U.S. DEPARTMENT OF THE INTERIOR
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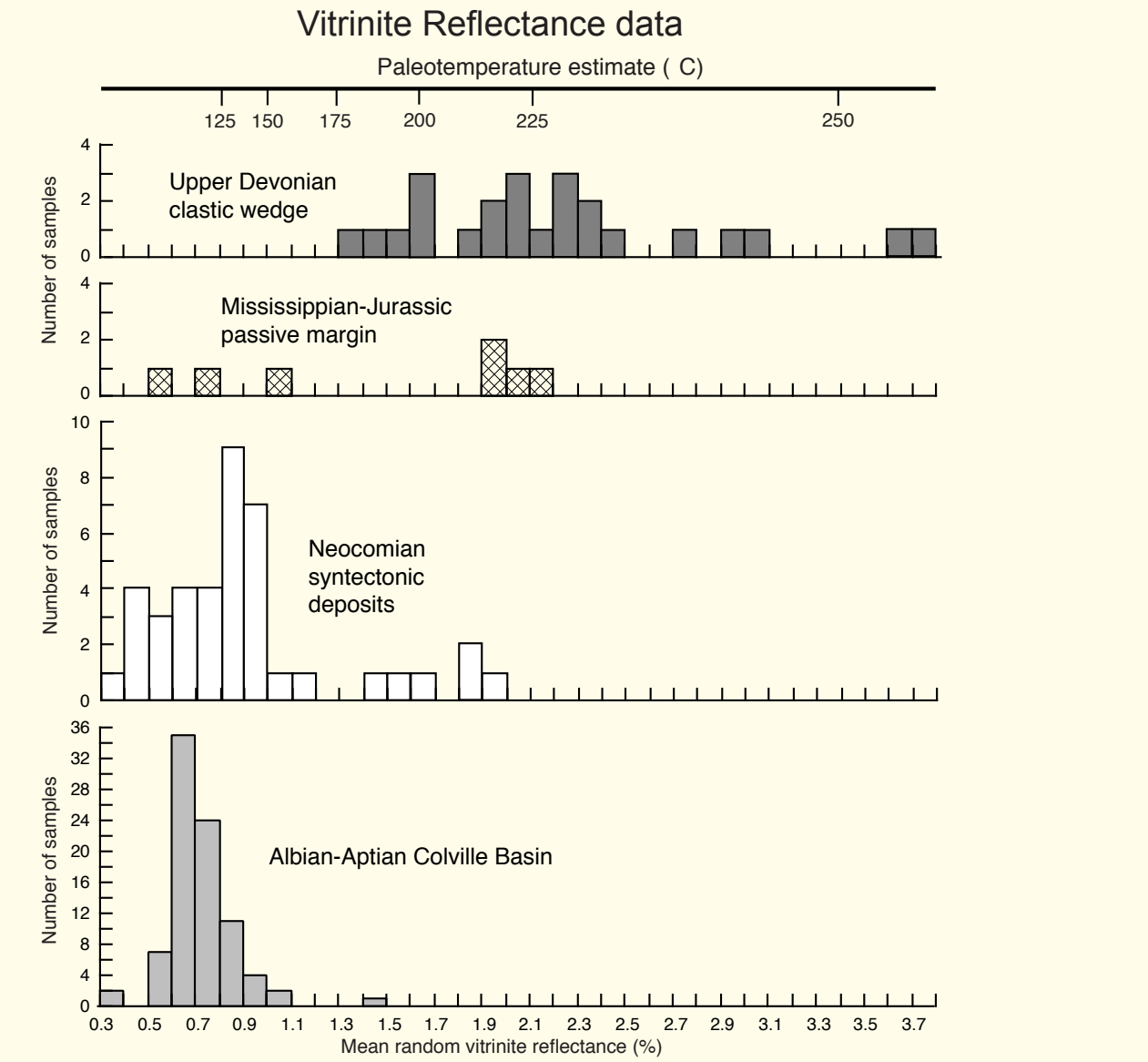
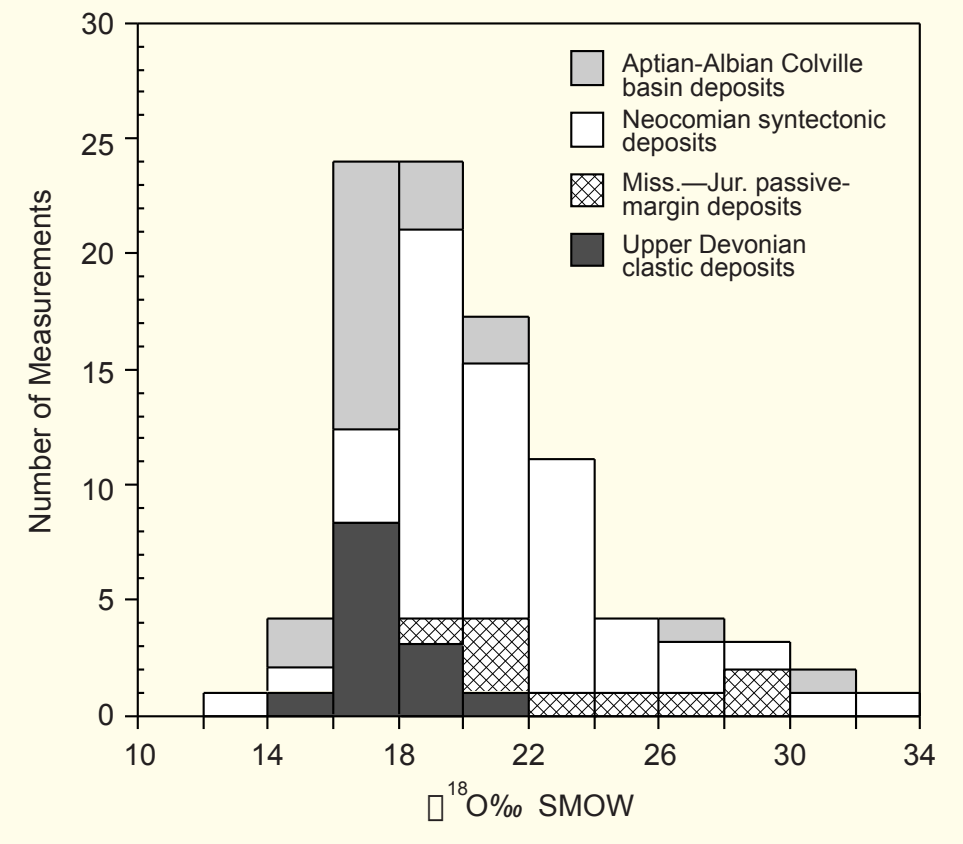
Sheet 2 of 2, Version 1.0

