The Precambrian

But first a small diversion into obscure corners of petrography

(the study of rocks)

Metamorphic Rock Textures

Claystone
(Unmetamorphosed)

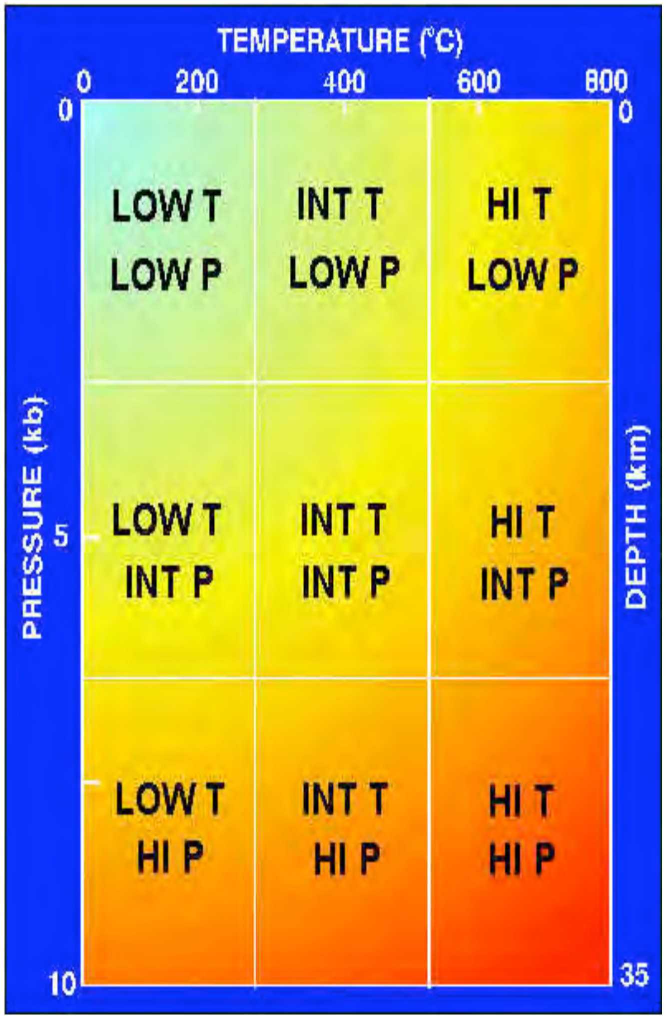
Slate Low Grade

Phyllite Low Grade

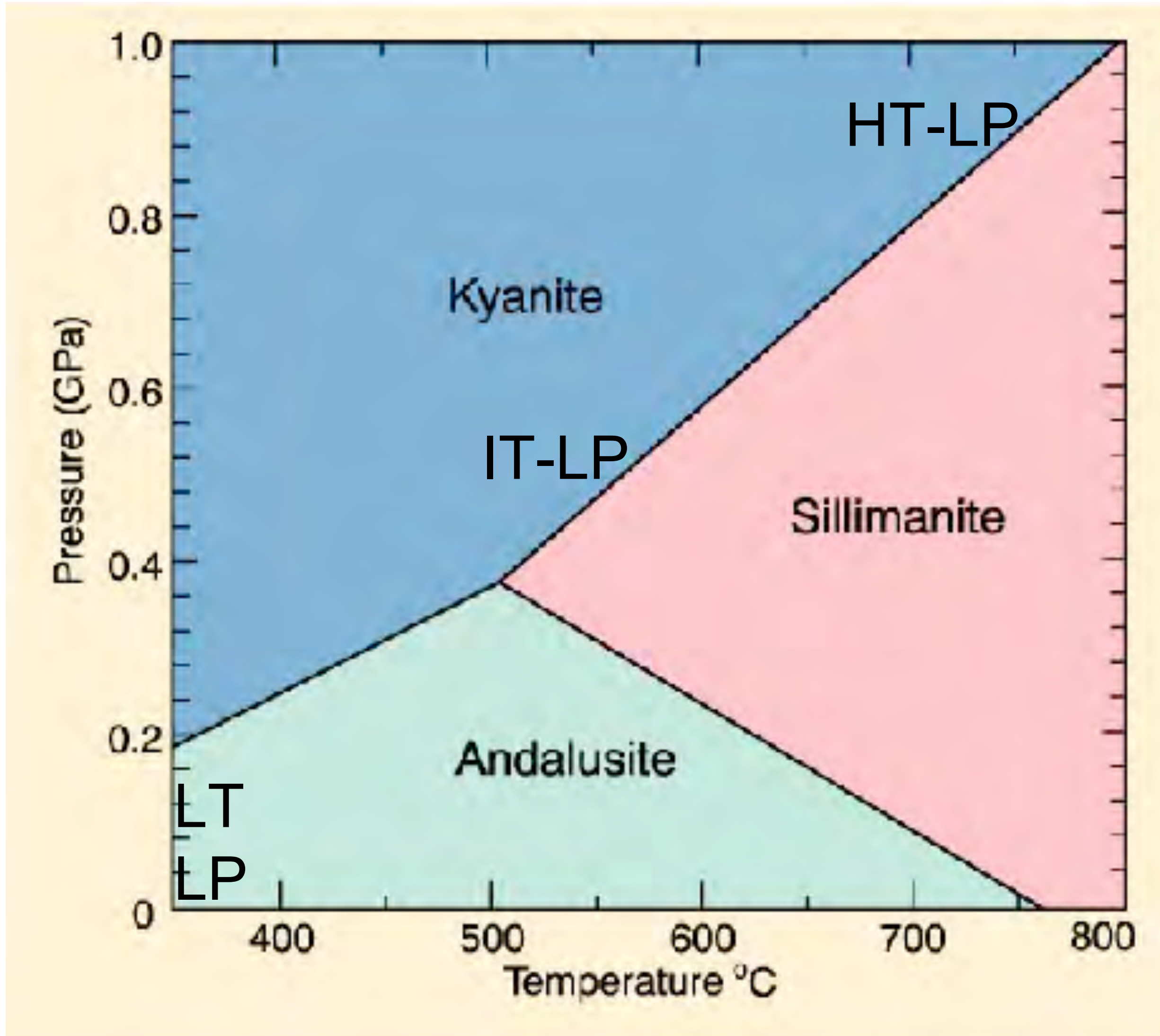
SchistMedium Grade

Gneiss: High Grade

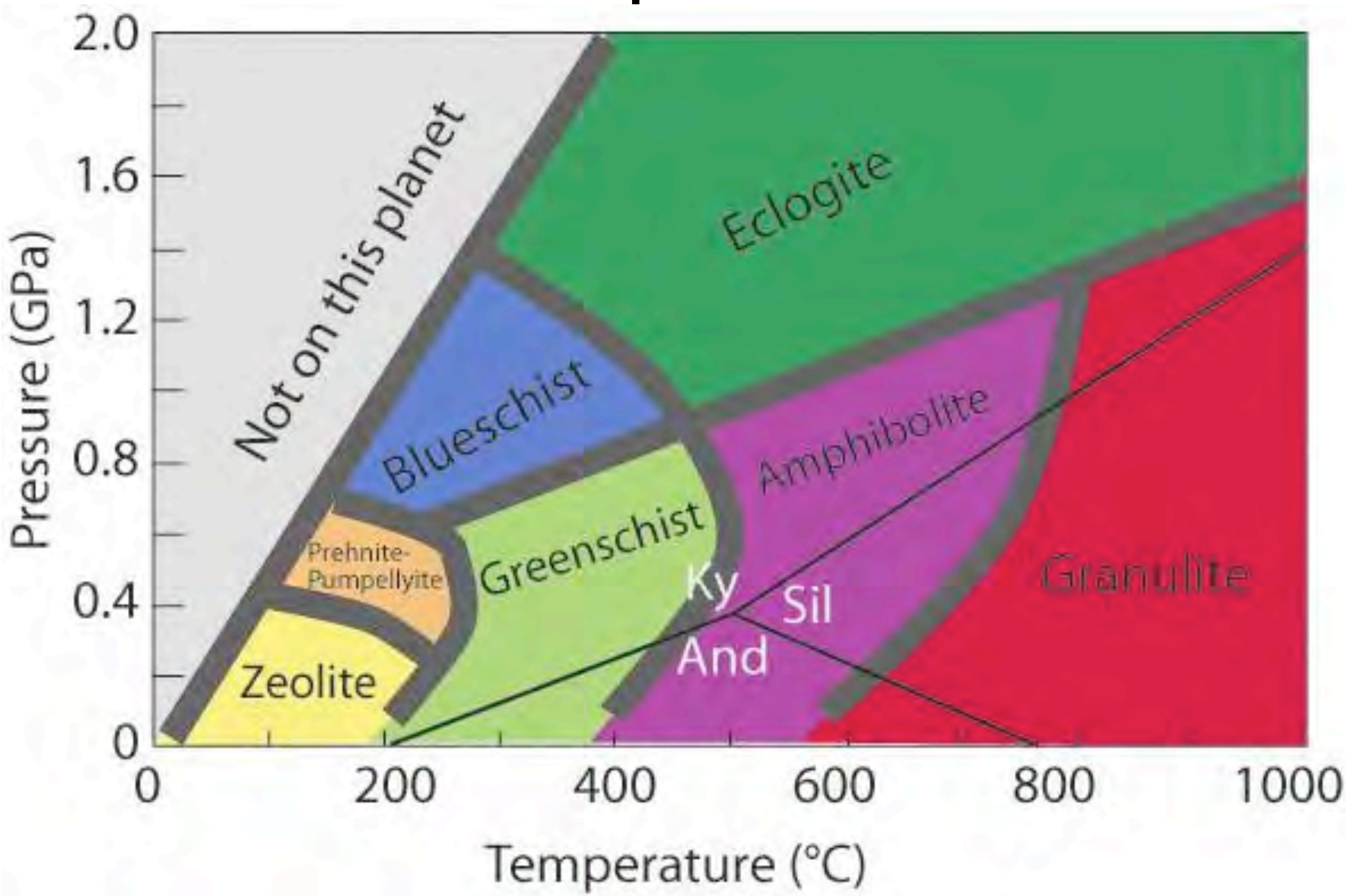
Temperature-Pressure-Grade



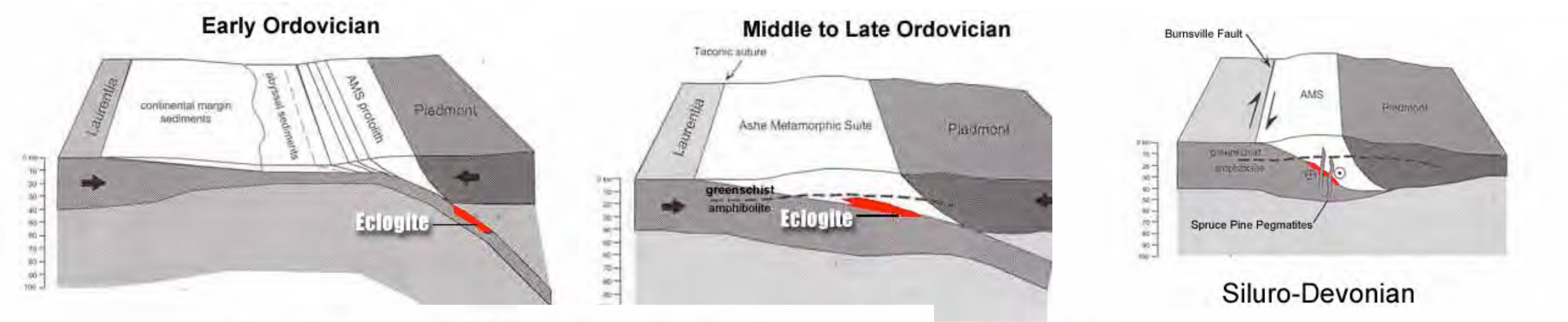
Grade Indicator Minerals Al2SiO5

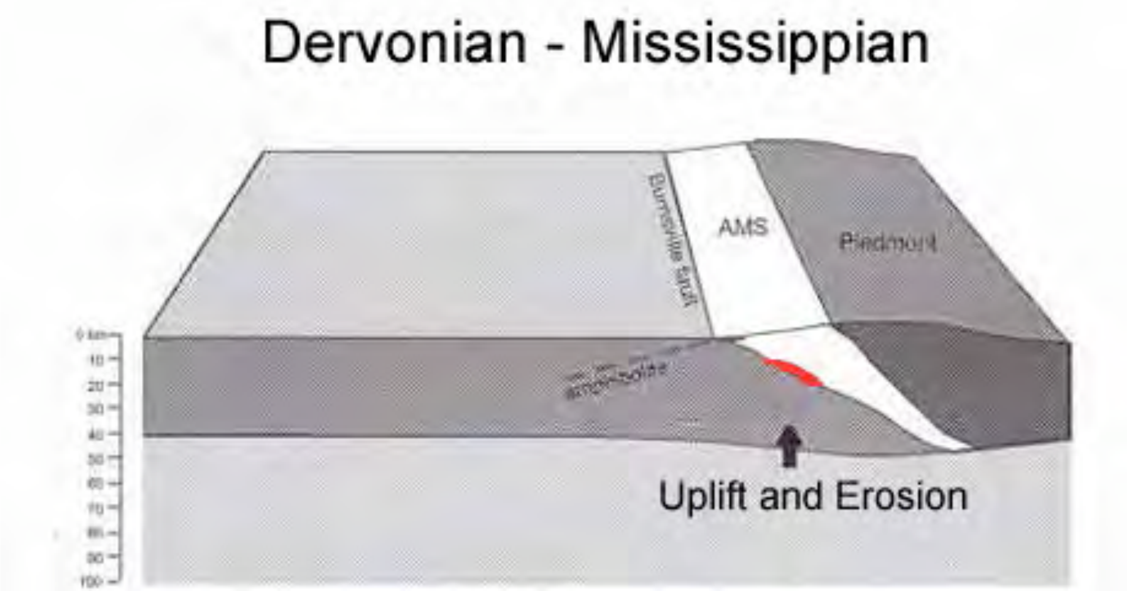


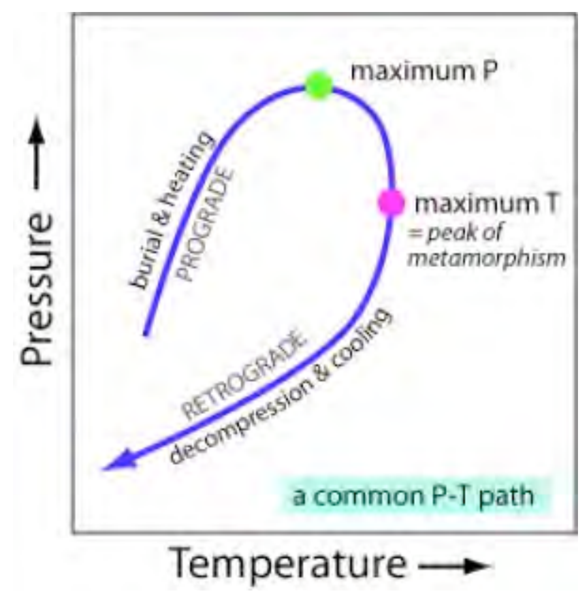
Metamorphic Facies



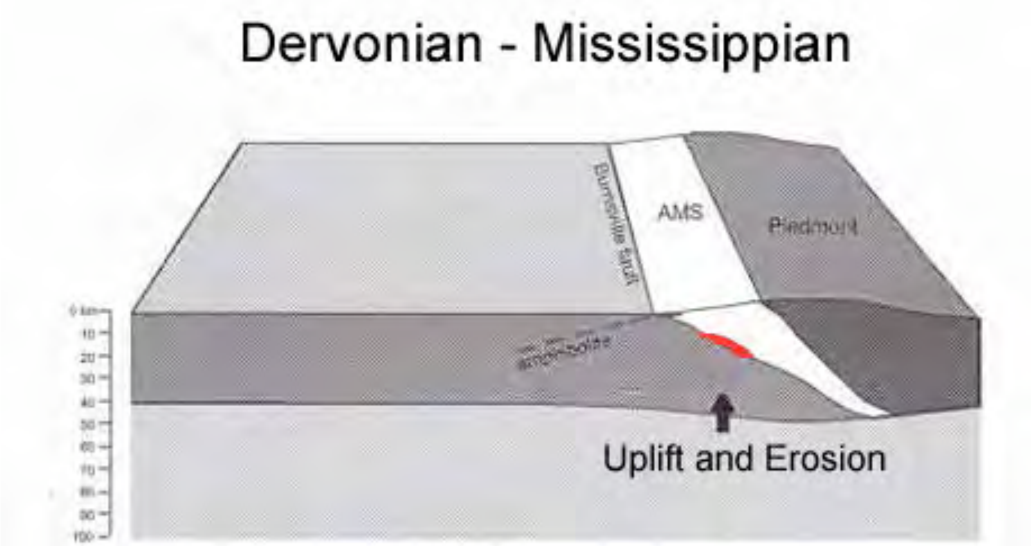
How do we make these rocks? A familiar example

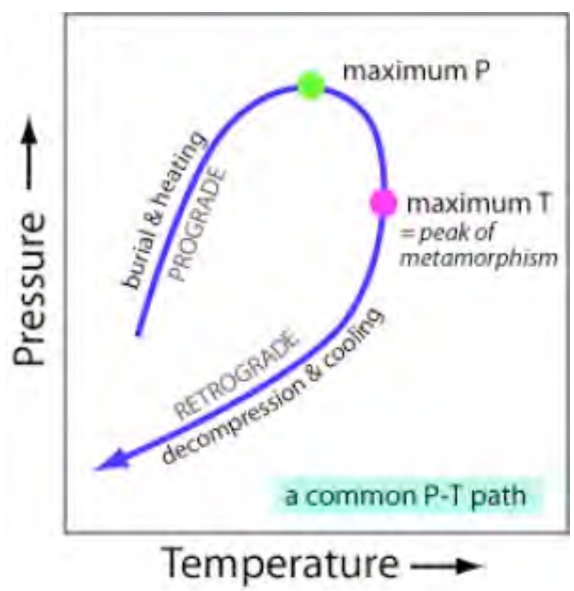


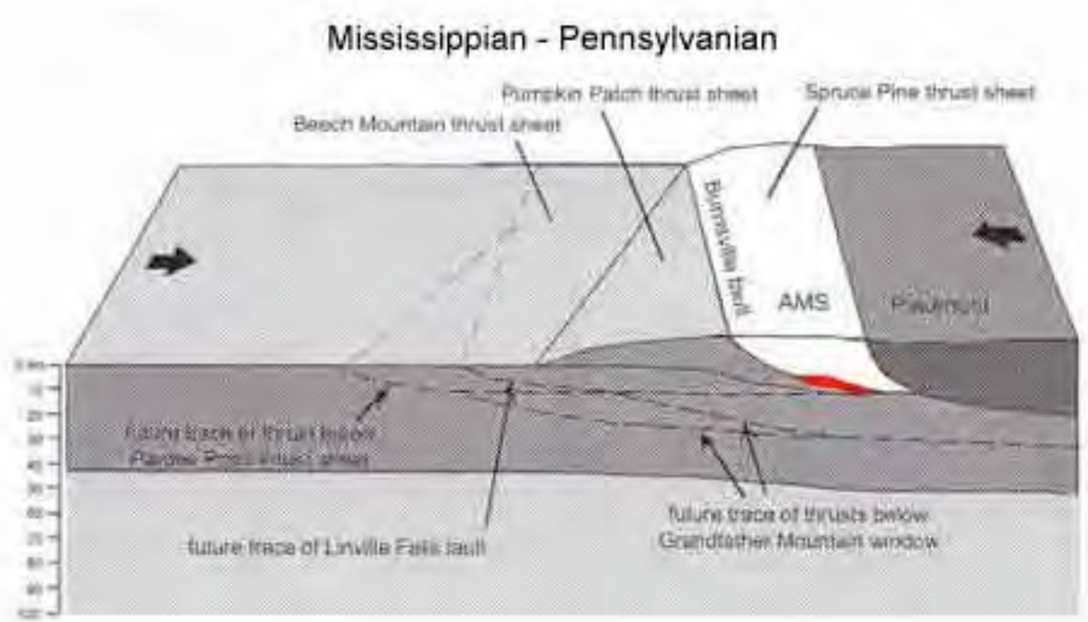




How do we get them to the surface?







