HOW OLD IS NORTH DAKOTA?

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Introduction

The universe is theorized to be over 13 billion years old, beginning when extremely hot and dense matter started to rapidly expand (Big Bang Model). Earth began forming approximately 4.6 billion years ago when parts of a protoplanetary disk (our early solar system) merged together by electrostatic attraction and gravity into a large spherical mass. You have probably heard about the age of the universe and Earth before, but have you ever stopped to wonder, how old is North Dakota?

While North Dakota became a state in 1889, the physical/geological components that make the surface and subsurface have been in existence for a much longer period of time. For the rest of this article, the term North Dakota will refer to the surface and subsurface geological components that make up the state.

The surface of North Dakota is covered by glacial and non-glacial sedimentary rocks that were deposited from about 100 million years ago up to the present day. Beneath this surface are numerous sedimentary rock layers (including those of the Williston Basin) that consist of sandstone, limestone, shale, etc.; that were deposited one on top of another all within the past 500 million years (fig. 1). Beneath these sedimentary layers, however, is a different, much older and mysterious group of rocks referred to as the Precambrian basement (fig. 1).

What is the Precambrian Basement?

Essentially, the Precambrian basement is the foundation of North Dakota, and consists of various igneous and metamorphic rocks (fig. 2) that formed over 500 million years ago, prior to the deposition of the Deadwood Formation (fig. 1). Over 330 petroleum exploration, mineral exploration, and water test wells have penetrated basement rocks in North Dakota (Anderson, 2007). Many of the significant oil-producing structures in North Dakota (such as the Nesson, Little Knife, and Billings anticlines) are believed to have formed as a result of movement (faulting) within the Precambrian basement.

Numerous ages have been produced from Precambrian basement samples using various radiometric dating techniques. This article will give a brief review of radiometric dating and discuss the radiometric ages relevant to determining the age of North Dakota.

Radiometric Dating

Many types of rock can be dated successfully using radiometric dating, a technique developed in the early 1900s after the discovery of radioactive decay in 1896 by A. Henri Becquerel, a French chemist. Radioactive decay refers to unstable "parent" isotopes changing into stable "daughter" isotopes (for example ^{40}K, a radioactive isotope of potassium, decays to the nonradioactive argon isotope ^{40}Ar). The decay rate of radioactive isotopes is

