WYOMING STATE GEOLOGICAL SURVEY
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Geology - Interpreting the past to provide for the future

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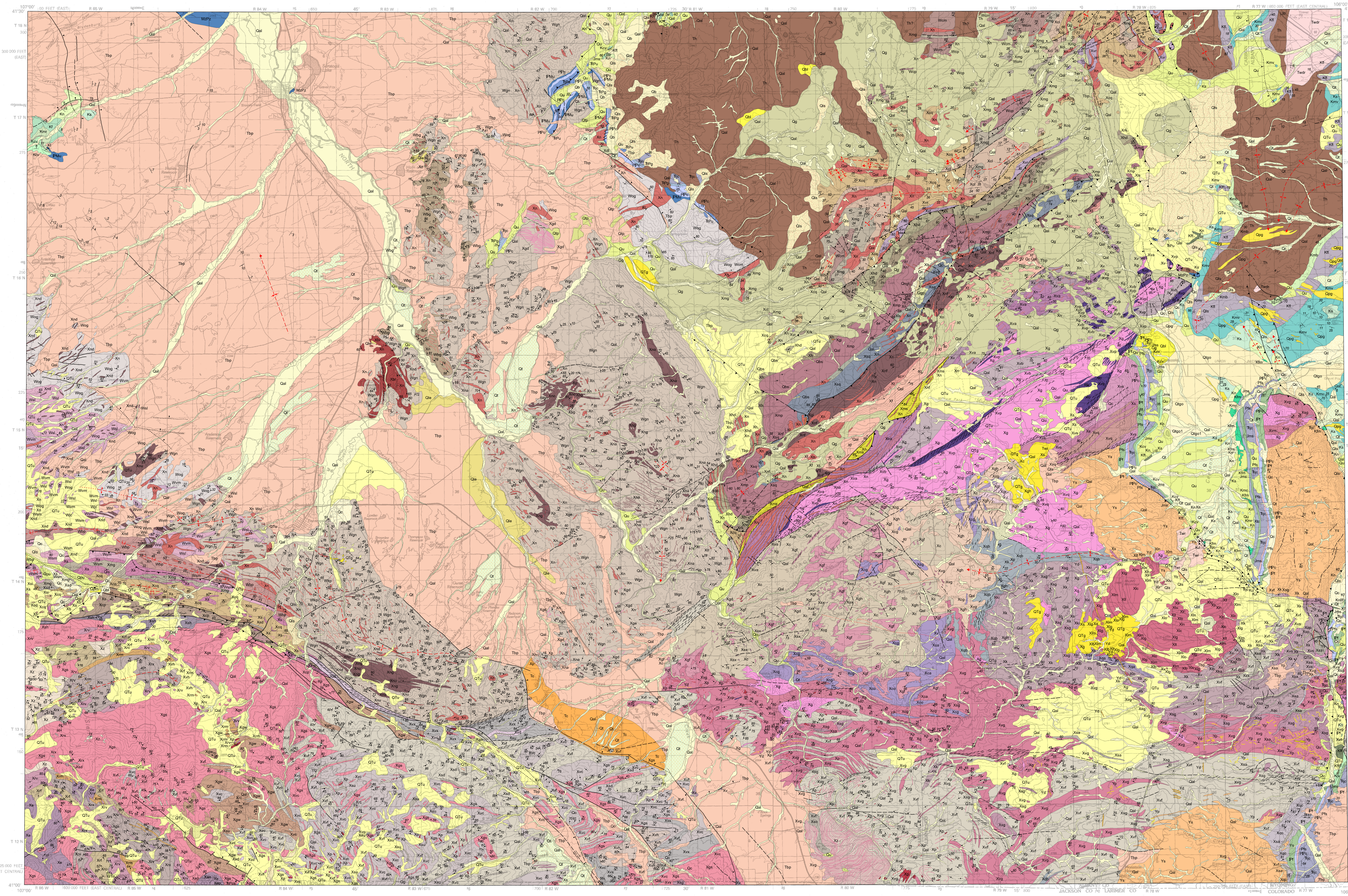
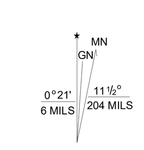
OPEN FILE REPORT 04-10
Saratoga 1:100,000 - scale Geologic Map
Version 1.1 July 2019



Base map from U.S. Geological Survey 1:100,000 - scale Metric topographic map of the Casper, Wyoming 30' x 60' Quadrangle, 1979
Projection: Universal Transverse Mercator (UTM), zone 13
North American Datum of 1927 (NAD 27)
10,000-meter grid ticks: UTM, zone 13
50,000-foot grid ticks: Wyoming State Plane Coordinate System, East zone

SCALE 1:100,000
Contour interval 50 meters

0 2 4 6 8 10 12 14 16 18 20 Kilometers
0 1 2 4 6 8 10 12 Miles
0 2,000 4,000 6,000 8,000 10,000 12,000 14,000 16,000 18,000 20,000 Meters
0 5,000 10,000 15,000 20,000 25,000 30,000 35,000 40,000 45,000 50,000 55,000 60,000 65,000 Feet



UTM GRID CONVERGENCE (GN)
1982 MAGNETIC DECLINATION (MN) AT CENTER OF SHEET
DIAGRAM IS APPROXIMATE

Prepared in cooperation with the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under Cooperative Agreements 03HQAG0097 and 04HQAG0045.

Digital cartography by Allory P. Deiss, Phyllis A. Ranz, and Alice J. Vogelmann

PRELIMINARY GEOLOGIC MAP OF THE SARATOGA 30' x 60' QUADRANGLE, CARBON AND ALBANY COUNTIES, WYOMING, AND NORTHERN COLORADO

by

Wayne M. Sutherland and W. Dan Hausel

2004

DESCRIPTION OF MAP UNITS

Cenozoic

- Qal — Alluvium
- Qc — Colluvium
- Qb — Boulder field, Kennaday Peak and adjacent areas
- Qbs — Block stream
- Qls — Landslide debris
- Qt — Terrace deposits
  - Qtg — Gravel-covered terrace
  - Qpg — Pediment gravels
  - Qtp — Terraces with polygonal ground
  - Qtgo — North Fork Little Laramie River glacial outwash
  - Qtgo1 — Middle Fork Little Laramie River glacial outwash
- Qg — Glacial deposits, undifferentiated
- Qngt — Neoglacial till (Holocene)
- Pinedale till (Pleistocene)
  - Qpu — Upper Pinedale glacial deposits
  - Qpm — Middle Pinedale glacial deposits
  - Qpl — Lower Pinedale glacial deposits
- Qbl — Bull Lake glacial deposits (Pleistocene)
- Qgp — Pre-Wisconsin glacial deposits (Pleistocene)
- Qle — Loess
- Qu — Quaternary deposits of all types combined where not mapped individually (Pleistocene)

Quaternary and Tertiary

- QTu — Quaternary and/or Tertiary deposits, undifferentiated
- QTg — Upland gravels (Pleistocene (?) and Pliocene)

Tertiary

- Tbp — Browns Park Formation (Miocene)
- Twr — White River Formation (Oligocene)
- Twdr — Wind River Formation (Eocene)
- Tc — Coalmont Formation (Eocene and Paleocene)
- Th — Hanna Formation (Paleocene)

Mesozoic

- Kmb — Medicine Bow Formation (Upper Cretaceous)
- Kfl — Fox Hills Sandstone and Lewis Shale, undivided (Upper Cretaceous)
- Kmv — Mesaverde Formation (Upper Cretaceous)
- Ks — Steele Shale (Upper Cretaceous)
- Kn — Niobrara Formation (Upper Cretaceous)
- Kf — Frontier Formation (Upper Cretaceous)
- Kfm — Frontier Formation and Mowry Shale, undivided (Upper Cretaceous)
- Kft — Frontier Formation, and Mowry and Thermopolis Shales, undivided (Upper Cretaceous)
- Kmr — Mowry Shale ((Upper Cretaceous)
- Kt — Thermopolis Shale (Lower Cretaceous)
- Kmc — Thermopolis Shale including Muddy Sandstone Member and Cloverly Formation, undivided (Lower Cretaceous)
- Kcv — Cloverly Formation (Lower Cretaceous)
- Ku — Cretaceous units, undivided
- KJ — Cretaceous and Jurassic units, undivided
- Jms — Morrison and Sundance Formations, undivided (Jurassic)
- ŦRjc — Jelm and Chugwater Formations, undivided (Triassic)

Mesozoic and Paleozoic

- ŦRPu — Jelm and Chugwater Formations (Triassic), and Goose Egg Formation, Forelle Limestone, and Satanka Shale (Permian), undivided
- ŦRPcs — Chinle and Chugwater Formations (Triassic), and Satanka Shale (Permian), undivided
- ŦRPg — Goose Egg Formation (Triassic and Permian)
- MzPz — Mesozoic and Paleozoic units, undivided

Paleozoic

- Pfs — Forelle Limestone and Satanka Shale (Permian)
- PIPc — Casper Formation (Permian and Pennsylvanian)
- IPf — Fountain Formation (Pennsylvanian)
- IPMu — Amsden Formation (Pennsylvanian) and Madison Limestone (Mississippian), undivided

Mesoproterozoic

- Yd — Dike
- Ys — Sherman Granite (1,433 ± 1.5 Ma)
- Yp — Pegmatite (1,514 ± 36 Ma)

Mesoproterozoic and Paleoproterozoic

Rocks within or south of the Cheyenne belt

- Xp — Pegmatite (1,510–1,763 Ma)

Paleoproterozoic

- Xg — Granite and quartz monzonite and related intrusive rocks (1,600–1,800 Ma)
- Xgw — White quartz monzonite (1,627 ± 4 Ma)
- Xgl — Luxullianite (1,699 ± 40 Ma)
- Xgr — Rambler Granite (1,770 ± 3.4 Ma)
- Xgs — Sierra Madre Granite (1,744–1,763 Ma)
- Xq — Quartz veins of unknown age
- Xgf — Small felsic intrusive
- Xgd — Granite dikes
- Xap — Aplite gneiss
- Lake Owen layered mafic complex (1,775.1 ± 3.0 Ma)
  - Xlm — Magnetite
  - Xlr — Magnetite gabbro-norite
  - Xlo — Olivine gabbro
  - Xlu — Olivine magnetite gabbro-norite
  - Xlg — Gabbro-norite
  - Xln — Norite
  - Xlt — Troctolite
  - Xll — Layered unit
  - Xlc — Cyclic succession
  - Xlb — Border phase
- Xgh — Horse Creek foliated granodiorite (1,777 ± 4 Ma)
- Xc — Mullen Creek layered mafic complex (1,777.6 ± 2.1 Ma)
  - Xca — Amphibolite
  - Xcg — Gabbro
  - Xco — Olivine gabbro
- Xe — Elkhorn Mountain gabbro
  - Xeo — Olivine gabbro
  - Xep — Peridotite
- Xv — Metavolcanic and metasedimentary rocks (1,778.4 ± 1.7 Ma)
- Xvf — Felsic gneiss
- Xva — Mylonitic biotite augen gneiss
- Xvb — Migmatitic biotite schist and gneiss in the Medicine Bow Mountains
- Xvs — Mafic schist and gneiss in the Medicine Bow Mountains
- Xvq — Quartz-plagioclase gneiss in the Medicine Bow Mountains
- Xvg — Amphibole gneiss in the Medicine Bow Mountains
- Xvp — Pelitic schist in the Medicine Bow Mountains
- Xvm — Marble in the Medicine Bow Mountains
- Xqa — Quartz-andesine gneiss in the Medicine Bow Mountains
- Xqb — Quartz-biotite schist in the Medicine Bow Mountains
- Xqc — Quartz-biotite-andesine gneiss in the Medicine Bow Mountains
- Xz — Encampment River Granodiorite (1,779 ± 5 Ma)
- Xk — Keystone quartz-diorite (1,784.7± 1.9 Ma)
- Xki — Keystone quartz-diorite interlayered with adjacent rock types
- Xka — Keystone quartz-diorite agmatite
- Green Mountain Formation, Sierra Madre
  - Xrv — Mafic metavolcanic rocks
  - Xrf — Felsic metavolcanic rocks
  - Xrm — Metagraywacke
  - Xrx — Mixed metavolcanic and metasedimentary rocks
  - Xrc — Chemical metasedimentary rocks
- Xs — Mafic intrusive rocks (~1,800 Ma)
  - Xsa — Amphibolite
  - Xsd — Diabase
  - Xsg — Gabbro and metagabbro
  - Xsb — Metabasalt
  - Xso — Olivine gabbro
  - Xsp — Metaperidotite
  - Xsx — Metapyroxenite
  - Xsu — Ultramafic rocks, undifferentiated
- Xvh — South Holroyd gneiss
- Xvc — Mafic metavolcanic rocks
- Xvd — Metasedimentary rocks, Sierra Madre
- Xvx — Mixed gneiss

