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Precambrian Basement Map of Wyoming: Structural Configuration

Wyoming State Geological Survey

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Wyoming State Geological Survey

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Precambrian Basement Map of Wyoming: Structural Configuration

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ABSTRACT

The Precambrian basement map of Wyoming, by D.L. Blackstone, Jr. (1993a), has been a primary and authoritative reference for Wyoming geology since its publication. However, the utility of paper maps has abated in recent decades, and the original dataset of wells that served as the backbone to the map was never published. To provide a similarly useful map that accommodates the increasing use of digital geospatial technology, the Wyoming State Geological Survey (WSGS) revised the Precambrian basement map of Wyoming. Well logs, seismic lines, cross sections, and digital elevation models were used to refine and reinterpret the structure of the Precambrian rocks throughout the state. All reference and WSGS-generated data, as well as associated metadata, are organized and publicly available in a U.S. Geological Survey (USGS) standardized geodatabase schema, available from the WSGS website and on the Interactive Oil and Gas Map of Wyoming.

INTRODUCTION

Precambrian basement structural configuration, both at the surface and in the subsurface, is a fundamental component for understanding the geology of a region. Igneous and metamorphic "basement" rocks—generally crystalline rocks that underlie stratified sedimentary cover—record Earth's earliest geologic processes that occurred throughout the Precambrian, ending about 541 million years ago.

In Wyoming, Precambrian rocks are exposed at the surface in basement-cored mountain ranges. Yet in the adjacent basins, these rocks are well below the surface, covered by a thick sequence of Phanerozoic strata. Even buried by thousands of feet of sedimentary rock, the basement influences tectonism and faulting; basin geometry; accumulation, preservation, and erosion of sediment; and hydrocarbon and mineral deposits—resulting in geology that can be favorable for exploration of natural resources. Understanding the structural configuration of the basement is important for governmental agencies that support development of natural resources as well as for scientific studies involving continent evolution and reconstruction.

The driving force behind this study is ongoing WSGS research into understanding the occurrence and distribution of critical minerals throughout Wyoming. Critical minerals are minerals and elements deemed essential to U.S. national security and the economy. Wyoming hosts substantial concentrations of many of these minerals, in part due to the wide variety of geologic environments present throughout the state. Many critical minerals in Wyoming are either found in, or originate from, Precambrian igneous and metamorphic rocks. An accurate and documented spatial analysis of the elevation and structure of Wyoming's Precambrian basement is therefore imperative to critical-mineral exploration and development within the state.

Previous work by Blackstone (1993a) utilized well data, gravity and magnetic surveys, cross sections, seismic reflection data, and other information to publish a structure contour map of the basement at the scale of 1:1,000,000. With little new data but some new interpretations and a consistent thousand-foot contour interval, the WSGS preliminarily revised Blackstone's map as plate 2 of Lynds (2013).

This study more thoroughly revises and updates the Precambrian basement map of Wyoming, focusing on basement elevation and faulting. In the 30 years since the Blackstone work was completed, additional oil and gas wells with associated well logs have been drilled, and new geophysical surveys and cross-section interpretations have been generated. As such, this map uses previous mapping and new data to reinterpret the elevation, relative to mean sea level, of Precambrian basement rock and associated structures, statewide, at the scale of 1:500,000.

METHODS

A primary objective of this study was to compile and verify an exhaustive well dataset to be used in interpreting the Precambrian basement structure and elevation. The final well dataset attempted to include wells shown on Blackstone's (1993a) map. Of the 272 wells originally noted on the 1993 map, 167 wells were confidently associ-

ated with a current Wyoming Oil and Gas Conservation Commission (WOGCC) API number, a unique number assigned to every oil or gas well drilled in the United States. The remaining 105 of Blackstone's (1993a) wells were either unable to be confidently identified, were completed to depths not useful to the current interpretation, or were omitted due to their spatial proximity to another well with a more confident or relevant formation interpretation. Beyond the Blackstone (1993a) wells, 309 additional wells were identified and incorporated from the WOGCC (2022) database using formation geologic marker and bottom formation queries and legible well logs, and 25 wells were added from Flawn (1967) and Flawn and others (1967).

Wells drilled to or through the Precambrian with accurate Precambrian elevation interpretations are ideal guides, yet they are rare in Wyoming since oil and gas reservoirs are almost always contained within the overlying Phanerozoic strata. In areas with scarce Precambrian well data, it was therefore necessary to include wells completed in Paleozoic units, which are much more common.

