An Introduction to Tafoni:

Nature's Rock Art

風化穴知多少: 大自然的岩石藝術

Prof. W.W.-S. Yim 嚴維樞教授

Department of Earth Sciences,

The University of Hong Kong

香港大學地球科學系

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Order of presentation 大綱

(1) What are they?

(2) Where are they found?

(3) Why are they important?

(4) Are there different types?

(5) How are they formed?

Definition 定義

Tafoni (singular: tafone)

Corsican word meaning ‘windows’

Cave-like features of variable size (up to 2 m in diameter) occurring in groups on inclined or vertical rock surfaces. They are a product of weathering and/or erosion found in all climate types, most abundant in coastal areas above present day sea level and semi-arid and arid deserts.

The weathering type is also known as alveolar or honeycomb.

Their origin is controversial.

Where are they found ?
在那裡可找到它們?

Polar region – Antarctica

Temperature regions – Normandy, Brittany, Corsica, New Zealand

Arid regions – Atacama Desert, Australia, Africa, New Mexico, central Asia

Mountainous regions – Alps, Vosge

Tropical humid regions – Hong Kong, Aruba, West Indies

Other – Mars

Why are they important in geomorphology?
為何它們在地貌上那麼重要？

- Appearance interesting and/or spectacular (names given to rock based on human imagination)

- Occurs in a range of rock types including granite, porphyry, various lavas, sandstone, eolianite, gneiss and schist

- Possible coastal indicator

- Possible arid or semi-arid indicator

- Origin controversial but may involve salt weathering, wind erosion and/or frost shattering

Tafoni types 風化穴類型 (www.tafoni.com)

(1) Sidewall or lateral tafoni (Tschang 1974)

(2) Basal tafoni –
base of outcrops and boulders

(3) Nested tafoni –
Cavities that occur inside one another

(4) Honeycomb (cell-like)

(5) Iconic or 'ruined' tafoni (Tschang 1974)

(6) Relic tafoni – no longer actively enlarging

How are they formed? 它們是怎樣形成的?

- Wind erosion
- Salt weathering
- Biological weathering by organisms e.g. snails
- Frost shattering
- Relic features
- Combination of the above

Origin of Tafoni in Hong Kong
香港風化穴起源

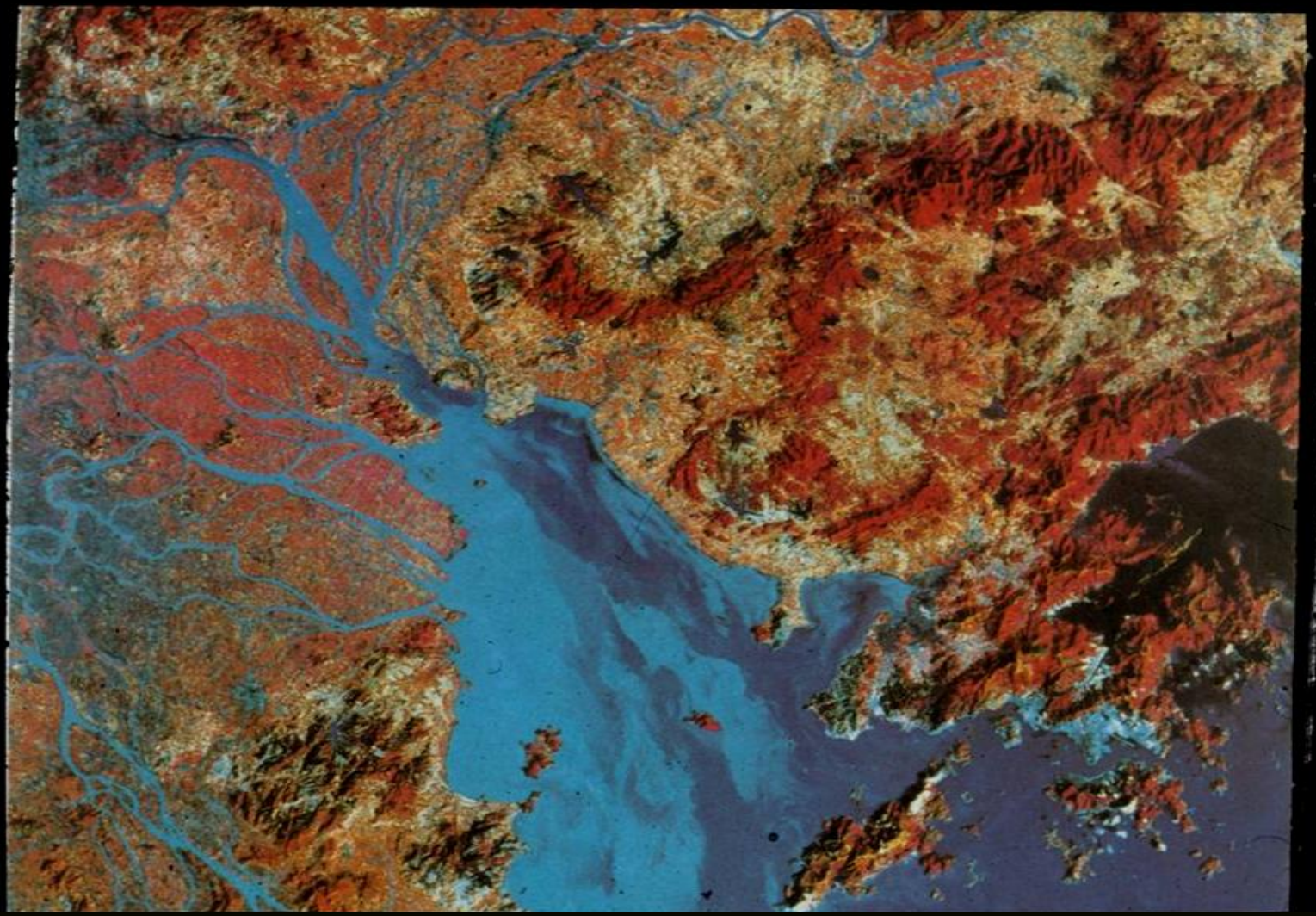
Are they forming now?