Paleoproterozoic and Neoarchean

Rocks north of the Cheyenne belt

- Xgi — Gaps Intrusion, in the central Medicine Bow Mountains (1,900–2,150 Ma)
- Xn — Mafic intrusive rocks (1,700–2,300 Ma)
  - Xna — Amphibolite
  - Xnr — Anorthositic
  - Xnd — Diabasic rocks
  - Xng — Gabbroic rocks
  - Xno — Olivine gabbro
  - Xnu — Ultramafic rocks
- Xbr — Baggot Rocks Granite (2,429 ± 4 Ma)
- Xbg — Granite and quartz monzonite
- Xge — Granite dikes

Paleoproterozoic

Snowy Pass Group, Sierra Madre, north of the Cheyenne belt

- Xsh — Slaughterhouse Formation
- Xcp — Copperton Formation
- Xb — Bottle Creek Formation
- Xcq — Cascade Quartzite (>2,092 ± 9 Ma)
- Xsi — Singer Peak Formation
- Xmg — Magnolia Formation (2,451 ± 9 Ma)

Snowy Pass Supergroup, Medicine Bow Mountains

- Xms — Metasedimentary rocks

Libby Creek Group—Upper part

- Xf — French Slate
- Xt — Towner Greenstone
- Xnf — Nash Fork Formation

Libby Creek Group—Lower part

- Xsq — Sugarloaf Quartzite
- Xls — Lookout Schist
- Xmp — Medicine Peak Quartzite
- Xh — Heart Formation
- Xhd — Headquarters Formation
- Xrk — Rock Knoll Formation

Deep Lake Group, undivided

- Xdl
  - Xvr — Vagner Formation
  - Xcq — Cascade Quartzite (>2,092 ± 9 Ma)
  - Xcl — Campbell Lake Formation and Lindsey Quartzite
  - Xmg — Magnolia Formation (2,451 ± 9 Ma)

Neoarchean

Rocks north of the Cheyenne belt

Phantom Lake Metamorphic Suite, Sierra Madre

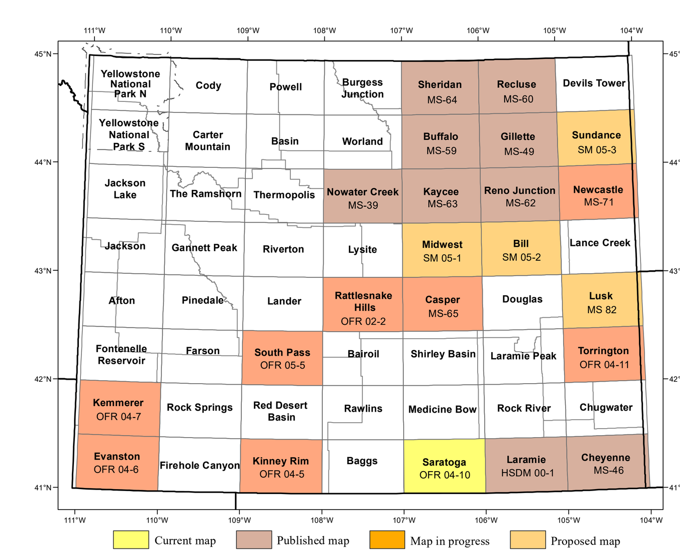
- Wbp — Bridger Peak Quartzite
- Wsm — Silver Lake Metavolcanics (2,680 ± 18 Ma)
- Wjc — Jack Creek Quartzite

Phantom Lake Metamorphic Suite, Medicine Bow Mountains

- Wcp — Conical Peak Quartzite
- Wcm — Colberg Metavolcanics
- Wbq — Bow Quartzite
- Wgn — Quartzo-feldspathic gneiss
  - Wbg — Biotite gneiss
- Wog — Red-pink orthogneiss (2,683 ± 6 Ma)
- Wsl — Spring Lake Granodiorite (2,710 ± 10 Ma)
- Wkp — Kyanite Pegmatite
- Wvm — Vulcan Mountain Metavolcanics

MAP SYMBOLS

- **Formation contact**
- **Fault**—Continuous where certain, dashed where approximate, dotted where concealed; ball and bar on downthrown block of normal fault; sawteeth on upper (tectonically higher) plate of thrust fault; arrows indicate direction of strike-slip motion
- **Anticline**—Continuous where certain, dashed where approximate, dotted where concealed; arrow on end indicates direction of plunge
- **Syncline**—Dashed where approximate, dotted where concealed; arrow on end indicates direction of plunge
- **Overturned anticline**—Dashed where approximate
- **Overturned syncline**—Dashed where approximate, dotted where concealed
- **Shear zone**
- **Breccia**
- 14 **Strike and dip of inclined bedding**
- **Strike of vertical bedding**
- 45 **Strike and dip of overturned bedding**
- 70 **Strike and dip of foliation**
- **Strike of vertical foliation**
- 25 **Minor anticline**
- 30 **Minor syncline**
- 22 **Minor fold**



Author's note: Units were updated in 2019 using current age dates; unit descriptions and references in accompanying report

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Preliminary Digital Geologic Map of the Saratoga 1:100,000-scale Quadrangle, Albany and Carbon Counties, Wyoming

by

Wayne M. Sutherland and W. Dan Hausel

July 28, 2005
Edited August 1, 2019

INTRODUCTION

This geologic map of the Saratoga 1:100,000-scale metric topographic quadrangle was first released as Wyoming State Geological Survey (WSGS) Open File Report 04-10, which was prepared in cooperation with the U.S. Geological Survey 2003 STATEMAP Cooperative Agreement # 03HQAG0097. This open-file report consisted of three color sheets, each emphasizing different groups of rocks, and was not in digital form. The three sheets were then digitized as part of the U.S. Geological Survey 2004 STATEMAP project under Cooperative Agreement # 04HQAG0045, but because the maps were only reviewed for accurate digitizing and correct attribution and not for technical content and other standards for the WSGS map series, the original open file report number, 04-10 is retained. The final digital map, after formal editorial reviews are completed, will eventually be converted to a WSGS map series and assigned a number in that series. The final map products will consist of a CD-ROM containing all the digital map files and a geologic report as well as a color geologic map printed on-demand.

The Saratoga (1:100,000) sheet is located in southeastern Wyoming, enclosing the communities of Albany, Centennial, Encampment, Fox Park, Keystone, New Jelm, Riverside, Saratoga, and Woods Landing. A large part of the Medicine Bow Mountains, the Sierra Madre Range, the Platte River valley and the extreme western edge of the Laramie basin lie within the map area. A major portion of the Medicine Bow National Forest lies within the Saratoga sheet surrounding the Savage Run, Platte River, Encampment River and part of the Huston Park wilderness areas.

The Saratoga 1:100,000 sheet encloses much of the Medicine Bow Mountains, a large part of the Sierra Madre, and also a significant portion of the Platte River valley, and the extreme western margin of the Centennial valley. These mountain ranges were uplifted during the Laramide orogeny, and erosion removed the overlying Phanerozoic sediments. However, deformed Phanerozoic sediments are preserved along the margins of the uplifts in the adjacent Platte River and Centennial valleys. These sedimentary rocks include rock units ranging from Pennsylvanian to Tertiary in age.

The Medicine Bow Mountains and Sierra Madre are Precambrian-cored Laramide uplifts. The margin of the Wyoming Province (or craton) is exposed in these mountains within the Saratoga 1:100,000. According to Eggler and others (1988), the Wyoming craton was established by 2.7 Ga, but was later affected by a regional metamorphic event recorded at 1.9 to 1.7 Ga.

The southern boundary of the Wyoming Province terminates against the Mullen Creek-Nash Fork shear zone. This shear, which forms part of the Cheyenne belt suture, represents a

continental-arc collision zone (Graff, 1978; Hills and Houston, 1979) separating the Wyoming Province to the north from cratonized (1.7 Ga) Proterozoic basement of the Colorado Province to the south. The Colorado Province south of the suture consists of volcanogenic island-arc basement rocks, intrusive granites and gabbroic complexes. These gabbroic complexes include two of the larger layered mafic complexes in the western US, the Lake Owen and Mullen Creek complexes. To the north, the Wyoming Province includes amphibolite grade schists and gneisses that are overlain by younger Archean and Proterozoic metasedimentary and metaigneous rocks.

Thirty-two 1:24,000 quadrangles that comprise the Saratoga 1:100,000 scale map are listed as follows: Albany, Barcus Peak, Blackhall Mountain, Centennial, Cow Creek, Cow Creek Ranch, Dudley Creek, Elkhorn Point, Encampment, Finley Reservoir, Foxpark, Gunst Reservoir, Horatio Rock, Indian Rocks, Kennaday Peak, Keystone, Lake Owen, Medicine Bow Peak, Morgan, Overlook Hill, Phantom Lake, Red Mountain, Rex Lake, Ryan Park, Sand Lake, Saratoga, Solomon Creek, Strouss Hill, Trent Creek, Turpin Reservoir, Walck Ranch, and Woods Landing.

ECONOMIC GEOLOGY

The Medicine Bow and Sierra Madre Mountains are underlain by the southern margin of the Wyoming Archon (>2.5 Ga) and cratonized Proterozoic (<2.5 Ga) metaigneous and metasedimentary rocks of the Colorado Province. The boundary between these two Precambrian terrains is formed of highly fractured cataclastics including rock with strong linear fabric such as mylonites and ultramylonites as well as numerous faults and shear zones. This boundary zone, referred to as the Mullen Creek-Nash Fork Shear zone and more recently as the Cheyenne belt, is in places, mapped over widths as much as several miles.

Fractures associated with this belt, as well as with subsidiary fractures north and south of the belt, are considered favorable zones for hosting mineral deposits. Those fractures that are deep-seated are considered to be favorable conduits for diamondiferous kimberlite, diamondiferous lamproite, and or diamondiferous lamprophyre as well as other mineral deposits. Due to the favorable geology, the entire region, including the Saratoga basin, is considered to have high-potential for the discovery of diamond (gem and industrial) deposits. This is further emphasized by the presence of the State Line and Iron Mountain kimberlite districts lying immediately east of the Saratoga 1:100,000, both of which have yielded diamonds and represent the two largest kimberlite districts in the US (Hausel, 1998; Hausel and others, 1979; 1981, 2003). Furthermore, diamonds have been recovered within the Saratoga Sheet on Cortez Creek in the Medicine Bow Mountains and at least one diamond was recovered from a Precambrian metaconglomerate during gold exploration in the 1980s. Even though much of the region remains unexplored for diamond, several kimberlitic indicator mineral anomalies have been identified providing additional physical evidence for hidden kimberlites within the region.

Examination of air photos during the compilation of the Saratoga 1:100,000 sheet identified 75 vegetation anomalies that appear similar to vegetation anomalies associated with kimberlitic soils in both the State Line and Iron Mountain kimberlite districts. Although anomalous vegetation is not in itself confirmation of a kimberlitic intrusion, in the presence of indicator minerals and isolated placer diamonds within the map area suggests that these anomalies might be a starting point for on the ground investigations including geophysical research, stream sediment sampling and shallow drilling. Very few of these vegetation anomalies have been

examined on the ground to date, and no conclusion as to their origins could be made during reconnaissance. The locations of these anomalies are marked on the map with an asterisk (*).

Although scattered mineralization has been found throughout the region, the broad region underlain by sheared rocks of the Cheyenne Belt is especially abundant with prospects and mines. The presence of common mineralization in this area is thought to be primarily due to the increased permeability of the rocks due to shearing. This is especially prevalent in the area near Encampment in the northwestern part of the map.

