- 1902
- Etymology: German, from Slovene or Croatian dialect kras, kars
- Type of rock, region composed of such rock
- An **irregular limestone region** with sinkholes, underground streams, and caverns

–karst£ic *k*r-stik\ adjective

Merriam-Webster

Karst is essentially limestone or dolomite, a type of rock comprised of layers of sea shells formed millions of years ago

Limestone landscape is a type of scenery created by chemical action on limestone rock

The term is related to Bosnia's Karst Plateau (near the Dalmation Plateau)

Types of Karst Topography & Landscapes

Karst topography is a landscape shaped by the dissolution of soluble bedrock (such as **limestone or dolomite**)

Most typically when carbonate rock, such as **limestone or dolomite**, is dissolved away by mildly acidic rain and ground water

Karst regions are often humid and display distinctive surface features

• Caves • Pinnacles • Towers • Pavements • Springs • Sinkholes •

Caves and Caverns

Sinkholes and Dolines

Underground drainage systems (streams and springs)

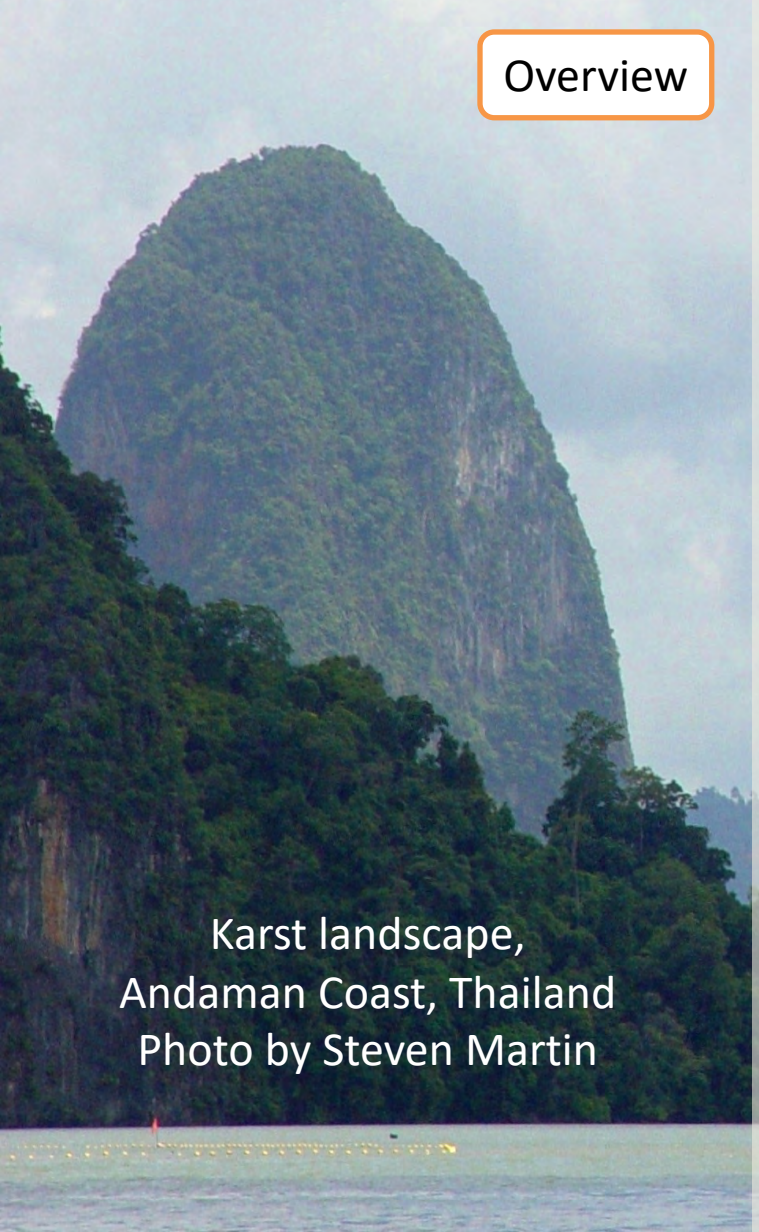
Pavement

Pinnacles

Towers (Haystacks)

Karst is a Complex Landscape Sculpted by Water

Overview



Karst landscape,
Andaman Coast, Thailand
Photo by Steven Martin

What is Karst?

- Karst is a distinctive topography in which the landscape is largely shaped by the dissolving action of water on carbonate bedrock (usually limestone, dolomite, or marble).
- This geological process, occurring over many thousands of years, results in unusual surface and subsurface features, such as sinkholes, vertical shafts, disappearing streams, and springs, including complex underground drainage systems and caves.

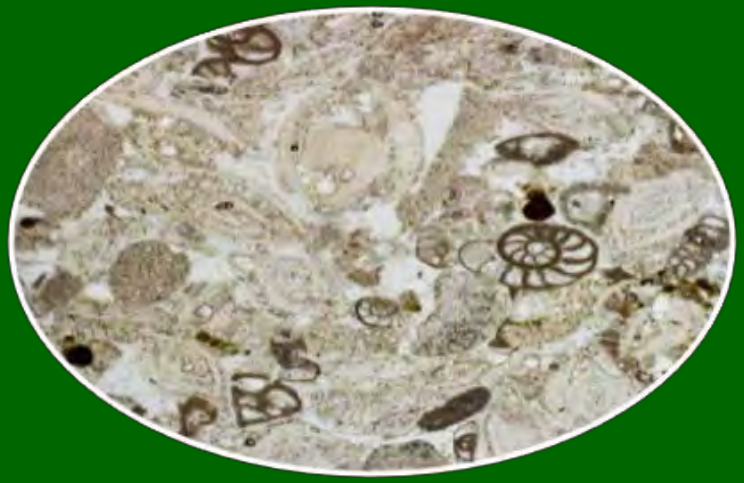
How Karst is Formed?

- The process of karst formation involves what is referred to as "the carbon dioxide cascade." As rain falls through the atmosphere, it picks up CO_2 which dissolves in the droplets.
- Once the rain hits the ground, it percolates through the soil and picks up more CO_2 to form a weak solution of carbonic acid: $H_2O+CO_2=H_2CO_3$.
- The infiltrating water naturally exploits any cracks or crevices in the rock.
- Over long periods, with a continuous supply of CO_2 -enriched water, carbonate bedrock begins to dissolve.
- Openings in the bedrock increase in size and an underground drainage system begins to develop, allowing more water to pass, further accelerating the formation of karst.

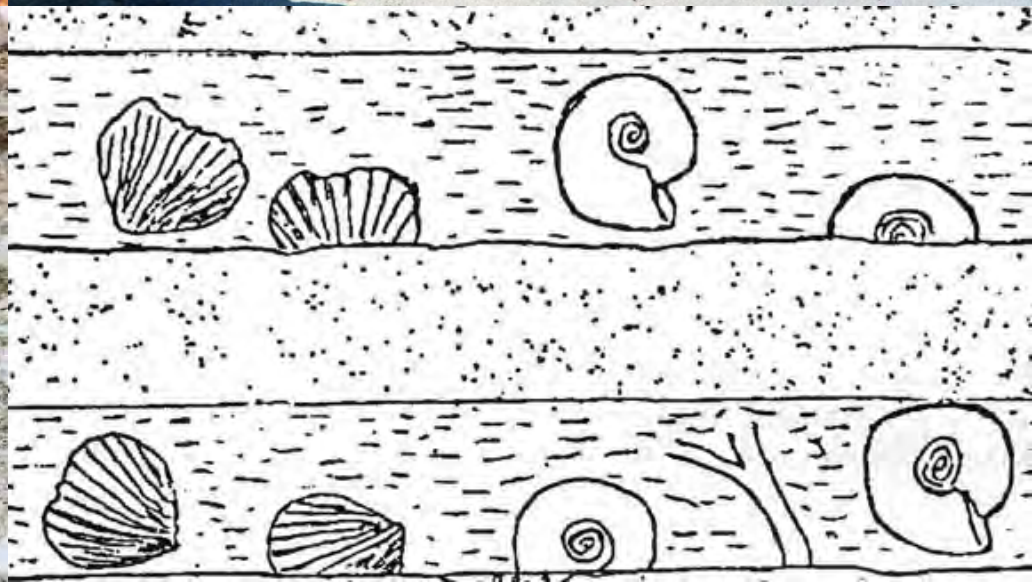
Caving Canada (2014)

Introduction to Limestone

A sedimentary rock made up of the mineral calcium carbonate ($CaC0_3$)



What is Limestone?
Where does it come from? And When?



Limestone

Limestone is sedimentary rock made up of the mineral calcium carbonate ($CaCO_3$)

Most sedimentary rock is layered

Fossils are a distinguishing feature

Non-marine Origin Limestone

Occurs due to **diagenesis*** (i.e., a process whereby rock is altered and gradually changes into limestone)

Sediments are deposited initially as unconsolidated debris

Consolidation comes about gradually due to *dewatering*

Cementing with a binding material (clay, calcium, lime)

*i.e., rocks formed through this process are often described as 'stone' (limestone, sandstone or mudstone)

Limestone of Marine Origin (monomineralic limestone)

Rock consisting of a single mineral (95% calcite) (i.e., calcium carbonate, **$CaCO_3$**)

Other rocks found in marine limestone include siderite, quartz, feldspar, mica, and various clay materials

Sediment comprised of calcium fragments (shells or skeletons) of dead marine animals and plants

Some sources of calcium

Algae, corals, calcareous sponges, foraminiferids (certain plankton), bryozoa (moss animals) , brachiopods (lampshells), echinoderms (starfish, sea urchins, sea cucumbers, sea lilies), mollusks (snails, bivalves, chitons, octopus, squid), crustacea (barnacles, lobsters, crabs, shrimp), and pteropods (snails, sea slugs, abalone, cowries, limpets)

Shading

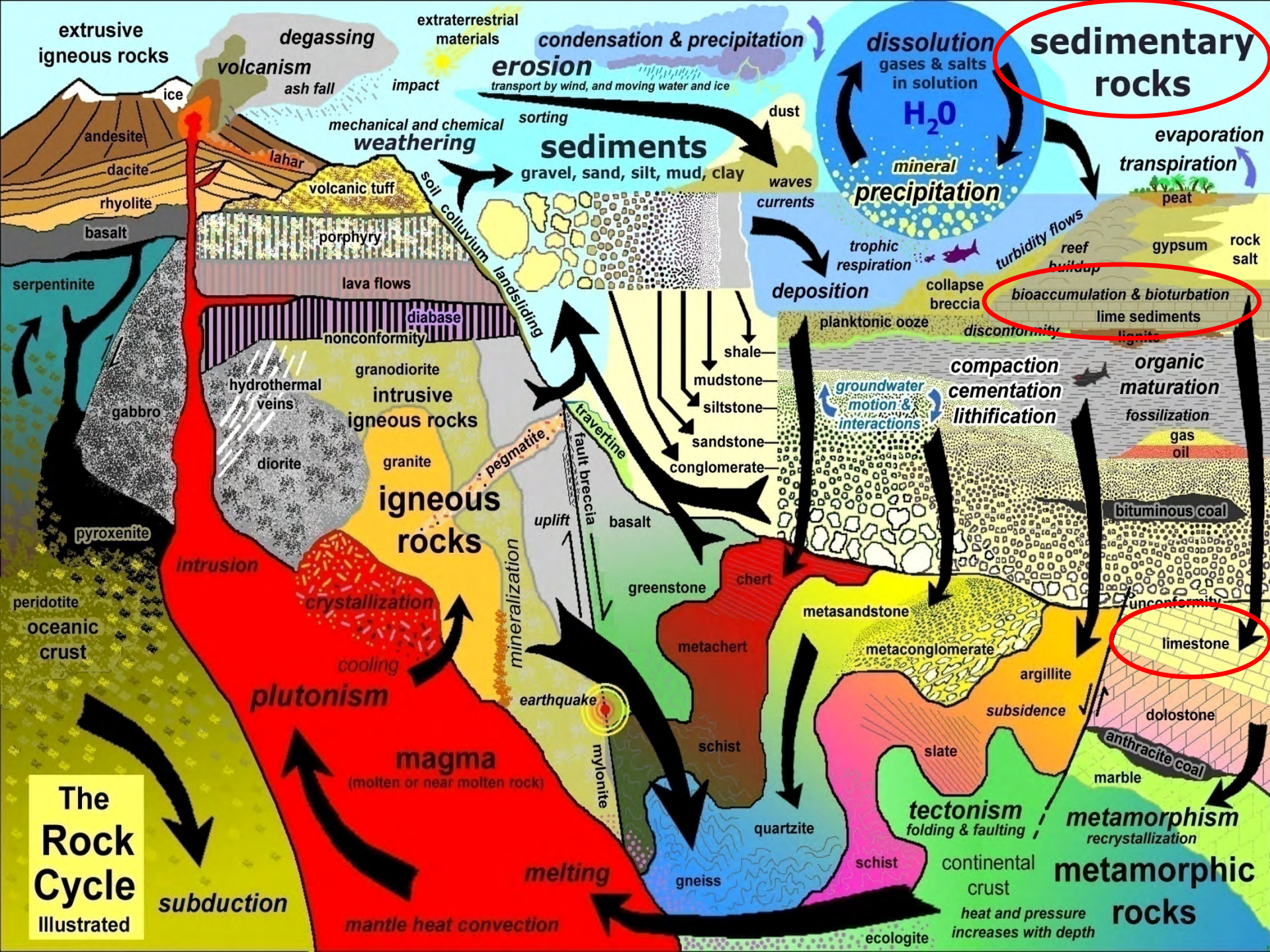
Pure limestone is chalky white.

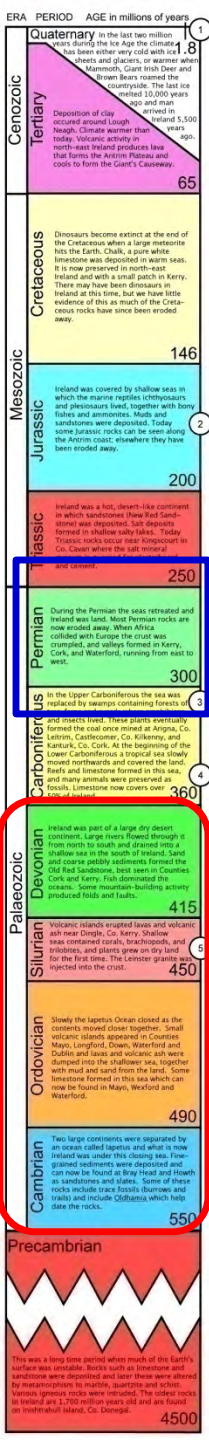
Limonite and **siderite** cause yellow-brown shades

Hematite causes red shades

Glauconite and **chlorite** cause green shades

Bitumen causes gray to black shades


extrusive igneous rocks
degassing
volcanism
ash fall
extraterrestrial materials
impact
condensation & precipitation
erosion
transport by wind, and moving water and ice
dissolution
gases & salts in solution
H_2O
mineral precipitation
sedimentary rocks
evaporation
transpiration
peat
ice
andesite
dacite
rhyolite
basalt
lahar
volcanic tuff
porphyry
lava flows
mechanical and chemical weathering
sorting
sediments
gravel, sand, silt, mud, clay
dust
waves
currents
soil
colluvium
landsliding
trophic respiration
turbidity flows
reef buildup
gypsum
rock salt
deposition
collapse breccia
bioaccumulation & bioturbation
lime sediments
planktonic ooze
disconformity
lignite
shale
mudstone
siltstone
sandstone
conglomerate
compaction
cementation
lithification
groundwater motion & interactions
organic maturation
fossilization
gas
oil
bituminous coal
unconformity
limestone
dolostone
anthracite coal
marble
serpentinite
gabbro
pyroxenite
peridotite
oceanic crust
diabase
nonconformity
granodiorite
hydrothermal veins
intrusive igneous rocks
diorite
granite
pegmatite
igneous rocks
travertine
fault breccia
uplift
basalt
greenstone
chert
metachert
metasandstone
metaconglomerate
argillite
subsidence
slate
schist
quartzite
gneiss
mylonite
earthquake
mineralization
intrusion
crystallization
cooling
plutonism
magma
(molten or near molten rock)
melting
subduction
mantle heat convection
tectonism
folding & faulting
metamorphism
recrystallization
metamorphic rocks
continental crust
heat and pressure increases with depth
ecologite
The Rock Cycle Illustrated

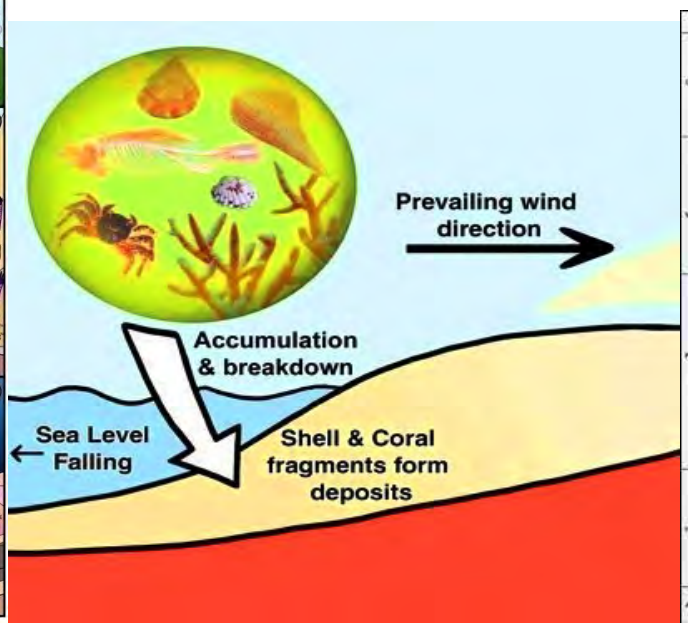


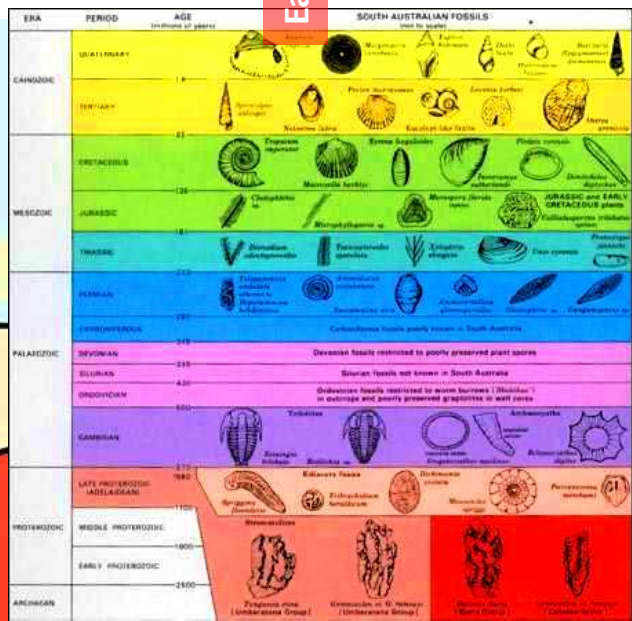
ERA	PERIOD	EPOCH	AGE (Millions of Years Ago)	SUCCESSION OF LIFE	TYPICAL LIFE FORMS	MAJOR GEOLOGIC EVENTS	GEOLOGIC RECORD BIG BEND REGION
CENOZOIC "Age of Mammals"	Quaternary	Pleistocene	1		Man Woolly mammoth	World-wide glaciation	Alluvium Intermontane basin and terrace deposits
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	12 25 36 60 63		Saber-tooth cat Horses Primitive mammals	Alps, Himalayas, Cascade ranges formed	Repeated epochs of uplift. Intru-sive and extrusive igneous activity. Continental deposits with mammal bones and teeth.
MESOZOIC "Age of Reptiles"	Cretaceous	Upper Lower	135		Dinosaurs First flowering plants	Rocky Mountains formed	Folds, thrust faults, and general uplift at end of period. Marine and non-marine deposition.
	Jurassic		181		First birds	Sierra Nevada Mountains formed	Prolonged period of erosion during which Paleozoic rocks were exposed in Marathon Basin, Solitario, and Persimmon Gap
	Triassic		230		Ammonoids		Folds, thrust faults in Ouachita System trough deposited. Uplift in Marathon Basin began.
PALEOZOIC "Age of Invertebrates"	Permian		280		Reptiles	Appalachian Mountains formed	
	Pennsylvanian Mississippian		310 345		Insects Coal forests Amphibians		
	Devonian		405		Brachiopods Fish		Novaculite, chert, and shale deposited in late part. Early record not clear.
	Silurian		425		Crinoids		No record
	Ordovician		500		Nautiloids		Chert, shale, and limestone deposited. Many marine shellfish.
	Cambrian		600		Trilobites		Sandstone, shale, and limestone de-posited in late part. No early record.
PRECAMBRIAN ERAS PROTEROZOIC ERA ARCHEOZOIC ERA			3,000		Algae Worm tubes Indirect evidence of life		No record

Approximate age of the earth more than 3 billion 300 million years

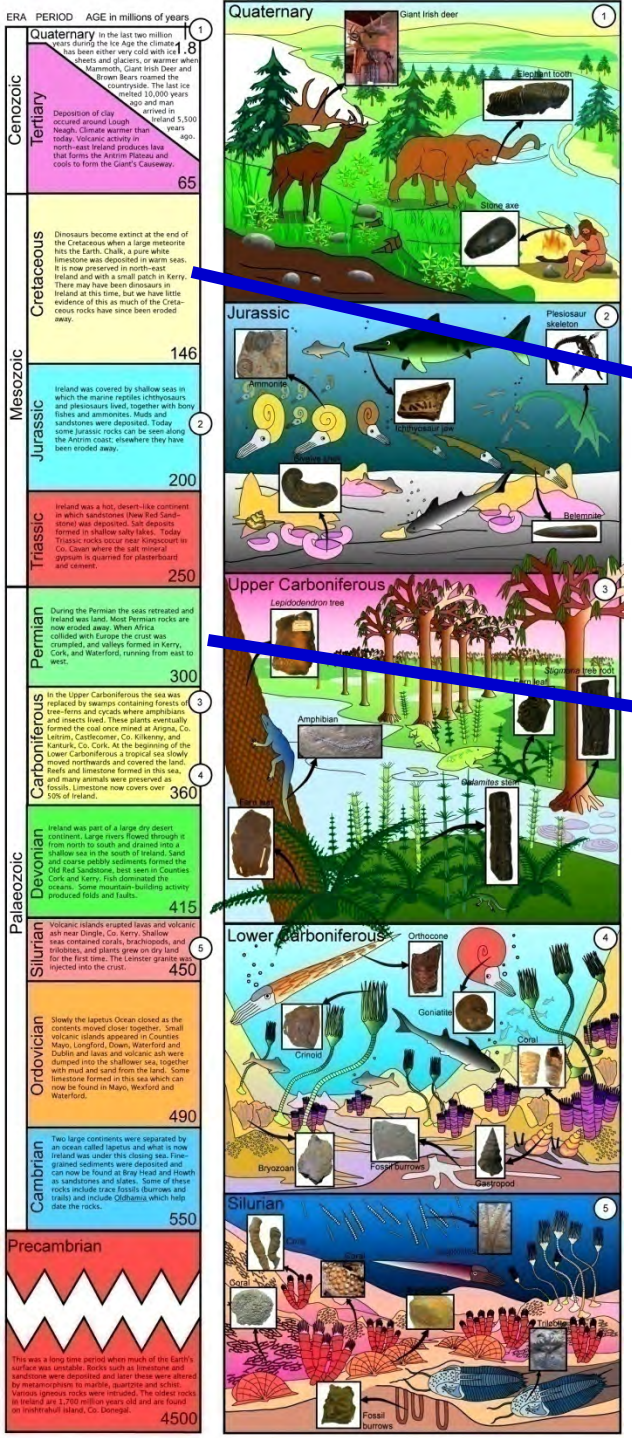
Ratburi Group

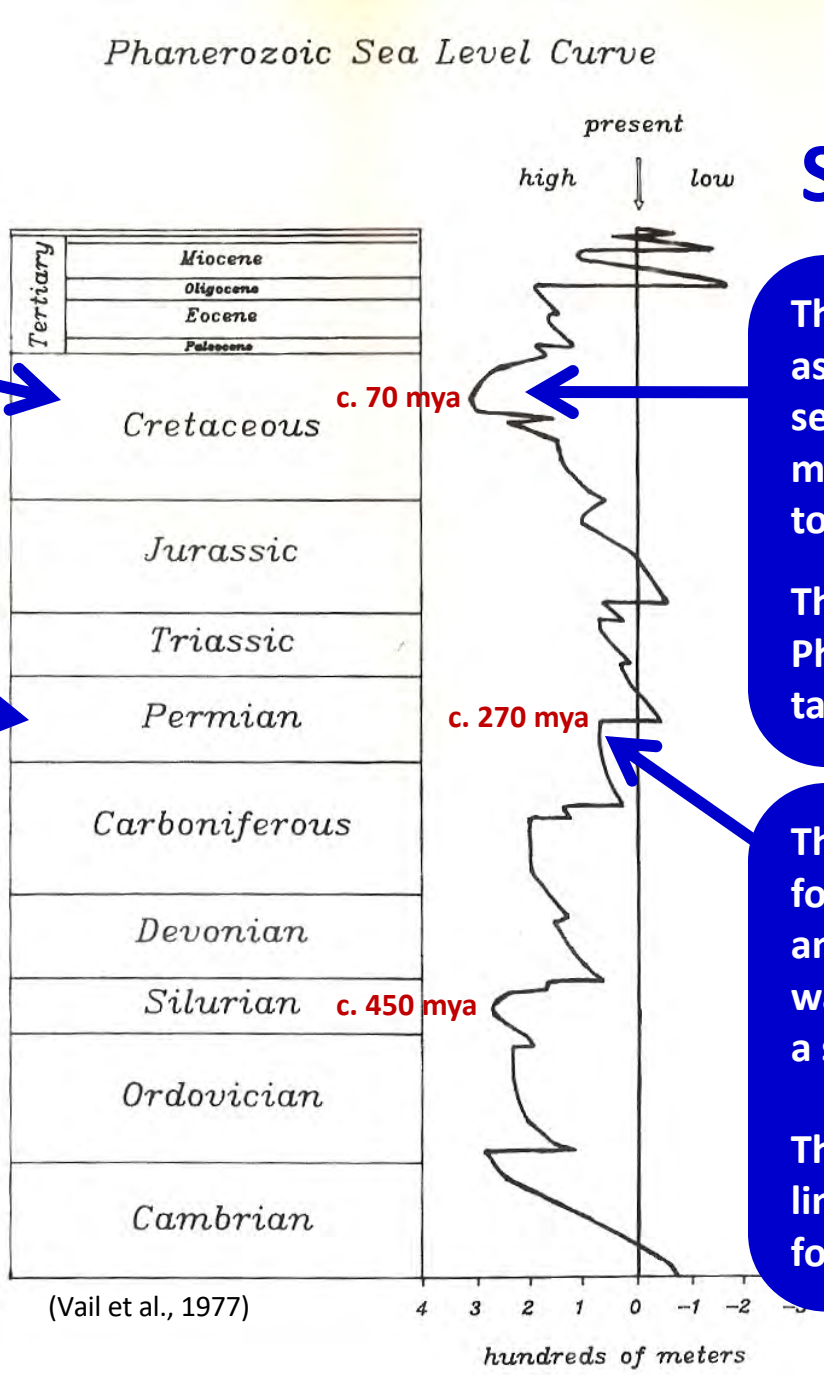
Early Limestone





Geologic Sea Levels





(Vail et al., 1977)