- **Probably not for the majority unless salt weathering from sea spray is important**

Are they relic features?

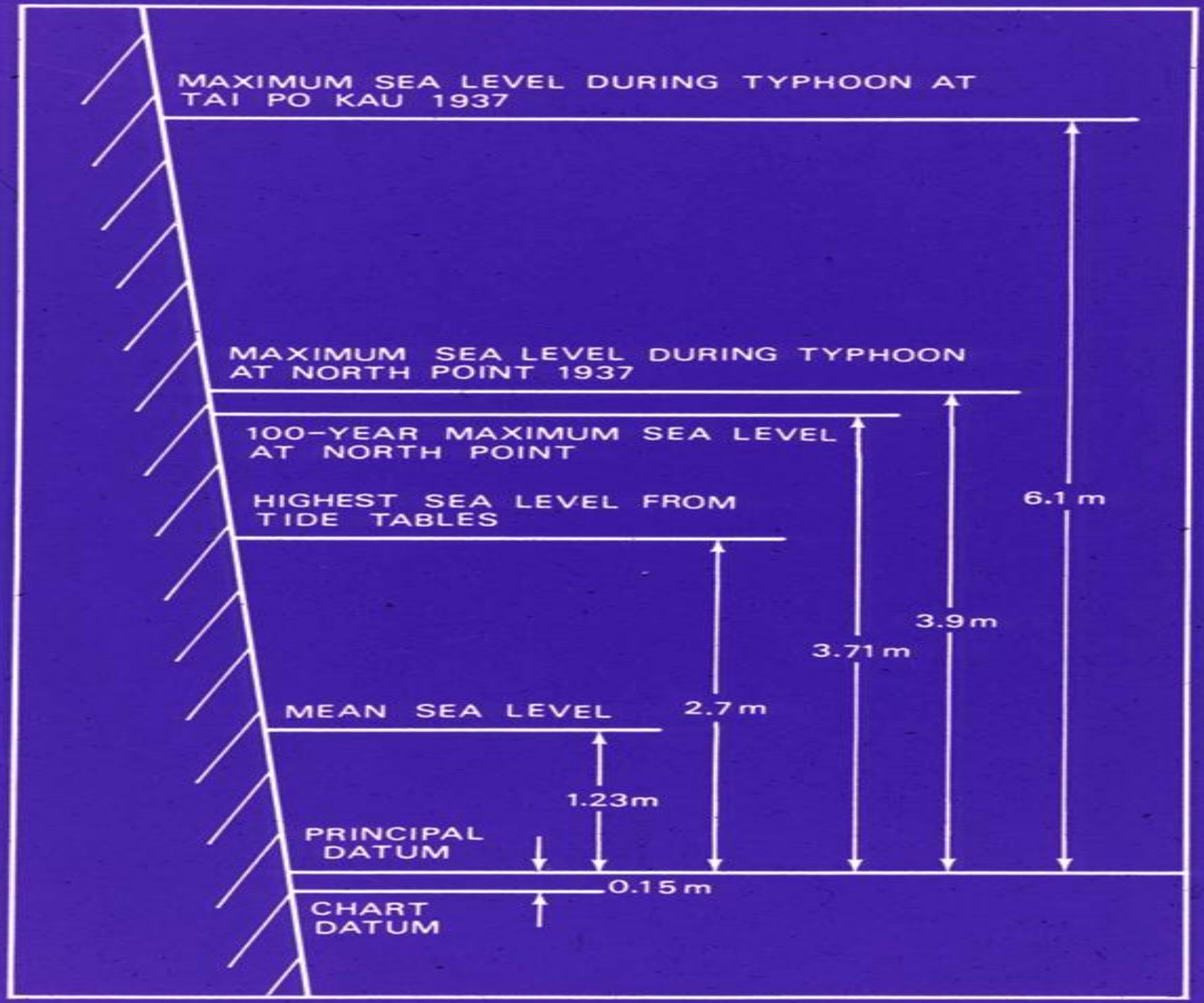
- **Probably yes during glacial periods when conditions were colder, drier and windier**

