Introduction to Karst Topography

With Emphasis on Thailand and the Andaman Coast

808-135 THAI GEOGRAPHY

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

Dr. Raymond Ritchie

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)
1. Introduction to Karst Topography
2. Introduction to Limestone
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6. Karst Landscapes in Thailand
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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

- Caves
- Pinnacles
- Towers
- Pavements
- Springs
- Sinkholes

**Caves and Caverns**

**Sinkholes and Dolines**

**Underground drainage systems**
(streams and springs)

**Pavement**

**Pinnacles**

**Towers (Haystacks)**

Karst regions are often humid and display distinctive surface features
**Karst is a Complex Landscape Sculpted by Water**

**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 CO₂ which dissolves in the droplets.
- Once the rain hits the ground, it percolates through the soil and picks up more CO₂ to form a weak solution of carbonic acid: \( \text{H}_2\text{O} + \text{CO}_2 = \text{H}_2\text{CO}_3 \).
- The infiltrating water naturally exploits any cracks or crevices in the rock.
- Over long periods, with a continuous supply of CO₂-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.
Introduction to Limestone

A sedimentary rock made up of the mineral calcium carbonate (CaCO₃)
What is Limestone? Where does it come from? And When?
Limestone

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, \( \text{CaCO}_3 \))

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), bryozoans (moss animals), brachiopods (lampshells), echinoderms (starfish, sea urchins, sea cucumbers, sea lilies), mollusks (snails, bivalves, chitons, octopuses, squid), crustaceans (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

**Glaucunite and chlorite** cause green shades

**Bitumen** causes gray to black shades
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.

Geologic Sea Levels

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 c. 270 mya and c. 70 mya.
Ammonites are excellent index fossils
– They link the rock layer in which a particular species or genus is found to specific geological time periods

“Ammonites” named after the Egyptian God “Amon-Ra” by the French who saw the fossil remains in the limestone rock used in Egyptian tomb construction.

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.

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

“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
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

Location of Thailand during the Permian (255 mya)

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
Cretaceous
80 mya

Indo-China is here

Malaya is here

Hybodont Shark Teeth
from Northeast Thailand

Siamosaurus (Theropod)
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)
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
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

10 million years ago...
The Andaman Sea had not yet formed
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 Siam, Burma, Malaysia, and Sumatra.
Simplified overview of regional terranes today

- West Burma terrane
- Shan-Thai terrane
- Indochina terrane
Karst Processes
Karst Processes

- Disappearing Streams
- Caves
- Springs
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.

- Rain passes through the atmosphere picking up CO₂
- Water percolates through soil picking up CO₂

CO₂ dissolves in the water creating carbonic acid \((H₂O + CO₂ = H₂CO₃)\)

Carbonic acid dissolves soft limestone resulting in karst features and landscapes.

\[ H₂O + CO₂ > H₂CO₃ \]
Production of \( \text{CO}_2 \)

Formation of Stalactites and Stalagmites

Release of \( \text{CO}_2 \) from dripwater in cave drives precipitation of calcite to make stalactites and stalagmites.

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3
\]

\[
\text{H}_2\text{CO}_3 + \text{CaCO}_3 \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^-
\]

Carbonic Acid  Calcite in limestone  Calcite dissolution

\[
\text{Ca}^{2+} + 2\text{HCO}_3^- \rightarrow
\]

\[
\text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}
\]

Calcite in stalactite or stalagmite or released in cave

Calcite precipitation
Non-calcareous meets limestone

- Input and throughput landforms
- Output & residual landforms

Non-calcareous landscape
- Bluffs with vertical runnels
- Stream-sink
- Blind valley

Limestone or marble landscape
- Solution flutes
- Grikes & clints
- Sinkholes
- Percolating water
- Flowstone
- Cave system
- Travertine
- Speleothems
- Limestone or marble

Groundwater
- Water table

Residual hills
- Spring
Karst topography is also commonly characterized by caves, sinkholes and streams that disappear and reappear.
- Caverns
- Sinkholes
- Disappearing streams

- Caverns
- Collapsed doline
- Sinkhole
- Doline and Uvala

**Southern Thai Landscape**
- Tower karst
- Haystack hills
Karst Processes

An Example of Karst Formation

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.

Fractures in the rock allow water to seep in.