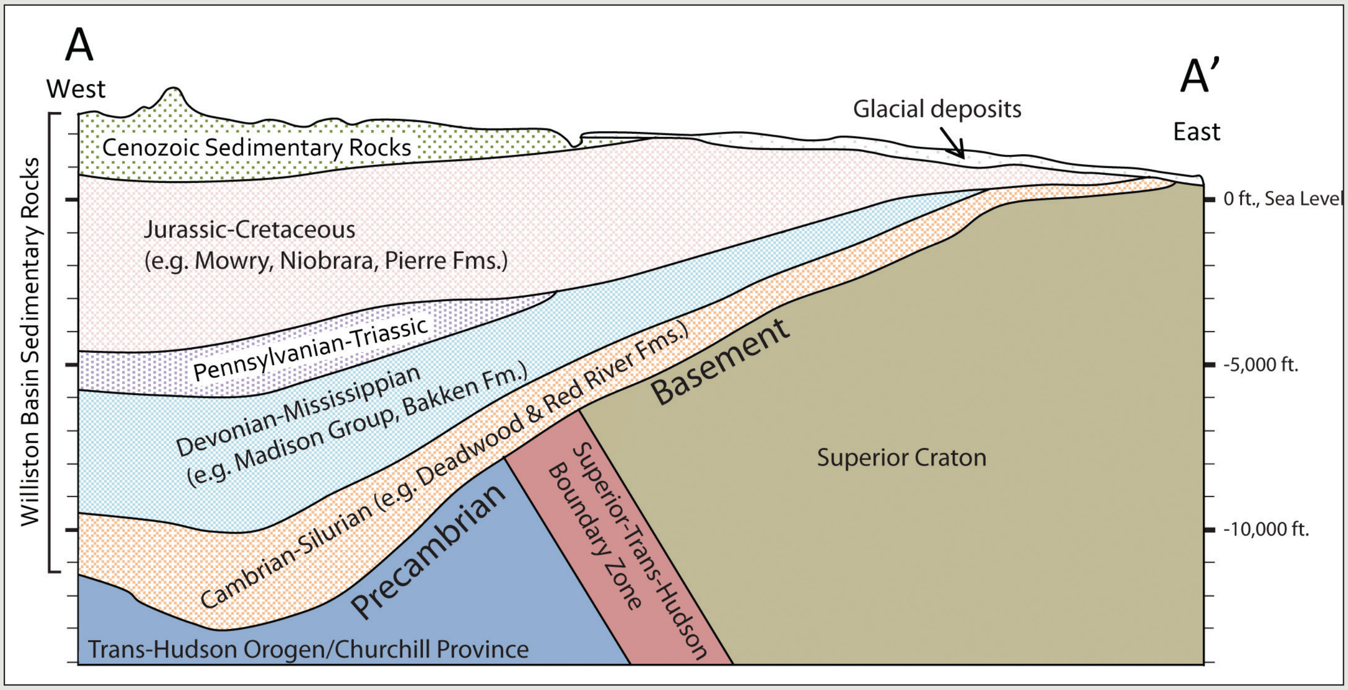

Figure 1. East-West cross section of North Dakota showing the approximate domains of the Precambrian basement units. The locations of A & A' are shown in figure 4.

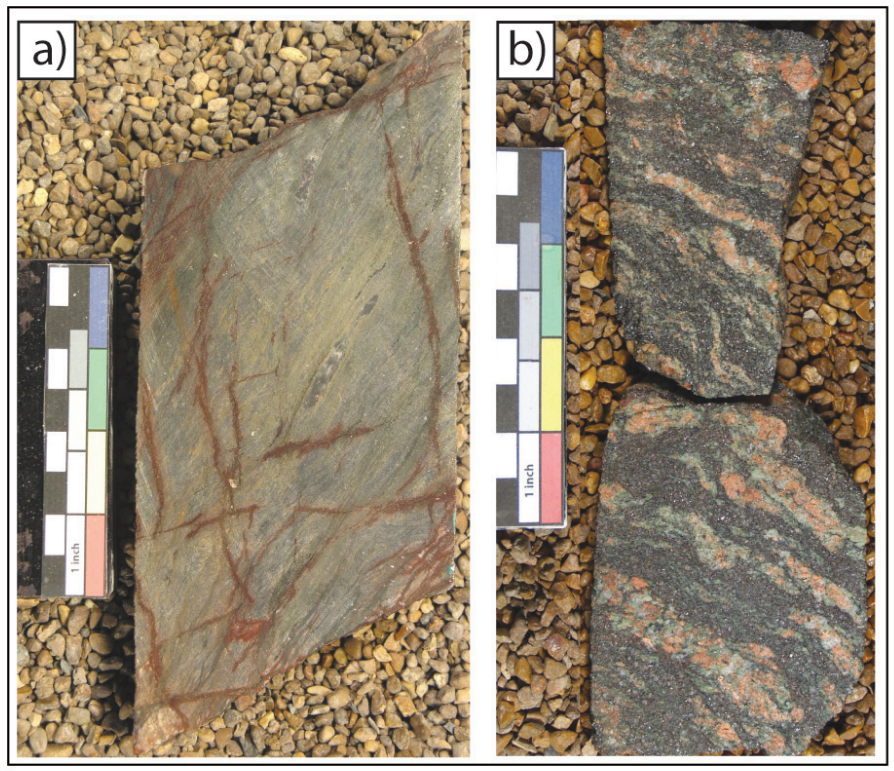

Figure 2. Examples of core from North Dakota's Precambrian basement. a) Biotite gneiss from Shell Oil Company's Mott #32X-3 (NDIC #6466) of Renville County taken from a depth of 9,211 feet below the surface. b) Chlorite Schist from Atlantic Richfield Company's Wunderlich #1 (NDIC #8803) of McHenry County taken from a depth of 8,784 feet below the surface.

measured in half-lives, which is the time it takes half the atoms of the parent isotope to change (decay) into the daughter isotope. For example, the $^{40}K/^{40}Ar$ half-life is 11.93 billion years (Steiger and Jäger, 1977), which means that if we had 100 atoms of ^{40}K, it would take 11.93 billion years for 50 of them to decay to ^{40}Ar.