Satellite photo of Hong Kong and the Pearl River Estuary
香港及珠江口衛星圖 (band 5)



Tafoni are usually found within 100 m above present sea level in southern Hong Kong

Present sea-level datums 現時海平面的版數據



Wind erosion during typhoons?
暴風期間的風蝕?

Arguments against this –

(1) Frequency and magnitude of typhoons are both too short

(2) Each typhoon may be drastically different e.g. track and landfall location

(3) Typhoons are usually associated with heavy rainfall

Supporting evidence from climate and sea-level changes in Hong Kong

從香港氣候及海平面變化找到的憑證

Based on 2 types of deposits present on the seafloor of Hong Kong –

(1) Marine deposits

Formed during 'warm' interglacial periods with 'high' sea levels with elevations similar to the present day.

(2) Terrestrial deposits

Formed during 'cold' glacial periods with 'low' sea levels about 120 m below the present day. Land bridges existed e.g. between Asia and north America and between the Kowloon Peninsula and Hong Kong Island.

Evidence from sea-floor drilling
經海底鑽探得到的証據

A drill barge

Drilling in action

A continuous 60-m core drilled for sand search

Difference between marine & terrestrial deposits
海洋和陸上沉積的分別

Feature	Marine deposits	Terrestrial deposits
Fossils	Marine fossils may be present e.g. corals, clams, snails, etc.	Terrestrial fossils may be present e.g. plant remains, pollen, etc.
Colour	Usually darker	Usually paler
Grain size	Usually finer	Usually coarser
Compaction	Usually softer	Usually firmer
Water content	Usually higher	Usually lower
Iron content	Usually lower	Usually higher

Drillhole in the West Lamma Channel for the Western Harbour Development Study
在西博寮海峽為西部海域發展研究開發的鑽坑

Samples at about 0.5 m Intervals in Borehole WB7

Borehole WB7

Legend	Depth in m P.D.	Origin	Description
	0.00		Sea level
	-10.20		Sea bed
	-17.20	M1	Very soft, grey clayey silt with shell fragments and subangular gravel in the top metre
	-23.80	M2	Soft to firm, grey clayey silt with occasional shell fragments and large bivalves at the base
	-27.60	T2	Yellow, brown and grey subrounded sand and gravel
	-35.70	M3	Firm; mottled, grey, yellow and brown clayey silt to -31.20 m; dark grey, clayey silt with a little sand and gravel below -31.20 m
	-37.05	T3	Mottled, white and grey silty sand with gravel below -36.85 m
	-51.20	M4	Soft to firm; mottled, grey, yellow and brown clayey silt to -46.13 m ; dark grey and grey clayey silt below -46.13 m
	-53.20	M5	Firm, mottled, grey, yellow and brown clayey silt becoming more grey at the base
	-60.20	T5	Firm to stiff, locally mottled, white,pink and grey clay to sand with occasional gravels
	-70.20	Residual soil	Completely decomposed rock (? granite)

Simplified logsheet

Offshore geological model of Hong Kong
香港離岸地質模式

Unit	Age	Estimated age (ka)	Maximum thickness (m)
M1	Postglacial	< 8.2	21.5
T1	Last glacial	8.2 – 70	6.5
M2	Last interglacial	90 – 140	15.7
T2	2nd last glacial	150 – 180	9.5
M3	2nd last interglacial	190 – 240	12
T3	3rd last glacial	250 – 300	7.3
M4	3rd last interglacial	310 – 340	14.1
T4	4th last glacial	350 – 370	6
M5	4th last interglacial	380 – 420	3.5
T5	5th last glacial	> 440	7