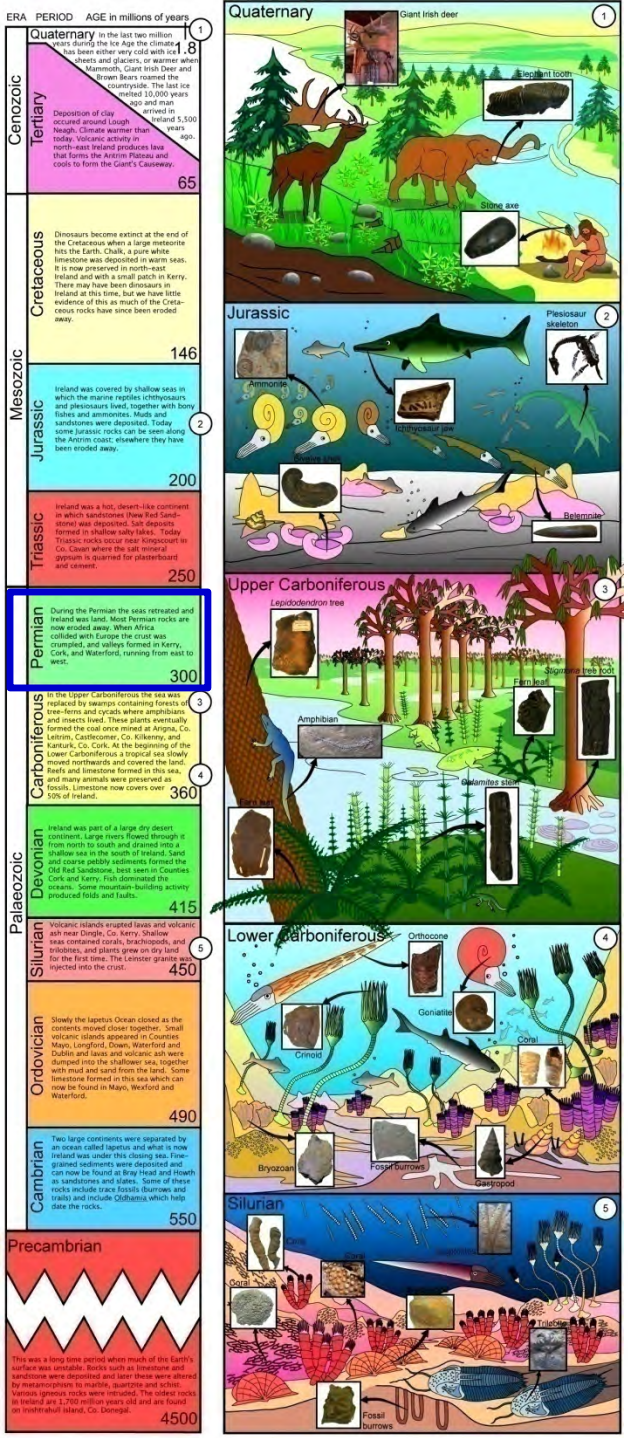
Thailand has formed as a region, yet the sea level is 200-300 meters higher than today!

The 'Tower Karst' of Phangnga and Krabi take shape

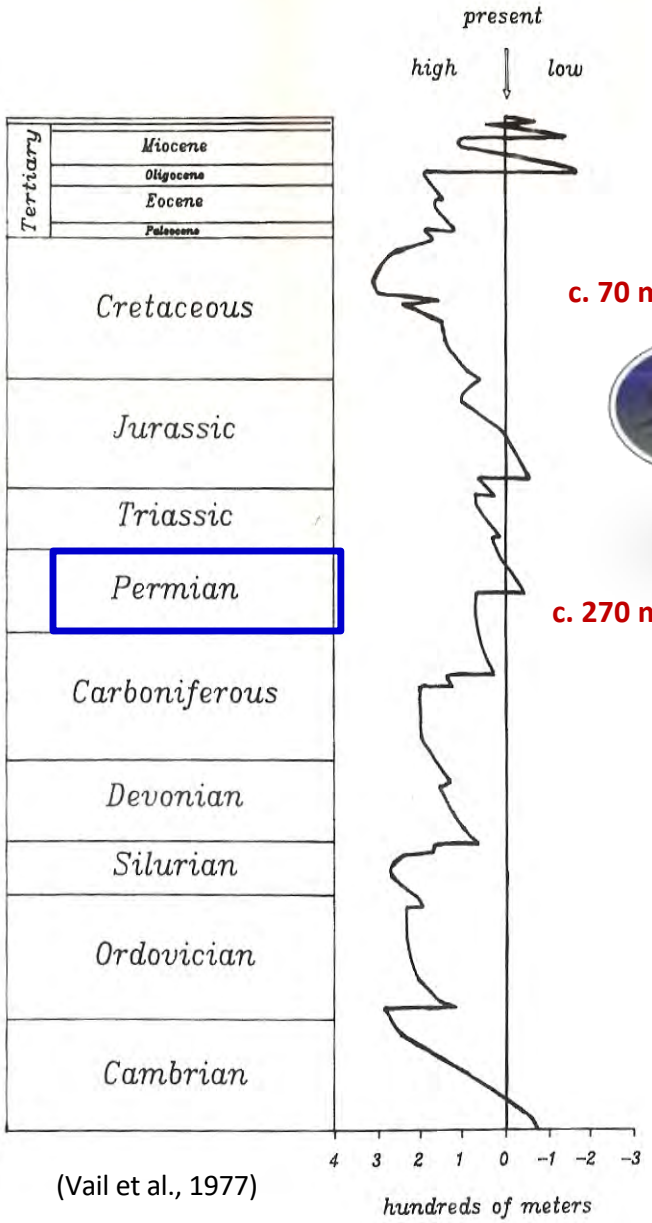
Thailand has not yet formed as a region, and much of the area was coral reef under a shallow sea!

Thailand's Permian limestone layers are formed

Thailand's Permian limestone layers are formed

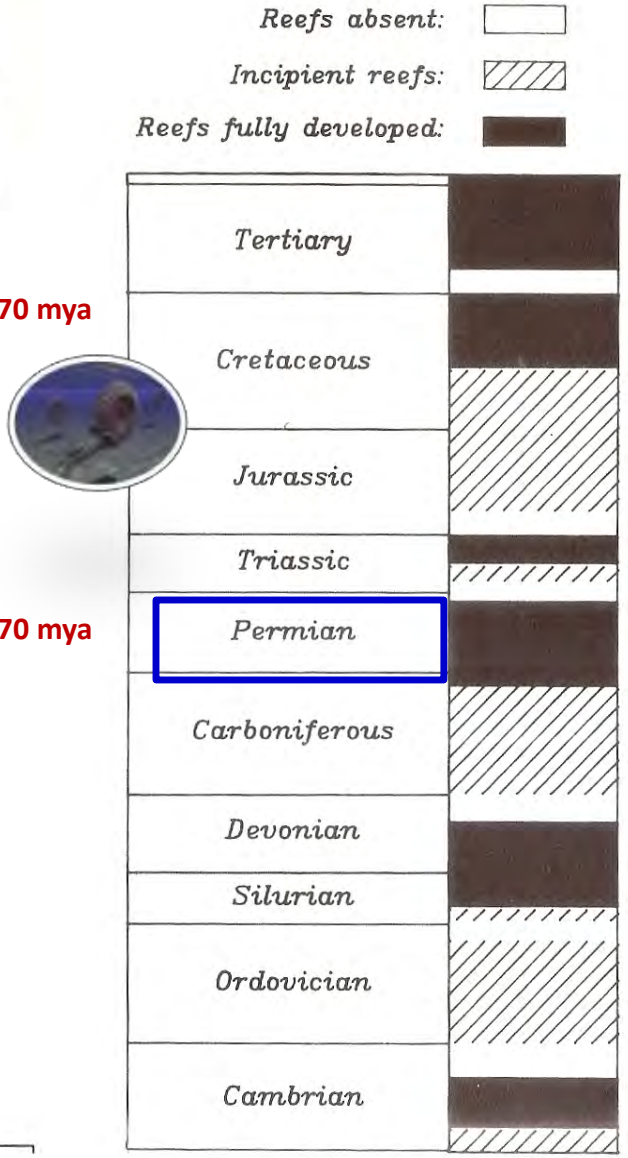


Phanerozoic Sea Level Curve



(Vail et al., 1977)

Tropical Reefs through Time



c. 70 mya

c. 270 mya

(Cooper, 1998)

Ammonites in Limestone

Ammonites are excellent index fossils

- They link the rock layer in which a particular species or genus is found to specific geological time periods

"If you see any limestone with **ammonites**, then it is at least 65 million years old or older...

Some **Permian** (298-252 mya) species of **ammonites** found in the limestone formations of Phangna and Karbi serve as an index to the age when the stone was formed."

Dr. Raymond Richie

Ammonites were successful and diverse during the **Paleozoic (600-252 mya)**.

However, at the end of the **Permian (298-252 mya)**, all but a single species went extinct.

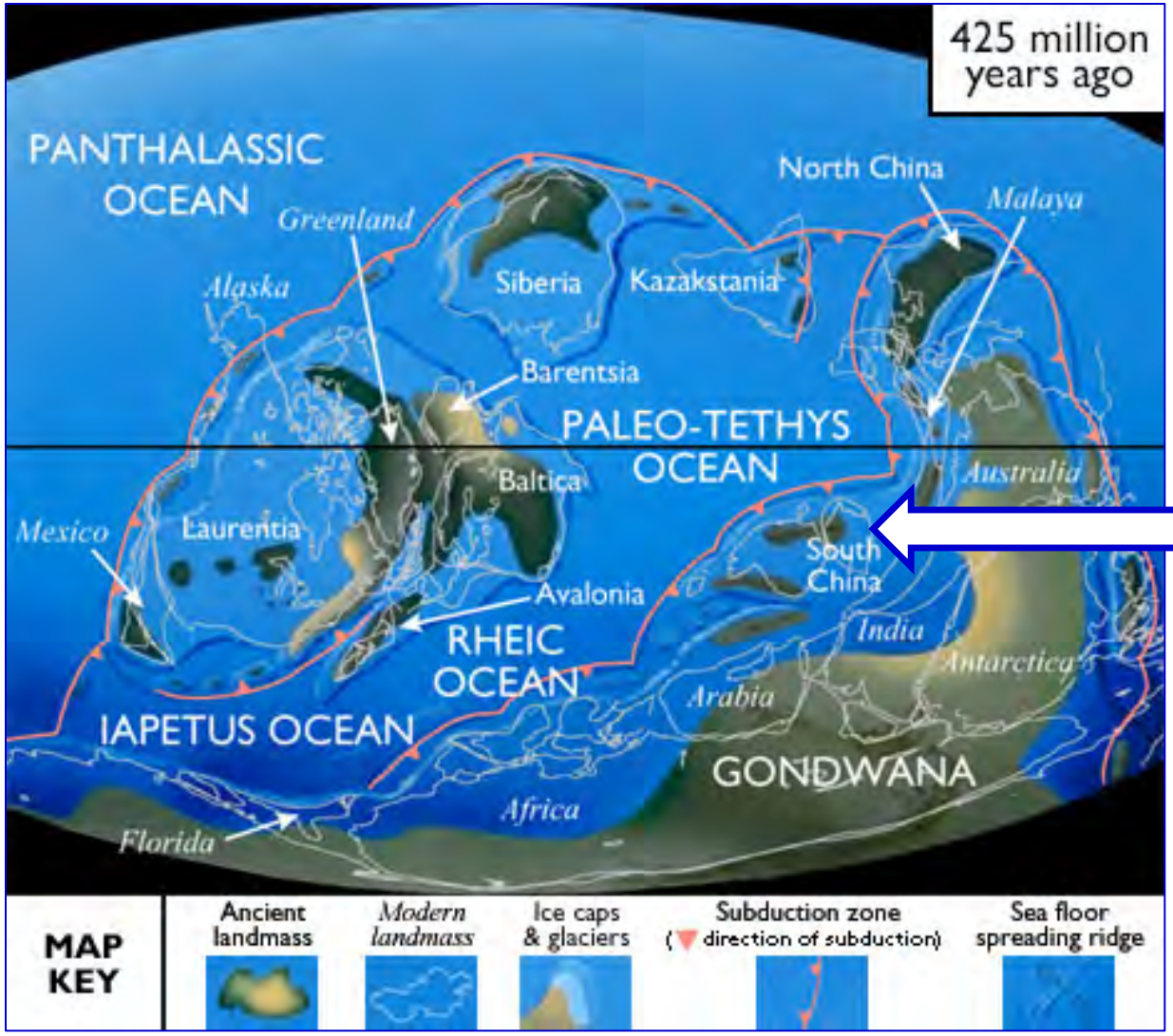
All of the species that survived the Permian extinction were descendants of that one genus

Ammonites went extinct during the Cretaceous period of the Mesozoic, dying out with the dinosaurs at the **Cretaceous–Tertiary (K–T) boundary (65 mya)**

"**Ammonite**" named after the Egyptian God "Amon-Ra" by the French who saw the fossil remains in the limestone rock used in Egyptian tomb construction.

A Brief Review of the Geologic History of Thailand

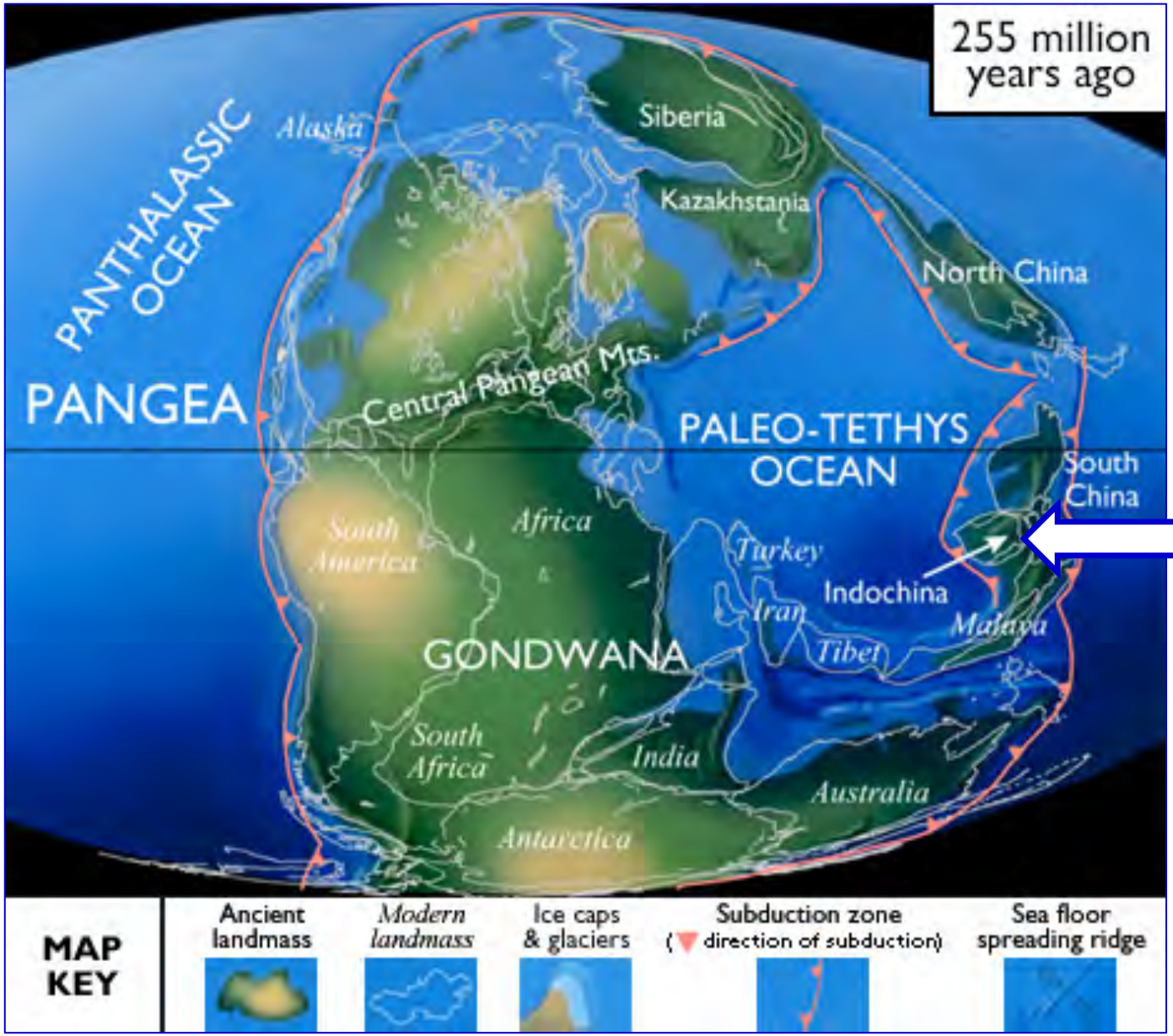
Silurian (Middle Paleozoic) 425 mya



Thailand (Indo-china) is a coral reef, forming as a submerged island in a shallow sea...

Once formed, it will emerge in this area

Permian (Upper Paleozoic) 255 mya



"The tectonic plates move about as fast as fingernails grow, about 2 cm per year; while that may not seem like much, it means they move some 200 kilometers over the span of a million years"

Dr. Raymond Richie

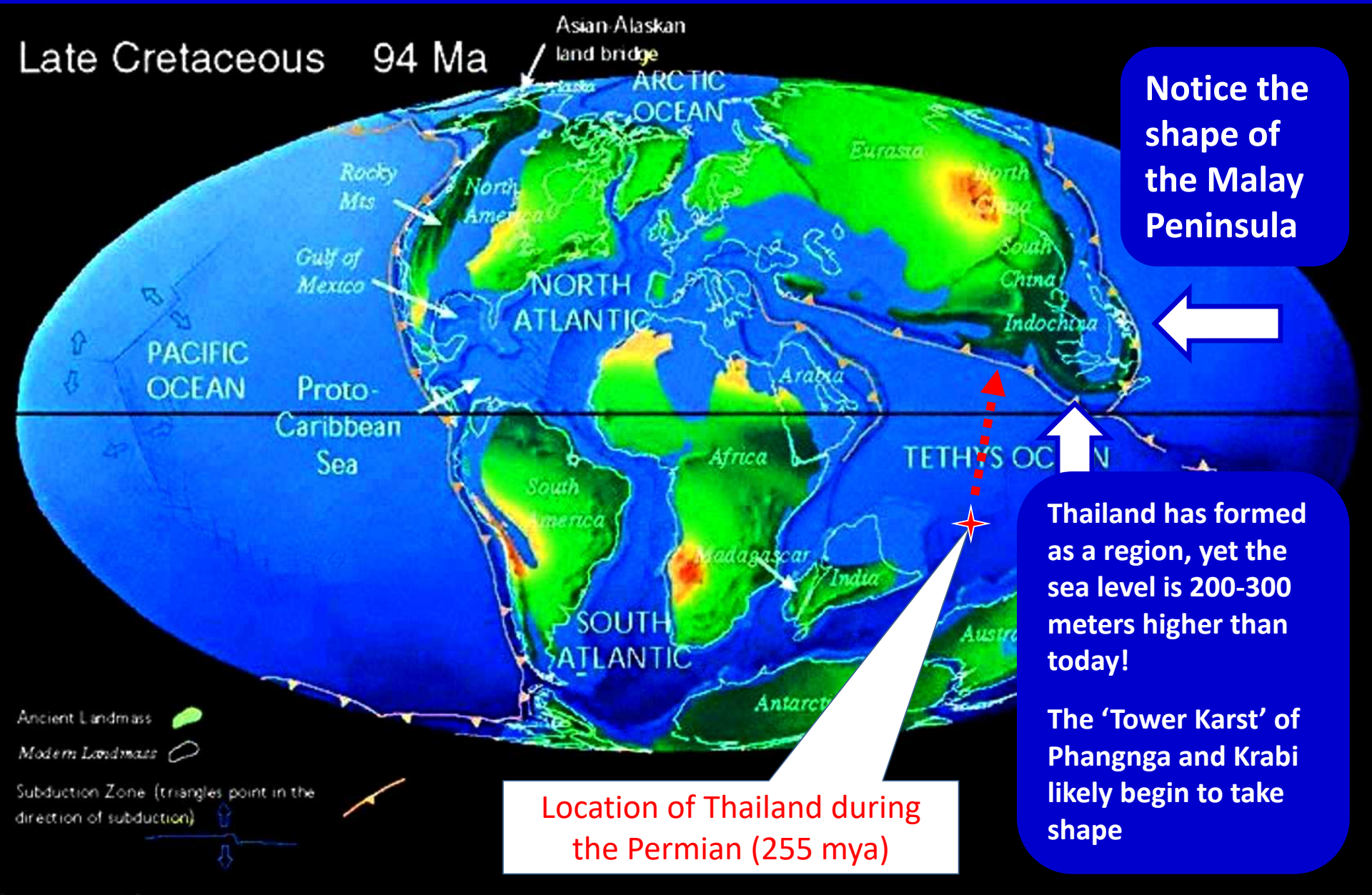
Thailand is here

Thailand, an island, begins its long journey toward the northeast...

Thailand has not yet formed as a region, and much of the area was under water reefs!

Thailand's Permian limestone layers are formed

Cretaceous (Upper Mesozoic) 90 mya



Notice the shape of the Malay Peninsula

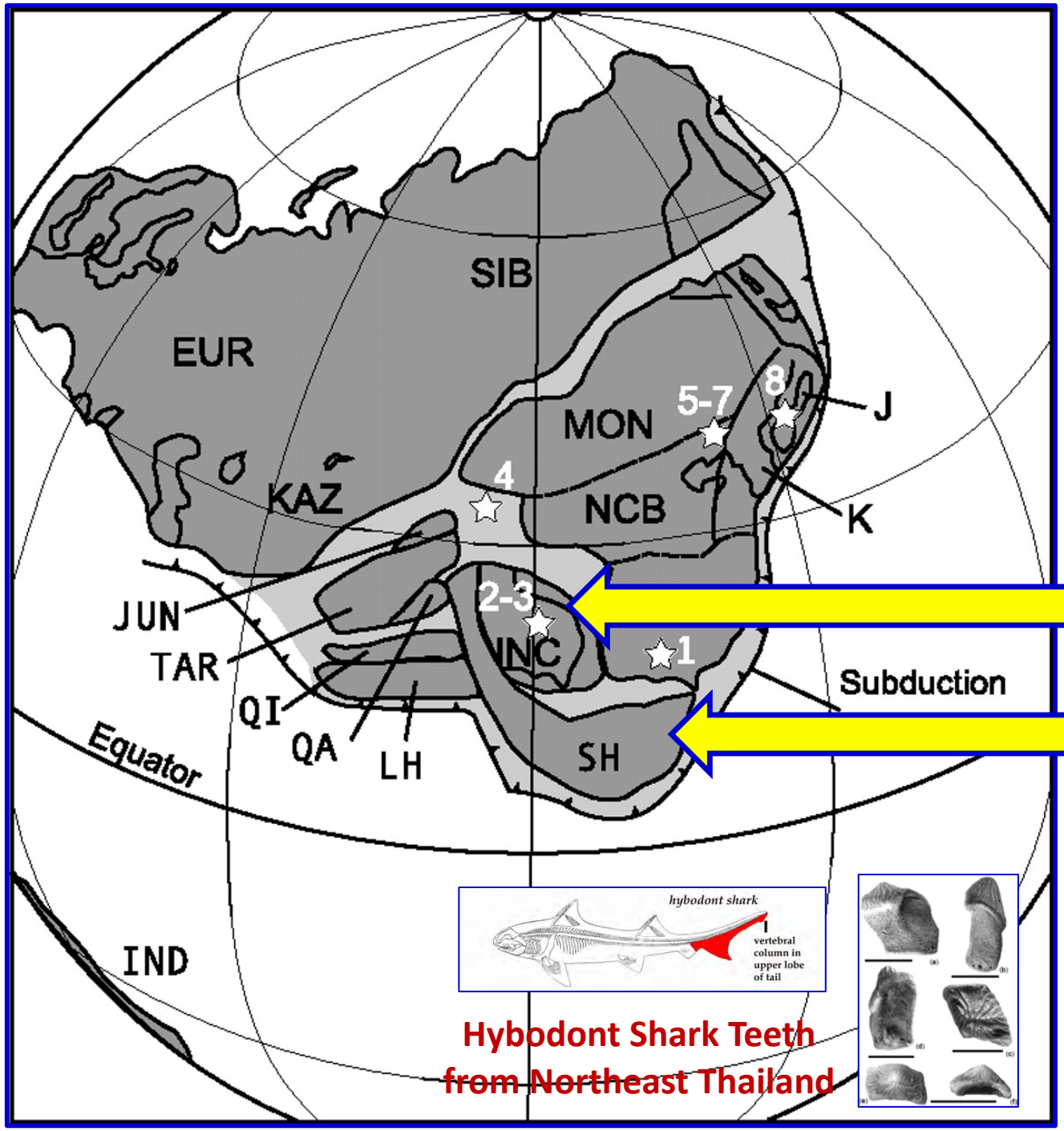
Thailand has formed as a region, yet the sea level is 200-300 meters higher than today!

