Isotope Geochemistry of Fault Zone Samples from the Livingstone Range Anticlinorium and their Significance to the Thermal and Fluid History of the Southern Canadian Foreland Fold and Thrust Belt

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Abstract

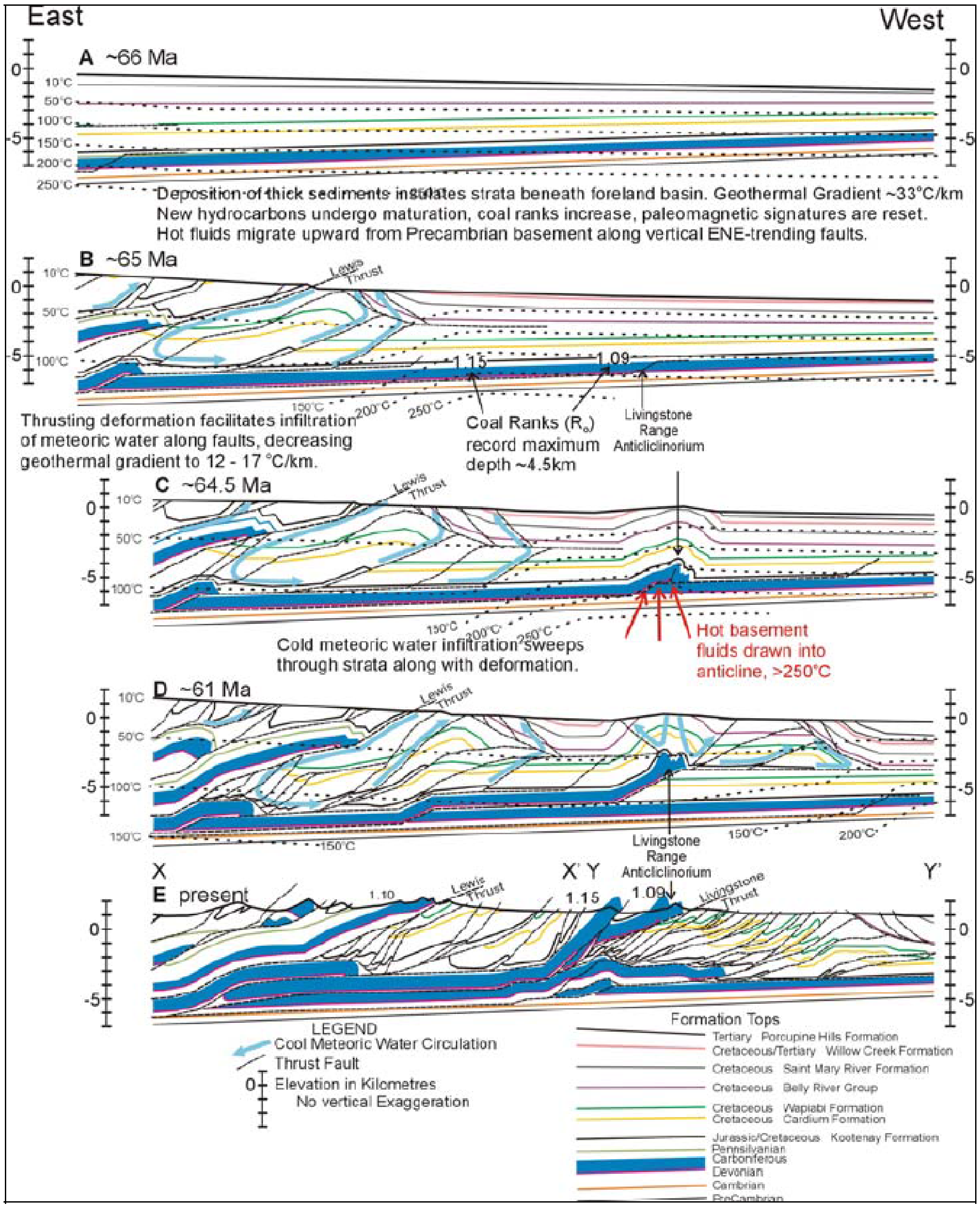
Pre-deformation fluid-flow in the Livingstone Range anticlinorium of southern Alberta is represented by quartz/dolomite/calcite+/-fluorite+/-sphalerite veins that cut perpendicular to and parallel with bedding. Dolomite in alteration haloes has radiogenic strontium isotopic ratios and enriched oxygen isotopic compositions that suggest a basement-derived fluid source. Dolomitized Paleozoic carbonates throughout the Foothills of the southern Canadian Cordillera show a trend of increasing radiogenic Sr and 18O-depletion that indicates regional dolomitization may have been caused by the infiltration of similar basement fluids.