End of Diversion: Precambrian Timescale

- 4500-3800 Ma Hadean
  - Solar system forms
  - ~4000 Ma Moon forms
  - ~3700 Ma surface solidifies
- 3800-2500 Ma Archean
  - 3500 Ma oldest fossils (bacteria)
  - 3700 Ma first banded iron formation (BIF)
  - Stromatolites found in South Africa & Australia
- 2500-543 Ma Neoproterzoic
  - First stable continents form
  - 1800 Ma eukaryotic fossils and last major BIF

Questions

- What kinds of rocks occur in pC?
- What processes formed these rocks?
- When did plate tectonic processes begin?
- Was the ancient world similar to the current world?

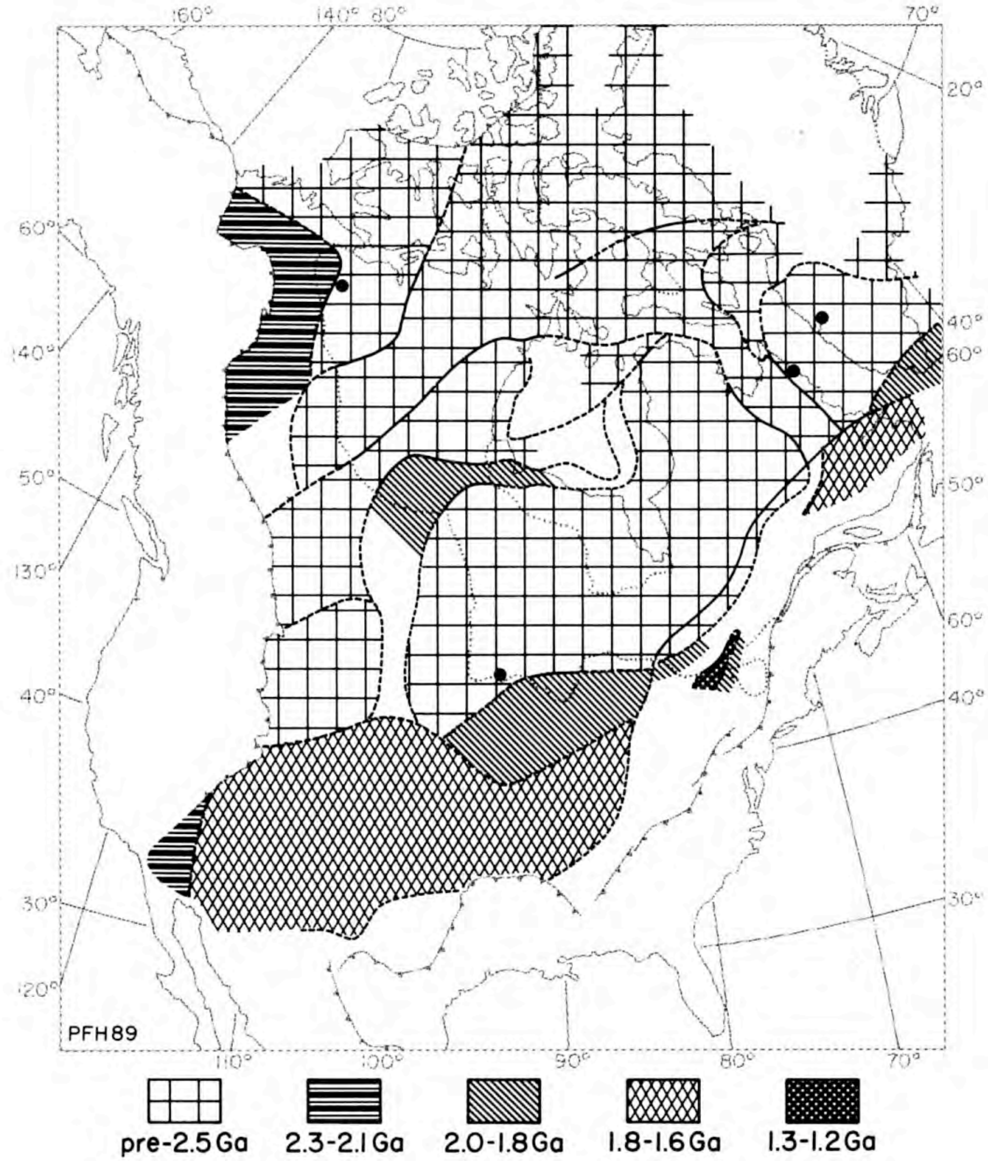


Figure 1. Distribution of crust by age of formation for the North American shield and platforms. Pre-drift restoration of Greenland after *Rowley and Lottes (1988).* Dotted lines indicate edge of shield. Areas of uncertain crust-formation age are unpatterned. Heavy dots locate crust over 3.5 Ga. Inferred Proterozoic sutures between areas of Archean (pre-2.5 Ga) crust are indicated by pattern offsets.

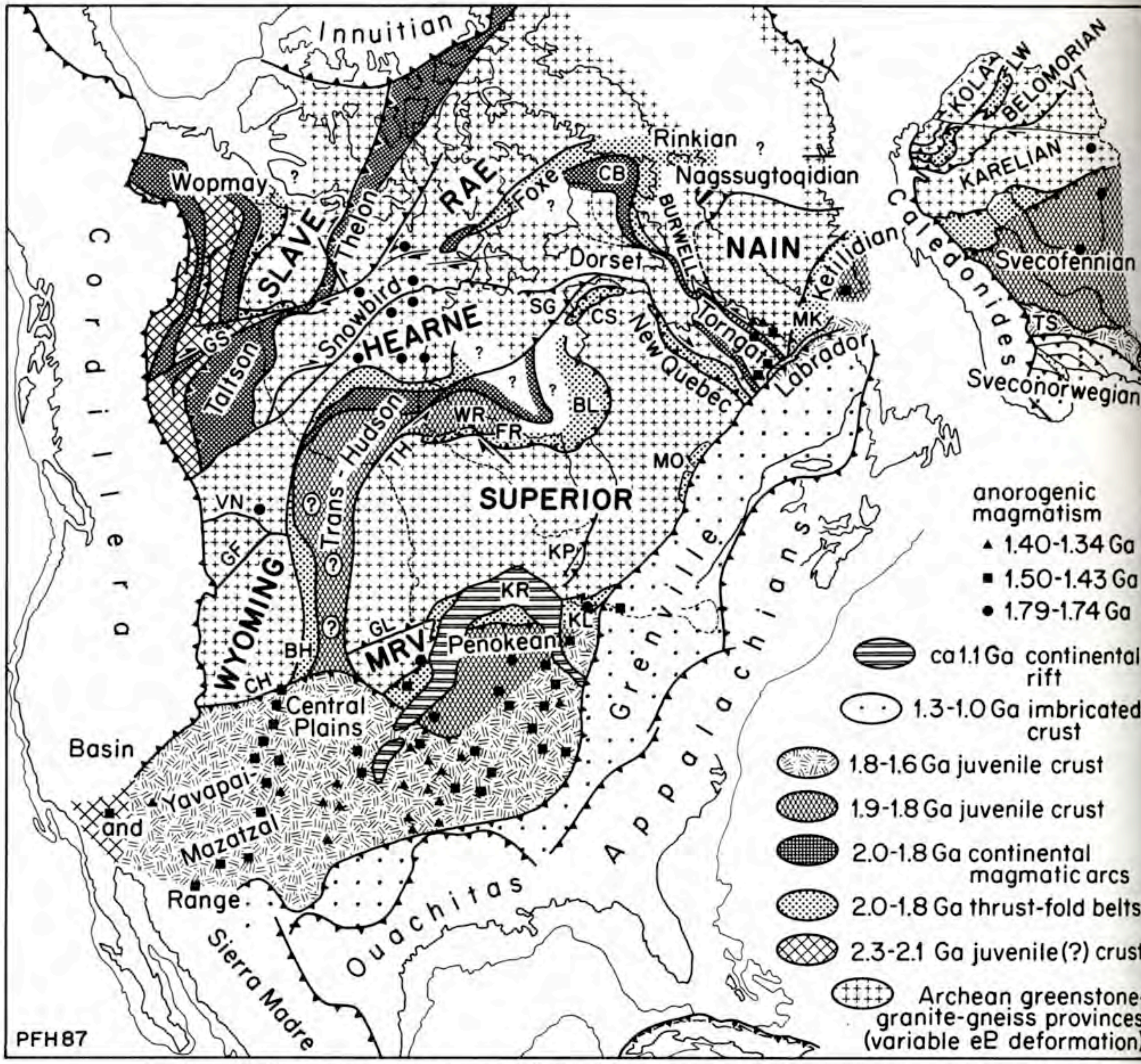


Figure 13. Precambrian tectonic elements of the North American craton (platform cover removed) and Baltic shield. Upper case names are Archean provinces; lower case names are Proterozoic and Phanerozoic orogens. BH, Black Hills inlier; BL, Belcher fold belt; CB, Cumberland batholith; CH, Cheyenne belt; CS, Cape Smith belt; FR, Fox River belt; GF, Great Falls tectonic zone; GL, Great Lakes tectonic zone; GS, Great Slave Lake shear zone; KL, Killarney magmatic zone; KP, Kapuskasing uplift; KR, Keweenawan rift; LW, Lapland-White Sea tectonic zone; MK, Makkovik orogen; MO, Mistassini and Otish basins; MRV, Minnesota foreland; SG, Sugluk terrane; TH, Thompson belt; TS, Trans-Scandinavian magmatic zone; VN, Vulcan tectonic zone; VT, Vetrenny tectonic zone; WR, Winisk River fault.

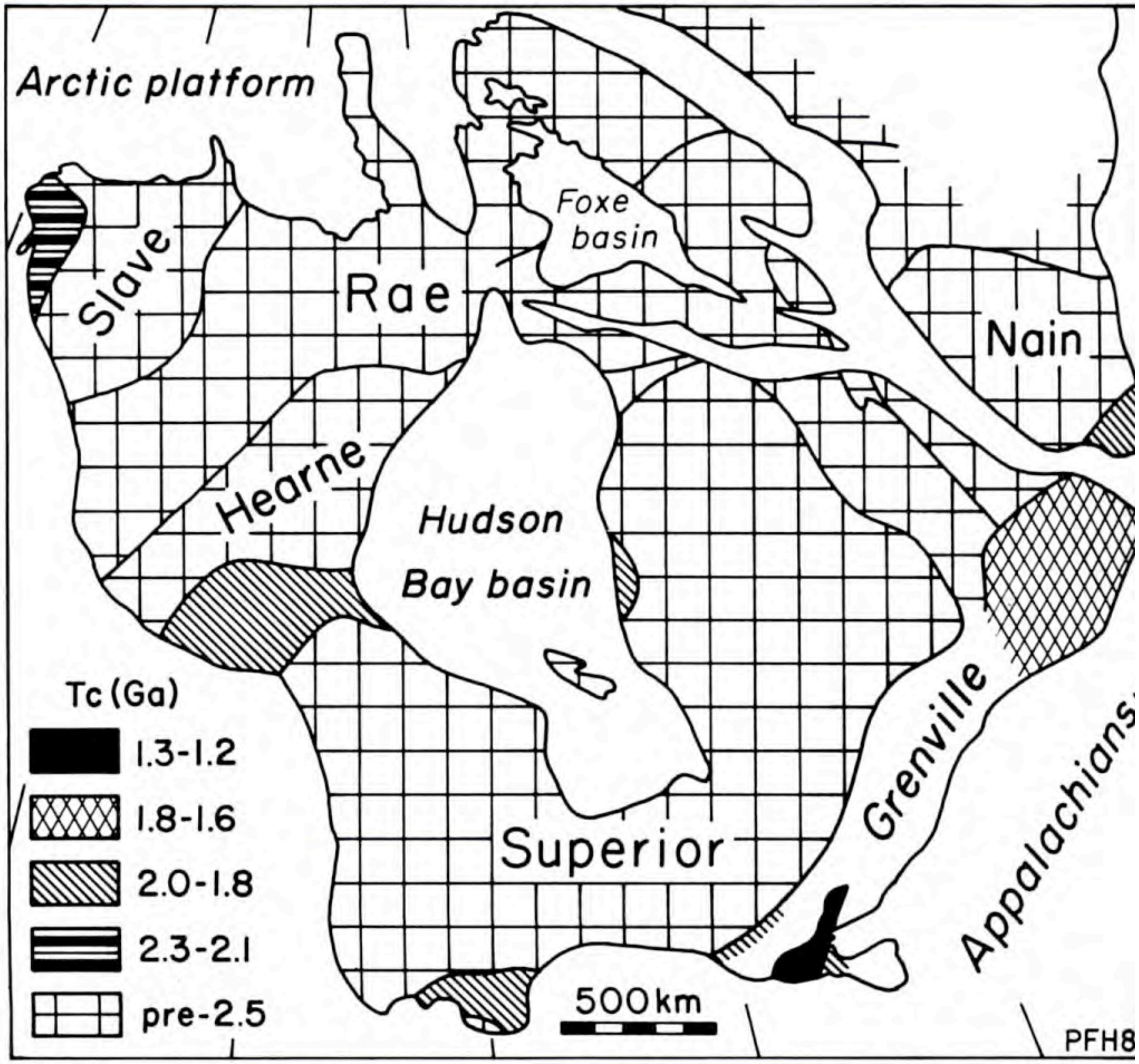


Figure 2. Distribution of crust by age of formation in the Canadian shie
and Greenland in pre-drift restoration. Inferred Proterozoic sutures inc
cated as in Figure 1. Note bias in favor of Archean crust in shield relati
to craton. Uplift of Proterozoic crust in southeastern shield may manife
mantle upwelling responsible for Atlantic geoid high.

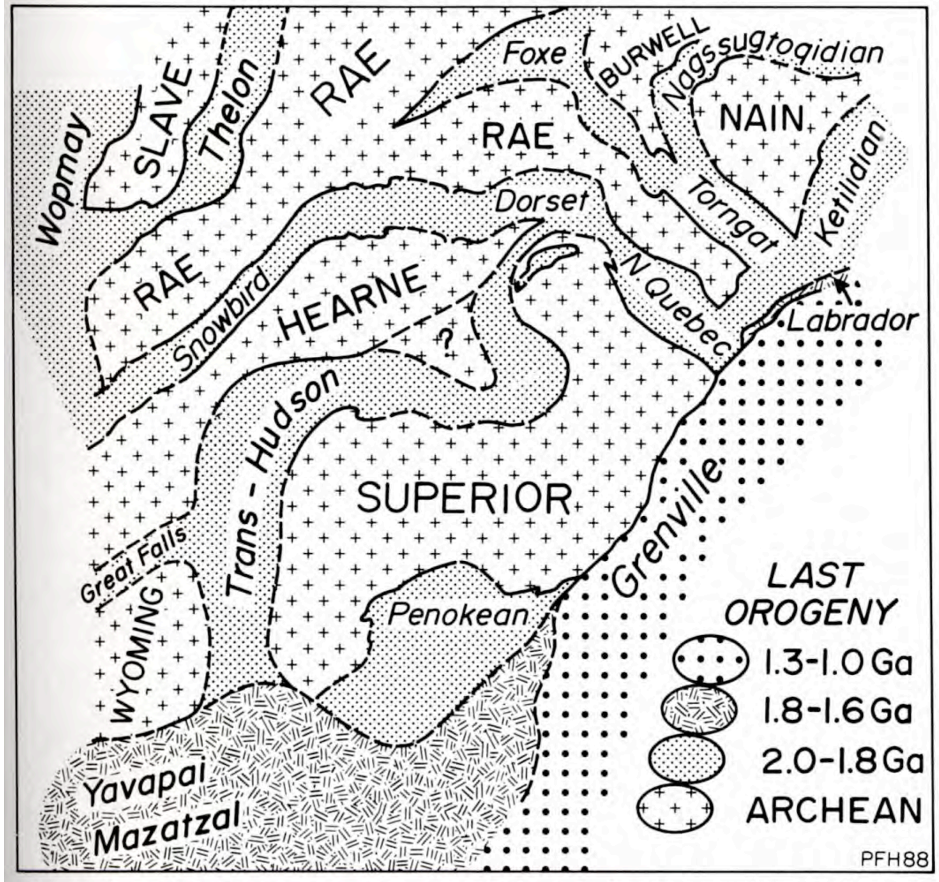
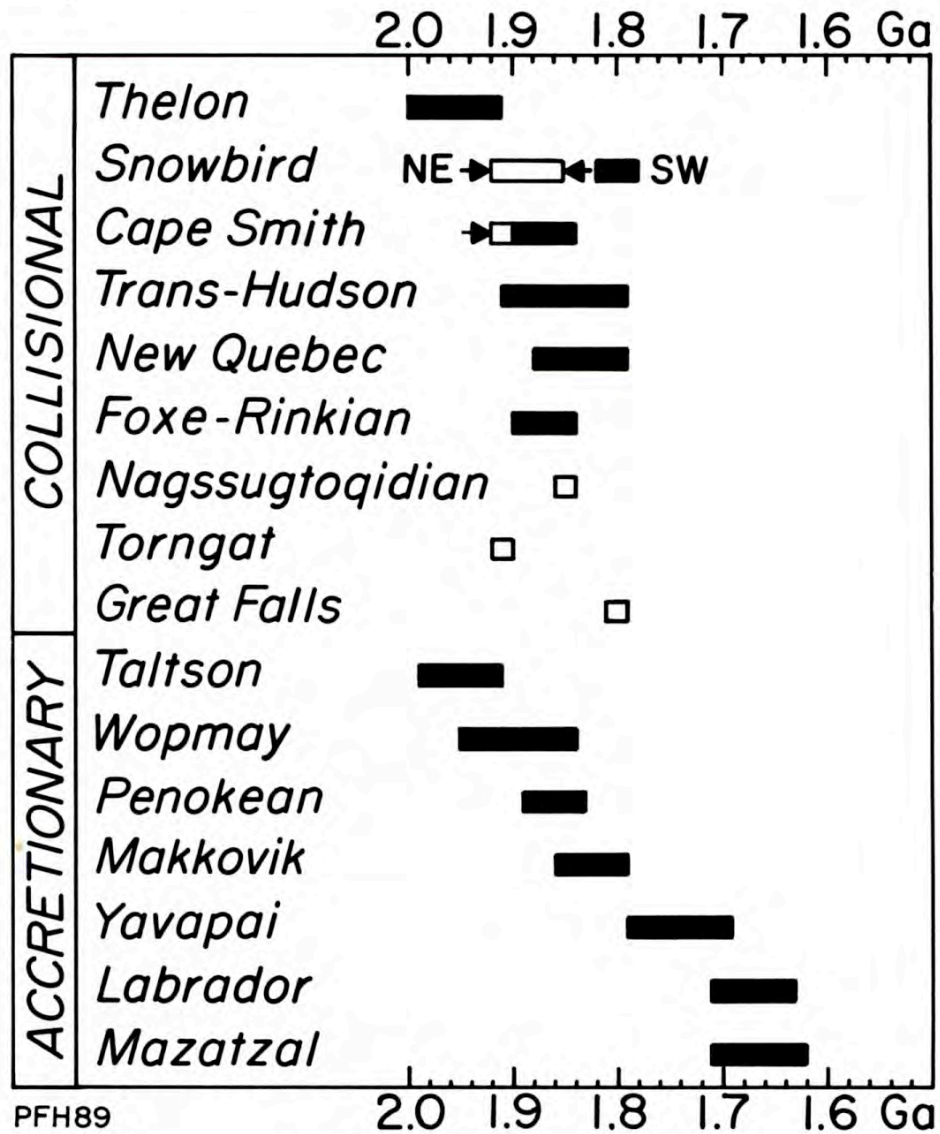
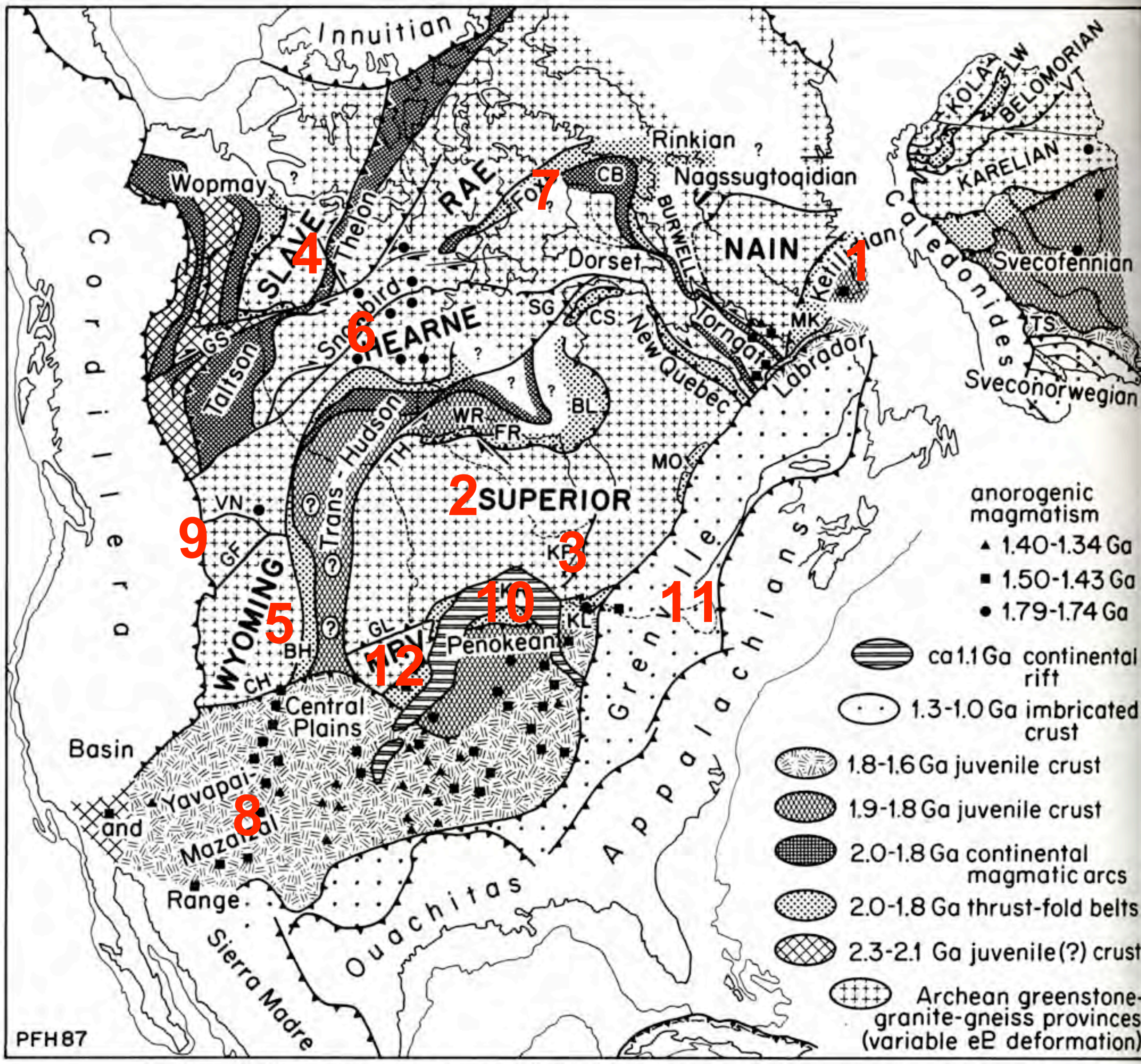


