PS New Insights from Detrital Zircons into the Northern Provenance of Triassic-Jurassic Strata, Sverdrup Basin, Canadian Arctic Islands*

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Search and Discovery Article #10853 (2016)**
Posted August 15, 2016

Abstract

Rifting of landmasses to the north of the Sverdrup Basin in the Canadian Arctic during the Jurassic ultimately led to the onset of seafloor spreading and opening of the Arctic Ocean in the Cretaceous. While there is general consensus on the basic tenets of this geological evolution, details of the early rift history and the tectonic setting of the basin before the onset of rifting remain poorly understood, and as a consequence much debated. However the use of detrital zircons as provenance indicators may provide important insight into both these issues. New detrital zircon Uranium-Lead ages data from Lower Triassic to Lower Jurassic strata in this study combined with previously published U-Pb detrital zircon data from the Sverdrup Basin are sub-dividable into two distinct provenance signatures. The first consists of abundant Mesoproterozoic zircons sourced mostly from the Devonian Clastic Wedge located to the south. The second signature is sourced from the north and comprises a significant component of near syn-depositional Permo-Triassic ages with minor Mesoproterozoic relative age probability. Triassic strata of Arctic Alaska share this same dual provenance signature, whereas those in northeastern Russia (Chukotka) only exhibit the northern signature. The northern source to the Sverdrup Basin found in both Arctic Alaska and Chukotka has a broad spectrum of Permo-Triassic ages suggestive of continuous magmatism. Previous studies have suggested that the source of these ages could be the Siberian Traps and Urals; however, the former would produce too narrow a range of ages, and granitoids from the northernmost Urals are generally not younger than the Early Permian. Research here suggests a wholly different mechanism for the formation and location for Permo-Triassic zircons. It is suggested that zircons were sourced from an active margin north of the Sverdrup Basin, which previously was assumed to be passive. In rocks that are Early Jurassic and younger, the abundance of Permo-Triassic zircons decreases upward, implying the progressive diminution of the northern sediment source. The absence of these zircons in Lower Jurassic strata indicates the elimination of the northern sediment source, which quite possibly represents the onset of the rift unconformity – a surface previously reported to be Middle Jurassic, but in fact may be Early Jurassic.

^{*}Adapted from poster presentation given at AAPG Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

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Abstract

The tectonic setting of northern Laurentia prior to the opening of the Arctic Ocean has long been complicated and contentious to resolve. By better understanding the provenance of detrital zircons in the Canadian Arctic prior to rifting, both the timing of rifting and the tectonic setting can be elucidated. Rifting of land masses north of the Sverdrup Basin, located in Arctic Canada, occurred in the Jurassic which ultimately lead to the onset of seafloor spreading in the Cretaceous. Neither the early rift history that led to opening of the Arctic Ocean, nor the tectonic setting of the basin before the onset of rifting is well defined in the literature.

New detrital zircon Uranium-Lead ages data from Lower Triassic to Lower Jurassic strata in the Canadian Arctic Islands combined with previously published U-Pb detrital zircon data from the Sverdrup Basin have identified two distinct provenance signatures. The predominant source of clastic sediment is the southerly-derived Devonian Clastic Wedge with abundant Mesoproterozoic zircons. The northern source, in contrast, has a significant component of near syn-depositional Permo-Triassic ages and minor Mesoproterozoic relative age probability. Triassic strata of northern Alaska share this similar dual provenance signature, whereas northeastern Russia has only the northern signature. This common source to the region has an abundance of near syn-depositional aged zircons through the entire Permian-Triassic with a broad spectrum of ages indicative of continuous magmatism. Previous studies have suggested that the source of these ages could be the Siberian Traps and Urals; however, the former would produce too narrow a range of ages, and zircons from the northernmost Urals do not occur after the Early Permian.

This research, therefore, suggests a wholly different mechanism for the formation and location for Permo-Triassic zircons. It is suggested that the zircons are sourced from an active margin north of the Sverdrup Basin, previously assumed to be passive. In rocks Early Jurassic and younger, the abundance of Permo-Triassic zircons decreases substantially, implying the diminution of the northern sediment source. The absence of these zircons in Lower Jurassic strata suggest the elimination of the northern sediment source by rifting, and that the rift onset unconformity, previously reported to be in the Middle Jurassic, is in fact in the Early Jurassic.

Study Area: Sverdrup Basin

- The Sverdrup Basin is located in the Canadian Arctic Archipelago and records near continuous sedimentation from the Carboniferous to the Paleogene
- The basin is underlain by an up to 10 km-thick sedimentary pile of Devonian clastic wedge strata that were deformed during the Late Devonian-Early Carboniferous Ellesmerian orogeny. Strata equivalent to the Devonian clastic wedge are widely distributed, including the northern Cordillera of North America, Arctic Alaska and northern Russia
- The Ellesmerian orogeny was succeeded by initial rifting of the Sverdrup Basin that began in the Early Carboniferous and ended in the Permian. Current models suggest that following the Permian, the Sverdrup Basin was tectonically quiescent and underwent thermal subsidence until rifting recommenced in the Jurassic



Fig. 1: Circum-Arctic orogens, terranes, and locations modified from Colpron and Nelson (2011) and Pease et al. (2014). AA, Arctic Alaska; AACM, Arctic Alaska-Chukotka Microplate; CH, Chukotka; NSI, New Siberian Islands; NZ, Novaya Zemlya; PE, Pearya; SAS, South Anyui Suture Zone; SV, Svalbard; WI, Wrangel Island; YTT, Yukon Tanana Terrane. Black circles represent approximate detrital zircon sample locations from AA (Miller et al., 2006; Gottlieb et al., 2014); CH (Miller et al., 2006; Tuchkova et al., 2011; Amato et al., 2015); WI (Miller et al., 2010); and YTT (Beranek et al., 2010b; Beranek and Mortensen, 2011). The outlines of the SAS and AACM are from Drachev (2011). Red circles represent approximate location of εNd or εHf values from AA (Amato et al., 2009); Arctic Canada (Anfinson et al., 2012b; Morris, 2013); New Siberian Islands (Akinin et al., 2015), and Siberia (Malitch et al., 2010).

