Preliminary Precambrian Basement Map Showing Geologic—Geophysical Domains, Wyoming

By P.K. Sims, C.A. Finn, and V.L. Rystrom

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By P.K. Sims, C.A. Finn, and V.L. Rystrom

Introduction

The Precambrian basement of Wyoming consists predominantly of the Archean Wyoming craton (province), and includes small parts of two Paleoproterozoic accreted orogens—the Trans-Hudson, on the east, and the Colorado, on the south. The Trans-Hudson is a major lithospheric unit in North America composed mainly of oceanic-arc rocks (1.9-1.84 Ga), but includes substantial volumes of Archean rocks. It is mainly known from exposures in northern Saskatchewan and Manitoba, in Canada (Lewry and Collerson, 1990, and references therein). Within the United States, rocks of the orogen are exposed only in the Black Hills uplift of South Dakota. The Trans-Hudson orogen separates the Wyoming province from the Superior province (Sims and others, 1991; Peterman and Sims, 1993). The Colorado orogen, formerly called the Colorado province (Bickford and others, 1986), is a >500-km-wide belt of oceanic arc rock (1.78-1.65 Ga) that extends southward into New Mexico (Sims and Finn, 2001), and composes a major part of the Transcontinental Proterozoic provinces of southwestern United States (Van Schmus and others, 1993). Formerly, the Wyoming sector of the Colorado orogen was called the Medicine Bow orogen (Chamberlain, 1998). The eastern extension of the Colorado orogen into the High Plains is named the Central Plains orogen (Sims and Peterman, 1986). The boundary between the Colorado orogen and the Wyoming craton is the Cheyenne belt (Karlstrom and Houston, 1984), a well-documented 5-km-wide mylonitic shear zone that verges northward (Duebendorfer and Houston, 1987). The Cheyenne belt transects and cuts off the older Trans-Hudson orogen on the south (pl.1; Sims and others, 1991).

The Archean and Proterozoic rocks in Wyoming crop out mainly in the cores of the state's several mountain ranges. In adjoining basins the Precambrian rocks are buried beneath younger Phanerozoic rocks as much as a few thousand meters thick (Blackstone, (1989). In the Yellowstone region in northwestern Wyoming, a veneer of flat-lying Cenozoic and recent volcanic rocks nearly completely obscures the Precambrian basement (Love and Christiansen, 1985).

A new aeromagnetic anomaly map (pl.2; Kucks and Hill, 2000; also available on the internet) provides a means of seeing through the sedimentary and volcanic cover to reveal magnetic signatures from buried Precambrian rocks and structural features in these rocks. Magnetic lows do not correlate closely with the positions of major basins (see Blackstone, 1989), so the anomalies primarily reflect variations in the lithology of the Precambrian basement rocks. Thus, the magnetic anomaly map provides a useful tool for understanding the geologic framework and regional tectonic features of Wyoming.

Acknowledgments

The principal sources of geologic data for the interpretation presented here (pl.1) were the excellent geologic map (Love and Christiansen, 1985) and basement map (Blackstone, 1989) of Wyoming. Constructive reviews by Ernie Anderson, Bob Bauer, and Bob Kucks improved the report.

Relation of aeromagnetic anomalies (Plate 2) to geology (Plate 1)

Archean Wyoming craton

The Wyoming craton consists mainly of three gross rock types: potassic granite-granodiorite (mainly granite), orthogneiss and paragneiss, and minor amounts of supracrustal metavolcanic-metasedimentary rocks. The granitic rocks produce high-amplitude positive aeromagnetic anomalies in exposed areas (e.g.), the granitic rocks (Wg,Plate 1) of the Wind River, Big Horn, and Laramie ranges; in covered areas, the anomalies are more subdued but generally remain positive (e.g.), the presumed granitic rocks (Ag,Plate 1), in the Powder River basin of northeastern Wyoming. These areas of high magnetic anomalies are termed magmatic domains (pl.1). Gneisses have a mixed magnetic expression. Those in the northern Wind River, Tetons, south-central Big Horn, and north-central Laramie ranges have associated magnetic lows, whereas those in the southern Beartooth Mountains produce magnetic highs. The cause of these contrasting magnetic expressions is the difference in mineral composition, mainly in abundance of magnetic iron oxides of the protoliths. The Archean metavolcanic-metasedimentary rocks also yield magnetic lows (e.g., the supracrustal rocks of the Elmers Rock area in the Laramie Mountains and the South Pass metasedimentary-metavolcanic succession in the southern Wind River Range (Bayley and others, 1973; Frost and others, 2000)). Accordingly, these supracrustal rocks are grouped with the gneisses having negative magnetic anomalies. In covered areas, the gneisses and supracrustal rocks that are expressed by negative magnetic areas are mapped together as a unit herein called gneissic domains (plate 2), rather than terranes, because geologic terranes have been defined and are commonly interpreted as being fault-bounded (Jones and others, 1977), generally implying a convergent plate-tectonic regime.