Figure 3. Exploded craton showing inferred Archean microcontinents (upper case names) and bounding Proterozoic orogens (italic lower case names). Separation of Archean provinces is arbitrary and not meant to imply a particular paleogeography.





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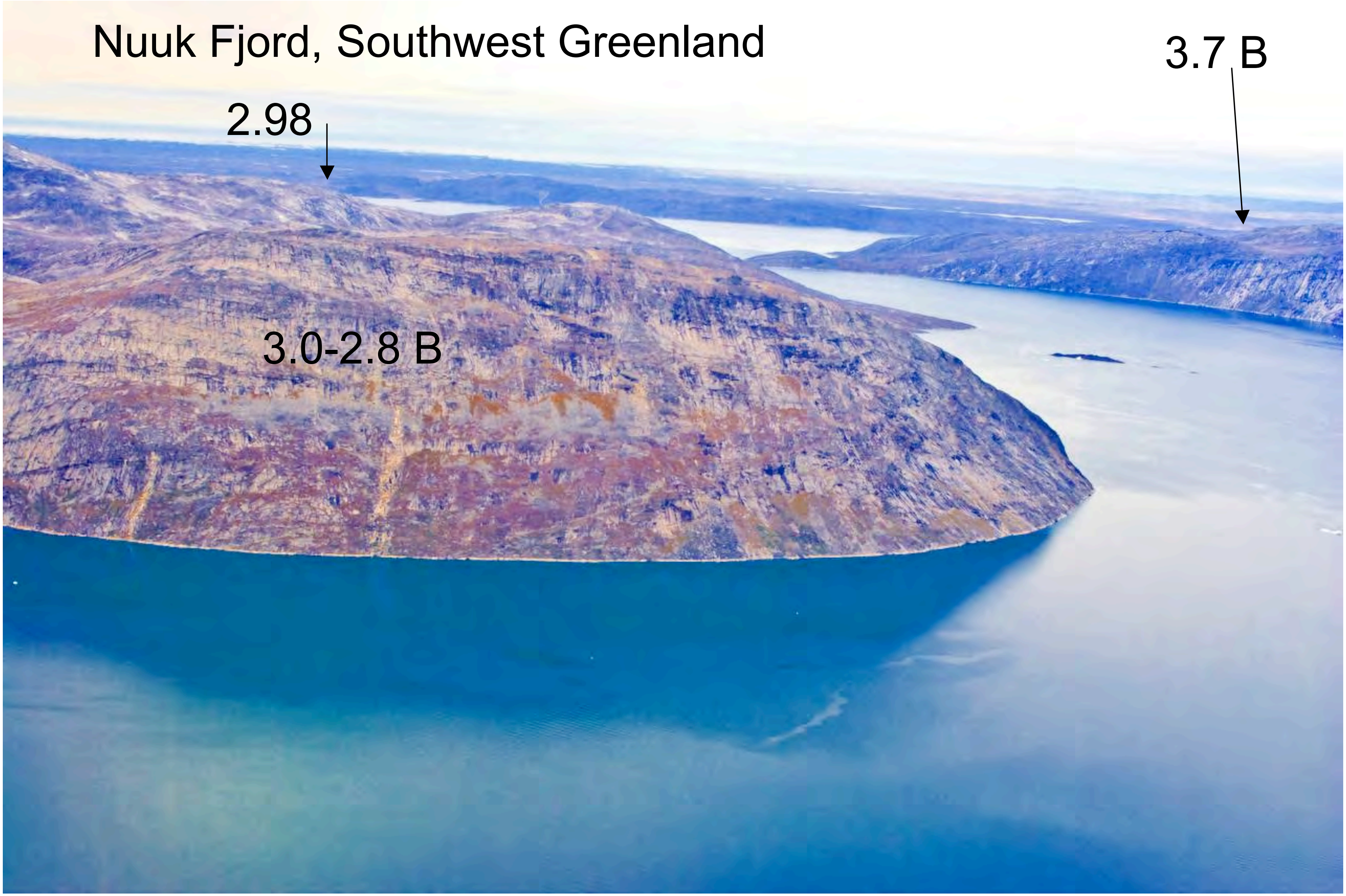

Nuuk Fjord, Southwest Greenland
2.98
3.7 B
3.0-2.8 B

Archean: Nuuk Greenland

1

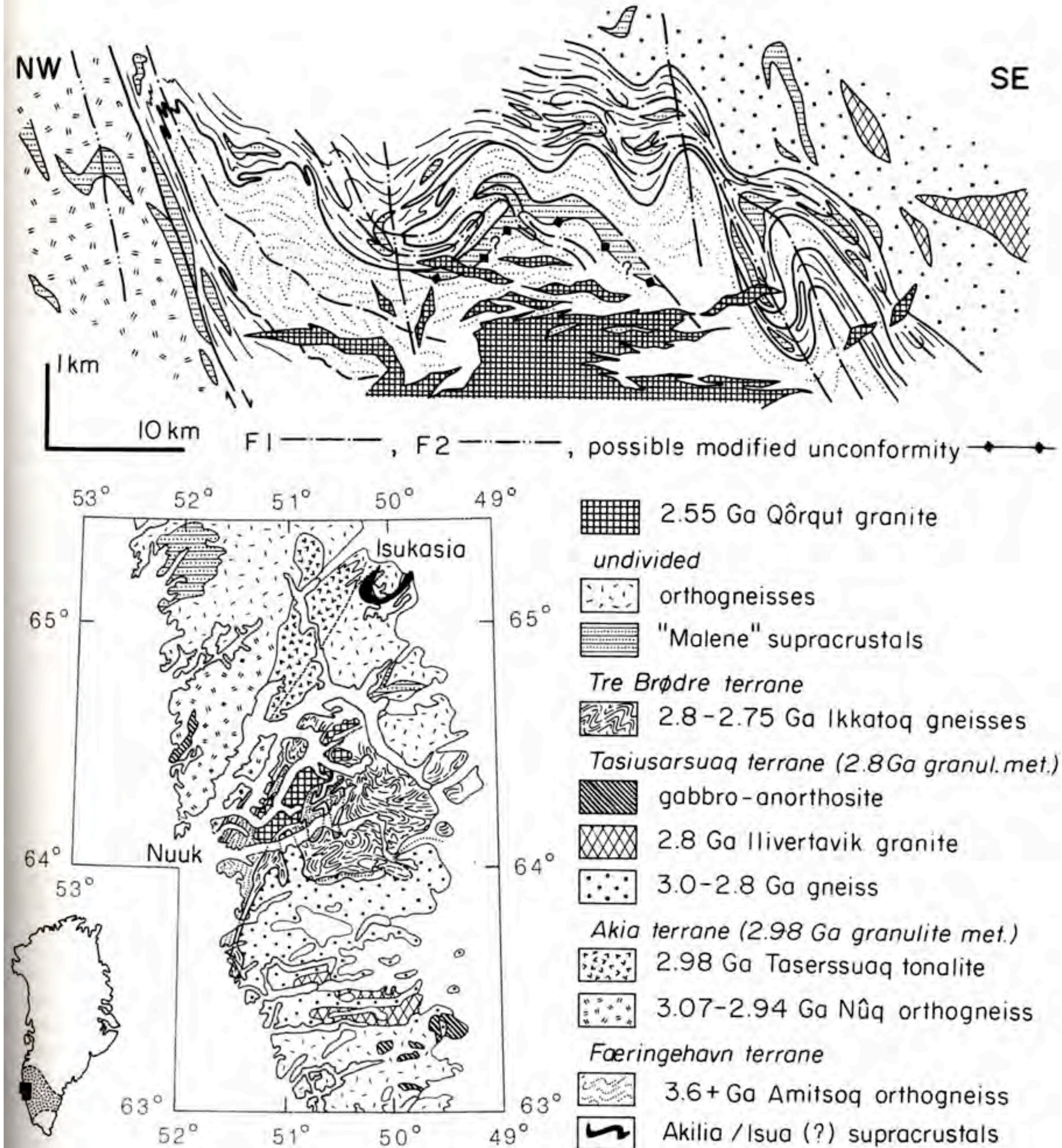
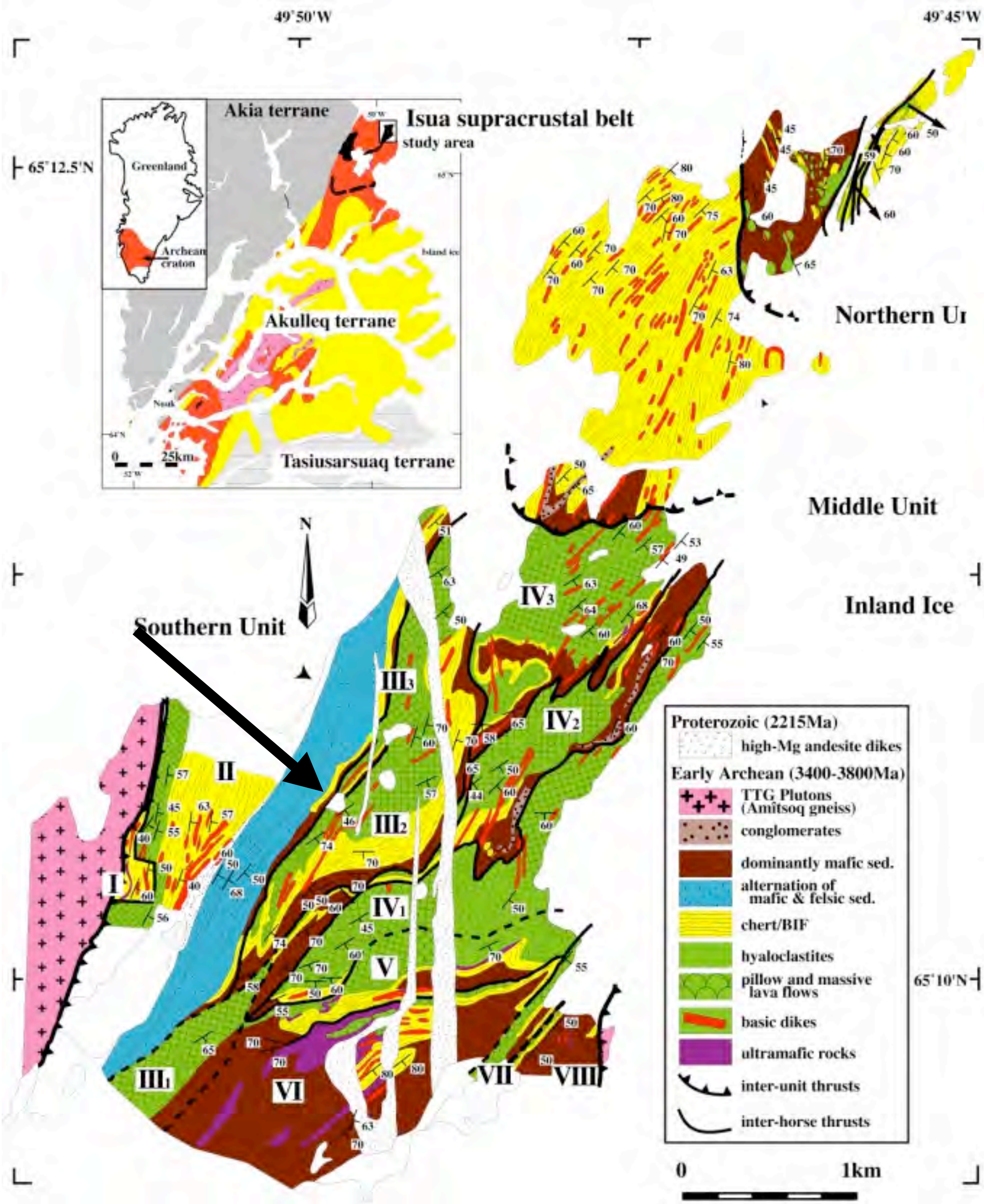


Figure 7. Geology and generalized cross-section of Archean terranes near Nuuk, southwest Greenland (central Nain province), modified after *Nutman and others (1989).*

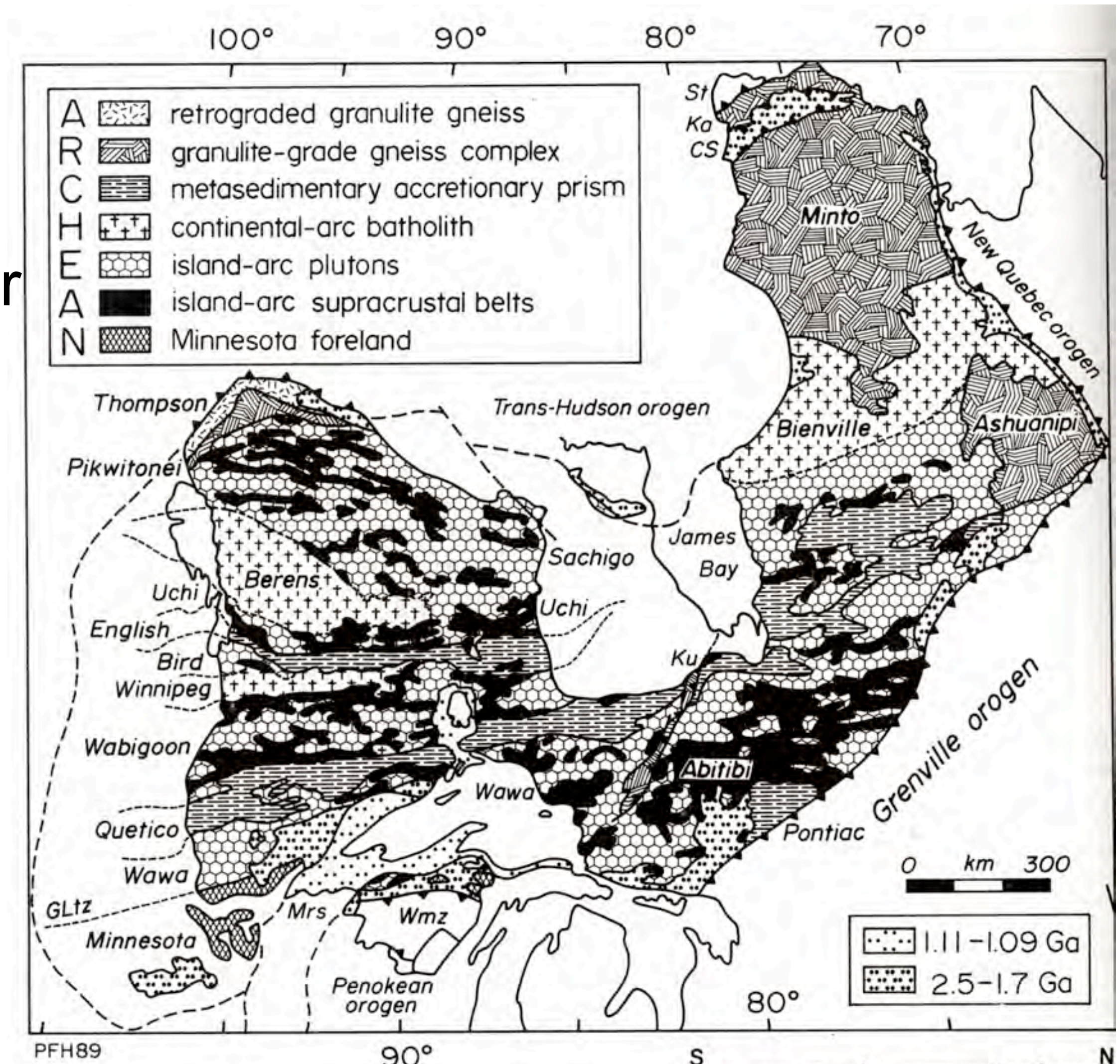


Amitsoq Orthogneiss

Archean (3.8 B) Pillow Basalt

Fault between 3.8 B Amitsoq gneiss (left side) and 3.8+ B Isua belt

Archean:
Hudson Bay
To
Lake Superior



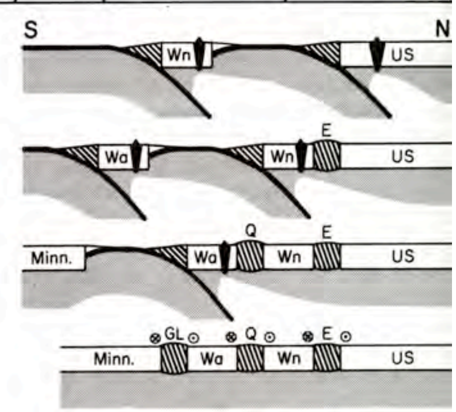


Figure 5. Geology of the Superior province showing subsurface extensions (dashed) of terrane boundaries. Map modified after *Card (1989)*. Cs, Cape Smith belt; GLtz, Great Lakes tectonic zone; Ka, Kovik antiform; Ku, Kapuskasing uplift; Mrs, Midcontinent rift system; St, Sugluk terrane; Wmz, Wisconsin magmatic zones of Penokean orogen. Cross-sections in lower left show plate tectonic evolution, modified after *Langford and Morin (1976)*, involving southward accretion of island arcs and terminal collision with the Minnesota foreland. E, English River accretionary prism; GL, Great Lakes tectonic zone; Q, Quetico accretionary prism; US, Uchi-Sachigo composite island-arc terrane; Wa, Wawa island-arc terrane; Wn, Wabigoon island-arc terrane.