Most rocks contain traces of many different radioactive isotopes, each with their own parent-daughter isotopic set. Each parent-daughter set can be thought of as a separate stop watch or "rock clock" that has been ticking through time (fig. 3). By measuring the parent to daughter isotope ratios, these "rock clocks" can be used to calculate the amount of time that has passed since particular types of geologic events took place. When determining the type of geologic event that a particular "rock clock" correlates with, the radiometric system of the clock must be examined in combination with the local and regional geology.

The $^{40}K/^{40}Ar$ clock is commonly used to date gneisses, granites and volcanic rocks. The $^{40}K/^{40}Ar$ clock is reset in a rock when temperatures rise above ~375°C (Berger and York, 1981) and will only resume "ticking" once temperatures cool below ~375°C. In an active mountain belt such as the Himalayas, where India is colliding with southern China, gneisses may be heated above and cooled below ~375°C several times as they undergo multiple cycles of burial, erosion, and other tectonic-related processes. The $^{40}K/^{40}Ar$ age of a gneiss should be interpreted as a metamorphic cooling age. In other situations, lava could erupt from a volcano and remain cooled near the surface as basalt, or granite could crystallize from magma at depth and reach the surface through erosion with minimal reheating. Both the described basalt and granite would produce $^{40}K/^{40}Ar$ ages that correlate with initial crystallization.

For example, if magma cooled to form a piece of granite 20 million years ago and that granite remained at temperatures below ~375 °C until the present day, the $^{40}K/^{40}Ar$ clock would produce an age of 20 million years old. However, if that 20 million-year-old granite was heated above and cooled below ~375 °C around 8 million years ago, and then remained cooled until the present day,

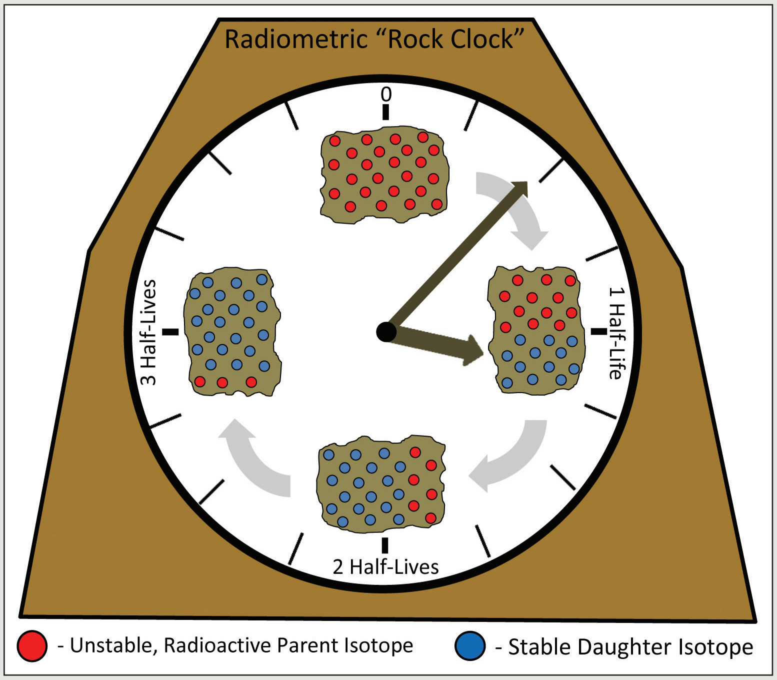

Figure 3. Illustration depicting the change in parent to daughter isotopic ratio within a radioactive decay series over the course of three half-lives. Over the duration of each half-life, which varies between each isotopic system from fractions of a second to billions of years, half of the unstable parent isotopes (red dots) decay into stable daughter isotopes (blue dots).