Age determination 年代測定

(1) Order of marine and terrestrial deposits

(2) Dating of suitable samples

Methods used -

Radiocarbon (reliable when younger than 8.2 ka)

Uranium-series (up to 500 ka)

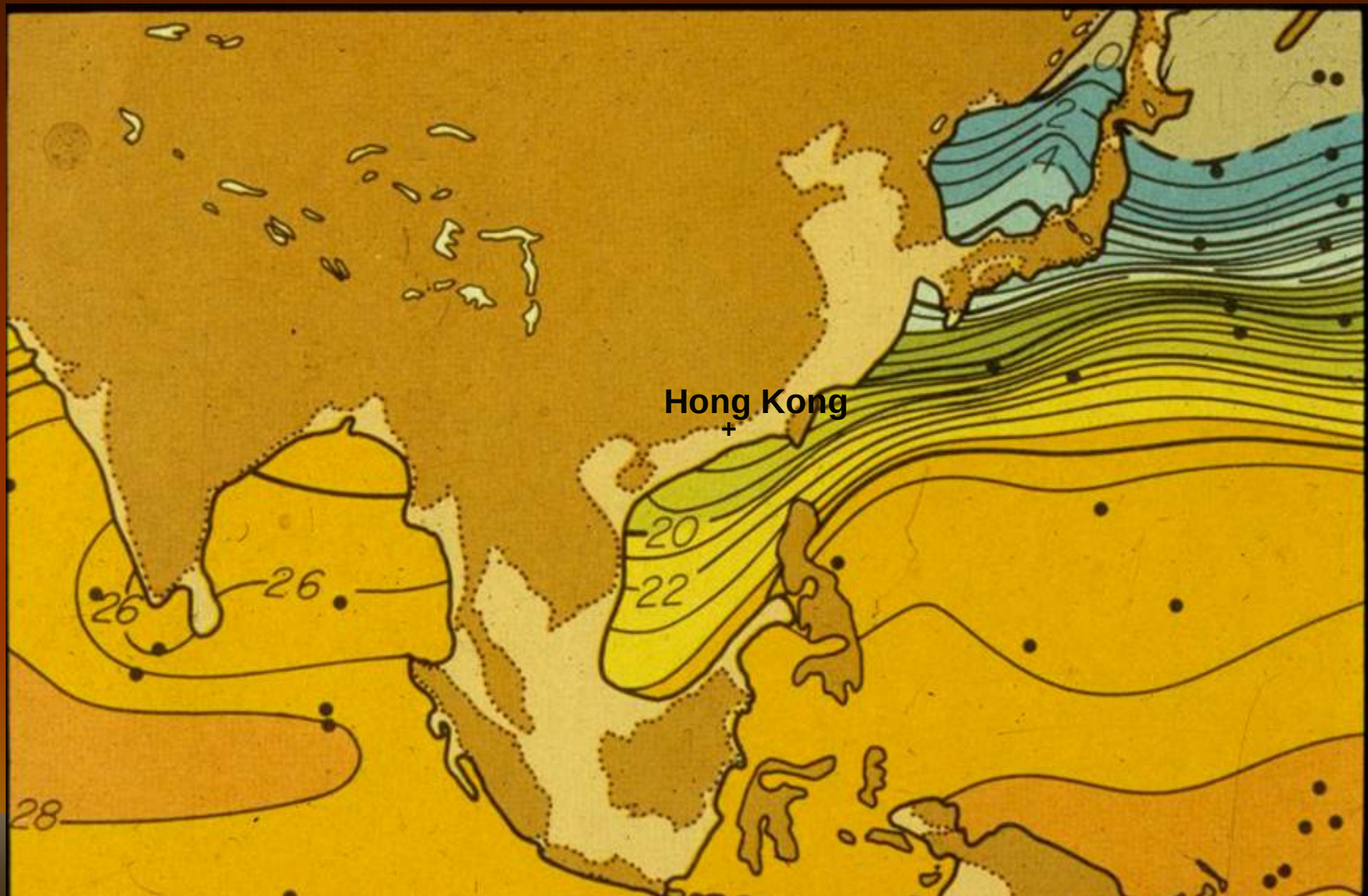
Luminescence (up to 1000 ka)

Cosmogenic nuclides (up to 5000 ka)

(3) Other methods e.g. fossil evidence, engineering properties

(4) Correlation with other parts of the world e.g. ice cores, loess succession, deep sea cores

What happened during glacial periods?
冰期間發生了什麼事?

