Petrogenesis of Malaysian granitoids in the Southeast Asian Tin Belt

Samuel Wai-Pan Ng

Funded by: DARKGROUP WYNG FOUNDATION UNIVERSITY OF OXFORD EARTHSCIENCES St. Anne's College *University of Oxford*

Granite Hunters

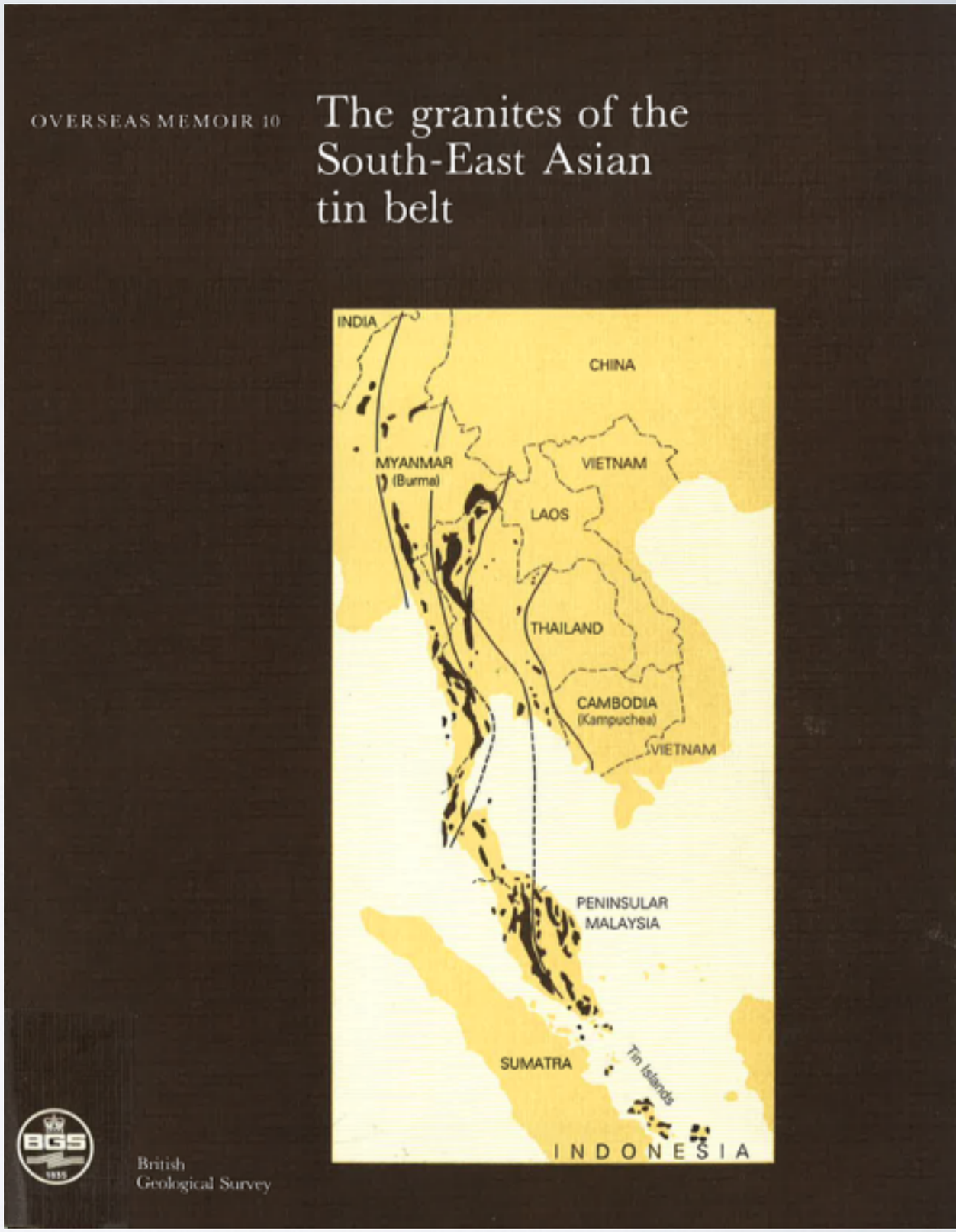
- University of Oxford
    - Professor Michael Searle
    - Professor Laurence Robb
        - Dr Nicholas Gardiner (currently in Curtin University)
- NordSIM, Naturhistoriska Riksmuseet
    - Professor Martin Whitehouse (co-appointed in Stockholm University)
- National Taiwan University
    - Professor Sun-Lin Chung (currently co-appointed in Academia Sinica)

Granite Hunters

- Universiti Malaya
    - Professor Emeritus Charles Hutchison (1933-2011)
    - Professor Azman Ghani
    - Dr Masatoshi Sone
    - Mr Muhammad Roselee (currently in Universiti Kebangsaan Malaysia)
- National University of Singapore
    - Dr Grahame Oliver (currently in Earth Observatory of Singapore, Nanyang Technological University)

The Granites of South-east Asian Tin Belt

E.J. Cobbing, P.E.J. Pitfield,
D.P.F. Darbyshire, D.I.J. Mallick
British Geological Survey (1992)



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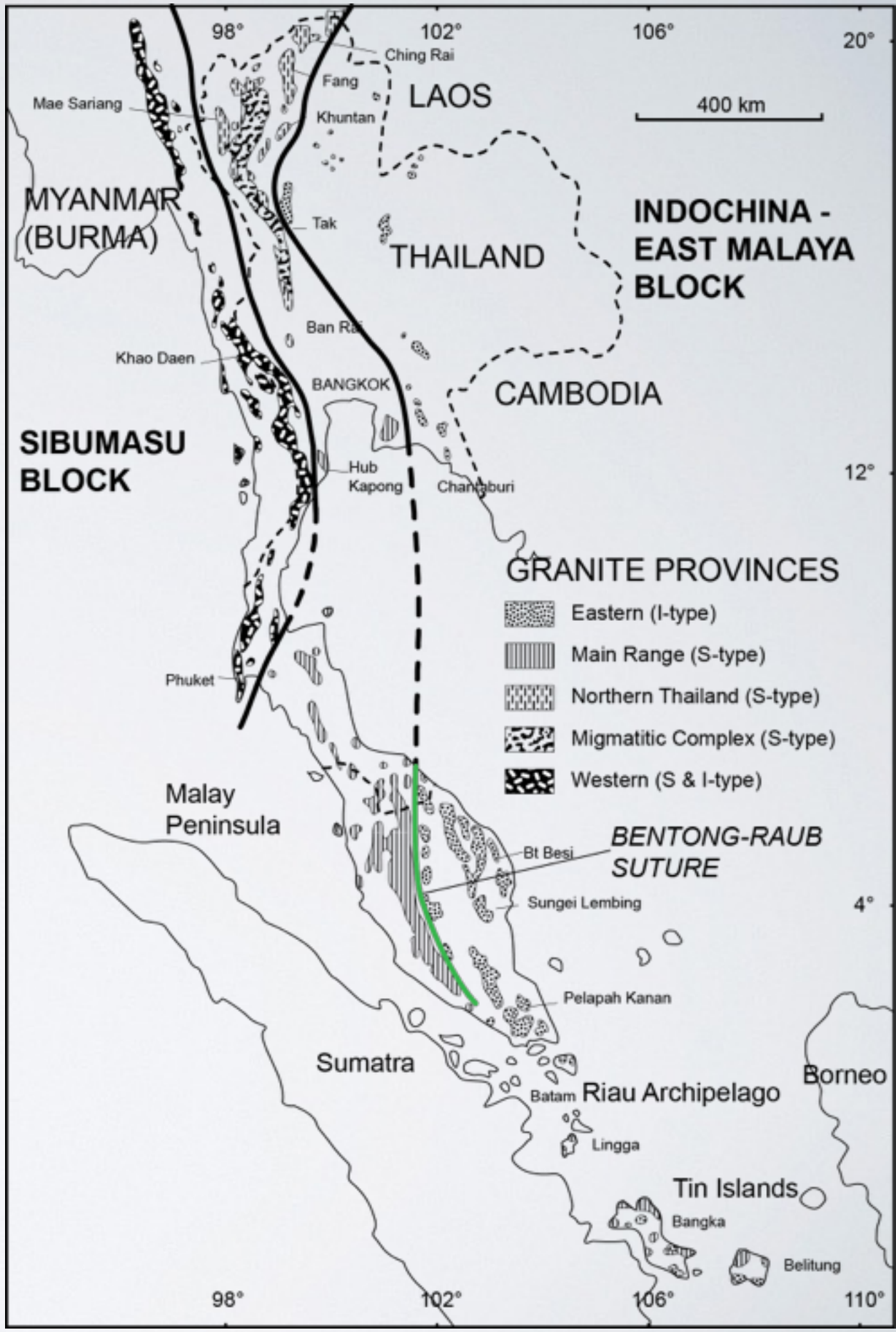

I- and S-type Granites

- I-type granite
  - Igneous protolith
  - Hornblende-bearing
  - More sodic
  - Metaluminous to weakly peraluminous (ASI < 1.1)
  - More oxidized
- S-type granite
  - Sedimentary protolith
  - Muscovite-bearing
  - More potassic
  - Peraluminous (ASI > 1.1)
  - More reduced

Revisit Cobbing et al. (1992) The Granites of South-east Asian Tin Belt

- Detailed mapping and field descriptions of granitoids
- Major and minor element database of granitoids
- Sr-Nd isotope data of granitoids from various authors
- Geochronology of granitoids (Dominantly K-Ar, Rb-Sr ages)
- Chappell and White's (1974) I- and S-type granites were adopted to classify Malaysian granitoids based on different behaviour in mineralogy and geochemistry
- Three granitic provinces defined according to Hutchison's (1973) model

Revisit Cobbing et al. (1992) The Granites of South-east Asian Tin Belt

- Detailed mapping and field descriptions of granitoids
  - Many of the outcrops have been removed for city development or agricultural activities
- Major and minor element database of granitoids
  - Did not cover the high field strength elements (especially rare earth elements) very much
  - Large degree of overlap between the two granitic provinces in terms of lithology, mineralogy and metallogenic affinity
- Sr-Nd isotope database of granitoids
  - They were contributed by different workers, obtained in different laboratory conditions
- Geochronology of granitoids
  - K-Ar mica ages and Rb-Sr whole rock ages do not represent the crystallization ages of granitoids
- Chappell and White's (1974) I-S genetic system was adopted to classify Malaysian granitoids based on different behaviour in lithology and geochemistry
  - The bipolar classification is not ideal, as it overlooked the similarities shared by the granitoids across the Bentong-Raub Line
- Three granitic provinces defined according to Hutchison's (1973) model
  - Some of the province boundaries were drawn on Tertiary structures

The Granites of South-east Asian Tin Belt

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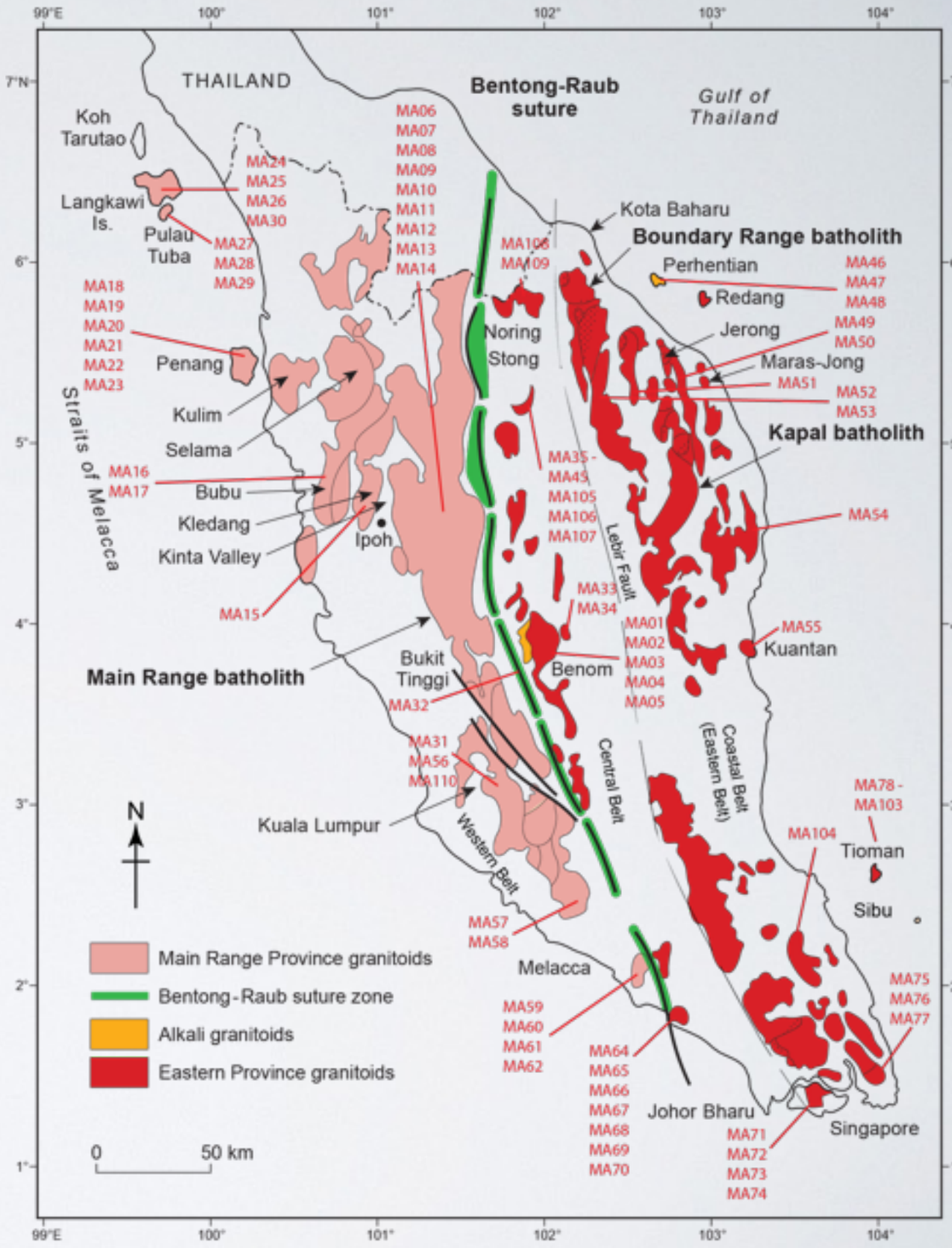


What did we do?

- Field observation and petrography
- National Taiwan University (Supervised by Sun-Lin Chung)
  - Major and trace element analyses
  - Sr-Nd isotopic analyses
- NordSIM, Swedish Museum of Natural History (Supervised by Martin Whitehouse)
  - SIMS (CAMECA IMS 1280) U-Pb zircon dating

Field Observation and Petrography

Eastern Province

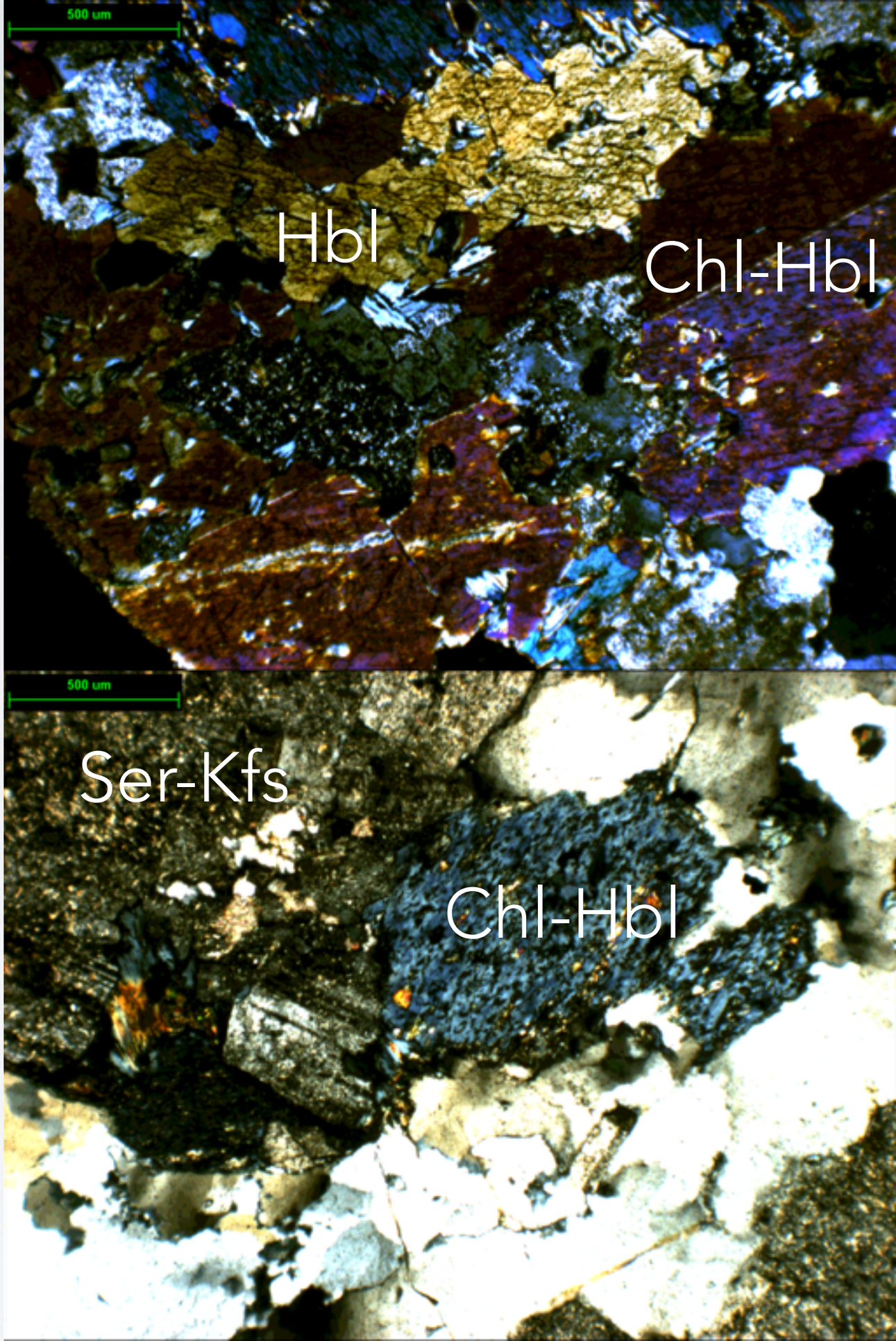
- Half of the granitoids are hornblende-bearing (MA55 Kuantan granite)

- Hornblende-biotite enclaves are found only in some of the outcrop (MA51 Kapal Batholith)

Eastern Province

Hornblende grains are sometimes chloritized, which is caused by fluid activities

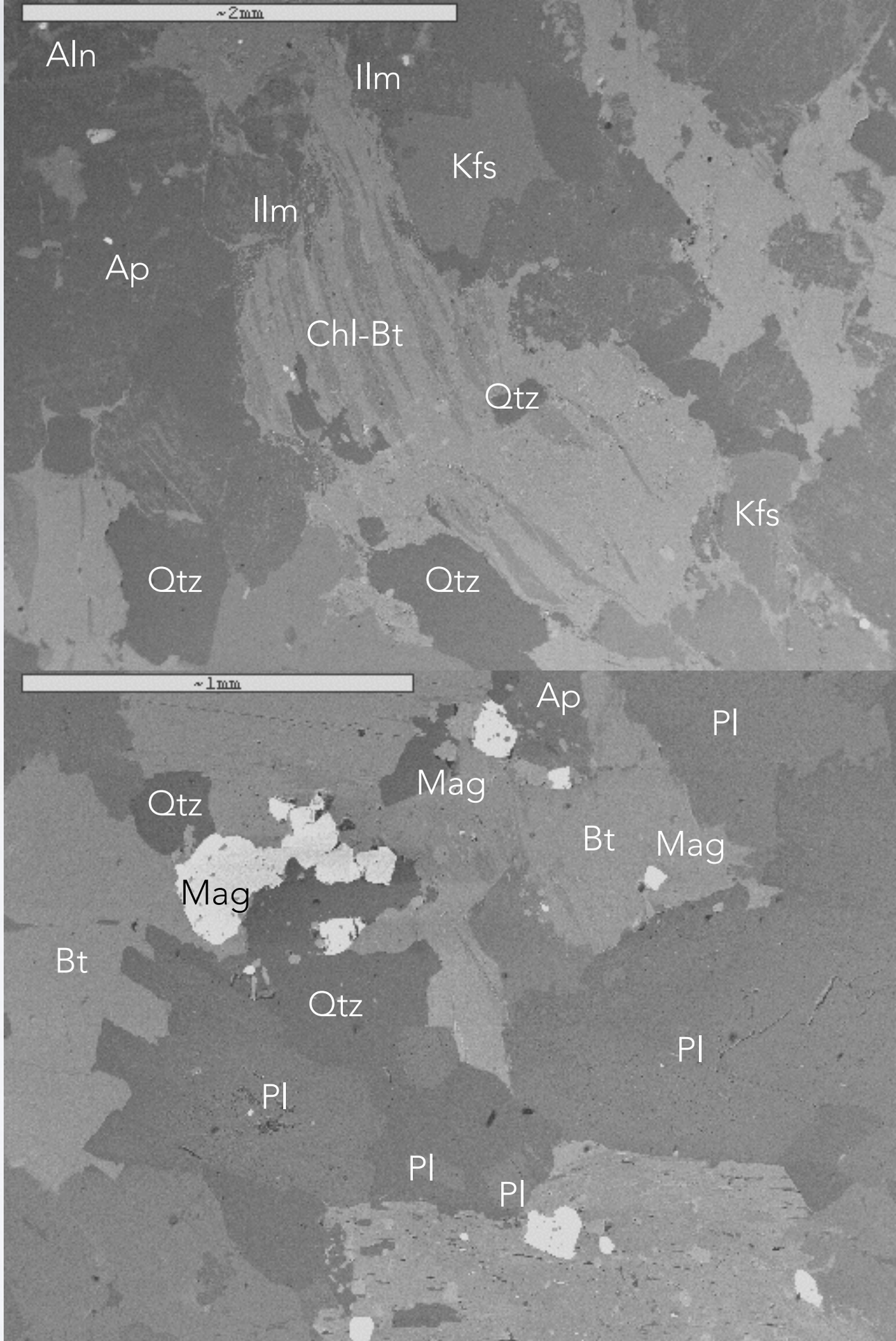
MA47 Perhentian syenite
MA52 Boundary Range Hbl-Bt granite