Immediately north of the Cheyenne belt, the Archean rocks of the craton margin are overlain locally by apron-like thick successions of mature metasedimentary rocks (unit Xs, p.1), especially quartzite and marble (Karlstrom and others, 1983; Houston, 1993). These rocks are associated with strong negative magnetic anomalies that parallel the northern margin of the Cheyenne belt.

Proterozoic Trans-Hudson orogen

Rocks of the Trans-Hudson orogen are not exposed in Wyoming, and the nearest exposures are in the Black Hills, in northwestern South Dakota. The frontal (foreland) thrust fault of the orogen is inferred to occupy a deep negative magnetic trough about 15 km east of the Hartville uplift. The thrust front trends northerly, sub parallel to the Hartville fault, which bisects the Hartville uplift (Sims and Day, 1999). The Trans-Hudson orogen is interpreted as being cut off by the Cheyenne belt.

Proterozoic Colorado orogen

The Colorado orogen consists of Paleoproterozoic metavolcanic-metasedimentary rocks and granite-gabbro plutonic rocks of island-arc affinity. Four bodies of mafic intrusive rocks (~1.75 Ga) are present near the Cheyenne belt suture, one in the Sierra Madre, two in the Medicine Bow Mountains, and one in the Laramie Mountains (anorthosite) (plate 1) (Premo and Loucks, 2000). They cause high-frequency to modest positive magnetic anomalies. The aeromagnetic data are not sufficiently detailed to delineate separate Proterozoic rock units in covered areas, and these areas are indicated on the map (pl.1) by the symbol Xr.

Intrusive rocks of Mesoproterozoic age

The ~1.4 Ga Laramie Anorthosite Complex (Ya, p.1) and Sherman Granite (Ys, p.1) of the ~1.4 Ga magmatic domain compose the northernmost segment of belts of these intrusive rocks in the Colorado province (Anderson and Cullers, 1999). They are part of a suite of this general age that dominate the northeast-trending Transcontinental Proterozoic provinces of the United States (Van Schmus and others, 1993).

The Laramie Anorthosite Complex consists of the Laramie Anorthosite and coeval syenites. The anorthosite gives a pronounced negative magnetic anomaly; the syenites, which border the anorthosite on the outside of probable ring structures, cause postive magnetic anomalies. The composite body transects and cuts out a segment of the older Cheyenne belt. To the south and east of the Laramie Anorthosite Complex, bodies of the Sherman Granite—an ilmenite-bearing granite (Anderson and Cullers, 1999)—are expressed by negative magnetic anomalies. The pattern of ring structures also exists in covered areas between the Laramie and Medicine Bow Mountains.

Faults

Faults and shear zones related to the two major Paleoproterozoic orogens and a crustal shortening episode during the Laramide orogeny affected the Precambrian rocks of Wyoming, and particularly the crystalline rocks in the Archean Wyoming craton. They appear as linear anomalies and sharp gradients on the magnetic map (Pl.2).

Ductile faults related to Trans-Hudson orogeny

The Hartville fault, exposed in the Hartville uplift , is a steep east-dipping ductile shear zone, interpreted as a west-vergent thrust in the foreland of the Trans-Hudson orogen (Sims and Day, 1999). The shear zone is presumed to flatten at depth. Archean rocks on both sides of the structure are grossly similar, but they are higher grade (amphibolite facies) in the hanging-wall block on the east than in the footwall (greenschist facies). Based on the mineral phases the east-side-up throw is estimated at about 5 km (K.R. Chamberlain, University of Wyoming, oral commun., 1993). The fault is marked on its east side by a north-northeast-trending positive magnetic anomaly (Pl.1). The north and south projections of the fault (Pl.l) are based on subdued but remarkably linear anomalies. The magnetic anomalies support the interpretation that to the south of the Hartville uplift the fault is cut off by the younger (1.78—1.76 Ga) Cheyenne belt (Sims and others, 1991).