The 'Tower Karst' of Phangnga and Krabi likely begin to take shape

Location of Thailand during the Permian (255 mya)

Cretaceous

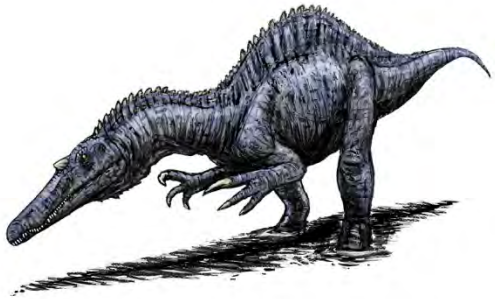
80 mya



Indo-China is here

Malaya is here

Hybodont Shark Teeth from Northeast Thailand

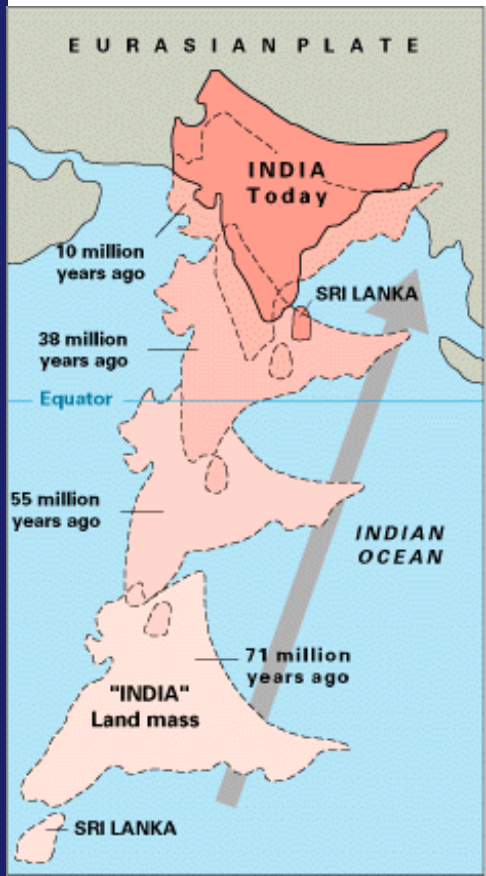


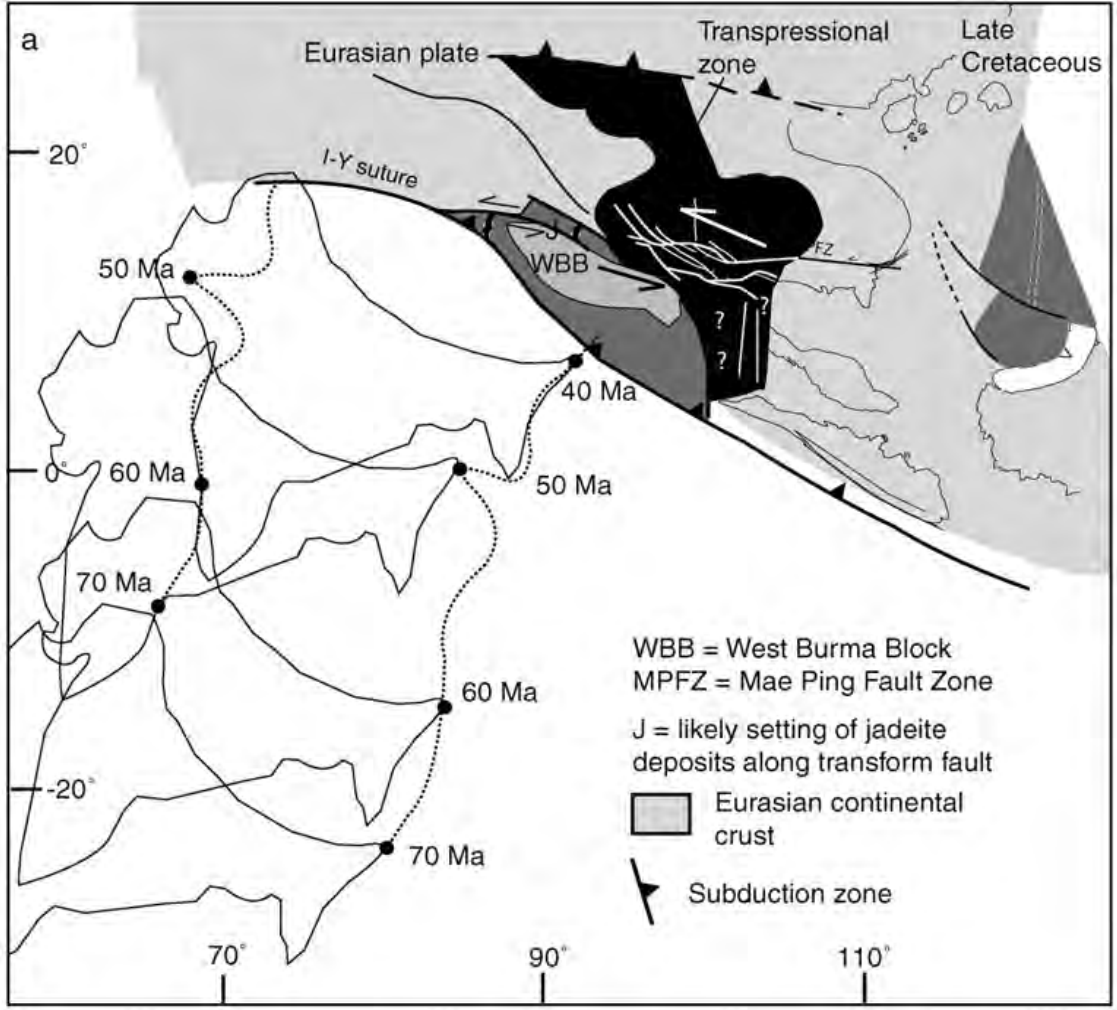
Siamosaurus (Theropod)

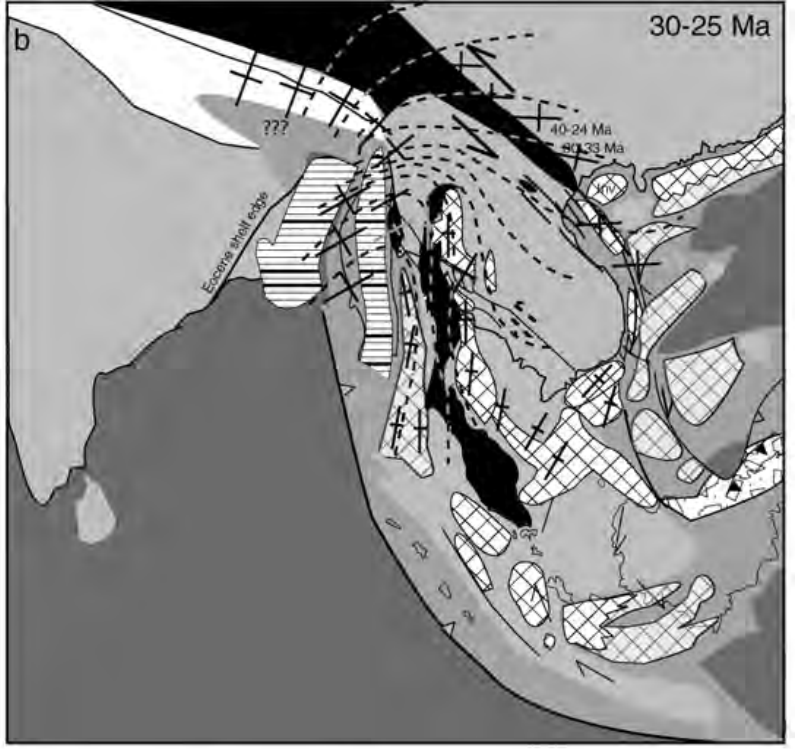
70 mya

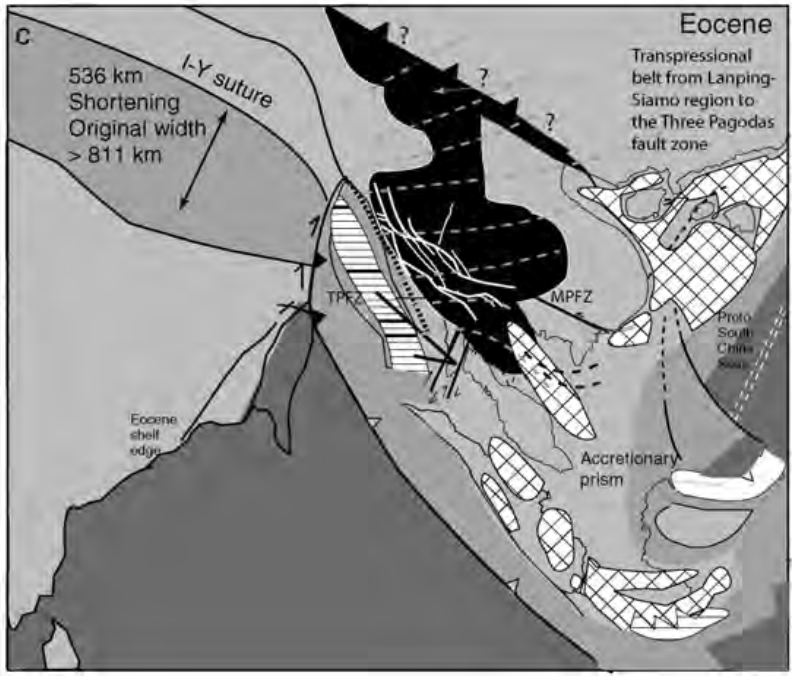
60 million years ago, the limestone along Peninsular Thailand was thrust up above sea level when the Indian subcontinent collided with mainland Asia.

(Gillespie, 2000)









Area of active uplift in SE Asia

Flexural basins accumulating thrust belt erosional debris

Post-rift basin with predominantly continental fill

Post-rift basin with predominantly marine fill

Continental rift with predominantly marine fill

Continental rift with predominantly continental fill

Shallow marine seas over mostly continental crust

Emergent continental area (approximate)

Oceanic crust

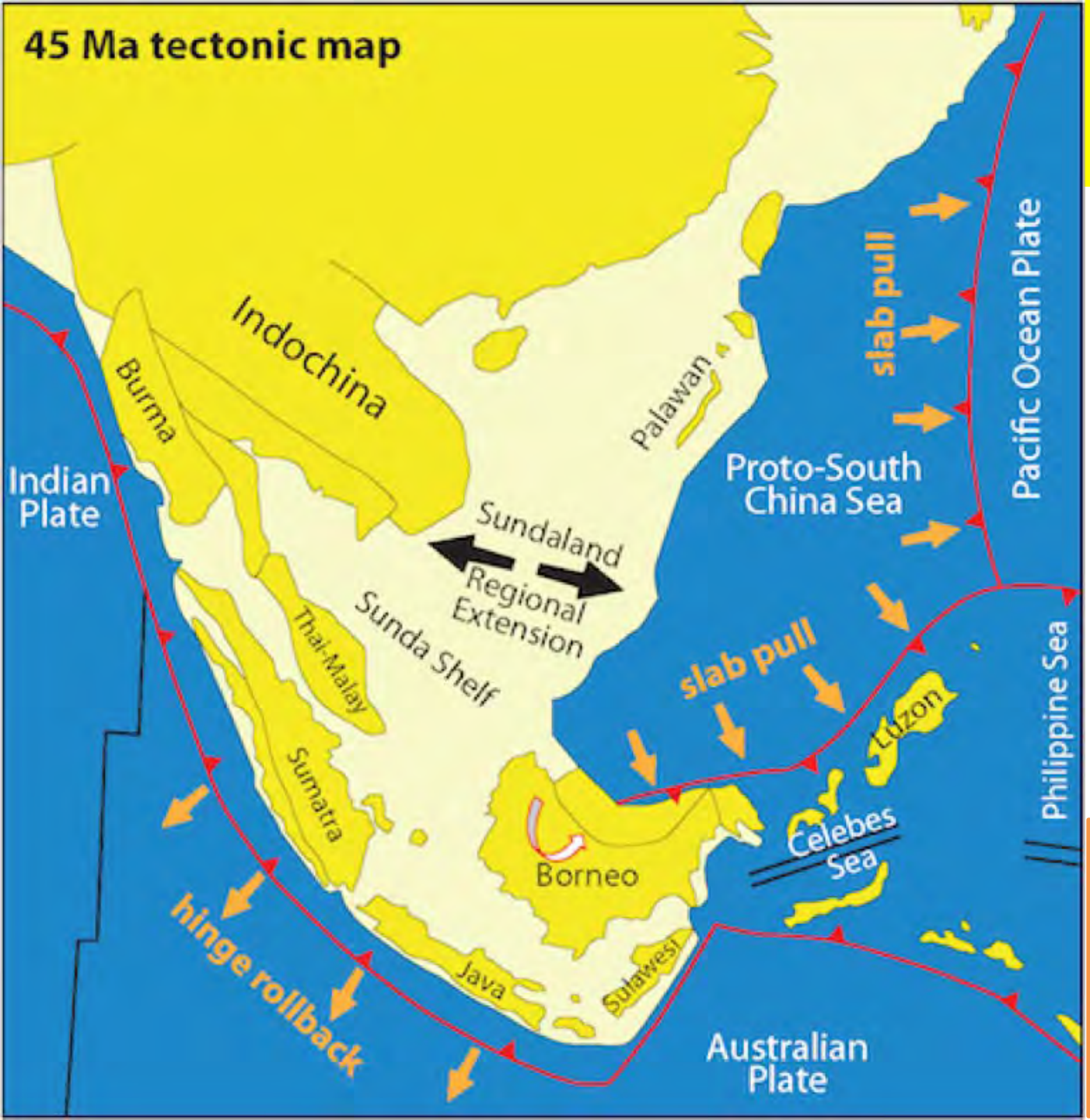
Inferred horizontal principal stress directions

Thrust

Strike-slip

Extensional

Shmax stress trajectory



45 mya

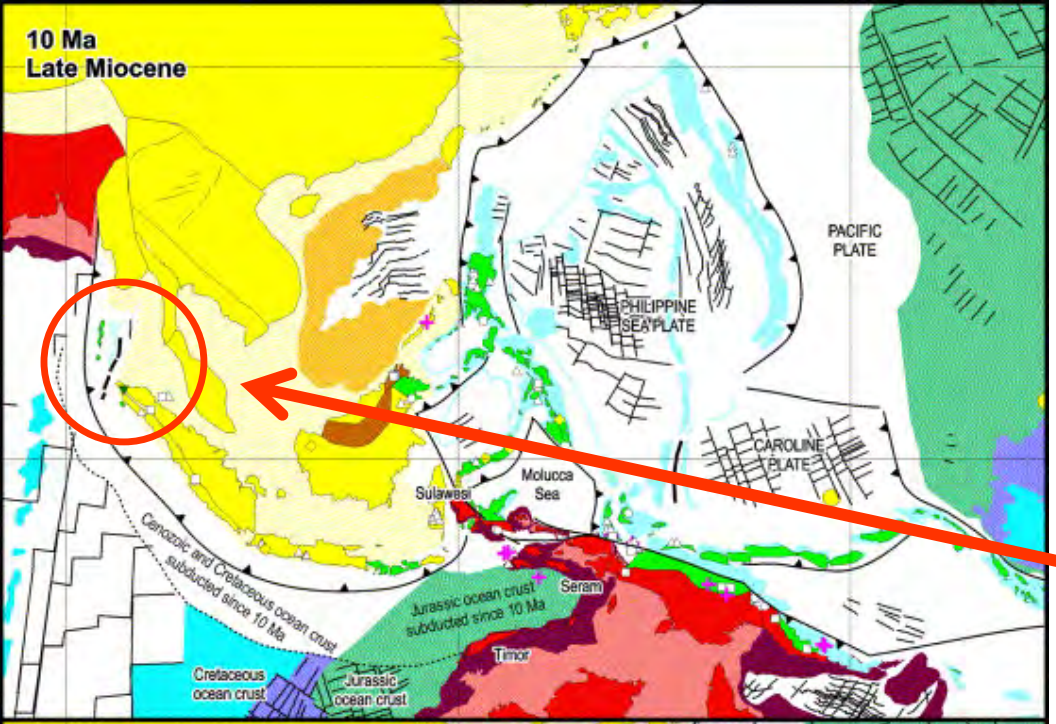
The collision of the Indian Plate with the Asian mainland twisted Southern Thailand and the Malay Peninsula clockwise and created ruptures along the 5,000 km ancient coral reef line (Gillespie, 2000).

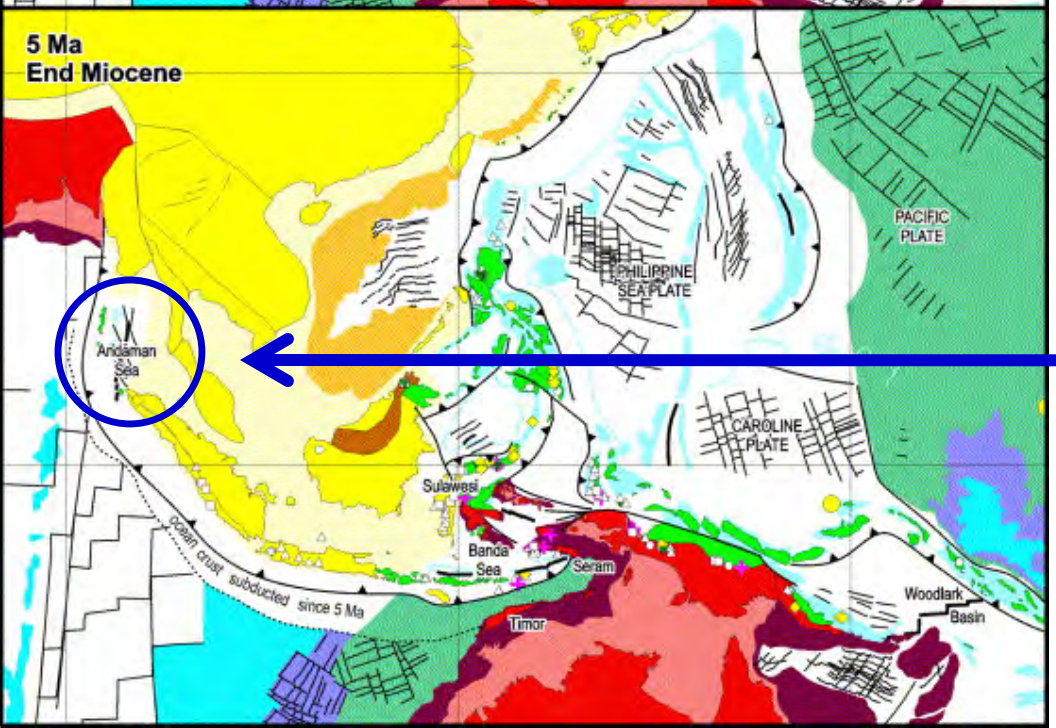
Note: Plates move in 3 different ways

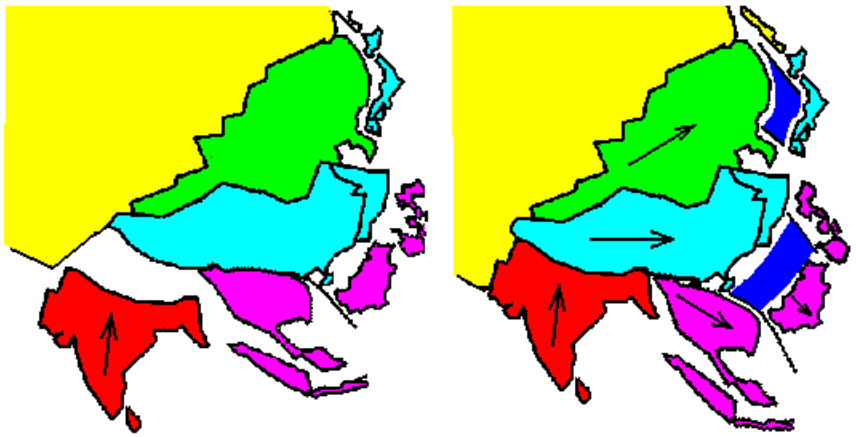
Divergent – moving away from each other

Convergent - moving toward each other

Transform plate - sliding past each other







10 million years ago...