South of the Cheyenne Belt, volcanogenic island arc volcaniclastics provide excellent hosts for magmatic massive sulfide mineralization (copper, zinc, lead, silver, gold), and some shear zone copper, gold, and associated gold placers. Some volcanogenic massive sulfide deposits occur in and around the Huston-Fletcher Park region (bordering the Saratoga quadrangle to the southwest).

North of the Cheyenne Belt, metaconglomerates found in several of the Precambrian units are considered potential sources for uranium and thorium. Similarities of these rocks to the gold-rich quartz-pebble metaconglomerates of the Witwatersrand, South Africa, indicate that they also have potential as gold hosts. At least one sample of metaconglomerate collected in the 1970s yielded 10 ppm Au. These conglomerates are also considered to be potential hosts for significant copper-gold-silver mineralization. This is based on the presence of a significant copper deposit in a sheared metaconglomerate at the Ferris-Haggarty mine in Deep Lake Group metasediments immediately west of the Saratoga sheet. The Ferris-Haggarty was considered to be one of the more important copper deposits in the world in the early 1900s. This conglomerate also yields anomalous silver and gold.

Layered mafic-ultramafic intrusives, ultramafic massifs and fragments with anomalous platinum (Pt), palladium (Pd), gold (Au), silver (Ag), copper (Cu), titanium (Ti), chromium (Cr), and vanadium (V) anomalies occur within the Proterozoic terrain – most notable are the Mullen Creek, Lake Owen, and Puzzler Hill complexes. The Mullen Creek mafic-ultramafic complex in the Medicine Bow Mountains hosts one of the only known historic Pt-Pd mines in North America, known as the New Rambler mine. This property lies adjacent to the Savage Run Wilderness (see Keystone Quadrangle), and the host ultramafic-mafic complex extends into the nearby Savage Run wilderness. The complex is considered to have high potential for the discovery of platinum-palladium (important precious and strategic metals) mineralization.

East of the Mullen Creek complex, the Lake Owen layered mafic complex is a Proterozoic gabbroic intrusion which hosts significant mineralization. Loucks and Glasscock (1989) noted 18 cyclic units within the Lake Owen complex that were defined by large scale repetitions of two or more lithologic units, and by compositional variations in the rock mineralogy. At least 12 stratigraphic horizons in the complex exhibit cumulus sulfide mineralization: four of which are known to contain PGE + Au at grades > 1 ppm (part per million)! One bornite-rich stratiform unit with anomalous Au + Pt +Pd is continuous for at least 2 km, while similar mineralization in another unit extends for 10 km! Loucks and Glascock (1989) also examined the vanadiferous magnetite horizons within the complex. An estimate of surface mineable oxide cumulates of 1.4 billion tons valued at $33 billion was made in 1988! This does not include the titanium, platinum group metals or gold values within the complex, which potentially could have greater value.

The Big Creek district in the southern Medicine Bow Mountains produced some copper and rare earth minerals from pegmatites during the 1940s. Much of the surface within the Saratoga

1:100,000 was prospected during the late 1800's and early 1900's (see Hausel, 1989, 1997 and Hausel and Sutherland, 2000). Many areas show an almost continuous coverage by historic prospects and mines. Even though most mines and prospects were not developed to any great extent, a few yielded attractive base and/or precious metal assays and were developed into commercial ventures. These included the Doane-Rambler, Keystone, New Rambler, Centennial and Douglas Creek mines. Several other mines were also developed within the map area on a smaller scale than these; and of course, there were many failures.

It should be noted that there is no evidence that any of the significant commercial mines (with the exception of the Centennial), were ever mined out. Mine operations ceased at many of these mines due to a variety of circumstances including declining metal prices and values, ore complexity below the zone of oxidation, outbreak of war, and other political or human-related factors. The Centennial mine ceased operations because the mineralized lode was off-set by faulting - the extension of the ore deposit was never found. The various deposits in the region were explored or mined for copper, gold, silver, lead, zinc, rare earth metals, mica, beryl and other industrial minerals. Potential for other gemstones (other than diamond) must also be considered as ruby has been identified associated with some vermiculite deposits in the region, and another transparent ruby and transparent green beryl were both recovered from a pegmatite from an undisclosed location in the Sierra Madre in the relatively recent past.

GEOLOGIC MAP UNITS

The geology for the Saratoga quadrangle was compiled from existing mapping and supplemented by aerial photo interpretation and cursory field checks. The rock units described here apply to the thirty-two 1:24,000 scale quadrangles that comprise the Saratoga 1:100,000 scale quadrangle. These rock units were generalized and combined. Most contacts on the 1:24,000 scale quadrangles are approximate, but are shown as solid lines, rather than dashed, for clarity and ease of compilation.

QUATERNARY

Alluvium (Qal): Alluvium comprises unconsolidated sand, silt, clay, coarse gravels and cobbles, located in and along most drainages. This unit, compiled from many sources including air photo interpretation, may include eluvial deposits, slope wash and small alluvial and colluvial deposits (Qc) along drainages.

Colluvium (Qc): Colluvial deposits; may include some alluvial deposits. This also includes talus deposits mapped by Oviatt (1977) in his glacial study of the Snowy Range area in the Medicine Bow Mountains.

Boulder field capping Kennaday Peak and adjacent ridges and slopes (Qb): Dominately boulder-size, angular to subangular metamorphic rock fragments that include quartzite, gneiss, amphibolite and schist capping Kennaday Peak and Cedar Pass Ridge (Barton, 1974). Mears (2001) considered at least part of this boulder cap to be pre-Bull Lake glacial till.

Block stream (Qbs): Block streams, also known as rock streams, a commonly linear type of mass movement of rock fragments associated with frost action, found at high altitudes or in

periglacial areas, were identified in aerial photo interpretation in west-central Medicine Bow Mountains.

Landslide debris (Qls): Locally derived landslide debris from unstable, generally steep slopes. This map unit was compiled from many sources (see references) and supplemented by air photo interpretation.

Terrace deposits (Qt): Gravel covered terrace **(Qtg)**, and/or cobble, sand, gravel and silt-covered terraces along mountain flanks and drainages. These terraces merge in places with eluvial, alluvial and colluvial deposits. Different terrace levels were not designated, although some areas have multiple levels of terraces. Some terraces may be equivalent to previously mapped geologic quadrangles as pediment gravels **(Qpg)**. Widespread terraces were noted in the Saratoga Valley, but were not mapped due to time constraints. Terraces exhibiting apparent polygonal ground, indicative of intensive frost action, in aerial photographs in the Ryan Park – Kennaday Peak area are designated **(Qtp)**. Glacial outwash terraces from the North Fork Little Laramie River **(Qtgo)** and glacial outwash terraces from the Middle Fork Little Laramie River **($Qtgo_1$)** are after Blackstone (1969)

Glacial deposits undifferentiated (Qg): Detailed mapping of glacial deposits is lacking in many areas, but their general extent has been mapped in many areas (Houston, 1968; Houston, 1977; Houston and Childers, 1977; Houston, McCallum, and Childers, 1977; Mears, 2001; Snyder, 1980). This designation includes all types of glacial deposits, but is dominated by moraines.

Holocene Neoglacial till (Qngt): This till was mapped by Oviatt (1977) in the Snowy Range area of the Medicine Bow Mountains and may include some alluvium and colluvium.

Pleistocene Pinedale till: This includes till mapped by Oviatt (1977 in the Snowy Range area of the Medicine Bow Mountains, and deposits mapped in the Cow Creek drainage of the Sierra Madre by Price (1973).Subdivisions mapped by Price (1973) include: Upper Pinedale glacial deposits **(Qpu)**; Middle Pinedale glacial deposits **(Qpm)**; and Lower Pinedale glacial deposits **(Qpl)**.

Pleistocene Bull Lake glacial deposits (Qbl): Deposits mapped in the Cow Creek drainage of the Sierra Madre by Price (1973); in the Turpin Reservoir area by Saulnier (1968) with adjustments using aerial photo interpretation; and near Centennial, after Mears (2001). Bull Lake glacial deposits are shown in several other areas on a general area map by Mears (2001) including an extensive moraine north of Ryan Park, the southern part of Libby Flats, and locations north of the Snowy Range and west of Sand Lake, but sufficient details were not available to map them separately in this compilation.

Pleistocene Pre-Wisconsin glacial deposits (Qgp): Deposits mapped in the Cow Creek drainage of the Sierra Madre by Price (1973). Pre-Bull Lake glacial deposits are shown on a general area map by Mears (2001) including the top of Kennaday Peak, several locations on Rock Creek Ridge (after Blackstone, 1975), and west of Centennial, but sufficient details were not available to map them separately in this compilation.

Loess (Qle): Deposits mapped in the Saratoga Valley by Houston (1968)

Undifferentiated Quaternary deposits (Qu): Quaternary deposits of all types combined where not mapped individually

QUATERNARY / TERTIARY

Undifferentiated Quaternary and/or Tertiary deposits (QTu) – Undifferentiated deposits may include alluvial, colluvial, terrace, landslide, and glacial deposits, and outcrops of various Tertiary formations. A small area of rocks originally identified by Montagne (1954) near the North Fork of Big Creek as 'Miocene- Pliocene undivided' is included within this unit. In the southern Sierra Madre, near the Colorado border, this unit also encompasses large areas of both the Miocene Browns Park Formation and Pleistocene Glacial till (Snyder, 1980; Houston and Graff, 1995), however details were unavailable for the separation of these units during this project.

Pliocene-Pleistocene (?) upland gravels (QTg) – Includes upland surfaces veneered with 40 to 200 feet of gravel and boulders in the Medicine Bow Mountains northeast of and southeast of Keystone (McCallum, 1964; Currey, 1965; McCallum and Orback, 1968; Houston, 1968; and Coalson, 1971). Also included in this designation are small outcrops of conglomerate mapped by Ferris (1964) 1.5 miles southeast of Encampment that he identified as 'Tertiary (?)'; the actual age of these deposits are unknown.

TERTIARY

Miocene Browns Park Formation (Tbp): The Browns Park Formation crops out primarily in the Saratoga Valley, but is also found as small outcrops in many areas of the Medicine Bow Mountains and Sierra Madre. Some early work identified many Browns Park outcrops as North Park Formation, but re-evaluation indicates that these are probably all North Park Formation (Snyder, 1980; Montagne, 1991). The Browns Park, exceeding 2400 feet in thickness, is variable in lithology, and includes tan, gray, and olive drab calcareous to siliceous sandstone and siltstone, with some thin limestones and white pumicite beds. A loosely consolidated, cross-bedded and sandy, ferruginous conglomerate containing Precambrian boulders up to three feet in diameter is prominent near the base of the formation, and is easily traced throughout the northern part of the Saratoga Valley (Montagne, 1991). Outcrops of the Browns Park Formation in the southern Sierra Madre, particularly in the Hog Park area are included in Undifferentiated Quaternary and/or Tertiary deposits (QTu) due to lack of details available for this mapping effort. Montagne's (1954) small outcrop of 'Miocene/Pliocene undivided' in the Blackhall Mountain area is included within the Brown's Park Formation.

Oligocene White River Formation (Twr): The White River Formation is found in several small outcrops scattered across the map area. Lithologically, it is poorly cemented with calcium carbonate and consists of white to light-gray, tuffaceous, fine-grained siltstone, clay, and shale, with some orangish colored layers, and occasionally with minor amounts of angular igneous and metamorphic rock fragments (Swetnam, 1961: Houston, 1968; Montagne, 1991).

Eocene Wind River Formation (Twdr): The Wind River Formation crops out along the northeast side of the Medicine Bow Mountains, and in the extreme northeast corner of the map, and consists of varicolored claystone, arkosic sandstone, and local conglomerate (Blackstone, 1969).

Eocene/Paleocene Coalmont Formation (Tc): This formation crops out in the southern Saratoga Valley for about six miles along the east flank of the Sierra Madre, and in places rests unconformably on Precambrian rock. The Coalmont consists of calcareous, brown, friable, cross-bedded arkosic sandstone, claystone, and carbonaceous shale that grade upward into coarse conglomerate that includes gneissic boulders up to 12 feet in diameter (Montagne, 1991). To the south in the North Park Basin, the Coalmont is as much as 7000 feet thick.