All wells included in the dataset were subjected to quality control efforts to confirm the following: location accuracy, relative to permitted location (WOGCC, 2022); datum elevation accuracy, relative to a 10-meter digital elevation model and datum elevation noted on well-log headers or completion reports (U.S. Geological Survey, 2009; WOGCC, 2022); and formation interpretation accuracy, relative to formation name, fault intercept, and depth. Formation elevation relative to mean sea level was calculated by subtracting the interpreted measured formation depth from the datum of the geophysical well log (usually kelly bushing elevation, rarely ground level or drilling floor elevation). The resulting dataset contains 501 wells used as guides in contouring Wyoming's Precambrian basement.

To generally constrain the basement elevation from wells that did not reach the Precambrian, the thickness of the relevant Paleozoic unit or units was estimated and added to the measured depth of the well. The thickness of Wyoming's Paleozoic units varies significantly over a large areal extent. Thickness estimations referenced type logs provided in Lynds (2013) and local to regional studies, especially including Fisher (1906), Stipp (1947), Anderman (1956), Berg (1956), Burk (1956), Faulkner (1956), McCrae (1956), Mills (1956), Peterson (1956), McCoy (1958), Beikman (1962), Martin (1965), Thomas (1965), Keefer and Van Lieu (1966), Sonnenberg (1985), LeFebre (1988), Love and others (1993), and Macke (1993). Many of these include basin- and unit-specific isopach maps.

To assist with Precambrian structural interpretation, published seismic lines, cross sections, geologic maps, and structure contour maps were consulted. Applicable data were georeferenced to ensure spatial accuracy and attributed as data sources accordingly, following Geologic Map Schema (GeMS) standards (U.S. Geological Survey National cooperative Geologic Mapping Program, 2020).

Referenced seismic interpretations and cross sections include Skeen and Ray (1983), Basham and Martin (1985), Brittenham and Tadewalk (1985), Ray and Keefer (1985), Sonnenberg (1985), Stone (1985a, 1985b, 1987, 2004), Blackstone (1986), LeFabre (1988), Besse (1999), and Cook (2002).

Geologic maps, ranging in scale from 1:50,000 to 1:500,000, were used to identify basement-involved faulting and guide the Precambrian basement rock interpretation when no other information was available. These maps include Houston and others (1978), Love and Christiansen (1985), Ver Ploeg (1985), Houston and Karlstrom (1992), Ver Ploeg and Boyd (2002), Sutherland and Hausel (2003, 2004), Ver Ploeg (2004), Ver Ploeg and others (2004), Hunter and others (2005), McLaughlin and Ver Ploeg (2006), Hausel (2007), Sutherland (2007), Ver Ploeg and Boyd (2007), Wittke (2007), Jones and Gregory (2011), Jones and others (2011), McLaughlin and others (2011), Sutherland and others (2013), and Stafford and others (2021). In a few areas, the location of oil and natural gas fields were important for identifying geologic structure, as defined by Toner and others (2021).

Structure contour maps of Paleozoic and some Mesozoic units were relied upon heavily in many areas. These maps provided the general basin structure from which to estimate the basement rock elevation and were also useful for determining the type and extent of faulting. Maps used include Anderman and Ackman (1963), Keefer (1970), Heasler and Hinckley (1985), Blackstone (1986, 1991, 1993b), Sims and Day (1999), and Lichtner and others (2021).

In the northwest corner of the state, no Precambrian rocks are associated with the Yellowstone caldera. As such, the outermost track of the caldera, as defined by the related system of faults (Koch and others, 2011; Mauch and others, 2022), was used to delineate the extent of Precambrian structure in this region.

In a north–south trend extending from Jackson Hole to the Utah state border, deformation associated with the Sevier orogeny folded and faulted Phanerozoic strata. Because most wells in this overthrust belt area do not penetrate to the underlying Precambrian basement rock footwall, basement subsurface interpretations are limited.

Outcrop elevations, necessary for characterizing Precambrian rocks exposed at the surface, were derived from a 10-meter digital elevation model (U.S. Geological Survey, 2009) intersected with Precambrian polygons at the 1:500,000 scale from Love and Christiansen (1985).

Using all available aforementioned data sources, statewide thousand-foot-interval contours were developed to illustrate the top of the Precambrian basement elevation relative to mean sea level. The contours attempt to honor not only well and seismic data but also basement-involved faults and subsurface features that influence the Precambrian structure. Because digital modeling can misrepresent and obscure fine details needed in complex structural areas, all contours in this revision were hand-generated.

In many places, the original information presented on Blackstone (1993a) was considered the best available data, and the contour lines and faults changed very little. In other places, the original contouring was no longer sufficient to explain new subsurface information (usually from wells), and the contours were reinterpreted, sometimes significantly, to fit the data. Most of these interpretations were made without the insight of seismic data and will likely be changed in the future as more information becomes available.

