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Preliminary investigation into the natural hydrogen generation potential of Precambrian rocks beneath the Williston Basin, southwestern Manitoba (parts of NTS 62G, J, K, O, 63B, C, G, K)

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In Brief:

- Precambrian samples were analysed and used to calculate their hydrogen generation potential by the radiolysis pathway
- Results will be integrated into a basin-scale hydrogen generation model lead by the Geological Survey of Canada

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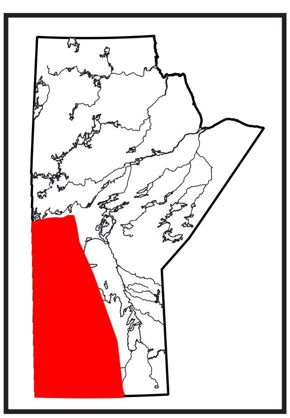

Summary

Molecular hydrogen (H_2) in the continental crust is generated through two main reaction pathways: 1) rock-water interactions (i.e., serpentinization) and 2) water radiolysis from the radioactive decay of U- and Th-rich minerals. Samples of Precambrian drillcore from the crystalline basement of the Williston Basin in Manitoba were collected and analyzed for whole-rock lithogeochemistry to confirm lithology and their hydrogen generation potential was assessed using a Monte Carlo radiolysis model. Helium (He) is a critical mineral also formed through the radiolysis reaction and can be used as a proxy for natural hydrogen exploration. From this small, limited sample set, hydrogen generation rates from radiolysis (reported as minimum/mean/maximum) are estimated to be 0.05/7.84/88.40 mol H_2/km^3/year for felsic rocks, 0.03/6.16/37.30 mol H_2/km^3/year for intermediate rocks, 0.001/2.86/25.30 mol H_2/km^3/year for mafic rocks and 0.06/6.31/28.90 mol H_2/km^3/year for iron formation. Refinement and further interpretations of the hydrogen generation potential of the basement will be integrated into a larger hydrogen generation model for the Western Canada Sedimentary Basin, a project led by the Geological Survey of Canada.

Introduction

Elevated hydrogen values (1.46–8.50 mol. % H_2) have been identified in oil and gas wells in Manitoba's Williston Basin sedimentary strata (Figure GS2025-10-1; Nicolas, 2024). The source of the hydrogen trapped within these sedimentary reservoirs is uncertain. Molecular hydrogen as free gas is rare in nature due to its high reactivity with other elements, its small molecule size, which makes it difficult to trap and accumulate (Zgonnik, 2020; Ballentine et al., 2025), and its consumption by subsurface microbiomes (Stevens and McKinley, 1995; Sherwood Lollar et al., 2007). Hydrogen is primarily generated in the crust through rock-water redox reactions (i.e., serpentinization), water radiolysis from the radioactive decay of U and Th hosted in minerals (Sherwood Lollar et al., 2014; Ballentine et al., 2025) or from high thermal maturity and decomposition of organic matter (Mahlstedt et al., 2022; Boreham et al., 2023). In southwestern Manitoba, beneath the sedimentary rocks of the Williston Basin, Precambrian rocks are likely the best source of hydrogen, along with highly organic-rich shale within the sedimentary strata being a possible source and/or caprock.

For this study, samples of Precambrian crystalline basement beneath the sedimentary cover were collected from several drillcore that penetrated the Precambrian basement (Figure GS2025-10-1). These samples were cut into thin sections and the geochemistry was determined to allow for an evaluation of the mineralogy and chemical composition of each sample, which allows for an estimation of hydrogen generation potential via radiolysis. This work is part of a larger project led by the Geological Survey of Canada (Calgary, Alberta) to model the hydrogen generation potential of the crystalline basement of the Western Canada Sedimentary Basin (WCSB).

Methodology and results

To select drillcore for sampling, an inventory of all the Precambrian drillcore was compiled from Bezys and Conley (1998) and McGregor (2011) and through searches conducted on the Manitoba Oil and Gas Information System (MOGWIS; Manitoba Business, Mining, Trade and Job Creation, internal database) and geoLOGIC systems ltd.'s geoSCOUT™. Only drillcore from within the Williston Basin that was stored at the Manitoba Geological Survey Midland Sample and Core Library (Winnipeg, Manitoba) were selected for further consideration. If only one drillcore was identified in a large area, it was tagged for sampling. If more than one drillcore from a small area was identified, only one drillcore