Eastern Province

Both ilmenite-series granitoid and magnetite-series granitoid are observed in the Eastern Province

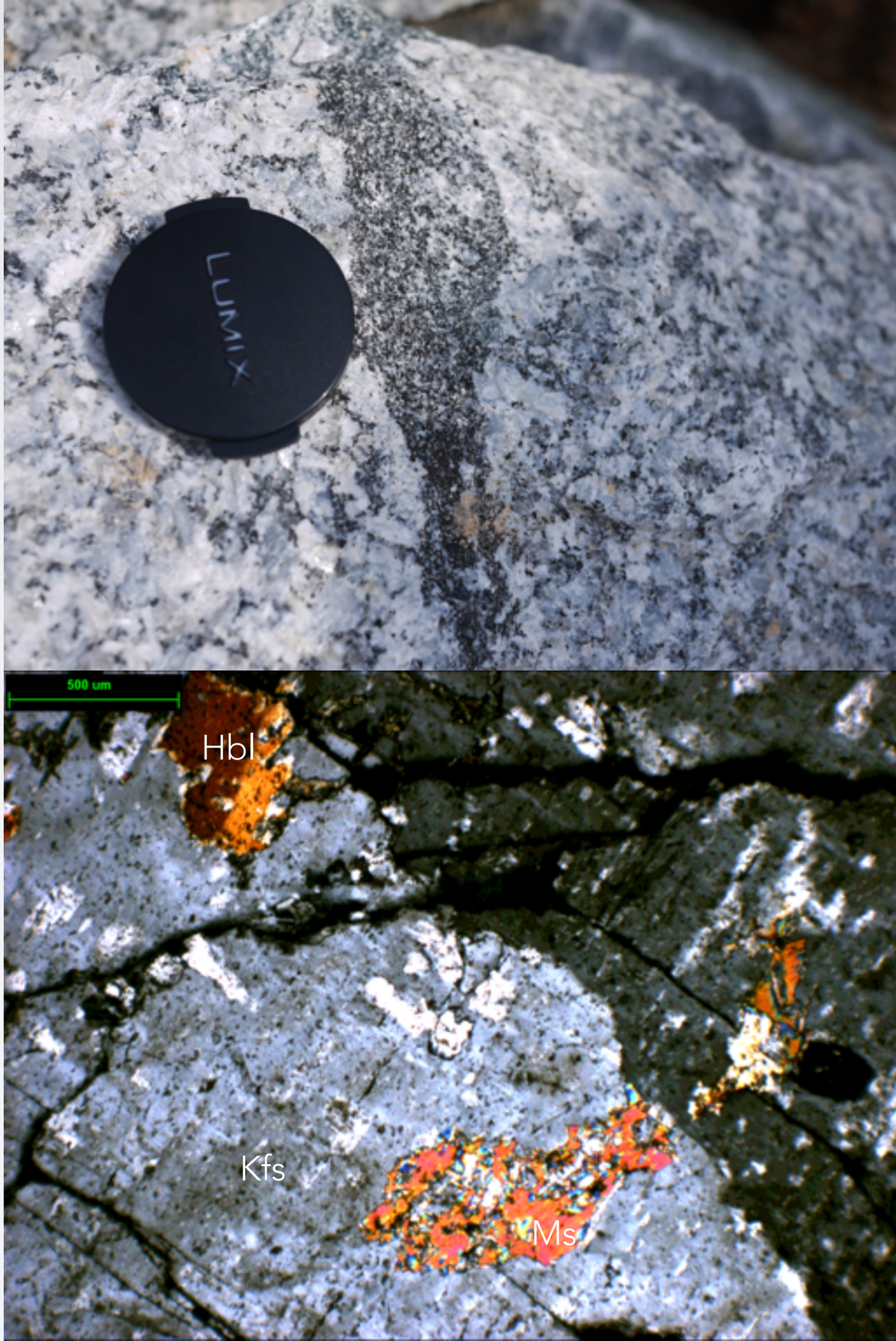
MA52 Boundary Range Hbl-Bt granite
MA74 Ubin Island Hbl-Bt granite



Eastern Province

Maras-Jong granite was interpreted as S-type in the Eastern Province, with Grt-Ms assemblage

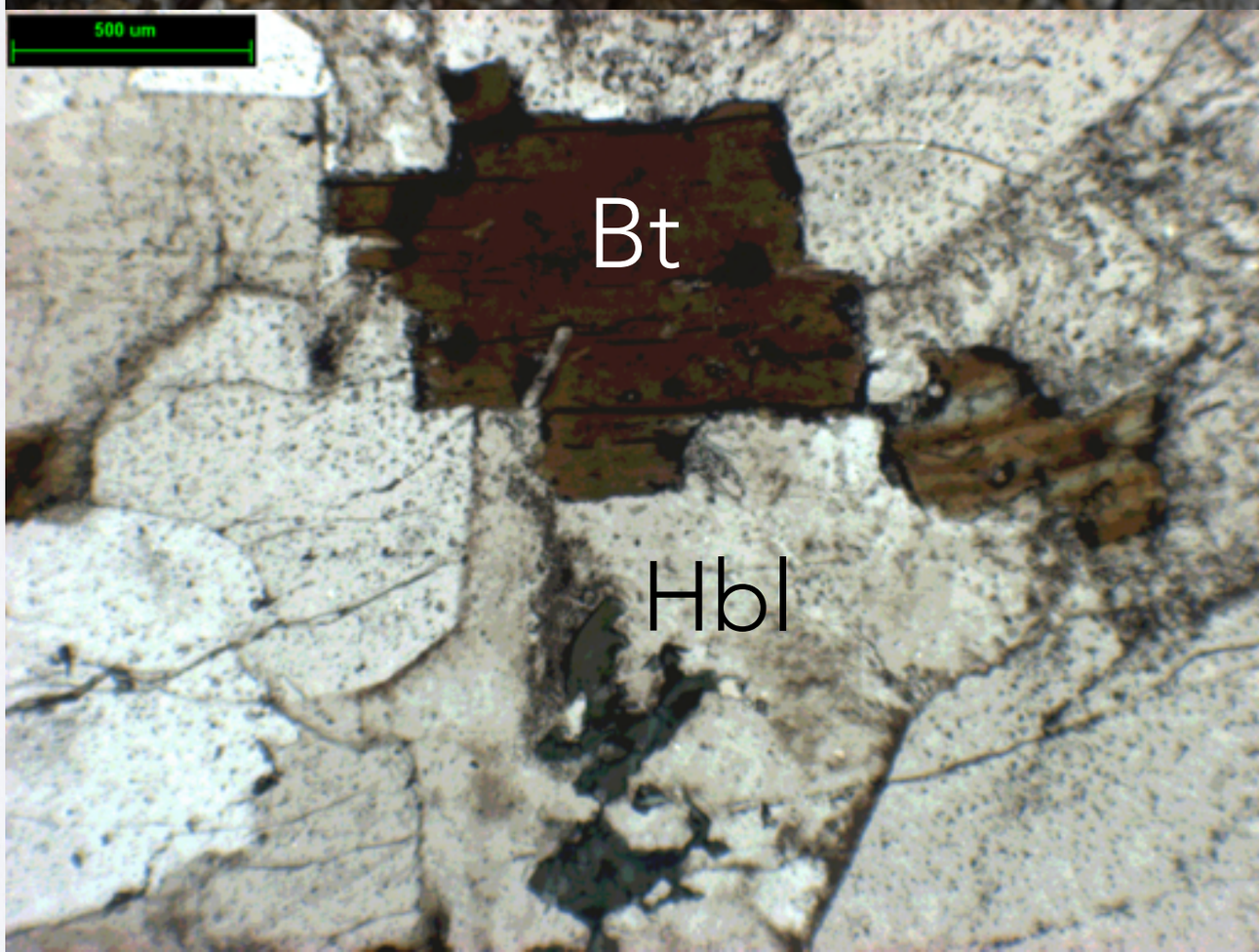
MA50 Maras-Jong Ms-Bt granite with Qtz-Tur vein
MA50 Maras-Jong Ms-Bt granite with tiny Hbl grain and secondary Ms



Main Range Province

The Main Range Province granitoids are more homogeneous in lithology. Most of them are hornblende-free biotite granite, with subordinate hornblende-bearing granitoids in the Bintang Batholith

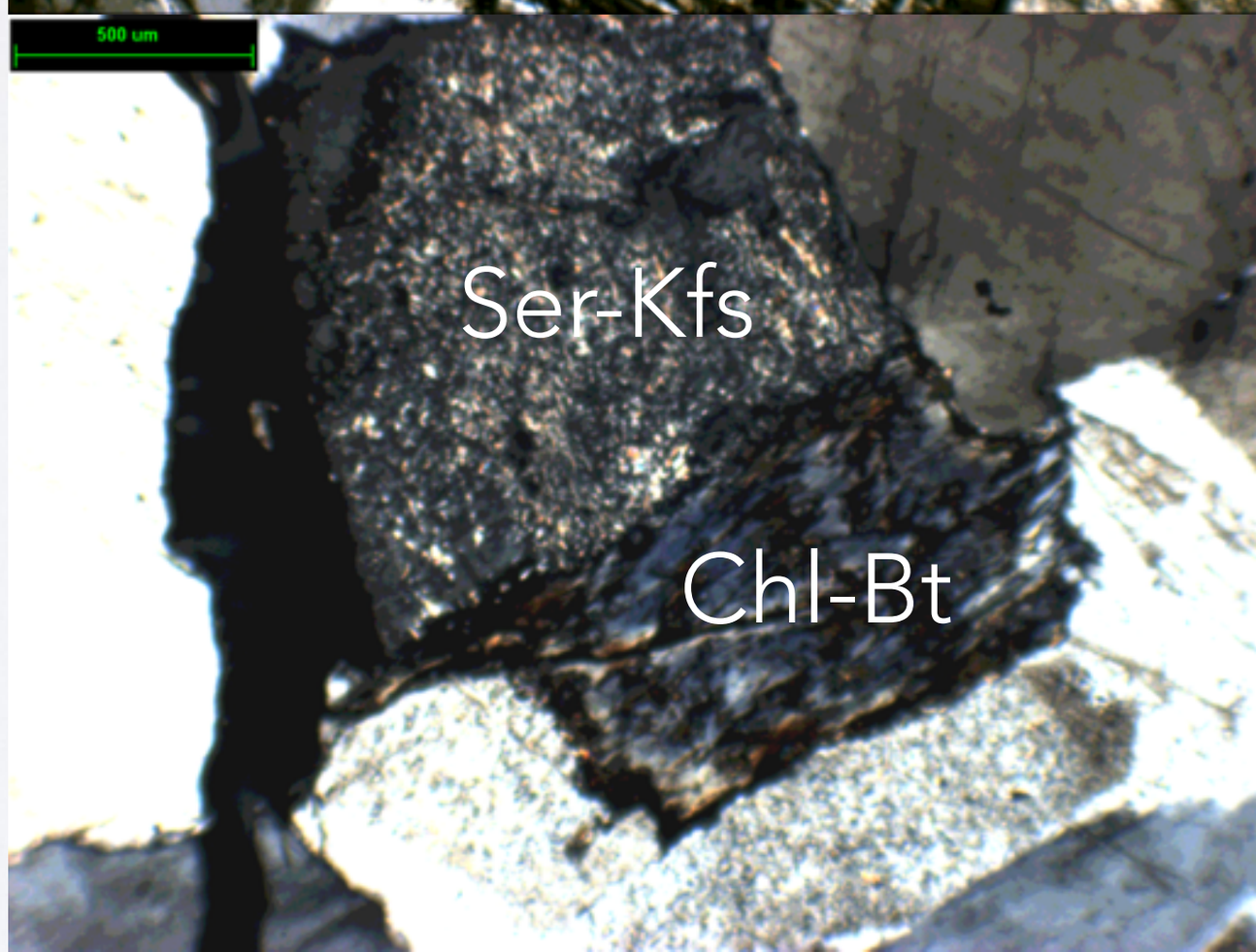
MA11 Cameron Highlands Bt granite
MA16 Taiping Hbl-Bt granite



Main Range Province

Muscovite grains usually exist as secondary mineral in the Main Range granitoids, and it is common that the K-feldspar and biotite grains were hydrothermally altered

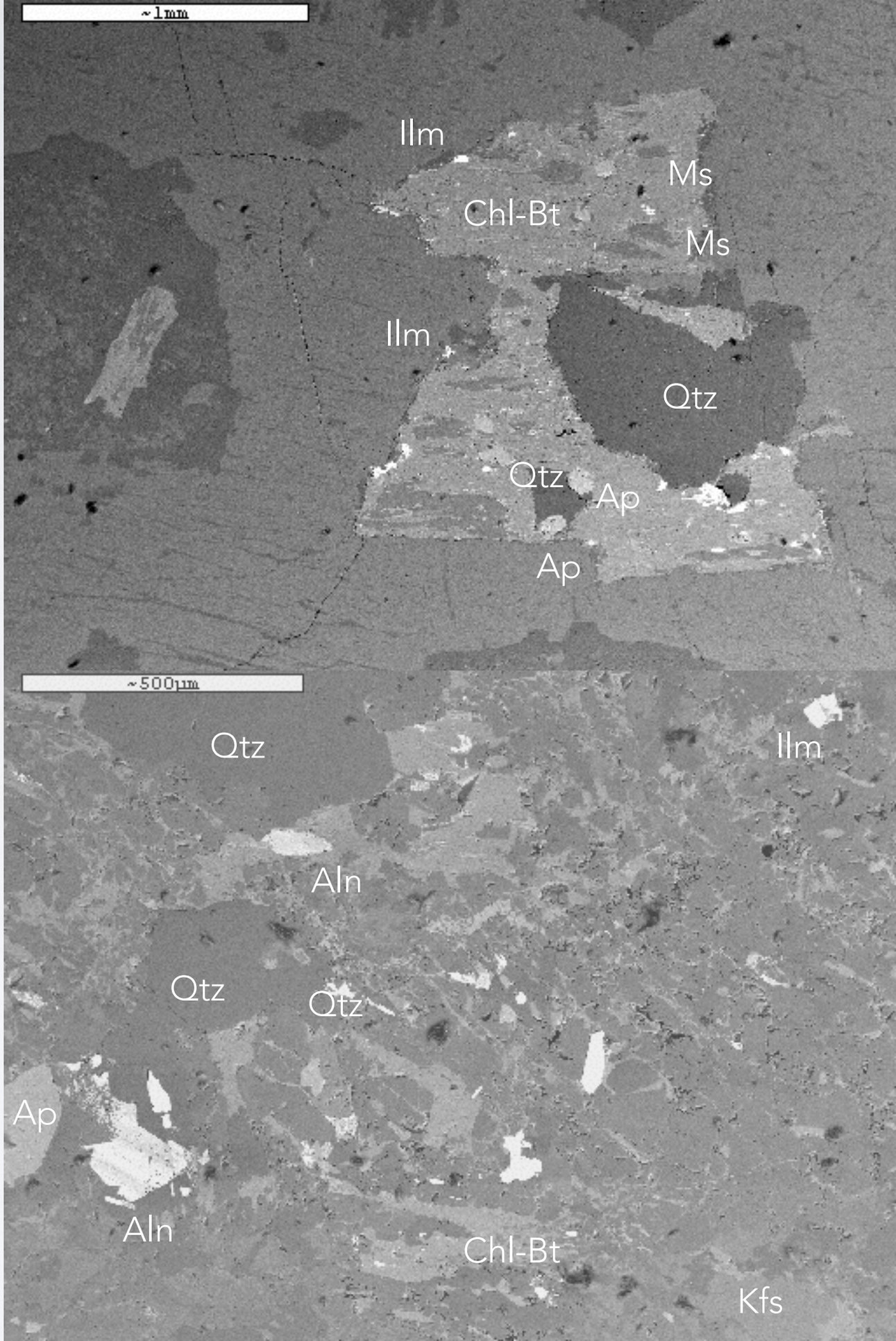
MA19 Penang Ms-Bt granite
MA52 Cameron Highlands Bt granite



Main Range Province

The accessory mineral assemblage of the Main Range Province granitoids is similar to that of the Eastern Province granitoids. However, all the granitoids here belong to the ilmenite-series