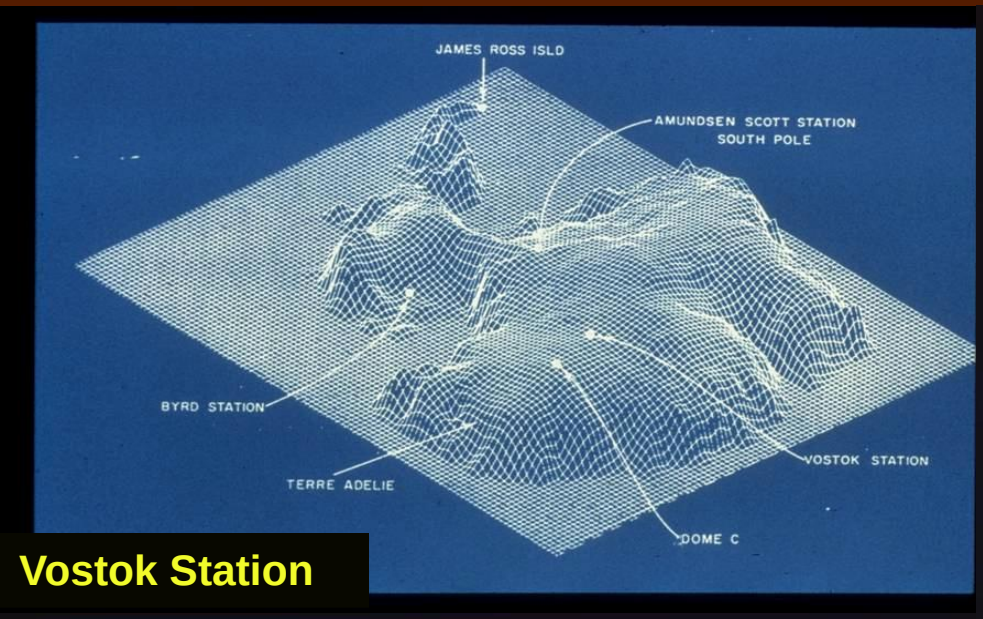


Evidence from loess deposits in China
中國黃土沉積的佐證

L stages - **Periods of loess deposition**
Glacial periods under colder, drier and windier conditions

S stages - **Periods of palaeosol formation**
Interglacial periods under warmer and more humid conditions