Banded Iron Formations

Middle Proterozoic
Mesabi Range, MN
Iron ore outcrop

Abandoned iron mine pits, Virginia, MN

Iron-bearing chert outcrop

Hull Rust Iron Mine (world's largest)

Archean Sudan Iron Formation, Stuntz Bay, MN

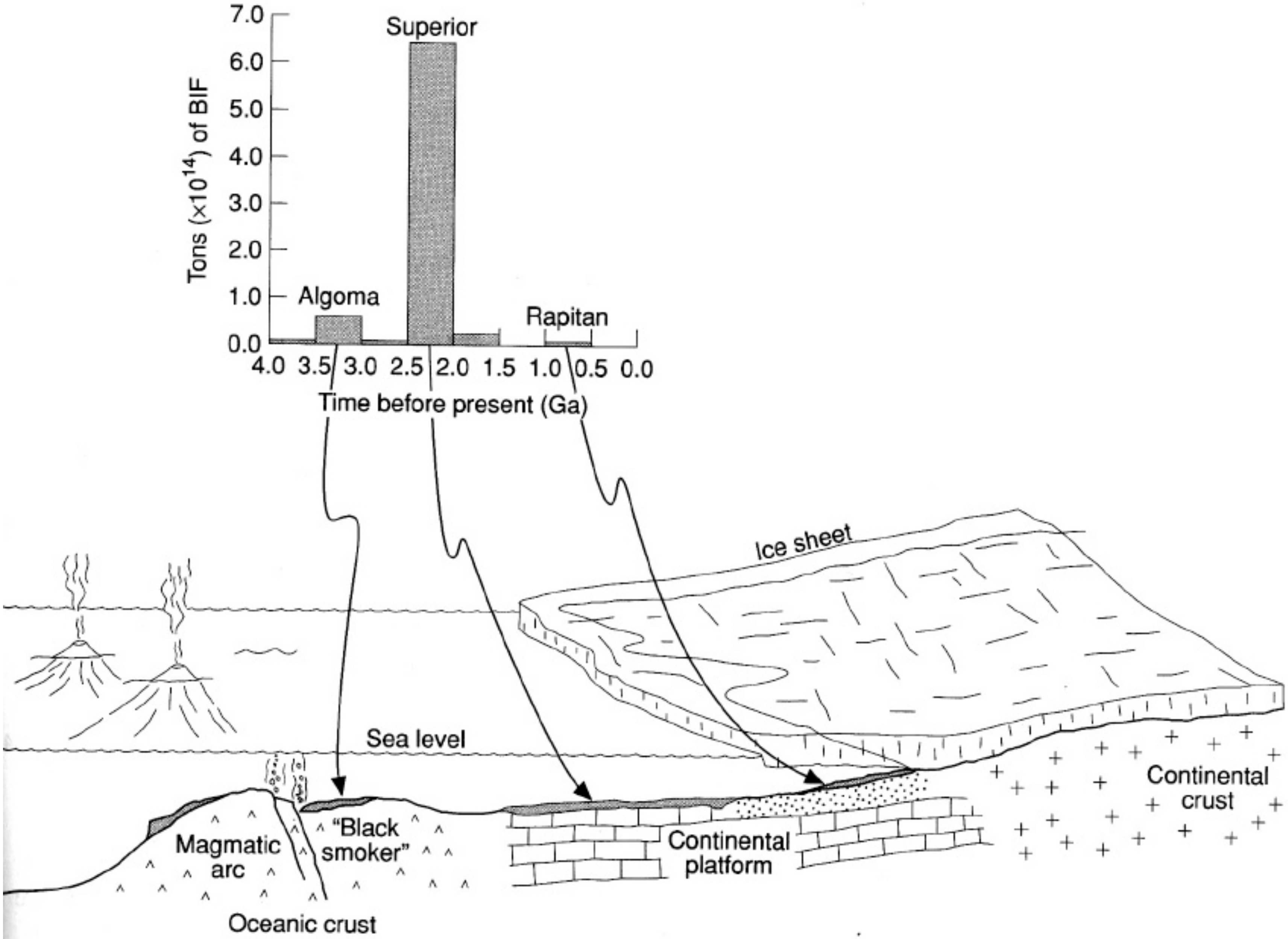


Figure 5.16 Tectonic and environmental model showing the depositional settings for Algoma, Superior, and Rapitan type BIFs (after Clemmey, 1985; Maynard, 1991). The inset histogram illustrates the approximate tonnages of BIF resource for each of the three major types as a function of time (after Holland, 1984).

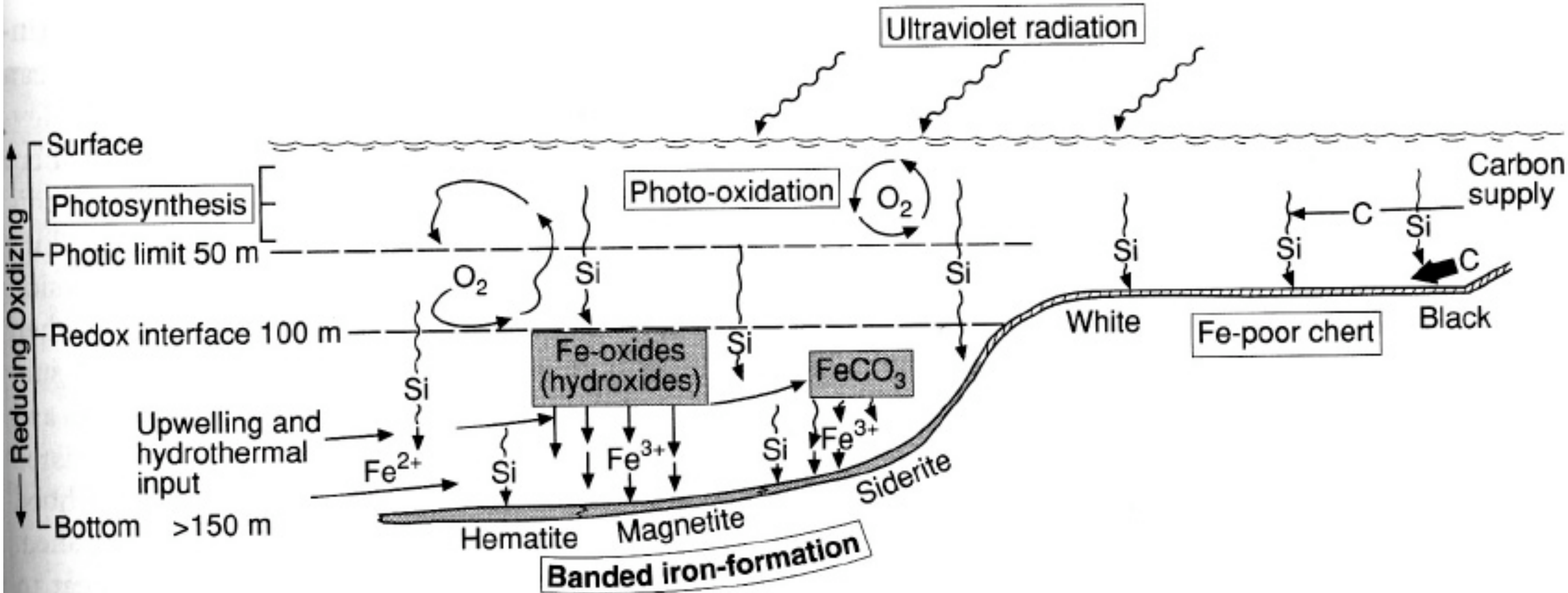


Figure 5.18 Model invoking upwelling and oxidation of ferrous iron from an oceanic source to explain the depositional environment for BIFs. Oxidation of ferrous iron and precipitation of ferric iron compounds occurs at a diffuse redox interface formed by the production of oxygen in the upper water levels, either by photosynthesizing organisms or by ultraviolet radiation induced photo-oxidation, or both. The lateral zonation of BIF facies (i.e. siderite–magnetite–hematite) shown here differs from the simple scheme envisaged by James (1954). Diagram modified after Klein and Beukes (1993).

Archean: Southeast Canada

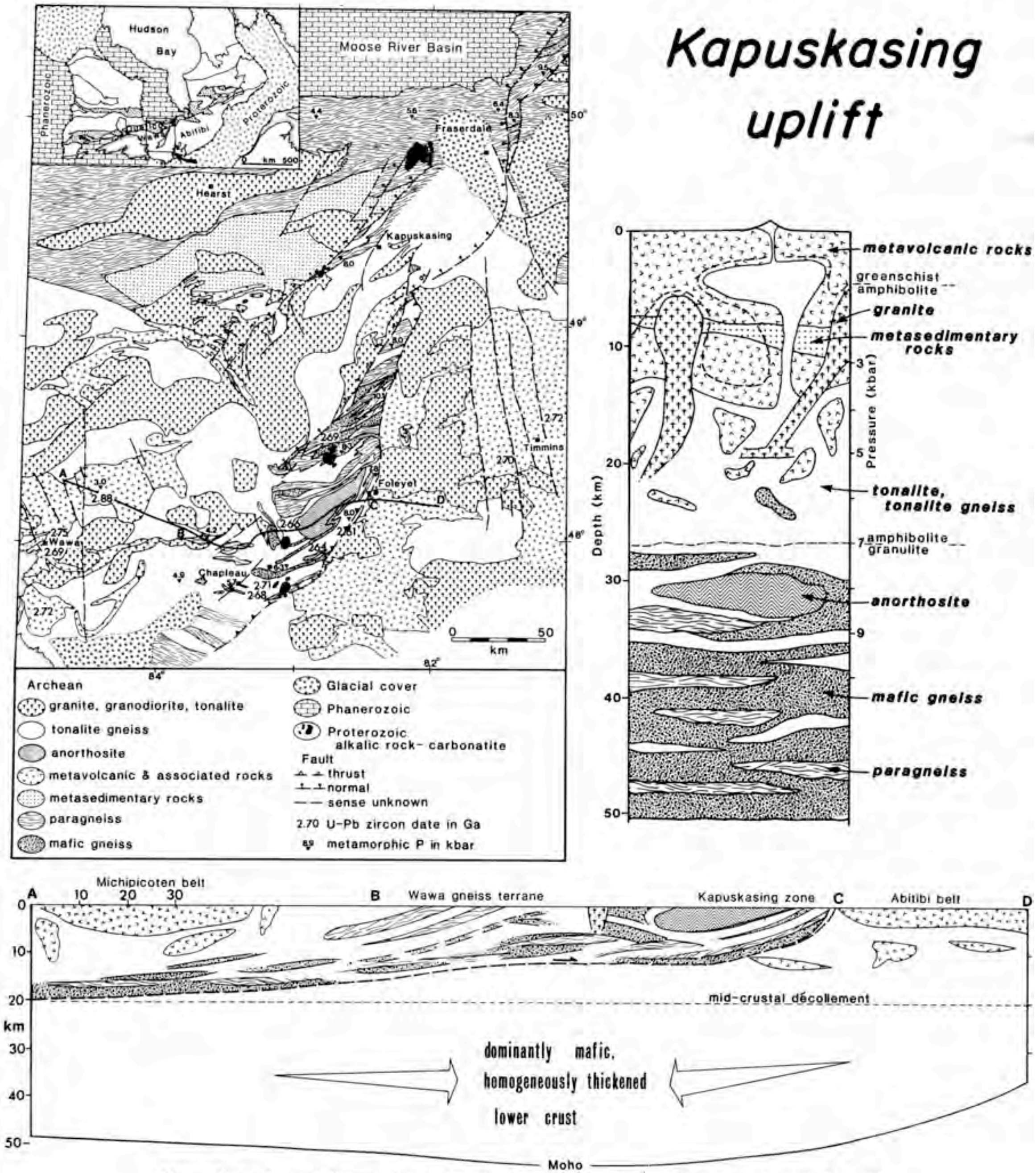
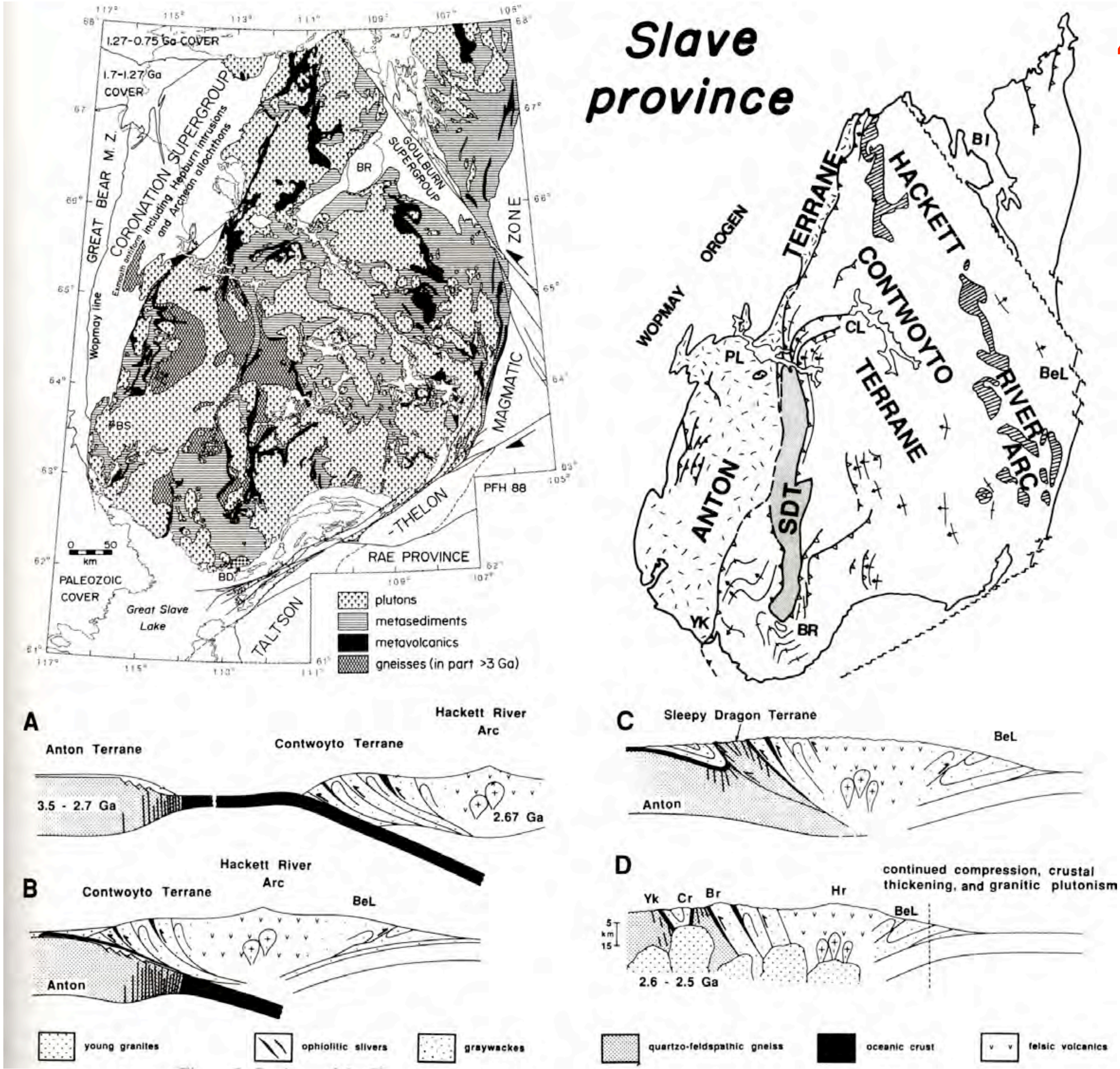
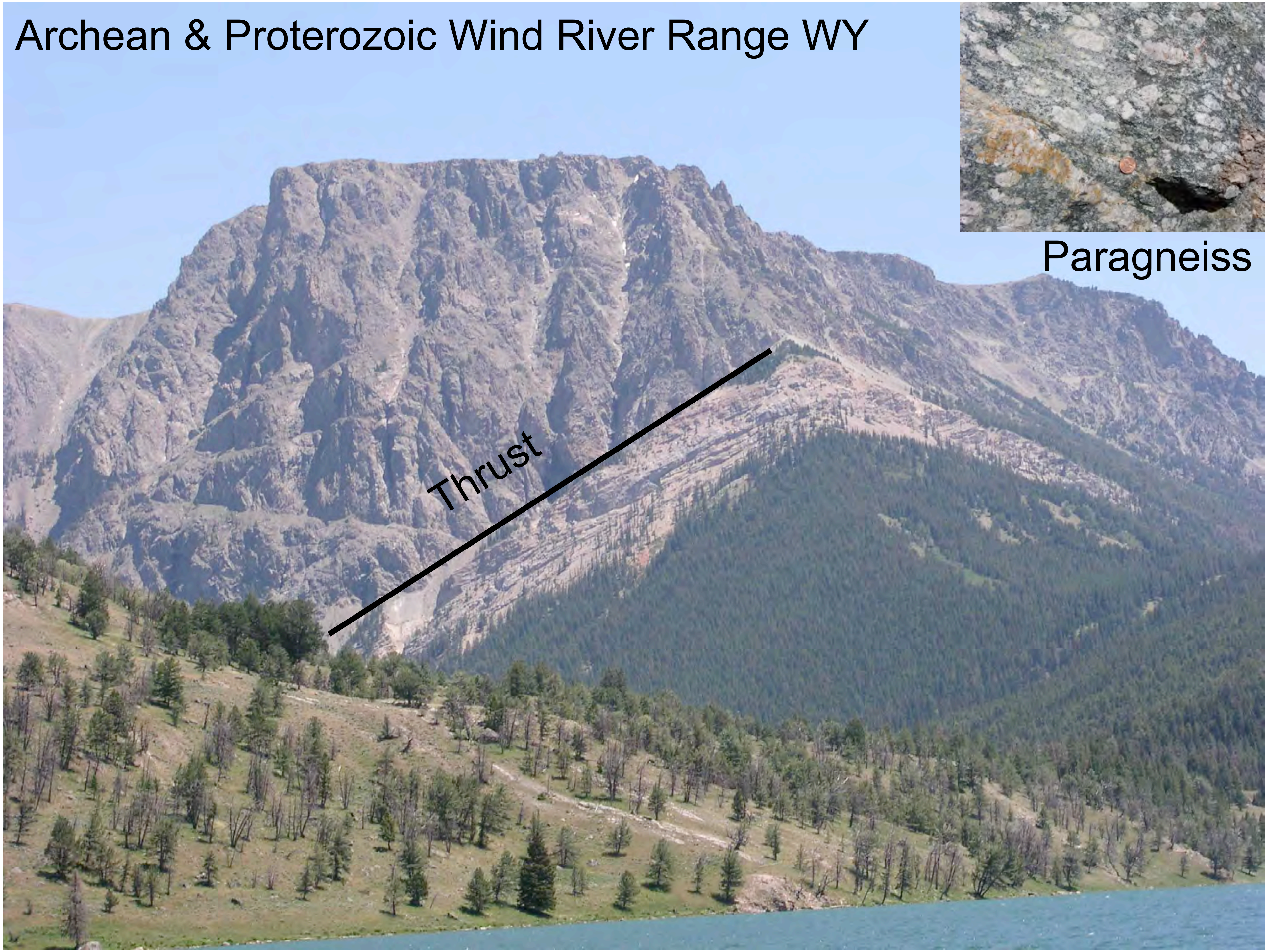


Figure 6. Geology of Kapuskasing uplift, south-central Superior province, according to *Percival (1989a)*. Crustal cross-section (below) consistent with metamorphic geobarometry is based on LITHO-PROBE seismic refraction and reflection profiling. Crustal column (upper right) is inferred from oblique cross-section exposed at surface.

