Evolution of the Paleoproterozoic Flin Flon Belt and lithotectonic association of VMS deposits

VMS Short course

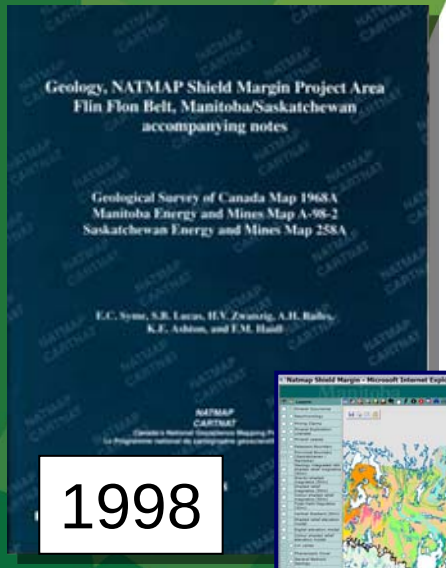
November 15, 2007

Ric Syme Manitoba Geological Survey

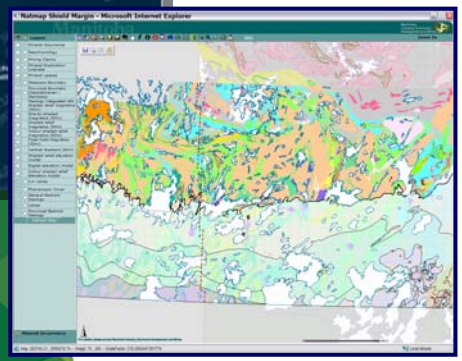
NATMAP Shield Margin team 1991-1996

A.H. Bailes (Manitoba Geological Survey)
H.V. Zwanzig (Manitoba Geological Survey)
S.B. Lucas (NRCan)
R.A. Stern (GSC)
K.V. Gilmore (Hudson Bay Exploration and Development)

Manitoba



1998



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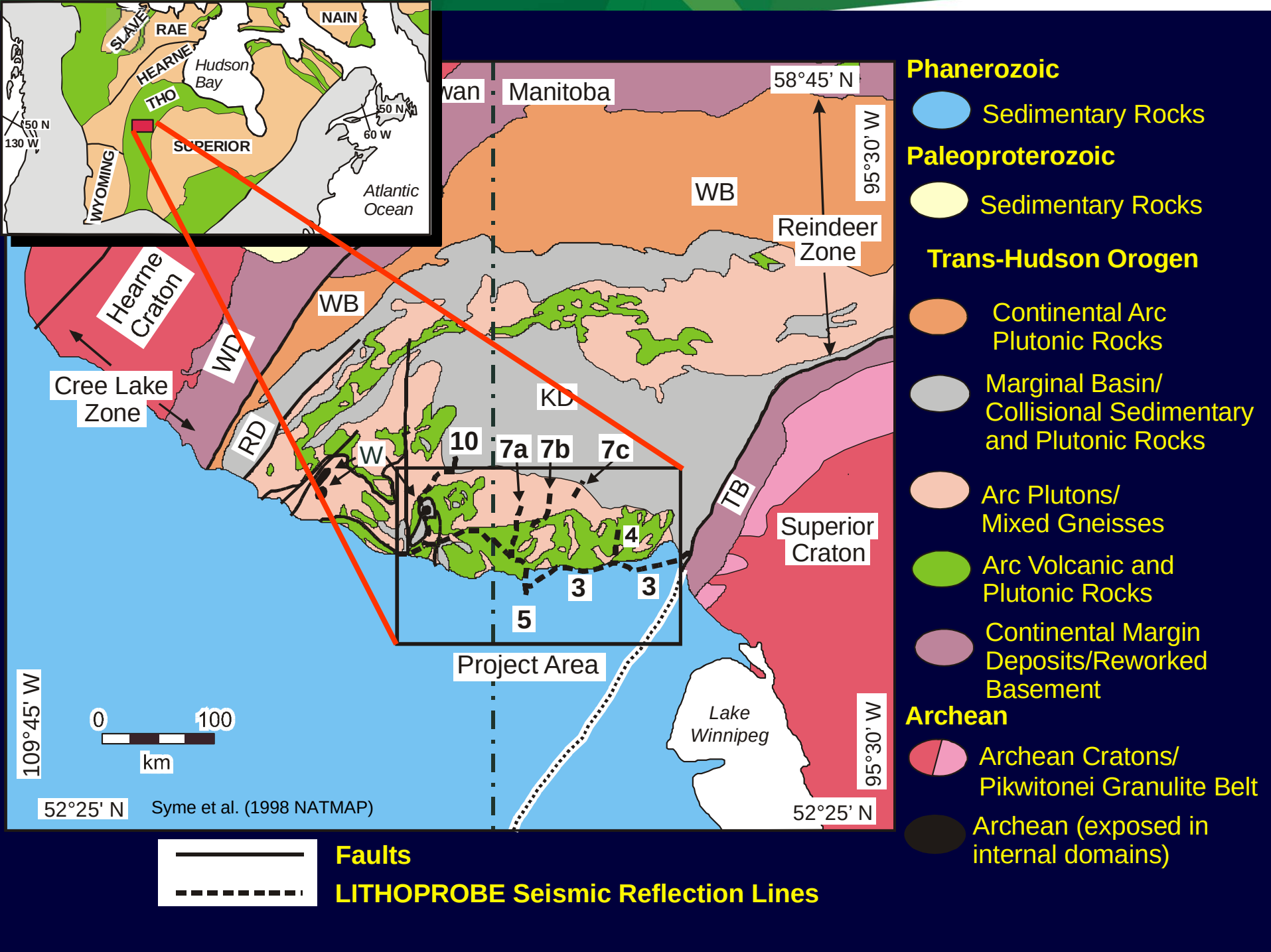
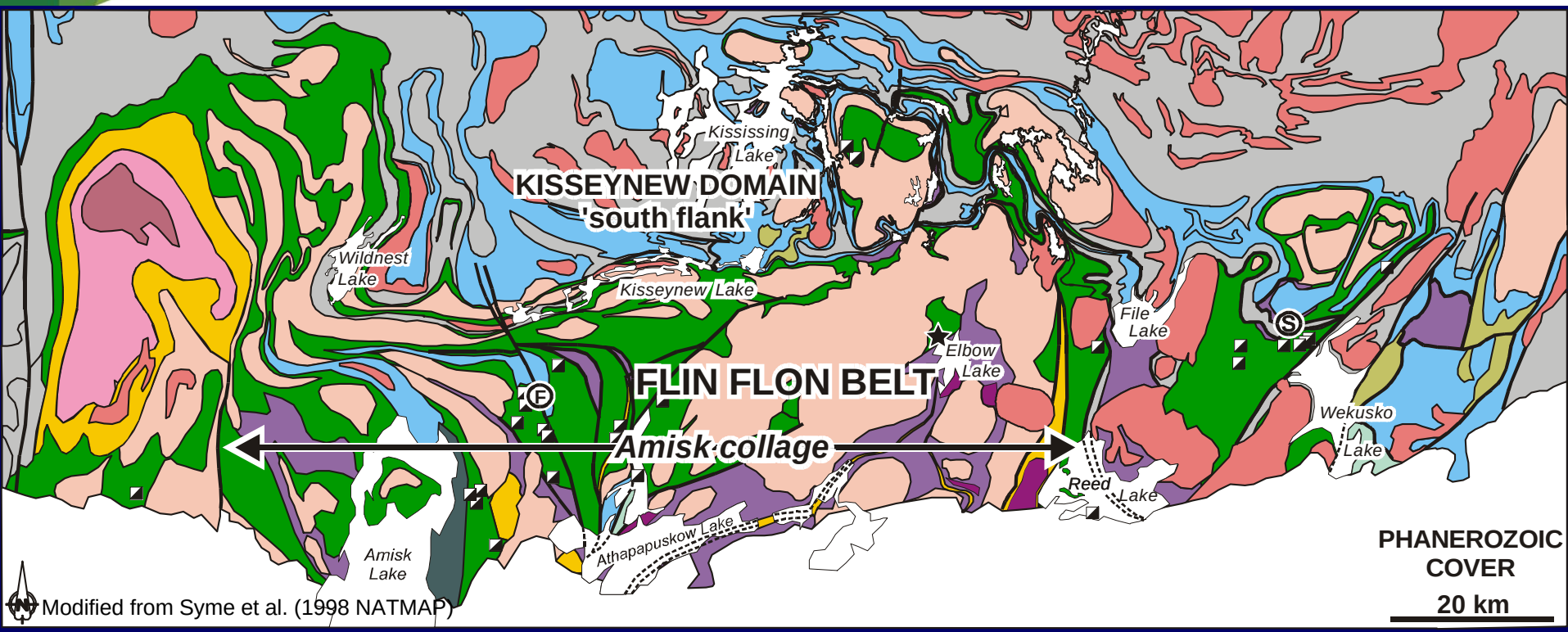

SLAVE
RAE
NAIN
HEARNE
Hudson Bay
THO
50 N
130 W
SUPERIOR
WYOMING
50 N
60 W
Atlantic Ocean
Manitoba
58°45' N
95°30' W
WB
Reindeer Zone
Hearne Craton
WB
WD
Cree Lake Zone
KD
RD
W
10
7a
7b
7c
TB
Superior Craton
4
3
3
5
Project Area
Lake Winnipeg
109°45' W
0
100
km
52°25' N
Syme et al. (1998 NATMAP)
95°30' W
52°25' N
Phanerozoic
Sedimentary Rocks
Paleoproterozoic
Sedimentary Rocks
Trans-Hudson Orogen
Continental Arc Plutonic Rocks
Marginal Basin/ Collisional Sedimentary and Plutonic Rocks
Arc Plutons/ Mixed Gneisses
Arc Volcanic and Plutonic Rocks
Continental Margin Deposits/Reworked Basement
Archean
Archean Cratons/ Pikwitonei Granulite Belt
Archean (exposed in internal domains)
Faults
LITHOPROBE Seismic Reflection Lines

Tectonic assemblages
Flin Flon Belt



PRE-ACCRETION ASSEMBLAGES (1.87-1.92 Ga)

- Juvenile arc and Undivided metavolcanic rocks
- Ocean floor (back arc) metabasalt/synvolcanic mafic intrusive
- Ocean plateau metabasalt
- ☆ Ocean island metabasalt
- Tectonite

PELICAN WINDOW GNEISSES

- Archean charnockite
- Orthogneiss and pelitic gneiss

- VMS deposit
- Fault

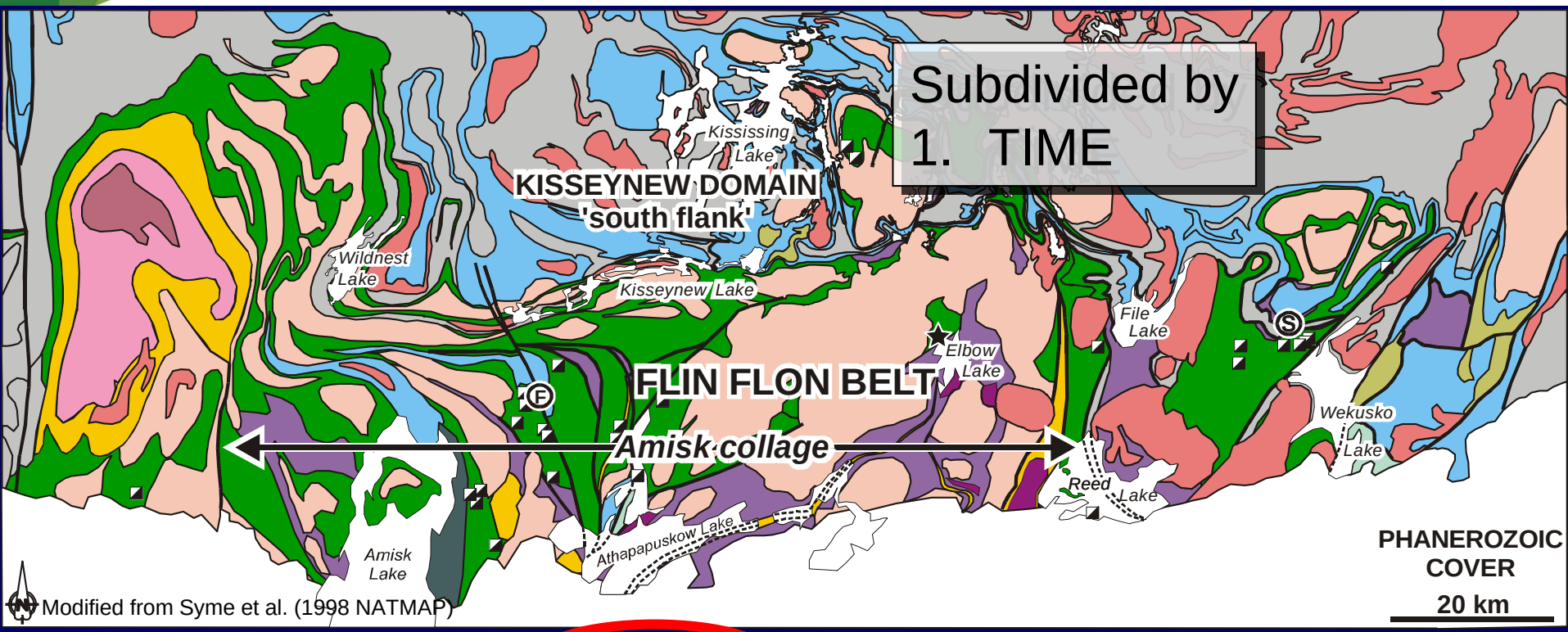
SUCCESSOR ARC and BASIN DEPOSITS

- Missi Group (1.83-1.85 Ga)
  - Continental sandstone / volcanics
- Burntwood Group turbidites (1.84 - 1.85 Ga)
- Schist-Wekusko Suite (1.85-1.88 Ga)

FELSIC-MAFIC PLUTONS

- 1.76 - 1.82 Ga (Kisseynew Belt plutons)
- 1.83 - 1.84 Ga (late successor arc plutons)
- 1.84 - 1.90 Ga (early juvenile arc + early-middle successor arc plutons)
- ca. 1.92 Ga ('evolved arc' plutons)

Tectonic assemblages
Flin Flon Belt



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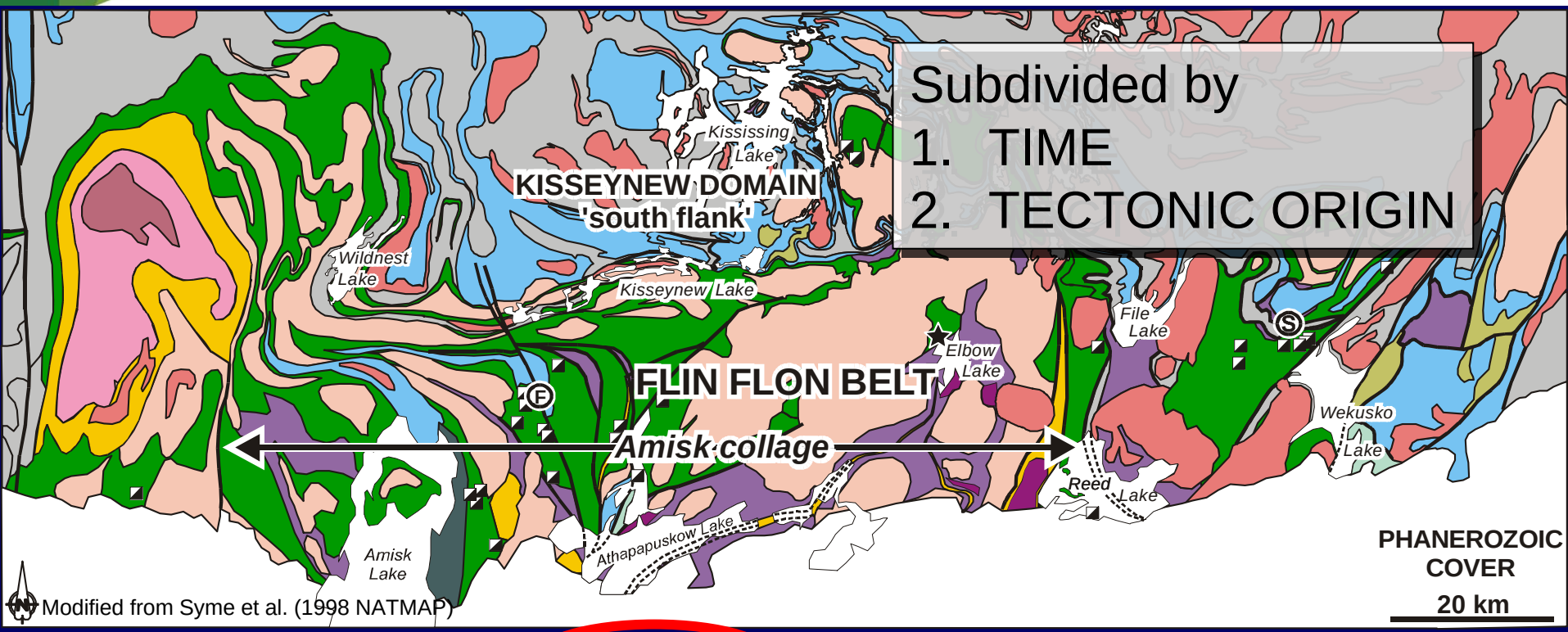

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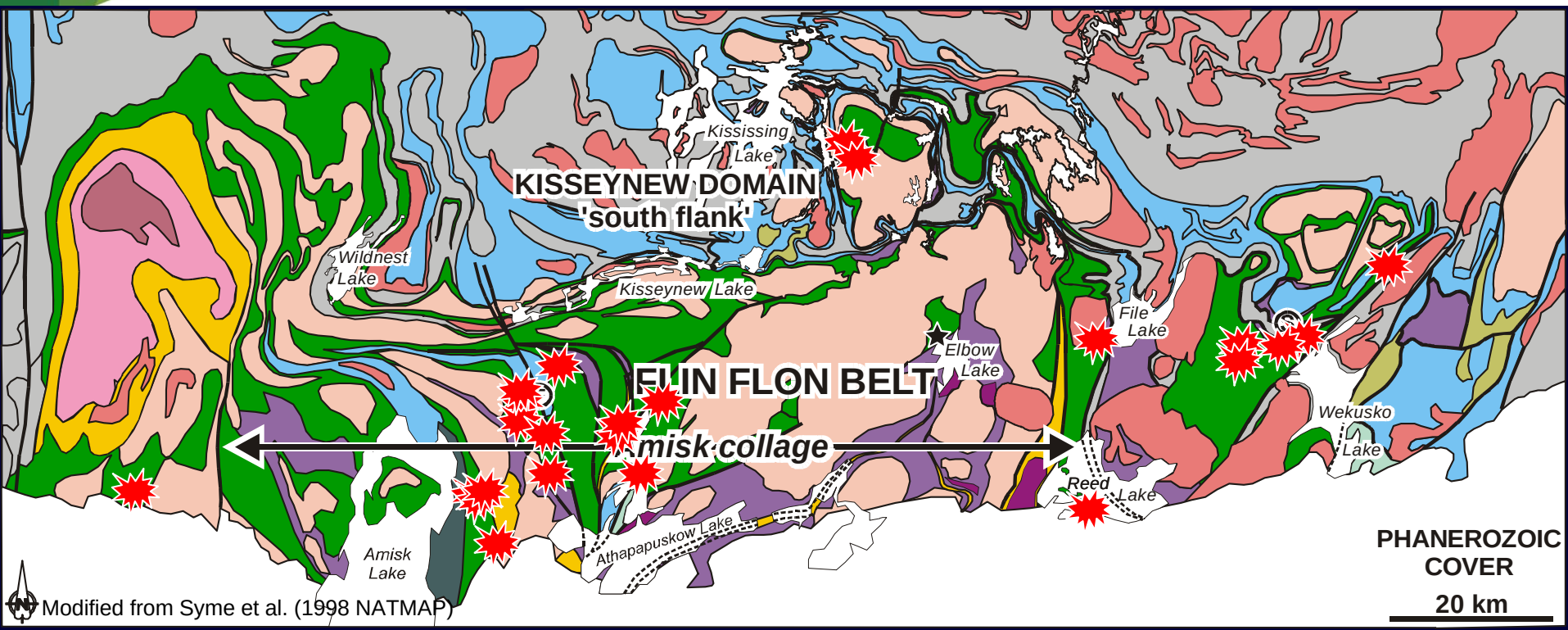
www.manitoba.ca/minerals