Paleocene Hanna Formation (Th): Houston (1968) referred to this unit as possibly including the Tertiary/Cretaceous Ferris Formation, although the Ferris is considered by some to occur much farther to the north of the Saratoga quadrangle. The Hanna Formation is made up of rounded to subrounded boulders, cobbles, and pebbles embedded in a friable matrix of yellow medium-grained arkosic sandstone (Montagne, 1991). To the north of the map area, near Hanna, the formation thickness reaches 7000 feet, includes thick coal beds, and unconformably overlies all pre-Tertiary formations. Barton (1974) reported the largest boulders in the Hanna to be about a foot in diameter, and cited a thickness of about 1500 feet near Kennaday Peak. On the eastern flank of the Medicine Bow Mountains, Blackstone (1970) described a coarse basal conglomerate of subrounded quartzite cobbles and boulders, and noted zones of large brown sandstone concretions.

MESOZOIC

Upper Cretaceous Medicine Bow Formation (Kmb): The Medicine Bow Formation consists of more than 400 feet of interbedded brown sandstone with some iron-stone concretions, coal, and black carbonaceous shale. Coal beds are common at the base (Houston, 1968; Blackstone, 1970). The formation hosts one conglomerate bed with cobbles of underlying sedimentary rock (Houston, 1968).

Fox Hills Sandstone and Lewis Shale undivided (Kfl): The upper 400 feet of this 2200-2600 ft thick unit is fine-grained gray sandstone; the middle part is interbedded fine-grained gray sandstone and shale; the basal part is predominantly light gray shale (Blackstone, 1970). Houston (1968) also notes local coal beds and zones of large iron-stone concretions.

Upper Cretaceous Mesa Verde Formation (Kmv): The 1300-1500 ft thick Mesa Verde is made up of the cross-bedded, gray, coal-bearing Pine Ridge Sandstone at the top. This is underlain by coal and carbonaceous shale; brown siltstones and gray shales that comprise the middle. Thick yellow to brown concretionary sandstone is found near the base (Blackstone, 1970).

Upper Cretaceous Steele Shale (Ks): This 2600-2900 ft thick unit is predominantly dark-gray marine shale, sandy in the upper part with interbedded thin, fine-grained buff sandstones in the upper part. A persistent sandstone, 1300 feet above the base, is locally referred to as the Shannon sandstone (Houston, 1968; Blackstone, 1970).

Upper Cretaceous Niobrara Formation (Kn): The Niobrara is 500 feet of highly fossiliferous, predominantly gray calcareous shale, interbedded with cream to yellow and orange weathered silty limestone (Houston, 1968; Blackstone, 1970). The thickness increases to 700 feet near Kennaday Peak (Barton, 1974).

Upper Cretaceous Frontier Formation (Kf): The Frontier consists of 450 feet of dark-gray marine shale interbedded with thin bentonites, and is topped with the 10 ft thick Wall Creek Sandstone Member (Houston, 1968; Blackstone, 1970). Septarian concretions are found near the base. This formation is as much as 650 feet thick in the northwestern Medicine Bows (Barton, 1974).

Frontier Formation and Mowry Shale undivided (Kfm): The Frontier Formation and the Mowry Shale were mapped as one unit in the Rex Lake Quadrangle by Blackstone (1970).

Frontier Formation, Mowry Shale, and Thermopolis Shale undivided (Kft): These units were mapped together as one unit, the Benton group, by Houston (1968), and are combined where separate outcrops cannot be distinguished at the 1:100,000 scale.

Upper Cretaceous Mowry Shale (Kmr): Silver-gray weathered, black siliceous shale with common fossil fish scales. Numerous bentonite beds dominate the 150 foot thick Mowry Shale (Houston, 1968; Blackstone, 1970).

Lower Cretaceous Thermopolis Shale (Kt): The 20 foot thick, clean, medium-grained Muddy Sandstone Member tops 110 feet of black marine shale containing thin, lenticular brown to olive-green sandstone layers (Houston, 1968; Blackstone, 1970).

Thermopolis Shale including Muddy Sandstone Member and Cloverly Formation undivided (Kmc): Rex Lake Quadrangle, Blackstone (1970).

Lower Cretaceous Cloverly Formation (Kcv): The 150 foot thick Cloverly Formation hosts a distinct white, cross-bedded, conglomeratic sandstone at its base, overlain by a pink siltstone in the middle, which is in turn overlain by a rusty to yellow sandstone at the top (Houston, 1968; Blackstone, 1970).

Cretaceous undivided (Ku): Cretaceous units within some parts of the Rex Lake Quadrangle were not separated during mapping by Blackstone (1970).

Cretaceous and Jurassic undivided (KJ): These units are combined in the Lake Owen area where outcrops are too small to depict individually at the 1:100,000 scale.

Morrison and Sundance Formations undivided (Jms): The Upper Jurassic Morrison Formation consists of 300 feet of white sandstone beds near the top that are underlain by variegated, purple, green, and maroon claystone and shale with abundant green chert. Locally present are fragments of dinosaur bones and calcareous nodules (Houston, 1968; Blackstone, 1970). This unit is roughly 600 feet thick in the northwestern Medicine Bows according to Barton (1974).

The Middle Jurassic Sundance Formation as described in the Southeastern Medicine Bows contains about 50 feet of white to pale yellow, cross-bedded and ripple-marked calcareous glauconitic sandstone, along with some oolitic limestone and gray and green shale in the lower part in more northern exposures, with abundant fossil Pachyteuthis densus (which are thick walled belemnite rostrum) in upper part (Houston, 1968: Blackstone, 1970; Houston and Orback, 1976). In the northwestern Medicine Bows, the Sundance is about 190 feet thick (Barton, 1974).

Upper Triassic Jelm Formation and Triassic Chugwater Formation undivided (ŦRjc): The Jelm Formation is 130-250 feet of orange and red siltstone and sandstone overlying distinctive clay-pebble conglomerate, which may include fragments of vertebrate bones and crocodile teeth (Houston, 1968; Blackstone, 1970; Love and others, 1993). Within the Lake Owen Quadrangle, this unit also includes the Canyon Springs Sandstone Member of the Sundance Formation (Houston and Orback, 1976).

On the east side of the Medicine Bow Mountains, the Chugwater Formation is composed of 550 feet of thinly bedded calcareous red shales, siltstones, and local thin sandstones, with some thin beds of limestone and gypsum; lower beds are Permian (Houston, 1968; Blackstone, 1970; Houston and Orback, 1976). In the Centennial Valley, this includes the unit referred to by Houston and Orback (1970) as the 'Red Peak Member of the Chugwater Formation and the upper Goose Egg Formation undivided.' On the west side of the Medicine Bows, near Kennaday Peak, the Chugwater is as much as 1200 feet thick (Barton, 1974).

PALEOZOIC/MESOZOIC

Triassic Jelm and Chugwater Formations, and Permian Goose Egg, Forelle, and Satanka Formations undivided (ŦRPu): These units were mapped together in the vicinity of Kennaday Peak by Houston (1968).

Triassic Chinle, Chugwater (Red Peak Member), and Permian Satanka Formations undivided (ŦRPcs): These grouped formations include more than 800 feet of red siltstone, shale, mudstone, and clay-pebble conglomerate southeast of Hog Park in the southern Sierra Madre, Jackson County, Colorado (Snyder, 1980).

Permian/Triassic Goose Egg Formation (ŦRPg): The Goose Egg Formation, shown in the northern parts of the quadrangle, is equivalent to the lower part of the Chugwater Formation in combination with the Forelle Limestone and Satanka Shale that crop out along the southeastern flank of the Medicine Bow Mountains (Houston, 1968; Love and others, 1993). The Goose Egg, about 120 feet thick, is made up of orangish-red gypsiferous shale and siltstone interbedded with gypsum layers and gray to purple dense platey limestone and dolomite members that contain abundant chert layers (Houston, 1968; Blackstone, 1970; Barton, 1974; Houston and Orback, 1976).

Paleozoic and Mesozoic units undivided (MzPz): Small areas of Paleozoic and Mesozoic formations in the northern Saratoga Valley were not subdivided when mapped by Montagne (1954 & 1991). Other combined outcrops of these units are shown along the east flank of the Medicine Bow Mountains.

PALEOZOIC

Permian Forelle Limestone and Satanka Shale undivided (Pfs): These units are combined within the Lake Owen Quadrangle (Houston and Orback, 1976) where the Forelle is too thin to map separately. The Forelle is a distinct and resistant 10-20 foot thick lavender to gray and white, crenulated limestone that often contains thin red to gray shale or siltstone in the middle (Houston, 1968; Blackstone, 1970; Houston and Orback, 1976). The Satanka Formation is made up of 120-220 feet of orange to red siltstones and shales that contain thin lenticular beds of

gypsum, limestone, and ferruginous sandstone (Houston, 1968; Blackstone, 1970; Houston and Orback, 1976).

Pennsylvanian/Permian Casper Formation (ℙℙc): The Casper Formation, as much as 320 feet thick, is made up of an upper yellowish to pink, calcareous, fine- to medium-grained, cross-bedded sandstone, a middle hard red and gray siltstone with some thin limestone beds, and a lower white and red cross-bedded sandstone (Houston, 1968; Blackstone, 1970; Houston and Orback, 1976). The Casper Formation is about 150 feet thick in the vicinity of Kennaday Peak in the northwestern Medicine Bow Mountains (Barton, 1974).

Pennsylvanian Fountain Formation (ℙf): The Fountain Formation represents 400 to more than 500 feet of predominantly pink to maroon calcareous arkosic sandstone, and contains additional beds of light-purple arkose, gray sandstone, red siltstone, red shale, and white limestone, with a few interbedded conglomerates (Houston, 1968; Blackstone, 1970; Houston and Orback, 1976). The Fountain Formation crops out along the eastern Flank of the Medicine Bow Mountains, and along the flanks of Sheep Mountain in the eastern part of the quadrangle.

Pennsylvanian Amsden Formation and Mississippian Madison Limestone undivided (ℙMu): The Amsden Formation, varying from 5 to 30 feet thick, and the Madison Limestone, about 10 feet thick, crop out in the northwestern Medicine Bow Mountains in the north-central part of the quadrangle. The white to gray and lavender Madison Limestone at the base of this map unit is overlain by the Amsden's red shale which contains banded chert nodules (Houston, 1968; Barton, 1974).

PRECAMBRIAN

Terminology and unit designations are based on those used by Houston, Karlstrom, Graff, and Flurkey (1992) for the Sierra Madre and Medicine Bow Mountains, with details added from numerous other sources shown in the attached references.

Mesoproterozoic

Proterozoic dikes (Yd): Fine- to medium-grained, pink granitic dikes that although not dated, are considered to be related to the Sherman Granite. These dikes are common in the Lake Owen area (Houston and others, 2003). This includes some dikes described by Houston and others (1968) as granitic dikes that may be of more than one age, and dikes of white to pink fine-grained rhyolite and porphyritic quartz latite.

Sherman Granite 1,433 ± 1.5 Ma (Ys): Pink, coarse-grained to pegmatitic microcline granite, dated at 1,433 ± 1.5 Ma by Frost and others (1999). The Sherman is typically equigranular with medium-grained characteristics more abundant near contacts, but a younger coarse-grained porphyritic phase is also present (McCallum and Houston, 1985).

Contacts are typically sharp where older rocks are locally cut by sills and dikes of the Sherman Granite. Plagioclase, microcline, and quartz tend to be equicrystalline, but biotite is highly variable in size. Based on crystal form, some biotite appears to replace hornblende or tourmaline. Local hybridization of both granite (more abundant potassium feldspar) and country rock (more

abundant amphibole and biotite) occurs where the granite is in contact with mafic hosts. Stretched and flattened xenoliths of earlier rock types are common but nowhere abundant. Where sheared and brecciated, the Sherman Granite is locally enriched in epidote and quartz and is a very deep red, which could be confused with the older granite.

pegmatite 1,514 ± 36 Ma (Yp): Pink to white granite pegmatite consisting principally of K-feldspar and quartz, and may be of more than one age (Houston and others, 1968). A pegmatite in the Woods Landing quadrangle has a reported U-Pb age of **1,514 ± 36 Ma** (Campbell and Shelton, in press).

