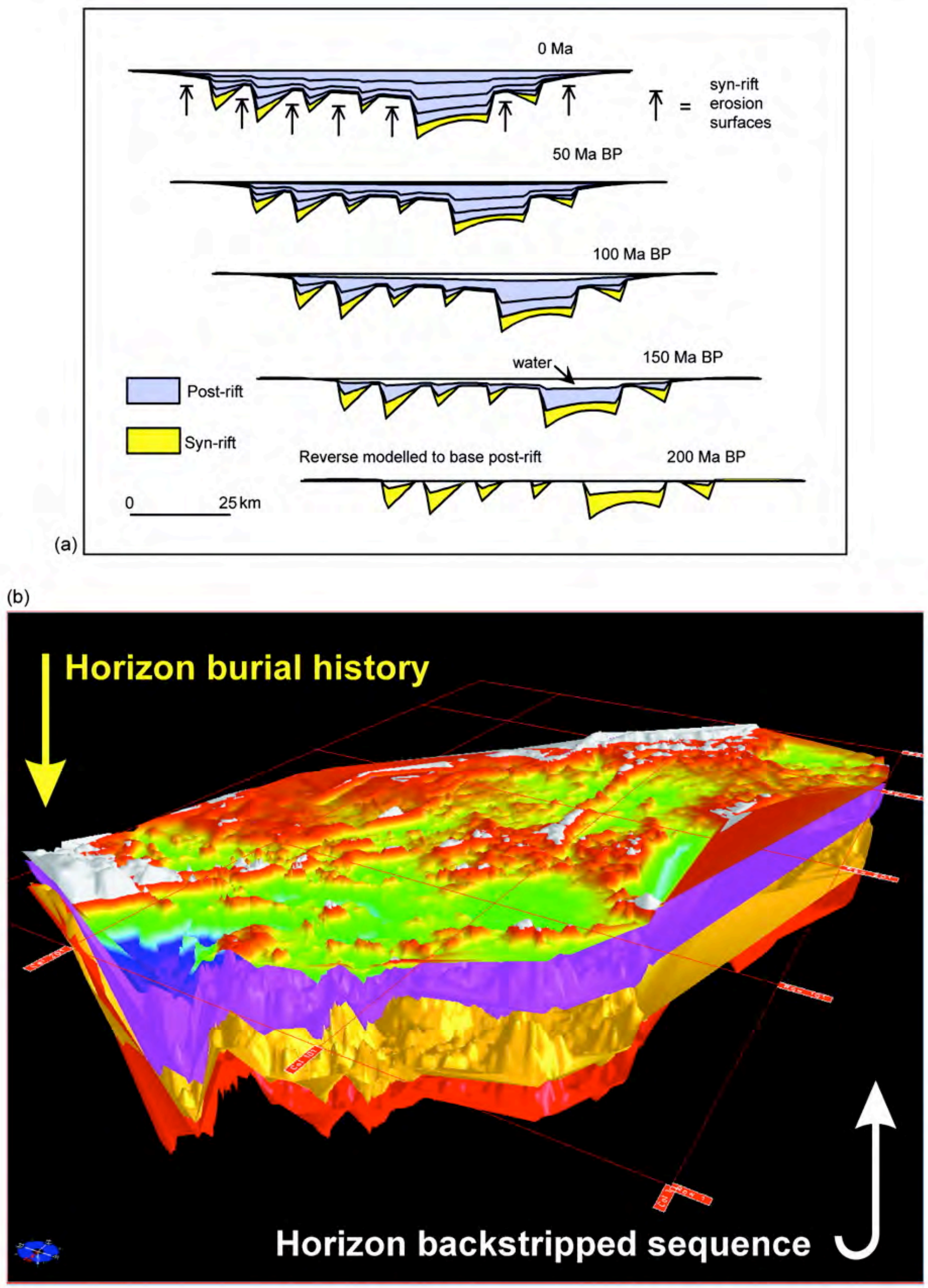


Another example of backstripping from More and Voring Basin
Offshore Mid Norway
(Roberts et al 2009)

http://pg.geoscienceworld.org/content/vol15/issue1/images/medium/27fig3.jpeg

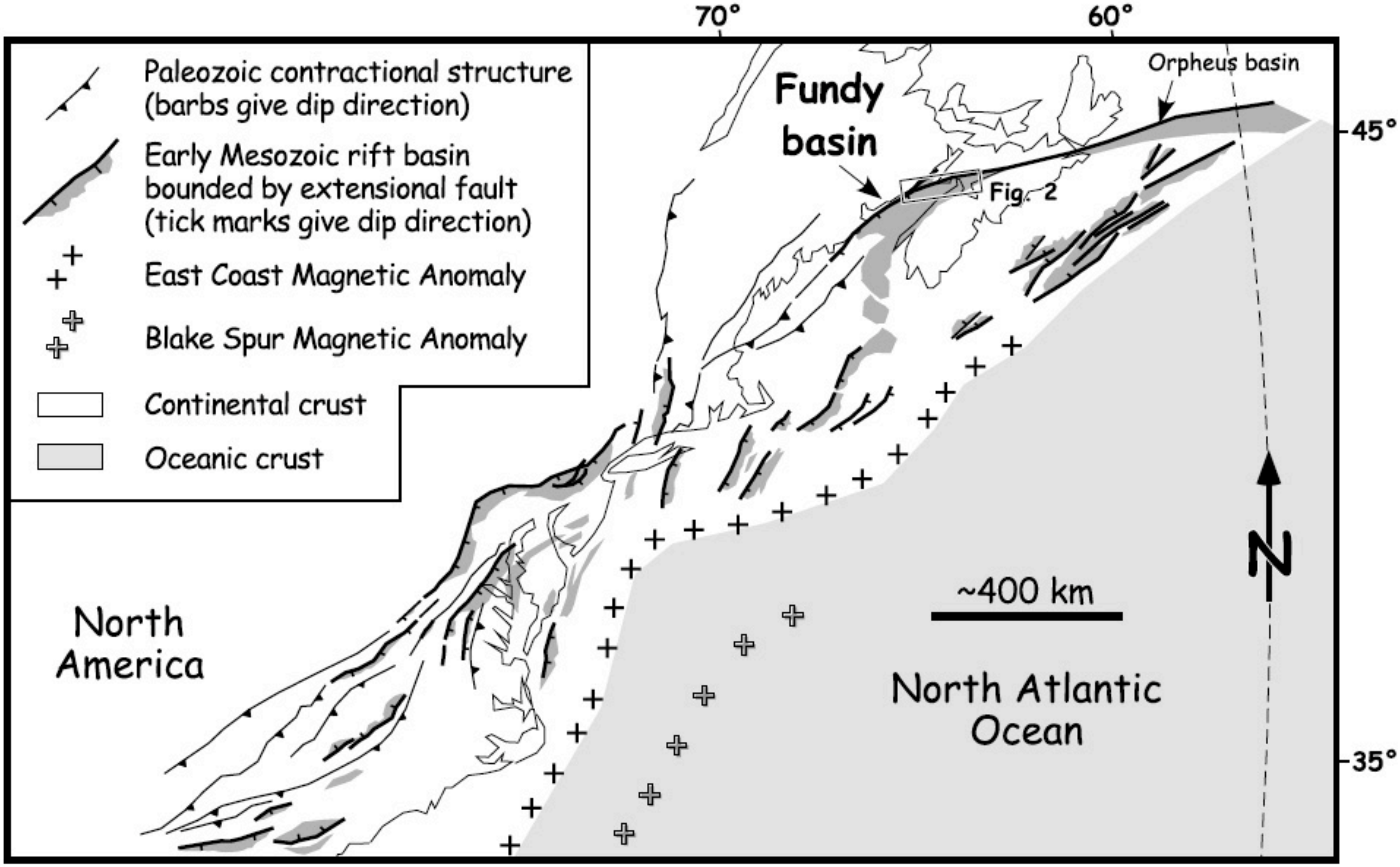


Figure 1. Major Paleozoic contractional structures, early Mesozoic rift basins, and key tectonic features of western North Atlantic Ocean [*Klitgord et al.*, 1988; *Olsen et al.*, 1989; *Welsink et al.*, 1989; *Rankin*, 1994; *Benson*, 2003]. The exact slip on most faults and the exact geometry and location of most subsurface rift basins is unknown. Rectangular box shows location of maps in Figure 2.

Withjack et al 2010

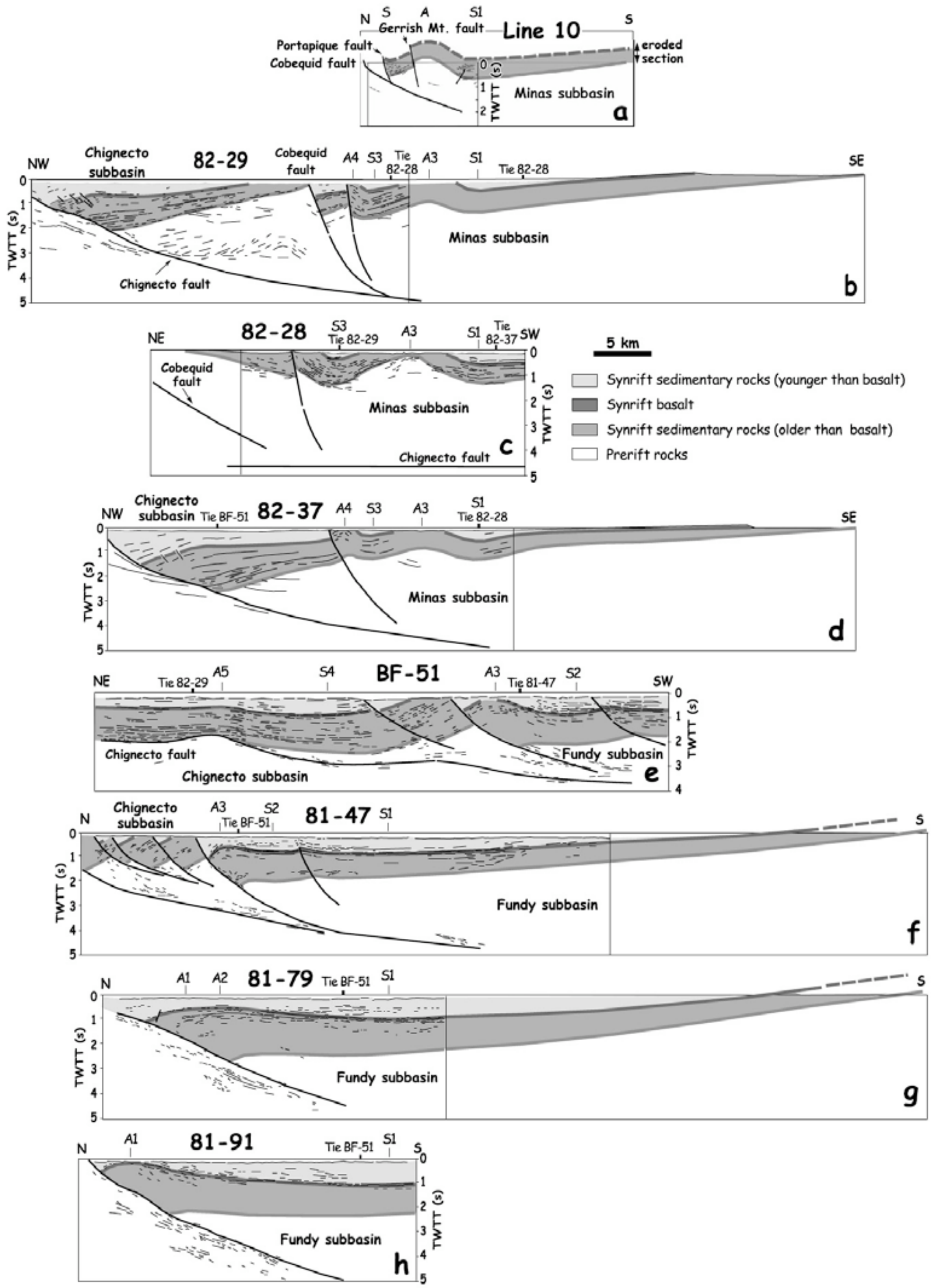


Figure 3

Examples of structural inversion in the Fundy Basin, offhsore Canada

Withjack et al 2010

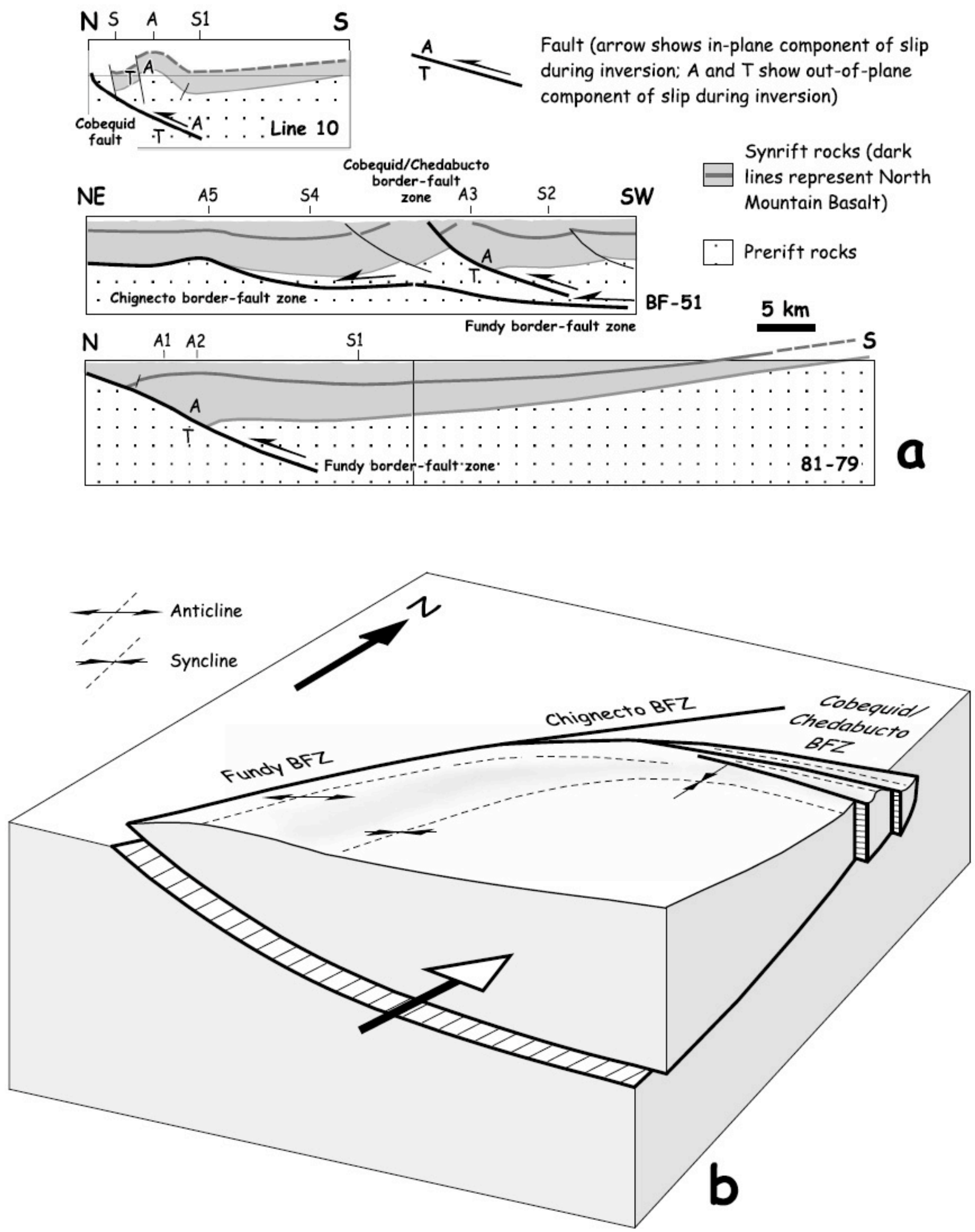


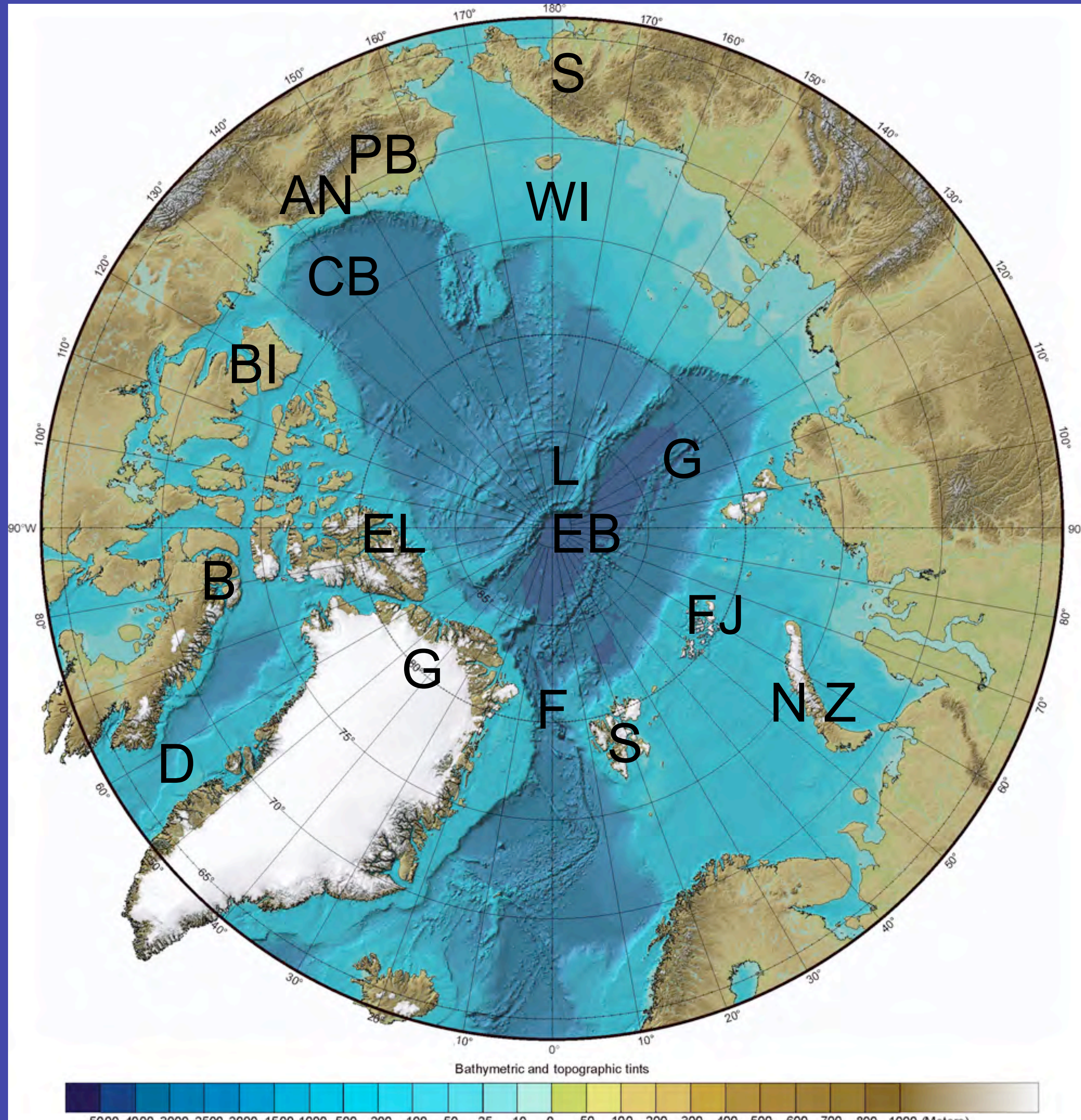
Figure 14. (a) Simplified cross sections through Fundy rift basin showing slip during inversion. Locations given in Figure 13b. (b) Schematic block diagram showing contrasting styles of inversion-related deformation in the hanging wall of the composite border-fault system of the Fundy rift basin. BFZ is border-fault zone. See text for discussion.

Model explaining styles of inversion in Fundy Basin.

How do we get compression in an extensional setting?

Withjack et al 2010

Siberia
Wrangel Island
Prudhoe Bay
ANWR
Canada Basin
Banks Island
Ellsmere Island
Greenland
Baffin Island
Lomonosov Ridge
Eurasia Basin
Gakkel Ridge
Franz Josef Land
Novaya Zemla
Svalbard
Fram Strait
Davis Strait



Longyearbyen Valley and town, Svalbard, Nortway (Flickr)

North Central Greenland (GEUS)

Ellemere Island (UN: ASTER image)

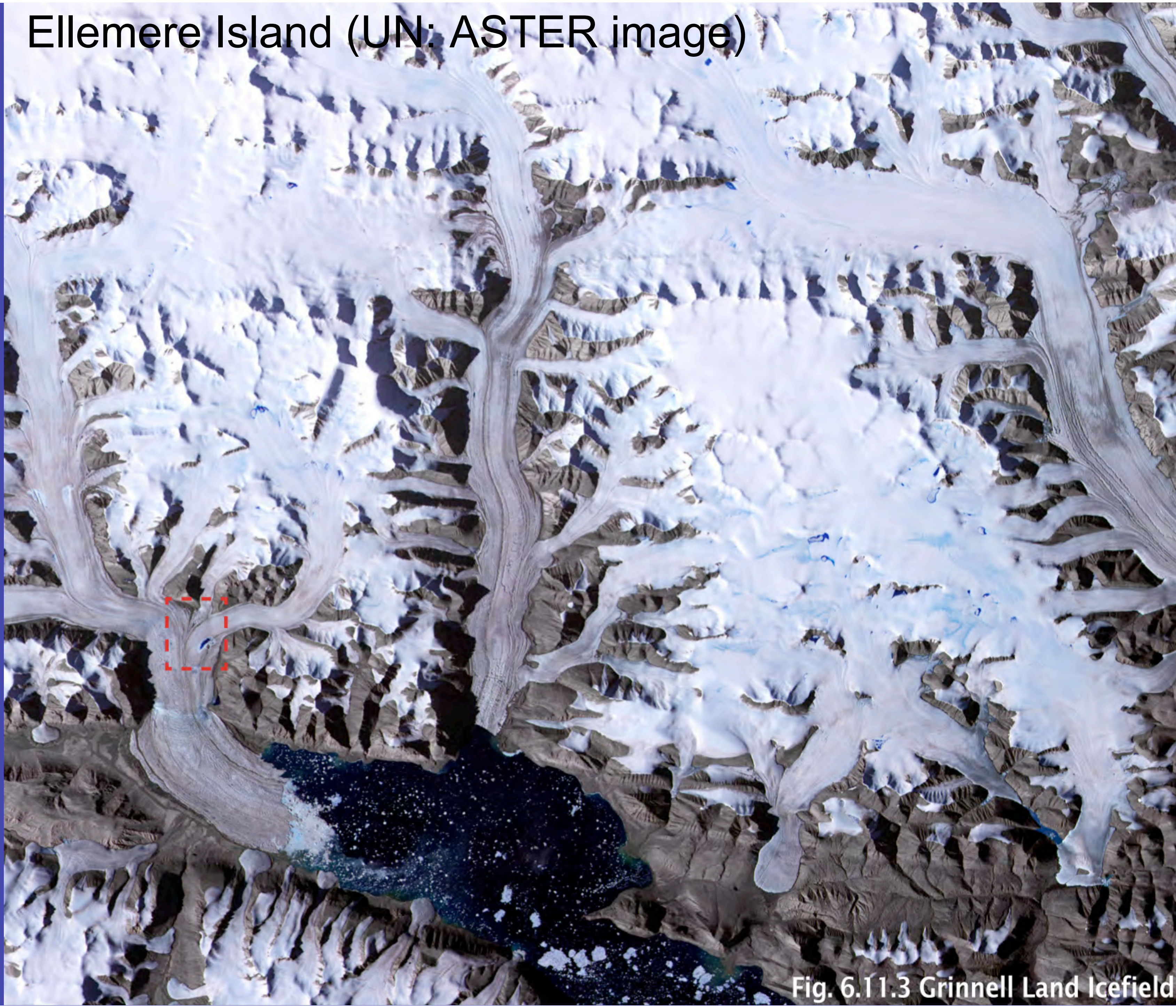


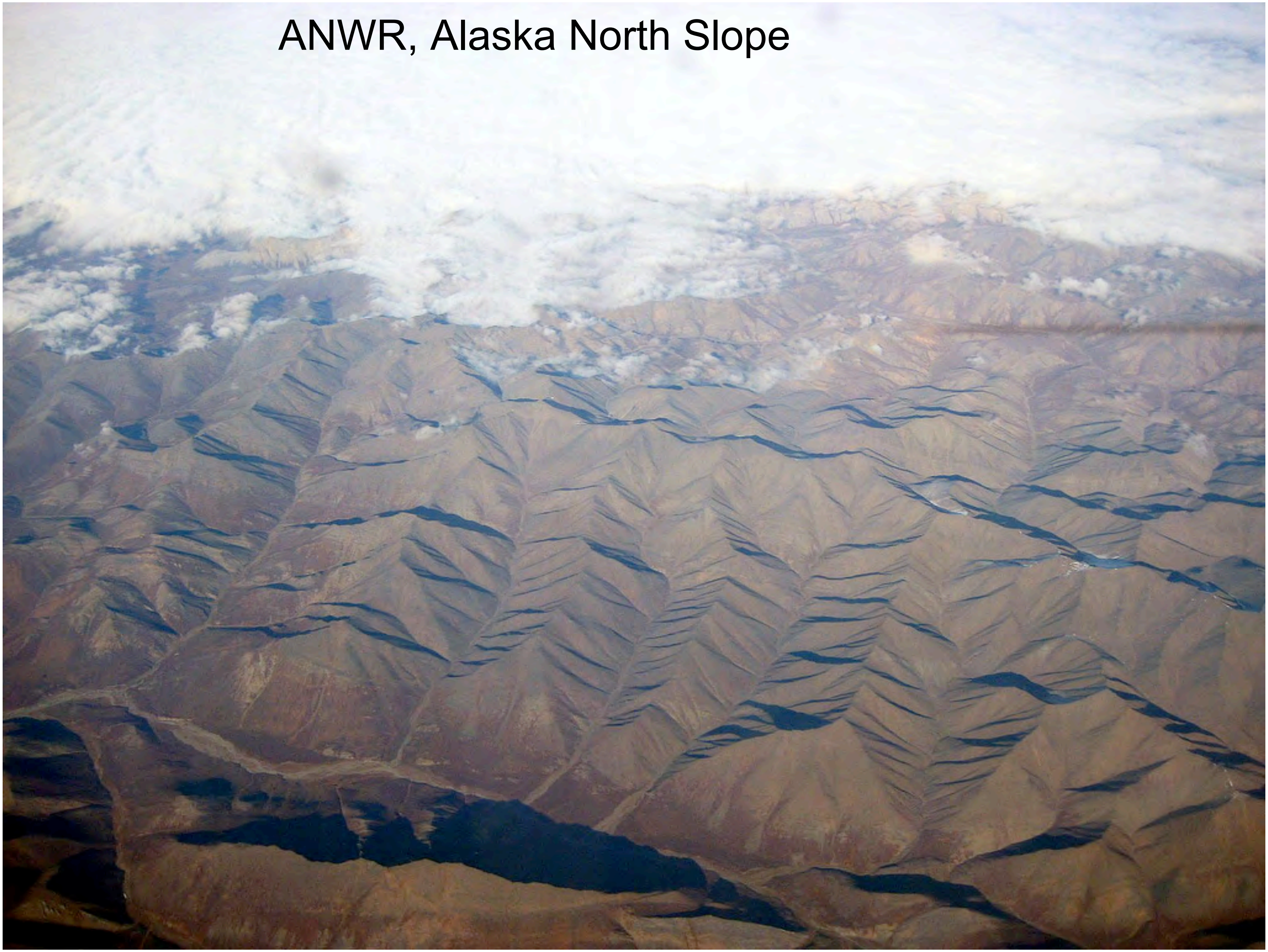
Fig. 6.11.3 Grinnell Land Icefield

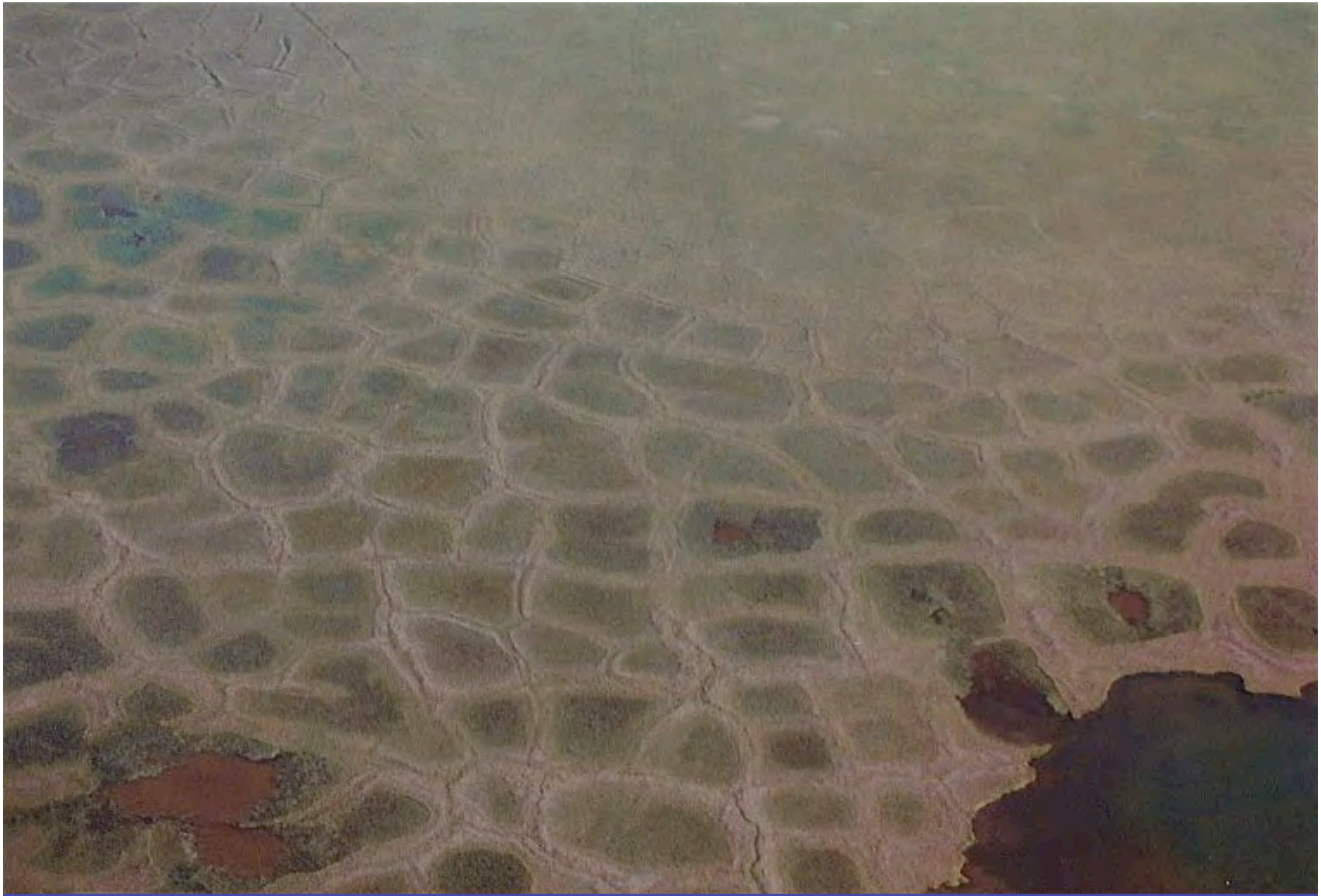
Nunavit, Ellesmere Island

http://www.flickr.com/photos/arctictraveler/3620711347/


Baffin Island (Flickr)

ANWR, Alaska North Slope




North Slope Coast, near Prudhoe Bay, Alaska (Flikr)

Kishchnikov River, Wrangel Island, Siberia

North Greenland

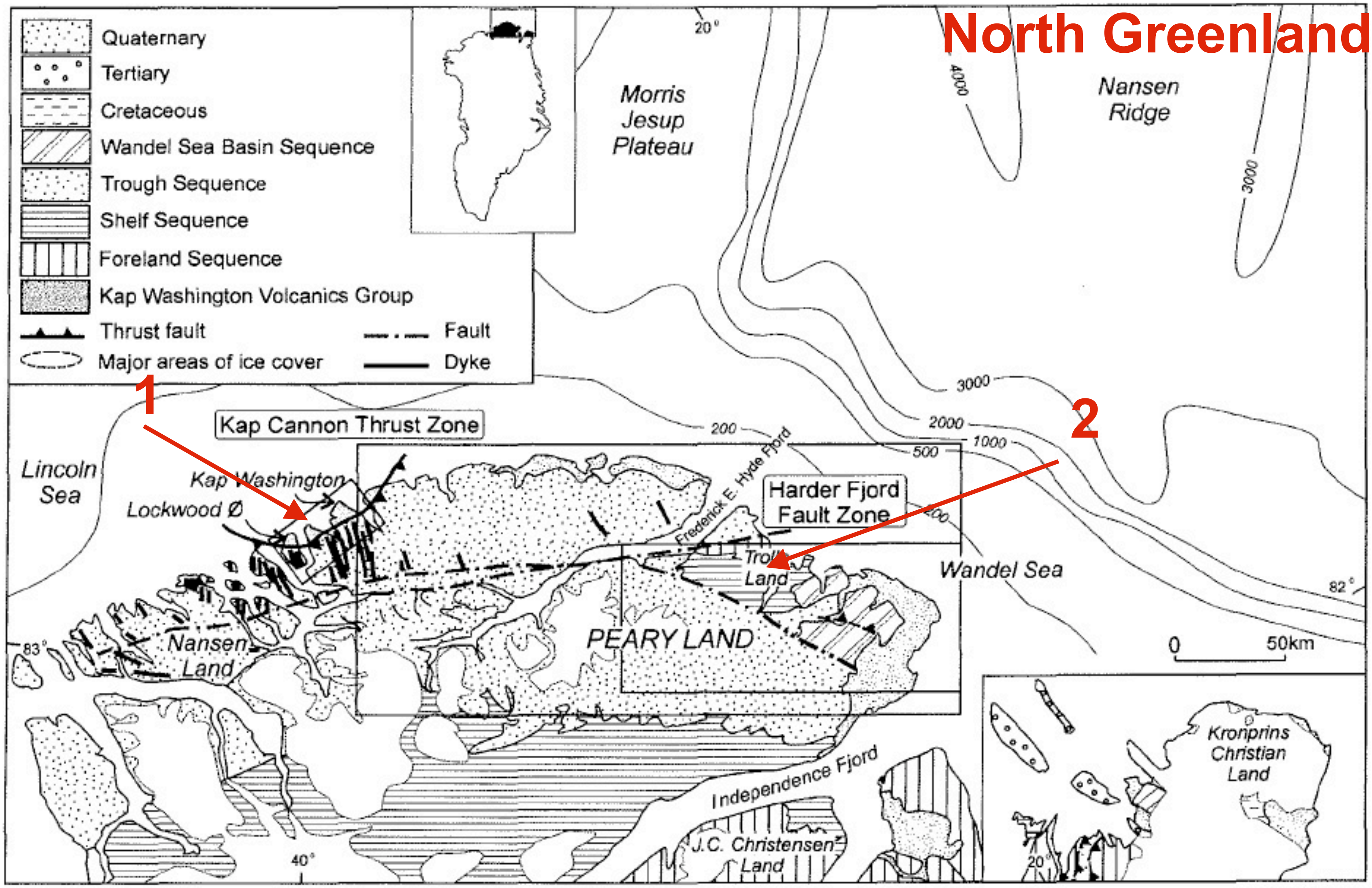


Fig. 1: General map of North and eastern North Greenland showing location of study areas.

