THE GEOLOGY OF NORTH AMERICA

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Summary

The regional geologic history of North America started with the formation of the world's oldest rock, the Acasta Gneiss in the Precambrian Shield. This region consists

of several Archean terranes such as the Superior, Slave, Rae, Hearne, Nain Province and Wyoming Provinces. These were affected by several Proterozoic orogenic events that included collision with other Archean terranes as well as addition of juvenile crust. This resulted in the Laurentian craton, an aggregate of eight Archean provinces welded between 1900 and 1600 Ma. Anorogenic magmas intruded many of these collision zones after this time. This was followed by the Grenville orogen at 1200 to 1000 Ma coeval with rifting in the Midcontinent. At this time, North America was part of the Rodinia supercontinent. Between about 800 Ma and 700 Ma, Rodinia split in half and created the Pacific Ocean to the west of Laurentia. The margins of the Laurentian craton are covered by overlap successions such as the Belt/Purcell Supergroup. In addition, there are small fragments of Gondwana craton that occur throughout North America. Subsequent rifting in the Paleozoic broke up the Laurentian craton. Then, the interior of the craton was the site of deposition of platform sediments. Next, a series of collisional orogens affected all the margins of North America; these include the Appalachian, Ouachita, Antler, and Innuitian as part of the formation of the Pangea supercontinent in the Late Triassic. The Mesozoic is a time of quiescence on the eastern and southern margin of North America with rifting and formation of passive margin sequences. In contrast, the north and western margin saw increased convergence and translation of various continental fragments; this resulted in the formation of the Cordillera stretching from Mexico northward to the Brooks Range in Alaska. These include the Somona and Laramide orogenies in the North American Cordillera. The Chicxulub impact crater in Mexico defines the boundary between the Mesozoic and Cenozoic. Geologic traces of this instantaneous event are found throughout Mexico, Central America, southern United States and Cuba. Despite this cataclysmic event, most orogenic processes were not affected and continued without interruption from the Mesozoic into the Cenozoic. This includes translation of terranes along the western margin of North America, subduction of various mid-ocean ridges such as the Kula-Farallon ridge, as well as formation of fold-and-thrust belts. Portions of the Cordillera were extended to form the Basin and Range province and Rio Grande Rift. Cenozoic to Recent hot spots affected two regions in North America to create the Hawaiian-Emperor volcanic chain and Yellowstone caldera. The significant recent geologic features related to glaciation, earthquakes or recent volcanism include features such as the San Andreas fault, Aleutian volcanic belt, New Madrid earthquake, and “channeled scablands” of Washington that formed during a single catastrophic flood from glacial Lake Missoula. Thus, a variety of geologic processes created a large array of natural and energy resources, as North America is the world’s largest producer of lead, gypsum, rhenium, phosphate, and gold. Unique geologic features such as erosion forming the Grand Canyon, mountains formed by thrusting near Banff, and volcanic activity at Popcatépetl and Hawaii are seen at numerous national parks throughout North America.

1. Introduction

The North American continent is bordered on its eastern and southern margins by a passive margin with normal oceanic crust that began to form during the Triassic. North and Central America are linked to South America by the Isthmus of Panama; this land bridge was created at ~ 3.5 Ma. To the west is an active margin involving subduction of oceanic crust as well as large-scale translation of continental fragments since the Devonian. Paleozoic fold and thrust belts next to the Canada Basin define the northern

edge of North America.

The North American continent preserves evidence for major crust-forming events dating back to >4.0 Ga. The Acasta Gneiss in the Slave Province, Northwest Territories of Canada is North America's oldest rock at 4.03 billion years. Within North America there is a long history of continental break-up and growth. These are linked to other regions of the world in the formation of supercontinents such as Rodinia that formed in the Mesoproterozoic, Gondwanaland that was amalgamated in the latest Precambrian to Early Cambrian time interval, and Pangea that amalgamated at the end of the Paleozoic Era and the fragmentation of which commenced early in Mesozoic times. Subsequent events have included collision of island arcs, back-arc basin closure, strike-slip displacement of various oceanic and continental fragments as well as passive margin development. The margin of North America has also been affected by ridge subduction and changes in oceanic plate motions. Recent geologic events have included mantle plumes, glaciation, and volcanic activity.