The Andaman Sea had not yet formed

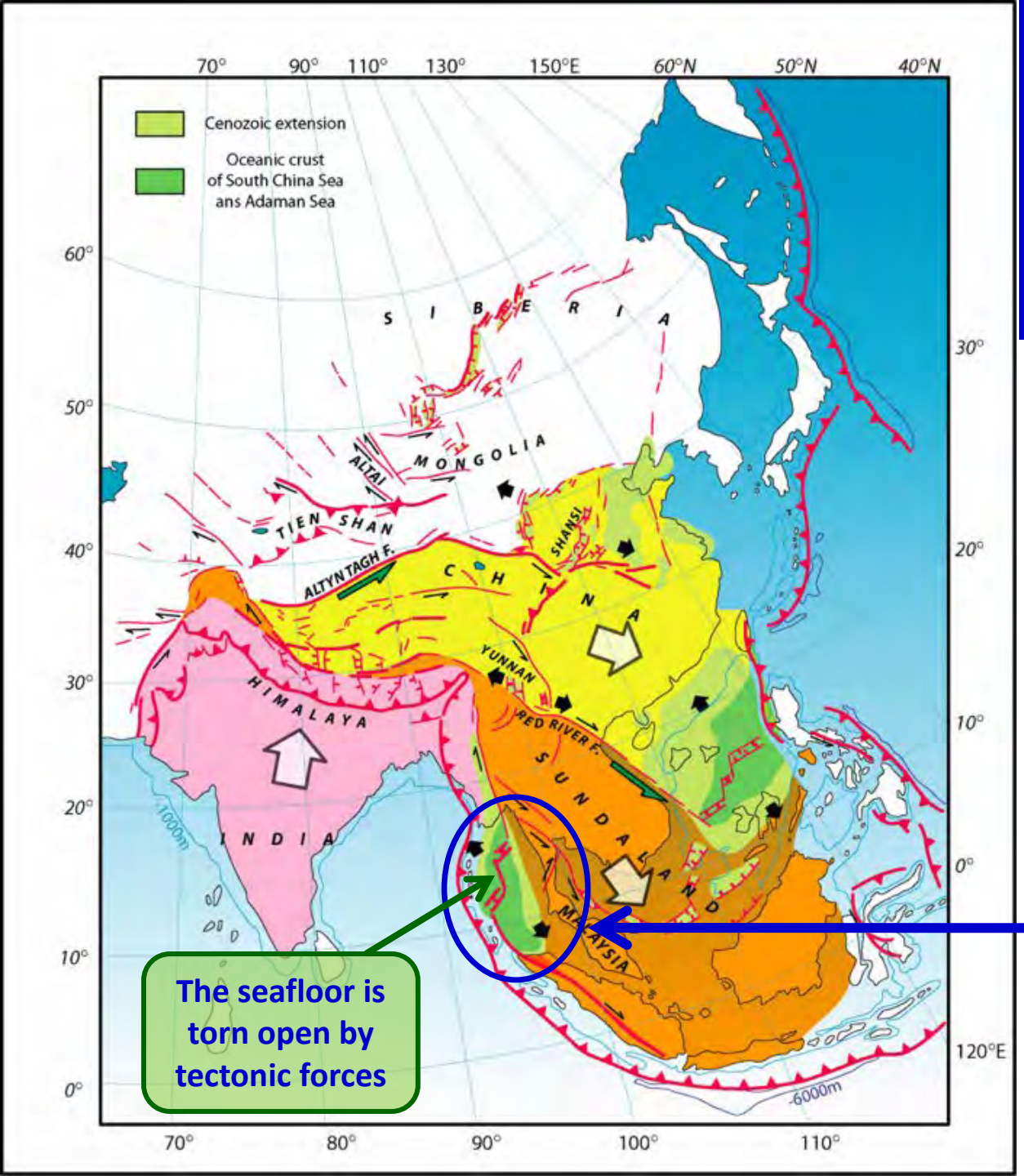
Andaman Sea
3–5 million years ago

The Burma and Sundra “micro-plates” were formed

Between the micro-plates, the **Andaman Sea** first took shape as an arc-shaped basin

Cenozoic

Late Tertiary – Quaternary 3-5 mya

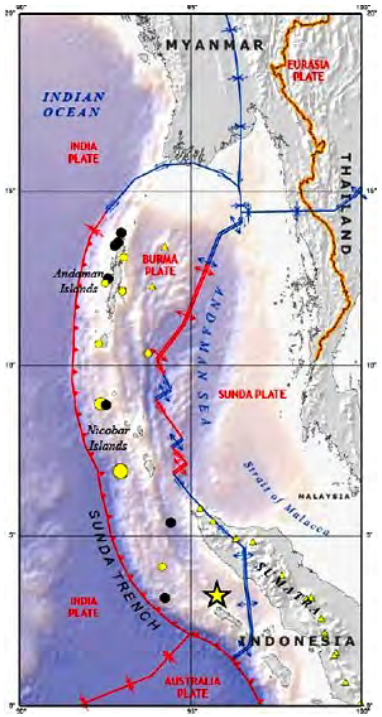


The seafloor is torn open by tectonic forces

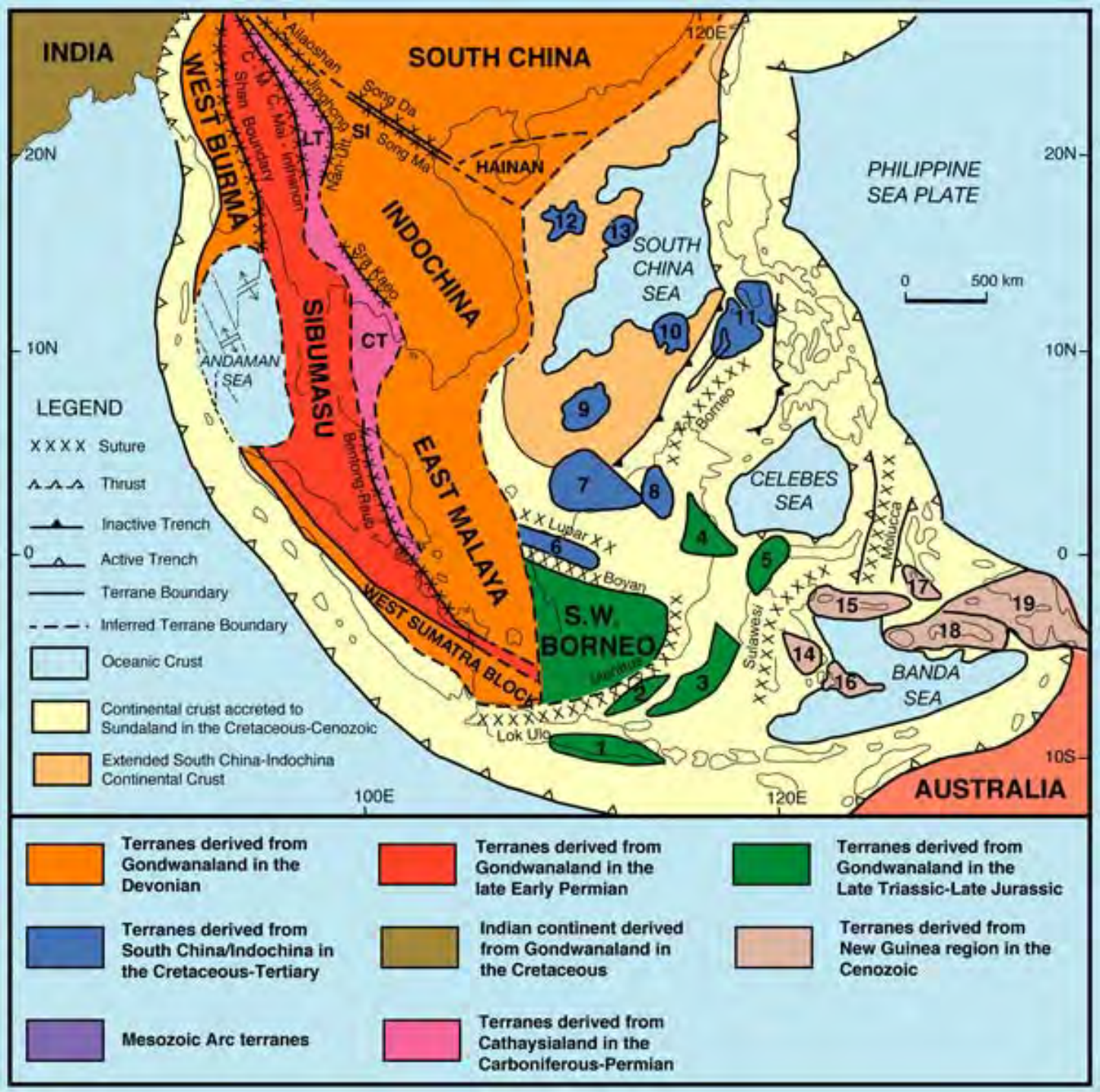
Andaman Sea forms

3–4 million years ago as the sea floor spreads

Sundaland is pushed southeast while the Burma plate moves Northwest



Today, the maximum depth of the Andaman Sea is 4,198 meters along a system of submarine valleys



Terranes derived over geologic history

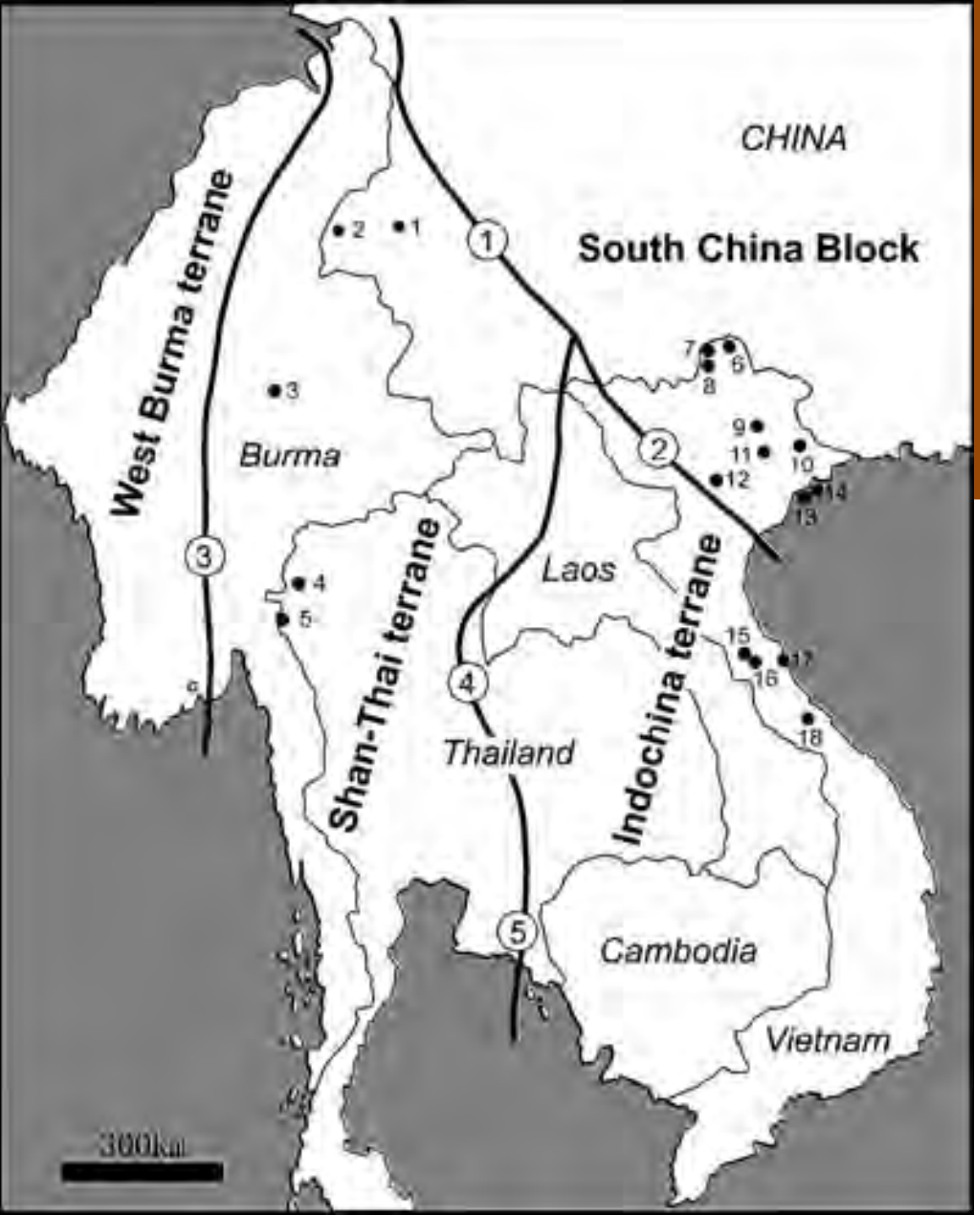
A '**terrane**' is like a massive blade of a bulldozer which pushes everything in its path into a long jumbled pile

Terranes most relevant to the study of Thailand

- West Burma
- Sibumasu
- Indochina
- East Malaya

"**Sibumasu**" derives its name from **Si**am, **Bu**rma, **Ma**laysia, and **Su**matra

Simplified overview of regional terranes today

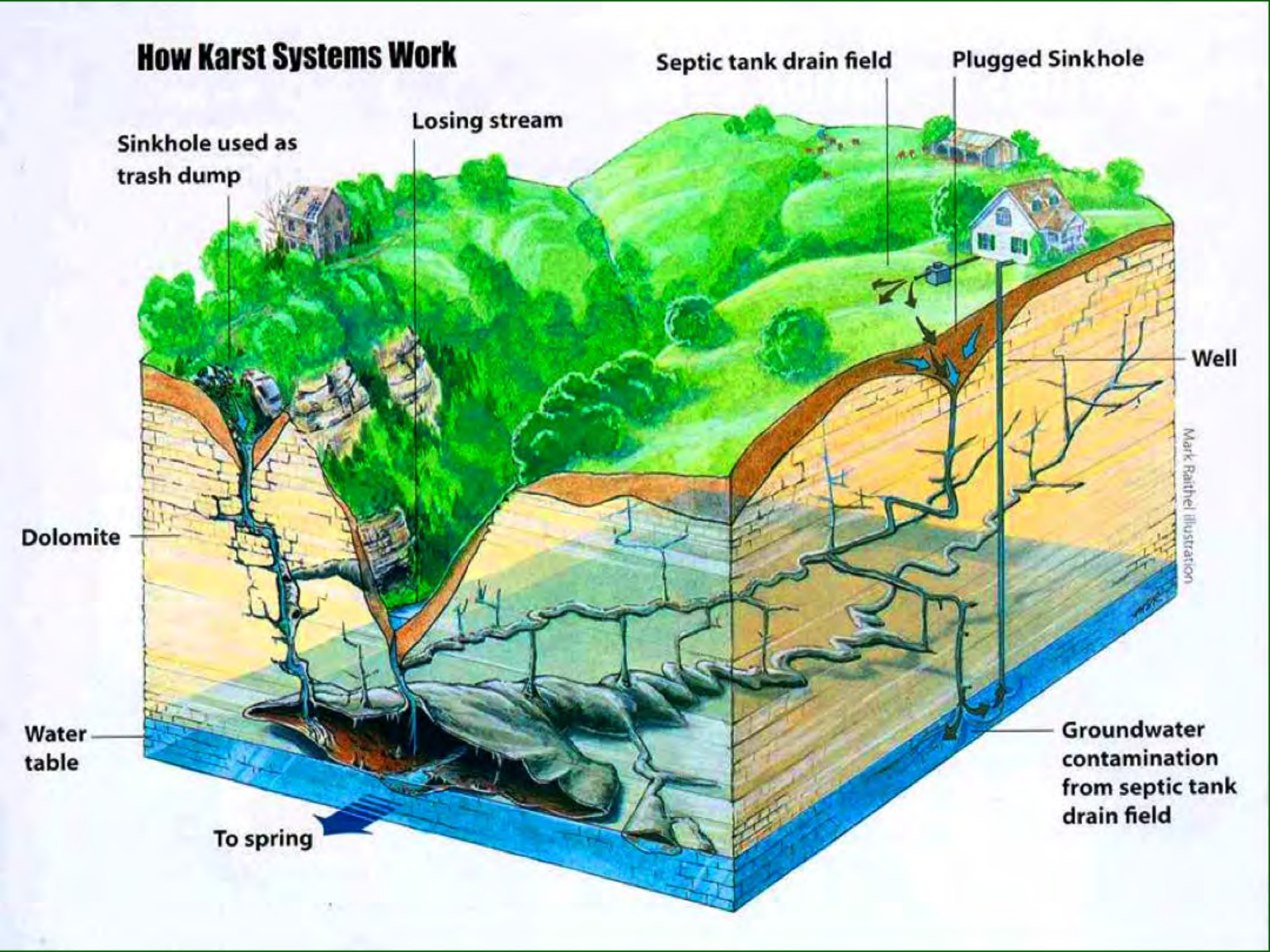


- West Burma terrane
- Shan-Thai terrane
- Indochina terrane

Karst Processes

Karst Processes

- Disappearing Streams
- Caves
- Springs

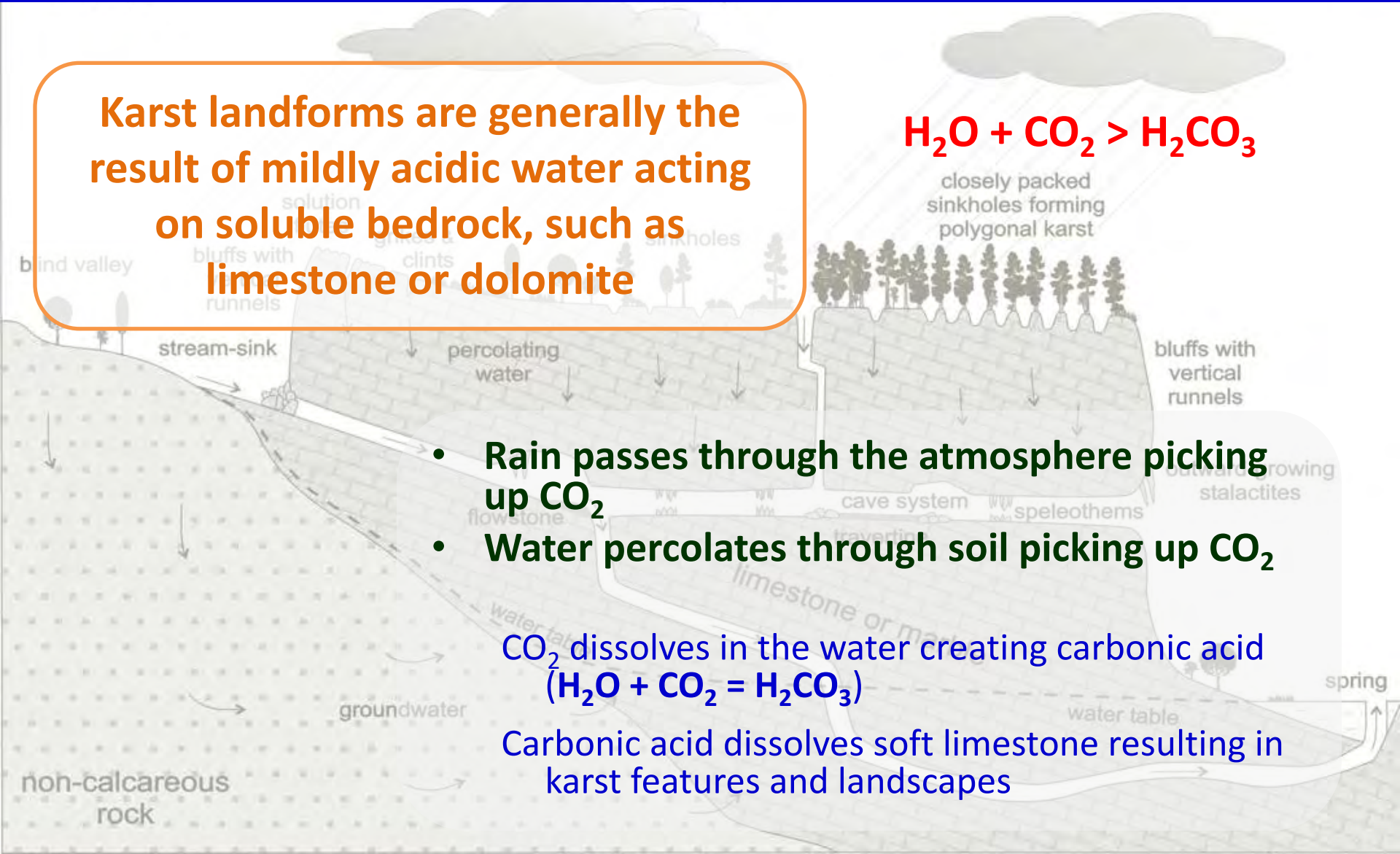

How Karst Systems Work
Septic tank drain field
Plugged Sinkhole
Losing stream
Sinkhole used as trash dump
Well
Dolomite
Water table
To spring
Groundwater contamination from septic tank drain field
Mark Raithel Illustration

How Does Limestone Become Karst Topography?

Carbonic Acid… Meets Limestone

Karst landforms are generally the result of mildly acidic water acting on soluble bedrock, such as limestone or dolomite

$H_2O + CO_2 > H_2CO_3$

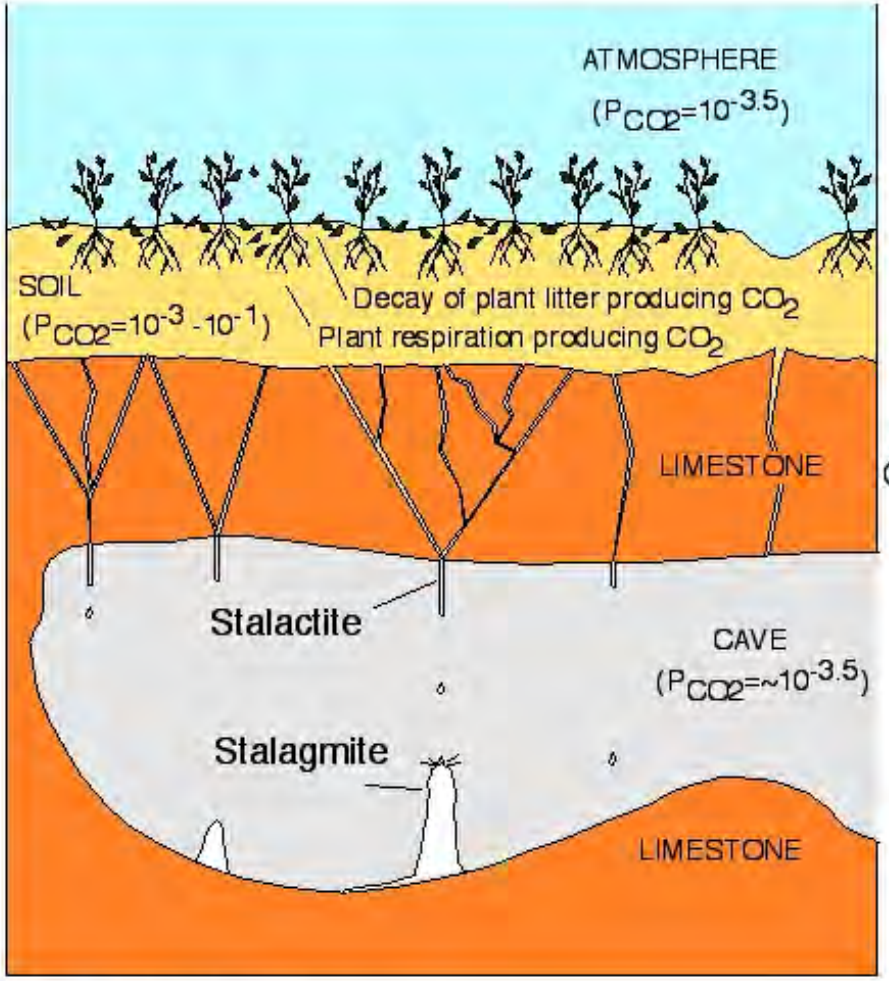


- **Rain passes through the atmosphere picking up CO_2**
- **Water percolates through soil picking up CO_2**

CO_2 dissolves in the water creating carbonic acid (**$H_2O + CO_2 = H_2CO_3$**)

Carbonic acid dissolves soft limestone resulting in karst features and landscapes

Production of $C0_2$
Formation of Stalactites and Stalagmites



LBR 12/1999 rev. 3/2002

Release of CO_2 from dripwater in cave drives precipitation of calcite to make stalactites and stalagmites.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

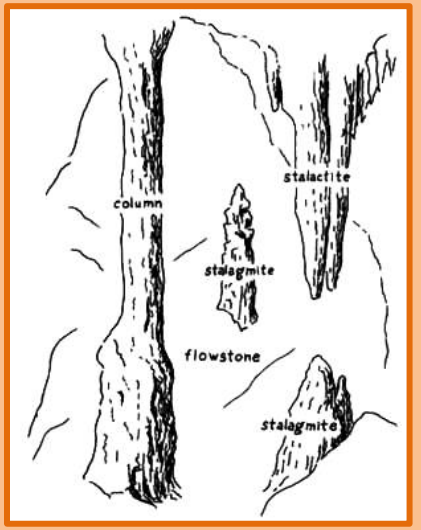
$$H_2CO_3 + CaCO_3 \rightarrow Ca^{2+} + 2\,HCO_3^-$$

Carbonic Acid — Calcite in limestone — **Calcite dissolution**

$$Ca^{2+} + 2\,HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

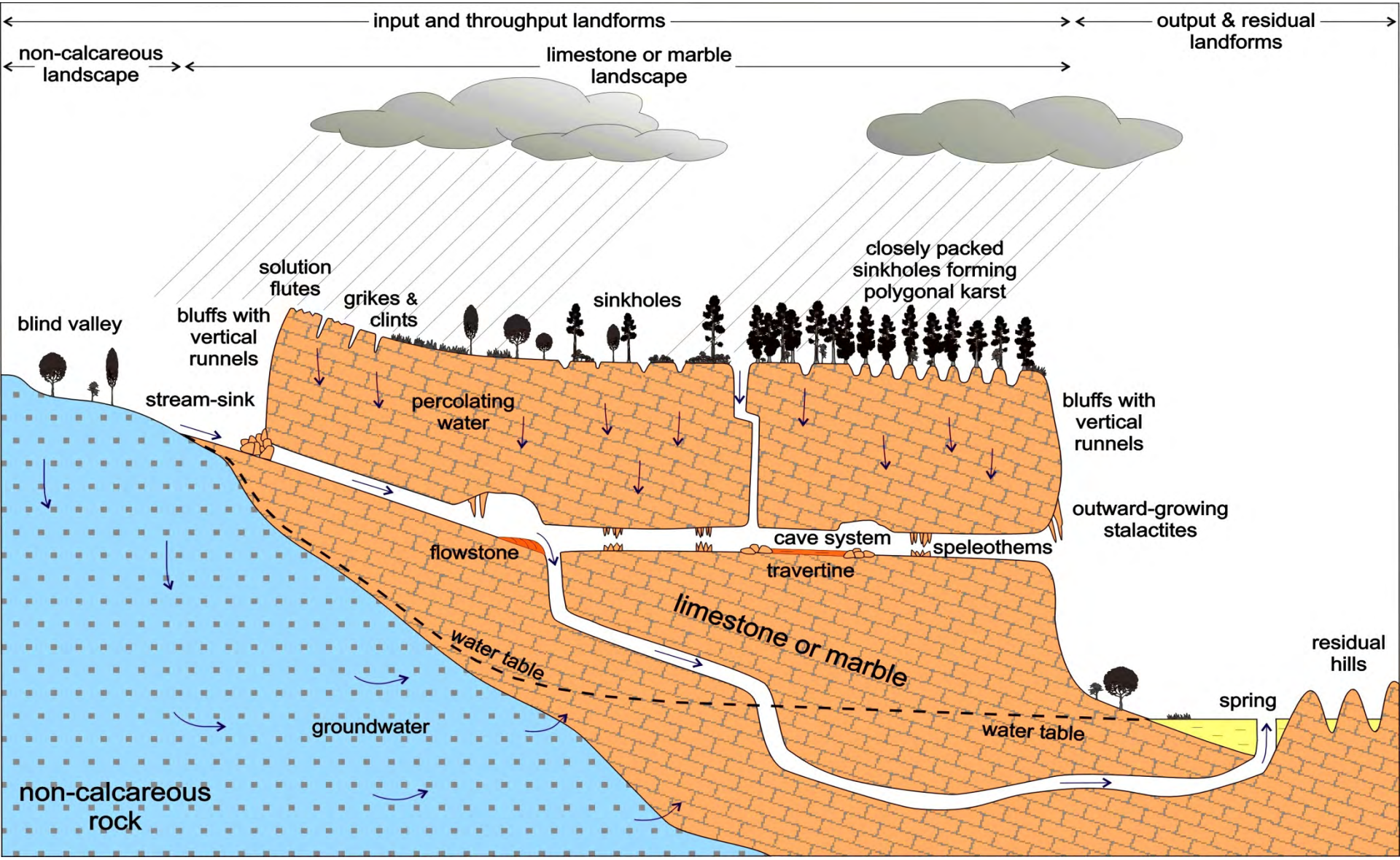
Calcite in stalactite or stalagmite — Carbon dioxide released in cave

