INVESTIGATION FOR GROUNDWATER RESOURCES IN SARABURI LIMESTONES, THAILAND

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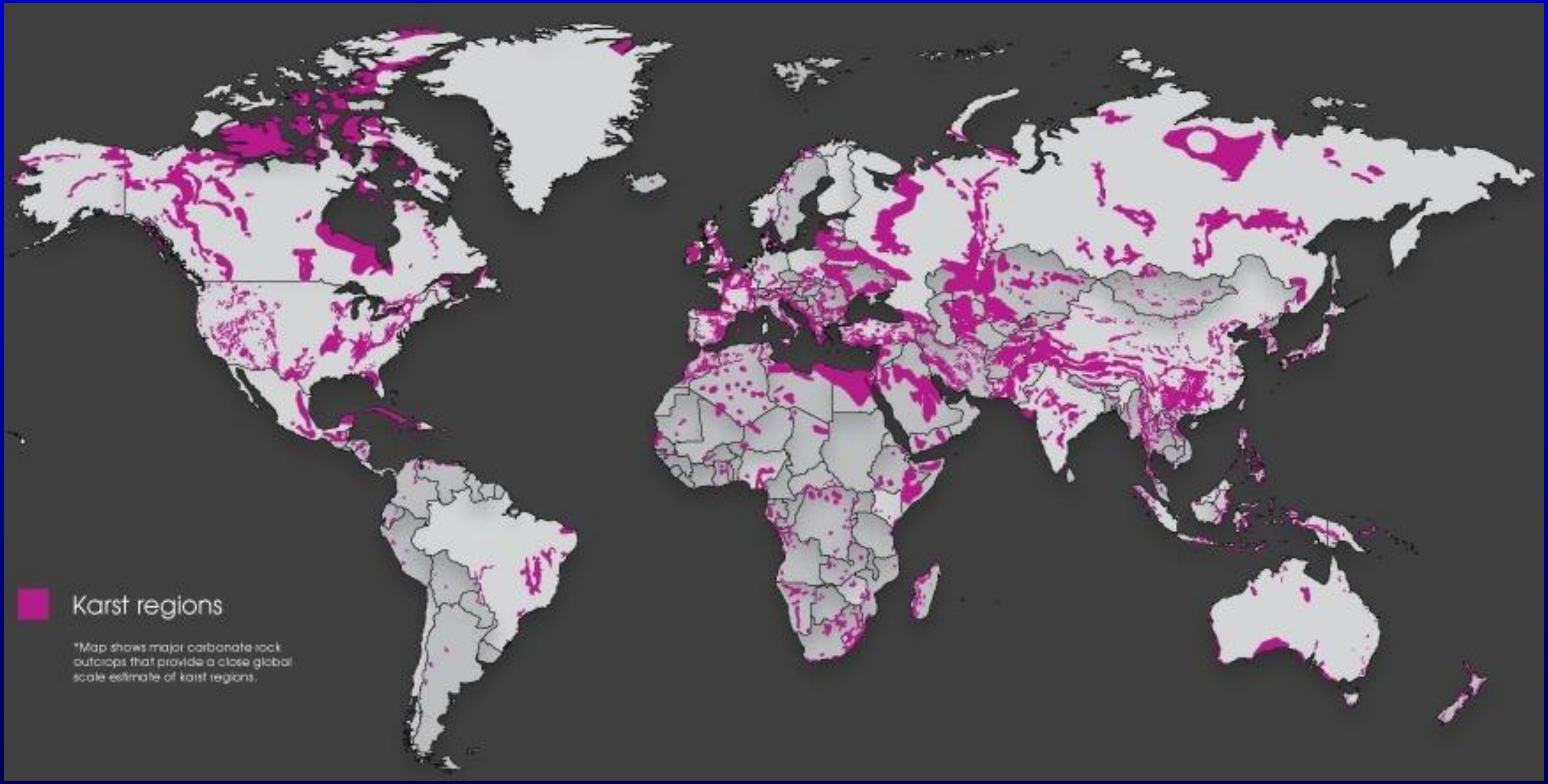
OBJECTIVES

INTRODUCTION TO KARST

THAILAND INVESTIGATION

1. *Karst inventory*
2. *Surface geophysical investigation*
3. *Perform dye study to determine hydraulic connectivity within the aquifer*
4. *Drilling, well construction (15 pumping wells and 15 observation wells) and aquifer tests*
5. *Collect and analyze water samples for stable and radioactive isotopes to delineate the source of water*

Distribution of Major Outcrops of Carbonates Rocks in the World



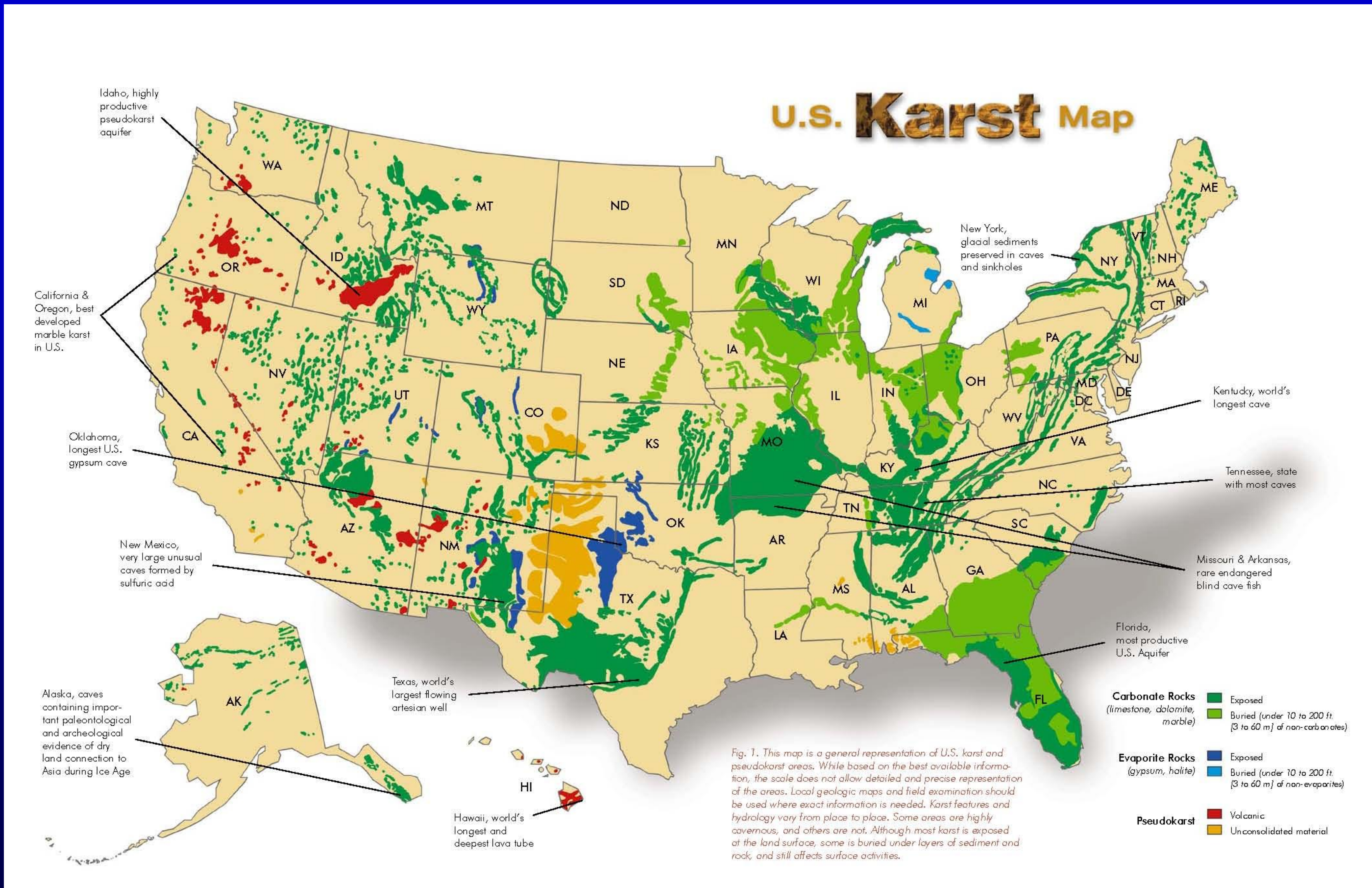


Fig. 1. This map is a general representation of U.S. karst and pseudokarst areas. While based on the best available information, the scale does not allow detailed and precise representation of the areas. Local geologic maps and field examination should be used where exact information is needed. Karst features and hydrology vary from place to place. Some areas are highly cavernous, and others are not. Although most karst is exposed at the land surface, some is buried under layers of sediment and rock, and still affects surface activities.

What is Karst?

Karst terrane is characterized by surface and subsurface features such as sinkholes, karst windows, springs, caves and losing, sinking, or gaining underground streams.

Karst is formed on rocks that dissolve, rather than being eroded mechanically (rivers, waves, etc.). Dissolution is the basic karst process.

Streams/rivers are continuously interconnected with the aquifers in the geological units traversed, recharging or discharging into karst aquifers have a strong reaction to hydrological events.

Principles of Karst Development

For karst landscape to form we have to have:

- Lithologic Conditions (rocks that dissolve)
- Hydrogeologic Conditions (surface, groundwater and precipitation)
- Structural Control

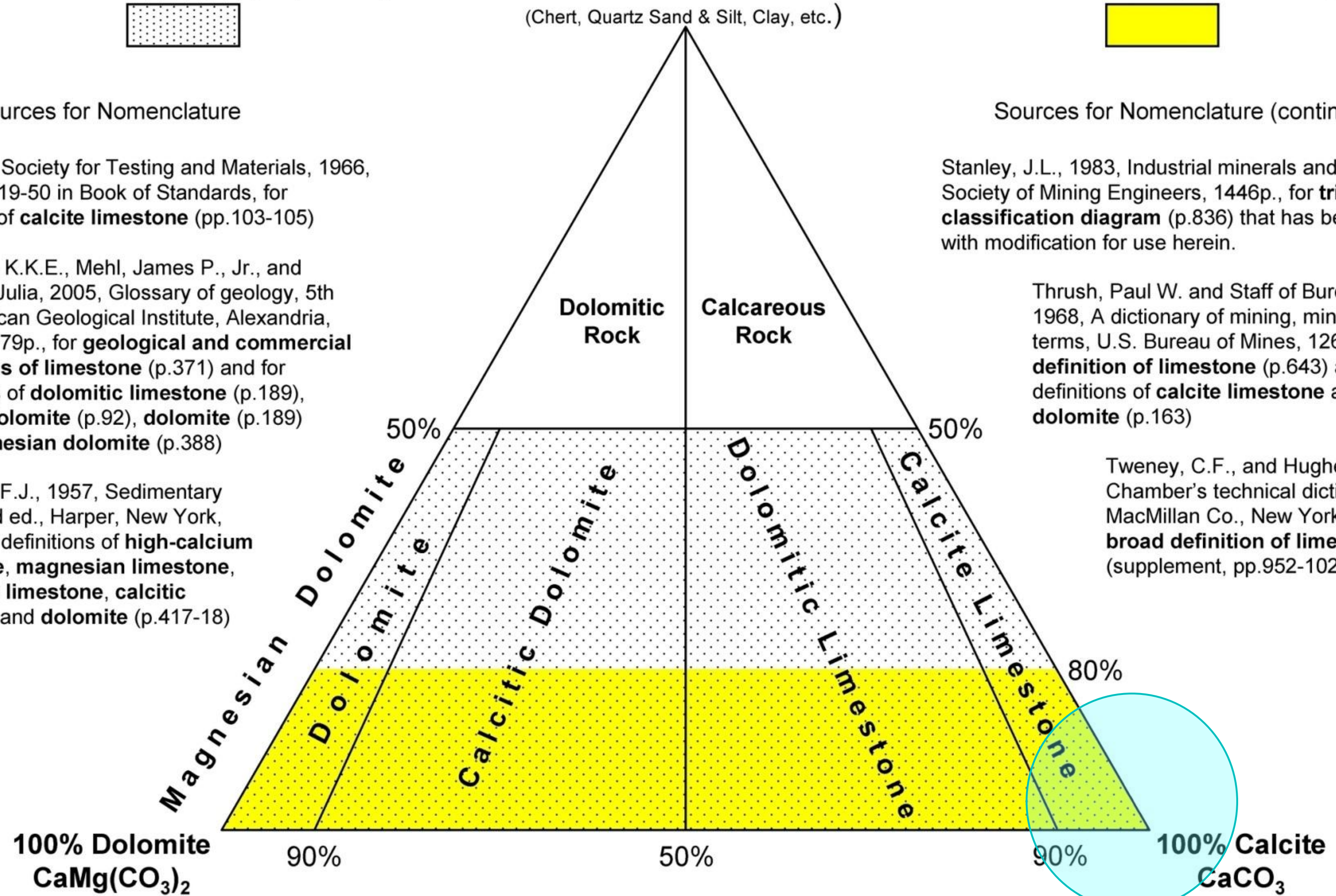
Lithologic Conditions

Definition and Classification of Limestone

Prepared by Missouri Department of Natural Resources, Division of Geology and Land Survey, 2011

Academic, Geological Definition of Limestone (stipple pattern)

Practical, Commercial Definition of Limestone (yellow color)



Sources for Nomenclature

American Society for Testing and Materials, 1966, ASTM C119-50 in Book of Standards, for definition of **calcite limestone** (pp.103-105)

Neendorf, K.K.E., Mehl, James P., Jr., and Jackson, Julia, 2005, Glossary of geology, 5th ed. American Geological Institute, Alexandria, Virginia, 779p., for **geological and commercial definitions of limestone** (p.371) and for definitions of **dolomitic limestone** (p.189), **calcitic dolomite** (p.92), **dolomite** (p.189) and **magnesian dolomite** (p.388)

Pettijohn, F.J., 1957, Sedimentary rocks, 2nd ed., Harper, New York, 718p., for definitions of **high-calcium limestone**, **magnesian limestone**, **dolomitic limestone**, **calcitic dolomite** and **dolomite** (p.417-18)

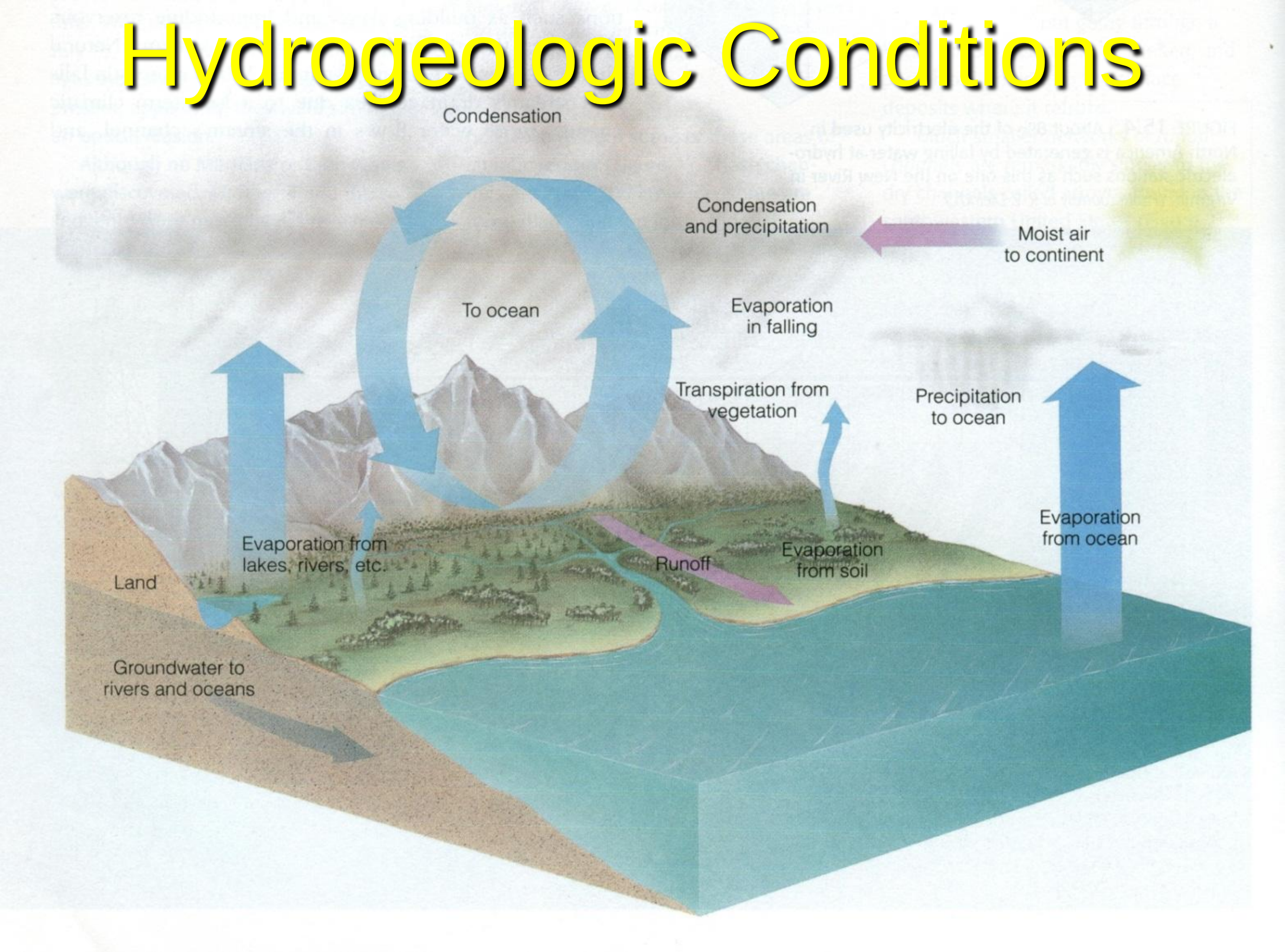
Sources for Nomenclature (continued)

Stanley, J.L., 1983, Industrial minerals and rocks, 5th ed., Society of Mining Engineers, 1446p., for **triangle classification diagram** (p.836) that has been adopted with modification for use herein.