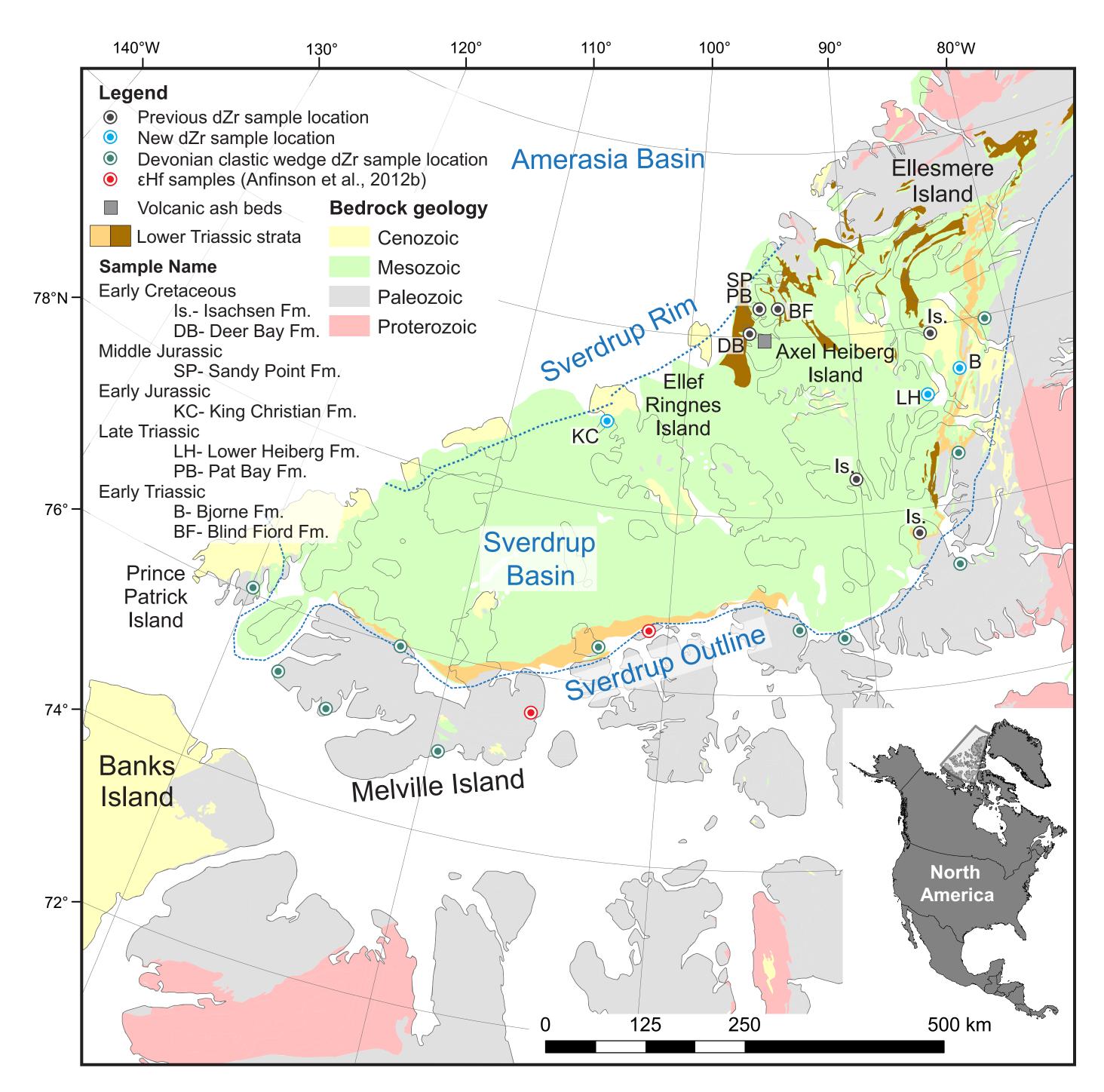


Fig. 2: Sverdrup Basin map with detrital zircon sample and volcanic ash bed locations. Detrital zircon data references from Isachsen Formation (Røhr et al., 2010); Sandy Point and Deer Bay formations (Omma et al., 2011); Pat Bay Formation (Miller et al., 2006; Omma et al., 2011 – both from approximately the same location); Bjorne Formation (Miller et al., 2006 – location approximately the same as this study); Blind Fiord Formation (Omma et al., 2011). U-Pb data from Devonian clastic wedge (Anfinson et al., 2012a); εHf data from Devonian Clastic Wedge (Anfinson et al., 2012b). Lower Triassic strata: Blind Fiord Formation (brown); Bjorne Formation (orange). General southern outline of the Sverdrup Basin from Embry and Beauchamp (2008). Surface and sea bottom bedrock geology is from Okulitch (1991). The Sverdrup Rim was first described by Meneley et al. (1975).