ASSOCIATION OF DEFORMATION AND FLUID EVENTS IN THE CENTRAL BROOKS RANGE FOLD-AND-THRUST BELT, NORTHERN ALASKA

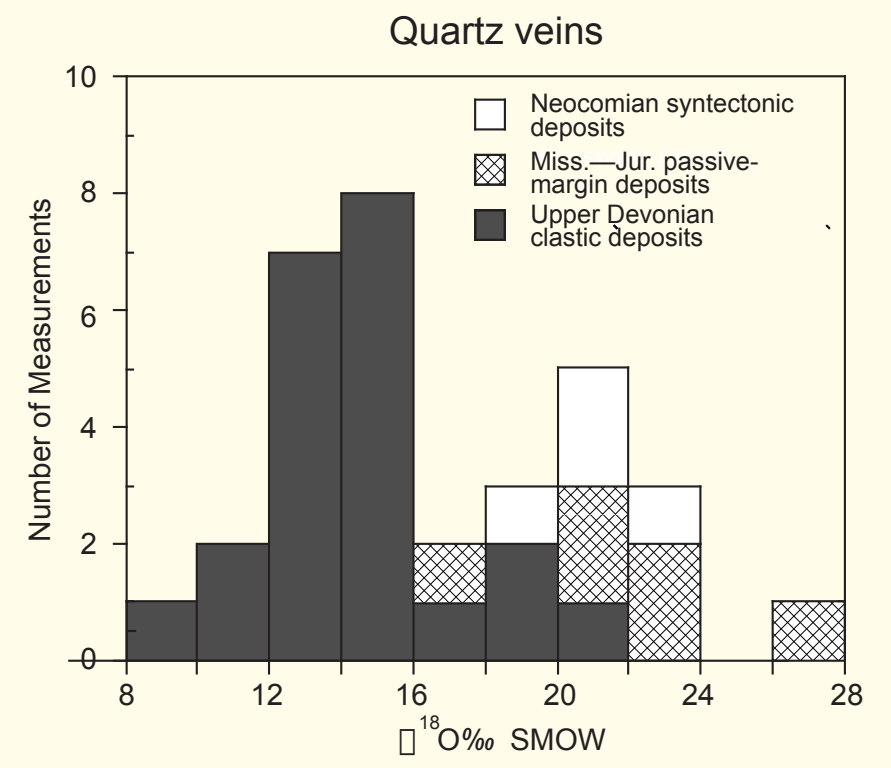
Vitrinite Reflectance and Stable Isotope Results



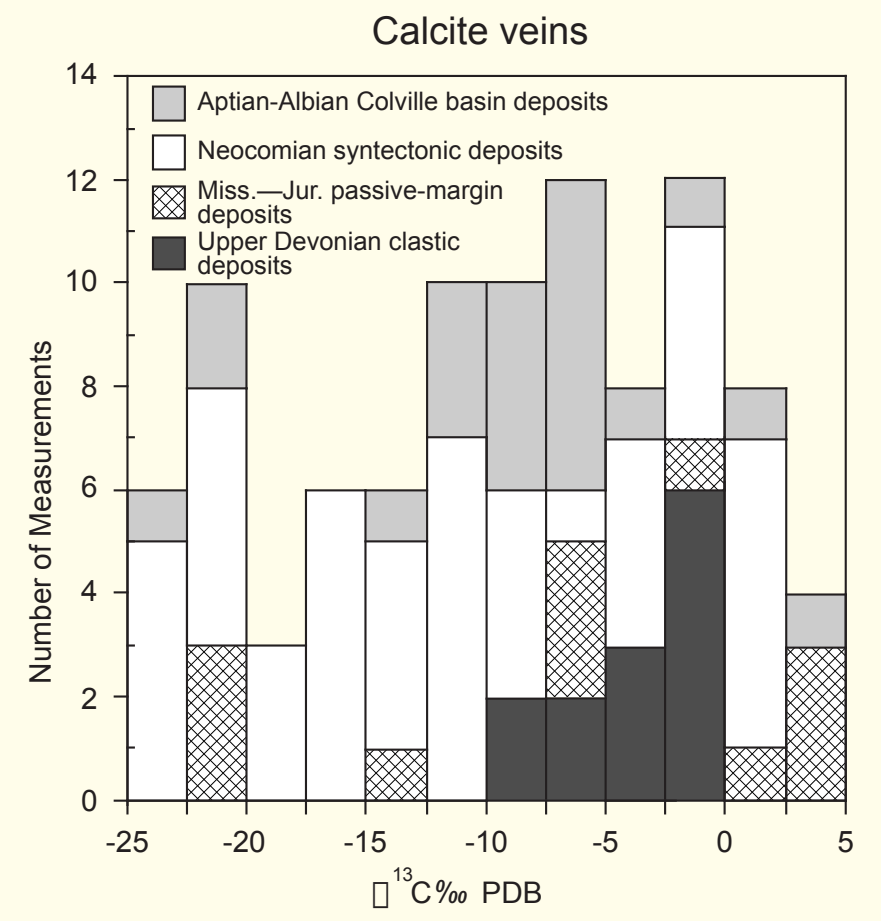
Histograms of vitrinite reflectance values and paleotemperature estimates displayed by tectonic-stratigraphic unit for samples from the study area. Note that all samples of Devonian rocks (and four samples of Mississippian to Jurassic passive margin rocks with Ro>1.2) were collected at or south of the present-day mountain front and have paleotemperatures >175 C.



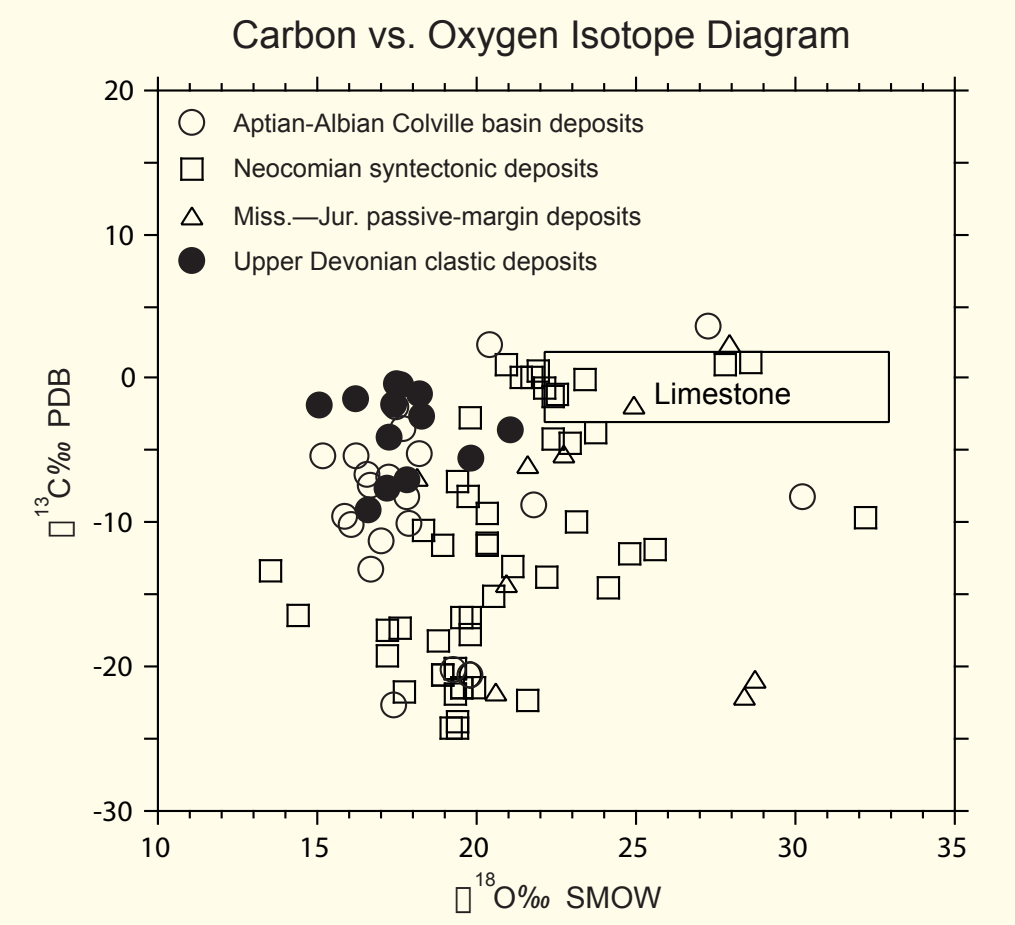
Histogram of □18O values (SMOW) of calcite veins hosted in Devonian to Cretaceous rocks from Brooks Range fold-and-thrust belt. Note that Devonian rock-hosted veins have lower values than veins hosted in younger rocks.