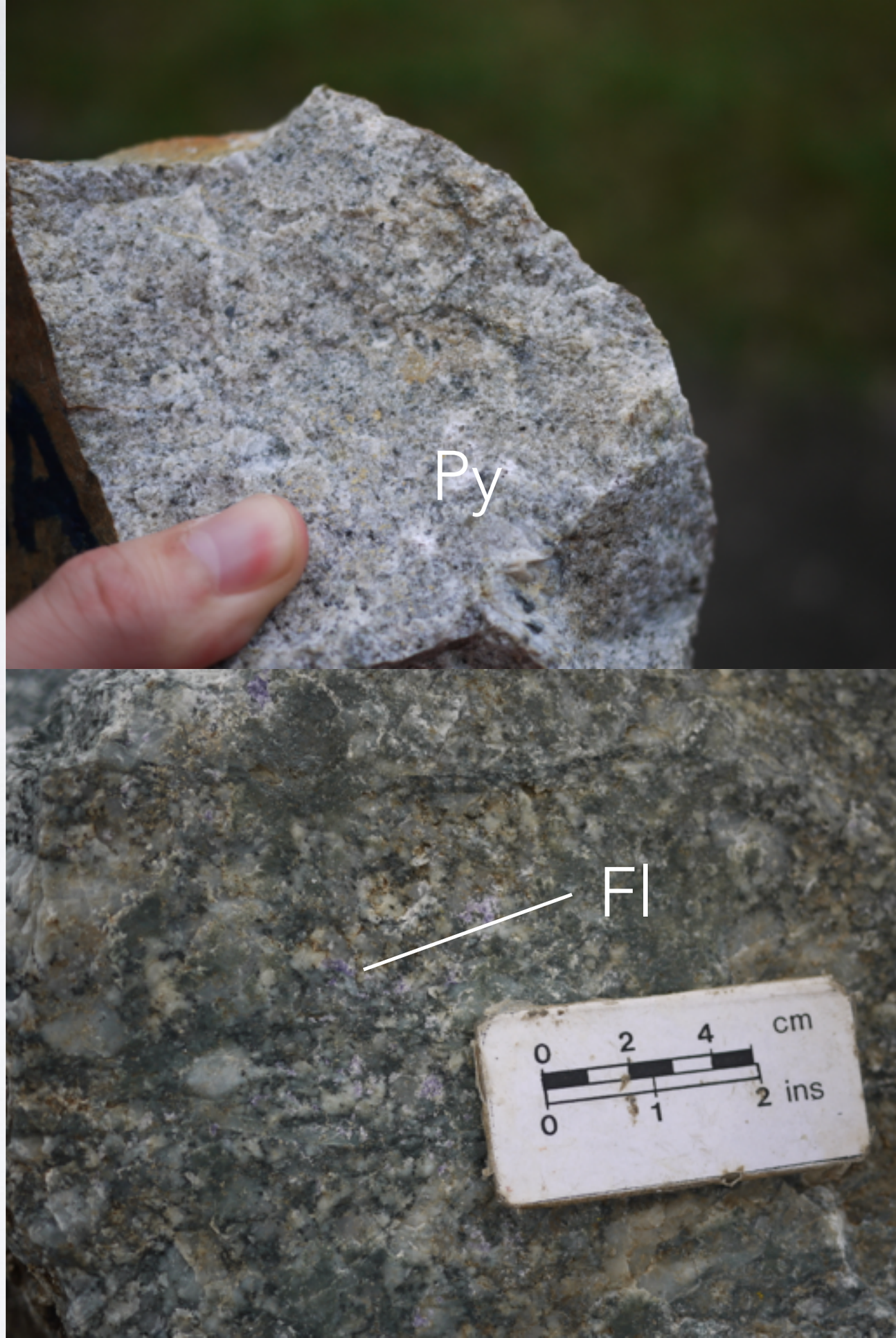
MA11 Cameron Highlands Bt granite



Main Range Province

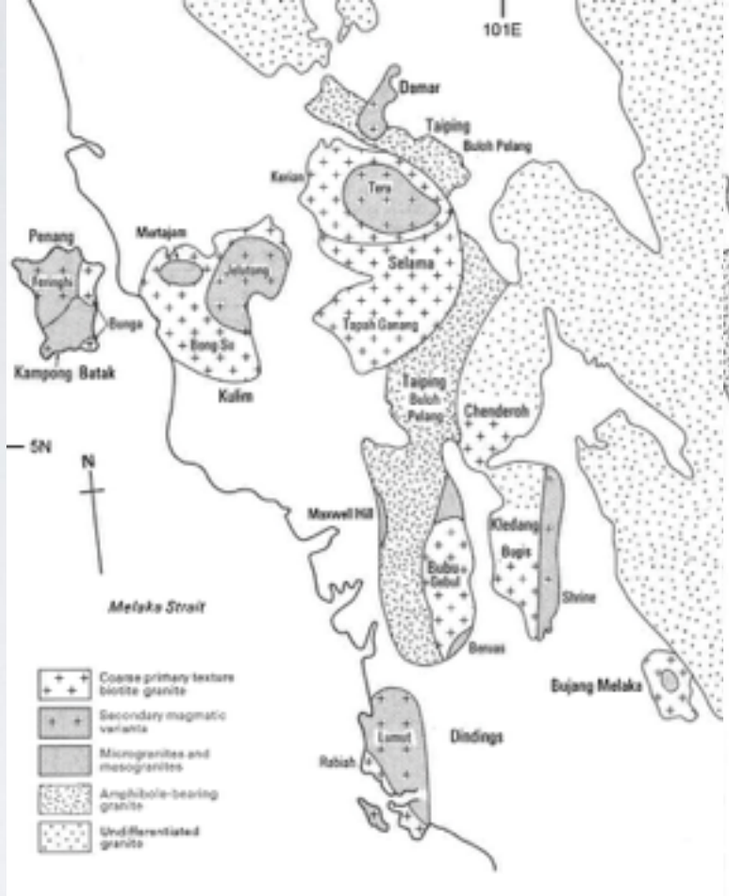
Hydrothermal activities were more extensive in the Main Range Province. Some granitoids are characterized by the presence of secondary pyrite and fluorite

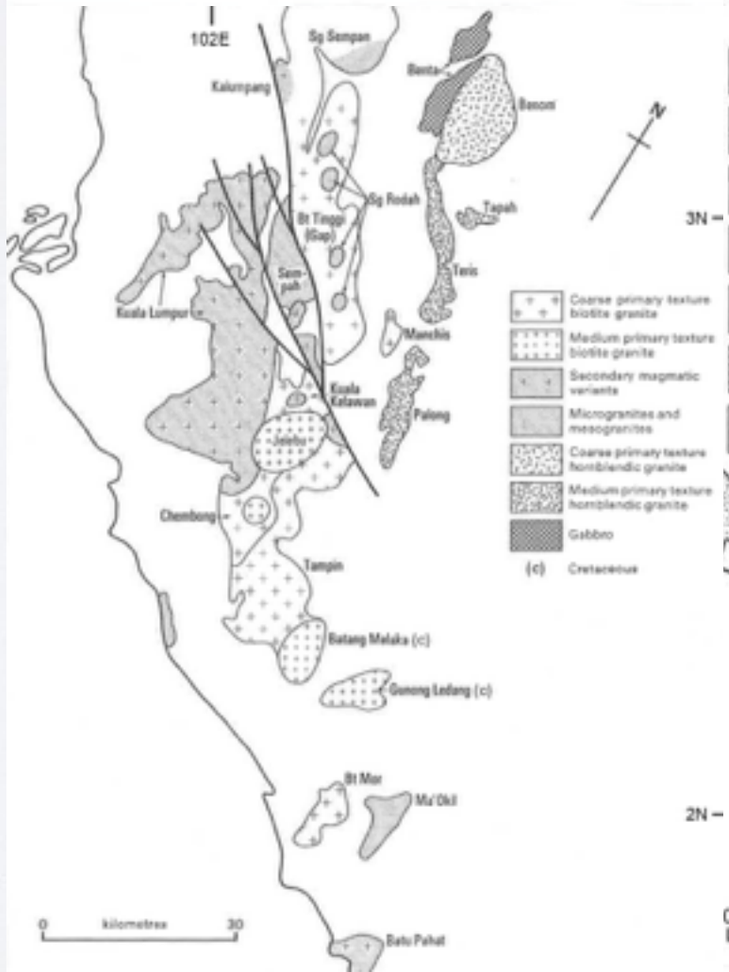
MA15 Ipoh Ms-Bt granite
MA17 Taiping Hbl-Bt granite



FIELD RELATIONSHIP

- Eastern Province
  - Hbl-Bt granites surround and gradually developed into Bt granites
  - The Bt granites are usually hydrothermally altered and mineralized
  - Both phases are with similar ages
- Main Range Province
  - Hbl-Bt granites surround and gradually developed into Bt granites
  - The Bt granites are usually hydrothermally altered and mineralized
- Fine-grained granitoids intruded into coarse-grained granitoids



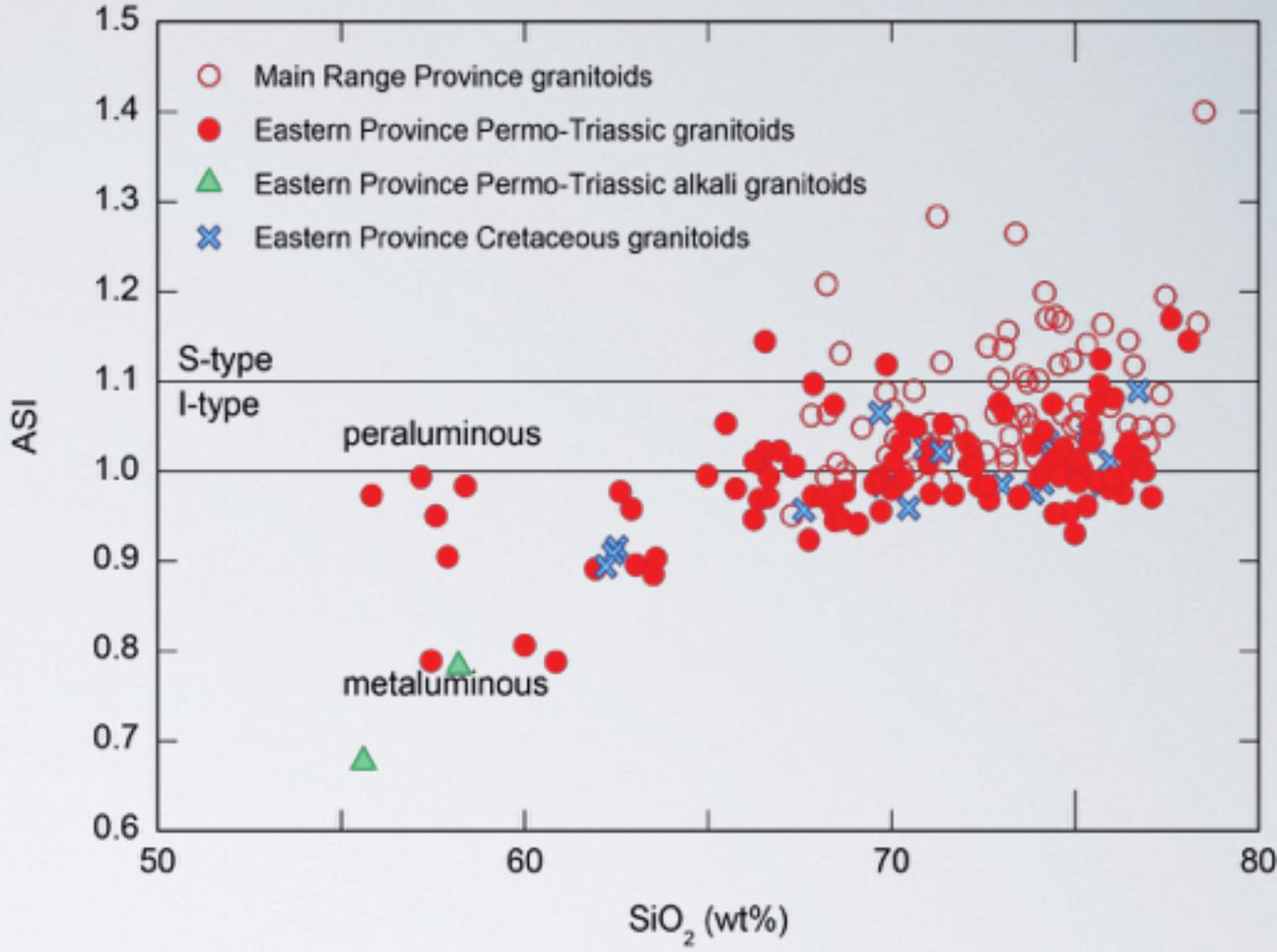


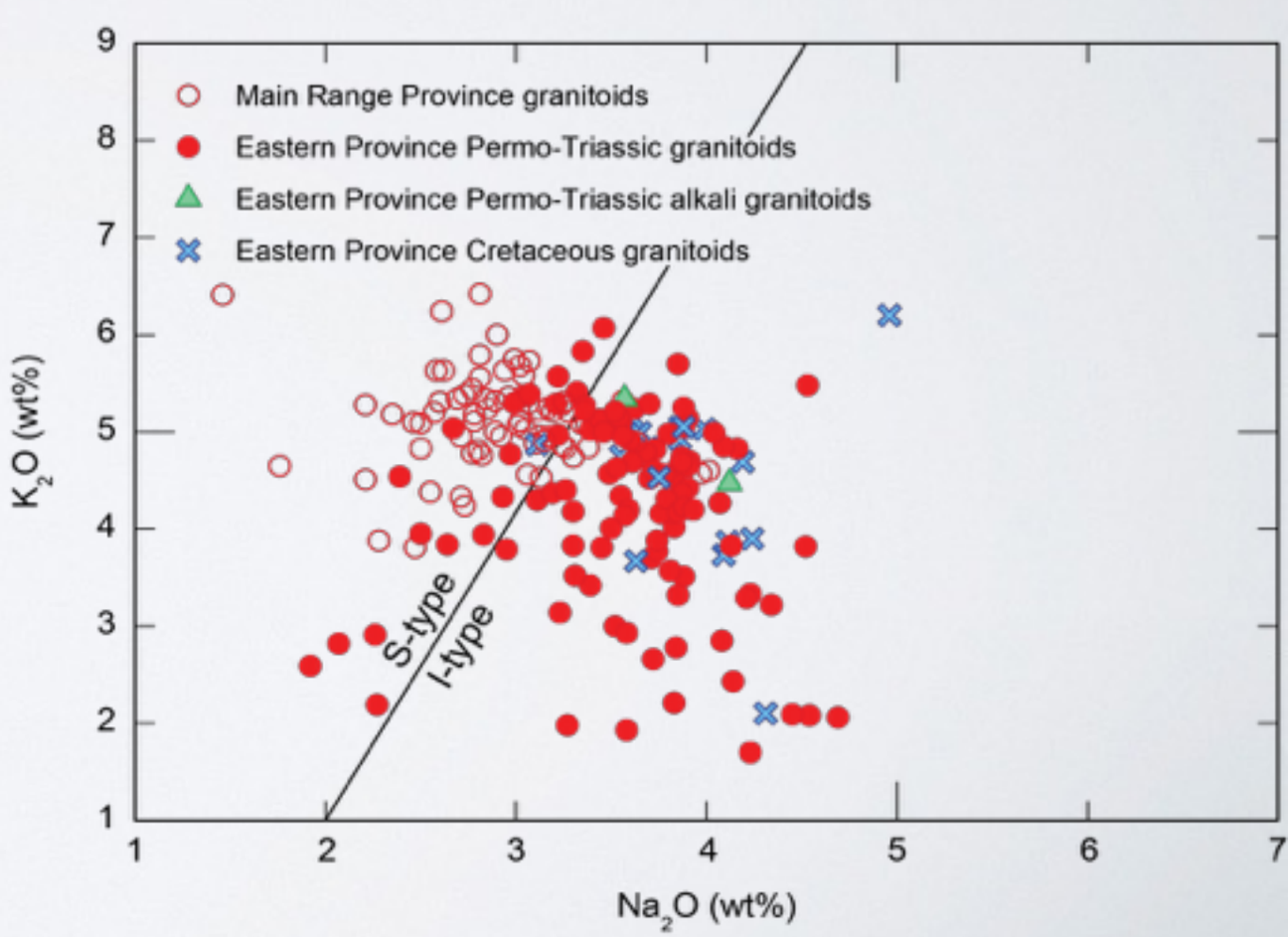
Geochemistry

National Taiwan University

Major Elements

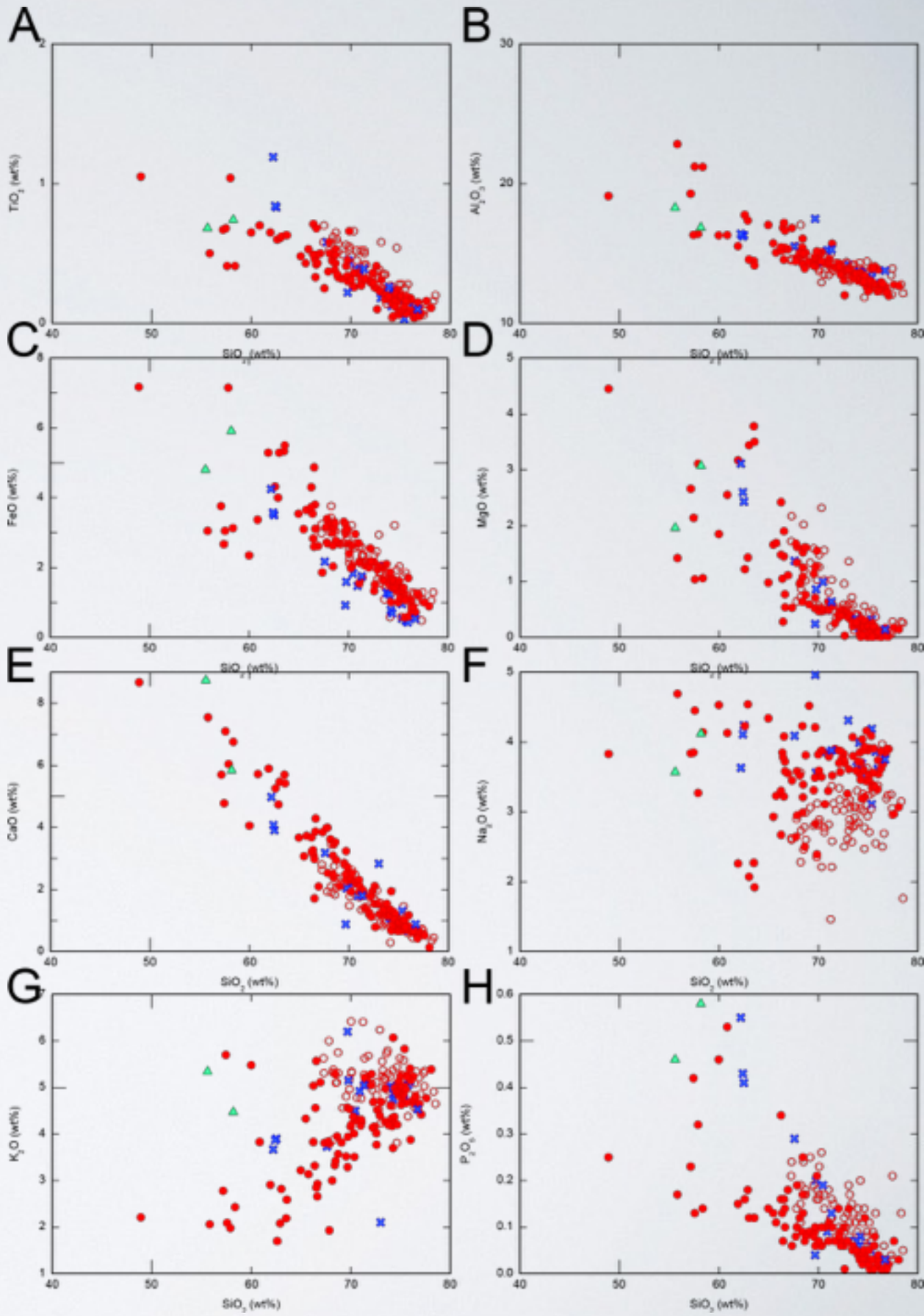
- Eastern Province
  - Metaluminous to weakly peraluminous
    - More sodic
- Main Range Province
  - Peraluminous
  - More potassic
- Large degree of overlap between the two granitic provinces





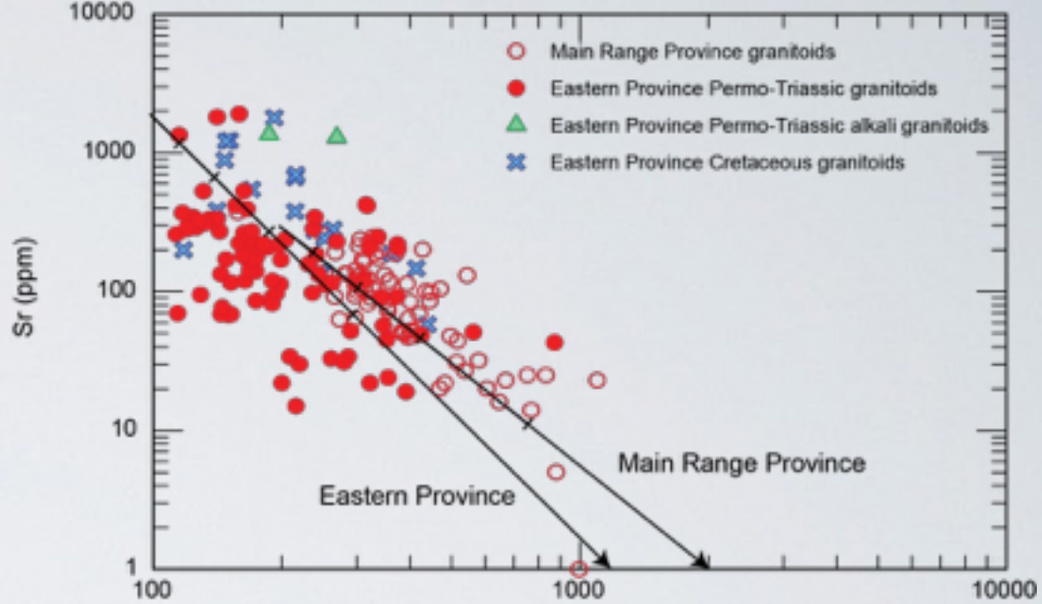
Granite Fractionation

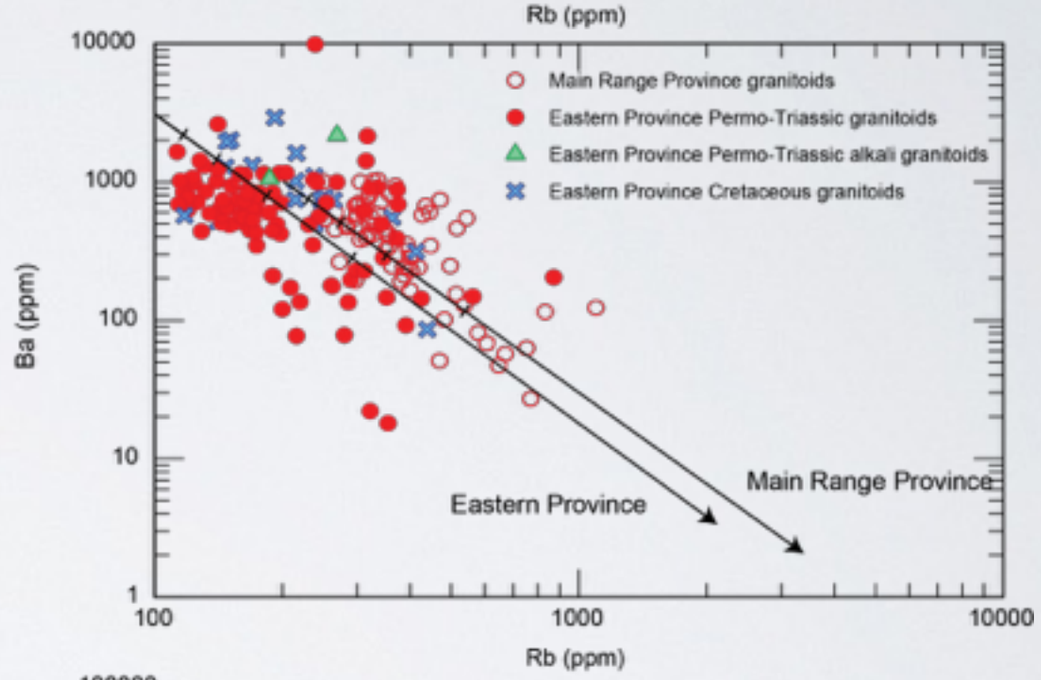
All the Malaysian granitoids experience crystal fractionation. The liquid-lines-of-descent of both Eastern Province and Main Range Province are largely overlapped with each other