Mesoproterozoic and Paleoproterozoic

Rocks within or south of the Cheyenne belt

pegmatite, 1,510-1,763 Ma (Xp): Granite pegmatite found both in and marginal to the Sierra Madre Granite and the white quartz monzonite and, although younger, may be genetically related to both. It is also present as discrete bodies in metavolcanic and metasedimentary rocks in the southern Sierra Madre, and may make up as much as 50 percent of the exposures in some areas of white quartz monzonite or biotite gneiss (Houston and Graff, 1995). Areas exhibiting abundant pegmatites are designated with a dotted pattern on the map.

Houston and others (1978) described several types and episodes of pink to white granite pegmatite both north and south of the Mullen Creek-Nash Fork shear zone in the Medicine Bow Mountains (Houston and others, 1968). Houston and others (1989) report Rb-Sr isochrons for pegmatites in the Medicine Bows of 1,510 ± 40 Ma, 1,565 ± 40 Ma, and 1,620 ± 40 Ma, after Hills and others (1968).

Paleoproterozoic

granite and quartz monzonite and related intrusive rocks 1,600-1,800 Ma (Xg): Includes Houston & Karlstrom's (1992) quartz monzonite gneiss (medium- to coarse-grained, pink to buff to gray gneiss consisting of equal amounts of quartz, potash feldspar, and plagioclase), alaskite, and pink gneissic granite, which forms a gradational contact with migmatitic biotite schist and gneiss in the Medicine Bow Mountains.

white quartz monzonite, 1,627 ± 4 Ma (Xgw): Medium- to coarse-grained, white to light gray quartz monzonite that intrudes the Sierra Madre Granite and is dated by Premo and Van Schmus (1989) as 1,627 ± 4 Ma, using the uranium/lead zircon method (Houston and Graff, 1995).

luxullianite 1,699 ± 40 Ma (Xgl): Medium-grained, pink to pinkish-white, tourmaline-rich (up to 30%) generally concordant bodies intruded into mylonite gneiss and amphibolitized metaigneous rocks in the northeastern part of the Keystone quadrangle near the New Rambler mine. The mineralogy, in order of relative abundance, includes: plagioclase (albite), quartz, microcline, tourmaline, muscovite, sericite, and garnet. Black tourmaline (schorl) varies from microscopic needles in quartz to euhedral crystals several millimeters long in aphanitic rocks, to crystals several inches long in pegmatitic phases. McCallum and Orback (1968) and Coalson (1971) suggest that this may be a late phase of the Rambler granite. Hills and Houston (1979)

report a Rb-Sr whole rock isochron of 1,699 ± 40 Ma for the luxullianite, which could be revised using more precise modern techniques.

Rambler Granite, 1,770.8 ± 3.4 Ma (Xgr): The medium-grained, pink Rambler Granite is a relatively small and highly irregular stock exposed northeast of the New Rambler Mine in the northeastern part of the Keystone quadrangle (McCallum and Orback, 1968; Coalson, 1971). The granite, which exhibits both conformable and cross-cutting relationships with surrounding rocks, consists of quartz, potash feldspar, sodic plagioclase, biotite, and chlorite with minor amounts of epidote, hornblende, muscovite, magnetite, and allanite. Premo and Loucks (2000) reported a date of 1,770.8 ± 3.4 Ma for the Rambler granite.

Sierra Madre Granite, 1,744-1,763 Ma (Xgs): Well-foliated to medium-grained to faintly foliated and coarse-grained, pink to red granite and quartz monzonite plutons, dikes, and sills in the Sierra Madre (Houston and Graff, 1995). A facies of the Sierra Madre Granite was dated as 1,744 ± 14 Ma, 1,749 ± 8 Ma, and 1763 ± 6 Ma, by Premo and Van Schmus (1989) using the uranium/lead zircon method.

quartz veins of unknown age (Xq): Mapped in the lower French Creek area by Matus (1958), and in the Mullen Creek complex by Sutherland and Hausel (2003). These quartz veins cut both the small felsic intrusives and rocks of the Mullen Creek complex.

small felsic intrusives (Xgf): Medium- to coarse-grained, pale red to pink to pinkish-white and gray granite and quartz monzonite that in places grades into granodiorite. These intrude the Mullen Creek mafic complex (McCallum and Orback, 1968). Similar granitic intrusives and some dioritic phases, mapped by Ramirez (1971), and Donnelly (1979) as younger felsic intrusives in the southwestern part of the Mullen Creek complex are included as are Ruehr's (1961) granite gneiss, some of Houston and others (1978) older granite, and McCallum and Kluender's (1983) granite. Some of these intrusives are associated with shear zones, but exhibit both concordant and discordant contact relationships, and are interpreted as both syn- to post-shear intrusions (McCallum and Orback, 1968; Ramirez, 1971). Contacts with the mafic complex are generally sharp where observed, and may be accompanied by intrusive breccias and mafic rock inclusions. Widespread contact effects are shown by prevalent hybridization adjacent to many of these bodies. Where hybridization is extensive, distinction between small felsic intrusives and the Horse Creek foliated granodiorite is difficult (Ramirez, 1971; Donnelly, 1979).

Metamict zircons from a sample of a granitic felsic intrusive in the Horatio Rock quadrangle showed considerable uranium loss and resulted in reversely discordant 207Pb/206Pb ages between 1,710 and 1,600 Ma. Although no definitive date was acquired, the date range could be interpreted as an approximately 1,550 Ma (≤1,600 Ma) magmatic event where the zircons inherited older cores or as an older magmatic event (≥1,710 Ma) that recorded younger metamorphic alteration (Toner and others, 2019).

granite dikes (Xgd): Pink, medium-grained, commonly sheared granite dikes and some sills of uncertain ages, both north and south of the Cheyenne Belt (Houston and others, 1968).

aplite gneiss (Xap): Pink to pinkish-gray aplite gneiss, commonly in the form of sills in the Lake Owen area and south of Sheep Mountain in the Medicine Bow Mountains (Houston and Orback, 1976).

Lake Owen layered mafic complex, 1,775.1+/- 3.0 Ma: The Lake Owen layered mafic complex is a Proterozoic gabbroic intrusion which hosts significant mineralization (Hausel, 2000). Loucks and Glasscock (1989) noted 18 cyclic units within the Lake Owen complex that were defined by large scale repetitions of two or more lithologic units, and by compositional variations in the rock mineralogy. Of these, at least 12 stratigraphic horizons in the complex exhibit cumulus sulfide mineralization. Mapping in the Lake Owen area, based on Houston and others (1968), Houston and Orback (1976), and particularly Houston and others (2003) defines the following units within the Lake Owen complex. More detailed descriptions of individual units in the cyclical successions are referenced to Houston and others (2003). A date from pegmatitic gabbro-norite pods (sample 20170921NK-A) within the layered unit yielded a U-Pb zircon age of 1,775.1 +/- 3.0 Ma (Sutherland and Kragh, 2018).

magnetite gabbro (Xlm)
magnetite gabbro-norite (Xlr)
olivine gabbro (Xlo) [previously log]
olivine magnetite gabbro-norite (Xlu)
gabbro-norite (Xlg)
norite (Xln)
troctolite (Xlt)

layered unit (Xll) alternating light and dark layers of olivine gabbro, norite, and anorthosite, varying in thicknesses from a few centimeters to a few meters 1,775.1 +/- 3.0 Ma (Sutherland and Kragh, 2018).

cyclic succession (Xlc): layers of olivine gabbro or norite alternating with layers of norite

border phase (Xlb): dark-gray to black and porphyritic basalt, which is locally brecciated and filled with gabbro, and may exhibit effects of contact metamorphism at the base.

Horse Creek foliated granodiorite, 1,777 ± 4 Ma (Xgh): The Horse Creek foliated granodiorite is a widespread unit within the Keystone quadrangle. It includes parts of Houston and others (1978) older granite and quartzo-feldspathic gneiss, Currey's (1965) quartz-feldspar gneiss, McCallum and Orback's (1968) broadly inclusive mylonitic biotite-epidote-plagioclase gneiss, Ramirez's (1971) Boat Creek granodiorite, Coalson's (1971) granitic gneiss, Donnelly's (1979) Horse Creek granodiorite, and McCallum and Kluender's (1983) felsic mylonite gneiss. This unit has also been referred to by Houston and others (1989) and Dubendorfer (1986) as the Horse Creek granite, which, Premo and Van Schmus (1989) reported as exhibiting a U-Pb zircon age of 1,777 ± 4 Ma. Extreme variations within parts of this unit, probably result from gradational interactions with surrounding units and cataclasis.

This unit varies from unfoliated to conspicuously foliated, with zones of moderate to severe cataclasis occurring primarily in the northern portions of the unit (McCallum and Orback 1968), and weak cataclasis noted by Ramirez (1971) in the western part of the unit. The rock unit is generally pink to gray in color, taking on a greenish cast where epidote is abundant. However, it becomes dark pinkish-gray to greenish-gray where it is more mafic west of the New Rambler mine. The rock is predominately fine to medium-grained, with lesser coarse-grained phases. Additional discussions of this unit can be found in Sutherland and Hausel (2003).

Mullen Creek layered mafic complex, 1,777.6 ± 2.1 Ma (Xc): This is a 60 mi^2 complex of fine- to coarse-grained mafic igneous and metaigneous layered rocks south of the Cheyenne Belt in the central Medicine Bow Mountains. These rocks have been mapped in part by Ruehr (1961), Houston and others (1968), McCallum and Orback (1968), Ramirez (1971), Houston and others (1978), and Donnelly (1979). Some researchers have suggested that the Mullen Creek complex

was a dismembered part of the Lake Owen layered mafic complex, which lies six miles to the east.

Loucks and others (1988) describe the Mullen Creek complex as lower crustal mafic cumulates derived from arc tholeiite magma from a Proterozoic intra-oceanic arc complex accreted to the Archean Wyoming Craton. The complex is tilted on edge, and has more than 21 cyclic units based on petrographic analyses, which resembles the stratigraphy of the Lake Owen complex (Loucks and Glasscock, 1989). Loucks and others (1988) calculated a U-Pb zircon age of 1,777.6 ± 2.1 Ma from a diorite within the complex.

The irregular shaped body of the Mullen Creek complex is metamorphosed to varying degrees and includes metabasalt, metagabbro, gabbro, olivine gabbro, metadiorite, diorite, quartz diorite, metadiabase, amphibolite, amphibolized metaigneous rocks, metapyroxenite, and hybrid rocks resulting from contamination or modification of the mafic rocks by felsic intrusions. Gradations from one rock type to another are common within the complex, and sparse outcrops coupled with deep weathering inhibit mapping contacts between them (Ramirez, 1971; Donnelly, 1979).

The Mullen Creek mafic complex is truncated on the northwest by the Mullen Creek-Nash Fork shear zone and along its northeastern edge by the Rambler shear zone. The complex cuts amphibole gneiss along its southeastern boundary, but is extensively metamorphosed along its southern edge where it appears to grade into the amphibole gneiss (Houston and others, 1989).

The following designations found within the Mullen Creek mafic complex are generally not mapped as separate units due to gradational relationships, poor outcrops, and insufficient data.

> **amphibolite (Xca)**: Fine-grained, massive to poorly foliated, dark-gray to black amphibolite, orthoamphibolite, and amphibolitized metaigneous rocks made up of hornblende, andesine, and accessory biotite, magnetite and clinopyroxene with secondary quartz and epidote. The amphibolite may contain local zones of chlorite schist, and gradational contacts are noted between orthoamphibolite and metagabbro in some areas (Ruehr, 1961).
>
> **gabbro (Xcg)**: Fine- to coarse-grained, massive to weakly foliated, dark greenish-gray to brown-black gabbro composed of amphibole and andesine-labradorite, and may include olivine gabbro, metaleucogabbro, norite and anorthosite. The gabbro exhibits 1mm to 1m alternating light and dark bands of metaleucogabbro and metagabbro that range from anorthosite to metapyroxenite, respectively in the vicinity of Jay's Roost (Ruehr, 1961; Donnelly, 1979).
>
> **olivine gabbro (Xco)**: Olivine gabbro, composed of plagioclase, clinopyroxene, olivine, orthopyroxene, and amphibole, with minor amounts of quartz, biotite, and opaque minerals, represents one of the least metamorphosed rock types within the Mullen Creek complex (Houston and others, 1968).