Thrush, Paul W. and Staff of Bureau of Mines, 1968, A dictionary of mining, mineral, and related terms, U.S. Bureau of Mines, 1269p., for **broad definition of limestone** (p.643) and for definitions of **calcite limestone** and **calcitic dolomite** (p.163)

Tweney, C.F., and Hughes, L.E.C., 1958, Chamber's technical dictionary, 3rd ed., MacMillan Co., New York, 1028p., for **broad definition of limestone** (supplement, pp.952-1028)

Hydrogeologic Conditions



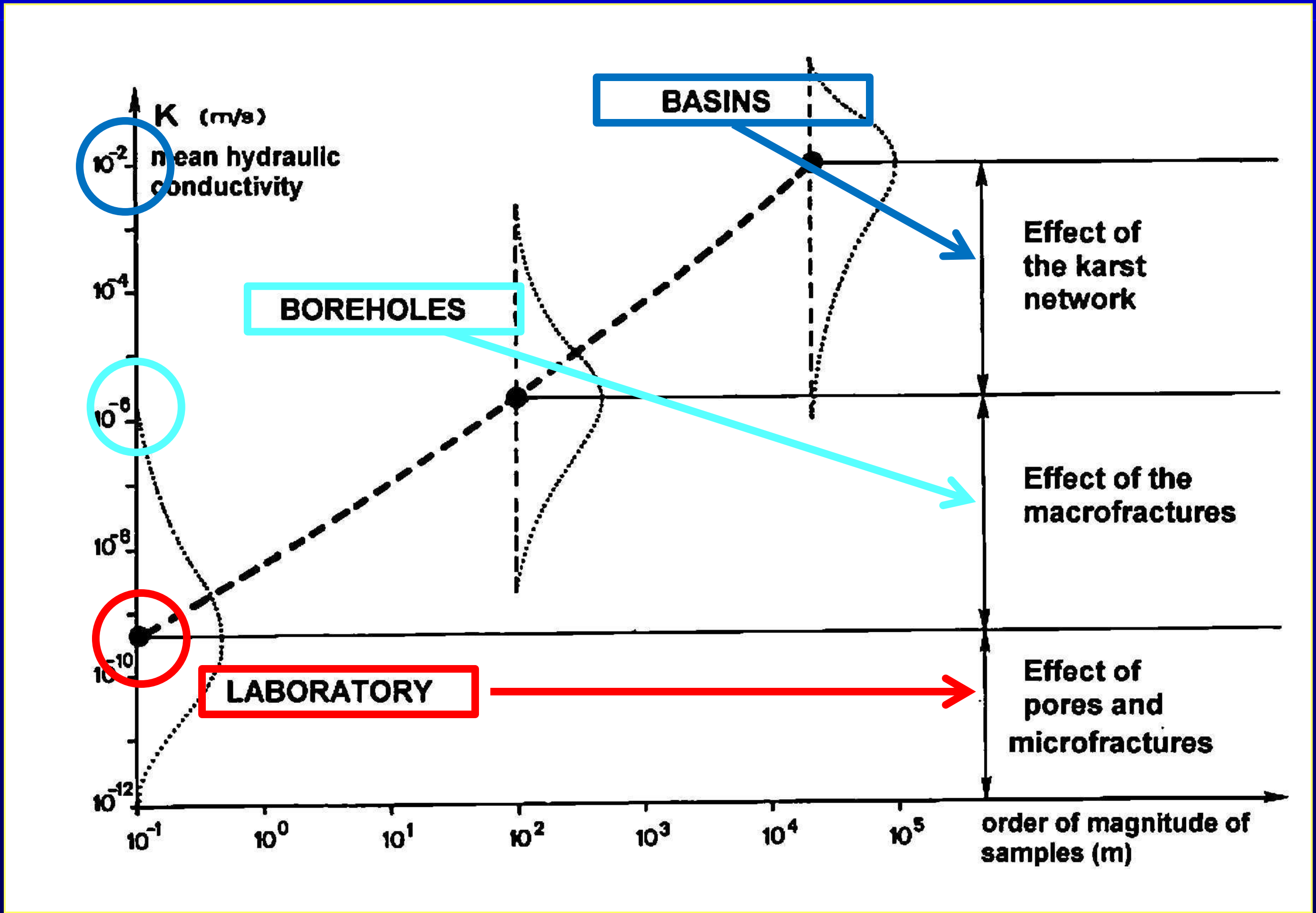
During the hydrologic cycle, water evaporates from the oceans and rises as water vapor to form clouds that release precipitation over oceans or land. Much of the precipitation falling on land returns to the oceans by surface runoff, thus completing the cycle.

(source: Monroe and Wicander 1997)

Structural Control

- Limestone has low primary permeability.
- Water flows through limestone along fractures, cracks/joints or bedding planes.
- Because the rock dissolves, the fractures are widened by dissolution, predominantly near the rock surface and less with depth.

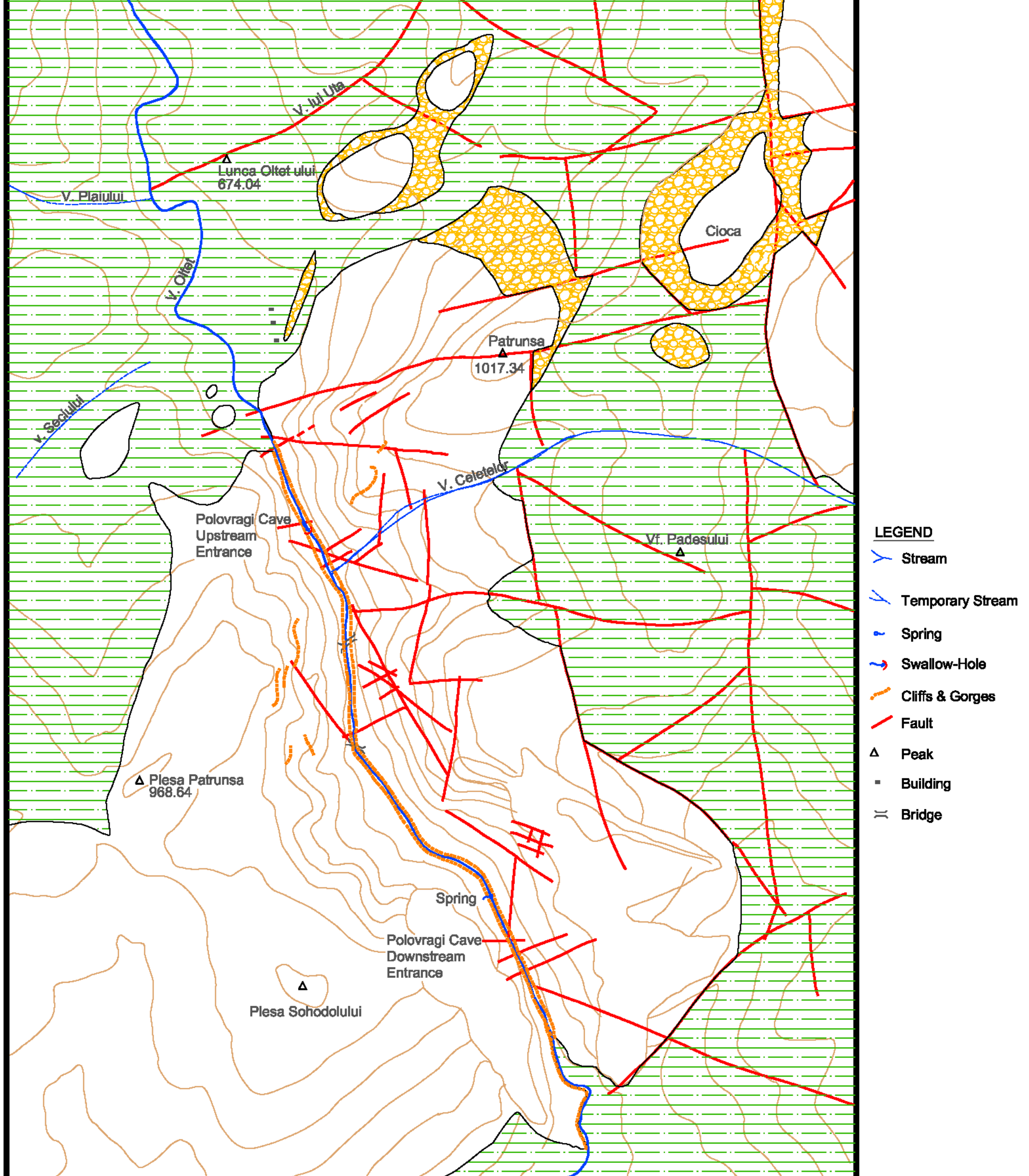
Methods for Characterization of Karst Aquifers and Scale Effects

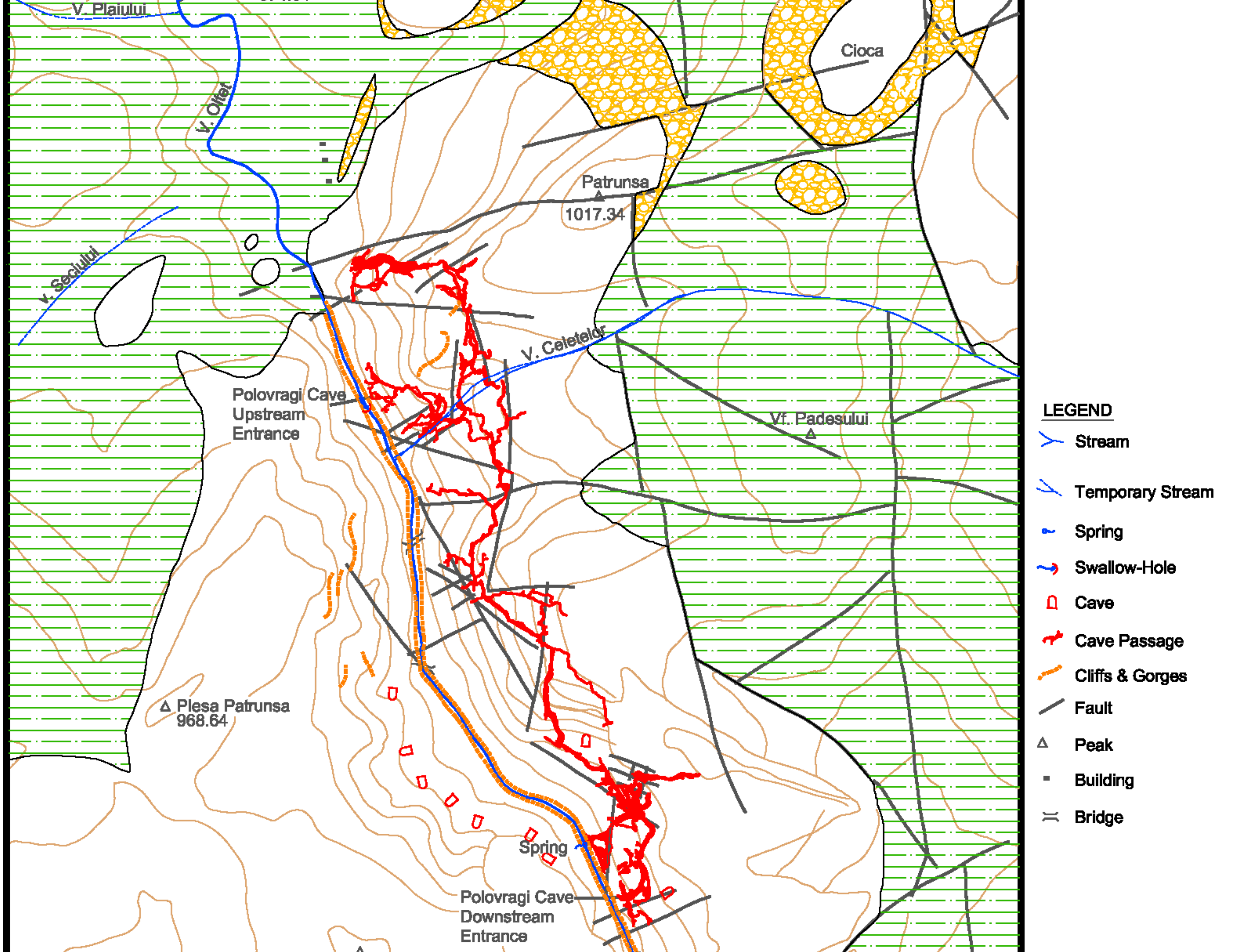


(from Kiraly, 2003)

Carbonate aquifer systems are highly heterogeneous and strongly anisotropic! The characterization of aquifer properties is usually not possible by one single method.

Karst Fracture Control




V. Plaiului
V. Oltet
V. Secului
Cioca
Patrunsa
1017.34
V. Celetelor
Polovragi Cave
Upstream
Entrance
Vf. Padesului
Plesa Patrunsa
968.64
Spring
Polovragi Cave
Downstream
Entrance
LEGEND
Stream
Temporary Stream
Spring
Swallow-Hole
Cave
Cave Passage
Cliffs & Gorges
Fault
Peak
Building
Bridge

Components of the Karst Drainage System

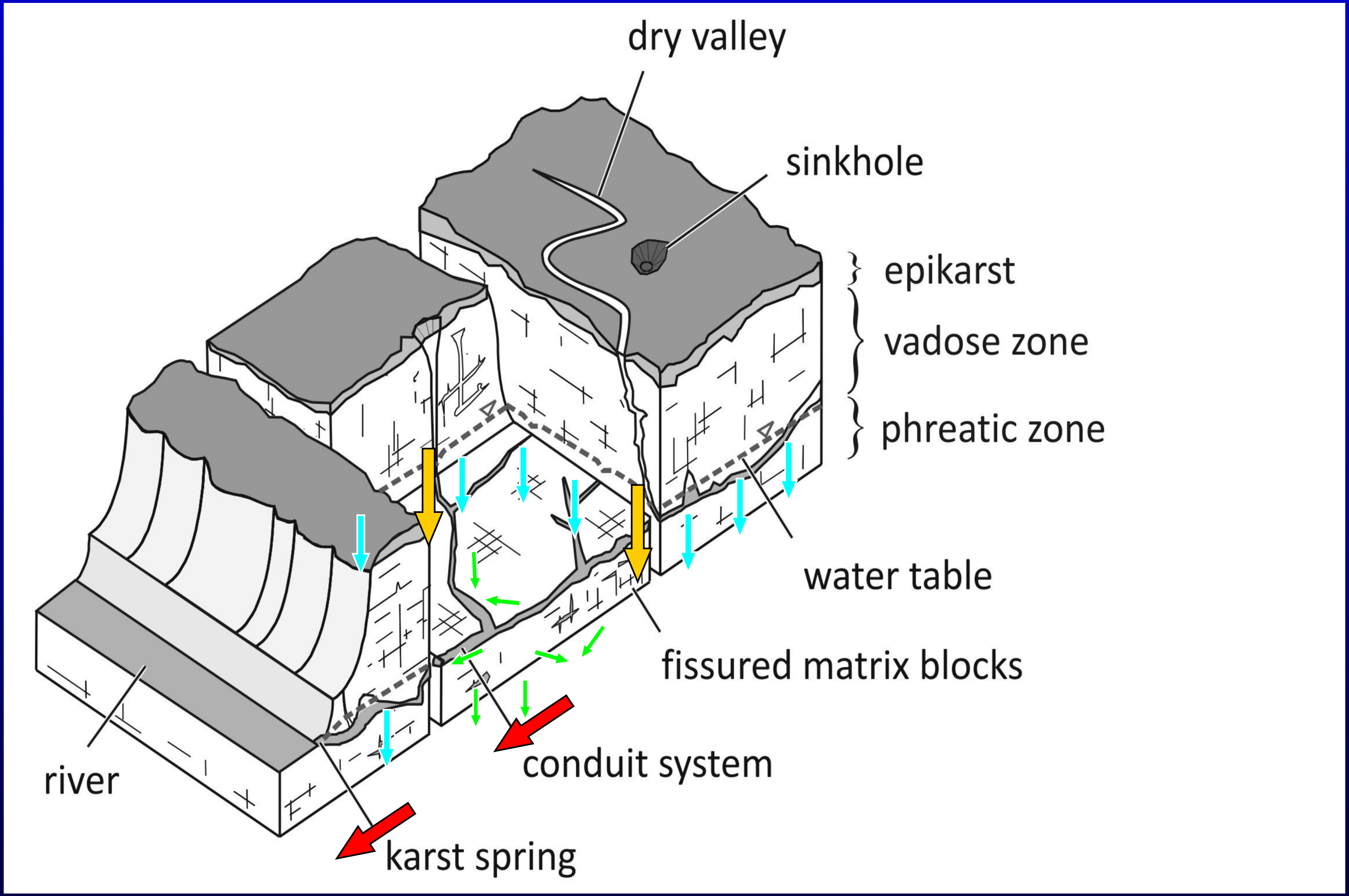
A. Unconsolidated, mantling sediment (cover or overburden - *soil*)

B. The development of internal drainage produces the unique weathered zone characteristic of karst - the epikarstic zone

C. Drainage shafts (vadose zone); and

D. A deeper, cavernous network of solution channels transporting water (and sediment) laterally to exit points (springs) (phreatic zone).