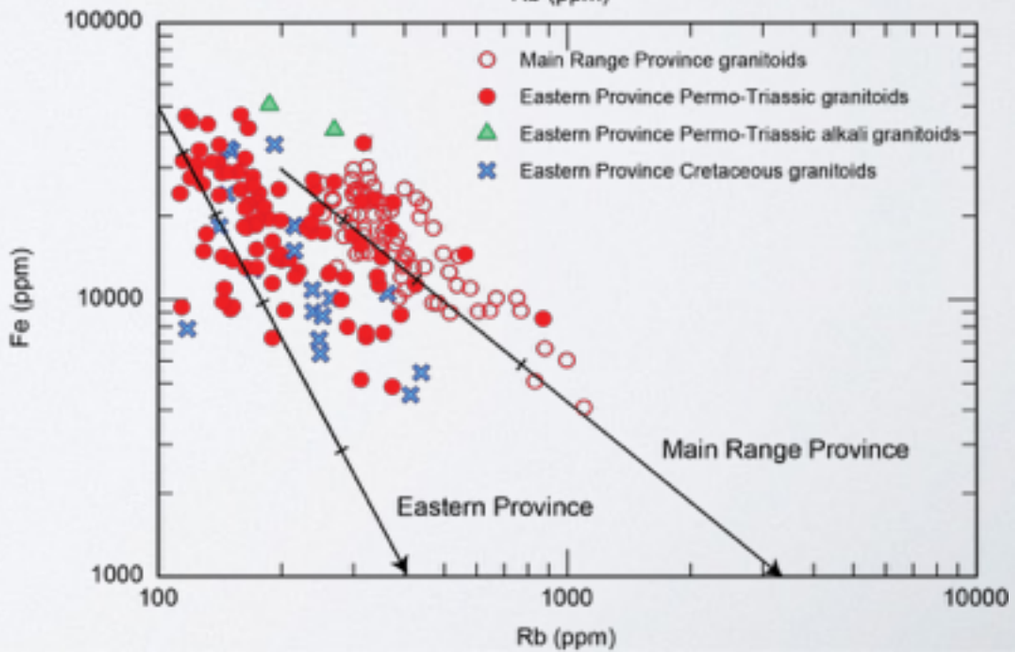


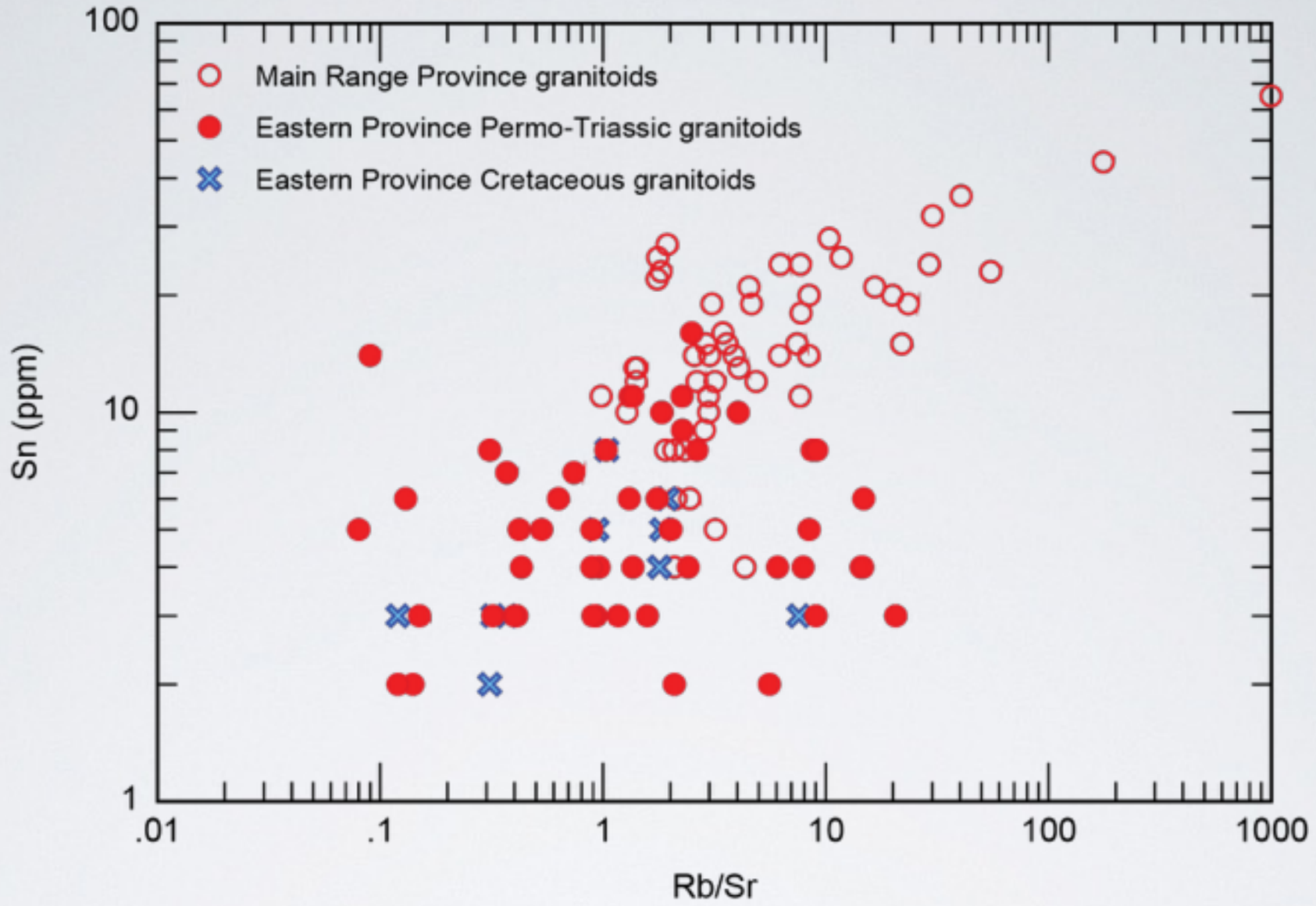
Granite Fractionation

The fractionation is controlled by the removal of Plagioclase (Sr), K-feldspar (Ba), biotite and hornblende (Fe)









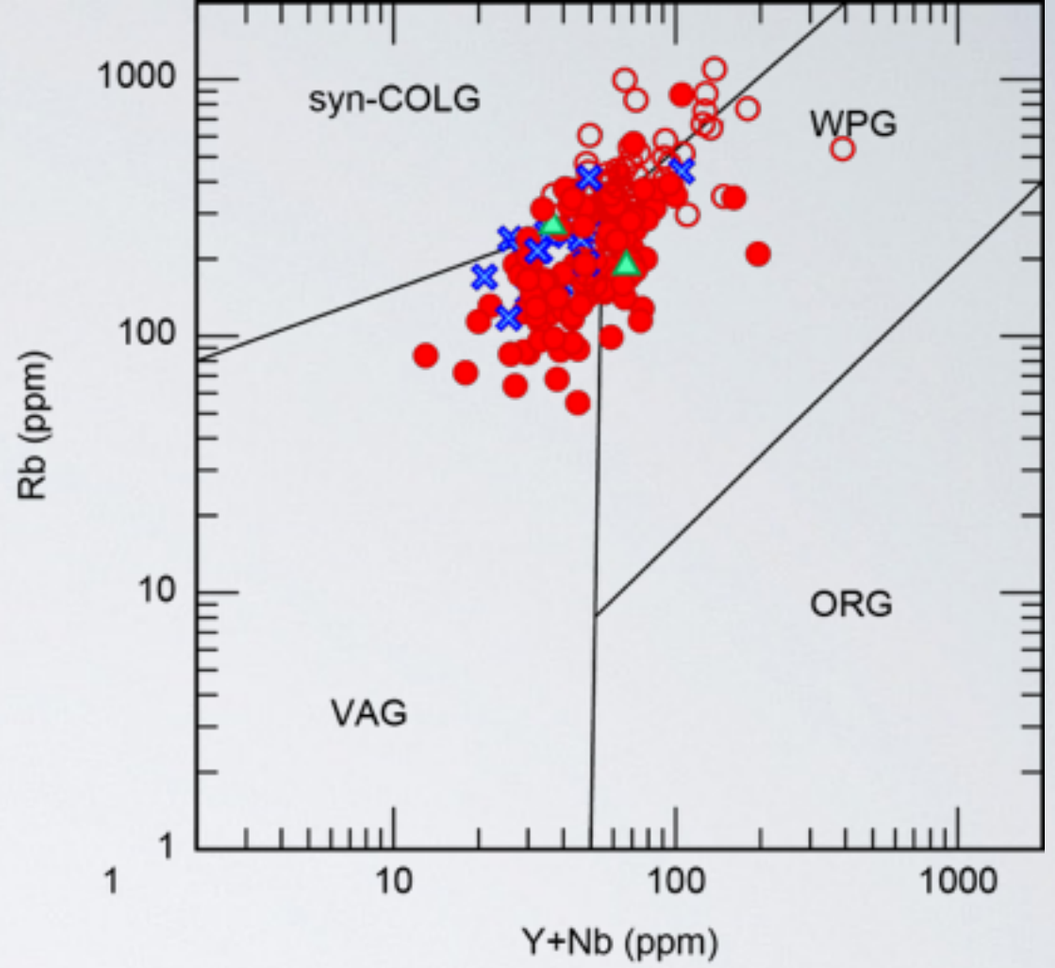
Sn Metallogenesis and Granite Fractionation

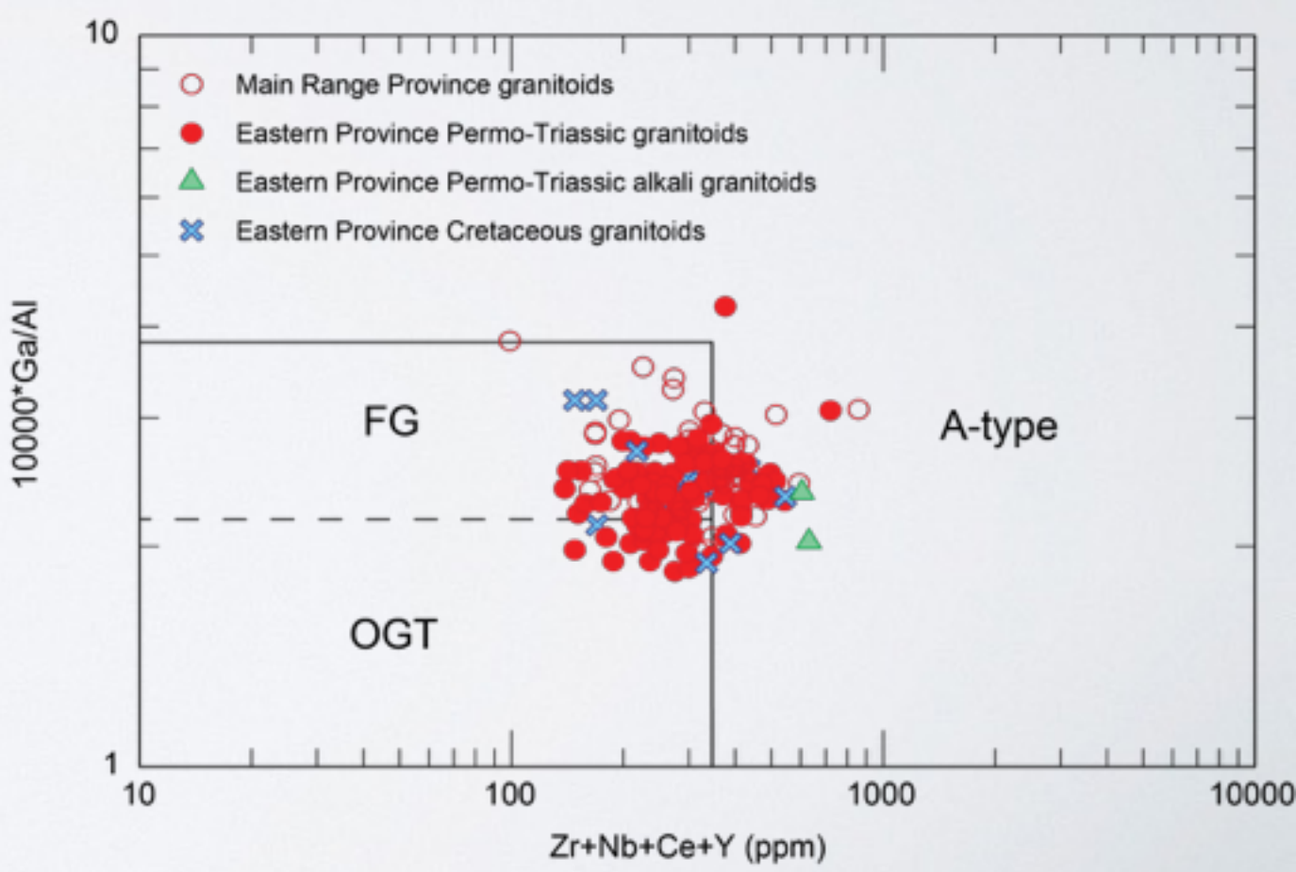
Cobbing et al. 1992

Trace Elements

The WPG or A-type signatures are given by the enrichment in HFSE

(e.g. Zr, Nb, Ce, Y)





Trace Elements

The enrichment of HFSE is a a signature of the Malaysian granitoids

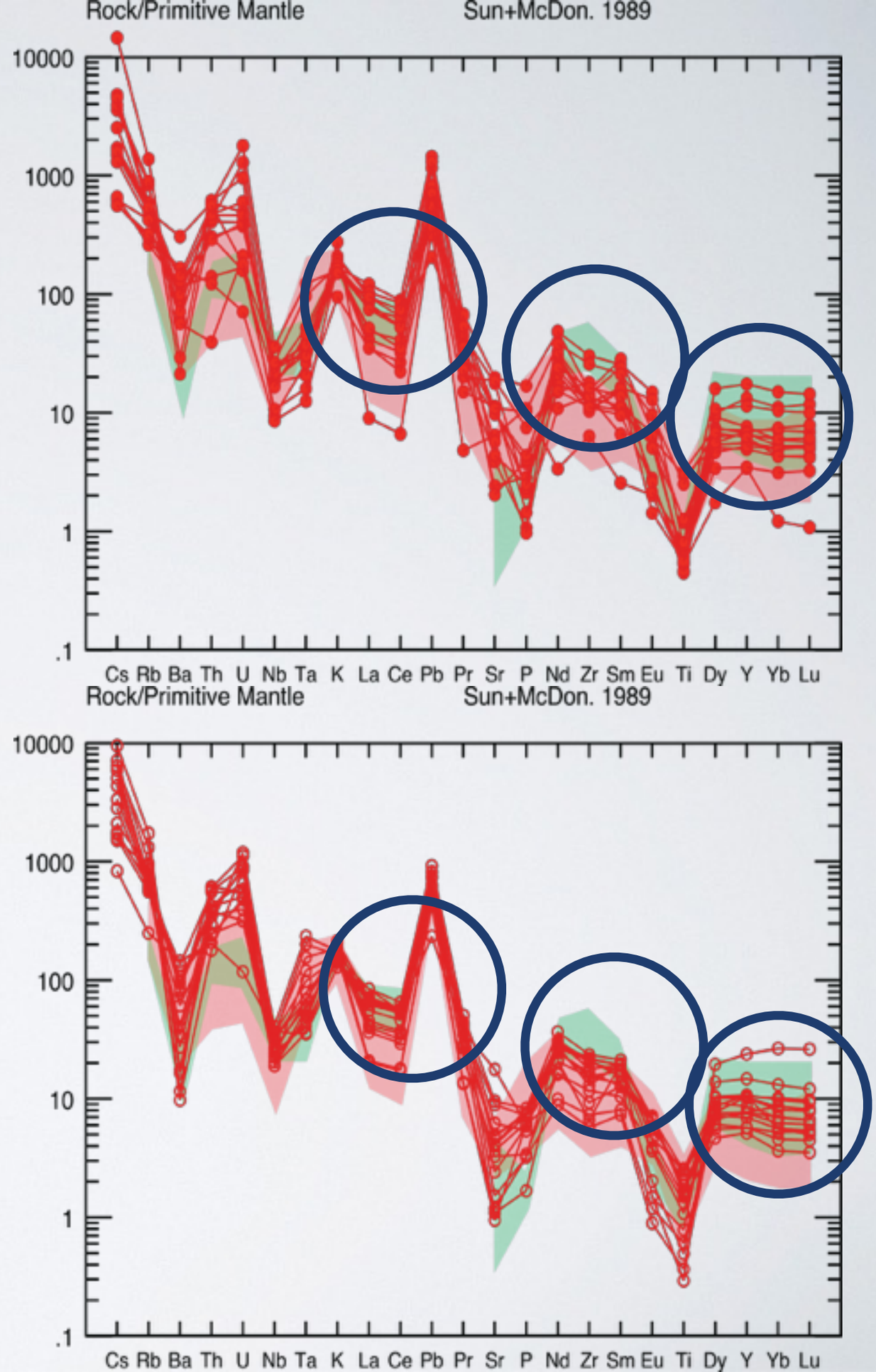
Red shading:

Cordilleran I-S granites (Grosse et al. 2011)

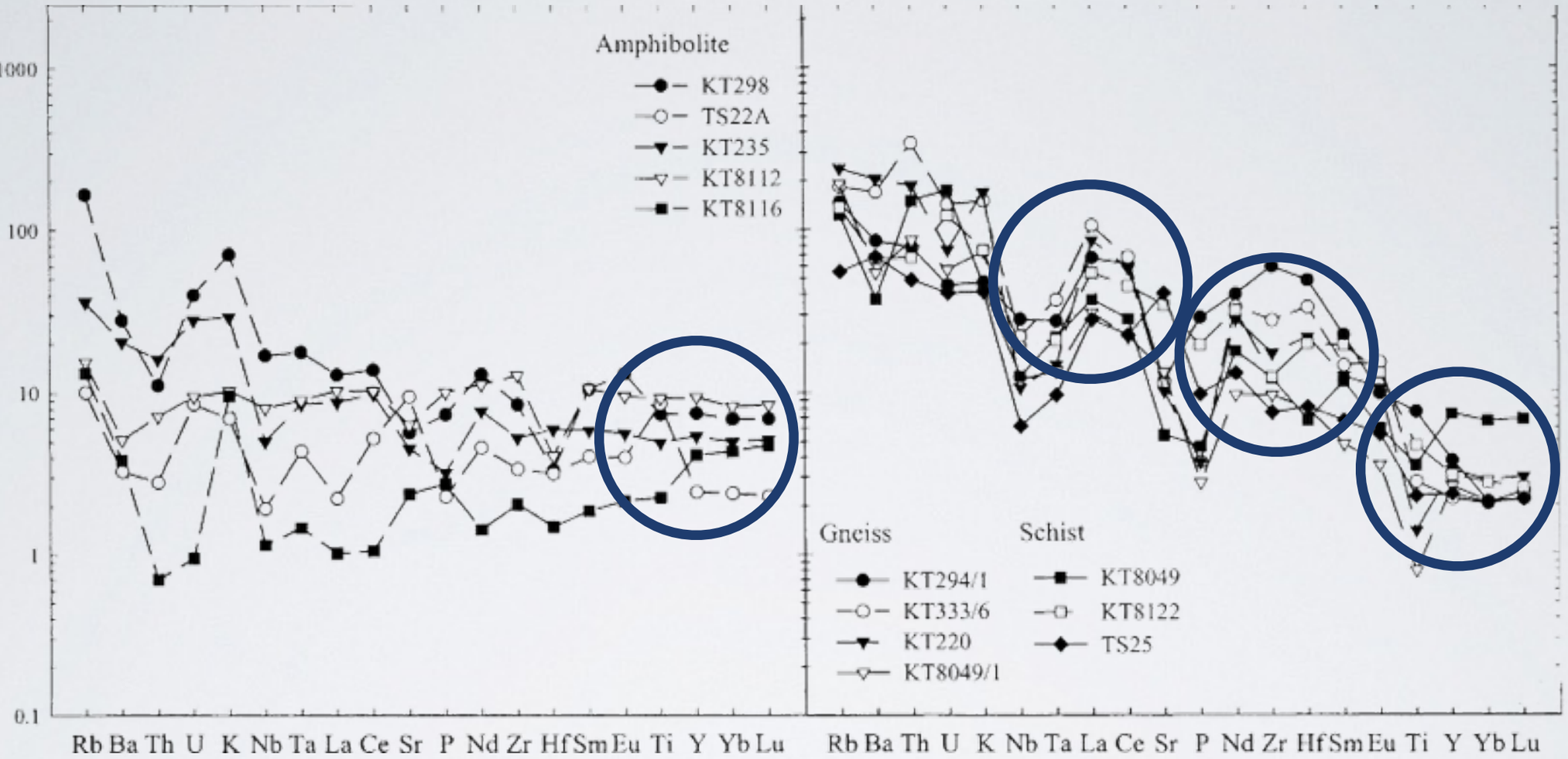
Green shading:

NE China A-type granites (Wu et al. 2002)

Upper: Eastern Province
Lower: Main Range Province

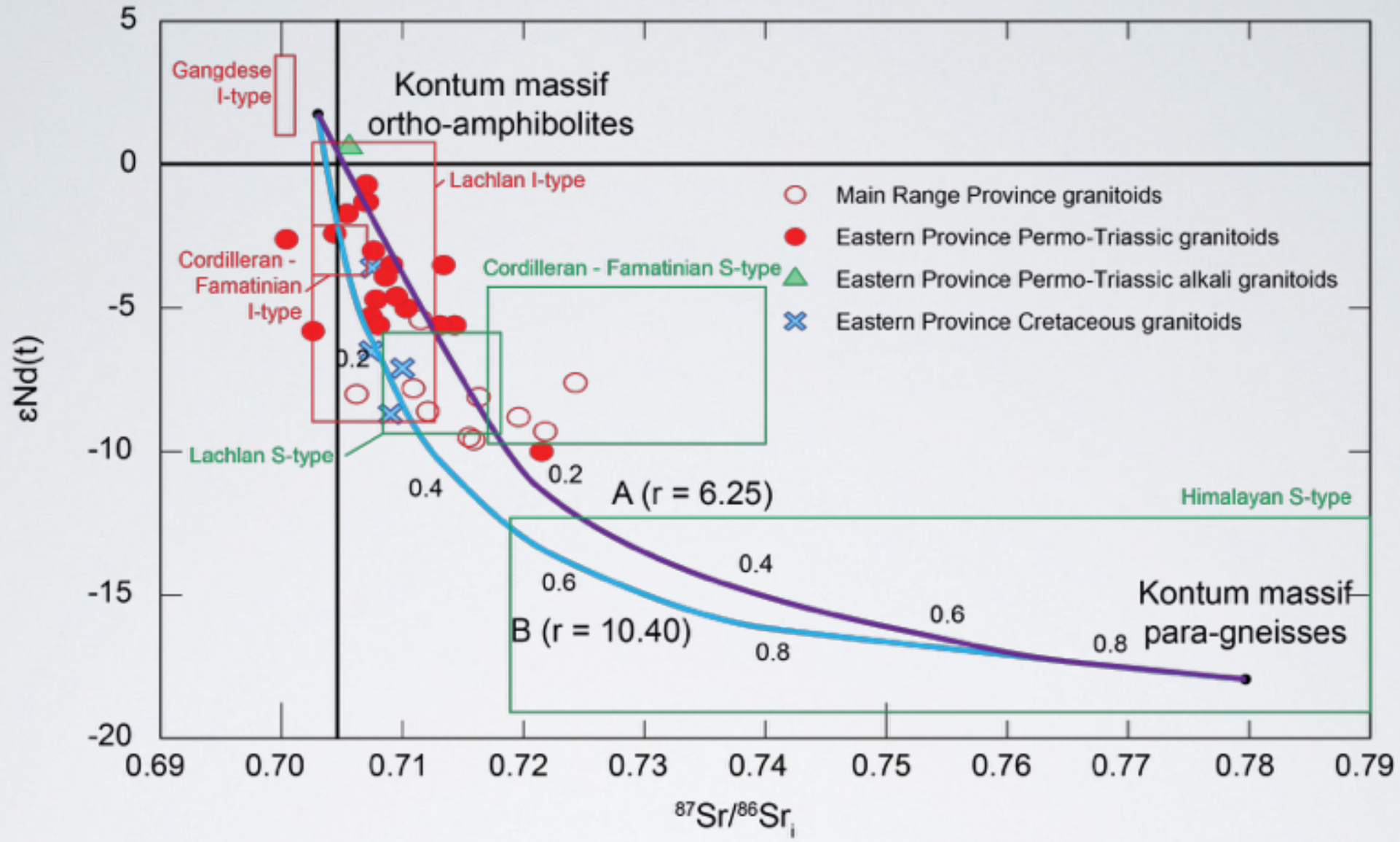


Kontum Massif
suspected Indochina basement



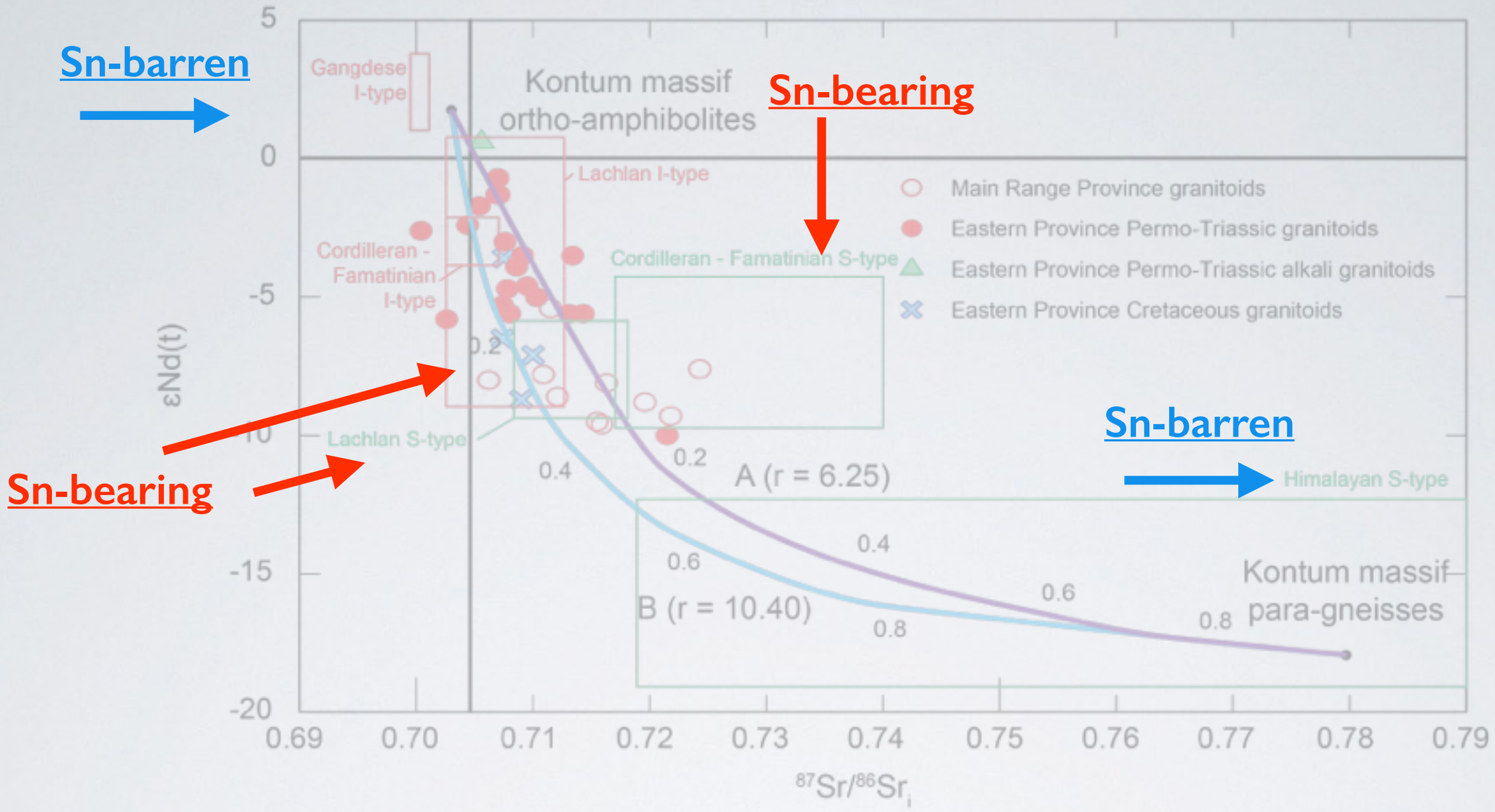
Lan et al. (2003)

- Ortho-amphibolites
  - Cambro-Ordovician metamorphosed intraplate basalt
- Para-gneisses
  - Mesoproterozoic meta-sedimentary rocks



Sr-Nd Isotopic Data

Comparison to the Kontum Massif

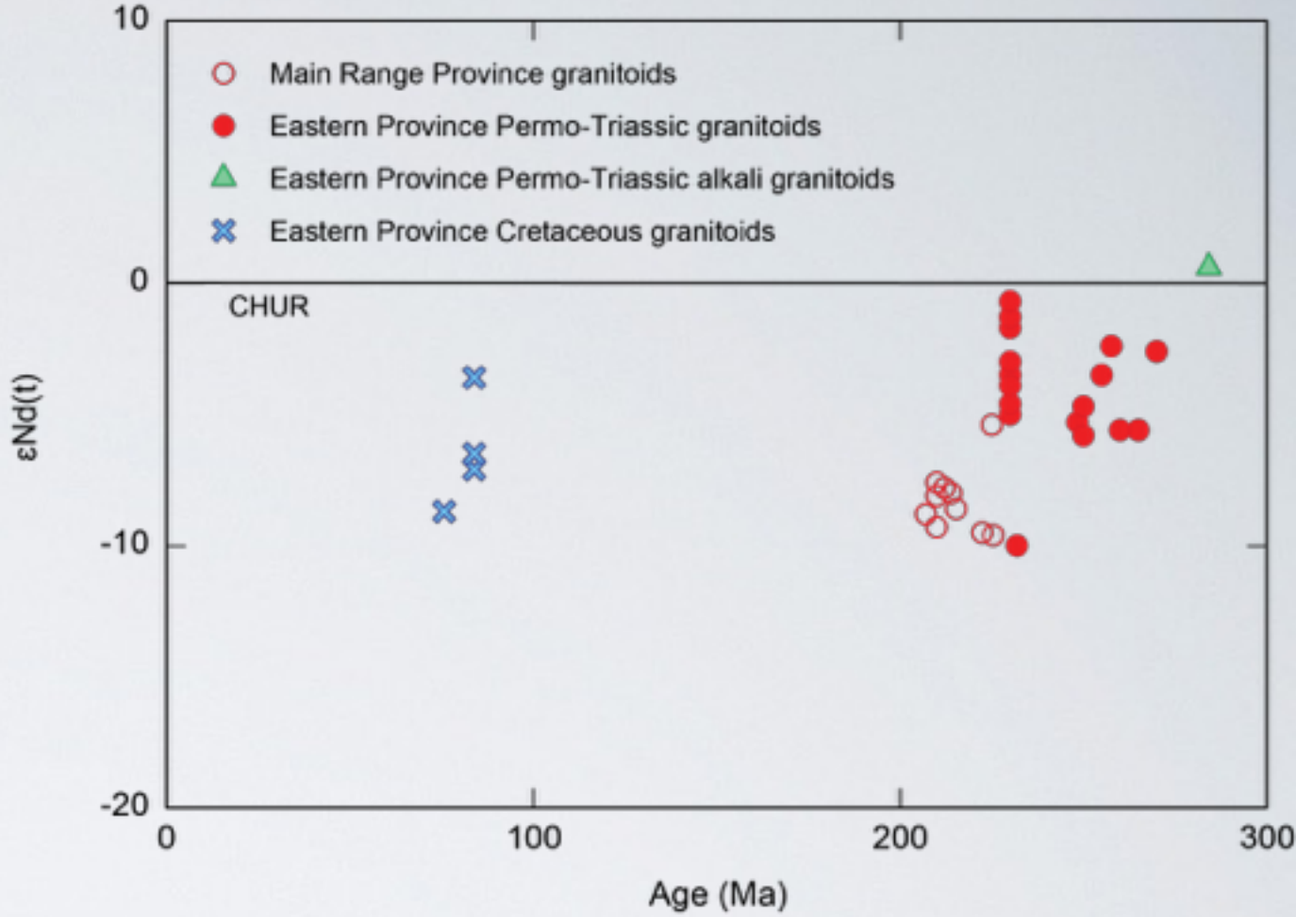


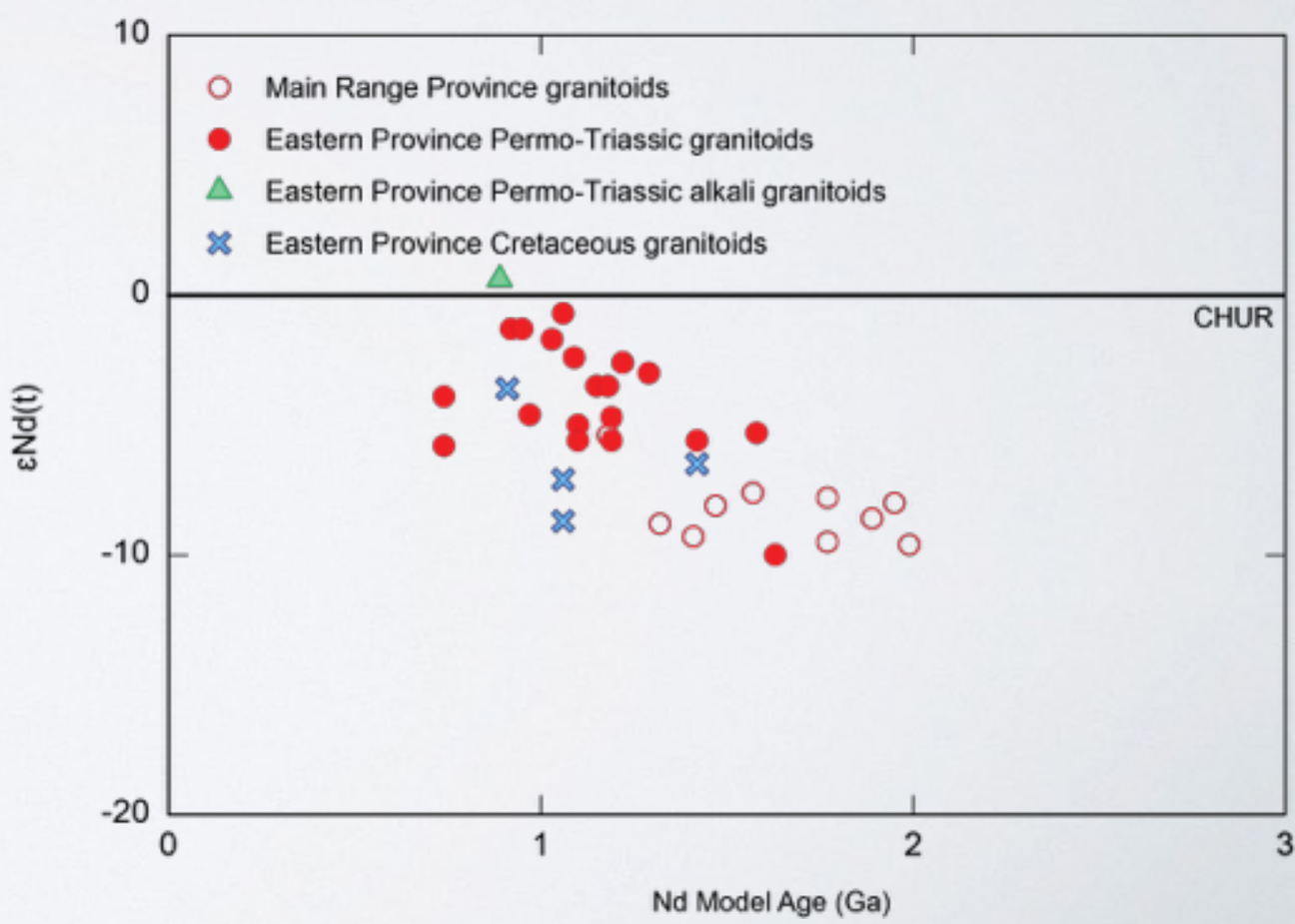
Sr-Nd Isotopic Data

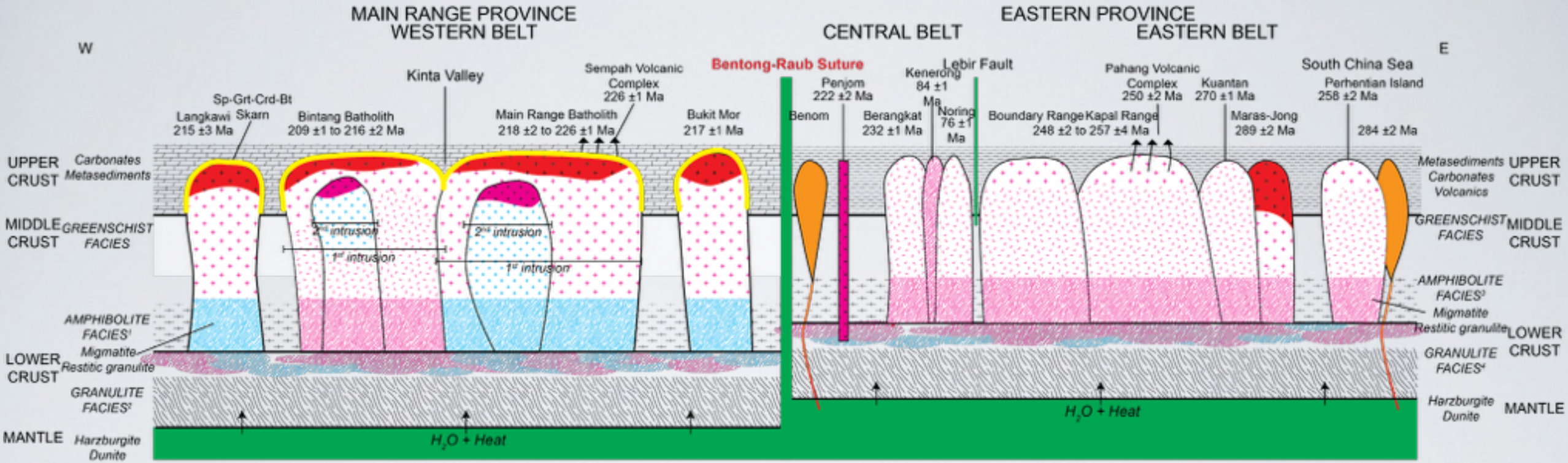
Comparison to the Kontum Massif

Sr-Nd Isotopes

The Eastern Province and Main Range granitoids can be discriminated from each other by their Sr-Nd isotopic compositions







PETROGENETIC MODEL

Malaysian Granitoids

Geochronology

NordSIM, Swedish Museum of Natural History

99°E 100° 101° 102° 103° 104°

THAILAND

Bentong-Raub suture

Gulf of Thailand

Koh Tarutao

Langkawi Is.