Evidence from ice cores in Antarctica
南極洲冰芯的證據

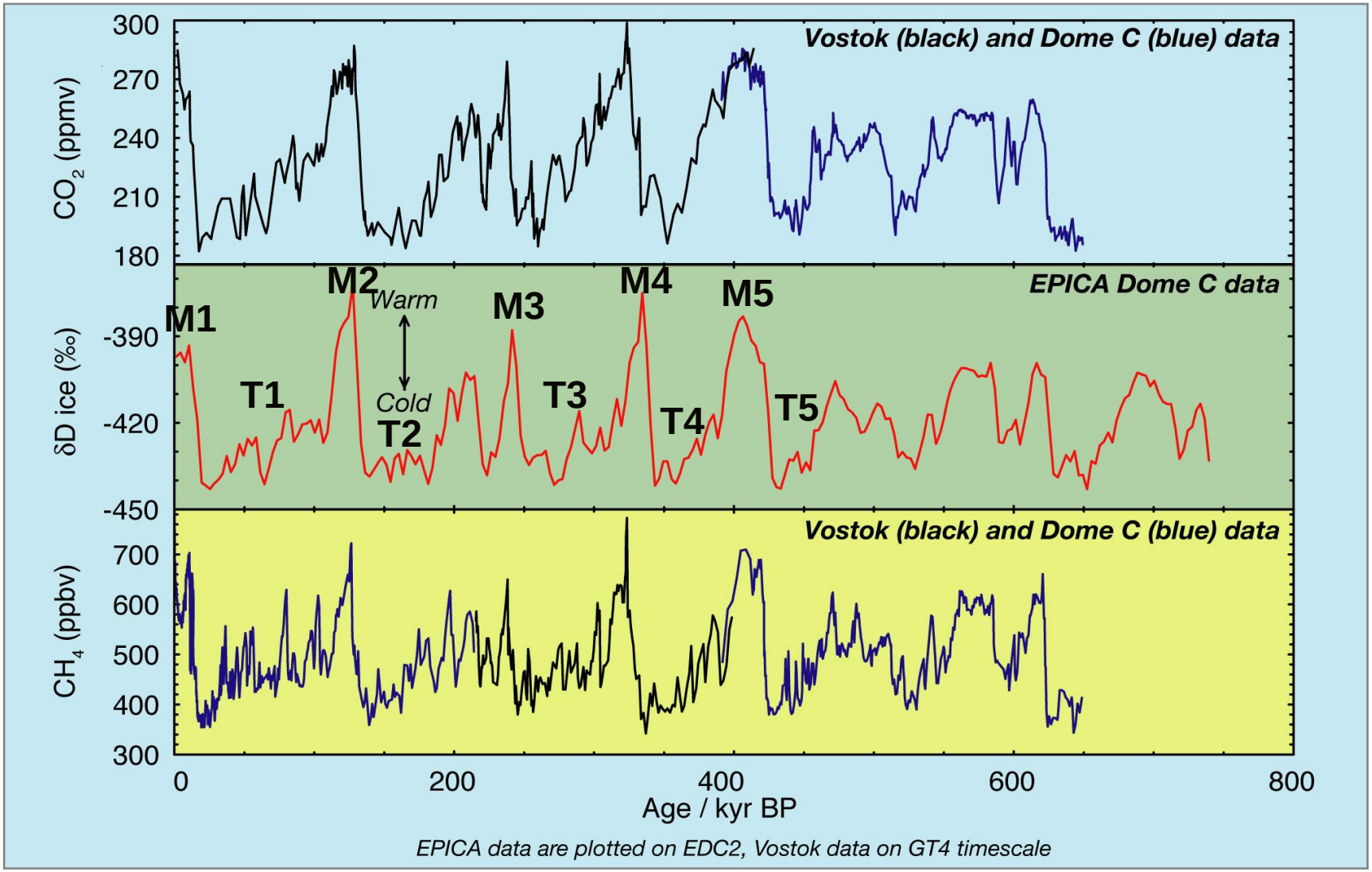


Vostok Station

Annual layers

南極洲冰芯記錄

Antarctic ice core records: Vostok and EPICA CO_2, CH_4 and δD



Petit et al., 1999 (Vostok), Siegenthaler et al., 2005 (Dome C - CO_2),
Spahni et al., 2005 (Dome C - CH_4), EPICA community members, 2004 (δD)

GLOBAL CHANGE IGBP

PAGES PAST GLOBAL CHANGES

Present day conditions 現今情況 (interglacial periods 期冰期)

Flooding of the Tin Shui Wai area during Typhoon Brenda in May 1989

Mean temperature – 24°C

Temperature range – 16 to 29°C

Sea level –within 3 m from present

Frost – uncommon

Rainfall – ca. 2225 mm/annum

Wind – southwest monsoon in summer and northeast monsoon in winter

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AGHK 香港地貌岩石保育協會 Association for Geoconservation, Hong Kong

Conditions during ice ages 冰河時期狀況 (glacial periods 冰期)

