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Review of Radiometric Ages from North Dakota's Precambrian Basement

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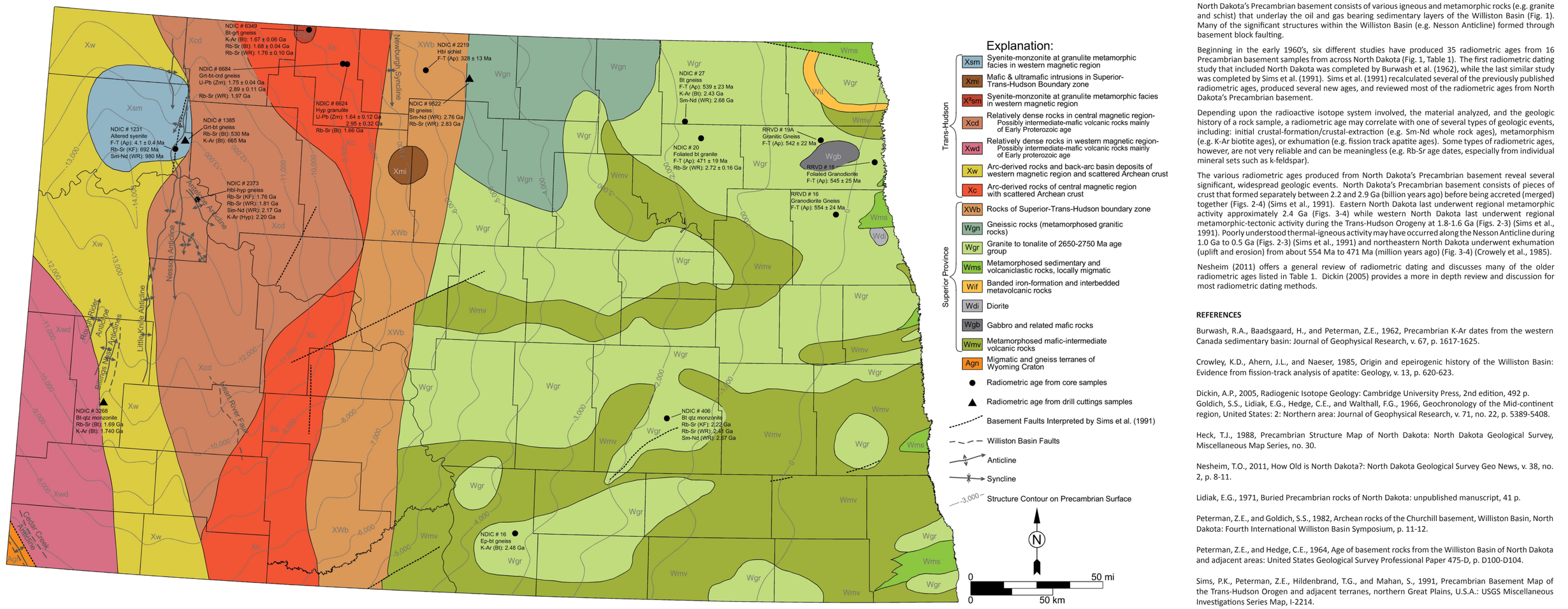

Figure 1. Precambrian basement map of North Dakota with well locations from which Precambrian samples were collected and analyzed to produce radiometric ages. The Precambrian geology is borrowed from Sims et al. (1991). The light grey labeled lines are structure contours on the Precambrian surface (Heck, 1988). Abbreviations include: bt = biotite, crd = cordierite, ep = epidote, KF = potassium feldspar, grt = garnet, hbl = hornblende, hyp = hypersthene, qtz = quartz, zrn = zircon, WR = whole rock, and F-T = fission track, K-Ar = potassium-argon, Rb-Sr = rubidium-strontium, Sm-Nd = samarium-neodymium, U-Pb = uranium-lead.