VMS deposits in the Flin Flon greenstone belt



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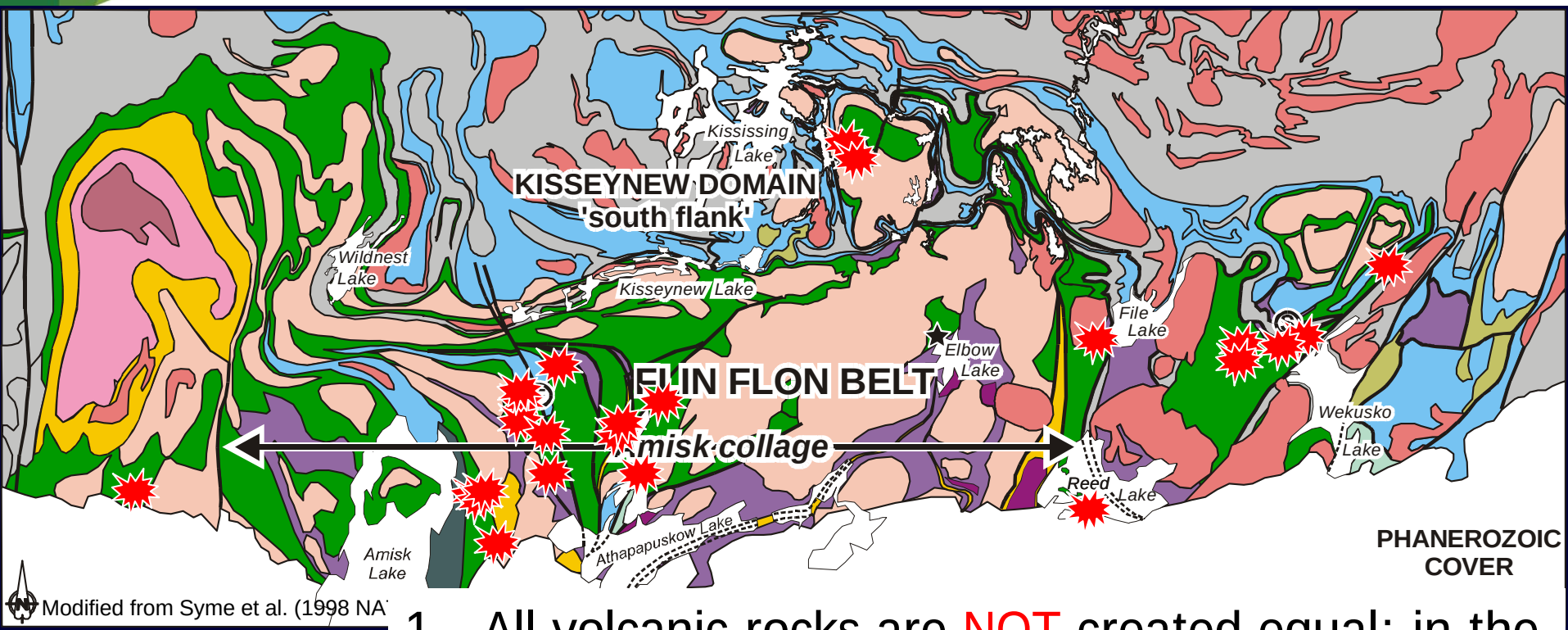
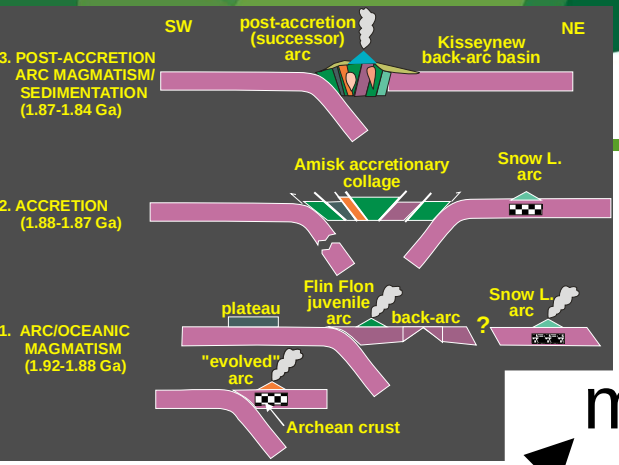


1. All volcanic rocks are NOT created equal: in the FFB, only the 1.9 Ga arc rocks contain VMS deposits
2. Regional mapping and geochemistry will identify the prospective portions of a greenstone belt

Introduction
Greenstone belt analysis



mapping

volcanic stratigraphy
physical volcanology
process-related grouping

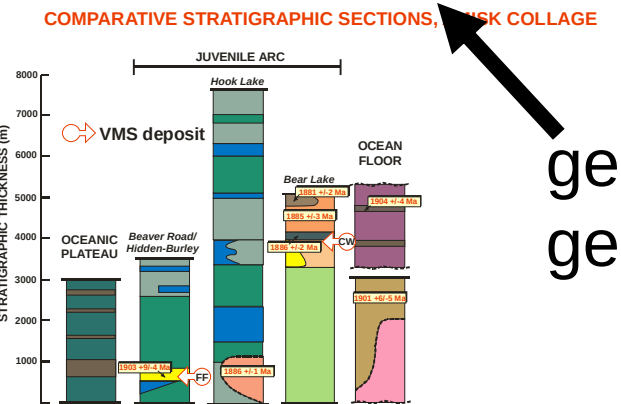
depositional setting

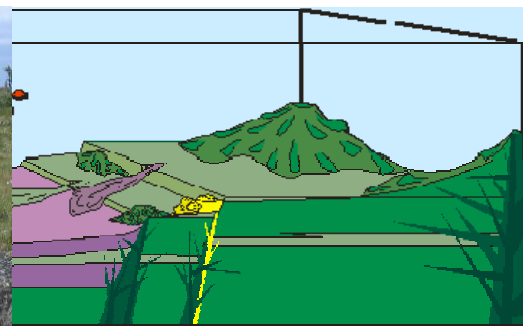
distinct volcanic associations

geochemistry
geochronology

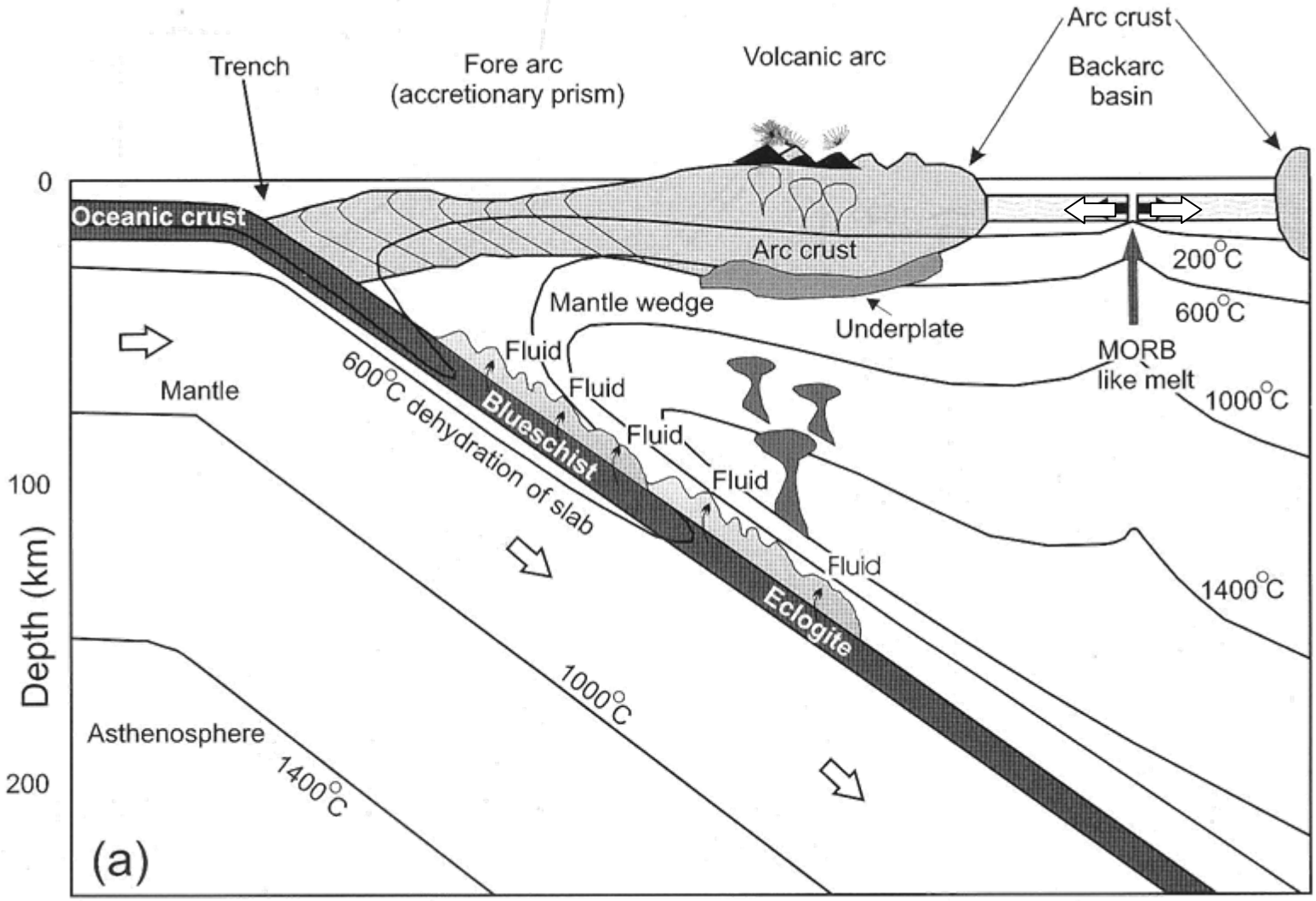
tectonostratigrahic assemblages

tectonic setting



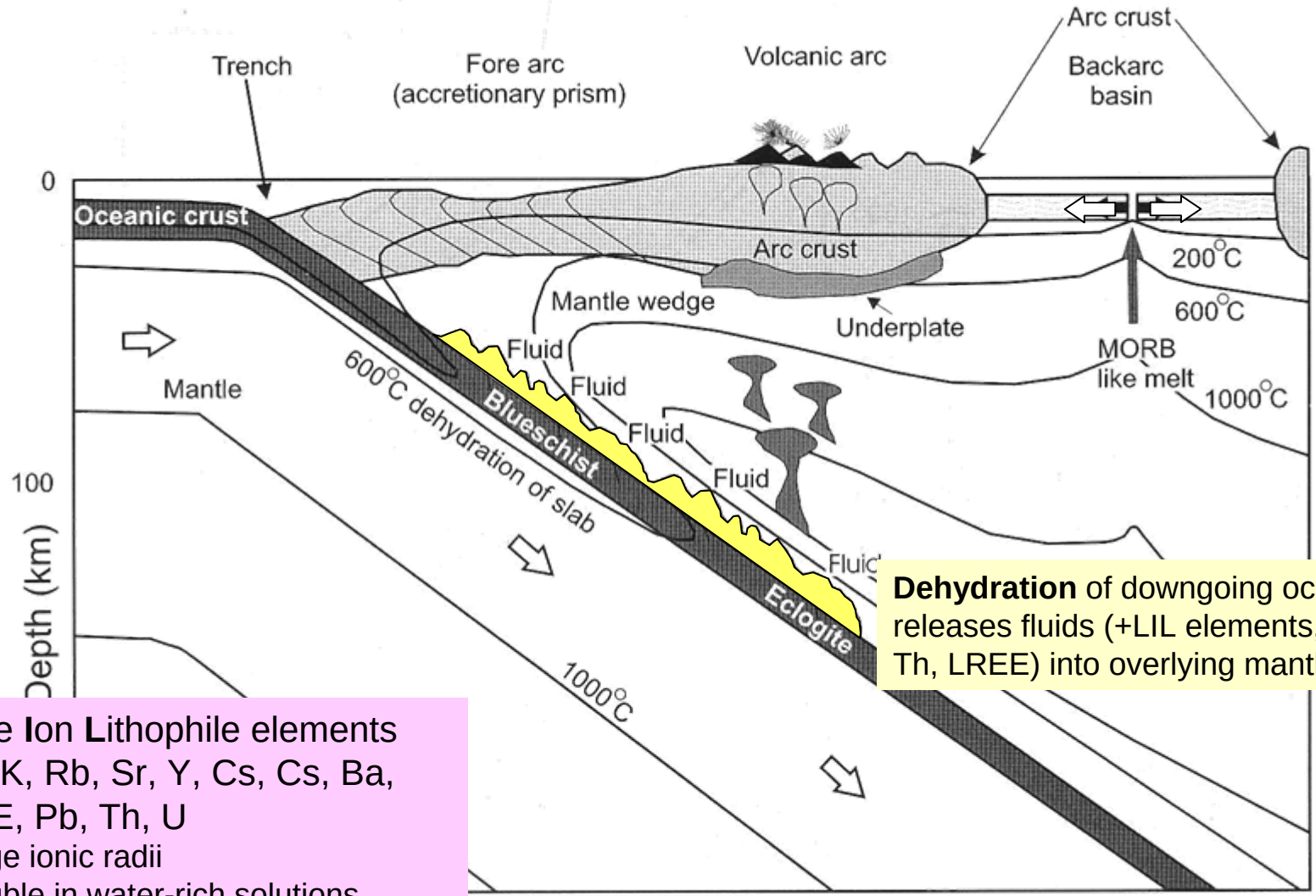


Introduction
Island arc environments



Murphy (2007), modified after Winter (2001)

Introduction
Island arc environments



Dehydration of downgoing oceanic slab releases fluids (+LIL elements, Th, LREE) into overlying mantle wedge

Large **I**on **L**ithophile elements
e.g., K, Rb, Sr, Y, Cs, Cs, Ba, REE, Pb, Th, U

- Large ionic radii
- Soluble in water-rich solutions

Murphy (2007), modified after Winter (2001)

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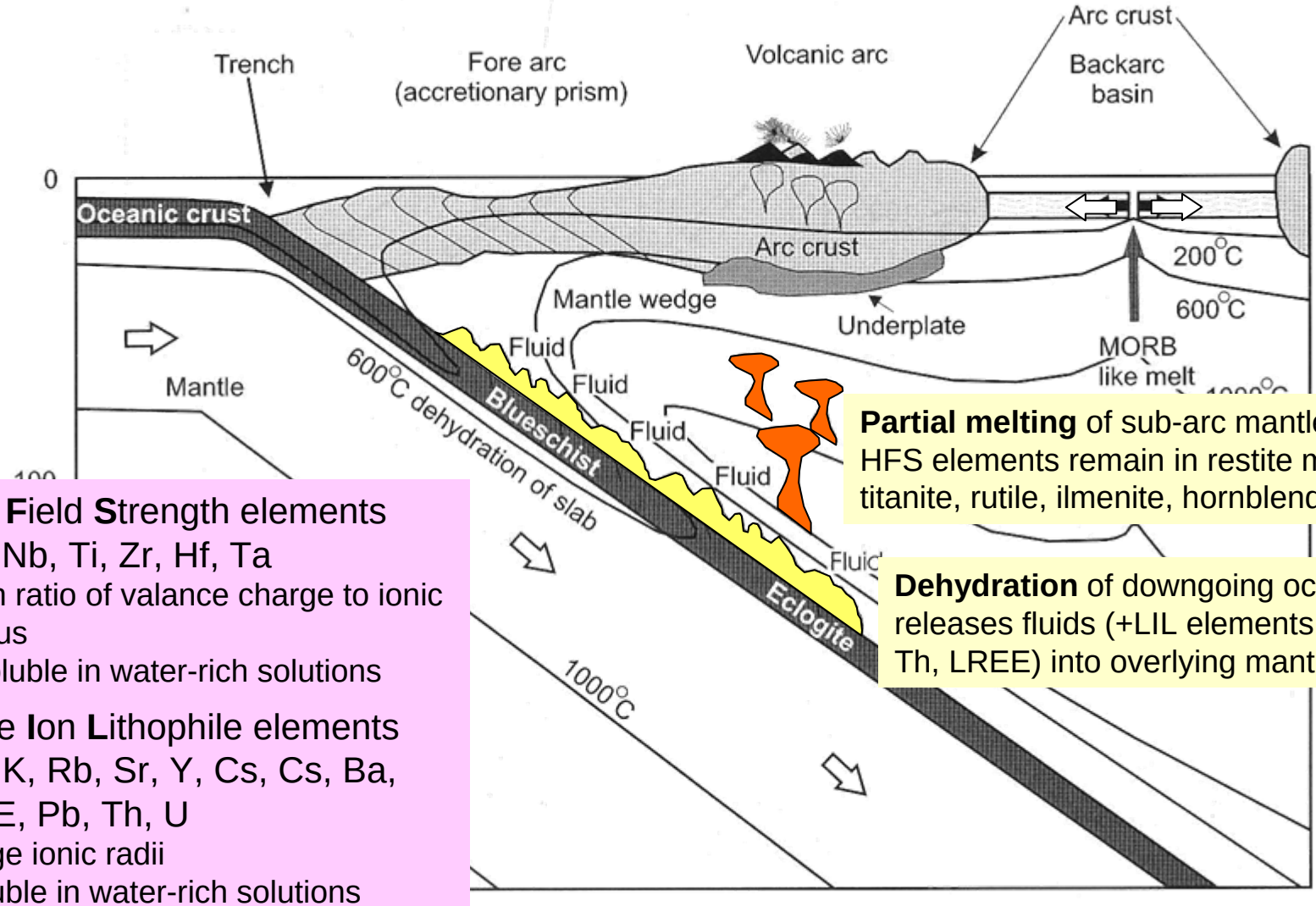
Island arc environments



Partial melting of sub-arc mantle wedge - HFS elements remain in restite minerals titanite, rutile, ilmenite, hornblende