Favoured by sparse vegetation cover

Mean temperature – 15°C

Temperature range – 8 to 21°C

Sea level – ca. 120 m below present

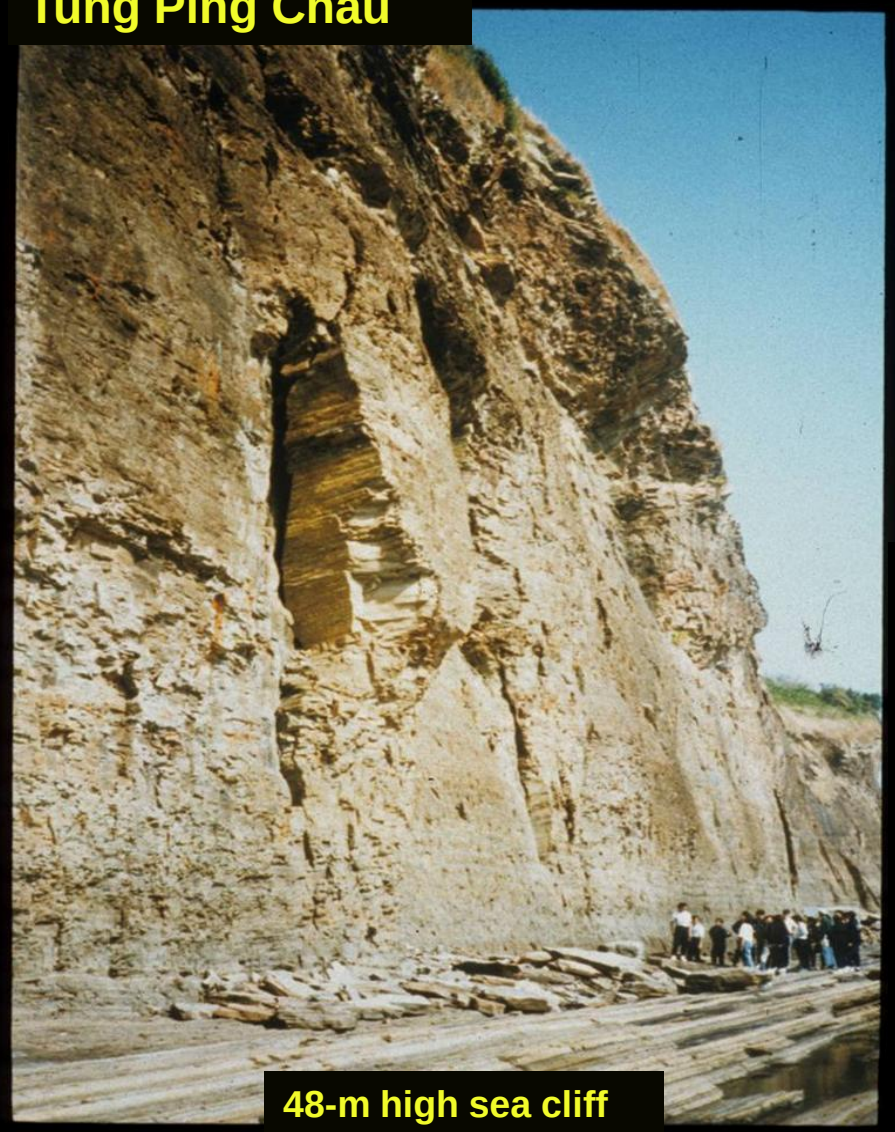
Frost – common on high ground during winter

Rainfall – drier than present

Wind – stronger during winter

Coastal erosion features
How long does it takes to form such features?
海岸侵蝕現象要多久才可形成?