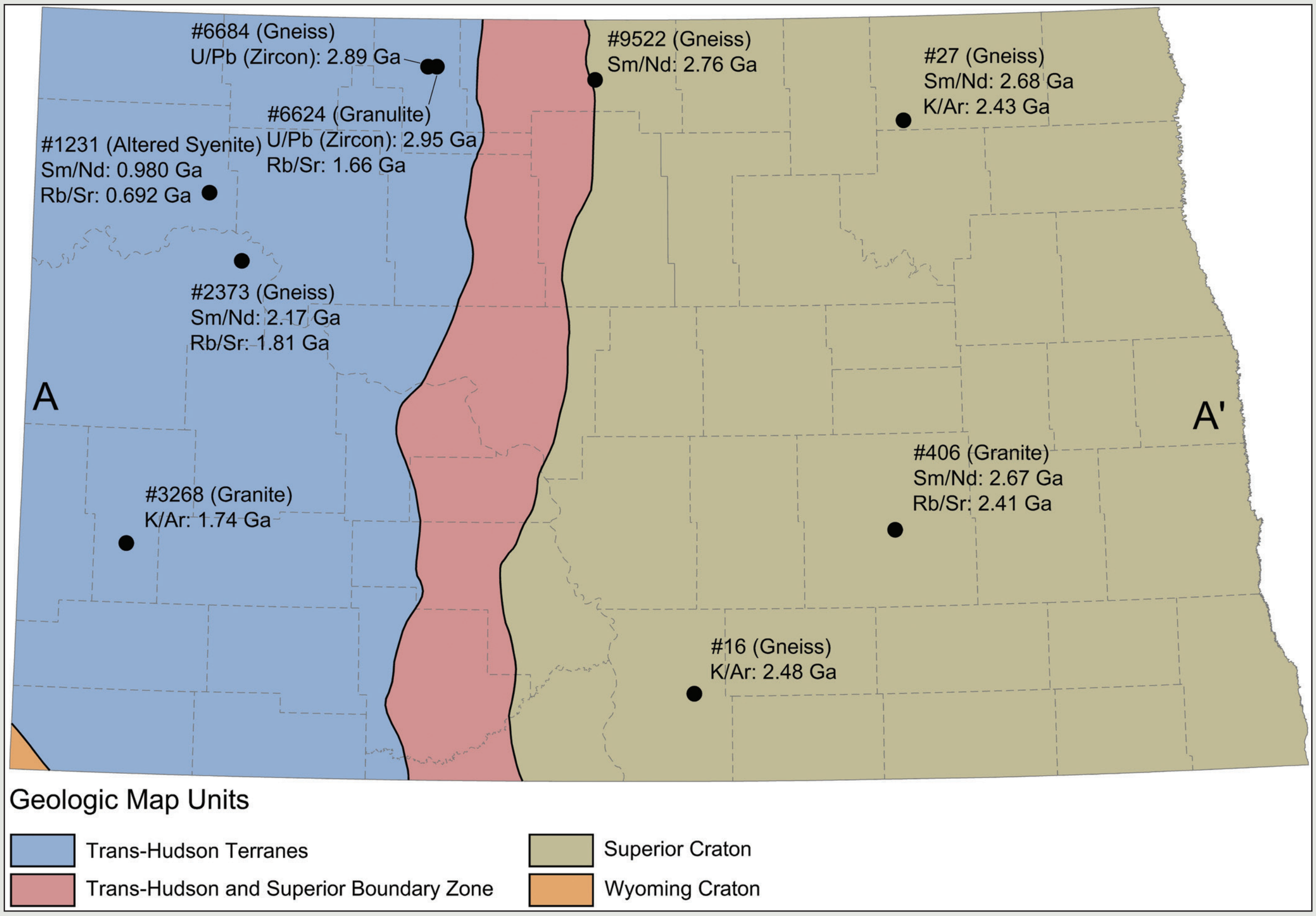

Figure 4. Geologic map of North Dakota's Precambrian basement with the locations of the radiometric dates referred to in this article. Each well location is shown by a black circle. Next to each well symbol is the North Dakota Industrial Commission well number, the rock type that was dated, the radiometric system used, and the calculated age of the rock in Ga (billions of years before present). Uranium/lead (U/Pb) ages are similar to samarium/neodymium (Sm/Nd) ages (initial crystallization) and rubidium/strontium (Rb/Sr) ages are similar to K/Ar ages (reheating events). A & A' show the locations of the edges of the figure 1 cross section. The geology and radiometric dates are from Sims et al., 1991.

the $^{40}K/^{40}Ar$ clock would produce an age of only 8 million years old. $^{40}K/^{40}Ar$ ages from North Dakota's Precambrian basement typically correlate with post-crystallization heating that took place during tectonic plate collisions.