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Stratigraphy

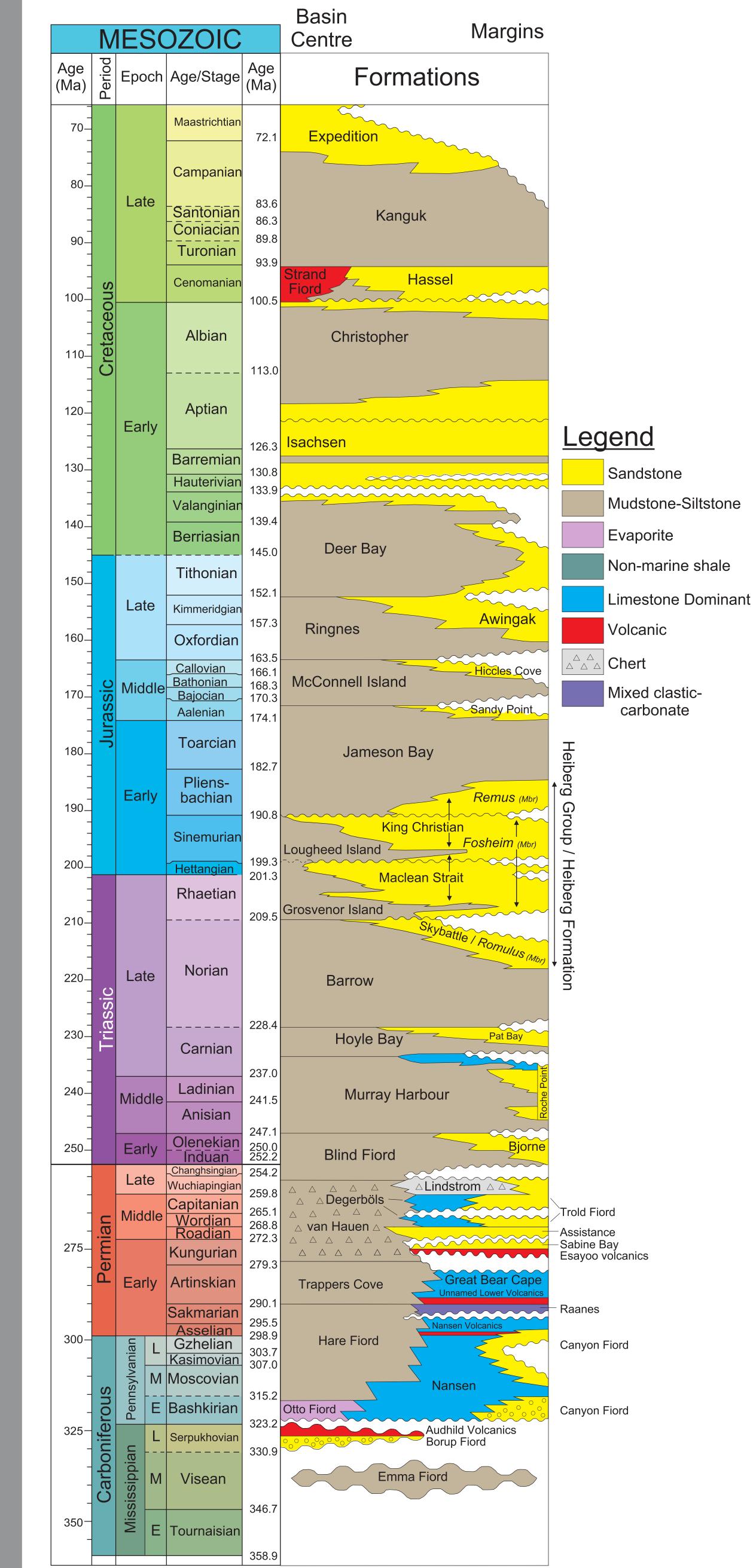
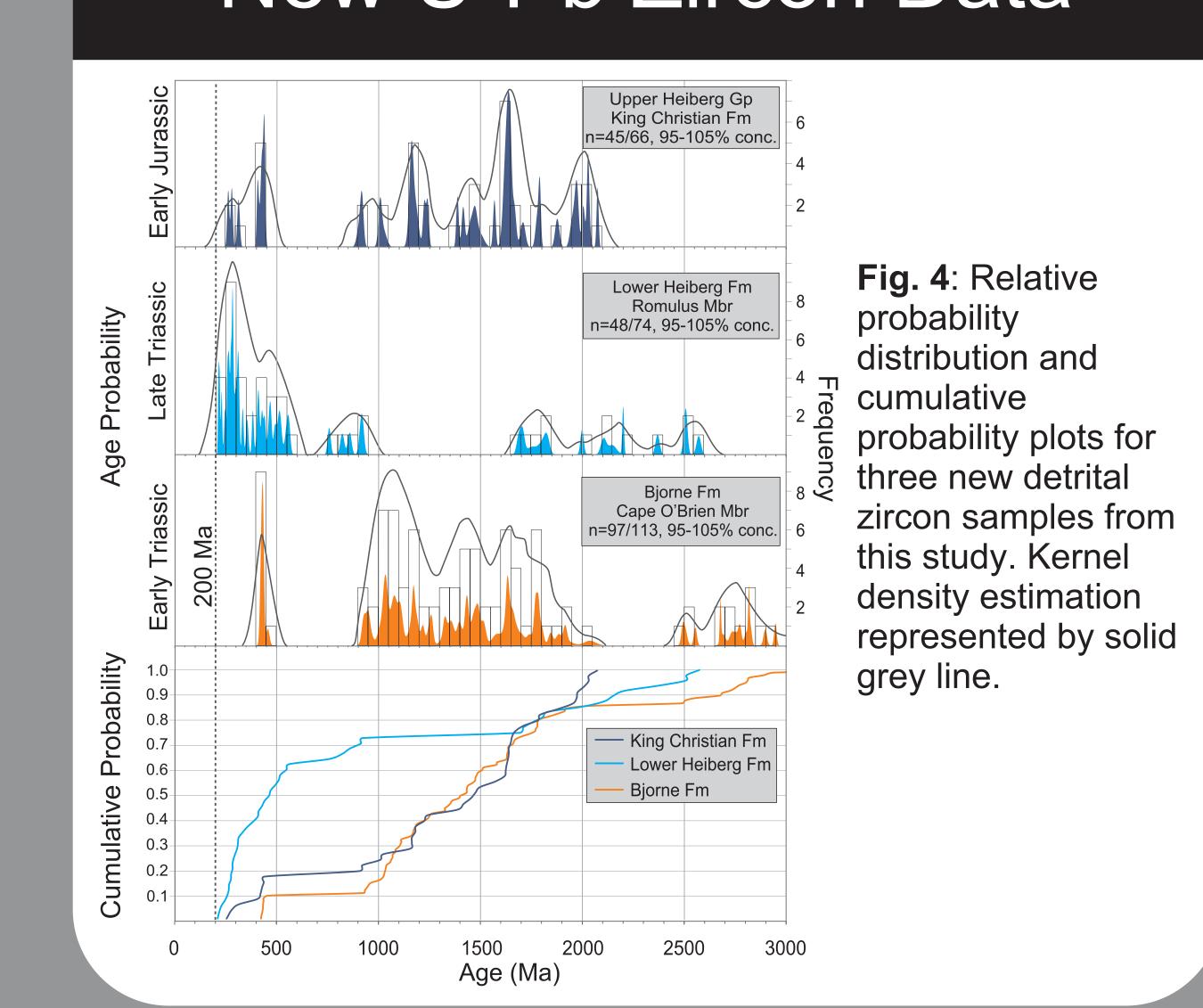
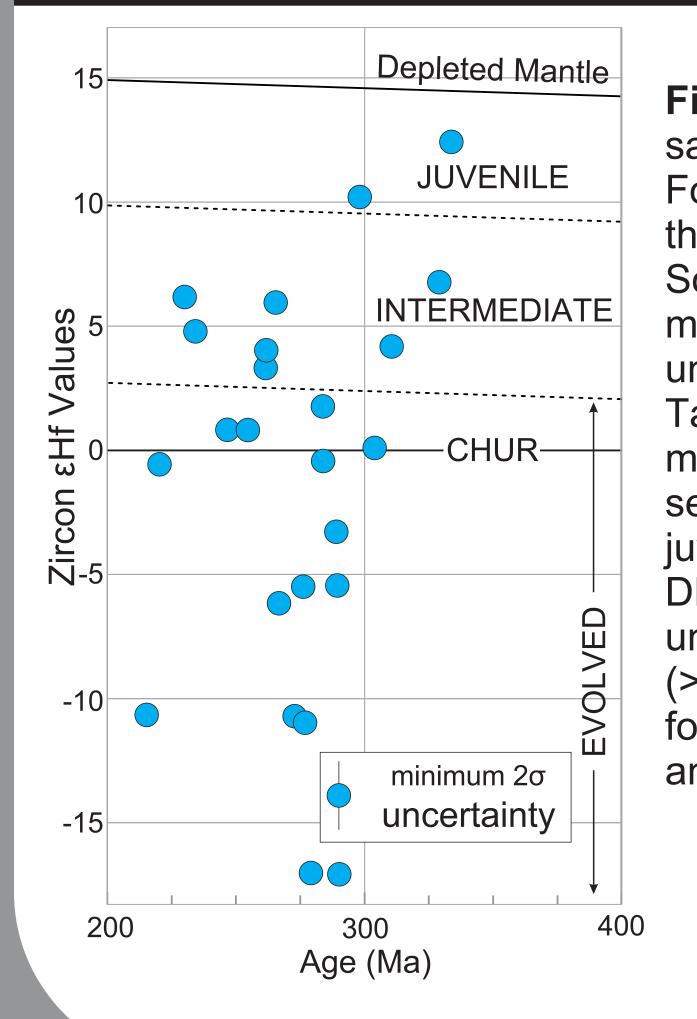


Fig. 3. Stratigraphic chart of the Sverdrup Basin modified from Embry and Beauchamp (2008); Paleozoic volcanics: Audhild (Trettin, 1988); Nansen (Mayr et al., 2002); ULV and Esayoo (Morris, 2013).