Calcite precipitation



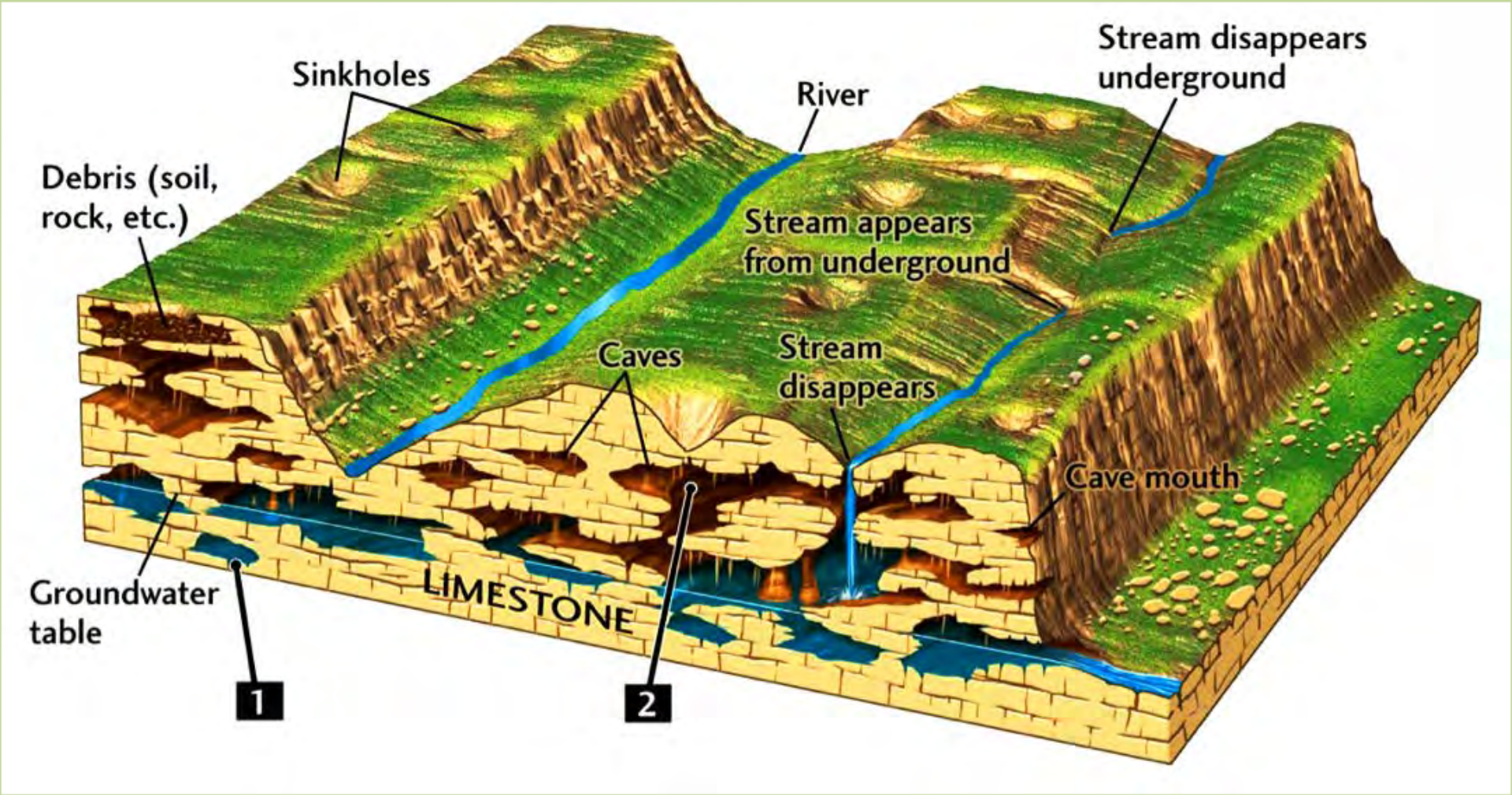
Stalactite
Stalagmite
Column
Flowstone

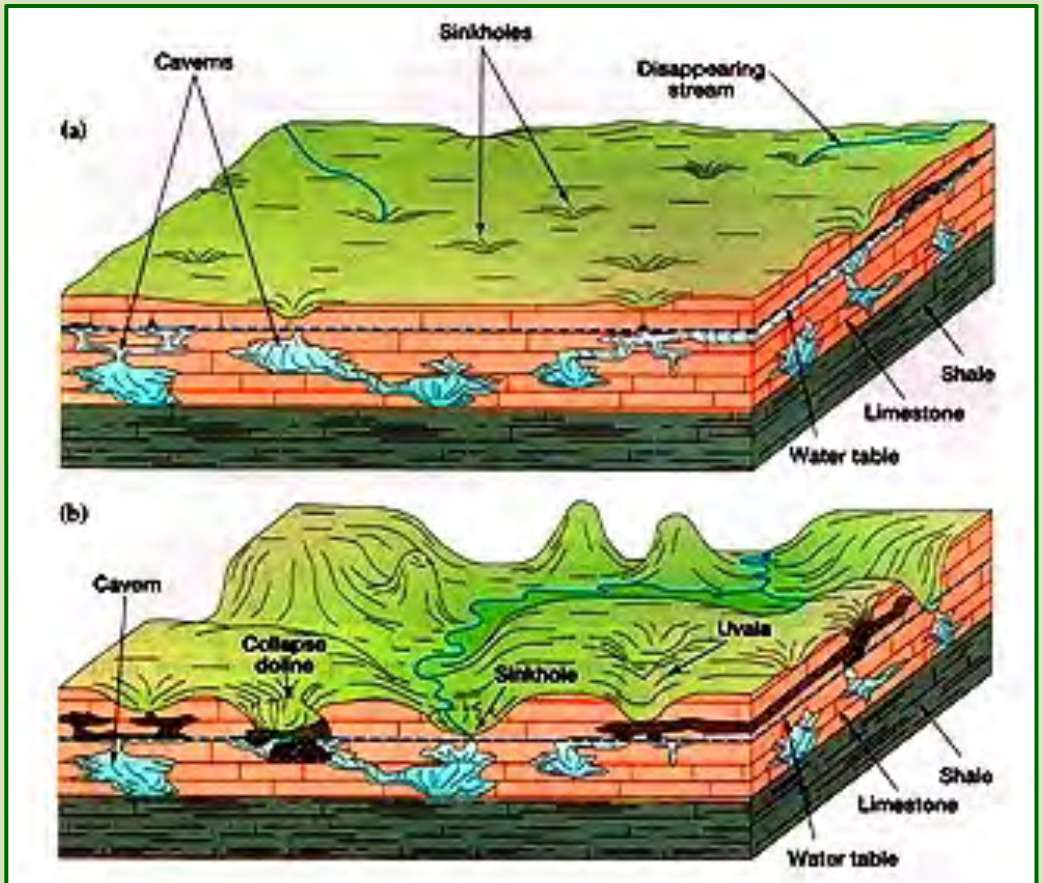
Non-calcareous meets limestone



Karst Topography

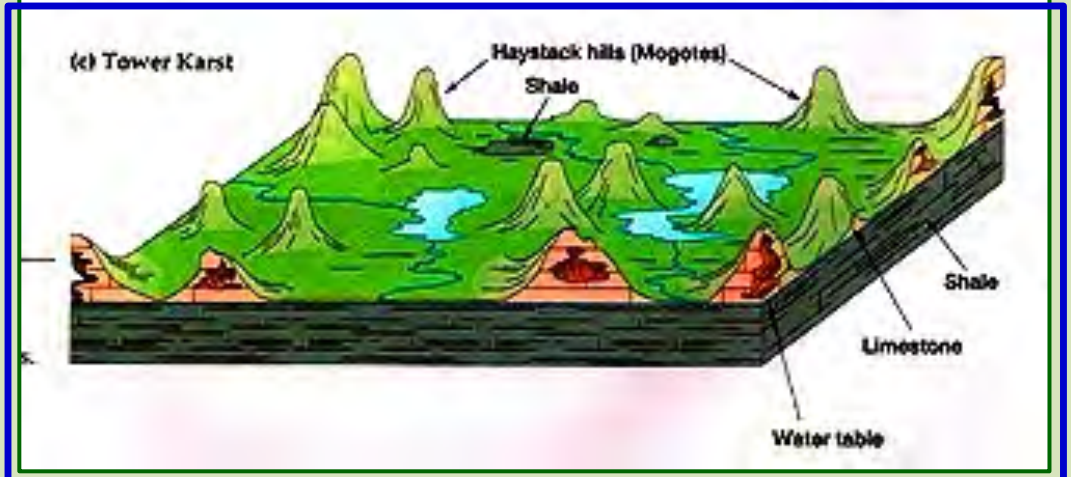
Karst topography is also commonly characterized by caves, sinkholes and streams that disappear and reappear





- Caverns
- Sinkholes
- Disappearing streams

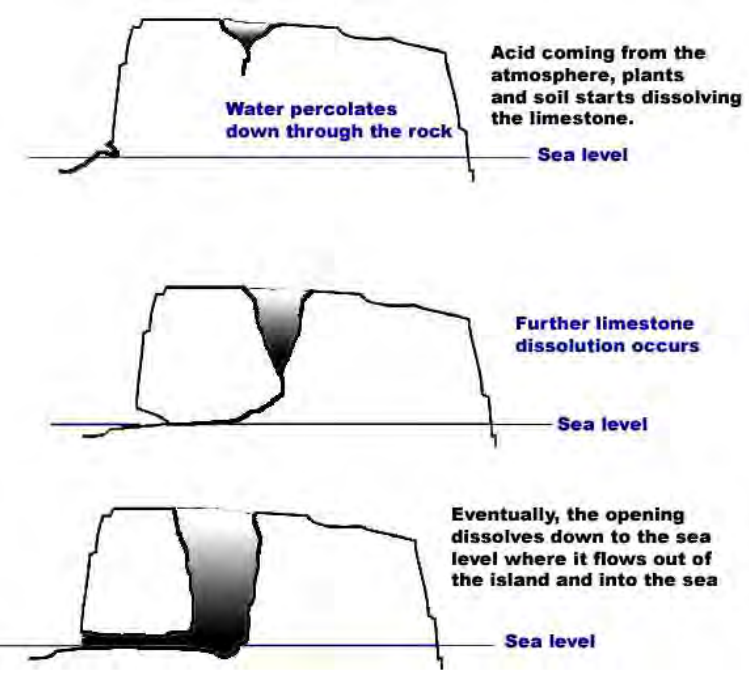
- Caverns
- Collaped doline
- Sinkhole
- Doline and Uvala

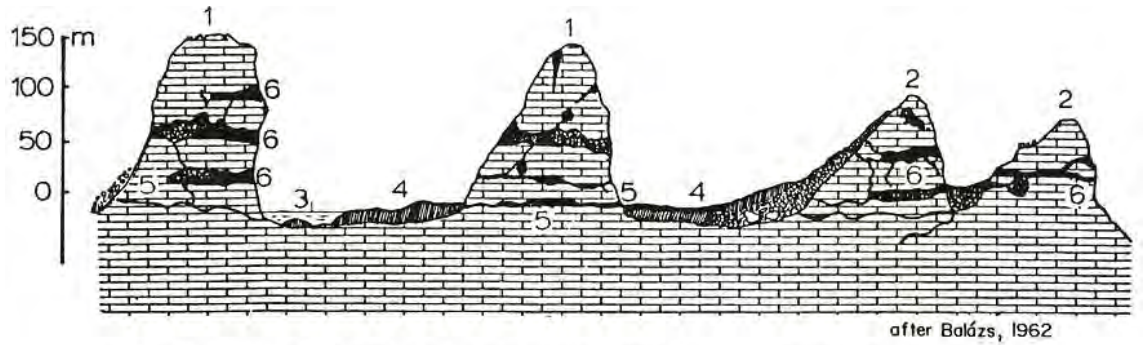


Southern Thai Landscape

- Tower karst
- Haystack hills

Karst Processes

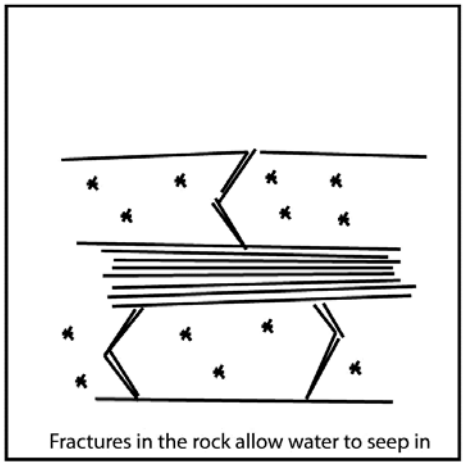


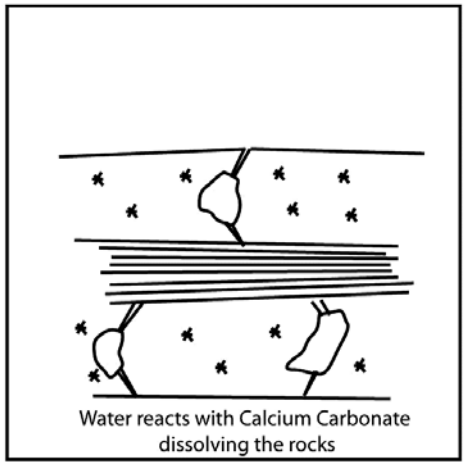


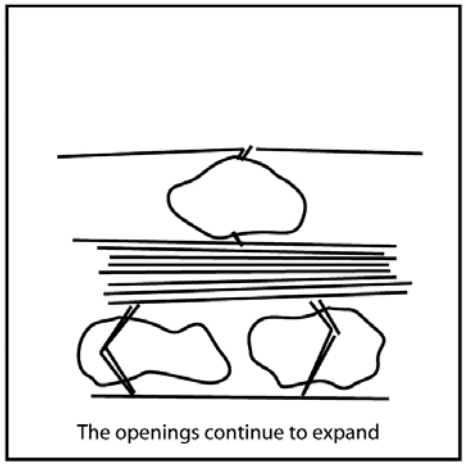
1. Tower karst hills trimmed by lateral fluvial erosion.
2. Typical kegelkarst hills.
3. River.
4. Karst border plain.
5. Active foot cave.
6. Inactive (fossil) foot cave.

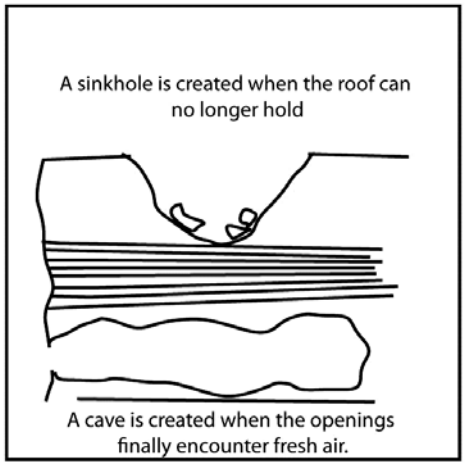
HORIZONTAL AND VERTICAL SCALES EQUAL

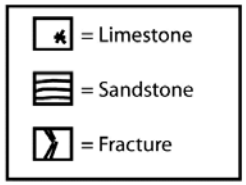
An Example of Karst Formation





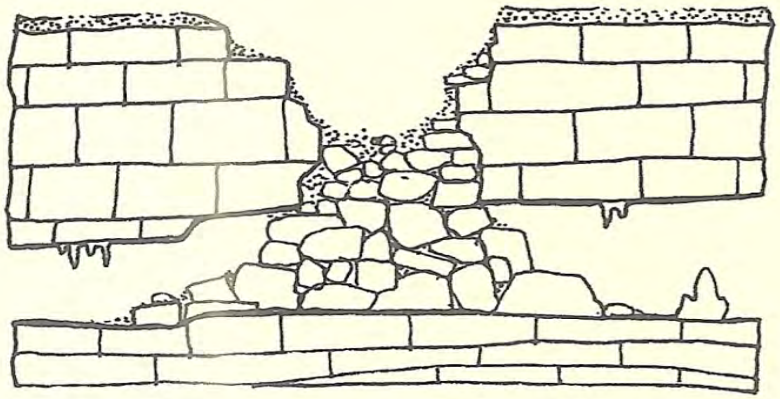




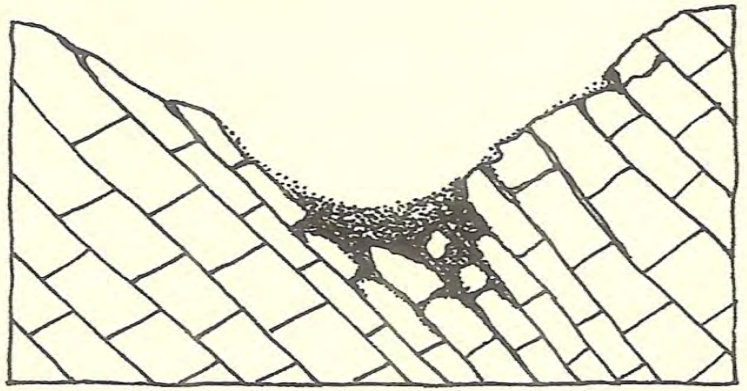


* Karst landforms do not need the sandstone inbetween the Limestone units.
This example is similar to what is seen at Crystal Caves.

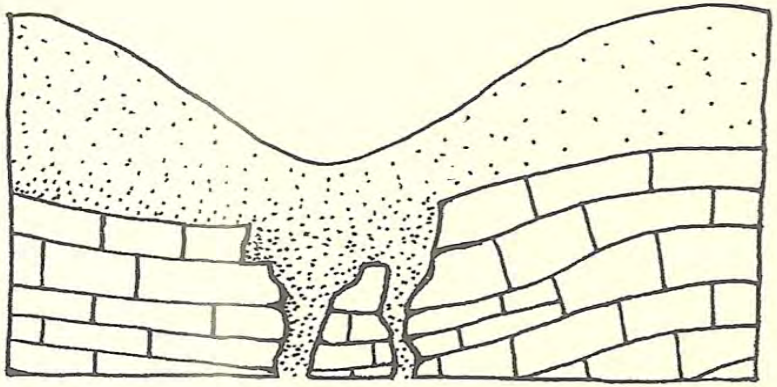
4 Types of Dolines



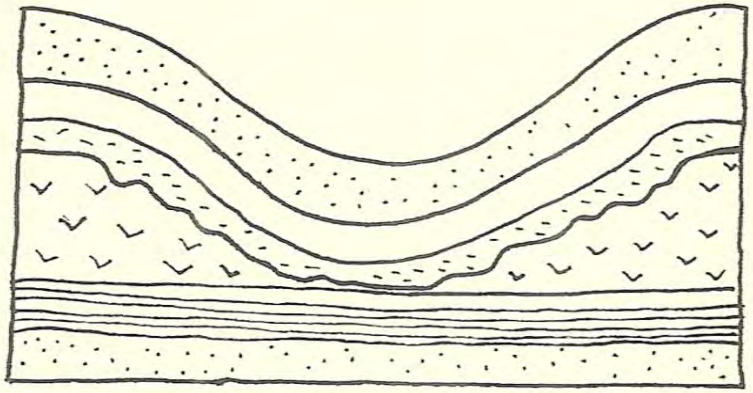
solution



collapse



suffosion



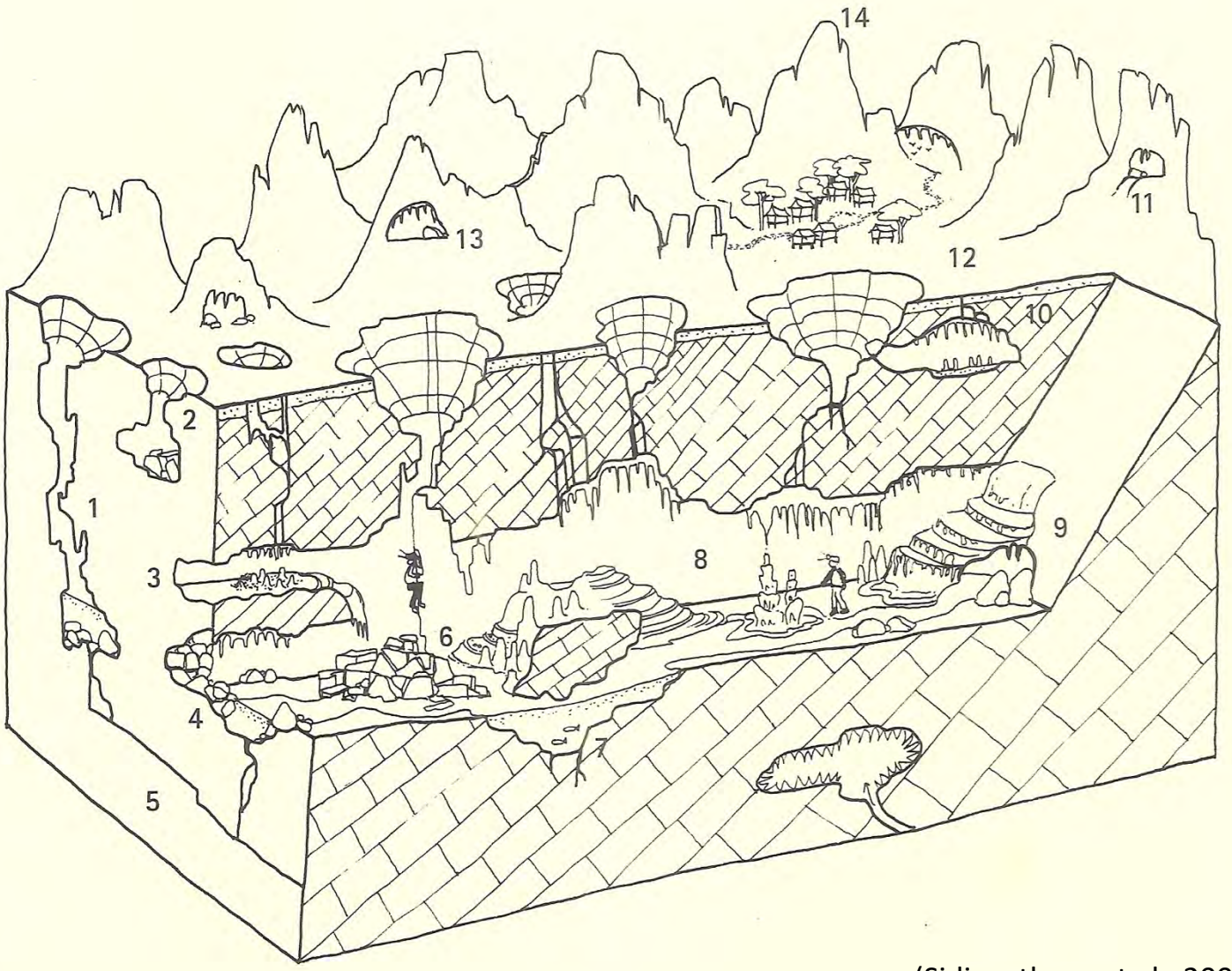
subsidence

(Sidisunthorn et al., 2006)

Karst Systems in Thailand

Typical features of sub-tropical, mountain karst systems in Thailand

1. vadose cave
2. collaps doline
3. abandoned outflow
4. active outflow
5. phreatic protocave
6. breakdown
7. sumped passage
8. active stream cave
9. flowstone blockage
10. hyrothermal cave
11. karst window
12. solution doline
13. inactive cave
14. towers