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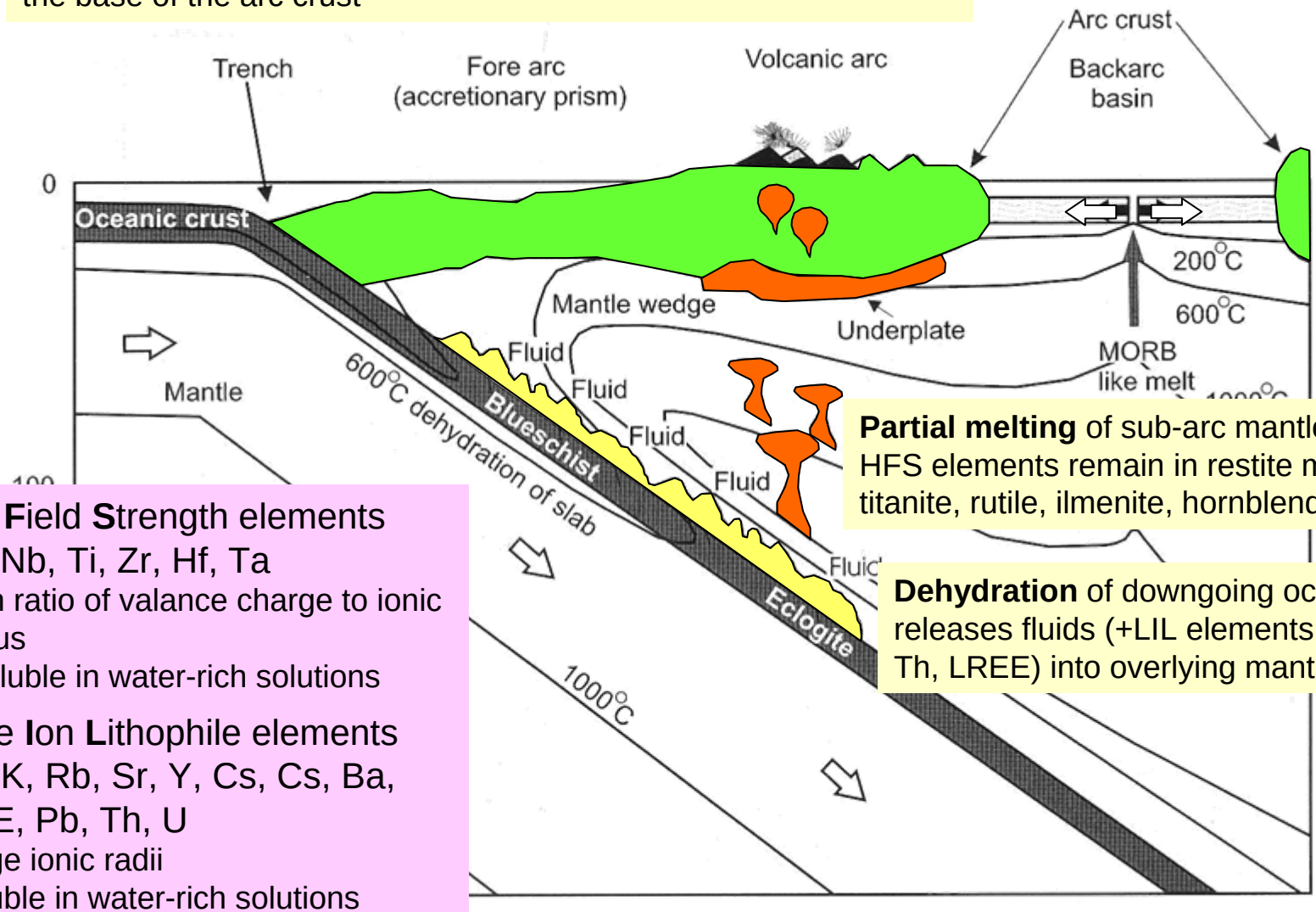
Introduction ...c environments

Arc magmas LIL-enriched, HFS-depleted and are modified from original composition by mama mixing, assimilation of older crust, storage+fractional crystallization, and homogenization (MASH) at the base of the arc crust



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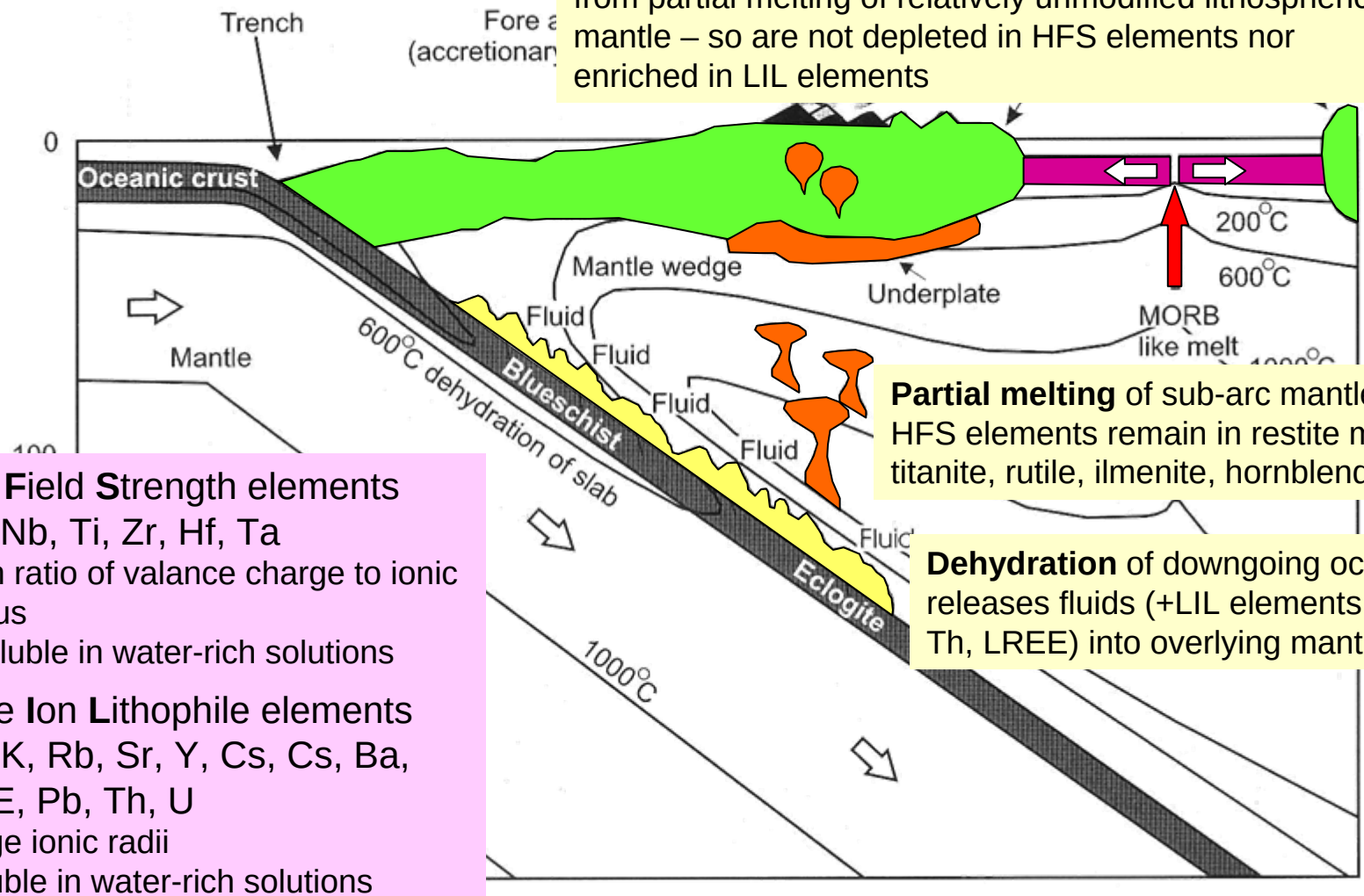
Back-arc magmas are MORB-like in character, derived from partial melting of relatively unmodified lithospheric mantle – so are not depleted in HFS elements nor enriched in LIL elements



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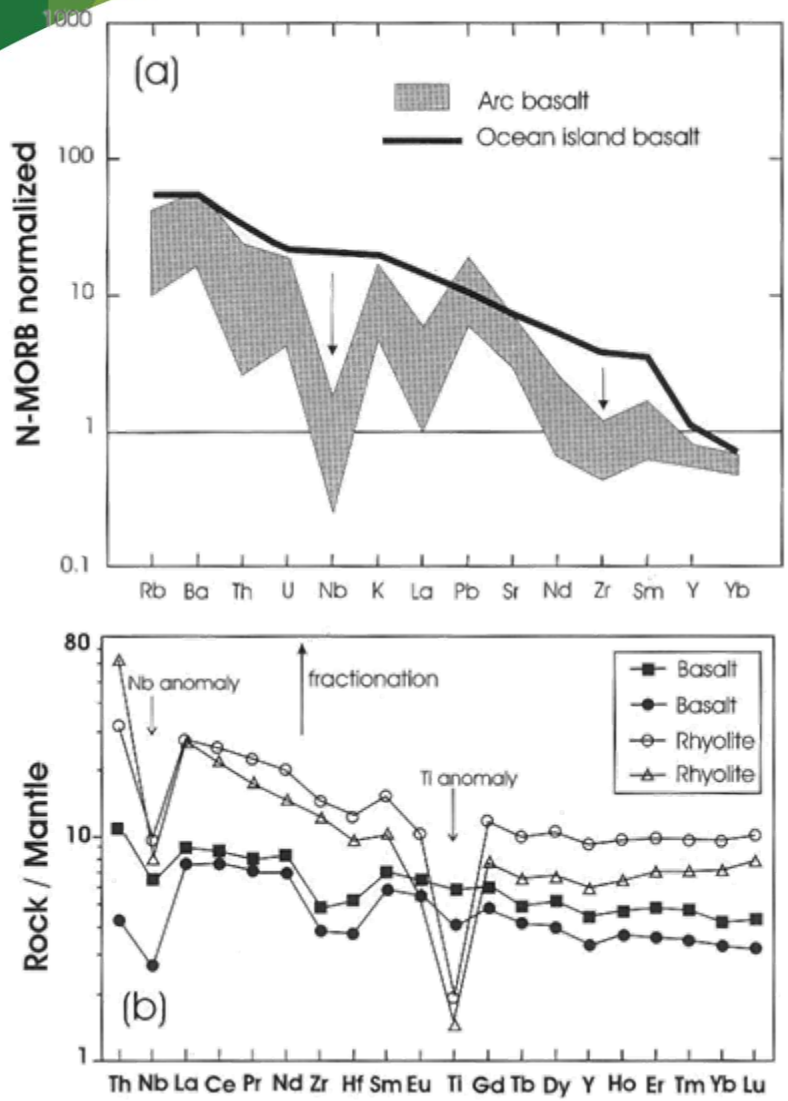
Murphy (2007), modified after Winter (2001)

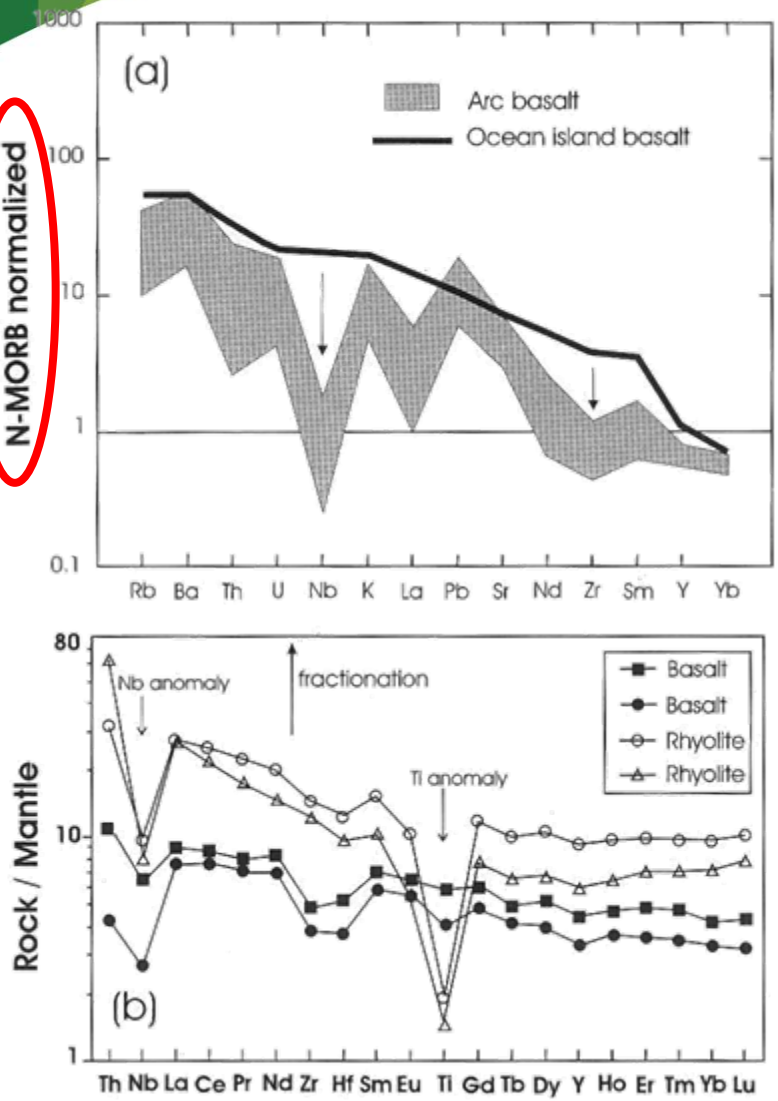
Introduction
Spider diagrams



Murphy (2007)

- Abundances of a range of trace elements are compared with a reference source; diverse reservoirs that could represent potential sources, e.g.:

Introduction
Spider diagrams



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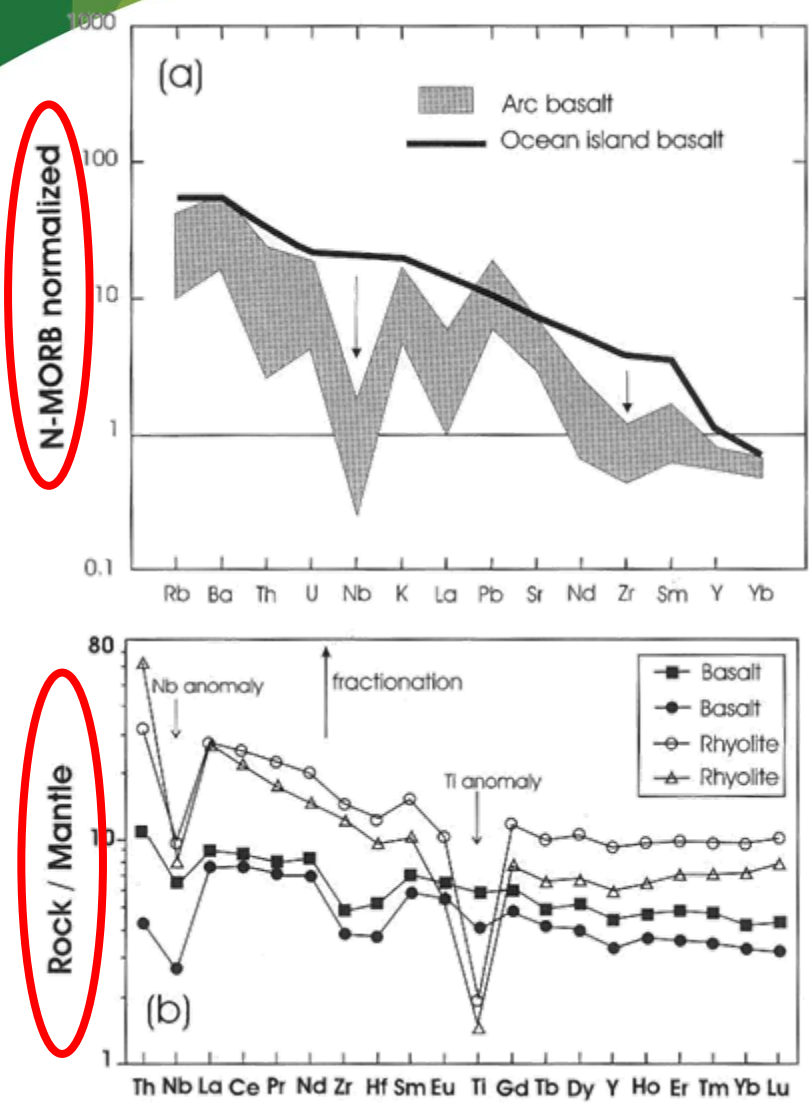

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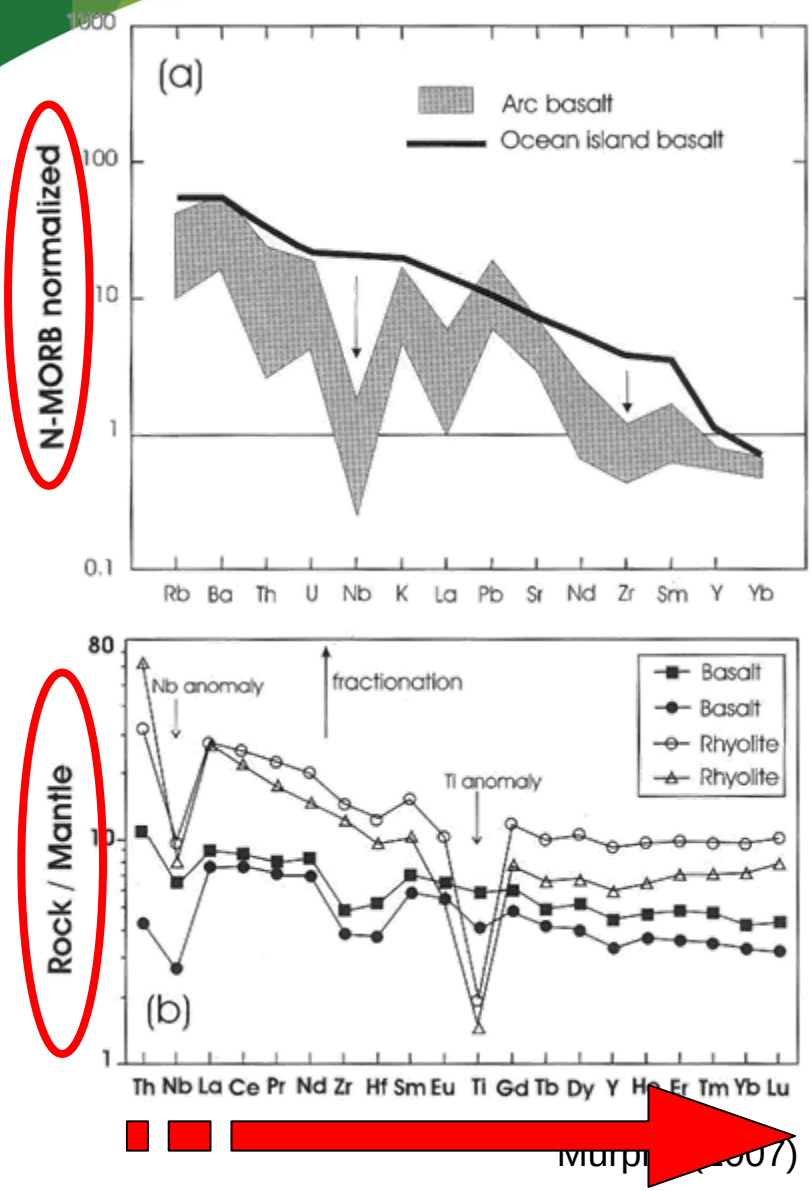
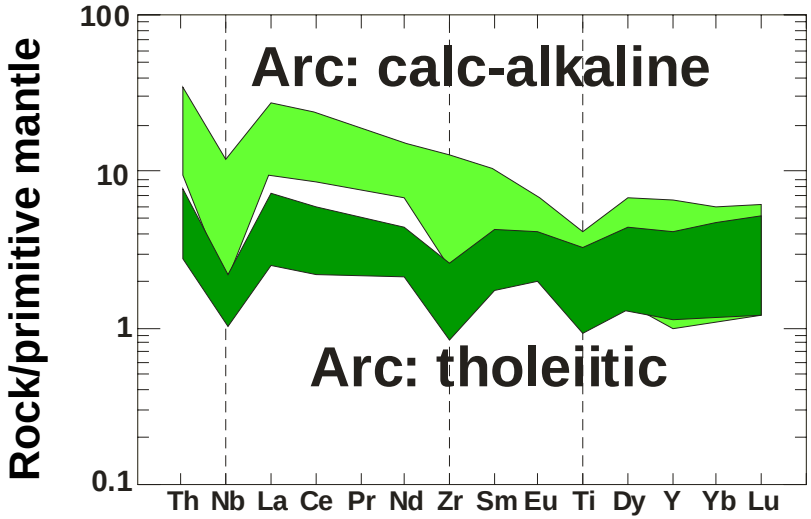