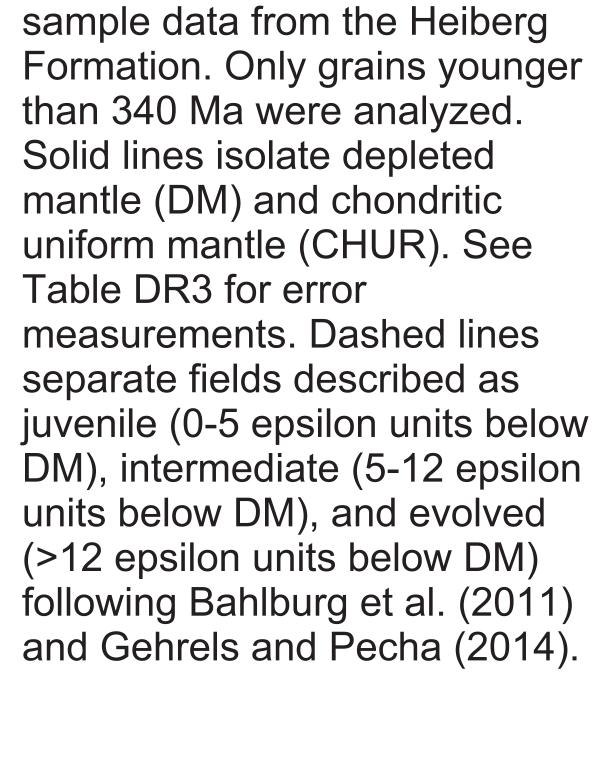
New U-Pb Zircon Data



New Hf Isotope Data



ntle **Fig. 5**: Plot shows εHf values for



Volcanic Ash Beds

- •The study location along northern Axel Heiberg Island (Fig. 6E) represents a geographically proximal location within the Sverdrup Basin to the proposed northern sediment source
- •Ochreous horizons, typically less than 10 cm thick and laterally continuous, were commonly observed in marine mudstones of the Blind Fiord, Murray Harbour, Hoyle Bay, and Barrow formations
- •X-ray powder diffraction identified *halloysite*, derived from the dissolution of volcanic glass or weathered volcanic ash, and *hydrotalcite*, formed from volcanic glass, and has been produced experimentally by a reaction between basaltic glass and seawater
- •Collectively, the presence of volcanically-derived minerals and macroscopic textural characteristics confirm that the ochreous layers are volcanic ash beds

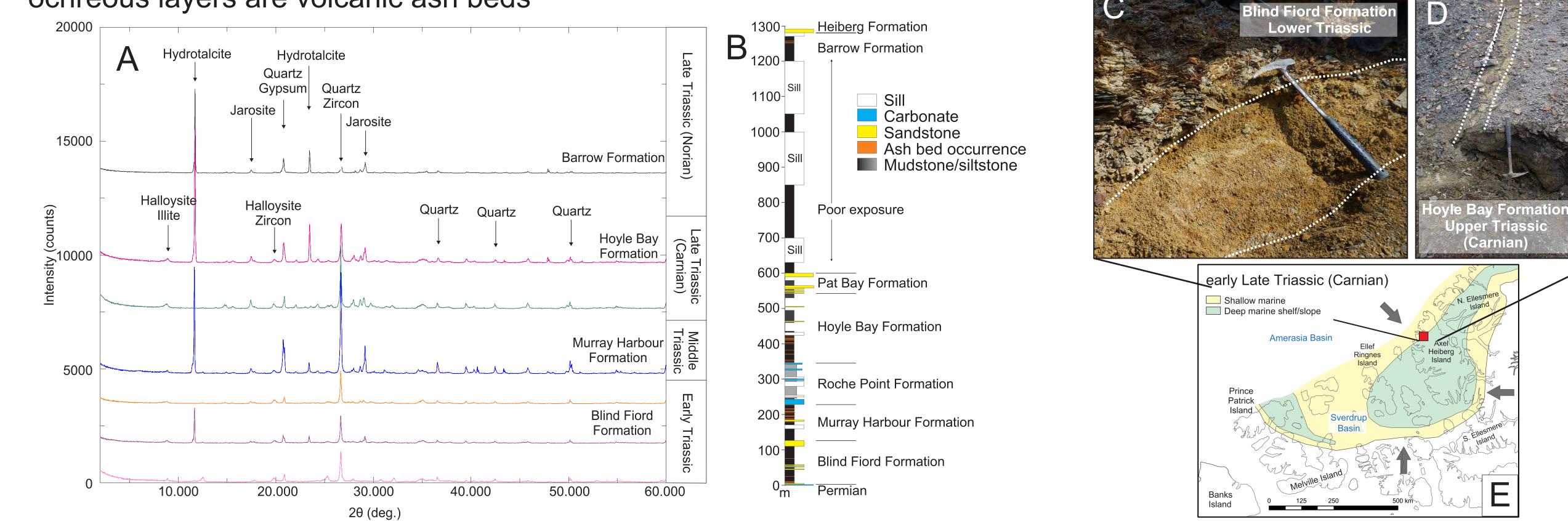
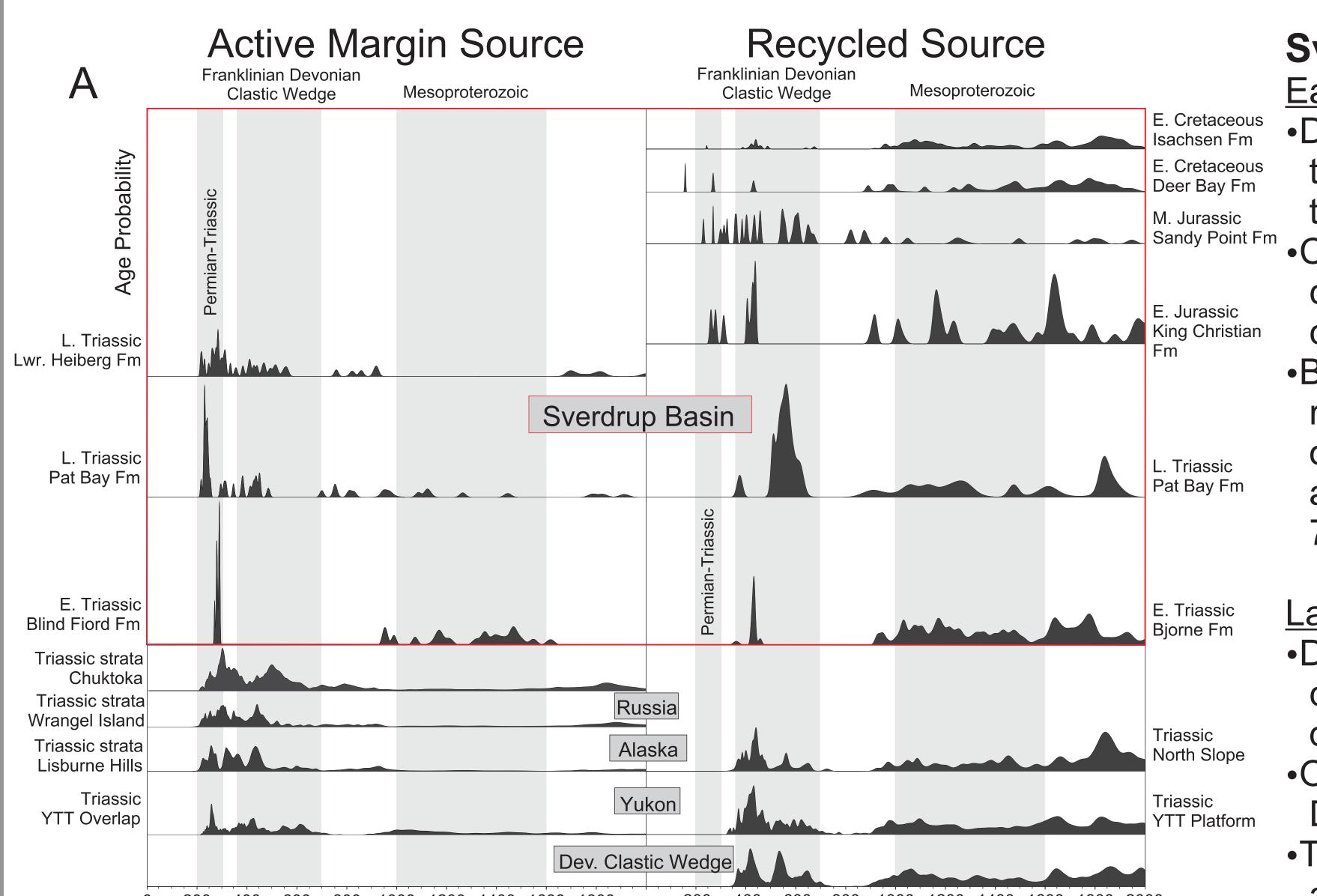