Conceptual Model of a Karst Aquifer



(from Geyer 2008)

Characteristics of Karst

- Carbonate Rock
- Irregular Bedrock Surface
- Sinkholes
- Caves
- Springs/Seeps
- Disappearing Streams

Characteristics of Karst

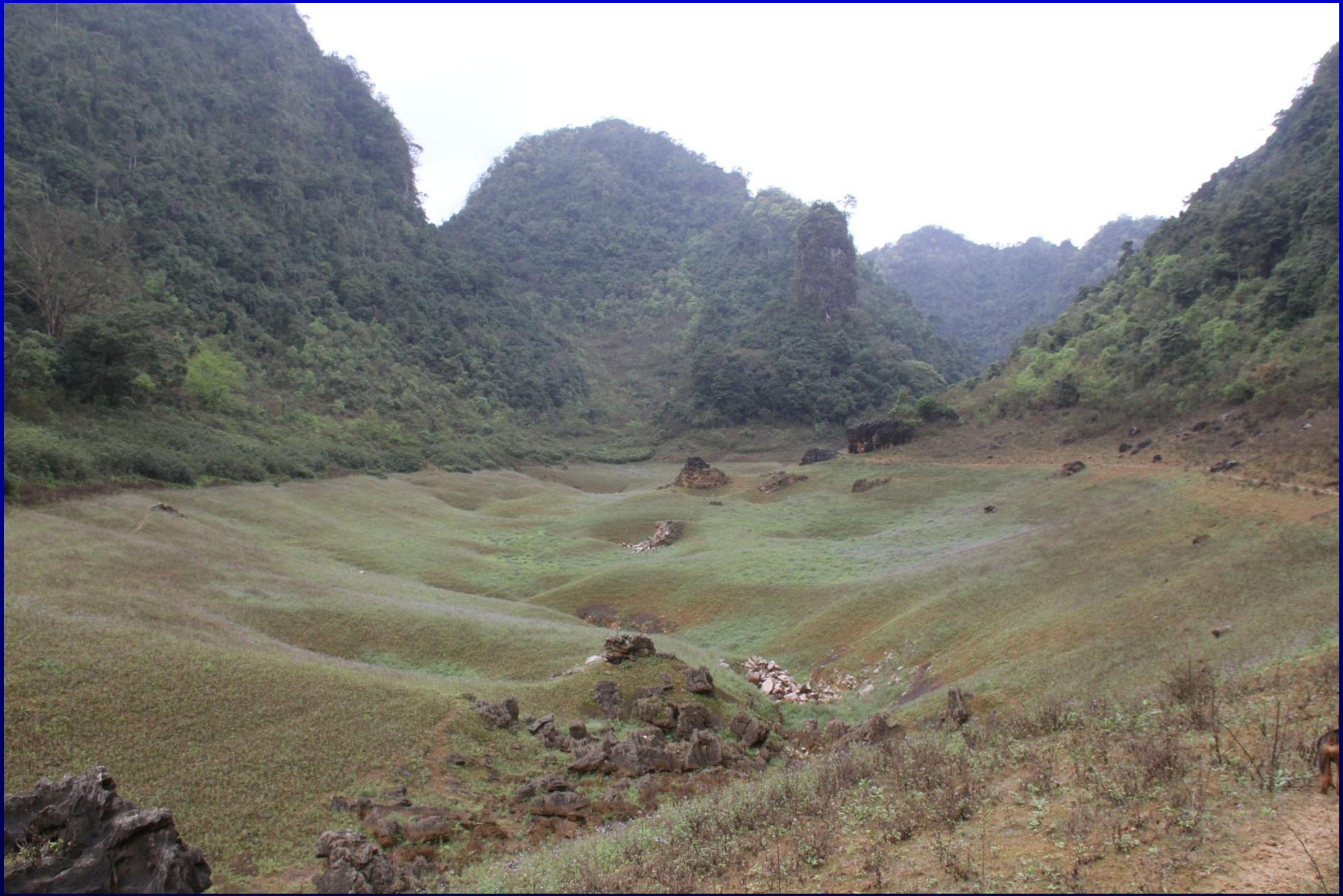
Carbonate Rock

Characteristics of Karst

Irregular Bedrock Surface

Characteristics of Karst

Sinkholes



Characteristics of Karst

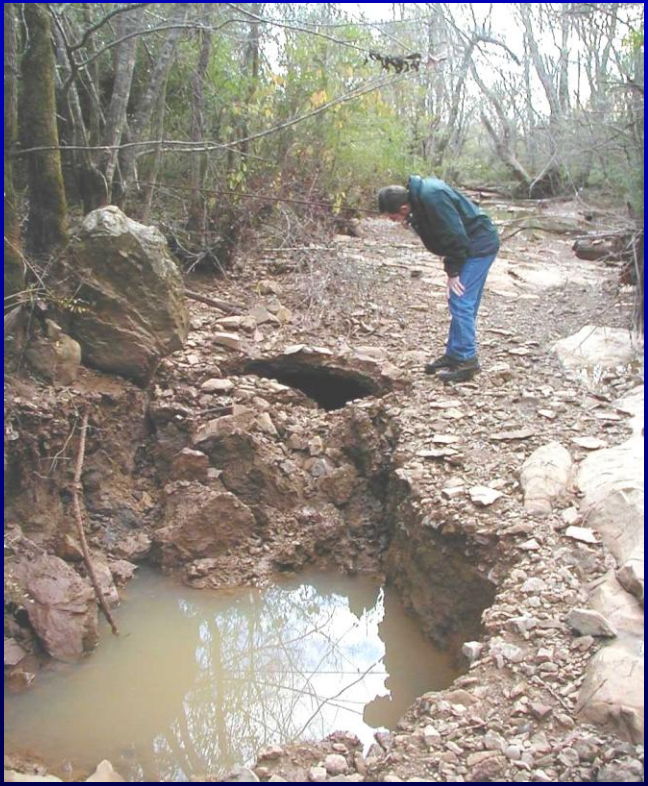
Caves

Characteristics of Karst

Springs

Characteristics of Karst

Sinking (Disappearing) Streams



Why is Karst a Special Problem?

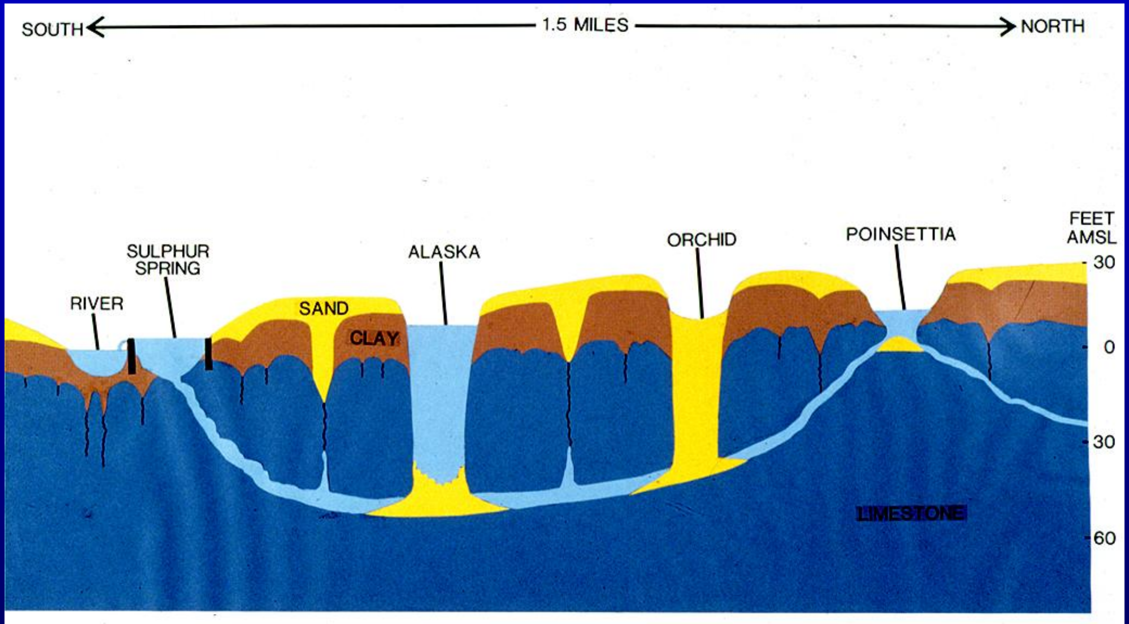
Limestone is dissolved by groundwater flowing through fractures in the rock.

Why is Karst a Special Problem?

Over time, groundwater dissolves cavernous pathways through the rock.

Why is Karst a Special Problem?

These cavernous pathways form integrated networks transmitting water through the ground.



CROSS SECTION THROUGH SULPHUR SPRING BASIN, TAMPA

Why is Karst a Special Problem?

In some cases very large volumes of water may be transmitted along preferential flow patterns.

Why is Karst a Special Problem?

Cavernous systems may have cultural resources associated with them.

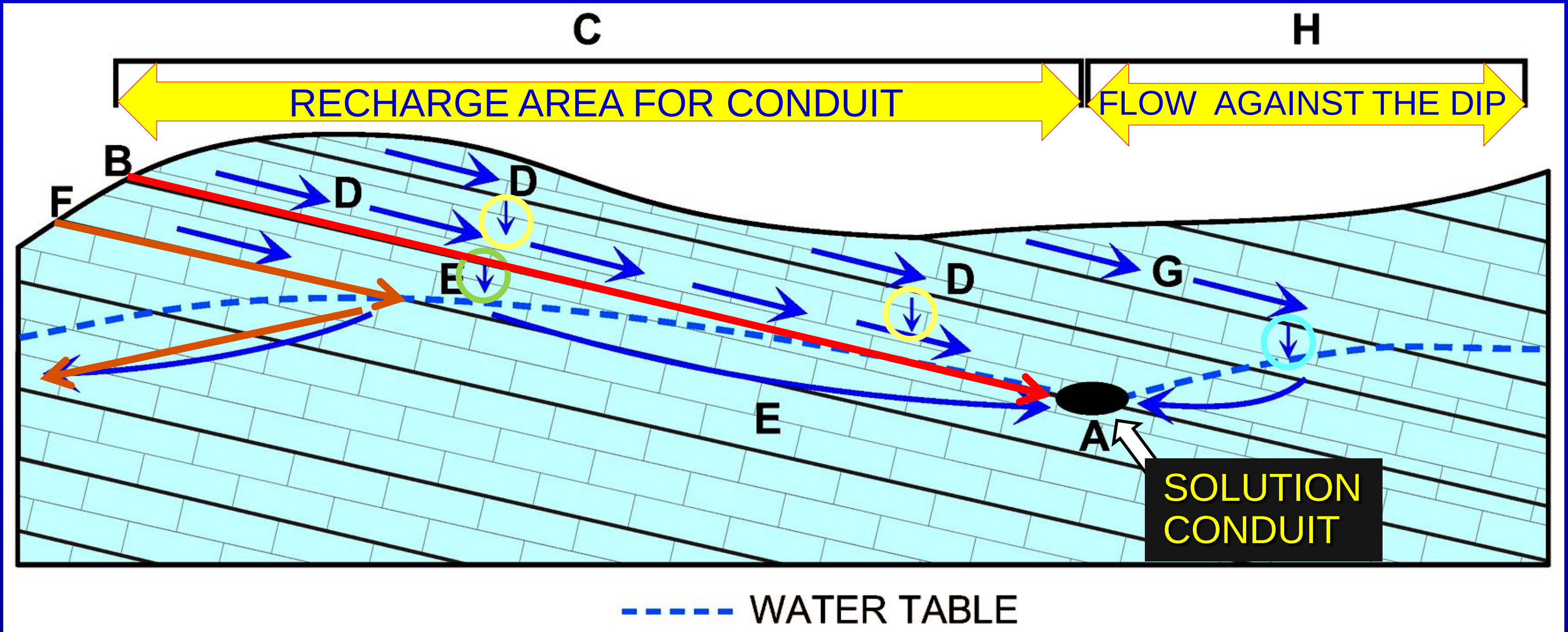
Why is Karst a Special Problem?

Pollutants may be transported rapidly, for great distances, with little dilution or natural clean-up.

Karst Aquifers

- Karst aquifers require specific investigation techniques because they are different from other hydrogeological environments such as fractured and granular aquifers.
- They evolve with time as the H_2CO_3 in the flowing water dissolves the carbonate rocks.
- If a well is drilled into a sand or gravel aquifer, water always will be encountered, whereas the extreme heterogeneity of karst makes it difficult to drill a successful well (Goldscheider et al., 2007).

Groundwater Flow in Carbonates



Cross section through a typical capture zone, view is in the direction of strike (strike is into/out of the diagram).

Modified from Ginsberg and Palmer, 2002

A – Main SOLUTION CONDUIT that drains to spring (not shown)

B–Capture zone for the spring includes region updip from the SOLUTION CONDUIT

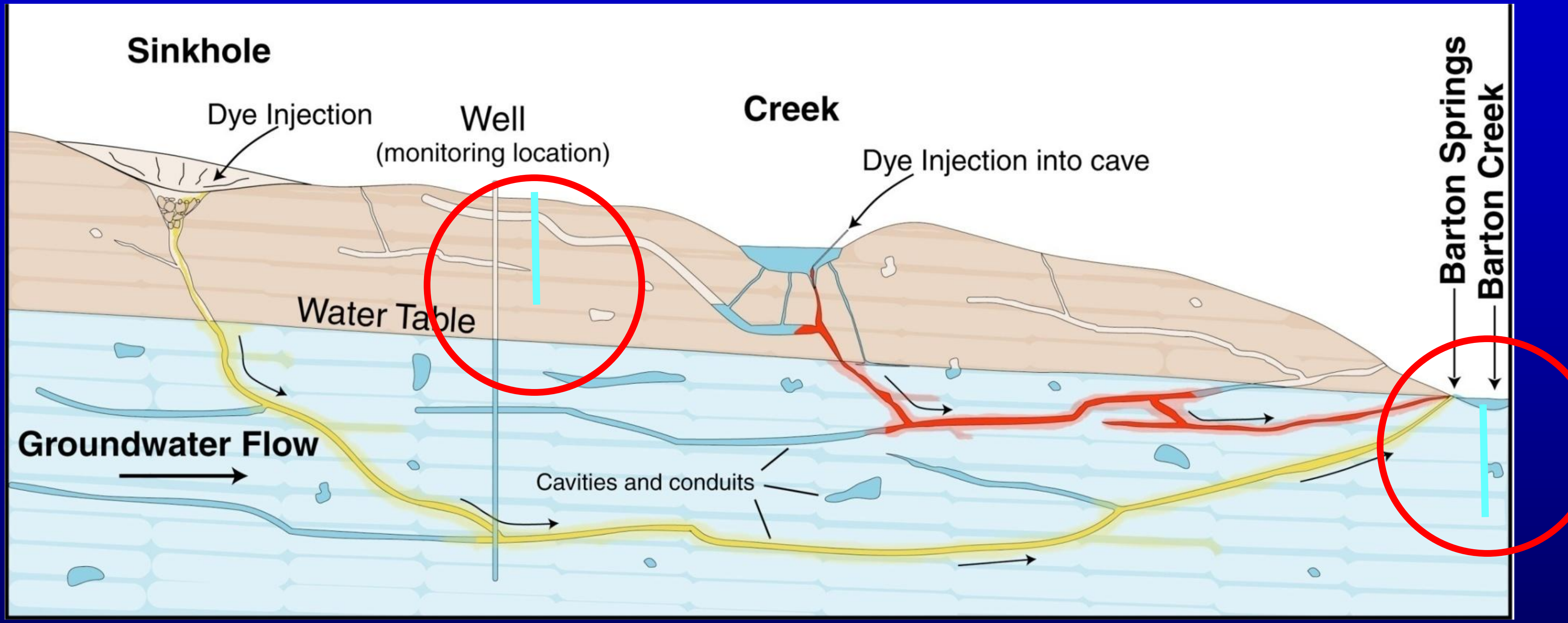
D – Major flows form conduits tributary to the SOLUTION CONDUIT

E – Minor seepage

F – Zone beyond estimated capture zone

G – Some vadose zone may pass above the strike-oriented SOLUTION CONDUIT

Karst Aquifers



Karst Aquifers

It is difficult to draw potentiometric maps on the basis of water-level measurements in wells in karst aquifers, and then to use these maps to predict the direction and velocity of groundwater flow unless there are measurements from a large number of wells. Other methods, such as tracer tests, are thus more appropriate to determine flow direction and velocity (Goldscheider et al., 2007).

Karst Aquifers

- The primary objective of a public/private water-supply system is to provide the consumer with a safe, dependable supply of drinking water.
- Karst groundwater supplies are particularly vulnerable to contamination because of the relatively direct connection to surface activities and the rapid transport of surface runoff and contaminants to the karst ground-water system.
- Occurrence and orientation of solution conduits, fractures, and bedding planes can complicate delineation of recharge areas.

Karst Aquifers

In karst terrane it is necessary to have a detailed understanding of the extent of the aquifer recharge area, and an understanding of how pollutants move through the system.

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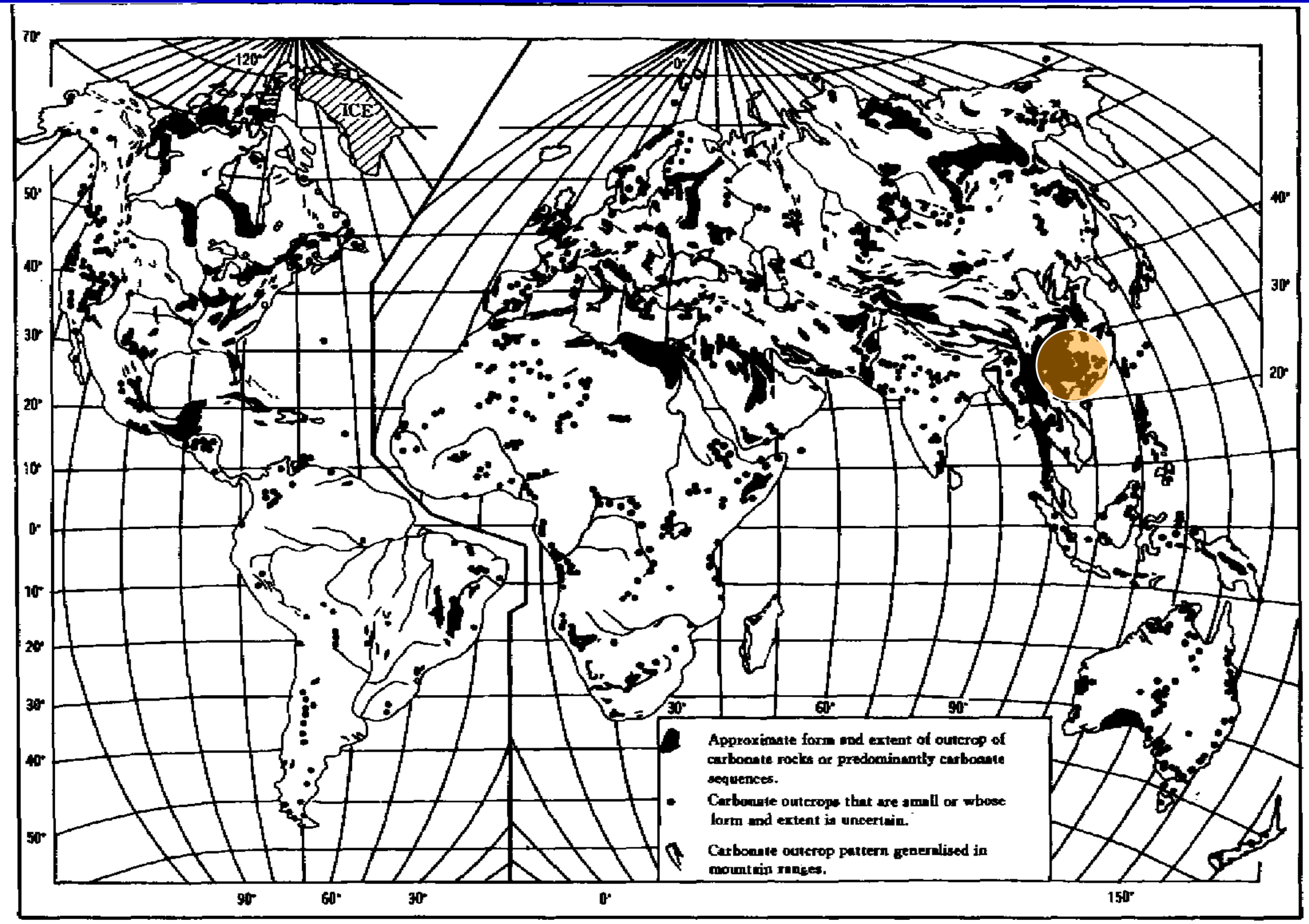