Water reacts with Calcium Carbonate dissolving the rocks.

The openings continue to expand.

A sinkhole is created when the roof can no longer hold.

A cave is created when the openings finally encounter fresh air.

* Karst landforms do not need the sandstone in between 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)
Thai Speleothems

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

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. hydrothermal crystals
22. cave clouds

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

- Thungyai-Hua Kha Khaeng Wildlife Sanctuaries
- Dong Phayayen - Khao Yai Forest Complex
# 2 World Heritage Karst Sites in Thailand

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

<table>
<thead>
<tr>
<th>Region and Provinces</th>
<th>World Heritage Property</th>
<th>Inscribed</th>
<th>Key Karst Features</th>
<th>Environmental Context</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Western Thailand</strong></td>
<td>Thungyai-Hua Kha Khaeng Wildlife Sanctuaries</td>
<td>1991</td>
<td>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.</td>
<td>Tropical monsoon climate. Evergreen and semi-deciduous forest in mountains with savannah in valleys and gallery forest along rivers. Outstanding biodiversity Values.</td>
</tr>
<tr>
<td>Kanchanaburi, Tak and Uthai Thani</td>
<td>Comprising 2 Wildlife Sanctuaries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Central and Northeastern Thailand</strong></td>
<td>Dong Phayayen - Khao Yai Forest Complex</td>
<td>2005</td>
<td>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.</td>
<td>Tropical monsoon forest with long dry season.</td>
</tr>
<tr>
<td>Saraburi, Nakhon Nayok, Nakhon Rachisima, Prachinburi, Srakaew and Buriram</td>
<td>Comprising 4 National Parks and 1 Wildlife Sanctuary</td>
<td></td>
<td></td>
<td>(Williams, 2008)</td>
</tr>
</tbody>
</table>
- 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)
Introducing a few distinctive karst landscapes Thailand
Spirit Cave(s) – Pang Ma Pha

Spirit Cave is one of the most important archaeological sites in Thailand. Well-preserved evidence of human subsistence during the Hoabinhian (12,000–10,000 BC) 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 ("Sumatr liths")

*(Higham, 2014)*

*(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

Krabi
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.

The Kuha Karuhas Pavilion was built at the end of the 19th century for King Chulalongkorn (Rama V).
Temple Caves
Spiritual & Religious Significance of Karstic Sites

Phallic Stalactite wrapped with ‘Ji Won’ cloth
Tham Ki Nok, Chiang Mai Province

Shiva with Trident
Tham Tep Ni Mit, Lampun Province

Wat Tham Suwan Khuha, Phangnga Province

(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
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)

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.

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

Photos by Steven Martin
Karst Topography on the Andaman Coast
Introduction to **Tower Karst** on the Andaman Coast, Thailand

Case Review
• 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)
Near the end of the Cretaceous (c. 60 mya) the ‘tower karst’ formations began to take shape.

Tower karst were further carved up during the Pliocene-Quaternary glaciation (2.5 mya) as local climatic patterns and sea level fluctuated.

60 mya (Cretaceous) sea levels were 200 - 300 meters higher than today.
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
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)
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)
Karstic Caverns, Krabi, Thailand
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.

(Subsidence)
The Andaman Coast is slowly sinking into the sea

(Submergence)
Sea levels rose with the ending of the Ice Age

(Gillespie, 2000)
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.

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.

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

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.

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

Karst topography is a tourism draw card in Thailand

Photo by Steven Martin

Phi Phi Island, Phangnga Bay, 2014
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
The Beach

The Beach Location

“The Perfect Beach”
Hat Maya, Phi Phi Leh, Thailand
Review and Concluding Remarks

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- Online Resources
- Glossary
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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.
Books

Research

Online Sources

Personal Interview
Relevant Books


Relevant Online Resources

- http://thescienceroom.org/karst/
- http://www.geocaching.com/geocache/GC1FNQ9_whisper-rocks
- http://clasfaculty.ucdenver.edu/callen/1202/Landscapes/KarCoast/KarCoast.html
- http://web.env.auckland.ac.nz/our_research/karst/
- http://karst.iah.org/karst_hydrogeology.html
- http://www.thailandcaves.shepton.org.uk/welcome
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’).
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( CO₃)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 (CaCO₃), 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).
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] A conical 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.