Fig. 6: (A) X-ray diffraction traces from volcanic ash beds; (B) Stratigraphic log from Bunde Fiord, Axel Heiberg Island highlighting stratigraphic location of volcanic ash beds. Ash beds not to scale. Location of Bunde Fiord highlighted by red square in (E); (C and D) Photographs of volcanic ash beds; (E) General facies distribution during the Late Triassic (modified from figure 36.20 in Embry, 2011). Arrows represent general sediment transport direction, based on Embry (1991, 2009).

Detrital Zircon data from the Circum-Arctic



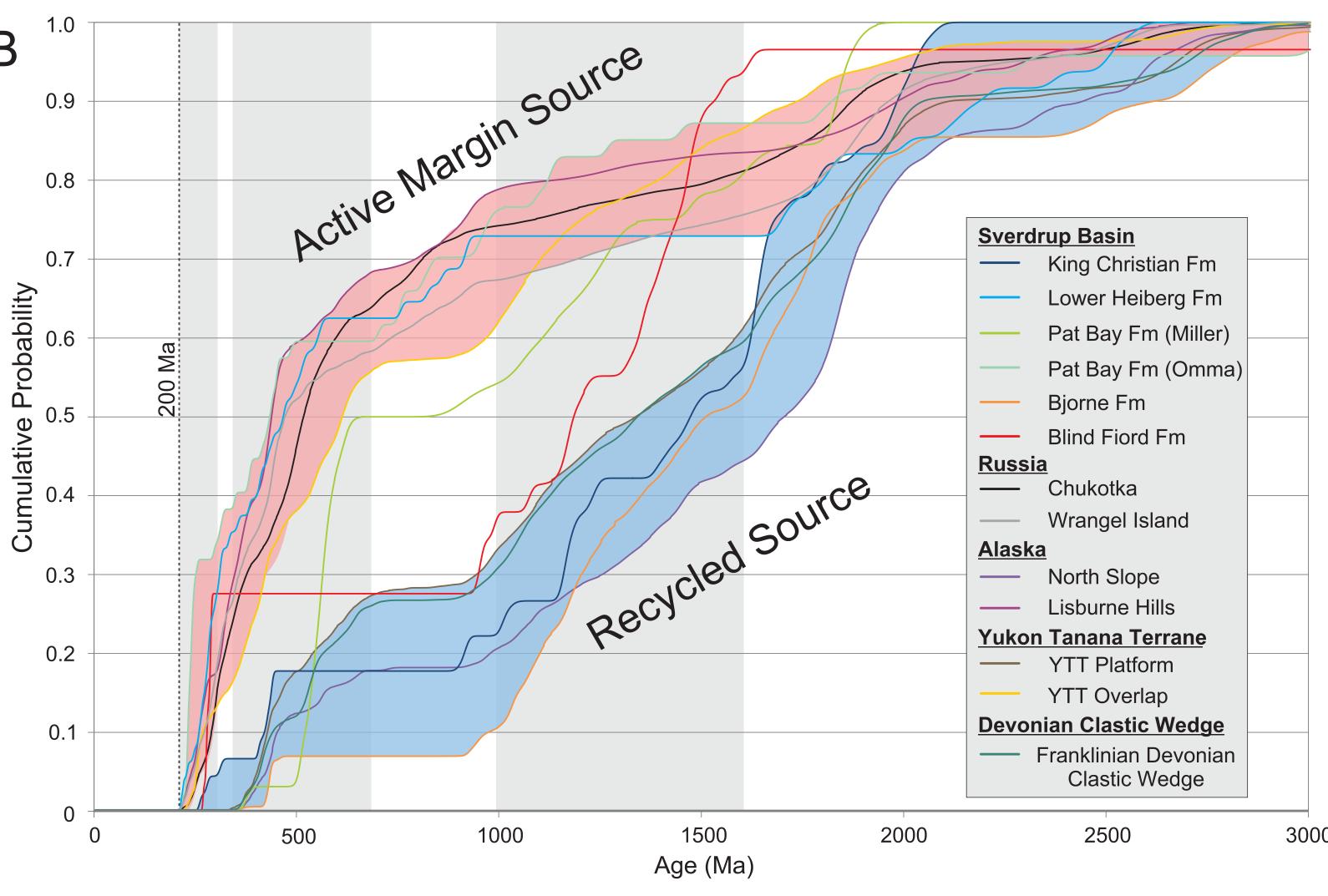


Fig. 7: Compiled results from this study as (A) relative probability distributions and (B) cumulative probability plots. Illustration of the detrital age spectra grouped by signatures of the Recycled Source and the Active Margin Source. Data from the Isachsen Fm (Røhr et al., 2010), from studies in the Canadian Arctic (Miller et al., 2006; Omma et al., 2011; Anfinson et al., 2012a), from Russia (Miller et al., 2006, 2010; Tuchkova et al., 2011; Amato et al., 2015), from Alaska (Miller et al., 2006; Gottlieb et al., 2014), from Yukon (Beranek et al., 2010b; Beranek and Mortensen, 2011), and

Sverdrup Basin:

Early Triassic detrital zircon provenance

- Detrital zircon signature from the Bjorne Fm is remarkably similar to samples from the Devonian clastic wedge. Triassic strata from the North Slope (Alaska) and coeval strata from the NW Cordillera
 Collectively the geographically dispersed areas suggest a
- common, areally expansive source, most likely was the Devonian clastic wedge and equivalents
- •Blind Fiord Fm has a wholly different signature interpreted to represent the northern source to the basin. Notable is the occurrence of a suite of Permian ages (ca. 290-265 Ma) and the absence of U-Pb ages that typify the Devonian clastic wedge (ca. 700-360 Ma)

Late Triassic detrital zircon provenance

- Detrital zircon U-Pb age data of the Pat Bay Formation varies considerably between samples indicative of two different sources during deposition
- One sample has an assemblage of ages that overlap within the Devonian clastic wedge spectrum
- •The other sample has a prominent range of near syn-depositional ages (ca. 255-217 Ma)
- •The Lwr Heiberg Fm has a near syn-depositional age-fraction with a continuous spectrum of ca. 300-215 Ma ages, indicative of derivation from the active margin source region.