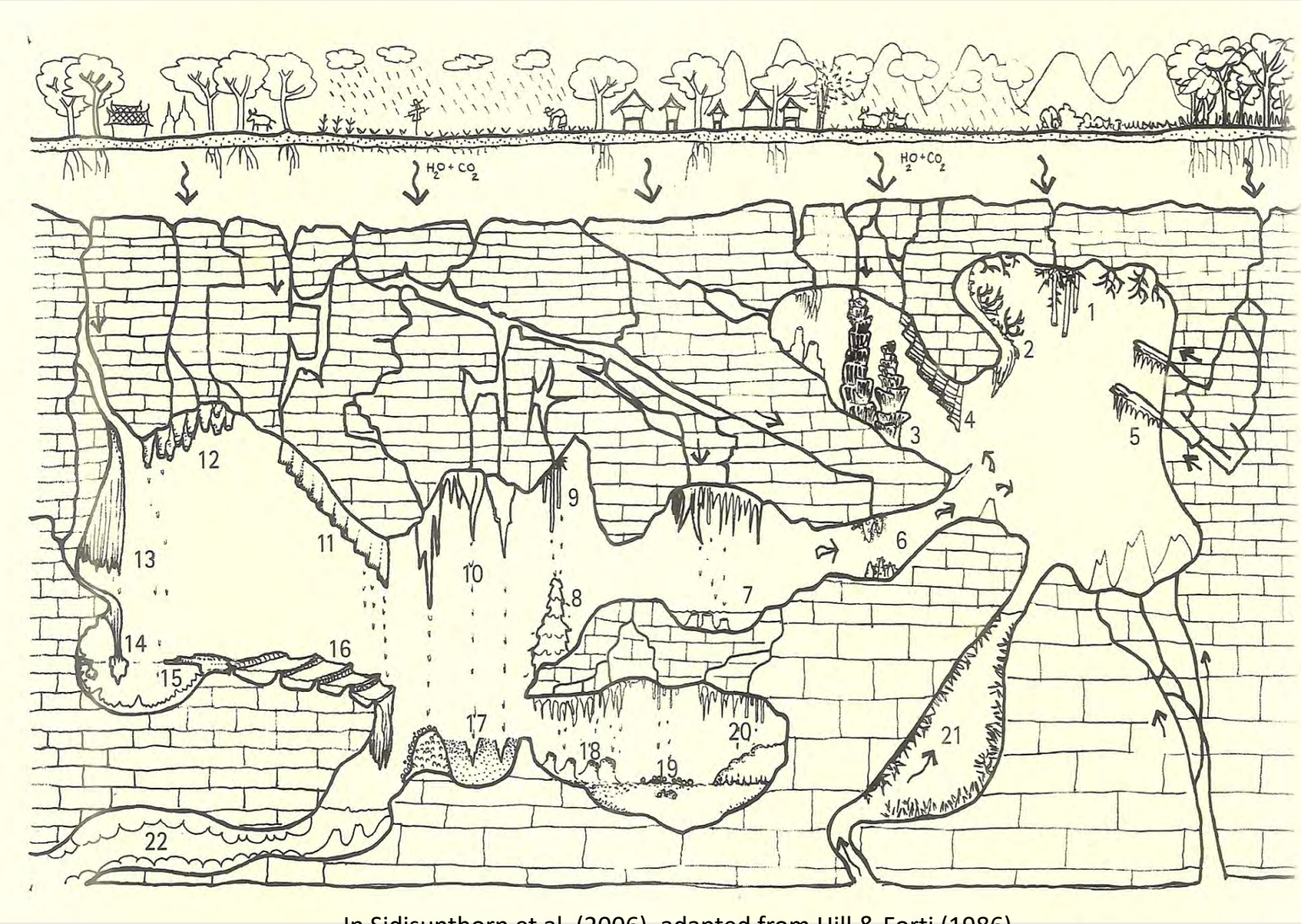


(Sidisunthorn et al., 2006)

1. anthodites
2. helicites
3. column
4. bacon
5. shield
6. popcorn
7. vulcanites
8. stalagmite
9. straws
10. stalctites
11. drapery
12. ‘nom tham’ stalactites
13. flowstone
14. pendulite
15. pool spar
16. gour pools
17. condulites
18. mud stalagmites
19. cave pearly
20. canopy
21. hydrothemal crystals
22. cave clouds

Thai Speleothems

Speleothems are secondary mineral deposits found in caves of various shapes, colors, mineralogy and modes of origin



In Sidisunthorn et al. (2006), adapted from Hill & Forti (1986)

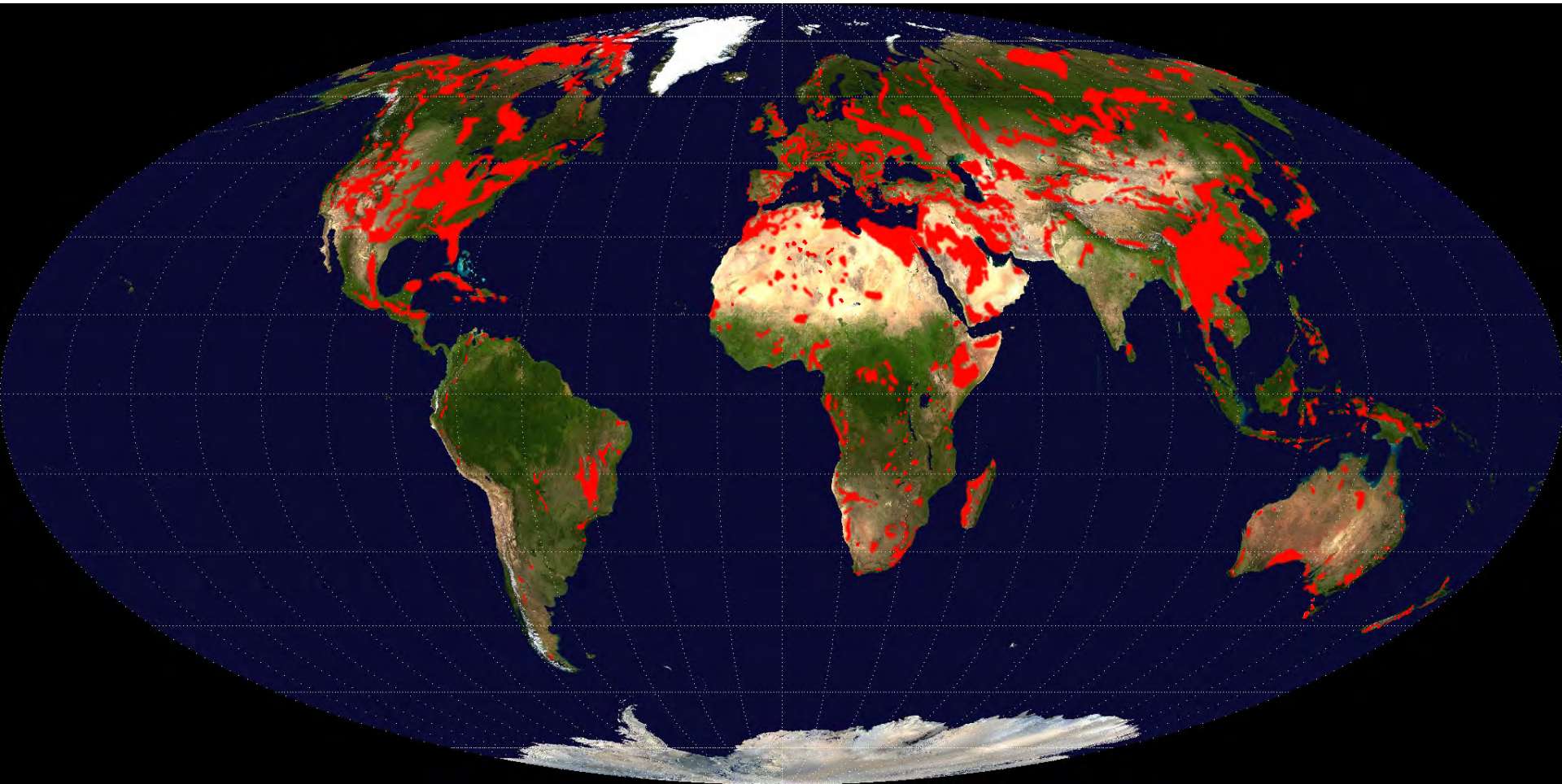
Karst Regions

Carbonate Outcrops of the World

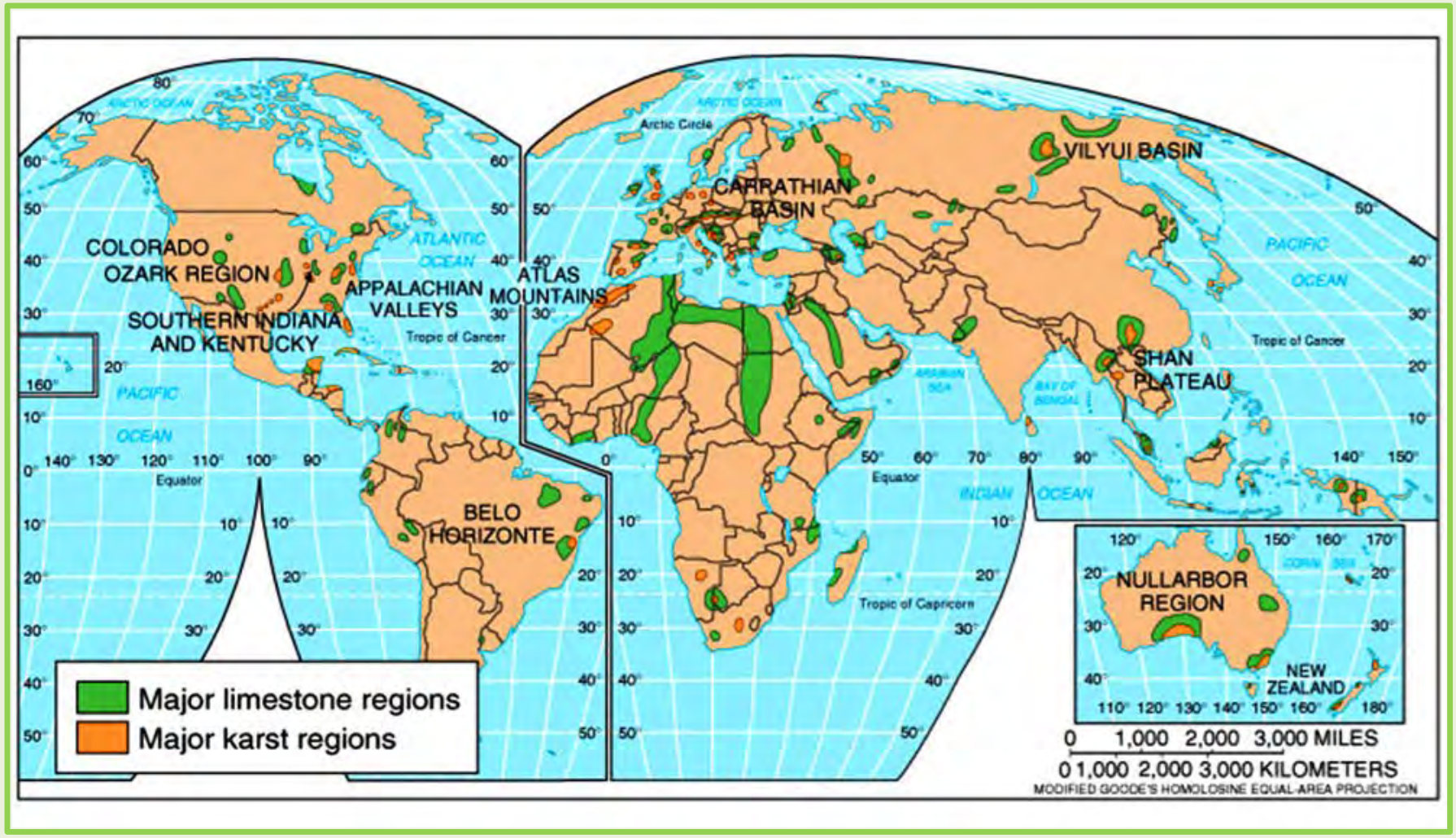
Carbonate rocks, such as limestone and dolomite, form about 12 % of the global land surface.

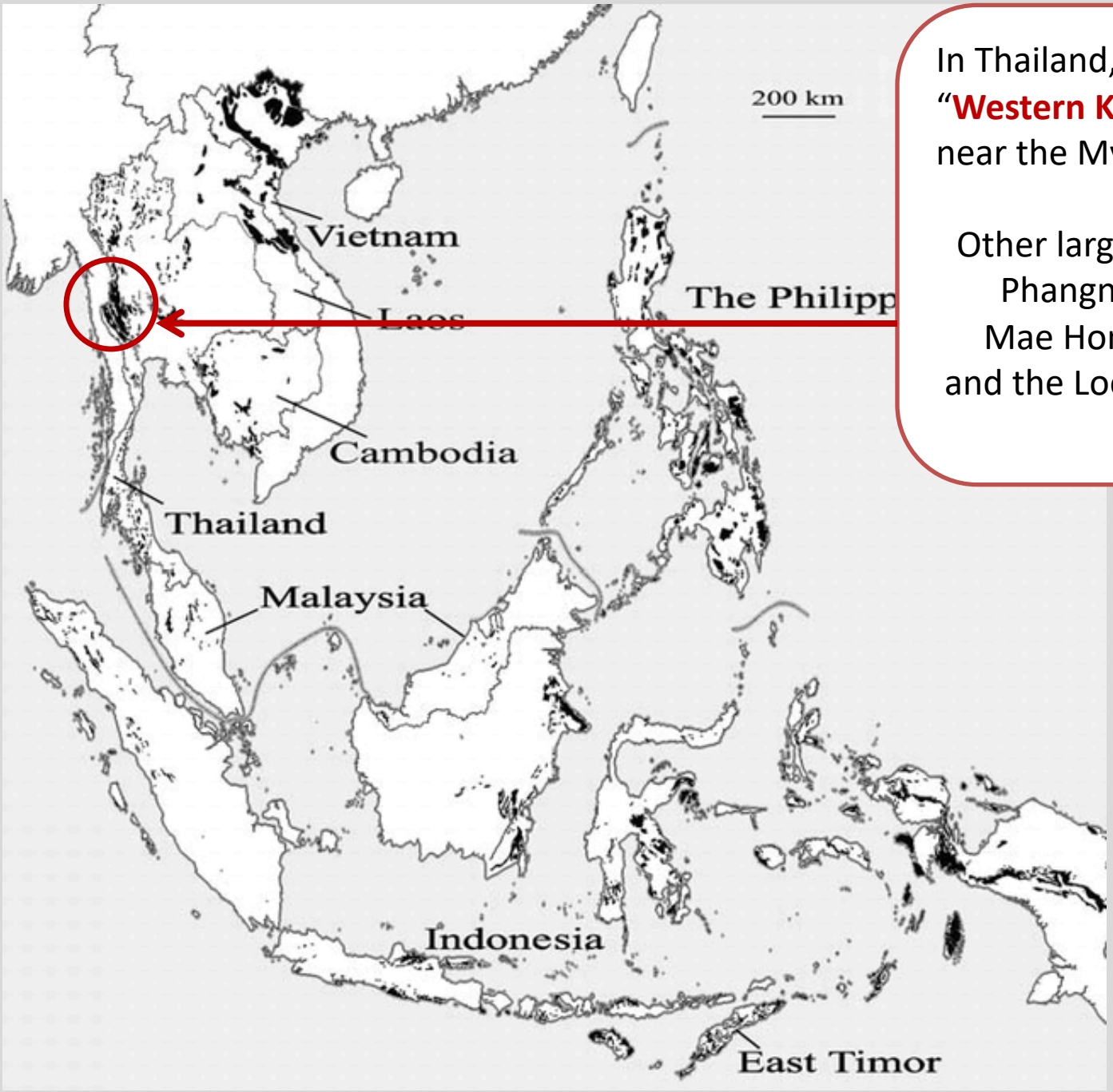
Most of these rocks are **karstified**, i.e., a part of the fractures are enlarged by chemical dissolution to a network of conduits and caves that are crucial for water circulation.

It is estimated that 25 % of the global population are supplied by drinking water from karst.



Limestone and Karst Regions



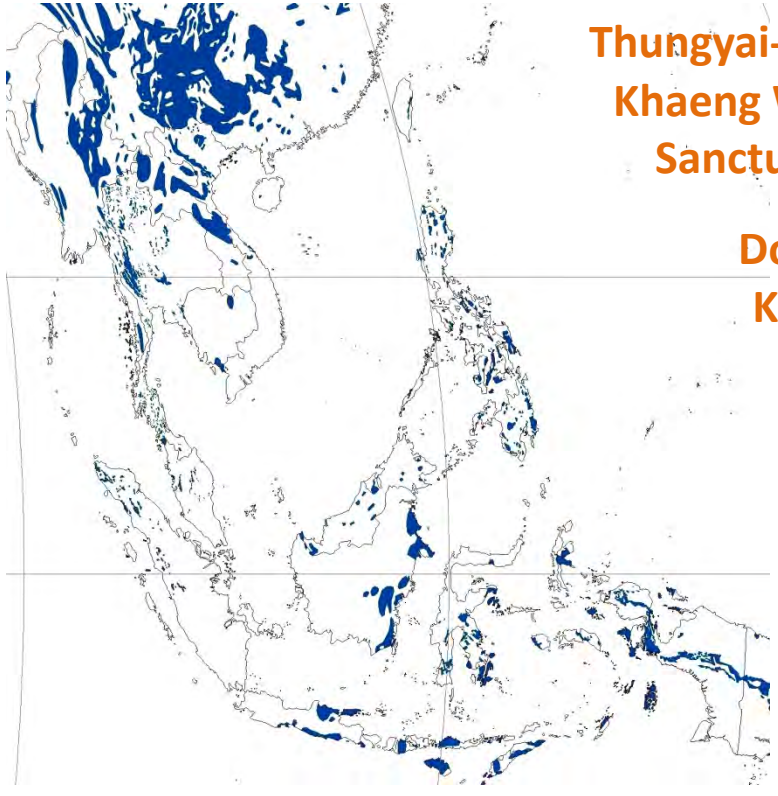


In Thailand, the 12,000 sq km "**Western Karst Complex**" lies near the Myanmar border.

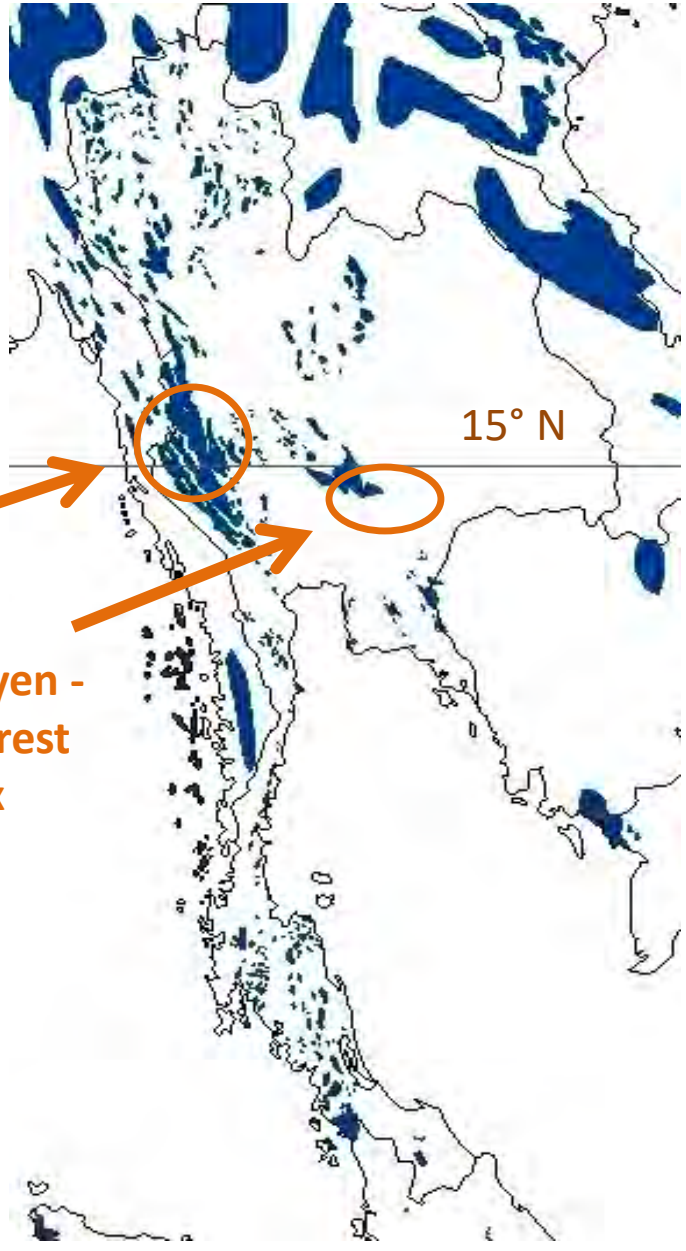
Other large karst areas are at Phangnga, Krabi, Saraburi, Mae Hong Son, Chiang Dao and the Loei/Chum Phae area (Gunn, 2004)

Karst Landscapes in South East Asia

- Most carbonate rocks are susceptible to karstification (although not all are well karstified)
- Thus the area of carbonate rock outcrop (**pictured**) provides an upper limit on the area of exposed karst terrain
- Extensive karstified carbonate rock also exists in subcrop, but is not mapped here.



Thailand has listed 2 World Heritage Karst Sites

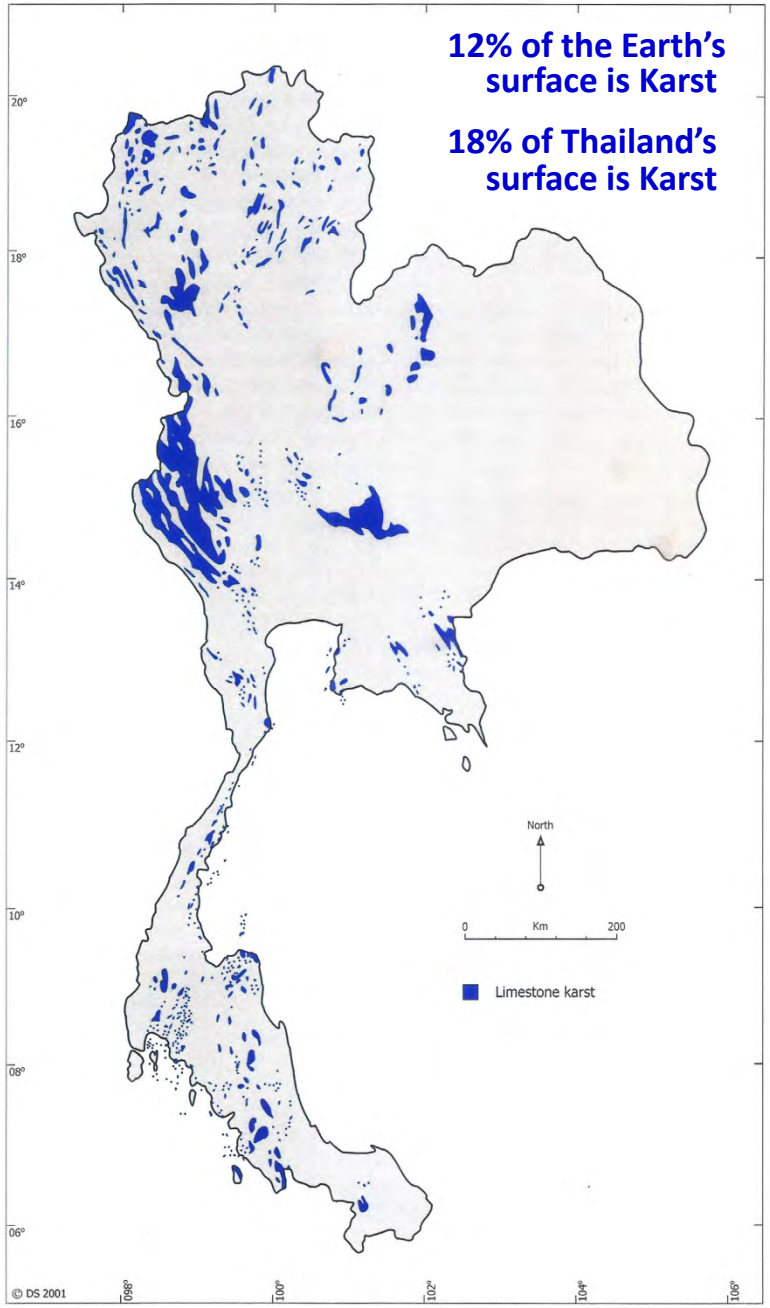


2 World Heritage Karst Sites in Thailand

As of 2008, UNESCO lists 45 World Heritage properties with internationally significant karst features

Region and Provinces	World Heritage Property	Inscribed	Key Karst Features	Environmental Context
Western Thailand Kanchanaburi, Tak and Uthai Thani	**Thungyai-Hua Kha Khaeng Wildlife Sanctuaries** Comprising 2 Wildlife Sanctuaries	1991	A large and geologically complex forested mountainous region to 1500 m with savannah plains. Karst over part of the area, likely to be important but scientifically unevaluated.	Tropical monsoon climate. Evergreen and semi-deciduous forest in mountains with savannah in valleys and gallery forest along rivers. Outstanding biodiversity Values.
Central and Northeastern Thailand Saraburi, Nakhon Nayok, Nakhon Rachisima, Prachinburi, Srakaew and Burirum	**Dong Phayayen - Khao Yai Forest Complex** Comprising 4 National Parks and 1 Wildlife Sanctuary	2005	Contains karst terrain in west of area with gorges and caves, habitat of endemic species of reptiles and bats. Karst scientifically unexplored, but likely to be significant.	Tropical monsoon forest with long dry season.

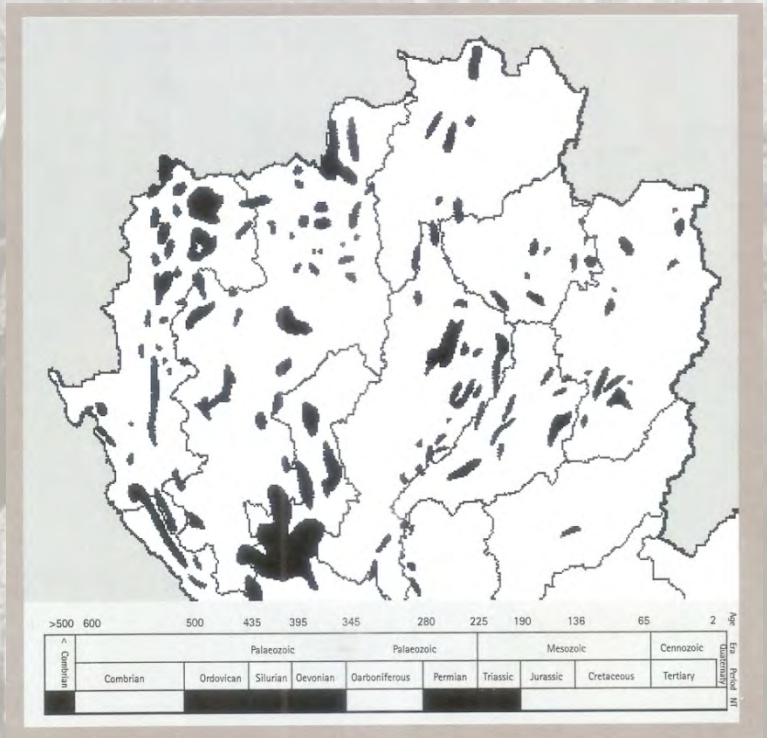
(Williams, 2008)



Limestone karst areas in Thailand.