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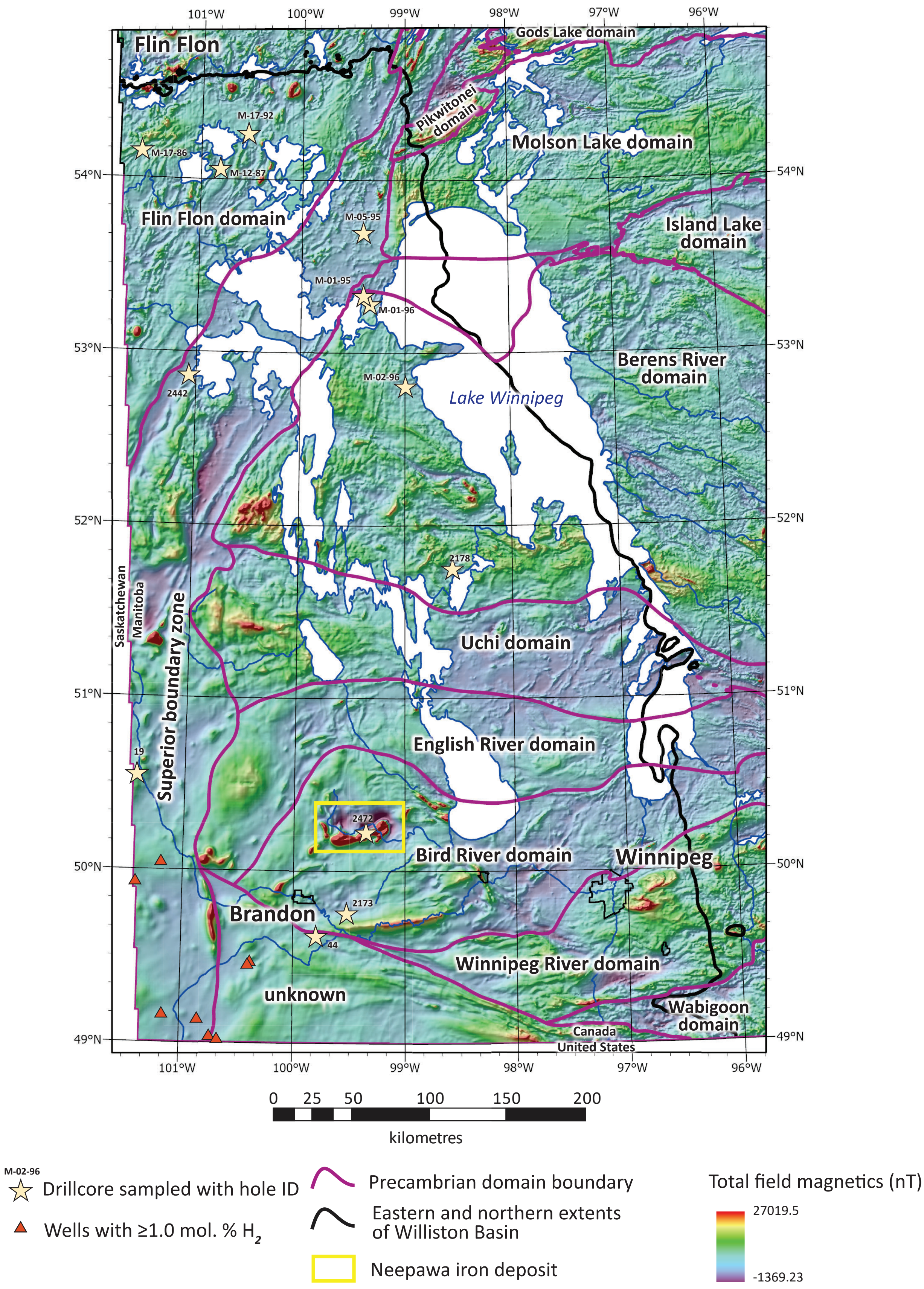

Figure GS2025-10-1: *Shaded total field magnetic anomaly map of the Williston Basin in southwestern Manitoba (Manitoba Business, Mining, Trade and Job Creation, 2025) showing the Precambrian domain boundaries (from McGregor, 2013), hydrogen gas shows in oil and gas wells (Nicolas, 2024) and the locations of the drillcore sampled for this study. Abbreviation: nT, nanotesla.*

with the thickest and best preserved Precambrian section was selected for sampling. In the areas with less drillcore availability, especially in the southern half of the study area, and to ensure a good geographic distribution of samples, all Precambrian drillcore in those areas were selected for sampling; this resulted in an unintentional sample bias toward felsic rock lithologies. In addition, only a very short drillcore section (<50 cm) of the Neepawa iron formation, at L.S. 15. Sec. 29, Twp. 14, Rge. 14, W 1st Mer. (abbreviated 15-29-14-14W1), was available for sampling. Due to its high iron content and hydrogen generation potential, this was a core of particular interest from a hydrogen modelling perspective.