Tung Ping Chau

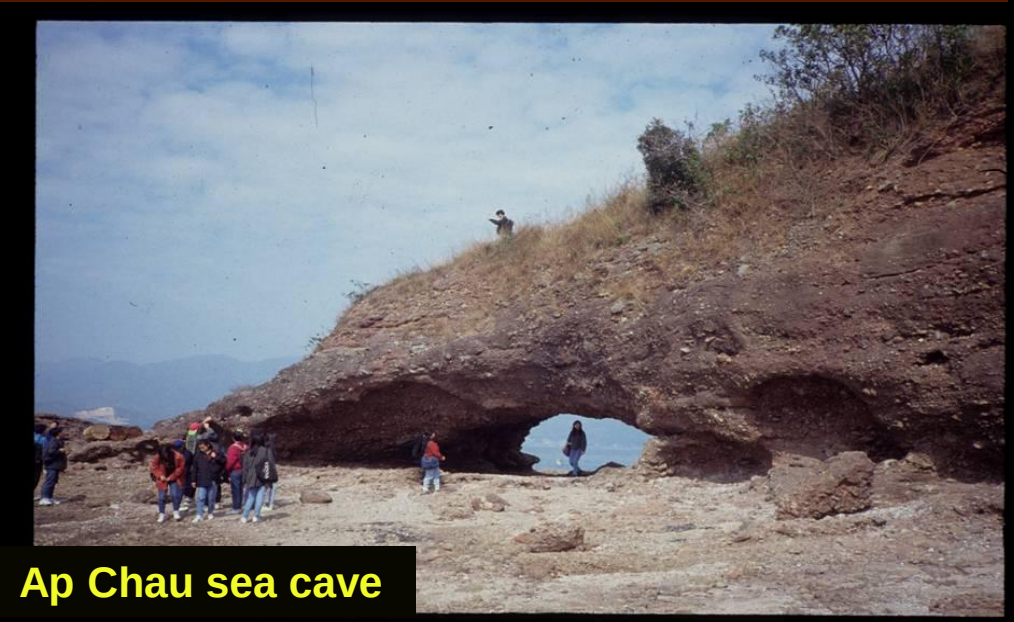


48-m high sea cliff

3-m high wave-cut notch

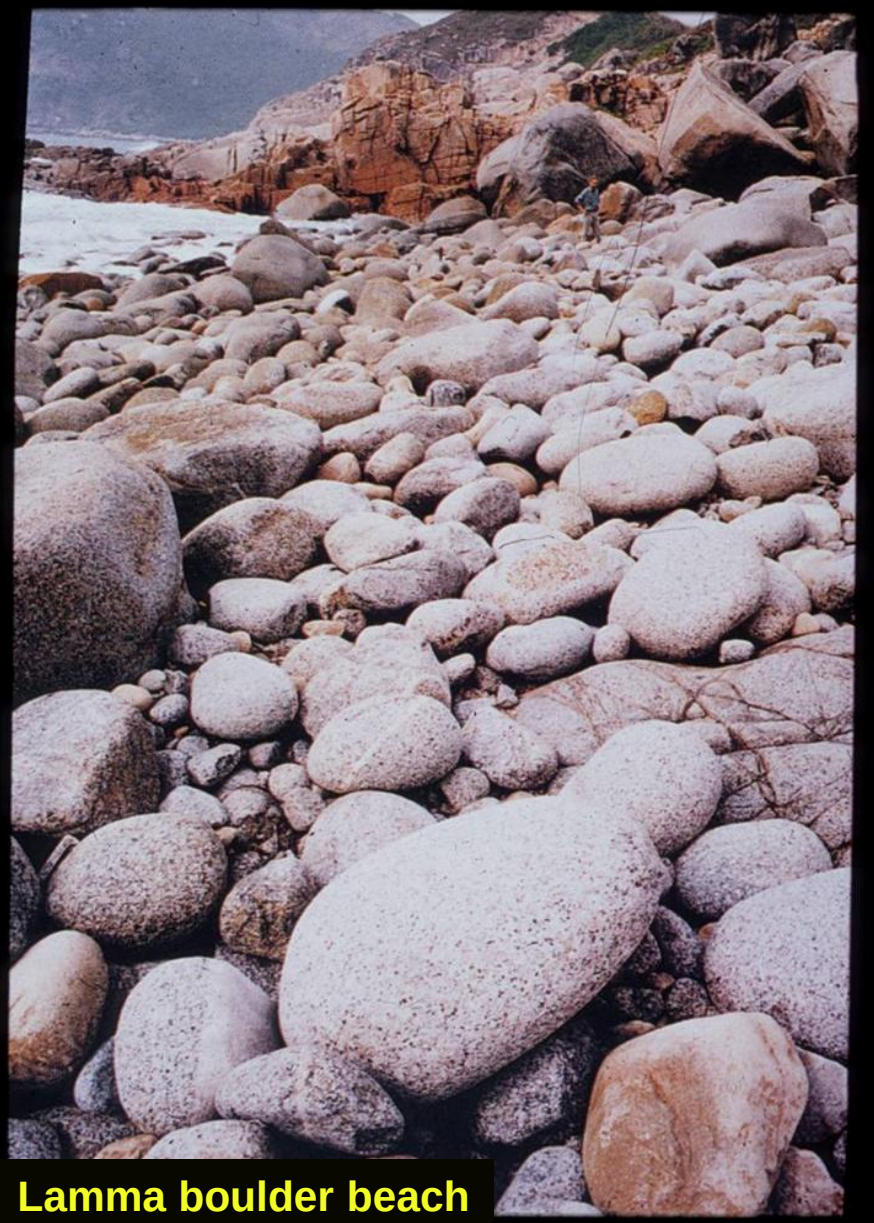
Wave-cut platform

Erosional coastal features 海岸侵蝕現象



Ap Chau sea cave

Tai A Chau granite coast



Lamma boulder beach

Depositional coastal features
海岸沉積現象

Tombolo in west Ping Chau

Age at least last interglacial

Beach-dune barrier, Tai Long Wan

Modern

Pleistocene inheritance concept
更新世承傳概念

Formed during glacial periods in the Pleistocene under colder, drier and windy conditions in comparison to the present day

In order words tafoni are probably formed by Pleistocene inheritance

Main conclusions on present day coastal features 現今海岸現象的主要結論

(1) Because of the resistant nature of the Hong Kong rocks, many coastal features are relic in their origin.

(2) The present day coastline is polycyclic. Repeated 'high' sea levels during the past 500,000 years have played a role in shaping the present day coastline.

(3) Erosional features formed during the last interglacial period 130,000 years ago can be found a few metres above the present.

Conclusions on tafoni in Hong Kong
風化穴總結

(1) They are environmental indicators of glacial periods in the past.

(2) They are formed by Pleistocene inheritance i.e. they are relic geomorphological features with a polycyclic origin.

(3) Identification of *in situ* tafoni below present sea level is needed to confirm (1) and (2).

Examples of side tafoni
Courtesy of Anna Li

Thank you