(source: Ford and Wiliams 2007)

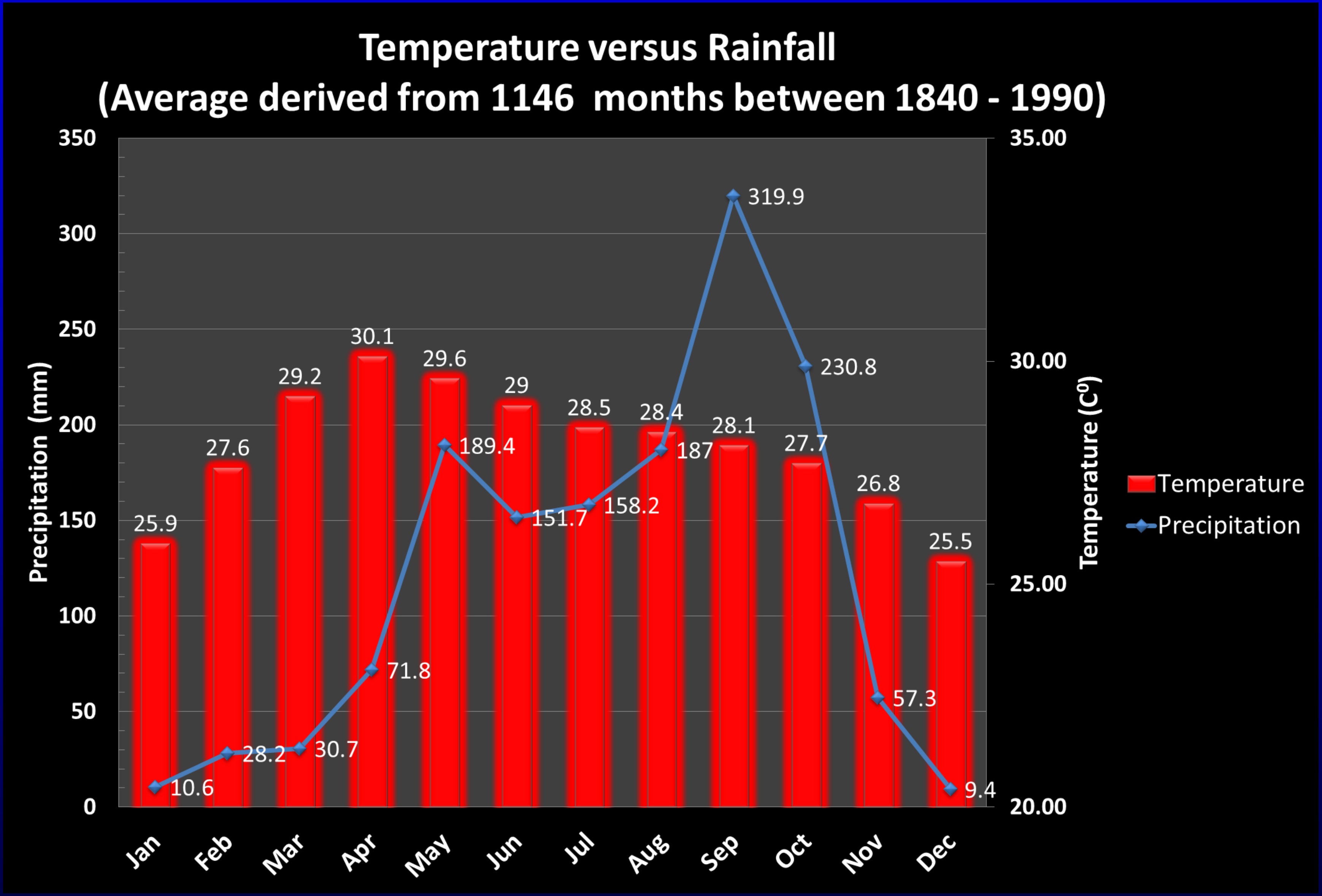
Why is Karst a Special Problem?

Because 25% of Thailand is underlain by carbonate rocks and millions of people are using karst waters on a daily basis.

Uttaradit
Si Satchanalai
Loei
Udon Thani
Nakhon Phanom
Nakhon Thai
Na Klang
Sukhothai
Sakhon Nakhon
VIETN
Mae Sot
Tak
Phitsanulok
Chum Phae
Kalasin
Mukdahan
Kamphaeng Phet
Phetchabun
Khon Kaen
Maha Sarakham
Chaiyaphum
Nakhon Sawan
Ban Phai
Yasothon
Amnat Charoen
Uthai Thani
Wichian Buri
Ubon Ratchathani
Nakhon Ratchasima
Si Sa Ket
Takhli
Lop Buri
Surin
Det Udom
Suphan Buri
Pak Chong
Katharalak
Bo Phloi
Ayutthaya
Nonthaburi
Bangkok
Sa Kaeo
Chon Buri
Ratchaburi
0
200 km
Si Racha
Phetchaburi
Klaeng
CAMBODIA
Pattaya
Chanthaburi
Rayong
Trat
Pran Buri
Prachuap Khiri Khan
THAILAND
Bang Saphan
Gulf of Thailand
Chumphon
Lang Suan
Ranong
Koh Samui
Chaiya

CLIMATE

- Tropical climate (monsoon type) with two distinct seasons is characteristic of the project area.
- The dry season begins in October and ends in May.
- Annual rainfall ranges between 1,500 and 2,000 mm and temperature between 20.0^0C and 40.7^0C.


Temperature versus Rainfall
(Average derived from 1146 months between 1840 - 1990)
Precipitation (mm)
Temperature (C⁰)
350
300
250
200
150
100
50
0
35.00
30.00
25.00
20.00
25.9
27.6
29.2
30.1
29.6
29
28.5
28.4
28.1
27.7
26.8
25.5
10.6
28.2
30.7
71.8
189.4
151.7
158.2
187
319.9
230.8
57.3
9.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Temperature
Precipitation

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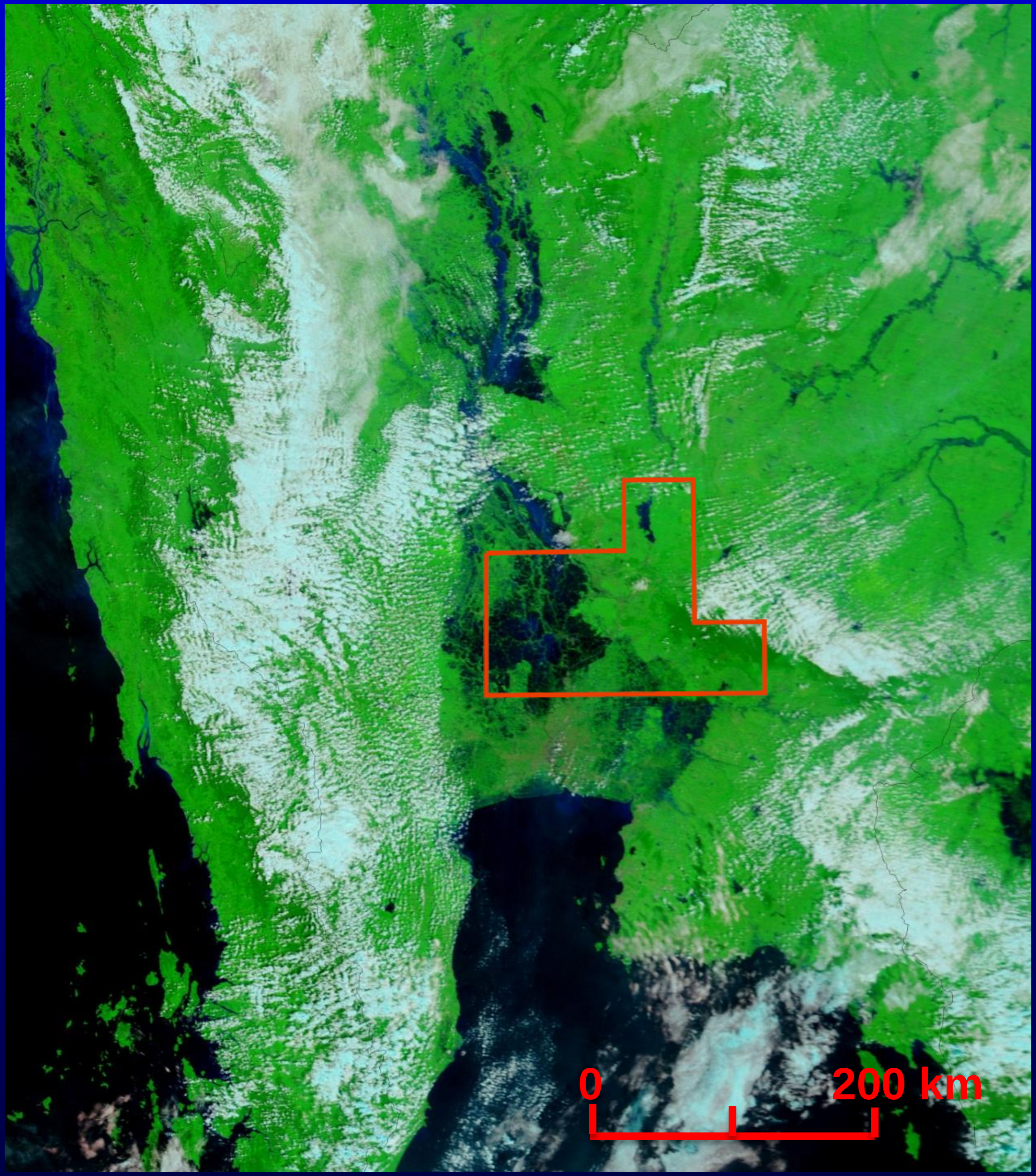


False-color satellite image showing extent of flooding on 19 October 2011; water is shown in dark blue.

Three weeks after the flood, dry period begins.

WATER SOURCES AND STORAGE IN THE PROJECT AREA

Rainwater is preserved in cisterns.

WATER SOURCES AND STORAGE IN THE PROJECT AREA

Water supply well and storage tank.

WATER SOURCES AND STORAGE IN THE PROJECT AREA

Industrial well

TD = 29.5 m, 12 inches diameter well

Q = 28 l/s or 100 m^3/hour

WATER SOURCES AND STORAGE IN THE PROJECT AREA

Mu Si Spring (Q = 150 l/s)

WATER SOURCES AND STORAGE IN THE PROJECT AREA

Man-made ponds

WATER SOURCES AND STORAGE IN THE PROJECT AREA

Small dams

WATER SOURCES AND STORAGE IN THE PROJECT AREA

Large dams (Pasak Dam)

WATER SOURCES AND STORAGE IN THE PROJECT AREA

Caves or large cavities intercepted during drilling activities could be potential storage for water.

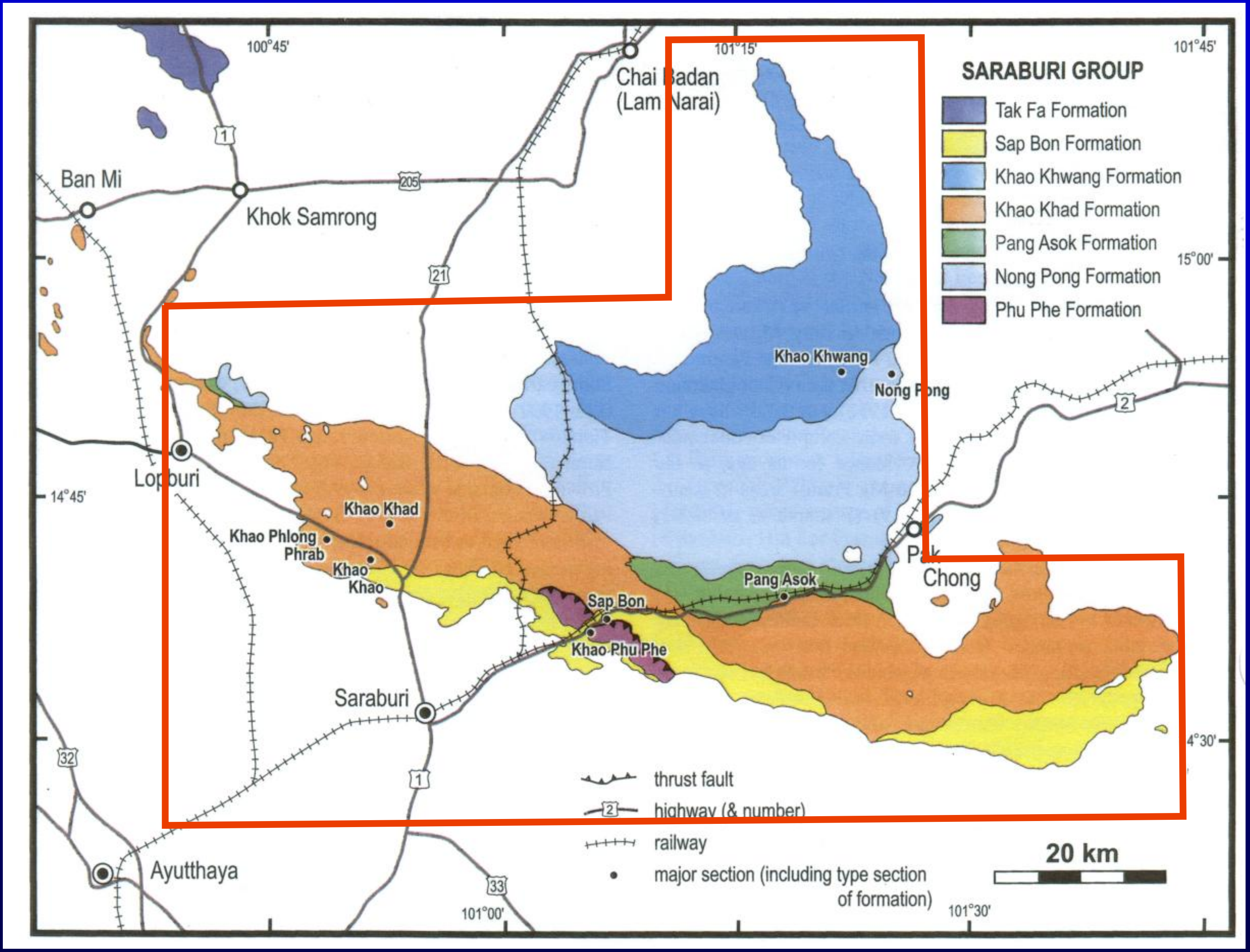
GEOLOGY

- The project area is underlain by the limestone of the Saraburi Group of Permian age (Ridd et al., 2011).
- In stratigraphic order from oldest to youngest, the rock units are the: Phu Phe, Khao Khwang, Nong Pong, Pang Asok, Khao Khad and Sap Bon formations.

ERA	PERIOD, SUBPERIOD		EPOCH	MILLIONS OF YEARS
Cenozoic	Quaternary		Holocene	11,477 ±85 yr
			Pleistocene	1.806±0.005
	Tertiary	Neogene	Pliocene	5.332±0.005
			Miocene	23.03±0.05
		Paleogene	Oligocene	33.9±0.1
			Eocene	55.8±0.2
			Paleocene	65.5±0.3
Mesozoic	Cretaceous		Upper / Late	99.6±0.9
			Lower / Early	145.5±4.0
	Jurassic		Upper / Late	161.2±4.0
			Middle	175.6±2.0
			Lower / Early	199.6±0.6
	Triassic		Upper / Late	228.0±2.0
			Middle	245.0±1.5
			Lower / Early	251.0±0.4
Paleozoic	Permian		Lopingian	260.4±0.7
			Guadalupian	270.6±0.7
			Cisuralian	299.0±0.8
	Carboniferous	Pennsylvanian	Upper / Late	306.5±1.0
			Middle	311.7 ±1.1
			Lower / Early	318.1±1.3
		Mississippian	Upper / Late	326.4±1.6
			Middle	345.3±2.1
			Lower / Early	359.2±2.5
	Devonian		Upper / Late	385.3±2.6
			Middle	397.5±2.7
			Lower / Early	416.0±2.8
	Silurian		Pridoli	418.7±2.7
			Ludlow	422.9±2.5
			Wenlock	428.2±2.3
			Llandovery	443.7±1.5
	Ordovician		Upper / Late	460.9±1.6
			Middle	471.8±1.6
			Lower / Early	488.3±1.7
	Cambrian		Upper / Late	501.0±2.0
			Middle	513.0±2.0
			Lower / Early	542.0±1.0
PRECAMBRIAN				

U.S. Geological Survey Geologic Names Committee, 2007, Divisions of geologic time—Major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2007-3015, 2 p.