North Dakota's Precambrian basement consists of various igneous and metamorphic rocks (e.g. granite and schist) that underlay the oil and gas bearing sedimentary layers of the Williston Basin (Fig. 1). Many of the significant structures within the Williston Basin (e.g. Nesson Anticline) formed through basement block faulting.

Beginning in the early 1960's, six different studies have produced 35 radiometric ages from 16 Precambrian basement samples from across North Dakota (Fig. 1, Table 1). The first radiometric dating study that included North Dakota was completed by Burwash et al. (1962), while the last similar study was completed by Sims et al. (1991). Sims et al. (1991) recalculated several of the previously published radiometric ages, produced several new ages, and reviewed most of the radiometric ages from North Dakota's Precambrian basement.

Depending upon the radioactive isotope system involved, the material analyzed, and the geologic history of a rock sample, a radiometric age may correlate with one of several types of geologic events, including: initial crustal-formation/crustal-extraction (e.g. Sm-Nd whole rock ages), metamorphism (e.g. K-Ar biotite ages), or exhumation (e.g. fission track apatite ages). Some types of radiometric ages, however, are not very reliable and can be meaningless (e.g. Rb-Sr age dates, especially from individual mineral sets such as k-feldspar).

The various radiometric ages produced from North Dakota's Precambrian basement reveal several significant, widespread geologic events. North Dakota's Precambrian basement consists of pieces of crust that formed separately between 2.2 and 2.9 Ga (billion years ago) before being accreted (merged) together (Figs. 2-4) (Sims et al., 1991). Eastern North Dakota last underwent regional metamorphic activity approximately 2.4 Ga (Figs. 3-4) while western North Dakota last underwent regional metamorphic-tectonic activity during the Trans-Hudson Orogeny at 1.8-1.6 Ga (Figs. 2-3) (Sims et al., 1991). Poorly understood thermal-igneous activity may have occurred along the Nesson Anticline during 1.0 Ga to 0.5 Ga (Figs. 2-3) (Sims et al., 1991) and northeastern North Dakota underwent exhumation (uplift and erosion) from about 554 Ma to 471 Ma (million years ago) (Fig. 3-4) (Crowely et al., 1985).

Nesheim (2011) offers a general review of radiometric dating and discusses many of the older radiometric ages listed in Table 1. Dickin (2005) provides a more in depth review and discussion for most radiometric dating methods.

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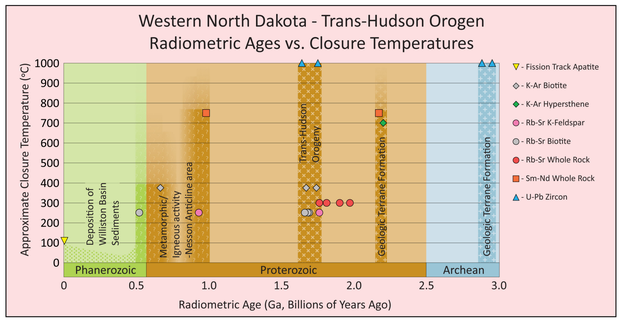

Figure 2. Closure temperature versus radiometric age diagram for Precambrian samples from western North Dakota. The Precambrian basement beneath the western portion of the state consists of geologic terranes that formed independently of one another during the late Archean through the early Proterozoic (2.9-2.2 Ga). These separately formed geologic terranes were merged together and accreted to the Superior Craton during the Trans-Hudson Orogeny in the middle Proterozoic (1.8-1.6 Ga). Poorly understood igneous and/or metamorphic activity occurred along the northern portions of the present day Nesson Anticline during the Neoproterozoic (1.0-0.5 Ga).

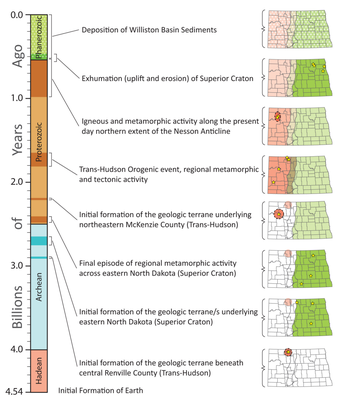

Figure 3. Geologic time scale with the timing of events for North Dakota's Precambrian basement based on previously reported radiometric ages.