For each drillcore, one to three samples were selected in the Precambrian portion based on lithological variations. If the lithology in the drillcore was similar throughout, one sample interval was selected. If a drillcore showed varying lithologies or major changes in grain size (e.g., granite versus pegmatite), one sample location per major lithological or grain-size change was selected. In addition, if a drillcore was particularly long, multiple samples from similar lithologies were selected but they were taken far apart from each other. A sample size of 3–4 cm long and a half to one-third of the core diameter was cut using a rock saw, or a broken piece of core was taken, if available. Sample depths were recorded and photographs of the core and the cut samples were taken.

A total of 22 samples were sent to the Geological Survey of Canada (Calgary, Alberta) for further selection and processing. From those samples, a smaller suite of 16 samples was selected based on lithological uniqueness. If the same core had multiple samples from various depths, only those which appeared to be different lithologies were sent for further processing, and the other samples were kept in archive for future consideration. A thin section of each sample was made and a subsample was sent for geochemical characterization at Activation Laboratories Ltd. (Ancaster, Ontario). The proportions of major, minor and trace elements were measured using inductively coupled plasma–optical emission spectroscopy (ICP-OES) and inductively coupled plasma–mass spectroscopy (ICP-MS), following fusion digestion with lithium metaborate/tetraborate. The lithogeochemistry results for the 16 samples are reported in Nicolas et al. (2025[1]). The geochemistry results were used to classify each sample based on their composition (felsic, >63% SiO_2; intermediate, 52–63% SiO_2; mafic, 45–52% SiO_2; ultramafic, <52% SiO_2) or, in instances of intense metamorphism/alteration, a possible original lithological interpretation. This information was then used to assign a lithology to the samples in the model (Table GS2025-10-1).

Hydrogen generation potential through the radiolysis reaction pathway was calculated using 'Radiolysis', an R package (D. Coutts, O. Warr, O. Ardakani and B. Sherwood Lollar, unpublished paper, 2025), for the 16 samples, which follows the Monte Carlo methods of Warr et al. (2023). Each sample was modelled individually to determine a realistic range of hydrogen generation rates. The model of Warr et al. (2023) and subsequent code of D. Coutts, O. Warr, O. Ardakani and B. Sherwood Lollar (unpublished paper, 2025) require inputs for U, Th and K concentrations, rock properties (density and porosity) and fluid density. These are input as truncated normal distributions (minimum/maximum/mean/standard deviation). In this case, U, Th and K concentrations were not modelled as truncated distribution (i.e., a standard deviation of zero, minimum and maximum concentrations set at 0 and 100, respectively, and a mean of the distribution set to the measured concentration) as these values were determined by lithogeochemical analysis. Rock properties (porosity and grain density) were taken from summarized data of Enkin (2018) for matching lithologies. Fluid density was given an appropriate range following Warr et al. (2023), which was set at 1.1 g/cm^3, with a standard deviation of 0.5 g/cm^3, and minimum and maximum values of 1 and 1.37 g/cm^3, respectively. The sample parameters used for modelling and the estimated hydrogen generation rates via radiolysis are presented in Table GS2025-10-1. The Monte Carlo models consisted of 1000 simulations per sample. These results are further summarized by grouping the output simulations based on composition (e.g., felsic, mafic) and finding the minimum, mean and maximum hydrogen generation rates.

