# The Cratonic Crossroads:
# New Age Control from the Williston Basin Basement Provides Insight into the Assembly of Laurentia

Jennifer N. Gifford[1], David A. Foster[2], Paul A. Mueller[2]

[1]St. Lawrence University, 23 Romoda Drive, Canton, NY 13617, jgifford@stlawu.edu; [2]University of Florida

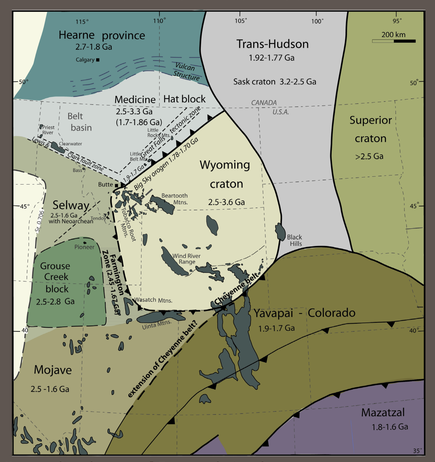
## Abstract:

The Great Falls Tectonic Zone (GFTZ) is an area of high angle structures striking NE to SW through Montana, separating the Wyoming craton from the Medicine Hat Block (MHB). It is part of a series of collisional belts, including the north-striking Trans-Hudson Orogen (THO) to the east, formed during the ~1.7-1.9 Ga amalgamation of Laurentia. Evaluating models for these collisions depends on high quality geochronology; however, sampling is hampered by the extensive Mesoproterozoic and younger cover rocks. One critical area is the basement to the Williston Basin (WB), near the presumed juncture of the GFTZ and THO. Deep Test Wells (DTW) penetrating the WB basement and surrounding areas provides valuable samples for high quality Ar-Ar on mineral separates and zircon U-Pb geochronology. The current data set is limited to poorly constrained Rb-Sr whole-rock model ages and K-Ar determinations on K-spar and biotite, yielding ages from ~0.65 - 2.9 Ga. Previous U-Pb geochronology is restricted to 7 discordant analyses, yielding upper intercept ages ranging from 1.7 - 2.9 Ga.

New elemental and isotopic data has vastly improved the controls on the protolith ages, thermal history, and petrogenesis of the basement at this critical juncture. Preliminary basement geochronology from cores Madison-1 and Madison-3 yielded ages of ~2.9 and ~3.0 Ga. These ages overlap with previously observed data from the Wyoming craton, helping refine the location of the northern margin in the THO and GFTZ, respectively. DTW MT-1 is located at the presumed intersection of the GFTZ and THO, and yielded a U-Pb age of ~1.8 Ga. This age overlaps with observed data from both the GFTZ and the THO, confirming the affinity of the basement. DTW MT-3 yielded U-Pb ages of ~1.8 Ga revealing further influence from the Paleoproterozoic orogenies, and ~2.5 Ga possibly revealing Medicine Hat Block material in an area thought to be primarily Wyoming craton. Ar-Ar work on biotite and K-feldspar from numerous DTW reveal the varied cooling history affecting the WB area, and potentially reveal timing of the formation of the structural basin.

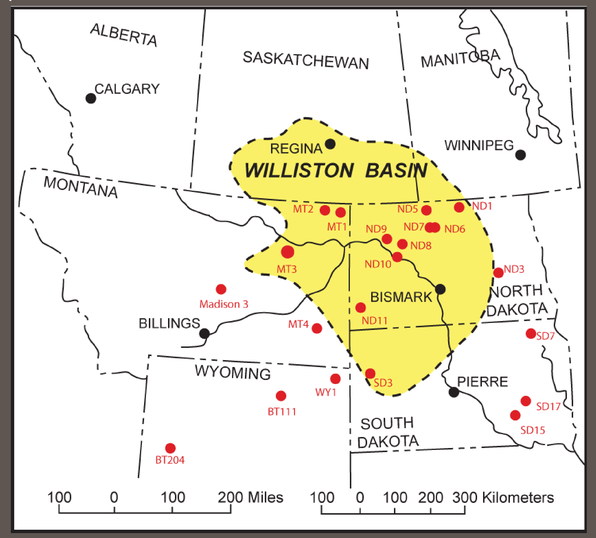
Further work on these samples will provide a valuable opportunity to characterize the age and nature of the basement from the marginal region of both the Wyoming and Superior cratons, and the concealed portions of the GFTZ and THO.