For symbolization purposes, polygons were created from the contour lines and attributed with respective intervening contour intervals using the USGS GeMS toolbox. To ensure data integrity and connectivity, topology was run on the polygons and all errors corrected.

RESULTS

The updated 1:500,000-scale basement map is shown in plate 1 and is intended to supersede Blackstone (1993a). The WSGS requests that all users keep map scale in mind; this map is not intended to be used at scales larger than 1:500,000.

Spatial data used in the creation of plate 1 are compiled in a USGS standard GeMS level-3 compliant geodatabase schema (U.S. Geological Survey National Cooperative Geologic Mapping Program, 2020). The GeMS geodatabase is the true product of this study, and the WSGS intends for this map to hereafter be a digital publication.

The GeMS geodatabase includes:

- ContactsAndFaults: line feature class containing the map study area (state boundary), faults and associated fault type, and contour lines representing the top of the Precambrian basement (contour interval is 1,000 feet)
- GenericPoints: point feature class containing all oil and gas wells and interpreted point locations from seismic and cross section sources; includes elevation values relative to mean sea level for all points, in addition to API number, well datum, datum elevation, formation, and location information
- MapUnitPolys: polygon feature class that conforms spatially with ContactsAndFaults and attributed contour interval

- DataSources: table listing all data sources used by and attributed to geodatabase features
- FGDC-standard metadata .xml files accompany each feature class

The map is recognized as a work in progress, but converting to an all-digital format will simplify future refinements. Any additional data that could help refine contour lines or fault interpretations are welcome by WSGS geologists.

Plate 1 and the GeMS database are available for download through the WSGS publication repository. The associated point, line, and polygon data can be viewed, along with additional downloadable well-attribute data, on the WSGS Interactive Oil and Gas Map of Wyoming.

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WYOMING STATE GEOLOGICAL SURVEY
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Interpreting the past, providing for the future

OPEN FILE REPORT 2022-5 (Revised 2023)
Plate 1
Precambrian Basement Map of Wyoming: Structural Configuration
1:500,000-scale

PRECAMBRIAN BASEMENT MAP OF WYOMING:
STRUCTURAL CONFIGURATION

Wyoming State Geological Survey

EXPLANATION

This map is a general representation of the Precambrian basement in Wyoming. Data used to create the map are interpretations from publicly available sources. While every effort has been made to ensure data and map accuracy, uncertainty in subsurface interpretation is introduced during data acquisition, compilation, and manipulation, and is also present due to variability in scale and geologic interpretation. Spatial information included in this publication is suitable for approximate reference only, and is not to be construed as final, absolute, or used as a substitute for direct local measurements.

Precambrian basement elevation
(feet below or above mean sea level)

-34,000 — 0 — 14,000

Faults

- **Fault**—Displacement uncertain
- **Normal fault**—Bar and ball on downthrown block
- **Thrust or reverse fault**—Triangles on upthrown block
- **Strike-slip fault**—Arrows indicate relative motion

Contours

- **Contour**—Precambrian basement elevation relative to mean sea level; contour interval 1,000 feet
- **Index contour**—Precambrian basement elevation relative to mean sea level; contour interval 5,000 feet

Control Points and Boundaries

- **Well**—Ordovician or younger subsurface interpretation
- **Well**—Cambrian subsurface interpretation
- **Well**—Precambrian bedrock subsurface interpretation
- **Highest peak in mountain range**
- **Caldera boundaries**—Associated with Yellowstone volcanism
- **Precambrian bedrock surface exposure**

Base Data

- **City**
- **State boundary**
- **County boundary**
- **Township and range**

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Map Projection: Wyoming Lambert Conformal Conic
False Easting: 500000, False Northing: 200000
Central Meridian: -107.5 degrees West
Standard Parallel 1: 41 degrees North
Standard Parallel 2: 45 degrees North
Latitude of Origin: 41 degrees North
Horizontal Datum: North American Datum of 1983 (NAD 83)
Spheroid: Geodetic Reference System 80

Base hillshade derived from USDA/NRCS – National Cartography & Geospatial Center 30-meter Digital Elevation Model (DEM) Mosaic, 2011; azimuth: 315°, sun angle: 45°, vertical exaggeration 1:2

UTM grid and 2022 magnetic north declination at center of figure, from www.ngdc.noaa.gov (diagram is approximate)

Scale 1:500,000

0 10 20 30 40 50 Miles

0 20 40 60 Kilometers

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