Histogram of □18O values (SMOW) of quartz veins hosted in Devonian to Cretaceous rocks from Brooks Range fold-and-thrust belt. Note that Devonian rock-hosted veins have lower values than veins hosted in younger rocks.



Histogram of □13C values (PDB) of calcite veins hosted in Devonian to Cretaceous rocks from Brooks Range fold-and-thrust belt.



Carbon versus Oxygen isotope diagram for calcite veins hosted Devonian to Cretaceous rocks from Brooks Range fold-and-thrust belt. Higher grade rocks of the Upper Devonian clastic wedge contain calcite veins with □13C values closer to 0‰ similar to values of limestones in the stratigraphic section, indicating host rock buffering of carbon isotopes (very low water/rock ratios). In contrast, calcite veins in Mississippian through Cretaceous rocks have highly variable, more negative □13C values, indicating a lack of host rock buffering of carbon isotopes. Anomalously low □13C values for some calcite veins (-16.5 to -24.2‰) in Mississippian through Cretaceous strata may be the result of oxidation of organic matter and/or methane and appear to coincide spatially with areas of high methane fluxes along fractures.

The vitrinite reflectance data and stable isotope compositions of calcite and quartz veins are consistent with at least two fluid events affecting Paleozoic-Lower Cretaceous rocks of the foothills and northern Brooks Range. These events are: (1) an earlier, higher-temperature (~250-300 C) event that resulted in veins emplaced in rocks of the Upper Devonian clastic wedge. The fluids responsible for vein precipitation had variable □18O values, but relatively constant □13C values buffered by limestone lithologies; (2) a younger (at least as young as the Aptian-Albian deposits of the Colville basin), lower-temperature (~150 C) event that deposited veins in Mississippian through Neocomian strata of the deformational wedge and in Colville basin deposits. These vein-forming fluids had similarly variable □18O values as the fluids affecting Devonian strata, but with distinctly lower □13C values as a result of oxidation of organic matter and/or methane.

Fission-Track Results

TABLE 1. FISSION TRACK RESULTS: LISBURNE WELL REGION

Sample Number (Unit) [1]	Type (Ap/Zi)	Number of grains	Latitude N	Longitude W	Elevation (+ m) or Depth (- m)	Chi2 probability (%)	Fission track age (Ma)	Uranium (ppm)	Track length (□m)	Standard deviation (□m)
Outcrop										
KRFT-16	Ap	25	68.489	155.714	540	0.0	72.2 ± 9.9	10.8	13.28 ± 0.27	1.95
Kfm	Zi	25				91.6	124.6 ± 5.3	198.4		
KRFT-17	Ap	25	68.499	155.712	540	29.0	51.9 ± 3.4	25.7	12.32 ± 0.29	2.26
Ko	Zi	25				96.8	136.8 ± 9.1	147.8		
KRFT-18	Ap	25	68.349	155.728	810	0.90	81.2 ± 6.3	22.0	12.47 ± 0.20	2.04
Mk	Zi	30				0.0	267.6 ± 18.9	117.6		
KRFT-19	Ap	25	68.357	155.726	810	0.10	51.6 ± 5.3	26.6	12.09 ± 0.17	1.73
Mk	Zi	17				0.0	252.1 ± 12.6	135.8		
KRFT-26	Ap	25	68.196	155.633	1510	1.20	97.6 ± 7.5	22.4	13.01 ± 0.20	2.06
Dh	Zi	20				93.7	161.8 ± 6.5	115.8		
KRFT-27	Ap	25	68.155	155.668	1370	1.40	75.4 ± 5.2	17.1	13.31 ± 0.18	1.86
Dn	Zi	19				55.7	157.2 ± 7.9	165.7		
KRFT-28	Ap	25	68.067	155.436	1240	58.6	44.7 ± 3.5	20.7	13.90 ± 0.17	1.14
Dn	Zi	25				69.2	119.3 ± 4.1	124.9		
KRFT-29	Ap	25	68.082	155.415	860	79.8	50.0 ± 4.4	20.5	13.93 ± 0.14	1.47
Dn	Zi	25				61.9	125.1 ± 4.3	148.1		
KRFT-30	Ap	7	68.171	155.248	1670	91.3	48.9 ± 10.0	6.8	-	-
Dn	-	-				-	-	-		
KRFT-31	Ap	27	68.639	155.769	405	0.50	59.8 ± 6.3	17.2	13.75 ± 0.19	1.98
Kt	Zi	25				0.0	151.6 ± 10.8	126.8		
KRFT-32	Ap	25	68.684	155.859	380	91.3	52.6 ± 7.6	7.9	14.86 ± 0.28	0.48
Kt	-	-				-	-	-		
KRFT-33	Ap	25	68.560	155.408	500	69.8	54.7 ± 5.1	10.6	14.03 ± 0.18	1.57
Kt	Zi	25				61.8	142.3 ± 4.6	165.8		
KRFT-34	Ap	26	68.486	155.434	705	7.5	91.5 ± 11.1	7.0	13.30 ± 0.34	2.55
Kt	Zi	25				42.9	129.9 ± 3.9	218.7		
Lisburne Unit#1 Well										
KRFT-5	Ap	20	68.485	155.743	- 634	5.1	92.1 ± 10.3	7.6	14.22 ± 0.27	0.96
Kfm	Zi	20				17.5	139.8 ± 10.4	106.4		
KRFT-4	Ap	26	68.485	155.743	- 1190	24.0	65.6 ± 6.2	8.9	13.01 ± 0.40	3.29
Ko	Zi	25				55.3	155.6 ± 7.6	98.5		
KRFT-3	Ap	8	68.485	155.743	- 1896	18.0	36.8 ± 10.7	7.4	10.67 ± 2.11	4.22
JTRo	-	-				-	-	-		
KRFT-2	Ap	10	68.485	155.743	- 2663	91.4	16.1 ± 5.9	6.8	-	-
JTRo	-	-				-	-	-		
KRFT-1	Ap	6	68.485	155.743	- 4148	62.7	20.5 ± 15.2	6.4	-	-
Ps	-	-				-	-	-		

[1] Unit, Kfm, Cretaceous Fortress Mountain Formation; Kt, Cretaceous Torok Formation; Ko, Cretaceous Okpikruak Formation; JTRo Triassic and Jurassic Otuk Formation; Ps Permian Siksikpuk Formation; Mk, Mississippian Kurupa sandstone; Dh, Devonian Hunt Fork Shale; and Dn, Devonian Noatak Sandstone.