Much of the geologic history of North America was summarized as part of the Geological Society of America's Decade of North American Geology (DNAG) project. Bally and Palmer (1989) provide a syntheses of these various DNAG volumes. Readers who want to dig deeper are encouraged to review this as well as other DNAG volumes.

2. Archean (>2500 Ma)

In North America, the Precambrian or Canadian Shield includes northeastern Canada, a large part of Greenland, and parts of Minnesota, Wisconsin, Michigan and the Adirondack Mountains of New York. Generally this region has subdued topography with numerous lakes and a veneer of Pleistocene glacial deposits. The Archean terranes include the Superior, Slave, Rae, and Hearne Provinces in northern Canada, Burwell Domain in Labrador, Nain Province in southern Greenland and Labrador, and Wyoming Province in the northern Rocky Mountains. These can be divided into two types: 1) those with intact crustal regions and only affected at their margins by Proterozoic assembly such as the Superior, Slave, Medicine Hat, Nain, and Wyoming Provinces, and 2) those that were significantly modified by younger collision such as the Hearne Province.

Both the Superior and Slave Provinces have three major lithologies: 1) volcano-sedimentary belts intruded by granitic suites (granite-greenstone terranes); 2) silicic terranes consisting of gneisses and tonalite-trondhjemite plutonic suites in either amphibolite or granulite facies; and 3) paragneiss belts developed by metamorphism of accretionary prisms. The borders of these cratons are Proterozoic orogenic belts or Phanerozoic onlap sequences.

The Superior Province greenstone terranes formed ~3000 to 2700 Ma. Recent U-Pb geochronology on detrital zircons indicates some of the region may be older than 3500 Ma (Bohm et al., 2000). In contrast to the Superior Province, the Slave Province in Nunavat and Northwest Territories has several older components including the Eokuk uplift, Kangguyak gneiss, Hanikahimajuk gneiss and Central Slave belt (Emon et al., 1999; Bleeker et al., 1999; Relf et al., 1999; Yamashita et al., 2000). The greenstone

terranes contain supracrustal assemblages of predominantly bimodal volcanic rocks and turbidites plus ironstones, cherts and minor carbonates. Individual volcanic centers trend from basalt to basaltic andesite with silicic suites (e.g., Ayer and Dostal, 2000; Hollings and Kerrich, 2000; Tomlinson et al., 2002). The margins of these greenstone terranes are usually tectonic or tonalite – trondhjemite suites. Archean greenstone terranes include Sachigo, Uchi, Wabigoon, Wawa, Abitibi, Winisk, Bird River, and La Grande River terranes. The greenstone terranes may represent continental growth in subduction-accretion complexes with amalgamation of oceanic plateaus represented by tholeiitic basalt-komatiite suites with island arcs and continental fragments followed by rifting represented by bimodal rhyolite-basalt suites (e.g., Henry et al., 2000; Percival et al., 2001; Polat and Kerrich, 2001a). The presence of magnesian andesites and adakites in the Wawa greenstone belt may indicate subduction of young, hot oceanic lithosphere in the Archean (Polat and Kerrich, 2001b).

The silicic igneous and metamorphic suites represent a variety of rock types including typical Archean gray gneisses and younger intrusive suites. The oldest suites are ~3800 Ma gneisses in the Minnesota River valley. In most of the craton, ages range from 3100 to 2800 Ma with a few isolated bodies of granite at about 2600 Ma. Examples of metasedimentary terranes include the English River, Quetico, Opatica, Nemiscau River, Opinaca River, and Pontiac suites. High-grade metamorphic terranes include Pikwonitei, Minnesota River Valley, Ashuanipi, and Minto complexes.