The Cheyenne belt, marked by a ~5 km-wide mylonite zone, is a well defined collisional suture in the Medicine Bow Mountains and Sierra Madre (Karlstrom and Houston, 1984). Based on a pronounced negative magnetic anomaly, the shear zone is projected to the east and west of its exposed areas to state borders.

Thrust faults of Laramide (~60 Ma) age

Uplift of the mountain ranges of Wyoming resulted mainly from thrust faulting associated with regional northeast-southwest shortening during the Laramide orogeny. The thrusts have sinuous surface traces and strike mostly northwest to west. The thrusts raised Precambrian basement rocks to high crustal levels (in present-day mountainous areas) and depressed the basement in adjacent areas (basins). Subsequent erosion has yielded the present topographic configuration. Contours on the basement surface (Blackstone, 1989) indicate throw on the major thrusts of a few to several thousand meters. An exception to Laramide thrusting is the spectacular Teton Range, in northwestern Wyoming, which owes its uplift to Pliocene or Pleistocene vertical movement along a north-trending fault. The uplifts are not isolated structures; instead, they are culminations of anastamosing "arches" (Erslev. 1993), which are controlled mainly by forward and back-thrusting.

The Laramide structures can be accounted for by compressive stresses transmitted tangentially through the crust (Sales, 1968). Sales proposed a west-northwest, regional left-lateral couple to explain the generally northwest-trending ranges and sinuous thrust faults. In a different model, the northeast-directed thrust system responsible for the complexly anastomosing patterns of Laramide "arches" is linked to increased interaction between the North American and Farallon plates during low-angle subduction (Erslev, 1993).

The Laramide thrust faults cut Mesozoic and older Phanerozoic strata as well as the Precambrian basement rocks. They are most conspicuous on the aeromagnetic map (pl.2) in the northern part of Wyoming, where they transect Archean rocks of the Wyoming craton. The Wind River thrust fault, whose trace is west of the Wind River Range, is known from COCORP deep-reflection data (Smithson and others, 1978) and is marked by a strong contract in magnetic expression across the fault; rocks in the hanging wall cause high-amplitude, high-frequency positive anomalies, whereas those in the footwall (at a deeper level) produce more subdued positive anomalies. Granitic rocks dominate on both sides of the thrust. Contours on the basement surface indicate a vertical displacement of ca. 30,000 ft (9250 m) on the Wind River fault (Blackstone, 1989).

A second major thrust, herein named the Bighorn thrust fault, whose trace is about 50 km west of the Bighorn Mountains, verges southwest. Vertical offset of the basement surface at the thrust is estimated to be of ca. 5,000 ft. (1540 m) (Blackstone, 1989). The Bighorn fault does not bring the Precambrian basement to the present surface; instead the basement rocks lie at a shallow depth beneath Phanerozoic strata in the Bighorn basin. However, the Precambrian basement is brought to the surface by a probable secondary, southwest-vergent thrust along the west face of the main mountainous area of the Bighorn Mountains; this thrust has a vertical displacement at the Precambrian surface of about 1,000 ft.

A northeast-vergent back-thrust on the east margin of the main Bighorn Mountains is marked by a steep gradient in magnetic anomalies. The upthrown block, to the west, is expressed by high-amplitude, positive magnetic anomalies; the downthrown block, to the east, beneath sedimentary strata, causes subdued positive magnetic anomalies. A sub-parallel backthrust a short distance to the east fails to bring the basement to the present topographic surface. Judged from contours on the basement surface (Blackstone, 1989), these backthrusts have throws of 2,000-3,000 ft. (600-900 m).

A lengthy, sinuous southwest vergent thrust fault occurs along the south margin of the Owl Creek-Bridger Mountains (Pl.1). It is expressed magnetically by a pronounced contrast in magnetic anomalies at the south margin of the Owl Creek-Bridger Mountains; anomalies to the north (upthrown side) are much sharper than those to the south. Where the fault crosses the Wind River magmatic domain, near Casper, Wyoming (Casper Arch), the east (upthrown) side causes a pronounced high-amplitude positive magnetic anomaly that contrasts sharply with lower anomalies on the west (downthrown) side. The fault may extend northward to the west flank of the Beartooth Mountains and eastward to the west flank of the Laramie Mountains. The fault could also extend southward along the length of the western side of the Laramie Mountains but it cannot be traced through the broad negative magnetic anomaly produced by the Laramie gneiss domain