215 ± 3 Ma[5]
216 ± 2 Ma[5]

Pulau Tuba

209 ± 1 Ma[1]
215 ± 6 Ma[1]
214 ± 3 Ma[5]
216 ± 2 Ma[5]
212 ± 2 Ma[5]

201 ± 2 Ma[5]

Penang

Straits of Melacca

Kulim

Selama

216 ± 2 Ma[5]

Bubu

Kledang

Kinta Valley

220 ± 1 Ma[5]

Ipoh

220 ± 3 Ma[5]
219 ± 2 Ma[5]
225 ± 1 Ma[5]
218 ± 2 Ma[5]

Main Range batholith

209 ± 2 Ma[1]
206 ± 2 Ma[1]
198 ± 2 Ma[1]
219 ± 9 Ma[1]
215 ± 2 Ma[1]

Bukit Tinggi

Kuala Lumpur

215 ± 7 Ma[3]
210 ± 7 Ma[3]

222 ± 2 Ma[5]
226 ± 1 Ma (d)[5]

Western Belt

Central Belt

Coastal Belt (Eastern Belt)

Lebir Fault

76 ± 1 Ma[5]

226 ± 1 Ma[5]

*220 ± 4 Ma (d)[5]
84 ± 1 Ma (l)[5]

Kota Baharu

Boundary Range batholith

Perhentian

258 ± 2 Ma[5]
284 ± 2 Ma (s)[5]

Redang

Jerong

*289 ± 2 Ma[5]

Maras-Jong

248 ± 2 Ma[5]

Noring Stong

257 ± 4 Ma[2]

232 ± 1 Ma[5]

248 ± 2 Ma[5]

Kapal batholith

227 ± 2 Ma[2]
250 ± 2 Ma (da)[5]

267 ± 2 Ma[2]
270 ± 1 Ma[5]

Kuantan

Benom

222 ± 2 Ma (d)[5]

80 ± 1 Ma[3]
80 ± 1 Ma[5]
80 ± 1 Ma[5]
80 ± 1 Ma (d)[5]
82 ± 1 Ma (di)[5]
81 ± 1 Ma (mg)[5]

Tioman

*244.5 ±3.1 Ma[5]

Sibu

285 ± 5 Ma[4]
276 ± 5 Ma[4]

Melacca

217 ± 1 Ma[5]

222 ± 2 Ma[5]
227 ± 2 Ma[5]
*226 ± 3 Ma[5]

Johor Bharu

237 ± 1 Ma[4]
244 ± 2 Ma[4]
238 ± 2 Ma (r)[4]
230 ± 6 Ma[4]
*231 ± 3 Ma[5]

Singapore

238 ± 2 Ma[4]
239 ± 2 Ma (r)[5]

N

0 50 km

Main Range Province granitoids
Bentong-Raub suture zone
Alkali granitoids
Eastern Province granitoids

99°E 100° 101° 102° 103° 104°

(d) - Granitic dyke
(da) - Dacite
(di) - Diorite
(l) - Leucogranite
(r) - Rhyolite
(s) - Syenite

1 - Liew, 1983; Liew and Page, 1985
2 - Liew, 1983; Liew and McCulloch, 1985
3 - Searle et al., 2012
4 - Oliver et al., 2014
5 - This work

THAILAND
Bentong-Raub suture
Gulf of Thailand
Koh Tarutao
Langkawi Is.
Pulau Tuba
Penang
Straits of Melacca
Kulim
Selama
Bubu
Kledang
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Main Range batholith
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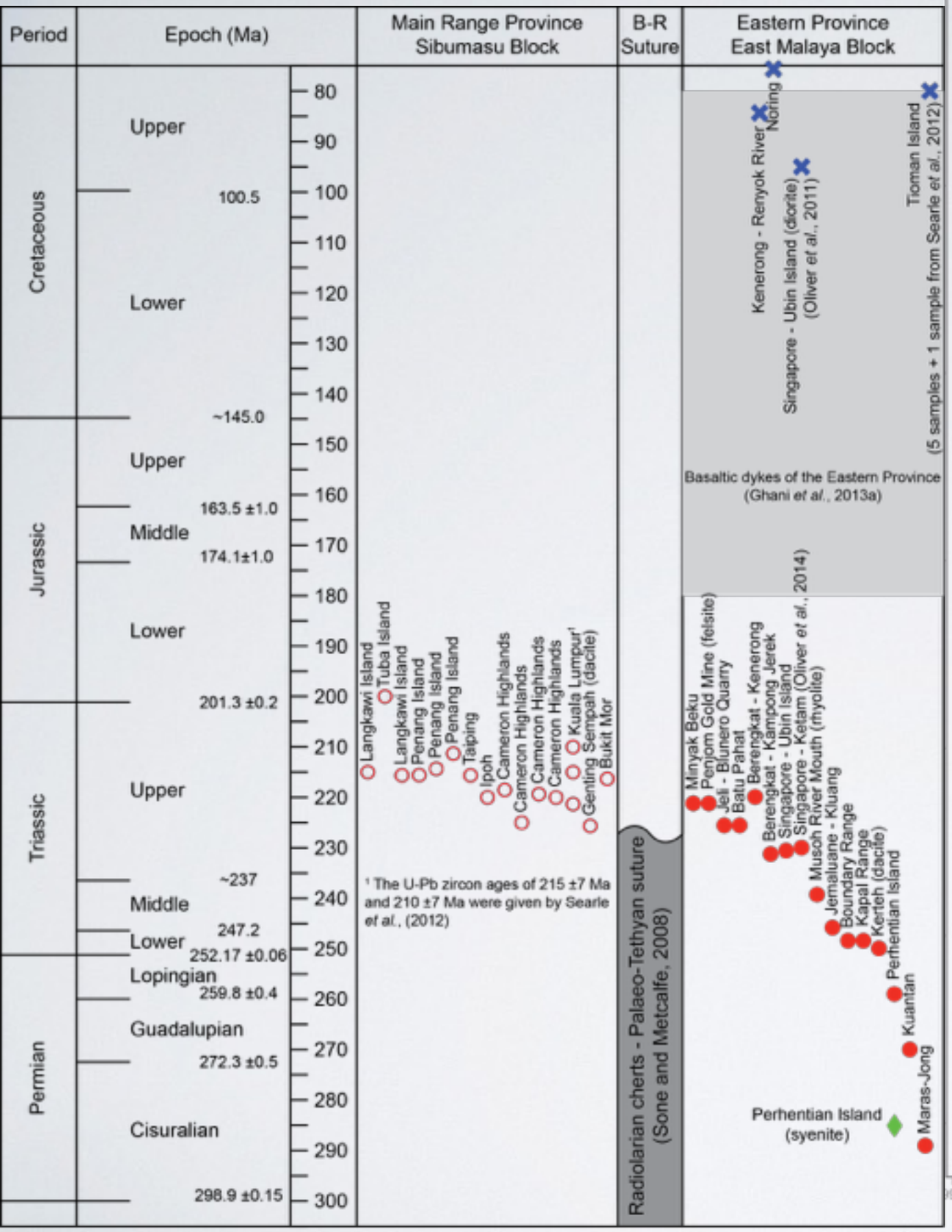
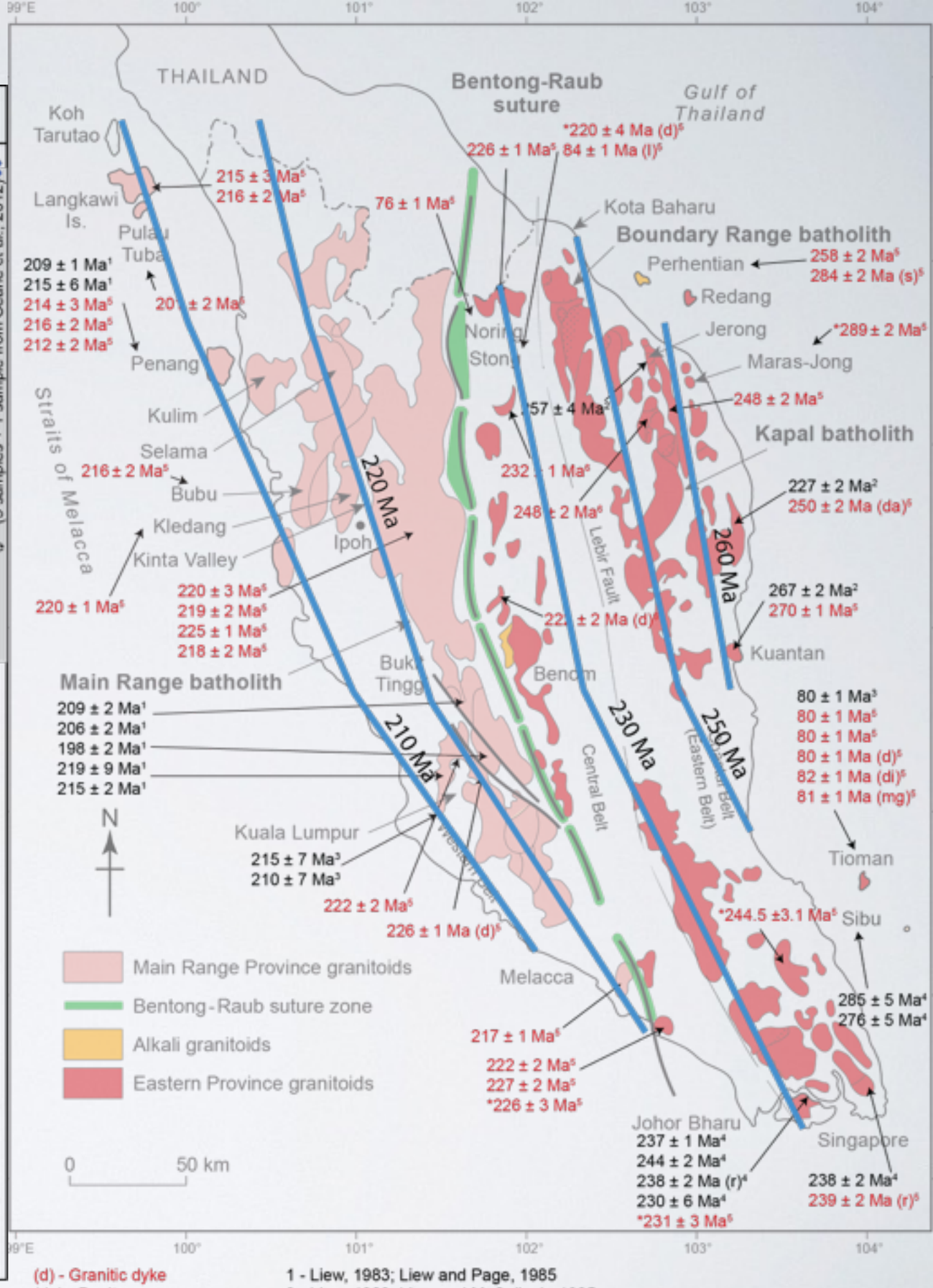
Western Belt
Central Belt
Coastal Belt (Eastern Belt)
Lebir Fault
Kota Baharu
Boundary Range batholith
Perhentian
Redang
Jerong
Maras-Jong
Noring Stong
Kapal batholith
Kuantan
Benom
Tioman
Sibu
Melacca
Johor Bharu
Singapore
220 Ma
210 Ma
230 Ma
250 Ma
260 Ma
N
0 50 km
Main Range Province granitoids
Bentong-Raub suture zone
Alkali granitoids
Eastern Province granitoids



The chart follows the International Chronostratigraphic Chart v 2014/02



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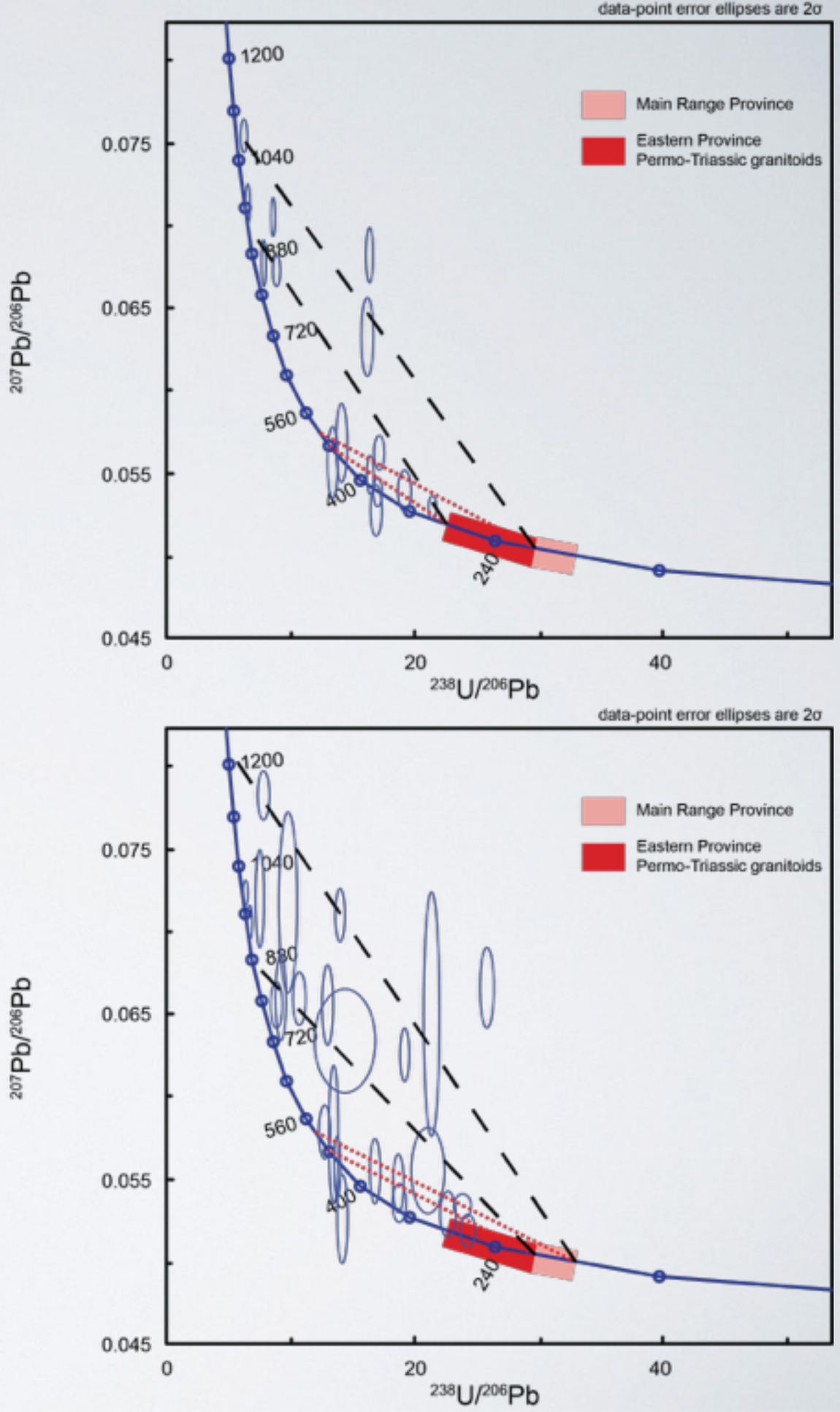
Inherited Zircon Ages

Discordia data obtained from all the samples formed inheritance chords with inherited zircon ages and intercept at Cambro-Ordovician and Mesoproterozoic

Upper: Eastern Province
Lower: Main Range Province



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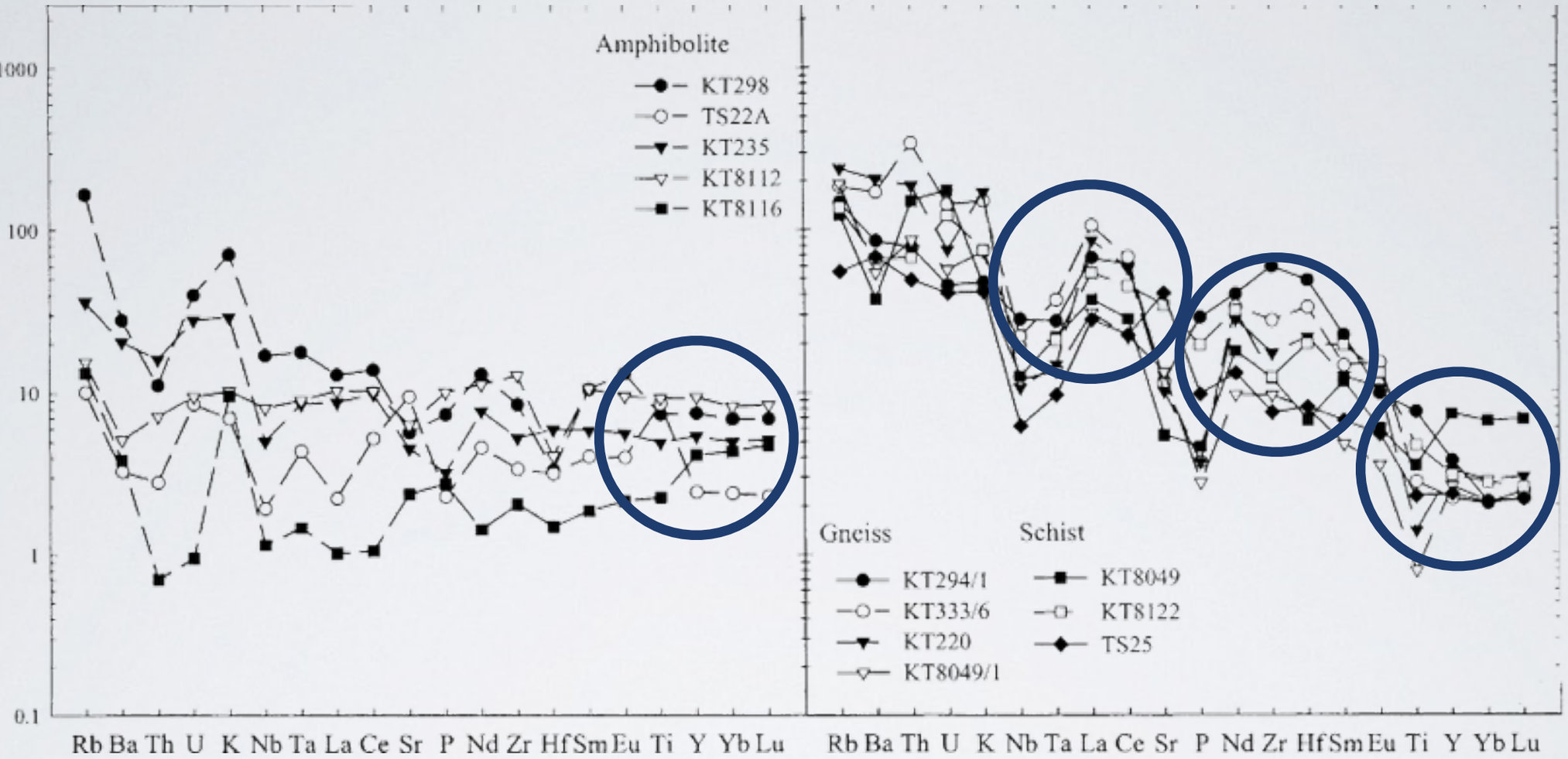


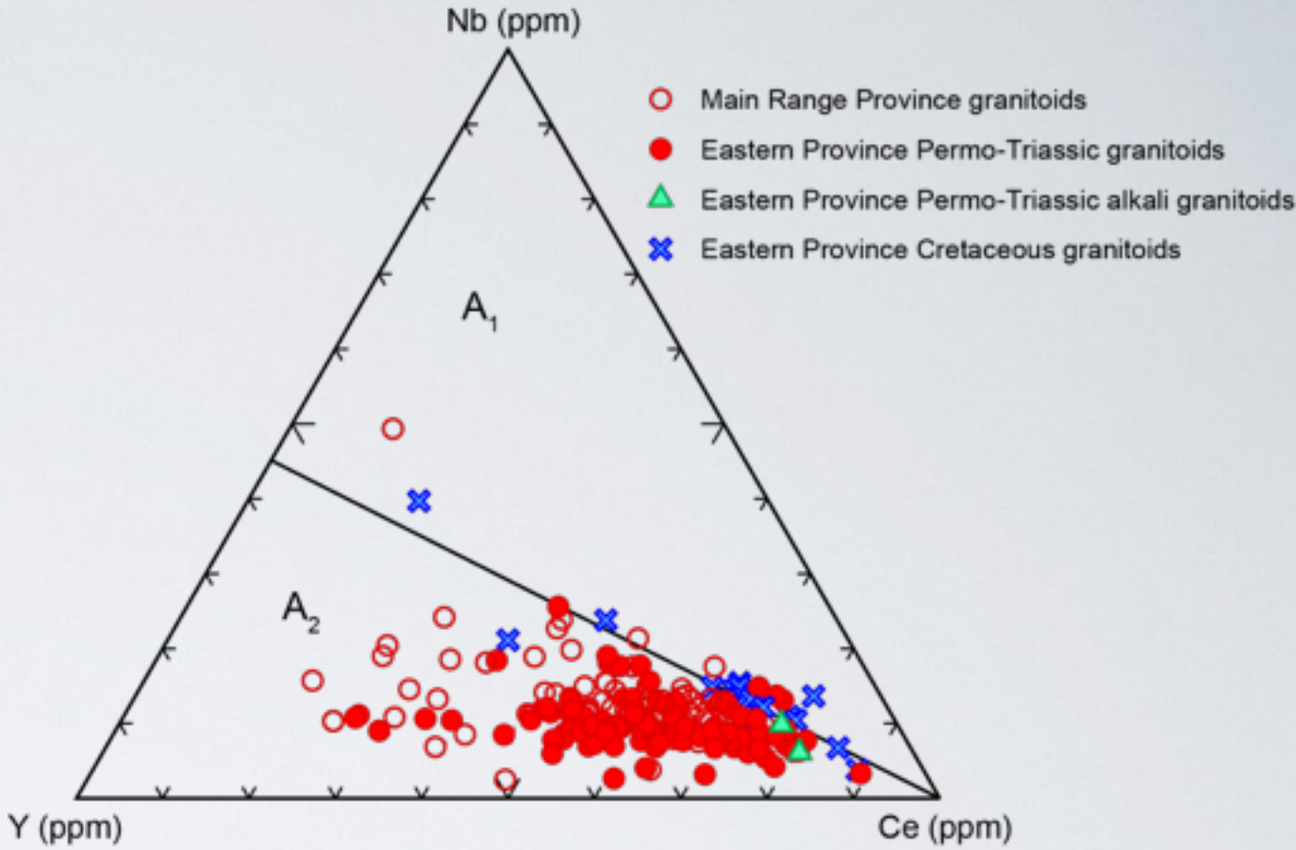
Lan et al. (2003)