## Precambrian Basement Provinces:




Generalized map of Precambrian basement provinces of southwestern Laurentia (after Foster et al., 2006).

## Sample Locations Williston Basin and Surrounds:




DTW sample locations portrayed on the outline of the Williston Basin (WB) (figure modified from Carlson & Anderson, 1965). The WB is a large intracratonic sedimentary basin known for its rich deposits of petroleum and potash. The basin is a geologic structural basin but not a topographic depression.

## Previous Research:

| Map #_Well Name | Analysis Method | Analysis Type | Age (Ga) |
|---|---|---|---|
| WY-1_Madison 1 | Rb-Sr | WRI | 2.64 ± 0.16 |
| | K-Ar | BT | 2.16 |
| | K-Ar | BT | 2.09 |
| | K-Ar | HBL | 2.42 |
| MT-1_Amerada 1 | Rb-Sr | WRI | 1.83 ± 0.12 |
| | U-Pb | ZI | 1.78 ± .02 |
| | Sm-Nd | WR | 2.43 |
| MT-2_Amerada Loucks 1 | Rb-Sr | WR | 1.76 |
| | Sm-Nd | WR | 2.28 |
| MT-3_ Shell North Pacific 32-33B | Rb-Sr | KS | 1.88 |
| | K-Ar | BT | 1.72 |
| | K-Ar | HBL | 1.77 |
| | U-Pb | ZI | 1.91 ± 0.03 |
| MT-4_Madison 2 | Rb-Sr | WR | 2.80 |
| | Rb-Sr | KS | 2.46 |
| | Rb-Sr | BT | 1.60 |
| | K-Ar | BT | 2.48 |
| | U-Pb | ZI | 2.88 |
| | Sm-Nd | WR | 3.09 |
| ND-5_Shell Mott 14-34 | Rb-Sr | WRI | 1.76 ± 0.10 |
| | Rb-Sr | BT | 1.68 ± 0.04 |
| | K-Ar | BT | 1.67 ± 0.06 |
| ND-8_Amerada ND "A" Unit 9 | Rb-Sr | BT | 0.53 |
| | K-Ar | BT | 0.67 |
| ND-9_Amerada 1 Iverson-Nelson Unit | Rb-Sr | KS | 0.69 |
| | Sm-Nd | WR | 0.98 |
| ND-11_Amerada 8 Scoria Unit | Rb-Sr | BT | 1.69 |
| | K-Ar | BT | 1.74 |
| SD-3_Mobil 1 Sipila B | Rb-Sr | WR | 1.71 |
| | Rb-Sr | WR | 1.63 |
| | Sm-Nd | WR | 3.05 |
| SD-7_Harvey Carr Farm Well | Rb-Sr | WR | 2.49 |
| | Rb-Sr | BT | 2.35 |
| | K-Ar | BT | 2.40 |
| | Sm-Nd | WR | 2.72 |

WR: whole rock model age, WRI: whole rock isochron, BT: biotite, KS: potassium feldspar, HBL: hornblende ZI: zircon age-concordia intercept

Selected geochronologic and isotopic data for DTW cores (summarized in Sims et al., 1991), including published data (e.g., Goldich et al., 1966; Richards et al. 1986, Peterman and Hedge, 1964) and unpublished ages from Z. Peterman and colleagues of the U.S.G.S.