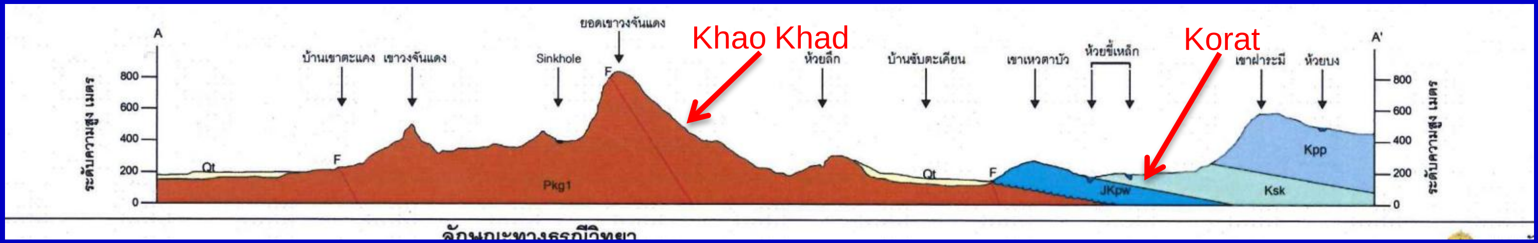
Limestone Project Karst

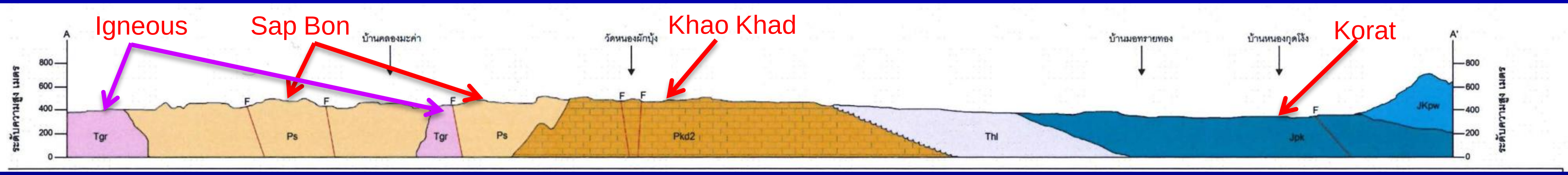


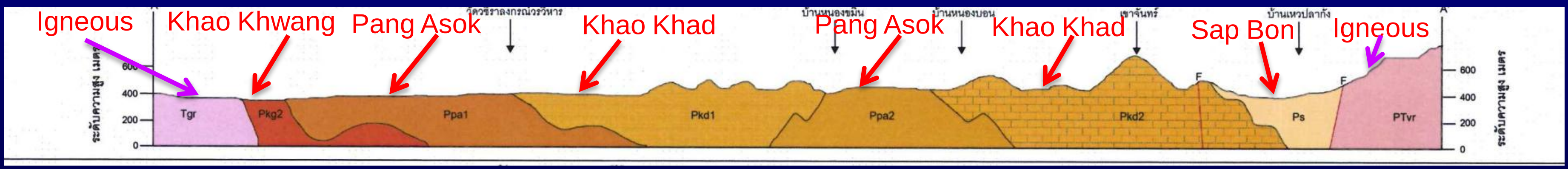
Geological map of the project area (from Ridd et al., 2011)

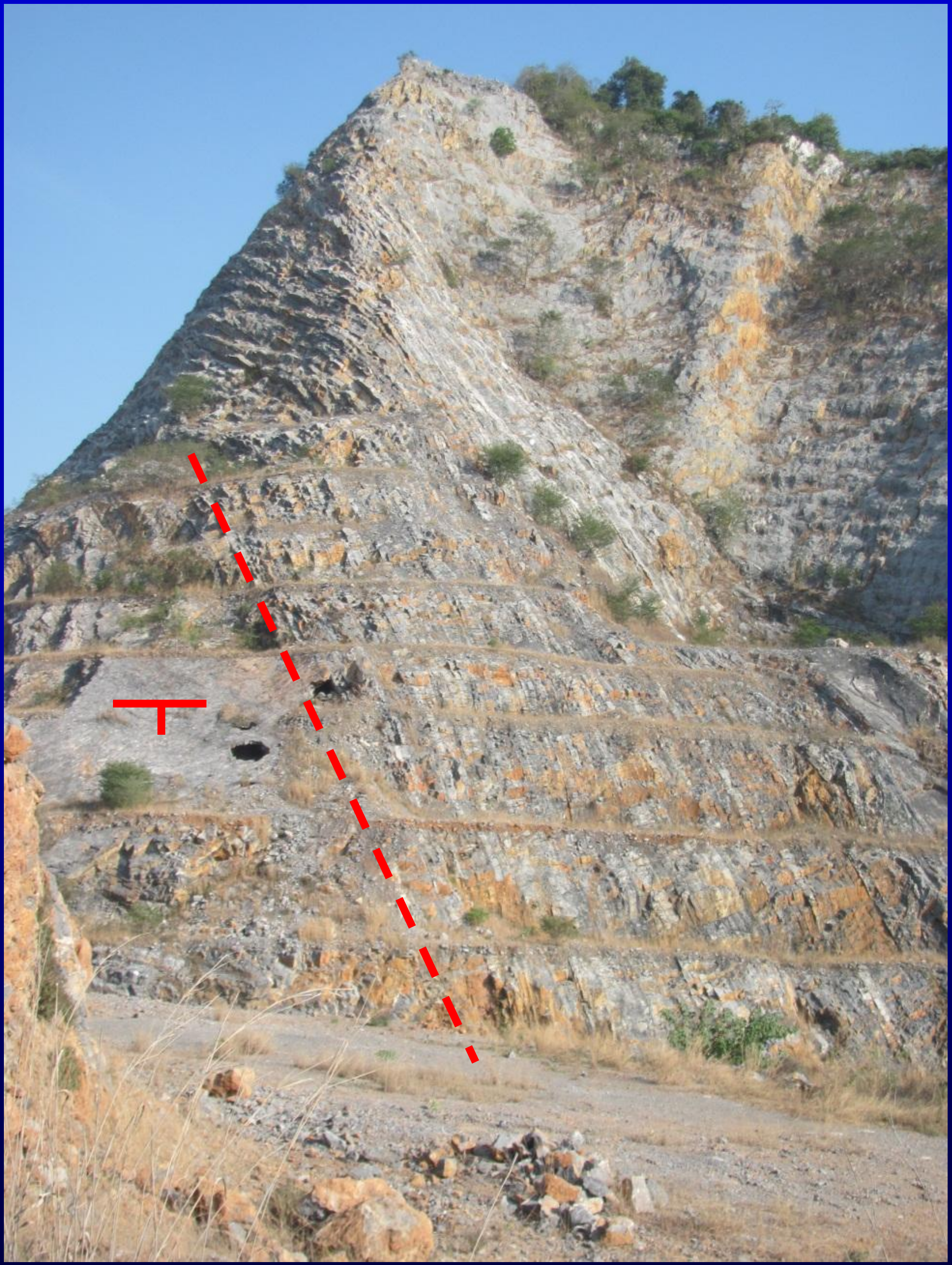
LEGEND (PERMIAN)

Ps	SAP BON (sandstone, shale, limestone)	Upper Permian	RATBURI (SARABURI GROUP)
P_{kd2}	KHAO KHAD 2 (limestone, bedded chert)	Lower-Middle Permian	RATBURI (SARABURI GROUP)
P_{kd1}	KHAO KHAD 1 (limestone, shale, sandstone)	Lower-Middle Permian	RATBURI (SARABURI GROUP)
P_{pa2}	PANG ASOK 2 (shale, sandstone, shale)	Lower-Middle Permian	RATBURI (SARABURI GROUP)
P_{pa2}	PANG ASOK 1 (shale, sandstone, shale)	Lower-Middle Permian	RATBURI (SARABURI GROUP)
P_{n}	NONG PONG (limestone, bedded chert, shale)	Lower-Middle Permian	RATBURI (SARABURI GROUP)
P_{kg2}	KHAO KHWANG 2 (limestone with chert, shale)	Lower Permian	RATBURI (SARABURI GROUP)
P_{kg1}	KHAO KHWANG 1 (limestone with chert, shale)	Lower Permian	RATBURI (SARABURI GROUP)
P_{p}	PHU PHE (limestone with chert bands, shale)	Lower Permian	RATBURI (SARABURI GROUP)


Khao Khad
Korat
A
A'
Sinkhole
800
600
400
200
0
Qt
F
Pkg1
JKpw
Kpp
Ksk


Igneous
Sap Bon
Khao Khad
Korat
A
A'
800
600
400
200
0
F
Tgr
Ps
Pkd2
Thl
Jpk
JKpw


Igneous
Khao Khwang
Pang Asok
Khao Khad
Pang Asok
Khao Khad
Sap Bon
Igneous
A'
600
400
200
0
F
Tgr
Pkg2
Ppa1
Pkd1
Ppa2
Pkd2
Ps
PTvr




The University
of Alabama

OBJECTIVES OF THAILAND INVESTIGATION

1. *Karst inventory*

Karst Landforms

1. *Karren*
    1. *Circular plan forms*
        a. *Rain Pits*
        b. *Kamenitza*
    2. *Linear forms*
        a. *Karren fields*
    3. *Depressions*
        a. *Sinkholes (dolines)*
        b. *Closed depressions*

3. *Springs*
4. *Sinking Streams*
5. *Waterfalls*

Karst landforms

1. *Karren*
   1. *Circular plan forms*
      a. *Rain Pits*
      b. *Kamenitza*
   2. *Linear forms*
      a. *Karren fields*


Sharpie
TWIN TIP
PERMANENT MARKER
Nontoxic

Karst landforms

1. *Karren*
    1. *Circular plan forms*
        a. *Rain pits*
        b. *Kamenitza*
    2. *Linear forms*
        a. *Karren fields*
    3. *Depressions*
        a. *Sinkholes (dolines)*
        b. *Closed depressions*

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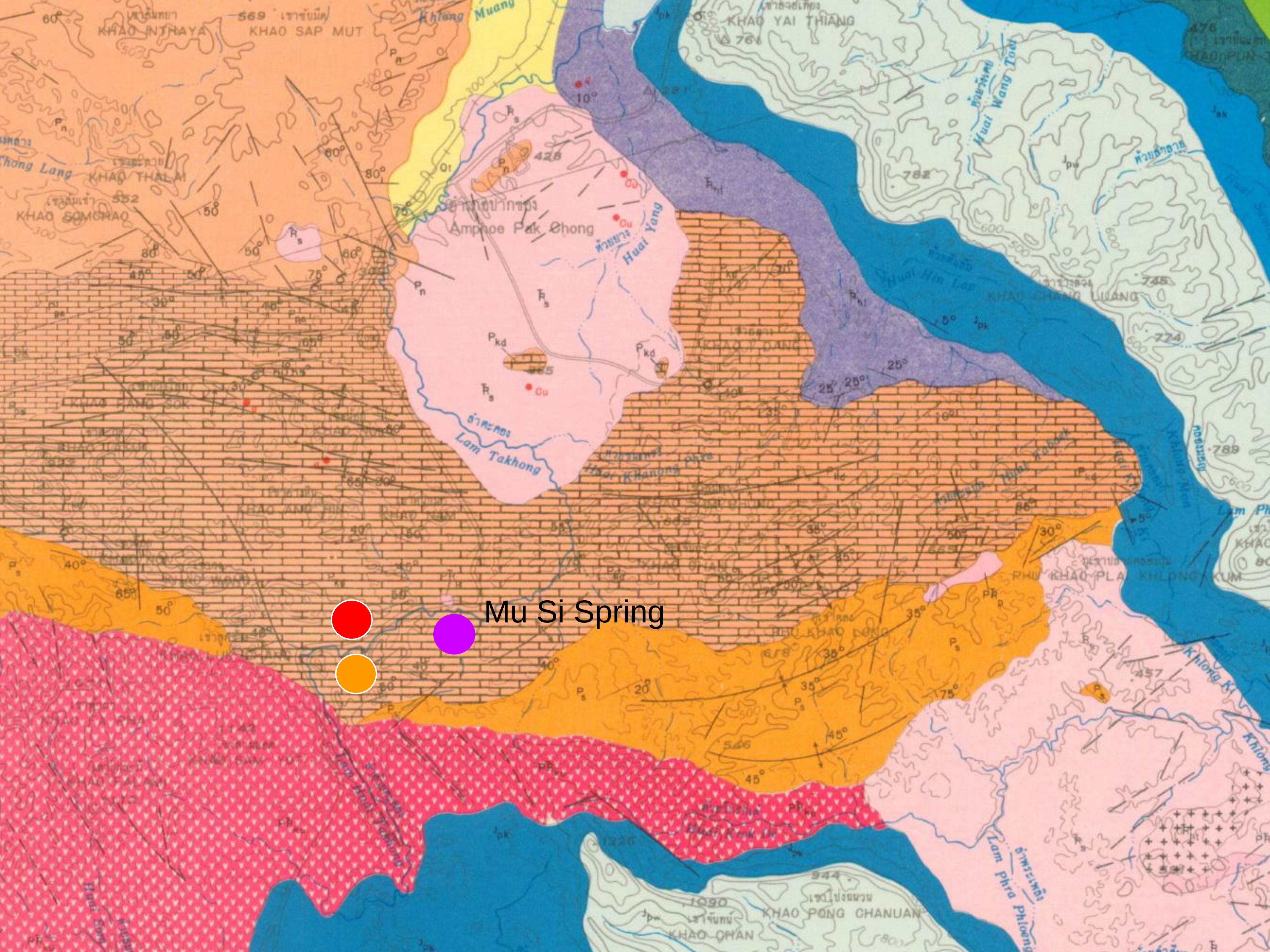
PELA GeoEnvironmental

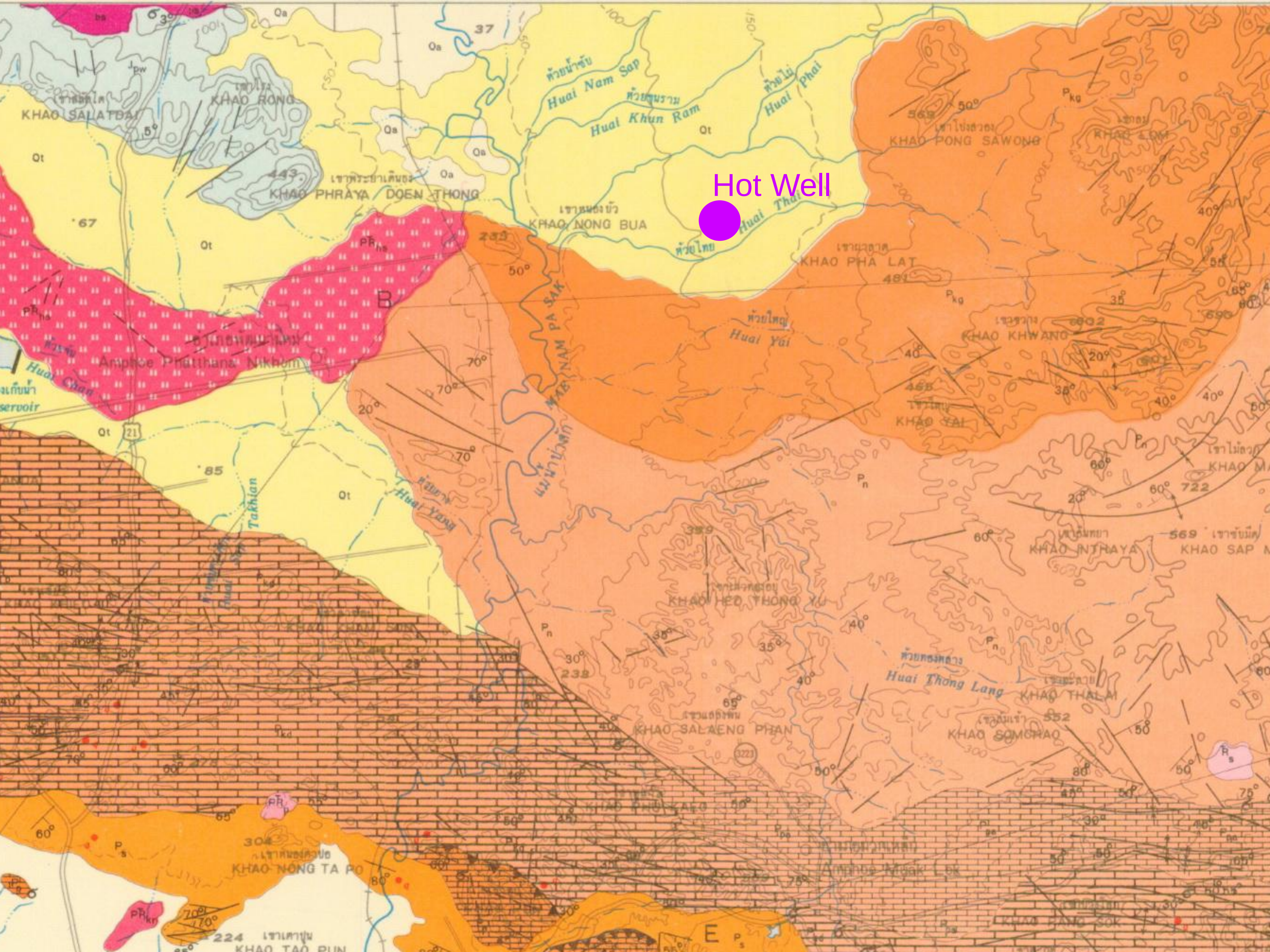
Karst landforms

1. *Karren*
    1. *Circular plan forms*
        a. *Rain Pits*
        b. *Kamenitza*
    2. *Linear forms*
        a. *Karren fields*
    3. *Depressions*
        a. *Sinkholes (dolines)*
        b. *Closed depressions*

3. *Springs*

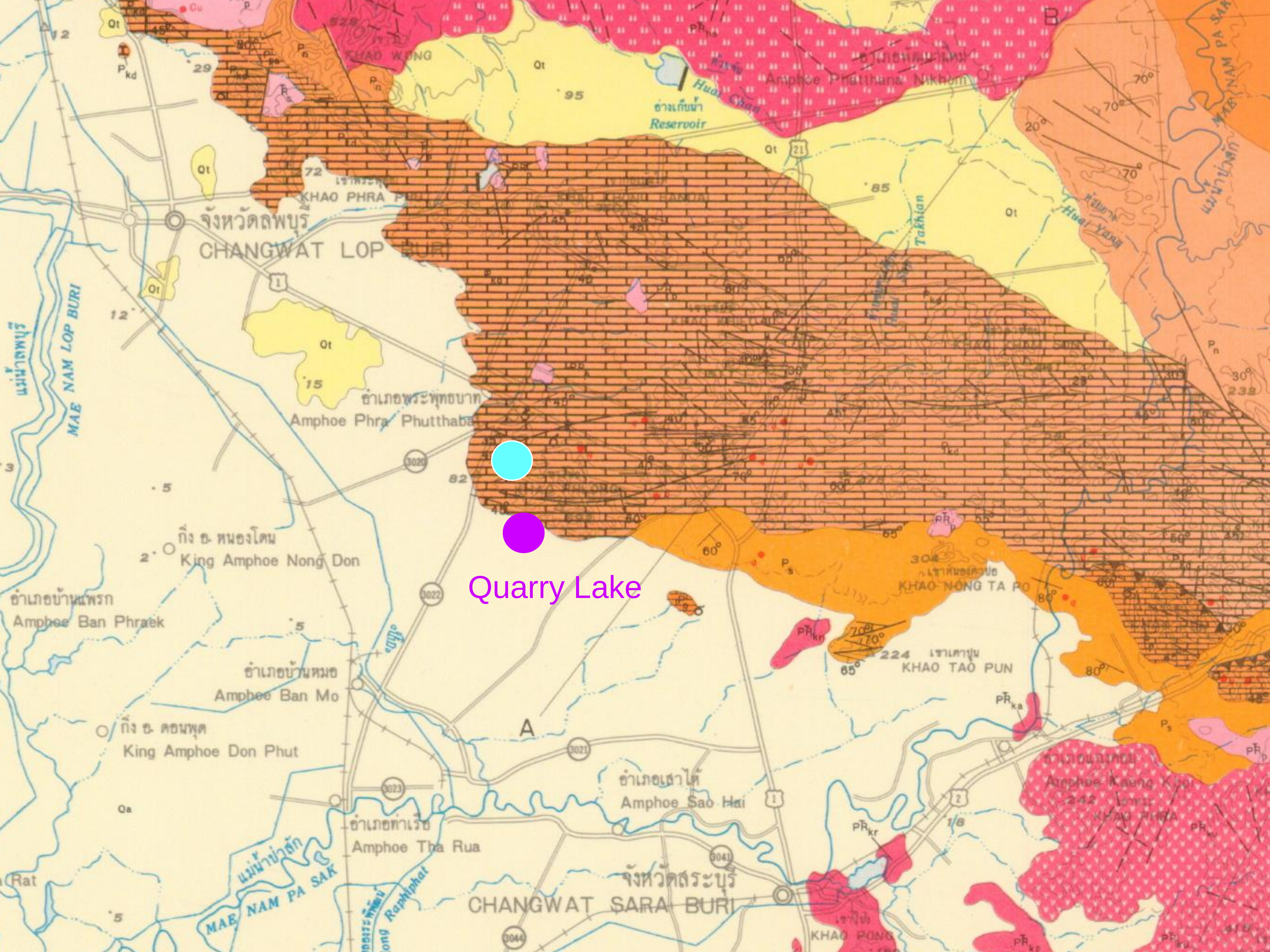

Mu Si Spring
KHAO INTRAYA
KHAO SAP MUT
KHAO YAI THIANG
Khlong Muang
KHAO THALAI
KHAO SOMCHAO
Amphoe Pak Chong
Huai Yang
Huai Wang Toei
Huai Hin Lap
KHAO CHANG LUANG
Lam Takhong
PHU KHAO PLA KHLONG KUM
PHU KHAO LONG
Khlong Ki
Lam Phra Phloeng
KHAO PONG CHANUAN
KHAO CHAN