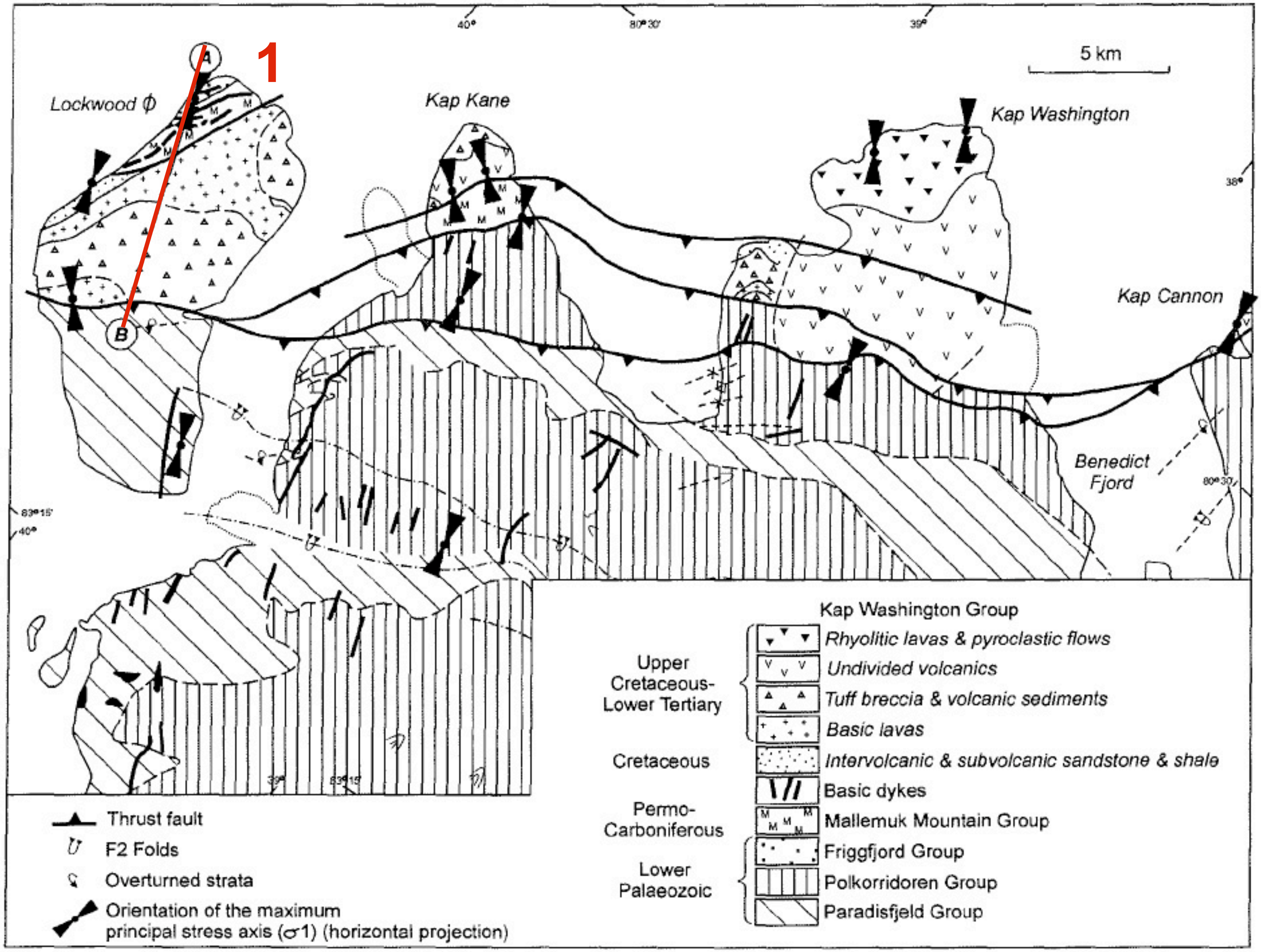


Fig. 2a: Simplified geological map of the Kap Cannon Thrust Zone, North Greenland. Large black arrows indicate horizontal projetion of the principal compressive stress axes.

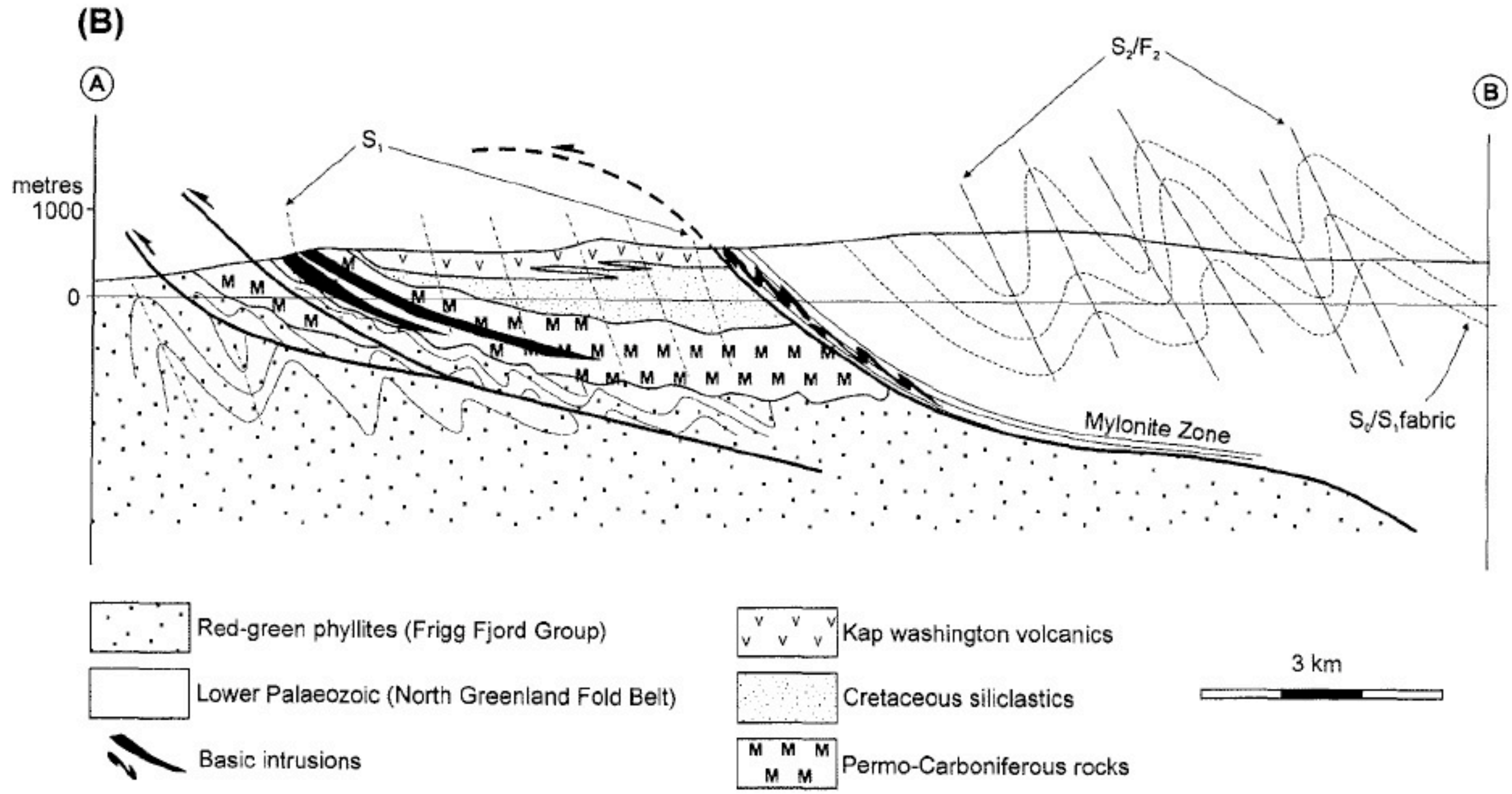


Fig. 2b: Cross-section of the thrust zone on Lockwood Ø.

Note thrusting along Artic “passive margin”: the Eurekan Orogeny

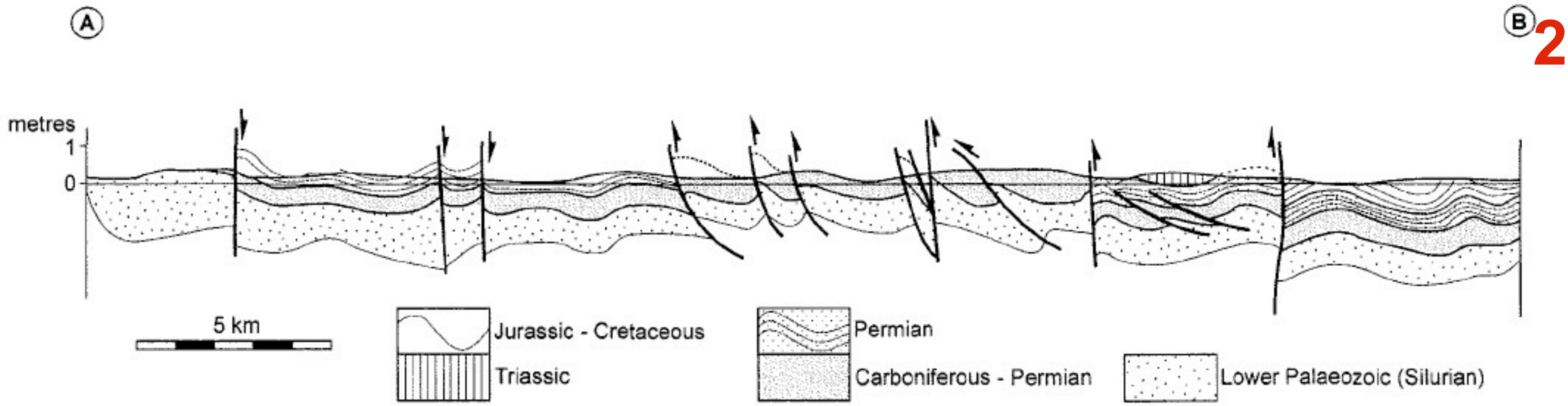
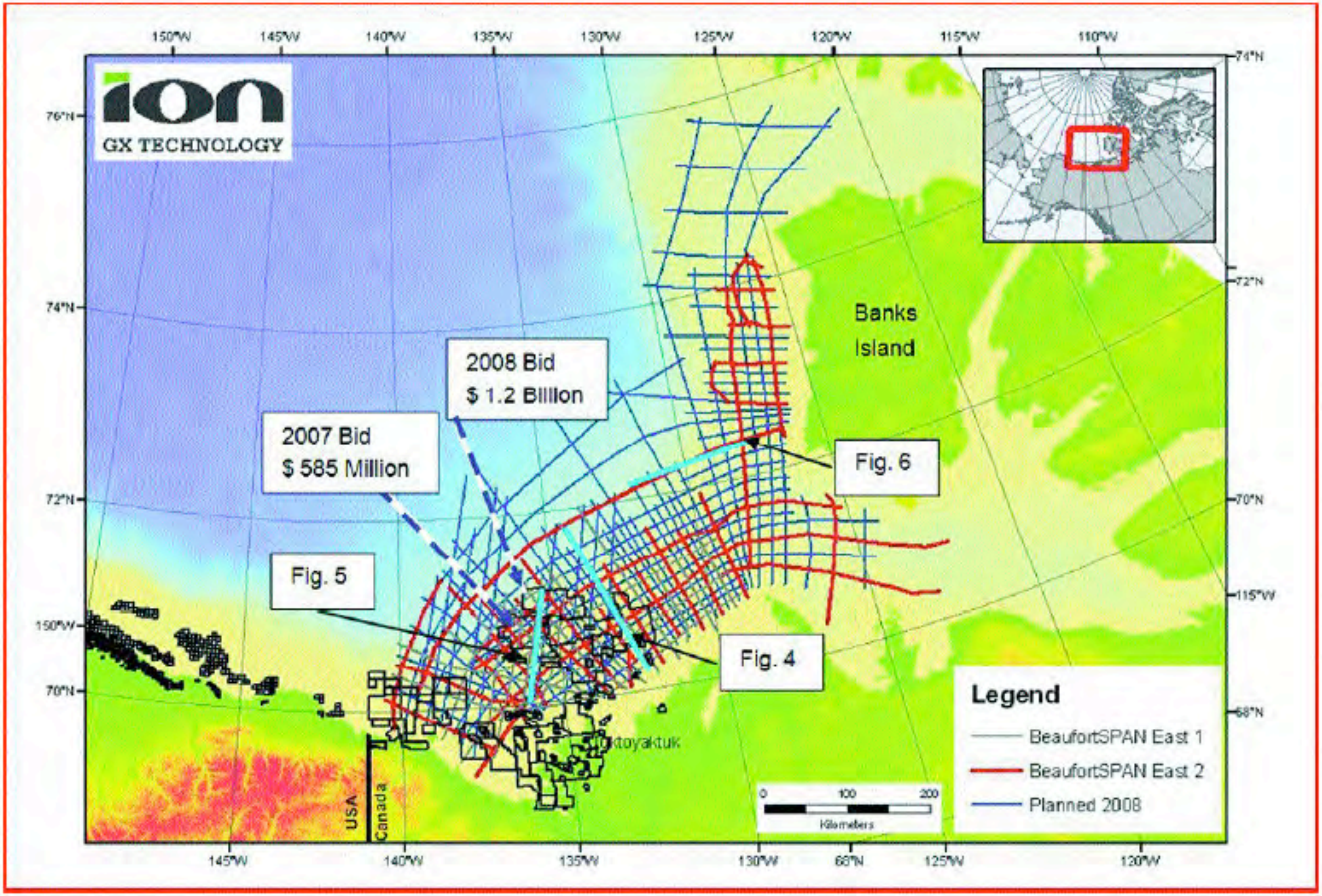


Fig. 9b: Simplified cross-section of Trolle Land showing main faults and fold relations.

Note thrusting along Artic “passive margin”.

How do we compress an extensional margin?



Dinkleman et al 2008

Seismic Horizons Identified and Mapped in the BeaufortSPAN East Data

Key Reservoir Intervals	Estimated Age (m.y.) at Base	Sequence/Formation on Cont. Crust (Canadian Arctic Passive Margin and Inner Mackenzie Delta)	Reflector Name and Character	Sequence/Formation on Oceanic Crust (Canada Basin Deep water and Outer Mackenzie Delta)
	5.3	Iperk	*5.3_LATE MIO (Trough)*	Iperk
●	11.6	Akpak	*11.6_MID MIO (Peak)*	Akpak
●	23.0	Mackenzie Bay	*23.0_LATE OLIG (Trough)*	Mackenzie Bay
●	33.9	Kugmallit	*33.9_BASE OLIG (Trough)*	Kugmallit
●	41.0	Richards	*41.0_MID EOCENE (Trough)*	Richards
●	52.2	Taglu	*52.2_EARLY_EOCENE (Peak)*	Taglu
	61.0	Aklak	*61.0_MID PAL (Peak)*	Aklak
	83.5	Fish River	*83.5_LateCRET (Peak)*	Fish River
●	136.4	Smoking Hills-Siku	*136.4_Valangianian_BKUP (Peak)*	Smoking Hills-Siku
	135-155?	Synrift	*TOP_OCEANIC_CRUST (Peak)*	Synrift / Ocean crust
	Ages Below are at Top 359.2	Missing Section	*360_LateDev (Peak)*	MOHO
	Siluro-Devonian	Weatherall	*Siluro_Dev Carbonate (Peak)*	
? ●	Ordovician-Silurian	Early Paleozoic	*Ordovician-Silurian Marker*	
	542	Early Paleozoic	*Proterozoic (Peak)*	
	?	Proterozoic	*Cryst_BSMT (Peak)*	
	?	Cryst_BSMT	MOHO (Peak)	
		MOHO		

Dinkleman et al 2008

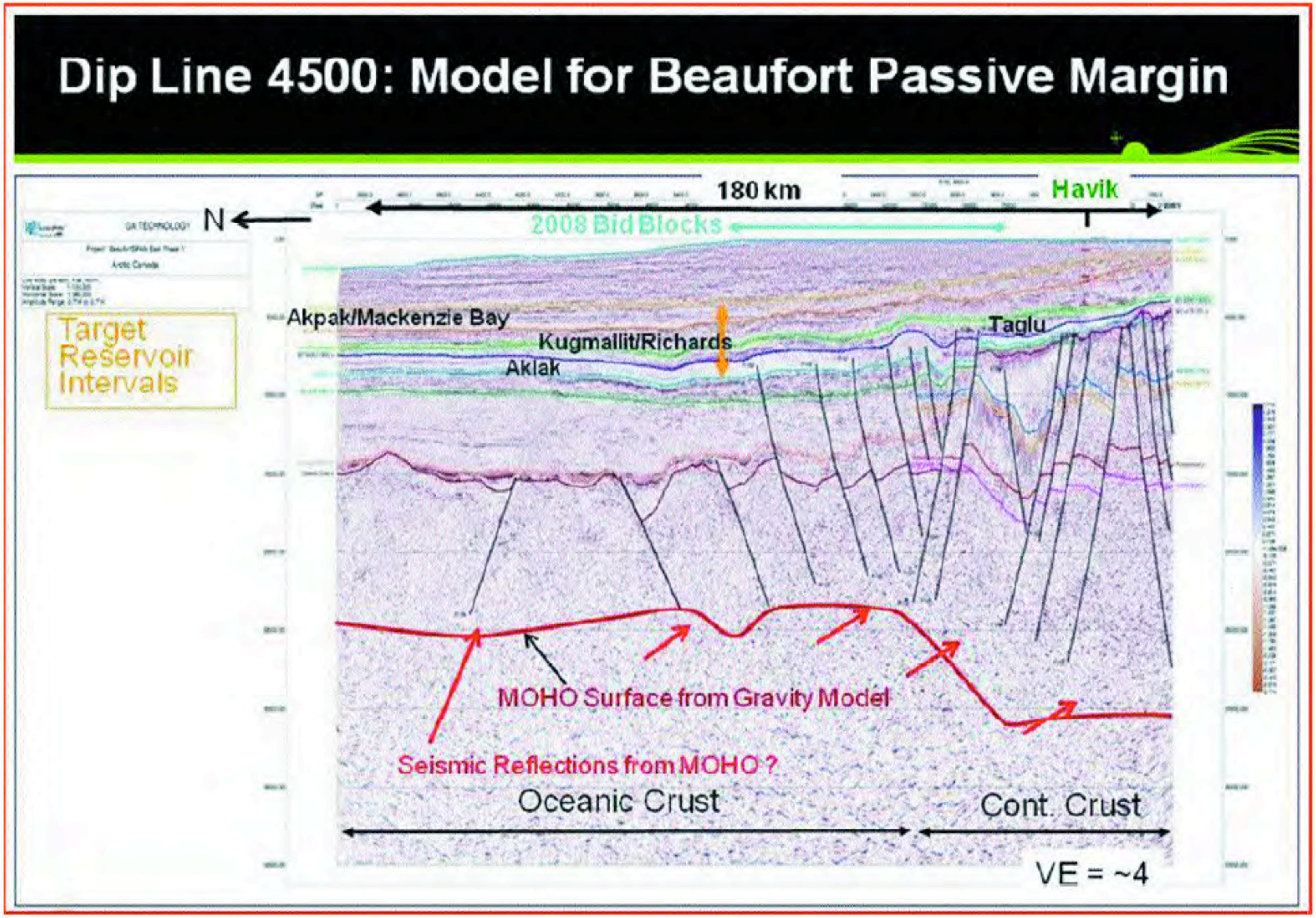


Figure 4. Cenozoic, Mesozoic and Paleozoic seismic horizons and the Havik well shown on BeaufortSPAN East survey line. VE=~4. The vertical scale is 40 km and

Dinkleman et al 2008

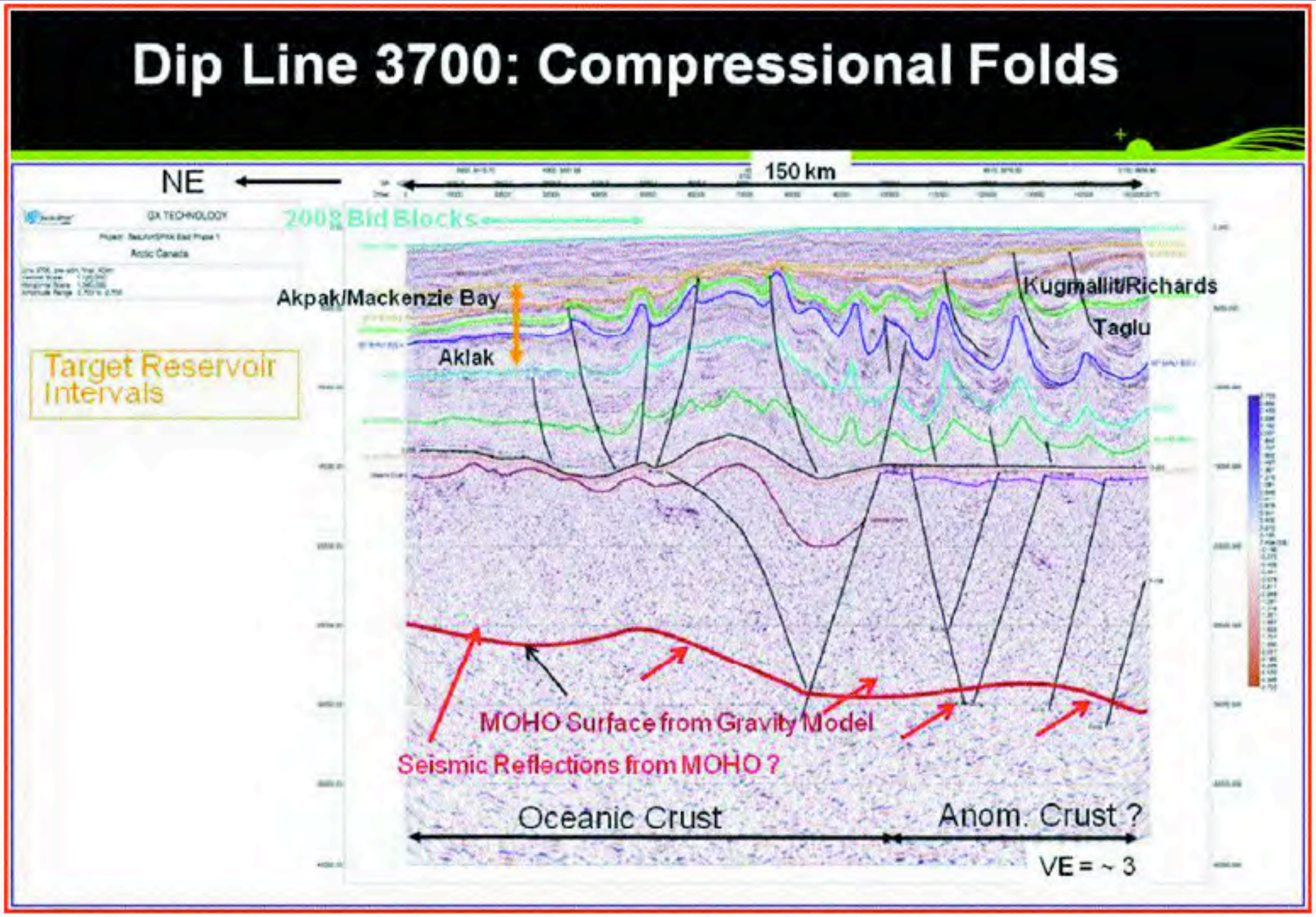


Figure 5. Deformation style and crustal profile for the Mackenzie Delta sedimentary wedge. The Eocene-Miocene Beaufort Foldbelt extends from "anomalous" crust northward across oceanic crust. The detachment surface is interpreted to be located near the 136.4_Valangianian_BKUP surface. Late Tertiary inversion of half-graben sediments below the Valanginian has formed an "outer high" in the foldbelt. Line location is shown on Figure 3. Deep red line is MOHO calculated