Archean
Northern
Canada



Archean & Proterozoic Wind River Range WY



Paragneiss

Archean: Exposures In Laramide uplifts

5

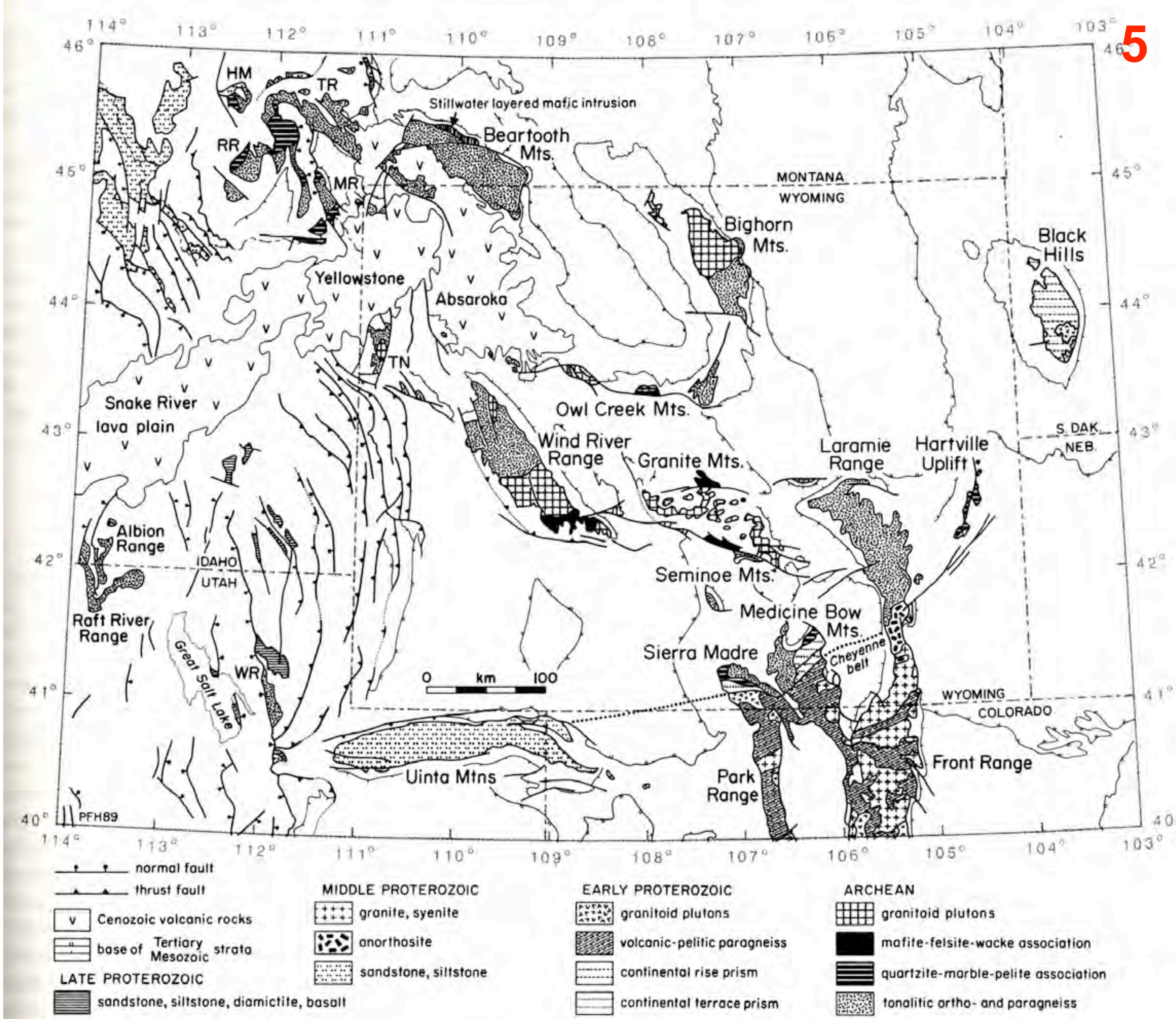
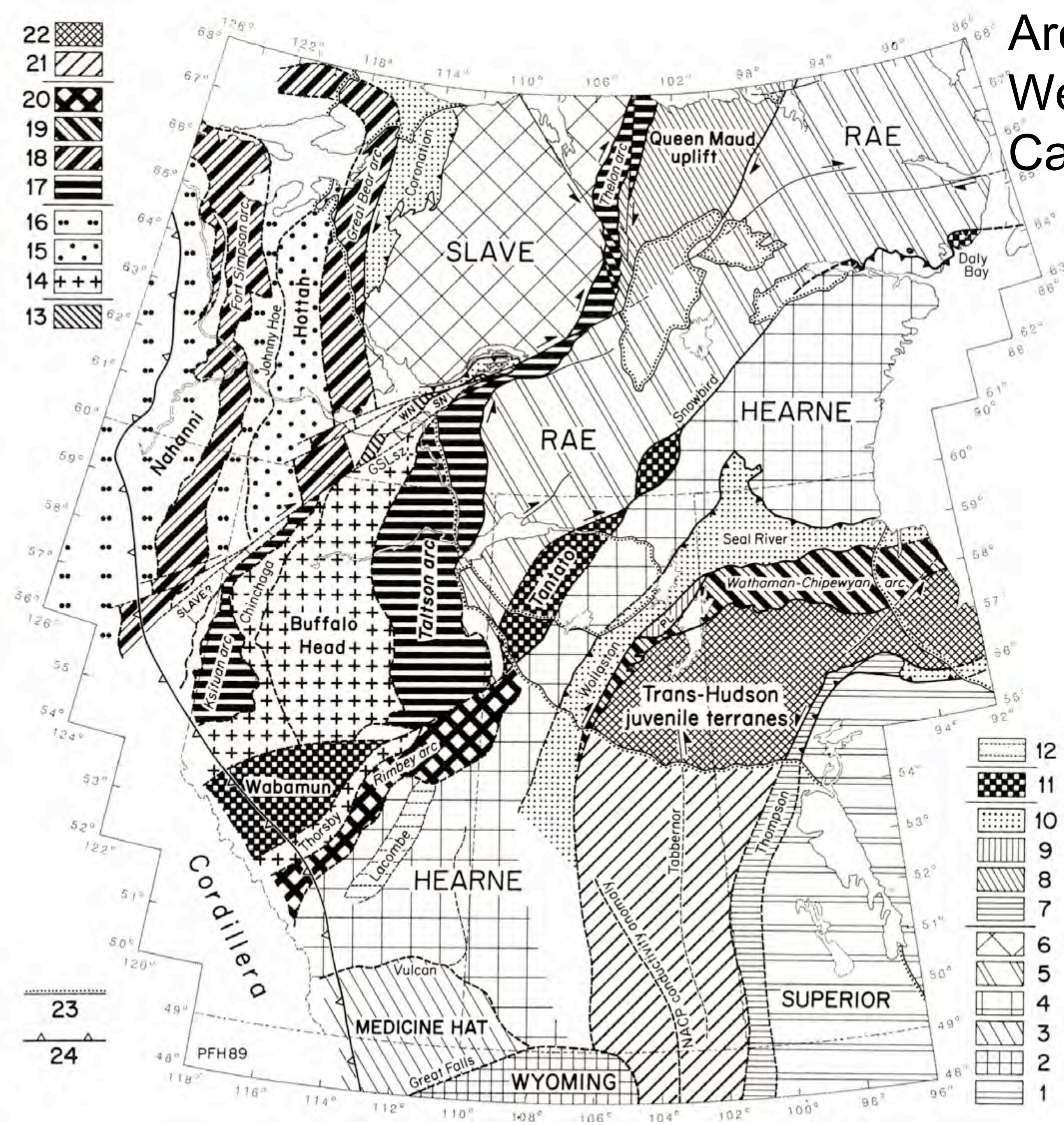


Figure 11. Laramide uplifts exposing Archean rocks of Wyoming province. Southeast margin of Wyoming province is exposed in Cheyenne belt. Deformation related to northwest margin (Great Falls tectnoic zone) increases toward Highland Mountains (HM), implying reactivation to form southeast margin of Belt basin defined by LaHood conglomerate (see Figure 36). MR, Madison Ranges; RR, Ruby Range; TN, Teton Range; TR, Tobacco Root Mountains.

6

Archean: Western Canada



North American Precambrian Elements

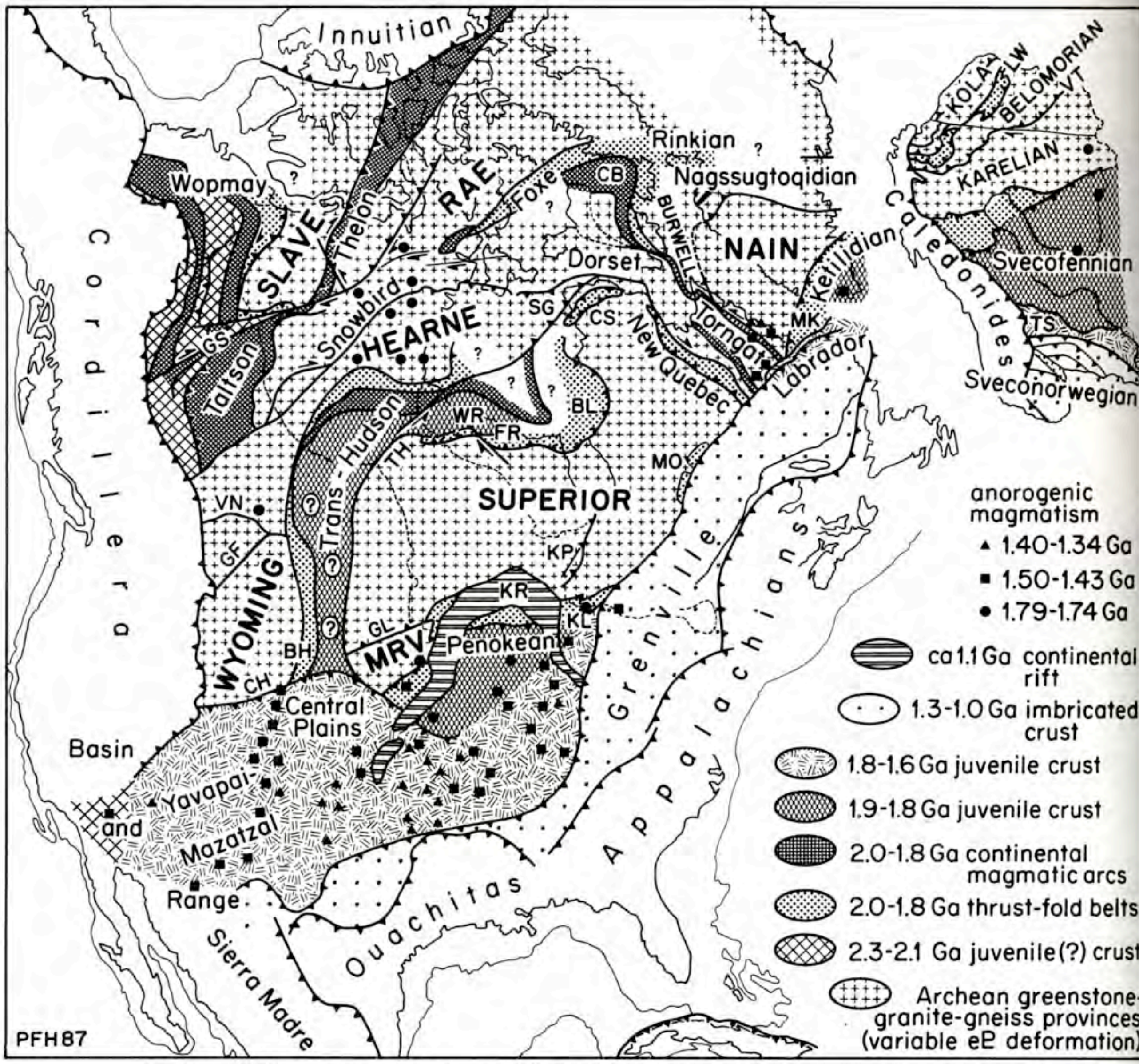


Figure 13. Precambrian tectonic elements of the North American craton (platform cover removed) and Baltic shield. Upper case names are Archean provinces; lower case names are Proterozoic and Phanerozoic orogens. BH, Black Hills inlier; BL, Belcher fold belt; CB, Cumberland batholith; CH, Cheyenne belt; CS, Cape Smith belt; FR, Fox River belt; GF, Great Falls tectonic zone; GL, Great Lakes tectonic zone; GS, Great Slave Lake shear zone; KL, Killarney magmatic zone; KP, Kapuskasing uplift; KR, Keweenawan rift; LW, Lapland-White Sea tectonic zone; MK, Makkovik orogen; MO, Mistassini and Otish basins; MRV, Minnesota foreland; SG, Sugluk terrane; TH, Thompson belt; TS, Trans-Scandinavian magmatic zone; VN, Vulcan tectonic zone; VT, Vetrenny tectonic zone; WR, Winisk River fault.

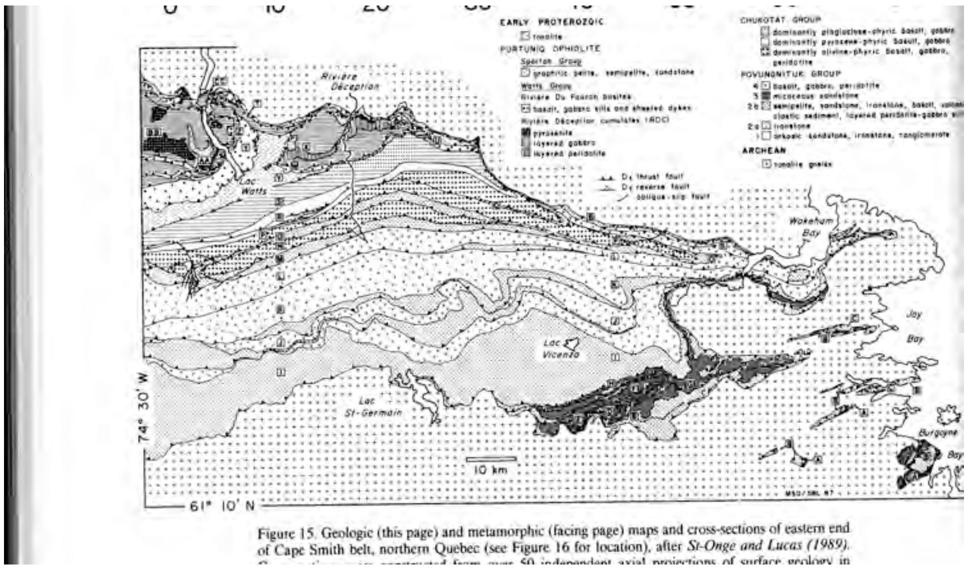
The Proterozoic

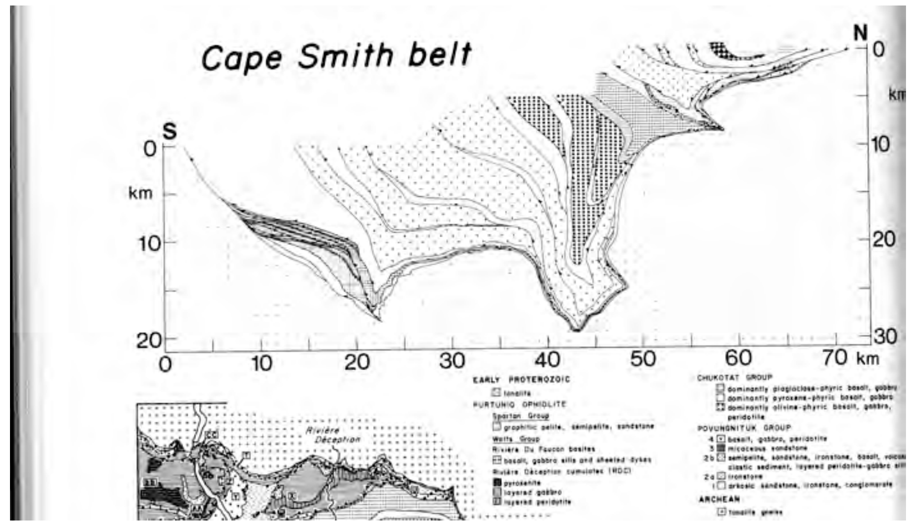
TABLE 2. COLLISION OROGENS BETWEEN ARCHEAN PROVINCES