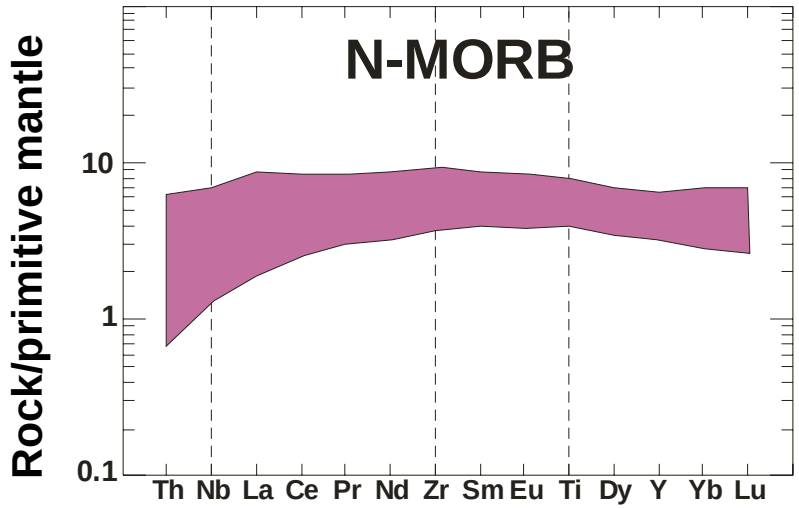
Murp (2007)

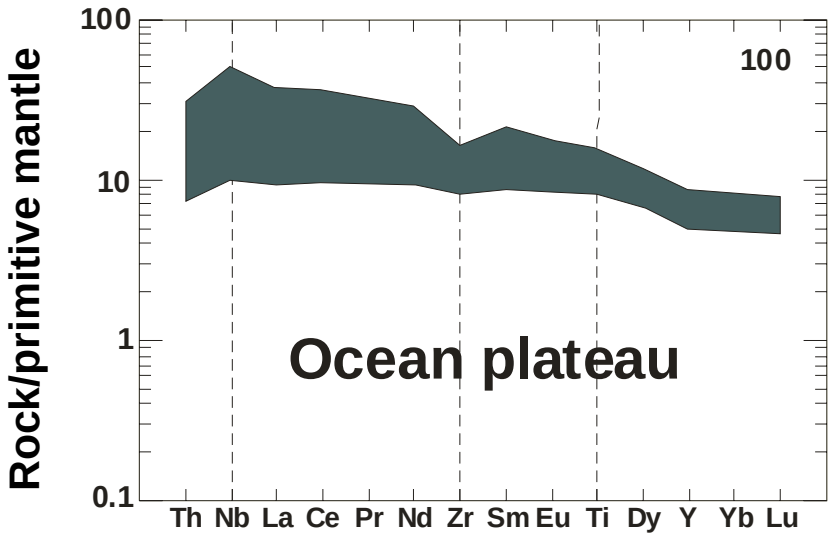
- Abundances of a range of trace elements are compared with a reference source; diverse reservoirs that could represent potential sources, e.g.:
  - MORB
  - Depleted mantle
- Elements are organized with increasing compatibility from left to right
- Variations provide information about extent of fractionation

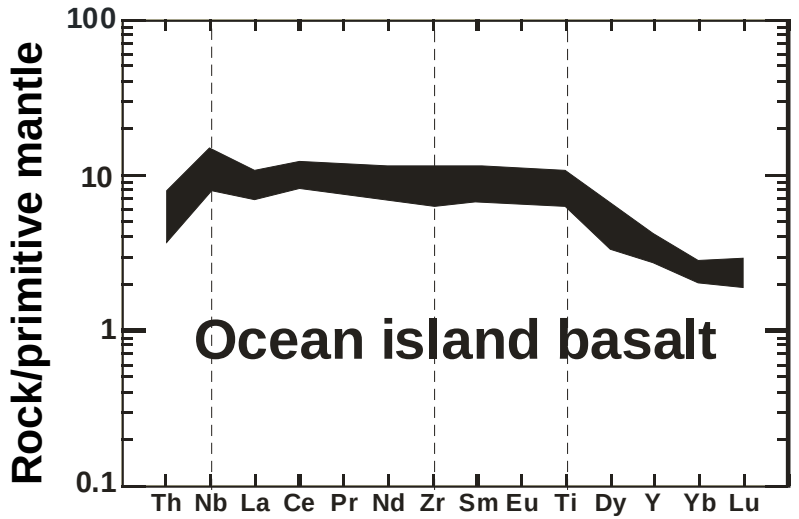
Using trace element geochemistry

1.9 Ga Assemblages in the Amisk Collage









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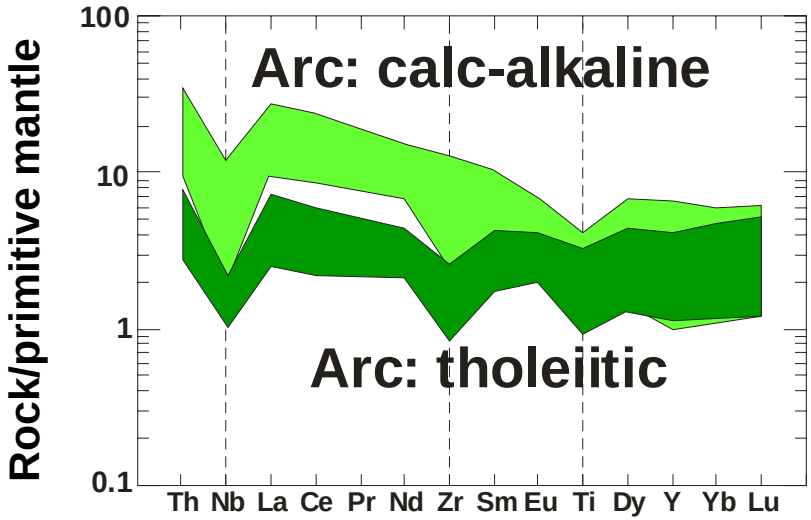
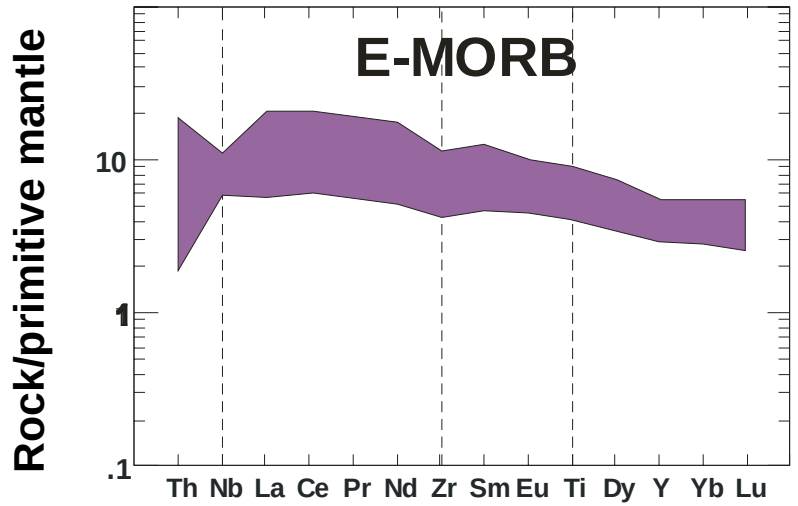
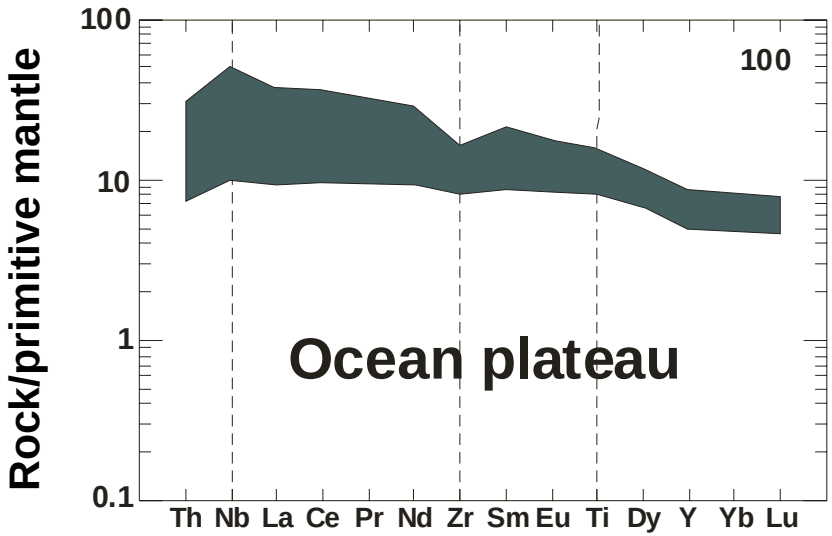
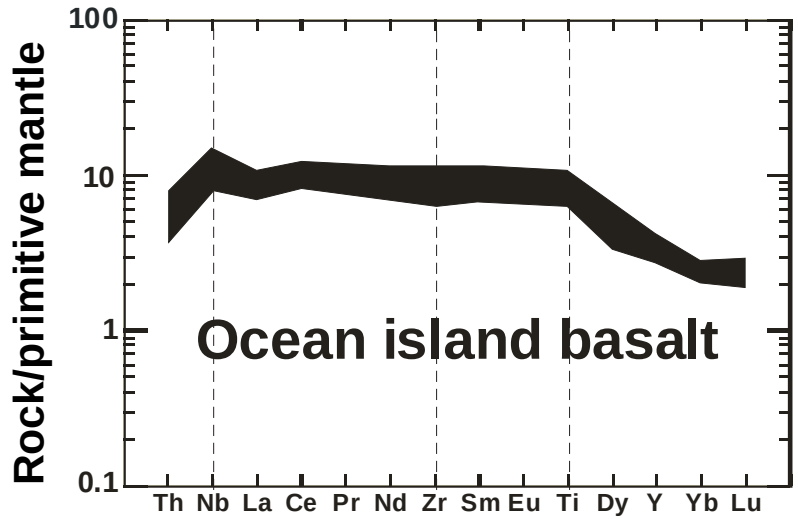
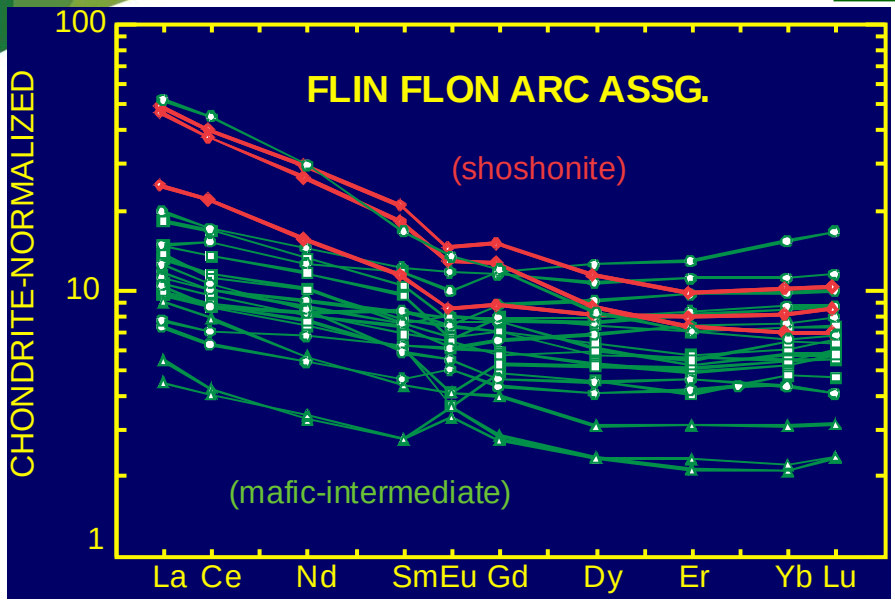