Dinkleman et al 2008

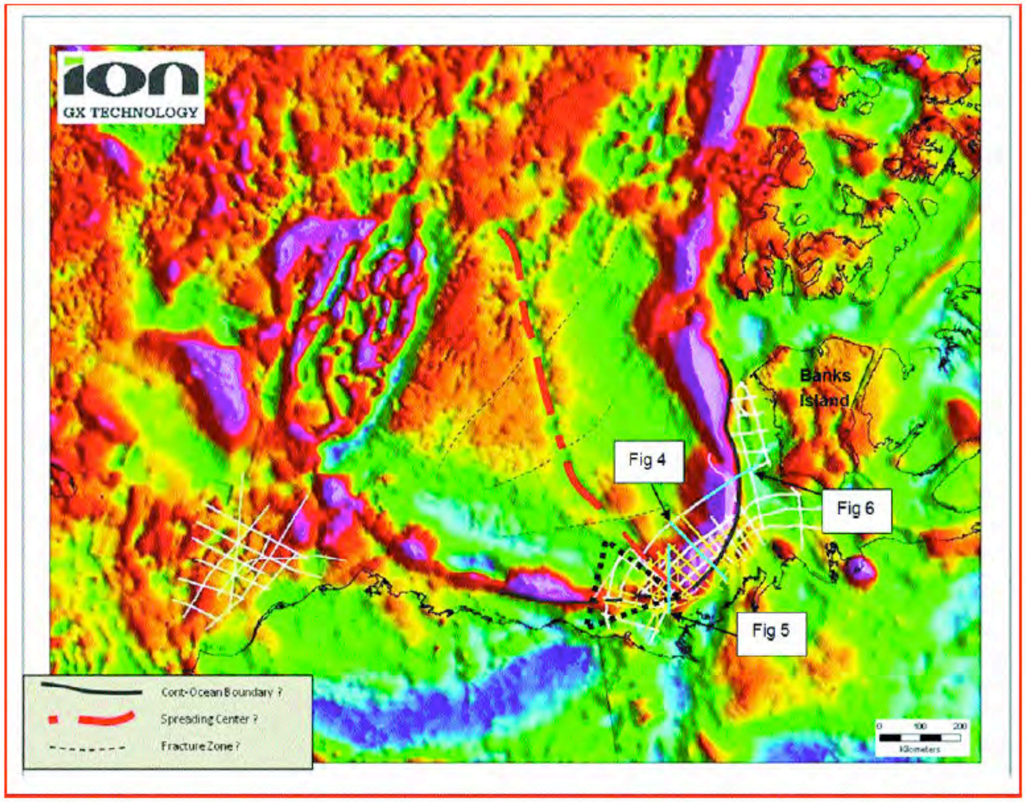
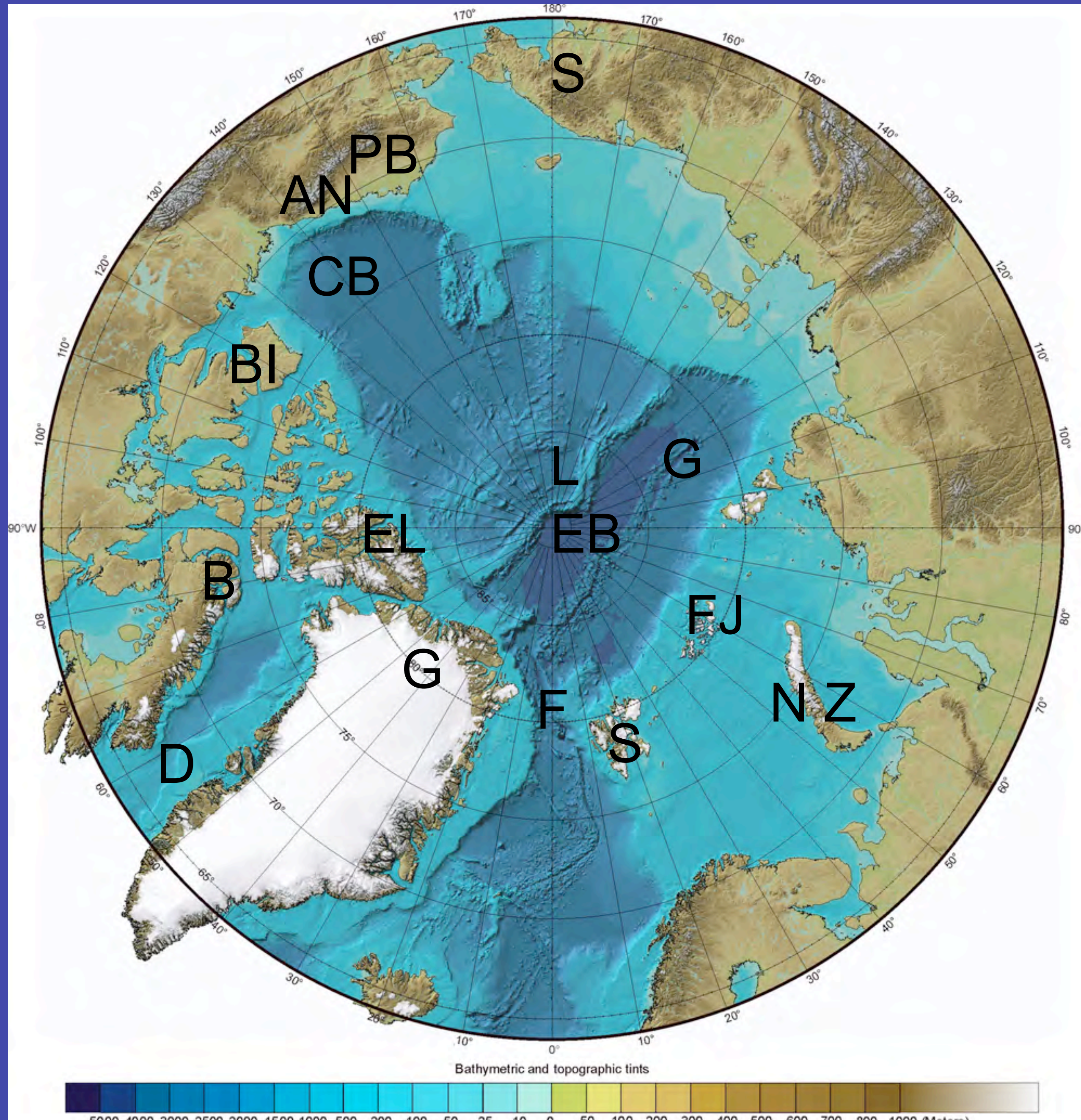
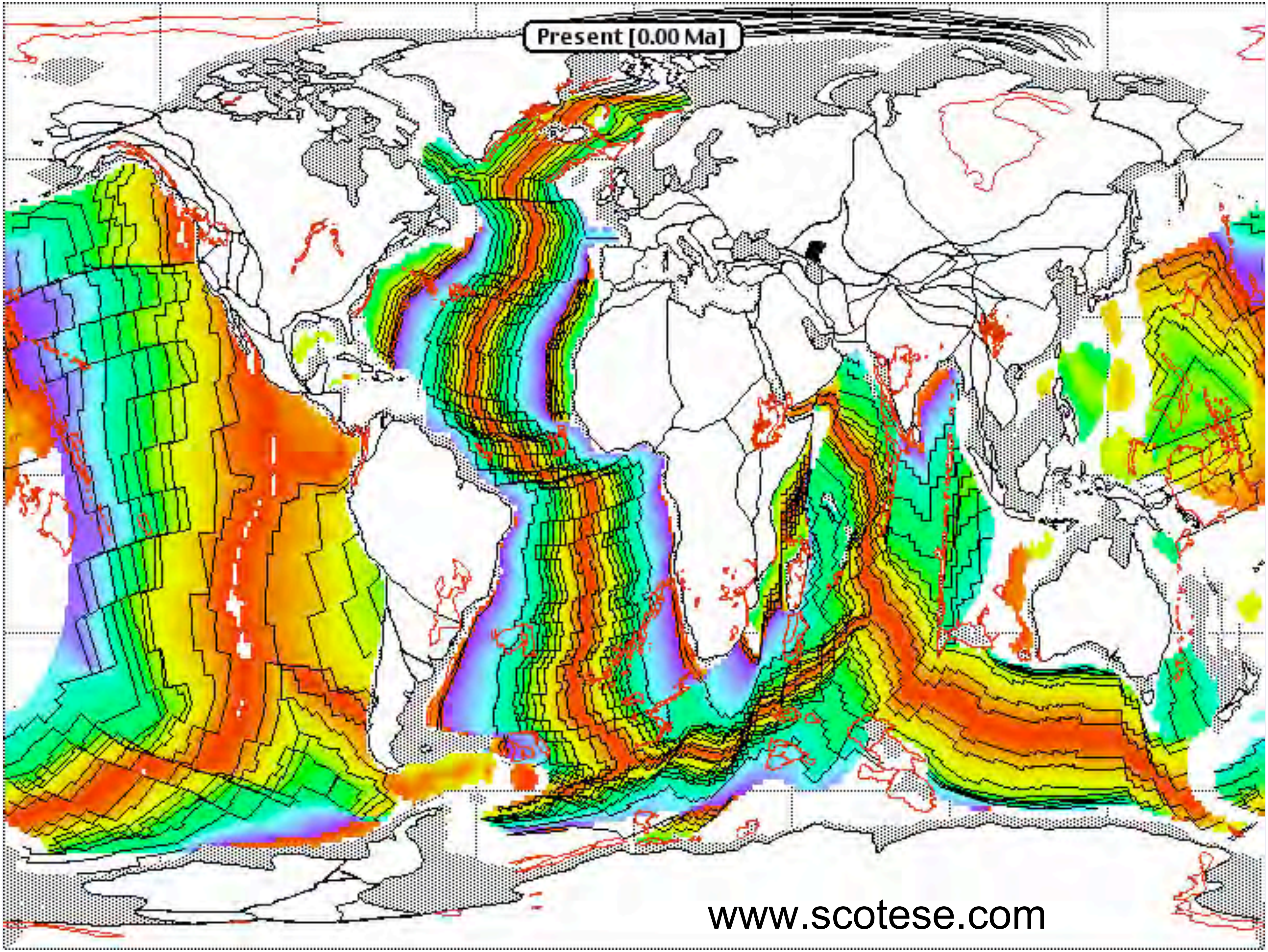


Figure 3. ArcticSPAN surveys located on Free Air Gravity Map of the Beaufort Sea, Mackenzie Delta, Banks Island and surrounding region (gravity data from Arctic Gravity Project, Kenyon and Forsberg, 2001). The COB is more or less coincident with that shown in Lane (2002) along Banks Island and farther south. However, the biggest differences between Lane's and our interpretations are in the central Mackenzie Delta region. The segment interpreted here as the extension of the spreading center underneath the delta has been mapped by Lane (2002) as the "B Fracture Zone." If his interpretation is correct, the delta region should be largely underlain by continental crust. . Also, should this interpretation be correct, a significant part of the delta is underlain by oceanic crust. The oceanic crust, as interpreted here, is more expansive than interpreted by Grantz and others (2008). Definition of the crustal type in this area (outlined by a triangle), currently designated as "anomalous crust," is a current interpretation effort.

Dinkleman et al 2008

Siberia
Prudhoe Bay
ANWR
Canada Basin
Banks Island
Ellsmere Island
Greenland
Baffin Island
Lomonosov Ridge
Eurasia Basin
Gakkel Ridge
Franz Josef Land
Novaya Zemla
Svalbard
Fram Strait
Davis Strait




Present [0.00 Ma]
www.scotese.com

Tectonic Evolution of the Arctic Region Since the Ordovician

By

L.A. Lawver,

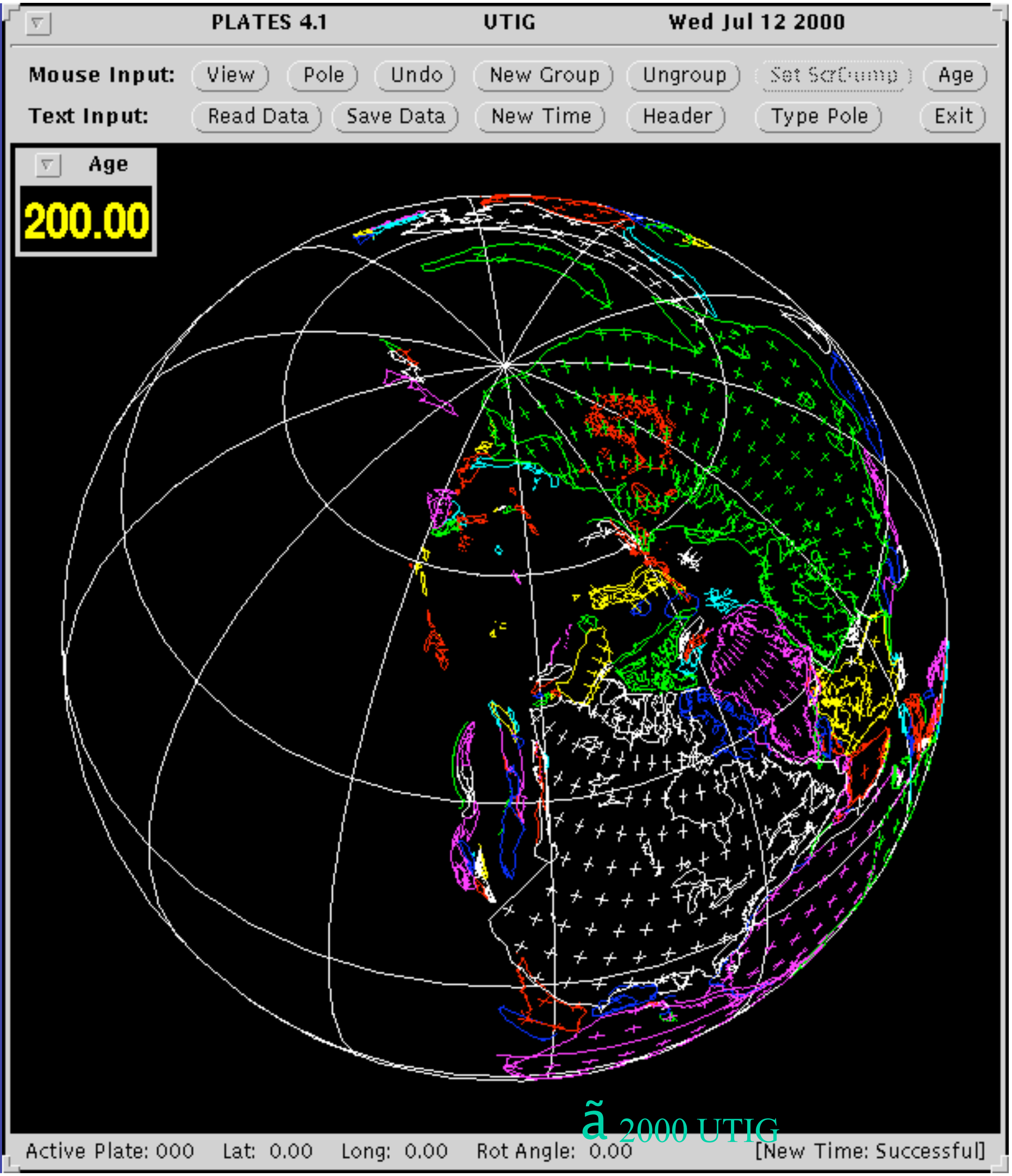
L.M. Gahagan,

and D.A. Campbell

July 9, 2000

The following animation
is an abbreviated version,
showing reconstructions
every 50 million years.
The original animation shows
reconstructions from 450 to 0 Ma,
every 1 million years.

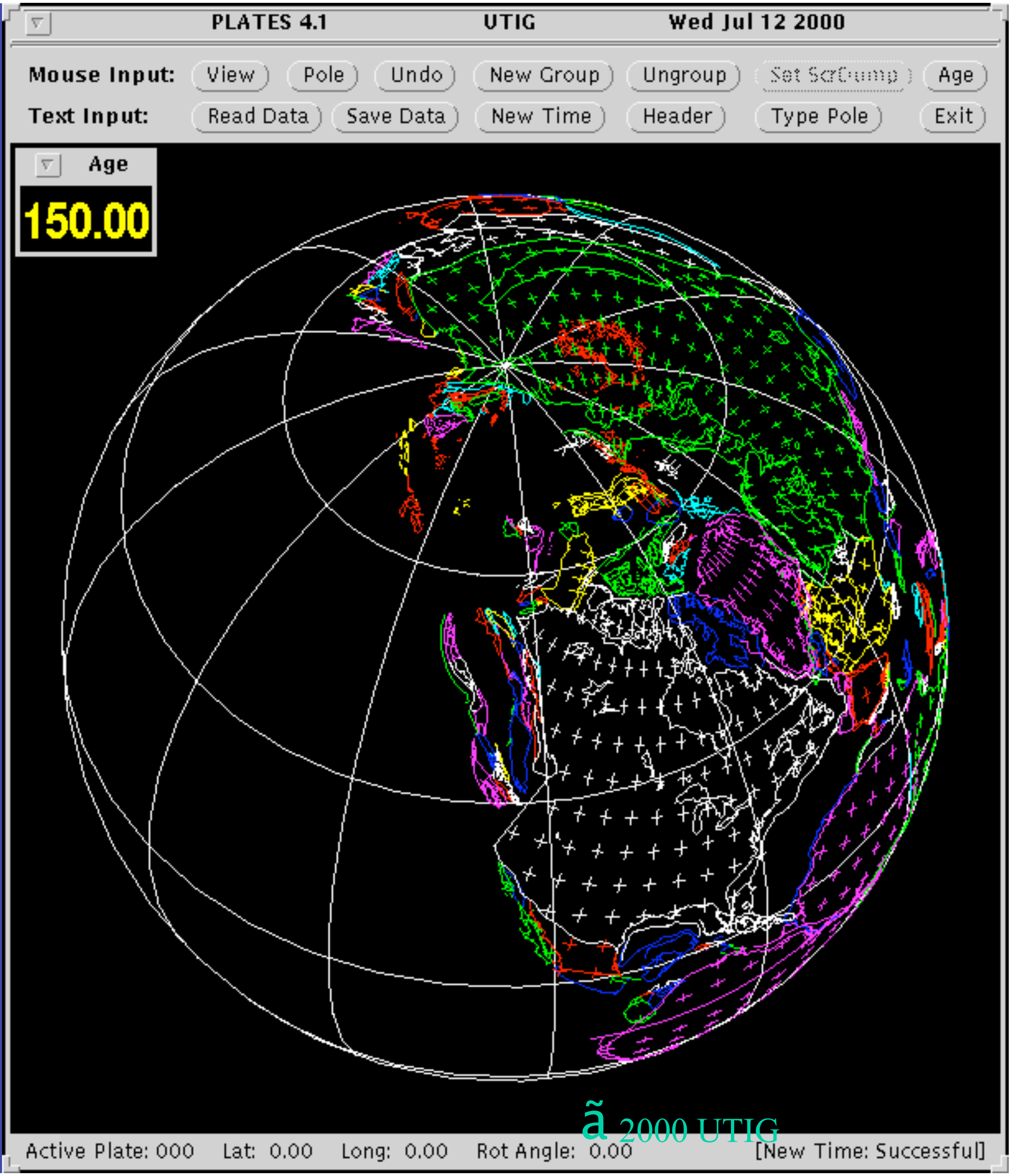
Jurassic
Early Sinemurian



ã 2000 UTIG

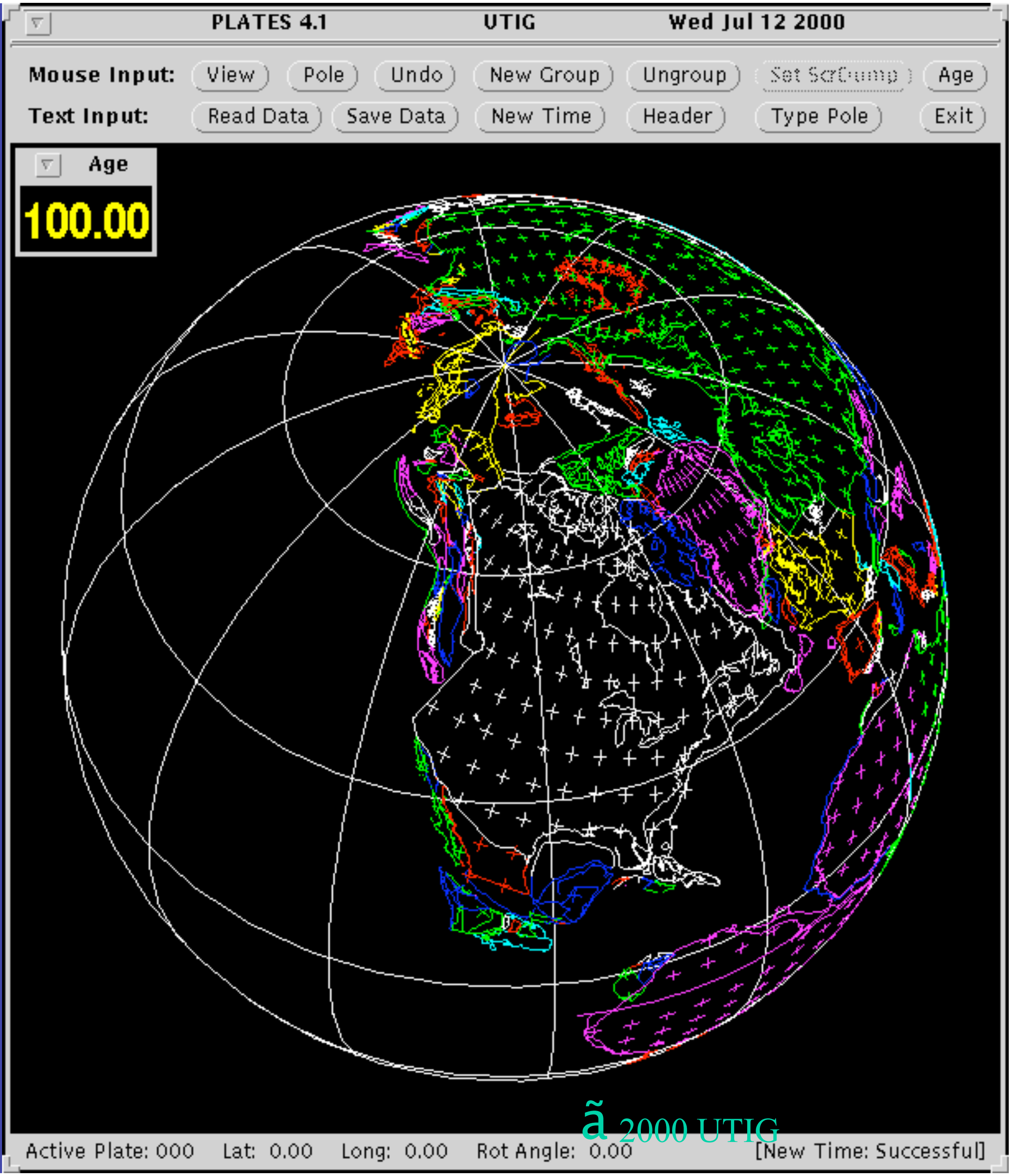
PLATES

Jurassic
Kimmeridgian



PLATES

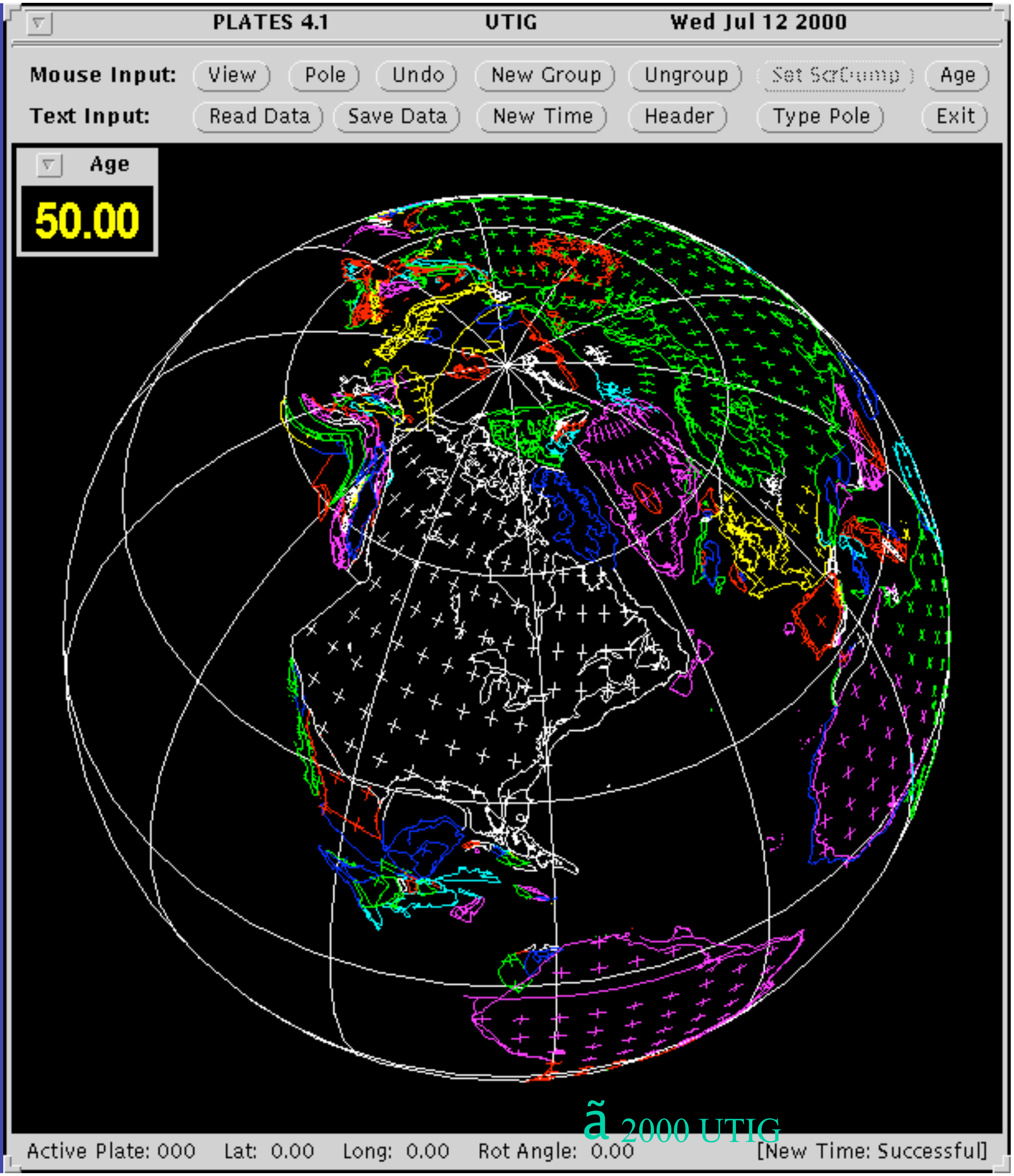
Cretaceous
Late Albian



PLATES

Paleogene
Late Ypresian

PLATES



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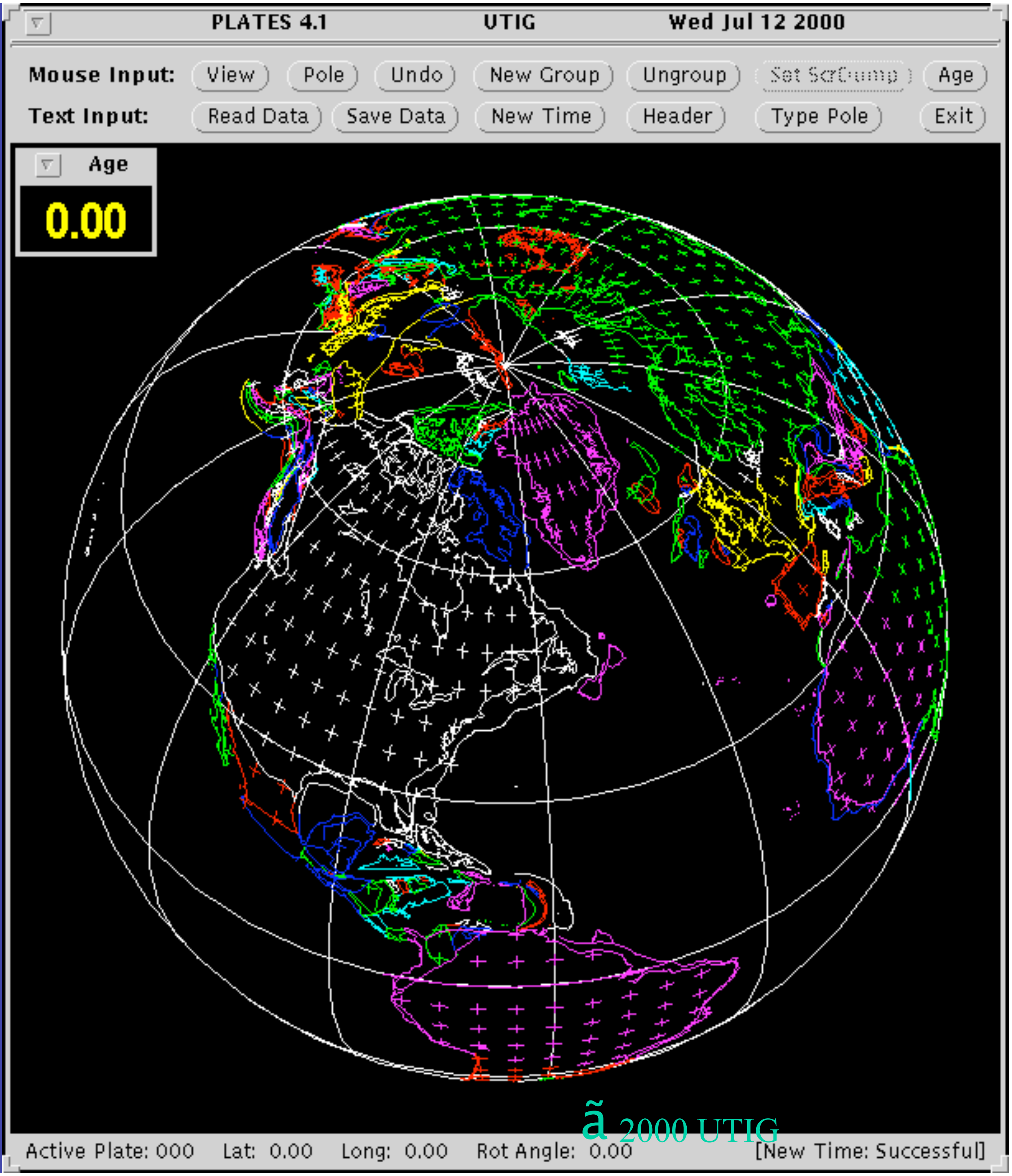
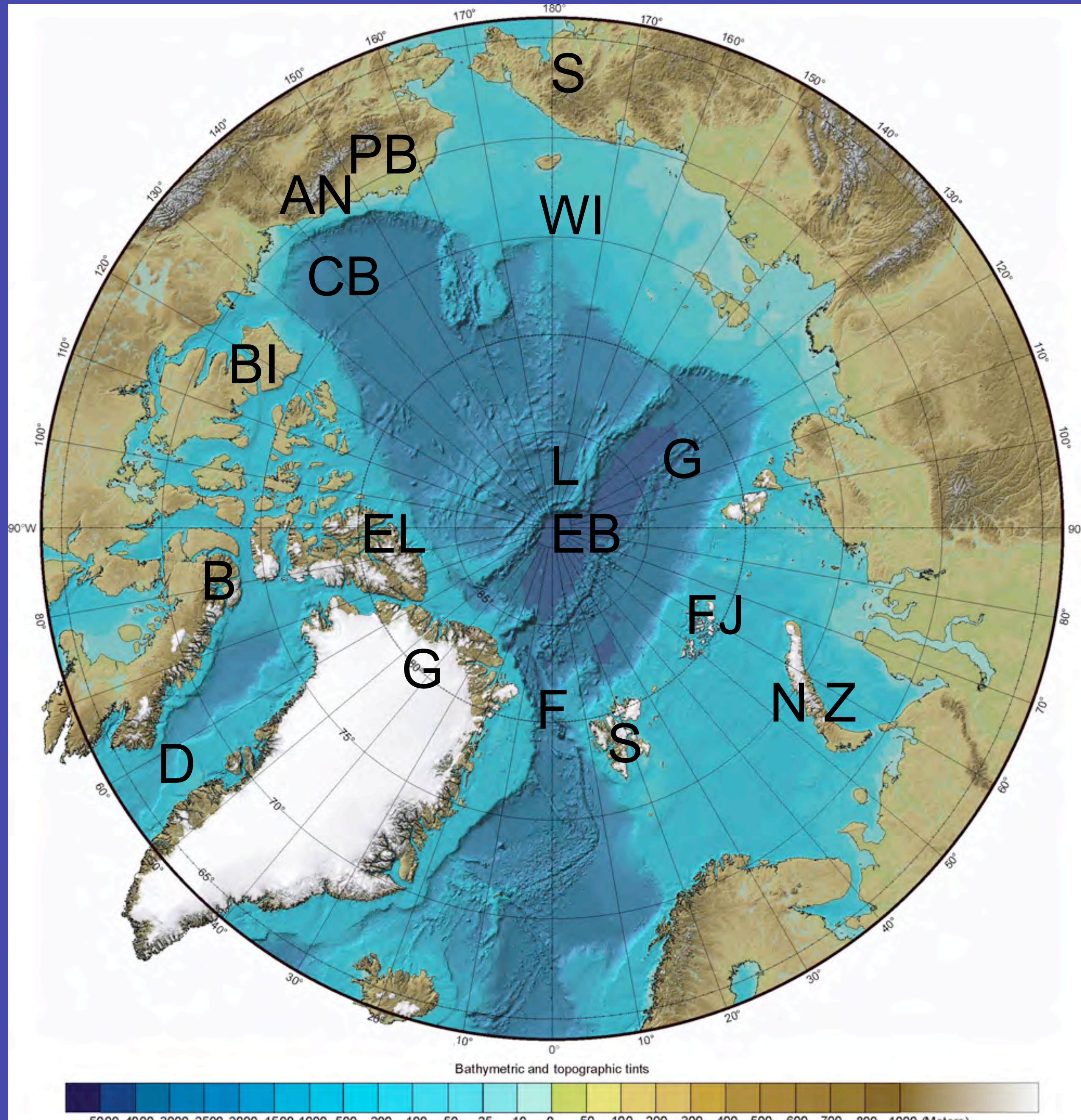
Quaternary