Another type of radiometric dating, ^{147}Samarium → ^{143}Neodymium ($^{147}Sm/^{143}Nd$), is better suited for determining the age of initial crystallization for granites and gneisses. The $^{147}Sm/^{143}Nd$ rock clock can only be reset if temperatures within a rock rise above at least 800° C, a temperature that would melt most rocks and is very rarely achieved in Earth's crust (Whitehouse, 1988). For example, if a body of granite crystallized from magma 20 million years ago and was significantly reheated only once at 8 million years ago, the $^{147}Sm/^{143}Nd$ age of that granite would be 20 million years (initial crystallization) whereas the $^{40}K/^{40}Ar$ age would be 8 million years (reheating event). We will examine when North Dakota's Precambrian basement rocks crystallized from magma and when they were last significantly reheated by combining radiometric ages such as $^{147}Sm/^{143}Nd$ and $^{40}K/^{40}Ar$.

The Age of North Dakota

During the 1960s through the 1990s, several studies by the United States Geological Survey (USGS) examined granites and gneisses from North Dakota's Precambrian basement using radiometric dating (Sims et al., 1991 and references within). Figure 4 shows the locations and radiometric ages for several of the rock samples analyzed by the USGS. The ages produced by the USGS vary from nearly three billion years to only seven hundred million years old - a span of over two billion years. Why do these ages vary so much?

The Precambrian basement of North Dakota has a prolonged geologic history which differs between the eastern and western parts of the state. Eastern North Dakota's basement consists of the Superior Craton (figs. 1, 4, and 5), which is a very old and stable piece of continental crust composed primarily of granites and granitic gneisses with some volcanic rock. According to the $^{147}Sm/^{143}Nd$ ages, the granites and other igneous rocks of eastern North Dakota's Precambrian basement all crystallized around 2.7 billion years ago (fig. 4). The $^{40}K/^{40}Ar$ ages indicate that significant reheating occurred throughout most of eastern North Dakota's basement approximately 2.4 billion years ago (fig. 4), which may have been when the Superior Craton formed through plate tectonic activity.

Western North Dakota's Precambrian basement is made up of multiple geologic terranes of different ages that were merged with the Superior Craton by tectonic plate movement. The western part of the basement consists of several distinct magmatic and oceanic terranes (like Japan) that crystallized independently from one another between about 2.9 and 2.2 billion year ago (fig. 5a). Based on numerous ~1.8 billion years old $^{40}K/^{40}Ar$ ages (fig. 4), these terranes were added (accreted) to the western side of the Superior Craton during the Trans-Hudson Orogeny (figs. 5b and 5c). The Trans-Hudson Orogeny was a mountain-building event that took place as the Superior Craton moved toward the Wyoming Craton (which today underlies part of west-central North America, including parts of Montana, Wyoming, southern Alberta and Saskatchewan) and closed up a relict ocean approximately 1.8 billion years ago (figs. 5b and 5c).

The 0.980 billion year $^{147}Sm/^{143}Nd$ age is thought to represent a later, localized magmatic event (fig. 4). This age and other young (<1.0 Ga) radiometric ages have been produced from basement rocks along the Nesson Anticline in eastern Williams County (fig. 4). The geologic setting of this later magmatic event is poorly understood, but could have been similar to the present-day Yellowstone hotspot.

Using the information reviewed in this article, there are three ways to look at the geologic age of North Dakota's foundation, the Precambrian basement. 1) The oldest known geologic terrane in North Dakota's basement consists of gneiss, which initially crystallized from magma approximately 2.9 billion years ago. 2) The youngest known geologic terrane within the Precambrian basement, also gneiss, crystallized around 2.2 billion years ago. 3) The various geologic terranes that make up the Precambrian basement finished merging around 1.8 billion years ago (Trans-Hudson Orogeny).

Regardless of your own perspective regarding North Dakota's geologic age, there have really only been a handful of samples collected and dated from its Precambrian basement. Future studies may one day produce new radiometric ages that will enhance our understanding of the basement. However, even with continued investigation, the Precambrian basement will remain as the oldest, deepest, and most mysterious part of North Dakota.