Arctic Alaska-Chukotka Microplate:

Alaska

- •Samples from the Upr Triassic strata (Lisburne Hills) have an agefraction of ca. 275-220 Ma, in addition to Paleozoic ages, and minor Mesoproterozoic ages
- Conversely, Triassic strata of the North Slope has a detrital zircon signature remarkably similar to the Devonian clastic wedge with a strong age-fraction of ca. 700-360 Ma and a broad spectrum of Proterozoic ages

Chukotka/Wrangel Island

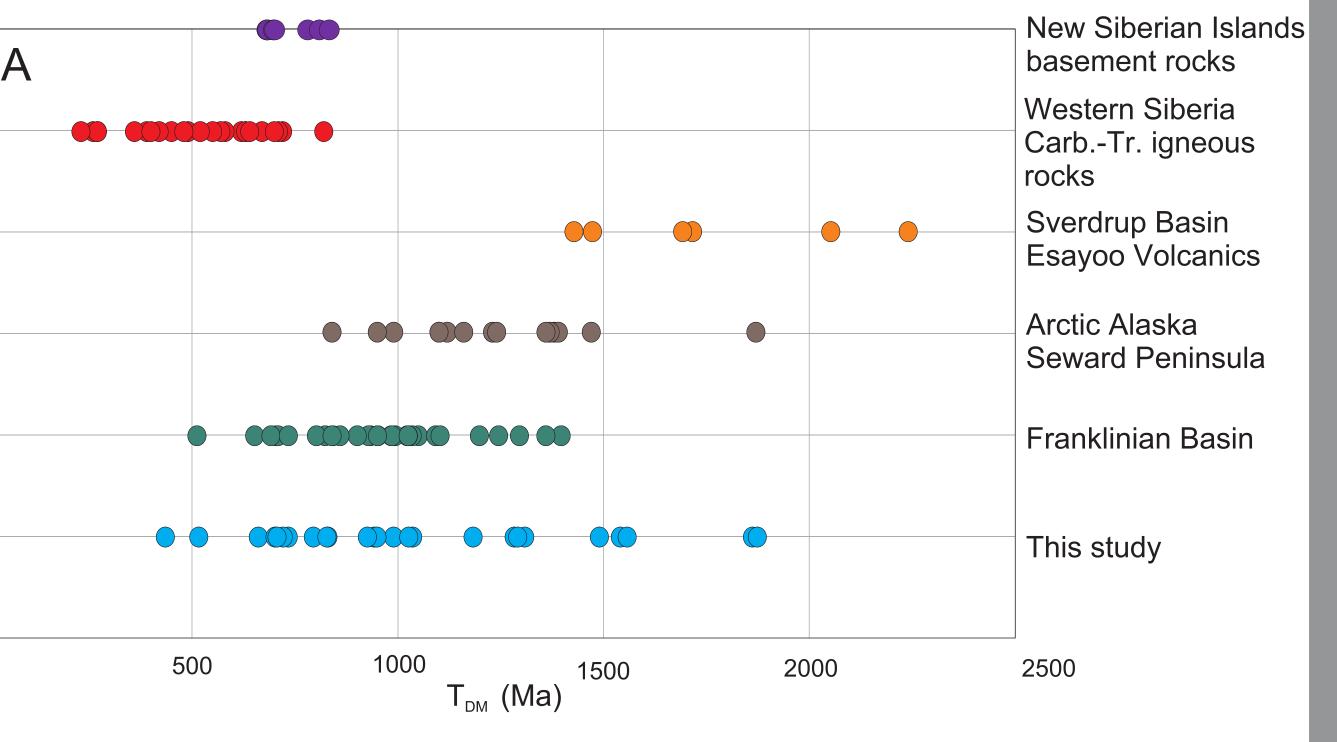
•Triassic samples from Wrangel Island and Chukotka document a general assemblage of near syn-depositional zircon ages and a minor representation of Mesoproterozoic ages

Yukon Tanana Terrane:

- A similar pattern of dual detrital zircon spectra is observed along the northwestern margin of Laurentia in the Yukon
- Sediment recycled from western interior basins of Laurentia has a detrital zircon signature consistent with derivation from a Devonian clastic wedge-type source
- •The detrital zircon signatures from Triassic strata sourced from the convergent, western margin of the YTT exhibit a suite of near syn-depositional Permian-Triassic zircon ages

Hafnium Isotope Comparison

- •Hafnium data are presented on Hf-evolution diagrams that show εHf values at the time of crystallization
- •Hf depleted model ages (Трм) provide a qualitative estimate of the time of separation of the source rocks, or their precursors, from a hypothetical depleted mantle reservoir.