Discussion

This initial analysis of Precambrian core demonstrates some relationships between hydrogen potential and lithology (Figures GS2025-10-2, -3), however, this sample set is small and limited in lithological variability, adding bias to the results. The U and Th content is higher in felsic rock samples, with a mean range of 1.38–21.18 combined ppm, which is expected due to magmatic differentiation (Whitfield et al., 1959; Sheng et al., 2025). Sample 106-25-M1786-67 is anomalous as it has a combined U and Th mean value of 66.6 ppm, which skews the results for felsic lithologies. This high value could be due to the presence of a single columbite grain; this will be verified in the thin section. Intermediate and mafic rocks samples have higher Fe and Mg values (5.87–12.34 wt. % Fe_2O_3 + MgO for intermediate; 9.78–23.96 wt. % Fe_2O_3 + MgO for mafic) and generally lower U and Th values (0.85–4.37 combined ppm for intermediate; 0.27–1.63 combined ppm for mafic), with no significant difference between intermediate and mafic rocks. However, sample 106-25-M296-157 is classified as an intermediate sample due to its SiO_2 content but plots similar to felsic rocks in the variation diagram in Figure GS2025-10-2; this inconsistency is likely due to alteration

[1] GS Data Repository Item DRI2025022, containing the data or other information sources used to compile this report, is available online to download free of charge at https://manitoba.ca/iem/info/library/downloads/index.html, or on request from minesinfor@gov.mb.ca, or by contacting the Resource Centre, Manitoba Business, Mining, Trade and Job Creation, 360-1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada.

Table GS2025-10-1: Sample parameters used for modelling and the hydrogen generation potential of samples by radiolysis calculated using the 'Radiolysis' R package; each sample was treated as an individual Monte Carlo model. Samples from Precambrian drillcore from beneath the Williston Basin, southwestern Manitoba. For all samples, fluid density was set at 1.1 g/cm^3 with a standard deviation (SD) of 0.5 g/cm^3, and a minimum (min) and maximum (max) value of 1 and 1.37 g/cm^3, respectively; minimum and maximum concentrations of U, Th and K were set at 1 and 100, respectively, with a standard deviation of zero. Abbreviation: IUGS, International Union of Geological Sciences.

Hole ID	Sample ID	Sample description	IUGS[1] classification	Model lithology	U (ppm)	Th (ppm)	K (wt. %)	H_2 generation (mol/km^3/year)			
					Mean	Mean	Mean	Min	Max	Mean	SD
44	106-25-44-3824	Granodiorite	Felsic	Granodiorite	0.65	3.37	1.81	0.05	13.10	3.77	2.39
19	106-25-19-4452	Granite gneiss	Felsic	Orthogneiss	1.12	6.55	2.58	0.37	8.35	2.83	1.58
2178	106-25-2178-318	Granite (altered)	Felsic	Granite	0.96	10.80	3.05	0.18	13.70	4.39	2.38
M-01-96	106-25-M196-166	Alkali granite	Felsic	Granite	0.54	0.84	1.41	0.05	4.36	1.42	0.80
M-05-95	106-25-M595-145	Sericitized granite	Felsic	Granite	1.77	3.22	9.59	0.28	26.10	8.39	4.99
M-12-87	106-25-M1287-95	Granodiorite	Felsic	Granodiorite	2.15	9.36	3.55	0.12	33.30	8.97	5.62
M-12-87	106-25-M1287-103	Granite biotite gneiss with pegmatite inclusion	Felsic	Orthogneiss	5.26	5.17	3.60	0.71	15.80	5.39	2.78
M-17-86	106-25-M1786-66	Granite biotite gneiss	Felsic	Orthogneiss	3.18	2.69	1.81	0.38	8.82	2.89	1.58
M-17-86	106-25-M1786-67	Pegmatitic granite	Felsic	Granite	36.40	30.20	6.80	1.17	88.40	30.70	17.30
M-17-92	106-25-M1792-64	Pegmatitic granite	Felsic	Granite	4.08	17.10	6.76	0.33	32.70	9.67	5.46
2472	106-25-2472-764	Iron formation	Iron formation	Metasedimentary - siliciclastic	1.25	4.19	3.81	0.06	28.90	6.31	4.48
M-02-96	106-25-M296-157	Syenodiorite (altered)	Intermediate	Diorite	0.73	3.64	7.67	0.08	37.30	10.40	6.91
2442	106-25-2442-1125	Diorite	Intermediate	Diorite	0.18	0.67	1.39	0.03	7.12	1.92	1.29
2173	106-25-2173-973	Mafic tectonite (metabasalt?)	Mafic	Metavolcanic - mafic	0.68	0.54	2.04	0.03	9.26	2.35	1.62
2173	106-25-2173-976	Mafic tectonite (meta-syenodiorite or meta-trachy-andesite?)	Mafic[2]	Metavolcanic - mafic	1.02	0.61	6.33	0.06	25.30	6.17	4.46
M-01-95	106-25-M195-149	Pyroxene-hornblende gabbro	Mafic	Gabbro	0.05	0.22	0.08	0.00	0.22	0.07	0.04

[1] With the exception of sample 106-25-2472-764

[2] IUGS classification indicates intermediate composition, but other geochemical signatures suggest an original mafic composition more similar to sample 106-25-2173-973.

and leaching, which was visible in the hand sample, suggesting the original rock composition may have been more felsic.