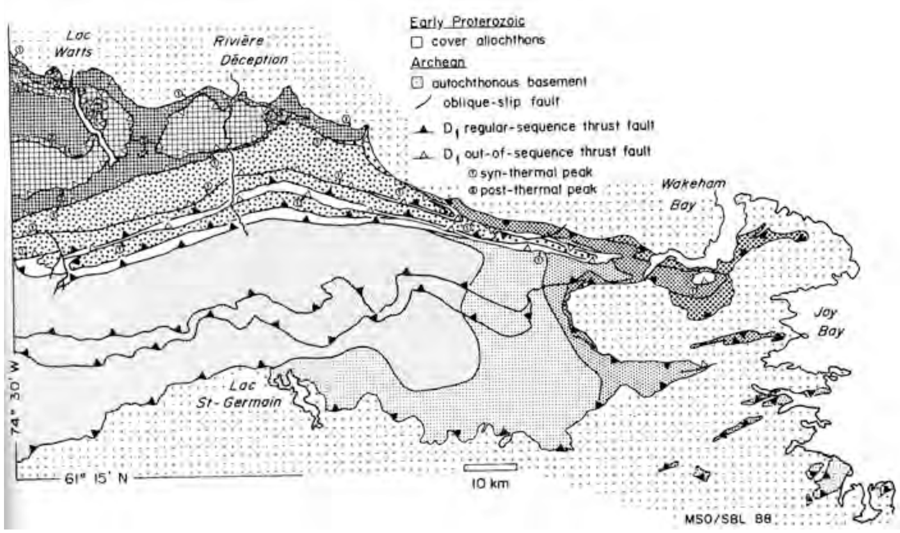
Orogen	Foreland	Hinterland	Obliquity	Orogenic U-Pb ages
Trans-Hudson	Superior	Hearne	Left	1.91–1.79 Ga
New Quebec	Superior	Rae	None	1.87–1.79 Ga
Torngat	Nain	Rae	Left	Post-2.4/pre-1.65 Ga
Nagssugtoqidian	Nain	Burwell	Left	1.87 Ga
Foxe/Rinkian	Rae	Burwell	Right(?)	1.90–1.84 Ga
Abloviak	Burwell	Rae	Left(?)	(?)
Snowbird	Hearne(?)	Rae(?)	(?)	Post-1.92/pre-1.85 Ga
Thelon	Slave	Rae	Right	2.02–1.91 Ga

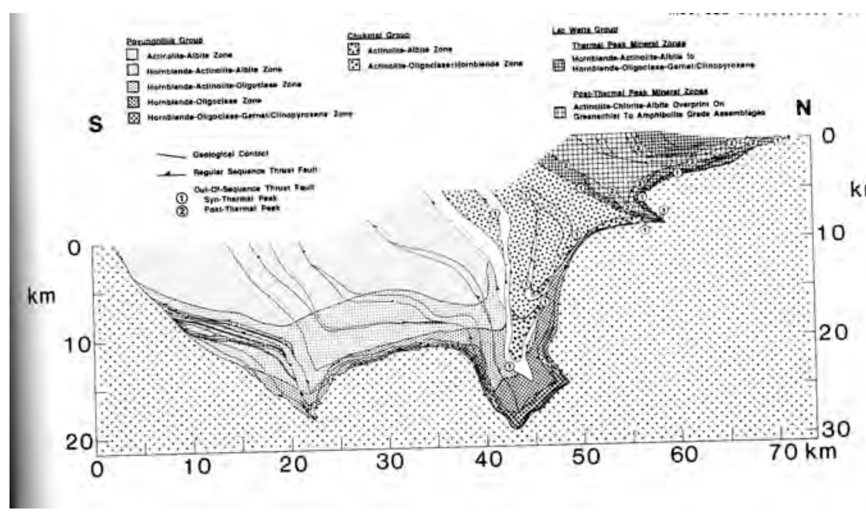
Geologic Map & Section

Metamorphic facies










Early Proterozoic Superstition Mountains, Arizona

Grand Canyon AZ: The Great Unconformity

Grand Canyon: Hance Rapids, Proterozoic Metasediments & Pegmatite Dike

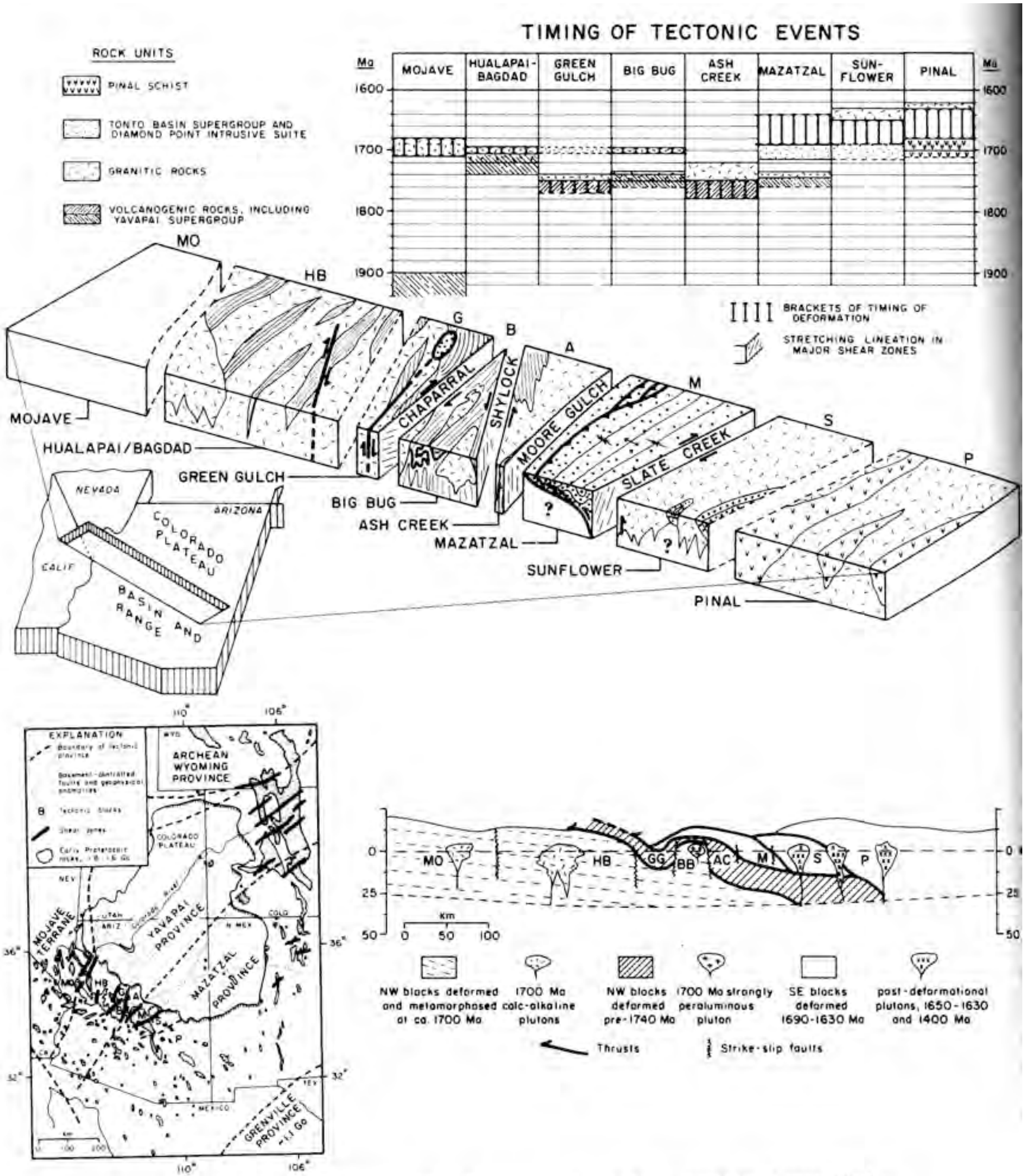


Figure 30. (Lower left) Exposures of Early Proterozoic rocks and inferred boundaries of tectonic blocks, according to *Karlstrom and Bowring, 1989.* (Above) Block diagram showing tectonostratigraphic blocks in Arizona and adjacent regions proposed by *Karlstrom and Bowring, 1988.* Moore Gulch fault separated composite northwestern region (5 blocks) from composite southeastern region (3 blocks). Timing of tectonic events based on U-Pb geochronology. (Lower right) Schematic NW-SE cross-section through central Arizona, from *Karlstrom and Bowring (1988),* showing minimum complexity of assembled blocks. At least three major terranes seem to be required by data on timing of deformation.

Early Proterozoic Belt Group, St Marys Lake, Glacier NP, Montana

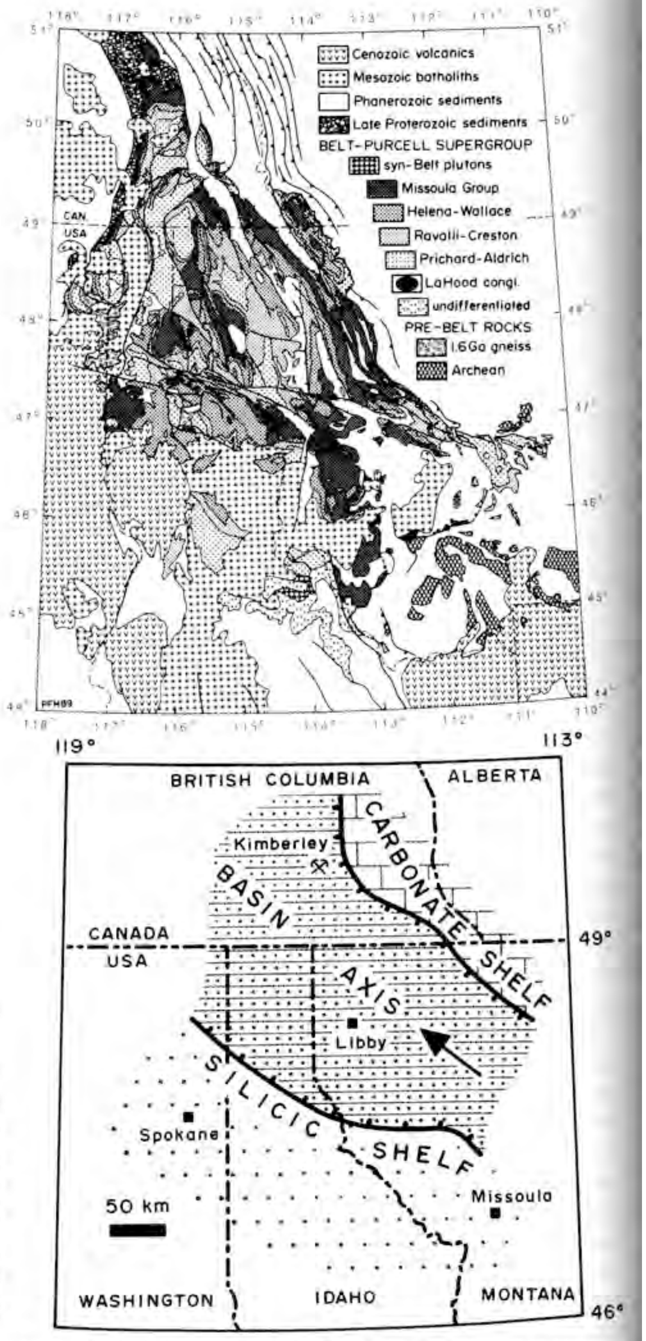
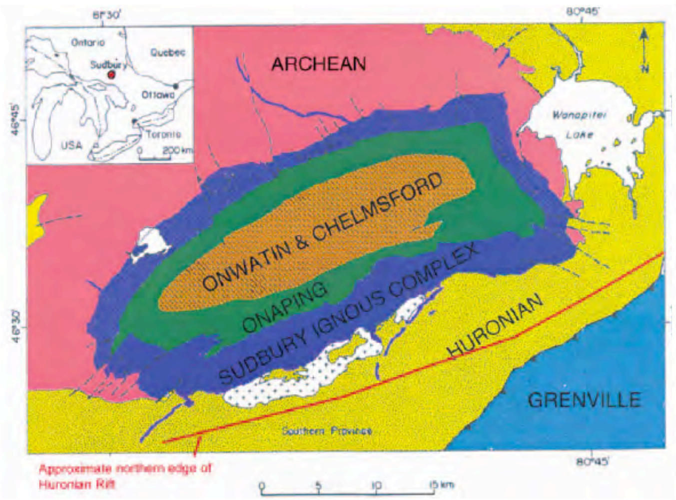


Figure 36. (Above) Geology of the Belt-Purcell Supergroup and environs (modified after compilation by D. Winston in *Roberts, 1986*). (Below) Paleogeographic restoration for lower Belt strata.

1.85 B Sudbury



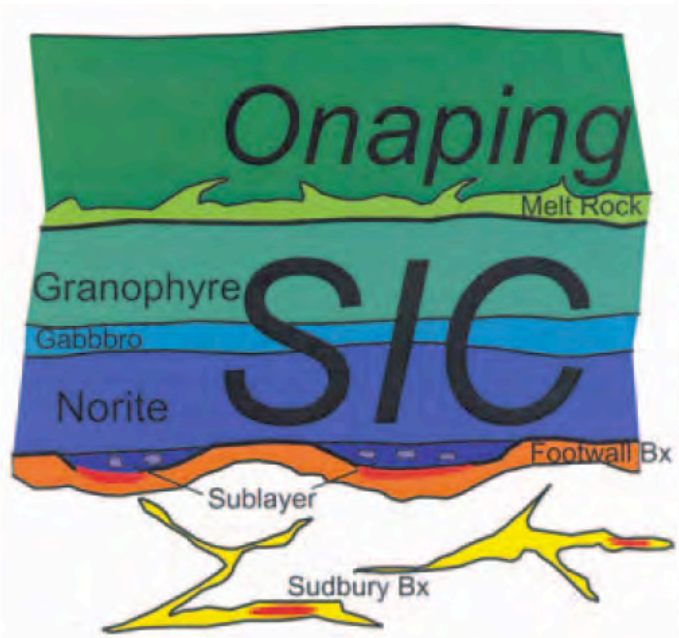


Figure 3. Schematic diagram showing main units resulting from the Sudbury "event." SIC—Sudbury Igneous Complex.

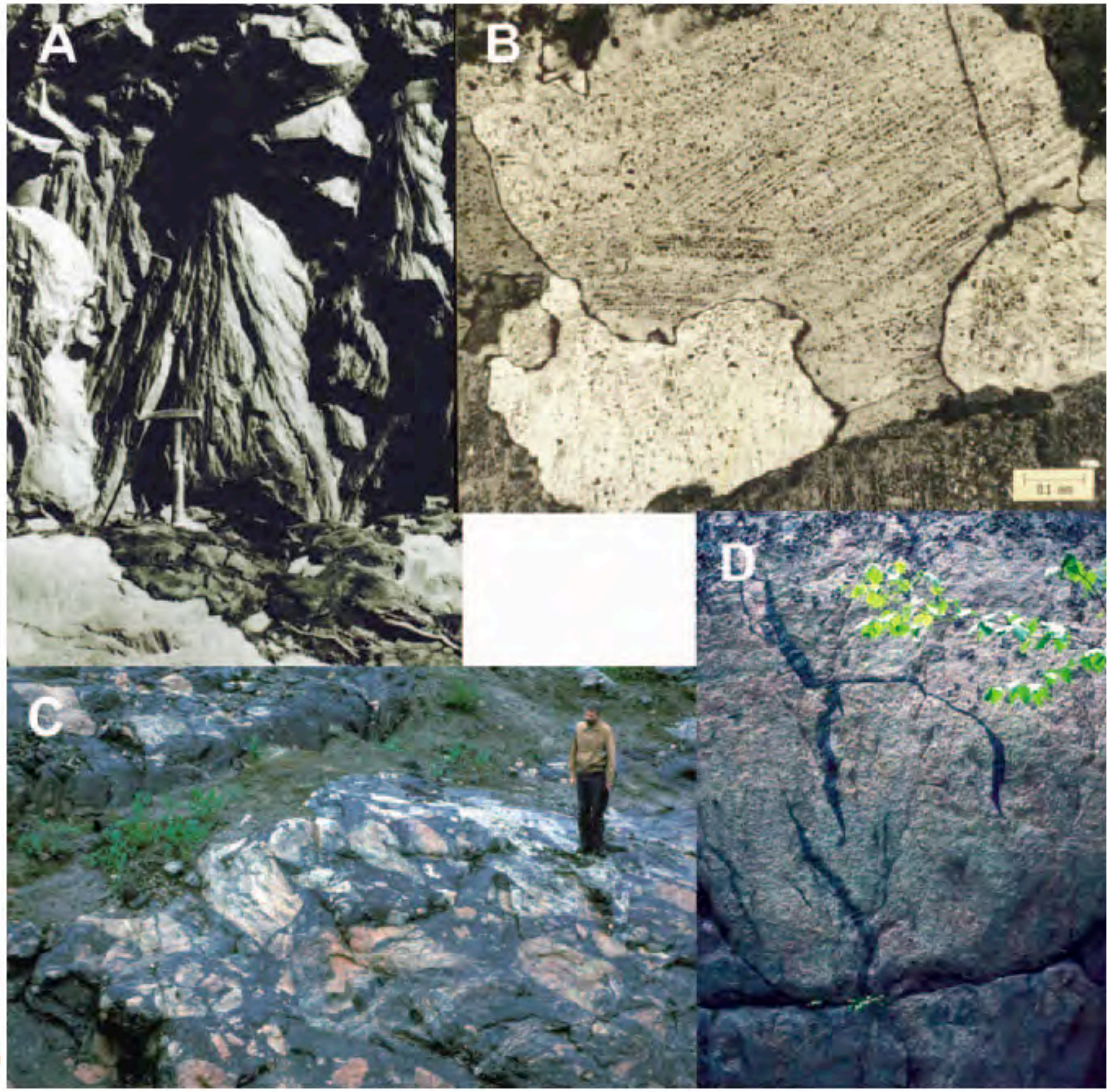
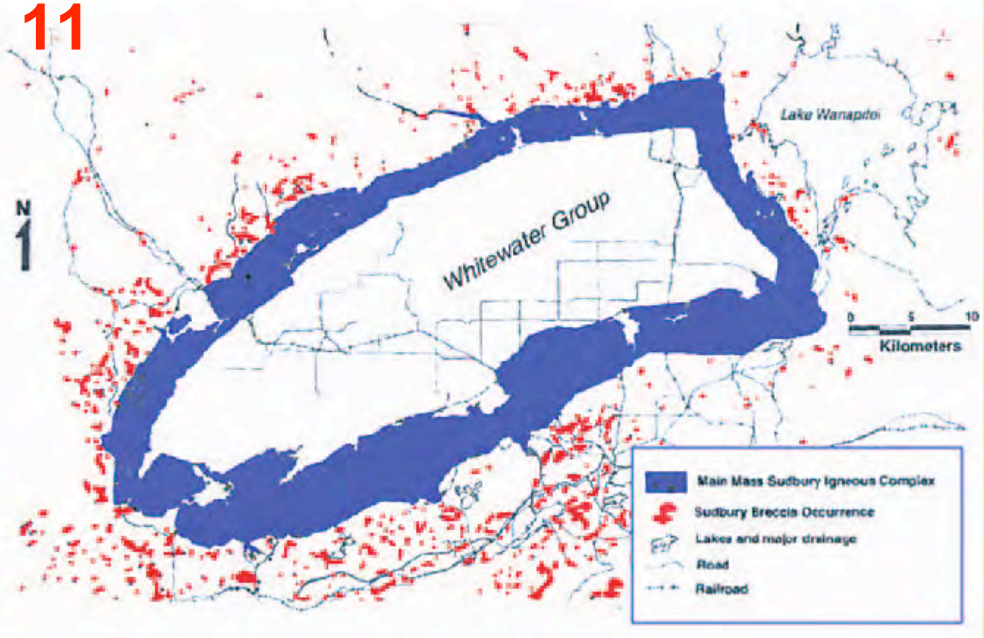


Figure 4. A: A shatter cone from the site south of Kelly Lake, Sudbury, where Bob Dietz first identified them (from Dietz, 1964). **B:** Shocked quartz showing at least two orientations of original lamellae of thetamorphic glass (photo thanks to Bevan French). **C:** Large area of Sudbury Breccia (photo thanks to Burkhardt Dressler). **D:** Thin veinlets of Sudbury Breccia cutting Archean granite (photo thanks to Burkhardt Dressler).