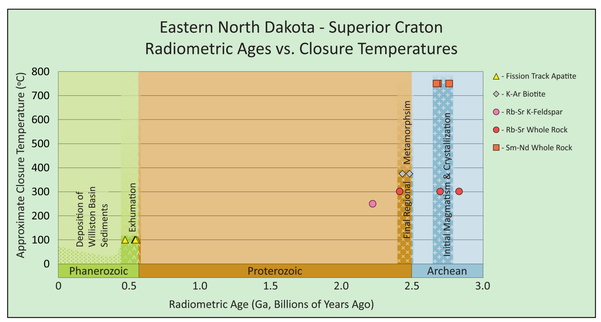

Figure 4. Closure temperature versus radiometric age diagram for Precambrian samples from eastern North Dakota (Superior Craton). The Precambrian basement beneath the eastern part of the state consists of the Superior Craton which initially formed during the late Archean (~2.7 Ga). The final phase of regional tectonic activity (metamorphism and deformation) across the Superior Craton of eastern North Dakota concluded during the early Proterozoic (2.4 Ga). Uplift and erosion (exhumation) later took place throughout the northeastern corner of the state, and possibly all of North Dakota, during the late Proterozoic-early Phanerozoic, just prior to the beginning of deposition of Williston Basin sediments.