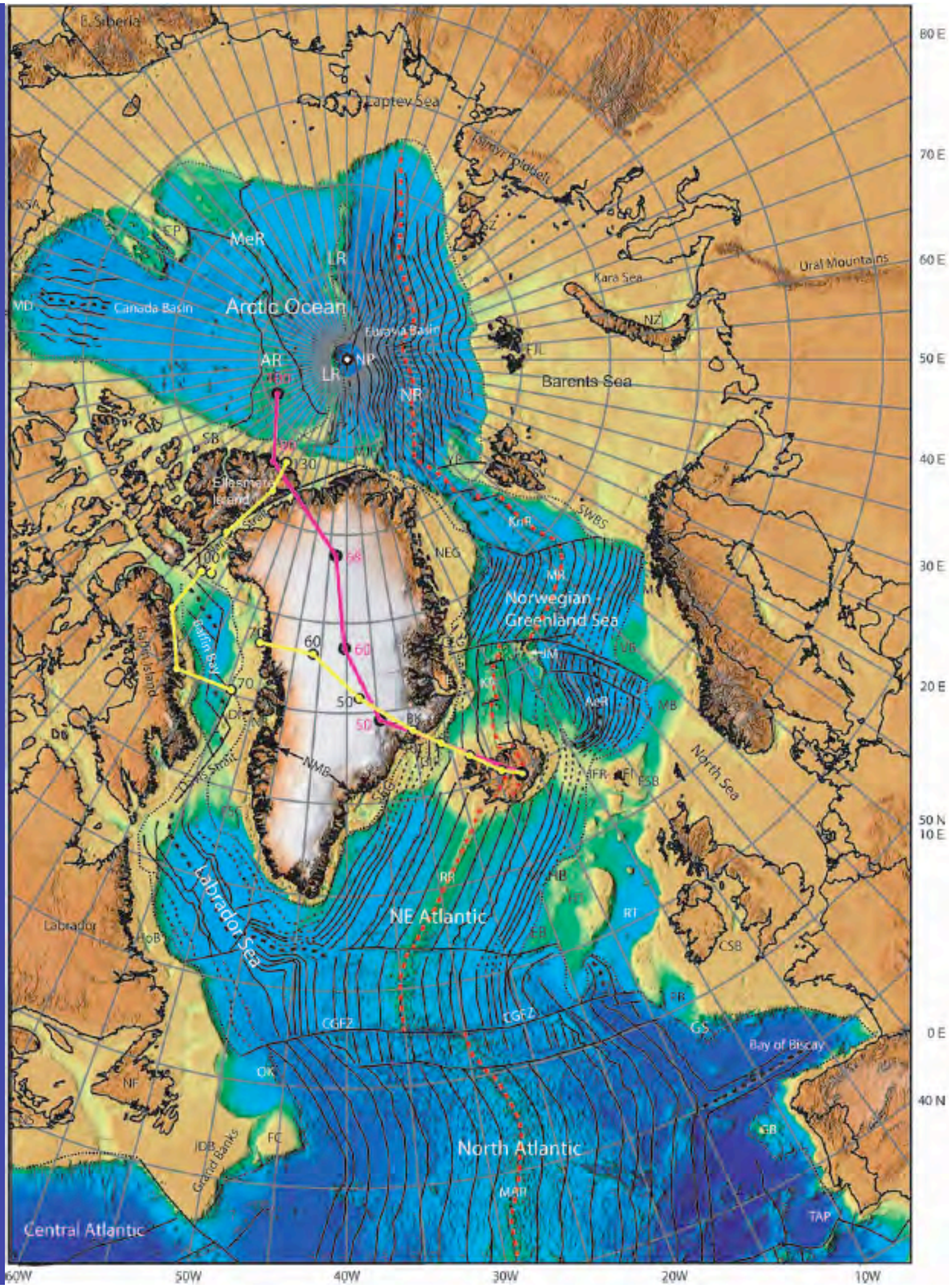


PLATES

Siberia
Wrangel Island
Prudhoe Bay
ANWR
Canada Basin
Banks Island
Ellsmere Island
Greenland
Baffin Island
Lomonosov Ridge
Eurasia Basin
Gakkel Ridge
Franz Josef Land
Novaya Zemla
Svalbard
Fram Strait
Davis Strait



Lundin & Dore 2005



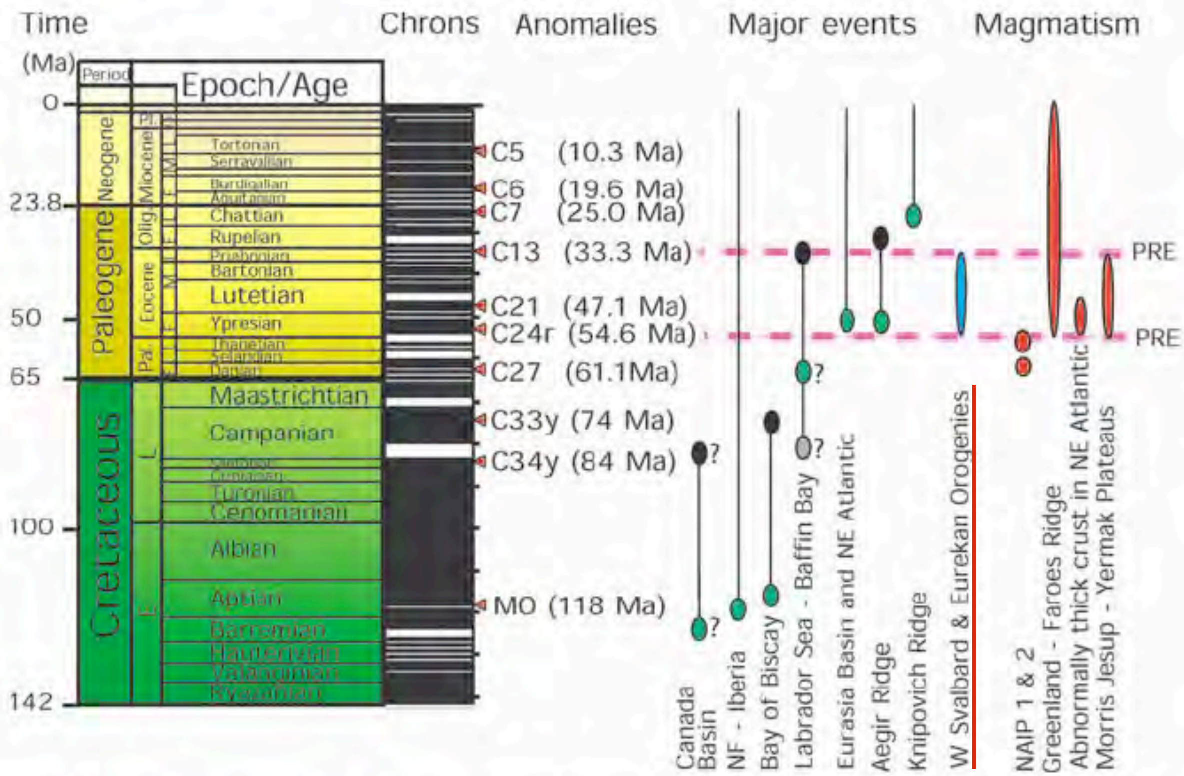


Fig. 2. Chronological diagram showing the relationship between major tectonic and magmatic events (after Eide 2002). PRE, Plate re-organization event.

Lundin and Dore 2005
NB: West Svalbard & Eurekan Oreogenies

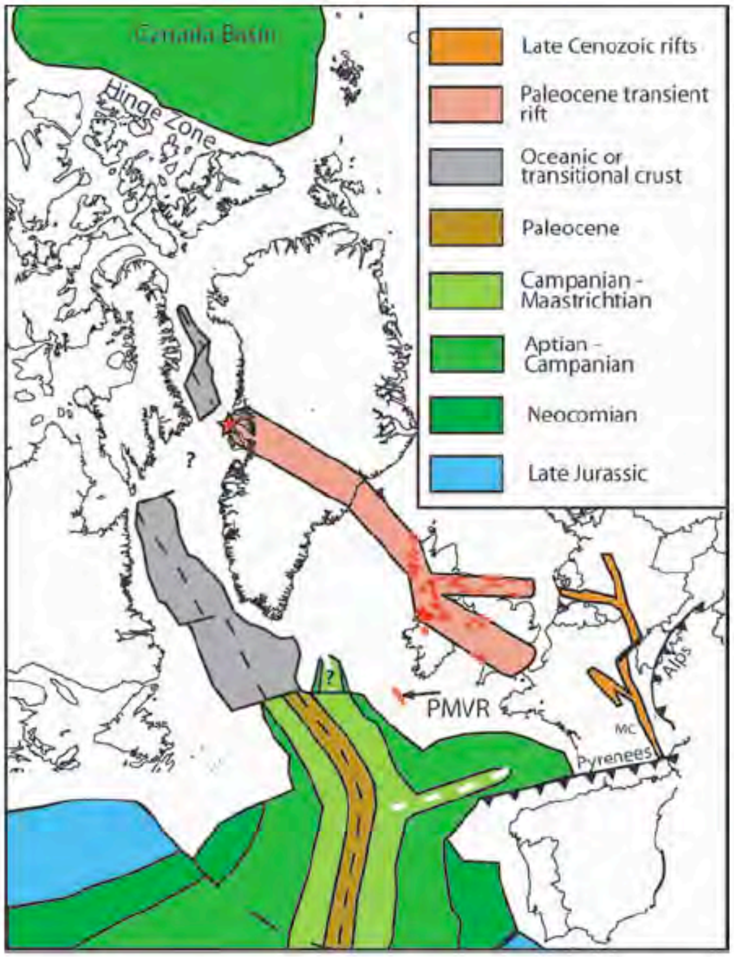


Fig. 4. North Atlantic plate reconstruction to 60 Ma (T. Torsvik, pers. comm. 2003) with simplified seafloor ages. The main dyke trend in the British Volcanic Province (shown by red lines), a zone of weak extension, is indicated with its suggested link to the West Greenland magmatic area (shown by red star) and early spreading centres in Baffin Bay. Note the consistency of this NW-trending extensional-magmatic belt with plate separation vectors that had been active from mid-Cretaceous times. The Late Cenozoic European rift system (from Ziegler 1992) is included out of age context on this map in order to illustrate later, more evolved fragmentation of the European plate, with associated magmatism, occurring approximately normal to the Alpine compressive front. Note that shortening related to the Eurekan Orogeny in the Canadian Arctic Islands has not been palinspastically reconstructed. MC, Massif Central; PMVR, Porcupine Median Volcanic Ridge.

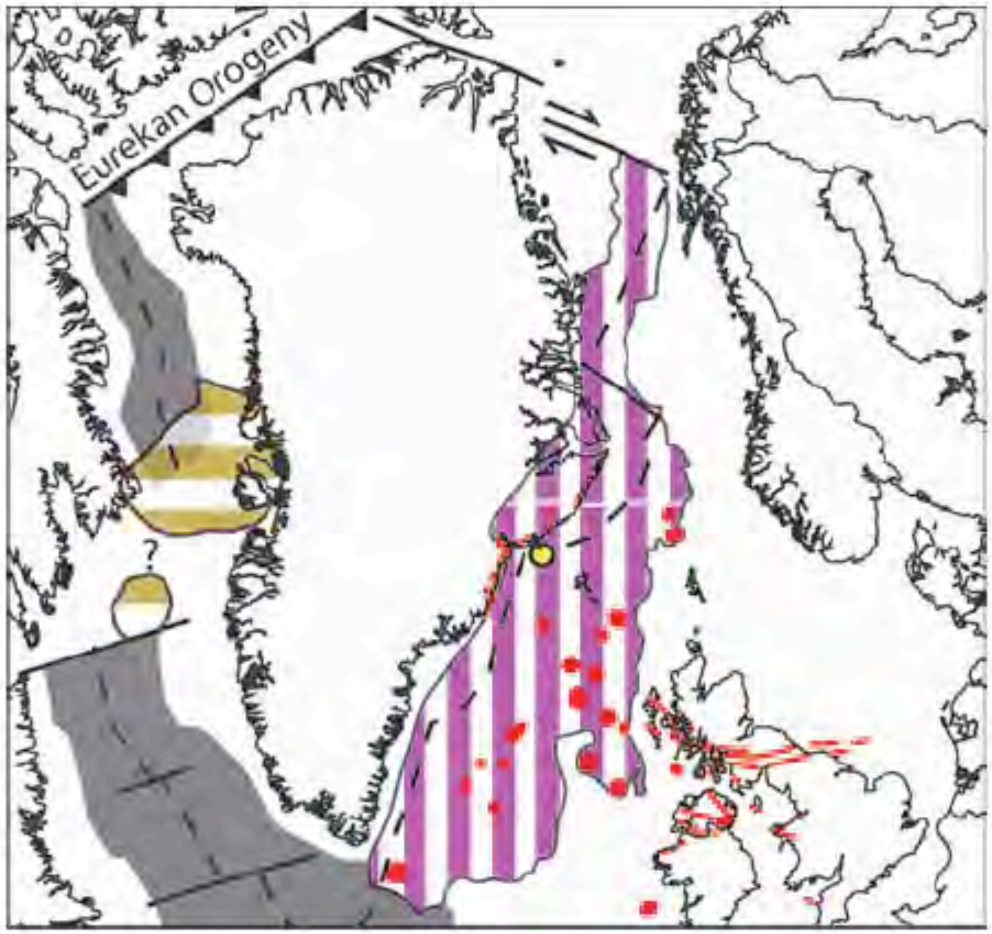
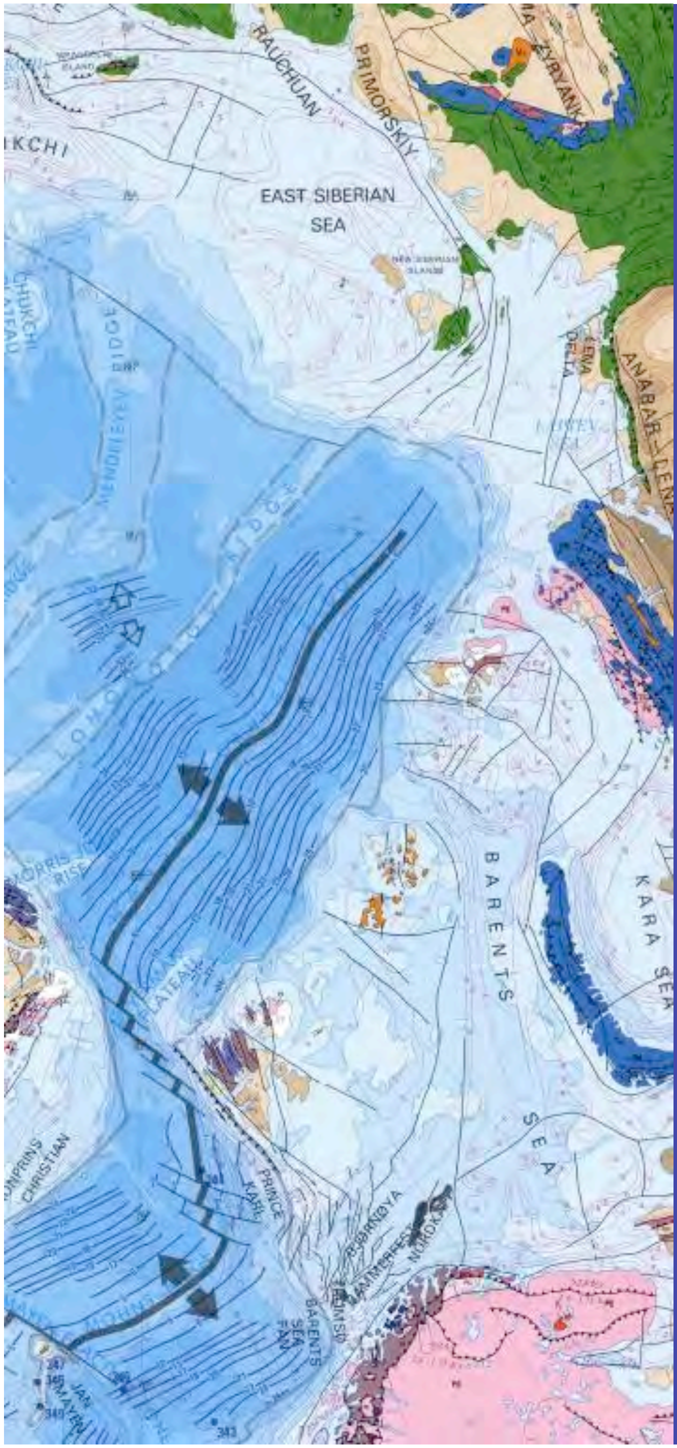
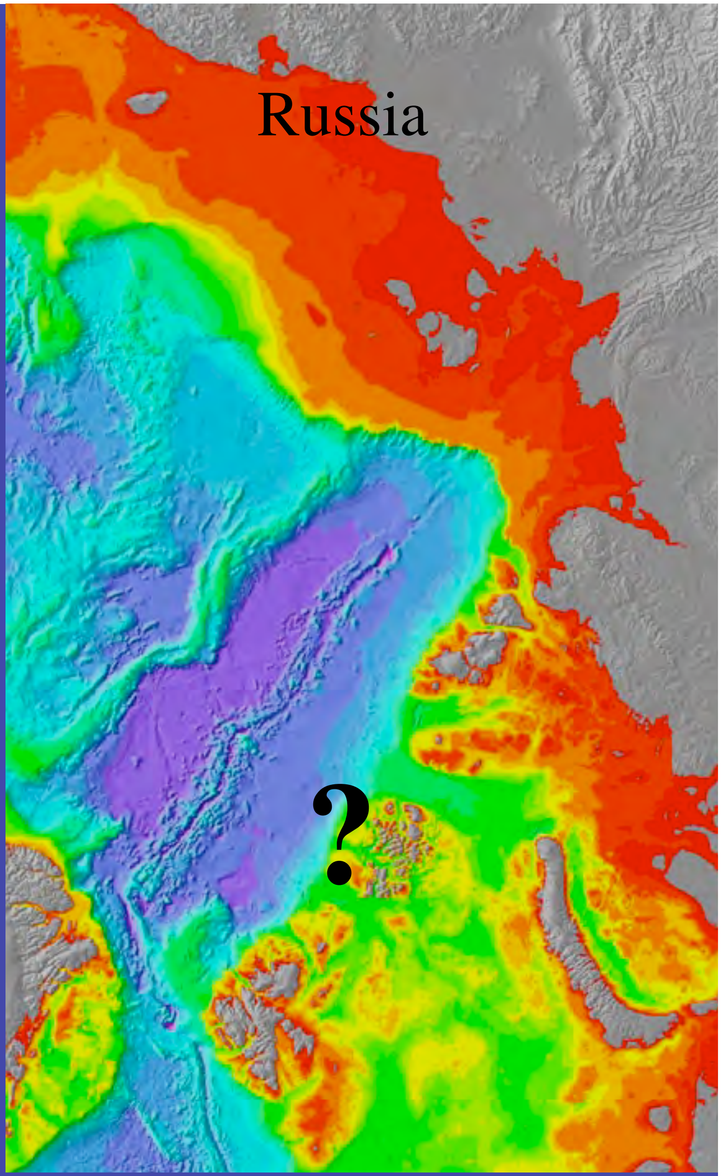


Fig. 3. North Atlantic plate reconstruction to Early Eocene (*c.* 54 Ma) (T. Torsvik, pers. comm. 2003) with distribution of basalt, flooded over the margins during break-up. The lava in West Greenland (brown striping) is older (*c.* 62–58 Ma) than the lava along the NE Atlantic margins (purple striping) (*c.* 56–53 Ma). Red blobs are seamounts, largely of Paleocene age. Red lines are simplified Early Paleocene dyke swarms. Grey represents oceanic or transitional crust. Note that shortening related to the Eurekan Orogeny in the Canadian Arctic Islands has not been palinspastically reconstructed.

Lundin and Dore 2005

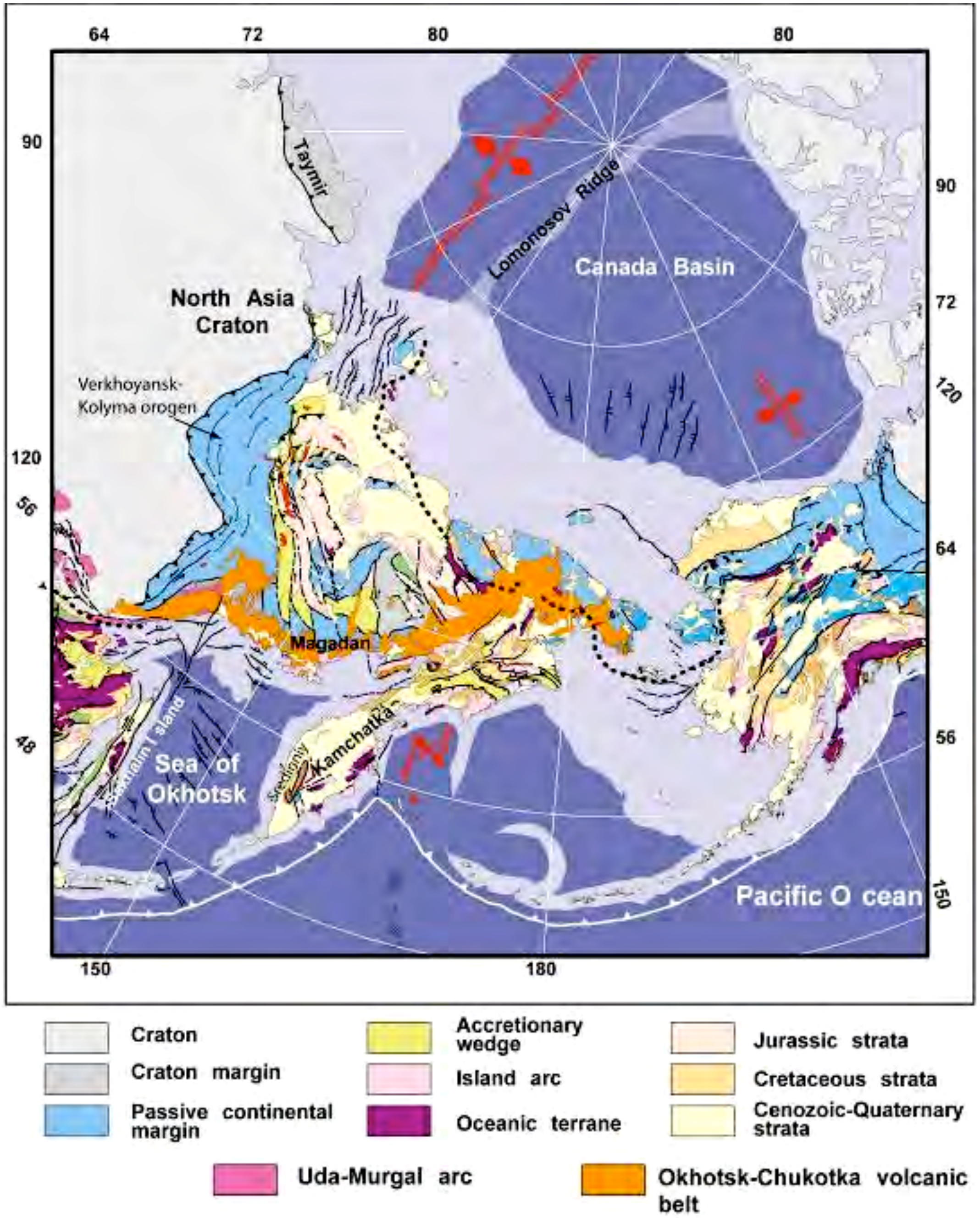


Eocene (55 Ma) opening of Eurasian Basin by Gakkel Ridge spreading



How does this rift end and/or propagate into continental crust?

Slide courtesy EL Miller, Stanford



NE Russia and N Am share:

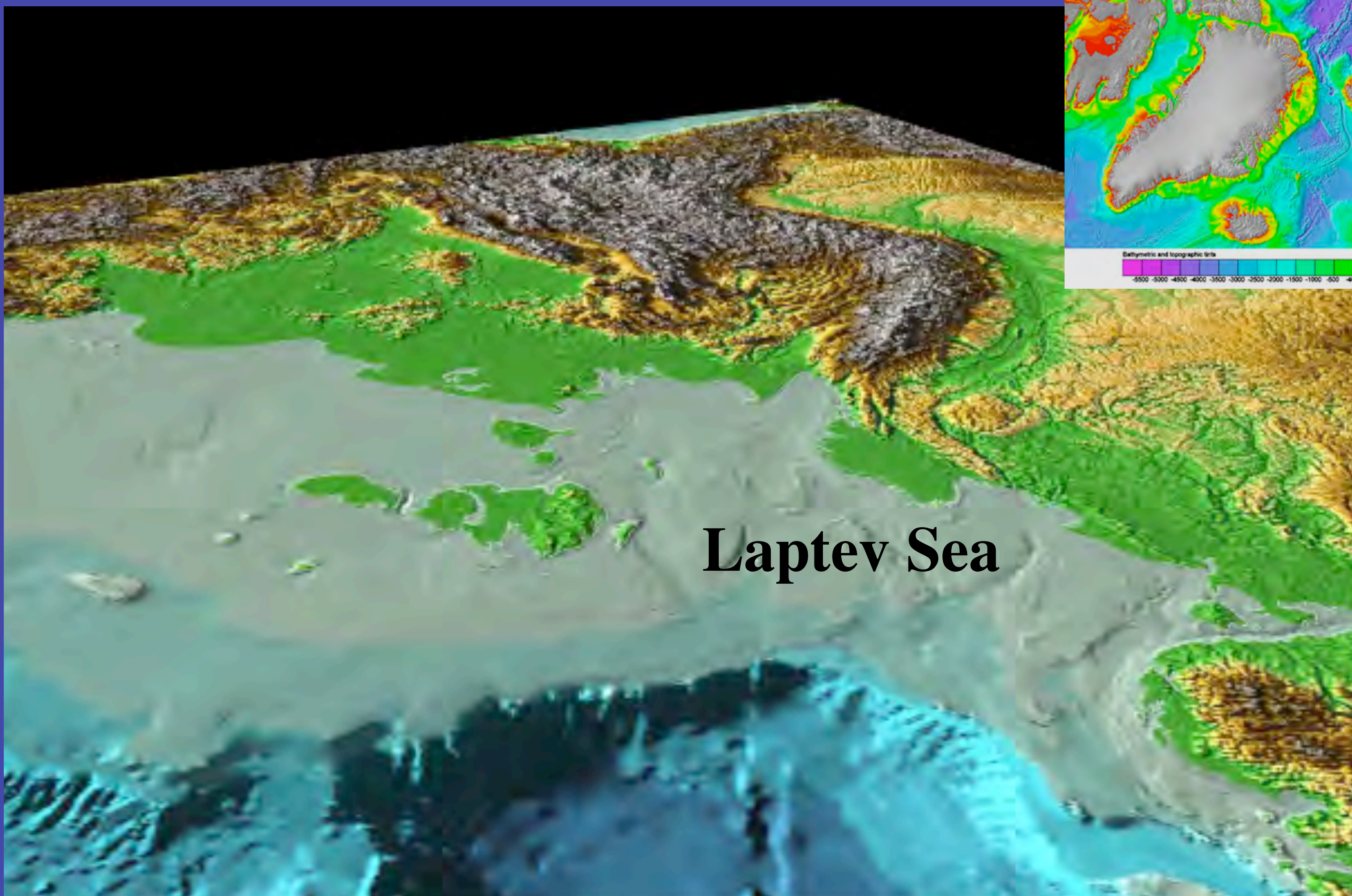
·A linked geologic and plate tectonic history whose details are critical for understanding evolution of our continents and the setting for our natural resources.

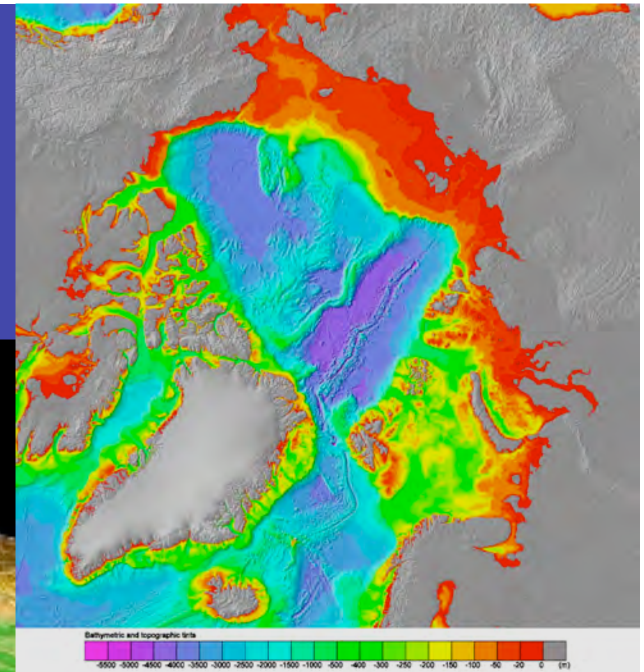
·Pacific plate margin
- *· active subduction*
- *· ore deposits, hydrocarbons*
- *·earthquake and volcanic hazards*

· Arctic margin
- *·vast poorly known continental shelves*
- *·hydrocarbon potential*

(base map from Nokleberg et al. 1998) Slide courtesy E L Miller, Stanford

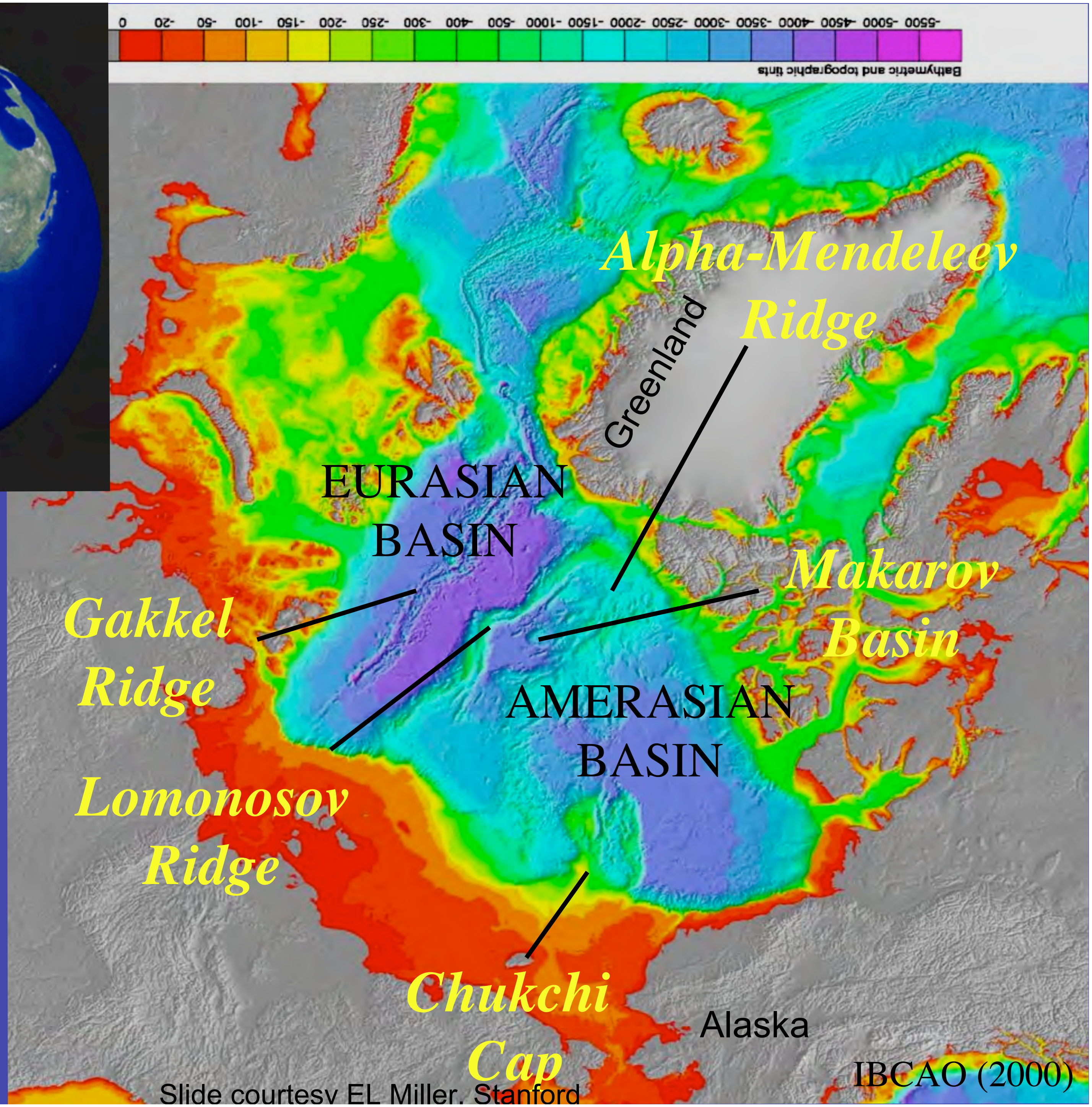
500 km of new ocean crust… Where and how is this extension accommodated through geologic time?