(Sidisunthorn et al., 2006)

- **4,000 known caves in Thailand**
- **4,000 undiscovered caves (estimated)**



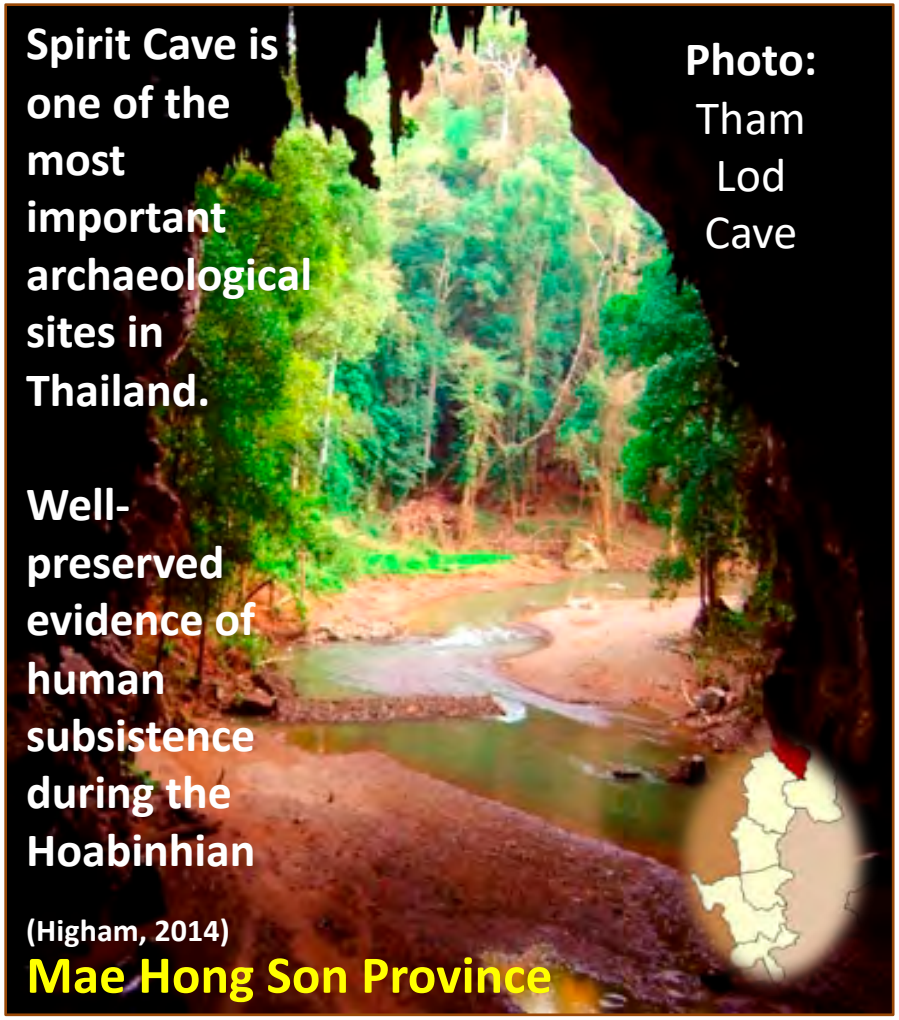
1. **Archeological and Paleoenvironmental Studies**
2. **Ecological** (e.g., Water resources and aquifers)
3. **Economic** (e.g., Bat guano, swiftlet nest harvesting, wild honey, and core material for manufacturing cement)
4. **Tourism** (e.g., tourism geography)
5. **Temples & Folklore** (e.g., Buddhism and Hinduism)

(Sidisunthorn et al., 2006)

Pindar Sidisunthorn
Simon Gardner
Dean Smart

Introducing a few distinctive karst landscapes Thailand

Spirit Cave(s) – Pang Ma Pha



Represents the transition to agriculture in hunter-gatherer societies

The Karst topography of Thailand provided habitat and shelter for ***Anatomically Modern Humans*** (AMH)

Hoabinhian (12,000–10,000 BC)

A cultural and ecological orientation to the use of rockshelters generally occurring near freshwater streams in an upland karstic topography

Assemblages of food remains including remains of extant shellfish, fish and small-to-medium-sized mammals

Edge-grinding and cord-marked ceramics

Unifacial flaked tool tradition

Core tools ("Sumatraliths")

(Gorman, 1970)

Lang Rong Rien – Krabi

Human occupation dated from *c.* 40,000 BP

One of the oldest habitation sites in Southeast Asia

An important location for studying the long-term human occupation of the region.

(Gunn, 2004)

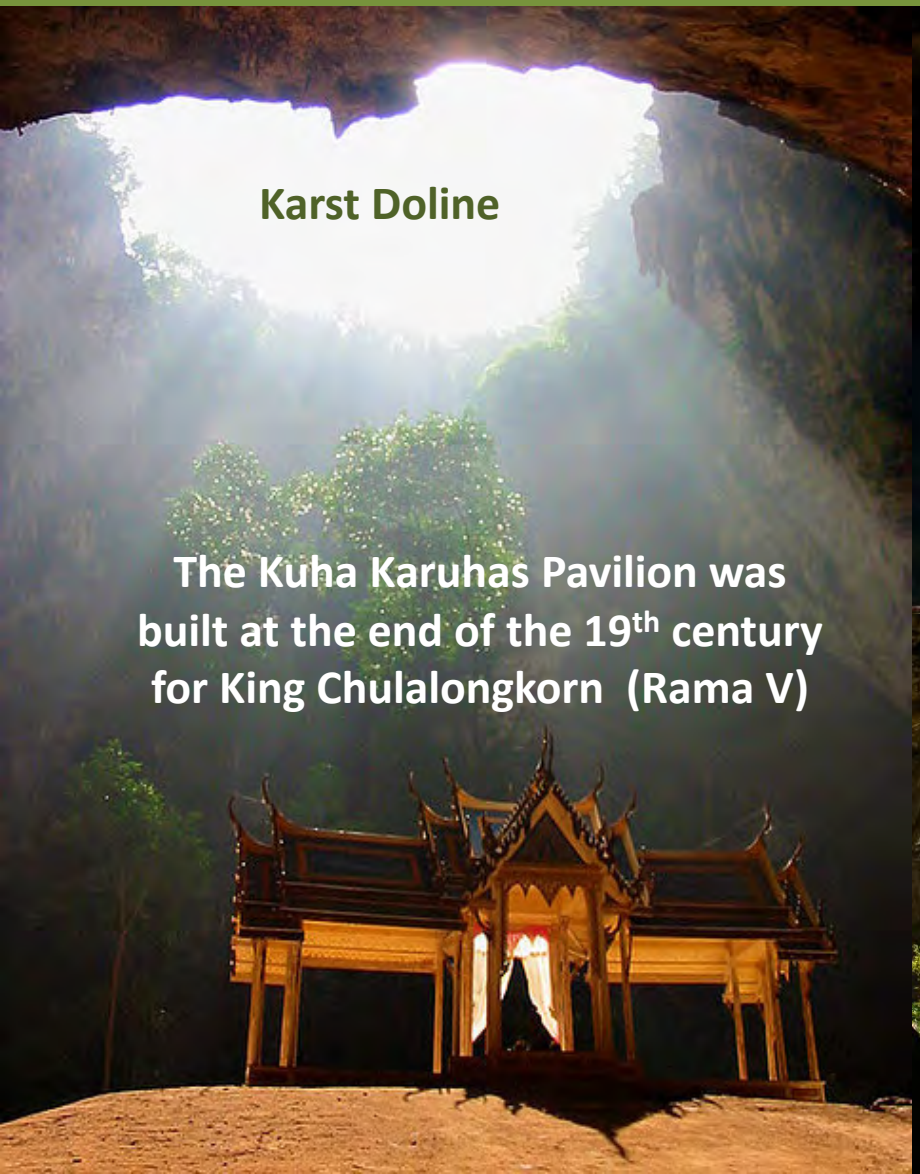
Located on a limestone tower that lies between two streams

The site was excavated by Douglas Anderson in 1983

Bones, artifacts, stone tools, and pottery

Phraya Nakhon Cave - Khao Sam Roi Yot National Park

The limestone hills of Khao Sam Roi Yot (i.e., 'Mountains with 300 peaks') at the shore of the Gulf of Thailand are a subrange of the Tenasserim Range



Temple Caves

Spiritual & Religious Significance of Karstic Sites

Wat Tham Suwan Khuha, Phangnga Province

Phallic Stalactite wrapped with 'Ji Won' cloth

Tham Ki Nok, Chiang Mai Province

Chiang Mai

Shiva with Trident

Tham Tep Ni Mit, Lampun Province

Lampun

(Sidisunthorn et al., 2006)

Limestone Landscape at Phitsanulok

Phi Phi Leh, Krabi, Andaman Coast Thailand

Photo by Steven Martin

Ko Phing Kan — Leaning Rock — James Bond Island

Tower Karst at James Bond Island

Mass Tourism Site!

Photo by Steven Martin

Sea Caves of Phangnga and Krabi

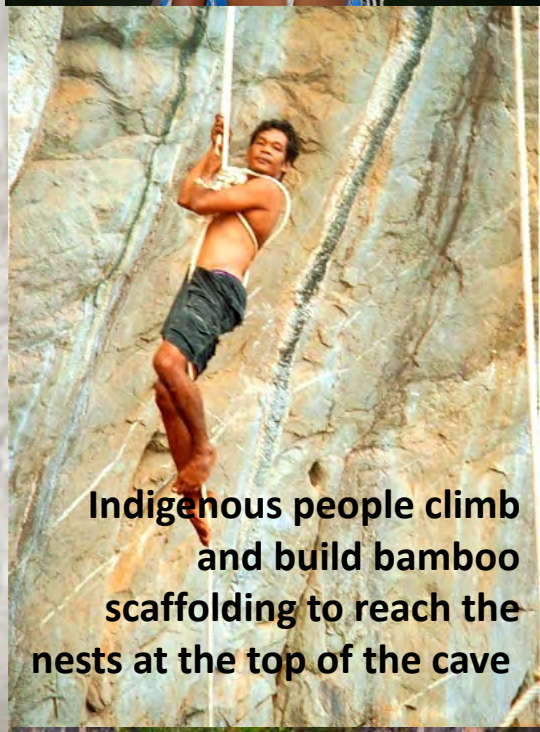
Tham Lawt

Edible-nest Swiftlet Sites on the Andaman Coast

- **Produces nests using only its own saliva** (i.e., no twigs or other materials)
- Nests are tiny translucent cups about the size of a small egg
- Used to make a bird nest soup
- Harvested up to three times a year without overly stressing the birds.

$$$

100 kg of nests are collected 3 times in a good year from the Andaman Sea island of Koh Petra



Indigenous people climb and build bamboo scaffolding to reach the nests at the top of the cave

Shell Cemetery (Su-san Hoi)

Only 3 sites of this type in the world: Chicago, USA; Japan; and Thailand

Shelly Limestone

A fossil bed comprised primarily of stubby-shaped gastropods (such as Viviparidea) ranging in size of 1-2 cm.

Mollusk beds comprised of clay mixed with plant remains and gastropod fragments

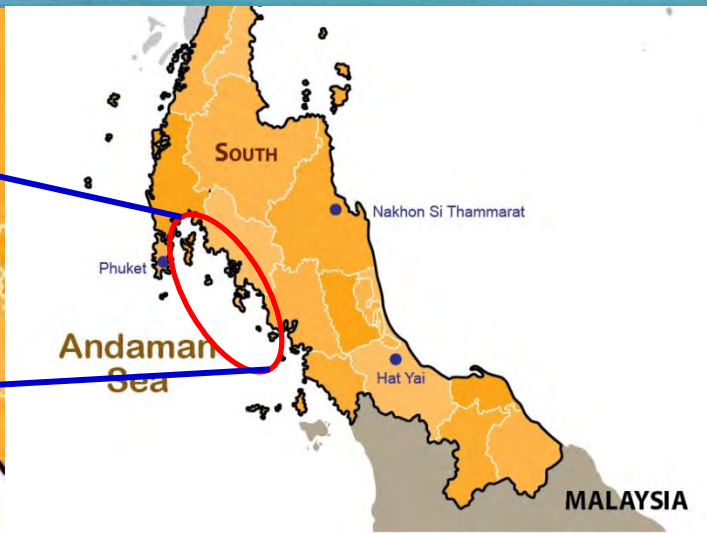
Formed 35 mya (?) when the region, a freshwater swamp, was invaded by seawater.

Limestone elements in the seawater fossilized the mollusk shells forming layers of shelly limestone

Photos by Steven Martin

Karst Topography on the Andaman Coast

Introduction to Tower Karst on the Andaman Coast, Thailand



- **The light gray limestone that forms the tower karst is part of the Ratburi Group**
  - a geologic unit that was deposited during the **Permian Period** between **286 and 245 million years ago** when sea levels were over one hundred meters higher than today.

- This unit also contains some sandstone and shale, and ranges in **thickness from 750 meters to 915 meters** in peninsular Thailand.

- This unit is more than **1900 meters thick in other parts of Thailand.**

(Gillespie, 2000)

Timeline — Phangnga Bay, Thailand

- **260 million years ago**, a shallow sea ran the entire length of Southern Asia which slowly built up deposits of shells and corals that were later buried under sediments washing in from the land.
  - The calcium carbonate remains were compressed deep in the earth to form limestone.
- **60 million years ago**, the limestone was then thrust up above the surface when the **Indian subcontinent collided with mainland Asia**.
  - The collision of the plates twisted Southern Thailand and the Malay Peninsula clockwise and created ruptures along the 5,000 km ancient coral reef line.
- **2.5 million years ago**, fluctuating sea levels during the **ice ages** allowed for extensive wave erosion of this soft sedimentary rock.
- Rivers cut courses through the karsts, resulting in a labyrinth of cave chambers and passageways.

(Gillespie, 2000)

Phangnga Bay, Thailand

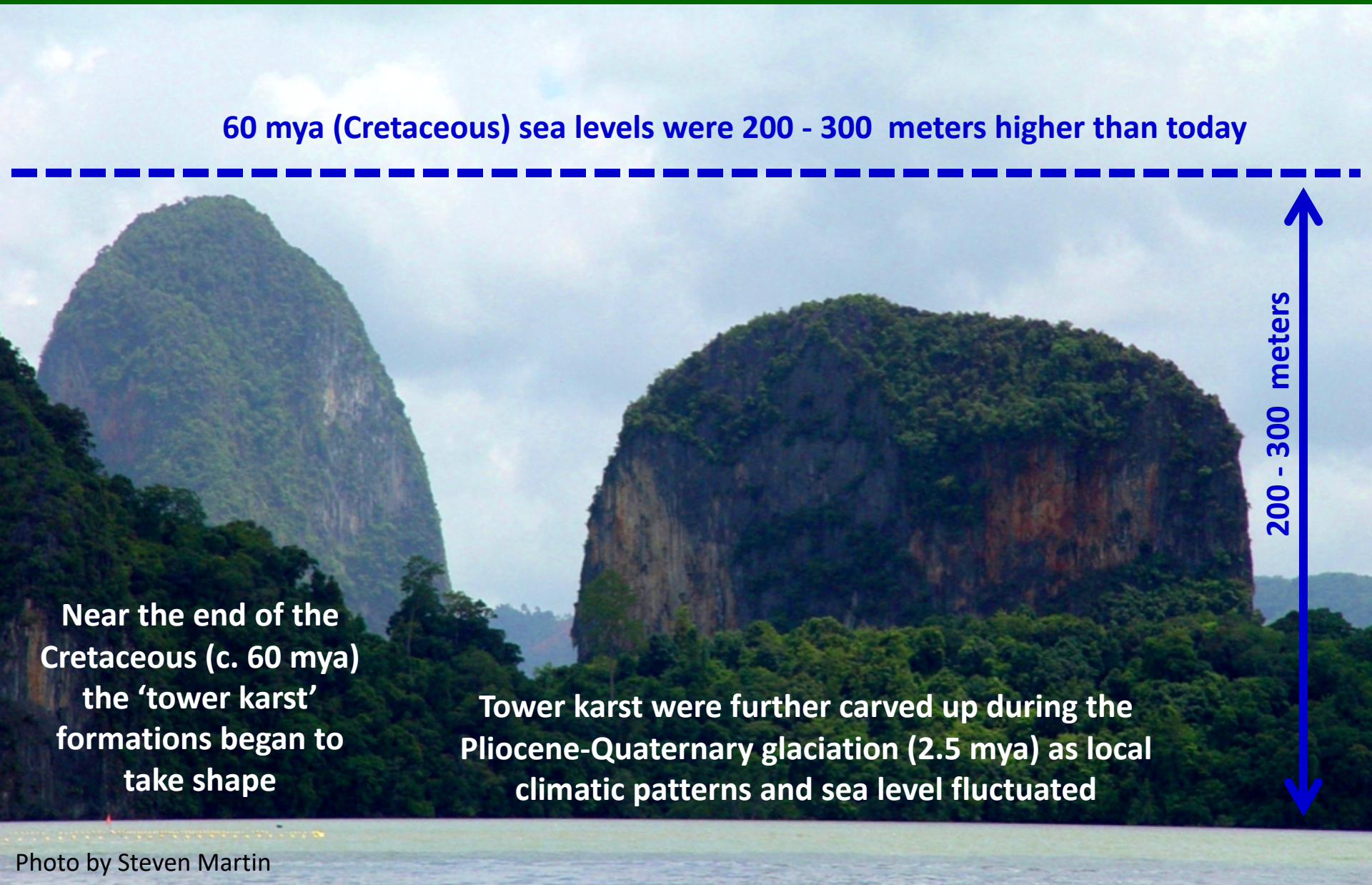


Photo by Steven Martin

Limestone outcrops occur in long narrow belts that **follow the lineation of the mountain chains** of peninsular Thailand

- **Facilitated ridge development** as surrounding rock layers were removed by weathering and erosion

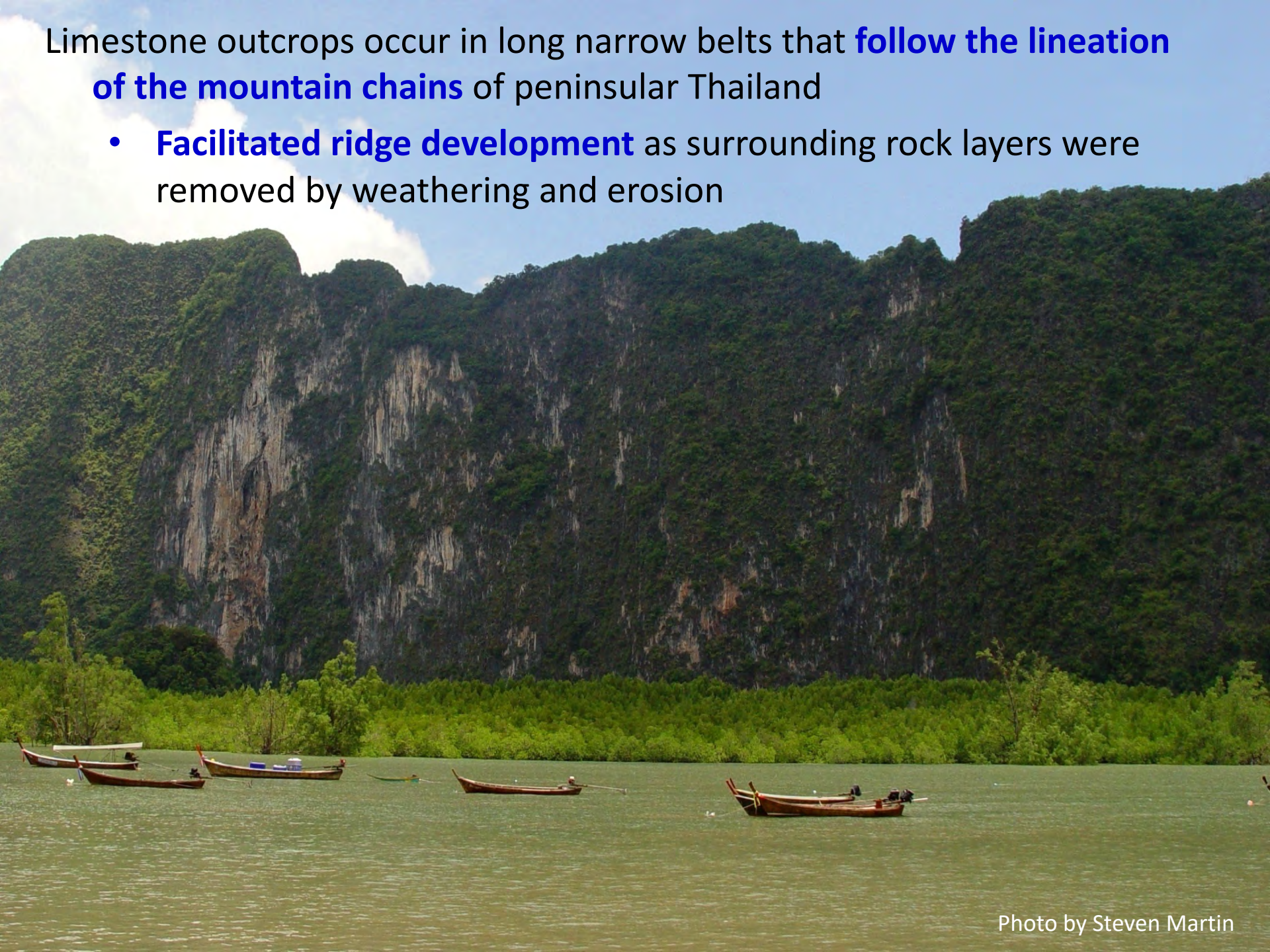


Photo by Steven Martin

Carbon dioxide (CO_2) and pH in the region

$C0_2$ content of local soils is up to 15 times greater than that of the atmosphere

- Roots of plants release carbon dioxide to the soil elevating $C0_2$ levels
- Microorganisms decompose dead plant and animal material in the soil

Aggressive dissolution of limestone below the surface

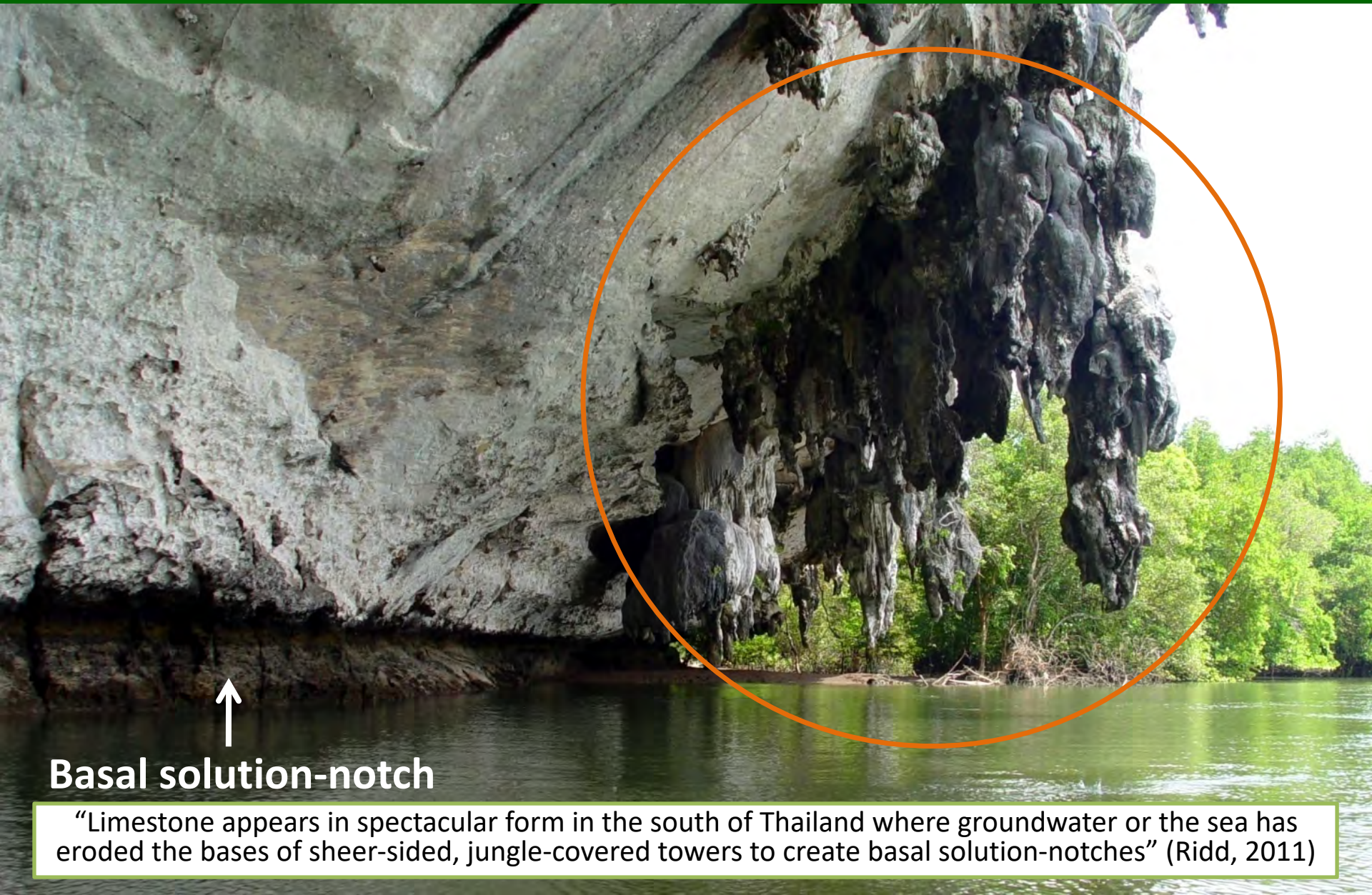
- pH as low as 3.0 (equivalent to vinegar) recorded in local swamps