Hydrogen generation rates from radiolysis for this sample set is shown in Figure GS2025-10-3 and are estimated to be (reported as minimum/mean/maximum) 0.05/7.84/88.40 mol H_2/km^3/year for felsic rocks, 0.03/6.16/37.30 mol H_2/km^3/year for intermediate rocks, 0.001/2.86/25.30 mol H_2/km^3/year for mafic rocks, and 0.06/6.31/28.90 mol H_2/km^3/year for iron formation. Intermediate, mafic and iron formation samples will be dominated by the rock-water interaction pathway of hydrogen generation, therefore the generation rates for those samples using the radiolysis model are expected to be lower. Samples with higher concentrations of U and Th, such as felsic to some intermediate rocks, indicate that radiolysis would be the dominant pathway of hydrogen generation, which is further demonstrated by the output of the Monte Carlo models. There are currently no accessible and efficient numeric models to estimate hydrogen generation rates through water-rock interactions for hydrogen prospectivity. Knowing which samples are more likely to generate hydrogen by a specific pathway, or combination thereof, will help provide parameters and inform mathematical models toward the gross estimation of hydrogen generation over time.

A detailed discussion on the hydrogen generative potential of these samples is beyond the scope of this report. These results will be incorporated into a WCSB-wide model, a project led by the Geological Survey of Canada.

Economic considerations

Understanding natural hydrogen generation and occurrences as a potential resource in Manitoba is important to the economic growth of the province. While hydrogen is still a new economic consideration for most of the world (Ballentine et al., 2025), breaking down and evaluating the science behind hydrogen generation in a region—such as the hydrogen generation capacity of the Canadian Shield—is critical to inform future exploration decisions and drill target identification, minimizing risk and maximizing success. Along with hydrogen source rocks,