Mu Si Spring (Q = 150 l/s)



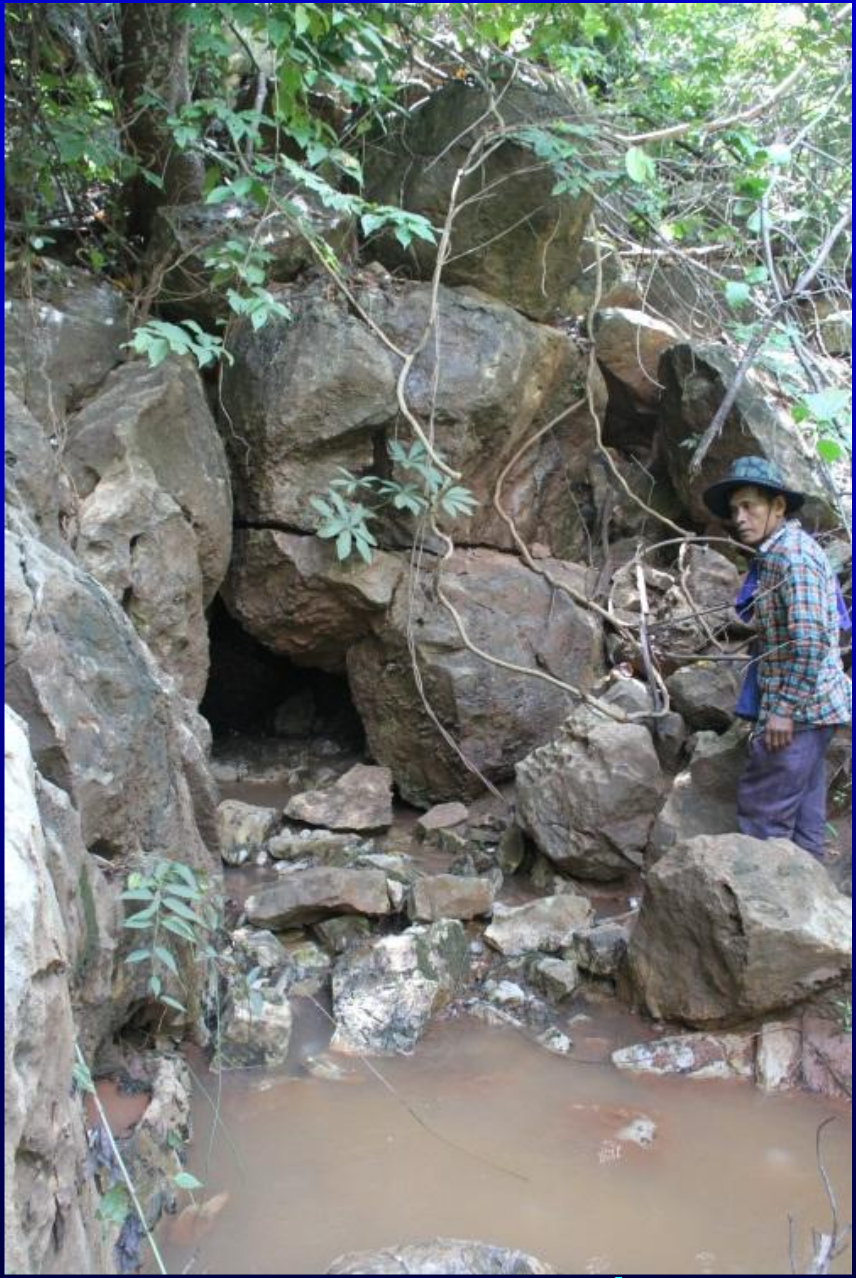
Hot Well
KHAO SALATDAI
KHAO RONG
KHAO PHRAYA DOEN THONG
KHAO NONG BUA
Huai Nam Sap
Huai Khun Ram
Huai Phai
Huai Thai
KHAO PONG SAWONG
KHAO LOM
KHAO PHA LAT
Huai Yai
KHAO KHWANG
KHAO YAI
MAE NAM PA SAK
Amphoe Phatthana Nikhom
Huai Chan
Huai Yang
Takhian
KHAO HEO THONG YU
KHAO INTHAYA
KHAO SAP
Huai Thong Lang
KHAO THALAI
KHAO SALAENG PHAN
KHAO SOMCHAO
KHAO NONG TA PO
Amphoe Muak Lek
KHAO TAO PUN

Hot Well (Q = 400 l/s)



Quarry Lake
CHANGWAT LOP BURI
จังหวัดลพบุรี
KHAO PHRA
KHAO WONG
Amphoe Phatthana Nikhom
Huai Chan
อ่างเก็บน้ำ
Reservoir
Takhian
Huai Yang
MAE NAM PA SAK
แม่น้ำป่าสัก
MAE NAM LOP BURI
แม่น้ำลพบุรี
อำเภอพระพุทธบาท
Amphoe Phra Phutthabat
กิ่ง อ. หนองโดน
King Amphoe Nong Don
อำเภอบ้านแพรก
Amphoe Ban Phraek
อำเภอบ้านหมอ
Amphoe Ban Mo
กิ่ง อ. ดอนพุด
King Amphoe Don Phut
อำเภอเสาไห้
Amphoe Sao Hai
อำเภอท่าเรือ
Amphoe Tha Rua
จังหวัดสระบุรี
CHANGWAT SARA BURI
KHAO NONG TA PO
เขาเต่าปูน
KHAO TAO PUN
Amphoe Kaeng Khoi
KHAO PHRA
KHAO PONG
A
B


D.O.



$Q = 1.50\ l/s$

Karst landforms

1. Karren

1. Circular plan forms

a. Rain pits

b. Kamenitza

2. Linear forms

a. Karren fields

3. Depressions

a. Sinkholes (dolines)

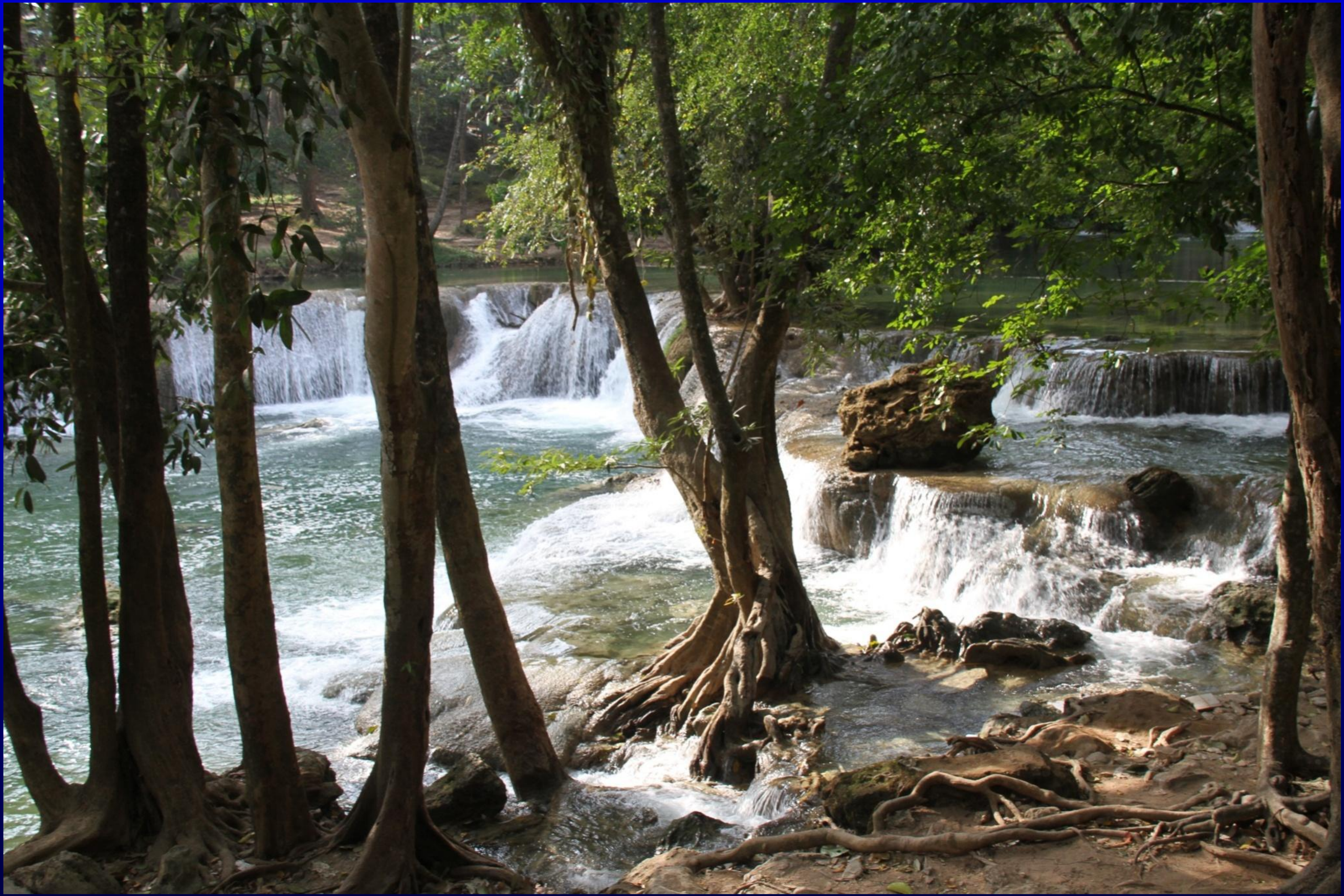
b. Closed depressions

3. Springs

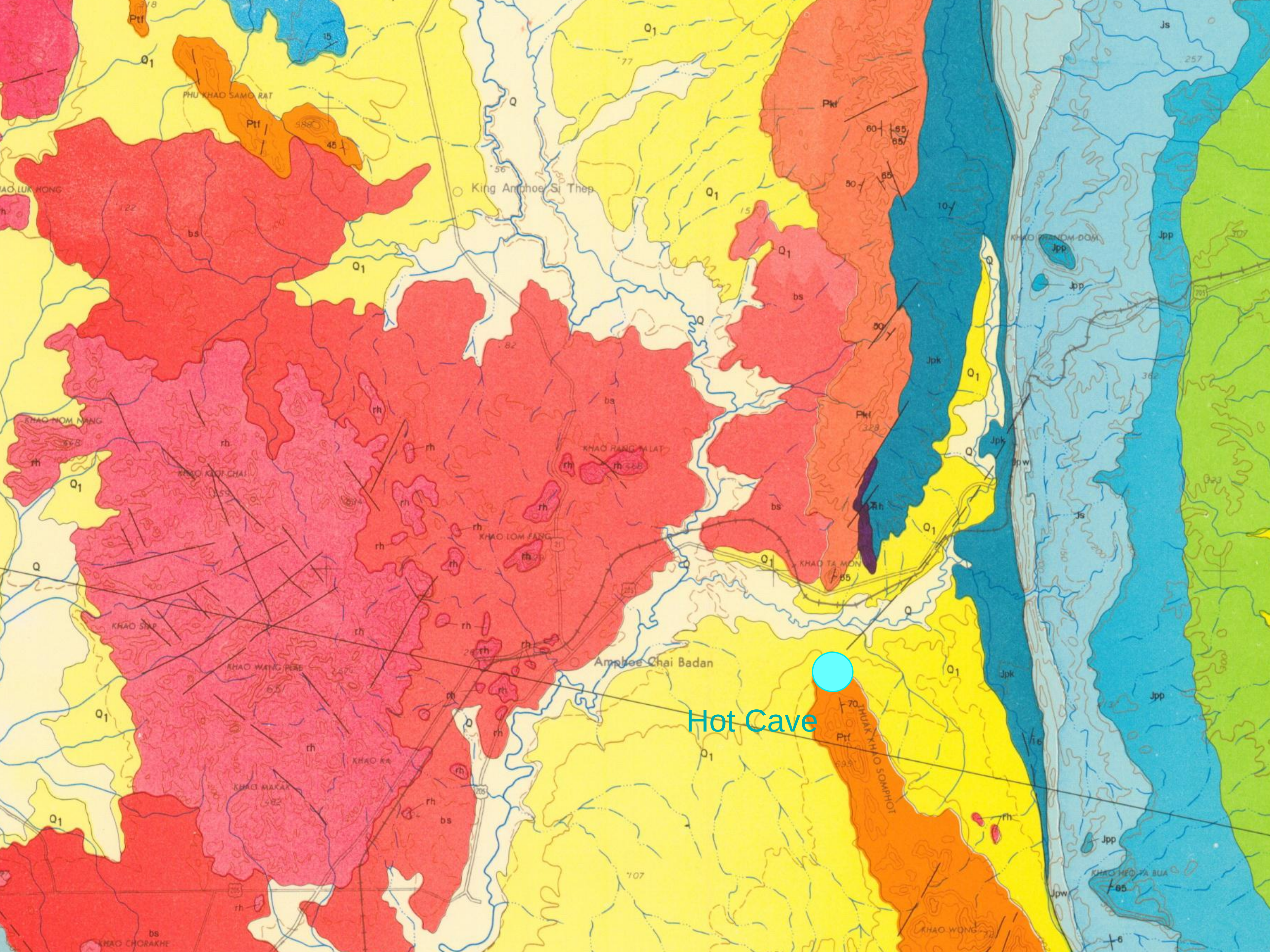
4. Sinking Streams

Karst landforms

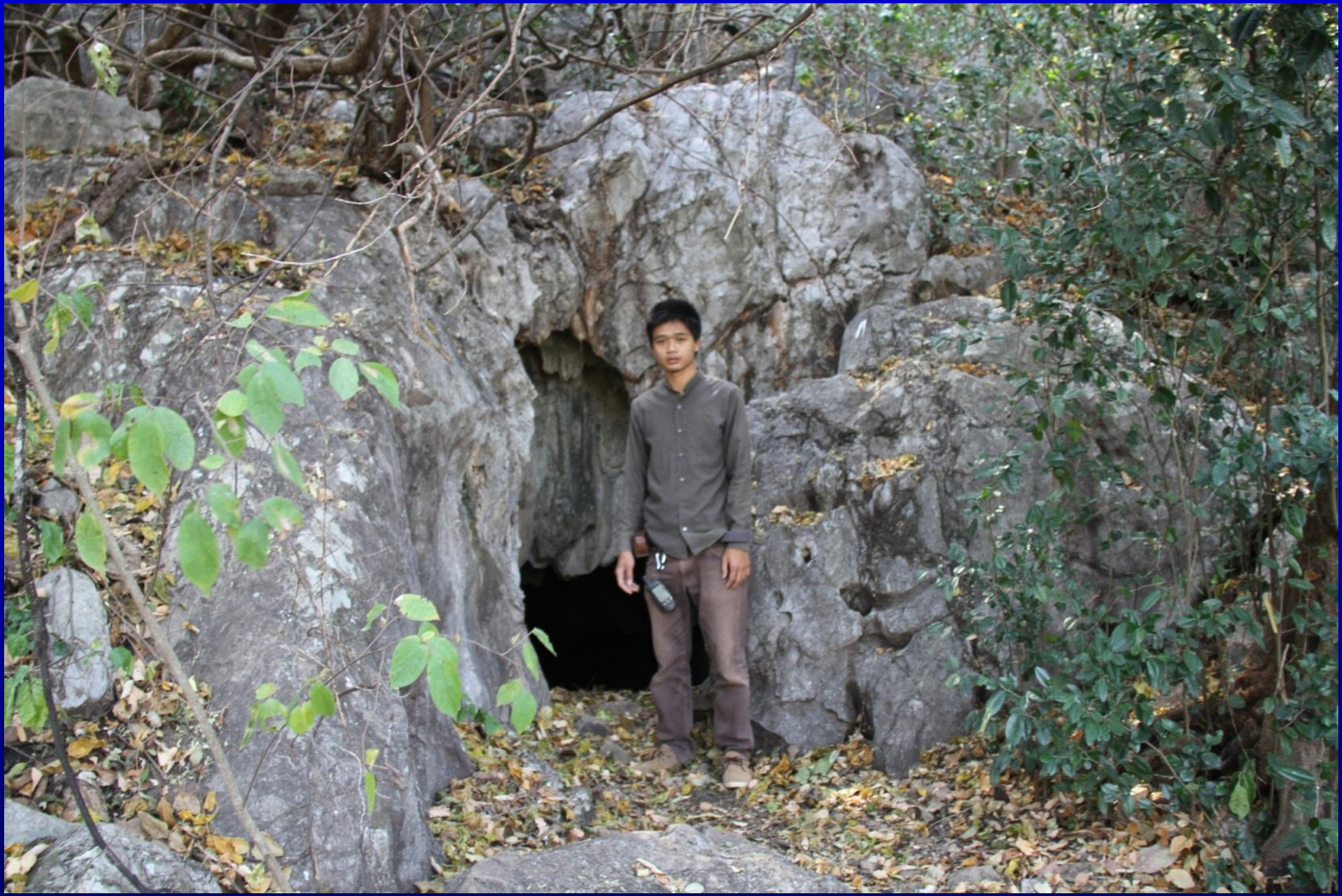
1. *Karren*
    1. *Circular plan forms*
        a. *Rain pits*
        b. *Kamenitza*
    2. *Linear forms*
        a. *Karren fields*
    3. *Depressions*
        a. *Sinkholes (dolines)*
        b. *Closed depressions*
3. *Springs*
4. *Sinking Streams*
5. *Waterfalls*



GEOTHERMAL ANOMALY



PHU KHAO SAMO RAT
King Amphoe Si Thep
KHAO NOM NANG
KHAO LOM FANG
KHAO SIAP
KHAO KA
KHAO TA MON
Amphoe Chai Badan
Hot Cave
THUAK KHAO SOMPHOT
KHAO PHANOM DOM
KHAO HEO TA BUA
KHAO WONG
KHAO CHORAKHE
Q
Q1
Ptf
Pkl
bs
rh
Jpk
Jpp
Jpw
Js



Hypogenic cave - A cave formed by water rising up from below and dissolving the rock, usually as the result of two different kinds of water mixing together.