(Gillespie, 2000)

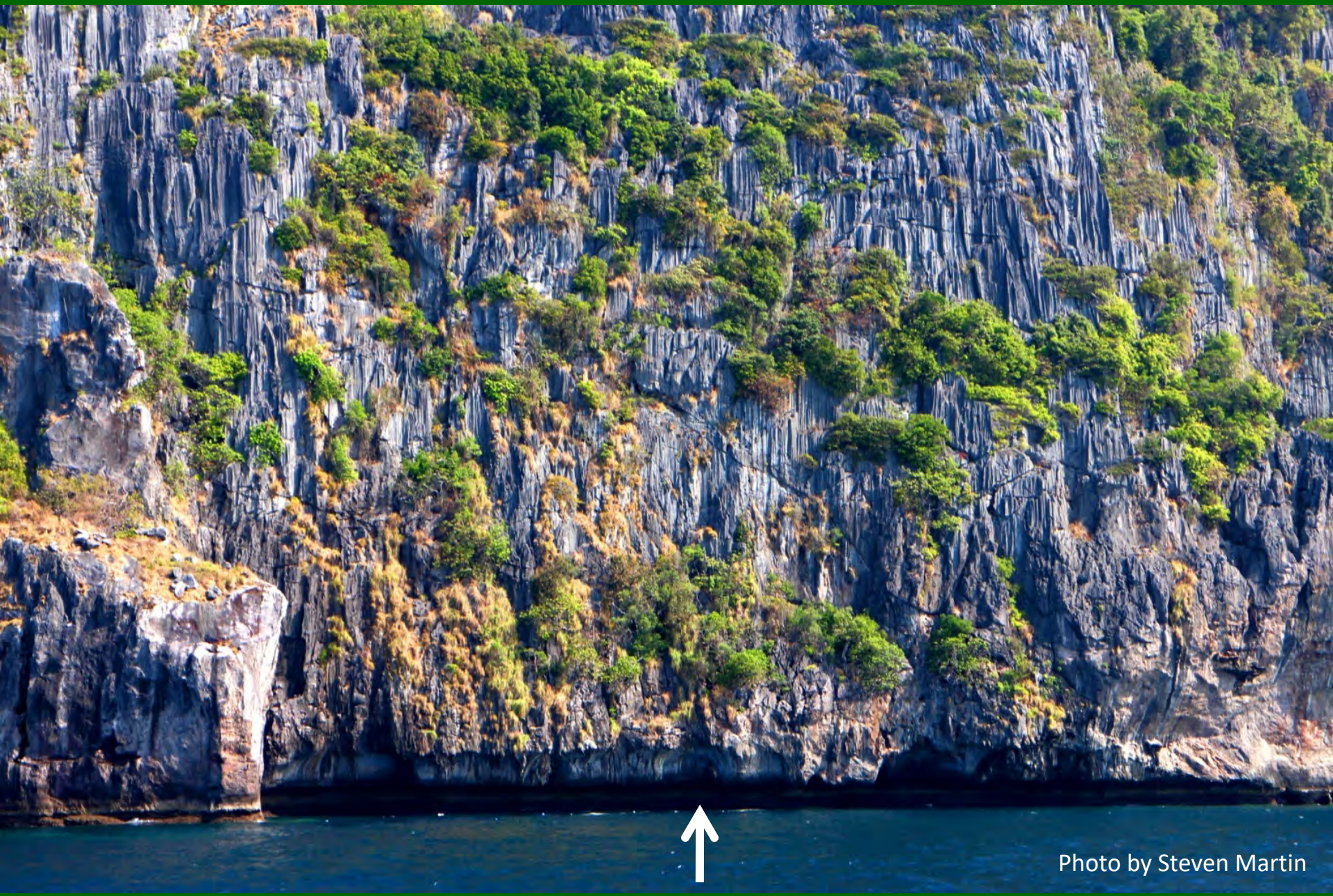
Potentially due to the **laterite** composition of the local soils

Very high carbon dioxide ($C0_2$) in the soil and very low pH in the water promote the *karstification* of limestone on the Andman Coast

Outward-growing Stalactites



"Limestone appears in spectacular form in the south of Thailand where groundwater or the sea has eroded the bases of sheer-sided, jungle-covered towers to create basal solution-notches" (Ridd, 2011)



basal solution-notch


Karstic Caverns,
Krabi, Thailand
Photo by Steven Martin

Andaman Coast Submergence

Photo by Steven Martin

Andaman Coast Subsidence and Submergence

- **On-going crustal plate collisions in Southeast Asia, the Malay Peninsula is experiencing a slow deformation**
  - **East coast of the peninsula is emerging** from the Gulf of Thailand (characterized by wide, sandy beaches)
  - **West coast is slowly subsiding** beneath the Andaman Sea (characterized by few beaches and is characterized by drowned river valleys, prominent headlands, mangrove forests, and isolated islands of partially submerged tower karst)
- **Submergence facilitated by the rise in sea level that occurred at the end of the Pleistocene epoch (10,000 BP).**
  - Great ice sheets that had covered much of North America and Europe melted and raised sea level about 100 meters or more.

(Gillespie, 2000)

Subsidence

The Andaman Coast is slowly sinking into the sea

Submergence

Sea levels rose with the ending of the Ice Age

MORPHOLOGY* OF TOWER KARST IN KRABI, SOUTHERN THAILAND

Harper (1999)

Two varieties of tower karst prominent in the region

Peak forest karst (isolated peaks)

Peak cluster karst (group of peaks with a common rocky base)

.....

Peak forest karst the most common peak shapes are tall, vertical-sided, cylindrical-shaped towers (Turm karst) and moderately steep-sided, cone-shaped towers (Kegel karst). The peak forest towers have maximum elevations that range from about 60 to 210 meters above mean sea level.

Peak cluster karst exhibits cone- and cylindrical-shaped peaks on broad masses of limestone. Some of these masses are elongated along the northeast-southwest direction of strike of the **Ratburi Limestone** and often have vertical cliff faces along their margins. The maximum elevations of the peak cluster towers range from about 240 to 400 meters above mean sea level.

The lower maximum elevations of the peak forest karst and its relative spatial proximity to the peak cluster karst suggest that the peak forest evolved from the peak cluster as a later stage of karst landform development.

The landscape in Krabi Province in southern Thailand is characterized by steep, limestone headland cliffs along its shoreline and by limestone (karst) towers both offshore from the headlands and inland along its alluvial plains.

The coastal karst towers rise directly out of the shallow waters of Phang Nga Bay or emerge from mangrove-fringed tidal flats whereas the inland karst towers are surrounded by Quaternary alluvial and colluvial deposits.

The tower karst in Krabi is developed in massive Permian limestone and dolomitic limestone of the Ratburi Group.

Late Quaternary sea level changes have also influenced karst development in the Krabi region by exerting controls on fluvial erosion-deposition cycles, water tables, and supply of allogenic surface waters.

*__Morphology__ (Geomorphology) refers to the external structure of rocks in relation to the development of erosional forms or topographic features

Karst Doline

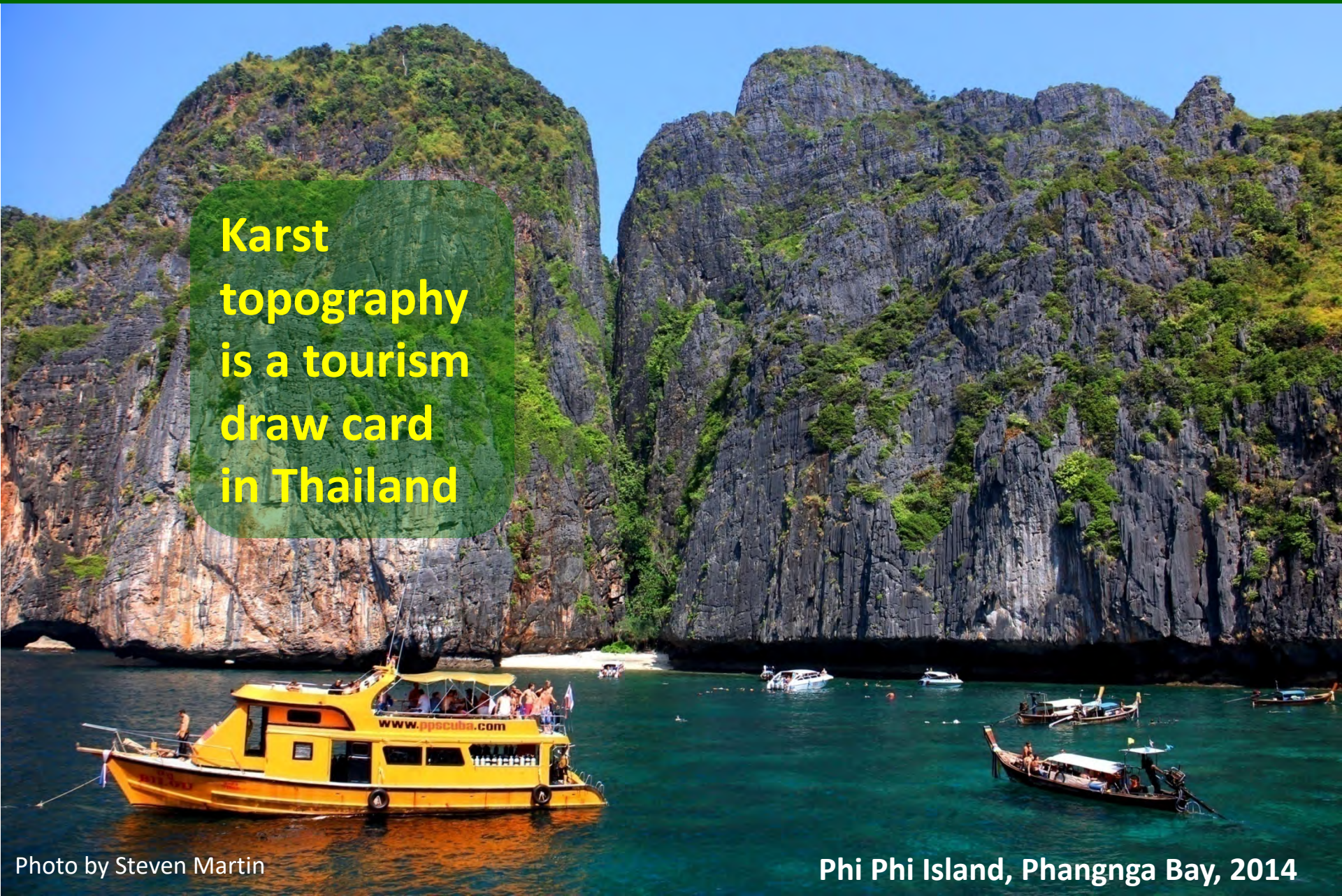
The Hong (i.e., 'Doline')
a dynamic karst topology

When the roof of a huge cave chamber collapses, a 'Hong' (Thai for "room") is created.

Sunlight allows colonizing plants to grow in the depression.

If the floor of the depression is below sea level, the hong may become a lagoon at high tide.

Tourism Geography



Tourism Geography

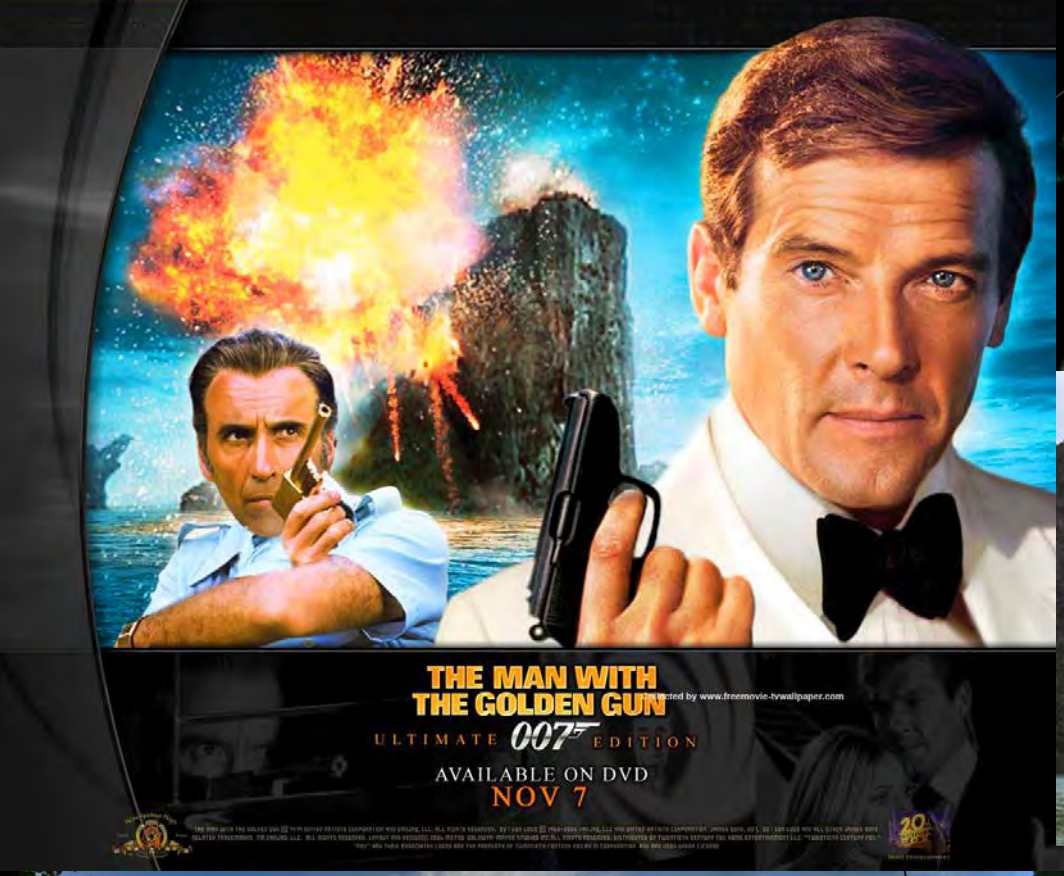
Karst landscapes and topography are draw millions of international tourists each year to Thailand

Marine tourism
Diving and snorkling
Kayak tours
Spelunking (caving)
Mass tourism!
Movie sets

The Man with The Golden Gun
The Beach
The Hangover

Phi Phi Island, Phangnga Bay, 2014

Photo by Steven Martin

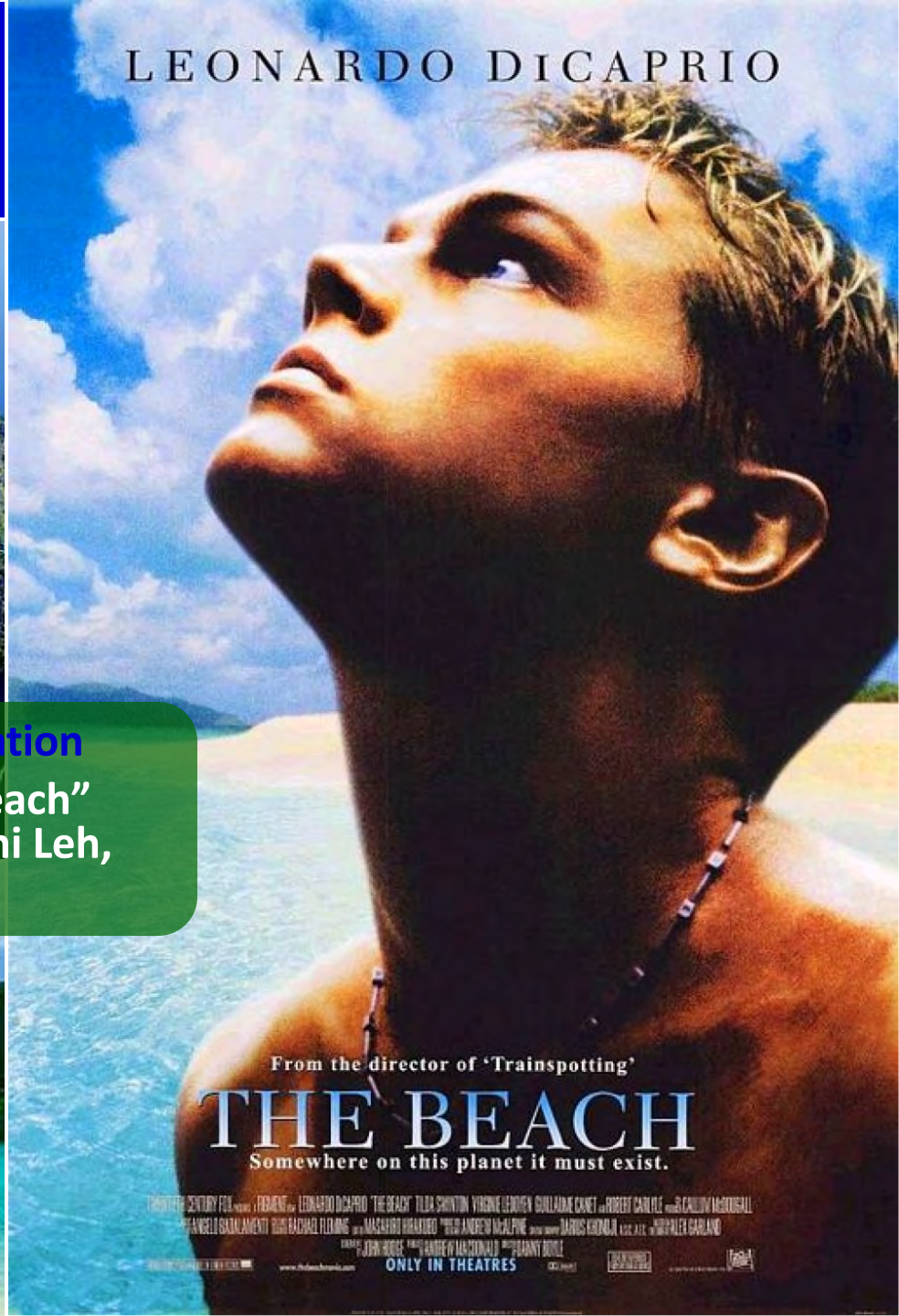


Man with the Golden Gun James Bond 007

The Beach

The Beach Location

“The Perfect Beach”
Hat Maya, Phi Phi Leh, Thailand



Review and Concluding Remarks

- Review
- Concluding Thoughts
- References
- Relevant Books and Papers
- Online Resources
- Glossary

REVIEW

1. Limestone
2. Thai Geologic History
3. Karst Processes
4. Karst Regions
5. Karst Landscapes in Thailand
6. Karst Topography of the Andaman Coast

Concluding Thoughts

The morphology of the Andaman Coast is dominated by Permian limestone outcrop – where precipitous, craggy karst towers stand like guardians overlooking a collage of seascapes and broad outwash plains.

Thailand offers a cross-section of geologic time – a testament to the nearly incomprehensible age of the Earth, where tectonic plates shifted at a snail's pace, sea levels rose to magnificent heights and fell at great intervals, and chemical weathering produced natural wonders which today draw millions of visitors from around the world.

Thank You For Your Attention

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Relevant Online Resources

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- http://thescienceroom.org/karst/
- http://www.dahndesign.com/tag/sinkholes/
- http://www.geocaching.com/geocache/GC1FNQ9_whisper-rocks
- http://clasfaculty.ucdenver.edu/callen/1202/Landscapes/KarCoast/KarCoast.html
- http://en.wikipedia.org/wiki/Karst
- http://web.env.auckland.ac.nz/our_research/karst/
- http://karst.iah.org/karst_hydrogeology.html
- http://core.ecu.edu/geology/harper/Gsa-ab99.htm
- http://www.thailandcaves.shepton.org.uk/welcome

Glossary

McGraw-Hill (2013)

Alluvium [GEOL] The *detrital* materials that are eroded, transported, and deposited by streams; an important constituent of shelf deposits. Also known as *alluvial* deposit.

Carbonation [GEOCHEM] A process of chemical weathering whereby minerals that contain soda, lime, potash, or basic oxides are changed to carbonates by the carbonic acid in air or water.

Cement [GEOL] Any chemically precipitated material, such as carbonates, gypsum, and barite, occurring in the interstices of clastic rocks.

Cementation [GEOL] The precipitation of a binding material around minerals or grains in rocks.

Cenozoic [GEOL] The youngest of the eras, or major subdivisions of geologic time, extending from the end of the Mesozoic Era to the present, or Recent. (65 mya to the present).

Column (i.e., stalacto-stalagmite) [GEOL] A columnar deposit formed by the union of a stalactite with its complementary stalagmite. Also known as column; pillar.

Consolidation [GEOL] 1. Processes by which loose, soft, or liquid earth become coherent and firm. 2. Adjustment of a saturated soil in response to increased load; involves squeezing of water from the pores and a decrease in void ratio.

Deposit [GEOL] Consolidated or unconsolidated material that has accumulated by a natural process or agent.

Deposition [GEOL] The laying, placing, or throwing down of any material; specifically, the constructive process of accumulation into beds, veins, or irregular masses of any kind of loose, solid rock material by any kind of natural agent.

Diagenesis [GEOL] Chemical and physical changes occurring in sediments during and after their deposition but before consolidation. (Literally meaning ‘two origins’).

Glossary

McGraw-Hill (2013)

Doline [GEOL] A general term for a closed depression in an area of karst topography that is formed either by solution of the surficial limestone or by collapse of underlying caves.

Dolomite [MINERAL] $CaMg(CO_3)_2$ The carbonate mineral; white or colorless with hexagonal symmetry and a structure similar to that of calcite, but with alternate layers of calcium ions being completely replaced by magnesium.

Dolomitic limestone [PETR] A limestone whose carbonate fraction contains more than 50% dolomite. Also known as dolomite rock; dolostone.

Fossil [PALEON] The organic remains, traces, or imprint of an organism preserved in the earth's crust since some time in the geologic past.

Geomorphology [GEOL] The study of the origin of secondary topographic features which are carved by erosion in the primary elements and built up of the erosional debris. The external structure of rocks in relation to the development of erosional forms or topographic features.

Karst [GEOL] A topography formed over limestone, dolomite, or gypsum and characterized by sinkholes, caves, and underground drainage. *Karstic*; *Karstification*.

Limestone [PETR] 1. A sedimentary rock composed dominantly (more than 95) of calcium carbonate ($CaC0_3$), principally in the form of calcite; examples include chalk and travertine. 2. Any rock containing 80% or more of calcium carbonate or magnesium carbonate.

Mesozoic [GEOL] A geologic era from the end of the Paleozoic to the beginning of the Cenozoic; commonly referred to as the Age of Reptiles. (245 mya to 65 mya).

Outcrop [GEOL] Exposed stratum or body of ore at the surface of the earth.

Paleozoic [GEOL] The era of geologic time from the end of the Precambrian (600 mya) until the beginning of the Mesozoic era (225 mya).

Glossary

McGraw-Hill (2013)

Plate tectonics [GEOL] Global tectonics based on a model of the earth characterized by a small number (10–25) of semirigid plates which float on some viscous underlayer in the mantle; each plate moves more or less independently and grinds against the others, concentrating most deformation, volcanism, and seismic activity along the periphery.

Sediment [GEOL] 1. A mass of organic or inorganic solid fragmented material, or the solid fragment itself, that comes from weathering of rock and is carried by, suspended in, or dropped by air, water, or ice; or a mass that is accumulated by any other natural agent and that forms in layers on the earth's surface such as sand, gravel, silt, mud, fill, or loess. 2. A solid material that is not in solution and either is distributed through the liquid or has settled out of the liquid.

Speleology [GEOL] The study and exploration of caves.

Speleothem [GEOL] A secondary mineral deposited in a cave by the action of water. Also known as cave formation.

Stalactite [GEOL] Aconical or roughly cylindrical speleothem formed by dripping water and hanging from the roof of a cave; usually composed of calcium carbonate.

Stalagmite [GEOL] A conical speleothem formed upward from the floor of a cave by the action of dripping water; usually composed of calcium carbonate.

Stratum [GEOL] A mass of homogeneous or gradational sedimentary material, either consolidated rock or unconsolidated soil, occurring in a distinct layer and visually separable from other layers above and below.

Subcrop [GEOL] An occurrence of strata beneath the subsurface of an inclusive stratigraphic unit that succeeds an unconformity on which there is marked overstep.

Submergence [GEOL] A change in the relative levels of water and land either from a sinking of the land or a rise of the water level.

Tectonics [GEOL] A branch of geology that deals with regional structural and deformational features of the earth's crust, including the mutual relations, origin, and historical evolution of the features. Also known as geotectonics.

Terrane [GEOL] A rock formation, a cluster of rock formations, or the general area of outcrops.

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