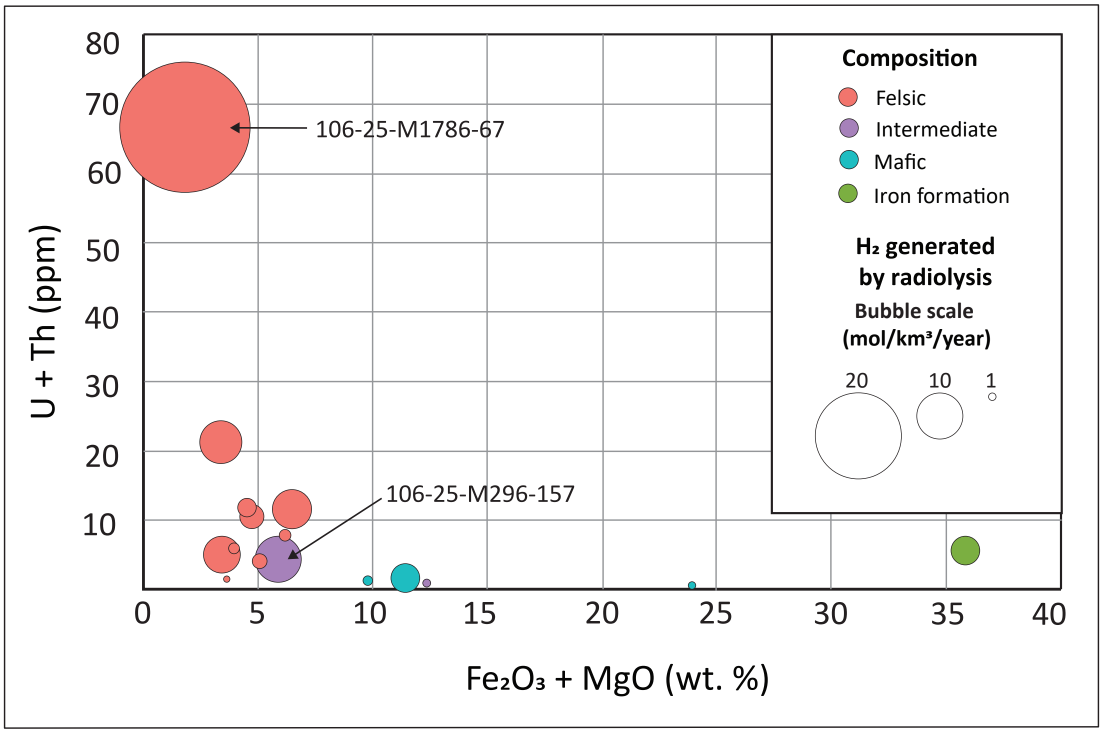

Figure GS2025-10-2: *Variation diagram showing the differentiation of U + Th as a function of the Fe_2O_3 + MgO content of the sample and their respective modelled hydrogen generation rates. Samples from Precambrian drillcore from beneath the Williston Basin, southwestern Manitoba. Felsic lithologies have >63% SiO_2, intermediate lithologies have 52–63% SiO_2, mafic lithologies have 45–52% SiO_2. Iron formation is highlighted on its own. Sample 106-25-M1786-67 is considered anomalous due to the likely presence of a columbite grain, and sample 106-25-M296-157 showed evidence of alteration and leaching.*

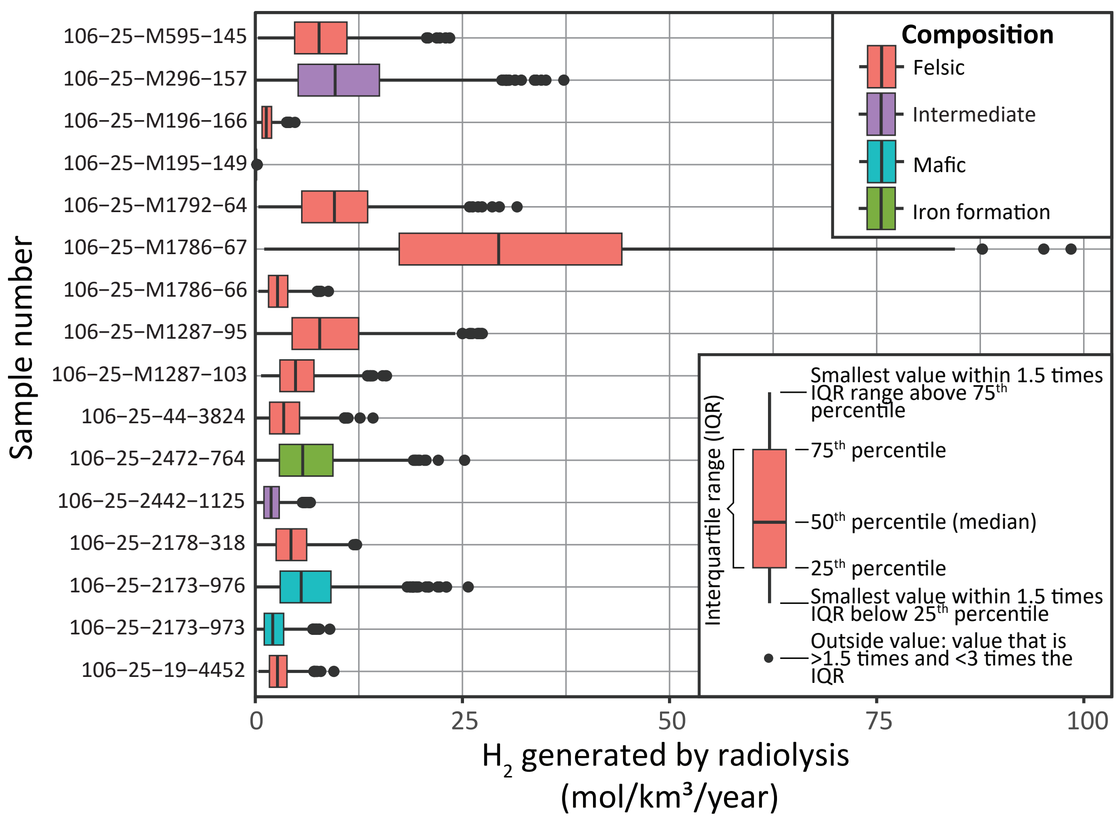

Figure GS2025-10-3: *Boxplot of sample bulk rock compositions and their modelled hydrogen generation rates. Samples from Precambrian drillcore from beneath the Williston Basin, southwestern Manitoba.*

an understanding of the Williston Basin's reservoirs and seals / cap rocks is necessary for derisking and characterizing the hydrogen system. It is important to emphasize one of the byproducts of the radiolysis process is helium, a critical mineral, which can be used as a proxy in natural hydrogen exploration.

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