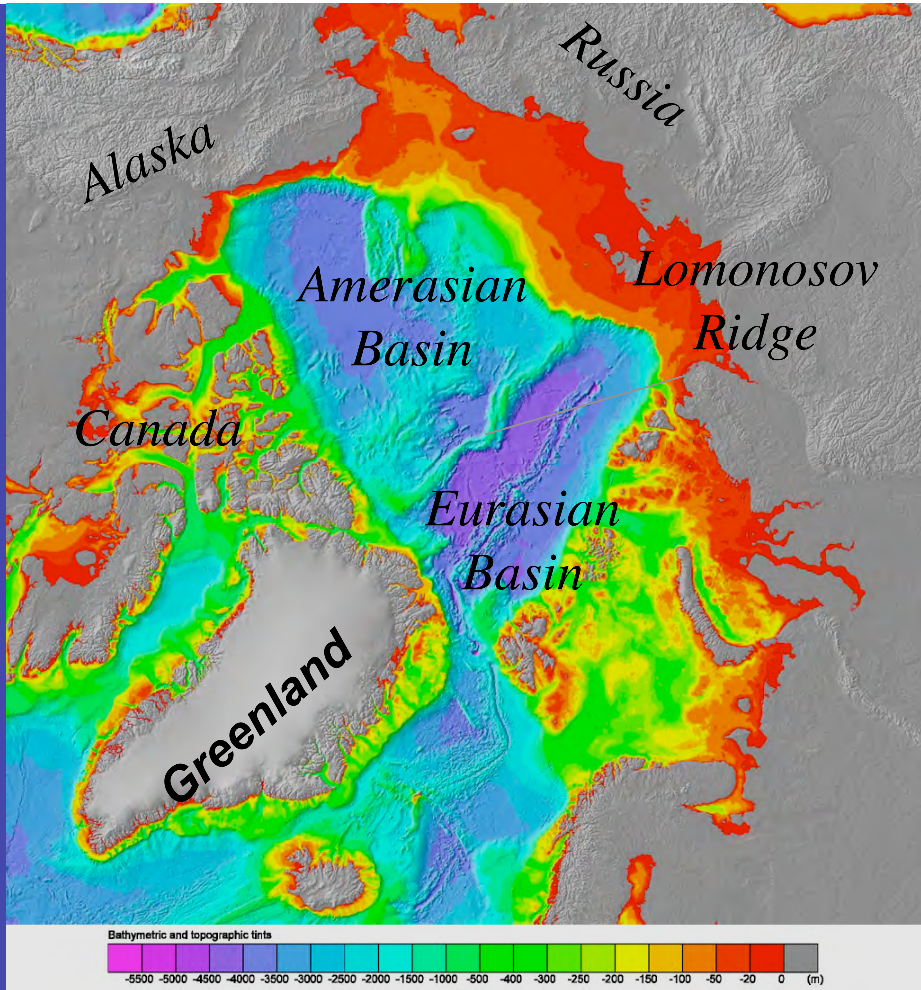


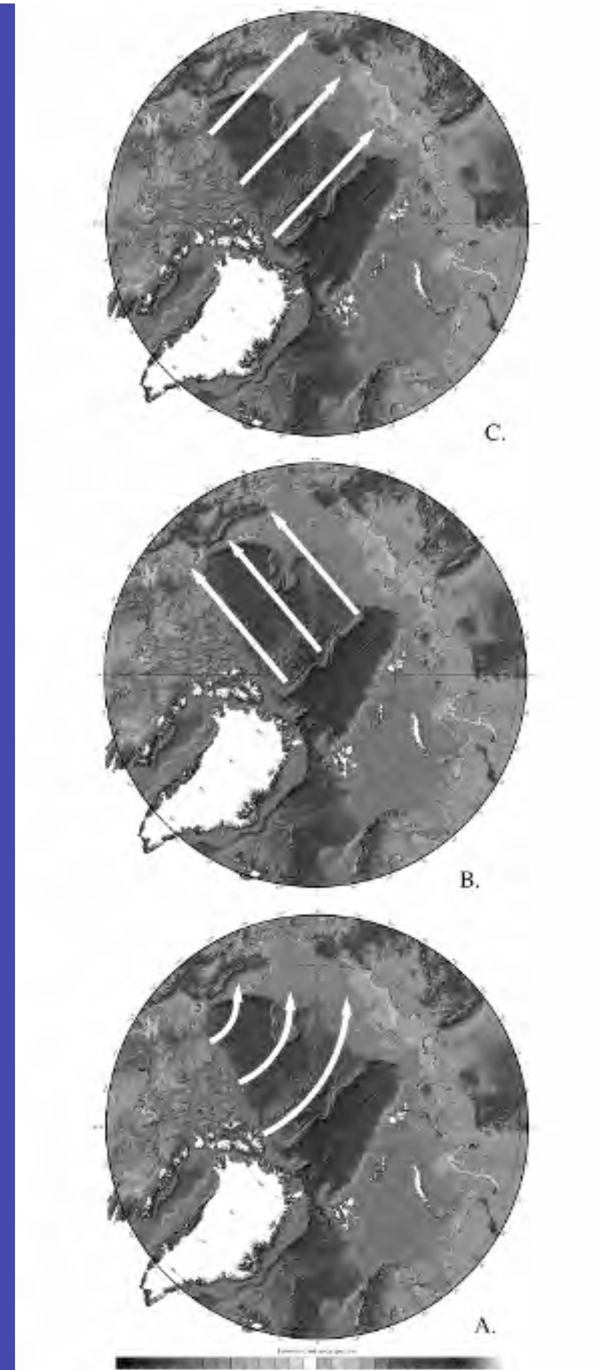


Slide courtesy EL Miller, Stanford

Interpretation of how the Amerasian Basin formed affects interpretations of Lomonosov, Alpha Ridges, Makarov Basin and Chukchi Cap







Other models proposed for the formation of the Amerasian Basin -none except the rotation model are viable for Alaska given the geologic and magnetic anomaly constraints

Rifting models for Amerasian Basin summarized by Lawver and Scotese (1990) with specific predictions for rift versus transform origin of margins and the geologic matches of margins. Base map IBCAO (2000)

Slide courtesy EL Miller, Stanford

Siberia
Wrangel Island
Prudhoe Bay
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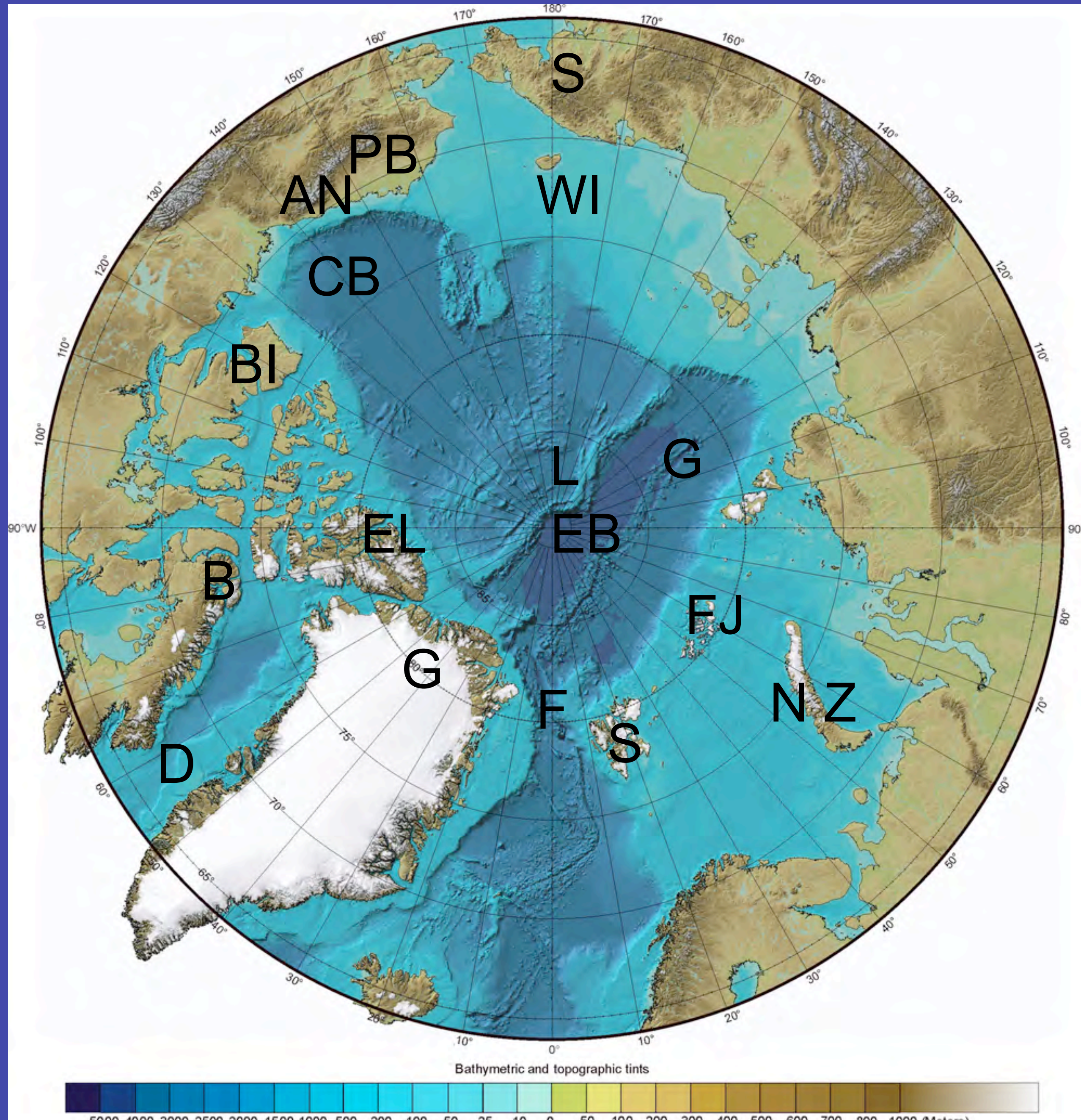
Canada Basin
Banks Island
Ellsmere Island
Greenland
Baffin Island
Lomonosov Ridge
Eurasia Basin
Gakkel Ridge
Franz Josef Land
Novaya Zemla
Svalbard
Fram Strait
Davis Strait



Canada Basin, Arctic Ocean: Evidence against a rotational origin

LS Lane 1997

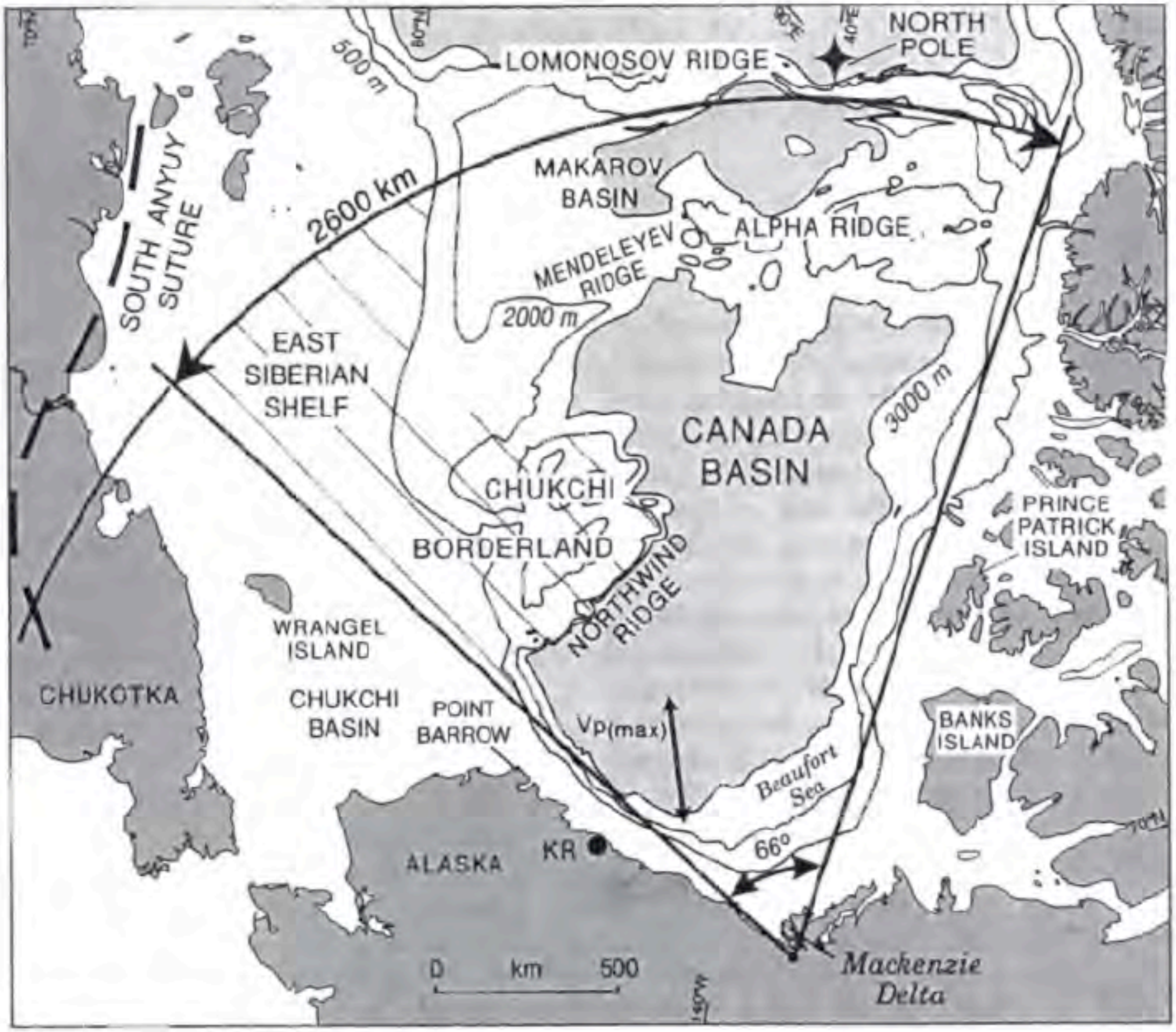
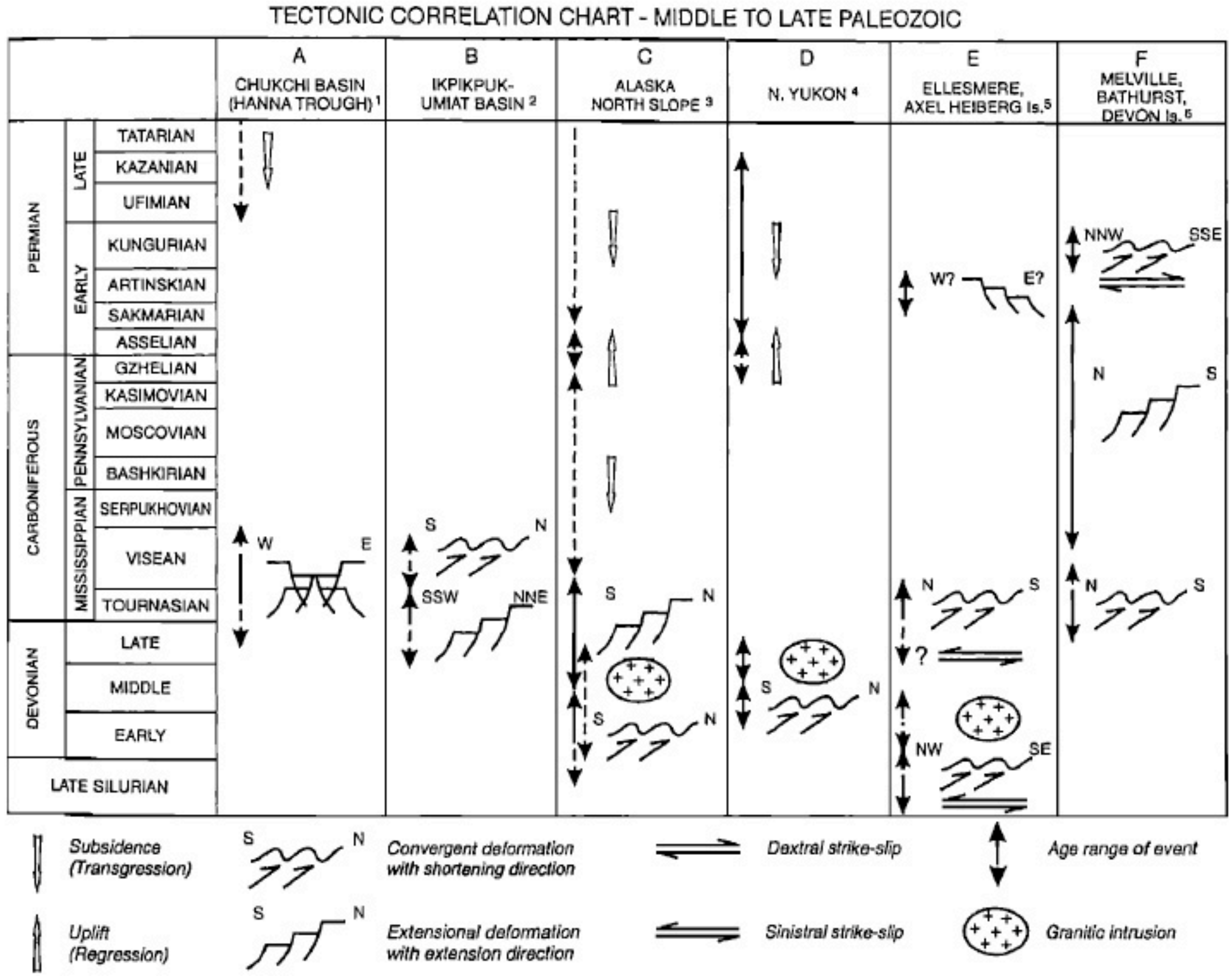


Figure 1. Bathymetric map of the Arctic (modified from Grantz et al. [1990a]) showing 66° of rotation on a hypothetical transform fault adjacent to Lomonosov Ridge. Hachured area is continental overlap of 600 km resulting from its restoration. Such a large overlap area is unlikely to result from intracontinental extension. Vp_{max} is the direction of maximum mantle P wave velocity [*Mair and Lyons*, 1981]. KR is Kuparuk River paleomagnetic site.



Sources: 1. *Thurston and Theiss* [1987]
2. *Mauch* [1985, 1989]
3. *Moore et al.* [1994]
4. *Bamber and Waterhouse* [1971]; *Lane et al.* [1993, 1995, unpublished data, 1997]
5. *Trettin* [1989]; *Beauchamp and Henderson* [1994]; *Beauchamp et al.* [1989]; *Theriault et al.* [1993]
6. *Beauchamp and Theriault* [1994]; *Harrison* [1995]; *Beauchamp et al.* [1995]

Figure 2. Tectonic correlation chart for middle to late Paleozoic time. Tectonic events in Alaska-Yukon do not correspond well to events in Canadian Arctic Islands, contrary to expectation if the regions were initially adjacent. Letters A to F are keyed to localities in Figures 3 and 5.

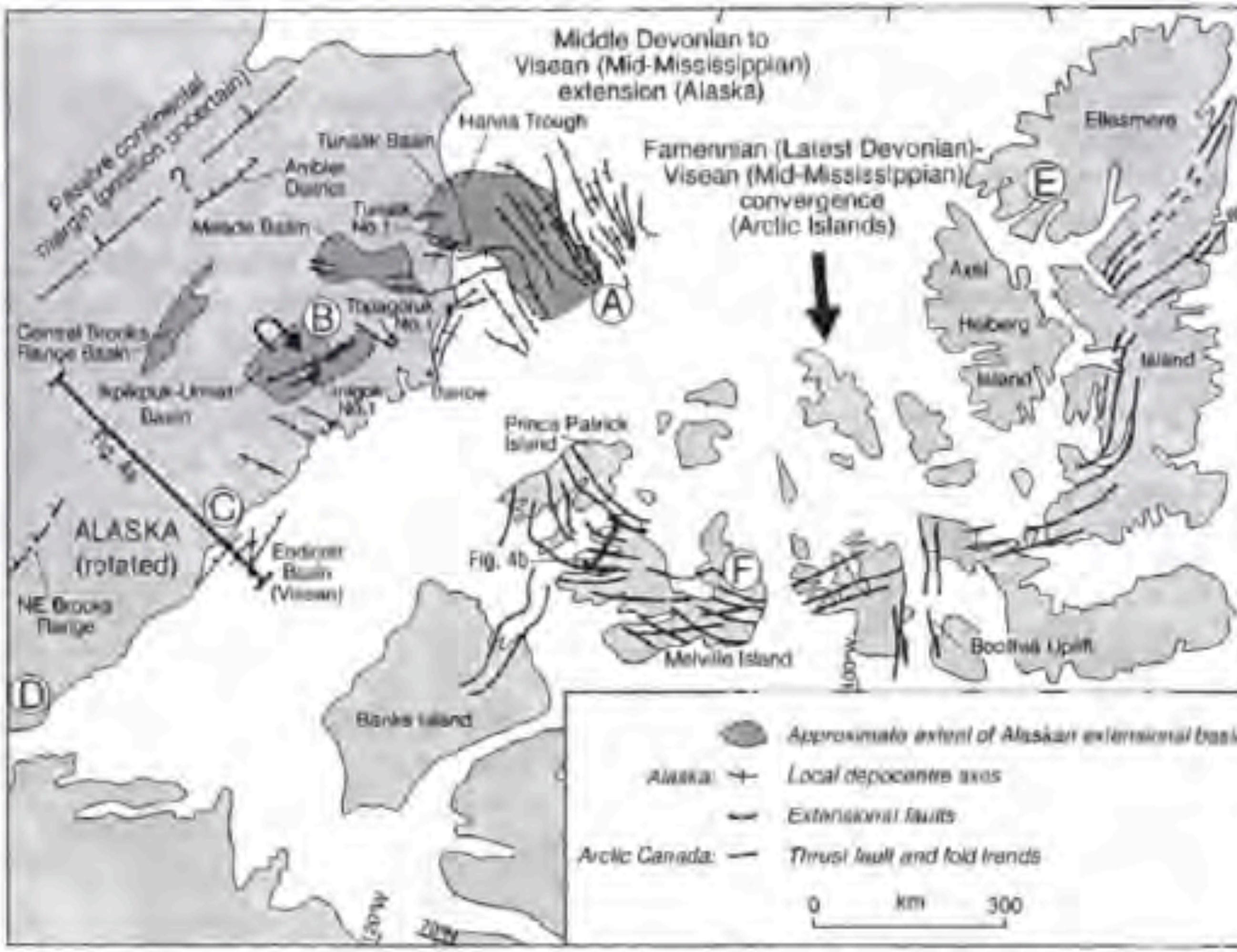


Figure 3. Late Devonian to Early Carboniferous tectonic setting of Arctic Alaska (rotated [*Embry*, 1990]) and Arctic Canada. Lettered localities are keyed to Figure 2. Ikpikpuk-Umiat Basin was extended then shortened during this interval, indicated by curved arrow. Rotational restoration of Arctic Alaska juxtaposes a rifted continental margin in the hinterland against an active orogenic foreland. Evidence of convergent deformation in central Arctic Islands is obscured by thick Sverdrup Basin deposits. Base map has not been palinspastically restored for Late Jurassic to Cenozoic shortening in the Brooks Range. Central Brooks Range Basin restores 75 km south (in present-day coordinates) [*Kelley and Brosgé*, 1995], and the northeast Brooks Range is inferred to have shortened by 46% [*Hanks*, 1993], implying a southward restoration of about 100 km for Devonian extensional strata there. Other sources are *Thurston and Theiss* [1987],

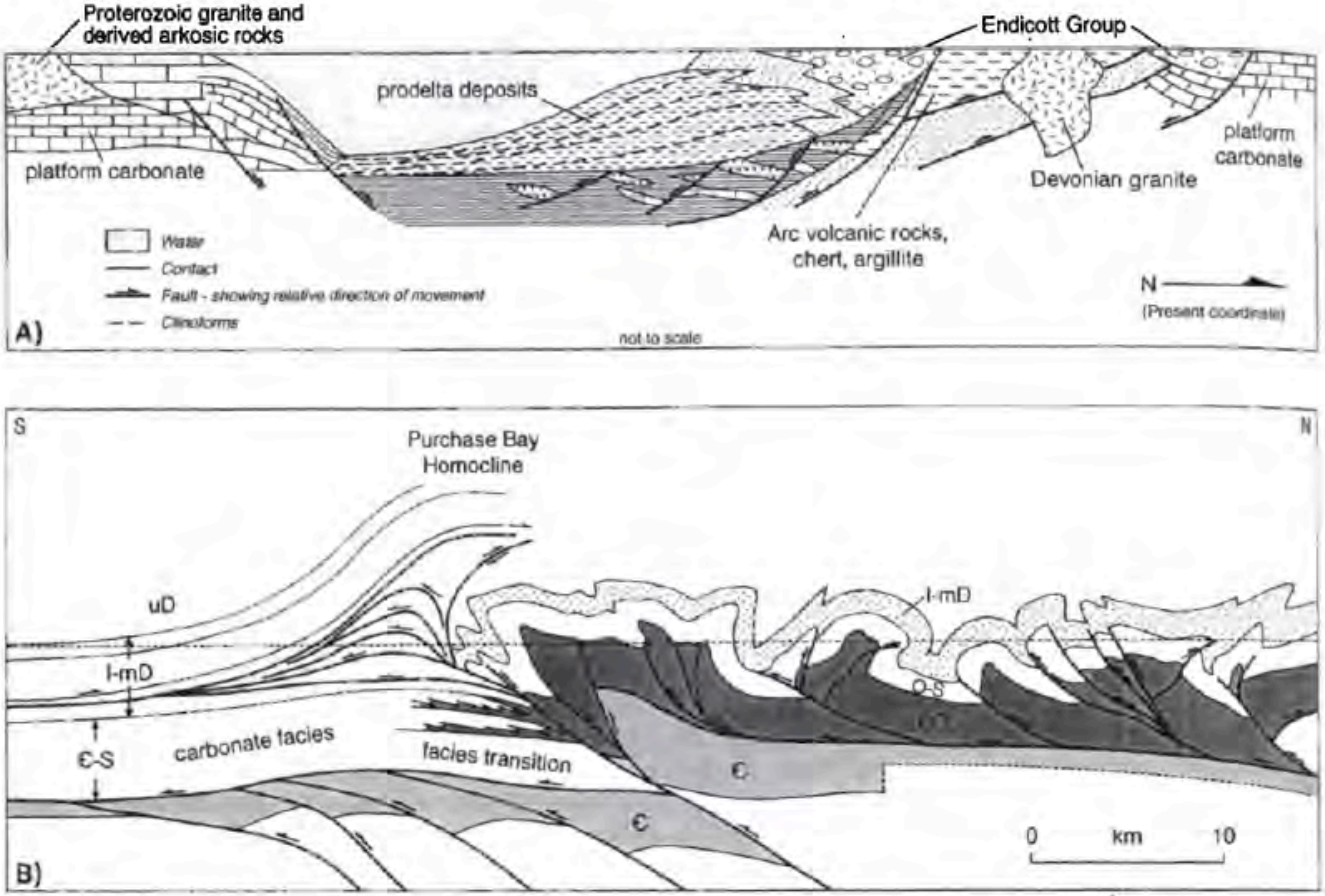


Figure 4. Cross sections illustrating distinctly different latest Devonian and earliest Mississippian tectonic settings of Arctic Alaska and Canadian Arctic Islands. Section locations are shown in Figure 3. (a), Paleogeographic diagram of Arctic Alaska, simplified from *Moore et al.* [1994, Figure 24](reproduced with permission of the publisher, The Geological Society of America, Boulder Colo., Copyright ©1994, The Geological Society of America Inc.); (b) Kinematic model illustrating development of the Purchase Bay Homocline, Melville Island, during late Ellesmerian Deformation (Phase D4 of *Harrison* [1995, Figure 160]). Units do not correlate exactly across the abrupt deformation gradient localized at the early Paleozoic carbonate-shale facies transition.