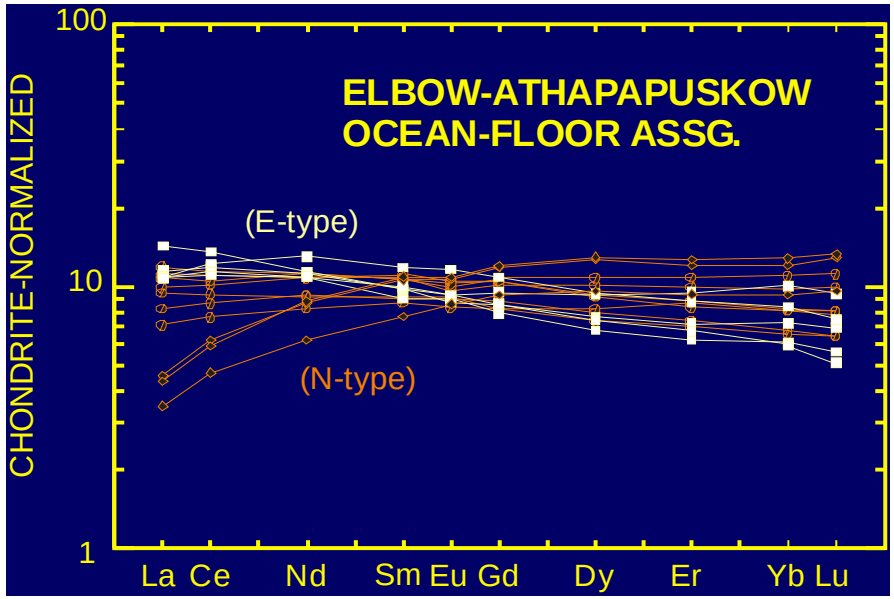


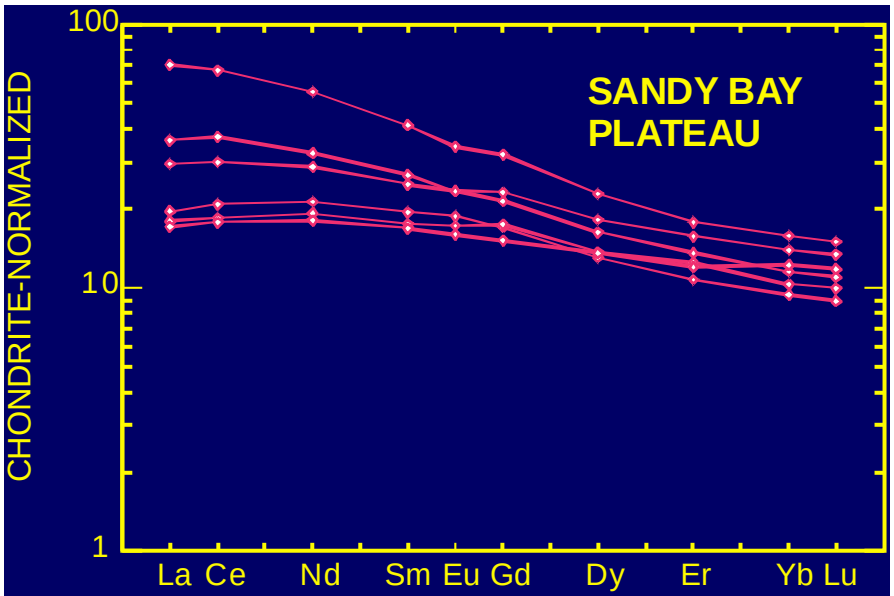


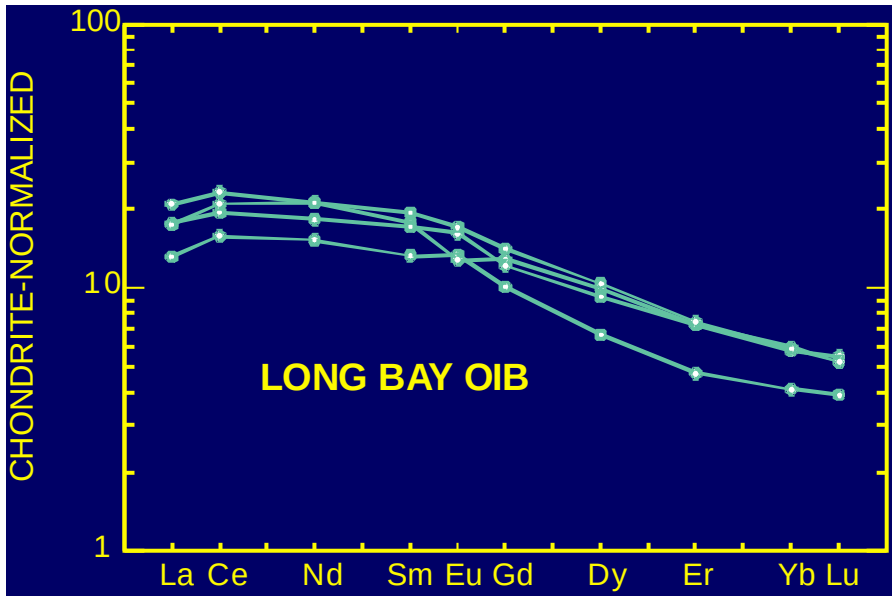


Using rare earth element geochemistry

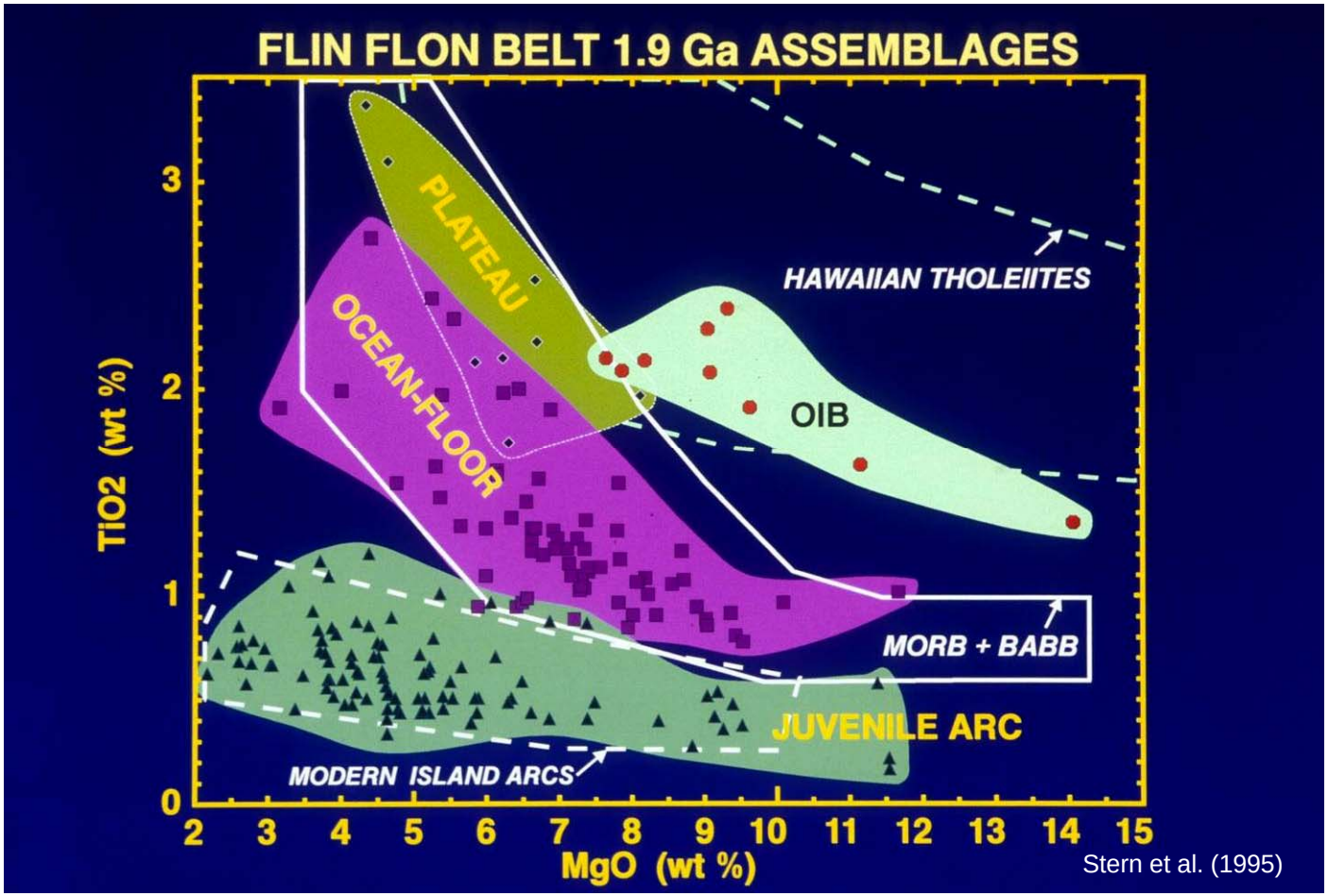




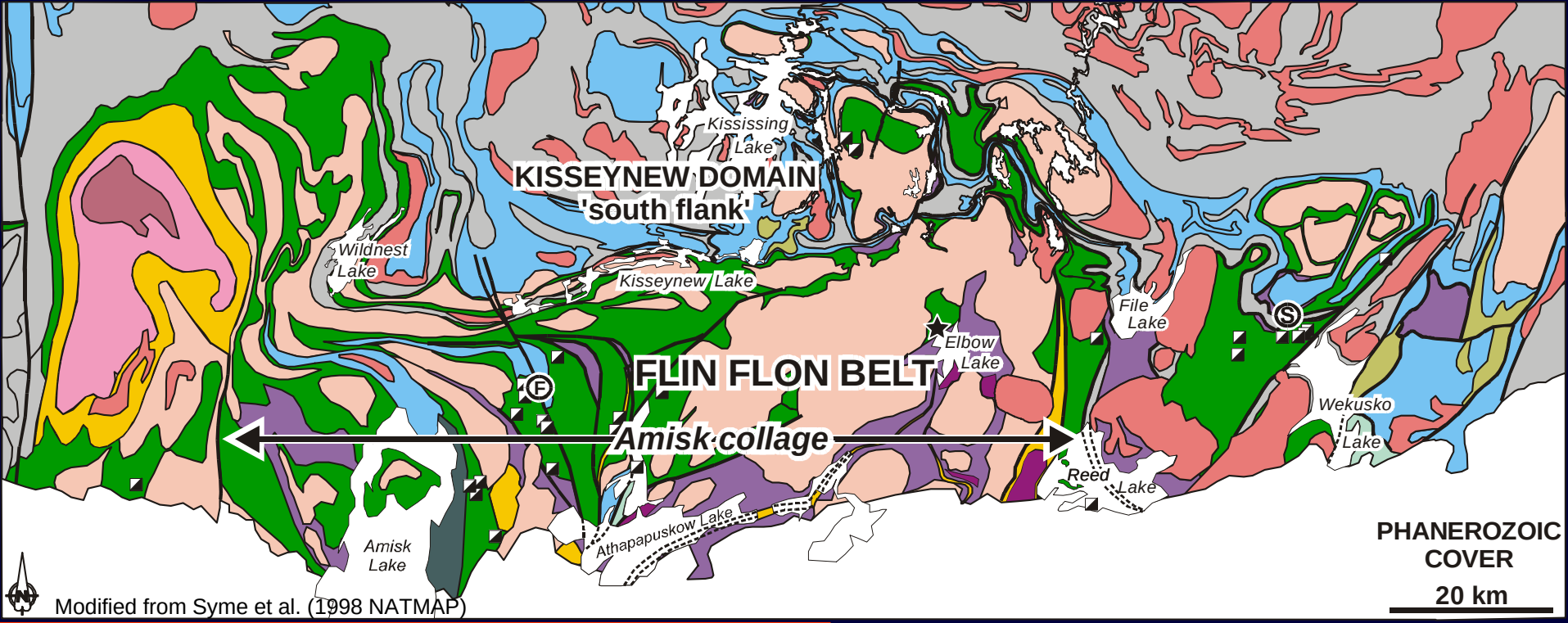




Geochemical differentiation of assemblages



- Major- and trace-element discrimination diagrams demonstrate that Flin Flon Belt volcanic rocks are compositionally similar to those in modern island arcs, ocean basins, and oceanic islands



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- ☆ Ocean island metabasalt
- Tectonite

Areal percentages of 1.9 Ga tectonostratigraphic assemblages in the exposed Flin Flon Belt

Juvenile arc	68%
Ocean floor/BABB	20%
Oceanic plateau	2%
Ocean island basalt	<1%
Evolved arc (plutonic)	<1%
affinity unknown	9%

Arc assemblages

1.91-1.88 Ga:

arc

back-arc

oceanic plateau

ocean island

volcanism and plutonism

1. Compositionally diverse

- tholeiitic 1.890, 1.903 Ga
- calc-alkaline 1.888, 1.882 Ga
- shoshonite 1.885 Ga
- boninite

Arc assemblages

1.91-1.88 Ga:

arc

back-arc

oceanic plateau

ocean island

volcanism and plutonism

1. Compositionally diverse

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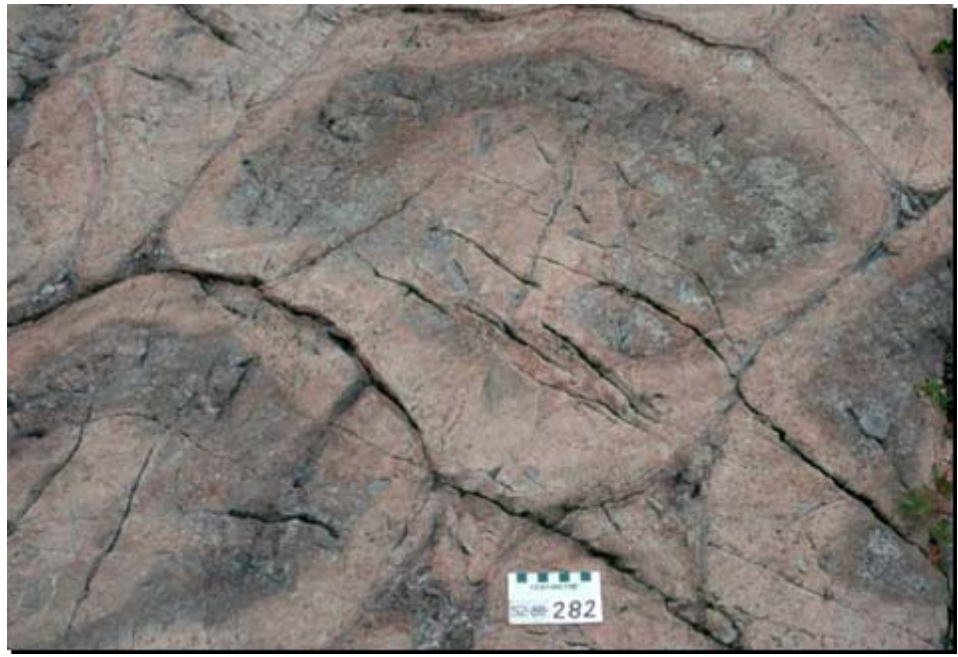
- calc-alkaline 1.888, 1.882 Ga
- shoshonite 1.885 Ga
- boninite
- dominantly basalt and basaltic andesite



Pillowed basaltic andesite with pumpellyite alteration, FF

Arc assemblages

1.91-1.88 Ga:

arc

back-arc

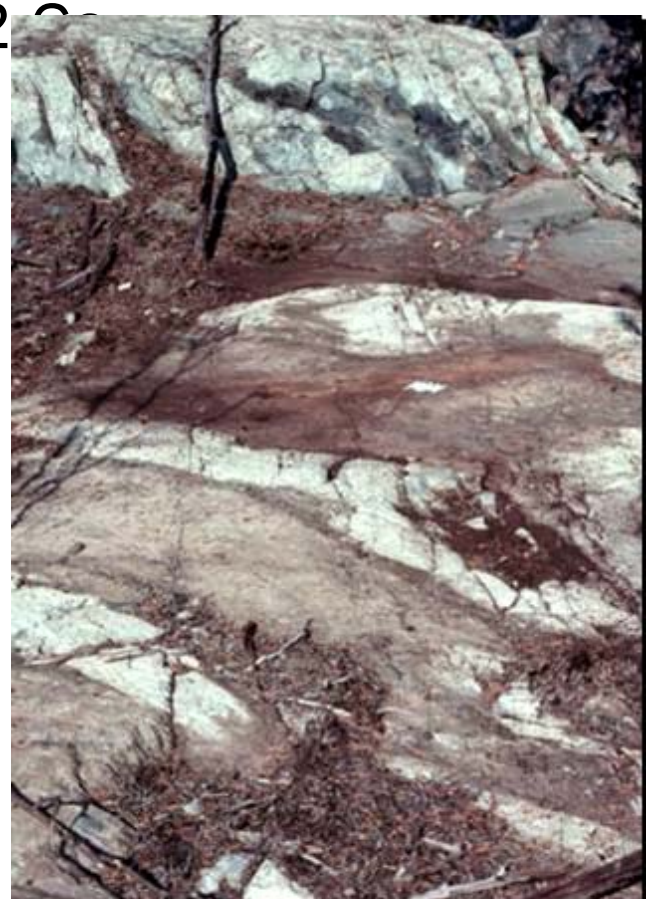
oceanic plateau

ocean island

volcanism and plutonism

1. Compositionally diverse

- tholeiitic 1.890, 1.903 Ga
- calc-alkaline 1.888, 1.882 Ga
- shoshonite 1.885 Ga
- boninite
- dominantly basalt and basaltic andesite
- rhyolite subordinate



Subaqueous rhyolite flow: massive lobes and hyaloclastite, Flin Flon

Arc assemblages

1.91-1.88 Ga:

arc

back-arc

oceanic plateau

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- volcaniclastic rocks common
-

Heterolithologic volcanic breccia, Flin Flon

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- volcaniclastic rocks common
- dominantly subaqueous

Heterolithologic volcanic breccia, Flin Flon

1.91-1.88 Ga:

arc

back-arc

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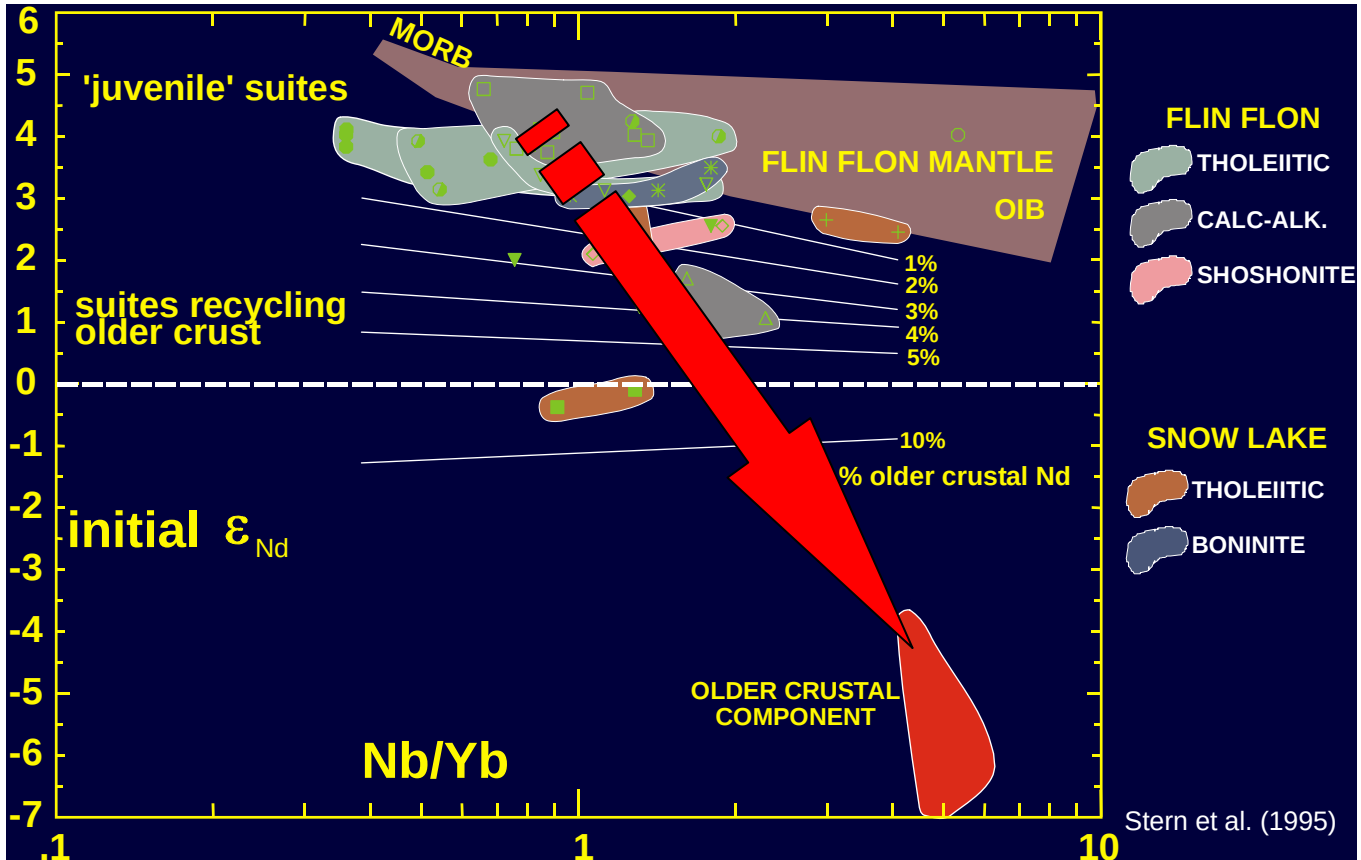
2. Dominantly juvenile

…but elevated Th/Yb, Ba/La, La/Nb and spread in Nd isotopic compositions (initial ε_{Nd} = -0.4 to +4.8) suggests recycling of small component of older Archean or Proterozoic crust via sediment subduction and, locally, intracrustal contamination.



Arc assemblages

1.91-1.88 Ga:

arc

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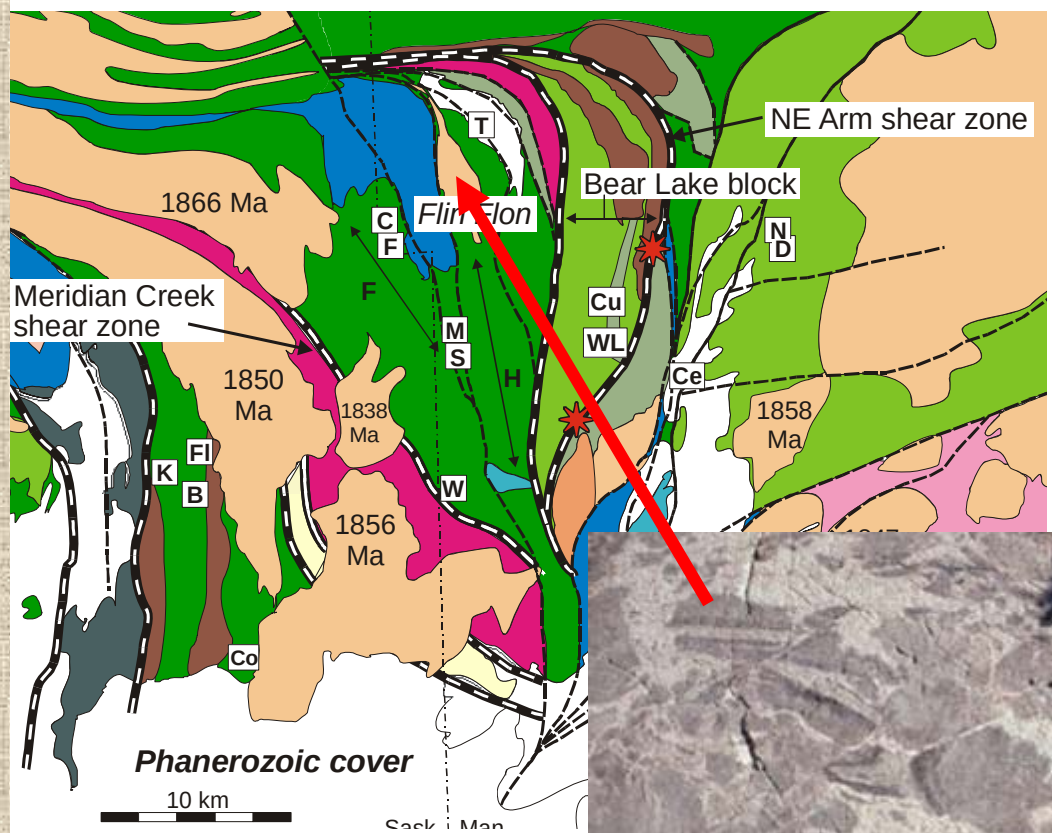


3. Synvolcanic plutonic rocks

Cliff Lake tonalite with abundant pillow basalt xenoliths
1.886 Ga

Arc assemblages

1.91-1.88 Ga:

arc

back-arc

oceanic plateau

ocean island

volcanism and plutonism

4. Host to volcanogenic massive sulphide deposits in the Flin Flon Belt

- associated with tholeiitic and calc-alkaline rocks
- environments include intra-arc rifts, fault-bounded depositional basins, calderas
  - ❑ at lithologic, geochemical and/or isotopic breaks in volcanic stratigraphy
  - ❑ in depositional basins
  - ❑ underlain by volcaniclastic rocks
  - ❑ commonly associated with rhyolitic rocks (flows, breccias) low $(La/Yb)_N$ and Zr/Y ratios
- products of a regime characterized by high heat flow
  - ❑ eruption of isotopically primitive, high T rhyolites
  - ❑ large scale hydrothermal alteration systems; disconformable footwall alteration
- +/- subvolcanic intrusions

Arc assemblages

1.91-1.88 Ga:

arc

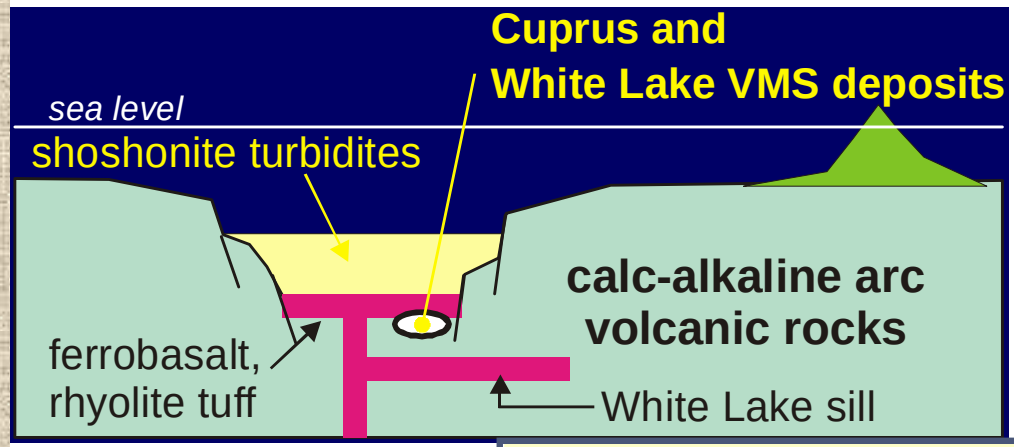
back-arc

oceanic plateau

ocean island

volcanism and plutonism

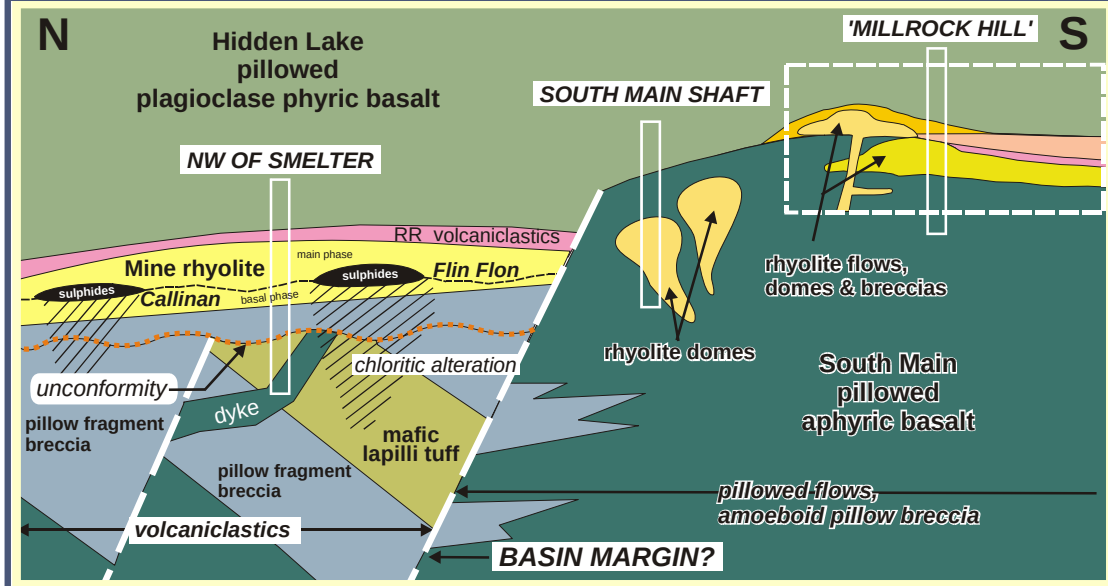
4. Host to most of the volcanogenic massive sulphide deposits in the Flin Flon Belt