11



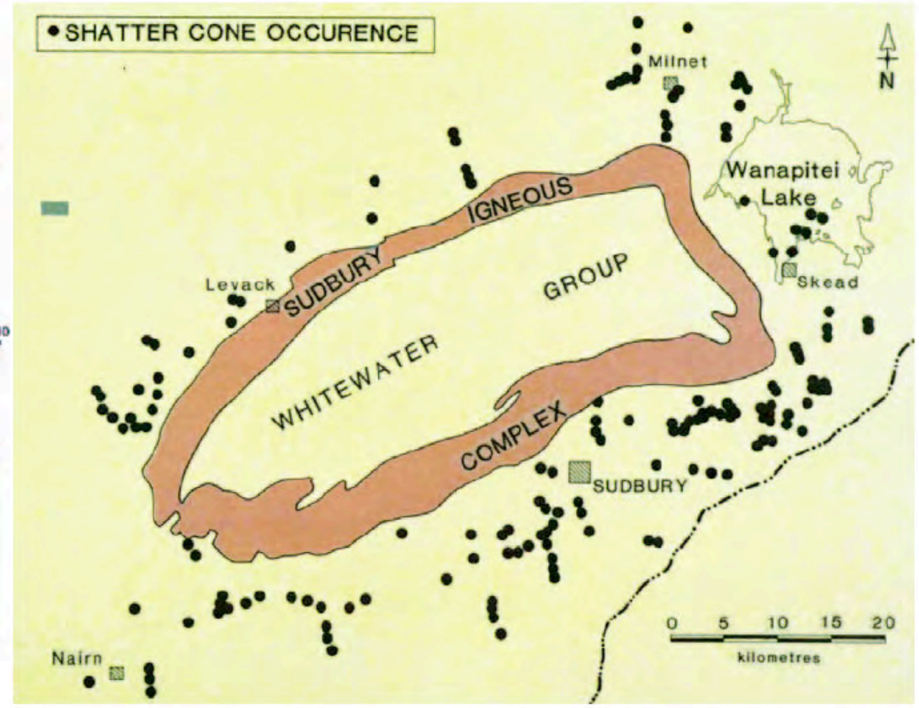
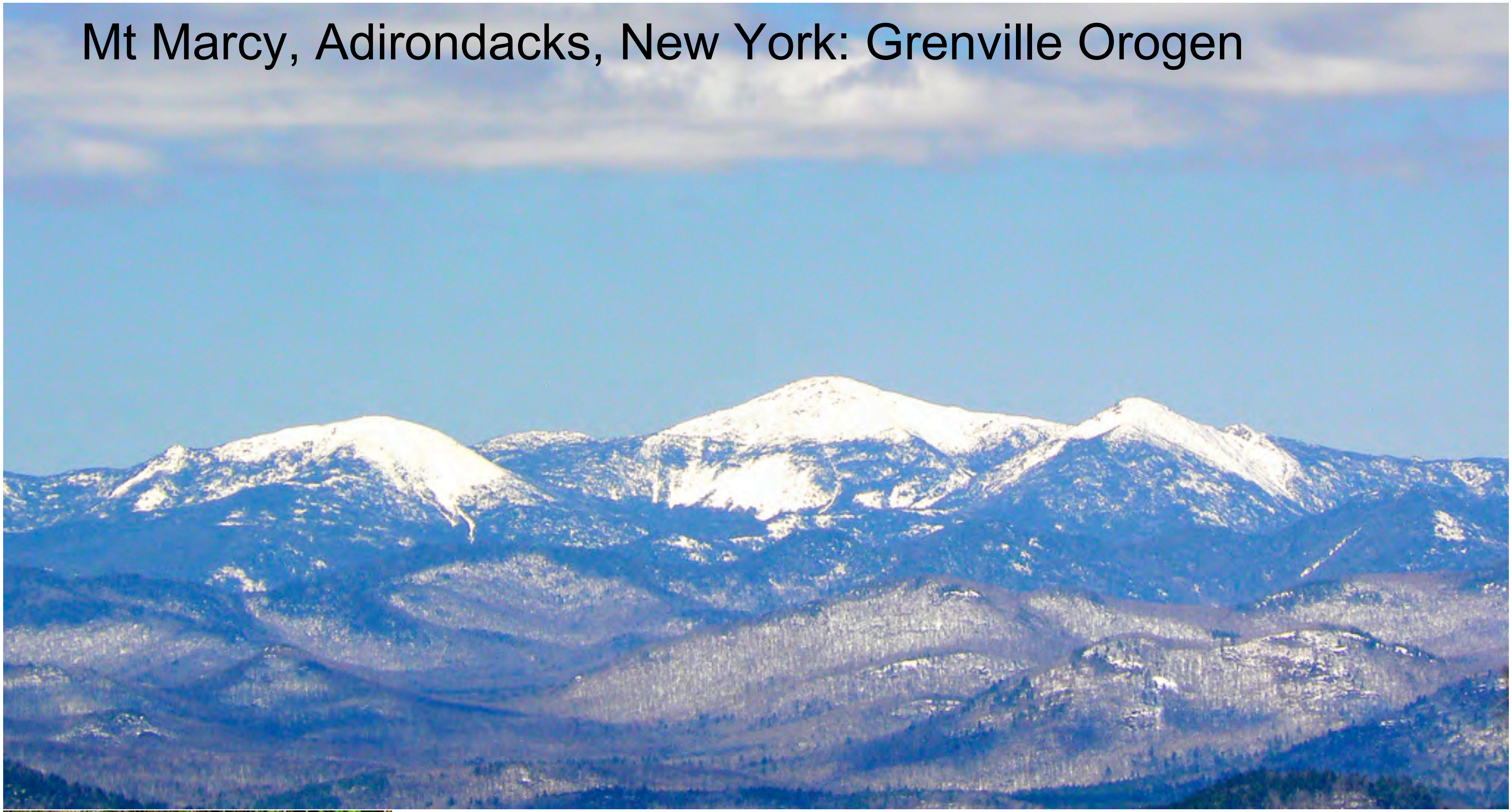
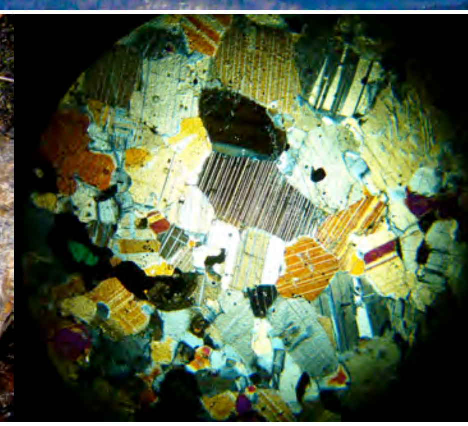


TABLE 1. PRINCIPAL GEOLOGICAL EVENTS IN THE SUDBURY AREA

Age in Ga	Event
>2.6	Formation of Archean greenstones, granite, and felsic gneiss
2.46	Onset of rifting, opening of Southern Ocean Deposition of Huronian Supergroup
2.22	Intrusion of gabbro sills (Nipissing Diabase)
1.9–1.8	Penokean Orogeny
1.85	Sudbury event
1.25	Intrusion of Sudbury dikes
1.1–1.0	Grenville Orogeny

Mt Marcy, Adirondacks, New York: Grenville Orogen





Anorthosite
Outcrop
Detail
Thin section


Adirondack 1.5 B Stromatolite
Australian Stromatolites

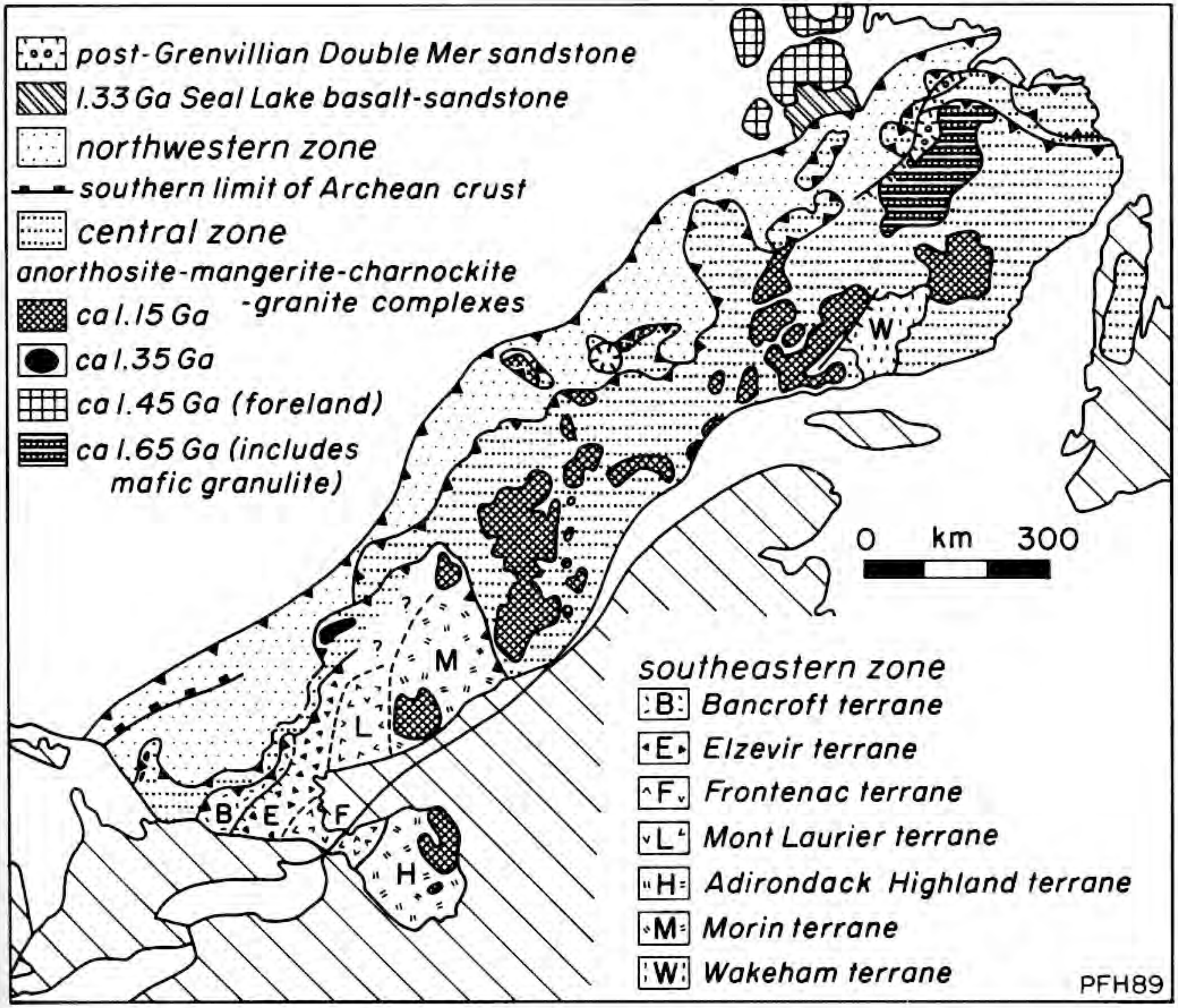


Figure 40. Geology of Grenville orogen in southeastern Canadian shield.

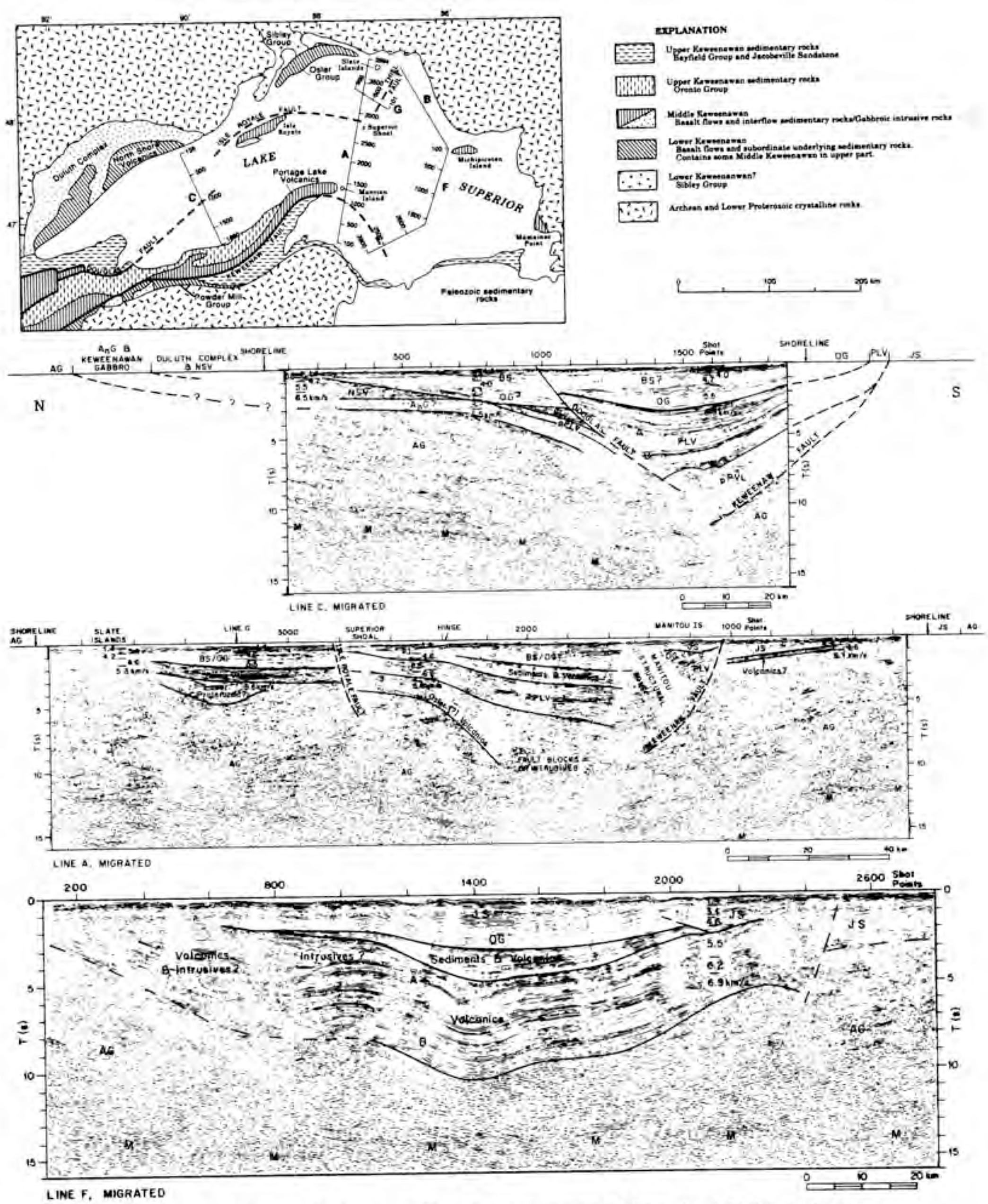


Figure 38. (Top) Generalized geology of Lake Superior segment of Midcontinent rift showing locations of GLIMPCE seismic reflection profiles. (Below) Migrated reflection profiles from *Cannon and others, 1989.* Vertical exaggeration is 1:1 for average velocity of 6 km/sec. Inferred subsurface units are projected updip to exposed extensions on land. AG, Archean gneiss; AnG, Animikie Group (Early Proterozoic); BS, Bayfield Group sediments; JS, Jacobsville sandstone; M, Moho (approximate depth); NSV, North Shore volcanics; OG, Oronto Group sediments; PLV, Portage Lake volcanics; pPLV, pre-Portage Lake sediments.

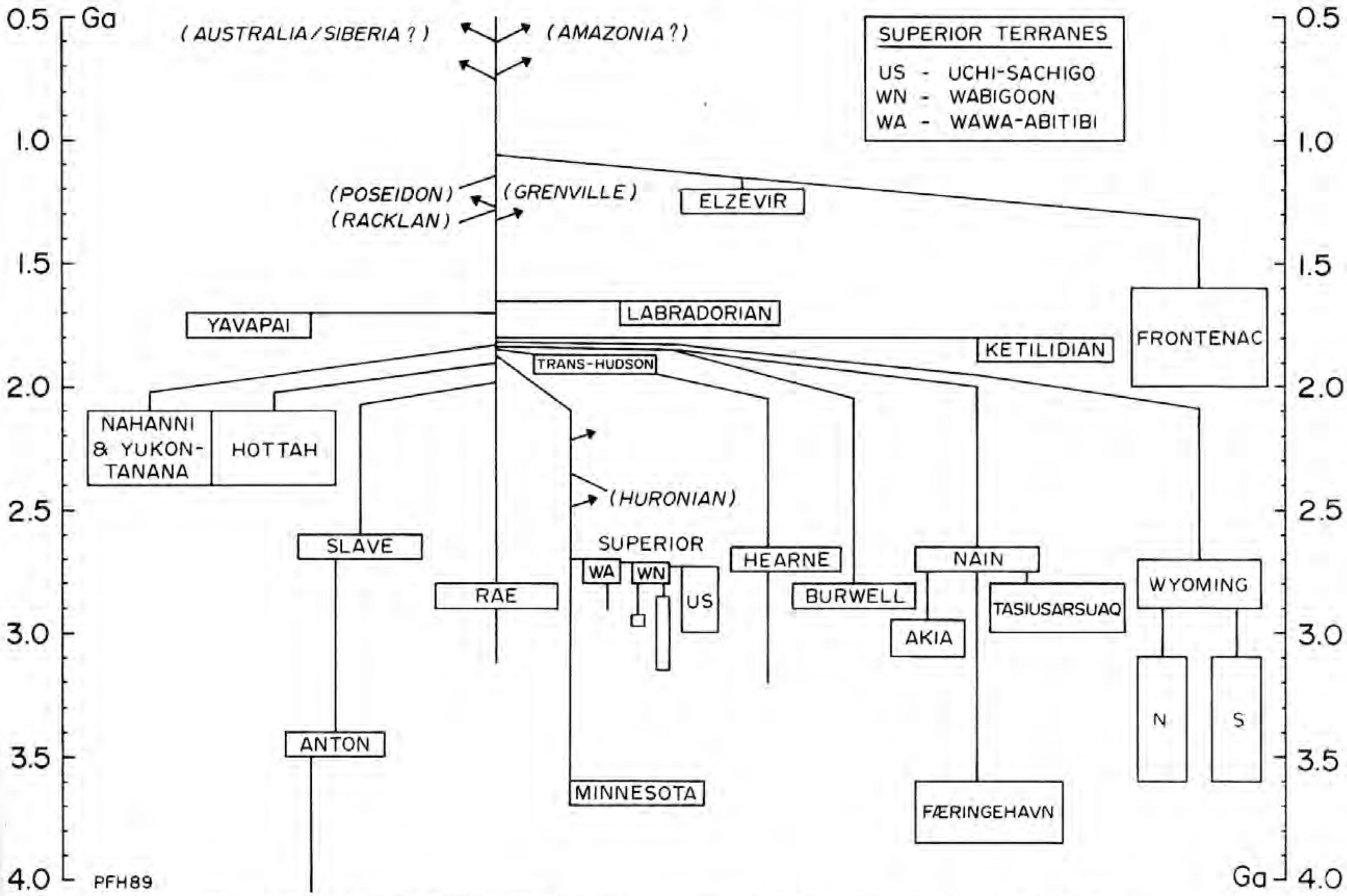
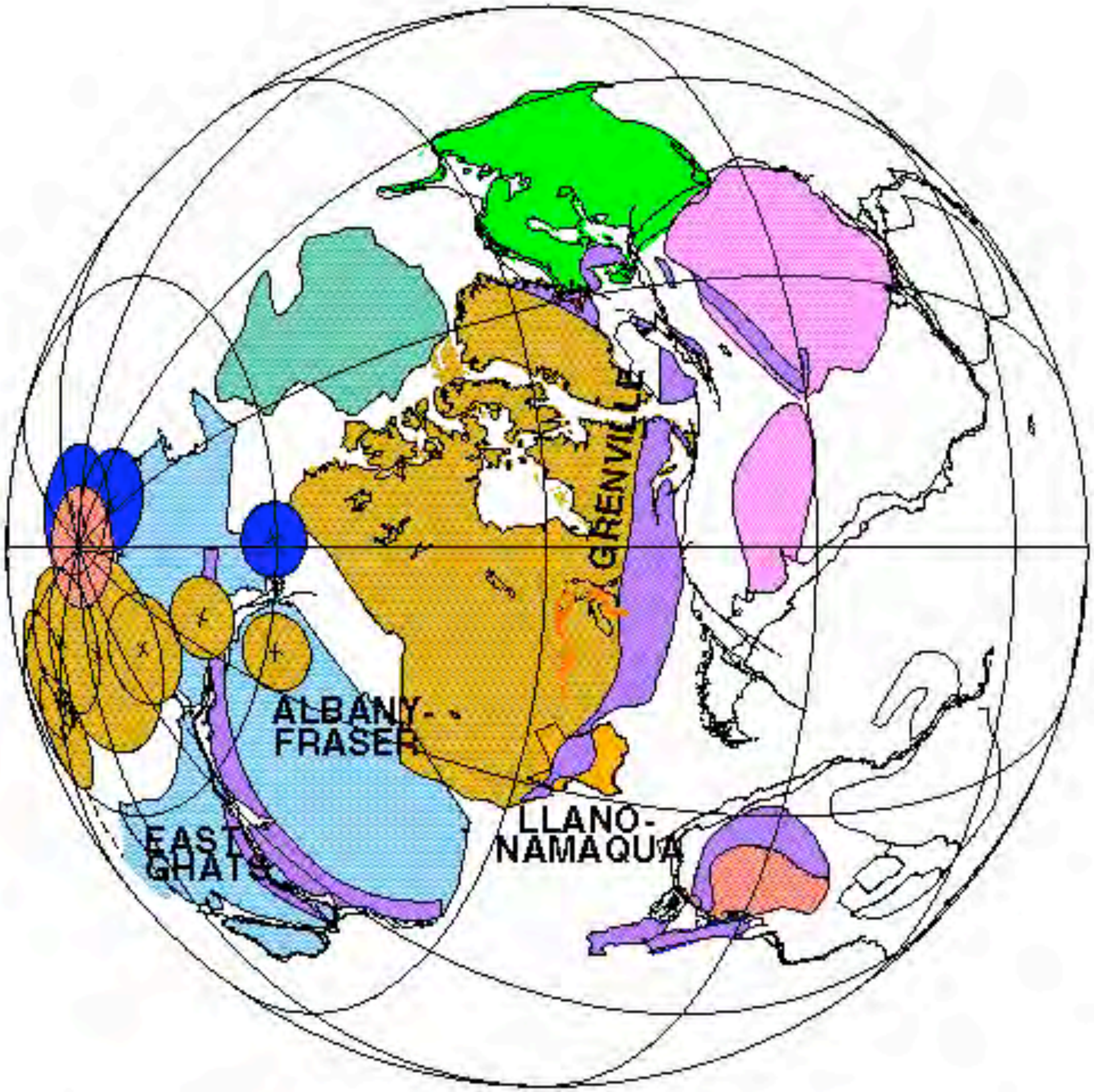