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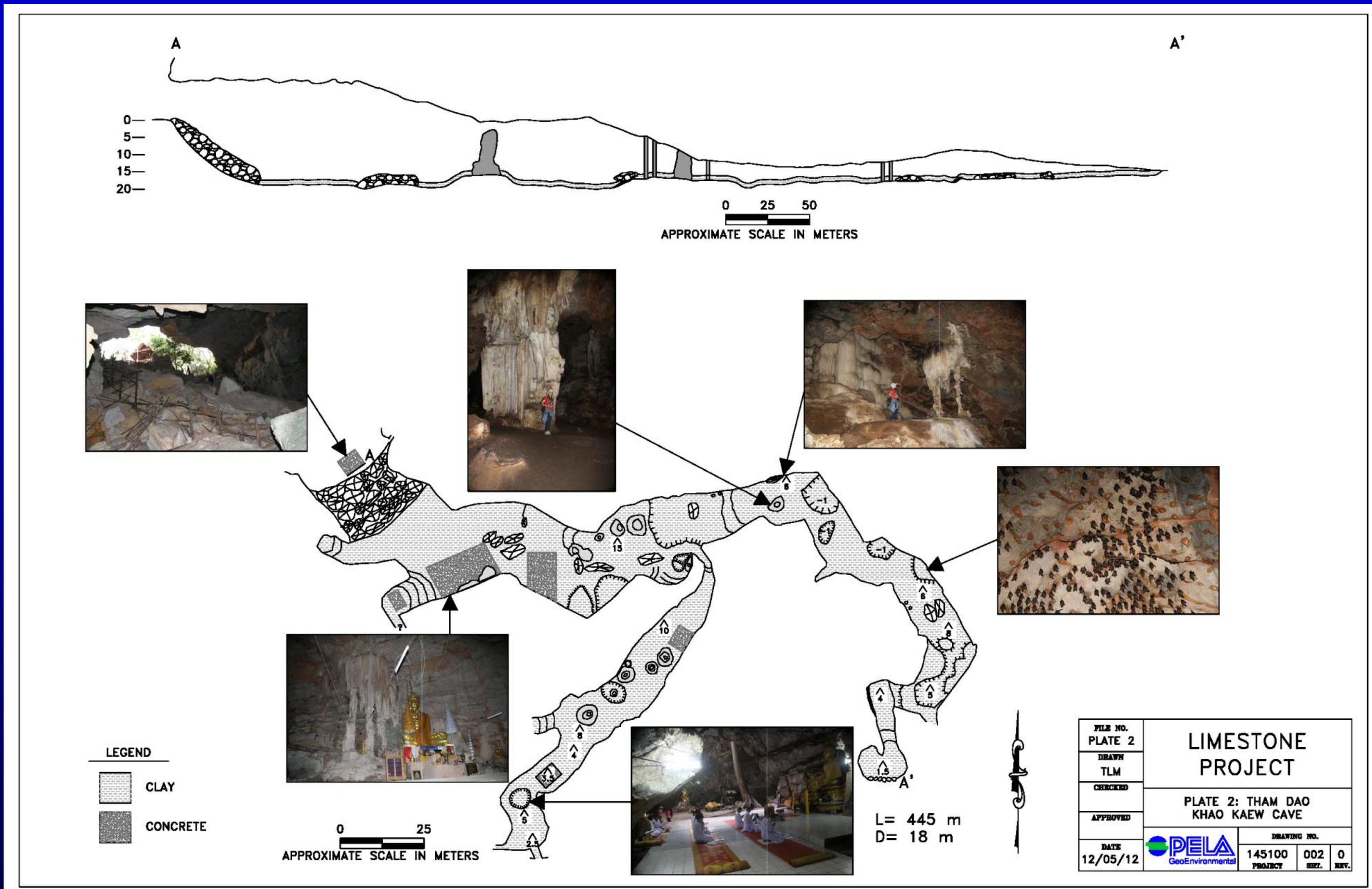
CAVES IN THE PROJECT AREA


A
A'
0
5
10
15
20
0 25 50
APPROXIMATE SCALE IN METERS
LEGEND
CLAY
CONCRETE
0 25
APPROXIMATE SCALE IN METERS
L= 445 m
D= 18 m
FILE NO.
PLATE 2
DRAWN
TLM
CHECKED
APPROVED
DATE
12/05/12
LIMESTONE PROJECT
PLATE 2: THAM DAO KHAO KAEW CAVE
PELA GeoEnvironmental
DRAWING NO.
145100
PROJECT
002
SHT.
0
REV.

OBJECTIVES OF THAILAND INVESTIGATION

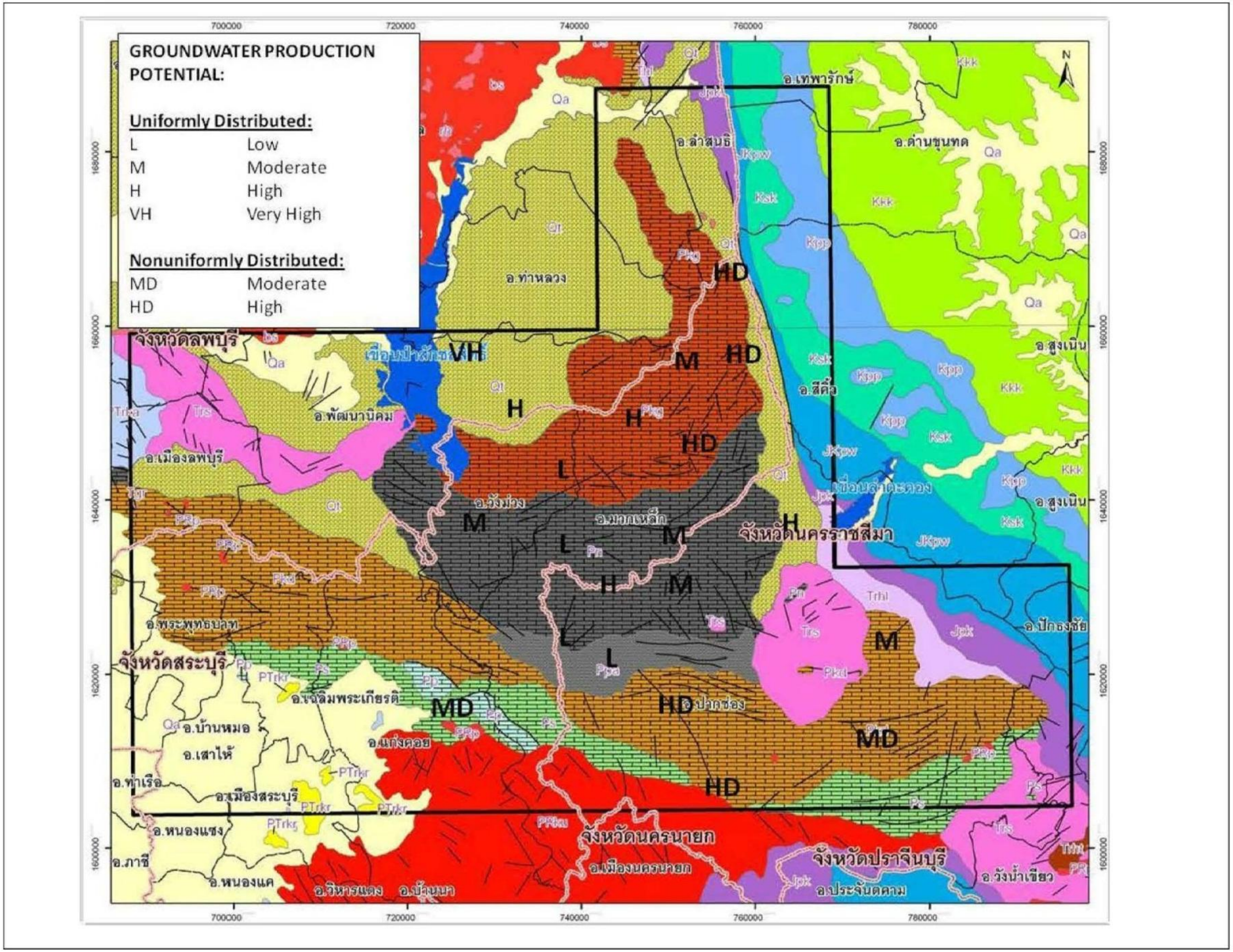
1. *Karst inventory*
2. *Surface geophysical investigation*

SURFACE GEOPHYSICAL INVESTIGATIONS

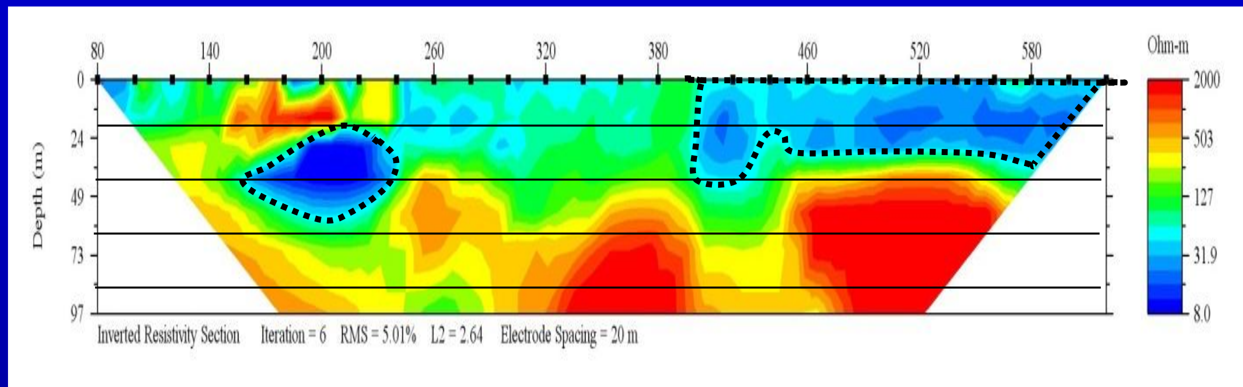
- To identify favorable locations for groundwater exploration in the Saraburi Group karstified aquifer system and characterize groundwater resources, an extensive resistivity geophysical survey was performed.
- Direct-current (DC) electrical resistivity was performed along 67 profiles distributed throughout Saraburi Province.
- The dipole-dipole array was used so that lateral variations in electrical resistivity indicative of karst features could be resolved.

SURFACE GEOPHYSICAL INVESTIGATIONS

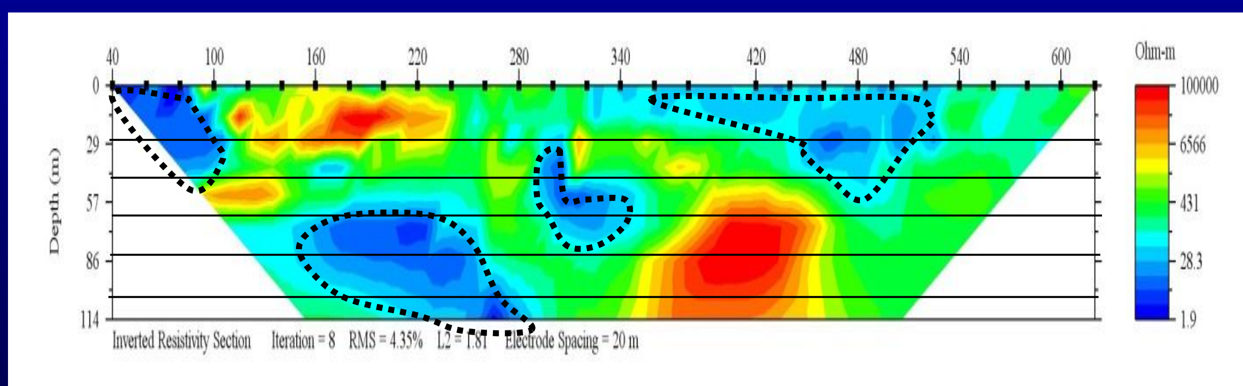
- Numerous deep (>50 m) low-resistivity anomalies were found along various inverted resistivity profiles. These anomalies were detected in all 67 profiles. Two profiles are included for illustration.
- The geologic map shows areas of groundwater potential, as low (L), moderate (M), high (H) and very high (VH). These anomalies may correspond to accumulations of groundwater in karst features within the limestone.


GROUNDWATER PRODUCTION POTENTIAL:
Uniformly Distributed:
L Low
M Moderate
H High
VH Very High
Nonuniformly Distributed:
MD Moderate
HD High
จังหวัดลพบุรี
จังหวัดสระบุรี
จังหวัดนครราชสีมา
จังหวัดนครนายก
จังหวัดปราจีนบุรี


Ban Khao Yai
ซับตะเคียน
Sap Takhian
47
48
Qt
MMA208
MMA204
MMA205
MMA206
MMA207
RS62
stk01
stk03
stk04
stk06
stk07
Ban Nong lao