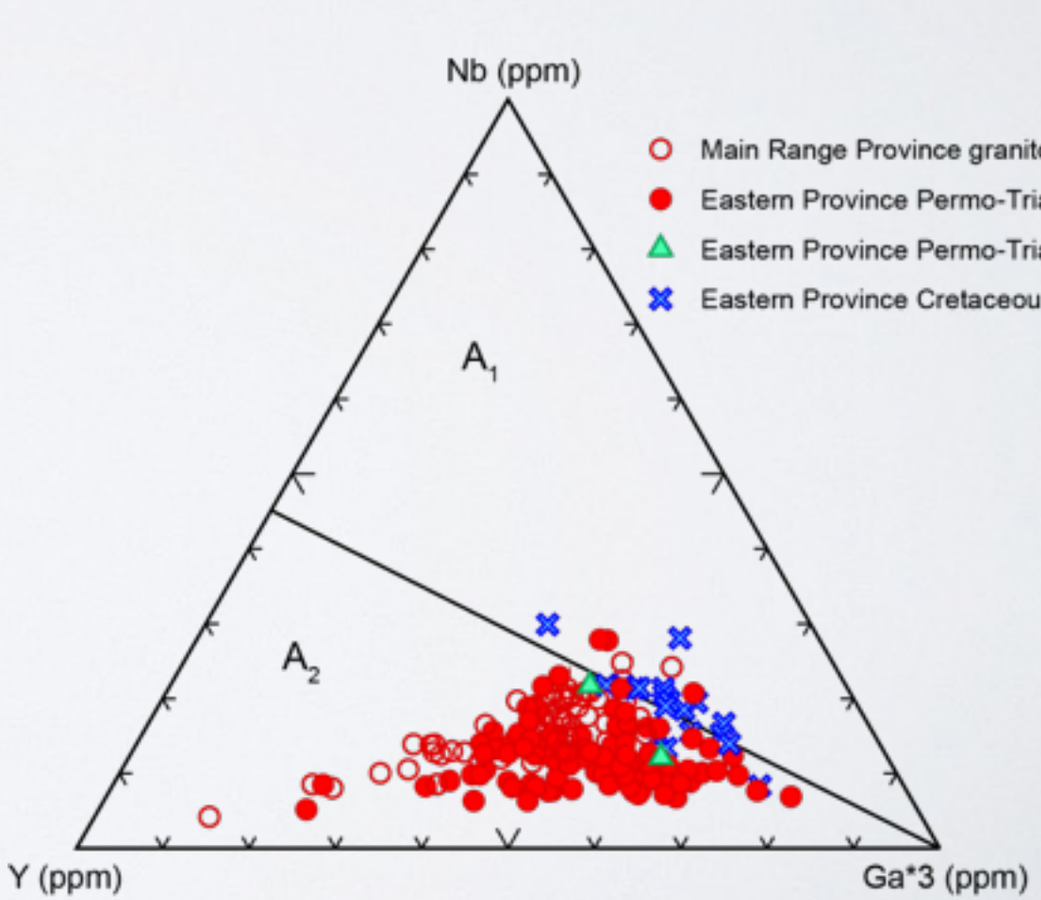
- Ortho-amphibolites
  - Cambro-Ordovician metamorphosed intraplate basalt
- Para-gneisses
  - Mesoproterozoic meta-sedimentary rocks

Cretaceous Granitoids

The Cretaceous granitoids can be discriminated from the Permo-Triassic granitoids in Eby's A-type classification system, in which the Cretaceous granitoids tend to have lower Y/Nb ratios.

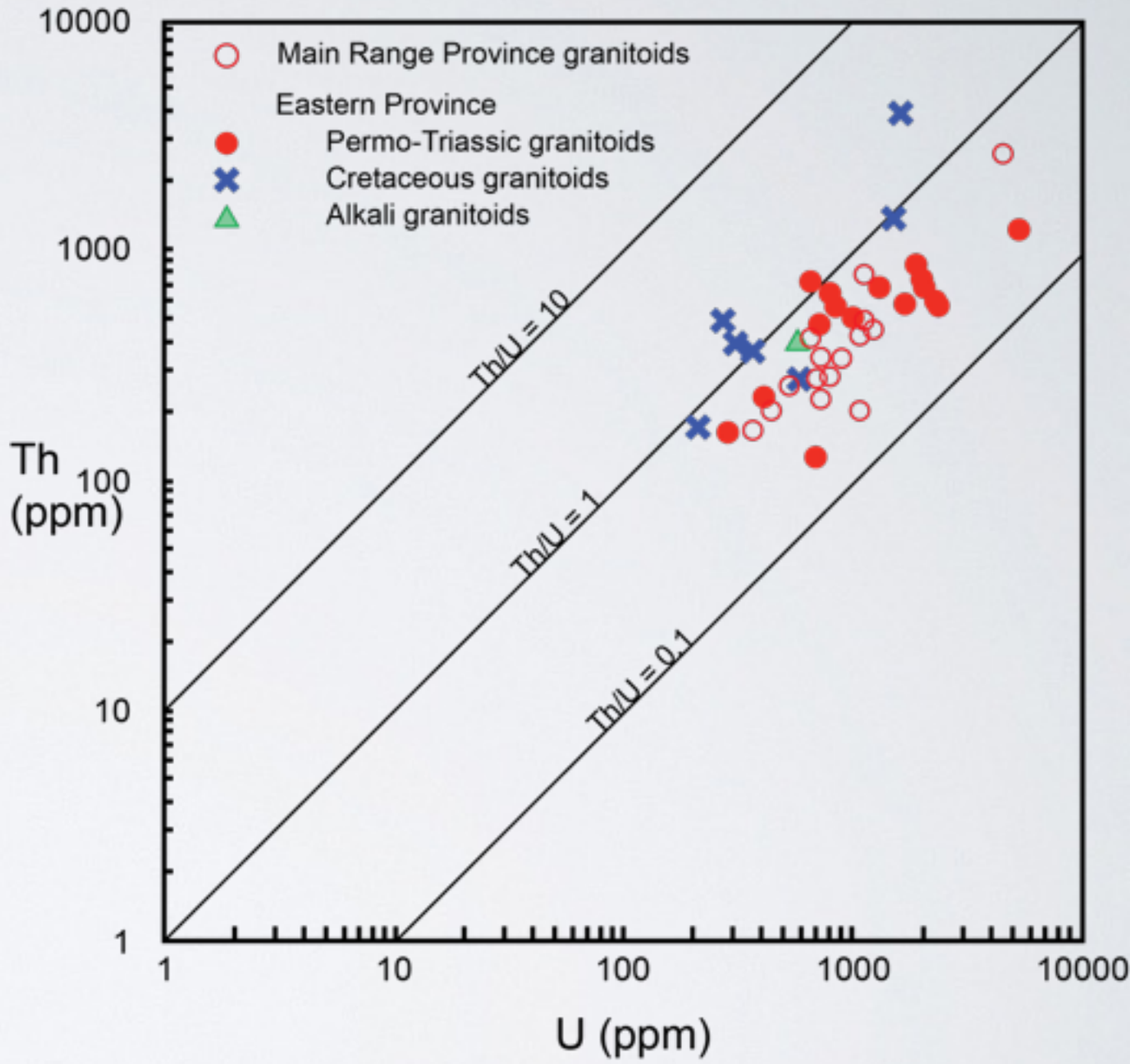
Related to the opening of the Gulf of Thailand and the Strait of Malacca.

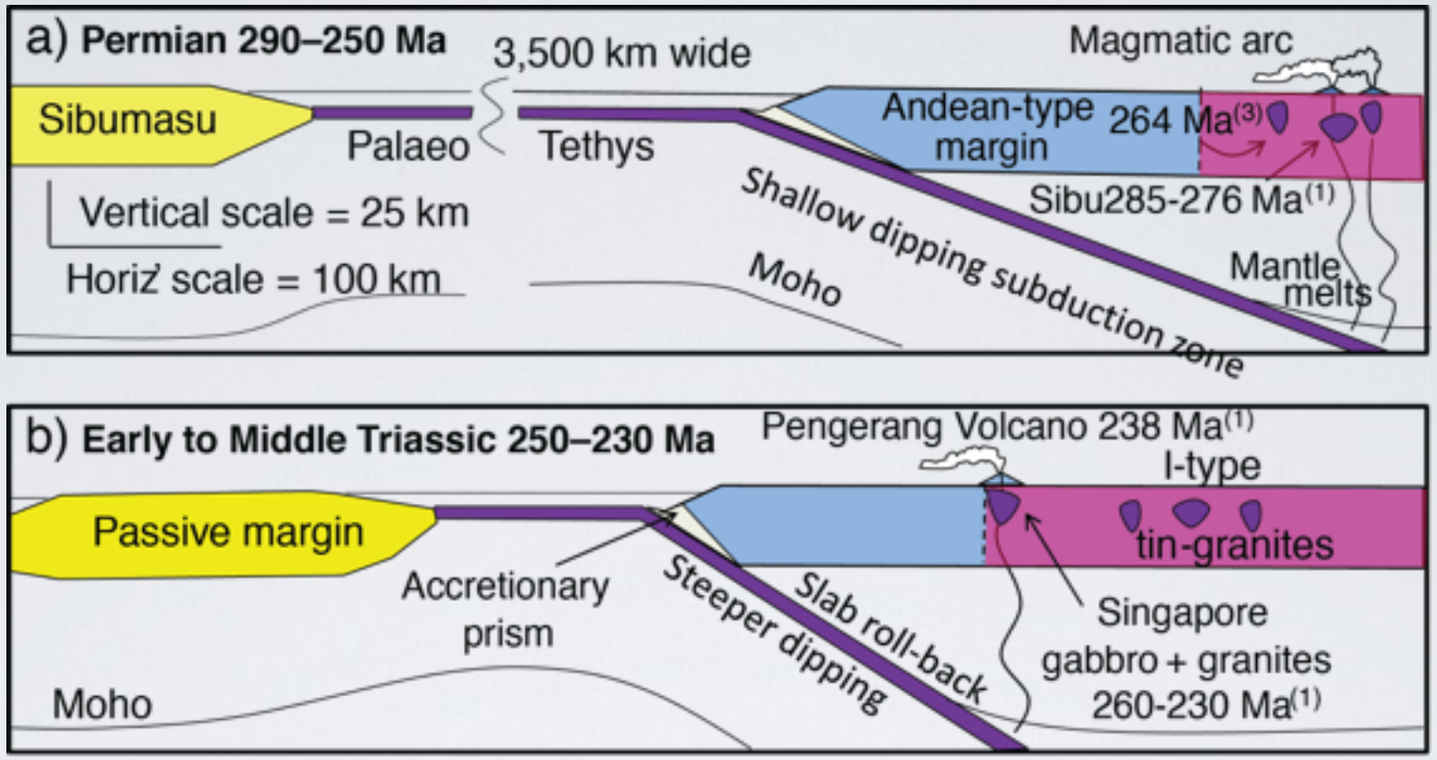




Cretaceous Granitoids

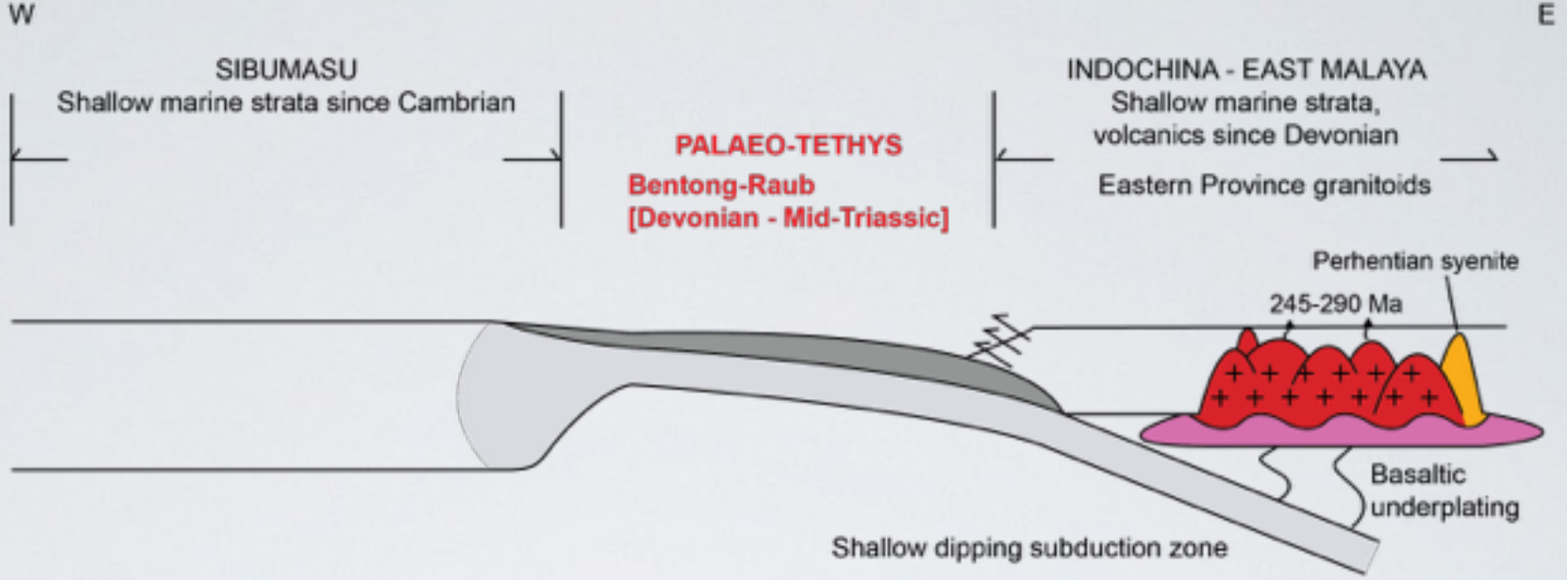
The zircons extracted from the Cretaceous granitoids tend to have higher Th/U ratios



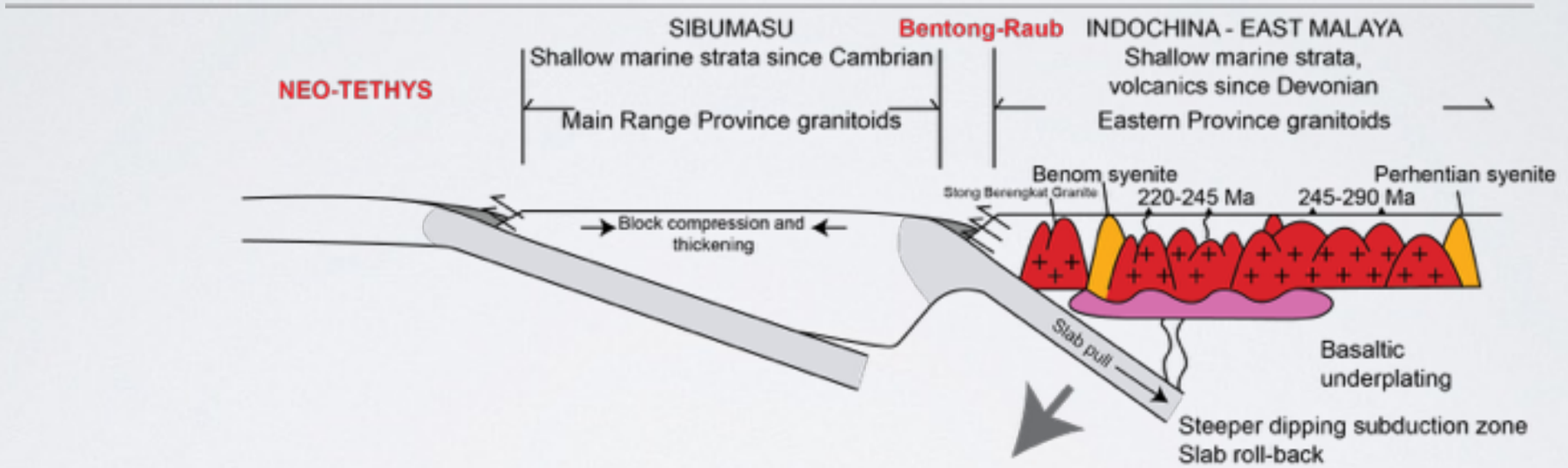


Tectonic Model

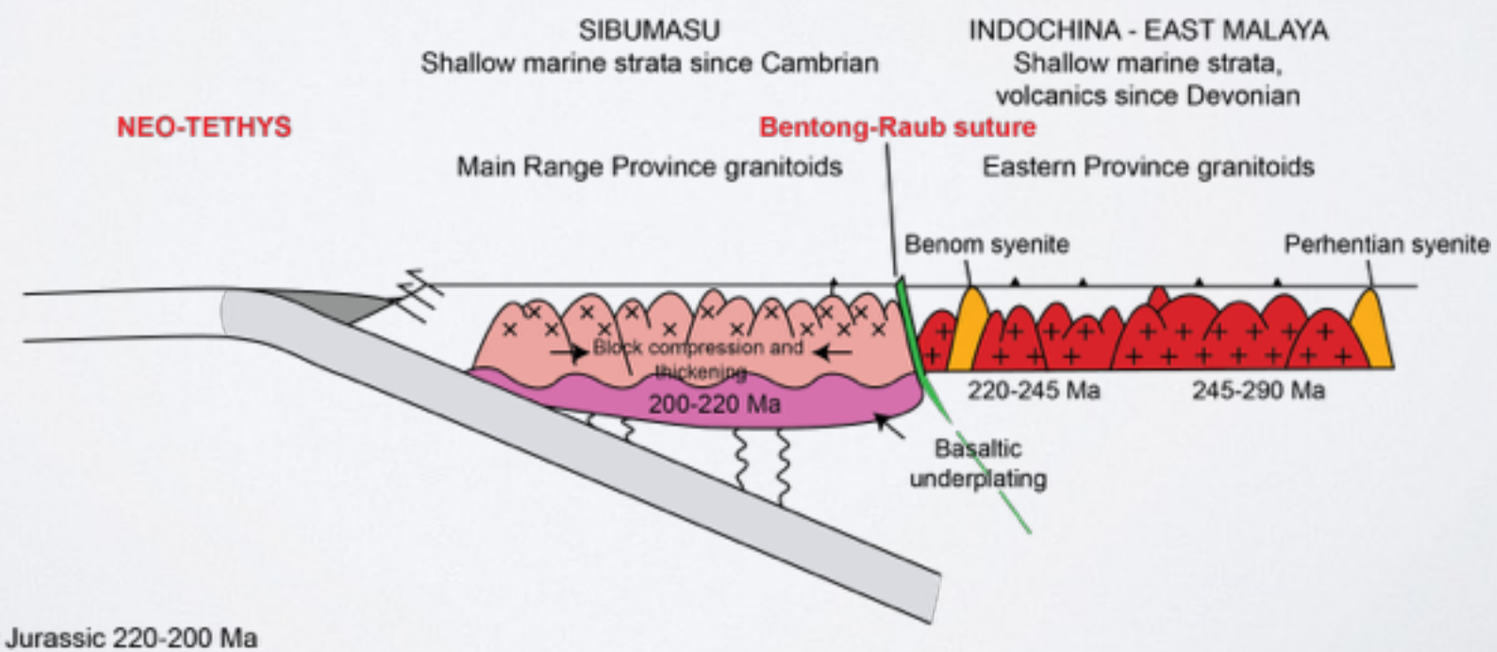
Oliver et al. (2014)



a) Early Permian to Middle Triassic 290-245 Ma



b) Middle to Late Triassic 245-220 Ma



c) Late Triassic to Early Jurassic 220-200 Ma

What did we learn in Malaysia?