During the early stages of Cretaceous/Tertiary deformation, the undeformed Upper Paleozoic strata became buried by a >4km-thick succession of shale-dominated foreland basin deposits (Figure A). The insulating effect of the sediment raised temperatures in the underlying strata at a geothermal gradient of ~33°C/km. The increased temperatures likely caused hydrocarbon maturation, the possible recrystallization of magnetic minerals that reset paleomagnetic signatures, and increased vitrinite reflectance values of coal. The eastward-migrating blanket of foreland basin sediments was systematically deposited ahead of the deformation front, which caused an eastward-migrating hot thermal anomaly to pass through the foreland basin ahead of the deformation.

The initial stage of fault-propagation folding in the Livingstone Range anticlinorium caused extensive fracture dilation in the Paleozoic rocks, which caused hot basement fluids to be drawn into the anticlines along folding-related faults (Figure C). The hot fluids migrated into the anticlinorium when the Livingstone thrust cut through steep ENE-trending reactivated faults that were conduits for the basement fluids. Isotopic compositions of fault-related veins and host rocks indicate that cross faults were the primary conduits for the infiltrating fluids. Isotope geothermometry of calcite, dolomite +/- quartz in veins in one cross fault and two thrust fault samples indicate that these early veins precipitated at temperatures of >250°C, which is 60-80°C higher than that expected from temperatures extrapolated from overlying coal.

As thrusting continued, the Livingstone Range anticlinorium underwent eastward translation and became elevated and affected by erosion, allowing deep infiltration of meteoric water that cooled the rocks to a geothermal gradient of 12-17 °C/km (Figure D). The presence of meteoric water in the Livingstone Range anticlinorium is recorded by late fault-related veins with strongly depleted δ^{18}O values (<-10‰PDB).

The widespread occurrence of strongly δ^{18}O-depleted veins in thrust faults in the Front Ranges and Foothills of the southern Canadian Foreland Fold and Thrust Belt is attributed to regional infiltration of meteoric fluids, which swept through the deformed rock from west to east along with the deformation.


East
West
A ~66 Ma
10°C
50°C
100°C
150°C
200°C
250°C
Deposition of thick sediments insulates strata beneath foreland basin. Geothermal Gradient ~33°C/km
New hydrocarbons undergo maturation, coal ranks increase, paleomagnetic signatures are reset.
Hot fluids migrate upward from Precambrian basement along vertical ENE-trending faults.
B ~65 Ma
Lewis Thrust
1.15
1.09
Thrusting deformation facilitates infiltration of meteoric water along faults, decreasing geothermal gradient to 12 - 17 °C/km.
Coal Ranks (R_o) record maximum depth ~4.5km
Livingstone Range Anticlinorium
C ~64.5 Ma
Cold meteoric water infiltration sweeps through strata along with deformation.
Hot basement fluids drawn into anticline, >250°C
D ~61 Ma
Livingstone Range Anticlinorium
X
X' Y
Y'
E present
1.10
Livingstone Thrust
LEGEND
Cool Meteoric Water Circulation
Thrust Fault
Elevation in Kilometres
No vertical Exaggeration
Formation Tops
Tertiary Porcupine Hills Formation
Cretaceous/Tertiary Willow Creek Formation
Cretaceous Saint Mary River Formation
Cretaceous Belly River Group
Cretaceous Wapiabi Formation
Cretaceous Cardium Formation
Jurassic/Cretaceous Kootenay Formation
Pennsilvanian
Carboniferous
Devonian
Cambrian
PreCambrian