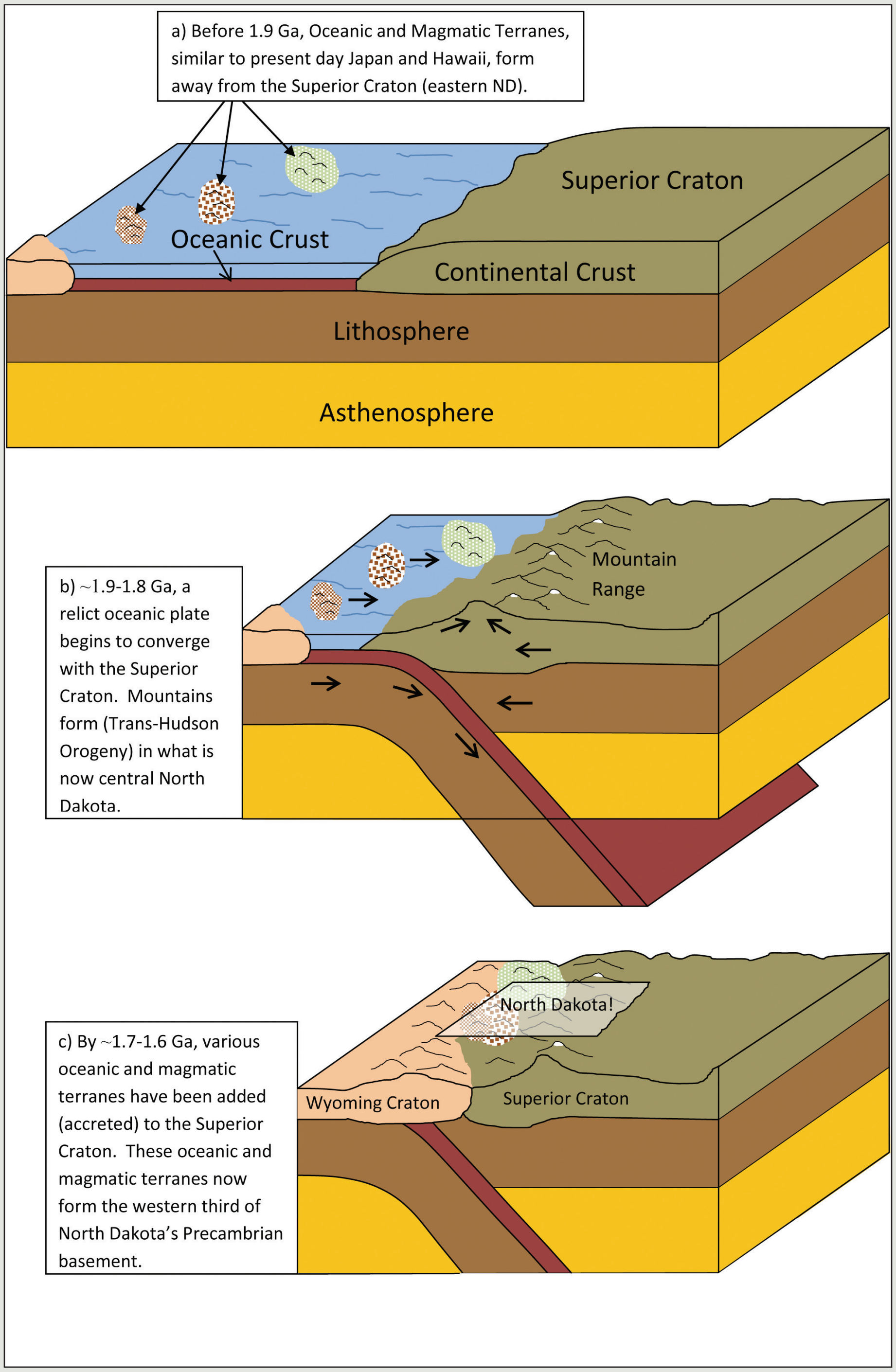

Figure 5. Schematic model depicting the formation of North Dakota's Precambrian basement when various 2.9 to 2.2 Ga (billion year old) oceanic and magmatic terranes were accreted (added) to the Superior Craton during the Trans-Hudson Orogeny 1.9-1.7 Ga.

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