A major feature of the Superior Province is the 500 km long Kapuskasing structural zone, which crosses all other trends in the province. The eastern margin is a westward dipping thrust fault that brought high-pressure metamorphic rocks in contact with the low-grade Abitibi terrane (e.g., Percival, 1986; Percival et al., 1992; Halls and Mound, 1998). Elsewhere, the boundary is a reverse fault possibly with a component of dextral shear (Nitescu and Halls, 2002). This feature exposes an almost 20 km oblique cross-section of the continental crust.

The Nain Province is a triangular Archean block bounded by three Proterozoic orogens: the Torngat, Ketilidian, and Nagssugtoqidian (Hoffman, 1989). Within the Nain Province, the Nuuk region contains relics of Early Archean (3850 to 3560 Ma) rocks (e.g., Friend et al., 1996; Nutman et al., 2000). There is some debate whether carbon isotopic evidence may imply life in these rocks. Within the Nain Province, there are four distinct terranes each with an independent history that were amalgamated between 2750 and 2550 Ma. In Labrador, Archean gneisses were intruded by granites and mafic dykes at ~2580 Ma and subsequently subjected to amphibolite- to granulite-facies regional metamorphism and ductile shearing at 2550 Ma. Later granite veins and dikes related to the Nain Plutonic Suite were emplaced at ~1310 Ma. Connelly and Ryan (1996) interpreted this as final docking of Saglek and Hopedale blocks to form a single, stable cratonic mass during the late Archean.

The Burwell Domain on the northern tip of Labrador lies between two strands of the Torngat orogen. Underthrusting of the Rae Province caused exhumation of the granulite-facies rocks within the Burwell Domain (Scott, 1998). The Burwell Domain is probably a western extension of the Nain Province (e.g., Scott, 1998; Connelly, 2001).
The Hearne Province (previously part of the Churchill Province) is a juvenile Late

Archean terrane surrounded by the Snowbird and Trans-Hudson orogens. The core of the Hearne province is greenschist grade metavolcanic rock that increases outward in metamorphic grade towards its boundaries. Felsic volcanism occurred at 2700 Ma. A post-tectonic nepheline syenite intruded at about 2540 Ma. Swarms of mafic dikes were intruded between 2540 and 2400 Ma. This lithotectonic unit may extend south as a possible klippe and is exposed in the Trans-Hudson orogen (Bickford et al., 2001). The thickness of the Hearne Province is typical for Archean shield or platform (34 – 50 km; Gorman et al., 2002).

The Rae Province (previously part of the Churchill Province) is bounded by the Thelon, Snowbird, New Quebec, and Torngat orogens. Felsic gneisses dominate this province. Overall, the Rae Province is at higher metamorphic grade than the Hearne Province. In southern Saskatchewan, there is a high-grade complex of ultramafic, mafic, and felsic orthogneiss with small, interlayered supracrustal units (Crocker et al, 1993). Quartz arenites in this province preserve sedimentary structures and are extremely mature, suggestive of crustal stability (Donaldson and de Kemp, 1998). Proterozoic ultrapotassic volcanics (minette dikes and flows) that intrude both the Rae and Hearne Provinces may indicate that an Archean mantle metasomatic event affected this region during a period of flat subduction (Cousens et al., 2001).