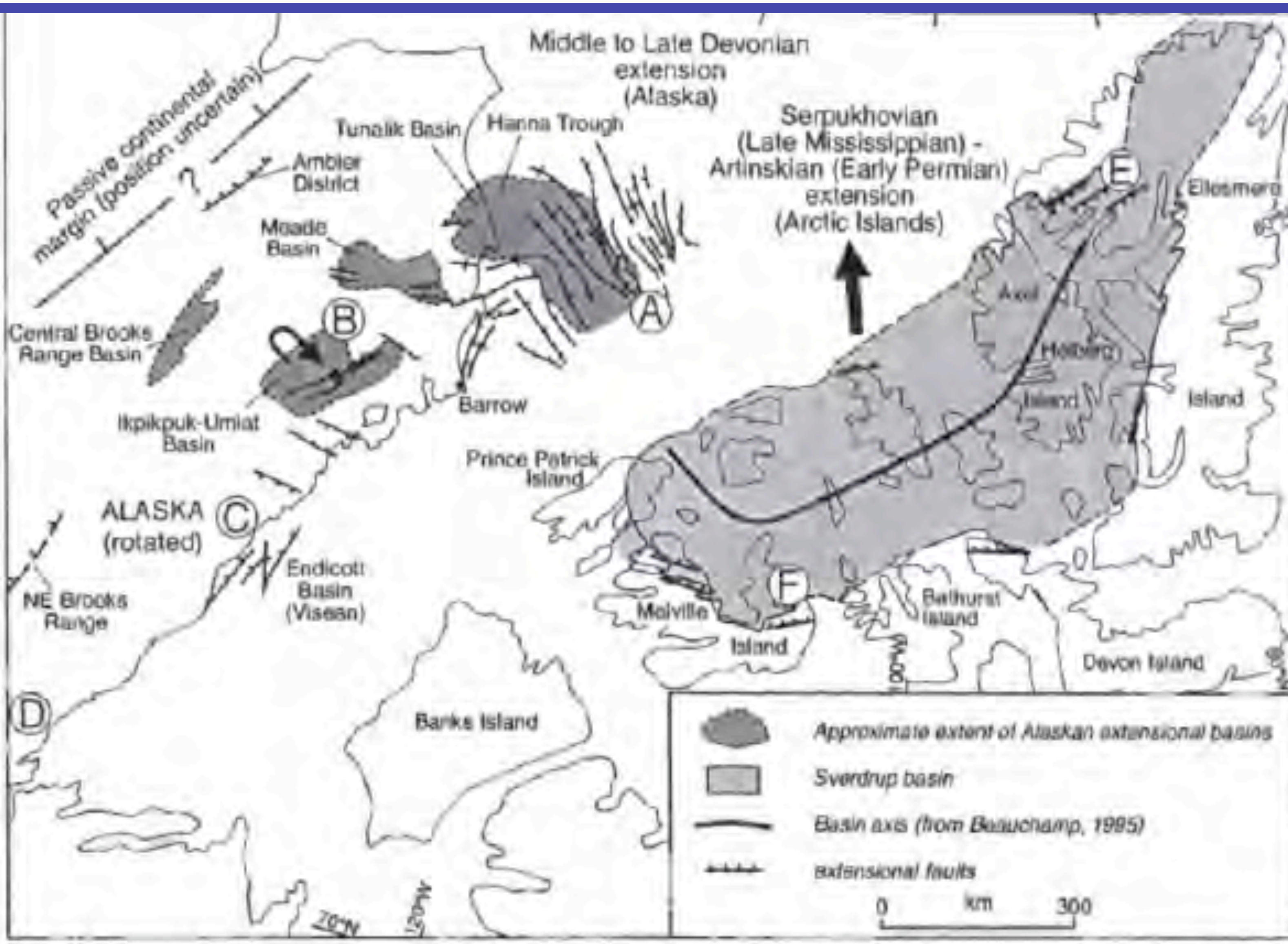


Figure 5. Carboniferous to Lower Permian Sverdrup Basin, with Alaska portion unchanged from Figure 3. Lettered localities are keyed to Figure 2. In Sverdrup Basin, geometry and extensional structures mimic earlier Ellesmerian trends (Figure 3); margins are from *Davies and Nassichuk* [1991], basin axis is from *Beauchamp* [1995]. Normal faults in Sverdrup Basin are mainly Serpukhovian-Bashkirian in age (see Figure 2 for sources). Sverdrup Basin extension direction is based on kinematic data from eastern Melville Island

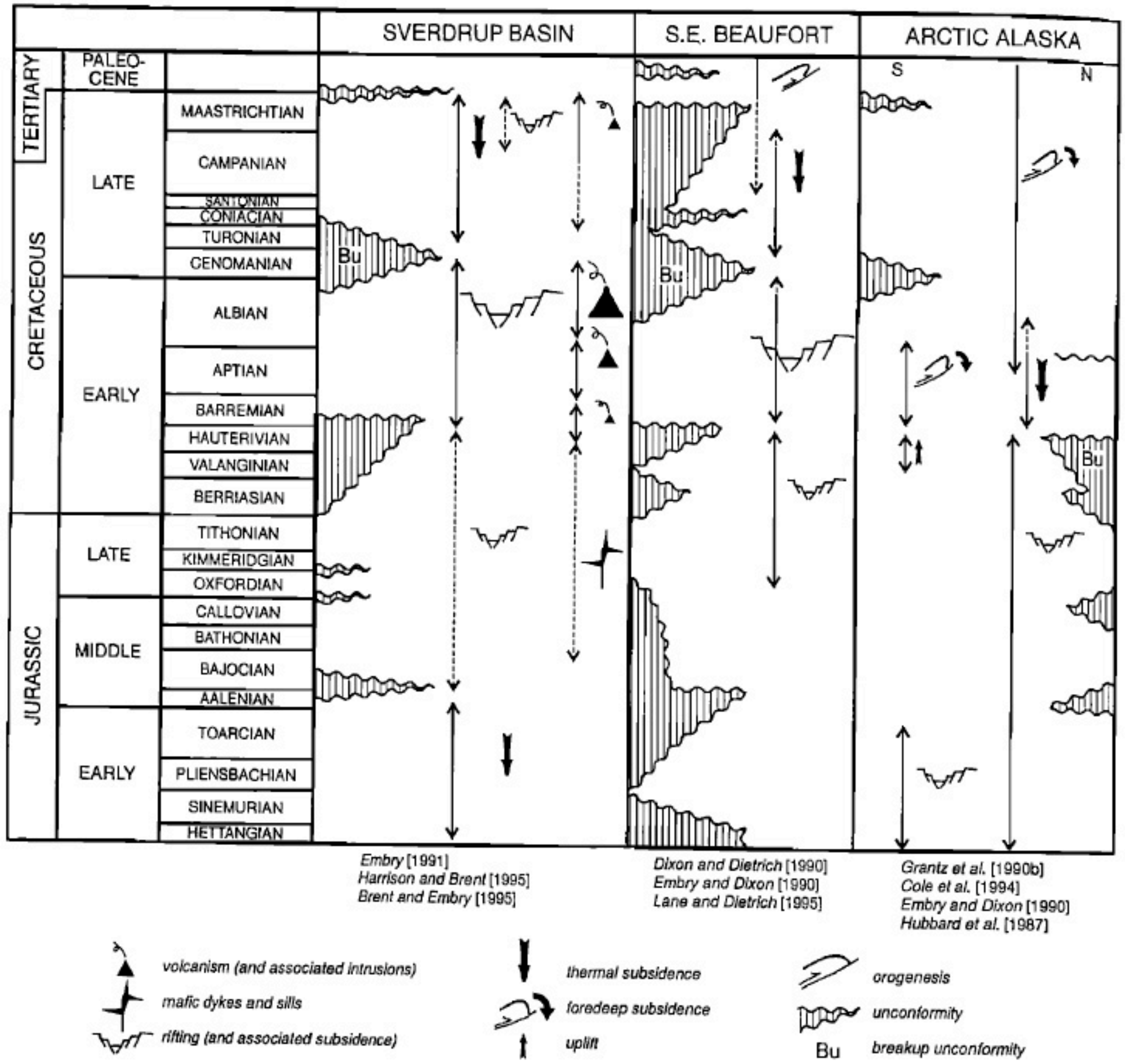


Figure 6. Tectonic correlation chart for Jurassic to Paleocene time. On Canadian margin, volcanism, reduction in rift faulting and inception of thermal subsidence indicate a post-Albian rift-drift transition. Rift-drift transition on Alaskan margin is widely interpreted to correspond to the Late Hauterivian unconformity. Alaskan tectonic evolution is complicated by the effects of Brookian Orogenesis. Evolution of a southerly area of Arctic Alaska [*Cole et al.*, 1994] is distinguished from more northerly areas [*Grantz et al.*, 1990b].

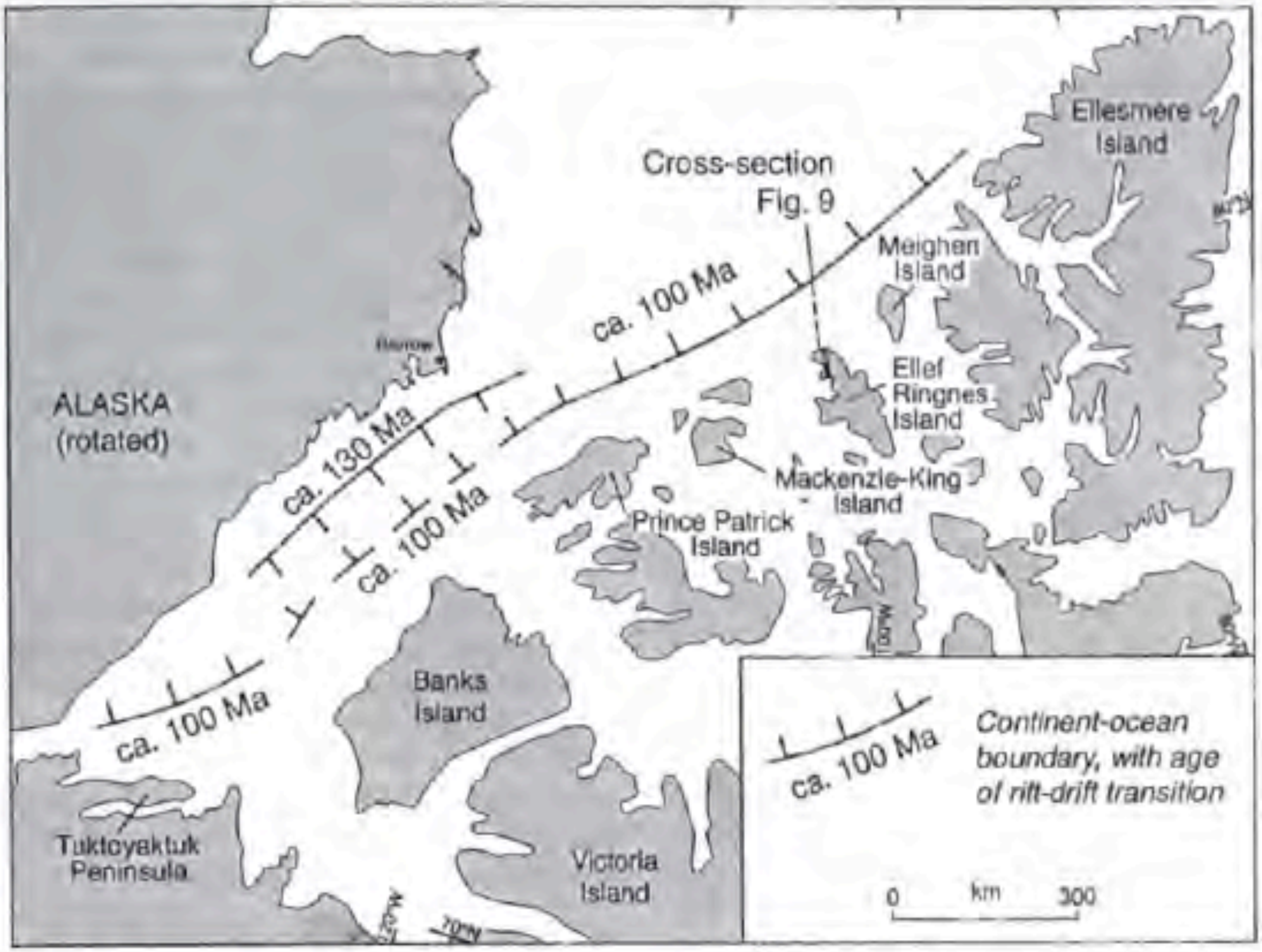


Figure 7. Rift-drift transition ages for Canada Basin margins on rotationally restored base [*Embry*, 1990]. Alaskan data from *Grantz et al*. [1990b] is based on extent of Dinkum Graben and may extend farther east (present coordinates) than shown. Beaufort Sea data are from *Embry and Dixon* [1990, 1994] and *Stephenson et al*. [1994b]. Evidence for a post-Albian age for Canadian Arctic margin is discussed in the text. Rift-drift transition in Banks Island segment is based on major mid-Cretaceous unconformity on Banks Island, although active rifting was interpreted as Aptian in age [*Miall*, 1979]. The data show no indication of younging toward a pivot, and rotational restoration of Alaska to Arctic Canada juxtaposes margins of distinctly different ages. Cross section on Ellef Ringnes Island is shown in Figure 9.

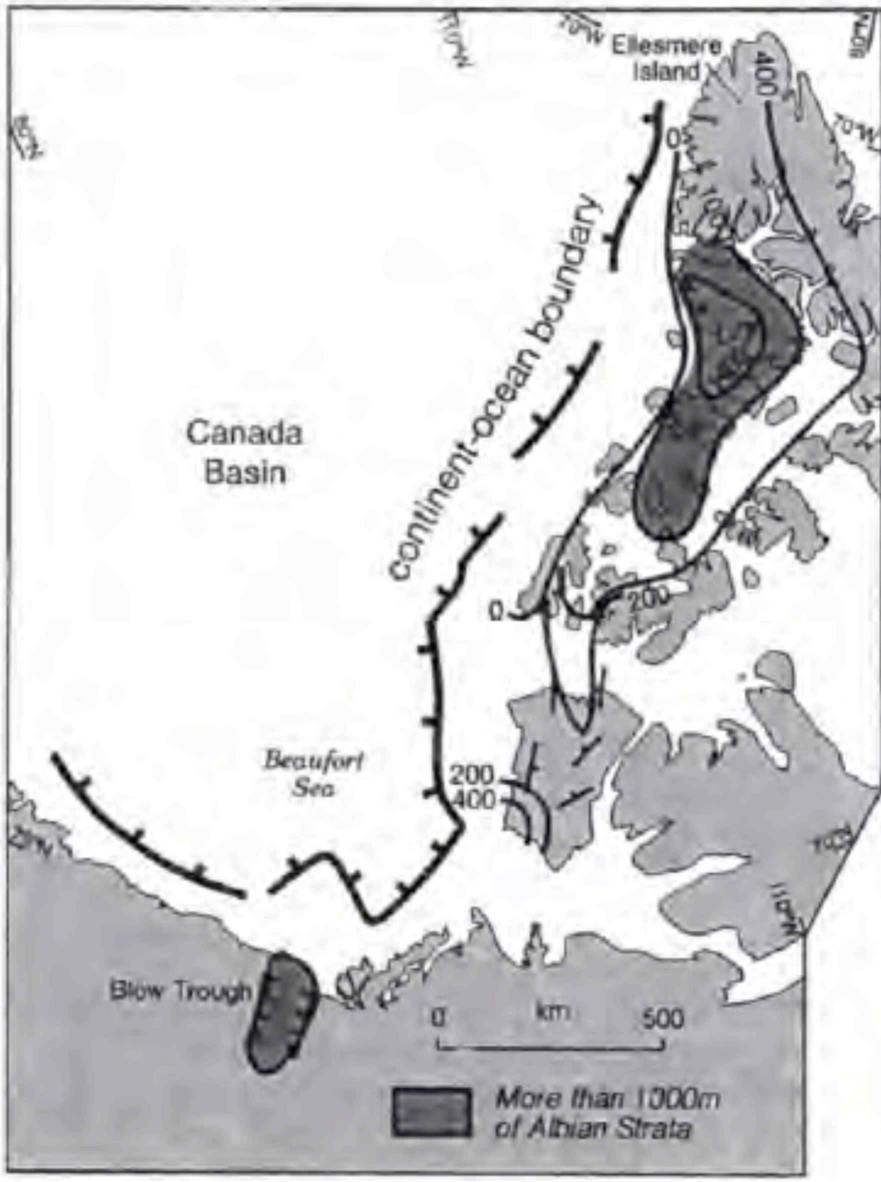


Figure 8. Aptian-Albian rifting and sedimentation event extends at least 2000 km from Ellesmere Island to northern Yukon. Contours are thickness of Aptian-Albian deposits [*Embry*, 1991]. Other sources are *Miall* [1979], *Young* [1977], and *Lane* [1988].

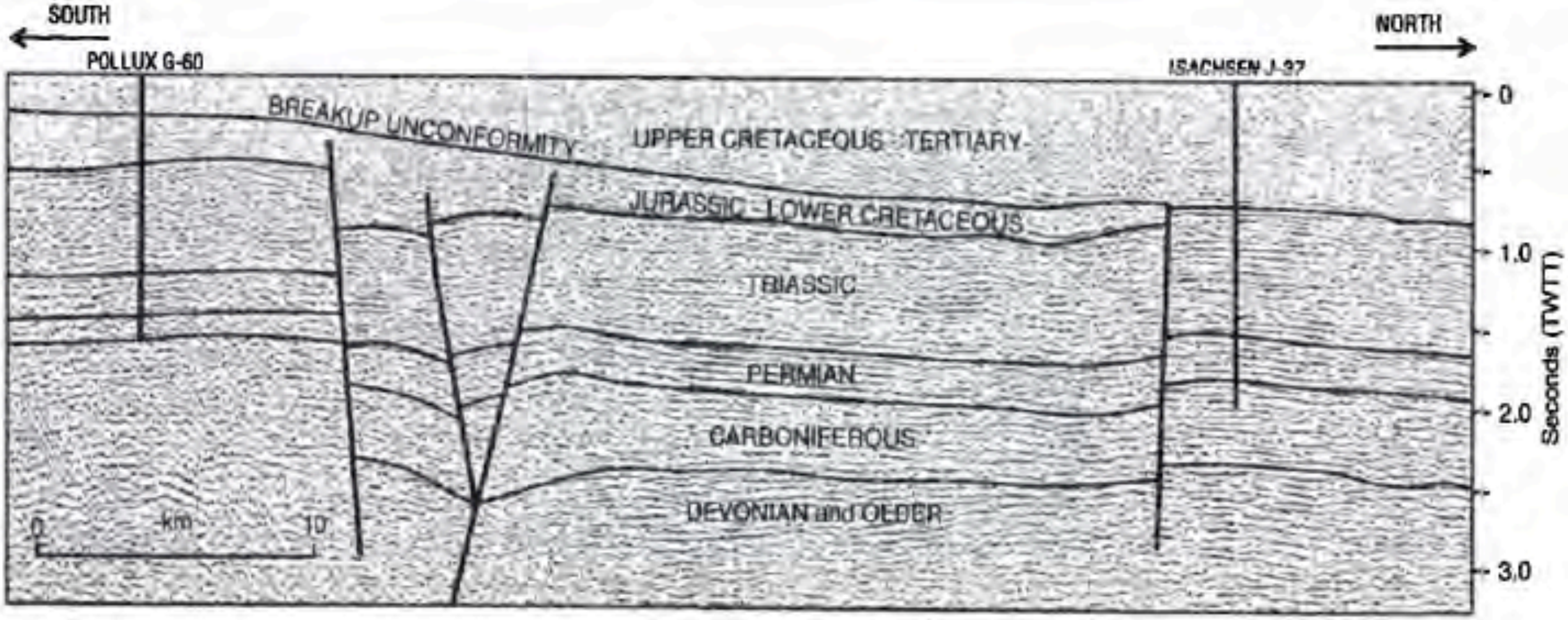


Figure 9. Interpretation of seismic line from northern Ellef Ringnes Island (see Figure 7 for location) [after *Embry and Dixon*, 1990; *Meneley et al.*, 1975]. Breakup unconformity separates faulted Lower Cretaceous strata from less faulted Upper Cretaceous strata (reproduced with the permission of the publisher, The Canadian Society of Petroleum Geologists, Copyright ©1975).

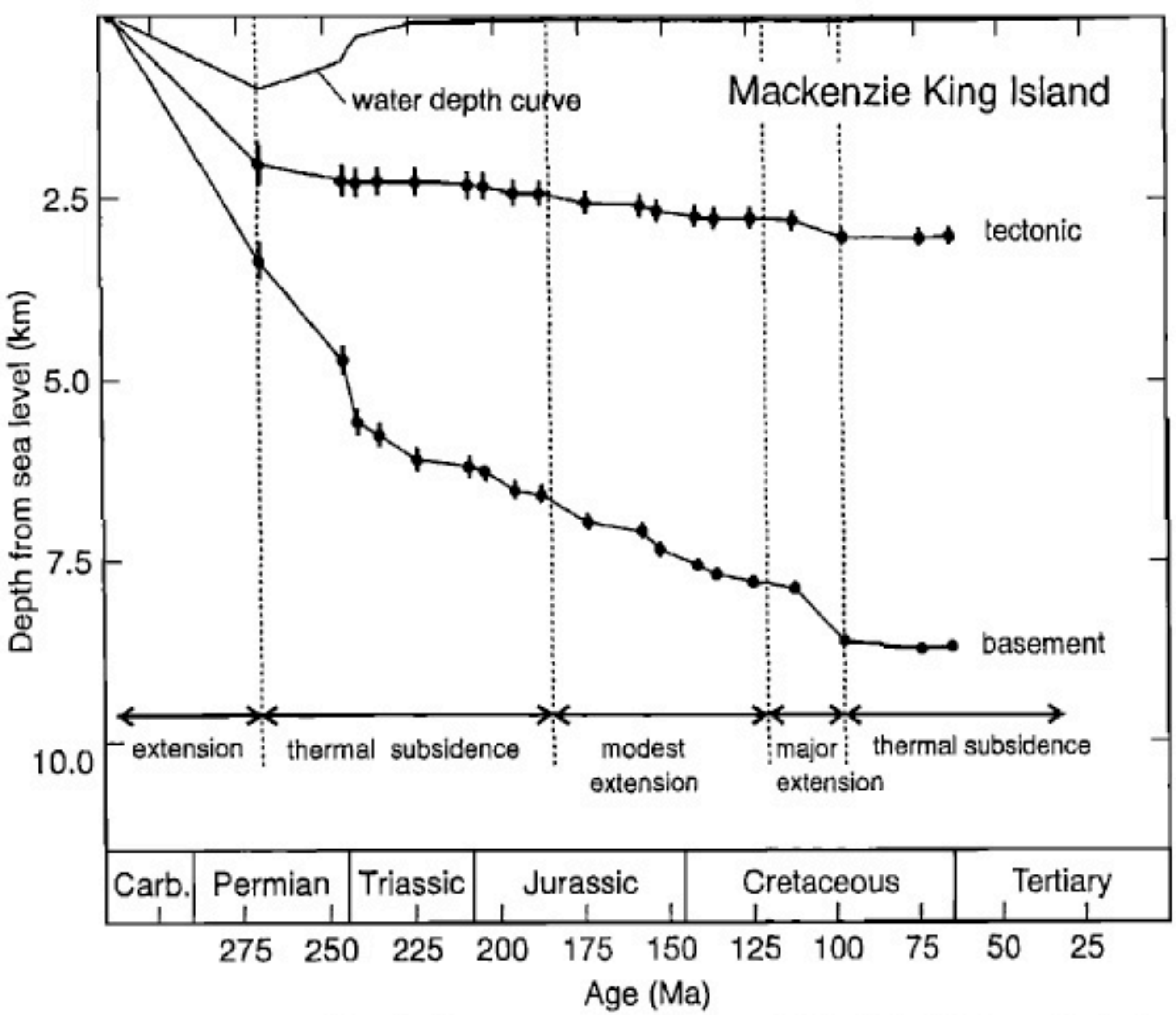


Figure 10. Basement and tectonic subsidence curves for Mackenzie-King Island (Figure 7), derived from backstripping analysis [*Stephenson et al.*, 1994a]. Tectonic stages are generalized Sverdrup Basin data simplified from Figures 2 and 6. During the regionally identified, tectonically driven Middle Jurassic to Early Cretaceous extension, subsidence on Mackenzie King Island shows only subtle variations until Albian (latest Early Cretaceous) time, when the maximum rate of subsidence occurred. Abrupt reduction in subsidence rate in the mid-Cretaceous corresponds to interpreted ocean basin formation and the end of major rift faulting.

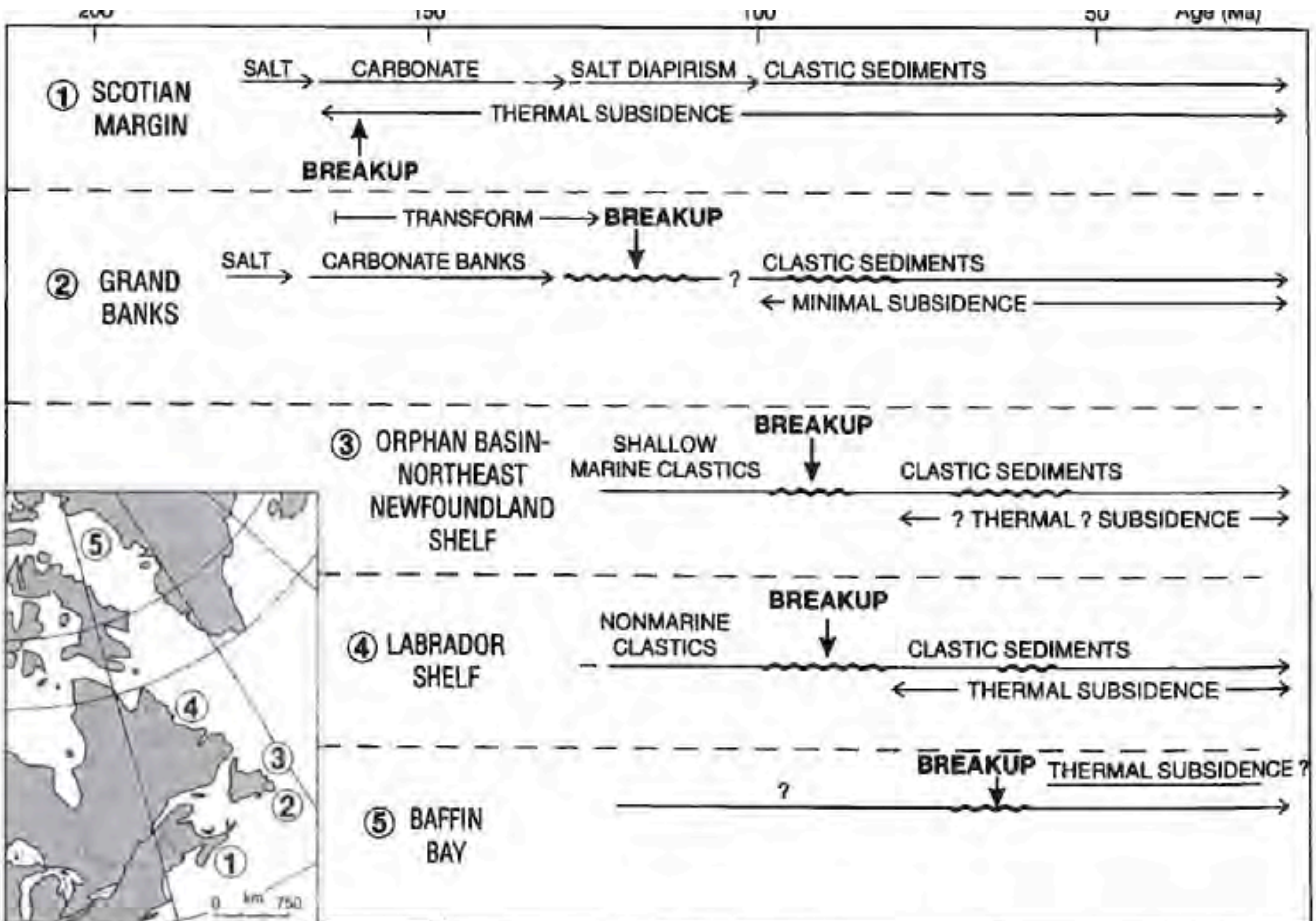


Figure 11. Summary of the tectonic evolution of five segments of the Canadian Atlantic continental margin. Each segment is keyed to its location on inset map. Simplified from *Keen et al.* [1990].

Figure 14. Linear aeromagnetic anomaly trends in Canada Basin, interpreted from *Verhoef et al.* [1996]. Positive anomalies are solid; negative anomalies are dashed. Also shown are linear negative gravity anomalies interpreted by *Laxon and McAdoo* [1994] as an extinct spreading axis (discussed in text). Abbreviations are AFZ, Amundsen Fracture Zone; BFZ, Beaufort Fracture Zone; PPL, Prince Patrick Lineament; and PSMA, polar shelf magnetic anomaly, interpreted as an expression of the continent-ocean transition [*Forsyth et al.*, 1990; *Stephenson et al.*, 1994b].

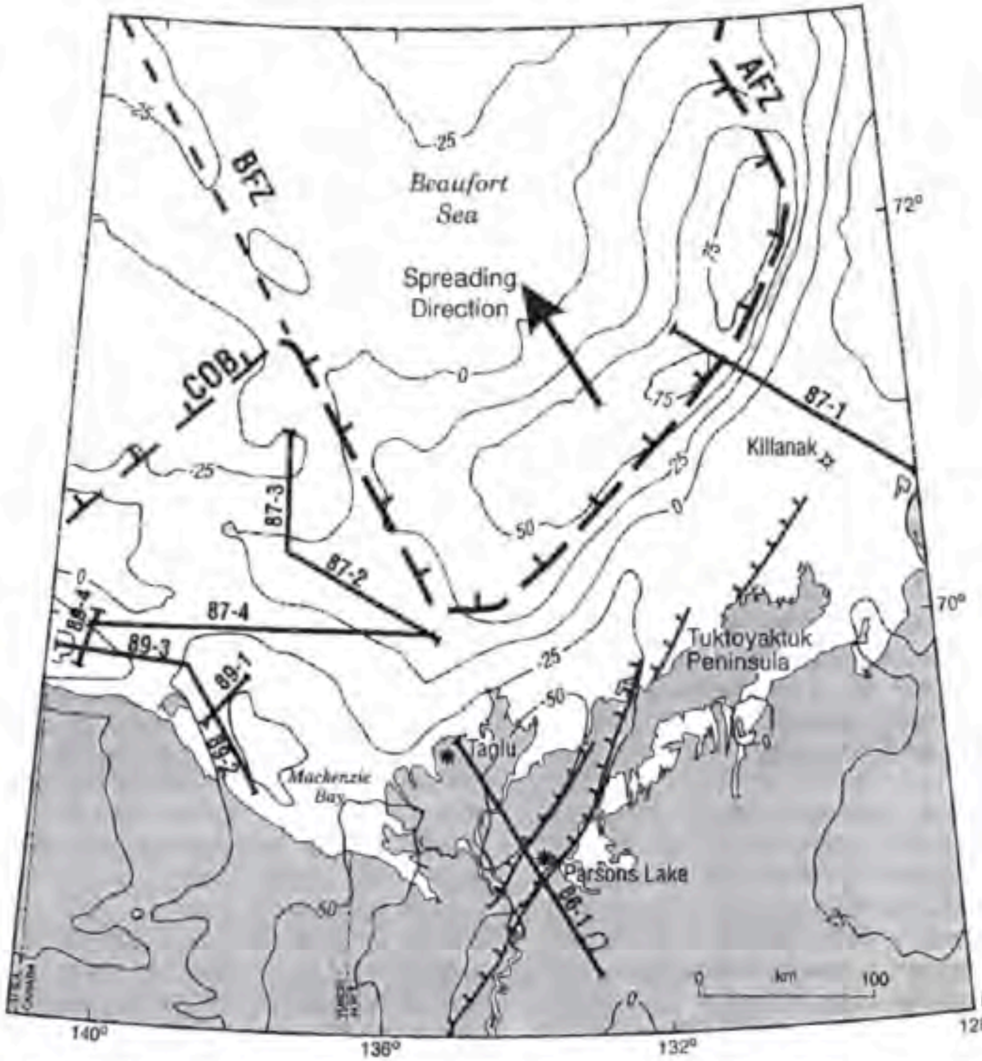


Figure 12. Beaufort Sea continental margin, gravity anomalies (25 mGal contour interval), and deep seismic reflection lines (numbered). Long-dashed line is continent-ocean boundary ((COB), ticks on ocean side); AFZ is the offset of the COB due to the Amundsen Fracture Zone [after *Stephenson et al.*, 1994b; *Lane*, 1994; *Nelson et al.*, 1995]. Major basin-margin normal faults beneath Tuktoyaktuk Peninsula are from *Lane and Dietrich* [1996]. Taglu and Parsons Lake gas fields are sites of dense seismic and drilling data where stratigraphy and structural geometry are well known [e.g., *Coté et al.*, 1975; *Hawkings and Hatelid*, 1975; *Cook et al.*, 1987]. Gravity low along Beaufort Fracture Zone (BFZ) was interpreted as a speculative extinct spreading axis by *Laxon and McAdoo* [1994]. Large arrow is ocean spreading direction indicated by crustal structure data.