Elkhorn Mountain Gabbro (Xe): Large bodies, dikes, and sills of medium-grained, dark-brown to black clinopyroxene-hornblende gabbro in the southern Sierra Madre. This gabbro also occurs as inclusions in the Sierra Madre Granite (Houston and Graff, 1995).

olivine gabbro (Xeo): Olivine-two pyroxene-amphibole-gabbro coronite in a one by two mile pluton within the Gabbro of Elkhorn Mountain near the Colorado border (Snyder, 1980). This pluton is cut by rare dikes of Gabbro of Elkhorn Mountain.

peridotite (Xep): Small black to olive-gray, red-weathering, amphibole peridotite bodies of various types including dunite, wehrlite, harzburgite, and hornblendite, many containing spinel and chromite, within or related to the Gabbro of Elkhorn Mountain near the Colorado border (Snyder, 1980).

metavolcanic and metasedimentary rocks, 1,778.4 ± 1.7 Ma (Xv) [previously Xvm]: This designation after Houston and others (1992) encompasses a wide variety of metavolcanic and metasedimentary rocks, and includes mylonitic quartz-feldspar gneiss within the Cheyenne Belt (Houston and Karlstrom, 1992). The mylonitic quartz-feldspar gneiss varies from fine- to medium-grained, sharply-defined alternating layers of white to gray quartz-microcline and dark-gray biotite-plagioclase-epidote gneiss, to medium- to coarse-grained, strongly foliated to massive, biotite-quartz-feldspar gneiss, to pink to leucocratic, fine- to medium-grained quartz-feldspar gneiss resembling a weakly metamorphosed alkalai feldspar granite. Evidence of mylonitization is present throughout the mylonitic quartz-feldspar gneiss, but interpretation by Duebendorfer(1986) proposes that widespread recrystallization has destroyed much of the mylonitized fabric (Houston and Karlstrom, 1992). Rhyolite from this unit, in the northern part of the Foxpark quadrangle, is dated at 1,778.4 ± 1.7 Ma (Carnes and others, in press)

Some outcrops of amphibole gneiss in the Medicine Bow Mountains (Xvg) on Saratoga 100k were mapped as (Xd) in the northern part of the Horatio Rock quadrangle and dated at 1,775 ± 1.8 Ma (Toner & others, 2019). These may be a part of the Lake Owen complex or the Mullen Creek complex.

Detailed rock identifiers and descriptions where available for other metavolcanic and metasedimentary rocks south of the Cheyenne Belt are describes as follows:

felsic gneiss (Xvf): This includes various descriptions, compositions, and designations in the Medicine Bow Mountains, and siliceous quartz-feldspar gneiss of possible volcanic origin in the southern Sierra Madre near the confluence of Hog Park Creek and Encampment River (King, 1961; Houston and others, 1968; Houston and Karlstrom, 1992; Houston and Graff, 1995).

mylonitic biotite augen gneiss in the Medicine Bow Mountains (Xva): Dark-gray to black, medium-grained, variably mylonitized, moderately to strongly foliated, hornblende-bearing biotite augen gneiss. Locally, this unit is migmatitic and contains 10-50 percent masses of pegmatite and coarse-grained granitic gneiss that are both concordant and discordant (Houston and Karlstrom, 1992).

migmatitic biotite schist and gneiss in the Medicine Bow Mountains (Xvb): This unit encompasses coarse-grained, migmatitic sillimanite-garnet-biotite schist and gneiss and weakly foliated biotite augen gneiss as mapped by Houston and Karlstrom (1992). Houston and Karlstrom (1992) interpret this unit as pelitic schist engulfed or intruded by granitic and granodioritic components that comprise 30-70 percent of the unit.

mafic schist and gneiss in the Medicine Bow Mountains (Xvs): This is a succession of volcanogenic rocks dominated by moderately to strongly foliated, dark-gray to purple, fine- to medium-grained hornblende-biotite-plagioclase schist and gneiss interlayered with marble,

calcite-garnet-diopside-epidote schist, and diopside-hornblende-chlorite-calcite gneiss. This unit also contains conformable amphibolite and felsic gneiss (Houston and Karlstrom, 1992).

quartz-plagioclase gneiss in the Medicine Bow Mountains (Xvq): Fine- to medium-grained, pink to gray gneiss with plagioclase, quartz, epidote, and biotite. This unit as described by Houston and Karlstrom (1992) is diverse in its composition, and is locally mylonitic.

amphibole gneiss in the Medicine Bow Mountains (Xvg): This complex unit south of the Cheyenne Belt is predominately fine-grained, but varies from medium- to coarse-grained in some areas. It ranges from brown to dark-gray on fresh exposures to light greenish-gray on weathered surfaces. The strongly foliated gneiss is characterized by dominant dark bands of amphibole that alternate with bands of felsic and intermediate gneiss ranging in thickness from a fraction of an inch to several feet. It also includes some interlayered biotite gneiss, sillimanite gneiss, quartzo-feldspathic gneiss, diopside-hornblende-calcite gneiss, impure marble, calcite-garnet-epidote gneiss, amphibolite, and calc-biotite gneiss. Descriptions and mapping are after Houston and others (1968), Houston and others (1978), Ruehr (1961), Currey (1965) and Donnelly (1979).

Houston and others (1978) suggested a possible sedimentary origin for part of the amphibole gneiss, but admit that the origin of much of the unit is uncertain. Contact between the amphibolite gneiss and the Mullen Creek layered mafic complex is gradational in the Devils Gate area, although contacts between the amphibole gneiss and metagabbro are generally sharp (Ruehr, 1961). Houston and others (1978) noted that the amphibole gneiss is cut by the mafic complex along the east side of the Mullen Creek complex, but the contact between the south side of the mafic complex and the amphibole gneiss is gradational, and the contact between the amphibole gneiss and quartz-biotite schist (Xqb) to the east of the Mullen Creek complex is also gradational.

Origin of thin hornblende gneiss and amphibolite interlayered with felsic gneiss (Xvf) in the southwestern Medicine Bow Mountains near the Platte River is uncertain (Myers, 1958). These complex layers are in part diagrammatically depicted on the 1:100,000 scale map.

pelitic schist in the Medicine Bow Mountains (Xvp): This unit is composed of weakly foliated, medium- to coarse-grained, dark-gray to black biotite-quartz-feldspar schist and gneiss with lesser amounts of fine-grained quartz-biotite schist and gneiss (Houston and Karlstrom, 1992).

marble in the Medicine Bow Mountains (Xvm): A small exposure of marble associated with amphibole gneiss is mapped in the northern part of Sheep Mountain. Other impure marbles have not been mapped, but occur on Centennial Ridge within the mafic schist and gneiss (Xvs), and interlayered with the amphibole gneiss (Xvg) in the vicinity of Smith North Creek, southeast of the Mullen Creek complex (Houston and others, 1968).

quartz-andesine gneiss in the Medicine Bow Mountains (Xqa): This unit consists of fine-grained, highly foliated, light-gray gneiss composed principally of andesine, quartz, and biotite that grades imperceptibly into quartz diorite (Xk) at the southwestern edge of the Lake Owen mafic complex (Currey, (1965).

quartz-biotite schist in the Medicine Bow Mountains (Xqb): Quartz-biotite schist crops out in the Keystone area where it is 2400 ft thick. The schist is generally very fine-grained and

exhibits an angular and blocky appearance in outcrops with rectangular jointing. In places, fresh partings along foliation exhibit a micaceous sheen. The schist is medium to dark gray to black on fresh surfaces, but appears brown where weathered. The schist appears to be in gradational contact with amphibole gneiss (Xvg) to its south and west, and with the Horse Creek foliated granodiorite (Xgh) to the north. The principal minerals in order of abundance are: quartz, plagioclase, biotite, and muscovite (Currey, 1965).

Swetnam (1961) described another quartz-biotite schist in the Pelton Creek area near the state line. That rock appears medium-grained and black and white banded, and contains quartz, biotite, potash feldspar, and muscovite, with foliation developed by biotite layering.

quartz-biotite-andesine gneiss in the Medicine Bow Mountains (Xqc): This unit, located in the Woods Landing area, is a fine- to medium-grained, moderate- to well-foliated, dark-gray gneiss with well-developed layering (Houston and others, 1968). Quartz is the most abundant mineral, and the rock resembles quartzite in some exposures. The unit includes quartz-plagioclase-biotite gneiss and quartz-hornblende gneiss mapped by King (1961). Primary constituents are quartz, biotite, andesine, hornblende, microcline, and muscovite. Alternating mafic and felsic layers 1/8 to 1/4 inch thick vary from sharp to gradational in much of the unit, and contain accessory apatite, sphene, and epidote, and magnetite (King, 1961).

Encampment River Granodiorite, 1,779 ± 5 Ma (Xz): Foliated, dark-gray intrusive rock varying in composition from granodiorite to quartz diorite to diorite, and characterized by inclusions of volcanic rocks of the Green Mountain Formation (Houston and Graff, 1995). Premo and Van Schmus (1989) determined a 1,779 ± 5 Ma uranium/lead zircon age for the intrusion.

Keystone quartz-diorite, 1,784.7 ± 1.9 Ma (Xk): The Keystone quartz diorite is a medium to light gray, medium-grained, quartz diorite in the Medicine Bow Mountains found east, south, and west of the Lake Owen mafic complex (Houston and others, 1968), and described by Currey (1965). The rock crops out as prominent massive, rounded to spheroidal blocks bounded by widely spaced joints, and faint foliation may be visible in some exposures. Principle constituent minerals in order of abundance are: plagioclase (andesine), quartz, hornblende, biotite, and epidote. Premo and Van Schmus (1989) provide a U-Pb zircon age for the Keystone quartz diorite of **1,781 ± 7 Ma**. Campbell and Shelton (in press) provide a U-Pb zircon age for the Keystone Quartz Diorite of 1,784.7 ± 1.9 Ma from the Woods Landing quadrangle.

Currey (1965) observed contacts between the quartz diorite and adjacent pre-existing metamorphic rocks to be gradational through a narrow transition zone (Xkel) where grain size decreases in the quartz-diorite as the contact is approached. The quartz diorite partially replaces older rocks, or is injected into the folia of older rocks within the transitional contact zone. Numerous inclusions of these older rocks suggested to Currey that a stoping process contributed to emplacement of the quartz diorite. Houston and others (1978) report that the quartz diorite is younger than adjacent quartz-biotite schist (Xqb) and amphibole gneiss (Xvg). Houston and others (in press) describe interlayering with felsic gneiss in the Lake Owen area.

Keystone quartz-diorite interlayered with adjacent rock types (Xki): Transition zone described above (Xk) varies from a few inches to greater than 600 feet wide Sutherland and Hausel (2003), and Houston and others (2003).

Keystone quartz-diorite agmatite (Xka): Brecciated layered gneiss, veined by quartz diorite that constitutes a majority of the unit southeast of the Lake Owen mafic complex (Houston and Orback, 1976).

Green Mountain Formation – Sierra Madre

Mafic metavolcanic rocks of the Green Mountain Formation (Xrv): A sequence of mafic metavolcanic rocks of upper greenschist to lower amphibolite facies, with locally well-preserved primary texture in the central Sierra Madre. Calc-alkaline metabasaltic rocks dominate the sequence in the Green Mountain and Fletcher Park areas, but grade laterally into and are interbedded with intermediate to felsic composition metavolcanic rocks and metagraywacke (Houston and Graff, 1995).

Felsic metavolcanic rocks of the Green Mountain Formation, 1,792 ± 15 Ma (Xrf): Felsic metavolcanic rocks in the Green Mountain area that are predominately fine-grained, white to gray to black metarhyolite and metadacite (Houston and Graff, 1995). A uranium/lead zircon age of 1,792 ± 15 Ma was reported by Premo and Van Schmus (1989) on zircon separated from metadacite porphyry from this unit on the east side of Green Mountain.