Syme et al. (1998)

Inferred tectonic setting of the Cuprus and White Lake VMS deposits

Schematic section through the Flin Flon VMS deposit



Syme et al. (1998) modified from Syme and Bailes (1993)

Ocean floor assemblages

1.91-1.88 Ga:

arc

back-arc

oceanic plateau

1. Appear to have been generated at oceanic ridges and back-arc basins

- N-type and E-type basalts
- mainly pillowed, in mappable “formations” that are each km’s thick
- No rhyolite; no thick volcaniclastic sequences

N-type pillowed basalt, Elbow Lake

N-type pillowed basalt, Reed Lake

Ocean floor assemblages

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arc

back-arc

oceanic plateau

ocean island

volcanism and plutonism

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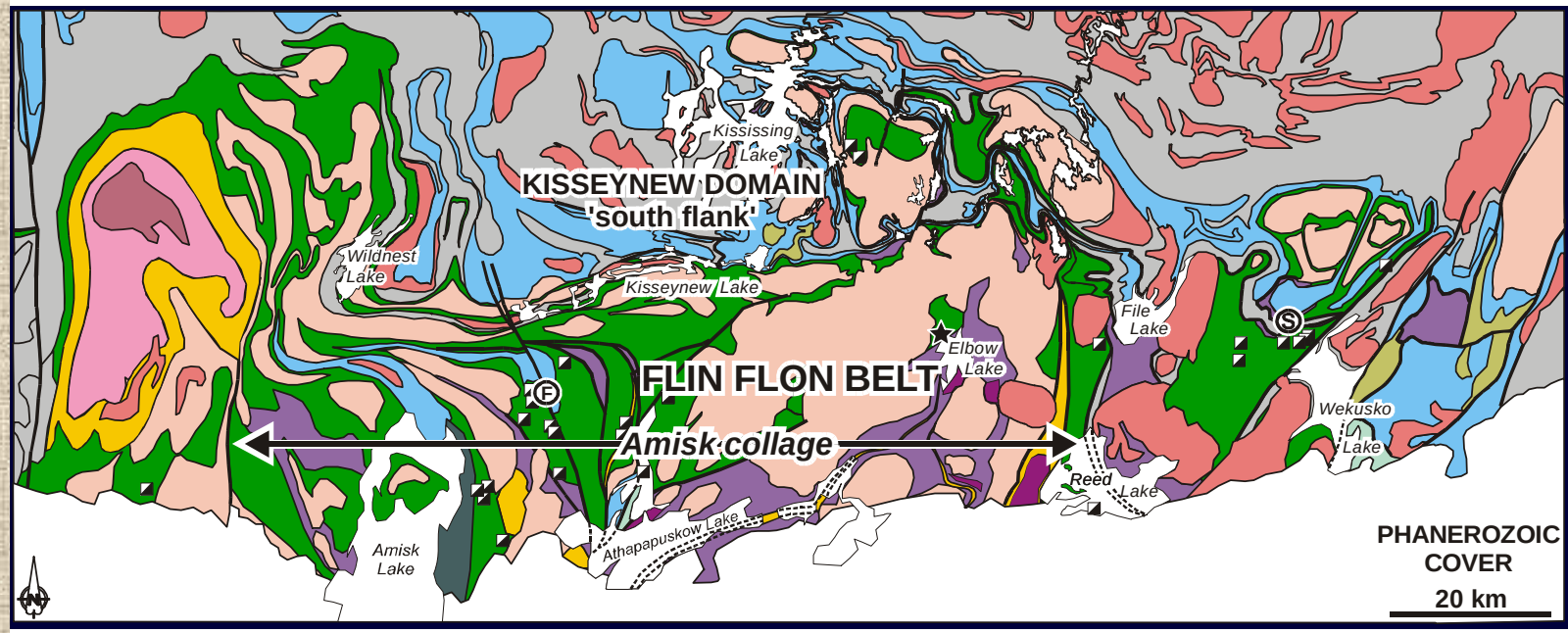
- Dominate FFB between Flin Flon and Snow Lake



Ocean floor assemblages

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arc

back-arc

oceanic plateau

ocean island

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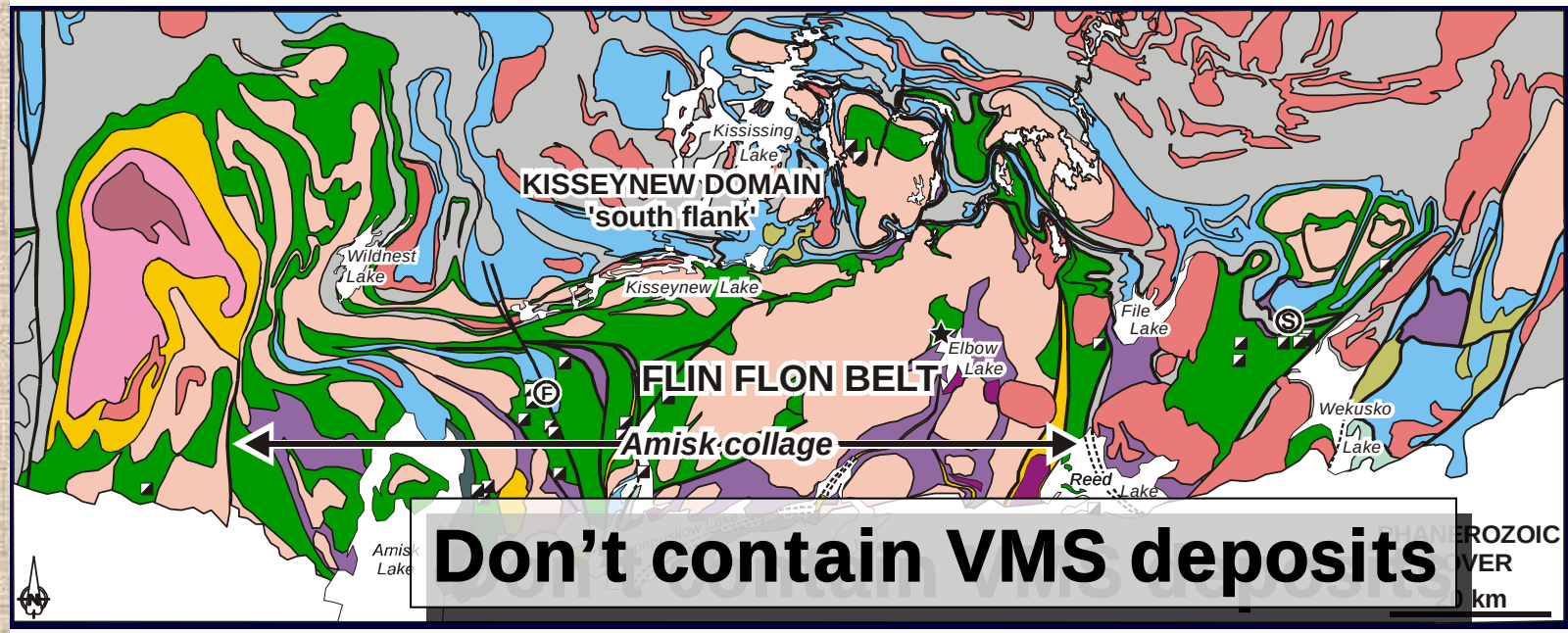

Ocean floor assemblages

1.91-1.88 Ga:

arc

back-arc

oceanic plateau

2. Kilometre-scale intrusive complexes

- Ages similar to arc assemblage (1.9 Ga)
- Layered series (peridotite, pyroxenite, gabbro) and younger vari-textured gabbro
- Represent mafic plutonic base of oceanic crust

Claw Lake layered peridotite-pyroxenite-gabbro (1.901 Ga)

Layered gabbros, Claw Lake

Ocean floor assemblages

1.91-1.88 Ga:

arc

back-arc

oceanic plateau

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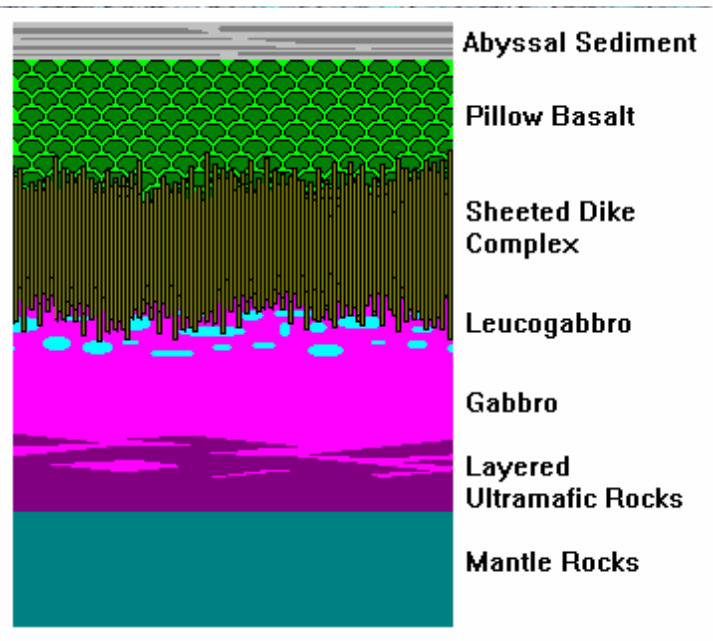


Oceanic plateau assemblages

1.91-1.88 Ga:

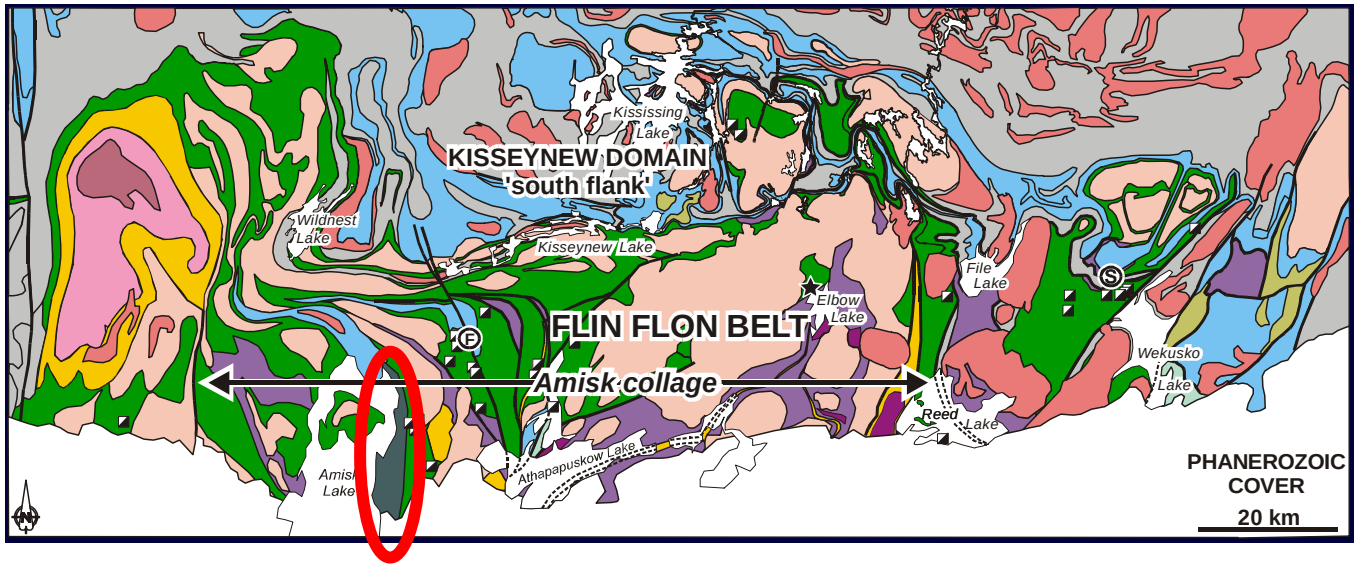
arc

back-arc

oceanic plateau

ocean island

volcanism and plutonism



1. Pillow basalts
2. Juvenile (initial ε_{Nd} = +4.5)
3. Evolved E-types
4. Potentially plume-related

Sandy Bay E-type pillowed basalt, Amisk Lake

Oceanic plateau assemblages

1.91-1.88 Ga:

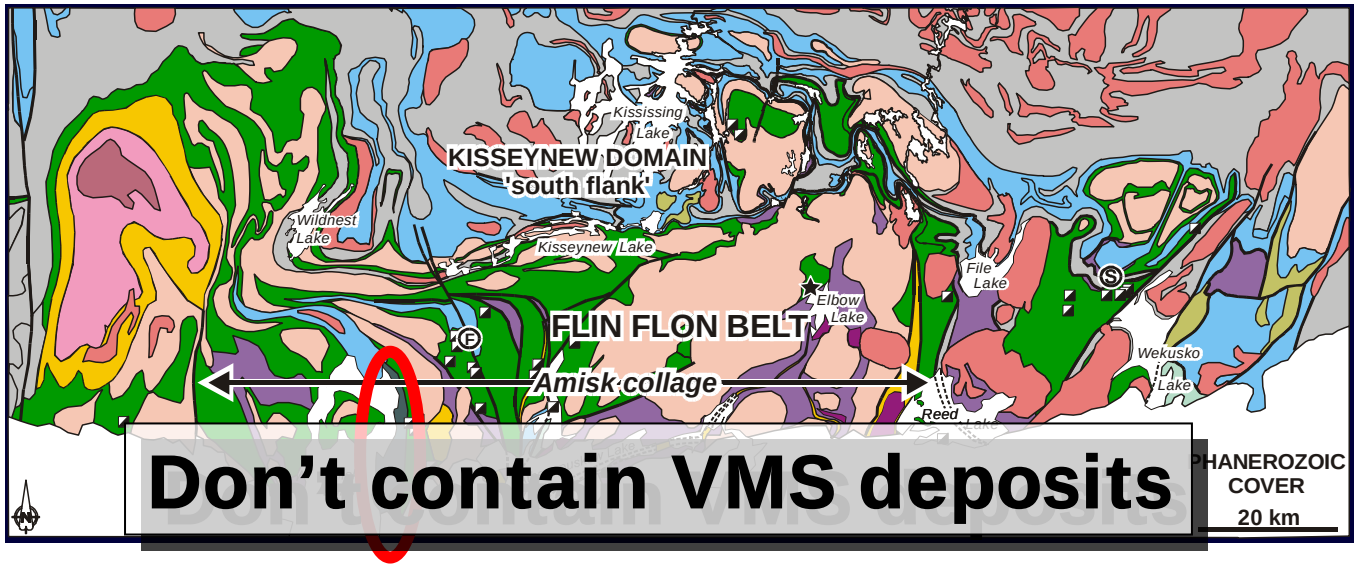
arc

back-arc

oceanic plateau

ocean island

volcanism and plutonism



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Sandy Bay E-type pillowed basalt, Amisk Lake

Ocean island basalt (OIB) assemblages

1.91-1.88 Ga:

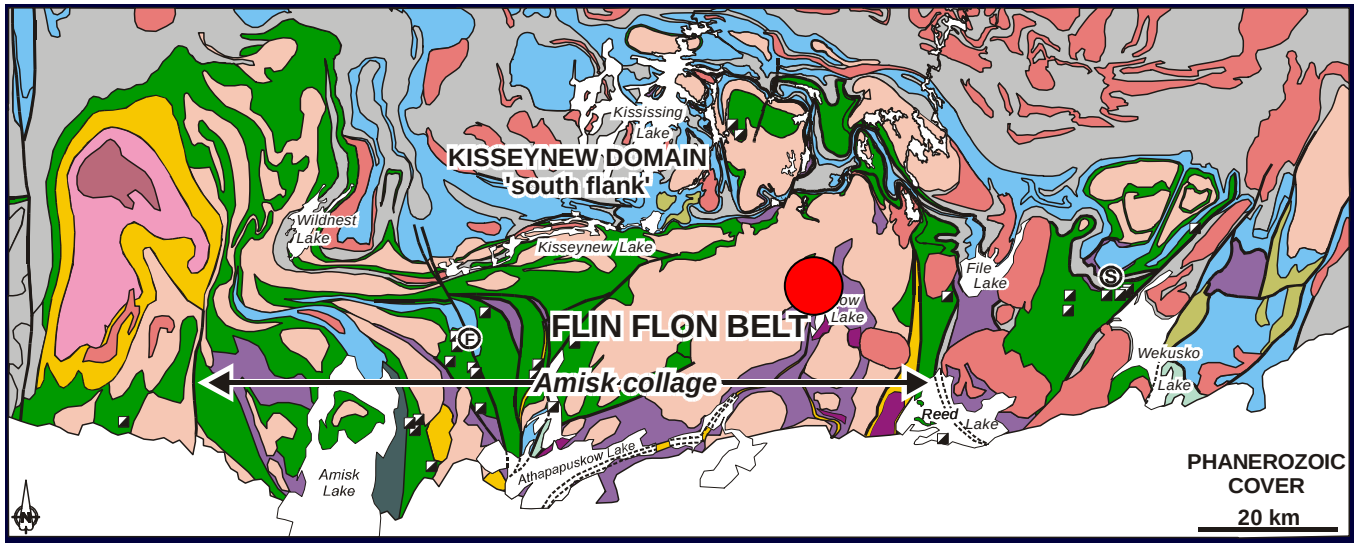
arc

back-arc

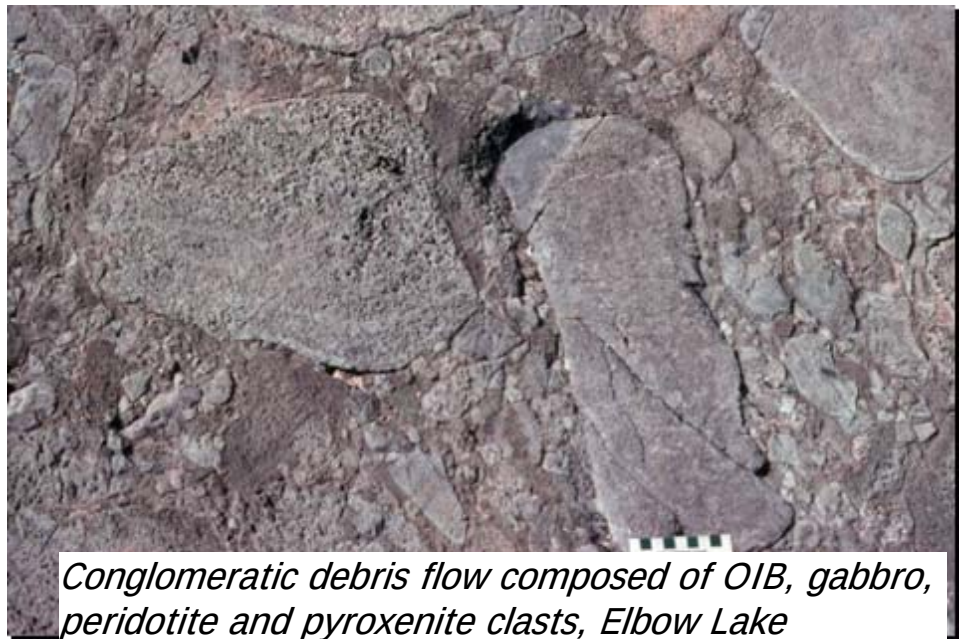
oceanic plateau

ocean island

volcanism and plutonism



1. Coarse-grained, graded subaqueous debris flow deposits
2. Juvenile (initial ε_{Nd} = +2.2 to +3.4)
3. Compositionally restricted (OIB)