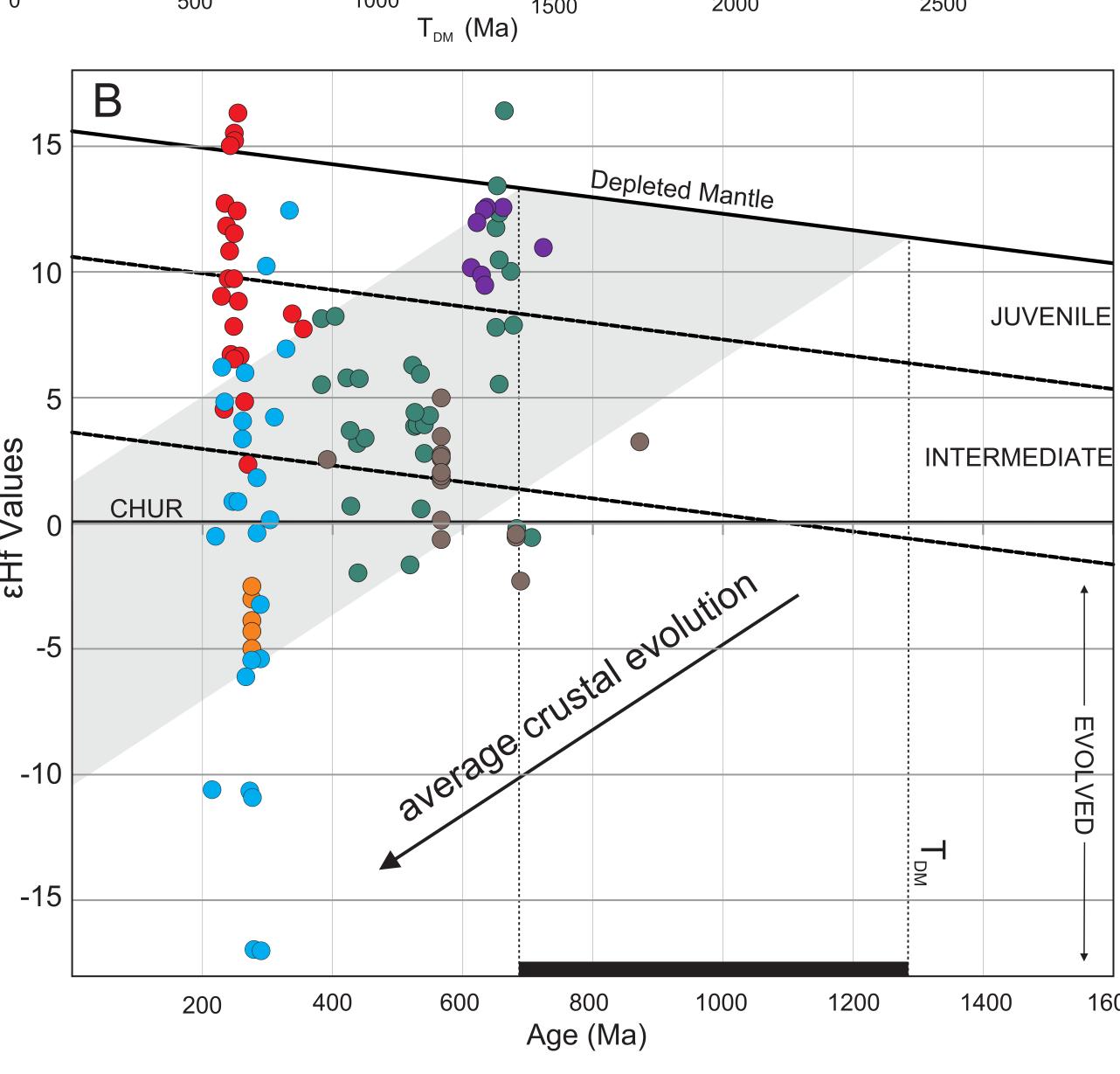
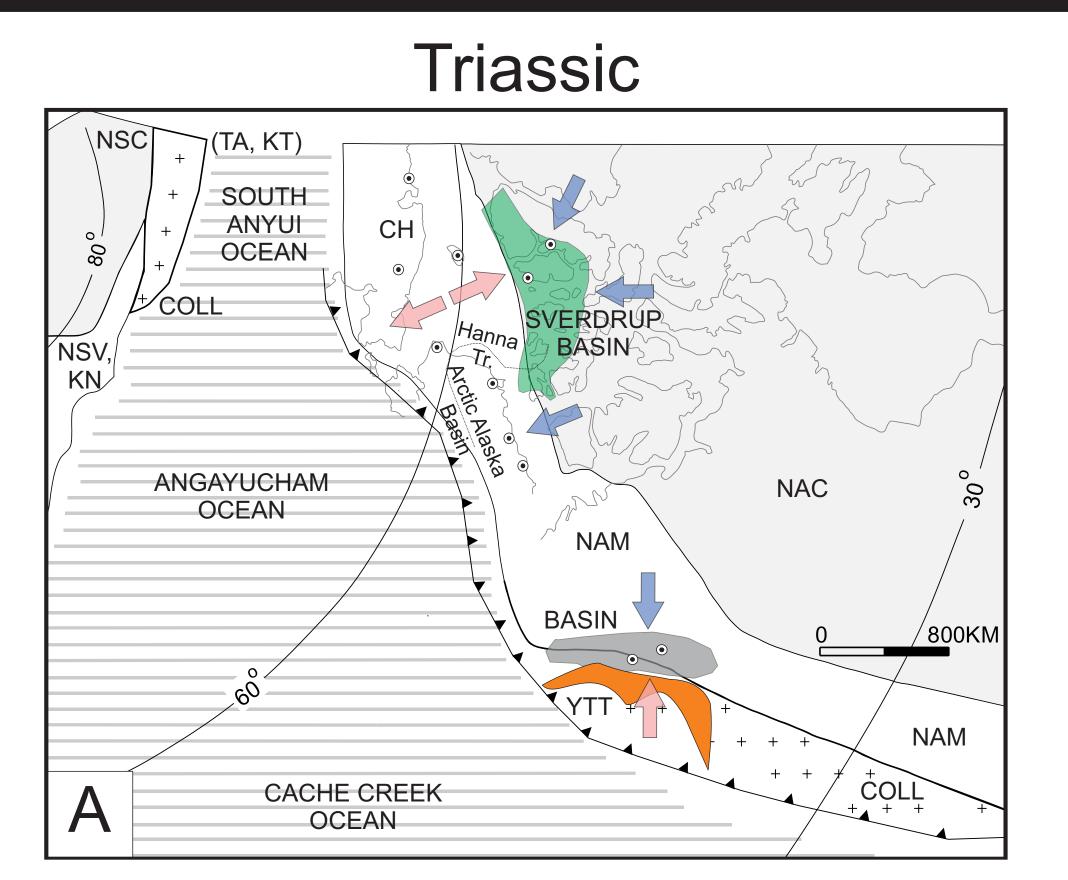
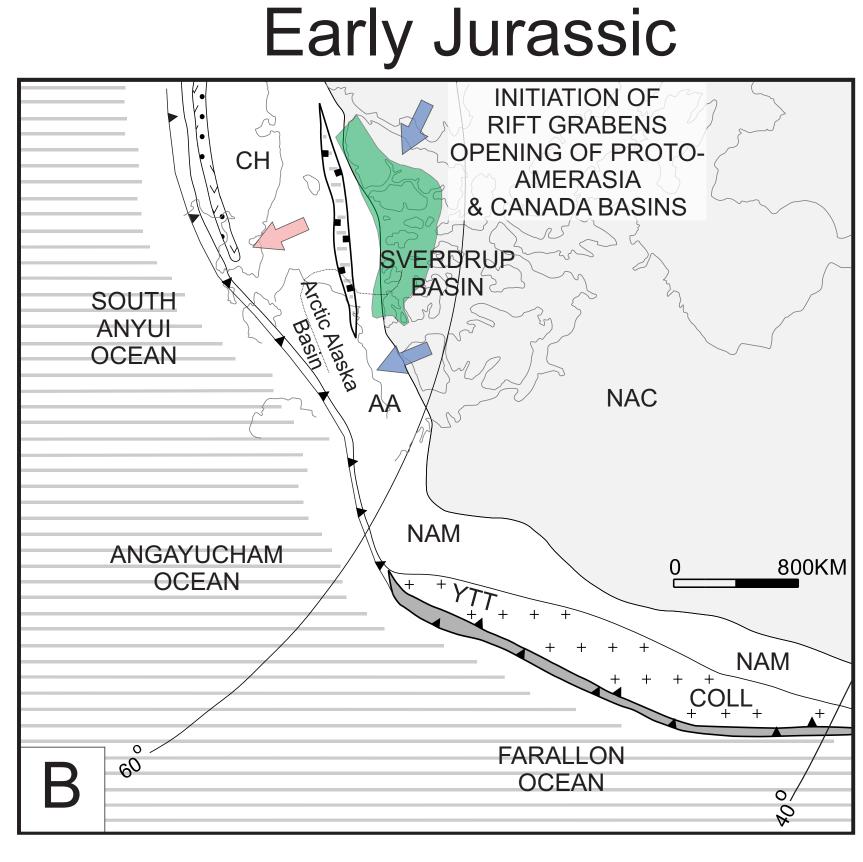


Fig. 8: (A) εHf values for sample data and relevant Hf isotope data comparisons. Data sets are as follows; detrital zircon from Neoproterozoic to Upper Devonian strata of the Franklinian Basin (Anfinson et al., 2012b); Carboniferous to Triassic zircon from igneous rocks of the northwestern Siberian Craton (Malitch et al., 2010); New Siberian Islands basement rocks (Akinin et al., 2015); Neoproterozoic to Devonian igneous rocks of Seward Peninsula, Arctic Alaska, converted from εNd values (Amato et al., 2009); Lower Permian Esayoo Volcanics from eastern Sverdrup Basin ca. 276 Ma, converted from εNd values (Morris, 2013). Grey box and black arrow represent interpreted average crustal evolution trajectories assuming present-day 176Lu/177Hf = 0.0093 (Vervoort and Patchett, 1996; Bahlburg et al., 2011; Gehrels and Pecha, 2014); (B) TDM calculated from either εNd or εHf.