Notes: Ages for apatite samples (Ap) calculated using □=352.7±4 for dosimeter glass SRM612 or □=379.2±3 for dosimeter glass CN5 (analyst: P. O'Sullivan). Ages for zircon samples (Zi) calculated using □=87.8±7.5 for dosimeter glass U3 (analyst: P. O'Sullivan). Errors quoted at ±1□.

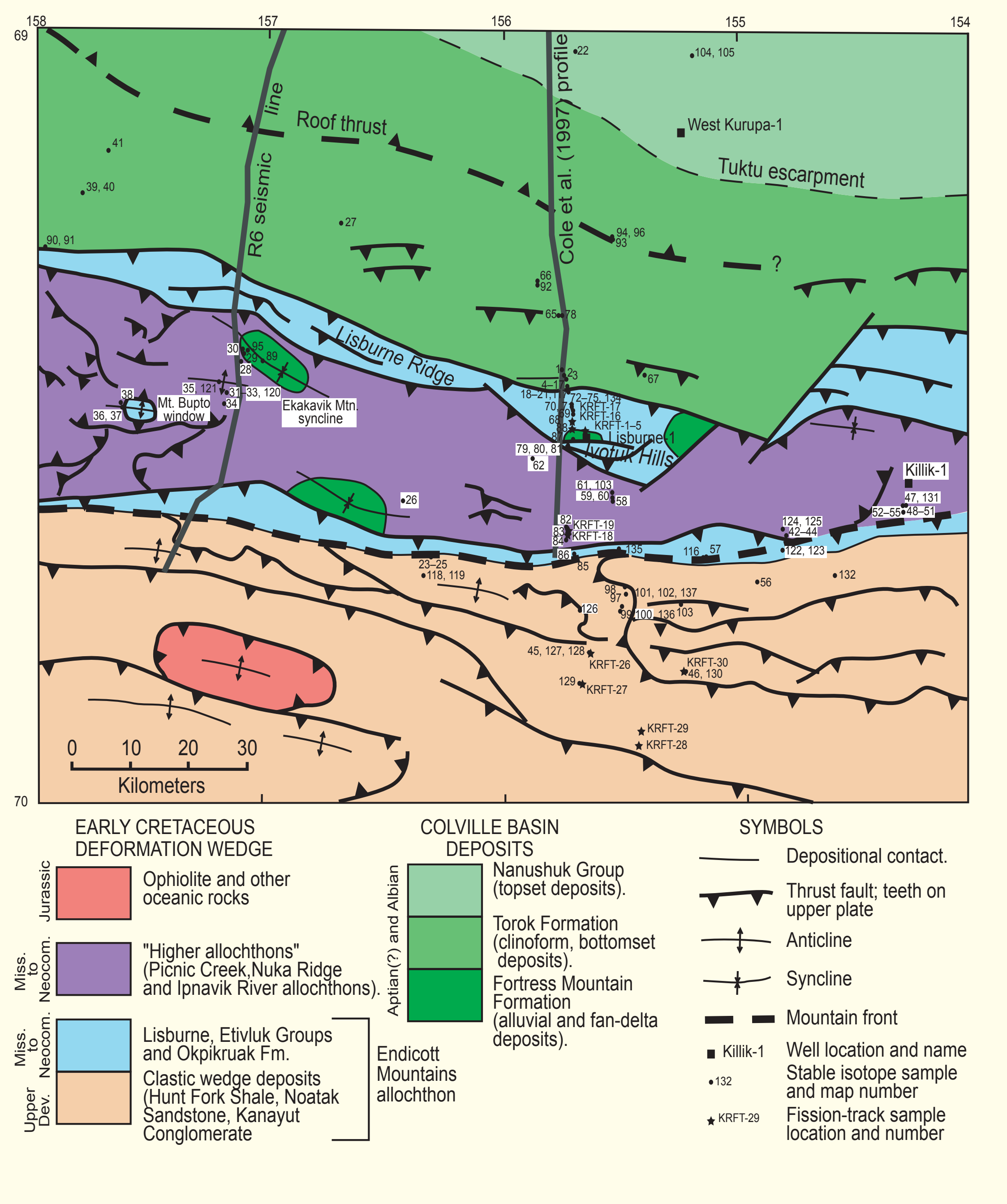
Interpretation of apatite fission track data

The AFTT results from the Albian-Aptian Fortress Mountain Formation indicate that these rocks were never buried deep enough to have totally reset their AFTT ages. Interpretation of the results from the Okpikruak Fm. suggest that: 1) they were exposed to elevated paleotemperatures above ~110 C following deposition, which resulted in the total resetting of the AFTT age, 2) they must have then cooled rapidly at the time recorded by the AFTT age, and 3) they have subsequently remained at cool temperatures. Based on the AFTT results, the region experienced at least three distinct cooling/denudation events since the rocks were exposed to their maximum post burial temperatures. The first recorded event occurred during the middle Cretaceous at ~100±5 Ma but was only recorded by a few of the samples. Two major recorded cooling/denudation events were recorded by all of the samples in the early Tertiary at ~60±5 Ma and ~45±5 Ma.

Interpretation of zircon fission track data

These results indicate that this part of the Colville basin was never buried sufficiently deep to have reset ZFTT ages. The data instead indicate that these deposits were derived from source areas that cooled from temperatures above ~260-225 C in the Early Cretaceous and Late Jurassic. Samples from Neocomian syntectonic deposits (Okpikruak Formation) yield similar results and indicate a similar provenance area for this unit. Coupled with the AFTT data, the ZFTT data indicate that the Okpikruak saw temperatures at or above 110C but below 225 C. In contrast, the ZFTT results from samples from Devonian and Lower Mississippian rocks south of the present day mountain front, yield ages younger than the stratigraphic age of the units sampled. Because the stratigraphic thickness of pre-middle Mesozoic strata that overlie these rocks was insufficient to generate such high temperatures by stratigraphic burial alone, these results suggest that the rocks instead were tectonically buried by allochthons emplaced during arc-continent collision and exhumed in the Late Jurassic and Early Cretaceous while contractional deformation was still ongoing. These data further indicate that these rocks did not see temperatures above 225 C after the Early Cretaceous, although cooling through ~110 C was not accomplished until the early Tertiary as indicated by the AFTT results from the same rocks.