Rb-Sr: ~0.53 Ga to 2.83 (whole-rock model age, biotite, K-feldspars, whole-rock isochron)

K-Ar: ~0.65 Ga to 2.5 Ga (whole rock model age, biotite, hornblende)

U-Pb: ~1.7 Ga to 2.9 Ga (zircon upper intercept ages)

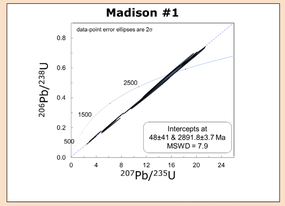
## The Problem, The Plan, and The Hope

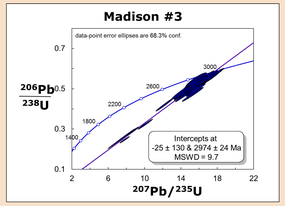
The Problem: We do not have a very well constrained view of the protolith ages, cooling histories, or petrogenesis for these samples.

The Plan: We will conduct comprehensive elemental and isotopic analyses of samples from a sub-set of 16 of the wells described in Sims et al., (1991). This subset contains cores from wells in North Dakota, South Dakota, Wyoming, and Montana that are suitable for preparation of both homogeneous powders for whole-rock elemental and isotopic studies as well as mineral separation for U-Pb and Ar-Ar analyses.

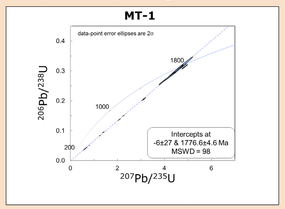
The Hope: These samples provide access to the margins of both the Superior and Wyoming cratons as well as the THO basement underlying the WB. Overall, the DTW samples offer the opportunity to place much better constraints on the nature of the basement to the WB and its relation to the Paleoproterozoic crust of the GFTZ and THO.

## Basement U-Pb Zircon Data:

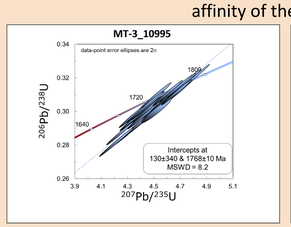


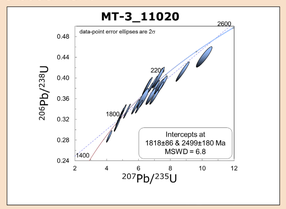




DTW Madison 1 and 3 U-Pb data on zircons showing coherent age spectra similar to published Wyoming craton ages. The location of Madison 3 was previously thought to be GFTZ suture crust.



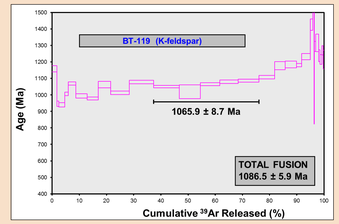

DTW MT-1 data on zircons shows a coherent discordia line. The age overlaps with observed data from both the GFTZ and the THO. The sample is located at the juncture of the two sutures and confirms the affinity of the basement

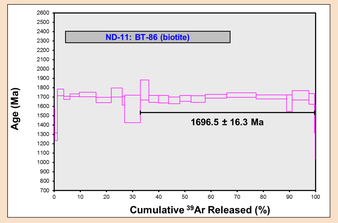


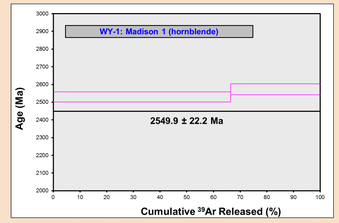




DTW MT-3 of two depths of core. MT-3_10995 shows a coherent age spectra similar to published GFTZ ages (e.g. Gifford et al., 2014). MT-3_11020 shows a lower intercept similar to GFTZ ages and an upper intercept similar to recently discovered ages attributed to the MHB (Gifford et al., 2014).