Metagraywacke of the Green Mountain Formation (Xrm): Dark-gray biotite-chlorite-quartz-feldspar schist in the northern Sierra Madre (Houston and Graff, 1995).

Mixed metavolcanic and metasedimentary rocks of the Green Mountain Formation (Xrx): A succession of interbedded felsic and mafic metavolcanic and metasedimentary rocks in the Sierra Madre (Houston and Graff, 1995).

Chemical metasedimentary rocks of the Green Mountain Formation (Xrc): Fine-grained metaquartzite (chert?), metalimestone, oxide-facies magnetite-rich iron formation, and massive and disseminated sulfide deposits that are interlayered with or disseminated in volcanogenic metasedimentary rocks, and includes some sedimentary exhalative sulfide deposits (Houston and Graff, 1995).

mafic intrusive rocks ~1,800 Ma (Xs) – Dark-gray to black mafic, generally sill-like and conformable intrusives up to a mile long, and varying from a few feet to several hundred feet wide. Cross-cutting intrusive relationships occur locally. Complete conversion to amphibolite dominates these rocks, and where interlayered with amphibolitized mafic volcanic rocks, distinction between these intrusives and flows and tuffs is difficult. Therefore, some mafic bodies may be included within the Green Mountain Formation (Xrv) and mafic metavolcanic rocks (Xvc) (Houston and Graff, 1995). Where original textures are preserved or where chemical composition and mineralogy are known, these mafic intrusives are designated as follows:

amphibolite (Xsa)
diabase (Xsd)
gabbro and metagabbro (Xsg)
metabasalt (Xsb)
olivine gabbro (Xso)
metaperidotite (Xsp)
metapyroxenite (Xsx)
ultramafic (Xsu)

South Holroyd gneiss (Xvh): This gneiss in the extreme southeastern Sierra Madre is locally distinguished by silver dollar-sized pods consisting of quartz, and muscovite, and sillimanite. However, this unit is dominated by layers of hornblende gneiss, quartz-pebble conglomerate, gray quartzite, and sillimanite-quartz-garnet-feldspar gneiss (Houston and Graff, 1995).

Mafic metavolcanic rocks (Xvc): Predominantly brown to purple amphibolite and hornblende gneiss with minor layers of biotite-quartz-feldspar gneiss in the Sierra Madre. Some fine-grained amphibolite with fragmental texture is interpreted to derive from lapilli tuff, and medium- to coarse-grained, massive amphibolite is interpreted to have been emplaced as intrusive rock (Houston and Graff, 1995).

Metasedimentary rocks, Sierra Madre (Xvd): White metalimestone, white to gray quartzite, brown oxide facies iron formation, and green to gray mica schist in the eastern Sierra Madre in the Cheyenne Belt (Houston and Graff, 1995).

Mixed gneiss (Xvx): Interlayered biotite-quartz-feldspar gneiss, hornblende-quartz-feldspar gneiss, hornblende-garnet-quartz-feldspar gneiss, amphibolite, augen gneiss, marble, diopside-calcite-garnet gneiss, quartzite, and other calc-silicate rocks in the Sierra Madre (Houston and Graff, 1995).

Paleoproterozoic and Neoarchean Rocks north of the Cheyenne belt

Gaps Intrusion, in the central Medicine Bow Mountains 1,900-2,150 Ma (Xgi): This intrusive is a medium-grained, granitoid-textured, plagioclase-rich, leucocratic, pink to gray felsic igneous rock associated with gabbroic intrusives emplaced in the lower Libby Creek Group. Most exposures may be foliated or brecciated and show evidence of shearing. The Gaps Intrusion is radioactive where sheared, and some sulfide-bearing quartz veins that cut this rock unit contain as much as 1,000 ppm uranium and 1,655 ppm thorium (Houston and Karlstrom, 1992).

mafic intrusive rocks ~1,700-2,300 Ma (Xn): Dark-gray to black to purple mafic dikes and sills metamorphosed to varying degrees, but with many preserved gabbroic and diabasic textures. In the Sierra Madre, these are mostly altered to amphibolite (Matus, 1958; Houston and Graff, 1995). In the Medicine Bow Mountains, smaller dikes and sills are predominantly basalt and diabase, and larger intrusions tend to be quartz gabbro and norite. Houston and Karlstrom (1992) interpret many of these mafic intrusions to be emplaced in faults. Age range cited is from Houston and others (1992), although Houston and Graff (1995) suggest a probable range of ages from 1990 to 2092 Ma in the Sierra Madre. The Houston and Graff (1995) range is based on a uranium/lead zircon age of 2,090 ± 9 Ma by Premo and Van Schmus (1989) of a pegmatitic phase of a metagabbro that intrudes the Cascade Quartzite, and a Sm/Nd whole rock date of 1,990 ± 30 Ma by Shaw and others (1986) of an ultramafic sill intruded into Vulcan Mountain Metavolcanics west of Spring Lake. More detailed rock identifiers and descriptions where available are as follows:

amphibolite (Xna)
anorthositic (Xnr)
diabasic (Xnd)
gabbroic (Xng) Premo and Van Schmus (1989) described an 2,092 ± 9 Ma U-Pb zircon date from a gabbroic intrusion cutting the Cascade Quartzite.
olivine gabbro (Xno)

ultramafic (Xnu)

Baggot Rocks Granite ~ 2,429 ± 4 Ma (Xbr): Pink granite ranging from massive to well-foliated and strongly sheared (Houston and others, 1992). Radiometric date after Premo and Van Schmus (1989).

granite and quartz monzonite (Xbg): Mapped in the Bennett Peak area near the North Platte River by Houston and others (1968) and assumed to be similar to the Baggot Rocks Granite.

granite dikes (Xge): Mapped near Elk Hollow Creek, north of Highway 130 on the west side of the Medicine Bow Mountains by Houston and others (1968), and suggested be contemporaneous with the Baggot Rocks Granite.

Paleoproterozoic

Snowy Pass Group, Sierra Madre, north of the Cheyenne belt

Slaughterhouse Formation (Xsh): This is a severely deformed and only partially preserved remnant of an estimated 4,000+ ft succession consisting of fine-grained, interbedded, red, yellow, and green metalimestone containing layers of buff metadolomite, quartzite, and dark-green phyllite. Fine-grained, chlorite-calcareous schist is underlain by dark-gray graphitic phyllite, which is underlain by metalimestone (Houston and Graff, 1995).

Copperton Formation (Xcp): The Copperton Formation, which has been structurally thinned by thrust faults, is made up of three units: an upper 500 ft thick, white massive quartzite; a middle laminated phyllite exhibiting an upper section of alternating beds of coarser-grained schist and cross-bedded quartzite, underlain by 1,000 ft of gray, thin alternating quartz and fine-grained mica-rich laminae; and a coarse-grained, highly sheared, kyanite-bearing, white basal quartzite as much as 2,000 ft thick (Houston and Graff, 1995).

Bottle Creek Formation (Xb): The 1300 ft thick Bottle Creek Formation is best expressed in the western Sierra Madre where an upper slabby and buff quartzite containing interbeds of phyllite is successively underlain by units of diamictite and quartzite. The diamictite units are paraconglomerate within a matrix of tan or green phyllite interbedded with pale-green schistose and feldspathic, medium- to coarse-grained quartzite (Houston and Graff, 1995).

Cascade Quartzite, >2,092 ± 9 Ma (Xcq): The 5000+ ft thick Cascade Quartzite is a locally cross-bedded, predominately white arkosic quartzite containing layers of quartz-pebble conglomerate and black chert-pebble conglomerate (Houston and Graff, 1995). Premo and Van Schmus (1989) described an 2,092 ± 9 Ma U-Pb zircon date from a gabbroic intrusion cutting the Cascade Quartzite.

Singer Peak Formation (Xsi): A discontinuous upper part of this unit consisting of poorly sorted paraconglomerate with angular granite clasts, green phyllite beds, and thin quartzite is restricted to the western part of the Sierra Madre. The lower part, about 2,800 ft thick to the west, and thinning out east of Silver Lake, consists of blue and green phyllite, buff to orange quartzite, and thick silvery phyllite that hosts red garnet at the base (Houston and Graff, 1995).

Magnolia Formation, 2,451 ± 9 Ma (Xmg): In the Sierra Madre, the Magnolia Formation is primarily coarse-grained white to gray quartzite marked by small-scale trough cross-beds and thin layers of phyllite, with lenticular beds of radioactive quartz-pebble conglomerate near the base (Houston and Graff, 1995). The Magnolia Formation tapers from a thickness of 1,500 ft south of Dexter Peak to almost nothing south of Encampment. Zircons dated by Premo and Van Schmus (1989) give a depositional age of 2,451 ± 9 Ma.

Snow Pass Supergroup, Medicine Bow Mountains

metasedimentary rocks (Xms): Mostly white to dark blue layers of quartzite, mylonitic quartzite, and some marble, slate, and phyllite within the northern part of the Cheyenne Belt (Houston and Karlstrom, 1992; Houston and others, 1992). Where individual quartz grains can be recognized, they are flattened and stretched. Houston and Karlstrom suspect the mylonitic quartzite is derived from the Medicine Peak Quartzite, but intense deformation negates an interpretation of origin for most of the quartzite.

Libby Creek Group – Upper part

French Slate (Xf): 2,000 ft of gray to black slate and phyllite containing beds of hematitic quartzite make up the French Slate. Alternating layers rich in muscovite, chlorite, and opaque minerals with layers rich in quartz define laminae probably represent original bedding. This rock unit of probable marine origin is truncated at its top by a major fault (Houston and Karlstrom, 1992).

Towner Greenstone (Xt): This unit consists of 1,600 ft of massive to schistose, green to purple amphibolite of basaltic composition with local thin beds of quartzite and very fine-grained quartzite or metachert. The Towner Greenstone is considered to be of marine origin (Houston and Karlstrom, 1992).

Nash Fork Formation (Xnf): The Nash Fork Formation is 6,500 ft of tan siliceous metadolomite accompanied by thick intercalated lenses of black phyllite, and less common thin interlayered beds of quartzite, chert, flat-pebble conglomerate, and iron formation. Stromatolitic bioherms characterize the metadolomite and suggest shallow-water marine deposition. The black phyllite is locally graphitic, and in some locations is pyrite- and graphite-rich (Houston and Karlstrom, 1992).

Libby Creek Group – Lower part

Sugarloaf Quartzite (Xsq): The 1,900 ft thick Sugarloaf Quartzite is made up of medium-grained, cross-bedded white quartzite, and is less feldspathic than the underlying formations of the lower Libby Creek Group (Houston and Karlstrom, 1992).

Lookout Schist (Xls): This unit consists of as much as 1,186 ft of layered schist with alternating mica- and quartz-rich layers along with abundant phyllite and arkosic, subarkosic, and micaceous quartzite. Primary depositional structures are locally preserved and include graded bedding in the basal part of the formation, which is magnetite-rich in exposures east of Lookout Lake (Houston and Karlstrom, 1992).

Medicine Peak Quartzite (Xmp): The Medicine Peak Quartzite consists of 4,350-6,000 ft of intermittently cross-bedded, white to bluish-gray, medium- to coarse-grained massive quartzite containing distinctive quartz-pebble conglomerate beds up to 6 ft thick. Discontinuous, emerald-green fuchsitic layers up to 58 ft thick occur near the top of the formation. A coarse- to very coarse-grained, cross-bedded quartzite that appears bluish-gray due to the presence of kyanite makes up the lower 200 feet of the formation (Houston and Karlstrom, 1992).

Heart Formation (Xh): The 2,200 ft thick Heart formation consists of a tan, medium-grained, upper arkosic quartzite exhibiting few primary structures, and a middle layered phyllite consisting of feldspar, chlorite, biotite, quartz, and muscovite. The middle layer is continuous in the northeastern part of the Medicine Bows, but becomes discontinuous to the southwest. The lower quartzite is similar to the upper, except that it exhibits abundant primary structures including ripples, cross-bedding, and ball and pillow structures, and it becomes more massive and finer-grained to the northeast (Houston and Karlstrom, 1992).