Geologic context of samples



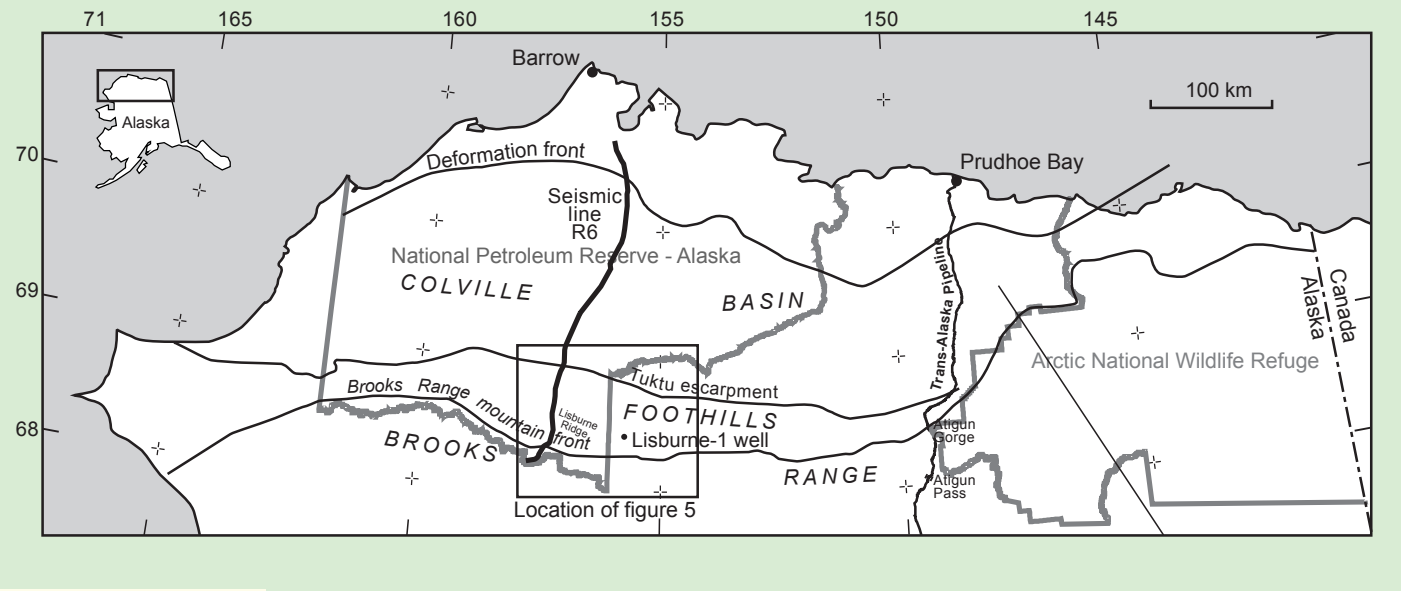
Geologic map of central Brooks Range study area showing location of fission track and stable isotope samples and sampled units. Geology from Mull and others (1994), Mull and Werdon (1994), and C.G. Mull (written communication, 2000)

A Key Point

Stable isotope data from veins indicate that Devonian clastic strata at low structural levels in the Brooks Range were heated to ~250-300 C. Zircon fission track data, which record cooling through ~225 C, indicate these temperatures were reached prior to 140-120 Ma.

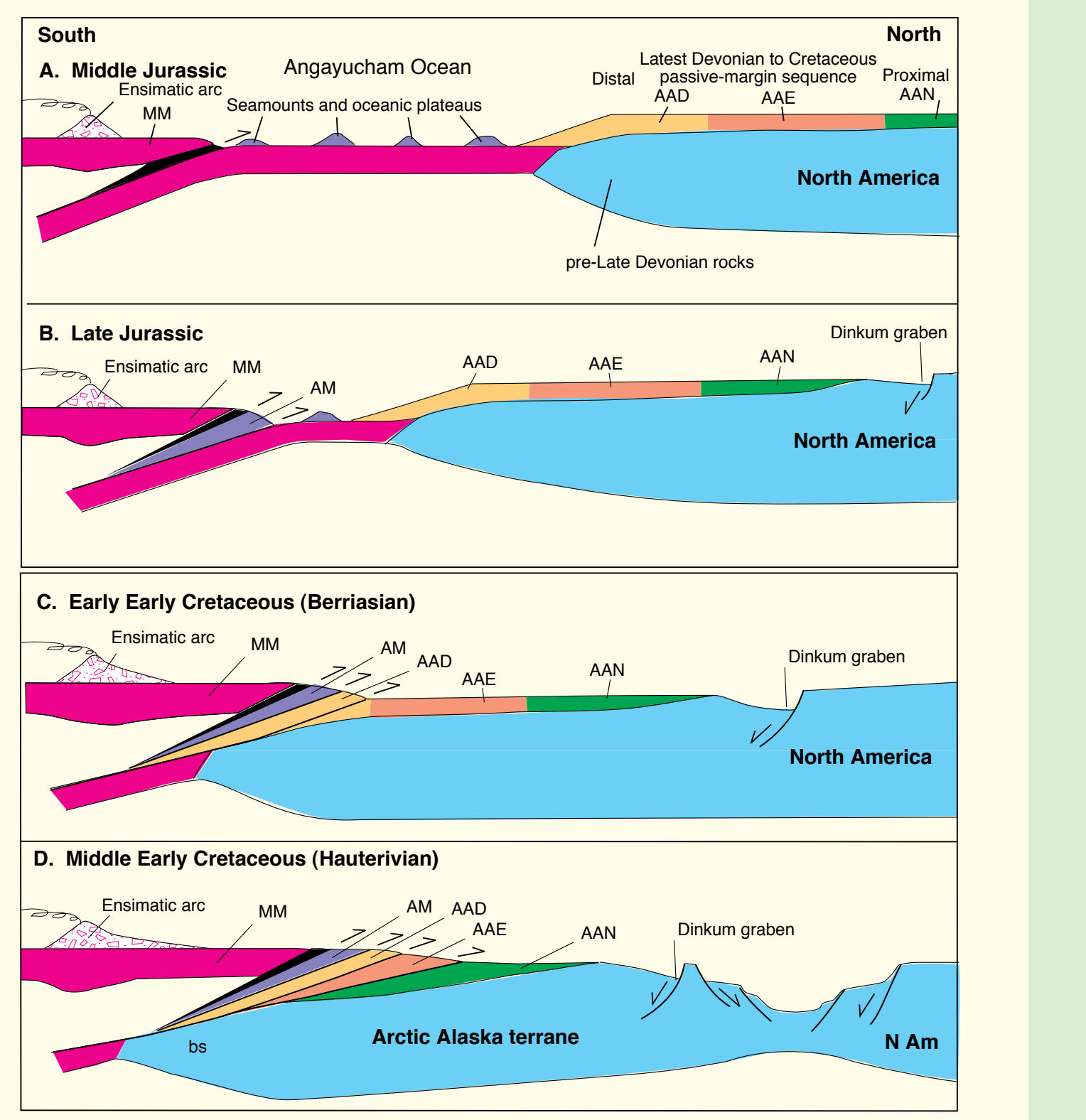
In contrast, stable isotope data from structurally higher and more forward Mississippian to Albian strata indicate these rocks saw temperatures of ~150 C. Fission track data from the same rocks indicate cooling from these temperatures occurred at 60-45 Ma.