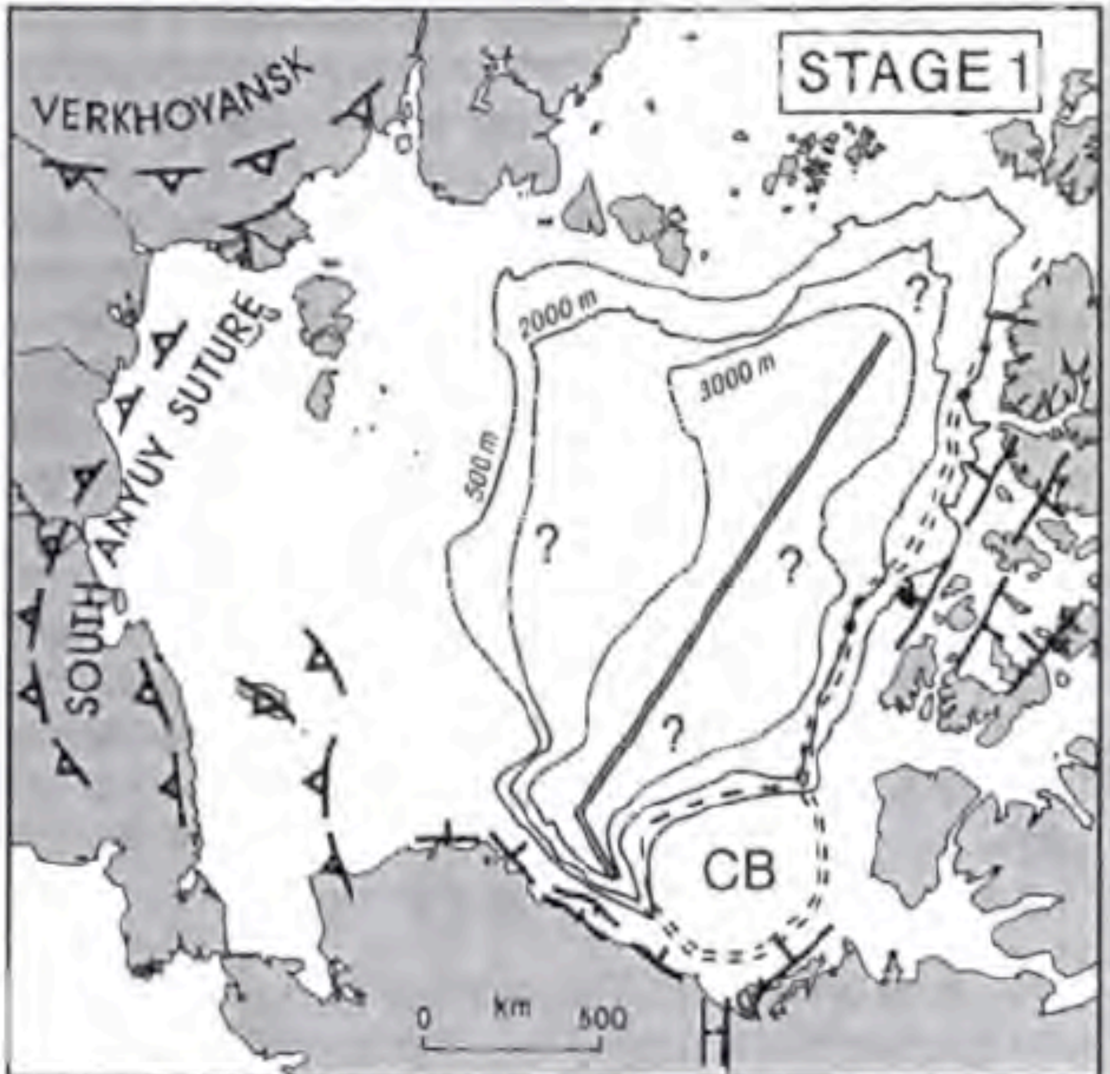


Figure 15. Speculative geometry at the end of stage 1 spreading. Solid double line is speculative stage 1 mid-ocean ridge. Dashed double line is future stage 2 spreading center. Spreading was accommodated by subduction of South Anyuy Ocean and convergence across Chukotka. CB is restored Chukchi Borderland.

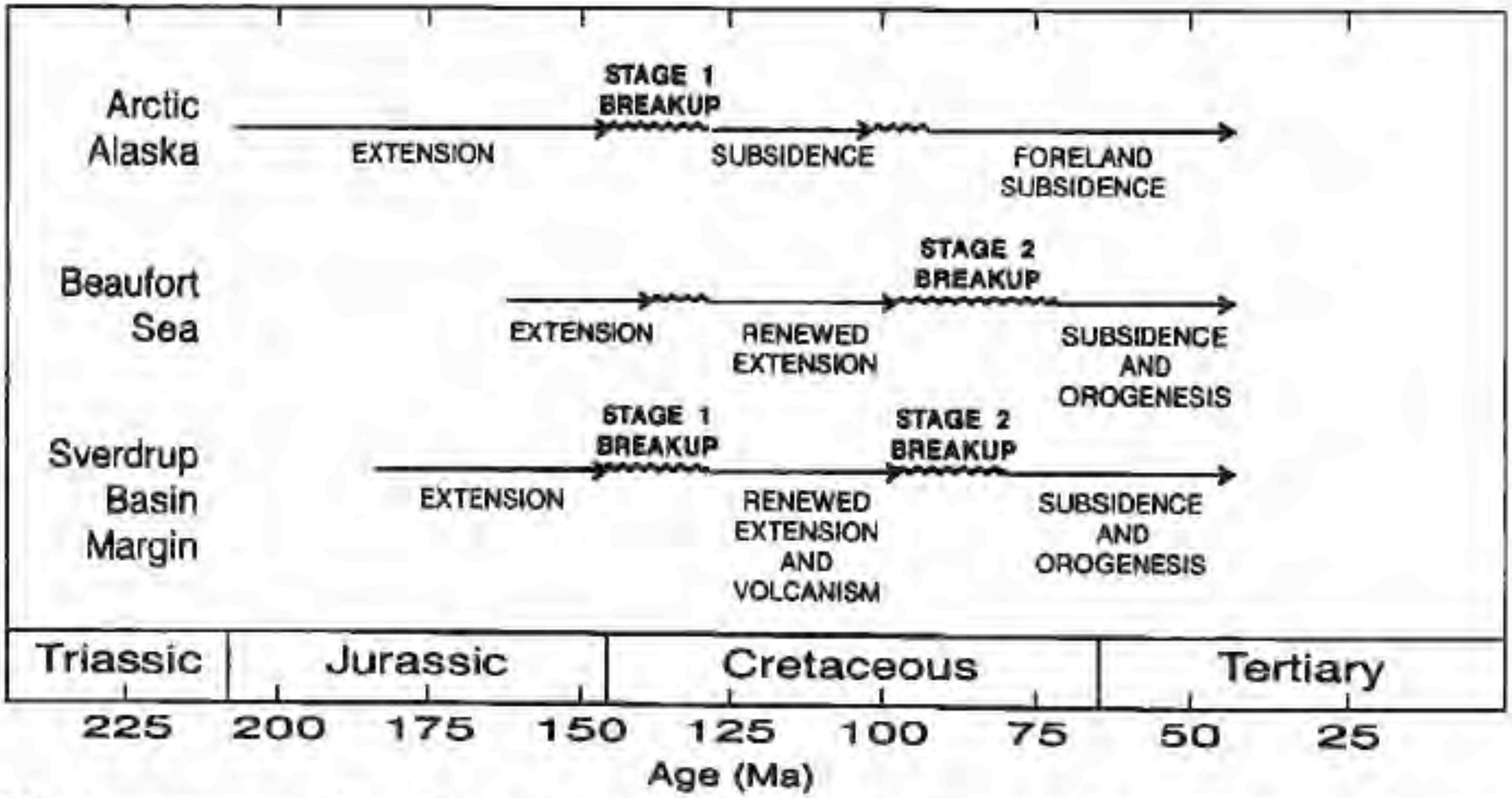


Figure 16. Interpretation of tectonic stages of Arctic Alaska, Beaufort Sea margin, and Sverdrup Basin margin, simplified from Figure 6, in the context of a multistage evolution for Canada Basin. Stage 1 rift-drift transition of Late Hauterivian age was recorded in Arctic Alaska and Sverdrup margins. The same unconformity in the Beaufort region was not associated with ocean crust formation because Chukchi Borderland remained in place (Figure 15). Major Aptian-Albian rifting along the Canadian margin rejuvenated the Sverdrup margin and removed Chukchi Borderland from the Beaufort Sea, initiating ocean crust formation there (Figure 15). Arctic Alaska felt the mid-Cretaceous uplift as a postrift unconformity.

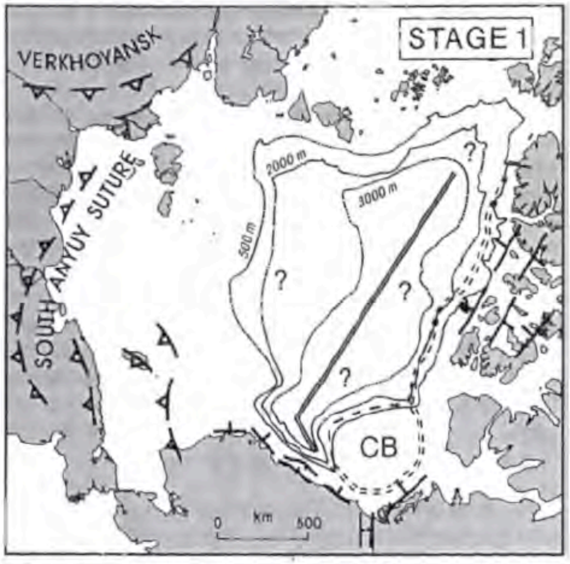


Figure 15. Speculative geometry at the end of stage 1 spreading. Solid double line is speculative stage 1 mid-ocean ridge. Dashed double line is future stage 2 spreading center. Spreading was accommodated by subduction of South Anyuy Ocean and convergence across Chukotka. CB is restored Chukchi Borderland.

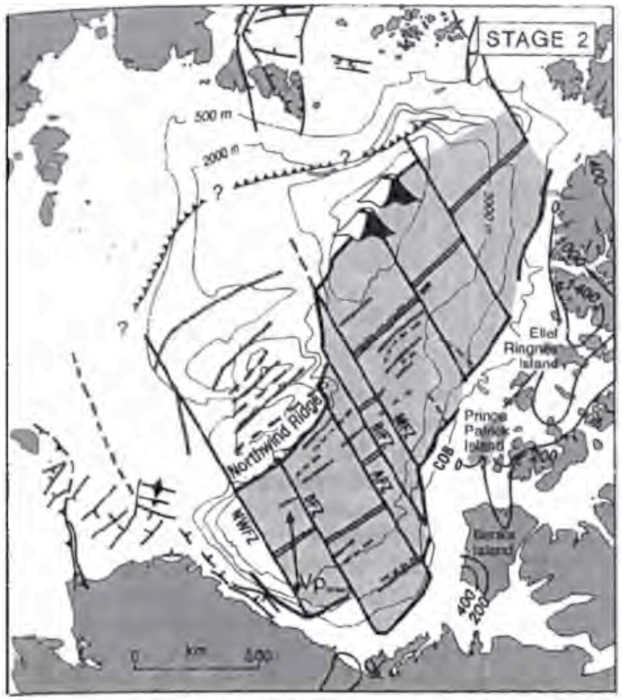


Figure 17. Canada Basin after stage 2 spreading. Continent-ocean boundary (COB) modified from *Lane* [1994]. Double lines are spreading ridges. Labeled fracture zones are BFZ, Beaufort; NWFZ, Northwind; AFZ, Amundsen; BIFZ, Banks Island; and MFZ, M'Clure. Fracture zone localities are constrained by the geometry of the Canadian continental margin. Area between Amundsen and M'Clure fracture zones is likely more complex than shown. Convergent zone (barbed line) is speculative [*Zonenshain et al.*, 1990]. Volcanoes on the linear submarine plateau (future Mendeleyev and central Alpha ridges) represent incipient eruption of Alpha Ridge plume. Solid and dashed grey lines are magnetic anomaly trends (positive and negative, respectively) pertinent to stage 2. Aptian-Albian isopachs are from Figure 8.

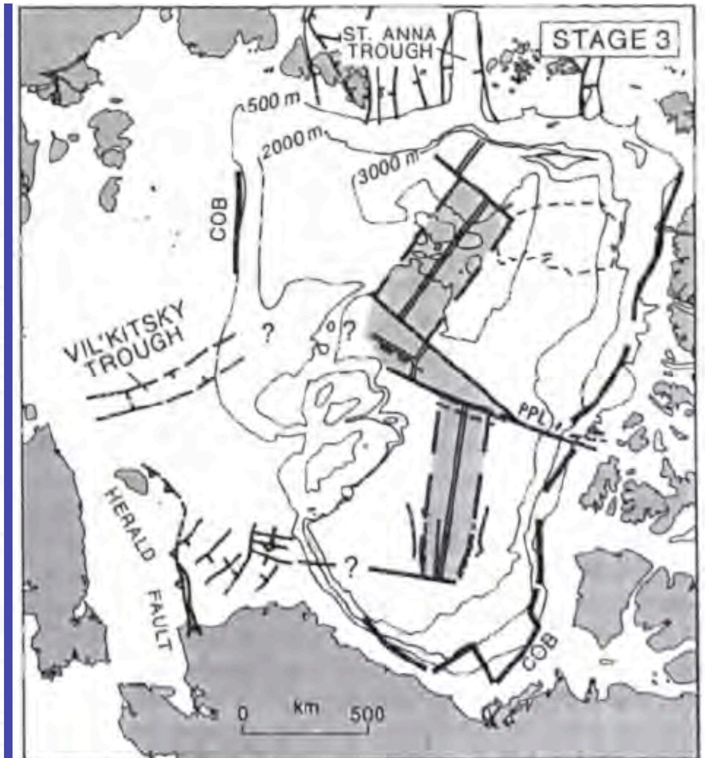


Figure 18. Stage 3 spreading, east-west in southern Canada Basin and NW-SE in the north. Accommodation zone and triple junction north of Chukchi Borderland are schematic. Prince Patrick Lineament (PPL) is shown. Double lines are spreading axes, long-dashed lines bracket stage 3 oceanic crust (shaded). Dashed outline in northern Canada Basin is site of future eastern Alpha Ridge. Continental accommodation in bordering regions is speculative but consistent with available data [*Lane*, 1994]. Grey lines are magnetic anomalies pertinent to stage 3.

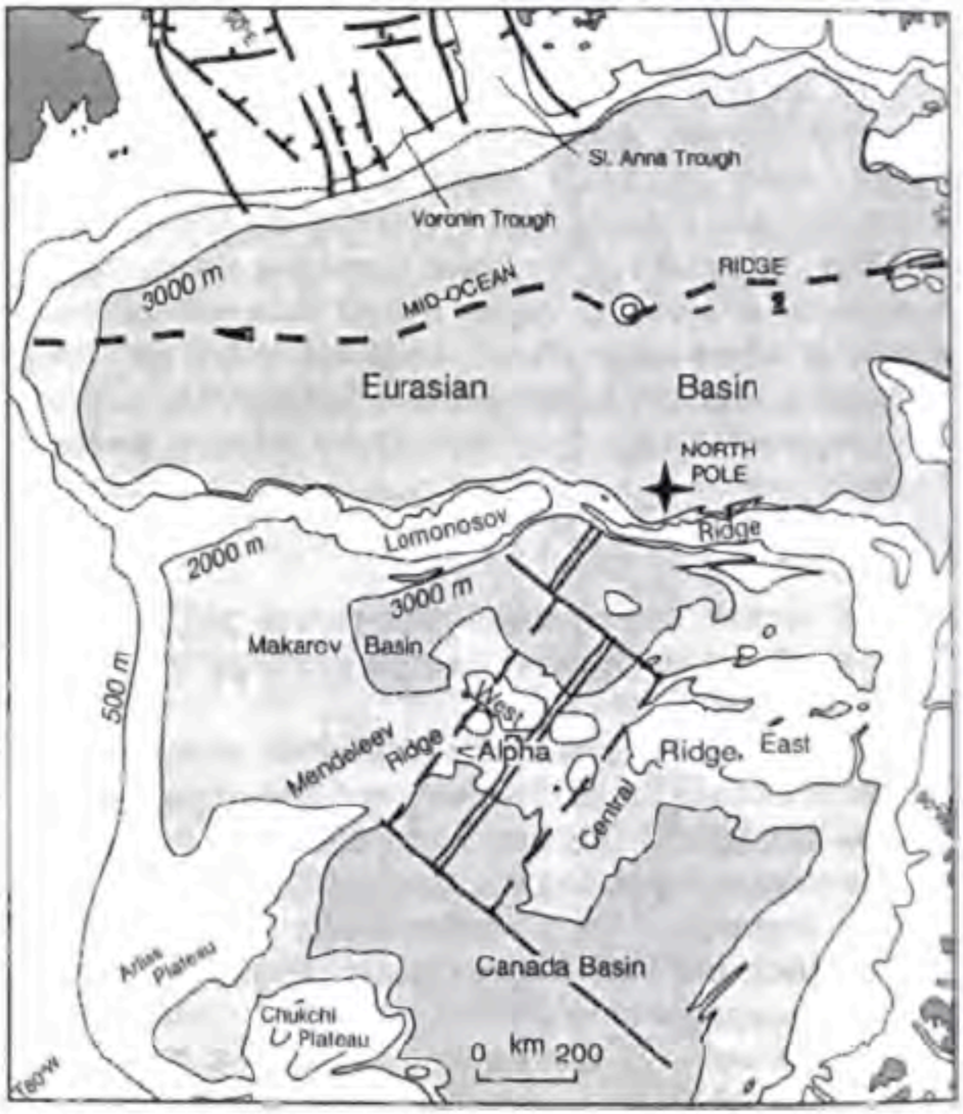


Figure 19. Bathymetry of Alpha and Mendeleyev ridges. Abrupt kink in Lomonosov Ridge, Eurasian Basin mid-ocean ridge, and European continental shelf at St. Anna Trough restore to a pre-opening position adjacent to kink in Alpha Ridge, suggesting a genetic link between western Alpha Ridge and the deflection of the European continental margin (Figure 18).

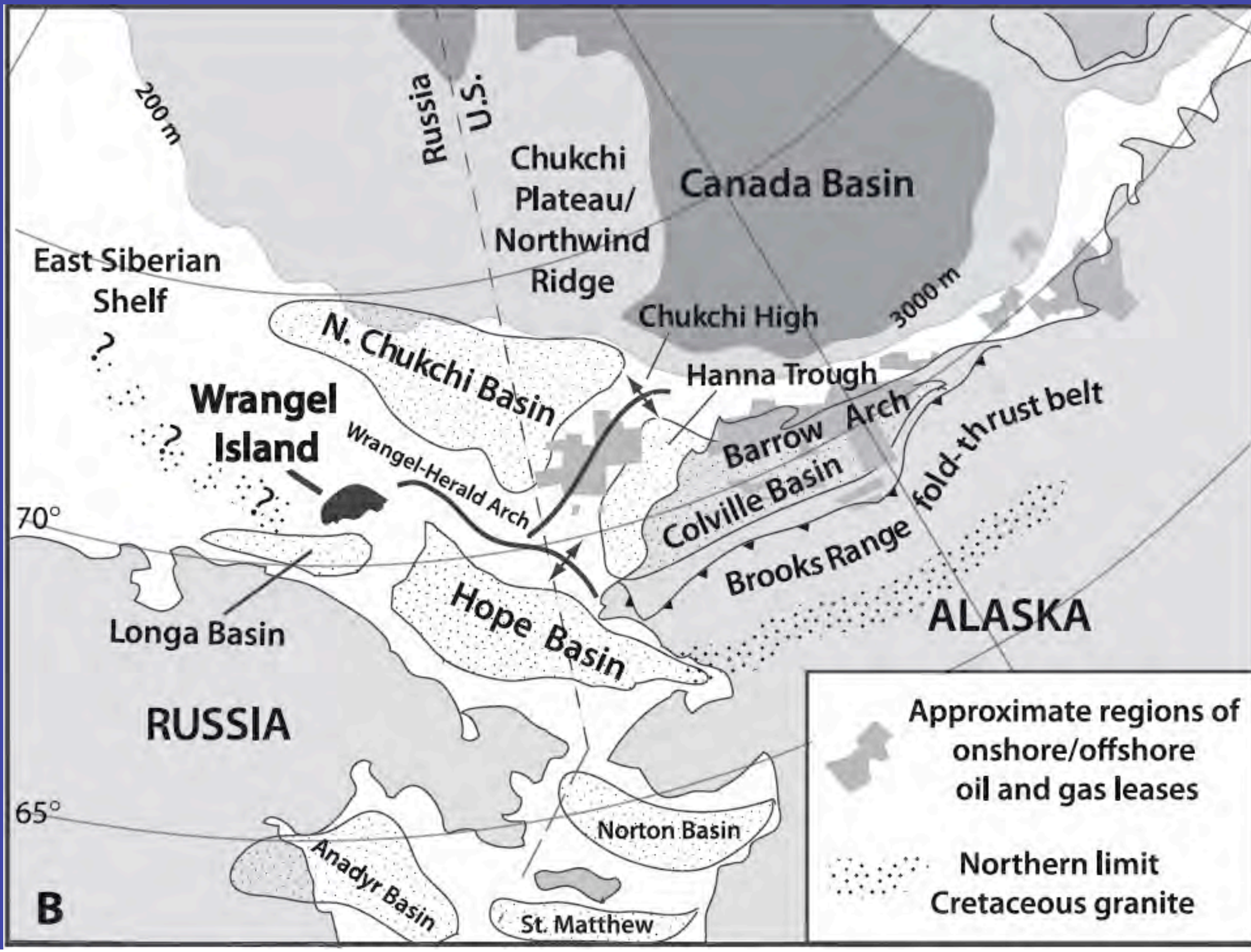
Lane's Conclusions

- The Alaska clockwise rotation model is based Late Paleozoic structural trends
- New data makes correlations of these features between Alaska and Canada Arctic Islands problematic
- N Alaska rift-drift is early Cretaceous
- Artic Islands rift-drift is mid-Cretaceous

Lane’s Conclusions

- Crustal data suggest northwest sea floof spreading away from Arctic Islands
- A multi-stage rifting model is proposed
- BUT: what does this model predict about the geology of Eastern Siberia?
- AND: where is that North American-Asian Plate Boundary?

Miller et al 2010



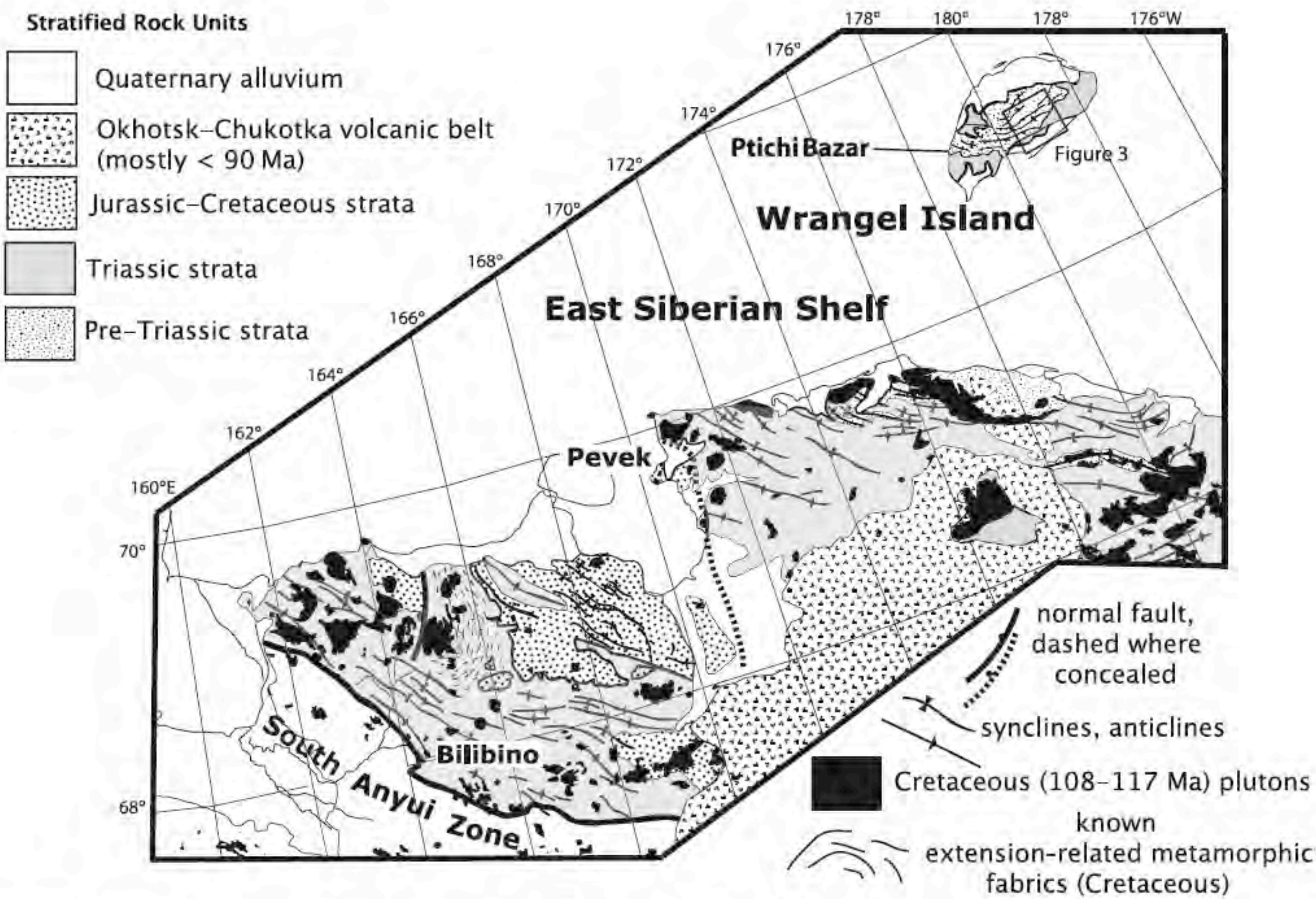
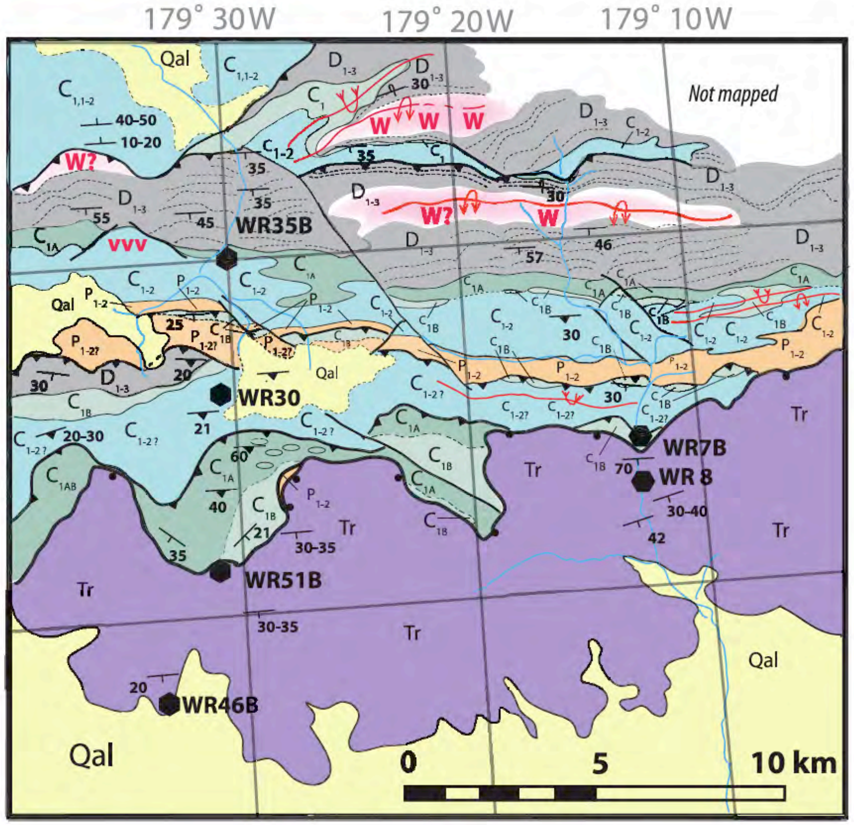
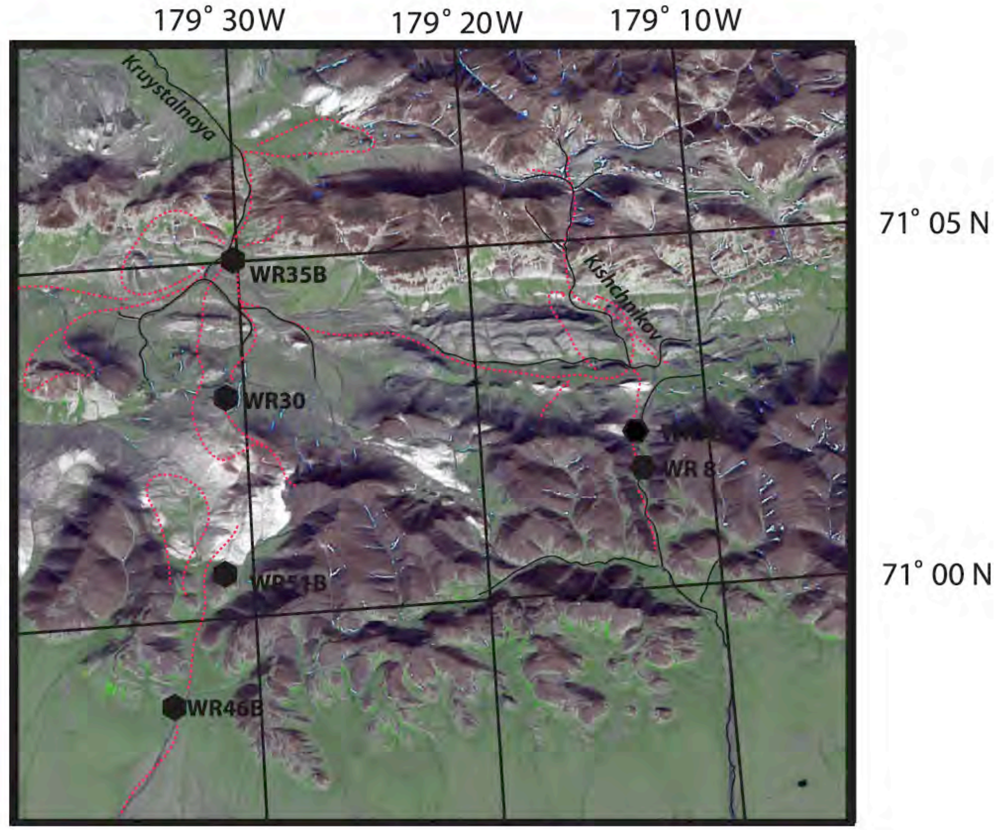


Figure 2. Simplified tectonic and geologic map of mainland Chukotka and Wrangel Island showing Jurassic–Cretaceous structural trends (folds and thrust faults) and crosscutting plutons compiled from Gorodinski (1980). The box shows the approximate location of the Figure 3 map on Wrangel Island





Legend

Qal	Quaternary alluvium
Tr	Dark slate/shale and sandstone turbidites
P_{1-2}	Black slate, siliceous argillite, chert
$C_{1-2\,?}$	Slate/shale/calc.siltstone interbedded with siliciclastic turbidites
C_{1-2}	Calcarenites and grey limestone interbedded with slate and siltstone
C_{1B} / C_{1AB}	Resistant, light-weathering dolomite and limestone C_1, undifferentiated
C_{1A}	vvv basalt and basalt breccia; intrabasinal sedimentary breccia; Chlorite-rich shale, thin sandstone and dolomite
D_{1-3}	Devonian?- Mississippian? clastic succession (major conglomerate and quartzite beds shown by dotted lines

angular unconformity

W	Areas clearly identified as Precambrian basement (Wrangel Complex)

Older on younger fault

Omission, younger on older fault

Overturned anticline, syncline

WR46B Detrital zircon sample

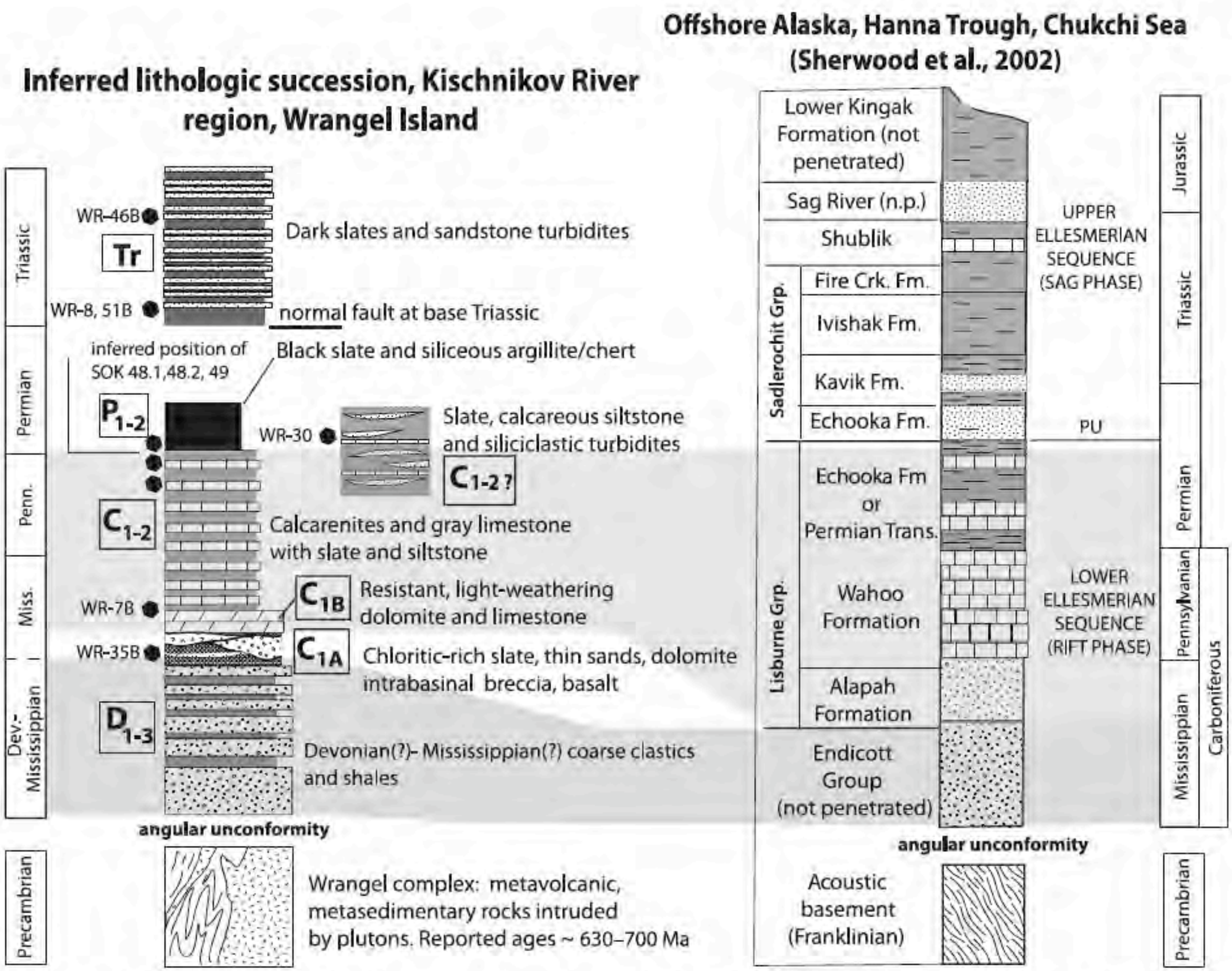


Figure 4. Tectonostratigraphic column for strata in the Kishchnikov River map area, showing general lithologies of the units mapped (Figure 3A) and correlation of lithologic divisions to previously mapped and fossil-dated units of Kos'ko et al. (1993) (boxes outlined in black). Suggested correlation of Wrangel Island map units to those of the Hanna Trough, Chukchi Sea (as described by Sherwood et al., 2002) (right column). Approximate stratigraphic positions of samples analyzed for detrital zircon geochronology are shown by hexagons and sample numbers. n.p. = not penetrated; black hexapons = detrital zircon samples.