Conglomeratic debris flow composed of OIB, gabbro, peridotite and pyroxenite clasts, Elbow Lake

Ocean island basalt (OIB) assemblages

1.91-1.88 Ga:

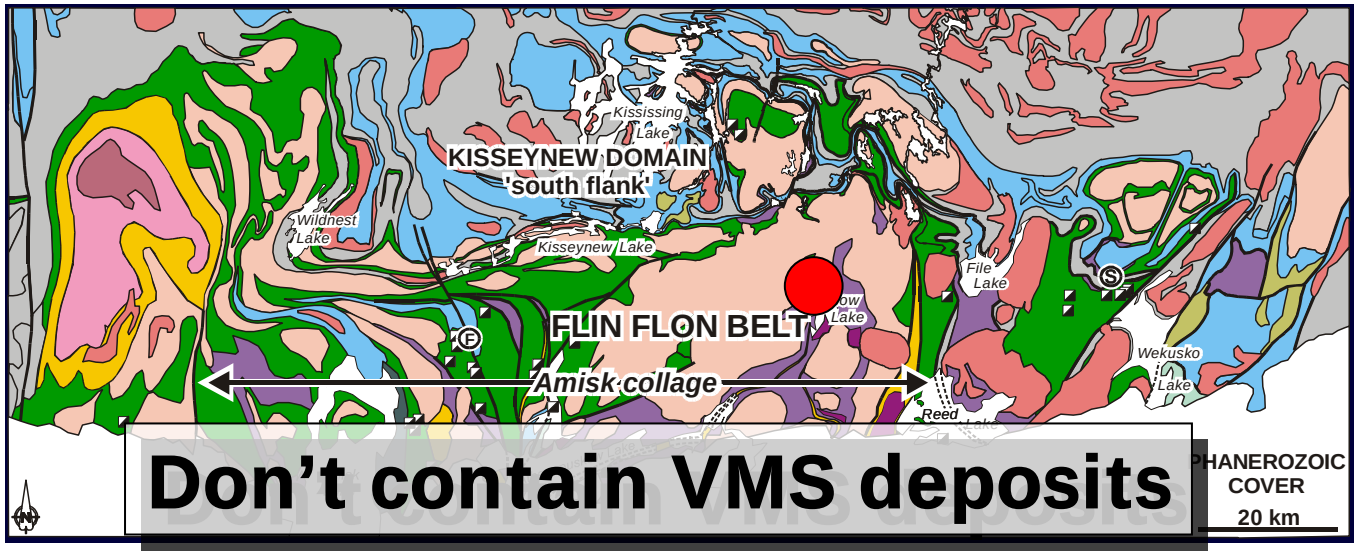
arc

back-arc

oceanic plateau

ocean island

volcanism and plutonism



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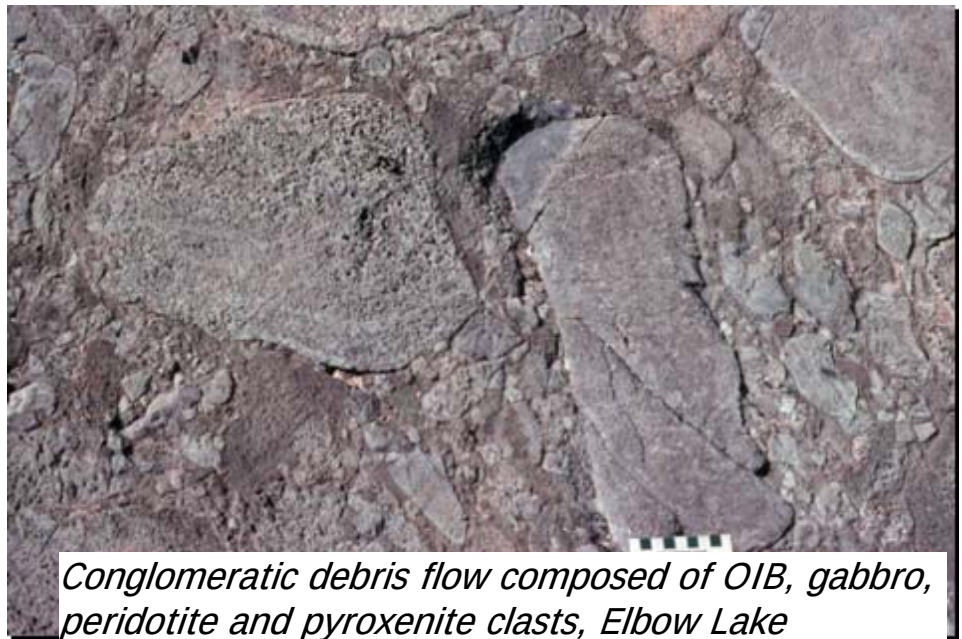


Conglomeratic debris flow composed of OIB, gabbro, peridotite and pyroxenite clasts, Elbow Lake

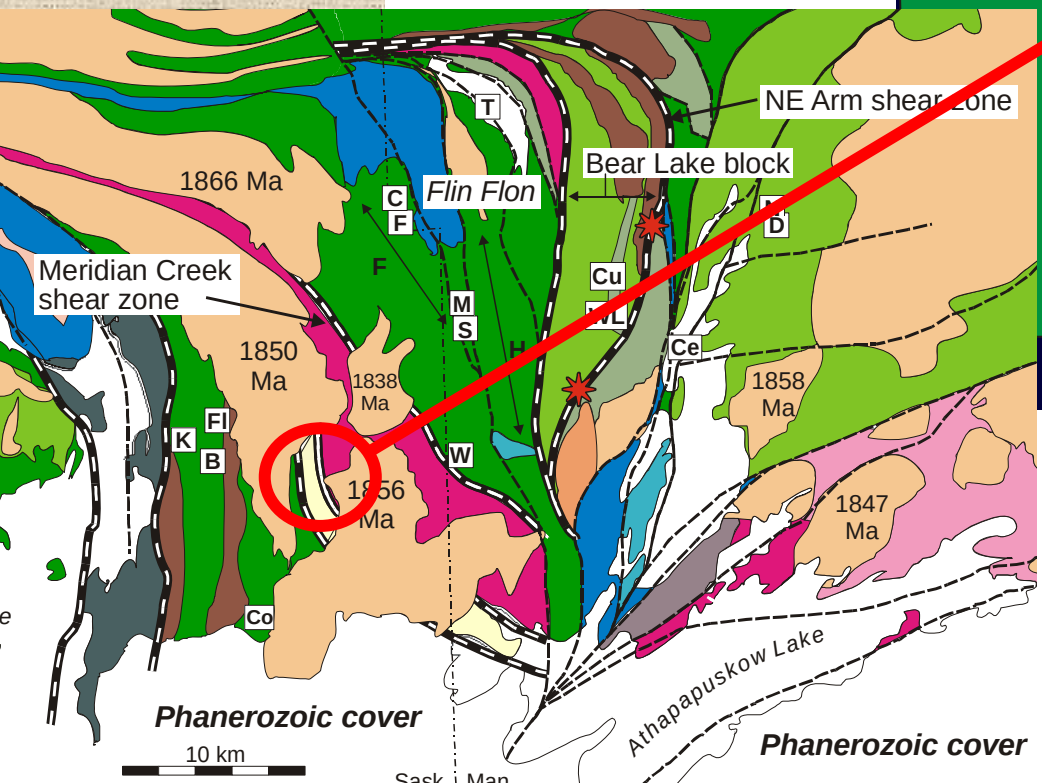
Tectonic juxtaposition

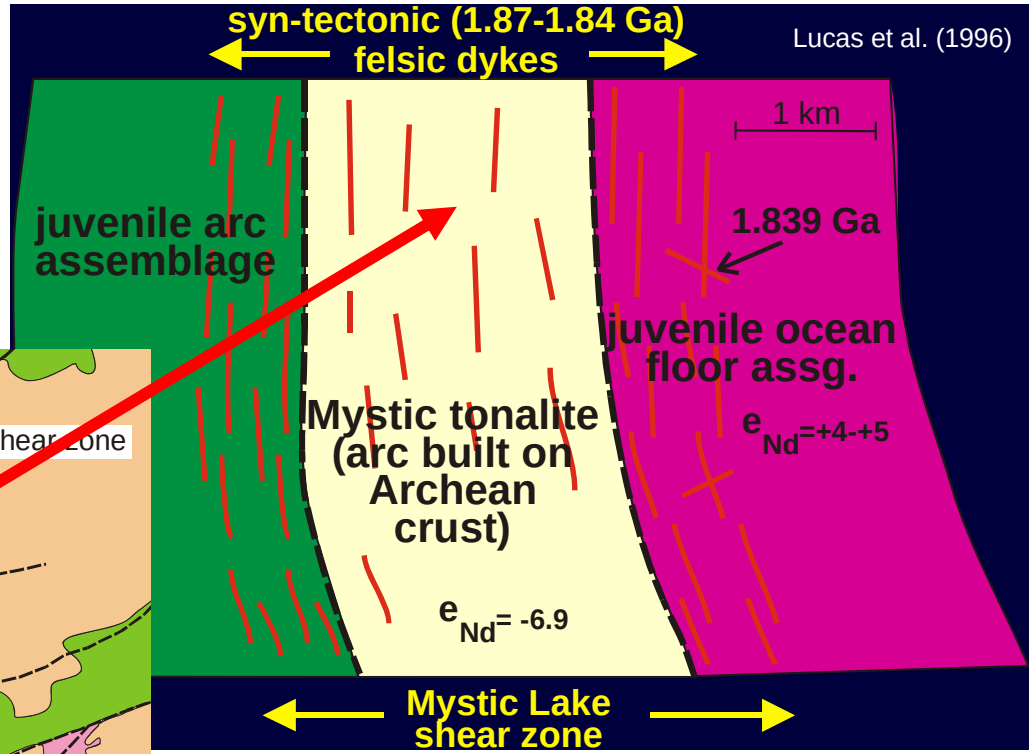
of arc and ocean floor assemblages to form the “Amisk Collage”

~1.87 Ga:

accretion, deformation and meta-morphism

geochronology of assemblage-bounding structures





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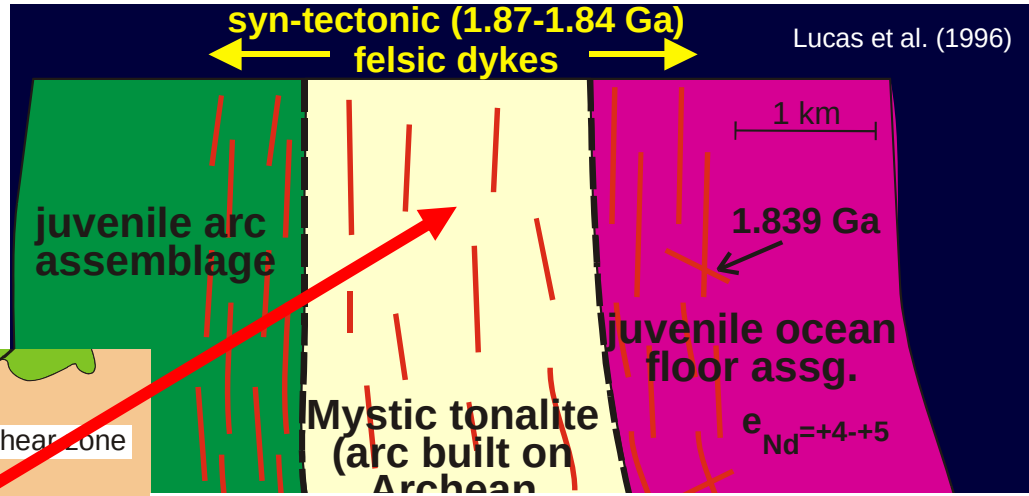
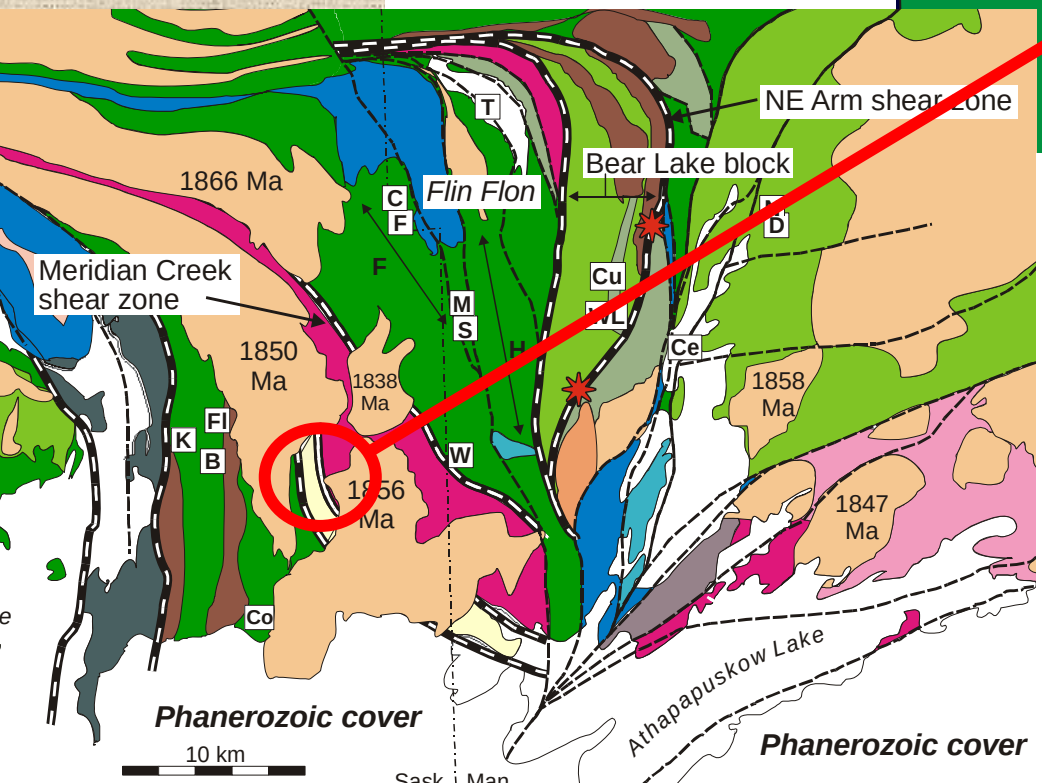




VMS deposits occur in a number of tectonically juxtaposed arc slivers, separated by major accretion-related shear zones, slivers of ocean-floor basalts, slivers of successor basin deposits

Early post-accretion

products of renewed arc magmatism and sedimentation, built on collage of 1.92-1.88 Ga arcs and ocean-floor assemblages

1.87-1.86 Ga:

Early successor arc and basins

plutonism, volcanism, sediment-ation

Diorite with comagmatic mafic enclaves, Neso Lake pluton ***1.858 Ga***

Schist-Wekusko assemblage polymictic volcanic conglomerate, Schist Lake ***1.858 Ga***

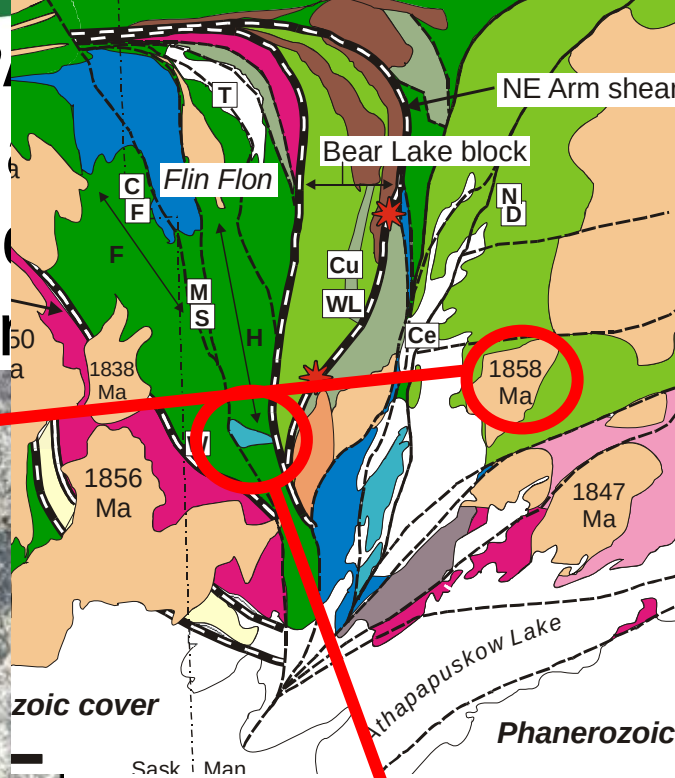
Ea

1.87-1.86 Ga:

products of renewed
sedimentation, built on
Ga arcs and ocean

Early successor arc and basins

plutonism, volcanism, sediment-ation



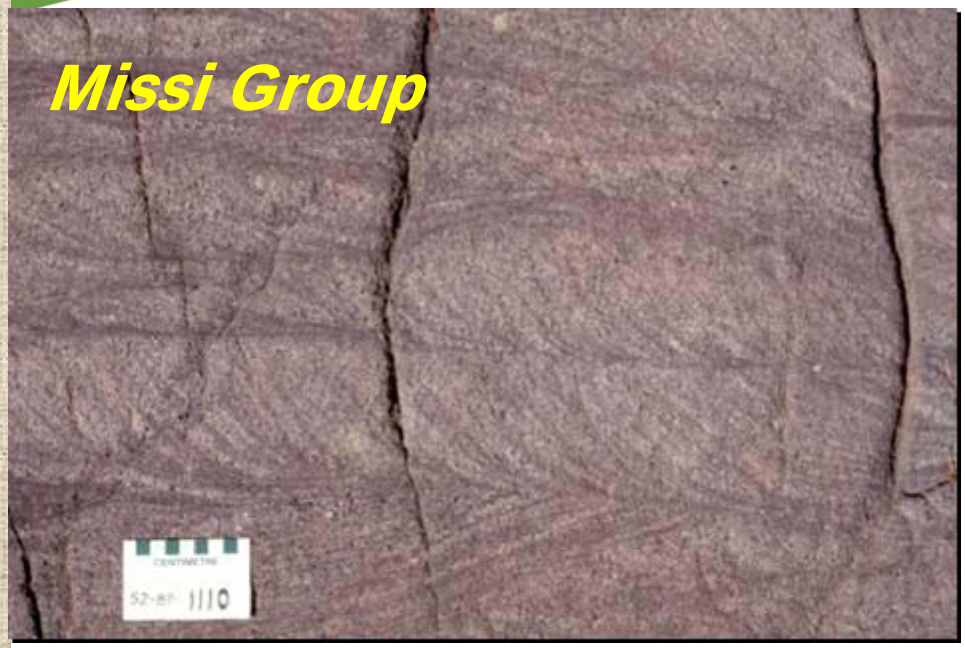
Schist-Wekusko assemblage polymictic volcanic conglomerate, Schist Lake ***1.858 Ga***