Together, these data indicate older, high-temperature fluid event was active during thrusting at 120-140 Ma, and the younger fluid event during deformation at ~60-45 Ma.

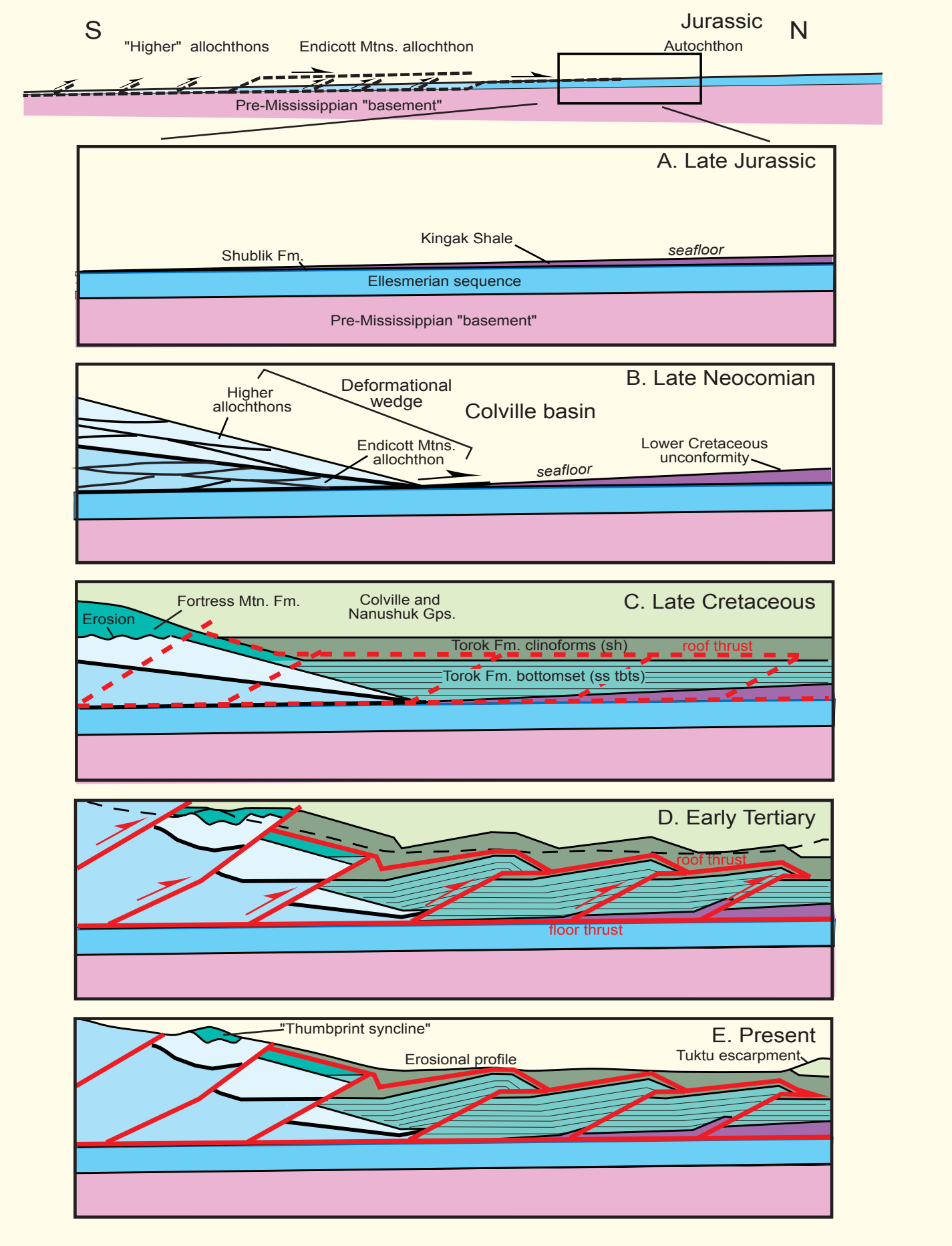


Location of study area

Tectonics

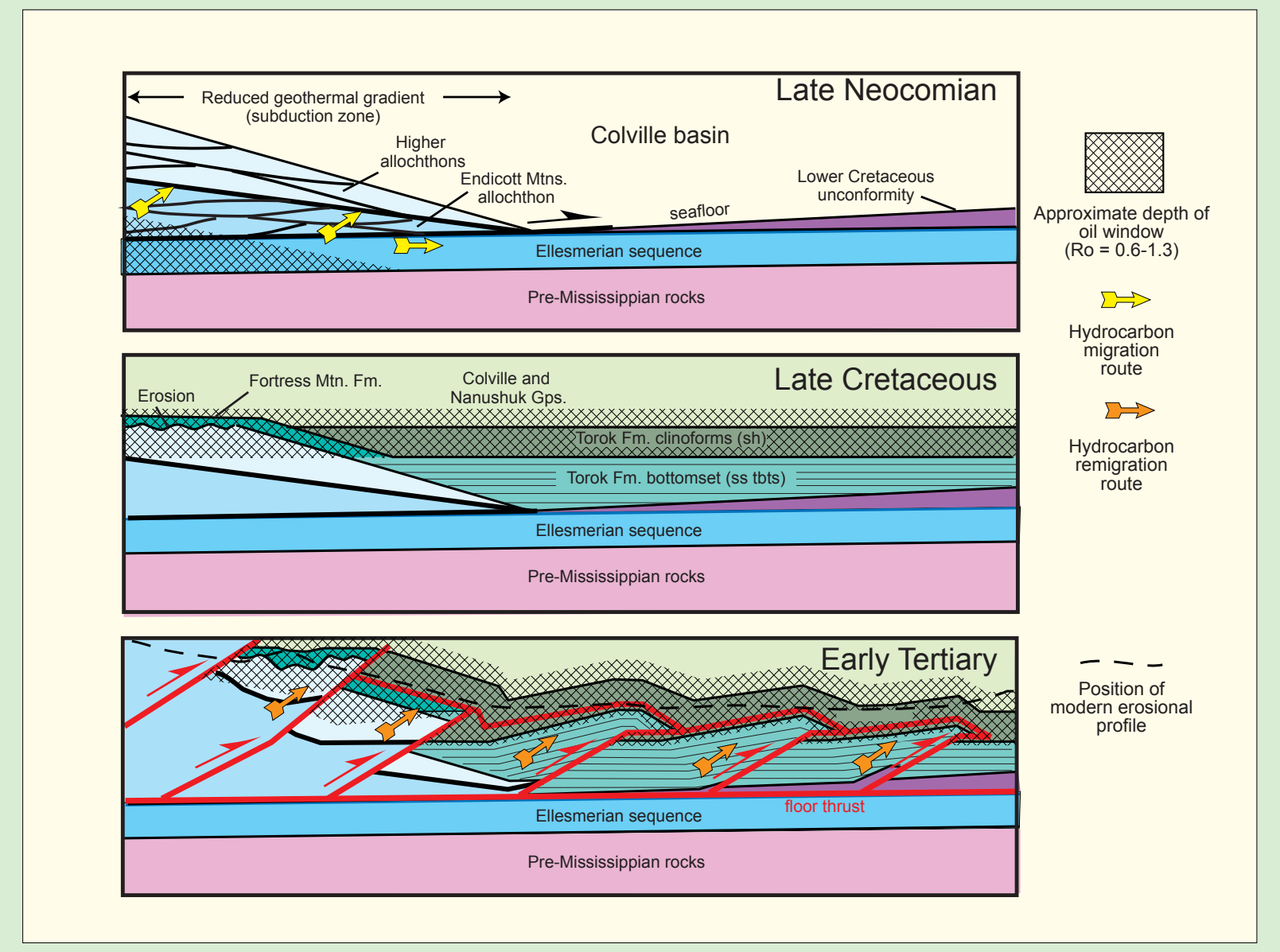


One-stage tectonic evolution model forBrooks Range and North Slope (Moore et al., 1994). Model shows Brooks Range formed as the result of arc-continent collision in the Jurassic and Neocomian. However, folding and thrusting of Albian and younger strata in the Colville basin and regional early Tertiary fission track ages indicate this interpretation is incomplete.

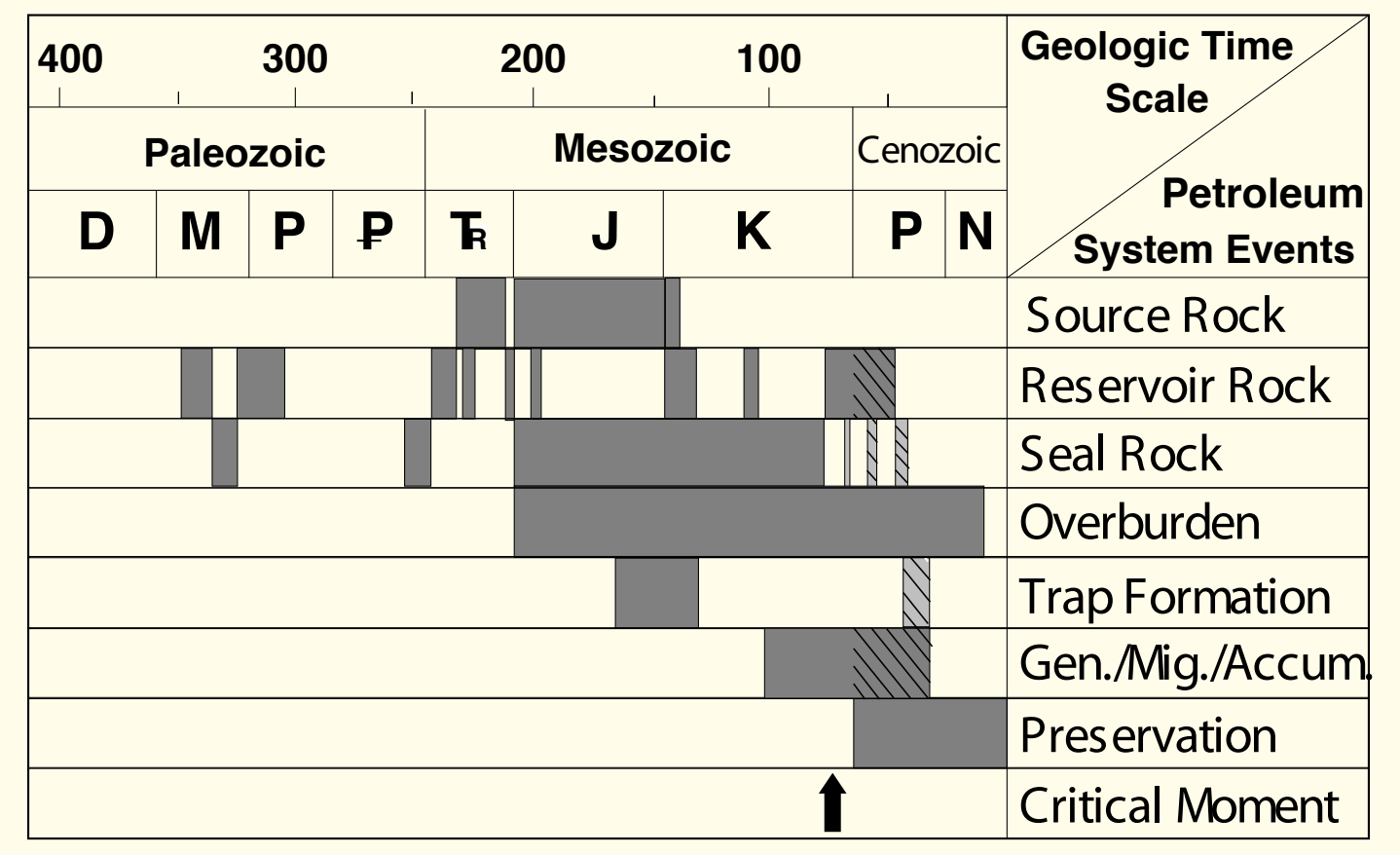


Revised two-stage model deformational model for Colville basin. Top, location of diagrams A-E on south-facing passive margin. Note restored positions of "higher allochthons" and Endicott Mountains allochthon. A., In Late Jurassic, location of diagram was in undeformed foreland with north-vergent thin-skinned deformation taking place outside diagram to south. B., By late Neocomian time, a deformational wedge consisting of Endicott Mountains allochthon and overlying higher allochthons formed constructional high that becomes the south flank of the Colville basin and causes basin subsidence due to tectonic loading. Allochthons are composed of a stacked series of duplexes and broken formation C., In the Aptian-Albian, and Late Cretaceous, voluminous sediments shed from sources to west and south prograded longitudinally along basin from west and onlapped deformational wedge to the south (internal duplex structure in deformational wedge shown only schematically). By end of the Cretaceous, over 8 km of clastic sediments have been deposited. D. In early Tertiary, renewed north-vergent deformation formed duplex with floor thrust in Kingak Shale of autochthon and roof thrust in clinoform strata of upper Torok Shale. To the south, the Early Cretaceous deformational wedge is deformed by linking thrusts in the duplex, whereas to the north only Colville basin strata are deformed by linking thrusts. A triangle zone is developed near present Tuktu escarpment. Dashed line indicates position of modern erosional profile. E. Erosion since the Tertiary has removed about 3 km of strata and has exhumed upper part of duplex.