The Laramide Ranges of Wyoming, southwestern Montana, Utah and Idaho contain Archean rocks. Exposures of Archean basement are found in Wyoming (Teton, Wind River and Laramie Ranges as well as Bighorn Mountains), Montana (Ruby and Madison Ranges, Tobacco Root and Highland Mountains, and Beartooth Plateau), and along the border of Utah and Idaho (Albion and Raft River Ranges). Most of the contacts with Proterozoic rocks are in the subsurface except for the Cheyenne belt of Wyoming, south of which juvenile (~1800 to 1600 Ma) terranes were accreted. The Wyoming Province differs from the northern Archean terranes as it has abundant supracrustal suites including marbles, metaironstones, metapelites, quartz pebble conglomerates and other shelf-type lithologies. Only a small percent of the region is composed of greenstone terranes such as the Sand Pass region of the Wind River Range (Wilks and Harper, 1997). The oldest rock in the Wyoming Province is a 3500 Ma trondhjemitic gneiss in the Beartooth Mountains (Mueller et al., 1996). Detrital zircons provide evidence for continental crust older than 3400 Ma (Mueller et al., 1998). This region is intruded by granite-granodiorite batholiths at 2700 to 2600 Ma. These are coeval with the Stillwater layered mafic complex. The Wind River Range in western Wyoming records a 250 m.y. history of plutonism with at least four metamorphic intervals. The highest metamorphic conditions were during M1 at >750 ^{o}C at 700 – 800 MPa compared to low-pressure contact metamorphism during M4. Frost et al. (2000) propose these formed in a tectonic environment similar to the long-lived Phanerozoic margin of western North America.

The Medicine Hat block consists of northwest-trending belts of Archean gneisses and plutonic rocks that range from 2700 to 2600 Ma. There is a single occurrence of a 3300 Ma diorite gneiss that is Alberta's oldest rock (Villeneuve et al., 1993). This block is relatively untouched by Proterozoic tectonic processes. Previously, the Medicine Hat block has been mapped as either a northern extension of the Wyoming Province or a southern extension of the Hearne province. Recent geophysical work identifies enough

differences between these three blocks to suggest it can stand alone as an Archean crustal fragment (e.g., Gorman et al., 2002). North dipping reflectors at the north and south boundaries of the Medicine Hat block can be interpreted as relict subduction zones (Gorman et al., 2002).

Layered anorthosite complexes are widely distributed throughout the Archean with the oldest being the Fiskenaesset complex of west Greenland intruded at 2900 Ma. Stable isotope geochemistry suggests this complex interacted with seawater implying a shallow emplacement depth (Peck and Valley, 1996). The Archean anorthosite bodies are unique as they typically have megacrystic calcic plagioclase. Some of the Archean layered complexes such as Stillwater lack the megacrystic textures. Examples of megacrystic Archean anorthosites include the Bad Vermillion Lake, Shawmere, Bird River, Big Trout Lake, Bell River, Bukesefjorden, Nordland, and Hutton Lake (e.g., Ashwal, 1993; Dymek and Owens, 2001)

Archean mineral deposits in North America include greenstone gold deposits, the Pb-Zn massive sulfides of the Abitibi terrane, Ni associated with komatiite in the Thompson and Raglan deposits, Ni-Co-Cu massive sulfide bodies at Voisey's Bay, Labrador, chromite deposits and platinum group minerals of the Stillwater Complex in Montana, diamonds from kimberlites in the Slave province, and some iron from Archean banded iron formations.

3. Proterozoic (2500 to 540 Ma)

The Laurentian craton is an aggregate of eight Archean provinces welded by orogenic belts representing collision zones that were active in the Proterozoic. Most of these developed between 1900 and 1600 Ma. Anorogenic magmas intruded many of these collision zones after this time. This was followed by the Grenville orogen at 1200 to 1000 Ma coeval with rifting in the Midcontinent (Fig. 1). The margins of the Laurentian craton are covered by overlap successions such as the Belt/Purcell Supergroup. In addition, there are small fragments of Gondwana that occur throughout North America.

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Biographical Sketch

Virginia Sisson works in the Earth Science department at Rice University and did her PhD in metamorphic petrology with a project in British Columbia, Canada. She has wide experience with field work in North America, in particular Alaska. However, she also works currently in Venezuela, Myanmar, and Guatemala. Her research interests lie in a wide range of petrological disciplines that can be used to resolve tectonic and geochemical processes at plate margins.