Reworking of margin of Wyoming craton

The southern and eastern margins of the Wyoming craton were reworked substantially during the Paleoproterozoic Trans-Hudson and Colorado orogenies. In the reworked zones, Proterozoic mesoscopic structures are widespread and in many places obliterate older Archean structures; the approximate tectonic fronts of these two younger orogenies are shown on the map (Plate 2). Such structural reworking has been demonstrated through geologic mapping in the Laramie Mountains (Bauer and Zeman, 1987) and Hartville Uplift in eastern Wyoming (Sims and Day, 1999). Archean rocks in the Wind River (Frost, Chamberlain, and others, 2000) and Bighorn Mountains, in the core of the craton, apparently lack conspicuous structures of Proterozoic age. Frost and others (2000) have, for example, indicated the existence of at least 4 deformation metamorphic events of Archean age in the Wind River Mountains, each of which is separated by granitic intrusions of different Archean ages. Thus, the structural evolution of the Archean infrastructure in the Wyoming craton is complex; detailed structural analysis such as done by R.L. Bauer and colleagues in the Laramie Mountains is required for a thorough understanding of the tectonics.

Peterman and Hildreth (1978) have shown by Rb-Sr biotite age data that a thermal metamorphic front in the age range 1,800-1,400 Ma exists in central Wyoming (Plate 1), some distance further into the craton than the Proterozoic tectonic fronts. The thermal front extends across central Wyoming from the northern tip of the Laramie Mountains through the Granite Mountains to the southern Wind River Mountains. Peterman and Hildreth (1978) proposed that the age pattern was generated by vertical uplift of several kilometers of the southern block, south of the age discontinuity, between 1,400 and 1,800 Ma. With this interpretation, the biotite ages register the time at which rocks of the presently exposed surface were uplifted and cooled through the 300 degrees C isotherm. Probably the uplift resulted mainly from post-collision movement along the Cheyenne belt; Chamberlain and others (1993) have shown from mineral-stability analysis that the Laramie Peak shear zone in the Laramie Range produced uplift of ~10km of the southern block of Archean rocks relative to the northern block. Such substantial differential movement is of the magnitude required to explain the age discontinuity along the thermal front. Vertical movement along the Hartville fault, of Trans-Hudson derivation (Sims and Day, 1999), also was large—on the order of 5 km, the east side having moved relatively upward (Chamberlain, oral comm., 1993). Thus, the terrane west of the Trans-Hudson orogen and north of the Cheyenne belt was characterized by differential fault movements on the scale of several km during Paleoproterozoic time, as a result of suturing. The east-west trend of the thermal front coincides for the most part to east-west-trending faults, thus accounting for the sharp age break in the metamorphic resetting.

Comparison with Superior province

The Wyoming province differs greatly from the Superior province of the Canadian shield in rock types, structural grain, and probably origin (Peterman and Futa, 1988; Frost and others, 1998). The Superior province consists of generally east-trending subdivisions that differ from one another in structural style, predominant rock type, metamorphic grade, and temporal history. The subdivisions, generally called subprovinces, are interpreted as tectonic entities such as volcanic arcs, back-arc basins, accretionary prisms, and seamount chains that were swept together by subduction and related processes of convergent tectonism (Card, 1990; Southwick, 1993). The principal intrusions are syntectonic rocks of calc-alkalic affinity, mainly tonalite-trondhjemite, although more alkalic post-tectonic plutons occur sporadically. The resultant crust is predominantly juvenile in origin. The Wyoming province lacks the diverse rock assemblages of the Superior province, as well as internal paleosutures, so far as known. The plutons in the Wyoming province are dominantly potassic igneous rocks; unlike intrusions in the Superior province, they were derived from reworking of an older (3.1-2.8 Ga) gneissic basement (Frost, 1993). Juvenile intrusions are rare in the Wyoming province.

The aeromagnetic anomaly map of the Superior province in Canada (Geological Survey of Canada, 1998) clearly shows features that contrast in orientation and tectonic style with those in the

Wyoming province. The Superior province magnetic map is characterized by generally elongate linear or gently curving alternating positive and negative anomalies that generally trend east-west. Granitoid rocks yield strong positive anomalies, as in Wyoming, and, except where iron-formations are present, mafic volcanic (arc rocks) and metasedimentary rocks cause quiet or negative anomalies. Faults or shear zones that bound terranes produce sharp magnetic breaks and faults transverse to lithologic trends generally give linear negative anomalies. The strongly contrasting aeromagnetic anomaly patterns in the two Archean provinces support the contention that the two Archean provinces were never juxtaposed, then later separated.