Figure 49. Cladogram (*Young, 1986*) summarizing accretion of North American craton. Boxes indicate times of crust formation of specific terranes. Merging of lines gives age of collision of respective terranes. Splitting of lines gives age of separation of terranes (bracketed names locate sites of separation; bracketed names with question marks identify terranes postulated to have separated). Note major episode of crust formation at 2.9 to 2.7 Ga, important confluence of Archean terranes at 2.0 to 1.8 Ga, accretion of juvenile crust at 1.9 to 1.7 Ga, and lack of convergent tectonism during 1.6 to 1.2 Ga period of anorogenic magmatism.



RODINIA
~1000-750 Ma

Dalziel, Mosher, & Gahagan
99-06-04

Thomas 2006

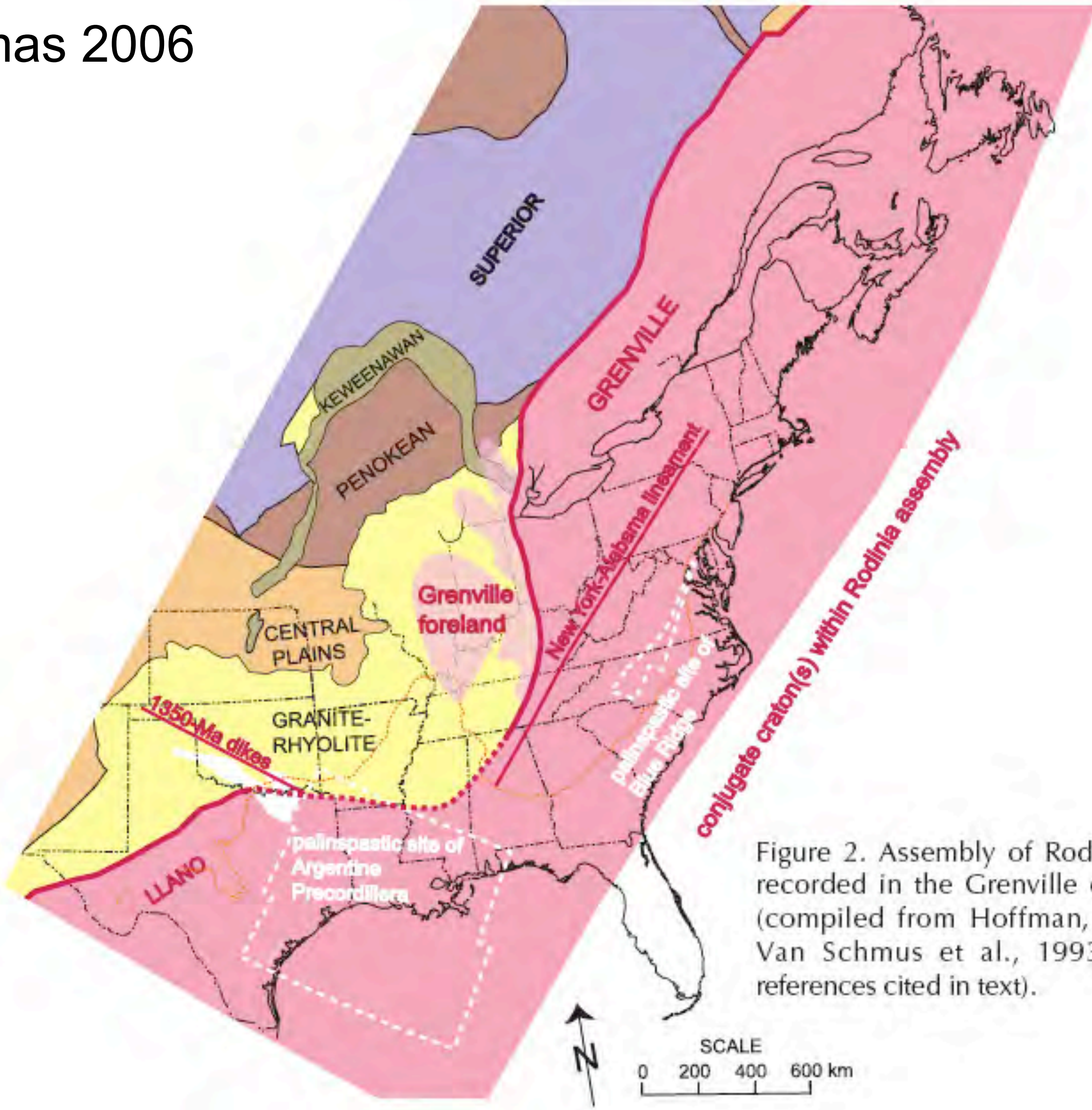


Figure 2. Assembly of Rodinia as recorded in the Grenville orogen (compiled from Hoffman, 1989; Van Schmus et al., 1993; and references cited in text).

Thomas 2006

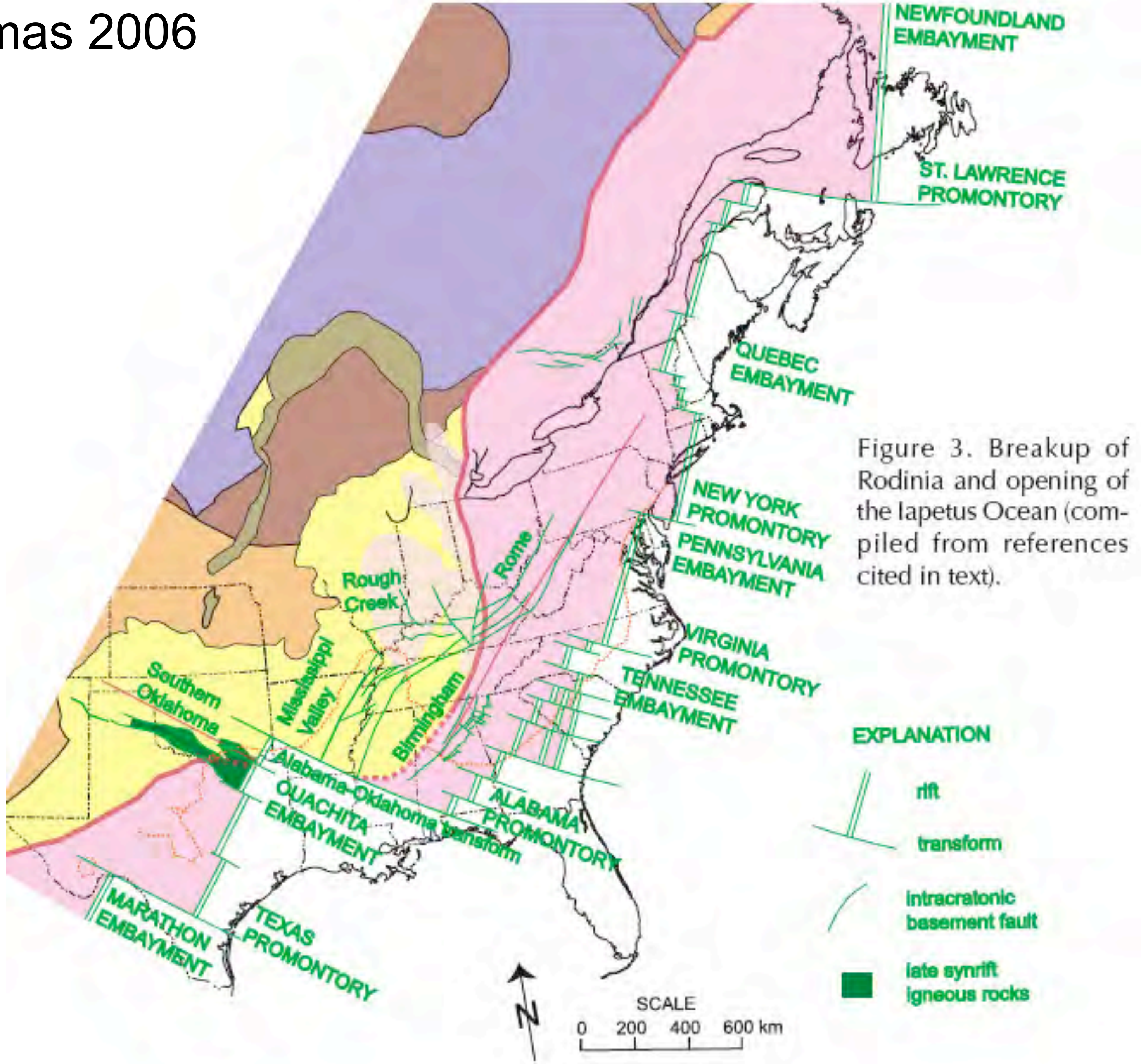
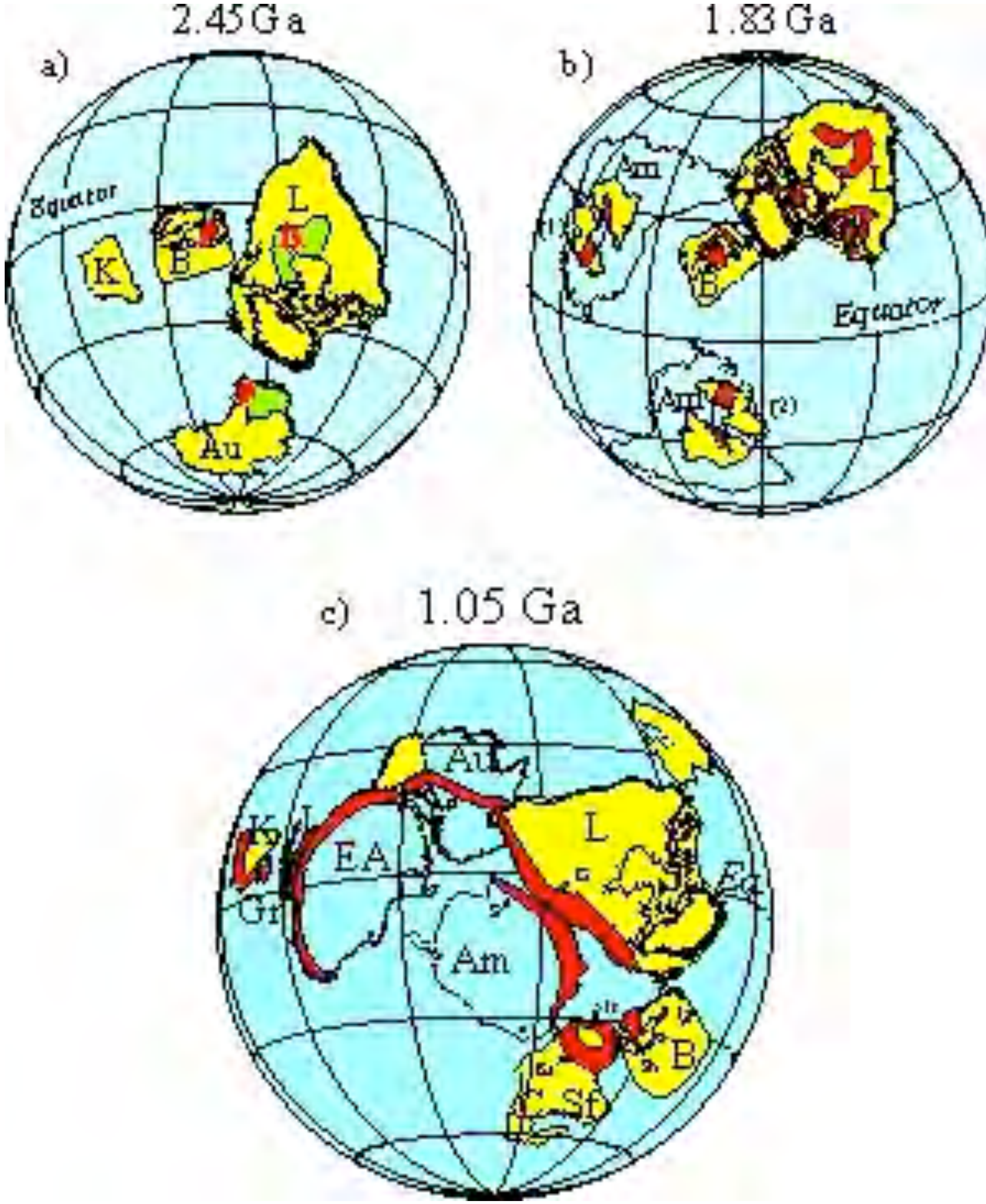


Figure 3. Breakup of Rodinia and opening of the Iapetus Ocean (compiled from references cited in text).

Kenorland

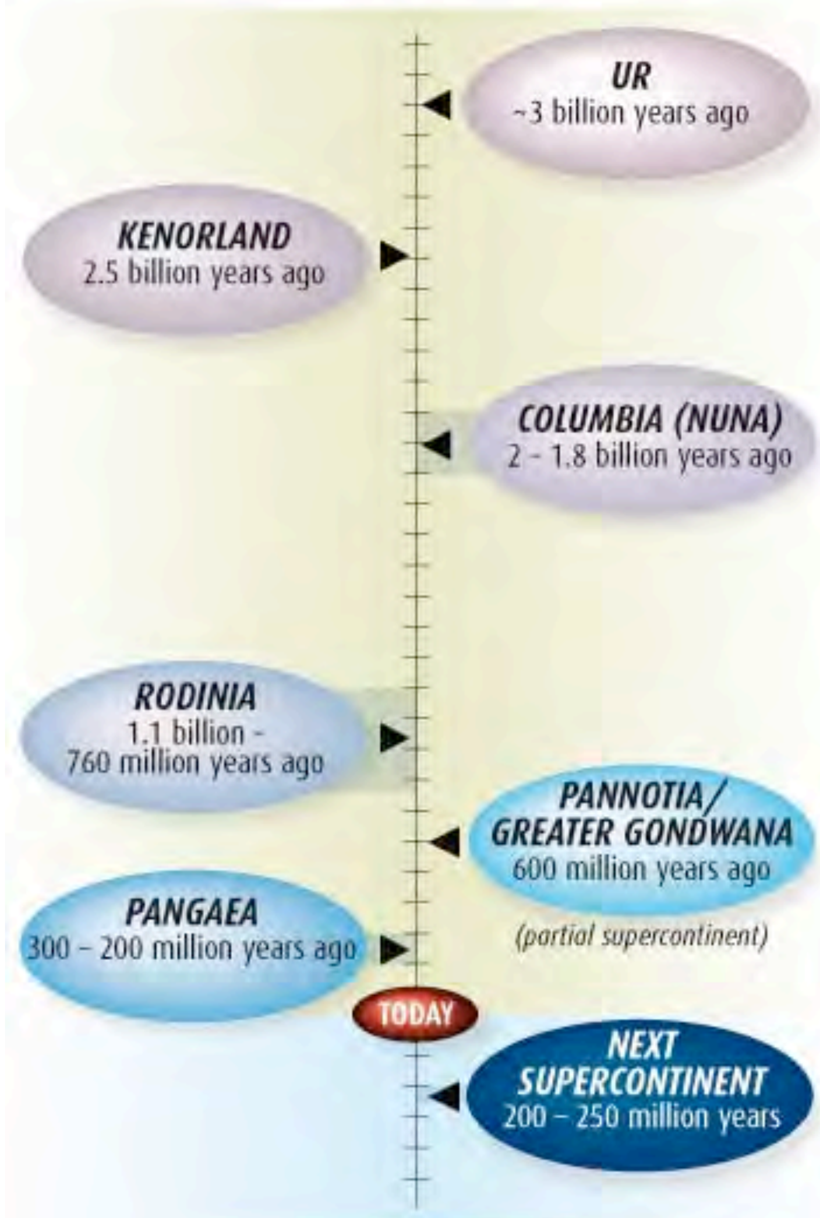
Columbia



Rodinia

SUPERCONTINENTS PAST AND FUTURE

At least two previous supercontinents existed, Pangaea and Rodinia. Further back evidence is hard to come by so their existence is more controversial



Questions

- What kinds of rocks occur in pC?
- What processes formed these rocks?
- When did plate tectonic processes begin?
- Was the ancient world similar to the current world?

Answers?

- 4500-3800 Ma Hadean
  - No evidence whatever: physics/astronomy/sci fi
- 3800-2500 Ma Archean
  - Older units are metamorphosed, deformed
  - Oldest units represent ocean crust
  - Plate tectonics operating near beginning Archean
- 2500-543 Ma Neoproterzoic
  - Sedimentary and igneous rocks preserved
  - 1800 Ma eukaryotic fossils
  - Last major BIF followed by possibly familiar atmospheric composition