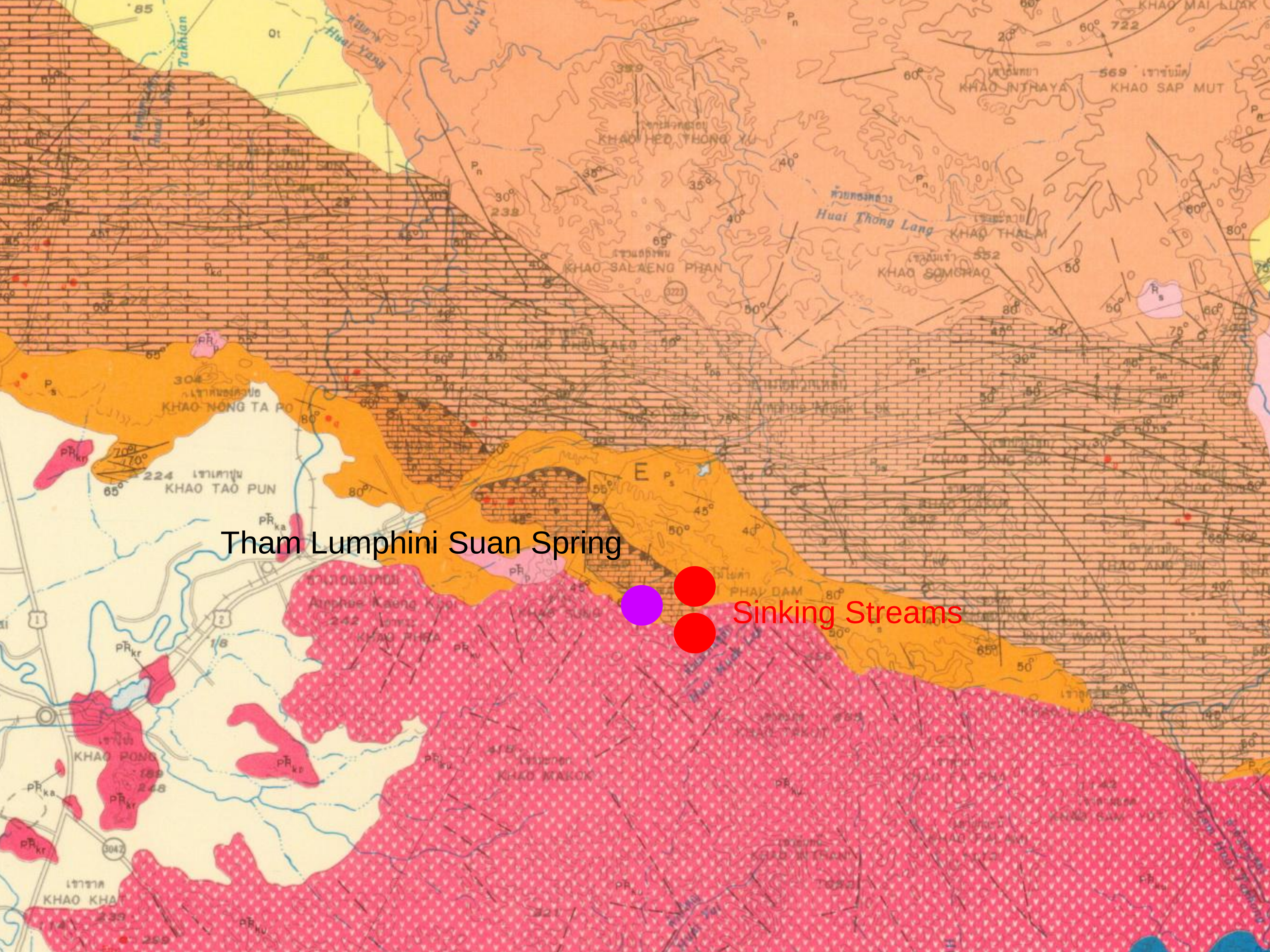
Southeast←STK04→Northwest

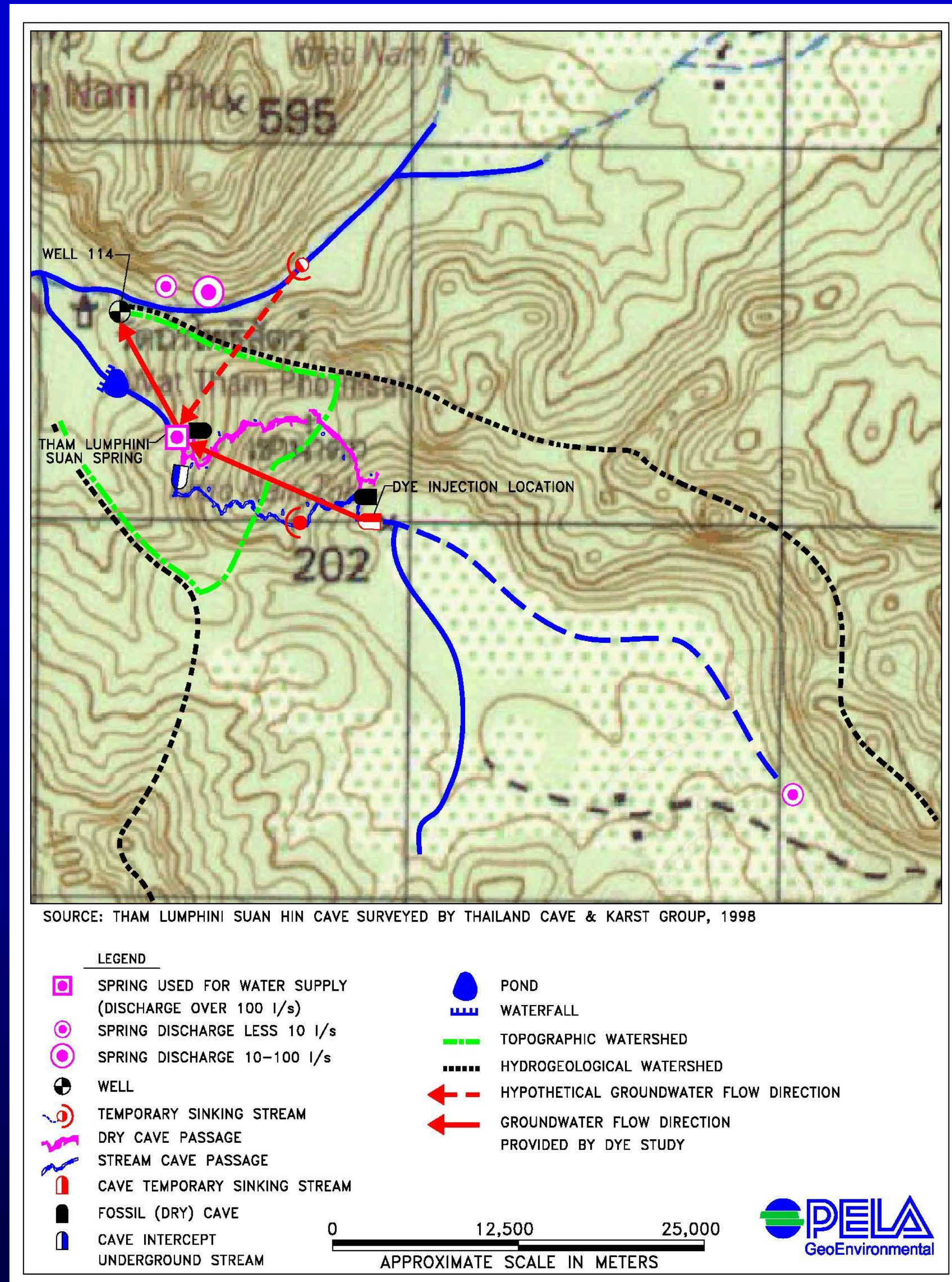


North←STK05→South

OBJECTIVES IN THAILAND INVESTIGATION

1. *Karst inventory*
2. *Surface geophysical investigation*
3. *Perform dye study to determine hydraulic connectivity within the aquifer*


Tham Lumphini Suan Spring
Sinking Streams
KHAO MAI LUAK
569 KHAO SAP MUT
KHAO INTHAYA
KHAO HED THONG YU
Huai Thong Lang
KHAO THALAI
KHAO SALAENG PHAN
552 KHAO SOMCHAO
304 KHAO NONG TA PO
224 KHAO TAO PUN
KHAO PONG
KHAO KHAT
KHAO MAKOK
KHAO PHA
Takhian
Huai Yang



595
202
WELL 114
THAM LUMPHINI SUAN SPRING
DYE INJECTION LOCATION
SOURCE: THAM LUMPHINI SUAN HIN CAVE SURVEYED BY THAILAND CAVE & KARST GROUP, 1998
LEGEND
SPRING USED FOR WATER SUPPLY (DISCHARGE OVER 100 l/s)
SPRING DISCHARGE LESS 10 l/s
SPRING DISCHARGE 10–100 l/s
WELL
TEMPORARY SINKING STREAM
DRY CAVE PASSAGE
STREAM CAVE PASSAGE
CAVE TEMPORARY SINKING STREAM
FOSSIL (DRY) CAVE
CAVE INTERCEPT UNDERGROUND STREAM
POND
WATERFALL
TOPOGRAPHIC WATERSHED
HYDROGEOLOGICAL WATERSHED
HYPOTHETICAL GROUNDWATER FLOW DIRECTION
GROUNDWATER FLOW DIRECTION PROVIDED BY DYE STUDY
0
12,500
25,000
APPROXIMATE SCALE IN METERS
PELA GeoEnvironmental

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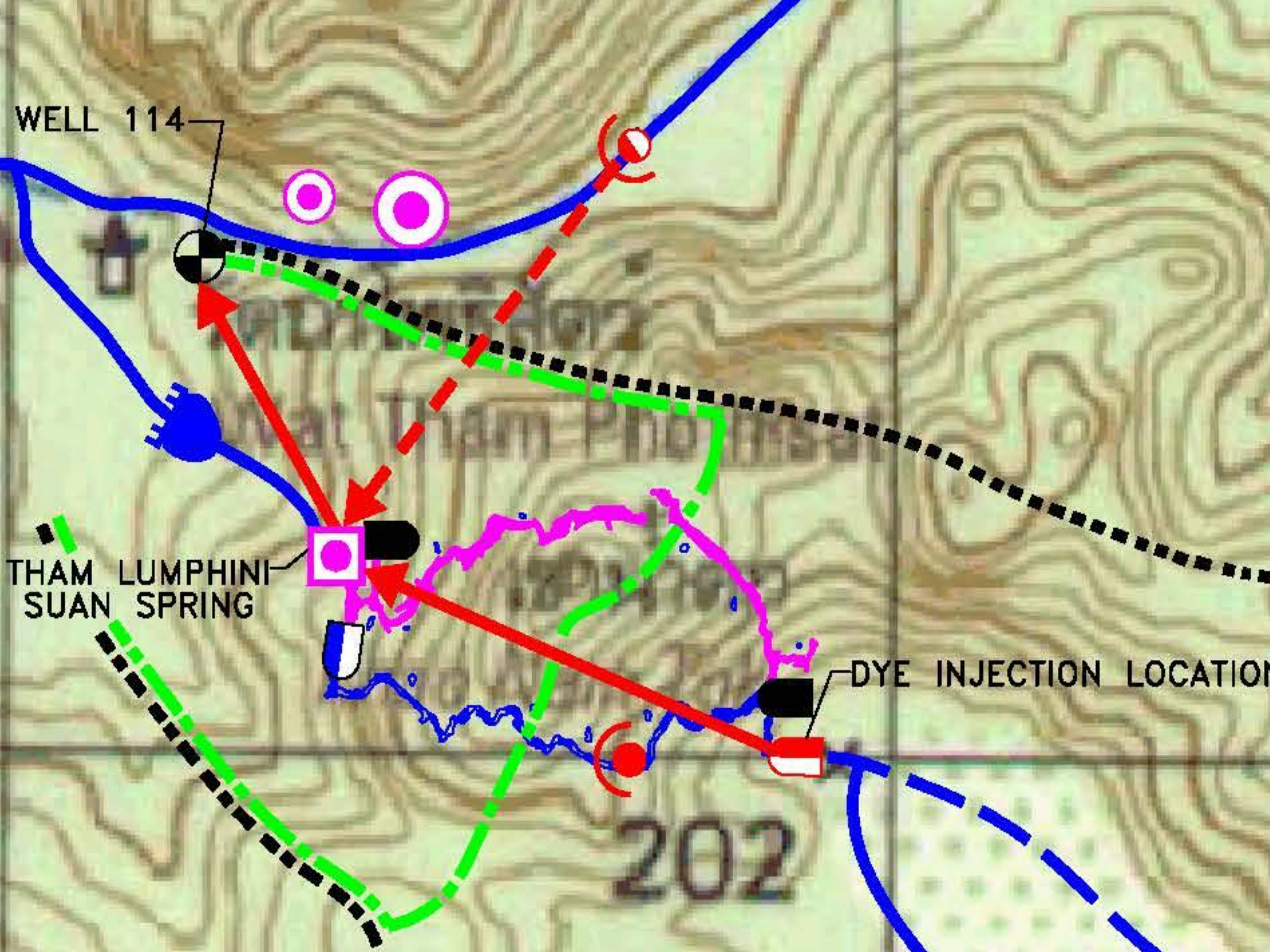
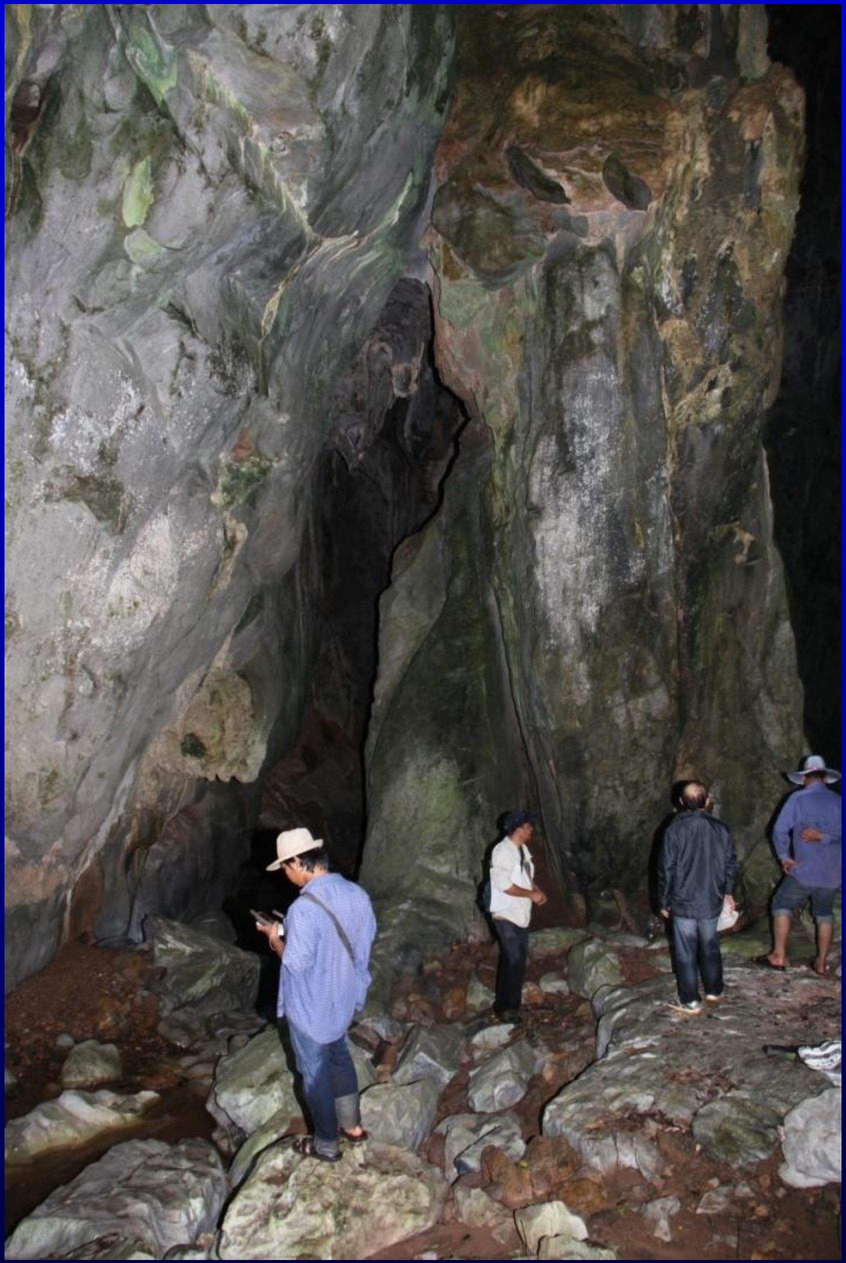


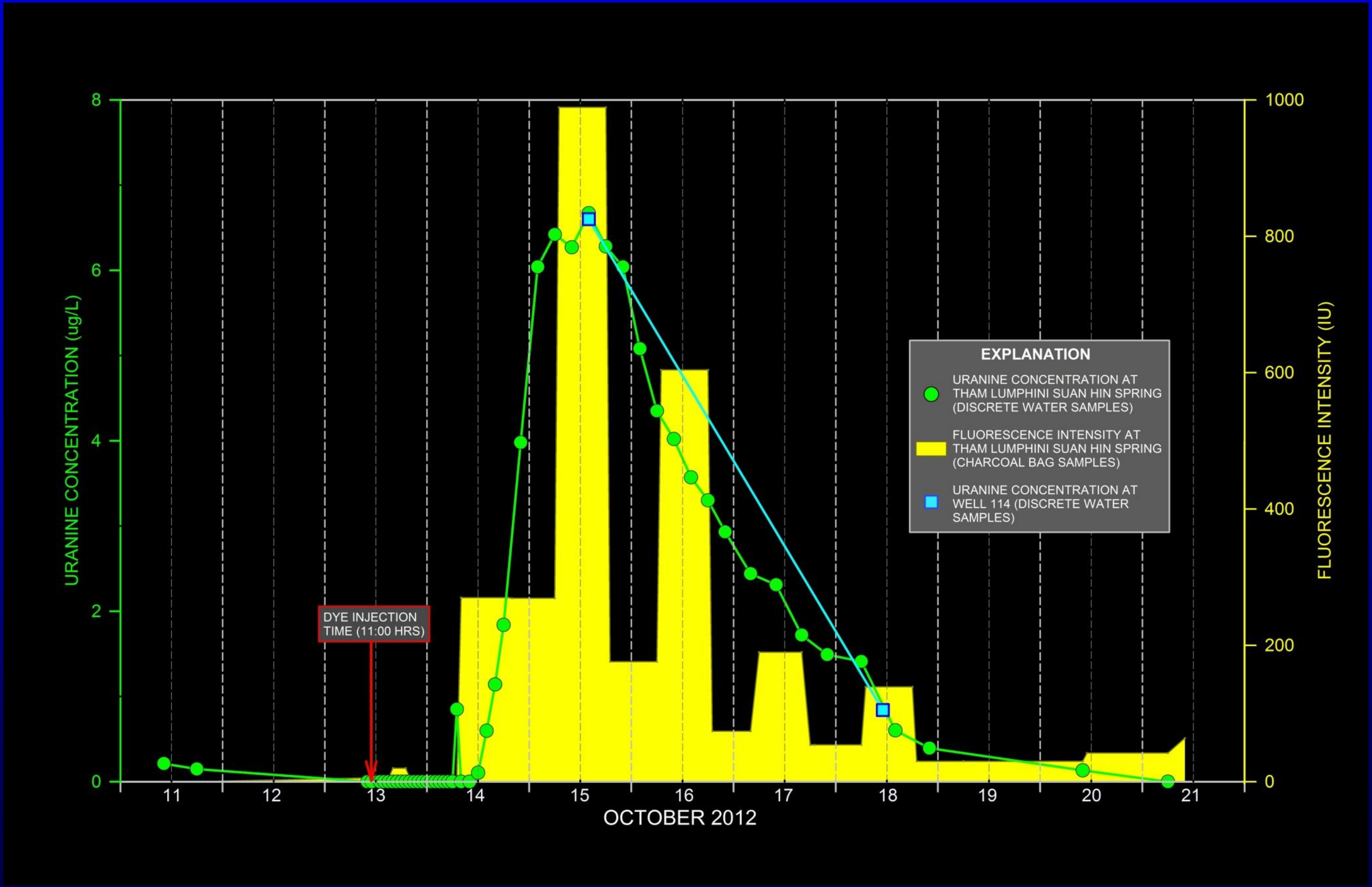
WELL 114
THAM LUMPHINI SUAN SPRING
DYE INJECTION LOCATION
Wat Tham Phonsai
202



Sinking stream October 2012

Tham Lumphini Suan Hin Sinking Stream Q = 8 l/s

Tham Lumphini Suan Hin Spring Q = 117 l/s)



URANINE CONCENTRATION (ug/L)
FLUORESCENCE INTENSITY (IU)
OCTOBER 2012
DYE INJECTION TIME (11:00 HRS)
EXPLANATION
URANINE CONCENTRATION AT THAM LUMPHINI SUAN HIN SPRING (DISCRETE WATER SAMPLES)
FLUORESCENCE INTENSITY AT THAM LUMPHINI SUAN HIN SPRING (CHARCOAL BAG SAMPLES)
URANINE CONCENTRATION AT WELL 114 (DISCRETE WATER SAMPLES)
0
2
4
6
8
0
200
400
600
800
1000
11
12
13
14
15
16
17
18
19
20
21

OBJECTIVES IN THAILAND INVESTIGATION

1. *Karst inventory*
2. *Surface geophysical investigation*
3. *Perform dye study to determine hydraulic connectivity within the aquifer*
4. *Drilling, well construction (15 pumping wells and 15 observation wells) and aquifer tests*

OBJECTIVES IN THAILAND INVESTIGATION

1. *Drilling, well construction (15 pumping wells and 15 observation wells) and aquifer tests*

Pumping wells - Diameter 200 mm	Observation wells - Diameter 100 mm
1. Depth 80 m - 5 wells	Depth 80 m - 5 wells
2. Depth 150 m - 5 wells	Depth 150 m - 5 wells
3. Depth 250 m - 5 wells	Depth 250 m - 5 wells


WRE


XRVS 455

CONCLUSIONS/PROJECT STATUS

1. *Karst inventory*
2. *Surface geophysical investigation*
3. *Perform dye study to determine hydraulic connectivity within the aquifer*
4. *Drilling, well construction (15 pumping wells and 15 observation wells) and aquifer tests*
5. *Collect and analyze water samples for stable and radioactive isotopes to delineate the source of water*

THANK YOU!