## Ar-Ar Thermochronology Data:




| Ar-Ar Data Summary | | |
|---|---|---|
| BT-204 | Bt = 1914.2±13.7 | Ks(TF) = 1191.9±6.5 |
| WY-1_Madison 1 | Hbl = 2549.9±22.2 | |
| BT-294 | Bt = 1914 | |
| ND-3_BT-57R | Ks = 2140 | |
| ND-8_BT-85 | Bt = 551.8±24.5 | Bt(TF) = 724.1±24.5 |
| ND-11_BT-86 | Bt = 1696.5±16.3 | Bt = 1727±16 |
| SD-7_BT-13 | Bt = 2315.5±14.0 | |
| BT-111R | Bt = 2415.7±13.3 | Ks = ~1000 |
| BT-119 | Ks = 1065.9±8.7 | Ks(TF) = 1086.5±5.9 |

Bt: biotite plateau age, Bt(TF): biotite total fusion age, Ks: K-feldspar plateau age, Ks(TF): K-feldspar total fusion age, Hbl: hornblende plateau age

Examples of Ar-Ar plateau reductions for biotite, hornblende and K-feldspar, and a summary table of preliminary Ar-Ar data. Biotite ages range from ~552 Ma to 2415 Ma, K-feldspar ages range from ~1000 Ma to 2140 Ma, a single hornblende sample yielded an age of ~2550 Ma revealing numerous thermal events effecting the area surrounding the structural Williston Basin, Great Falls Tectonic Zone, and Trans-Hudson Orogeny.

## Conclusions:

- DTW Madison 1 and 3 further characterize the Wyoming craton as ~2.9 Ga and ~3.0 Ga in areas where outcrops are not available
  - Madison 1 further yielded a hornblende Ar-Ar cooling age of ~2.55 Ga revealing a potential thermal event that effected the Wyoming craton
- DTW MT-1 confirms the ~1.78 Ga age and affinity of the crust at the supposed intersection of the Great Falls Tectonic Zone and the Trans-Hudson Orogen
- DTW MT-3 was thought to be located on Wyoming craton crust, but instead yielded ages similar to published Great Falls Tectonic Zone/Trans-Hudson Orogeny (~1.82 Ga) and Medicine-Hat Block crust (~2.50 Ga)
- Various DTW cores located around the Willison Basin yield Ar-Ar cooling ages possibly related to thermal events in the Great Falls Tectonic Zone (ND-11 ~1.73 ± 0.16 Ga) as well as older (SD-7 ~2.32 Ga) and younger (ND-8 ~ 0.55 Ga) thermal events effecting the borad area, and potentially relating to the structural formation of the Williston Basin

## Acknowledgements:

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**References:**

Carlson, C.G. & Anderson, S.B. (1965) Sedimentary and tectonic history of North Dakota part of Williston Basin. AAPG Bull., 49, 1833–1846.

Gifford, J.N., Mueller, P.A., Foster, D.A., Mogk, D.W. (2014) Precambrian Crustal Evolution in the Great Falls tectonic zone: Insights from Xenoliths from the Montana Alkali Province. Journal of Geology, v. 122, n. 5, p. 531-548

Goldich, S.S., Lidiak, E.G., Hedge, C.E., Walthall, F.G. (1966) Geochronology of the mid-continent region, United States; Part 2, Northern area. Journal of Geophysical Research, v. 71, p. 3671-3696.

Peterman, Z.E. & Hedge, C.E. (1964) Age of basement rocks from the Williston basin of North Dakota and adjacent areas. U.S.G.S. Professional Paper 475-D, p. D100-D104

Richards, J.R., Baron, D.M., Goldich, S.S. (1986) Age of the basement staurolite-biotite schist of northeastern South Dakota. in Peterman, Z.E., and Schnabel, D.C., eds. Shorter Contributions to Isotope Research: U.S.G.S. Bulletin 1622, p. 65-75.

Sims, P.K., Peterman, Z.E., Hildebrand, T.G., and Mahan, S. (1991) Precambrian basement map of the Trans-Hudson orogen and adjacent terranes, northern Great Plains, U.S.A. U.S. Geological Survey Miscellaneous Investigations Series Map I-2214, 53 p., 1 sheet, scale 1:250 000.

Sims, P.K. (1995) Archean and Early Proterozoic tectonic framework of north-central United States and adjacent Canada. U.S.G.S. Bulletin 1904-T, 12 p.