NDIC No.	API #	Original Operator	Well Name	Latitude	Longitude	Location Sec.	T.	R.	Sample depth (ft.)	Rock type	Age	System	Material	Significance	Reference
16	33029000010000	N. Ordinance	Franklin Invest. Co. #1	46.2889	-100.0821	35	133 N.	75 W.	? (5350-5359)	Ep-bt gneiss	2.48 Ga*	K-Ar	Biotite	Metamorphism	Burwash et al., 1962
27	33019000010000	Union Oil	Chris Skjervheim #1	48.5719	-98.7950	28	159 N.	63 W.	? (3406-3409)	Bt gneiss	2.43 Ga*	K-Ar	Biotite	Metamorphism	Burwash et al., 1962
2373	33053004100000	Amerada	Antelope Unit "A" 1	48.0121	-102.7747	1	152 N.	95 W.	15128	Hbl-hyp gneiss	2.20 ± 0.11 Ga	K-Ar	Hypersthene	Crustal-Formation	Burwash et al., 1962
406	33093000060000	H. Hanson Oil	M. M. Mueller #2	46.9342	-98.9063	20	140 N.	65 W.	3305	Bt-qtz monzonite	2.22 Ga*	Rb-Sr	K-feldspar	Insignificant	Peterman and Hedge, 1964
1231	33105004950000	Amerada	Iverson+Nelson U. #1	48.2802	-102.9836	2	155 N.	96 W.	13603	Altered Syenite	692 Ma*	Rb-Sr	K-feldspar	Metamorphism?	Peterman and Hedge, 1964
1385	33105005180000	Amerada	N.D. "A" U. #9	48.3309	-102.9087	16	156 N.	95 W.	14825-14827	Grt-bt gneiss	530 Ma*	Rb-Sr	Biotite	Metamorphism	Peterman and Hedge, 1964
2373	33053004100000	Amerada	Antelope Unit "A" 1	48.0121	-102.7747	1	152 N.	95 W.	15128	Hbl-hyp gneiss	1.76 Ga*	Rb-Sr	K-feldspar	Metamorphism	Peterman and Hedge, 1964
3268	33007000540000	Amerada	Scoria U. #8	46.8665	-103.4129	10	139 N.	101 W.	13645	Bt-qtz monzonite	1.69 Ga*	Rb-Sr	Biotite	Metamorphism	Peterman and Hedge, 1964
1385	33105005180000	Amerada	N.D. "A" U. #9	48.3309	-102.9087	16	156 N.	95 W.	? (14796-14828)	Grt-bt gneiss	665 Ma	K-Ar	Biotite	Metamorphism	Goldich et al., 1966
3268	33007000540000	Amerada	Scoria U. #8	46.8665	-103.4129	10	139 N.	101 W.	? (13505-13750)	Bt-qtz monzonite	1.74 Ga	K-Ar	Biotite	Metamorphism	Goldich et al., 1966
20	33071000010000	Union Oil	Aanstad Str. Test #1	48.4830	-98.6665	29	158 N.	62 W.	3218-3222	Foliated bt granite	2.72 ± 0.16 Ga**	Rb-Sr	Whole Rock	Initial Crystallization?	Lidiak, 1971
6349	33075007300000	Shell Oil	Mott #14-34	48.9819	-101.9520	34	164 N.	87 W.	? (9050-9476)	Bt-grt gneiss	1.76 ± 0.10 Ga	Rb-Sr isochron	Whole rock	Metamorphism	Peterman and Goldich, 1982
6624	33075007630000	Shell Oil	Osterberg #22X-1	48.8029	-101.6418	1	161 N.	85 W.	? (9310-9509)	Hyp granulite	1.64 ± 0.12 Ga	U-Pb	Zircon	Metamorphism	Peterman and Goldich, 1982
6624	33075007630000	Shell Oil	Osterberg #22X-1	48.8029	-101.6418	1	161 N.	85 W.	? (9310-9509)	Hyp granulite	2.95 ± 0.32 Ga	U-Pb	Zircon	Initial Crystallization	Peterman and Goldich, 1982
6684	33075007660000	Shell Oil	Osterberg #21-2	48.8050	-101.6622	2	161 N.	85 W.	? (9263-9375)	Grt-bt-crd gneiss	1.75 ± 0.04 Ga	U-Pb	Zircon	Metamorphism	Peterman and Goldich, 1982
6684	33075007660000	Shell Oil	Osterberg #21-2	48.8050	-101.6622	2	161 N.	85 W.	? (9263-9375)	Grt-bt-crd gneiss	1.97 Ga*	Rb-Sr isochron	Whole rock	Insignificant	Peterman and Goldich, 1982
6684	33075007660000	Shell Oil	Osterberg #21-2	48.8050	-101.6622	2	161 N.	85 W.	? (9263-9375)	Grt-bt-crd gneiss	2.88 ± 0.11 Ga	U-Pb	Zircon	Initial Crystallization	Peterman and Goldich, 1982
1231	33105004950000	Amerada	Iverson+Nelson U. #1	48.2802	-102.9836	2	155 N.	96 W.	13595-13609	Altered Syenite	4.1 ± 0.4 Ma	Fission-track	Apatite	Insignificant	Crowley et al., 1985
20	33071000010000	Union Oil	Aanstad Str. Test #1	48.4830	-98.6665	29	158 N.	62 W.	3218-3222	Foliated bt granite	471 ± 19 Ma	Fission-track	Apatite	Exhumation	Crowley et al., 1985