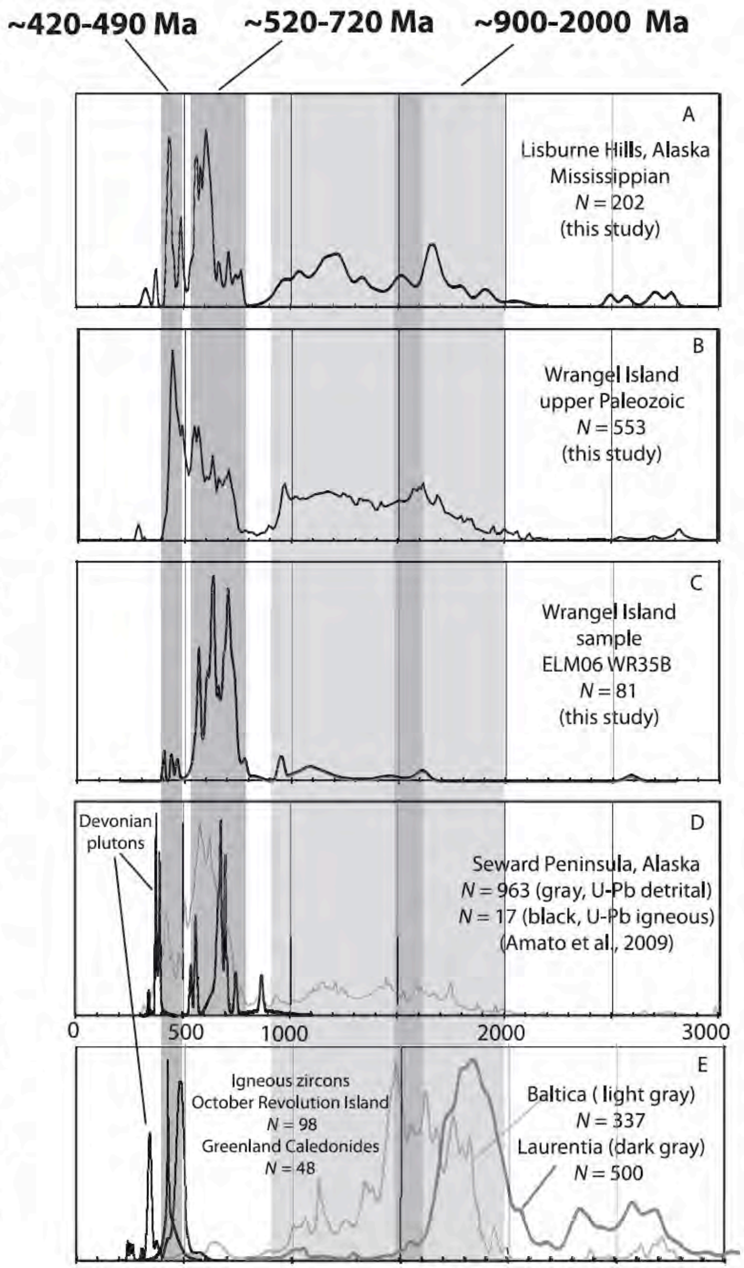


Figure 7. Comparison of relative age probability distributions of 0–3000-Ma detrital zircon populations from upper Paleozoic stratigraphic units on Wrangel Island (B, C) with data from the Lisburne Hills Kapaloak sequence, Alaska (A), and the Seward Peninsula, Alaska (D), from Amato et al. (2009). (E) Baltic shield data (gray line) are from detrital zircon suites dated from Neoproterozoic to early Paleozoic strata (pre-Caledonian) deposited adjacent to the Baltic shield of Europe compiled from Knudsen et al. (1997), Ahall et al. (1998), Kôstler et al. (2002), and Bingen et al. (2005), as compiled by Grove et al. (2008). The patterned bar represents the specific age range (1490–1620 Ma) of basement terranes in Baltica that are not present in North America, referred to as the Laurentian magmatic gap (e.g., Van Schmus et al., 1993). The thicker dark gray line is a compilation of detrital zircon suites dated from Neoproterozoic to early Paleozoic (pre-Caledonian) strata from the northern and central Canadian Cordillera from Gehrels and Ross (1998). Data plotted were reanalyzed by laser ablation–inductively coupled plasma–mass spectrometry and are unpublished. Black lines are igneous zircons dated from the Greenland Caledonides from Kalsbeek et al. (2008) and Severnaya Zemlya (October Revolution Island) from Lorenz et al. (2007). For discussion, see the text.

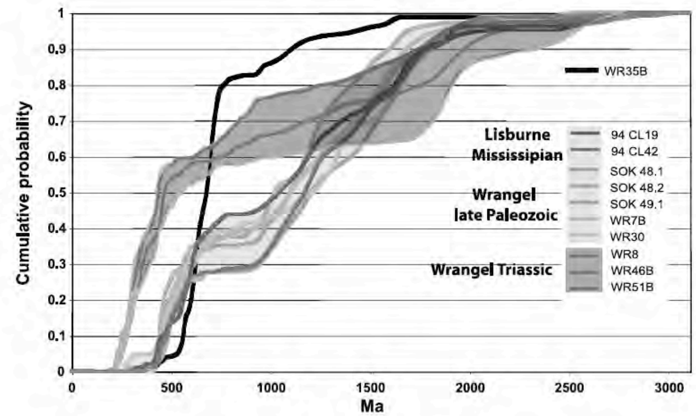


Figure 9. Cumulative probability diagram for all Wrangel Island samples and the Lisburne Hills Mississippian, emphasizing the change in upper Paleozoic sources versus Triassic sources for sediment. The light-gray-shaded region encompasses all cumulative probability curves for data from Paleozoic samples from both Wrangel and the Lisburne Hills; the dark-gray-shaded region encompasses the data from the three Triassic samples. The black line is sample ELM06 WR35B, which is inferred to have been derived from local basement exposures.

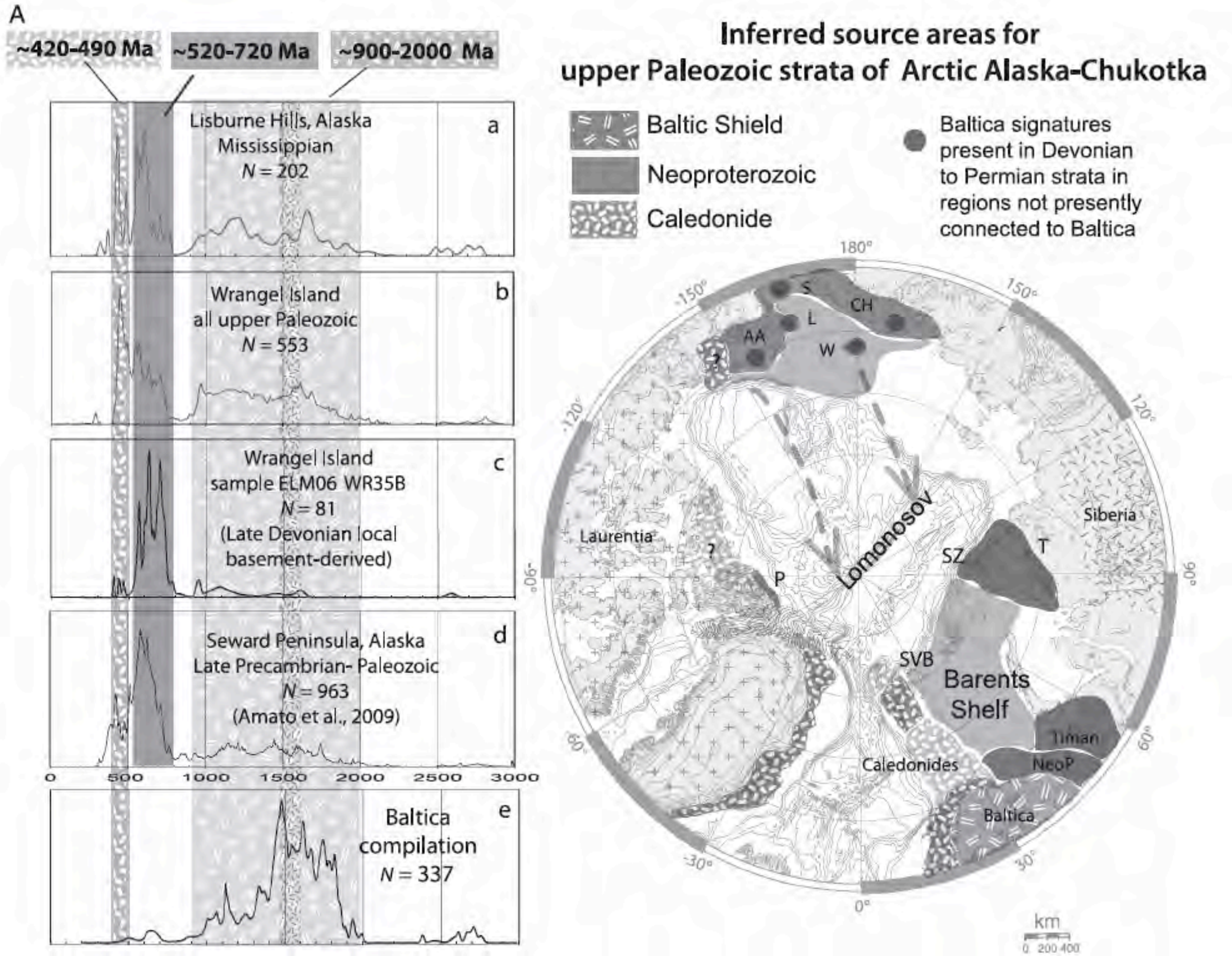


Figure 10. Simplified maps of the Arctic today, showing the location of samples discussed in this article and their relationship to possible sedimentary source regions in the circum-Arctic region, including the Baltica, Laurentian, and Siberian shields. Selected data discussed in this article are shown as relative age probability distributions (Ludwig, 2003) that are patterned to match source areas on the maps. (A) Salient aspects of the U-Pb geochronology of detrital zircon suites from Paleozoic strata now on the Pacific side of the Arctic Ocean with their preferred restoration (gray dashed lines) back to their source regions prior to the opening of the Amerasian and Eurasian basins. Note that Paleozoic strata of the Arctic Alaska-Chukotka microplate are deposited on Neoproterozoic basement and have potential sources in Baltica and the Neoproterozoic belts that rim Baltica. For more detail and sources of information, see previous figures and

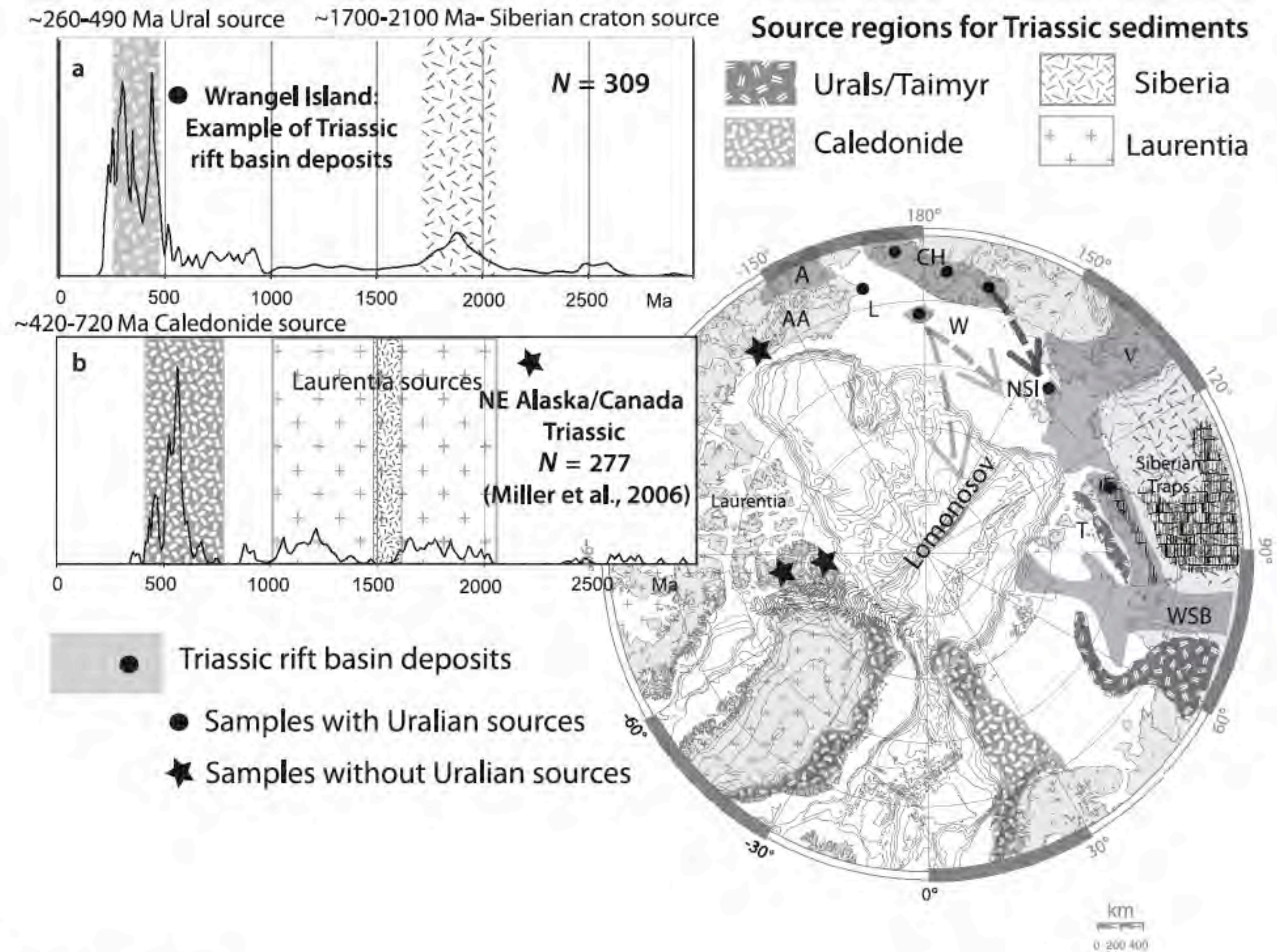


Figure 10. Continued.

Figure 11. Examples of proposed plate reconstructions of the Arctic region that are testable using the expanding detrital zircon database now available. These particular plate reconstructions are modified from Grantz et al. (2009), which are from Lawver et al. (2002). Their 435–450-Ma reconstruction in panel A assumes that Chukotka and Arctic Alaska belong to different plates prior to the Caledonian orogeny. The 290-Ma reconstruction after the Caledonian orogeny (B) shows the Caledonian suture passing through the Bering Strait and restores Wrangel Island to the Canadian Arctic Islands prior to the rotational opening of the Amerasia Basin. The Lomonosov Ridge acts as a transform boundary in this model. The black star with fan represents Jurassic magmatic sources for detrital zircons present in Late Jurassic–Early Cretaceous sediments of Chukotka and the New Siberian Islands (black stars), indicating that by 145.5 ± 4.0 Ma (Jurassic–Cretaceous boundary, Gradstein et al., 2004), the illustrated Anyui-Angayucham Sea (AS) no longer existed (Miller et al., 2008). W = Wrangel Island; AA = Arctic Alaska; AS = Angayucham-Anyui Sea; BS = Barents Sea; CAI = Canadian Arctic Islands; CH = Chukotka; NOAM = North America; OM = Omolon; SC = Scandinavian Caledonides; SV = Svaalbard. Closure of the Iapetus Ocean in the Silurian–Devonian (S1–D3) and closure of the Rheic Ocean in the Devonian–Carboniferous (D2–C1). For further discussion, see the text.

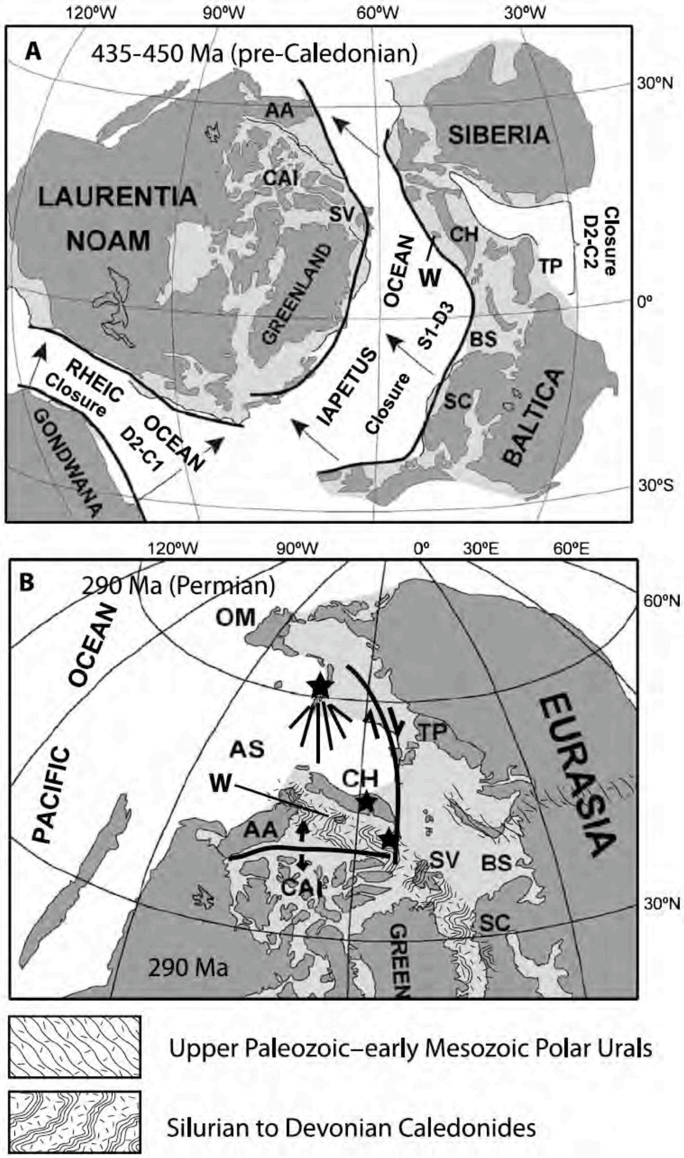
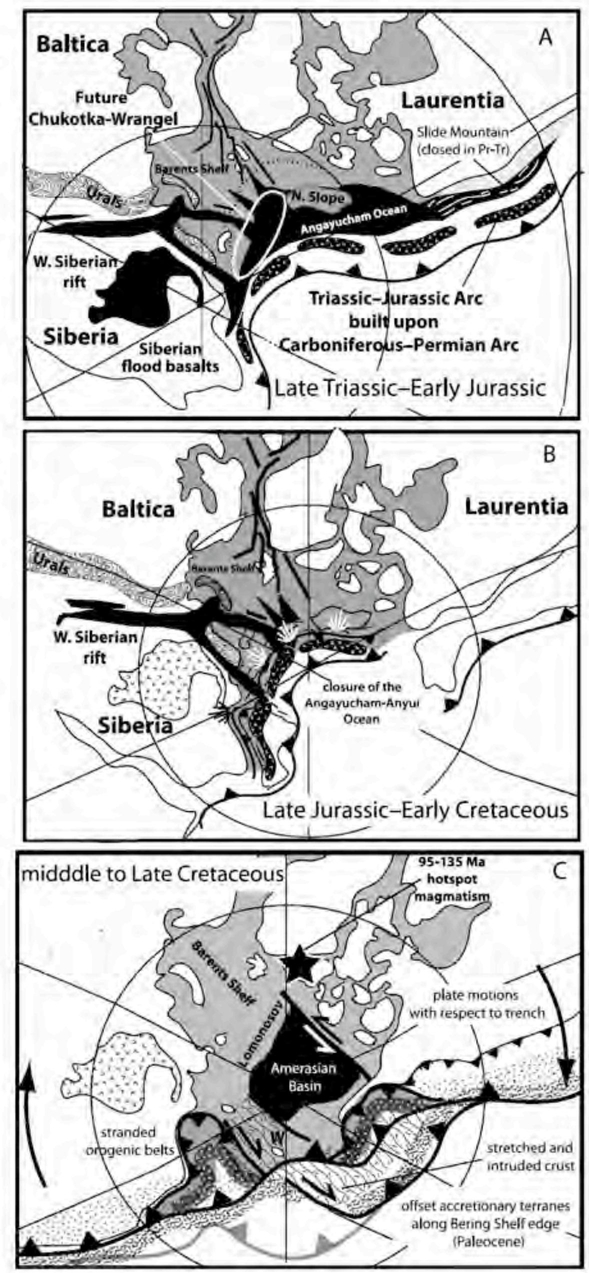
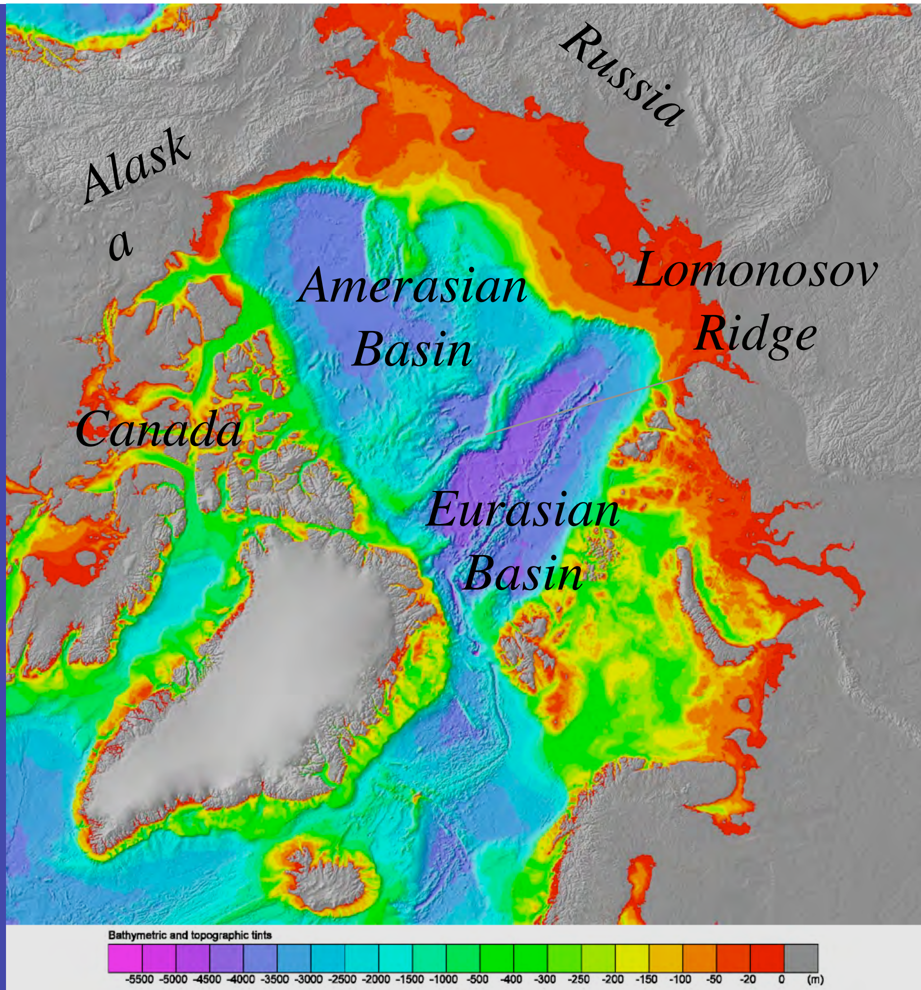
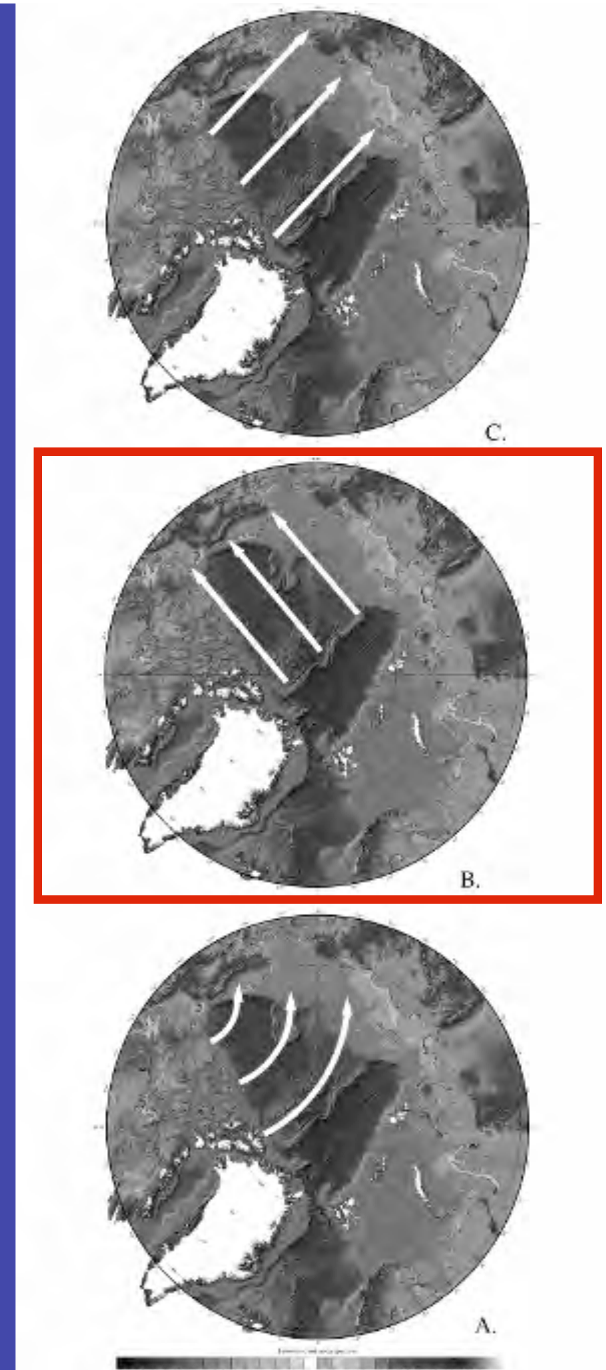


Figure 12. Cartoons depicting the deposition and subsequent translation of stratigraphic sections away from their source regions in the Arctic based on the results of U-Pb detrital zircon geochronology discussed in this article. Base maps are from C. Scotese's paleomap project (Scotese, 2003). Timing relations are discussed in more detail in Miller and Hudson (1991), Miller et al. (2002, 2008, 2009), and Miller and Verzhbitsky (2009). (A) Late Triassic–Early Jurassic: The location of Permian–Triassic rifts is shown in black together with the present trend of the Urals (from Ziegler, 1988; Nikishin et al., 2002). These rifts are shown connecting to the Angayucham and Anyui Ocean as per discussion of Triassic strata in this article. The inferred original position of future Chukotka and Wrangel is shown by a white ellipse. (B) Late Jurassic–Early Cretaceous: Deformation results in collision of a Jurassic arc built on an upper Paleozoic arc, possibly by back-arc basin closure. Jurassic to Lower Cretaceous sediments shed toward the foreland during this orogeny are shown schematically by small fan patterns and are described by Miller et al. (2008). (C) Late Cretaceous: Opening of the Amerasia Basin showing inferred progressive move-outs of the subduction zone toward the Pacific, with magmatism, rifting, and extension in their wake.







Other models proposed for the formation of the Amerasian Basin -none except the rotation model are viable for Alaska given the geologic and magnetic anomaly constraints

Rifting models for Amerasian Basin summarized by Lawver and Scotese (1990) with specific predictions for rift versus transform origin of margins and the geologic matches of margins. Base map IBCAO (2000)

Slide courtesy EL Miller, Stanford


Triassic Turbidites, Wrangel Is
NB
http://pangea.stanford.edu/research/groups/structure/gfx/TriassicWrangel.jpg