- There are granites and granites (Read, 1948)
    - I-S system may represent one of the spectra of granite compositions
        - Difference in granite composition can be subtle, but may indicate subduction direction
- Sn mineralization is usually occurred in more reduced magma (i.e. S-type granite), degree of fractionation is also a significant parameter. Pure S-type granite cannot have tin mineralized, but mixture of I- and S-types magma can intensify fractionation.

Current Work

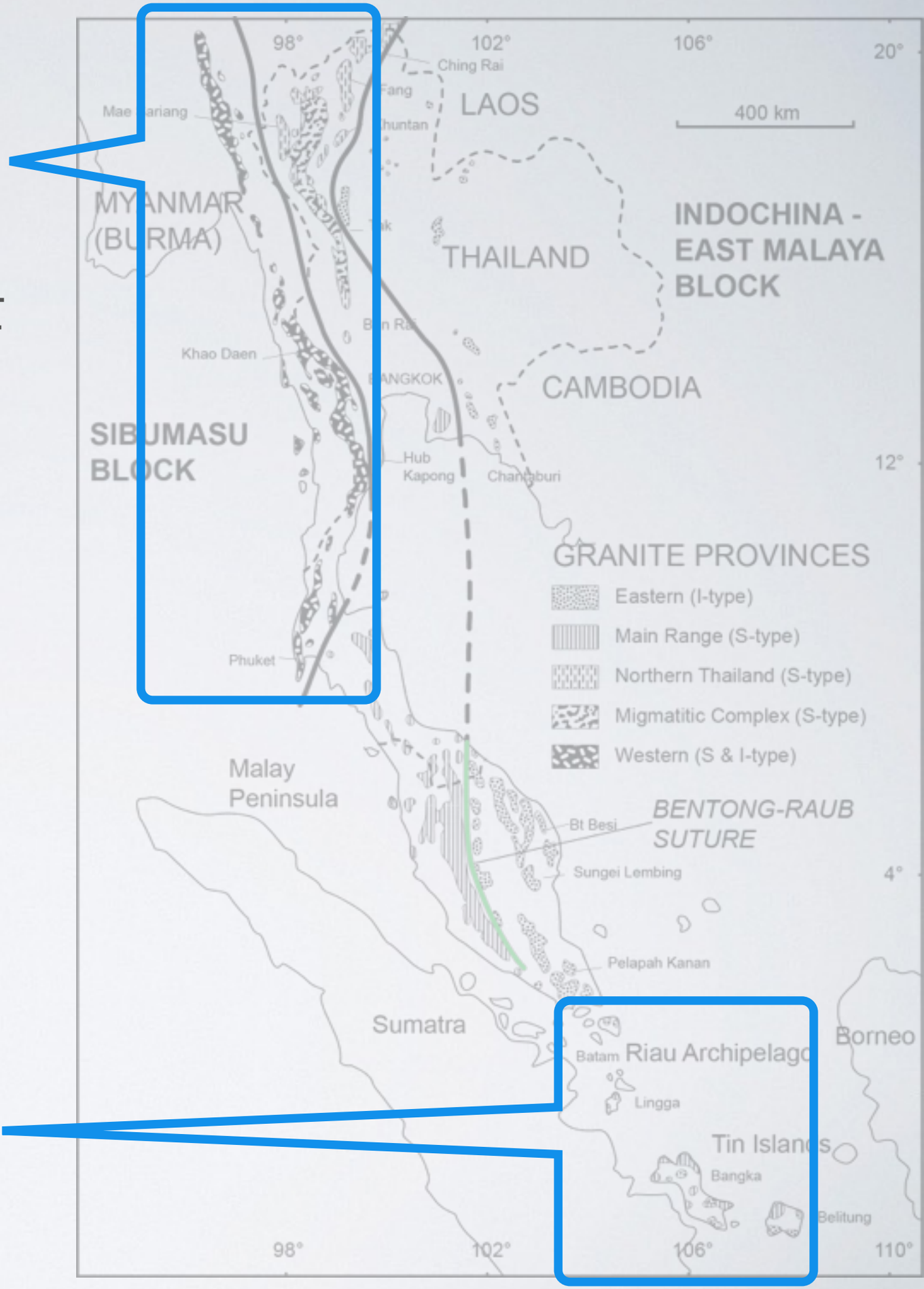
The University of Hong Kong

Oxford group
led by Gardiner et al.

The Granites of South-East Asian Tin Belt

E.J. Cobbing, P.E.J. Pitfield,
D.P.F. Darbyshire, D.I.J. Mallick
British Geological Survey (1992)

HKU group
led by Ng et al.



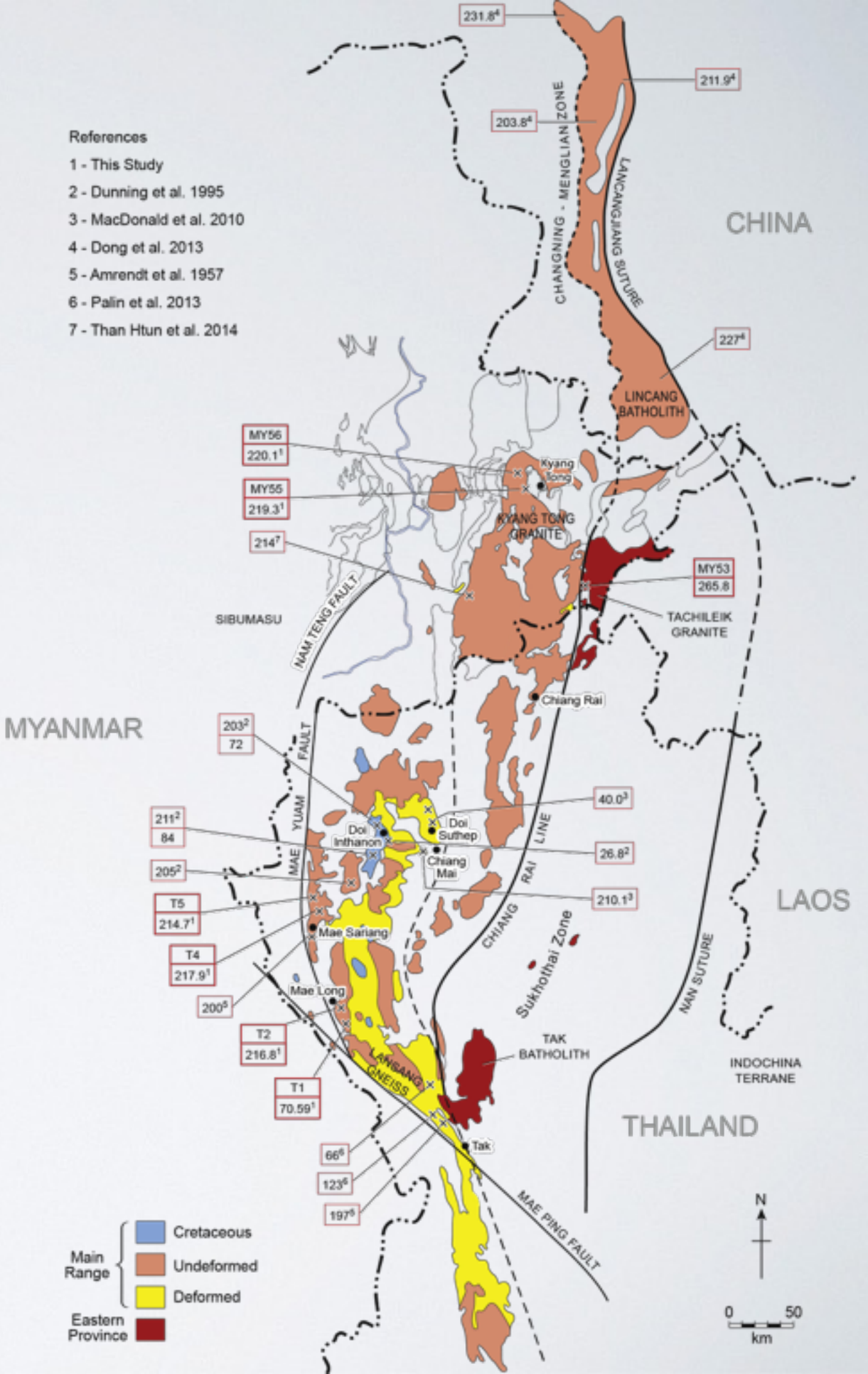
The Granites of South-east Asian Tin Belt

Northern Thailand section
Gardiner et al. (2015)

- Eastern Province: ~266 Ma
- (Cretaceous pluton: ~70 Ma)
- Main Range Province: ~220 Ma

Myanmar section
Barley et al. (2003)

- Oldest hornblende-bearing granitic gneiss is dated at 170 Ma

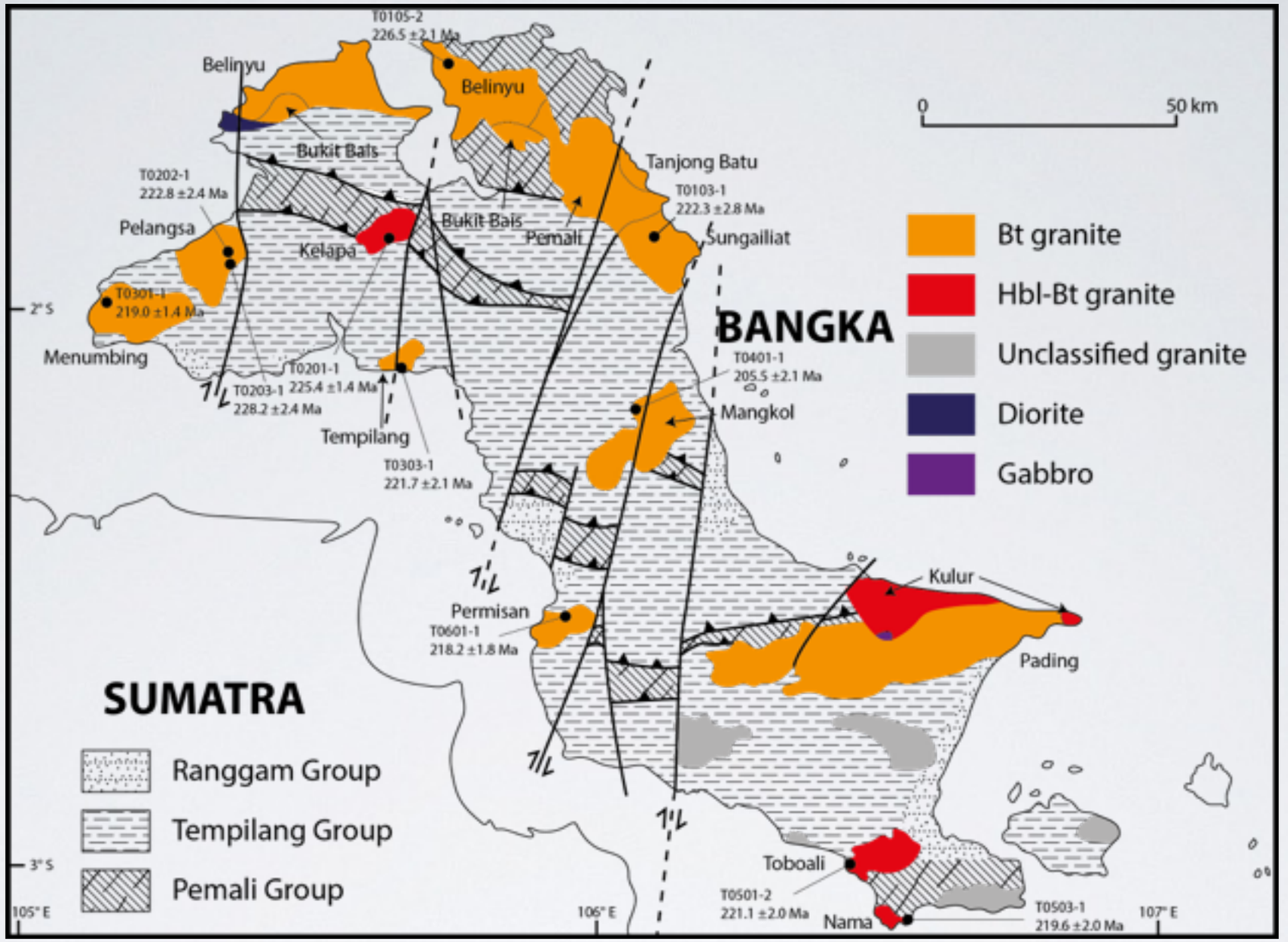


Granite Hunters

- NordSIM, Naturhistoriska Riksmuseet
  - Professor Martin Whitehouse (co-appointed in Stockholm University)
- Universiti Malaya
  - Professor Azman Ghani
- Universiti Kebangsaan Malaysia
  - Mr Muhammad Roselee

Granite Hunters

- Earth Observatory of Singapore, Nanyang Technological University
  - Dr Grahame Oliver
- Universitas Syiah Kuala
  - Mr Sayed Murtadha (will be in Universiteit Utrecht)
- Ludwig-Maximilians-Universität München
  - Professor Ernst Hegner
  - Dr Claudia Teschner

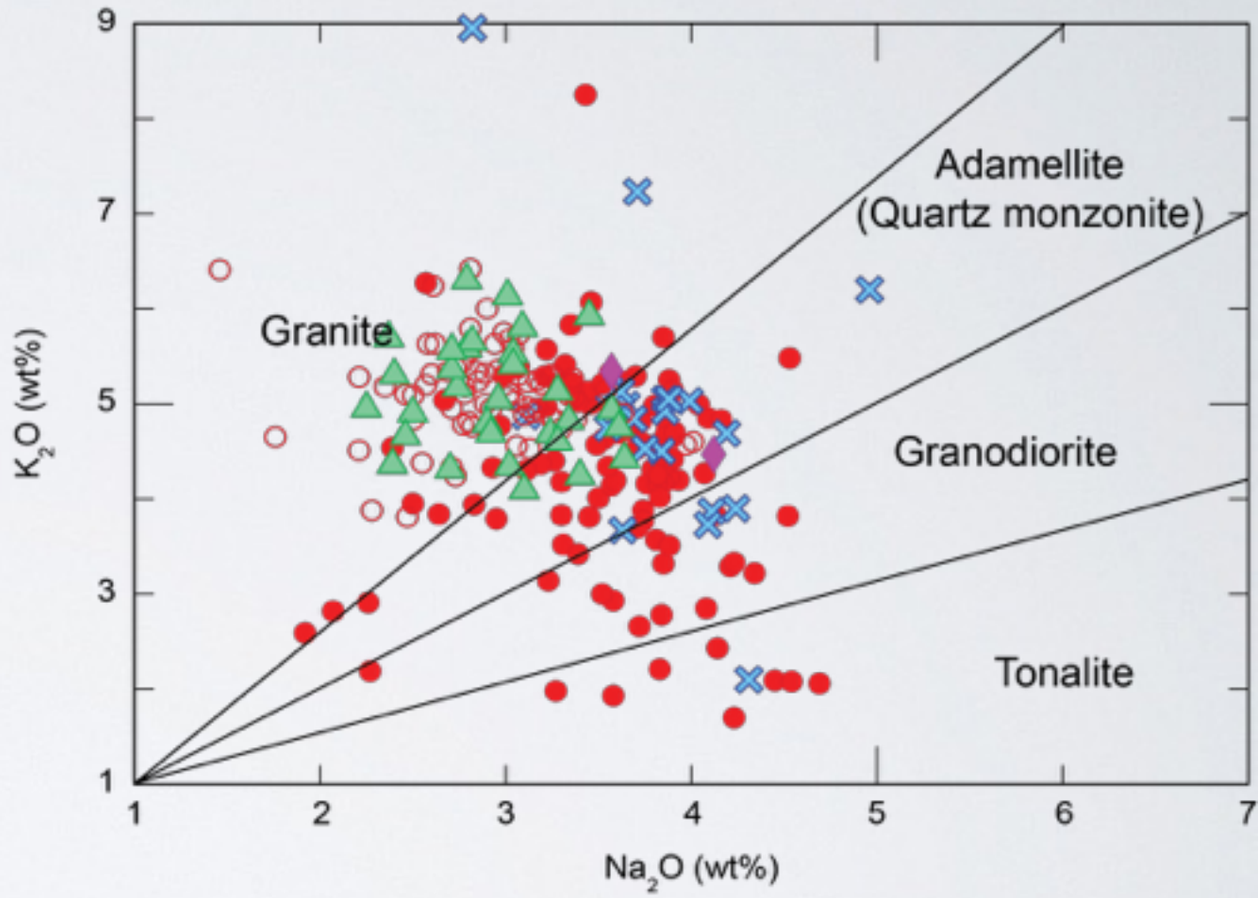


Indonesian Tin Islands
Bangka Island

Main Range Province: ~225-220 Ma (Ng et al. *unpublished*)

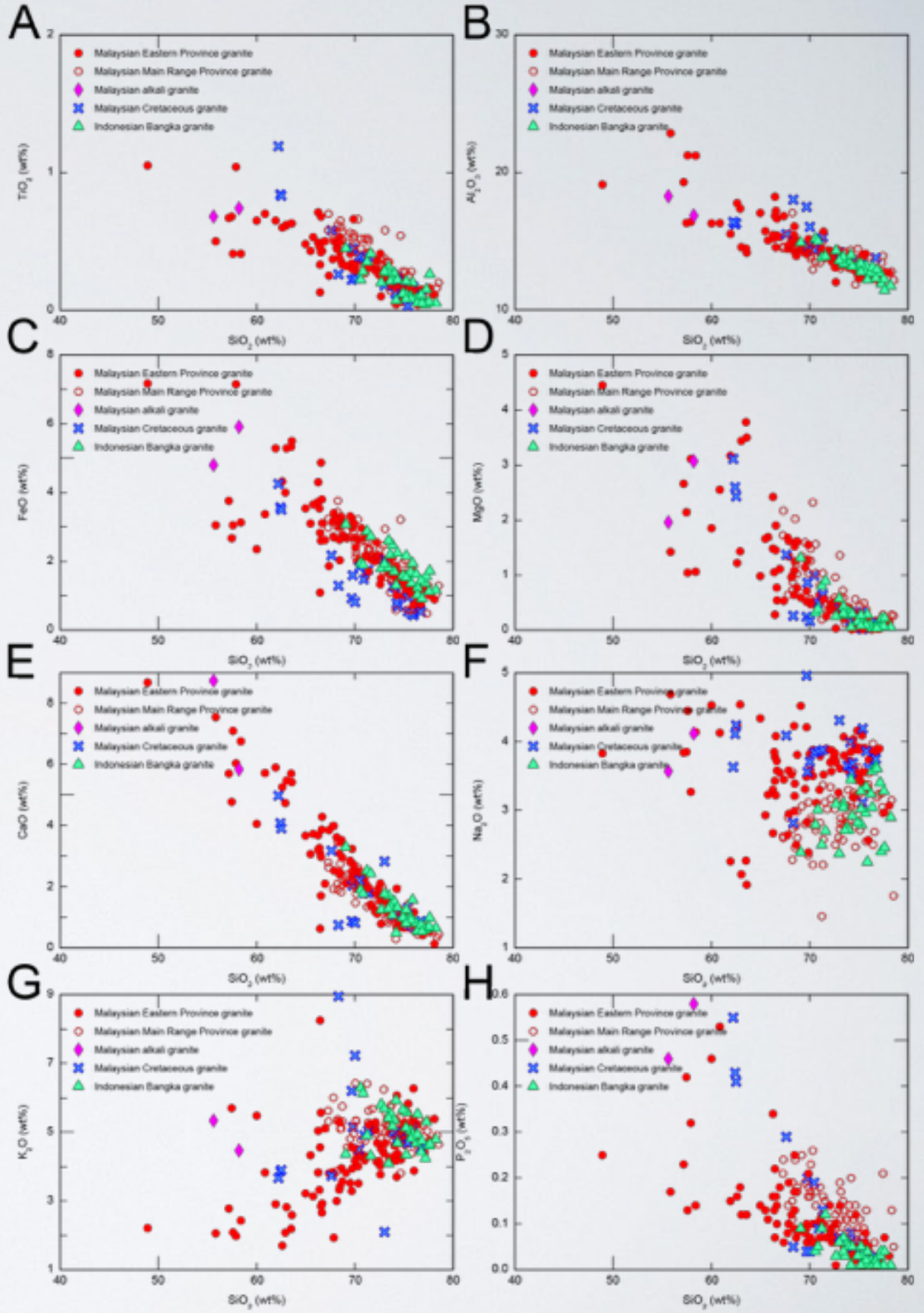
The Granites of South-east Asian Tin Belt

Geochemistry similar to the Main Range granitoids



The Granites of South-east Asian Tin Belt

Geochemistry similar to the Main Range granitoids



The Granites of South-east Asian Tin Belt

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