27	33019000010000	Union Oil	Chris Skjervheim #1	48.5719	-98.7950	28	159 N.	63 W.	3395-3409	Bt gneiss	539 ± 23 Ma	Fission-track	Apatite	Exhumation	Crowley et al., 1985
-	-	Bendix	RRVD #16	48.0685	-97.5476	14	153 N.	54 W.	1079-1093	Granodiorite gneiss	554 ± 24 Ma	Fission-track	Apatite	Exhumation	Crowley et al., 1985
-	-	Bendix	RRVD #18	48.3529	-97.2310	8	156 N.	51 W.	649-659	Foliated granodiorite	545 ± 25 Ma	Fission-track	Apatite	Exhumation	Crowley et al., 1985
-	-	Bendix	RRVD #19A	48.4717	-97.6649	30	158 N.	54 W.	1292-1299	Granitic gneiss	542 ± 22 Ma	Fission-track	Apatite	Exhumation	Crowley et al., 1985
2219	33090004180000	California Co.	Bert Henry #4	48.7939	-100.9636	6	161 N.	79 W.	7273-7287	Hbl schist	328 ± 13 Ma	Fission-track	Apatite	Insignificant	Crowley et al., 1985
27	33019000010000	Union Oil	Chris Skjervheim #1	48.5719	-98.7950	28	159 N.	63 W.	? (3406-3409)	Bt gneiss	2.68 Ga	Sm-Nd model age	Whole Rock	Crustal-Formation	Sim et al., 1991
406	33093000060000	H. Hanson Oil	M. M. Mueller #2	46.9342	-98.9063	20	140 N.	65 W.	3305	Bt-qtz monzonite	2.41 Ga	Rb-Sr model age	Whole Rock	Metamorphism	Sim et al., 1991
406	33093000060000	H. Hanson Oil	M. M. Mueller #2	46.9342	-98.9063	20	140 N.	65 W.	3305	Bt-qtz monzonite	2.67 Ga	Sm-Nd model age	Whole Rock	Crustal-Formation	Sim et al., 1991
1231	33105004950000	Amerada	Iverson-Nelson U. #1	48.2802	-102.9836	2	155 N.	96 W.	13603	Altered Syenite	980 Ma	Sm-Nd model age	Whole Rock	Crustal-Formation?	Sim et al., 1991
2373	33053004100000	Amerada	Antelope Unit "A" 1	48.0121	-102.7747	1	152 N.	95 W.	15128	Hbl-hyp gneiss	1.81 Ga	Rb-Sr model age	Whole Rock	Metamorphism	Sim et al., 1991
2373	33053004100000	Amerada	Antelope Unit "A" 1	48.0121	-102.7747	1	154 N.	95 W.	15128	Hbl-hyp gneiss	2.17 Ga	Sm-Nd model age	Whole Rock	Crustal-Formation	Sim et al., 1991
6349	33075007300000	Shell Oil	Mott #14-34	48.9819	-101.9520	34	164 N.	87 W.	? (9050-9476)	Bt-grt gneiss	1.67 ± 0.06 Ga	K-Ar	Biotite	Metamorphism	Sim et al., 1991
6349	33075007300000	Shell Oil	Mott #14-34	48.9819	-101.9520	34	164 N.	87 W.	? (9050-9476)	Bt-grt gneiss	1.68 ± 0.04 Ga	Rb-Sr	Biotite	Metamorphism	Sim et al., 1991
6624	33075007630000	Shell Oil	Osterberg #22X-1	48.8029	-101.6418	1	161 N.	85 W.	? (9310-9509)	Hyp granulite	1.66 Ga	Rb-Sr	Biotite	Metamorphism	Sim et al., 1991
9522	33009015540000	Coastal O&G	Bjornseth #12-21	48.7570	-100.6613	21	161 N.	77 W.	(6600-6626)	Bt Gneiss	2.76 Ga	Sm-Nd model age	Whole Rock	Crustal-Formation	Sim et al., 1991

Table 1. Summary of radiometric ages from North Dakota's Precambrian basement. The radiometric ages are color coated based on their geologic significance: red = age of initial crustal-formation and/or crystallization, green = age of metamorphism, brown = age of exhumation (uplift and erosion), and blue = insignificant age. Rb-Sr ages tend to be insignificant because the Rb-Sr radioactive isotopic system tends to be unreliable (Dickin, 2005). The fission track ages from Amerada Petroleum's Iverson-Nelson Unit #1 and Bert Henry #4 are considered insignificant because the analyzed samples were collected from depths with temperatures near or above the Fission Track closure temperature of Apatite. Mineral abbreviations include: bt = biotite, crd = cordierite, ep = epidote, grt = garnet, hbl = hornblende, hyp = hypersthene, qtz = quartz. *Radiometric age revised by Sims et al., 1991. **Calculated with a Rb-Sr half-life of 50.0 b.y. (billion years), which is slightly older than the Rb-Sr half-life currently used (48.8 b.y. - Dickin, 2005). Therefore, the reported age is probably too old by ~0.05 Ga and should be ~2.67 Ga.