Headquarters Formation (Xhd): The upper part of this unit is a layered chlorite-biotite-quartz phyllite containing alternating quartz-rich and mica-rich layers, and exhibits climbing ripples near its contact with the overlying Heart Formation. The lower part of the formation consists of interlayered paraconglomerate, quartzite, and schist. The lowermost paraconglomerate contains subrounded to subangular clasts of granite, quartzite, and schist in a massive or faintly stratified matrix of sand and silt-sized fragments of quartz, potash feldspar, plagioclase, and mica. The 2,100 ft thick Headquarters Formation has dropstones within the paraconglomerate that are interpreted as glaciomarine (Houston and Karlstrom, 1992).

Rock Knoll Formation (Xrk): Approximately 1,250 feet of medium-grained gray arkose containing phyllitic partings up to 1 ft thick and paraconglomerate layers up to 3 feet thick. Paraconglomerate clasts consist of quartz, quartzite, and granite. Feldspars within the Rock Knoll are primarily plagioclase, as they are throughout the lower part of the Libby Creek Group and in the underlying Vagner Formation (Houston and Karlstrom, 1992).

Deep Lake Group undivided (Xdl): Undivided components of the Deep Lake Group described below as mapped in the Kennaday Peak area by Houston and others (1968).

Vagner Formation (Xvr): This unit exhibits complexly folded phyllitic quartzite underlain by marble composed of intricately folded layers rich in calcite and quartz, which in turn is underlain by paraconglomerate with angular to subrounded variably sized clasts of granite, quartzite, and schist. The phyllite is layered with alternating quartz-rich and mica-rich layers suggestive of varves. The unit is variable in thickness up to a maximum of 2,600 feet. The Vagner is interpreted to be of glaciomarine origin because of dropstones, poor sorting, subangular clasts in the paraconglomerate, fine laminations in the phyllite, and lateral persistence of the marble (Houston and Karlstrom, 1992).

Cascade Quartzite, >2,092 ± 9 Ma (Xcq): This is a white, well-sorted, pebbly quartzite and subarkose with 5-10 cm thick layers of interbedded quartz and black chert-pebble

conglomerate. The unit, which commonly exhibits planar and trough cross-bedding and an interpreted southwest directed paleocurrent flow, is as much as 2,800 ft thick, but is locally thinned by erosion of the upper beds (Houston and Karlstrom, 1992). Premo and Van Schmus (1989) described an 2,092 ± 9 Ma U-Pb zircon date from a gabbroic intrusion cutting the Cascade Quartzite.

Campbell Lake Formation and Lindsey Quartzite (Xcl): The upper part of the Campbell Lake Formation is black to gray, locally cross-bedded quartz-rich phyllite. The lower part is a paraconglomerate with 1 inch to 30 inches diameter rounded to subangular clasts of white granite, phyllite, and quartzite, supported within a matrix that makes up 80 percent of the rock, and is composed of quartz, plagioclase, mica, and rock fragments. Because it is discontinuous, the Campbell Lake Formation, which varies in thickness from 0 to 205 ft as described by Houston and Karlstrom (1992) is combined with the Lindsey Quartzite.

The 1,350 ft thick Lindsey Quartzite, underlying the Campbell Lake Formation, is made up of medium-grained white to gray quartzite and subarkose with thin phyllite layers and partings. It exhibits well-preserved cross-bedding, and is interpreted as fluvial deposition in a braided stream with more distal sources than the underlying Magnolia Formation (Houston and Karlstrom, 1992).

Magnolia Formation 2,451 ±9 Ma (Xmg): In the Medicine Bow Mountains, the Magnolia Formation averages 1,200 ft thick, and consists primarily of coarse-grained arkosic quartzite with abundant trough cross-beds and local thin quartz-pebble conglomerates that form upward-fining sets. Discontinuous basal conglomerates are radioactive (up to 1,620 ppm uranium) and grade upward into coarse-grained micaceous quartzite (Houston and Karlstrom, 1992).

Neoarchean Rocks north of the Cheyenne belt

Phantom Lake Metamorphic Suite, Sierra Madre

All three subunits of the Phantom Lake metamorphic suite in the Sierra Madre have subjected to multiphase deformation that has obscured stratigraphic relationships. Its separation into three units has allowed for easy correlation between the Sierra Madre and Medicine Bow Mountains. However, petrological, geochemical, and isotopic evidence presented by Souders and Frost (2006) indicates that the Jack Creek quartzite and Bridger Peak quartzite may actually be the same geologic unit, and that the Phantom Lake metamorphic suite was deposited in an intra-ocean arc basin between 2.71 and 2.68 Ga.

Bridger Peak Quartzite (Wbp): 2,600 feet of gray to white quartzite varying from quartz arenite to argillaceous and arkosic quartzite with well-developed lenticular beds of quartz-pebble conglomerate at the base in the Vulcan Mountain area, and common interlayered sericite schist in the upper part toward its eastern outcrops (Houston and Graff, 1995).

Silver Lake Metavolcanics 2,680 ± 18 Ma (Wsm): The most abundant rocks in this complex metavolcanic sequence include gray quartz-plagioclase-mica schist, fine-grained amphibolite, dark amphibole gneiss, pelitic schist, white feldspathic quartzite, calcareous quartzite, and paraconglomerate. Some fragmental textures can be observed, graded

bedding is preserved locally, and abrupt facies changes are common. A lack of marker horizons, poor preservation, and ambiguous top and bottom criteria lead to stratigraphic confusion within the Silver Lake metavolcanics (Souders and Frost, 2006). Granite-boulder paraconglomerate interbedded with feldspathic quartzite and pelitic schist throughout the unit is note worthy. Thickness varies dramatically from 3,300 ft in the central Sierra Madre to 1,000 ft in the eastern Sierra Madre (Houston and Graff, 1995). U-Pb zircon geochronology by Souders and Frost (2006) from a porphyritic metadacite in the Silver Lake metavolcanic suite give an estimated crystallization age of 2,680 ± 18 Ma. Chamberlain (personal commun. 2009) suggested that zircon grain morphology may indicate a sedimentary origin rather than volcanic for the dated material.

Jack Creek Quartzite (Wjc): Dominated by white quartzite, and containing lenses of paraconglomerate, quartz-pebble conglomerate, gray and green phyllite, metagraywacke, and marble. This unit is 1,650 ft thick in the northwestern Sierra Madre, including the 328 ft thick Deep Gulch Conglomerate Member at the base, which consists of well-developed pyritic and radioactive quartz-pebble conglomerate. The unit is finer grained in the north-central Sierra Madre where conglomerate layers are missing, and thins to a 'feather edge' about five miles west of Encampment (Houston and Graff, 1995). Souders (2004) states that the Jack Creek Quartzite and the Bridger peak Quartzite are indistinguishable in the field, and suggests that they may actually be the same geologic unit as opposed to the interfingering, time-transgressive sequence as described by Graff (1978).

Phantom Lake Metamorphic Suite, Medicine Bow Mountains

Conical Peak Quartzite (Wcp): This unit, commonly exhibiting both large-scale planar and trough cross-beds, consists of fine-grained white micaceous subarkose containing beds of calcareous quartzite and metabasalt. The Conical Peak Quartzite conformably overlies the Colberg Metavolcanics, and reaches a maximum exposed thickness of about 2,625 feet (Houston and Karlstrom, 1992).

Colberg Metavolcanics (Wcm): Heterogeneous assemblage of amygdaloidal basalt, pillow basalt, tuff, lapilli tuff, paraconglomerate, and quartzite rich in amphibole and biotite that is interpreted to be metagraywacke. The most abundant volcanic rocks are tholeiitic metabasalt, and the metatuffs vary in composition from rhyolite to basalt. The paraconglomerates contain granite, quartzite, and volcanic clasts in a coarse-grained matrix of amphibole, biotite, and quartz. The rounded granite boulders are up to 19 inches in diameter, and the thickness of the paraconglomerate is as much as 1,312 feet. Thickness of the Colberg Metavolcanics ranges from a thin trace in the Northwest Medicine Bow Mountains to 8,200 feet in the north-central part of the mountains (Houston and Karlstrom, 1992).

Bow Quartzite (Wbq): This unit, exhibiting medium- to large-scale planar cross-beds and some oscillation ripple marks, is 95 % white to pink muscovitic quartzite, feldspathic quartzite, and arkose, but locally contains layers of conglomerate, biotite and hornblende schist, and siliceous metalimestone. The Bow Quartzite varies in thickness from 656 to 1,900 feet (Houston and Karlstrom, 1992; Houston and others, 1992).

Quartzo-feldspathic gneiss (Wgn): Well foliated to massive and faintly foliated, pink to gray felsic gneiss primarily composed of plagioclase, potash feldspar, and quartz. The gneiss in the

Medicine Bow Mountains is commonly interlayered with biotite-rich and biotite-poor gneiss, and uncommonly with augen gneiss, hornblende gneiss, amphibolite, quartzite, paraconglomerate, and marble (Houston and Karlstrom, 1992). In the Sierra Madre, the interlayered felsic gneiss includes pink granite gneiss, gray biotite-quartz-feldspar gneiss, tan garnet-quartz-feldspar gneiss, white quartz-microcline gneiss, and local layers of kyanite gneiss, hornblende gneiss, and amphibolite (Houston and Graff, 1995). Based on the intrusion of this unit by 2.71 Ga granodiorite and granite, dated by Premo (1982), Houston and Graff (1995) assign an early Archean age for the gneiss. Souders and Frost (2006) state that it is unlikely that this basement gneiss could predate the 2.71 Ga Spring Lake granodiorite by >100 million years based on Nd isotopic studies.

> **Biotite gneiss (Wbg)**: Dark-gray, well-foliated biotite gneiss, interlayered with hornblende gneiss, was mapped in the area north of Baggot Rocks by Houston (1978) with a radiometric date of 2,410 ± 50 Ma (Hills, Gast, Houston, and Swainbank, 1968). This gneiss was assigned a Late Archean age by Houston and others (1992) and regionally included as a subdivision within the quartzo-feldspathic gneiss (Wgn) [see Houston and others, 1968].

Red-pink orthogneiss, 2,683 ± 6 Ma (Wog): Well-foliated to massive, red to pink granitic to tonalitic orthogneiss in the northern and east-central Sierra Madre. More massive phases of this unit intrude the Spring Lake Granodiorite (Houston and Graff, 1995). In the Medicine Bow Mountains, this unit is predominantly pink foliated granite, but includes granodiorite, quartz monzodiorite, and trondhjemite (Houston and Karlstrom, 1992). Structure is typically concordant with country rock in the Medicine Bows, but in various locations, the unit can exhibit either gradational or cross-cutting relationships with the quartzofeldspathic gneiss (Wgn). Radiometric date of 2,683 ± 6 Ma is after Premo and Van Schmus (1989).

Spring Lake Granodiorite, 2710 ±10 Ma (Wsl): Well-foliated gray granodiorite dated using U-Pb zircon techniques by Premo and Van Schmus (1989). This unit outcrops extensively in the northern Sierra Madre (Houston and Graff, 1995), and intrudes both the Vulcan Mountain metavolcanics and the lower part of the Phantom Lake Metamorphic Suite (Houston and others, 1992).

Kyanite pegmatite (Wkp): This granite pegmatite contains blades of blue and white kyanite, and intrudes or grades into kyanite-biotite-quartz-plagioclase gneiss of the quartzo-feldspathic gneiss (Wgn) (Ferris, 1964; Houston and Graff, 1995).

Vulcan Mountain Metavolcanics (Wvm): The Vulcan Mountain Metavolcanics is an estimated 1,148 feet of highly deformed mafic metavolcanic succession in the Sierra Madre that is primarily made up of fine-grained amphibolite and hornblende-plagioclase gneiss, with isolated interlayers of chlorite schist, quartzite, paraconglomerate, and marble. Pillow structures and amygdules are locally preserved in the amphibolite, which also hosts conformable interlayered intrusions of ultramafic and gabbroic composition. Although the contact is obscured, the Vulcan Mountain metavolcanics are interpreted to lie unconformably on top of the basement quartzofeldspathic gneiss and correlate with the Overland Creek Gneiss in the Medicine Bow Mountains (Houston and others, 1992); Houston and Graff, 1995).

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