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Revised Triassic-Jurassic Tectonic Model for Northern Laurentia





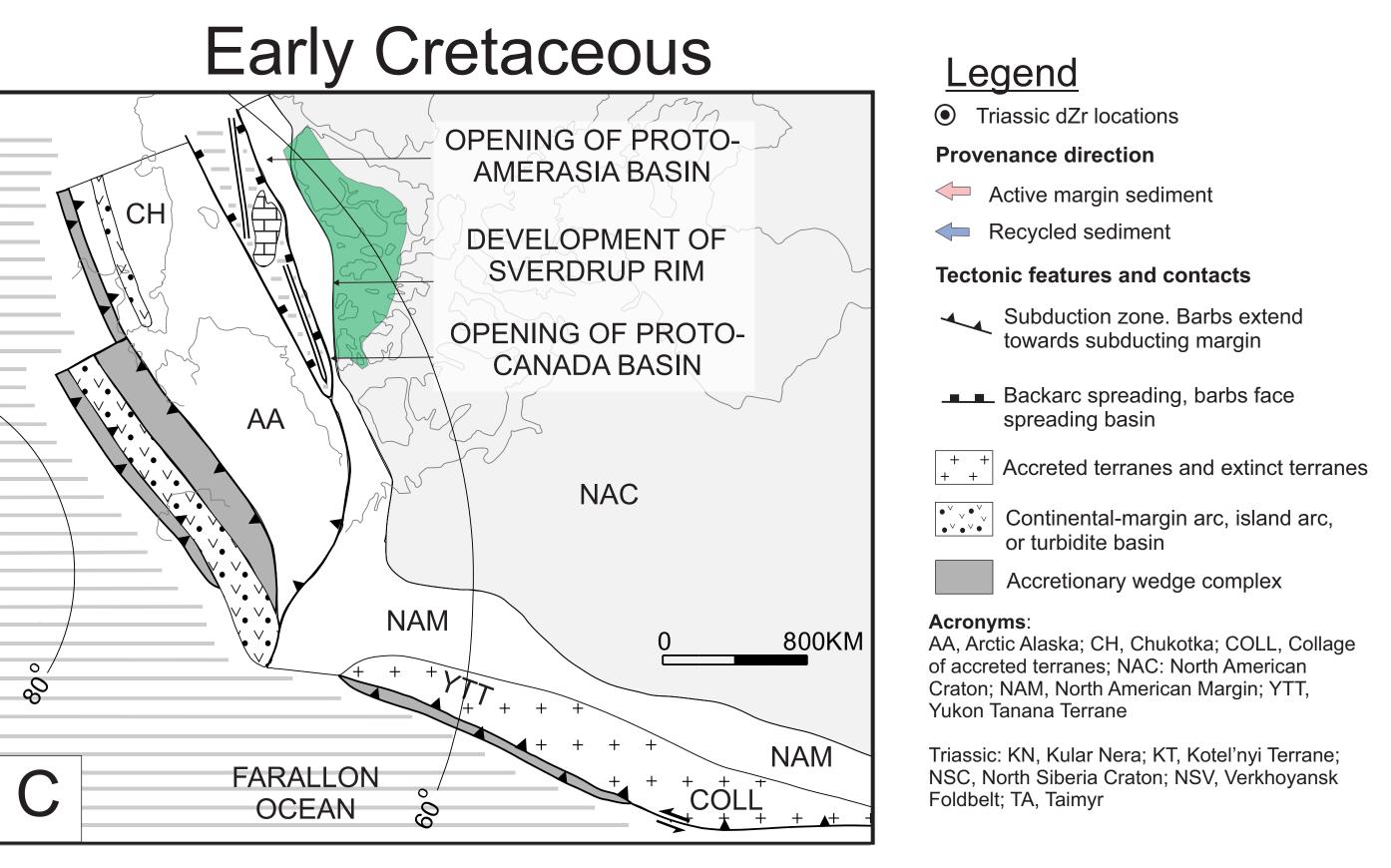


Fig. 9: Evolution of the northern margin of Laurentia adapted from paleographical maps of Plafker and Berg (1994) and Nokleberg et al. (2000). Outline of YTT (orange polygon) is from Nelson et al. (2006). Axis of Hanna Trough and Arctic Alaska Basin from Gottlieb et al. (2014). Proposed tectonic model: (A) In the Triassic, the Sverdrup basin occupied a retro-arc position to Chukotka along strike with the Triassic basin adjacent to the Yukon Tanana terrane arc; (B) Early Jurassic extension to form the AACM; (C) and in the Early Cretaceous during the post-rift stage of Sverdrup Basin, the Amerasia and Canada basins opened as the South Anyui Ocean closed.

- The abundance of Permian-Triassic zircons and discovery of volcanic ash beds in the Sverdrup Basin suggests the region to the north was tectonically active during the Triassic
- The remarkably similar dual detrital zircon provenance patterns from the Sverdrup Basin, YTT, and AACM allows us to redefine the outboard margin of the AACM as convergent thereby providing a model for subsequent Jurassic rifting driving the closure of the South Anyui ocean
- The lack of near syn-deposition detrital zircon ages in the Lwr Jurassic King Christian Fm supports that initial crustal extension dismembered the northern sediment source from the Sverdrup Basin by the Early Jurassic
- The limited record of magmatism lack (i.e. an absence of near syn-depositional zircons) in Jurassic-Cretaceous strata marks the syn-rift phase (ca. 190-130 Ma) of the Sverdrup Basin
- Jurassic to Early Cretaceous rifting of the proto-Amerasia basin developed as a retro-arc system far inboard from the convergent boundary, driven by subducting slab rollback, causing the separation of AACM from northern Laurentia
- Detrital zircon ages from the Lower Cretaceous Isachsen Fm exhibit only a single grain (ca. 244 Ma) younger than 400 Ma, with deposition occurring after the breakup unconformity ca. 130 Ma.
- The breakup unconformity marks the commencing of seafloor spreading in the Amerasia Basin which begins the post-rift phase with magmatism persisting for more than 30 M.y.

Acknowledgements

This work was supported by the Geological Survey of Canada and the University of Ottawa. Fieldwork was assisted by the Polar Continental Shelf Program. Dr. Carol Evenchick provided a sample of the King Christian Formation, and the authors are grateful to Dr. Ashton Embry for guidance in the field in 2011. Tara Kell gratefully provided assistance with the XRD analysis. Ray Chung, Ron Christie and Tom Pestaj are thanked for technical assistance preparing mineral separates and maintaining the SHRIMP ion probe at the Geochronology Laboratory in Ottawa. We thank Victoria Pease, two anonymous reviewers and associate editor Damian Nance for their thoughtful comments that helped improve the manuscript. Lastly, the first author would like to thank Katrina Angus and Anika Bergen for their personal support and guidance during the development of this research. This is a Circum-Arctic Lithosphere Evolution (CALE) contribution.

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