Geologic summary

The Precambrian basement of Wyoming consists mainly of three major geologic terranes, the Archean Wyoming craton (province), the Paleoproterozoic Trans-Hudson orogen, and the Paleoproterozoic Colorado orogen. The Colorado orogen collided with the Wyoming craton at 1.78-1.75 Ga. Collision of the Colorado orogen and the Trans-Hudson orogen with the Archean craton produced strong structural overprinting along the southern and eastern margins of the craton.

The Wyoming craton consists mainly of two gross rock units—granitoid plutons (2.8—2.55Ga) and gneiss and migmatite—together with subordinate (<10 percent) supracrustal metavolcanic-metasedimentary rocks. The granitoid rocks are mainly potassic granite; they were derived principally from reworked older (3.1-2.8Ga) gneiss (Frost, 1993). The magnetic contrast between granitoid rocks and gneiss provides a means to map these gross rock units in covered areas; the two gross rock units are referred to on pl.1, respectively, as (1) *magmatic domains* and (2) *gneiss domains*. The overall structural pattern of the Archean units shown by magnetic data is crudely semi-circular and open to the north. This pattern is ca. subparallel to the outer, oval margin of the Wyoming craton, as presently interpreted. This distribution of rock types derived from aeromagnetic data over the Archean craton was not known previously.

The Wyoming province differs in many respects from the Superior province of the Canadian Shield. The Superior province consists of numerous subdivisions, called subprovinces, that differ from one another in structural style, predominant rock type, metamorphic grade, and geologic history. The general concensus of many investigators is that the subprovinces represent multiple oceanic-arc terranes that were accreted by subduction and related processes of convergent tectonism. The resulting rock assemblages in the Superior province are dominantly juvenile, whereas those in the Wyoming province were dominantly formed by reworking of older Archean crust. Juvenile crust is rare in the Wyoming province. The different magnetic patterns of rocks in the two provinces support previous contentions that the two provinces were not joined in Archean time, then rifted apart.

The Colorado orogen, accreted to the Wyoming craton in the Paleoproterozoic along the Cheyenne belt, is a >500-km-wide belt of Proterozoic island-arc rocks. Collision deformed the arc rocks adjacent to the northeast-trending Cheyenne belt (Houston and Graff, 1995; Premo and Loucks, 2000) as well as rocks of the Wyoming province. As a result of the collision, Archean rocks of the Wyoming province were intensely redeformed and metamorphosed for a distance of at least 75 km inboard from the suture in the Laramie Mountains. In the same way, collision along the east margin of the craton with the Paleoproterozoic Trans-Hudson orogen intensely deformed Archean cratonic rocks in the Hartville uplift (Sims and Day, 1999) and the Laramie Mountains (Bauer and Zeman, 1997).

Mesoproterozoic (~1.4 Ga) anorthosite and related syenites of the Laramie Anorthosite Complex and granite (ilmenite-bearing Sherman Granite) intrude rocks of the Colorado orogen in the Laramie and adjacent Medicine Bow Mountains. Both the anorthosite and granite transect the Cheyenne belt in the Laramie Mountains, and intrude crystalline rocks of the Wyoming province.

These intrusions comprise the northernmost segment of a wide belt of 1.4 Ga granitic intrusions that occur throughout the Colorado orogen (Sims and Finn, 2001).

Wyoming owes its spectacular mountainous terranes mainly to a regional episode of compressional deformation during the Laramide orogeny (ca.60 Ma). The basement blocks composed of Precambrian rocks were uplifted locally to high levels in the crust during the deformation, and subsequent erosion has molded the uplifted rocks into the present-day topography. Vertical displacement of the basement surface was as much as 30,000 ft. (9250 m). By contrast, Sevier-aged thrusting, of approximately the same age, in western Wyoming (Pl.1) was thin-skinned, and the lack of disruption of magnetic anomalies in the region indicates that the basement rocks were little disturbed and not significantly uplifted during the thrusting. High-angle faulting of Pliocene-Pleistocene age formed the superbly scenic Teton Range (Reed and Houston, 1993). Vertical relief on the east face of the mountains is about 25,000 ft. (7800 m) (Blackstone, 1989).

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