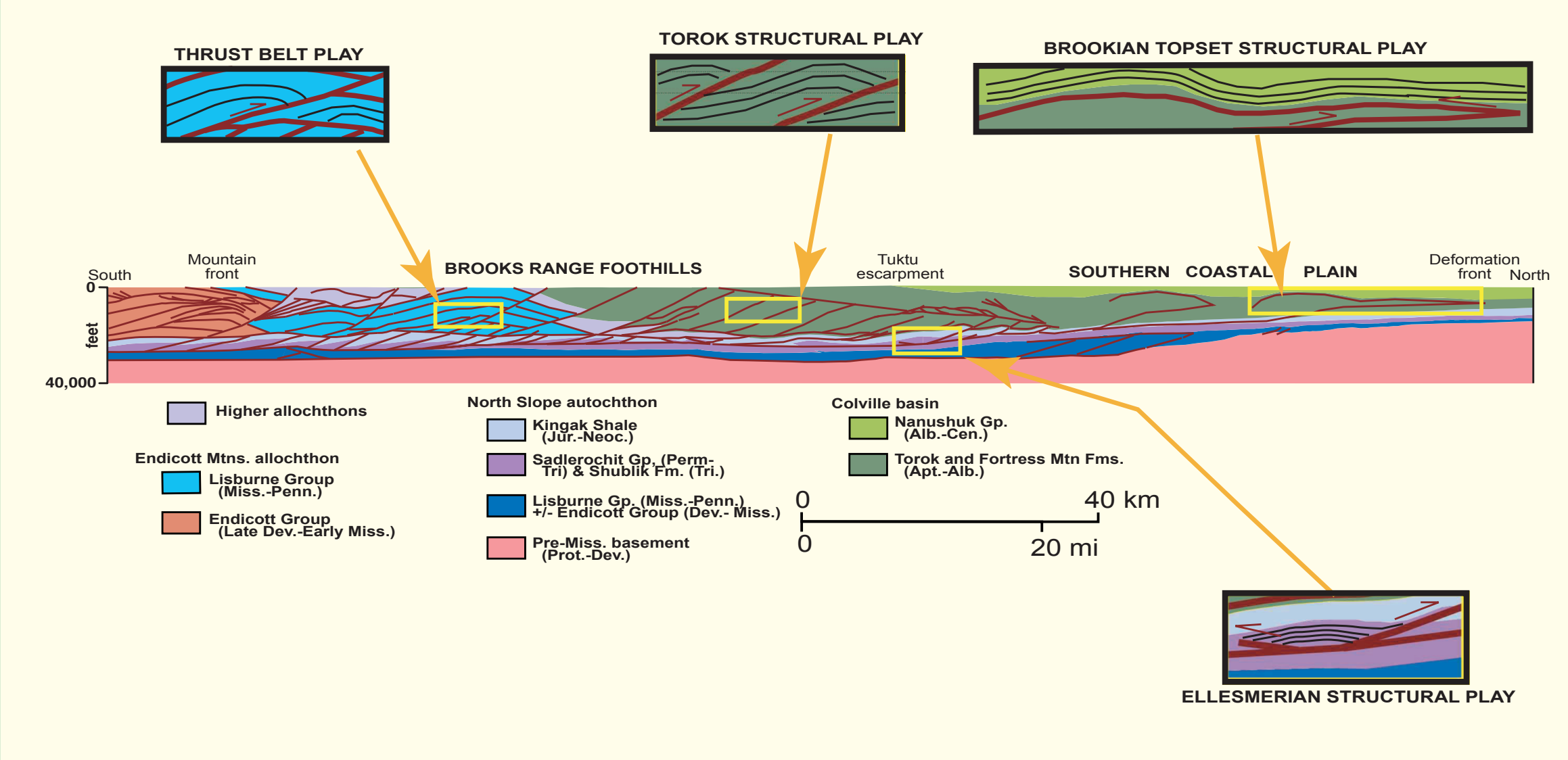
Hydrocarbon Generation and Migration



Thermal analysis and relation to hydrocarbon generation of structural model. Approximate position of rocks in the oil window (shown by hatchures). Top, in late Neocomian, oil window lies beneath deformational wedge in thrust belt. Hydrocarbon migration at this time is toward frontal part of deformational wedge and up depositional dip in underlying autochthon. Ellesmerian sequence in foreland is too thin to cause maturation due to sedimentary burial in most areas (underlying pre-Mississippian rocks are previously deformed and metamorphosed). Middle, during Late Cretaceous, position of oil window moves upward through section as sedimentary burial under Torok and Nanushuk Groups of Colville basin increases. To south, oil window intersects deformational wedge due to sedimentary onlap of Colville basin strata. Oil migration at this time is local, with accumulations forming principally in stratigraphic traps and pre-existing structural traps. Bottom, oil window developed at time of maximum burial is deformed and uplifted by thrusts during early Tertiary deformation. At depth, early formed hydrocarbon traps, now overmature, are breached by faults releasing hydrocarbons that migrate upward along active faults into newly formed traps. Oil generation and local migration may be occurring in upper part of structural section (not shown).



Events chart summarizing petroleum development for structural plays in NPRA.



Structural environment of structural play types in NPRA (Moore and Potter, 2003; Potter and Moore, 2003).

Conclusions

1. Field, well, and seismic data indicate the Brooks Range fold-and-thrust belt was the result of two orogenic episodes, one in the Jurassic and Neocomian; the other in the Tertiary.

2. Apatite and zircon fission track data indicate thrust-related exhumation occurred principally from 140-120 Ma and 60-45 Ma in our study area.

3. Stable isotopic data from quartz and calcite veins indicate an earlier, higher-temperature (~250-300 C) event that resulted in veins emplaced at low structural levels of the Early Cretaceous deformational wedge and (2) a younger (at least as young as the Aptian-Albian deposits of the Colville basin), lower-temperature (~150 C) event that deposited veins in higher and more forward parts of the deformational wedge and in Colville basin deposits of Albian age.

4. Analysis of the combined structural, fission track, and isotopic data sets indicate the older, higher temperature fluid was active during arc-continent collision at or before 140-120 Ma, whereas the younger, lower temperature fluid system was active during deformation that occurred at 60-45 Ma.

5. Basin modelling indicates that peak generation of the primary source rock units in the Colville basin (Shublik Fm., Kingak Fm., pebble shale unit) occurred at about 90-100 Ma (Burns, 2002) by sedimentary loading. Thus the timing of generation and structural trap formation was not ideal.

6. Nonetheless, significant accumulations of hydrocarbons might be expected because of the richness and abundance of source rock strata in northern Alaska and because of the abundance of stratigraphic traps in foreland basin that could have sequestered hydrocarbons until deformation released hydrocarbons and allowed remigration into new-formed traps the early Tertiary. The isotopic data suggest that these fluids may have interacted with hydrocarbons. The primary resource is expected to be gas in structural plays.

References

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