Later post-accretion

1.86-1.84 Ga:

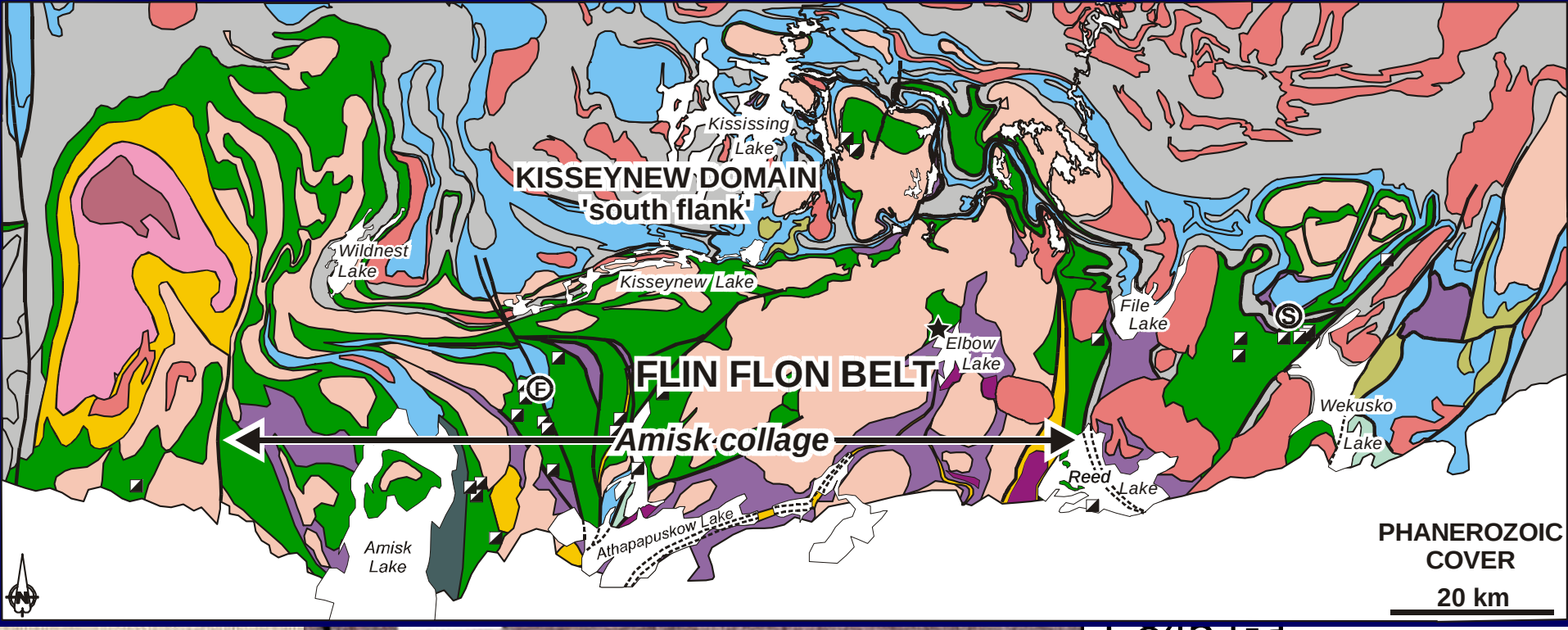
Later successor arcs and basins

plutonism, volcanism, sediment-ation



Fluvial-alluvial conglomerate, pebbly sandstone, and sandstone; local mafic-felsic calc-alkaline and tholeiitic volcanic rocks. Depositional age ca. 1.845 Ga

Greywacke-siltstone-mudstone turbidites. Derived psammitic to pelitic gneisses in the Kisseynew Belt. Deposition ca. 1.855-1.84 Ga, coeval with Missi Group



1.845 Ga

plutonism, volcanism, sediment-ation

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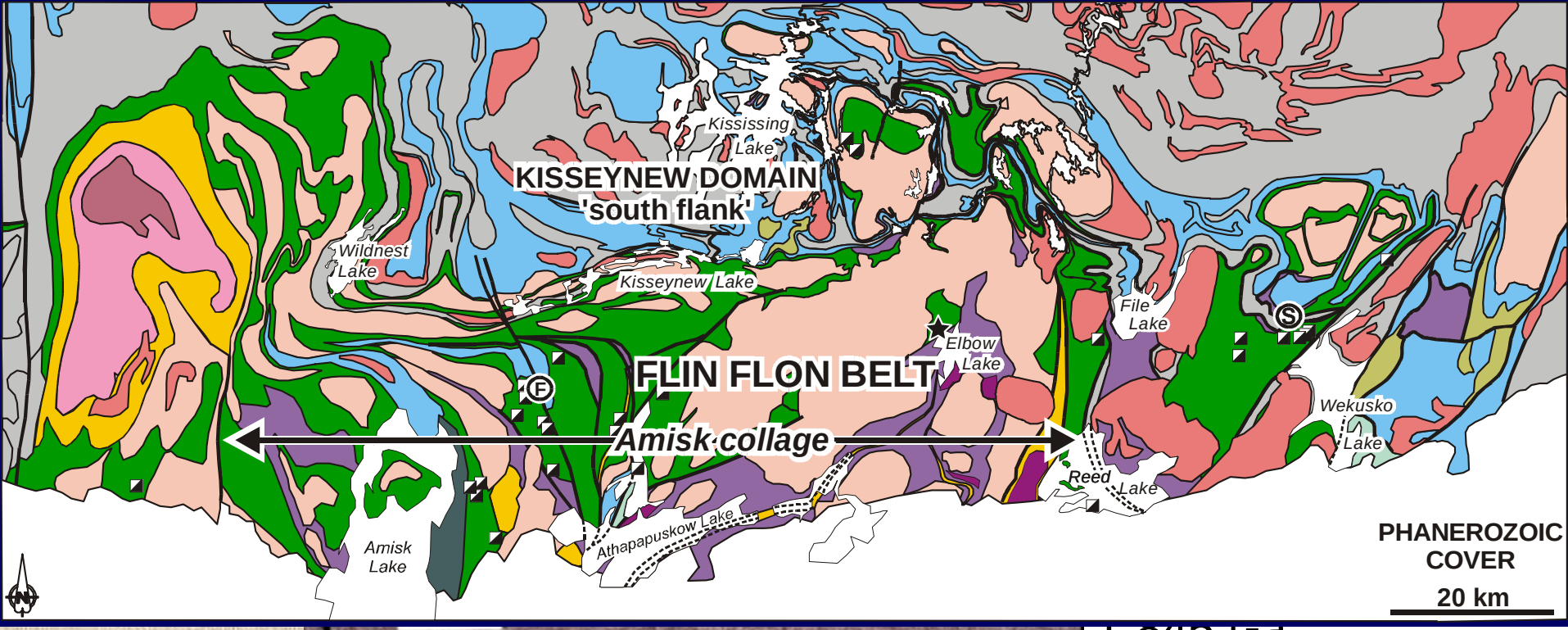
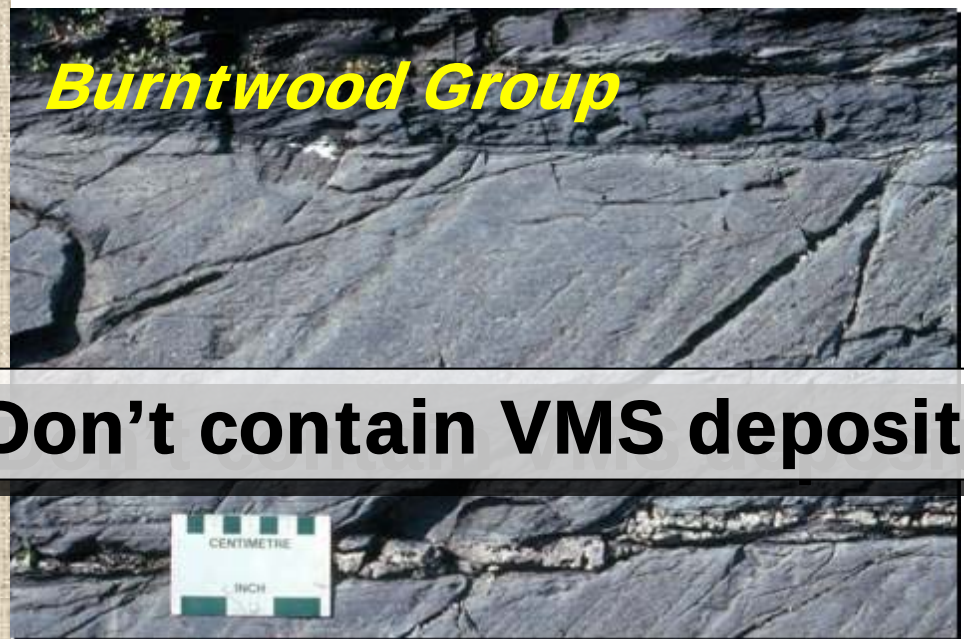


1.845 Ga

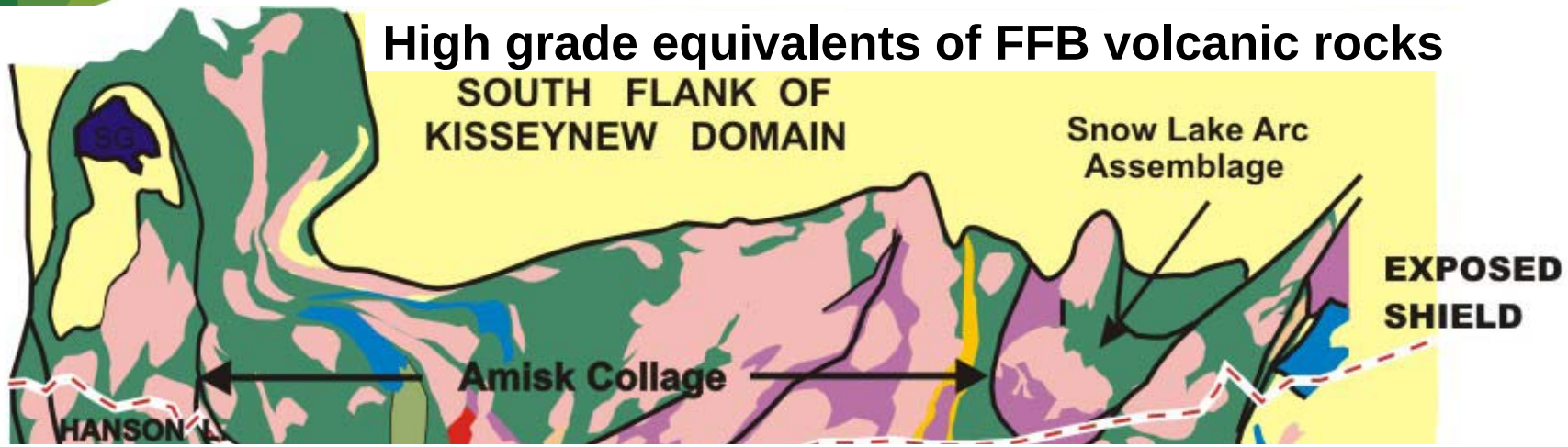
plutonism, volcanism, sediment-ation



Don't contain VMS deposits

Greywacke-siltstone-mudstone turbidites. Derived psammitic to pelitic gneisses in the Kisseynew Belt. Deposition ca. 1.855-1.84 Ga, coeval with Missi Group

This is important because…

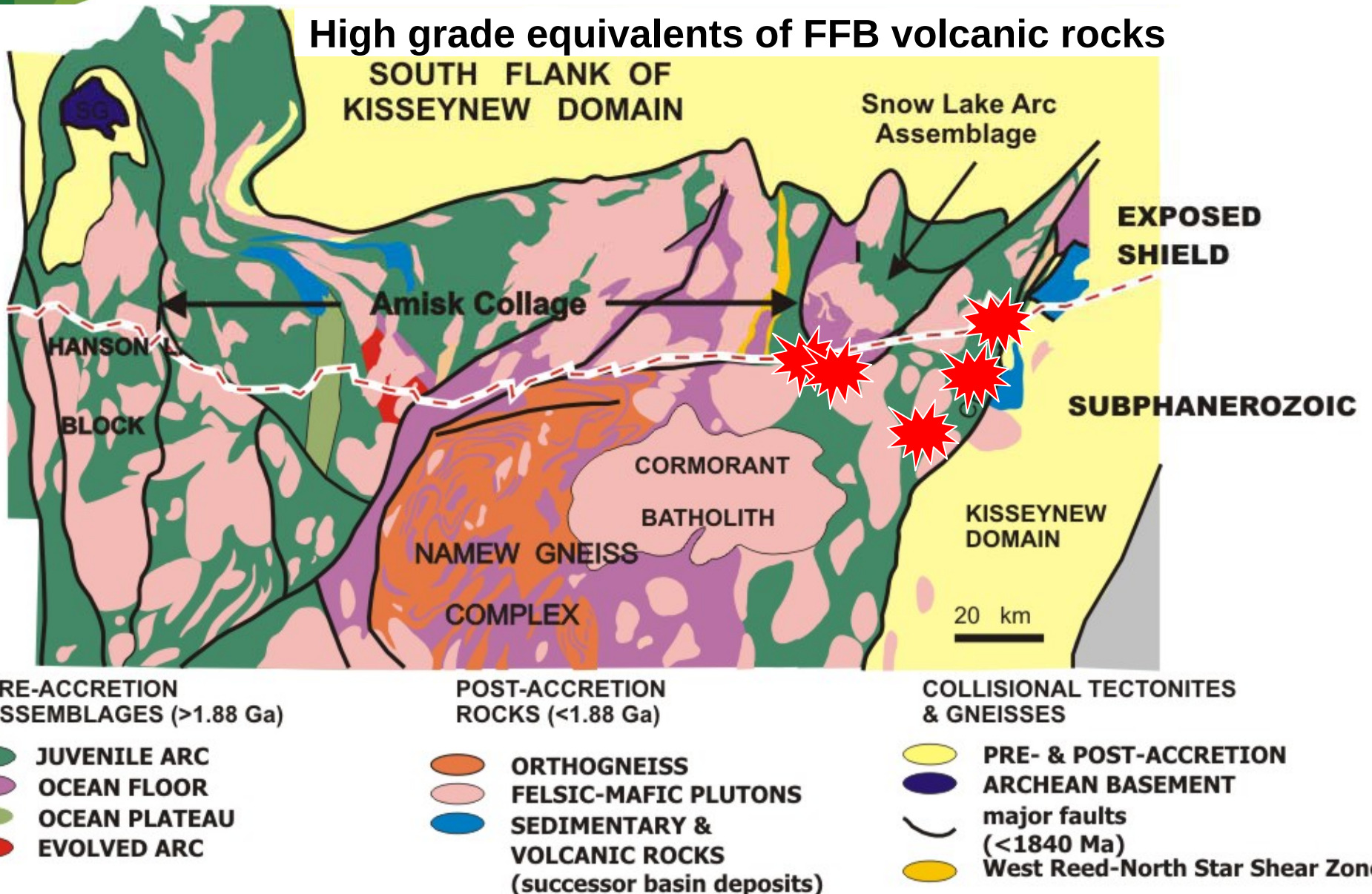


The Flin Flon Belt doesn't end at the Phanerozoic boundary

- The arc and ocean-floor assemblages identified on the exposed Shield continue S of the Phanerozoic boundary
- Many of the exciting new exploration targets in the FFB are in the Subphanerozoic extension of the FFB

This is important because…

High grade equivalents of FFB volcanic rocks



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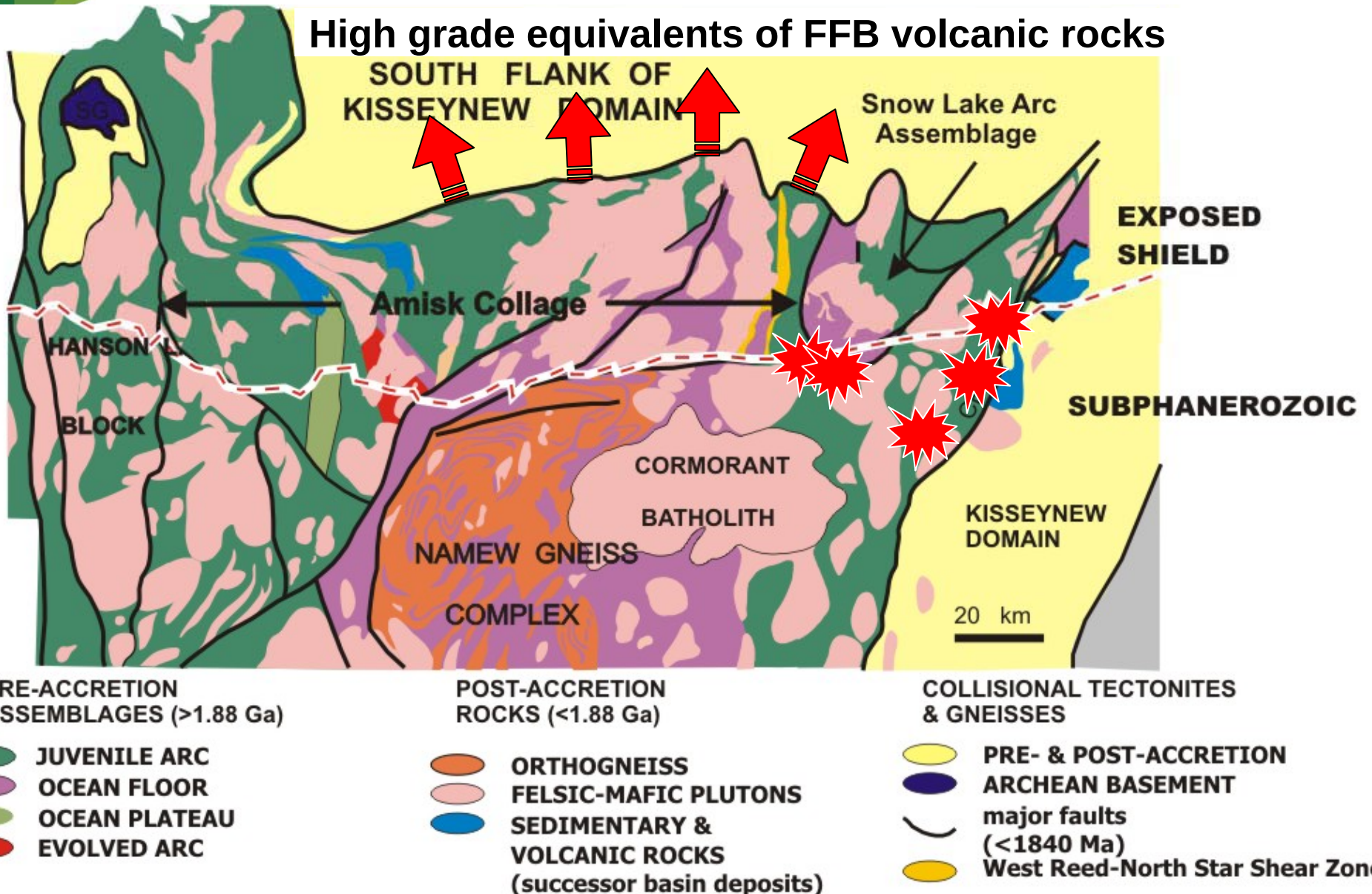

Conclusions

1. Greenstone belts are very complex and include a variety of rocks that were emplaced at different times and in completely different tectonic settings
2. VMS deposits are usually associated with just one or a few of these assemblages (FFB = arc)
3. Mapping and geochemistry will help focus on the productive assemblages